Tungsten (W) Fractionation in Enstatite Chondrites

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Background

Enstatite chondrites are highly reduced, undifferentiated meteorites that inform our understanding of Solar System formation and evolution. Given the highly reduced nature of enstatite chondrites, as determined from their mineral and chemical compositions, it is assumed that Fe exists as Fe^0.

Recent high-precision bulk Hf and W concentrations for enstatite chondrites indicate near identical W concentrations in high-Fe EH and low-Fe EL chondrites. This behavior is contrary to expectation, as W is siderophile so is expected to be present in higher concentrations in EH chondrites.

This project investigates this discrepancy by comparing bulk metal abundances and W concentrations in metal grains between EH and EL chondrites.

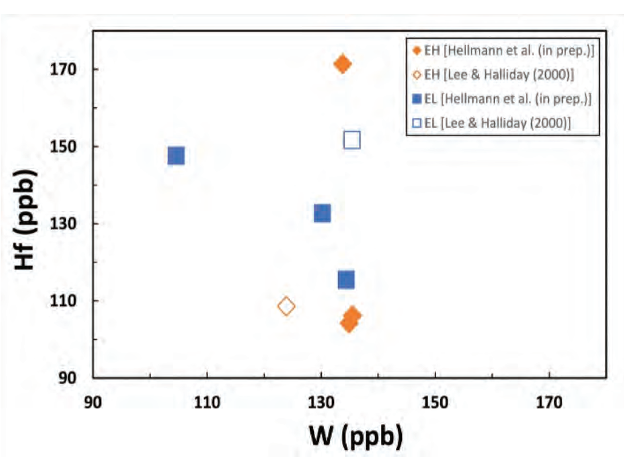

Figure 1: Bulk W vs. Hf concentrations. Modified from Jan Hellmann (Personal Communication, 2023).

Figure 2: Cross section of the highly brecciated EH chondrite Abee (EH4).

Objectives

Goal 1: To quantify the amount of metal in EH and EL chondrites.

Hypothesis 1: EH chondrites have more metal than EL chondrites.

Goal 2: To determine the W concentrations in metal grains in EH and EL chondrites.

Hypothesis 2: The average W content of the metal grains is lower in EH chondrites than in EL chondrites.

Methods: LA-ICP-MS

Laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS): iCapQ ICP-MS coupled to an Iridia laser ablation system [Carnegie Institution] were used to measure W and other siderophile element concentrations in metal grains. Grains were ablated using 50 µm spot sizes.

Methods: Image Processing

Metal modal abundances were quantified via image segmentation and processing of reflected light photomicrographs using Fiji/ImageJ photo-analytical software. Image segmentation is a computer vision technique that assigns labels to groups of pixels in order to partition an image into segments. Of the various methods and algorithms that exist for image segmentation, global threshold based image segmentation was used for this study.

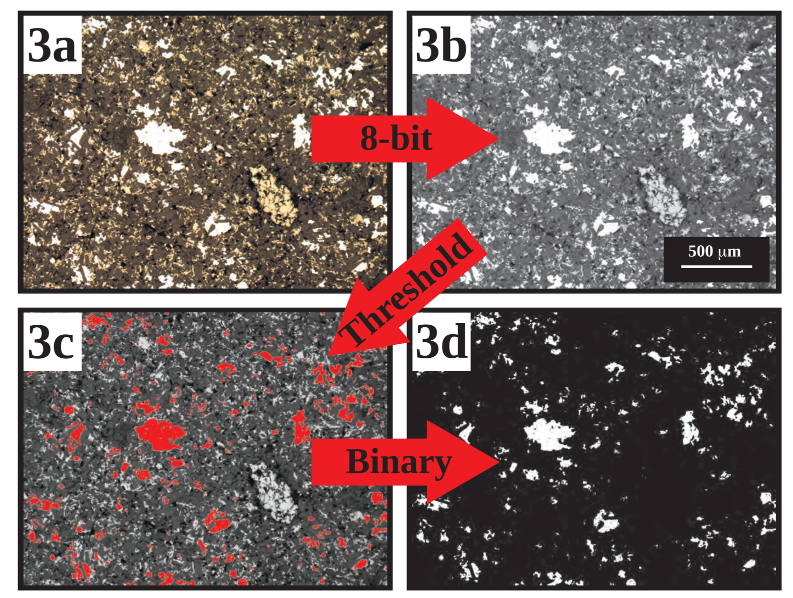

Figure 3: Global threshold segmentation steps using Abee (EH4) photomicrographs. **3a)** Original color photomicrograph **3b)** Photomicrograph converted to grayscale (8-bit). Pixels now range in intensity from 0 to 255. **3c)** Threshold determination: areas highlighted in red are those with pixel intensity values greater than the assigned threshold value. **3d)** Binary image generated from the application of the threshold. Analyzed for % area of white pixels.

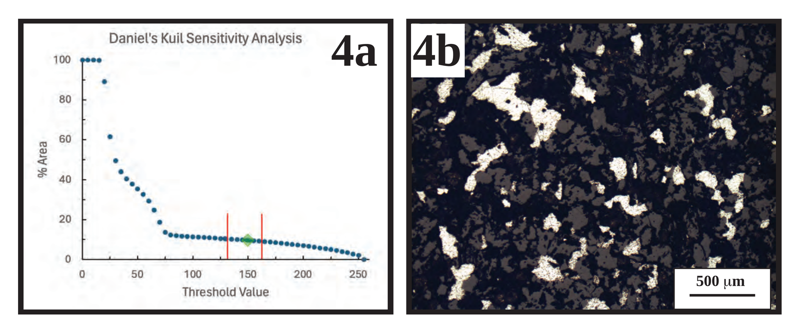

Figure 4: Sensitivity analysis on Daniel's Kuil (EL6). **4a)** Graph illustrating that perturbations of the threshold around the pixel intensities linked to the metal grains minimally impact the % area output. The green diamond represents the threshold applied to isolate the metal grains. **4b)** Photomicrograph used for sensitivity analysis.

Results: Image Processing

Metal Content Results:
Two-sample t-test results (assuming unequal variance; α set to 0.05): p-value was 0.088 (there is no statistical difference between the amount of metal in EH vs. EL chondrites). Therefore, the null hypothesis cannot be rejected. There is no difference in the amount of Fe-metal between EH and EL chondrites.

The findings of this study thus indicate that EH and EL chondrites cannot be systematically differentiated based on their metal modal abundances.

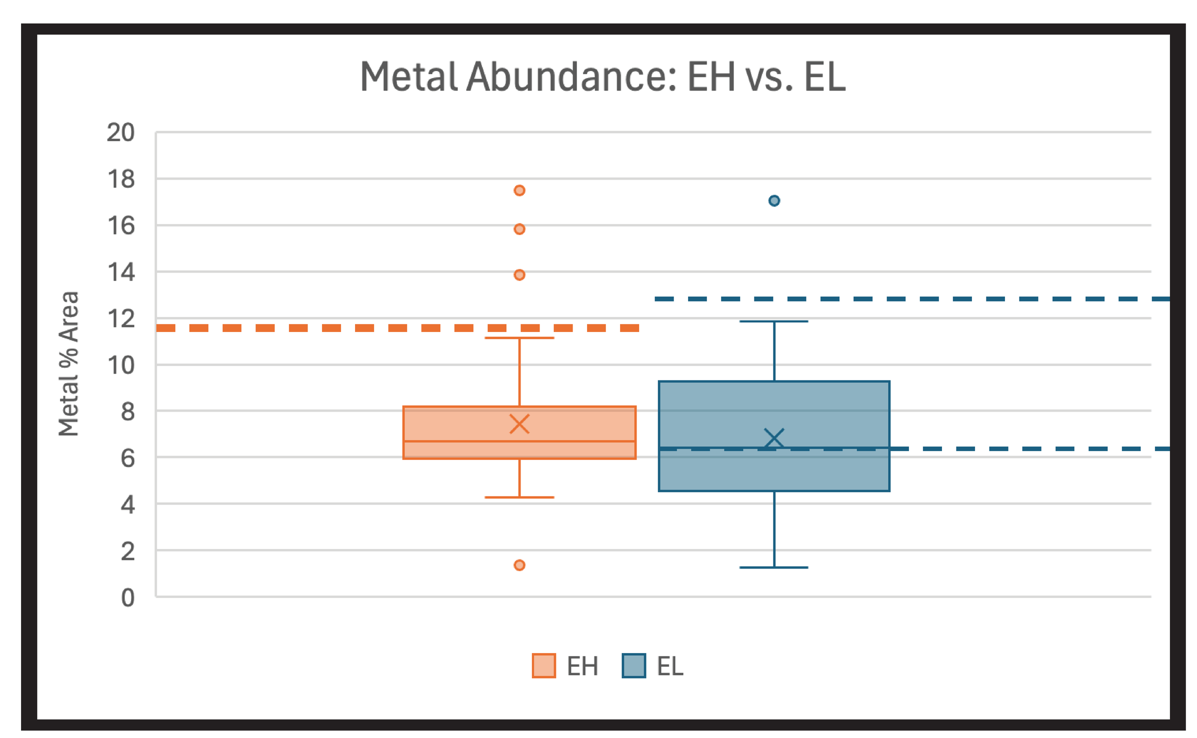

Figure 5: The spread of metal % area measurements in EH chondrites (Abee (EH4) and St. Mark's (EH5)) and EL chondrites (Daniel's Kuil (EL6) and Khairpur (EL6)). The dashed lines illustrate the data points from the Keil (1968) point counting analyses. Each dashed line corresponds to the metal modal abundance of a meteorite.

Results: LA-ICP-MS

Tungsten (W) concentrations show uniformity throughout all samples, with a relative standard deviation of 13.4%. Given that the relative standard deviations for Fe, Ni, and Co (the main constituents of kamacite) are 10.7%, 17.8%, and 9.5%, respectively, the consistency of W concentrations across samples is notable.

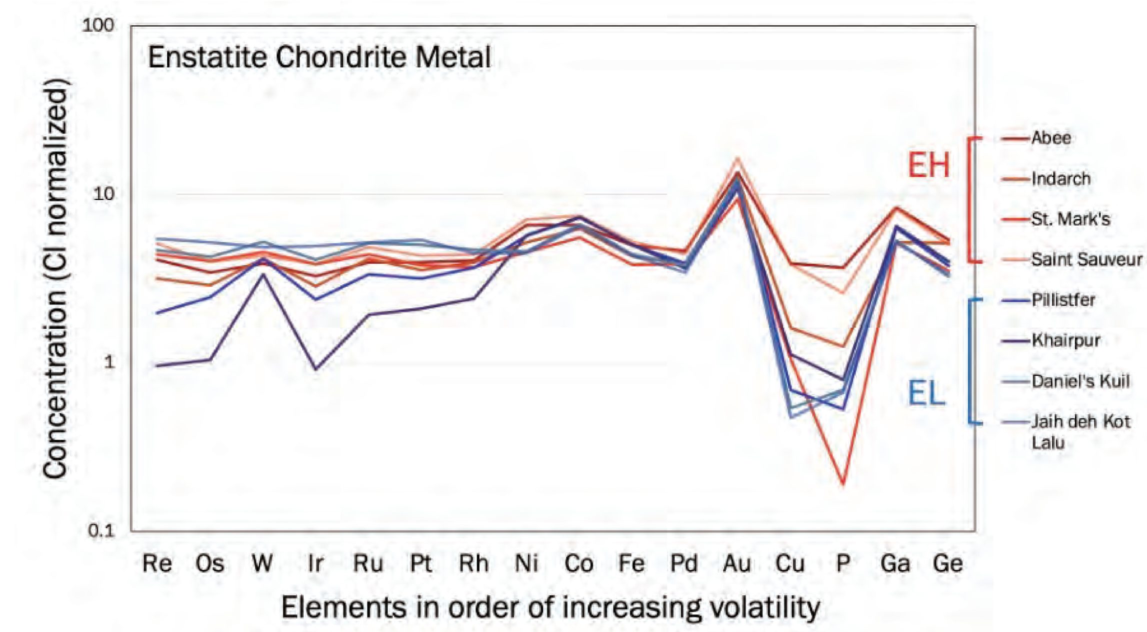

Figure 6: CI-chondrite (Lodders & Fegley, 1998) normalized elemental abundance patterns obtained via LA-ICP-MS analyses. Each colored line corresponds to a meteorite sample. The concentrations illustrated are the averaged values from the 6 to 8 laser ablation analyses conducted on metal grains within each sample.

Tungsten Content Results:
Two-sample t-test results (assuming unequal variance; α set to 0.05): p-value was 0.45 (there is no statistical difference between the W concentrations in EH vs. EL chondrites). Therefore, the null hypothesis cannot be rejected. **There is no difference in the W concentrations of the metal grains between EH and EL chondrites.**

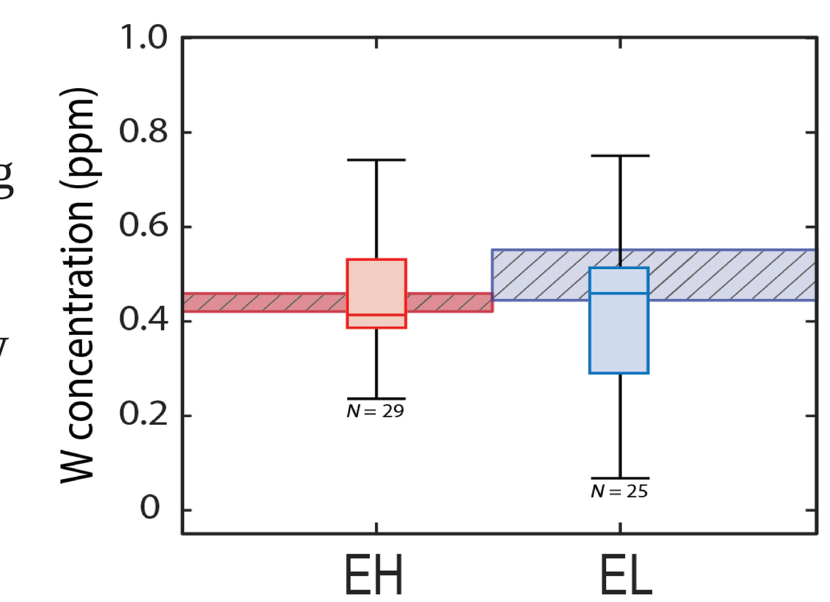

Figure 7: The spread of W concentrations in metal grains between EL and EH chondrites, compared to those determined by Hellmann et al. (2024), represented as reference bars behind the box plots. N denotes the number of samples analyzed.

Conclusions

1. There is no difference in the amount of metal in EH and EL chondrites

2. There is no difference in the average W concentrations of metal grains between EH and EL chondrites.

3. The results from this study support the argument that physical metal-silicate separation (Hf-W fractionation) did not occur prior to the accretion of the EH and EL chondrite parent bodies.

References:

Hellmann, J. L., Van Orman, J. A., & Kleine, T. (2024). Hf-W isotope systematics of enstatite chondrites: Parent body chronology and origin of Hf-W fractionations among chondritic meteorites. *Earth and Planetary Science Letters*, *626*. https://doi.org/10.1016/j.epsl.2023.118518.

Keil, K. (1968). Mineralogical and Chemical Relationships among Enstatite Chondrites. *Journal of Geophysical Research*, *73*(22), 6869-7219. https://doi.org/10.1029/JB073i022p06945

Lodders, K., & Fegley, B. Jr. (1998). *The Planetary Scientist's Companion* (1). Oxford University Press.