CLASSIFICATION OF VIR SPECTRA FROM HED METEORITES. [1]C. E. Viviano, [2]Andrew W. Beck, [3]Jean-Philippe Combe, and [1]Brett W. Denevi, [1]Johns Hopkins University Applied Physics Laboratory, [2]Marietta College, Department of Petroleum Engineering and Geology, 215 Fifth St., Marietta, OH 45750, [3]Planetary Science Institute, 1700 East Fort Lowell, Suite 106, Tucson, AZ 85719-2395. <Christina.Viviano@jhuapl.edu>.

Introduction: Unlike many other remotely-sensed bodies in the Solar System, the diversity of lithologies present on asteroid 4Vesta is well-constrained, as Vesta is the likely source for the most voluminous set of extraterrestrial materials from an identified parent body: the HED (Howardite, Eucrite, and Diogenite) meteorite clan. Using a high spatial-resolution Framing Camera (FC) and a Visible and InfraRed spectrometer (VIR), the Dawn spacecraft imaged the vestan surface regolith at ~10-100 m resolution at most, respectively. Results from the Dawn mission to Vesta leverage the geologic context of HED meteorite clan and constrain, spatially, where these lithologies may occur on the surface. Early results showed that Vesta's surface is dominated by spectral signatures consistent with howardites – breccias representing physical mixtures of endmember orthopyroxenitic diogenite and basaltic (clinopyroxene + plagioclase) eucrite components [1]. However, regional variations in the relative amounts of the components that make up these breccias can also be observed. Visible and near-infrared spectroscopy is particularly sensitive to the differences in the pyroxene compositions of the two lithologies.

Olivine is a key petrologic indicator that is typically suggestive of lower crustal or mantle materials when present in sufficient abundance to be distinguishable by remote spectrometers (e.g., at least tens of percent when in mixture with highly absorbing pyroxenes [2]). However, no clear olivine detections have been associated with the south polar Rheasilvia basin [3]. Instead, the most olivine-rich (greater than or equal to 40% olivine) locations are found in shallow exposures in the northern hemisphere craters Bellicia and Arruntia [4]. Olivine is not a dominant mineral in most HED lithologies (save for a few olivine rich diogenites [2]) and is therefore not expected to be ubiquitous in high concentrations on Vesta's surface, especially in northern regions where craters do not sample lower crustal/mantle material. Thus, detecting subtle additions of olivine in shallowly excavating craters is key to understanding Vesta's magmatic evolution.

Olivine associated with shallow northern hemisphere craters may have implications for localized crustal-forming processes, versus a magma ocean crystallization for crustal petrogenesis [5], or exogenically emplaced [6]. However, olivine-rich spectral signatures of Bellicia and Arruntia could also be interpreted as olivine-free [7], contending the spectra could be modeled as mixtures of hypersthene, pigeonite and diopside. This noritic petrology is consistent with Type B diogenites, and presence of Type B diogenites in the northern regions was further supported by mapping via Dawn's Gamma Ray and Neutron Detector [8]. Full interpretation of the petrologic history of these key olivine exposures and their implications for Vesta's crustal evolution relies on detailed examination of their VISNIR spectral characteristics in spatial context.

Methods: Previous investigations of ferrous lithologies on terrestrial bodies have demonstrated that 1-μm band position and shape can be analyzed using methods based on those of [9], and that the 2-μm band center can be used to test and corroborate the results [10]. Methods of [9] allow classification of ferrous mineral mixtures using on the 1-μm absorption, on a plot of 1-μm band center and 1-μm band asymmetry. A selected sampling of HED spectra from RELAB are plotted in the above-described 1- and 2-μm classification scheme in order to demonstrate that different lithologies of the HEDs cluster in different regions of this parameter space.

Using the 1- and 2-μm classification scheme, we then applied this methodology to an updated and calibrated VIR dataset, that includes a flat-field correction to minimize vertical striping, a correction to

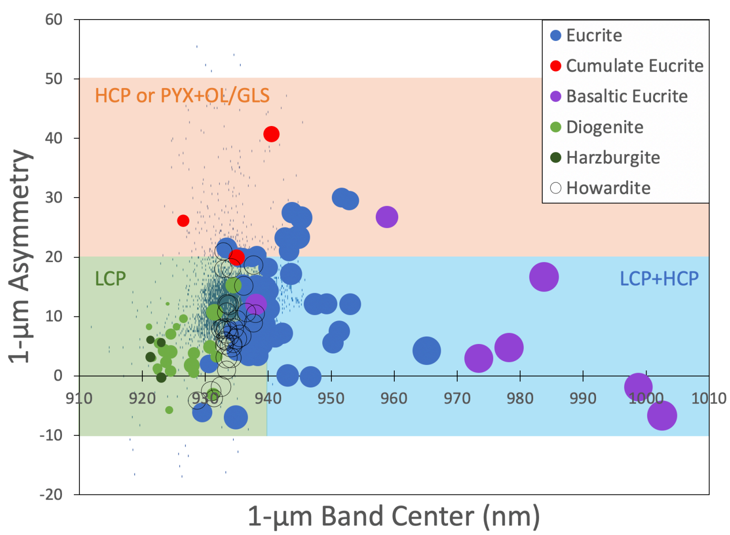

Fig. 1. Application of the 1- and 2-μm classification scheme (see [9], zoomed to relevant region) to a select number of HEDs from the RELAB database to demonstrate ability to tease out different classes. Relative size of bubble represents 2-μm band center. Plotted on a more constrained x-range to highlight variability in these samples. VIR spectra from pilot study (see section 1.6.3) are plotted as points in the background. Dunitic diogenite not plotted (see text).

mitigate the geometric shift that exists between the VIR-VIS and VIR-IR images, and a temperature dependent and radiometric correction improving calibration artifacts. Data are photometrically corrected (including a correction for variations in the geometry of illumination and for multiple scattering effects).

Results: Our initial application of the classification to HED meteorite spectra are promising and reveal significant differences between lithologies. As pyroxene compositions vary significantly between the diogenite and eucrite lithologies, this technique differentiates between pyroxenites (fields 1-2, Fig. 1) and basaltic lithologies (fields 4, Fig. 1). These initial results reveal that the distribution of the HED spectra in this classification scheme HED is heavily clustered near the 'LCP' region of the classification diagram (Fig. 1). However, several trends are apparent. In the 1-µm asymmetry vs. 1-µm band center space, the diogenite group all fall within the 'LCP' field. The olivine-rich diogenites ("harzburgites", sometimes referred to as 'olivine-diogenites' in the literature) have some of the most shifted 1-µm band centers towards short wavelengths, consistent with a primitive material. As demonstrated in [2], the influence of olivine in these samples does not affect the spectra in a detectable manner. If olivine were spectrally-significant, the points would plot higher in the 1-µm asymmetry values, indicating mixing of olivine. The ≥ 90 vol.% olivine dunitic diogenite (MIL 03443) was included in this analysis; it deviates strongly with a 1-µm band center at ~1060 nm (falls well off the right edge of the plot, in the in the yellow zone from Fig. 1). Samples labelled 'eucrite' in the database fall in a broad cluster roughly with 1-µm center values between 935 and 965 nm. Cumulate eucrites and basaltic eucrite occupy a significantly different distribution in this space, a lithologic discrepancy which was not explicitly mapped in [4].

The application of the classification scheme (Fig. 2) reveals that Antonia crater has excavated material with relatively higher values for the 1- and 2-µm band centers (green and blue channel of the composite), possibly indicating an increase of high-Ca pyroxene of the excavated materials. This region was chosen for testing as Antonia crater shows large variations of pyroxene absorption band position.

The 1- and 2-µm center data from this scene were also plotted in the classification diagram with laboratory HED spectra (Fig. 1). The point cloud from this scene does reveal spread in this classification range. Pixels with longer wavelength of their 1-µm band center that fall in the blue (LCP+HCP) zone correspond to locations in the scene surrounding Antonia crater (cyan colors in Fig. 2).

Discussion and Conclusions: Understanding the distribution of lithologies across the surface, and at depth, offers insight into the relative roles of serial magmatism versus magma ocean crystallization in Vesta's differentiation. Since diogenites are believed to represent deep crustal or even mantle materials, finding diogenite-like spectral signatures exposed, uniformly, at deeper locations or as exposed by some of the largest impact craters would be consistent with a magma ocean scenario, e.g., [11, 12]. In contrast, finding diogenitic signatures exposed from a variety of depths across the globe via a wide range of crater sizes, and locally intermixed with the more evolved eucrites, would be consistent with a crustal emplacement via locally stratified plutons near Vesta's surface (e.g. [2, 13-15]). Using the technique presented here across the surface of Vesta on the global VIR dataset would help to elucidate mechanisms of formation for Vesta's crust and upper mantle.

References: [1] De Sanctis et al., (2012), *Science*, 336, 697-700. [2] Beck et al. (2013) *Met. Planet. Sci*., 48 (11), 2155-2165. [3] McSween et a. (2013), *JGR*, 118, 335-346. [4] Ammannito, et al. (2013), *Nature*, 504, 122-125. [5] Cheek and Sunshine (2020), *Icarus*, 345. [6] Le Corre et al. (2015), *Icarus*, 258, 483-499. [7] Combe et al. (2015), *Icarus*, 259. [8] Beck et al. (2017), *Icarus*, 286, 35-45. [9] Horgan et al. (2014), *Icarus*, 234, 132-154. [10] Viviano et al. (2019), *Icarus*, 328, 274-286. [11] Righter and Drake (1997), *Met. Planet. Sci.*, 32, 929-944. [12] McSween et al. (2013), *Met. Planet. Sci.*, 48, 2090-2104. [13] Shearer et al. (2010), *Geochim. Cosmochim. Acta*, 74, 4865-4880. [14] Mittlefehldt et al. (2012) *Met. Planet. Sci.*, 47, 72-96. [15] McSween et al. (2019), *Geochem.*, 79, 125526.

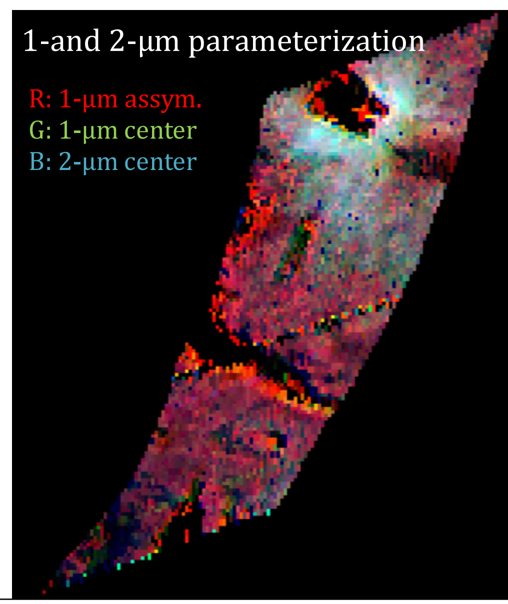

Fig. 2. Application of the preliminary classification scheme to VIR data over Antonia crater (covered in top of scene). 1-micron asymmetry (red), 1-micron band center (green), and 2-micron band center (blue). Black pixels represent spectra that failed the assumptions of calibration and/or parameterization.