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## Oxygen isotopic and petrological constraints on the origin and relationship of IIE iron meteorites and H chondrites

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**OXYGEN ISOTOPIC AND PETROLOGICAL CONSTRAINTS ON THE ORIGIN AND RELATIONSHIP OF IIE IRON METEORITES AND H CHONDRITES.** K. McDermott<sup>1</sup>, R. C. Greenwood<sup>1</sup>, I. A. Franchi<sup>1</sup>, M. Anand<sup>2</sup> and E. R. D. Scott<sup>3</sup>. <sup>1</sup>PSSRI, The Open University, Milton Keynes MK7 6AA, UK. <sup>2</sup>Dept. of Earth and Envir. Sci., The Open University, Milton Keynes MK7 6AA, UK. <sup>3</sup>HIGP, Univ. Hawaii, Honolulu, HI 96822, USA. Email: k.h.mcdermott@open.ac.uk.

**Introduction:** Silicate inclusions are observed in about half of the 21 IIE iron meteorites. These diverse objects can be used to constrain the formation and evolution of the IIE irons by studying their major element chemistry and oxygen isotopic composition. Silicate inclusions vary from chondrule-bearing clasts, such as the inclusions located in the IIE-An meteorite Netschaëvo [1], to highly elongated ribbons of quenched basaltic melt such as those observed in Weekeroo Station. Such variation represents a range of thermal histories, and various degrees of melting and cooling from one or multiple parent bodies [1].

On the basis of their similar mineralogy, composition and oxygen isotopic signatures, a possible relationship between the H chondrites and IIE irons has been proposed [2]. However high precision laser fluorination of the H chondrites (n=9) [3], showed a relatively poor overlap with IIE silicate inclusion data collected by conventional methods of oxygen isotope analysis [2]. In order to provide more insight into the potential relationship between the H chondrites and then IIE irons, high precision analysis of the IIEs silicates is required [4]. The present study was undertaken to address this deficiency and provide high precision laser fluorination data of the IIE silicates that could be compared directly to previous high precision H chondrite analysis. In addition to comparing the oxygen isotopic composition of the two meteorite groups, a detailed geochemical investigation of the silicate-bearing IIE irons is currently being undertaken. A study of the metal in IIE irons and the possible relationship with H chondrites is discussed by [5].

**Analytical techniques:** Oxygen isotope analyses were performed by infrared laser-assisted fluorination [7]. The IIE samples studied were: Colomera (feldspar, augite mineral separates), Kodaikanal (augite, glass), Miles, Netschaëvo, Tarahumara, Weekeroo Station (augite and bulk silicate), Watson 001 and NWA 5608. In addition, we have also carried out new oxygen isotope analyses of 12 equilibrated H chondrites.

Geochemical analysis were performed using a Cameca SX-100 Electron Microprobe and a FEI Quanta 200 FIB-ASEM. The analysis undertaken includes textural observation and quantitative point analysis of individual phases observed and large area element mapping. The samples analysed include polished thin sections, polished mounts and large area slabs that allow study of multiple inclusions from a single sample.

**Petrographic analysis:** Samples examined so far display similar textures and compositional variability to that previously reported [1]. Textures range from the chondritic chondrule-bearing inclusions of Netschaëvo (Fa<sub>16</sub>) and chondrite-like Watson 001 (Fa<sub>20</sub>) to the

highly differentiated Kodaikanal (An<sub>42</sub>, Ab<sub>0.4</sub>, Or<sub>57</sub>). Compositional variation reflects differing degrees of melting experienced by the individual members of the group. Netschaëvo has been reported as the most primitive of the IIE group [1], and our sample reveals the presence of complete and relict chondrules located in a number of silicate inclusions (Fig. 1), similar to previously observed [8,9].

**Oxygen isotope analysis:** Oxygen isotope results for silicate inclusions in IIE irons show a range of  $\Delta^{17}\text{O}$  values from 0.58‰ for Netschaëvo to 0.89‰ for Colomera (Fig 2). The mean  $\Delta^{17}\text{O}$  value for the eight IIE samples studied is  $0.71 \pm 0.11\text{‰}$  ( $2\sigma$ ). In terms of their  $\delta^{18}\text{O}$  values the IIE silicates show a considerable range in values from 3.06‰ for Netschaëvo to 6.25‰ for Miles, the mean  $\delta^{18}\text{O}$  is  $4.40 \pm 0.59\text{‰}$  ( $2\sigma$ ). As pointed out by [10], this most likely reflects the fact that some of the IIE silicate inclusions are the products of extensive differentiation. Mineral separates from Kodaikanal ( $\Delta^{17}\text{O} = 0.77 \pm 0.02\text{‰}$  ( $2\sigma$ )) and Colomera ( $0.89 \pm 0.02\text{‰}$ ) appear to define distinct mass fractionation lines. For comparison, the oxygen isotope analysis of 12 equilibrated H chondrites gave a mean  $\delta^{18}\text{O}$  of  $4.11 \pm 0.56\text{‰}$  ( $2\sigma$ ) and  $\Delta^{17}\text{O}$  of  $0.74 \pm 0.10\text{‰}$  ( $2\sigma$ ).

**Discussion:** In contrast to previous results, the new high precision laser fluorination data for the IIE silicates reveals almost complete overlap with the equilibrated H chondrites (Fig. 2). The two sets of data are broadly comparable with the exception of three outliers, Netschaëvo, Colomera and Miles. If data for the un-equilibrated H chondrites (H3) [6 and this study] were added this would extend the range of  $\Delta^{17}\text{O}$  for H chondrites down to 0.43‰. However, un-equilibrated H chondrites do not extend the range of H chondrites to higher  $\Delta^{17}\text{O}$  values and therefore Colomera remains outside the H chondrite range. The nature of the sample of Miles analysed is unknown and so it is not possible to determine if the high  $\delta^{18}\text{O}$  value is due to fractionation effects. Analysis of a characterized sample is planned. The broad range in  $\Delta^{17}\text{O}$  values for the members of the IIE group is much larger than that of homogenised planetary bodies such as Mars ( $0.026\text{‰}$  { $2\sigma$ } [11]) or Vesta ( $0.014$  { $2\sigma$ } [11]) so the IIEs clearly originate from a heterogeneous parent body or bodies, such as 6 Hebe as suggested by [12].

The IIEs display a range of radiogenic ages (primarily Ar-Ar) and are used to define 2 sub-groups of IIEs. The older IIEs, (4.41 – 4.49 Ga) include most of the differentiated IIE silicates, that may have been formed by differentiation within the H chondrite body [13]. However, the range of  $\Delta^{17}\text{O}$  values from this sub-group is as extensive as all the IIEs. Therefore, if formed by a

different process to the younger IIEs, then the melting that produced the older differentiated IIEs was localised in an area of the parent body, or bodies that was still heterogeneous with respect to oxygen.

Colomera is a differentiated, older IIE, which falls away from the oxygen isotope H chondrite field and the other IIE values (Fig 2). The silicates in this IIE must have sampled material distinct from the current H chondrite population, either elsewhere on the H chondrite body or on a different body. As well as having a relatively low  $\Delta^{17}\text{O}$ , the mineral composition of the silicate inclusions in Netschaëvo are more reduced than H chondrites [9] and so may also be derived from a distinct parent body. The younger group (3.68-3.74 Ga [13]) with the exception of Netschaëvo, all plot towards the top of the H chondrite field, and are thought to have resulted from either a similar process as the older group and then their isotopic ages may have been reset by a shock heating event. However Kodaikanal is highly differentiated and so may be the result of differentiation of the impact melt of the same body or bodies. The presence of chondrules in the silicate inclusion of Netschaëvo, previously observed [8,9] suggests that the precursor material for the IIEs must have been chondritic (Fig. 1).

**Conclusion:** As more data has been collected from the different silicate bearing members of the IIEs the evidence for a genetic relationship with the H chondrites has become more convincing in line with the petrographical similarities. The heterogeneous oxygen isotopic compositions of the IIEs are consistent with impact melting on the H chondrite parent body. Further work investigating the isotopic variability within individual meteorites and the relationship to mineralogy will be used to explore the origin of the isotopic variability in IIEs.

**References:** [1] Mittlefehldt D. W. *et al.* 1998. In *Rev. Min.* 36 (4) 1-195. [2] Clayton R. N. and Mayeda T. K. 1996. *GCA* 60:1999-2018. [3] Folco L. *et al.* 2004. *GCA* 68:2379-2397. [4] Goldstein J. I. *et al.* 2009. *Chemie der Erde* 69:293-325. [5] Wasson T. and Scott E. R. D. 2011. *This volume*. [6] Clayton R. N. *et al.* 1991. *GCA* 55:2317-2337. [7] Miller M. F. *et al.* 1999. *Rapid Commun. Mass Spectrom.* 13:1211-1217. [8] Bunch T.E. *et al.* 1970, *CMP*, 25:297. [9] Olsen E. and Jarosewich. E. 1971, *Science*, 174:583. [10] Franchi I. A. 2008. *Rev. Min. Geochem.* 68:345-397. [11] Greenwood R. C. *et al.* 2005. *Nature*, 435:916-918. [12] Gaffey M. J. and Gilbert S. L, 1998. *MAPS*, 33:1281-1295. [13] Bogard D. D. *et al.* 2000, *GCA*, 64:2133-2154. [14] McDermott K. H. *et al.* 2010, *MAPS*, 45:133.

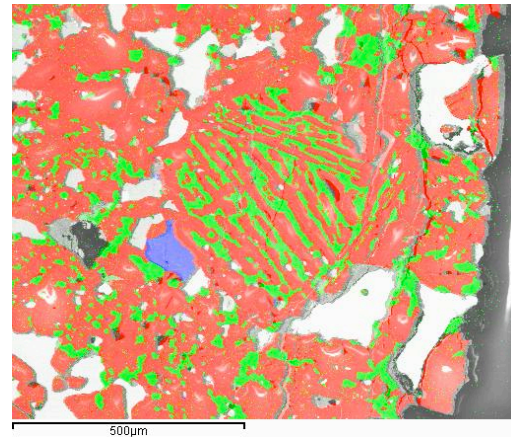


Figure 1: False colour image, overlaying a backscattered image, of a relict chondrule located in the silicate inclusion of Netschaëvo. Sample courtesy of the Smithsonian Institute. Red: Mg rich area, showing the presence of Olivine and Orthopyroxene. Green: Al and Na rich areas showing the presence of Alkali feldspar. Blue: Represent the Ca and P rich areas indicating the presence of calcium phosphata

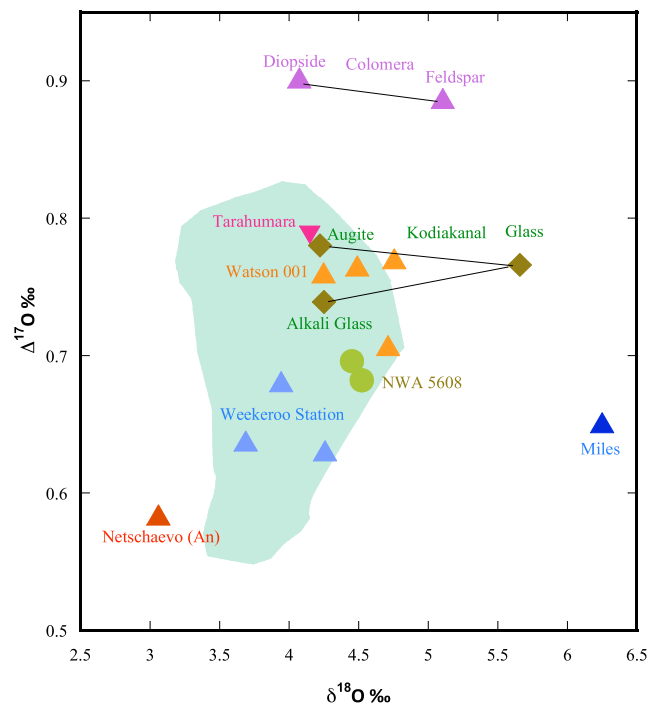


Figure 2: High precision laser fluorination IIE silicate data (coloured points) [14] and the high precision H chondrite data (aqua shaded area) [3 and 6]. The graph shows the location of the different IIE members.