

NEGATIVE SM, EU AND YB ANOMALIES IN ENSTATITE FROM UECs: THE RESULTS OF EVAPORATION OR IGNEOUS FRACTIONATION? Weibiao Hsu and Ghislaine Crozaz. Dept. of Earth and Planetary Sciences and McDonnell Center for the Space Sciences, Washington University, One Brookings Drive, St. Louis, MO 63130

Enstatites in unequilibrated enstatite chondrites (UECs) exhibit various REE patterns, ranging from relatively flat to extremely HREE-enriched (the latter being characteristic of igneous fractionation). These patterns tend to be mirror images of those observed in oldhamite [1]. The abundances of REEs also show large variations from one enstatite grain to another; these have been found to be associated with the amount of melt inclusions trapped in the enstatite crystals [2, 3]. We have also found that some enstatites from UECs have negative Eu, Yb and Sm anomalies (listed here in the order of decreasing occurrence) and suggested that the REE depletions might be due to evaporative loss during chondrule formation [2, 3]. In order to test this suggestion, we report here Mg and Si isotopic measurements in enstatite from UECs. As will be shown below, the isotopic data do not support an evaporative origin for the REE depletions in enstatite. We considered whether the REE depletions in enstatite might be due to igneous fractionation under the highly reducing conditions at which UECs formed.

Evaporation, a process that enriches refractory components by preferentially vaporizing volatile constituents, is generally indistinguishable from condensation in terms of elemental distributions. However, the isotopic compositions produced by evaporation are significantly different from those resulting from condensation in the sense that evaporation tends to enrich the heavy isotopes in residues. Evidence of evaporation has been found in Ca, Al-rich refractory inclusions (CAIs) of carbonaceous chondrites. These inclusions are among the most primitive objects known; they formed during the earliest stages of solar system formation. Ce depletions are observed in CAIs and they are correlated with large mass-dependent isotopic fractionations (*e.g.*, Mg, Si, Ca and Ti), as expected for evaporation residues from a melt [4, 5]. Laboratory evaporation experiments under oxidizing conditions have successfully duplicated the observations in CAIs, and produced residues that are enriched in heavy isotopes of O, Mg and Si, and depleted in Ce, a relatively volatile REE under oxidizing conditions [6, 7]. Equilibrium condensation calculations have shown that under highly reducing conditions, Yb, Eu and, to a lesser extent, Sm are relatively volatile compared to other REEs [8]. However, synthetic evaporation experiments under such conditions have not yet been made. Taking the results for oxidizing environments as a guide, one would expect that evaporative loss of REEs in enstatite would also result in the enrichment of heavy isotopes of the major elements. With this in mind, we measured the Mg and Si isotopic compositions of enstatite from four UECs (Qingzhen, Y-691, MAC88136 and EET90299) with the Washington University ion microprobe, to determine whether or not the REE depletions in this mineral are associated with Mg and Si isotopic mass fractionations.

To correct for instrumental mass fractionation during isotopic measurements, a standard of similar chemical composition, in this case enstatite from the Bustee aubrite, was used. Enstatite in aubritic meteorites, which is generally believed to have crystallized from a magma, shows no significant mass fractionation in Mg and Si. In UECs, the Mg and Si isotopic compositions were measured both in enstatites with and without REE depletions. A total of 116 analyses were made. These include forty eight measurements in enstatite with negative Eu, Yb and Sm anomalies, sixteen in enstatite with negative Eu and Yb anomalies, twenty one in enstatite with a negative Eu anomaly, eight in enstatite with negative Yb and Sm anomalies and seven in enstatite without REE anomalies. Figure 1 shows the Mg and Si isotope mass fractionations in enstatite from two UECs (similar results were obtained in the two other meteorites studied). As can be seen in this figure, most Mg and Si isotope compositions are unfractionated, within 2σ errors, relative to those of aubritic enstatite. Eight measurements show small mass fractionations with $F^{30}\text{Si}$ up to 15 ‰. However, their Mg isotopic compositions are normal, *i.e.*,

unfractionated. In addition, these Si isotope mass fractionations are not correlated with the depletions of REEs in enstatite. One measurement in enstatite without REE depletions has a $F^{30}\text{Si}$ of 12.5 ‰. The Mg and Si isotopic data, therefore, do not support our previous suggestion that the REE depletions in enstatite of UECs are due to evaporative loss during chondrule formation. Thus, alternative explanations have to be considered.

In nature, REEs tend to occur in the trivalent state. In extreme cases (*e.g.*, highly reducing conditions), Eu and Yb can be divalent because of the enhanced stability of the half-filled (Eu^{2+}) and completely-filled (Yb^{2+}) 4f sub-shell. The presence of Sm^{2+} in minerals has also been suggested by Goldschmidt [9]. During melt crystallization, divalent REEs will be more incompatible in pyroxene, because of their larger ionic radii, than trivalent REEs. If part of the Eu, Yb and Sm was divalent under the highly reducing conditions that are believed to have prevailed during the formation of enstatite chondrites, it would be possible to account for the observed negative anomalies in enstatite.

However, this interpretation does not take into account the observation that not all enstatite grains have negative Eu, Yb and Sm anomalies despite the likelihood that they were formed under similar reducing conditions. In addition, we have shown that the enstatite REE patterns are strongly controlled by the amount of trapped melt glass inclusions [3] and, thus, the Eu, Yb and Sm depletions must be a characteristics of the melts themselves and not a consequence of REE fractionation during enstatite crystallization. The complementary REE patterns observed in enstatite and oldhamite are consistent with the chondritic REE patterns of bulk samples of enstatite chondrites but their origin still remains unexplained.

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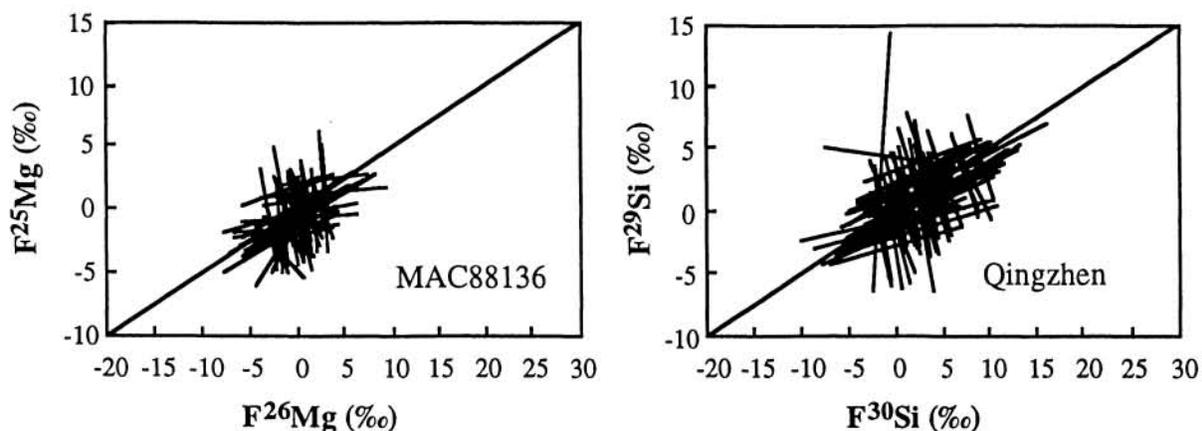


Figure 1 Enstatite isotopic data, Mg in MAC88136 and Si in Qingzhen (similar Mg and Si isotopic compositions were obtained for all four UECs studied). F values of 0 indicate that the isotopic compositions are normal, *i.e.*, unfractionated.