OLIVINE AND THE ONSET OF THERMAL METAMORPHISM IN EH3 CHONDRITES. C. Bendersky[1] M. K. Weisberg[2,3], H. C. Connolly, Jr.[2,3], and D. S. Ebel[3]. [1]Dept. Astronomy and Geology, Mount Hollyoke College, South Hadley, MA 01075. [2]Dept. Physical Sciences, Kingsborough College, City University of New York, Brooklyn, NY 11235. (mweisberg@kbcc.cuny.edu). [3]Dept. Earth and Planetary Sciences, American Museum of Natural History (AMNH), NY, NY 10024.

Introduction: Enstatite chondrites (EC) have mineral assemblages that indicate they formed under highly reducing conditions in the early Solar System [e.g., 1], unlike other chondrites. They are also the only chondrites whose bulk oxygen isotopic composition lie on the terrestrial mass fractionation line, close to that of the Earth-Moon system [2, 3]. Thus, EC not only sampled what could be considered extreme conditions in the solar nebula but also may provide clues to the oxygen isopotic evolution of the Earth-Moon system. To identify the EC that have been the least metamorphosed since their formation is to find the ones that contain the most information about pre-accretion processes in a region of the solar nebula where reducing condition prevailed.

Grossman and Brearley [4] recently showed that the mobilization of Cr in olivine can be used to identify the least metamorphosed members of ordinary (O) and CO chondrite groups. Previous studies of EC olivine show that it is near-pure Mg_2SiO_4 in the equilibrated EC, whereas it is Mn- and Cr-rich in the unequilibrated EC [5, 6, 7]. We studied olivine in 5 EH3 chondrites to (1) further test the utility of olivine as an indicator of metamorphic grade in EC and extend the work of [8], (2) identify the most primitive EH3 chondrites and (3) decipher the thermal history of the EC parent body.

Methods and Results: We studied micro textures and compositions of olivine in five EH3 chondrites (Kota Kota, Parsa, Qingzhen, Sahara 97096, and Yamato 691) using the Hitachi S4700 field emission scanning electron microscope (FESEM) and Cameca SX100 electron microprobe at the AMNH. Olivine makes up 2 to 7 vol% of EH3 chondrites [7]. It occurs in chondrules associated with enstatite, as isolated fragments and in rare barred olivine chondrules and their fragments. Some olivine contains blebs of low Ni, Fe-metal associated with areas of more Mg-rich olivine, suggesting reduction of Fe from the olivine to form metal. The blebs vary in size and location in the olivine. In some cases, metal blebs are oriented along crystallographic planes or structural features in olivine (e.g., parting planes or fractures; Fig. 1) [6, 7]. These linear blebs are generally ~0.20 µm in size, with the largest >1.0 µm.. We also found Cr-enrichments in some of these linear regions suggesting that Cr was remobilized from olivine into sulfide and oxide phases (Fig. 1). The olivine shows a range in composition from $Fo_{99.8}$ to Fo_{93}. Cr_2O_3 ranges from below detection

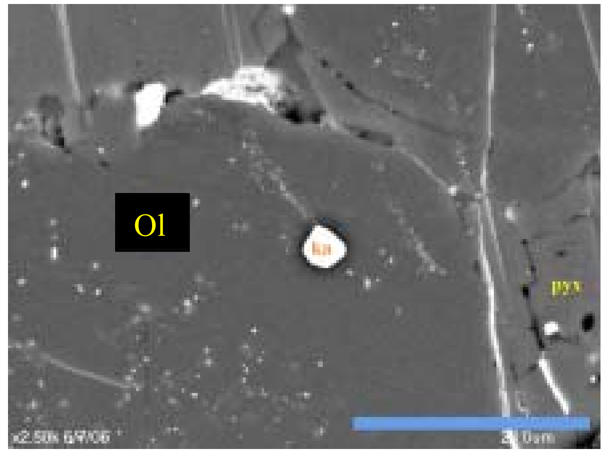

Fig. 1: Submicron metal+sulfide blebs (white) in Kota Kota olivine. Some blebs show a Cr peak suggesting the presence of Cr-bearing sulfide or oxide.

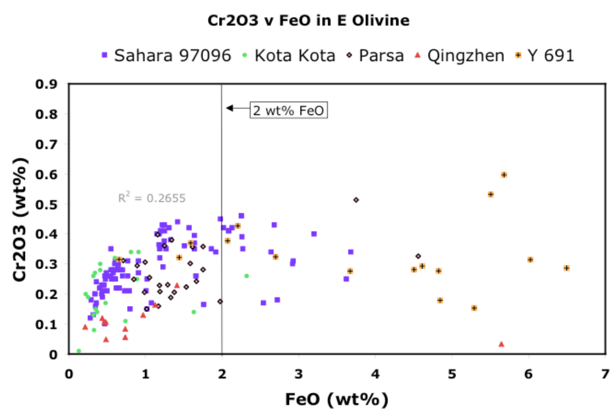

Fig. 2: Cr2O3 wt% (vertical axis) vs FeO in olivine.

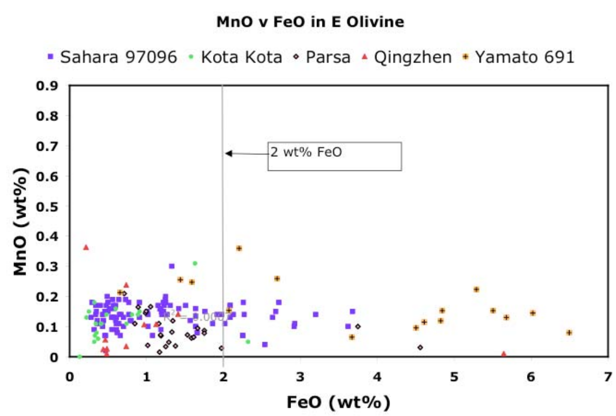

Fig. 3: MnO wt% (vertical) vs. FeO in olivine.

(bd) to 0.6 wt%and MnO from bd to 0.4% (Fig. 2, 3). There is a weak correlation between Cr_2O_3 and FeO content for olivine compositions < 2 wt% FeO, but no relationship in olivine with FeO > 2 %. (Fig. 1). MnO and CaO show no correlation with the FeO content of olivine (Fig. 2, 3).

Discussion: The presence of olivine in chondrites distinguishes E3 from E4-6 chondrites [9], consistent with other petrologic indicators such as the presence of glassy mesostases in chondrules [10]. Grossman and Brearley [4] showed that Cr in olivine is remobilized during the earliest stages of thermal metamorphism in O and CO chondrites. They subdivided petrologic types 3.00 to 3.20 using increments of 0.05 on a plot of standard deviation vs. the mean wt% Cr_2O_3 in olivine (Fig. 4). The CO curve is shifted down and left relative to the O chondrite line. However, [4] excluded low FeO olivine in their study because they found that FeO correlated with each of Cr_2O_3, MnO, and CaO. They concluded that these correlations are due to volatility control during chondrule formation and are not the result of metamorphism.

In our study of EC olivine, we found no significant correlations between FeO and minor elements, except for a weak correlation of FeO with Cr_2O_3 in olivine with < 2 wt%FeO. Therefore we use our entire population of olivine compositions. Our initial results (Fig. 4) are presented in a modified diagram after [4]. Fig. 4 shows that the EC olivine values plot near the values for the CO chondrites, and suggest that Y691, Sahara 97096 and Parsa are the most primitive EH3 chondrites. This is consistent with sulfide thermometry which indictes low degrees of metamorphism for these meteorites.

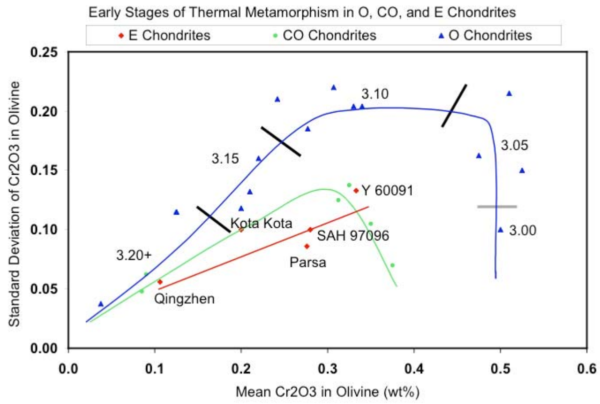

Fig. 4: Standard deviation vs. mean Cr2O3 in olivine. Data and curves for O and CO chondrites were reproduced from [4].

Our initial results also suggest a relationsip between the exsolution features in olivine grains and the degree of metamorphism based on Cr content of olivine (i.e., Fig. 4). For example, Y 691 shows linear exsolution features within the olivine grains. Exsolution is absent on the perimeter of the olivine grains. Both Sahara 97096 and Parsa olivine show exsolution of blebs within the olivine grains and on the perimeter of the olivine grain. The largest exsolution blebs measure greater than 1.0µm. At a higher degree of thermal metamorphism exsolution features dominate the area within and around the crystal. Exsolution features surround up to 50% of the olivine grain perimeter. Qingzhen olivine grains contain isolated exsolution blebs, large and small, in and around olivine and the olivine is heavily depleted in minor elements. More data are needed to confirm these trend.

Conclusions: During thermal metamorphism Cr is redistributed from olivine into metal and sulfide phases that form exsolution features in and around the olivine grains. The earliest stages of thermal metamorphism generate exsolution features of metal that are linear within the olivine grains. The size of the exsolved blebs may be directly related to the degree of heating, with a final result of producing isolated metal blebs, which remain in and around olivine that is depleted in minor elements. Olivine compositional variations in the most primitive EC may be useful for characterizing the most primitive EC and classifying them into petrologic sub-types. Distinctive exsolution features in the olivine may also prove useful for determining metamorphic grade and understanding the mobilization of Cr from olivine into other phases during metamorphism. Some of the E chondrites may be at least as primitive as O and CO chondrites of petrologic type 3.1. Yamato 691, Sahara 97096 and Parsa, appear to be among the most primitive of the EH3 chondrites.

References [1] Keil (1968) *JGR* 73, 6945-6976 [2] Clayton R. N. and Mayeda T. K. (1984) *JGR* 89, C245-C249. [3] Javoy M. (1995) *Geophys. Res. Lett.* 22, 2219-2222. [4] Grossman JN., and Brearley A. J. (2005). *MAPS* 40, 87-122. [5] Leitch CA., and Smith J. V. (1982) *GCA* 46, 2083-2097. [6] Lusby D. et al. (1987) Proc. *LPSC* 17, JGR. Suppl. 92, E679-E695. [7] Weisberg M. K et al. (1994) *Meteoritics*. 29, 326-272. [8] Weisberg M. K. et al. (2005) *LPSC* XXVI, #1420. [9] Prinz M. et al. (1985) *Meteoritics* 20, 731-732. [10] Kimura M. and Lin Y. (1999) *Antarc. Meteorite Res.* 12, 1-18.

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