PHOSPHORUS ZONING IN SNC OLIVINES J.R. Beckett, M.C. McCanta, and E.M. Stolper; Division of Geological and Planetary Sciences, Caltech, Pasadena CA 91125 (john@gps.caltech.edu).

Introduction: Olivines can be dominant (chassignites), major (olivine-phyric and lherzolitic shergottites), or minor (nakhlites) phases in SNC meteorites, and their chemical and textural features provide insights into the origin and evolution of Martian magmas [1]. Many elements in olivine, especially the divalent cations, are prone to diffusion during prolonged cooling (or reheating) of igneous rocks, so information on early magmatic history, although perhaps recorded in the olivine as it grew, is often lost. It has recently been shown, however, that zoning in P (and, sometimes, associated Cr and Al) can preserve a record of these details [2, 3]. Here, we describe P and Cr zoning in a chassignite (Chassigny), olivine-phyric shergottites (DaG 489, EETA 79001, RBT 04261/2, and Y980459), and a lherzolitic shergottite (ALHA 77005).

Analytical conditions for maps: We obtained K_α X-ray maps for P, Cr, Al, Fe, and Ti using Caltech's JEOL JXA-8200 electron microprobe at 15 keV and 400nA. Typical step size and counting time were 1 μm and 800 msec/step, though lower resolution was sometimes used for large crystals or reconnaissance.

Results: *Olivine-phyric shergottites:* Olivine in the olivine-phyric shergottites displays several styles of P zoning. Fig. 1a shows an X-ray map for olivine from the unusually primitive (high bulk MgO and silicate mg#) Y980459 [4]. P shows oscillatory zoning comparable to that seen in terrestrial (and other meteoritic) igneous olivines and some experimentally grown olivine [2, 3; also the lunar vitrophyre Apollo 12009 (Beckett; unpublished data)]. Variations in Cr (Fig. 1b) correlate spatially with P but are much fainter. P-correlated Al was extremely faint or absent in our SNC olivines (except as noted below; see shock effects section) and in no case was Fe correlated with P. Fig. 2 (RBT 04262) shows two crystals from a glomerocryst, the larger with an interior set of high P regions outlining low P chambers (i.e., this crystal may have originally formed by the agglomeration of multiple crystals); near the margins are discontinuous sets of P-enriched bands. The smaller crystal in the upper left has oscillatory zoning reminiscent of Hawaiian microphenocrysts [2]. P enriched zones were also observed in olivine from EETA 79001A and DaG 489.

Cumulates: The dunite Chassigny and lherzolitic shergottite ALHA 77005 are thought to be cumulates that cooled relatively slowly [5, 6]. P shows enriched zones and strong oscillatory zoning (Figs. 3-4) with spatially correlated, though faint, Cr. The crystal from ALHA 77005 (Fig. 3) has a central herringbone spine with wispy "ribs" and oscillating P-enriched bands towards the crystal margins. The Chassigny crystal (Fig. 4) has P-enriched ghosts of relict crystals in the interior (i.e., what appears to be a single large slowly grown cumulate crystal originated as multiple rapidly-grown crystals) and a set of P-enriched bands that generally outline euhedral crystal forms (but note that growth direction changed (dashed line vs. upper vertex outlined by P-bands). Later low-P growth (adcumulus?) led to the observed anhedral crystal. Preservation of P and Cr zoning in ALHA 77005 and Chassigny implies short residence times at high temperature rela-

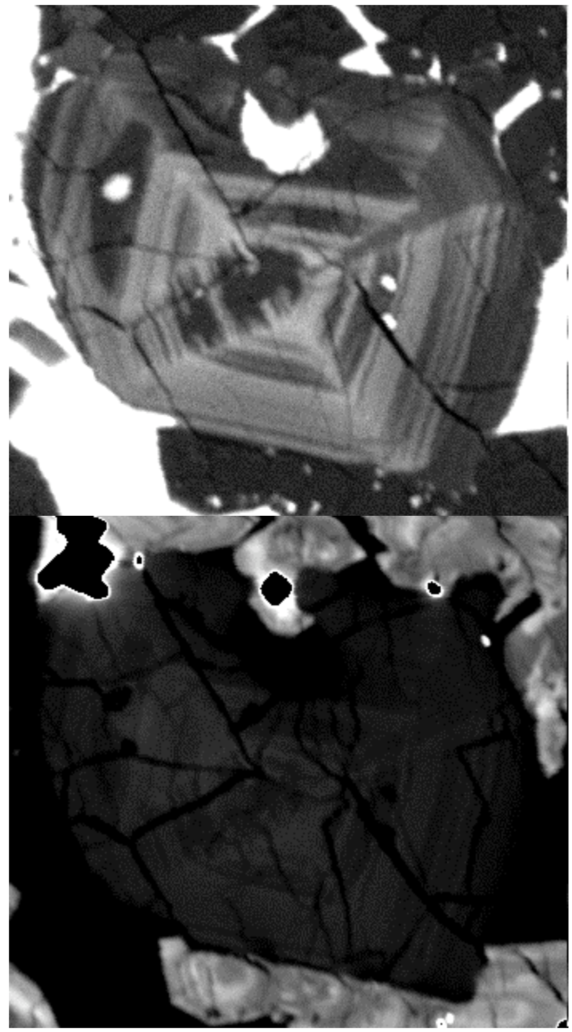

Fig. 1. P (top) and Cr (bottom) K_α X-ray maps of olivine-phyric shergottite Y980459. Bright white areas inside the grain in the P map are melt inclusions. Field of view (FoV): 350x310μm.

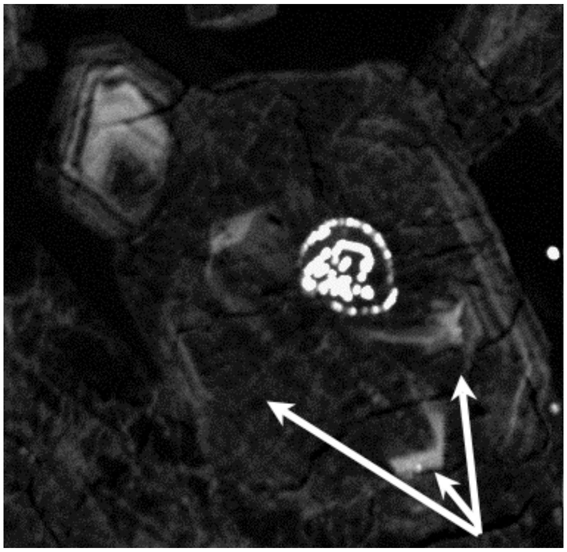

Fig. 2. P K_a X-ray map of glomerocryst in RBT 04262. Bright rosettes are part of a melt inclusion; arrows point to possible ghost crystals. FoV: 370x380μm.

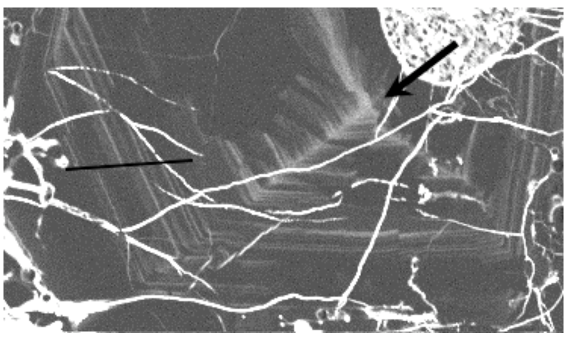

Fig. 3. P K_α X-ray map of a portion of an olivine in ALHA 77005. Arrow labeled HB points along long axis of herringbone structure; thin line indicates a microfracture. FoV: 300x500 μm.

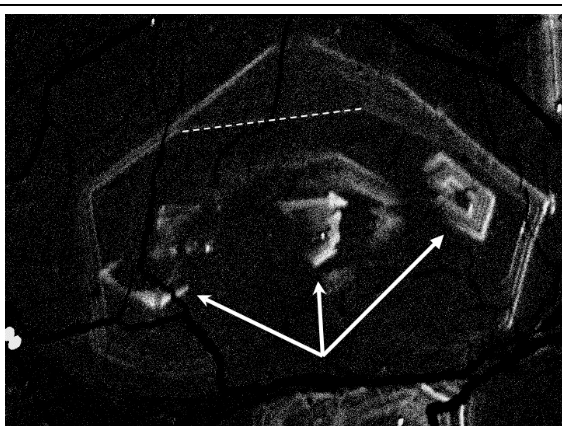

Fig. 4. P K_α X-ray map of olivine grain in Chassigny; arrows point to possible ghost crystals, dashed line indicates a former crystal surface.. FoV: 820x500 μm.

tive to diffusive homogenization though P diffusion may be so slow that this is not a strong constraint.

Shock effects: While the P zoning described above is also observed in terrestrial, chondritic, and synthetic olivines [2-3], shock events can modify these features. In ALHA 77005, for example, there are numerous 5-25 μm offsets in P bands (Fig. 3), which [2] did not observe in terrestrial olivines. These offsets do not penetrate the entire crystal, are independent of macroscopic cracks, and, although offset, remain sharp. Y98059 (Fig. 1) also has offsets associated with unfilled macroscopic cracks that may postdate shock. Another type of P distribution (see Fig. 2) plausibly related to shock is an intersecting mosaic of elongate to cellular P-rich features that resemble microcracks, leading to mottling, wavy and discontinuous bands near crystal margins (e.g., Figs. 1a and 3 vs. 2), and in extreme cases (not shown but observed in DaG 489 and RBT 04261/2) to virtually complete loss of igneous P enrichment zones. The resulting mosaic of P-enrichment (also Al but not Cr) may be a direct consequence of shock (e.g., injection of shock melts into olivine or remobilization of P from P-enriched bands) or indirect (opportunistic in-filling of shock induced microcracks). Relative contributions are uncertain but we observed P mosaics only in RBT 04261/2 and DaG 489, the most altered of the meteorites we examined, but not in ALHA 77005, the most severely shocked.

Implications: P zoning provides an otherwise inaccessible window into the early crystal growth of olivine; the features observable in P are not present in the more abundant divalent cations, either because they did not form during crystal growth or they have been obscured by later diffusive homogenization. "Ghost crystals" outlined by P are consistent with an initial pulse of rapid crystal growth, perhaps associated with undercooling; this is a persistent feature of olivine in magmatic systems. Moreover, the frequent presence of multiple crystals within what are now individual phenocrysts (Figs. 2, 4), suggests that agglomeration is a very common process during early crystallization of olivine. Features consistent with rapid crystallization and early agglomeration, suggest a near-surface, relatively rapidly changing environment for the Martian "cumulates". Subsequent shock has affected the distribution of P [5-6] but observed P zoning within olivine is usually dominated by igneous processes.

References: [1] Shearer C.K. et al. (2006) Am. Min. 91, 1657-1663. [2] Milman-Barris M.S. et al. (2008) *CMP* in press. [3] McCanta M.C. et al. (2008) *LPS* this volume. [4] Mikouchi T. et al. (2004) *AMR* 17, 13-34. [5] Floran R.J. et al. (1978) *GCA* 42, 1213-1229. [6] McSween H.Y. et al. (1979) *Sci.* 204, 1201-1203. [5] Fritz J. et al. (2005) *MPS* 40, 1393-1411. [6] Edmunson J. et al. (2005) *MPS* 40, 1159-1174.