

**THE TISHOMINGO IRON METEORITE AND A POSSIBLE GENETIC LINK TO GROUP IVB IRON METEORITES – EVIDENCE FROM MOLYBDENUM ISOTOPES.** E.A. Worsham<sup>1</sup>, R.J. Walker<sup>2</sup>, C.M. Corrigan<sup>3</sup>, T.J. McCoy<sup>4</sup>, <sup>1,2</sup>Dept. of Geology, University of Maryland, College Park, MD 20742 USA, <sup>3,4</sup>Dept. of Mineral Sciences, National Museum of Natural History, Smithsonian Institution, Washington, DC 20560 USA

**Introduction:** Some iron meteorite groups, classified based on their major and trace element chemical compositions, are thought to represent the cores of individual differentiated planetesimals. Such iron meteorites are referred to as ‘magmatic’. In particular, the IVB suite consists of 13 meteorites, which likely represent the core of the IVB parent body. These irons are compositionally unique among iron groups, having both relatively high Ni (about 16-18 wt %) and refractory element abundances, and low concentrations of volatile elements [1].

Ungrouped iron meteorites account for about 15% of the iron meteorites in collections. There are several possible origins for these meteorites. These include formation during impact melting on chondritic bodies, extreme fractional crystallization, and the separation of metallic liquids due to liquid immiscibility in a planetary core that is already represented by an existing magmatic group. Some ungrouped iron meteorites may also represent parent bodies for which there are no other samples [2]. It has been suggested that the IVB group should be expanded to include the ungrouped iron meteorite Tishomingo [e.g. 3,4]. Like IVB irons, Tishomingo is enriched in refractory elements relative to volatile elements [2,3,4]. Both Tishomingo and the IVB irons also have highly siderophile element (HSE) patterns that are remarkably similar. Most striking is the fact that their Pt abundances are nearly identical (Fig. 1). Despite the obvious similarities, grouping Tishomingo with IVB irons has its complications. The difference in P concentrations in Tishomingo versus what is extrapolated from fractional crystallization trends of the IVB irons is inconsistent with Tishomingo being an evolved member [2,5,6]. Most importantly, it has much higher Ni (32.5 wt. %) compared to the IVB suite. The higher Ni, yet the nearly identical Pt concentrations (and otherwise quite similar HSE pattern to IVB irons) mean that Tishomingo cannot be linked to IVB via crystal-liquid fractionation or by oxidative reduction of Fe (both of which would lead to different Pt abundances relative to IVB). Yet, if Tishomingo is not somehow related to the IVB suite, it means that two parent bodies generated metal domains with notably similar chemical characteristics.

Establishing or rejecting a genetic link could help elucidate details of the complex formation history of the IVB parent body and how the IVB irons came to have such unusual chemical attributes. If Tishomingo

and the IVB irons can somehow be genetically linked, it will be necessary to explain how, having such different Ni and P concentrations, they could have originated on the same parent body. As a corollary, if the two cannot be linked, how two unrelated parent bodies can come to have such similar HSE patterns must be explained.

In order to support or reject a link between Tishomingo and the IVB iron meteorites, the Mo isotopic composition of Tishomingo and several other iron meteorites of various groups (including IVB) are being investigated. Most planetary bodies show distinct Mo isotopic compositions due to nucleosynthetic anomalies, thus providing a way to genetically link meteoritic material representing specific parent bodies [7]. These isotopic anomalies are reported in  $\epsilon$  notation (parts in 10,000 deviation from terrestrial standards), which range in iron meteorites from 0 to +2  $\epsilon$  in <sup>92</sup>Mo [7].

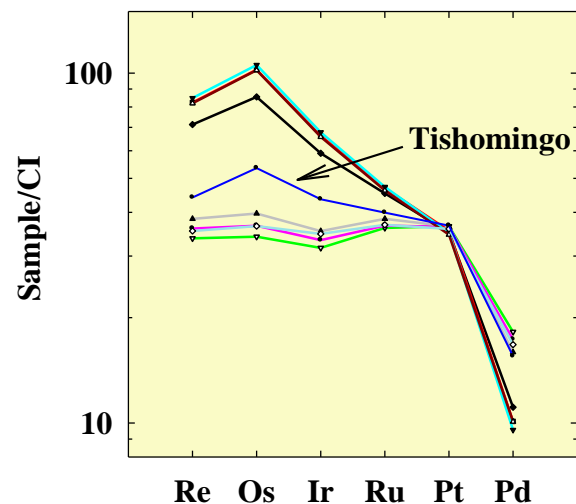


Fig. 1. Highly siderophile element patterns for some IVB iron meteorites and Tishomingo. The HSE concentrations are normalized to those of CI carbonaceous chondrites.

**Experimental Methods:** In order to get the most information from an iron meteorite sample, we attempted to make use of the Mo that comes through the chemistry for the separation and purification of W. About 0.5 to 3.0 g of several iron meteorites were digested in 8M HCl in Teflon beakers at ~130 °C over at least 24 hours. The Fe matrix was selectively removed

via solvent extraction using diisopropyl ether. Once most of the Fe was removed, the samples were purified for W using cation and then anion exchange chromatography, at which point, Mo cuts were obtained as waste from the anion stage. Molybdenum was further purified with two stage anion exchange chromatography. Blanks were negligible. Yields for these iron meteorite samples were not quantitative, as Mo cuts were obtained from chemistry that was not tailored to its retention, but an ample amount remained for analysis. We suspect that the Mo is lost in the ether extraction phase, but that hypothesis has yet to be tested. Any isotopic effects from the non-quantitative yield have not been explored. In the future, a procedure designed to retain and purify Mo, in which samples are digested in carius tubes in aqua regia followed by cation and two-stage anion exchange chromatography, will be used. This procedure has proven more successful in retaining quantitative amounts of pure Mo.

A procedure to precisely measure Mo isotopic composition in iron meteorites by both multiple collector inductively coupled plasma mass spectrometry (MC-ICP-MS) and negative-mode thermal ionization mass spectrometry (N-TIMS) is being developed at the University of Maryland. Because the deviations from terrestrial standards for solar system materials are epsilon-scale, the precision of these analytical procedures must be highly refined. In both analytical methods we have begun to establish procedures wherein the external reproducibility of terrestrial standards suggests that epsilon deviations can be resolved, however, work is ongoing to produce robust results.

**Discussion:** Here, we speculate on the implications of a genetic link, or lack thereof, between IVB iron meteorites and the ungrouped Tishomingo. If the Mo isotopic composition of Tishomingo does not overlap with the IVB irons, which have the largest deviations from terrestrial of the major iron meteorite groups [7], it would suggest that Tishomingo and the IVB irons, would most likely have had to originate on two separate parent bodies that had very similar histories and source material. Campbell and Humayun [6] presented the case that IVB irons formed from a nebular volatile-depleted source that preferentially accreted a small percentage of refractory element-rich material and subsequently underwent considerable oxidation. If the Mo isotopic compositions do not match, it would be possible to surmise that a Tishomingo parent body was subject to analogous processes, such that it underwent nearly identical nebular processing and metal accumulation. However, it must have undergone a higher degree of oxidation to account for the higher Ni. It must have also had a lower initial HSE abundance to obtain the same Pt concentration in the fractionated melt. Ad-

ditionally, the initial metal liquid must have had very similar concentrations of S and P.

If the Mo isotopic compositions of Tishomingo and the IVB irons do overlap, it would provide evidence that they came from the same parent body. However, resolving the disparity between the expected high P concentrations in Tishomingo, given the simple crystal-liquid fractionation of the IVB irons argued by [1], with its observed low P, and the fact that Tishomingo has a much higher Ni concentration is a bit of a quandary. These problems could be explained by differential oxidation on a possible IVB-Tishomingo parent body, where either the oxidative conditions varied with time or location. The similarity of the Pt concentrations continues to be a problem with this scenario, however. Assuming the IVB group is a representative sampling of the IVB core, the observed homogeneity with respect to Pt among the suite argues against the IVB core having had variable Pt and, therefore, variable oxidation. Tishomingo may represent a non-magmatic member of the partially differentiated IVB parent body, where impact melting in the still relatively metal-rich silicate portion could produce the similar HSE and volatile-depleted characteristics, as the nebular source would be the same. However, the Mo isotopic composition may be expected to be different with a significant contribution from a foreign impactor, and the effect on the Ni abundance is unclear. Another possibility is that some degree of liquid immiscibility during core crystallization is responsible for the composition of Tishomingo. Of course, these scenarios require further inquiry. Furthermore, it is possible that two parent bodies sourced from similar material could have Mo isotopic compositions that are indistinguishable. More work is needed to address this issue. Regardless of a resolvable genetic link or lack thereof, it is clear the IVB irons and Tishomingo have complicated, possibly related, histories.

**References:** [1] Walker R. J. et al. (2008) *Geochim. Cosmochim. Acta*, 72, 2198–2216. [2] Corrigan C. M. et al. (2005) *LPS XXXVI*, Abstract #2062. [3] Kracher A. (1980) *Geochim. Cosmochim. Acta*, 44, 773-787. [4] Birch W.D. (2001) *MAPS*, 36, A247-A254. [5] Yang J. and Goldstein J.I. (2003) *MAPS*, 38, A33. [6] Campbell and Humayun (2005) *Geochim. Cosmochim. Acta*, 69, 4733–4744. [7] Burkhardt et al. (2011) *Earth & Planet. Sci. Lett.*, 312, 390-400.