MAGMATIC PROCESSES ON THE ASTEROID 4-VESTA: IMPLICATIONS FOR DIFFERENTIATION OF SMALL ROCKY BODIES. A. G. Distel[1], R. M. Palin[1,2], E. J. Chin[3], [1]Department of Geology and Geological Engineering, Colorado School of Mines, Golden, CO 80401. [2]Department of Earth Sciences, University of Oxford, Oxford, UK. [3]Scripps Institution of Oceanography, University of California, San Diego, CA 92093-0212.

Introduction: The asteroid 4-Vesta is unique among the main asteroid belt, as it is internally differentiated into a Fe-Ni core, ultramafic mantle, and basaltic crust [1, 2]. As such, it represents an important extraterrestrial analogue for studying the complex processes of planetary formation and differentiation early in the solar system [2, 3].

The howardite-eucrite-diogenite (HED) clan of achondritic meteorites are igneous rocks derived from various depths within the crust of Vesta, and so provide valuable constraints on the geochemistry and mineralogy of its interior [1, 2, 4]. However, the petrogenesis and thermal history of Vesta's mantle and crust remain incompletely understood. Recent models of its early evolution favor a magma ocean that experienced multiple episodes of equilibrium and fractional crystallization, producing magmas that ascended through the overlying crust to crystallize eucrites and diogenites [5-8].

Prior quantitative petrological modeling using equilibrium thermodynamics has provided great insight into the crystallization sequences expected for various magma ocean bulk compositions that cooled at different rates [5-8]. Other models have provided insight into the absolute pressure and temperature conditions of post-intrusion thermal metamorphism of eucritic meteorites [6-9]. Yet, due to the heterogeneity of Vesta's surface, chemical and geological features recorded by some HED meteorites and some Dawn mission data cannot be fully reproduced [6-8]. The research outlined herein builds upon previous studies' results and will provide new insight into the validity of competing models for Vesta's magmatic evolution, which in turn has broader implications for the evolution of other, larger rocky worlds in our solar system.

Methodology: We have studied two HED meteorites: the un-brecciated eucrite NWA 11455 and the brecciated diogenite NWA 4664. Microstructures, mineral proportions, and bulk-rock composition data from each sample indicate that the former is an extrusive igneous rock that formed following magma ascent through the Vestan crust, whereas the latter is a cumulate that formed due to fractional crystallization of a parent melt whilst it was ascending. Using published estimates of the residual melt produced from an almost completely solidified (e.g., 80, 85, 90, 95, and 99% crystal fraction), core-depleted, chondritic magma ocean, we have applied thermodynamic modeling using the software MELTS to forward-model both fractional and equilibrium crystallization scenarios [10, 11]. We test the crystallization sequences for each fraction during ascent through a proto-crust at pressures, temperatures, and oxygen fugacities suitable for a small protoplanetary body [5, 6, 10, 11]. MELTS-derived predictions of the sequence, composition, and proportion of solids that crystallize from these parent magmas are then correlated with the equivalent characteristics of each sample to identify the most suitable set of parameters leading to their formation.

Petrology of the studied samples: Eucrite NWA 11455 exhibits a microgabbroic texture and is mainly composed of exsolved pyroxene (Fs-host and Aug-lamellae) and anorthite ($An_{89.63}$) (Figure 1). Minor quartz and Fe-metal also occurs. Diogenite NWA 4664 is a brecciated orthopyroxenite. The crystalline components are primarily orthopyroxene ($Wo_{3.31}En_{69.87}Fs_{26.82}$), although it is highly disrupted and is volumetrically dominated by a pulverized matrix of uncertain constitution. Minor olivine (Fo_{75}), plagioclase ($An_{83.33}$), and metals also occur with some orthopyroxene grains displaying symplectite textures at their rims (Figure 2).

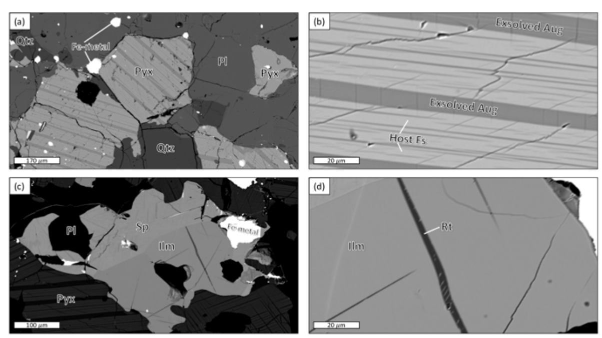

Figure 1: Back-scattered electron (BSE) images of eucrite NWA 11455. (a) Textural relationships between pyroxene, plagioclase, quartz, and Fe-metals. (b) Exsolution features in orthopyroxene. Host ferrosilite grains with exsolved augite lamellae. (c) Textural relationships between spinel, ilmenite, and Fe-metal. (d) The ilmenite grain from (c) with rutile exsolution.

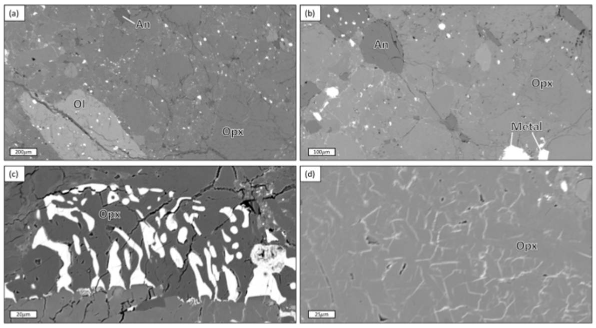

Figure 2: Back-scattered electron (BSE) images of diogenite NWA 4664. (a) Textural relationships between anorthite, orthopyroxene, and olivine. (b) Textural relationships between anorthite, orthopyroxene, and metal. (c) Symplectite texture in orthopyroxene. (d) Metal dislocations in orthopyroxene.

EPMA-derived compositions and estimated area proportions were used to calculate a bulk composition for each sample, which were compared to published datasets for other HED meteorites [1]. Both NWA 4664 and NWA 11455 fall within the reported compositional ranges for diogenites and eucrites, although the latter is atypically rich in TiO_2 (Figure 3).

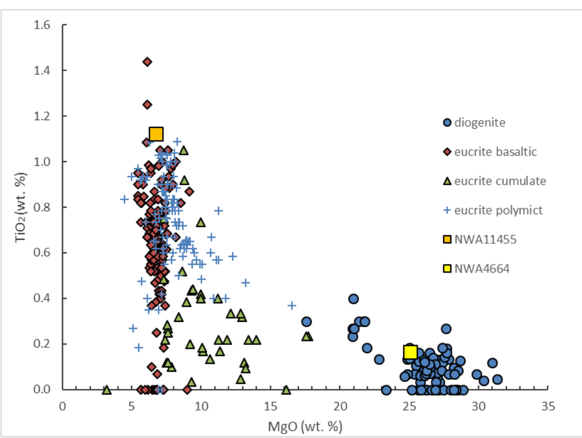

Figure 3: Geochemical plot showing TiO_2 vs. MgO (wt. %) contents for published HEDs (from Mittlefehldt, 2015) alongside un-brecciated eucrite NWA 11455 and brecciated diogenite NWA 4664.

Preliminary Results: Preliminary modeling using the core-depleted magma ocean composition from [6] and a fractional crystallization system suggests that the composition of the magma ocean at 80% solidification is a suitable starting liquid composition for crystallizing diogenites and eucrites [5]. The model parameters that currently best fit the mineral compositions of NWA 4664 and NWA 11455 using the 80% solidified liquid composition is a fractional crystallization model that follows an isobaric path at 500 bars and an iron-wüstite buffer. The MELTS calculated pyroxene compositions correlate with NWA 4664; however, they do not completely correlate with the calculated pyroxene compositions for NWA 11455 (Figure 4).

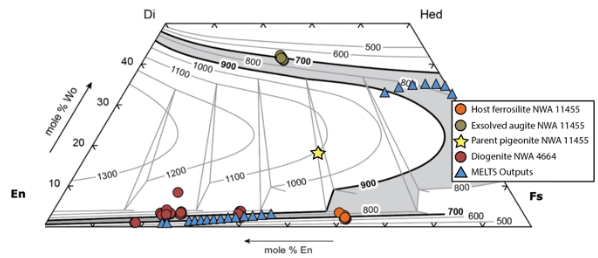

Figure 4: Pyroxene quadrilateral showing analyzed compositions of ferrosilite host grains and exsolved augite in NWA 11455, calculated parent pigeonite composition for NWA 11455, analyzed compositions of orthopyroxene in NWA 4664, and calculated fractional crystallization MELTS pyroxene compositions.

Conclusions: Preliminary results suggest that the magma that crystallized to form eucrites and diogenites underwent both equilibrium and fractional crystallization. The calculated MELTS pyroxene compositions for a fractional crystallization system that follows an isobaric path at 500 bars does correlate with the pyroxene compositions of the diogenite NWA 4664, however, neither fractional or equilibrium crystallization alone produce mineral proportions and compositions that correlate with those of the eucrite NWA 11455. This suggests that both equilibrium and fractional crystallization were instrumental in the petrogenesis of eucrites. This work, however, is still in progress and more models will be run in order to increase the certainty of these conclusions.

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