# Oxygen isotopic constraints on the origin and parent bodies of eucrites, howardites, and diogenites

## Conference or Workshop Item

**OXYGEN ISOTOPIC CONSTRAINTS ON THE ORIGIN AND PARENT BODIES OF EUCRITES, HOWARDITES, AND DIOGENITES.** Edward R. D. Scott[1], Richard C. Greenwood[2], Ian A. Franchi[2], and Ian S. Sanders[3], [1]HIGP, Univ. Hawaii, Honolulu, HI 96822, USA (escott@hawaii.edu), [2]PSSRI, Open University, Walton Hall, Milton Keynes MK7 6AA, UK, [3]Dept. of Geology, Trinity College, Dublin 2, Ireland.

**Introduction:** Precise oxygen isotope analyses of howardites, eucrites, and diogenites (HEDs) using laser fluorination techniques show that most have indistinguishable oxygen isotopic compositions implying a homogeneous source [1, 2]. But these two studies disagreed on the interpretation of the rare outliers. Wiechert et al. [1] inferred that Ibitira, Pasamonte, and Caldera deviated significantly in their composition and concluded that Vesta was isotopically heterogeneous and had partially melted. Greenwood et al. [2] attributed the anomalous composition of Pasamonte to projectile contamination and inferred that Vesta crystallized from an isotopically homogeneous magma ocean.

We have analyzed the oxygen isotopic composition of additional HEDs to help resolve this issue and constrain the origin of the outliers. Last year we reported oxygen isotopic data for 9 eucrites confirming that Pasamonte and Ibitira are isotopically anomalous and adding A-881394 and NWA 1240 to the list of outliers [3]. Bulk chemical constraints exclude contamination by chondritic projectiles. Instead the four anomalous eucrites were probably derived from separate parent bodies, as inferred for NWA 011 [4] and Ibitira [5].

Here we report oxygen isotope data for 9 additional eucrites, 4 diogenites and 1 dunite that may be derived from the HED body [6], and additional leaching experiments to assess possible weathering effects. To optimize the chances of finding isotopically anomalous samples we selected meteorites showing abnormal chemical, mineralogical or textural features, especially those characteristic of samples with abnormal oxygen isotopes. Because Ibitira and NWA 011 are both unbrecciated and unshocked, like the angrites, we focused on unbrecciated and unshocked eucrites, as well as those with unequilibrated pyroxenes like Pasamonte, which is a breccia.

**Methods:** Oxygen isotope analyses were performed by infrared laser-assisted fluorination [7]. To assess the potential influence of weathering on the composition of the outliers, we used both ethanolamine thioglycollate (EATG) [8] and 6M HCl as both methods are effective at removing terrestrial weathering products in hot and cold desert finds [9]. The latter was also applied to the two fall outliers that we previously analyzed.

**Results:** Oxygen isotope analyses for the 18 eucrites and 4 diogenites are plotted on Fig. 1. Most samples have uniform $\Delta^{17}$O values but five are clearly outliers: Ibitira, Pasamonte, A-881394, NWA 1240, and PCA 91007. Leaching experiments using HCl and EATG on A-881394, NWA 1240, and PCA 91007 indicate that their anomalous isotopic compositions are a primary feature and are not the result of terrestrial weathering.

The 13 eucrites and 4 diogenites with uniform isotopic compositions have $\Delta^{17}$O values lying within 2σ (±0.016‰) of the mean value of -0.242‰. ($\Delta^{17}$O values were calculated using the linearized format of Miller [10]. The five eucrite outliers are NWA 1240, which plots 3.8σ from the mean $\Delta^{17}$O value of the 17 normal eucrites and diogenites, Pasamonte and PCA 91007, which are 4.6-4.8σ away, and A-881394 and Ibitira, which lie respectively 15σ and 21σ from the mean value. NWA 1240 also has a $\delta^{18}$O value that differs significantly as it lies 5.3σ below the mean value of normal eucrites.

*Diogenites.* The 4 diogenites analyzed all have unusual properties. GRA 98108 is one of the few unbrecciated diogenites and contains ~30% olivine [11]. GRO 95555 is unique because it is unbrecciated, unshocked, and granular in texture [12]. NWA 1461 is the most magnesian diogenite known and has a coarse-grained, partly cataclastic texture [13]. Y-75032 is composed of heavily shocked clasts with especially Fe-rich pyroxene in a glassy impact melt matrix [14]. Despite the unusual features of these diogenites, their $\Delta^{17}$O values are indistinguishable from those of the normal eucrites.

*Pasamonte-type eucrites*. To test whether any other eucrites with Pasamonte-like unequilibrated pyroxenes have abnormal oxygen isotopic compositions, we analyzed three unmetamorphosed eucrites, NWA 1000 and Y-981651, which are both type 2-3 eucrites [15, 16], a monomict breccia with Pasamonte-like clasts, Y-82202 [17], and four polymict eucrites with Pasamonte-like clasts, Y-75011, Y-74159, Y-74450, and Y-790260. None have aberrant oxygen isotopic compositions.

*NWA 2968*. Our 12 analyses of leached samples of this dunite, which contains >95% olivine Fa 7.5 [6], scatter much more than typical eucrites because of weathering. However their mean $\Delta^{17}$O value of -0.23±0.02 (1σ) (not plotted) is close to the eucrite-diogenite mean, consistent with the conclusion of Bunch et al. [6] that it comes from Vesta. Our data and those of Greenwood et al. [18] exclude the possibility that NWA 2968 comes from the parent body of main-group pallasites.

*PCA 91007.* The $\Delta^{17}$O value for this unbrecciated eucrite is 4.8σ above the mean eucrite-diogenite value and is indistinguishable from that of Pasamonte. Their $\delta^{18}$O values are also indistinguishable. PCA 91007 contains vesicles, like Ibitira but unlike Ibitira, it does not have sub-eucrite levels of alkalis. Its concentrations of Ni, Os, and Ir [19] are high for a basaltic eucrite and approach the levels in polymict eucrites, as in Pasamonte. However, in both cases, these levels are much lower than would be expected if the oxygen anomalies were due to contamination with an ordinary chondrite projectile.

*Comparison with published data.* Our mean $\Delta^{17}O$ value for the 17 normal eucrites and diogenites of -0.242±0.004‰ (±2 SEM) compares very well with that of Greenwood et al. [2], viz., -0.239±0.003‰. The discrepancy between these values and that of Wiechert et al. [1], -0.218±0.004‰, probably reflects differences in the procedures used to relate the working standard oxygen gas for the mass spectrometer with the internationally accepted reference material: Vienna Standard Mean Ocean Water (VSMOW).

**Discussion:** We infer that the anomalous eucrites do not have aberrant oxygen isotopic compositions because of weathering or projectile contamination. For isotopically normal eucrites, the scatter of our $\Delta^{17}O$ values is close to that obtained on a terrestrial standard (UWG-2 garnet) run during this study. Hence we conclude that the HED parent body was homogeneous with respect to $\Delta^{17}O$, neglecting projectile contamination in howardites [1, 2]. The absence of any samples with $\Delta^{17}O$ values between 2σ and 4σ from the mean eucrite-diogenite value, the agreement between our mean $\Delta^{17}O$ value for the 17 normal eucrites and diogenites and that of Greenwood et al. [2], and the wide spread of the $\Delta^{17}O$ values of the aberrant eucrites all strengthen our conclusion that they are not derived from a heterogeneous HED parent body.

The existence of other kinds of meteorites including main-group pallasites, angrites, and IIIAB irons that plot in the HED region of oxygen isotope space [20] as well as V-type asteroids that lie far from the Vesta family in orbital (a-e-i) space [e.g., 21] also support the idea that the aberrant eucrites come from additional parent bodies.

*Origin of aberrant eucrites.* The six aberrant eucrites including NWA 011 [4] are unbrecciated, except for Pasamonte, and unshocked. Their major element compositions and mineralogy are comparable to those of normal eucrites but most have anomalous minor or trace element abundances. The mean Fe/Mn ratio in NWA 011 pyroxenes (~65) is higher than in normal eucrites [4], but values for the other aberrant eucrites lie within the normal eucrite range of ~28-40 [22]. Bogard and Garrison [23] found that about half the unbrecciated eucrites had Ar-Ar ages of 4.48±0.02 Gyr and suggested they were extracted from Vesta at that time by impact and stored in a small asteroid. Such an asteroid could have escaped the impact heating that affected most of the Vestan rocks during the 4.1-3.5 Gyr epoch [24]. We suggest that the six abnormal eucrites formed in Vesta-like bodies but were similarly removed at ~4.5 Gyr and stored in bodies with diameters of ≈10 km. These small bodies fortuitously escaped the orbital perturbations caused by Jupiter and protoplanets that removed their Vesta-like parents, and were not demolished during the 4.1-3.5 Gyr epoch [25].

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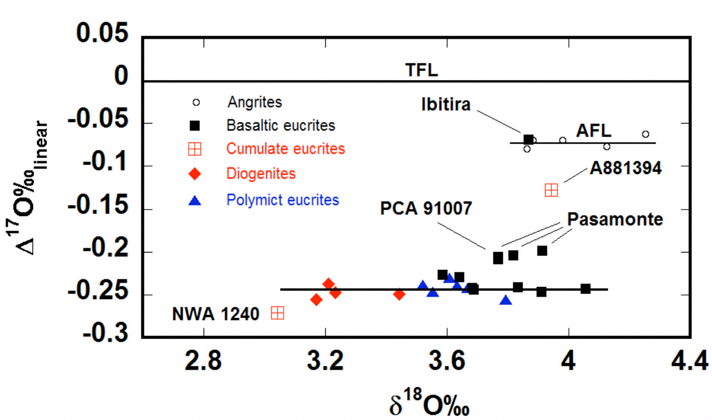


Fig. 1. Oxygen isotope variation diagram for the 22 achondrites analyzed in this study and five angrites from [2]. TFL= terrestrial fractionation line, AFL = angrite fraction line. The line drawn through the HED data excludes outliers and is indistinguishable from that of [2].