Vesta's Missing Mantle: Evidence from new harzburgite components in Howardites. T.M. Hahn[1], H.Y. McSween[1], and L.A. Taylor[1], [1]Planetary Geosciences Institute, Department of Earth and Planetary Sciences, University of Tennessee, Knoxville, TN 37996, USA (thahn1@vols.utk.edu).

Introduction: One of the most fundmental planetary processes is differentiation. This differentiation process is crucial to our understanding of the Earth and other rocky bodies in the solar system. The asteroid 4 Vesta, and its associated howardite, eucrite, and diogenite (HED) meteorite suite, are the ideal candidates for unraveling this process.

Iron meteorites presumably represent core samples and basaltic eucrites denote crustal material [1]. Mantle material, presumed to be the most voluminous portion of a body [2], is however, scarce in meteorite collections, although some have suggested that pallasites likely represent core-mantle boundaries [1]. Recent work by [3] identified Mg-rich (En >85 & Fo >78) clasts of olivine and pyroxene, as isolated grains in howardites, presumed to be from the Vestan mantle, as determined by isotope and trace element analyses. Their work inferred that these clasts likely represent a harzburgite lithology due to the chemical composition and close proximity of grains. Several other studies [4, 5,6,7] have documented Mg-rich grains of olivine and pyroxene in howardites.

Models for the differentiation of Vesta [8] predict harzburgite lithologies within the mantle. These harzburgite lithologies should be represented by high mg#s and lower Fe/Mn [8]. Although isolated olivine and pyroxene grains have been identified in [3] and harzburgite diogenites (presumably crustal plutons) in [6], no magnesian harzburgite components have been identified in howardites.

In this study we identify Mg-rich lithic components that represent harzburgite lithologies from the mantle of Vesta. Associated with these clasts are pyroxene-chromite symplectites. Symplectites have been interpreted to represent the breakdown of a metastable phase or precipitation of immiscible melts [9]. Similar symplectite textures can be found in terrestrial mantle rocks [10], lunar rocks [11], and mesosiderites [12] and may offer supporting evidence that these harzburgite lithologies are mantle derived.

Methods: Three thin-sections from the Dominion Range (DOM) howardite pairing group were analyzed in this study (DOM 10105,6; DOM 10100,6; and DOM 10120,6).

Mineral Analyses were conducted at the University of Tennessee, Knoxville on Cameca SX-100 electron microprobe (EMP). Mineral analyses were conducted with a 1 μm spot size with analytical conditions as follows: 15 keV & 30 nA for pyroxene, olivine, sulfides, and metals; 15 keV & 10 nA for plagioclase; and 20 keV & 100 nA to examine Mn, Cr, and Ni in olivine and pyroxene. Standard PAP corrections were made, and standardization using natural and syntehic standards was conducted at the beginning and end of each day to check for possible drift.

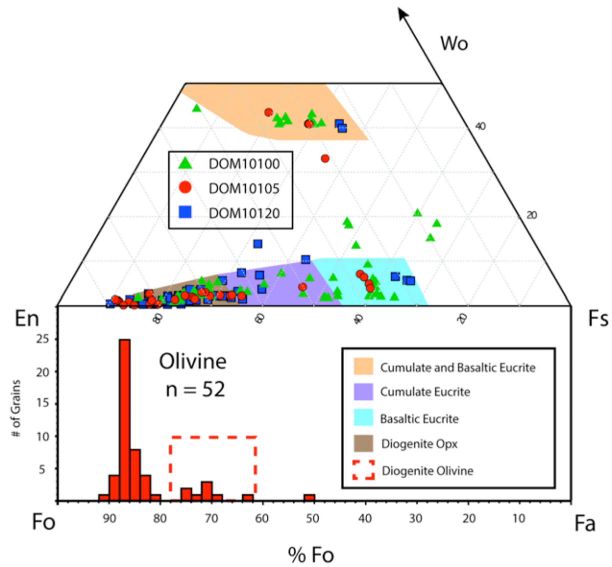
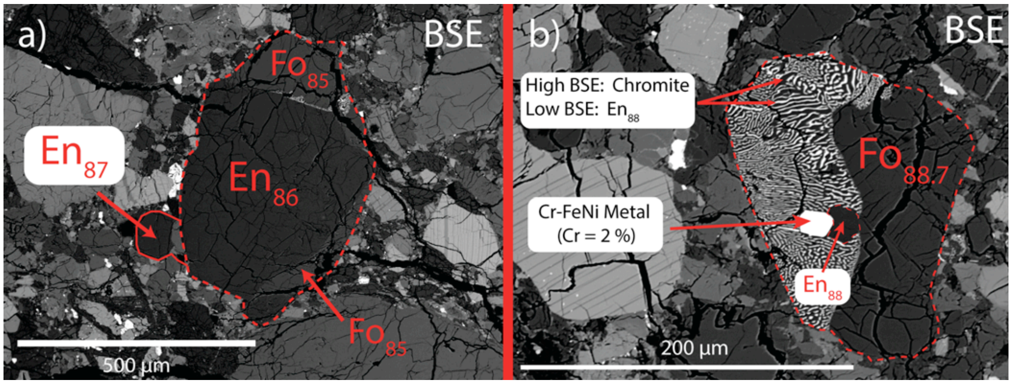


Figure 1: Pyroxene and associated olivine compositions for thin-sections DOM 10100, 10105, and 10120. Compositional color ranges from [6].

Elemental x-ray maps of each section were made with EMP in order to produce data for modal abundance determinations in ENVI 4.2 to best characterize the compositions and distribution of clasts within the howardites. The production of lithologic maps, adopted from [6] provide a means for locating exotic grains or clasts, which possibly represent pieces of the mantle.

Results: The Mg-rich grains within the howardites occur as coherent clasts of pyroxene and olivine (harzburgite) that preserve recrystalized textures, as well as disaggregated mono-mineralic clasts. The recrystalized nature of the clasts are inferred by smooth grain boundaries and lack of zonation. It should be noted, however, that no triple junctions are observed. Figure 1 shows the pyroxene compositions of all three howardites with associated occurances of olivine.

Harzburgite Clasts. Each thin-section contains harzburgite clasts, as well as, numerous isolated grains of pyroxene and olivine that fall above the diogenite range (En >85 & Fo >78). The Fe/Mn measured for pyroxene and olivine are 15-50 and 25-60, respec-



a) Harzburgite clast for section DOM 10105. Note sympletite along grain boundary and primary igneous contacts. b) Harzburgite clast from DOM 10105. The clast has a symplectite intergrowth of chromite and Mg-rich pyroxene. A Cr-rich FeNi metal appears within the symplectite.

tively. For most of the mono-mineralic clasts, Mg-rich pyroxene and olivine occur in close promimity to each other. Figure 2 shows two occurances of Mg-rich harzburgite clasts.

Symplectite. Associated with the harzbugite clasts are symplectites composed of Mg-rich pyroxene (mg# 88) and chromite with <1 wt% Al_2O_3 and 8 wt% MgO. The analyses for the chromite show minor amount of SiO_2 (~4 wt%). A grain of FeNi metal is associated with the symplectite in Figure 2b and contains 2 wt% Cr, 3 wt% Ni, and 1 wt% Co. Textural evidence suggests the symplectite is contained by pyroxene grain boundaries. Elemental x-ray maps (Mg, Fe, Cr, and Si) were created in order to show the distribution of the important elements and to allow for a bulk composition reconstruction.

Discussion: Mg-rich olivine and pyroxenes have been described in previous howardites [3,4,5,6,7]. All but a few of these, however, occur as mono-mineralic fragments and offer no evidence for textural relationships.

Harzburgite Clasts. The discovery of Mg-rich pyroxene (En_{86}) in contact and equilibrium with olivine (Fo_{85}) is substantial. This finding supports [3] and [5] that these mineral fragments are samples of the Vestan mantle.

Evidence that these Mg-rich grains are Vestan has been shown by the recent isotope work of [3]. Fe/Mn within these howardites is also evidence that these clasts are indigenous to Vesta. These findings support the hypothesis that the Vestan upper mantle is harzburgitic. Concentration of nickel (10s of ppm) within these mantle olivines has implications for the amount of metal that was separated out to form Vesta's core [8]. The Fe/Mn, Mg#, and Ni concentrations within these mantle clasts can help constrain models for the differentiation process of Vesta.

Symplectite. Similar symplectite assemblages have been found in terrestrial mantle rocks, which may offer supporting evidence that these are indeed clasts of harzburgite from the mantle of Vesta. The symplectite assemblages found within the Dominion Range howardites are exclusively associated with the Mg-rich harzburgite clasts. Islands of pyroxene occur within the symplectite and suggests that the two are genetically related. The minor amounts of SiO_2 in the chromite phase is unusal but may be attributed to analytical principles behind the EMP, due to the small scale (<5 µm) of the lamellae or may actual be accommodated within the chromite structure. Further analyses and different analytical techniques may aid in the interpreation of the symplectite but at this time we do not yet understand its origin. We do, however, note the the symplectite appears to be an integral part of the harzburgite clasts.

Conclusion: We have recognized numerous Mg-rich olivine and pyroxene components within howardites that occur as harzburgite and mono-mineralic clasts. This work provides excellent examples of clasts from Vesta's mantle that preserve primary igneous contacts. Future work aimed at analyses of trace elements within the Mg-rich pyroxenes will provide further insight into the mantle and allow a better model of the differentiation of Vesta.

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