**OSMIUM ISOTOPE ANOMALIES IN GROUP IVB IRONS: COSMOGENIC OR NUCLEOSYNTHETIC CONTRIBUTIONS.** S. Huang[1], and M. Humayun[1], [1]National High Magnetic Field Laboratory & Department of Geological Sciences, Florida State University, 1800 E. Paul Dirac Drive, Tallahassee, FL 32310; huang@magnet.fsu.edu; humayun@magnet.fsu.edu.

**Introduction:** Evidence for isotope anomalies in primitive chondrites, and in iron meteorites, have been reported in Mo [1,2], Ru [3], Ba [4], Nd [5, 6], and Sm [6]. Osmium is a highly refractory element for which isotopic anomalies in bulk chondrites or differentiated meteorites have not been reported, yet. Brandon et al. [7] reported Os isotope anomalies in primitive chondrites, with the largest effects in Tagish Lake, that they interpreted to be the result of partial dissolution of refractory carriers. Magnification of these Os isotope anomalies has been reported [8, 9]. A definitive test of whether the solar nebula had large-scale isotope anomalies [e.g., 1, 10] or not [7] is better achieved by the analysis of differentiated meteorites, since the presolar grain carriers of isotope anomalies are destroyed, and any grain-scale isotope anomalies are eradicated, during melting. It is, therefore, very interesting that endemic Mo [2] and Ru [3], but not Pd [11], isotope anomalies have been reported in iron meteorites, particularly in some members of Group IVB. Since Group IVB irons are enriched in refractory siderophile elements [17], we undertook a search for Os isotope anomalies to determine whether isotope anomalies are found in other refractory elements.

It is important to observe that these irons also have some of the longest cosmic-ray exposure ages of any group of meteorites. Cosmogenic neutron capture burn-out of $^{182}$W is a contributor to $^{182}$W isotope effects in these irons, complicating interpretations of $^{182}$Hf-$^{182}$W ages [12, 13]. We, therefore, analyzed 10 out of the 12 group IVB irons to separate the effects of cosmogenic isotope anomalies from any effect that may be intrinsic to the precursor of IVB irons, a feature that must be shared by all IVB irons.

**Analytical Methods:** Pieces of iron were removed from larger samples using a small-kerf hack-saw. The exterior surfaces were ground off with corundum paper, samples were cleaned in milli-Q water, and ethanol, and then dissolved in aqua regia (3 nitric acid: 1 hydrochloric acid) in a sealed glass tube. Osmium was extracted from the chilled solution immediately on opening by solvent extraction with $CCl_4$, and purified by microdistillation [e.g., 14]. Aliquots of the Os were introduced into a ThermoFinnigan Neptune™ multi-collector ICP-MS with an ESI Apex™ nebulizer at FSU. High-precision Os isotopic data were collected using the MC-ICP-MS, normalized for mass fractionation to $^{192}$Os/$^{188}$Os= 3.083 using the exponential law. To test the external reproducibility, we prepared two synthetic standards from commercially available Os reagents which had different $^{187}$Os/$^{188}$Os and $^{186}$Os/$^{188}$Os ratios. Gravimetrically prepared mixtures of these two reagents were equilibrated in aqua regia in sealed glass tubes, and the Os was extracted in the same manner as described above for samples. Os isotopic analyses of these mixtures are shown in Fig. 1.

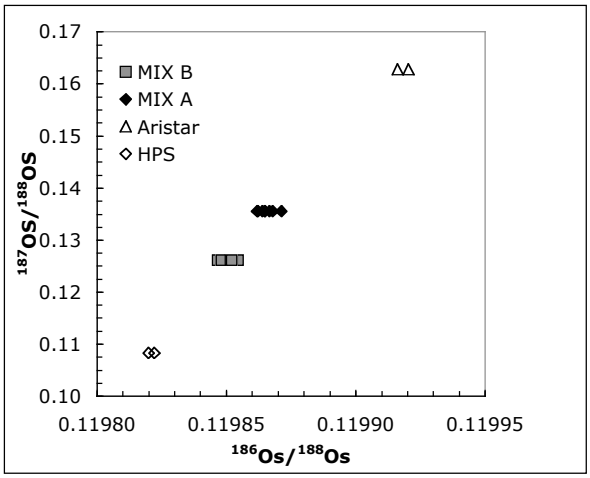


**Figure 1:** External reproducibility of $^{186}$Os/$^{188}$Os and $^{187}$Os/$^{188}$Os analyses by MC-ICP-MS on synthetic reagent mixtures from Oct. 2007 to Dec. 2007.

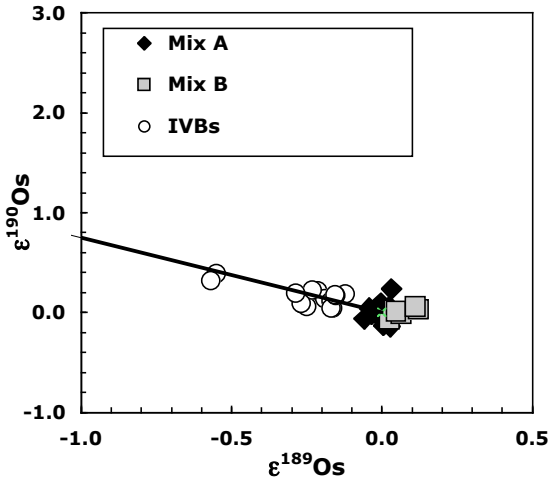


**Figure 2:** Replicate $^{189}$Os/$^{188}$Os and $^{190}$Os/$^{188}$Os of 6 group IVB irons, and two terrestrial standards (Mix A, Mix B). The line represents cosmic-ray neutron capture burn-out of Os.

For the Mix A terrestrial standard, external reproducibility over three months of $\varepsilon^{186}$Os is ±0.37, $\varepsilon^{187}$Os is ±0.35 epsilon units, of $\varepsilon^{189}$Os is ±0.06 epsilon units, and of $\varepsilon^{190}$Os is ±0.20 epsilon units.

**Osmium isotope anomalies in IVB irons:** The results of the measurements of Os isotopic composition in six IVB irons are shown in Fig. 2 plotted on $\varepsilon^{190}$Os vs. $\varepsilon^{189}$Os (both ratios normalized to $^{188}$Os). We found that five out of the six IVB irons (Cape of Good Hope, Iquique, Kokomo, Santa Clara and Tawallah Valley) form a cluster with $\varepsilon^{189}$Os= –0.1 to –0.3, distinct from the terrestrial standards. Two replicate analyses of Tlacotepec exhibit $\varepsilon^{189}$Os = –0.6.

**Cosmogenic Os isotope effects:** The effect of cosmic-ray induced neutron burn-out on Os isotopes was calculated using thermal and epithermal neutron capture cross-sections for W, Re, Os and Ir isotopes [15], with neutron fluence as a free parameter. Emphasis was placed on determining correlations between isotope ratios. The epithermal neutron capture on $^{185}$Re, $^{187}$Re, and $^{187}$Os, is important in assessing impacts on $^{186}$Os and $^{188}$Os. The model was compared with results from Leya's calculations for W isotopes [13] and found to be in good agreement. The neutron capture effect decreases in the order of $^{184}$Os (which is not measured precisely enough), $^{186}$Os, $^{187}$Os and $^{189}$Os. Radiogenic contributions to $^{186}$Os and $^{187}$Os make it difficult to distinguish cosmogenic effects on these isotopes, but correction of the cosmogenic contribution to $^{186}$Os will be important for its use as a tracer. The pure cosmogenic effects are best seen in Figure 2, on a plot of $\varepsilon^{190}$Os vs. $\varepsilon^{189}$Os, where the solid line shows the cosmogenic effect as $^{189}$Os is burned to $^{190}$Os by epithermal neutrons. The magnitude of the cosmogenic effect is largest in Tlacotepec, which also exhibits the largest $^{182}$W deficit [13, 16]. The cosmogenic effect fully accounts for the $\varepsilon^{189}$Os deficit and the $\varepsilon^{190}$Os excess observed in Fig. 2.

**Nucleosynthetic effects?** The isotope effects previously reported for Mo and Ru in group IVB irons are consistent with a slight excess of r-process isotopes over s-process isotopes [1-3]. Such effects should result in a slight excess of $\varepsilon^{189}$Os with correlated deficit in $\varepsilon^{190}$Os, the opposite of what is observed here. We can interpret our Os isotopic data to conclude that the maximum possible nucleosynthetic effect in Os is a slight excess of s-process over r-process Os in contrast to the Mo-Ru results [2, 3] on similar iron meteorites, or we can interpret our results to indicate that there are no nucleosynthetic effects in Os, but that the five irons defining the cluster all exhibit a small cosmogenic deficiency of $\varepsilon^{189}$Os. The good match between cosmogenic Os and our data (Fig. 2) does not lend support to a large cosmogenic reversal of original nucleosynthetic effects in Os.

We note here that the neutron capture cross-sections of Mo and Ru isotopes are too small (<160 barns) to re-interpret the previous Mo-Ru results in terms of a cosmogenic effect. We also note that iron meteorites are deficient in most elements that would allow a precise determination of the neutron fluence, with the possible exception of $^{103}$Rh, which neutron captures to $^{104}$Pd. The small number of existing Pd isotope data do not indicate that any anomaly in $^{104}$Pd occurs for Santa Clara, the only group IVB meteorite currently measured for Pd isotope composition [11].

The absence of nucleosynthetic anomalies in Pd was interpreted as the result of adding a refractory element carrier with excess r-process/s-process to normal solar system isotopic compositions [11]. This explanation was easily supported by chemical abundances that exhibit a 3x enrichment of refractory siderophile elements over Pd, Ni and Fe in the Group IVB parental magma [17]. However, Os is one of these enriched siderophile elements, so the absence of nucleosynthetic anomalies in Os poses a challenge for interpretations of the Ru and Mo anomalies.

**Acknowledgements:** Funding for the acquisition of the MC-ICP-MS at FSU was provided by NASA Planetary Major Equipment and SRLIDAP, and by NSF. This research was supported by NNG06GF50G.

**References:**

[1] Yin Q. et al. (2002) *Nature*, 415, 881-883. [2] Chen J. H. et al. (2004) *LPS XXXV*, Abstract #1431. [3] Papanastassiou D. A. and Chen J. H. (2006) *LPS XXXVII*, Abstract #1976. [4] Ranen M. C. and Jacobsen S. B. (2006) *Science*, 314, 809-812. [5] Carlson R. W. et al. (2007) *Science* 316, 1175-1178. [6] Andreasen R. and Sharma M. (2006) *Science*, 314, 806-809. [7] Brandon A. D. et al. (2005) *Science*, 309, 1233-1236. [8] Reisberg L. C. et al. (2007) *LPS XXXVIII*, Abstract #1177. [9] Yokoyama T. et al. (2007) *EPSL,* 259, 567-580. [10] Boss A. P. (2004) *ApJ*, 616:1265-1277. [11] Chen J. H. and Papanastassiou D. A. (2005) *LPS XXXVI*, Abstract #1495. [12] Leya I. et al. (2003) *GCA*, 67, 529-541. [13] Markowski A. et al. (2006) *EPSL*, 242, 1-15. [14] Puchtel I. S. et al. (2005) *EPSL*, 237, 118-134. [15] Mughabghab S. F. (1984) *Neutron Resonance Parameter and Thermal Cross Sections*, Academic Press, New York. [16] Scherstén A. et al. (2006) EPSL, 241, 530-542. [17] Campbell A. J. and Humayun M. (2005) *GCA* 69, 4733-4744.