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**OXYGEN ISOTOPE COMPOSITION OF THE PRIMITIVE ACHONDRITES** R. C. Greenwood<sup>1</sup>, I. A. Franchi<sup>1</sup>, J.M. Gibson<sup>1</sup> and G. K. Benedix<sup>2</sup>, <sup>1</sup>Planetary and Space Sciences Research Institute, Open University, Milton Keynes, MK7 6AA, UK. E-mail: [r.c.greenwood@open.ac.uk](mailto:r.c.greenwood@open.ac.uk); <sup>2</sup>Department of Mineralogy, Natural History Museum, London SW7 5BD.

**Introduction:** Primitive achondrites are meteorites with near-chondritic bulk compositions and non-chondritic textures [1]. They are thought to be either highly metamorphosed chondrites, or residues formed by low degrees of partial melting [1]. They thus record the conditions at the onset of asteroidal melting and form an important link between chondrites and the extensively melted achondrites (i.e. HEDs, mesosiderites and magmatic irons [1, 2].

In terms of their oxygen isotope composition the primitive achondrites occupy a small region of oxygen three-isotope space immediately below the terrestrial fractionation line (TFL) [2]. This is a crowded area, with the primitive achondrite groups showing significant overlap, not only amongst themselves, but also with differentiated groups such as the HEDs [2]. These overlaps reflect both the heterogeneous isotopic composition of the primitive achondrites and the extensive weathering displayed by many of these meteorites.

To improve our understanding of these important meteorites we are undertaking a detailed isotopic study of the primitive achondrites. Although there is debate about which groups can be classed as primitive achondrites [1], for the purposes of this study we have been investigating the brachinites (n=8), winonaites (n=9), acapulcoites and lodranites (n=20) and various related samples (Divnoe, NWA 4042, LEW 88763, Dhofar 732, NWA 1500).

**Analytical techniques:** Oxygen isotope analyses were performed by infrared laser-assisted fluorination following the procedures outlined by [3]. To reduce the influence of weathering a number of the more altered samples have been leached using a solution of ethanolamine thioglycollate [4]. This treatment removes iron oxides, hydroxides and metallic iron, but not silicate-bound iron.

**Results:** The oxygen isotope composition of all the unleached samples analyzed in this study are shown on Fig. 1. It is clear from this diagram that while the acapulcoites and lodranites define a distinct field there is considerable overlap between the winonaites and brachinites. In particular, Winona and Tierra Blanca appear to fall in the brachinite field, while Brachina plots close to the winonaites. Acid leaching was performed on a number of samples to assess the impact of terrestrial weathering on the measured values. The results of these experiments are shown on Fig. 2. The winonaites Tierra Blanca and Winona display significant isotopic shifts on leaching, such that they move

from the brachinite to the winonaite field. In contrast, there is little difference between the leached and unleached Brachina samples. NWA 725 and Dhofar 125 show slight shifts following leaching (Fig. 2).

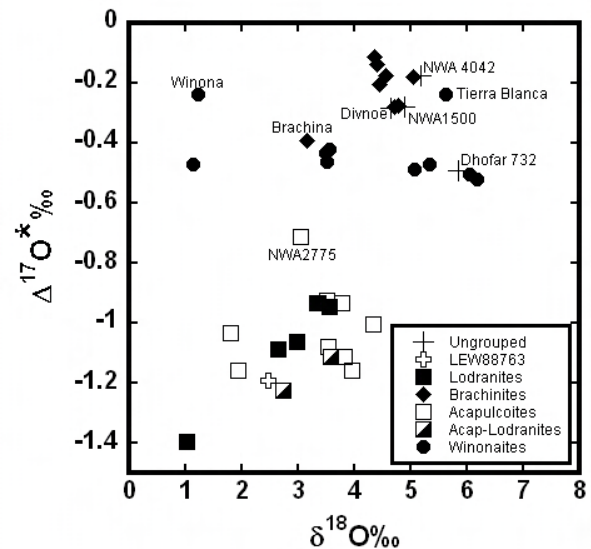


Fig 1.  $\delta^{18}\text{O}$  against  $\Delta^{17}\text{O}^*$  for the primitive achondrites. See key for symbols. The values for  $\Delta^{17}\text{O}^*$  are calculated using the linearised format of [5].

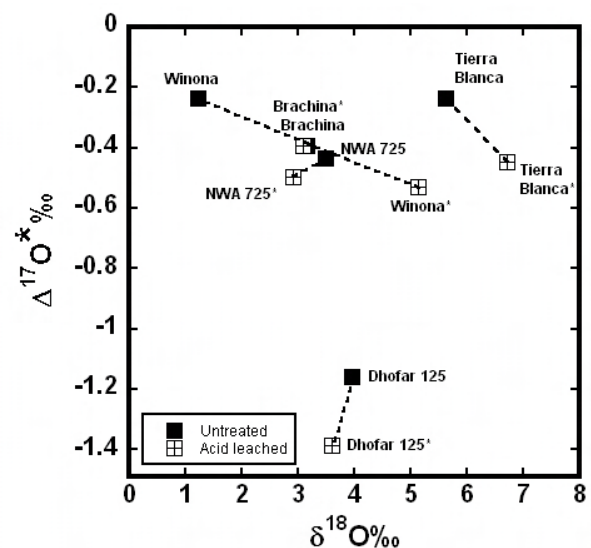


Fig 2. Graph showing results of acid washing selected primitive achondrites. See text for discussion

When the results for the leached samples are incorporated with the other untreated samples a clearer pic-

ture emerges (Fig 3). The winonaites now define a unique linear trend with a mean  $\Delta^{17}\text{O}^*$  [5] of  $-0.48\text{‰} \pm 0.07(2\sigma)$ . Two winonaites NWA 1617 [6] and Y 74025 [2] have been reported with  $\Delta^{17}\text{O}$  values of  $-0.86$  and  $-0.73$  respectively. One of these (NWA 1617) has been reclassified as an acapulcoite and the other may warrant reinvestigation. The brachinites define a relatively diffuse field and, as discussed, Brachina itself lies close to the winonaites. The mean  $\Delta^{17}\text{O}^*$  value for the brachinites, including Brachina, is  $-0.22\text{‰} \pm 0.18(2\sigma)$  and excluding Brachina this becomes  $-0.19\text{‰} \pm 0.13(2\sigma)$ . The acapulcoites-lodranites define a broad field on Fig. 3 and have a mean  $\Delta^{17}\text{O}^*$  value of  $-1.05\text{‰} \pm 0.30(2\sigma)$ .

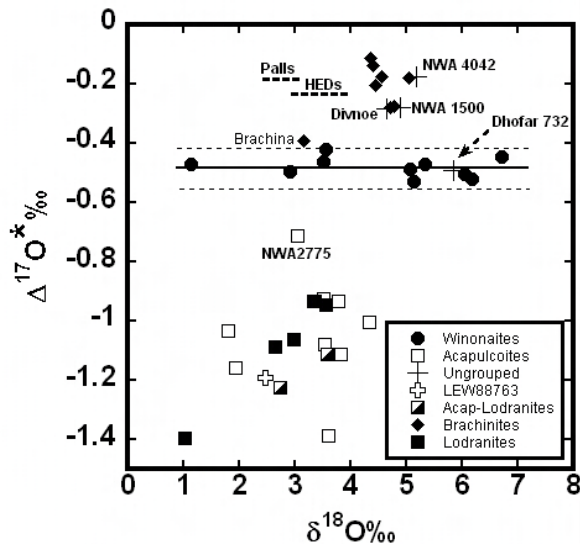


Fig 3.  $\delta^{18}\text{O}$  against  $\Delta^{17}\text{O}^*$  for the primitive achondrites incorporating results from acid washes of selective samples. Mean  $\Delta^{17}\text{O}^*$  value for the winonaites shown as a solid line, dashed line either side is  $\pm 2\sigma$  error. See key for symbols. Palls = pallasites

**Discussion:** Compared to more differentiated groups (HEDs, mesosiderites and pallasites), the primitive achondrites show significantly greater levels of oxygen isotope variation (Fig. 3). This is a reflection of three factors: i) individual samples are often highly weathered, ii) classification criteria sometimes result in apparently ambiguous assignments and iii) the primitive achondrites display high levels of primary isotopic heterogeneity. In trying to understand the earliest stages of planetary differentiation we need to quantify the amount of inherent heterogeneity within the primitive achondrites. To do this the influence of weathering needs to be removed and unique classification criteria established for each group. It is clear that we are still some way from this ultimate goal.

Preliminary acid leaching studies demonstrate that the influence of weathering can be removed to reveal a more coherent picture, as appears to be the case for the winonaites. However, at least some of the wide variation in the acapulcoite-lodranite group may be due to weathering.

As discussed, Brachina plots away from the other brachinites and lies close to the winonaite field (Fig. 3). Compared to other brachinites Brachina is distinct in containing significant plagioclase ( $\sim 10\%$ ) [1]. It is therefore a possibility that Brachina is a unique meteorite and not related to the other brachinites. However, brachinites are a geochemically diverse group and are unlikely to be samples from a single parent body [1, 7]. A number of other primitive achondrites (NWA 4042, Divnoe, NWA 1500, Dhofar 732,) although not members of the groups discussed here, have similar oxygen isotope compositions. In addition, LEW 88763, although officially classified as a brachinite, has an oxygen isotope composition similar to the acapulcoites and lodranites [2] (Fig1, 3) In the light of such relationships some redefinition of the classification criteria for existing primitive achondrite groups may be warranted.

Even despite the problems of weathering and classification the primitive achondrites show significantly greater oxygen isotope variation than differentiated groups (Fig. 3). This variation is reflected in the  $2\sigma$  error on the mean  $\Delta^{17}\text{O}^*$  values which decrease in the order acapulcoites-lodranites > brachinites > winonaites and presumably reflects increasing degrees of isotopic homogenization.

**Conclusions:** Primitive achondrites preserve evidence of the earliest stages of planetary melting and hence bridge the gap between chondrites and differentiated achondrites. In using oxygen isotopes to study this process the influence of weathering needs to be eliminated and robust classification criteria defined. Initial results appear to confirm the conclusions of earlier studies [2] that the primitive achondrites retain significant levels of primary oxygen isotope heterogeneity.

**References:** [1] Middlefehldt D.W. et al. (1998) *Reviews in Mineralogy* 36, (4) 1-195. [2] Clayton R. N. and Mayeda T. K. (1996) *Geochim. Cosmochim. Acta* 60, 1999-2018. [3] Miller M. F. et al. (1999). *Rapid Commun. Mass Spectrom.* 13, 1211-1217. [4] Cornish L. and Doyle A. (1984) *Palaeontology* 27: 421-424. [5] Miller M. F. (2002) *Geochim. Cosmochim. Acta* 66, 1881-1889. [6] *Met. Bull* (2004). 88, MAPS 39, A215-A272. [7] Krot A. N. et al. (2003) *Treatise on Geochemistry* 1, 83-128.