TUNGSTEN ISOTOPIC CONSTRAINTS ON THE FORMATION AND EVOLUTION OF IRON METEORITE PARENT BODIES

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Introduction: The ^{182}Hf-^{182}W short-lived chronometer (half-life = 8.9 Myr) has proven useful for dating metal-silicate separation (i.e., core formation) in planetary bodies [1-4]. Hafnium and W are both refractory elements and thus expected to be present in chondritic proportions in planetesimals, but W is siderophile and partitions preferentially into the metal core, whereas Hf is lithophile and strongly enriched in the silicate mantle. Horan et al. [5] reported W isotope data for a representative suite of magmatic and non-magmatic iron meteorites and showed that all irons display similar W isotope compositions within a narrow range between –5.1 and –3.1 ε_W (ε_W is the deviation of the ^{182}W/^{184}W of a sample from the value of the terrestrial standard in parts per 10,000). This indicates that all irons segregated within ~5 Myr of each other. We present new high-precision W isotope data for a comprehensive set of iron meteorites that reveal small variations in W isotope compositions both within and between some of the groups.

Methods: The W isotope compositions of 35 iron meteorites from eight magmatic (IC, IIAB, IIF, IID, IIIAB, IIIF, IVA and IVB) and three non-magmatic groups (IAB, IIE, IIICD) have been measured using a Nu Plasma MC-ICPMS at the ETH Zürich. Tungsten isotope compositions were typically measured with total ion beam intensities of ~10 V, resulting in within-run statistics of 0.1 to 0.2 ε units. The instrumental mass bias was corrected by normalizing all W isotope ratios relative to ^{186}W/^{183}W and ^{186}W/^{184}W using the exponential law. Small isobaric interferences on masses 184 and 186 were corrected by monitoring ^{188}Os. Some tests has shown that the magnitutde of the Os correction is less than 25 ppm for a sample containing up to 3% Os relative to total W but generally the Os content were significantly lower. The stable ^{184}W/^{183}W ratio is used as a monitor for the accuracy of our measurements and to evaluate possible nucleosynthetic and cosmogenic effects. The ^{184}W/^{183}W of all iron meteorites examined here agrees with the value obtained for the terrestrial standard within analytical uncertainties. The ε_W of all samples were determined relative to two standard runs bracketing the sample run. The 2σ uncertainties for the individual measurements were calculated by combining the uncertainties on the sample and the uncertainty on the two bracketing standards. Each sample solution has been measured several times and replicate of different fragments of the same meteorites has been analyzed as well. The reported 2σ uncertainty for each sample is calculated by combining the uncertainties of the individual measurements of this sample.

Results: All iron meteorites examined here display a ^{182}W deficit relative to chondrites (ε_W = -1.9 [3,4,6]) with ε_W values between –2.5 (for the IIE iron) and –4.3 (for the IID iron Carbo). In general, the non-magmatic iron meteorites (i.e., groups IAB-IIICD and IIE) have more radiogenic ε_W values than most of the magmatic iron meteorites. Within the IIAB, IID, and IVB groups there are small but resolvable W isotope heterogeneities (Table 1). Irons from the sub-group IIA appear to have slightly more radiogenic ε_W (-3.3 to -3.5) than those from sub-group IIB (-3.6 to -4.1). Similarily, the IAB irons (average ε_W = -3.0±0.1) are slightly more radiogenic than the IIICD irons (average ε_W = -3.3±0.1).

Discussion: Differences among the W isotope composition of iron meteorites can be interpreted as real time differences provided that the W isotopes have not been destroyed or produced in significant amounts by any later, local processes. Burnout of W isotopes by exposure to cosmic rays may lower ^{182}W abundances in iron meteorites with exposure ages of several 100 Myr [7,8]. The neutron capture rate, and therefore the cosmogenic effect on ^{182}W, changes with depth and size of the meteorite. An approximation of the expected cosmogenic effect is given by the exposure age of iron meteorites combined with theoretical calculations: the higher the exposure age, the larger the expected cosmogenic effect. There is no clear correlation between ε_W and exposure age. Moreover, cosmogenic effects would not only affect ^{182}W but would also cause changes in the abundances of other W isotopes and, hence, should cause a downward shift of ^{184}W/^{183}W. We do not find such an effect and the average ^{184}W/^{183}W of all irons examined here is 0.02±0.02 ε (2σ). However, a more detailed study of cosmic-ray production of W isotopes is required and is currently underway.

Provided that the W isotopes in irons have not been modified by exposure to cosmic rays, the W isotope heterogeneities in some of the magmatic iron meteorite groups indicate a protracted timescale for core formation (Table 1). Irons having low ε_W values may sample a part of a core which segregated early, whereas irons having higher ε_W may derive from a later segragated part of a core. Such a scenario may be compatible with trace elements (eg. Ir) and Re-Os systematics of IIAB irons, which were interpreted to indicate the assimilation of fresh chondritic metal in the late stages of core crystallization [5, 9].

Group	Range of ε_W	Model age (Myr)
IID	-4.3 to –3.2	0 to 8.6
IIAB	-4.1 to –3.3	1.1 to 7.0
IIIAB	-3.6 to –3.3	4.5 to 7.0
IVA	-3.9 to –3.4	2.4 to 6.1
IVB	-4.1 to –3.4	1.1 to 6.1
IAB	-3.0	10.1
IIICD	-3.4 to –3.3	6.1 to 7.0
IIE	-2.8 to –2.5	12.7 to 18.0

Table 1: Model ages calculated relative to the W isotope composition of Carbo, which has the lowest ε_W value measured in this study.

The non-magmatic IAB, IIICD, and IIE irons have more radiogenic ε_W values than most of the magmatic iron meteorites, indicating a relatively late metal-silicate fractionation, possibly as a result of impact-related mixing processes in their parent bodies. The IABs exhibit a slightly higher average ε_W than the IIICDs, indicating a 3.1 (+2.2;-2.1) Myr gap in the last Hf-W fractionation of these two groups. The IABs and IIICDs may thus derive from two different parent bodies or may sample two different areas with distinctive thermal histories on one asteroid.

References:

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