THE DIVERSITY OF ANOMALOUS HEDs: ISOTOPIC CONSTRAINTS ON THE CONNECTION OF EET 92023, GRA 98098, AND DHOFAR 700 WITH VESTA. M. E. Sanborn[1], Q.-Z. Yin[1], D. W. Mittlefehldt[2], [1]Department of Earth and Planetary Sciences, University of California at Davis, One Shields Avenue, Davis, CA 95616 USA (E-mail: mesanborn@ucdavis.edu), [2]Astromaterials Research Office, NASA Johnson Space Center, Houston, TX, USA

Introduction: The possibility for multiple parent bodies, instead of a common parent body of Vesta, for eucrites has been suggested based on the variable oxygen isotopic composition observed in some eucrites [1,2]. Recently, we added an extra dimension to the discussion based on the ε^{54}Cr composition of the same eucrites with known Δ^{17}O to compare with the normal eucrites [3]. The combined Δ^{17}O and ε^{54}Cr isotope systematics for Pasamonte, PCA 91007, A-881394, and Ibitira indicate their likely origin from multiple different parent bodies than the normal eucrites. Often the qualifier *anomalous* is used to identify HEDs with Δ^{17}O values that deviate significantly (>3σ) from the mean HED Δ^{17}O. However, variations in eucrites and diogenites also include unique geochemical characteristics such as bulk composition, trace element abundances, or volatile concentrations, in addition to Δ^{17}O. Here, we investigate three such geochemically anomalous HEDs: Elephant Moraine (EET) 92023, Graves Nunataks (GRA) 98098, and Dhofar 700. In addition, to verify the homogeneity of ε^{54}Cr observed for normal HEDs thus far, a set of seven eucrites and diogenites considered normal samples were also investigated.

Samples: EET 92023 is an unbrecciated eucrite with siderophile abundances higher than typically seen in eucrites and a bulk REE composition that resembles the eucrite Moore County [4]. The Δ^{17}O isotopic composition of EET 92023 deviates significantly (~15σ) from normal eucrites with a Δ^{17}O close to that of the anomalous eucrite A-881394 [5].

In contrast, the unbrecciated, non-cumulate eucrite GRA 98098 has a normal Δ^{17}O composition [2]. Two geochemical features make GRA 98098 stand out as unusual compared to other eucrites. First, it is highly enriched in incompatible elements and exhibits a fractionated REE pattern [6]. Second, the volatile element Cl is found in higher concentrations than is typically seen in eucrites within the apatites of GRA 98098 [7].

Dhofar 700 is an unbrecciated diogenite. The Δ^{17}O composition of Dhofar 700 is consistent with the Δ^{17}O values observed in other diogenites [8]. The unusual nature of Dhofar 700 is in the bulk Fe content and abundances of select trace elements. Dhofar 700 is much more enriched in Sc than other diogenites and is among the most Mg-poor diogenite observed [8].

In addition to these three *anomalous* samples, three normal diogenites (Millers Range (MIL) 07001, Johnstown, and Shalka) and four normal eucrites (Stannern, Binda, Moama, and Moore County) were analyzed. A total of ten eucrites and diogenites were analyzed.

Methods: All samples were crushed in an agate mortar and pestle. An approximately 20 mg aliquot of the bulk powder was placed in a PTFE Parr bomb capsule with a 3:1 mixture of concentrated HF and HNO_3 and heated in a 190° C oven for 96 hours.

Chromium was separated from the sample matrix using a three-column chromatography procedure [9]. The purified Cr separates were measured using a Thermo *Triton Plus* thermal ionization mass spectrometer at UC Davis following the procedure described in [3]. The ^{54}Cr/^{52}Cr ratio is reported as parts per 10,000 deviation (ε-notation) from a measured Cr terrestrial standard, NIST SRM 979.

Results and Discussion: Figure 1 shows the position of the normal and anomalous eucrites and diogenites in Δ^{17}O-ε^{54}Cr isotope space. The normal eucrites Stannern, Binda, Moama, and Moore County all overlap in ε^{54}Cr with other normal eucrites [10]. While Moama overlaps in ε^{54}Cr, it does plot slightly above the average Δ^{17}O for the other normal eucrites. However, it is not clear if this reported Δ^{17}O for Moama was made on an acid cleaned aliquot, and as such the reported Δ^{17}O [11] may be affected by terrestrial contamination. This is perhaps unlikely as Moama was recovered from the field where it fell within a few months. Another possibility is an inter-laboratory bias. Either way it requires verification by future work to establish Moama's identity as anomalous, or not. Nevertheless, all of the normal eucrites appear to be consistent in terms of ε^{54}Cr. Likewise, the normal diogenites MIL 07001, Johnstown, and Shalka are consistent with previously measured diogenites, as well as the normal eucrites.

Dhofar 700, with its high bulk Fe content and elevated Sc abundances, plots along with the normal diogenites with an ε^{54}Cr of -0.60 ± 0.09.

Of the two anomalous eucrites analyzed in this study, GRA 98098 does not have a Δ^{17}O that deviates > 3σ from the eucrite average. The ε^{54}Cr value (-0.50 ± 0.08) plots in the extreme right end of the normal eucrites field and therefore only overlaps in ε^{54}Cr with some normal eucrites. The ε^{54}Cr does overlap with some anomalous eucrites as well, such as Asuka 881394, Ibitira, and Bunburra Rockhole, but is clearly resolved in terms of Δ^{17}O value.

EET 92023 has an ε^{54}Cr value of -0.51 ± 0.08. Its Δ^{17}O value is similar to the anomalous eucrites Bunburra Rockhole and Asuka 881394 deviating from the mean HED $\Delta^{17}O$ by approximately 5σ. The $\varepsilon^{54}Cr$ also overlaps both anomalous eucrites as well.

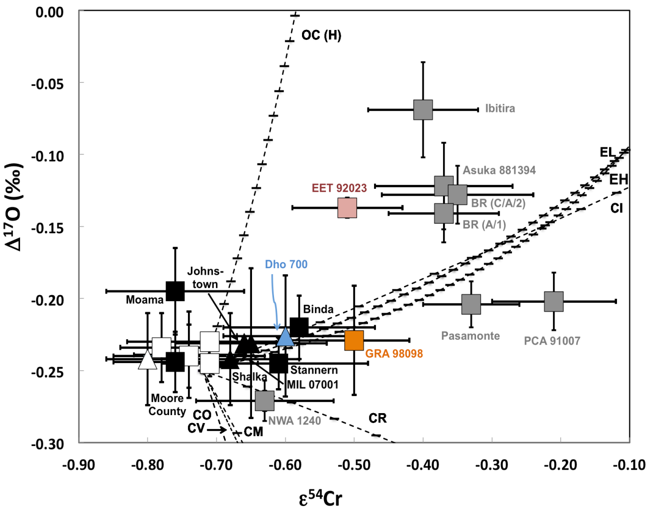

Figure 1. $\Delta^{17}O$-$\varepsilon^{54}Cr$ plot of the normal and anomalous eucrites. Open squares represent literature normal eucrite data. Black squares and triangles represent normal eucrites and diogenites (this study), respectively. Colored squares and triangles are anomalous eucrites and diogenites, respectively (this study). Gray squares are anomalous eucrites from our previous work [3] (BR = Bunburra Rockhole). Literature data are from [1-3,5,8,10-12] and references therein. Various dashed lines represent mixing curves between the average eucrite end member and specific chondritic end-members as indicated, each mark indicates a 2% input of the chondritic end-member.

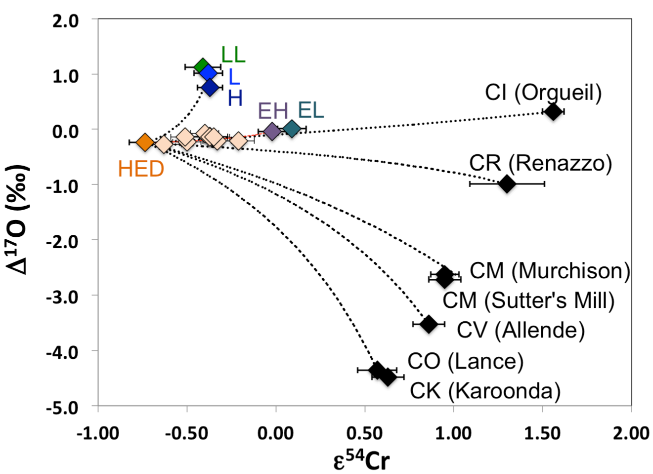

Figure 2. Overview $\Delta^{17}O$-$\varepsilon^{54}Cr$ plot showing mixing lines between normal eucrites with ordinary, enstatite, and carbonaceous chondrites. Literature sources are the same as those in Fig. 1

The position of EET 92023 in $\Delta^{17}O$-$\varepsilon^{54}Cr$ isotope space further confirms its anomalous nature. The similarity of EET 92023, A-881394, and Bunburra Rockhole indicate a common isotopic reservoir for all three, which is distinct from the normal eucrites. Whether some eucrites originated from multiple vestoid parent bodies, or from a common parent body with distinct isotopic reservoirs interior to Vesta, still remains to be determined. In the latter case in which isotopically distinct reservoirs were maintained on a single parent body, a global magma ocean on Vesta would be unlikely. Thus, the resolution of this problem has important implications for the dynamic evolution of small bodies in the early Solar System.

Even with the anomalous geochemical features of Dhofar 700, the combined $\Delta^{17}O$-$\varepsilon^{54}Cr$ systematics does not indicate a different origin from other diogenites. With the normal and geochemically anomalous diogenites now analyzed, there are none that appear to deviate from the average HED composition. This indicates that, as of now, all diogenites formed from a common reservoir/parent body.

The relationship of GRA 98098 with the normal eucrites and other anomalous eucrites is more ambiguous. The $\varepsilon^{54}Cr$ overlaps with some of the normal eucrites, as well as with other anomalous eucrites. However, the $\Delta^{17}O$ is within the normal eucrite average. One possibility is that GRA 98098 is sampling a source reservoir that is a mixture of the normal eucrite composition and a chondritic component. To test the possibility that GRA 98098 is sampling a mixture of end-members, potential mixing lines between end-members of various chondrite and normal eucrites were calculated. As shown in Fig. 1 and Fig. 2, only three possible end-members pass through GRA 98098: EH, EL, and CI. The mixing line between CI chondrite and normal eucrite passes just within error through GRA 98098. It requires closer examination of the mineralogy, chemistry and redox conditions to evaluate whether any of these mixing scenarios could explain the observed features of GRA 98098. In contrast, source mixing cannot account for the observed $\Delta^{17}O$ and $\varepsilon^{54}Cr$ values of EET 92023, and other anomalous eucrites, except NWA 1240 (Figs 1 and 2).

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