VESTAN METEORITE: PETROGRAPHY AND GEOCHEMISTRY OF A NEW HOWARDITE-NORTHWEST AFRICA 10459 A.C. Martin[1], M.S. Phillips[1], C.B. McCarty[1], L.A. Taylor[1], [1]Planetary Geosciences Institute, Department of Earth and Planetary Sciences, University of Tennessee, Knoxville, TN 37996, USA (amart115@vols.utk.edu)

Introduction: Asteroids are among the most important bodies in the solar system for answering questions about planetary origin, evolution, and early solar-system conditions. Vesta, the second largest body in the asteroid belt, is host to features akin to terrestrial planets, such as the presence of a FeNi core, ultramafic mantle, and basaltic crust [1]. Additionally, Vesta is the purported parent body of a significant number of achondrites − howardite-eucrite-diogenite (HED) meteorites [2]. These samples provide fundamental ground-truth studies for the petrologic evolution of Vesta. [2,3,4]. The original connection between HED meteorites and Vesta was recognized by similarities in spectral reflectance between the two [5]; more rigorous spectroscopic studies have since confirmed and expanded this observation to include all HED meteorites [3,6].

Space-weathering processes on Vesta have generated a regolith composed primarily of eucritic and diogenitic mineral and lithic fragments, which have been excavated from the crust and upper mantle of Vesta, respectively. Exogenous material from impactors has also been recognized, both spectrally and petrographically. Howardites can therefore provide an excellent record of lithologic diversity, which provides insights into differentiation anwe investigated the geochemical diversity of a proposed howardite pairing group − sample Northwest Africa (NWA) 10459 – from Mauritania. Our goal was to characterize important petrographic and geochemical features. Specifically, we report Fe/Mn values measured in orthopyroxene (Opx) and clinopyroxene (Cpx) and textural relationships between mineral phases in basaltic eucrite clasts.

Methods: Three polished thin-sections of NWA 10459 were studied petrographically. Mineral compositions were determined with wavelength-dispersive spectrometry (WDS) using a Cameca SX-100 Electron Microprobe (EMP). False color lithologic distribution maps (see in Fig. 1, 3) were constructed using an integration of X-ray maps with the digital image-processing program ENVI [7].

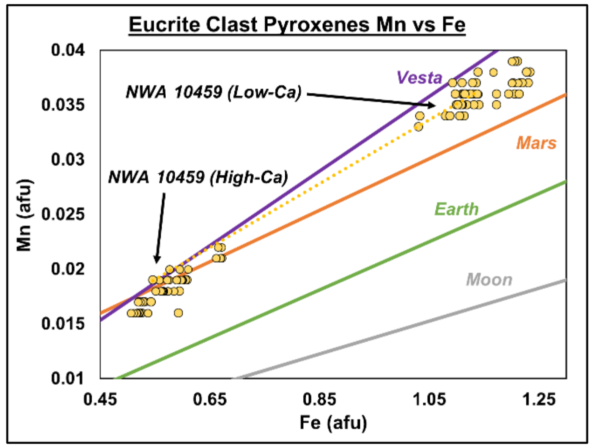

Figure 2: *Data from NWA 10459 are shown as yellow circles in the above plot. There are two groups of data due to the two types of pyroxenes from the clasts that correspond to Opx and Cpx,with a close match to the Vesta line [7].*

Petrography: Sample NWA 10459 is a complex polymict regolithic breccia consisting of several basaltic clasts (3-8 mm), set in a comminuted groundmass of glass, pyroxene, and plagioclase. Minor amounts of FeNi metal, troilite, ilmenite, and chromite are also present.

Basaltic eucrite clasts are a dominant feature in these sections, which consist of 39 % plagioclase, 37 % Opx, 17 % Cpx,

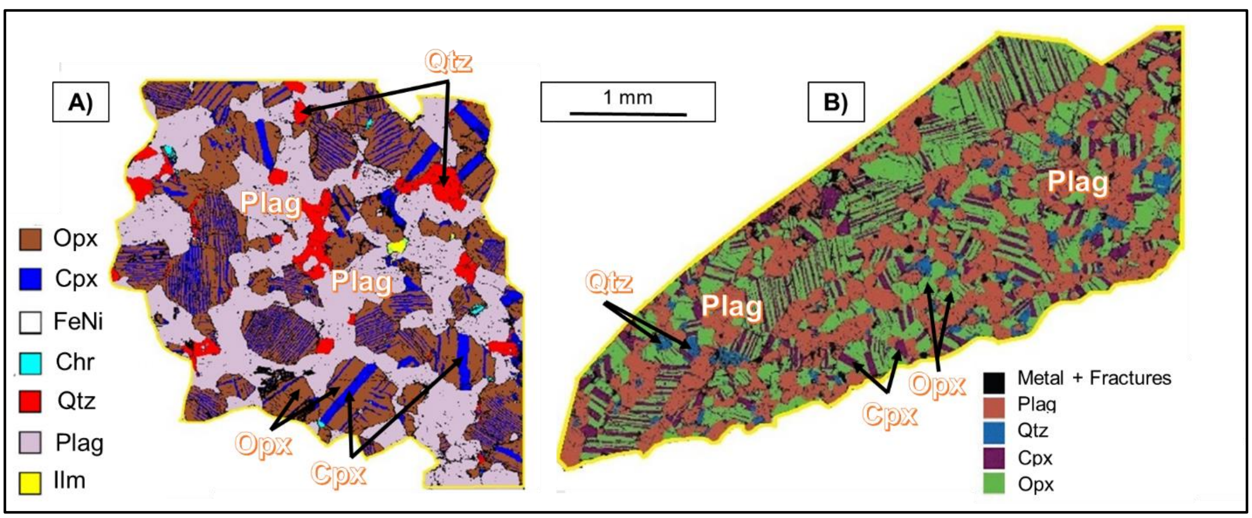

Figure 1*: Lithograohic modality map of basalt clasts in NWA 10459 are outlined in yellow above.*

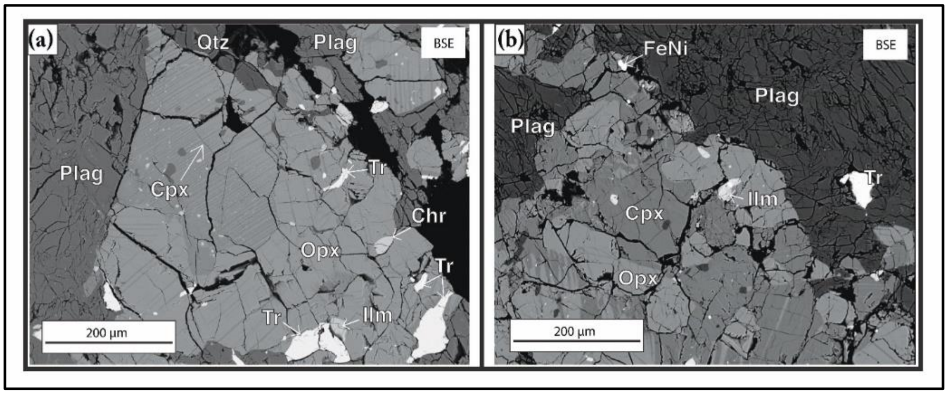

Figure 3: *BSE images, shown above, exibit pyroxene grains with exsolution (a) and granular (b) texture. Arrow from Cpx in (a) points to exsolution lamellae. Plag = plagioclase; Cpx = clinopyroxene; Opx = orthopyroxene; Tr = troilite; Chr = chromite; Qtz = quartz; Ilm = ilmenite*

3 % silica, and 4 % opaque phases of FeNi metal, troilite, ilmenite, and chromite, all in addition to a thin (<200 um) fusion crust (Figure 1). Anhedral plagioclase subophitically encloses orthopyroxene grains that range in size from 50-500 µm. Often these fragments are polygranular constituents of larger, optically continuous grains up to 1.5 mm. The pyroxene grains are extensively fractured and fragmented; distinct exsolution lamellae are also apparent. Subhedral Cpx is typically fractured, and appears to retain optical continuity, with sizes of 1-2 mm.

Geochemistry: *Pyroxene*- The basaltic clasts of interest contain two distinct pyroxene compositions: high-Ca ($En_{60.4 \pm 2.3}$ $Wo_{3.5 \pm 2.5}$) and low-Ca ($En_{60.4 \pm 2.3}$) (Figure 4). Pyroxenes show an inverse correlation between Ca and Fe concentrations. This variation in composition is mostly due to changes in Ca, with moderate variation in Fe-Mg.

Pyroxenes that contain exsolution lamellae generally consist of an Opx host with Cpx lamellae (2-10 µm; Figure 3a). Variations in lamellae thickness and abundance likely reflect differences in crystal orientation, cooling rate, and original composition, and can be used to estimate the depth of emplacement. Additionally, pyroxene grains can exhibit a granular association, which indicates metamorphic re-crystallization or alteration during mesostasis (Figure 3b). The Fe/Mn values of Opx and Cpx are plotted relative to representative regression lines for common terrestrial bodies [8]. The Fe/Mn values provide insight into parent body association; each body has a distinct Fe/Mn signature related to heliocentric distance [8]. Sample NWA 10459 is vestan in origin, which is supported by the slope of Fe and Mn systematics in pyroxene data (Figure 2).

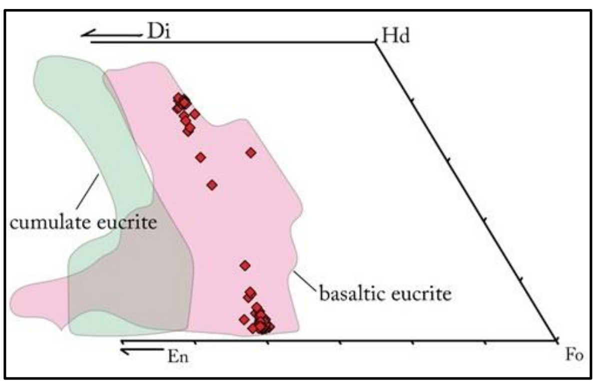

Figure 4: *Pyroxene quadrilateral for polymict breccia NWA 10459 basalt clasts; comparison data from [9].*

Plagioclase- Plagioclase grains ($An_{88 \pm 3.3}$), constitute 39% of the eucritic clasts, and are post-cumulate phase oikocrysts that contain no apparent zonation. All plagioclase grains have compositions typical of basaltic eucrites [9].

FeNi Metal- The FeNi phases in the basaltic clasts occur as inclusions in pyroxene, indicating a strongly reduced environment of crystallization [10]. The FeNi metal phases show a bimodal distribution in their Ni content; Ni-rich phases contain up to 5.15 % Ni, whereas Ni-poor phases contain less than 0.05 % Ni. Matrix grains almost exclusively contain Ni-rich phases, some indicating FeNi meteorite origin.

Accesorry Minerals- Basalt clast accessory minerals include chromite, ilmenite, troilite, silica, and merrillite. Chromite occurs as euhedral grains in the basalt clast. Chromite compositions are used to classify basaltic eucrites. Ilmenite, troilite, and silica occur as anhedral phases associated with granular textured pyroxenes, and represent late-stage crystallization of the melt.

Summary: Sample NWA 10459 is a classic example of a polymict breccia, which originated from impact mixing in the vestan regolith. Pyroxene Fe/Mn values are consistent with a vestan origin, which is possible because Vesta, along with HEDs, are spatially associated with the 3:1 mean-motion resonance, that perturbs and delivers these meteorites to Earth [8]. Furthermore, NWA 10459 contains basaltic clasts that are similar to basaltic eucrites when compared to primary mineral compositions of pyroxene, plagioclase, and chromite. The brecciated texture and vestan origin of sample NWA 10459 indicates a classification as a howardite.

References: [1] Keil K. (2002) *Astroids III, 573-584.* [2] McSween, H.Y., et al. (2011) Sp. Sci. Rev. 163, 141; [3] Binzel, R.P. & Xu, S. (1993) Science 260, 186; [4] Binzel, R.P., et al. (1997) Icarus 128, 95; [5] McCord, T.B., et al. (1970) Science 168, 1445; [6] Drake M.J., (1979) In: Gehrels Matthews, eds., Asteroids. Arizona Press, 765; [7] Beck, A.W., et al. (2012) MaPS 47, 947; [8] Karner, J., et al. (2006) Amer. Mineral. 91, 1574; [9] Mittlefehldt, D., et al. (2012) MaPS 47, A276; [10] Moore, C.B., et al. (1969) MaPS 10.