THE IIE IRON METEORITE FAMILY TREE: A STUDY OF THE PETROGRAPHY AND OXYGEN ISOTOPES OF THIS NON-MAGMATIC GROUP.

K. H. McDermott[1], R. C. Greenwood[1], I. A. Franchi[1], M. Anand[1] and E. R. D. Scott[2]. [1]Planetary & Space Sciences, The Open University, Milton Keynes MK7 6AA, UK. [2]HIGP, Univ. Hawaii, Honolulu, HI 96822, USA.
Email: k.h.mcdermott@open.ac.uk.

Introduction: We are currently undertaking a petrographic and isotopic investigation of silicate inclusions in IIE Iron meteorites, in order to further understand the formation conditions and early evolution of this important group. All the silicate-bearing members of the IIEs that have been dated so far define two distinct age groups, the Old (4.1-4.5Ga) [1] and the Young (~3.7 Ga) [2]. Comparing the properties of the samples in each of these groups should help to define how and why the younger group formed.

This ongoing study of the IIE silicate inclusions has previously clarified that there is indeed a very strong similarity between the oxygen isotopic composition of the IIEs and H chondrites [3]. Although subject to greater uncertainty, previous results had suggested that the overlap was only partial [4]. These new high precision results across a suite of well characterized IIEs offers the opportunity to develop our understanding of the nature of the relationship between the IIE and the H chondrites.

Analytical techniques: Oxygen isotope analyses were performed by infrared laser-assisted fluorination [5]. The IIE samples studied were (bulk silicate unless otherwise stated): Colomera (feldspar, augite mineral separates), Kodaikanal (augite, glass), Miles (Feldspar), Netschaëvo, Tarahumara, Weekeroo Station (Feldspar) (augite and bulk silicate), Watson 001, NWA 5608, Garhi Yasin and Techado. In addition, we have also carried out new oxygen isotope analyses of a further 12 bulk samples of equilibrated H chondrites, 2 un-equilibrated H chondrites [3] and used data from H chondrite falls [6]. Textural and quantitative point analysis were performed using a Cameca SX-100 Electron Microprobe and a FEI Quanta 200 FIB-ASEM.

Major element composition and textural analysis: Textures range from the chondrule-bearing inclusions of Netschaëvo (Fa_{14}) and chondrite-like Watson 001 (Fa_{20}) to the highly differentiated Kodaikanal (An_{42}, $Ab_{0.4,\ Or57}$). Compositional variations reflect different degrees of melting and differentiation experienced by the individual members of the group. The volatile major element concentrations of the mineral orthopyroxene differs between the two age groups of the IIE silicates, most obviously in the case of MnO (Fig 1), which may be the result of volatile loss after an impact or due to initial low MnO in these samples.

Oxygen isotope analysis: Oxygen isotope data for silicate inclusions in IIE irons show a range of $\Delta^{17}O$ values from 0.57 ‰ for Garhi Yasin to 0.90‰ for Colomera (Fig. 2). The mean $\Delta^{17}O$ value for the IIE samples studied is 0.71 ± 0.11‰ (2σ). In terms of the $\delta^{18}O$ values, the IIE silicates show a considerable range in values from 3.06‰ for Netschaevo to 6.25‰ for Miles separates, the mean $\delta^{18}O$ is 4.7 ± 0.59‰ (2σ). Mineral separates from Kodaikanal, Colomera and Miles, appear to define distinct mass fractionation lines within individual samples. For comparison, the oxygen isotope analysis of 12 equilibrated H chondrites gave a mean $\delta^{18}O$ of 4.16 ± 0.56‰ (2σ) and $\Delta^{17}O$ of 0.72 ± 0.10‰ (2σ) [3].

Discussion: High-precision laser fluorination data for the IIE silicates display substantial overlap with the high-precision data for equilibrated H chondrites (Fig 2) [3]. $\Delta^{17}O$ values for the IIE group show a significantly larger range then is found for differentiated planetary bodies such as the moon (± 0.021 ‰ (2σ) [7]) (Mars (0.026‰ (2σ) [8]) or Vesta (0.014 ‰ (2σ) [8]), hence the IIEs clearly originated from a heterogeneous parent body or bodies. [3]

The majority of the IIE samples analysed form a cluster that plots in the equilibrated H chondrite field, (Fig. 2). In the case of Miles, Weekeroo Station and Kodaikanal, the bulk analysis plot in the H chondrite field but feldspathic mineral separates have greater $\delta^{18}O$ values with similar $\Delta^{17}O$, most probably the result of equilibrium inter-mineral isotopic fractionation.

A small subset of IIE samples plot away from the main equilibrated H chondrite field (Fig 2). Colomera has a similar $\delta^{18}O$ to the other IIE members but a much larger $\Delta^{17}O$ which plots within the oxygen isotope field for the L chondrite meteorite group. Therefore it is possible that Colomera formed from a distinct parent body similar to the L chondrites. The three primitive IIE silicates form a second outlier and have a similar $\Delta^{17}O$ composition to that of the un-equilibrated (H3) chondrites. These relationships can also be seen on a plot of $\delta^{18}O$ v. $\delta^{17}O$ (Fig 3). Three distinct trends are displayed. The most prominent represents the differentiated IIE meteorites and equilibrated H chondrites, the second for the primitive IIE silicates and un-equilibrated H chondrites and the final one for Colomera and the L3 chondrites which plot slightly above the line for the differentiated IIE meteorites. The data for the H and L chondrites is also plotted.

In terms of their oxygen isotopic composition no obvious difference between the two age groups of the IIEs has been observed. In contrast on a plot of MnO v. MgO differences in the Mn concentrations in the two age groups are observed (Fig 1). Variation in the MnO content (Fig 1), when compared to MgO, suggests that the Young group were either reset by a localised impact event, resulting in the depletion of Mn from the local system, or the younger group formed from material with lower Mn concentrations compared to the older group. The age of the younger group may signify the date of a possible impact between a chondritic parent body and a NiFe body which reset some IIE ages but not all, as proposed by [9].

Conclusion: From oxygen isotopic data alone it is reasonable to suggest that the differentiated IIE silicates are genetically linked to the equilibrated H chondrites as they fall along identical trend lines, with similar $\delta^{18}O$ values, the only offset related to mass fractionation associated with differentiation processes (Fig 2). Similarly, the primitive IIE silicates are linked to the unequilibrated H chondrites. In order to preserve the distinction between equilibrated and unequilibrated H chondrite material through the IIE (impact?) requires either a fortuitous distribution of heat input into a complex target or that the various IIE precursor materials were at a temperature close to their peak H chondrite metamorphic temperatures and were subsequently heated by similar amounts during the IIE forming impact. This clearly argues that the H3 and H4-6s originate from a common, heterogeneous parent body. The exception to this is Colomera where the oxygen data shows a possible relationship with the L chondrites. Further work is required to explore whether there is additional petrographic or trace element evidence for this possible relationship.

The two age groups of the IIE silicates were possibly formed due to a localised impact which reset the ages and removed volatile elements such as Mn from the silicate melt. Future work will be to follow up this theory by analysing the variation of other volatile major and trace elements between these two distinct age groups.

References: [1] Mittlefehldt D. W. *et al*. 1998. In *Rev. Min.* 36 (4) 1-195. [2] Bogard D. D. *et al*, 2000, *GCA*, 64:2133-2154. [3] McDermott K. H. *et al*, 2010, *MAPS, 45:133* [4] Clayton R. N. and Mayeda T. K. 1996. GCA 60:1999-2018 [5] Miller M. F. *et al*. 1999. *Rapid Commun. Mass Spectrom.* 13:1211-1217. [6] Folco L. *et al*. 2004. *GCA* 68:2379-2397. [7] Hallis L. *et al*. 2010. *GCA* 74 6885-6899 [8] Greenwood R. C. *et al*, 2005. Nature, 435:916-918. [9] Bogard D.D 2011: *Chemie Der Erde-Geochemistry*, 71**,** 207-226.

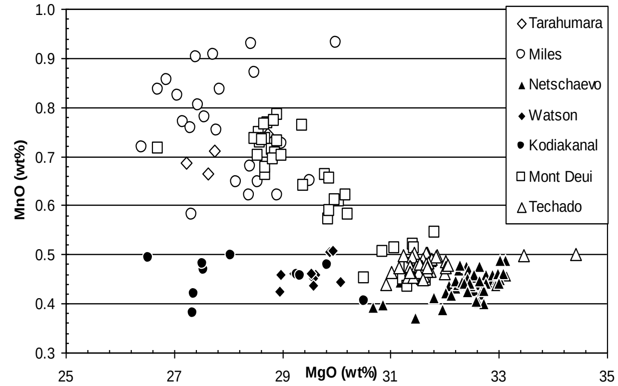

Figure 1: MgO vs. MnO showing the variation in orthopyroxene for the Old (open symbols) and Young (closed symbols) IIE meteorite groups.

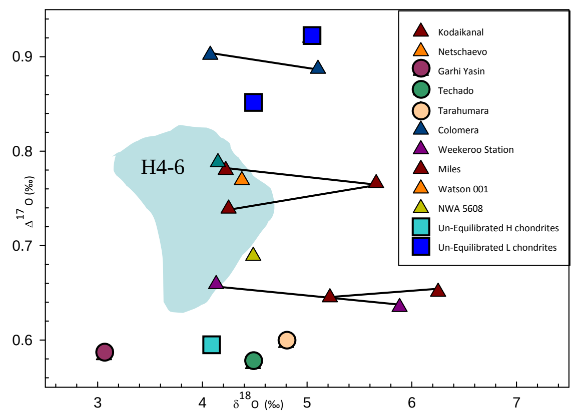

Figure 2: $\Delta^{17}O$ plot of the IIE silicates, H chondrites (Blue cloud) [3 and 6] and un-equilibrated L chondrite data [4]
Round symbols – Primitive IIEs
Triangle symbols - Differentiated IIEs

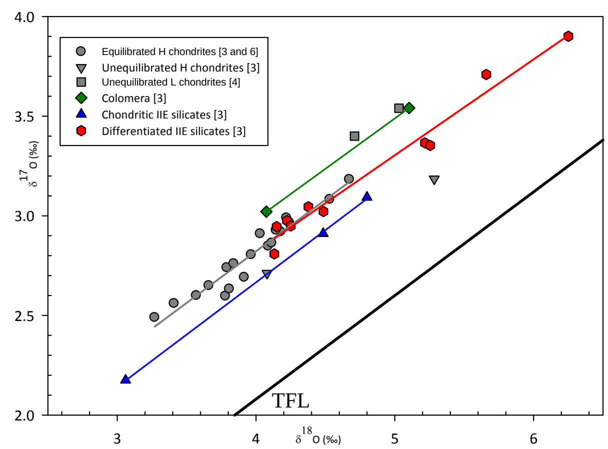

Figure 3: Three isotope plot of the oxygen isotopic composition of the silicates in the IIE Irons and the relationship with the ordinary chondrites [3 and 6]. L chondrite data [4].