MAGMATIC CUMULATE TEXTURES PRESERVED BY TRACE ELEMENTS IN DIOGENITE METEORITES J. B. Balta, A. W. Beck, H. Y. McSween. Planetary Geoscience Institute and Department of Earth & Planetary Sciences, University of Tennessee, Knoxville, TN 37996-1410, jbalta@utk.edu

Introduction: Orthopyroxene (OPX) in diogenite meteorites has previously been noted to vary significantly in trace element composition, despite near-uniformity in major elements. For example, [1] noted that Al_2O_3 and TiO_2 vary by factors of 3 and 4, respectively, within grains that are nearly homogeneous in Mg#. Similar results for OPX compositions were presented by [2] and [3], who argued that the trace element composition variations were so large as to be inconsistent with formation by simple fractional crystallization of a basaltic magma, and required a unique liquid composition. These workers also concluded that primary igneous processes are best preserved in the zonation and variation, seen in the minor and trace elements, as Fe and Mg have been homogenized by equilibration. Clearly, the OPX trace element compositions in diogenite meteorites reflect varying degrees of diffusive equilibration and complex crystallization histories in addition to magmatic processes.

[4] measured consistent trends in olivine and OPX composition in diogenites and proposed a new classification system based on the abundances of olivine and OPX in the meteorite. They also analyzed trace element compositions in OPX and, in addition to significant variation in total composition, found complex trends within polymict diogenites. Within single meteorites, certain trace elements, particularly Cr_2O_3 and Al_2O_3, could be either positively or negatively correlated with Mg#, which those authors tentatively linked to the presence of plagioclase during crystallization. However, even within a small area of a single OPX grain, trace element compositions vary considerably (Fig 1).

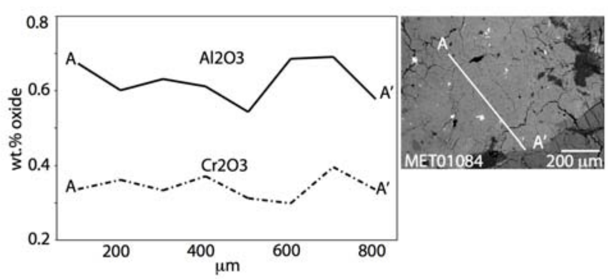

Fig 1. An EMP transect across a single OPX grain in diogenite MET01084.

Recent authors (e.g., [5]) have used high-current electron microprobe (EMP) maps of olivine trace elements to explore magmatic histories. To better constrain the magmatic histories of diogenite meteorites, we have performed similar analyses of trace elements in olivines and OPX in the 3 classes of diogenites, harzburgitic (Hzbg.), orthopyroxenitic (Opxn.), and dunitic, as defined by [4].

Analytical Procedure: Using the Cameca SX-100 EMP, we produced high-current composition maps of the three types of diogenites. Meteorites were analyzed for P, Cr, Al, and Mg in ~1000 x 1000 µm sections, with current set to 200 nA and counting times of 900 ms. Due to the time required to collect data for each map (~60 hours), only a few maps could be constructed for any given sample. Backscatter electron images (BSE) were also collected for each sample. Image contrasts were re-scaled manually to illustrate variation in trace elements.

Results and Discussion: Trace elements in both olivine and OPX display previously unseen spatial patterns preserving original cumulate textures within the meteorites, none of which are apparent in major element zoning.

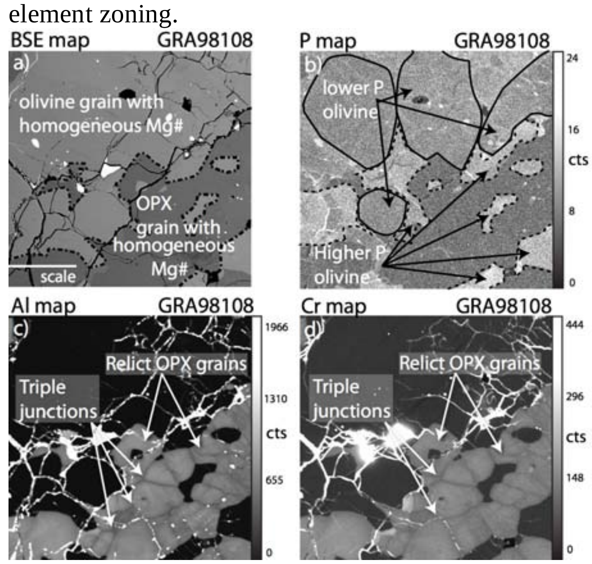

Fig 2. Trace element maps of olivine and orthopyroxene in Hzbg. diogenite GRA98108. (a) Homogeneous olivine and OPX grains in BSE are composites of (b) high and low P areas in olivine and (c, d) small, relict grains, distinguished by low Al and Cr rims in OPX. Black lines in (b) added manually at boundaries.

BSE maps of olivine in Hzbg. diogenite GRA98108 show what appear to be single, large olivine grains with no Fe/Mg zoning (Fig 2a). P-maps of olivine, however, reveal distinct high- and low-P areas (Fig 2b). The low-P areas appear to outline original crystals that are 200 µm and have well-developed crystal faces. High-P areas surround original crystals, are smaller (20 μm), appear more anhedral, and also can occur as inclusions within OPX. Olivine in Hzbg. diogenite ALHA77256 contains areas of high and low P outlining what appear to be original crystals as well.

GRA98108 OPXs preserve Cr and Al zoning displaying prominent cumulus textures (Fig 2c and 2d). What appear to be single, subhedral OPX grains in BSE images (Fig. 2a) are actually composites of many smaller, euhedral, and equant OPX grains, whose primary grain boundaries are seen in Cr and Al distributions. Between these grains, well-defined magmatic triple-junctions are preserved. Cr and Al contents increase away from the boundary and are constant and high at the cores of the grains. OPXs in the other Hzbg. diogenite, ALHA77256, also contain relict grains that can be seen in Cr and Al compositional maps.

OPX in an Opxn. portion of diamict diogenite MET01084 was also mapped using this technique, and has a similar pattern of Cr zoning preserving primary magmatic grain boundaries (Fig 3b). Interestingly, this meteorite shows similar magmatic pyroxene sizes despite the differences in petrologic type and composition from GRA98108 and ALHA77256.

Olivine in diamict diogenite LEW88008, and olivine in dunite MIL03443, which is likely also part of the diogenite group [8], were mapped using this technique as well. However, neither of these maps showed organized P zoning in olivine.

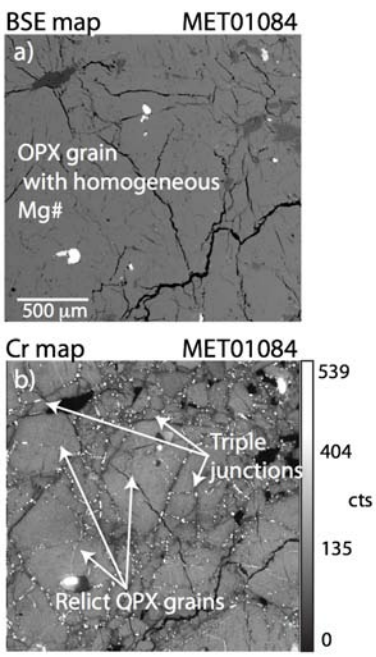

Fig 3. Images from an Opxn. portion of diamict diogenite MET01084 showing (a) what appears to be a single, homogeneous OPX grain, (b) that is actually composed of relict grains revealed in a Cr compositional map.

The preservation of primary igneous trace element zoning within these diogenites has important implications for their magmatic histories. First, the distribution of high- and low- P areas in GRA98108 and ALHA77256 olivines suggests a magmatic cumulate history for those grains. Low-P areas outline larger, original cumulate grains, while high-P areas appear to be intercumulus material between olivine grains, or trapped within OPX. Assuming Henry's Law behavior for the partitioning of P in olivine, the intercumulus material likely formed from a more evolved, higher-P liquid than the original grains.

Conversely, low OPX trace element compositions at the boundaries between relict grains appears at odds with the behavior measured in the olivine grains. As both Al and Cr are incompatible in pyroxene (and olivine), pyroxene crystallization should enrich the melt in those elements and produce higher Cr and Al contents at the edges, rather than in the centers, as seen with P in olivine. Similarly, low OPX trace elements at grain boundaries is at odds with textural evidence seen in the OPX maps (triple junctions, relict grains) suggesting smaller primary cumulus grains that have equilibrated into larger grains.

At present, we can suggest a few possible mechanisms for generating this pattern: 1) the liquid crystallizing the pyroxenes could have saturated in feldspar and chromite, such that the liquid Al and Cr decreased with increasing crystallization, 2) the pyroxene subgrains were subject to a brief re-melting event, such that incompatible trace elements near their edges entered a melt and were removed upon melt extraction, 3) a small amount of residual melt was trapped between the pyroxene grains when they first settled into a cumulate, which allowed for diffusion of trace elements from the edges of the pyroxenes into the melt prior to compaction and melt extraction. In the latter two cases, it remains difficult to understand why pyroxenes would be subject to these depletions while neighboring olivine grains were not. It is important to note that [2] also documented decreases in Cr, and to a lesser extent Al, from core to rim of some diogenite OPX grains, which they also attributed to either primary zoning (i.e. our #1), or equilibration with trapped melt (i.e. our #2 or #3). Future analyses of the spatial and compositional details of these features may provide new constraints on the magmatic history of diogenites.

References: [1] Mittlefehldt (1994), *Geochim. Cosmochim. Acta*. **58**, 5. [2] Fowler et al., (1994), *Geochim. Cosmochim. Acta*. **58**, 18. [3] Fowler et al., (1995), *Geochim. Cosmochim. Acta.* **59**, 14. [4] Beck and McSween (2010), *MAPS* **45,** 5. [5] Milman-Baris et al., (2008), *Contrib. Min. Petr.*,**155**, 6. [8] Beck et al., (2011), *MAPS in review*.