

CHEMICAL CONSTRAINTS ON THE PARENT BODIES OF NC- and CC-TYPE MAGMATIC IRON METEORITES. C. D. Hilton, R. D. Ash, H. A. Tornabene, and R. J. Walker; Department of Geology, University of Maryland, College Park, Maryland, 20742, USA (chilton@umd.edu)

Introduction: It is now well established from nucleosynthetic isotopic compositions of certain elements (e.g., Cr, Ti, Ni, Mo, Ru, W) observed in bulk meteorites that isotopically distinct domains, referred to as the non-carbonaceous (NC) and carbonaceous (CC) domains [1], were present in the early Solar System [1-8]. These domains were spatially and/or chronologically separated during the first few Myr of Solar System history, possibly with the NC and CC domains representing the inner and outer Solar System, respectively [1, 3-6]. The cause(s) of the isotopic heterogeneity, within and between the NC and CC domains, is not well established, with potential options including thermal destruction of certain carrier phases [2, 5], or late addition of isotopically distinct materials [3, 6].

Whether or not these isotopically distinct domains were also chemically distinct remains an open question. Differences in chemical compositions may provide insights to the processes driving the isotopic heterogeneity, as well as the spatial extent of each domain. If, for example, these domains reflect inner and outer Solar System materials, are chemical compositions of CC parent bodies consistent with forming in a more oxidizing environment, as has been envisioned by some for the outer Solar System [5]? If isotopic heterogeneity is primarily a result of thermal processing, do isotopic compositions correlate with volatile element enrichments/depletions?

New insights to the chemical compositions of the NC and CC domains may be gained from the study of siderophile elements, especially highly siderophile elements (HSE; Re, Os, Ir, Ru, Pt, Pd), in magmatic iron meteorite groups. Magmatic irons are interpreted to sample portions of asteroidal cores, based upon chemical compositions that can be explained largely by fractional crystallization [9-11]. Because cores concentrate the siderophile elements present in a planetary body, their compositions can be used to determine the chemical characteristics of the entire parent body.

The HSE parental melt compositions of magmatic iron meteorite groups can be calculated by applying experimentally-determined solid metal-liquid metal partition coefficients [9-11]. Successful modeling of core crystallization also requires accurate estimation of initial S, P and C concentrations, and tracking their evolution during melt crystallization, as they strongly affect HSE partitioning coefficients [12]. By matching the HSE patterns of irons from a group to the appropriate chemical model, it is possible to constrain the pa-

rental melt S, P and C contents, and from there calculate the composition of the bulk core.

Parental melt concentrations of the HSE provide insights to the oxidation conditions of a parent body. If it is assumed the parent body had a broadly chondritic bulk composition, the abundances of HSE present in a core primarily reflect the ratio of reduced iron, which migrates to the core during melting and differentiation, to the oxidized iron, which remains in the silicate portion if the planetesimal [9-11]. Additionally, HSE span a range of 50 % condensation temperatures (T_{50}) from 1817 K (Re) to 1318 K (Pd) [13], allowing for an assessment of volatility trends among NC/CC parent bodies. Past studies have constrained the parental HSE compositions for the IIC [14], IVA [10], and IVB [9] groups, as well as the South Byron Trio (SBT) grouplet [11]. Initial estimates of the parental melt HSE abundances of the IIAB, IIIAB, IID, IIF, and IIIF iron meteorite groups are reported here.

Analytical Methods: Iron meteorites were analyzed for HSE concentrations by ablating two to six tracks (1.5-2 mm each) across each meteorite piece using laser ablation ICP-MS at the University of Maryland [9-10]. Additionally, 0.04-0.5 g iron meteorite chips were analyzed for bulk concentrations of HSE by isotope dilution [9-11]. Osmium concentrations were determined using a *Triton* thermal ionization mass spectrometry and concentrations of the other HSE were determined using a *Neptune Plus* multi-collector inductively-coupled plasma mass spectrometer.

Results: Results of fractional crystallization models were iteratively fitted to the abundances of HSE for each group or grouplet by varying initial S, P, and C abundances. Calculated initial HSE abundances (bulk core) for each group were determined from the best fit models. Modeling methods have previously been reported in [11]. Calculated parental melt HSE compositions are shown in **Fig. 1**.

Discussion: The CC-type iron meteorite parent bodies exhibit a larger range of absolute and relative parental melt HSE abundances, compared to NC-type iron meteorite parent bodies. Cores of CC-type bodies range from an estimated 3 to 19 % the mass of the body, while this range is only 17 to 25 % for NC-type bodies. One possible interpretation of this is that the variance reflects a formation environment for the CC-type irons that was more heterogeneous with respect to oxidation state than the NC domain. Further, although the examples are limited, the cores of the CC-type parent bodies are, on average, relatively smaller than the

NC-type bodies. This suggests that the CC domain was a generally more oxidizing environment, consistent with some models for the early outer Solar System [5]. However, no clear chemical dichotomy exists for parental melt HSE compositions, e.g., patterns for IIC (CC) and IVA (NC) parental melts are virtually identical (Fig. 1).

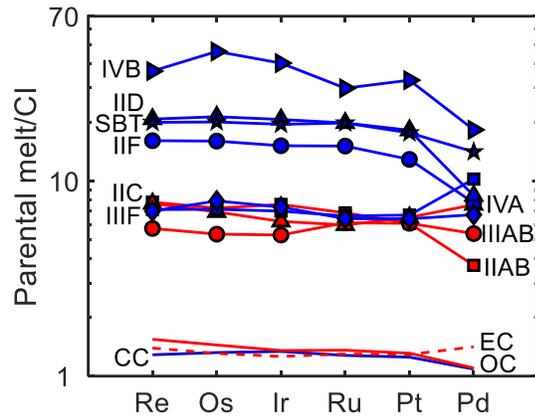


Figure 1. Calculated parental melt compositions of HSE for group IIAB, IIC, IID, IIF, IIIAB, IIIIF, IVA, IVB irons, as well as the South Byron Trio (SBT) grouplet. Published data are from [9-11, 14]. Average HSE compositions of carbonaceous chondrites (CC), ordinary chondrites (OC), and enstatite chondrites (EC) are shown for reference and taken from [15-16]. Blue and red symbols reflect CC- and NC-type bodies, respectively, based on prior Mo and Ru isotope composition measurements [4-8]. HSE are ordered from left to right with respect to decreasing 50% condensation temperatures [13].

The Pd/Os vs. Os (ppm) of the magmatic iron meteorite parental melts are compared in Fig. 2. Osmium concentrations reflect the relative oxidation conditions of the different bodies while Pd/Os ratios reflect volatility processes ≥ 1318 K [13]. Variation in the Pd/Os ratios of NC-type iron meteorite parent bodies are decoupled from differences in relative oxidation conditions, whereas CC-type irons form a slight negative trend. The Pd/Os ratios of NC-type bodies increase with decreasing content of more volatile elements, such as Ga ($T_{50} = 968$ K) and Ge ($T_{50} = 883$ K) [13] (evinced in Roman numeral classification). The Pd/Os ratios of CC-type irons are also decoupled from the Roman numeral group classifications. The decoupled behavior of Pd/Os with Ga and Ge content of both NC- and CC-type magmatic irons suggests that these parent bodies (and potentially their precursor materials) experienced at least two stages of thermal processing, one at relatively higher temperatures (to affect Pd/Os) and the other at relatively lower temperatures (to affect Ga and

Ge). Thermal processing of precursor materials at temperatures ~ 1675 K has been proposed as the cause of isotopic heterogeneity in the early Solar System [5]. If so, this may be the relatively higher temperature process recorded by variable Pd/Os ratios of magmatic irons.

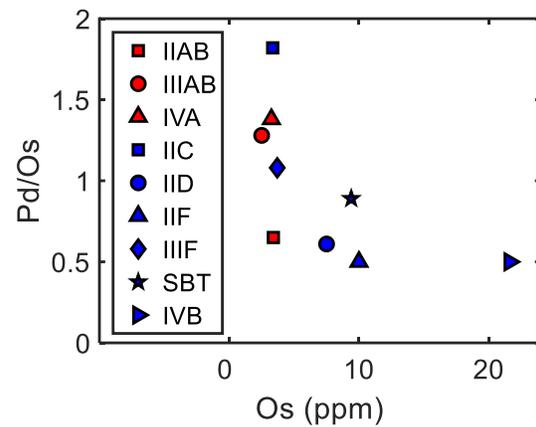


Figure 2. Pd/Os vs. Os (ppm) of magmatic iron meteorite parental melts. The color scheme is the same as Fig. 1.

Acknowledgements: We thank the curatorial teams of the meteorite collections at Arizona State University, the Cascadia Meteorite Laboratory, the Field Museum of Natural History, the Russian Academy of Sciences, the Smithsonian Institution, and the University of California, Los Angeles for providing samples. This study was supported by NASA Emerging Worlds grant NNX16AN07G.

References: [1] Warren (2011) *Earth Planet. Sci. Lett.* **311**, 93-100. [2] Trinquier *et al.* (2009) *Science* **324**, 374-376. [3] Nanne *et al.* (2019) *Earth Planet. Sci. Lett.* **511**, 44-54. [4] Budde *et al.* (2016) *Earth Planet. Sci. Lett.* **454**, 293-303. [5] Worsham *et al.* (2019) *Earth Planet. Sci. Lett.* **521**, 103-112. [6] Kruijer *et al.* (2017) *Proc. Natl. Acad. Sci.* **114**, 6712-6716. [7] Worsham *et al.* (2017) *Earth Planet. Sci. Lett.* **467**, 157-166. [8] Bermingham *et al.* (2018) *Earth Planet. Sci. Lett.* **487**, 221-229. [9] Walker *et al.* (2008) *Geochim. Cosmochim. Acta* **72**, 2198-2216. [10] McCoy *et al.* (2011) *Geochim. Cosmochim. Acta* **75**, 6821-6843. [11] Hilton *et al.* (2019) *Geochim. Cosmochim. Acta* **251**, 217-228. [12] Chabot *et al.* (2017) *Meteorit. Planet. Sci.* **52**, 1133-1145. [13] Lodders (2003) *J. Astrophys.* **591**, 1220-1247. [14] Tornabene *et al.*, (2019) *LPSC L*, Abstract #1236. [15] Horan *et al.* (2003) *Chem. Geol.* **196**, 5-20. [16] Fischer-Gödde *et al.* (2010) *Geochim. Cosmochim. Acta* **74**, 356-379.