HAS DAWN GONE TO THE WRONG ASTEROID?: OXYGEN ISOTOPE CONSTRAINTS ON THE NATURE AND COMPOSITION OF THE HED PARENT BODY. R. C. Greenwood[1], J-A. Barrat[2] E. R. D. Scott[3], E. Janots[4], I. A. Franchi[1], B. Hoffman[5], A. Yamaguchi[6] and J. M. Gibson[1] . [1]Planetary and Space Sciences, The Open University, Walton Hall, Milton Keynes, MK7 6AA, UK (Email: r.c.greenwood@open.ac.uk).[2] Université de Brest, CNRS UMR 6538 (Domaines Océaniques), I.U.E.M., Place Nicolas Copernic, 29280 Plouzané Cedex, France. [3]Hawaii Institute of Geophysics and Planetology, University of Hawaii at Manoa, Honolulu, Hawaii 96822, USA. [4]ISTerre,Grenoble, France. [5]Natural History Museum, Bern, Bernastrasse 15, CH-3005 Bern, Switzerland, [6]National Institute of Polar Research, Tokyo 173-8515, Japan.

Introduction: The howardites, eucrites and diogenites (HEDs) are by far the largest group of achondrites (61 falls, 1001 finds), representing just under 6% of all meteorite falls [1]. Asteroid 4 Vesta is generally considered to be the source of the HEDs, based on spectral evidence [2] and the presence of daughter asteroids between Vesta and the 3:1 resonance [3]. The perceived strength of the HED-Vesta connection was an important motivation in the planning of the current NASA Dawn mission [4]. However, a recent Mg-isotope study has called into question the HED-Vesta link, on the basis that the HED parent body must have been small (<100 km diameter) to satisfy thermal models [5].

In this study, we use the results from the oxygen isotope analysis of 122 HED samples to examine the nature of the HED parent body. We look at its level of isotopic heterogeneity and reexamine the likely origin(s) of HED-like basaltic meteorites with anomalous oxygen isotope compositions [6]. Our aim is to examine whether Vesta is a viable source for the HEDs.

Methods: Oxygen isotope analysis was performed by infrared laser-assisted fluorination [7]. All analyses were obtained on whole rock samples (0.5-2 mg), which were either untreated or leached in EATG to remove weathering products [8]. A minimum of two replicates were analyzed for most samples. Analytical precision (1σ) is approximately: ±0.040‰ for $\delta^{17}O$; ±0.080‰ for $\delta^{18}O$; ±0.024‰ for $\Delta^{17}O$ [7]. $\Delta^{17}O$ values have been calculated using a linearized format [9].

Results: Eucrite, cumulate eucrite and diogenite falls (n=20) give a mean $\Delta^{17}O$ value of -0.239 ±0.014‰ (2σ). This dataset is an expanded version of that previously reported [10]. If diogenites are excluded, and looking only at eucrite and cumulate eucrite falls and finds (n=53), the mean value is unchanged and the precision only mildly decreased, i.e. $\Delta^{17}O$= -0.239 ±0.018‰. Diogenite falls and finds alone (n=43) show remarkably similar variation to the eucrites and cumulate eucrites, with a mean $\Delta^{17}O$ value of -0.242 ±0.014‰ (2σ). Diogenites analyzed as part of this study cover the full compositional range and include the olivine diogenite Mil 07001, which previous studies indicated had an anomalous oxygen isotope composition [11]. Our analysis of Mil 07001 (EATG-washed) indicates that it has a normal oxygen isotope composition, with a $\Delta^{17}O$ value of -0.233±0.004‰ (2σ). Finally, polymict eucrite and howardite falls and finds (n=26) show significantly greater scatter than the eucrite and diogenite data, but essentially have an identical mean $\Delta^{17}O$ value of -0.238 ±0.026‰ (2σ).

Heterogeneity of the HED parent body: The narrow range of $\Delta^{17}O$ values measured in eucrites, cumulate eucrites and diogenites demonstrates that the HED parent body has an extremely homogeneous oxygen isotope composition. In fact, the level of homogeneity is equivalent to that seen in the SNCs [12] and lunar rocks [13]. In comparison, primitive achondrite groups show much greater levels of $\Delta^{17}O$ variation [14], reflecting the less extensive levels of melting on their parent asteroids [15]. Thus, oxygen isotope variation [10], and features such as the extremely low levels of Highly Siderophile Elements in HEDs [16] indicating efficient core formation, point to early large-scale melting on the HED parent body and the development of a magma ocean [16]. The almost identical $\Delta^{17}O$ values of the eucrites and diogenites are consistent with the generally held view that both originate from the same parent body. This is supported by the fact that polymict eucrites and howardites have a similar mean $\Delta^{17}O$ value to both the eucrites and diogenites; being essentially brecciated mixtures of these two lithologies [15]. The relatively high standard deviation of the mean $\Delta^{17}O$ value for the polymict eucrites and howardites may reflect the influence of non-HED impactor material found in at least some of these breccias [15].

Evidence from anomalous eucrites: A relatively small group of HED-like meteorites have anomalous oxygen isotope compositions (i.e. at least 3σ outside the mean value for normal HED samples) [6]. Anomalous eucrites so far identified include: NWA 011 [17], Ibitira [18], Pasamonte [18], NWA 1240 [6], PCA 91007 [6], A-881394 [6] and Bunburra Rockhole [19]. The unbrecciated eucrite EET 92023 is an additional member of this group, with an oxygen isotope composition close to that of A-881394.

There are three possible origins for anomalous HEDs: (i) the HED parent body is isotopically heterogeneous [18]; (ii) they come from a non-HED parent asteroid [6]; (iii) they formed by impact processes [10]. As discussed, the narrow range of $\Delta^{17}O$ values measured in the majority of HEDs excludes the possibility of an isotopically heterogeneous source asteroid. In the case of samples such as NWA 011, Ibitira, A-881394 and probably EET 92023, a range of features would seem to indicate that they are not from the same parent body as the HEDs [6]. For the remaining examples: NWA 1240, PCA 91007, Pasamonte and Bunburra Rockhole, the possibility that their anomalous composition reflects impact processes on the HED parent body cannot be ruled out. Fresh uncertainty concerning their origin comes from new evidence revealed by the recently characterized howardite JaH 556 [20].

Impact processes (JaH 556 and Dho 007): JaH 556 is a weathered impact melt breccia, comprising highly shocked clasts set in a finely recrystallized vesicular matrix. The bulk oxygen isotope composition of JaH 556 is anomalous, with a $\Delta^{17}O$ value of -0.11‰ (Fig.1). In contrast, EATG-washed clasts in JaH 556 have normal HED $\Delta^{17}O$ values (Fig.1). JaH 556 has highly a enriched siderophile element content and contains clasts that appear to be relict chondrules, with olivine compositions consistent with an H chondrite precursor. Both the siderophile element content of JaH 556 and its bulk oxygen isotope composition point to it containing a 10-15% H chondrite component. An important feature of JaH 556 is the fact that the petrographically observable H chondrite-derived component is significantly lower than that calculated on the basis of siderophile element or oxygen isotope data. An impact origin for an anomalous HED could be overlooked in the case where a lower percentage of impactor material is present, or was non-chondritic (i.e. low siderophile element content).

Although officially classified as a cumulate eucrite, Dho 007 is a polymict breccia with a high siderophile element content [21]. It has a very heterogeneous oxygen isotope composition, with $\Delta^{17}O$ values that range from -0.114‰ to -0.181‰. Further work is currently being undertaken on the sample, but it is likely that some form of impact mixing was at least partly responsible for its anomalous oxygen isotope composition.

So is Vesta the source of the HEDs? The oxygen isotope composition of the HEDs requires a source that experienced early global-scale melting. In addition, the lithological diversity of these meteorites indicates that their source asteroid must have been relatively large. The possibility that some anomalous HEDs formed by impact processes is in keeping with the highly brecciated character of these meteorites and also the shattered surface of Vesta, as revealed by Dawn.. The spectral similarities between Vesta and the HEDs is a further major line of evidence linking the two [2]. In conclusion, the oxygen isotope data presented here is consistent with Vesta as the source of the HEDs.

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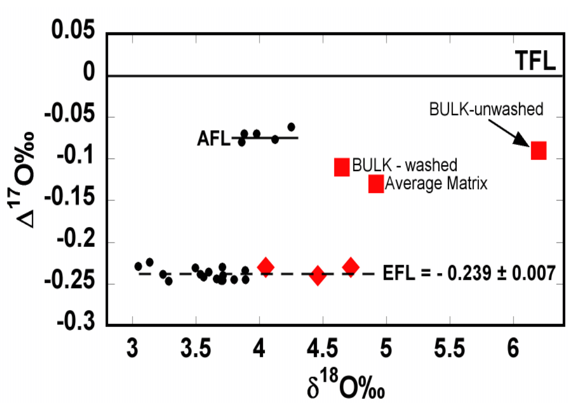

Fig.1 Oxygen isotope composition of JaH 556. Red squares: bulk and matrix samples. Red diamonds: separated clasts. AFL=Angrite Fractionation Line; EFL= Eucrite Fractionation Line; TFL=Terrestrial Fractionation Line. HED and angrite data [10].