MILTON AND THE SOUTH BYRON TRIO: AN OXIDIZED PARENT BODY WITH AN OUTSIDE-IN CRYSTALLIZING CORE.

T.J. McCoy[1], C.M. Corrigan[1], K. Nagashima[2], V.S. Reynolds[1,3], R.J. Walker[4], W. F. McDonough[4], and R.D. Ash[4]. [1]Department of Mineral Sciences, Smithsonian Institution, Washington, D.C. 20560-0119, USA. [2]Hawai'i Institute of Geophysics and Planetology, Univ. of Hawai'i at Mānoa, Honolulu, HI 96822, USA. [3]Dept. of Geography and Earth Sciences, UNC-Charlotte, Charlotte, NC 28223 USA. [4]Department of Geology, University of Maryland, College Park, Maryland 20742 USA.

Introduction: The nature of core crystallization is obscured by the apparent absence of paired core and core-mantle boundary samples among the meteorite collection. Models of core crystallization include inwards and outwards concentric crystallization and dendritic crystallization [1]. Although main group pallasites (PMG) show geochemical affinities to group IIIAB irons, suggesting formation on the same parent body [2], cooling rates of pallasites are faster than those of IIIAB irons, precluding a common parent body origin [3]. A definitive link between pallasites and irons would greatly expand our understanding of core-mantle relationships and core crystallization. The recent selection of the Psyche mission, with its goal of understanding core crystallization, makes the need for such a linkage particularly important.

A link between the Milton pallasite and the South Byron trio irons (henceforth MSB) has been suggested based on metallography and siderophile element abundances [4,5]. The Milton pallasite is ungrouped due to its high Ni, Ir and Ga concentrations (150 mg/g, 50 and 15 µg/g, respectively), anomalous oxygen isotope signature ($\Delta^{17}O$ = -3.14‰), and FeO-rich (Fa_{17}) olivine [4]. The metal composition of Milton is similar to the high-Ni irons South Byron, ILD 83500, and Babb's Mill (Troost's Iron), grouped as the South Byron trio [6]. Ranges of Ni, Ir and Ga in these irons are 175-178 mg/g, 7.15-35 and 18.6-20 µg/g, respectively). We report new results on highly-siderophile elements and oxygen isotopes to strengthen the link between these and better understand the origin of this parent body.

Results: As high-Ni irons, the structures of three of the four are similar and dominated by plessite. South Byron and ILD 83500 contain sub-mm spindles of kamacite, as do larger plessitic areas of Milton. Rare sulfides and chromites are present, as are minute schreibersites that are associated with the kamacite spindles. Milton also exhibits swathing kamacite surrounding silicates and oxides. Babb's Mill (Troost's Iron) has been substantially reheated, both in space and, for some specimens, artificially on Earth [7].

Element concentrations were obtained by laser ablation inductively coupled plasma mass spectrometry (ICP-MS) at the University of Maryland using techniques similar to those of [8]. CI chondrite-normalized siderophile element patterns for Milton, Babb's Mill (Troost's Iron), South Byron and ILD 83500 are remarkably similar (Fig. 1). Refractory siderophiles are enriched at ~10-100 x CI. Volatile siderophiles exhibit smaller enrichments at ~1-10 x CI. Elements that are readily oxidized (V, Cr, Mn, W, Mo, Fe, and P) are commonly depleted. Finally, as observed by [6], differences in platinum group elements (e.g., Re, Os, Ir) are consistent with fractional crystallization, with Milton as the earliest crystallizing and ILD 83500 as the latest.

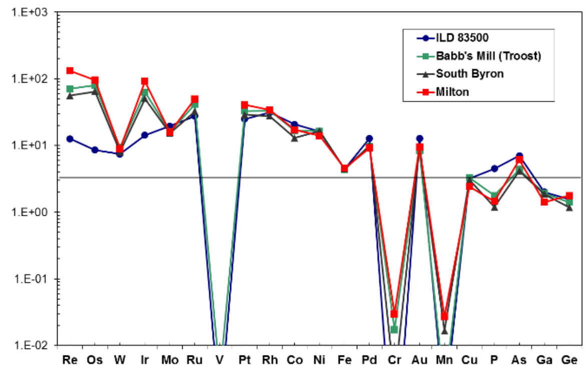

Fig. 1 CI-normalized concentrations of siderophile elements determined by LA-ICP-MS. Elements are ordered by volatility.

Highly siderophile element (HSE) isotope dilution elemental measurements were accomplished by static, multi-collector ICP-MS using faraday cups and interspersal of samples and standards for instrumental fractionation correction. Osmium was analyzed by thermal ionization mass spectrometry. HSE abundances determined by isotope dilution are similar to those determined by LA-ICP-MS.

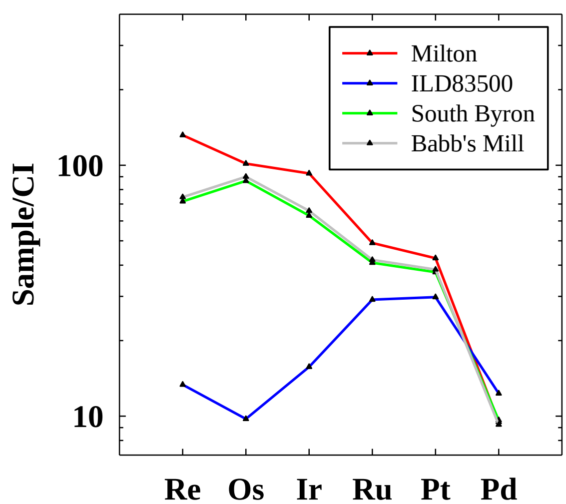

Fig. 2 CI-normalized HSE elements by isotope dilution.

Oxygen isotopic compositions of chromite and olivine were measured with ims-1280 SIMS at Hawai'i. We used ~3-5 nA Cs^+ primary beam and 3 Faraday cups for simultaneous detection of ^{16}O, ^{17}O, and ^{18}O. Chromites in all four meteorites plot on a single mass-dependent fractionation line, with a spread of ~15‰ in $\delta^{18}O$ (Fig. 3). Their $\Delta^{17}O$ (=$\delta^{17}O$-0.52x$\delta^{18}O$) are nearly identical with a mean of -3.6‰ (±0.6‰, 2SD). Milton olivine has the same $\Delta^{17}O$ within uncertainty. These values strongly support a common parent body origin for these four meteorites. The spread in $\delta^{18}O$ likely result from instrumental fractionation (i.e., matrix effect).

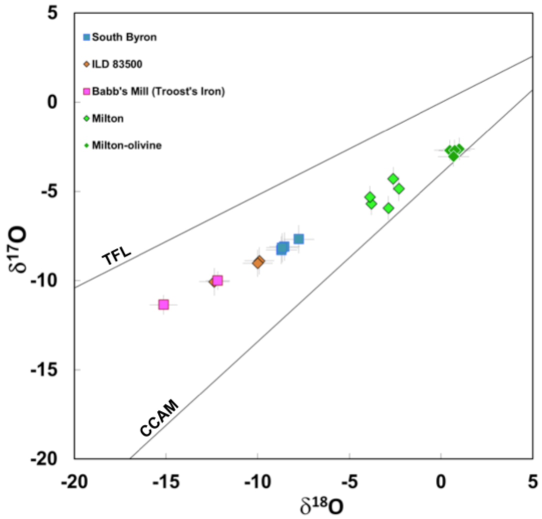

Fig. 3 Oxygen isotopic composition of chromite in Milton and the South Bryon Trio irons and olivine in Milton.

Discussion: The shared characteristics, including metallography, siderophile element abundances and oxygen isotopic compositions, of Milton and the South Byron trio are consistent with formation in the same parent body. This represents the first sampling of the core and core-mantle boundary of a common asteroid.

The composition of the MSB core was determined by a combination of condensation, oxidation, and fractional crystallization.

Condensation. In most high Ni irons (e.g., IVA, IVB, Tishomingo), high-T condensation had a significant role, forming a Ni-enriched, volatile-depleted siderophile element pattern [9,10]. In MSB, volatile siderophiles are depleted relative to refractory siderophile by ~2 orders of magnitude, far less than the 3-4 order of magnitude depletion observed in IVA [11] irons or the 4-5 order of magnitude depletion in IVB irons [10]. While condensation may have a role in determining the bulk Ni concentration of this group, it was not the dominant process.

Oxidation. The uniform depletion of redox sensitive elements suggests that oxidation was a dominant process in establishing the high-Ni concentration of the MSB core. Following the model of [10] for IVB irons, the low $(Fe/Ni)_{CI}$ ratio of 0.27-0.33 and high $(Ni/Pd)_{CI}$ ratio of 1.27-1.71 suggests oxidation sufficient to oxidize Fe but not Ni. If we assume an initial $(Fe/Ni)_{CI}$ ratio of ~1, 73% of the Fe is lost by oxidation, nearly identical to the degree of oxidation (72%) for the IVB iron parent body [10]. Supporting evidence for oxidation includes the presence of chromite in all four meteorites and olivine enriched in FeO relative to main group pallasites and phosphates in Milton [4, this work]. The nature and timing of oxidation are uncertain, but probably occurred prior to core formation in either an oxidizing region of the nebula or through accretion of an oxidizing agent (e.g., ice) during accretion. An outcome of this oxidation is an appreciably smaller core and correspondingly larger ratio of mantle to core.

Fractional Crystallization. Variations in HSE among the suite (Figs. 1,2) are consistent with fractional crystallization of metal with a comparatively low but poorly-constrained initial S and P content. Fractional crystallization of the South Byron trio was suggested by [6]. Milton appears to have crystallized first, with South Byron and Babb's Mill (Troost's Iron) at essentially the same point in the crystallization sequence, and ILD 83500 last. The high P concentration in ILD 83500 is consistent with concentration of incompatible P in the crystallizing melt. Re-Os results for all of the meteorites are consistent with closed system behavior since formation early in Solar System history.

The crystallization sequence for Milton and the South Byron trio irons has interesting implications for the physical process of core crystallization. With the pallasite Milton as the first-crystallizing material, if we assume that pallasitic material represents the core-mantle boundary, then crystallization commenced at the core-mantle boundary and occurred inwards. This type of core crystallization could be consistent with either concentric inwards crystallization or dendritic crystallization with inwards growing dendrites [1], but precludes concentric outwards crystallization. A consequence of inwards crystallization is the possibility of forming a core dynamo early in the history of the MSB parent body. With a possible thicker mantle surrounding a smaller core, core crystallization and cooling might have been protracted. This dynamo should have produced a paleomagnetic signature in meteorites formed on the MSB parent body, including possible oxidized crustal meteorites we have yet to sample.

References: [1] Haack and Scott (1993) *GCA* **57**, 3457. [2] Mittlefehldt et al. (1998) *Planetary materials.* 4-1. [3] Yang et al. (2010) *GCA* **74**, 4471. [4] Jones et al. (2003) 34th LPSC, #1683. [5] Reynolds et al. (2006) *MAPS* **41**, A147. [6] Wasson et al. (1989) *GCA* **53**, 735. [7] Yang et al. (2011) *MAPS* **46**, 1227. [8] Walker et al. (2008) GCA **72**, 2198. [9] Kelly and Larimer (1977) *GCA* **41**, 93. [10] Campbell and Humayun (2005) *GCA* **69**, 4733. [11] McCoy et al. (2011) *GCA* **75**, 6821.