Mapping igneous components in Vesta regolith using GRaND data. S. Narayanan[1], A. W. Beck[2], P. N. Peplowski[3], and D. J. Lawrence[3]. [1]Johns Hopkins University, [2]Marietta College, 215 Fifth St., Marietta, OH 45750, awb003@marietta.edu, [3]Johns Hopkins Applied Physics Lab

Introduction: The distribution of "pure" igneous lithologies on Vesta has been examined using Dawn GRaND [1] and VIR [2] data. Both studies concluded that little of the surface was igneous, instead it is nearly all howardite, or a polymict mixture of igneous lithologies. The VIR data [2] were further used to quantify the admixed components via a binary system into two broad igneous groups: 1) "eucrite", grouping together several subgroups of basalt (main group and Stannern trend basaltic eucrites) and group of gabbroic rocks (cumulate eucrite), vs. 2) diogenite, grouping orthopyroxenite, harzburgite and norite igneous lithologies together. Similarly, GRaND data were used to resolve the polymict surface as well, again as a binary system [3].

Igneous petrology on Vesta is more complex than a simple binary system [4,5], and depicting the surface in terms of all its primary components may further elucidate the geologic history of the asteroid. These previous efforts [i.e. 2,3] did not have the benefit of meteorite datasets with accurate classification of each sample, and proper constraints best suited for application to remote sensing data (i.e. GRaND, VIR).

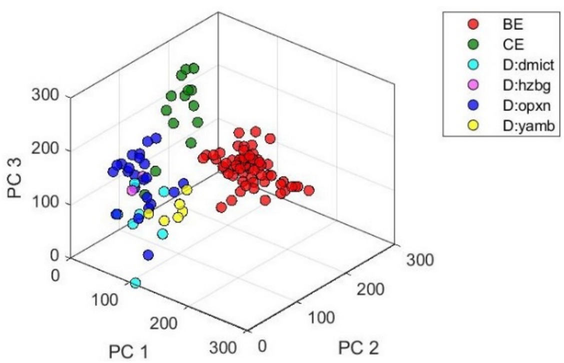

Fig. 1. PCA in HEDs. BE = basaltic eucrite, CE = cumulate eucrite, D= diogenite

Beck et al. [6] has since constructed such a dataset specifically for use with GRaND data, and one which thoroughly classifies each sample. Here we use this dataset to resolve the relative proportions of five vestan igneous lithologies admixed into the surface.

Methods: PCA transforms a dataset into a set of principal components (PCs), or set of orthogonal (uncorrelated) eigenvectors, and reduces the dimensionality of the data. An eigenvector matrix is generated during PCA and dictates how eigenvectors will be projected in PC-space.

Here we first conducted a PCA on four GRaND measurables (Fe, fast counts, sigma A, Cp) from igneous lithologies in the [6] HED dataset. This did two things, it: 1) generated an eigenvector matrix, which can transform this or any other dataset containing Fe, fast, sigma A and Cp into a PC space defined by the HED igneous lithologies, and 2) created a 3D PC1,2,3 "key" for how PC behaviors in that space reflect various enrichments of an HED igneous lithology.

Then, we took the now produced eigenvector matrix to transform the GRaND (Vesta) data, projecting it onto the PC-space generated with the meteorite PCA.

Note: We stress that the surface is still very much polymict (i.e. not a pure igneous lithology) and that our method reveals the enrichment of an endmember in that mixture, not exclusivity.

Results: 95.5% of variance is resolved with PC1 and Fe is the main factor in that variance. PC2 resolves 4.53% of the variance and is largely controlled by sigma

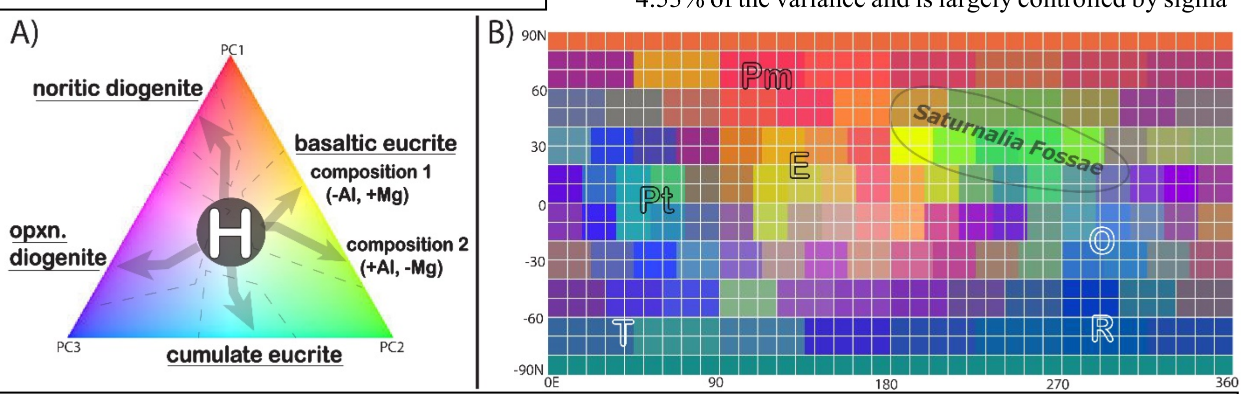

Fig. 2. **A)** Vestan igneous lithology trends in R (PC1), G (PC2), B (PC3) space away from howardite (H). Note, two compositions of basaltic eucrite are resolvable. This is a key for the **B)** igneous lithology enrichment map of Vesta, generated via meteorite eigenvector matrix-transformation of GRaND data from Vesta. E = Eutropia, O = Oppia, Pm = Pomponia, Pt = Portia, R = Rheasilvia, T = Tarpeia

A, and PC3 accounts for 0.02% of variance and is largely controlled by Cp. PC4 was determined, but it's contribution to overall variance was nearly 0% and it was dismissed.

The four main HED igneous lithologies are resolvable with the 3PCs (Fig. 1). Given the paucity of harzburgitic diogenite data (n=2), they were dismissed, as were dimict diogenites (not a single igneous lithology). A PCA of the new dataset was then rerun (not shown). Two groupings of basaltic eucrite were distinguished in PC-space. These groups will be referred to as "basaltic eucrite composition 1" and "basaltic eucrite composition 2," An ANOVA (Analysis of Variance) test was conducted for each chemical factor contributing to both groups, revealing statistically significant variation ($p \leq 0.05$) between the groups in (decreasing significance): Al ($p=0.008$), Mg ($p=0.018$), Si ($p=0.031$) and Na ($p=0.032$) and V ($p=0.03$). Plots of these chemical abundances for both groups revealed, most significantly, that basaltic eucrite composition 1 was depleted in Al and enriched in Mg, while basaltic eucrite composition 2 was enriched in Al but depleted in Mg.

Assigning the 3PCs to the RGB color scheme allows unique color combinations to signify enrichment in one of the igneous lithologies (Fig. 2a). We then transformed the Vesta (GRaND) Fe, fast counts, sigma A and Cp data with the HED eigenvector matrix calculated in the PCA transformation. Assigning each GraND data point an RGB value based on its PC1,2,&3 values results in an igneous lithology enrichment map for the regolith (Fig. 2b) - the key is the Fig. 2a.

Type B diogenite (norite) is identified by high PC1 (R), low to no PC2 (G), and low PC3 (B), resulting in **red** to **magenta** colors. The north pole is most enriched in noritic diogenite, with the strongest signal coincident with Pomponia crater ("Pm", Fig. 2b).

Orthopyroxenitic diogenite is identified by moderate to low PC1 (R), low to no PC2 (G) and moderate to high PC3 (B), resulting in identification by **blue** to **purple** colors. Orthopyroxenite enrichment is largely restricted to Rheasilvia basin ("R", Fig. 2b) and a large lobe of material extending from 90°E in Rheasilvia to 30°N. Note that areas of cumulate eucrite enrichment (discussed below) interrupt orthopyroxenitic diogenite-rich terrains at the south pole near Tarpia crater ("T", Fig. 2b) and in the ejecta lobe near Portia crater ("Pt", Fig. 2b).

Cumulate eucrite (gabbro) is identified by low to no PC1 (R), moderate PC2 (G) and moderate PC3 (B), resulting in **teal** to **aquamarine** colors. Cumulate eucrite enrichment is observed to be associated with Oppia crater ("O", Fig. 2b), the south pole, and Portia crater.

Basaltic eucrite composition 1 (↑Al, ↓Mg) is identified by moderate PC1 (R), moderate PC2 (G) and low to no PC3 (B), resulting in **yellow** to **orange** colors. Enrichment of this lithology is found at 50° latitude by 40° longitude, centered on Eutropia crater ("E" Fig. 2b).

Basaltic eucrite composition 2 (↓Al, ↑Mg) is identified by moderate to low PC1 (R), moderate to high PC2 (G) and low to no PC3 (B), resulting in **lime** to **green** colors. The area most enriched in this composition corelates well with Saturnalia Fossae, a northern region with deformation features that have been associated with the Veneneia impact event [7].

Discussion: Noritic diogenite had been previously identified in Vesta's north polar regions, and its source was proposed to be Pomponia crater [1]. This study supports that hypothesis. Our detection of orthopyroxenitic diogenite enrichment in Rheasilvia and in an ejecta lobe on the left side of Fig. 2b corroborates similar findings of (orthopyroxenitic) diogenite abundances in those areas as well [2,3].

The novel findings of this study are the first confirmed detection of a localized cumulate eucrite enrichment in the regolith, and the detection of enrichment in two different basaltic eucrite compositions.

[8] speculated that the "orange material" associated with Oppia crater may be associated with cumulate-eucrite-enriched regolith. That analysis, which was based on VIR-derived band centers and GRaND-derived Fe abundances and Cp, indicated that Oppia may be as much as 25% cumulate-eucrite-like material. We confirm this result. Further, we detect cumulate eucrite enrichment associated with orthopyroxenitic diogenite within Rheasilvia basin and associated with orthopyroxenitic diogenite in Rheasilvia ejecta material. This suggests cumulate eucrite petrogenesis is more closely tied to that of diogenites than basaltic eucrites. This has been proposed based on meteorite geochemistry [5] and is now supported by our mapped data.

Our identification of basaltic eucrite-rich terrains matches well with those previously identified as "eucritic" by [2,3]. However, our mapping demonstrates that basaltic eucrite associated with the oldest terrain, that near Eutropia, is Al-rich and Mg-poor, while the basaltic eucrite terrain in Saturnalia Fossae is Al-poor and Mg-rich. This is likely due to slight variations in pyroxene (Mg-bearing) to plagioclase (Al-bearing) abundances between the two terrains.

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References: [1] Beck et al. (2017) *Icarus*, 286:35-45. [2] Ammannite et al. (2013), *Meteorit. Planet. Sci.* 48:2185-2198. [3] Prettyman et al. (2013), *Meteorit. Planet. Sci.* 48:2211-2236. [4] McSween et al. (2011), *Space Sci. Rev.* 163:141-174. [5] Mittlefehldt et a. (1998), *RiMS* 36: p.195. [6] Beck et al. (2015), *Meteorit. Planet. Sci.* 50:1311-1337. [7] Scully et al. (2014), Icarus 244:23-40. [8] Le Corre et al. (2013): 1568-1594.