ON THE FORMATION OF ENSTATITE IN UNEQUILIBRATED ENSTATITE CHONDRITES. Weibiao Hsu and Ghislaine Crozaz. Dept of Earth and Planetary Sciences and McDonnell Center for the Space Sciences, Washington Univ., One Brookings Drive, St. Louis, MO 63130.

The highly reduced enstatite chondrites are generally believed to have formed in a region of the solar nebula with a much higher than average C/O ratio. Their major mineral, enstatite, is essentially Fe-free and, under electron bombardment, shows either red or blue cathodoluminescence (CL) that, according to some [1], is associated with the concentrations of minor elements such as Mn and Cr. Unequilibrated enstatite chondrites (UECs) also contain some more oxidized "Fe-rich" (>3% FeO) low-Ca pyroxenes (e.g., [2,3]). Weisberg *et al.* [4] suggested, on the basis of petrological and chemical data, that some of the red enstatite may be the product of reduction of this Fe-rich pyroxene and that the blue enstatite rims on these crystals grew by direct nebular condensation. Last year, we reported REE concentrations in UEC enstatites [5] and showed that the REE patterns tend to be mirror images of those in the major REE carrier, oldhamite, either relatively flat or with modest HREE enrichments. Eu and Yb anomalies, when present in enstatite, are negative. We have since confirmed that all the enstatite grains we had measured had a red CL. To better understand the relationship between red and blue enstatite and their respective origins, we have measured trace element concentrations in blue enstatite of the most unequilibrated enstatite chondrite, Qingzhen (EH3).

As in other UECs, most of the enstatite in Qingzhen has a red CL. Both red and blue enstatite occur as single grains or in chondrules (most often porphyritic) that usually include mixtures of red and blue enstatite. We found some blue enstatite completely surrounded by a thin rim of red enstatite (but not the opposite as reported by [4]) and also analyzed a barred blue enstatite chondrule. Since enstatite is not the major REE carrier in UECs, a relatively large primary ion beam was used (~15nA) and special attention was paid to the possibility of contamination by oldhamite (CaS) by monitoring the Ca and S signals throughout the analysis.

McKinley *et al.* [6] have previously observed that the CL color of enstatite is not uniquely correlated with its composition. With the exception of the bright blue enstatite, which has much lower minor element concentrations, red and blue enstatite were found to have a considerable overlap in composition. The present study confirms (and extends to trace elements) these observations; there are no REE patterns or abundances that uniquely characterize either type of enstatite. Figure 1 reports data for oldhamite, red, and blue enstatite from the same porphyritic chondrule. The REE pattern of red enstatite has a small depletion of the LREEs as well as negative Eu and Yb anomalies that seems to be mirrored in the oldhamite REE pattern. REE concentrations in blue enstatite are much lower (~0.01xC1) and, considering the large associated errors, consistent with those in red enstatite. REE patterns for a blue enstatite grain (2 analyses) and an adjacent red enstatite are also very similar (Figure 2). The two analyses of red enstatite are in excellent agreement but REE concentrations are lower in red than in blue enstatite. Four analyses of a single blue barred chondrule with thin red enstatite bars (not shown) yielded 4 similar REE patterns (also characterized by negative Eu and Yb anomalies) but with different REE concentrations. The range of concentrations is attributed to the presence (in different amount in each analysis) of small (typically ~1μm) trapped melt inclusions of sulfide and albitic compositions which are common in enstatite [7]. These inclusions, which are hard to avoid even in an electron microprobe analysis, probably contributed to the overlap in red and blue enstatite compositions observed by [6].

We believe that the REE patterns of both red and blue enstatite are controlled by the composition of the melts they trapped during their rapid crystallization. The similarity of REE patterns measured in adjacent crystals of both types implies that red and blue enstatites have a common origin. The data, therefore, do not confirm the model advocated by Weisberg *et al.* [4] in

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which red and blue enstatites had independent modes of formation. The relatively flat REE patterns observed in enstatite are compatible with an igneous origin despite the fact that REE equilibrium partition coefficients (e.g., [8]) for pyroxene indicate that this mineral strongly favors the incorporation of the HREEs over that of the LREEs. When the chondrules formed by rapid cooling, equilibrium could not be maintained and small amounts of melt were trapped in the growing crystals. Although the trapped melt is volumetrically insignificant, its essentially flat chondrite-normalized REE composition dominates the REE pattern of enstatite, a mineral in which REEs are otherwise strongly incompatible elements. In support of this explanation, the same effect has actually been observed in an experiment simulating the formation of chondrules [9]. The data for the barred chondrule indicate that it has the largest amount of trapped melt, an observation that is consistent with its very high cooling rate (greater than for porphyritic chondrules) as implied by dynamic crystallization experiments [10]. Because Eu and Yb are the most volatile REEs under reducing conditions [11], their depletions in enstatite is attributed to evaporative loss during chondrule formation. The complementarity of oldhamite and enstatite REE patterns noted by [5] suggests that the REE-rich oldhamite did not form by condensation from an otherwise solar gas with a C/O ratio>1 (as concluded by [11]) but rather was a byproduct of the igneous process that led to the formation of the enstatite.

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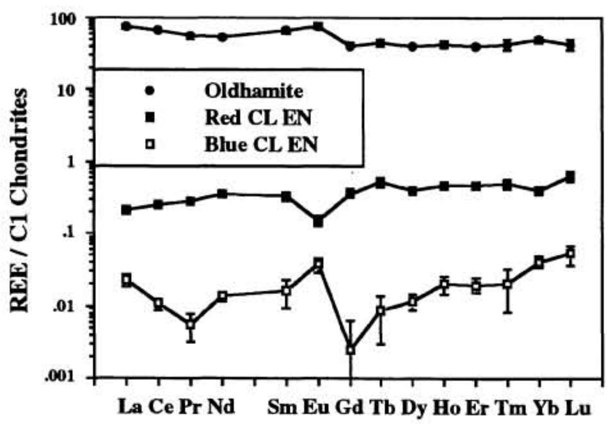

Fig.1 REE patterns for oldhamite and enstatites in a porphyritic chondrule

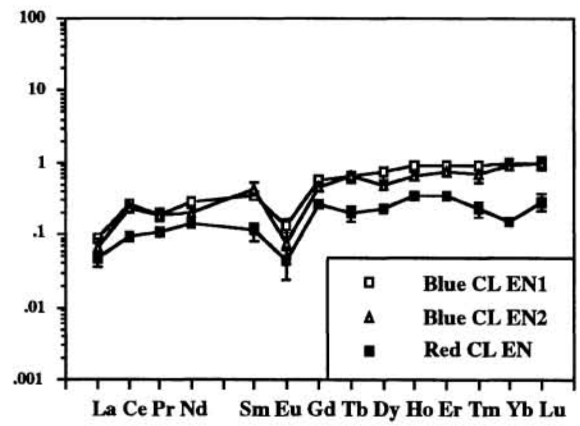

Fig. 2 REE patterns for red and blue CL enstatites