PHOSPHORUS ZONATION IN H CHONDRITE OLIVINES: THE EFFECTS OF INCREASING PETROLOGIC GRADE. M. C. McCanta[1], J. R. Beckett[2], and E. M. Stolper[2] [1]Tufts University (Geology Dept., Lane Hall, 2 North Hill Rd, Medford MA 02155, molly.mccanta@tufts.edu), [2]California Institute of Technology (Division of Geological and Planetary Sciences, MS 170-25, Pasadena CA 91125).

Introduction: Olivine is a liquidus or near-liquidus phase in many magmatic systems and is, therefore, a potential indicator of magmatic conditions and timescales for many igneous rocks. Recent studies have shown that phosphorus zonation is ubiquitous in igneous olivine from a wide range of igneous rocks (komatiites, basalts, andesites, dacites) and planetary settings (Earth, Moon, Mars, meteorite suites) [1-3]. This minor element zoning is decoupled from zoning in Fe-Mg and is retained even if the major elements have been rehomogenized. P zoning is often correlated with Cr or Al in rapidly cooled samples (e.g., Hawaiian microphenocrysts [1]) but not all samples exhibit Al or Cr-zonation, specifically those samples thought to have been held at high temperature for extended periods following crystallization. Cr zoning is more often retained than Al, suggesting that the retention of zoning in olivine is related to the diffusive reequilibration time for each element and that the diffusivities DAl>DCr>DP for P-correlated cations.

Ordinary chondrites are variably metamorphosed rocks that originally contained large amounts of igneous chondrules and their fragments. [3] established that olivines in type IIA chondrules from the highly unequilibrated chondrites LEW 86549 (L3.0) and RC075 (H3.1) exhibit both P and Cr zonation produced during crystallization. In this study, we obtained additional data for RC075 to establish the zoning patterns of type IIA chondrule olivine and analyzed olivines in type IIA chondrules from a suite of more equilibrated H chondrites. We examined these variably metamorphosed olivines to study the processes and timescales by which zoning of P and associated elements may be relaxed during thermal processing.

The sample suite chosen for this study consists of H chondrite meteorites spanning the complete range of petrologic grades: RC075 (H3.1), Dhajala (H3.8), Forest Vale (H4), Allegan (H5), and Guareña (H6). We selected mostly type IIA (high-FeO, porphyritic olivine) chondrules because of their low abundances of liquid and solid alloys and sulfides, which could potentially scavenge P and complicate interpretation of P distributions in the olivines. In relatively unequilibrated chondrites a variety of compositional signatures can be used to establish chondrule type, but we were forced to depend on textural criteria for more equilibrated chondrites [4-5].

Methods: X-ray intensity maps and major and minor element quantitative analyses were obtained on the Caltech JEOL JXA-8200 electron microprobe. Iron, Al, Cr, Ti, and P X-ray maps were acquired simultaneously under operating conditions of 15 kV and 400 nA, a beam diameter of 1 µm, pixel spacing of 1-2 µm, and count times of 800-2000 msec/step. Quantitative traverse analyses were collected at 15 kV and 40 nA with a beam diameter of 1 µm. For the major elements, count times were 20 s on peak and, for P, Cr and Al, they were 160 s on peak. Additional single point analyses were collected within previously mapped high and low P zones at 15 kV, 100 nA, and 640 s on peak count times. These conditions were necessary to minimize errors on Al analyses to acceptable values (~15%). Natural minerals standards were used for calibration.

Results: P zoning is present in type IIA chondrule olivines from all studied chondrites and is not correlated with that of the major divalent cations (i.e., Fe, Mg) (Fig. 1). Interior olivines from type IIA chondrules of all petrologic grades consistently contain P zonation comparable in style and concentration to that observed in RC075 (Fig. 1). In the higher grade meteorites (≥ 3.8), olivines near chondrule rims are devoid of P zonation even as those in the interior remain zoned (Fig. 2). In contrast, all near-rim olivines in RC075 retain P zoning. Although sectioning effects could be important, we observed no correlation between metamorphic grade and distance from the rim over which P zoning was absent. Correlated Cr zoning is only found in RC075 (Fig. 1). Correlation of P-Al zonation is weak but clear in RC075. It is absent in all of the more equilibrated chondrites we examined.

Additionally, olivines in type IA and barred olivine chondrules were mapped in RC075 and Guareña. P zonation was not observed in either chondrule type consistent with loss of P from the silicate liquid from which the olivine crystallized.

Implications:

Reequilibration of minor elements in olivine. Even in the most equilibrated of H chondrites, chondrule olivine in the centers of type IIA chondrules retain igneous P zoning and this suggests that thermal processing under the metamorphic conditions experienced by H chondrites did little to modify igneous P signatures of the olivine grains. On the other hand, igneous P zoning appears to have been lost in near-rim olivines, even in the H3.8 Dhajala. Diffuse halos of P-rich material are observed surrounding several chondrules in Dhajala. This zoning loss appears to have affected all near-rim olivine in H3.8-H6 similarly, suggesting the process leading to the destruction of P zoning in near-rim olivine grains in unequilibrated chondrites (>H3.1, <H3.8) was complete by H3.8.

Cr and Al zoning is observed in RC075 chondrule olivine but not in the more equilibrated Hs (Fig. 1). This observation is consistent with DP<<DCr or DAl and with the statement of [6] that Cr zoning is absent in olivine for petrologic grades > 3.6. Although the behavior of Al is poorly constrained by our data, results on Hawaiian olivines [1] suggest that DCr<DAl. This implies that Al is likely to have been diffusively reequilibrated during metamorphism on the H chondrite parent body similar to Cr.

Conclusions: All samples, regardless of metamorphic intensity, retain P zoning produced by the original igneous crystallization of type IIA chondrules. This suggests that thermal diffusion time scales for P in olivine are exceedingly slow even at high temperatures. It is possible that the destruction of P zones in olivine occurs primarily through recrystallization rather than thermal relaxation. The presence of P zoned olivines in Allegan and Guareña, however, suggests that, although recrystallization is a hallmark of higher petrologic grades [7], this process cannot be complete as all of the igneous olivines have not been destroyed. In contrast, the disappearance of P zoning in near-rim olivines from equilibrated chondrites, suggests that P zoning in olivine can be vulnerable to resetting.

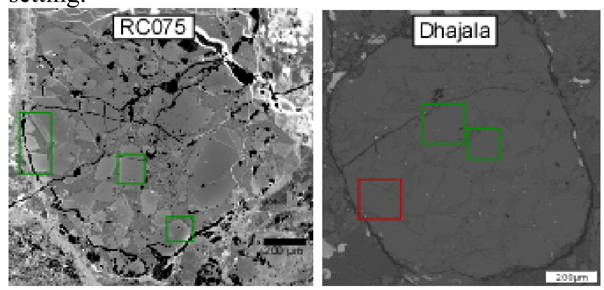

Figure 2. BSE images of Type IIA chondrules from RC075 and Dhajala. Olivines which have been mapped for P zonation are boxed. Green boxes indicate P zoning was present; red boxes indicate P zoning was absent.

References: [1] Milman-Barris M.S. et al. (2008) CMP *155, 739-765*. [2] Beckett J.R. et al. (2008) *LPS* XXXIX, Abstract#1726. [3] McCanta M.C. et al. (2008) *LPS* XXXIX, Abstract#1807. [4] Scott E.R.D. and Taylor G.J. (1983) *JGR* 88, B275-B276. [5] Jones R.H. (1990) *GCA* 54, 1785-1802. [6] Grossman J.N. and Brearley A.J. (2005) *MPS* 40, 87-122. [7] Van Schmus W.R. and Wood J.A. (1967) GCA 31, 747-765.

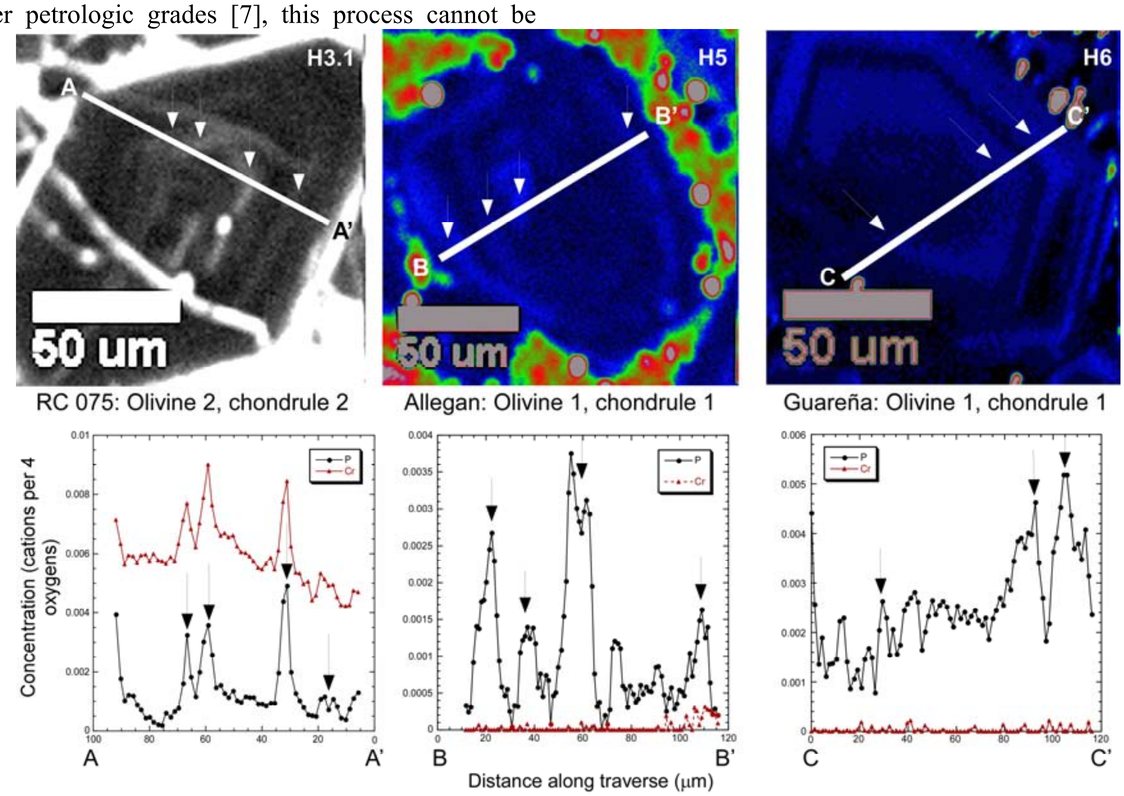

Figure 1. Phosphorus X-ray intensity maps and quantitative traverses in select H chondrites. Black lines are P concentrations; red lines are Cr concentrations.