High field strength element systematics in iron meteorites

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In classical view, high field strength elements (HFSE: Zr, Hf, Nb, Ta) are strongly lithophile elements that are typically stored in the silicate portion of planetary bodies. This view was partially challenged by experimental results and high precision Nb/Ta and Zr/Hf measurements in differentiated meteorites, suggesting that Nb might behave moderately siderophile at high pressures [1,2]. Niobium is depleted in the silicate Earth and the Moon whereas the Martian mantle, eucrites, and angrites display chondritic Nb/Ta ratios [2]. To asses the HFSE budget during planetary differentiation, we performed high precision measurements of HFSE and Lu concentrations in iron meteorites and their silicate inclusions.

Meteorites analyzed include both nonmagmatic (IAB) and magmatic groups (IC, IIAB, IIIAB). In addition to the metals, IAB silicate inclusions were analyzed. Measurements were performed by isotope dilution after chemical separation from matrix elements using MC-ICPMS [3]. Assuming ±50% blank uncertainty, typical detection limits are 10 ppt for Lu, 1 ppb for Zr, 50 ppt for Hf, 25 ppt for Nb, and 50 ppt for Ta.

The IAB silicate inclusions display near chondritic Zr/Hf but superchondritic Zr/Nb (110-270) and subchondritic Nb/Ta (2.5-18), indicating depletion of Nb and, to a lesser extent, of Ta. Measured Zr contents in the metals reach up to 40 ppb, Hf contents reach up to 1 ppb. Niobium contents range from 100 ppt to 4 ppb, whereas Ta is always below detection limit. IAB group meteorites display some of the highest HFSE contents, suggesting the presence of small silicate inclusions. Lower HFSE contents indicate a higher purity of the metals. Lutetium contents range from 100 ppt to 4 ppb, but, unlike the HFSE, overlap between all groups. A strong increase of Lu/Hf ratios (176Lu/177Hf up to 5) with decreasing Nb and Hf contents suggests that the Lu is hosted in small phosphate grains in the metals.

Collectively, a positive co-variation of Nb and Hf in the metal samples indicates (1) that significant amounts of Nb are hosted in small silicate impurities (2) that the (Hf free) metal endmember still contains ca. 50 ppt Nb. Such low Nb abundances in the metals, however, cannot account for any significant Nb depletion in the silicate portion of the parent body and in the silicate inclusions. A third component, possibly Ti-rich minerals such as high Nb rutiles that have been observed previously in iron meteorites [4], is required as host for the missing Nb and Ta.

References

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