Investigation of Siderophile Behavior and Tungsten Systematics in Ordinary Chondrites

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Introduction

Our Solar System began when a nebula of dust and gas collapsed under gravitational forces into a protoplanetary disk (Bouvier et al., 2010). Cosmic sediments from that disk accreted into planets and planetesimals. Chondrites are chemically primitive, silicate-rich meteorites composed of nebular material from this protoplanetary disk. Ordinary chondrites are from S-type asteroids and are commonly used to provide insight into early Solar System processes such as the timing of core formation.

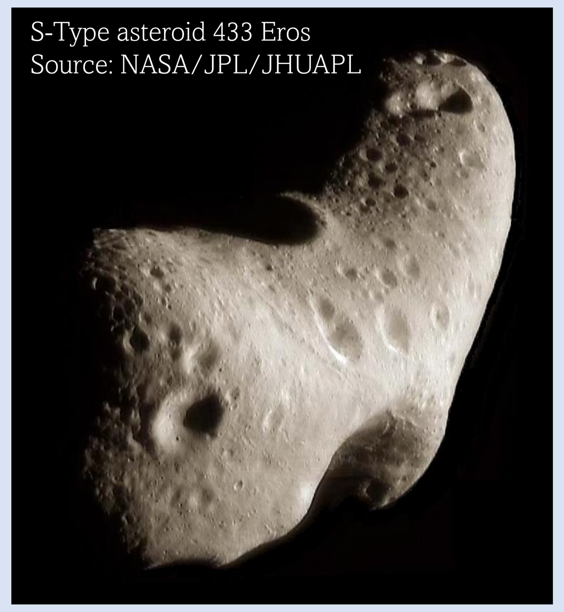

S-Type asteroid 433 Eros
Source: NASA/JPL/JHUAPL


Image of a Protoplanetary Disk (HL Tau)
Source: ALMA

Ordinary chondrites contain metal in varying amounts, so they can be useful for constraining processes that involve the diffusion of siderophile elements. One such example is the use of ^{182}Hf-^{182}W ($t_{1/2}$ = 8.9 Myr) radiometric dating to constrain the timing of core formation. Hafnium is lithophile, so it preferentially resides in silicate structures while tungsten is siderophile, so it preferentially resides in metallic iron (Vernazza et al., 2014). As Hf decays to W, the difference in chemical affinity causes W to preferentially diffuse out of the silicate and into the metallic grains.

Archer et al. (2019) conducted a study in which four H5 chondrites that contained small (<150 microns) and large (>150 microns) metal grains were analyzed for Hf-W closure ages. In two of those chondrites, both the small and large grains displayed similar closure ages, however, in the other two, the closure ages were different. To explain this, they proposed that small metal grains exchange more W at lower temperatures than large grains. To test their suggestion, this study analyzed the behavior of siderophile elements under a range of texture and petrologic conditions.

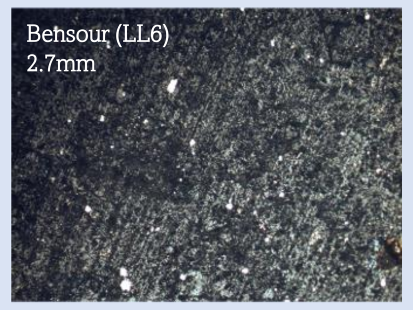
Hypotheses:

I. Siderophile elements in ordinary chondrites that have experienced a higher degree of thermal metamorphism will be more equilibrated than those that experienced less thermal metamorphism.

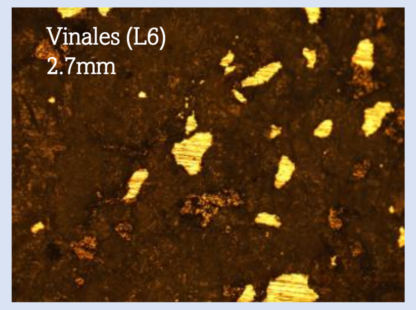
II. Metal grains that have a higher surface-area/volume ratio, will contain more tungsten than metal grains with a lower ratio

Ordinary Chondrites

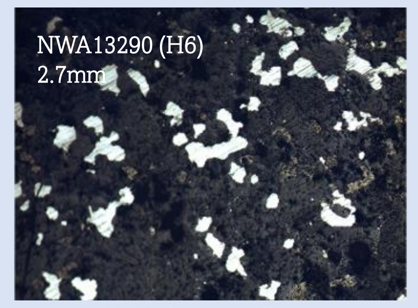
Ordinary chondritic meteorites are categorized as H, L, or LL depending on the amount of total and metallic iron. H chondrites have the most total and metallic iron, L chondrites have less, and LL chondrites have the least. OCs also contain Fe in different oxidation states, so petrologic type is correlated to oxygen fugacity.



LL: Very low in metallic iron, most oxidized

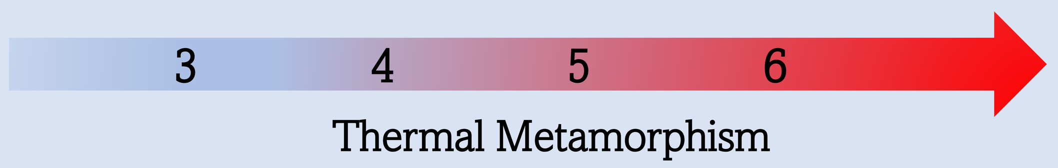


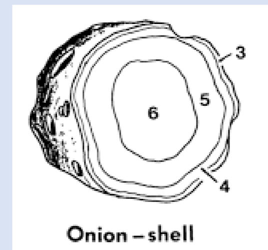
L: Low in metallic iron



H: High in metallic iron, most reduced

Ordinary chondrites are also categorized from type 3 to 6 according to the degree of thermal metamorphism the sample has experienced. Type 3 correlates to the lowest degree of thermal metamorphism, and type 6 correlates to the highest degree.

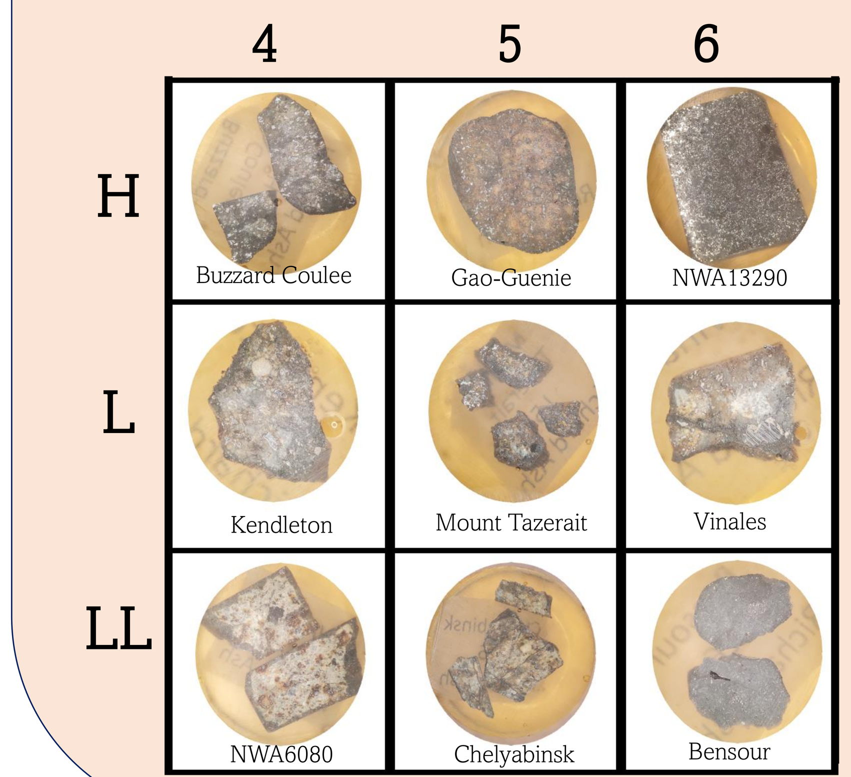




Onion – shell

Methods/Materials

Samples were mounted in epoxy resin and polished. Then viewed under a microscope to search for suitable metal grains for analysis. An Element-2 ICP-MS coupled to a New Wave UP213 laser was used to ablate the surface of each metal grain chosen for analysis.

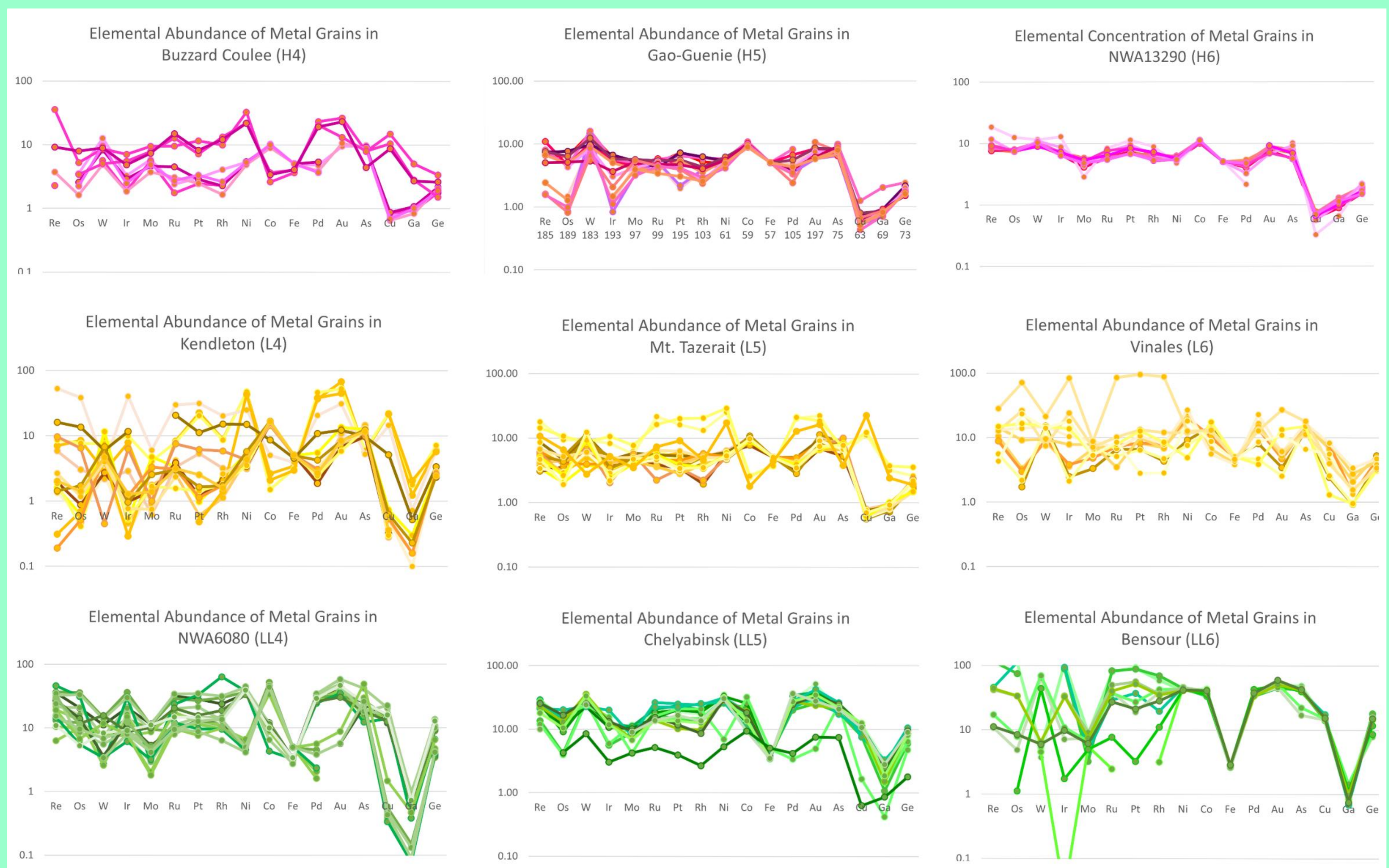


Accuracy/Precision:

Precision was determined by repeated analysis of the Coahuila standard. For W, the standard deviation was consistently better than 5%.

Accuracy was assessed by including the Filomena iron in each of the analysis runs and comparing the concentration with literature values (Wasson et al., 2007). W is within 7% of accepted values.

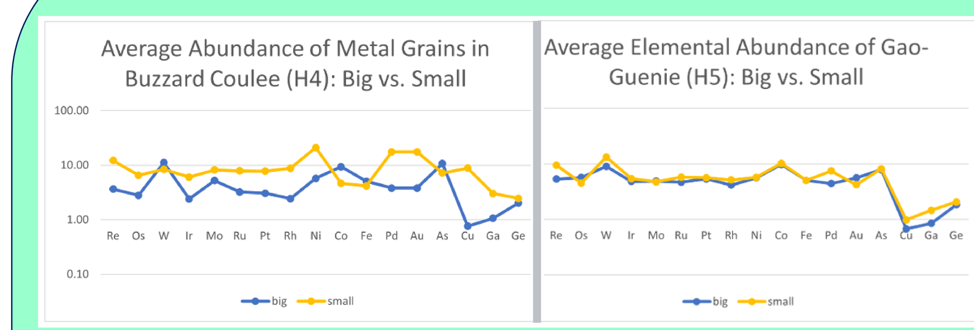
Results/Discussion



CI-normalized abundance graphs of siderophile elements (arranged in order of volatility) analyzed in the metal grains of each sample.

- ❖ H chondrites are the most uniform and equilibration increases with thermal metamorphism.
- ❖ LL chondrites are more complicated; refractory and volatile elements behave differently.

This may be an indication that the **degree of equilibration is more dependent on the specific metamorphic history, texture, and oxygen fugacity of each chondrite than previously thought.

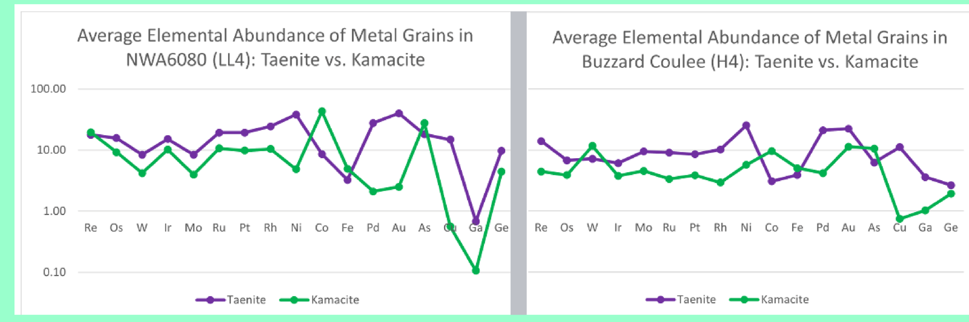


- ❖ small/yellow (<150 microns)
- ❖ large/blue (>150 microns).

Small H4 grains tend to contain a higher abundance of siderophile elements than the large grains.
**The big grains contain more W, but this is because they are kamacite.

- ❖ taenite (high Ni, purple)
- ❖ kamacite (low Ni, green).

In the LL chondrite, W preferentially diffuses into taenite. In H chondrites, W preferentially diffuses into kamacite. **W behavior depends upon the oxygen fugacity of the sample.**



Conclusions

- ❖ I. The metal grains within the H chondrites are consistent with this hypothesis, however, the L and LL chondrites are more complex.
- ❖ II. While smaller grains tend to contain a higher abundance of siderophile elements, the behavior of tungsten is more dependent on the oxygen fugacity of the sample.

Ordinary chondrites are complex as they encapsulate varying degrees of thermal metamorphism, iron content, texture, and oxygen fugacity. All though there are some consistencies, the behavior of siderophile elements is largely dependent on the specific metamorphic/formation history of each chondrite.

Archer G., Walker R., Tino J., Blackburn T., Kruijer T., Hellmann J. 2018. Siderophile element constraints on the thermal history of the H chondrite parent body. Geochim. Cosmochim. Acta 245 pp 556-576 | Bouvier, A., Wadhwa, M. 2010. The age of the Solar System redefined by the oldest Pb–Pb age of a meteoritic inclusion. Nature Geoscience 3, pp 637–641 | Wasson J. T., Huber H., Malvin D. J. 2007. Formation of IIAB meteorites. Geochim. Cosmochim. Acta 71, 760-781 | Vernazza P., Zanda B., Nakamura T., Scott E., Russell S. 2014. The formation and evolution of ordinary chondrite parent bodies. Asteroids IV. University of Arizona Press. pp 617