**Zn ISOTOPIC STUDY OF ENSTATITE METEORITES.**  Frederic Moynier, Randal Paniello, Matthieu Gounelle, Francis Albarede, Frank Podosek and Brigitte Zanda; 1 Department of Earth and Planetary Sciences and McDonnell Center for Space Sciences, Washington University in St Louis, One Brookings Drive, St Louis, MO 63130, USA; 2 LMCM, CNRS & MNHN, UMR 7202, CP52, 57 rue Cuvier, 75 005 Paris, France; 3 Laboratoire de Sciences de la Terre, Ecole Normale Superieure de Lyon, France

**Introduction:** The enstatite meteorites are composed of the undifferentiated enstatite chondrites and the differentiated enstatite achondrites, also known as aubrites. The enstatite meteorites are the most reduced group of meteorites [1]. Oxygen isotope composition of both enstatite chondrites and aubrites plot along the terrestrial mass fractionation line [2].

Enstatite chondrites are separated into two groups: the Fe-rich EH and the Fe-poor EL. Each group is comprised of several petrographic types according to their increasing degree of thermal metamorphism: EH3,4,5 and EL3,5,6. A possible genetic relationship between EL and EH is still debated. Based on the inverse variation of moderately volatile element abundances with petrographic type between EH and EL groups, Kong et al. [3] proposed that both groups are derived from one common parent body, whereas Keil et al. [1] considered that they were derived from two separate parent bodies based on the absence of clasts of EL in EH (and vice versa).

Aubrites are Fe-O-poor enstatite orthopyroxenites, which formed under very reducing conditions [1]. It is generally assumed that the aubrite protolith was similar in composition to material of enstatite chondrite composition [4].

Large variations in the abundance of moderately volatile elements, like Zn, are observed in enstatite meteorites. Zn abundances decrease in the sequence (average concentrations in parenthesis): EH (250 ppm [5]), Shallowater (32 ppm [6]), EL (17 ppm [5]), aubrites main group (0.5-2 ppm [7, 8]). In addition, Zn abundance shows some variations within the different groups: for example, the un-metamorphosed EL3 ([Zn]=213ppm; [3]) is much less depleted in Zn than the highly metamorphosed EL5.6 ([Zn]=6 ppm, [3]); or the EH5 St Marks ([Zn]=48-100ppm) is Zn depleted compared to the average of the EH ([Zn]=250 ppm). Mullaney et al. [9, 10] analyzed the Zn isotope composition of several enstatite meteorites and found unusually large isotope fractionation with enrichment in heavy isotopes in EL and EH and light isotopes in aubrites.

Nebular processes or volatilisation during thermal metamorphism have been proposed as possible origins for the loss of moderately volatile elements, but this is still debated. Volatilization is known to fractionate isotopes, so comparing the isotope compositions of volatile elements in meteorites may help to understand the conditions of evaporation.

Here, we investigate the degree of isotopic fractionation of Zn in aubrites (aubrite main groups and Shallowater), EL chondrites and EH chondrites by multiple collector inductively coupled plasma mass spectrometry (MC-ICP-MS), using the Nu Plasma from the ENS Lyon.

**Results:** Isotope ratios are plotted in Fig. 1. As expected from mass-dependent isotopic fractionation, all the samples plot onto a straight line of slope 2 on a δ66/64Zn vs. δ66/64Zn diagram (Fig. 1). The isotopically heaviest sample is the EL6 Blithfield (δ66Zn=7.35 ‰) and the lightest sample is the aubrite Pena Blanca Spring (δ66Zn=7.08 ‰). On average, the different groups of meteorites are isotopically distinct and give the following values (from the isotopically lightest to the heaviest): Aubrite main group (δ66Zn=3.11±1.10 ‰); EH3,4,5 (δ66Zn=0.31±0.44 ‰); the Shallowater aubrite (δ66Zn=1.48±0.05 ‰); and the EL6 (δ66Zn=4.89±1.37 ‰).

**Discussion:**

**a. Enstatite meteorites are the rocks with the most extreme Zn isotopic composition in the Solar System**

The aubrite Pena Blanca Spring (δ66Zn=7.04 ‰) and the EL6 Blithfield (δ66Zn=+7.35 ‰) are, respectively, the isotopically lightest and heaviest sample known so far in the Solar System.

With few exceptions, the Zn isotopic compositions of terrestrial rocks are relatively homogeneous, with typical δ66Zn values between 0 and 0.60 ‰ in igneous rocks [11-13] and up to 0.70 ‰ in some sedimentary rocks and ores [14]. Some tektites (hypervelocity impact glasses) are enriched in the heavy isotopes (δ66Zn up to +2.49 ‰ [15]) and represent the most fractionated terrestrial samples in terms of Zn isotopes.

In the Solar System, the only other natural samples known so far with enrichment in heavy Zn isotopes with the same magnitude as EL6 are lunar regolith samples (δ66Zn up to +6.39 ‰ [16, 17]). The enrichment in heavy isotopes of the lunar regolith has been attributed to evaporation due to a combination of micrometeorite vaporization and sputtering.

Ordinary (-1.30 < δ66Zn < 0.55) and carbonaceous (0.16 < δ66Zn < 0.52) chondrites [14] show a limited range of variation compared to enstatite chondrites (-1.07<δ66Zn <0.31 for EH and 2.26<δ66Zn <7.35 for EL).
b. Origin of the Zn isotopic fractionation in enstatite chondrites

The EL chondrites measured in this study are all isotopically heavier than the EH which could signal that both groups have distinct parent bodies. However all the EL analyzed are highly metamorphosed (EL6) whereas the EH are from less metamorphosed groups (EH3,4,5). Therefore the isotopic difference may reflect substantial loss of Zn by evaporation during the metamorphism. To test this hypothesis, we will measure the isotopic composition of several EL3.

c. Origin of the Zn isotopic fractionation in aubrites

Shallowater is isotopically heavier than any other aubrite (\(\delta^{66}Zn = 1.48\)). The Shallowater parent body experienced a severe impact history [1] and evaporation of Zn with enrichment in heavy isotopes is the best explanation for the enrichment of heavy isotopes compared to chondrites. This result confirms that Shallowater parent body is distinct from the parent body of other aubrites.

Zn depletion in aubrites is not due to evaporation:

Aubrites are strongly depleted in Zn compared to both EH and EL [7] and they are enriched in light isotopes (\(\delta^{66}Zn\) down to \(-7.08\)). This is the exact opposite of what would be expected if the depletion in Zn were due to evaporation, assuming the aubrites started with an enstatite chondrite-like Zn isotopic composition. If the origin of the isotopic fractionation is evaporation, the isotopic composition becomes heavier when the Zn content decreases. Thus, our Zn isotopic data for aubrites show that evaporation cannot be the origin of the depletion in volatiles.

Zn depletion in aubrites is not due to silicate crystal-melt fractionation: The Zn isotopic composition of aubrites is very heterogeneous (from -7.05 to -0.44). On Earth, igneous processes are inefficient at fractionating Zn isotopes to a large extent [11]. In addition, other differentiated meteorites do not seem to show significant Zn isotope fractionation or the magnitude is small when compared to aubrites: HED (\(\delta^{66}Zn\) between -1.76 to +1.67; Paniello et al. 2009); ureilites (\(\delta^{66}Zn\) between 0.25 to 1.04 [18]).

Metal/silicate/sulfide fractionation: In enstatite chondrites Zn is distributed between the silicate phases, reduced metal and sulfidic phases, which may contribute to Zn isotope fractionation to some extent. For example, [19] showed that the sulfides of the Canyon Diablo iron meteorites were isotopically lighter by \(-1\%\)amu in comparison to the metal. The separation of these phases (e.g. metal/sulfide segregating into the core, or preferential evaporation of sulfides with regard to silicates) would let the aubrite parent body become strongly fractionated. To further test this possibility we will measure the Zn isotopic composition of the different phases (silicate, reduced metal and sulphide) in enstatite chondrites.

---

**Fig.1:** \(\delta^{66}Zn\) vs \(\delta^{68}Zn\). All data fall onto the mass-dependent fractionation line of slope 2. The Aubrites are enriched in light isotopes (with the exception of Shallowater, which is enriched in heavy isotopes); EH scatter around zero and EL6 are enriched in heavy isotopes. The typical errors is 0.10‰ (2s).

**References:**