A COMPARISON OF ZONING PROFILES IN FEO-RICH PO CHONDRULE OLIVINES AND EXPERIMENTAL ANALOGUES: EVIDENCE FOR METAMORPHIC REHEATING OF CHONDRULES. Rhian H. Jones[1] and Gary E. Lofgren[2]. 1. Institute of Meteoritics, Department of Geology, University of New Mexico, Albuquerque, NM 87131, USA. 2. Code SN-2, NASA Johnson Space Center, TX 77058, USA.

Introduction. Metamorphic sequences are recognised in the ordinary chondrites [1] and in the CO3 carbonaceous chondrites [2]. Properties of chondrules which vary with degree of metamorphism include changes in silicate mineral compositions, and increasing homogeneity of chondrule silicates with increasing petrographic grade [1]. There is some debate concerning the environment of metamorphism, particularly for petrologic type 3 chondrites. Metamorphic changes may occur either as a result of reheating on a parent body after accretion [3], or by cooling at different rates in the nebula [4]. We have examined FeO-rich olivines in natural chondrules and experimental analogues in order to try to determine which of these two metamorphic models is more appropriate.

Natural chondrules. FeO-rich porphyritic olivine chondrules (type II chondrules) are common components of ordinary chondrites (~23 vol% [5]). Type II chondrules in Semarkona (LL3.0) show no evidence of metamorphic effects [5], consistent with Semarkona being one of the least equilibrated ordinary chondrites [6]. We have compared zoning in olivines from these chondrules with olivines from similar chondrules in ALH A81251 (LL3.3), in which olivine compositions are intermediate between those of unequilibrated and equilibrated chondrites [7]. Typical olivine zoning profiles for FeO, MnO, Cr_2O_3 and CaO are illustrated in Fig. 1. In Semarkona, Fe, Cr, Mn and Ca are all strongly correlated, and concentrations of each element increase towards the rims of grains. In ALH A81251, Fe, Mn and Ca are correlated and similar to Semarkona profiles but Cr concentrations are flatter and tend to decrease towards the rim.

Experimental samples. Porphyritic olivine textures have been reproduced in dynamic crystallization experiments at cooling rates of 2-100 °C/hr [8,9], from peak temperatures close to the liquidus. Bulk composition CH1 used in these experiments is very similar to type II PO chondrule bulk compositions in Semarkona [5,9]. In order to compare experimental samples with natural chondrules we have examined zoning profiles in runs of different cooling rates, and in runs which have been annealed subsequent to cooling at these rates. Run conditions are summarized in Table 1. All runs were carried out at an oxygen fugacity 0.5 log units below the iron-wüstite buffer. Examples of zoning profiles in olivines obtained in these runs are illustrated in Fig. 2, which shows the effect of varying cooling rate, and Fig. 3, which shows how zoning profiles are modified by a period of annealing.

TABLE 1: CH1 run conditions

Run	CR[1]	Ann[2]
51	2	-
50	2	1000; 6
63	5	-
62	5	1191; 7
58	100	-
61	100	1239; 7

1 Cooling rate (°/hr)
2 Annealing T; time (°C; days)

Effect of variation in cooling rate. In the experimental samples which have not been annealed (Fig. 2), Fe, Cr and Mn all show strong correlations, with constant compositions in the cores of grains and increases in concentration towards the rims. Ca zoning is less pronounced but correlates with the other elements. Core and rim FeO contents are higher at higher cooling rates. For MnO, Cr_2O_3 and CaO core contents at different cooling rates are similar, but rim contents are higher with higher cooling rates. Modifications in Cr profiles at the rims of olivines (2 °/hr profile) may be caused by chromite crystallization [5]. A direct comparison with Semarkona type II olivines (Fig. 1) indicates that zoning profiles in these olivines are consistent with an origin by igneous crystallization, with cooling rates at the higher end of the experimental range, i.e. around 100 °/hr. Ca contents in experimental olivines are commonly lower than those observed in chondrules [8]. Zoning profiles from ALH A81251 do not correlate with the igneous zoning trends obtained in these experiments: in the cooling experiments Cr always correlates with Fe and Mn, irrespective of cooling rate.

Effect of annealing. A period of annealing modifies the zoning profiles produced in the cooling experiments (Fig. 3). Although the temperatures and times of annealing in the samples used varies, the effects can be seen clearly. FeO profiles flatten out and core contents tend to increase relative to those in Fig. 2. This could be the result of internal equilibration in the grain, and/or exchange of FeO/MgO may be taking place with the mesostasis. Similar, but less pronounced, changes are observed for MnO and CaO. More significant changes occur in Cr: Cr_2O_3 contents decrease during the annealing period, leaving zoning profiles which are flattened or inverted, i.e. decreasing towards the rim. This indicates that Cr is readily mobilized and must be equilibrating with mesostasis. Although the diffusion coefficient of Cr in olivine has not been measured experimentally, it appears to be qualitatively similar to Fe-Mg interdiffusion under the conditions of these experiments. Zoning profiles in ALH A81251 compare favorably with annealed zoning profiles, particularly for Cr. Similar effects for Fe and Cr profiles are observed in Parnallee (LL3.6), and markedly decreasing mean Cr_2O_3 contents in type II chondrule olivines with increasing petrologic subtype are observed in the LL chondrite group as a whole [7]. Metamorphic annealing in a parent body is unlikely to have been at such high temperatures as the experimental charges, but is likely to have been at lower temperatures for significantly longer periods of time [3]. This would allow similar relative rates of equilibration for Fe, Cr, Mn and Ca in the chondrules of ALH A81251. Annealing at high temperatures (>1000 °C) for short periods of time may be envisaged in the nebular gas [10]. However, the physical setting required for an isothermal heating event, in the otherwise relatively rapid cooling environment of chondrule formation, is problematical.

Conclusions. Zoning profiles in olivines in type II chondrules in Semarkona are consistent with an igneous origin, and cooling rates of 100 °/hr or higher are indicated by comparison with experimental charges. Zoning profiles in similar olivines in ALH A81251 are not consistent with an origin by cooling alone. The difference between Semarkona and ALH A81251 profiles cannot be explained by differences in cooling rate. Rather, profiles from ALH A81251 are consistent with modification of Semarkona-like profiles by an annealing process. Annealing is unlikely to have taken place in the nebular gas. A reheating model for metamorphism is preferred.

References [1] Van Schmus WR and Wood JA (1967) GCA 31, 747-765. [2] McSween HY Jr (1977) GCA 41, 477-491. [3] Dodd RT (1969) GCA 33, 161-203. [4] Watanabe S et al. (1985) EPSL 72, 87-98. [5] Jones RH (1990) GCA 54, 1785-1802. [6] Sears DW et al. (1980) Nature 287, 791-795. [7] McCoy TJ et al. (1991) GCA, in press. [8] Lofgren GE (1987) LPSC XVIII, 566-567. [9] Lofgren GE (1989) GCA 53, 461-470. [10] Planner HN and Keil K (1982) GCA 46, 317-330.

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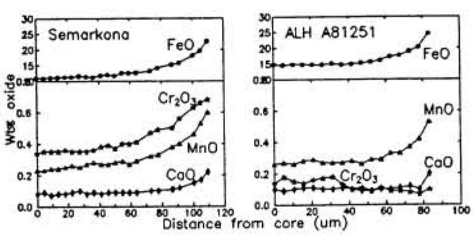

Fig. 1: Zoning profiles (core to rim) in olivine in type II chondrules from Semarkona and ALH A81251.

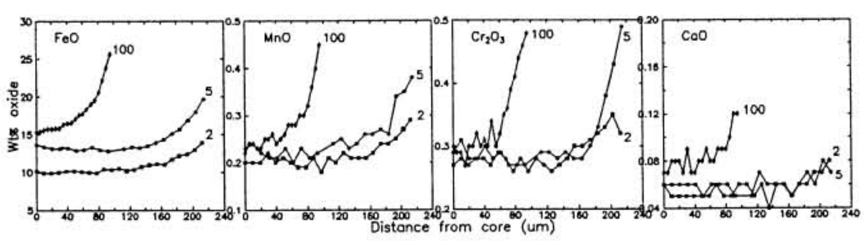

Fig. 2: Zoning profiles (core to rim) in olivines from experiments carried out at cooling rates shown (°/hr).

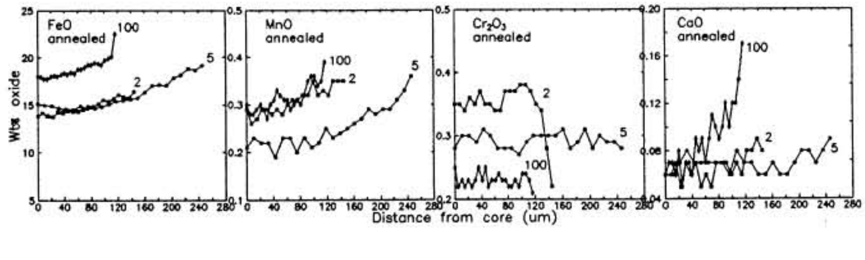

Fig. 3: Zoning profiles (core to rim) in olivines from experiments which have been annealed subsequent to cooling at the rates shown.