

THE FORMATION OF FEO-RICH PYROXENE AND ENSTATITE IN UNEQUILIBRATED ENSTATITE CHONDRITES: A PETROLOGIC-TRACE ELEMENT (SIMS) STUDY. M.K. Weisberg¹, M. Prinz¹, R.A. Fogel¹, and N. Shimizu². (1) Dept. Mineral Sci., American Museum Natural History, New York, NY 10024. (2) WHOI, Dept. Geology and Geophys., Woods Hole, MA 02543.

FeO-rich pyroxenes (Fe-Pyx) are a major constituent of some of the chondrules and fragments in unequilibrated enstatite chondrites (UEC). They contain structurally oriented zones of Cr-, Mn-, V-rich, FeO-poor enstatite (En) that has a red cathodoluminescence and is associated with μm -sized blebs of low-Ni, Fe-metal, and in some cases silica. This represents clear evidence for the process of reduction. The Fe-pyx is nearly always rimmed by minor element-poor En having a blue CL. More commonly, red and blue En occur as larger grains in chondrules and fragments throughout the UEC's, unassociated with Fe-pyx, constituting the major silicate phases. REE abundance patterns of the Fe-pyx are LREE-depleted and red En has a similar pattern. Blue En rims, however, have a flat REE pattern at $\sim 1\times$ Chondritic (Ch). The Fe-pyx in UEC's originated from an earlier generation of chondrules that formed in a nebular region that is more oxidizing than that required for enstatite chondrites. Following solidification these chondrules were introduced to a more reducing nebular environment. Some of the red En crystals that are common throughout UEC's may be the products of reduction of Fe-pyx. Blue En rims grew onto the surfaces of the Fe-pyx and red En via condensation from the nebula.

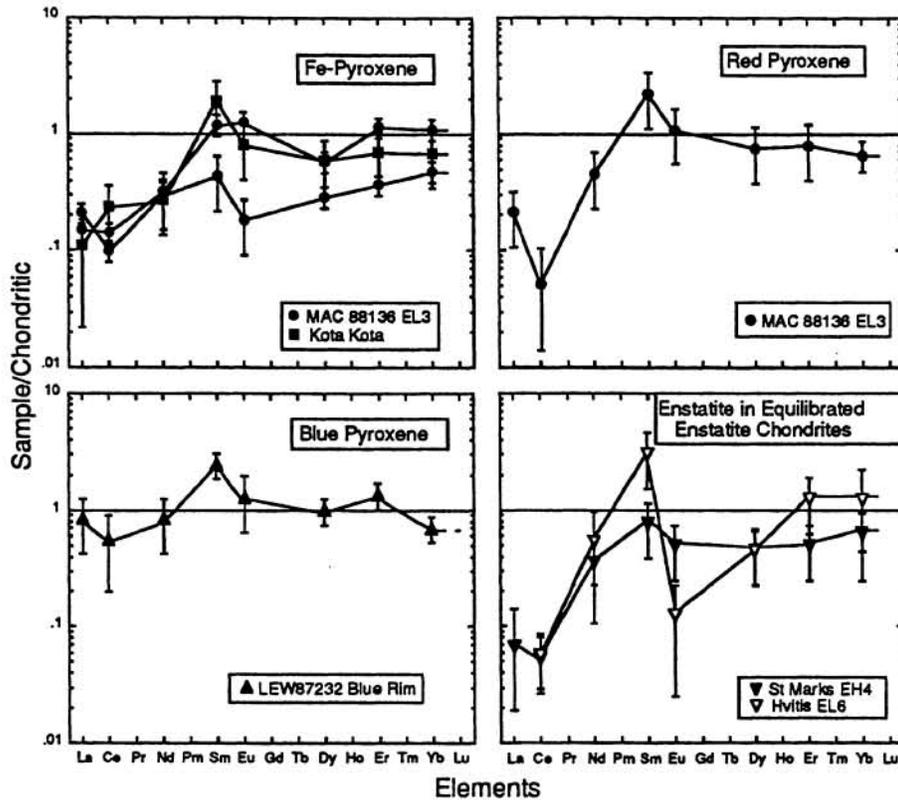
INTRODUCTION: Enstatite chondrites record the most reducing conditions known in the early solar system. Their oxidation state may be the result of condensation in a nebular region having an enhanced C/O ratio [1], reduction of more oxidized materials in a reducing nebula, reduction during metamorphic reheating in a parent body [2], or a combination of these events. The presence of more oxidized Fe-rich silicates [3,4,5,6], two types of En (distinguished by red and blue CL) [7,8], and the juxtaposition of Fe-pyx surrounded by blue En in the UEC's is intriguing and led us to examine the question of enstatite chondrite formation. Previously, we presented data on the petrologic-geochemical characteristics of the Fe-pyx and coexisting red and blue En [9]. Here we report on minor and trace element abundances (determined by ion probe-SIMS) on these three types of pyroxenes in the following meteorites: Kota Kota and LEW87223 (EH3), MAC88136 (EL3), St. Marks (EH4), and Hvittis (EL6). More data are currently being collected.

RESULTS: Fe-pyx (Fs₄₋₃₇) grains occur in some chondrules and fragments in UEC's and show evidence of the onset of reduction. They contain μm -sized blebs of low Ni (<1%), Fe-metal associated with (low-FeO) red En, and in some cases silica, along grain boundaries, twin lamellae, veins, and fractures. Fe-pyx chondrules and fragments are nearly always rimmed, or partially rimmed, by blue En. Electron probe analyses (WDS) show that Fe-pyx is enriched in minor elements which range (in wt.%) from 0.5-1.7 Cr₂O₃, 0.1-0.8 MnO, <0.1-2.6 Al₂O₃, 0.5-3.1 CaO. Minor elements determined by SIMS (Table 1) agree with the WDS data and, in addition, show that Fe-pyx has up to 148 ppm V and 787 ppm Ti. REE patterns were measured in 3 Fe-pyx grains and all have LREE-depleted patterns with La \sim 0.1-0.2 \times Ch and Yb \sim 0.5-1 \times Ch (Avg. La/Yb=0.2). **Red En** (Fs_{<4}) occurs along structurally controlled zones within the Fe-pyx as well as individual crystals in chondrules and fragments, unassociated with Fe-pyx. It is a major silicate component in UEC's. Minor and trace element abundances are generally similar to that of Fe-pyx (Table 1), and they have similar REE patterns (Fig. 1). **Blue En rims** are characterized by minor element concentrations below electron microprobe detection limits (<0.03wt.%) but, in some cases, have Na₂O (up to 0.07%) and Al₂O₃ (up to 2%) abundances that are higher than in Fe-pyx and red En. Ion probe analyses, however, reveal up to (in ppm) 91 Ti, 11 V, 434 Cr, 161 Mn, and 1 Sr (Table 1). The REE pattern for blue En differs significantly from that of Fe-pyx and red En and is flat at $\sim 1\times$ Ch. **En in EH4 and EL6 chondrites** has blue CL, with Ti, V, and Cr abundances similar to the blue En rims; however, some blue En rims have much higher Al, Na, Mn and Sr concentrations. In addition, the REE patterns of these pyroxenes are LREE-depleted with La <0.07 \times Ch for Hvittis (EL6) and below detection for St. Marks (EH4); HREE are flat at $\sim 1\times$ Ch, and the Hvittis En has a large negative Eu anomaly.

DISCUSSION: 1) The occurrence of chondrules that consist mainly of Fe-pyx suggests that all Fe-pyx fragments in UEC's originated from broken chondrules [5,9]. The fractionated REE pattern of Fe-pyx, typical of that expected for crystal/melt partitioning of REE's in pyroxene, is consistent with this interpretation. 2) The high Fe content of the Fe-pyx testify to formation in a nebular region that is more oxidizing than that required for enstatite chondrites. 3) The similarity in REE patterns, trace element contents and the numerous reduction features found in red En and Fe-

FORMATION OF PYROXENE IN E CHONDRITES: Weisberg M.K. et al.

pyx strongly imply formation of some red En, a major silicate component in UEC's, by reduction of Fe-pyx. Some red En may have crystallized from chondrule melts having Fe-pyx-like precursors. 4) The blue En rims did not form via crystallization from a melt. Crystallization of pyroxene from any known chondrule melt composition would not produce pyroxene which is so remarkably low in Cr and Mn; partition coefficients of these elements in pyroxene are too high [10]. Additionally, the flat REE pattern of blue En rims is not that expected from crystal/melt partitioning of REE's in pyroxene. Growth during parent body metamorphism is also an untenable hypothesis. UEC's are relatively unmetamorphosed and rims having sharp boundaries, like the blue En rims, are not observed in metamorphosed chondrites (e.g., ordinary chondrites). Secondly, metamorphism of enstatite chondrites appears to reduce all minor element abundances in En; therefore, the high Al, Na, Mn and Sr contents of some blue En rims are inconsistent with their growth during subsolidus heating on a parent body. Finally, the REE's in the Fe-pyx, red En, and equilibrated En in the EH4 and EL6 chondrites exhibit a similar LREE-depleted pattern, whereas the blue rims have a flat 1xCh pattern. The blue En with REE concentrations that are near C1, imply a nebular condensation origin. Their low FeO contents are consistent with a nebular environment classically thought of as having given rise to the E chondrites; a nebula with low fO_2 .



REFERENCES: [1] Larimer J.W. and Bartholomay M. (1979) GCA 43, 1455-1466. [2] Ringwood A.E. (1966) GCA 30, 41-104. [3] Rambaldi E. et al. (1983) EPSL 66, 11-24. [4] Rambaldi E. et al. (1984) Nature 311, 138-140. [5] Lusby D. et al. (1987) JGR 92, E679-E965. [6] Kitamura M. et al. (1988) Proc. NIPR Symp. Antarc. Met. 1, 38-50. [7] Leitch C.A. and Smith J. V. (1982) GCA 46, 2083-2097. [8] McKinley S.G. et al. (1984) JGR 89, B567-572. [9] Weisberg M.K. et al. (1992) LPSC XXIII, 1509-1510. [10] Lofgren G.E. and DeHart J.M. (1992) LPSC XXIII, 801-802.

Figure 1. REE's in the three types of low-Ca pyroxene from enstatite chondrites. (Error bars = %MD.)

Table 1. Minor/trace element abundances (ppm) in pyroxene from enstatite chondrites.

	Fe-pyx	Red	Blue	Hvittis	St. Marks
Ti	33-787	153-230	7-91	17	37
V	42-148	66-102	9-11	4	17
Cr	2028-6638	2448-3132	314-434	177	399
Mn	805-3201	503-1530	154-161	57	63
Sr	1-3	bd-3	0.4-1	bd	0.4
# grains	5	2	3	1	1

bd-below detection.