CHONDRULES IN ENSTATITE CHONDRITES - NATURE AND SOURCE OF ENSTATITE. S.G. McKinley, E.R.D. Scott and K. Keil., Department of Geology and Institute of Meteoritics, University of New Mexico, Albuquerque, NM 87131

Introduction. Leitch and Smith (1-3) argue that chondrules in enstatite chondrites formed as a result of mixing of solids and liquids from two different sources. They believe two sources are required to account for the presence, in four EH4 chondrites, of both red and blue luminescing enstatite, which they find to be distinctly different in composition (lower Cr, Mn, Ca, Ti and Al and higher Na in blue enstatite). However, our random 4-element analyses of enstatite in Allan Hills A77156, Kota Kota and Indarch (all EH4 chondrites) showed that there is considerable overlap in composition between red and blue luminescing enstatites and that several histograms for Mn and Cr concentrations did not show a bimodal distribution (4). In addition, we distinguished dull blue enstatites, which have Mn concentrations intermediate between those of bright blue and red enstatites, and high Cr concentrations like those of red enstatite. To elucidate further the discrepancy between our results and those of Leitch and Smith, and the origin of E chondrules, we have made more petrologic studies of enstatite chondrites.

Results. We have analyzed 10-30 enstatite grains in 30 chondrules of all textural types from a suite of EH chondrites (refs. 5,6), Qingzhen (type 3), Allen Hills A77156 (type 4) and St. Mark's (type 5), for Fe, Cr, Mn, Si and, in a few chondrules, Na also. We also analyzed for these elements and Na in euhedral enstatite crystals wholly or partially enclosed by metal-sulfide inclusions in St. Mark's, A77156, Adh Kot (EH4), and Kota-Kota (they are absent in Qingzhen). Chondrules were analyzed in two ways: a representative suite of crystals for analysis was chosen under the microscope and then supplemented by analyses of grains that showed extreme luminescence colors. Four chondrules were then reanalyzed using a grid pattern giving 20-50 enstatite analyses on each.

Results from the first technique on Qingzhen and A77156 chondrules gave three kinds of patterns on Mn-Cr plots (in order of decreasing abundance): a) a single cluster of analyses for grains with uniform or mixed colors (Figs. 1 and 3), b) two clusters one of which was composed of bright blue enstatites with very low Mn and Cr concentrations, and c) a continuous spread of data from bright blue enstatites that plotted near the origin (like Fig. 2). For (b) and (c), Fe concentrations were generally positively correlated with Mn and Cr. Random analyses of two chondrules, each with two clusters of data (pattern b) from the first technique, gave continuous spreads (c). Fig. 2 shows one of these. For the other two chondrules with (a) and (c) patterns, results from the two techniques are similar. Five chondrules in St. Mark's all contain bright blue enstatites with <0.07% Cr and <0.04% MnO. We found virtually all enstatite to be bright blue in St. Mark's.

Discussion.

a) We confirm our previous finding (4) that composition is not uniquely correlated with luminescence color, e.g., high-Cr enstatites may luminesce blue, bright blue, red, violet or have indeterminable colors (Fig. 1). Thus evidence for red and blue enstatites in a single chondrule does not necessarily require "mechanical aggregation of both crystals and liquids of both color types" (4).

b) Enstatites all having, for example, high CrO₂ concentrations (>0.08% CrO₂) would according to refs. 1-3 come from a single source. However, our MnO-CrO₂ plot (Fig. 3) shows that chondrules with high-Cr enstatite may have distinctly different enstatite compositions. Thus chondrule precursor material had not two, but many, different compositions (7). We suggest that heterogeneities result from sorting of precursor dust in the nebula, not from collision of planetesimals (3).

c) Some chondrules (in our EH3-4 sample) contain a few bright blue enstatites with concentration of Cr, Mn and Fe that are distinctly lower than those of other grains, consistent with refs 1-3. Although we recognize that some olivine crystals in chondrules are relict or foreign in that they did not crystallize in situ (8-10), we doubt that all of these bright blue enstatites fall in this category, for the following reasons.

d) Some bright blue luminescing areas in Qingzhen and A77156 chondrules are on the edge of, or within grains which have different colors and compositions.

e) In some chondrules we find positive correlations of Mn, Cr and Fe concentration in enstatites (Fig. 2) with no textural evidence to suggest that bright-blue enstatites have a unique origin. Fractionation during crystallization may produce these trends; intermittent crystallization may produce a hiatus in composition.

f) Overall, the proportion of bright-blue enstatites, which have low Cr and Mn concentrations, increases from type 3 to type 5 (ref. 12); A77156 and Qingzhen have fewer than St. Mark's. Thus metasomatism is probably causes changes in luminescence colors and reduces minor element concentration.

g) Euhedral enstatite crystals in metal-sulfide aggregates are metamorphic and not primary, as Smith and Leitch believed (3). Euhedral enstatites are absent in Qingzhen and increase in size and abundance from EH4 through EH5 to EH6 chondrites and Happy Canyon (~7). Metal-silicate boundaries have high energy and promote growth of
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euhedral silicates, as in pallasites (11). Our analyses of euhedral crystals, which are all bright-blue, gave, with virtually no exceptions <0.10% Cr$_2$O$_3$, <0.09% MnO, <0.06% Na$_2$O. Thus annealing of chondrites, and perhaps chondrules, may cause changes in the ranges of colors and compositions of enstatites by recrystallization.

h) A possible argument against a metamorphic origin for any bright blue enstatites in EH3-4 chondrites is that Leitch and Smith (3) found them to contain higher Na$_2$O concentrations (generally >0.075 wt.%) than red enstatites, whereas Keil (12) found <0.05% Na$_2$O in EH5 and EL6 enstatites (largely bright blue). However, our analyses of 32 bright-blue grains in EH3-4 chondrules, found only 12% to have >0.075% Na$_2$O.

i) Leitch and Smith (2) find that olivines are also bimodal in composition; orange (or red) olivines having more Cr and Mn than blue. However, we found one chondrule in A77156 that contains a barred olivine crystal with bars that are largely red but blue along some internal segments. Such an intergrowth "jeopardizes" models in which red and blue segments have different sources (3).


Figs. 1-3. Concentrations of MnO, Cr$_2$O$_3$ and FeO in enstatite grains in six chondrules from Qingzhen (Q) and Allan Hills A77156 (A). Dashed lines represent detection limits.