EXPLORING THE PLANETARY GENEALOGY OF TARDA - A UNIQUE NEW CARBONACEOUS CHONDRITE. S. Dey[1], Q.-Z. Yin[1], and M. Zolensky[2]. [1]Department of Earth and Planetary Sciences, University of California at Davis, Davis, CA 95616, USA (Email: supratim@ucdavis.edu); [2]Astromaterials Research and Exploration Science, NASA Johnson Space Center, Houston, TX 77058, USA.

Introduction: The Tarda meteorite is a recently observed fall from southern Morocco. Tarda fell on 25th August, 2020, and the first piece was recovered the following day [1]. Eyewitnesses from locations up to 150 km away reported a bright yellow fireball lasting around 3 seconds. Initial petrographic and geochemical analyses for characterizing and classification show that Tarda is a petrologic type 2 ungrouped carbonaceous chondrite (C2 ungrouped) [1]. It is a matrix-rich breccia with ~80 vol.% fine-grained matrix and small chondrules that are predominantly forsteritic [1].

The oxygen isotopic composition of Tarda was analyzed by K. Ziegler at the University of New Mexico, Albuquerque [1]. Seven untreated (not acid-washed) fragments of Tarda weighing between 2.0 mg and 4.7 mg were analyzed by laser fluorination. The measured $\Delta^{17}O$ (linearized, using TFL slope = 0.528, relative to V-SMOW) of Tarda ranges between -0.102‰ and -0.443‰, with an average $\Delta^{17}O$ = -0.284‰ [1]. The $\Delta^{17}O$ values for Tarda lie between CI and CR chondrites (see Fig. 1) and do not resemble any known chondrite groups.

However, it is difficult to decipher the provenance of a meteorite based on oxygen isotopic data alone. Nucleosynthetic isotope anomalies (e.g. ^{54}Cr, ^{50}Ti) combined with the oxygen isotopic composition ($\Delta^{17}O$) has emerged as a powerful tool in establishing planetary genealogy. Isotope systematics have revealed a stark dichotomy among planetary materials in the $\varepsilon^{54}Cr$-$\Delta^{17}O$ space that reveals the spatial origin of meteorites from the inner Solar System (non-carbonaceous reservoir, NC) or the outer Solar System (carbonaceous reservoir, CC) [2–7].

In this study, we use the nucleosynthetic anomalies of ^{54}Cr combined with oxygen isotopic composition to decipher the provenance of Tarda and explore its genetic connection to known chondrite groups.

Methods: The Tarda sample studied here was collected pre-rain. An interior fusion-crust free chip of Tarda was ground to a powder and homogenized 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 chemistry extraction procedure to separate Cr from all other matrix elements [8]. 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).

Results and Discussion: Our Cr isotopic measurements for Tarda combined with $\Delta^{17}O$ is presented in Fig. 1 in the $\varepsilon^{54}Cr$-$\Delta^{17}O$ space.

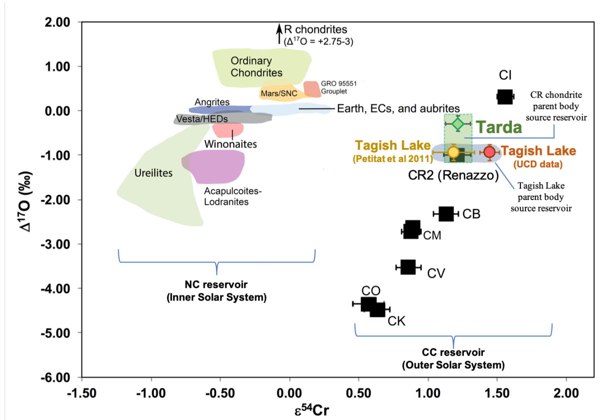

Fig. 1: $\varepsilon^{54}Cr$-$\Delta^{17}O$ diagram showing Tarda (green diamond) represents a previously unknown isotopic reservoir from the CC region. The green shaded region shows a hypothetical common Cr-O isotopic reservoir for Tarda and CR chondrites. The blue shaded region represents the potential Cr-O isotopic reservoir for Tagish Lake parent body. The error bars on the Y-axis show the range of $\Delta^{17}O$ reported in the literature. Error bars for $\varepsilon^{54}Cr$ data are 2SE. Oxygen isotope data for Tarda is from [1], and for Tagish Lake is from [9,10]. Previously reported Cr isotopic data for Tagish Lake is from [11].

Planetary genealogy of Tarda: Tarda represents a unique, previously unknown source isotopic reservoir in the $\varepsilon^{54}Cr$-$\Delta^{17}O$ space (Fig. 1). We discuss two possible scenarios for Tarda's provenance below.

Scenario 1 – Tarda is a CR2 chondrite: Our results reveal that Tarda's nucleosynthetic $\varepsilon^{54}Cr$ signature is indistinguishable from previously reported

CR2 and CR6 chondrites [4], but has a higher $\Delta^{17}O$ value than known CR2 chondrites (see Fig. 1).

However, aqueously altered carbonaceous chondrites, like CI, CM, and CR chondrites, show a wide range of whole-rock oxygen isotope compositions that are thought to be a result of variable degrees of alteration of low $\Delta^{17}O$ anhydrous silicates with relatively high $\Delta^{17}O$ water [12]. As such, various meteorites originating from the same carbonaceous chondrite parent body can define a range in the $\varepsilon^{54}Cr$-$\Delta^{17}O$ space, with a well-constrained $\varepsilon^{54}Cr$ value and a variable $\Delta^{17}O$. For example, this has been recently observed in the regolith CM chondrite Diepenveen compared to other CM chondrites like Murchison and Sutter's Mill [13]. Similarly, for CR chondrites, the less aqueously altered CR6 have a lower $\Delta^{17}O$ compared to the moderately altered CR2 (Renazzo), but all of them have consistent $\varepsilon^{54}Cr$ anomalies [4].

In this scenario, Tarda could be a possible high $\Delta^{17}O$ end-member of the CR2 chondrites. The green shaded region in Fig. 1 shows a hypothetical Cr-O isotopic reservoir for the CR chondrite parent body. If this is true, Tarda could have formed on the CR parent body where it was aqueously altered close to the surface.

Scenario 2 – Tarda is genetically related to Tagish Lake: The Tagish Lake meteorite is classified as an ungrouped C2 chondrite, which shows some affinities to CI and CM chondrites [9,14]. Its mineralogy is dominated by hydrated minerals showing a broad range in the degree of aqueous alteration on the Tagish Lake parent body [14,15]. From the limited information available on Tarda, it seems to have similar mineralogy as Tagish Lake but has a higher proportion of chondrules. Tagish Lake shows a broader range in oxygen isotope composition than other known carbonaceous chondrites, however, it defines a mass fractionation trend parallel to the TFL [10]. Therefore, its range in $\Delta^{17}O$ is narrower, with an average $\Delta^{17}O$ (linearized, TFL slope = 0.528) = -0.93‰ [9,10]. The variation in the oxygen isotopic composition of Tagish Lake is consistent with the degree of aqueous alteration in various specimens [10]. Tarda also shows a wide range of oxygen isotopic composition ranging from CI to CY chondrites [1].

The Cr isotopic composition of Tagish Lake (whole-rock) has been reported by [11], with $\varepsilon^{54}Cr = 1.19 \pm 0.15$ (yellow circle in Fig. 1). This is indistinguishable from our measured $\varepsilon^{54}Cr$ value for Tarda (see Fig. 1). Note that although Tagish Lake (yellow circle in Fig. 1) overlaps with CR chondrites in the $\varepsilon^{54}Cr$-$\Delta^{17}O$ space (Fig. 1), it does not necessarily mean Tagish Lake originated from the CR parent body, only that Tagish Lake parent body and the CR parent body both formed from precursor materials derived from the same Cr-O isotopic reservoir.

However, the $\varepsilon^{54}Cr$ value of a Tagish Lake whole-rock sample measured at UC Davis is distinct from that reported in [11] (see Fig. 1, red circle). This could be a result of small fragments of Tagish Lake analyzed by different labs not being an accurate representation of the whole-rock composition, due to possible small-scale heterogeneities. Tagish Lake shows the highest known deficits (~ -16ε) as well as the highest excesses (~ +139ε) in $\varepsilon^{54}Cr$ anomalies within its constituent minerals [11], therefore, any small-scale heterogeneities could result in significant differences in the measured whole-rock $\varepsilon^{54}Cr$. Moreover, it is possible that the Tagish Lake parent body shows a wider range in $\varepsilon^{54}Cr$ (e.g. as observed in ordinary chondrites), thus defining a wider area in the $\varepsilon^{54}Cr$-$\Delta^{17}O$ space as the Tagish Lake parent body source reservoir (blue shaded region in Fig. 1). This can only be verified with more analyses of a variety of Tagish Lake specimens.

Our study of the $\varepsilon^{54}Cr$-$\Delta^{17}O$ isotope systematics shows Tarda's nucleosynthetic $\varepsilon^{54}Cr$ signature is consistent with that defined by Tagish Lake, thus indicating a possible genetic connection between them.

However, Tarda's higher $\Delta^{17}O$ compared to Tagish Lake presents a contradiction. A higher $\Delta^{17}O$ is usually explained by higher degree of aqueous alteration [12]; but based on the larger amount and appearance of chondrules and anhydrous silicates in Tarda, as well as fewer carbonates, Tarda seems to have experienced less aqueous alteration than Tagish Lake.

Further petrographic and geochemical analyses in the future could reveal if either of the above scenarios is true, or if Tarda is a completely new type of meteorite.

References:

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