

Formation and Metamorphism in Enstatite Chondrites. John M. DeHart⁺ and Gary E. Lofgren*. ⁺Energy Laboratories, Inc., 254 N. Center St., Casper, WY 82601. *Mail Code SN4, Johnson Space Center, NASA Road 1, Houston, TX 77058.

Introduction. Many components in enstatite chondrites represent materials that formed in the most reducing conditions known in the primordial solar nebula. These conditions form Fe-poor to Fe-free enstatite that emit varying intensities of red to blue Cathodoluminescence (CL). For any constant setting of electron beam conditions (i.e. the same potential and beam intensity), the color and intensity of the CL emission in pyroxenes appear to be related to a combination of minor element composition (1,2 see Table 1) and structure (3,4;) and similar CL properties have been reproduced in synthetic enstatites using dynamic crystallization experiments and isothermal annealing (5), relating these properties to possible formation mechanisms. We have examined the distribution of these different types of enstatite in a suite of E chondrites to see if there are any relationships between their abundances and E-chondrite formation mechanisms, chemical group, or metamorphic type and report the results here.

Experimental. CL imaging was done using the methods described in our earlier work (5). In order to quantify the images, they were examined by point counting using a grid consisting of 9 lines vertically and horizontally at 600 micron intervals. The CL of the points were classified according to the pyroxene types and other phases that have a distinct association of CL color and intensity to composition. Representative electron microprobe measurements of each phase and CL type are listed in Table 1. In cases where the specimen did not have a continuous surface area where the grid could be placed, the data was normalized to 81 data points in order to compare similar surface areas. The ratios of each pyroxene type to all pyroxene points were then calculated and the results for each specimen were then tabulated for comparison (see Figure 1).

Observations. CL differences related to chemical group. The results demonstrate a clear difference in the pyroxene populations in EL3 and EH3 chondrites. Pyroxene in EL3 chondrites are dominated by violet-blue pyroxene while pyroxene in EH3 and EH4 chondrites are dominated by bright to dull red pyroxenes. The objects composed of violet-blue pyroxene appear randomly distributed in ALH85119 but also occur as aggregates of chondrules and clasts in two of the four EL3 chondrite sections (MAC88136 and PCA91020) as well as nearly the entire section of EET90299.

There is also a distinct difference in the pyroxene CL types in EL5 and EL6 chondrites when compared to EH6 chondrites. The pyroxene in the EL5 and 6 chondrites exclusively emit a magenta CL while pyroxene in the EH6 chondrite is dominated by the mottled blue CL type which is consistent with the Zhang et. al. (3) observations. It also appears that there was either insufficient time or heating to completely reduce and homogenize the pyroxenes to a single CL type in LEW88180. Laths of red pyroxene are observed to be poikilitically enclosed by blue pyroxene in this specimen.

CL differences related to metamorphic type. EL3s are dominated by violet-blue and red CL pyroxenes while EL5 and 6 chondrites are entirely composed of pyroxenes that emit magenta CL. EH3 and 4 chondrites are dominated by pyroxenes emitting red CL while the EH6 section is dominated by pyroxenes emitting a mottled blue CL.

Discussion. There appears to have been two types of environments in the E-chondrite forming region. The first environment produced the Fe-poor enstatites that emit red to dull red CL while the second environment was either so Fe-poor or so highly reducing that Fe and the minor element activators of red CL (Cr^{3+} , Mn^{2+} , etc.) were not incorporated into the pyroxene, producing the enstatite that emits the violet-blue CL. EH3 and 4 chondrites appear to be composed of products of this first environment while the chondrules and clasts composed of violet-blue CL appear to be products of the second environment. The EL3 chondrites are comprised of components from both regions, with the objects composed of enstatite emitting violet-blue CL being dominant in the type II clast in PCA91020 (6) and in the section of EET90299 (88 and 69 percent, respectively) to comprising only 32 percent of the pyroxenes in ALH85119. Although there is insufficient microprobe data at this time to support the idea that these clasts composed of violet-blue CL also carry the chemical signature for the EL chondrites, the CL data certainly suggests this as a possibility.

The mottled blue texture of some pyroxenes appear to be the product of reheating. It is only found relict grains previously described (7) and is the dominant phosphor in the EH6 chondrite. Their similarity argues that EH6 materials could have been the original precursors of these relict grains.

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Several important differences in CL properties appear to be associated with metamorphism. While there appears to be little or no difference in the CL properties of EH3 and EH4 chondrites, these is a drastic difference between these and the EH6 chondrite. One could infer from the data that if metamorphism produced the CL differences in the enstatite in these meteorites, then 20 to 60 percent of the enstatite in an EH5 specimen should emit mottled blue CL. Also the CL properties of EL3 are considerably different from the EL5 and EL6 specimens. An EL4 should have properties intermediate between these two if a true metamorphic sequence exists in the EL chondrites.

Conclusion Two formation regions which differed in their redox conditions are required to explain the distribution of pyroxene CL types in E chondrites. If the black pyroxene identified and described by Weisberg, et. al. (8) represents the precursor materials of E chondrites, then these environments represent increasingly reducing conditions where volatile loss and reduction of metals produced their chemical differences. Alternately, the components containing the violet-blue CL could represent a second chemical reservoir which was mixed and processed with the highly oxidized reservoir represented by the black pyroxene to produce chemistry and mineralogy observed in E-chondrites.

References: (1) Leitch and Smith (1982) *GCA* **46**, 2083-2097. (2) McKinley et al. (1984) *Proc. 14th Lunar Planet. Sci. Conf., Pt.2, J. Geophys. Res.* **89, Supplement**, B567-572. (3) Zhang et al. (1994) *LPSC XXV*, pp. 1547-1548. (4) DeHart J.M. and Lofgren G.E. (1994) *LPSC XXV*, pp. 319-320. (5) Lofgren G.E. et al. (1992) *LPSC XXIII*, pp. 799-800. (6) Lofgren G.E. and DeHart J.M. this volume. (7) Lofgren G.E. et al. (1992) *LPSC XXIII*, pp. 801-802. (8) Weisberg et al. (1992) *LPSC XXIII*, pp. 1509-1510.

Table 1

Representative electron microprobe analyses of the phases emitting CL in this study.

CL Phosphor	SiO ₂	TiO ₂	Al ₂ O ₃	Cr ₂ O ₃	FeO	MnO	MgO	CaO	Na ₂ O	Total
Mottled Blue Pyroxene	59.88	0.01	0.35	0.00	0.35	0.02	40.07	0.10	0.04	100.82
Banded Violet-Blue Pyroxene	59.90	0.00	0.24	0.04	0.28	0.02	39.59	0.47	0.01	100.55
Dull Red Pyroxene	59.52	0.09	0.47	0.51	1.68	0.05	38.83	0.26	0.01	101.42
Bright Red Pyroxene	59.61	0.02	0.12	0.21	1.11	0.13	39.63	0.12	0.01	100.96
Magenta Pyroxene	59.82	0.03	0.35	0.03	0.30	0.00	39.54	0.10	0.00	100.17
Dull Orange Na-rich phase	69.84	0.01	20.75	0.03	0.49	0.00	0.02	0.08	9.00	100.22
Dull Blue Glass	98.47	0.00	0.11	0.04	0.21	0.01	0.37	0.00	0.02	99.23

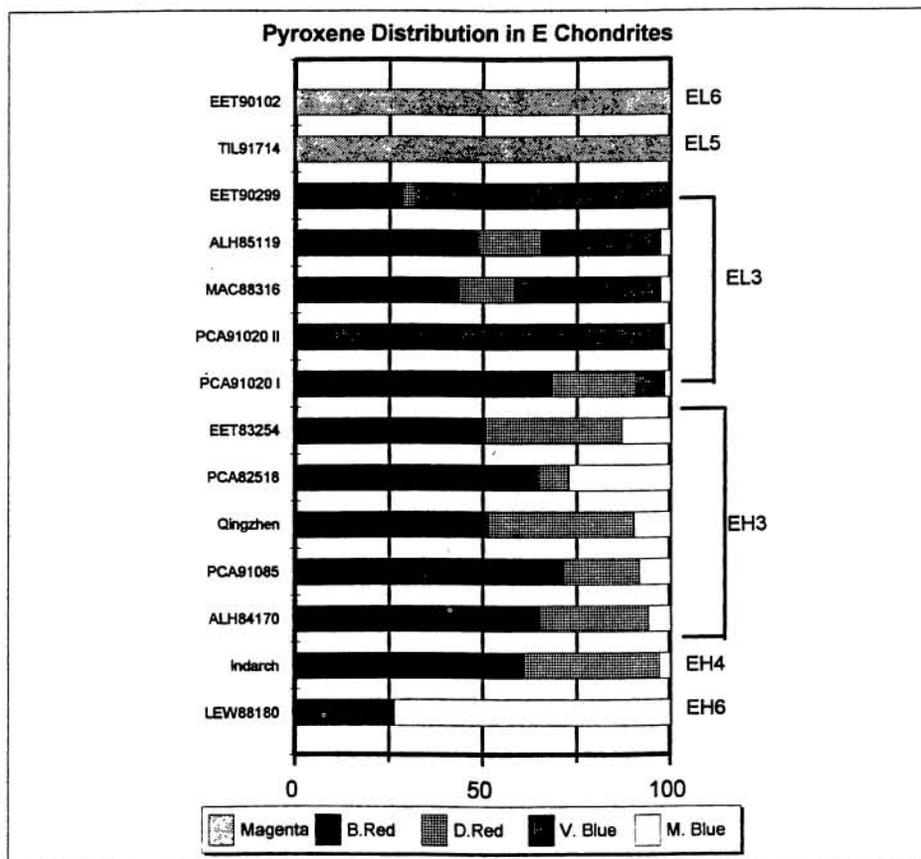


Figure 1. Percent Occurrence of the types of luminescent pyroxene in E chondrites.