Dawn's GRaND to reveal the complex geochemistry of Vesta. T. H. Prettyman[1], H. Y. McSween, Jr.[2], C. A. Raymond[3], W. C. Feldman[1], J.-Y. Li[4], L. A. McFadden[4], C. T. Russell[5], P. Tricarico[1] [1]Planetary Science Institute (prettyman@psi.edu), [2]University of Tennessee, [3]Jet Propulsion Laboratory, [4]University of Maryland, [5]University of California, Los Angeles.

Introduction: The howardite, eucrite and diogenite (HED) meteorites are thought to originate from a single, largely-intact parent body (4 Vesta), which underwent igneous differentiation, forming a core, ultramafic mantle, and basaltic crust from which the meteorites were ejected [1]. The NASA Dawn mission, to orbit Vesta in 2011, will provide additional data on Vesta's shape, gravity field, surface mineralogy, geochemistry, and surface morphology needed to place the meteoritic data in context, providing a more detailed picture of Vesta's thermal evolution [2]. HST photometric mapping shows that Vesta's surface is heterogenous, probably due to impacts, which removed portions of the eucritc surface exposing pyroxene-rich diogenite [3]. Vesta's south polar basin may contain outcrops of Vesta's olivine-rich deep-crust or mantle, which is not well-represented by the meteorites [4]. Measurements by Dawn of compositional layering and elemental correlations will help determine how Vesta differentiated (e.g., by fractional crystallization of a magma ocean [5] vs. serial magmatism [6]).

Based on an analysis of whole-rock compositions compiled by Usui and McSween [7], the elemental systematics of Vesta's crust on a regional scale are well-represented by linear mixing of end-member basaltic eucrite, cumulate eucrite, and diogenite compositions; however, there are hints that Vesta may be more diverse than implied by this model. For example, the discovery of K-rich impact glasses in howardites suggests that K-rich rocks may be mixed with HED compositions on some portion of Vesta's surface [8]. In addition, the trace element chemistry of diogenites indicates considerable diversity in magmatic processes [9], and petrologic study demonstrates that olivine-bearing diogenites were formed by mixing orthopyroxenite and harzburgite lithologies [10].

GRaND: The Dawn payload includes a gamma ray and neutron detector (GRaND), which will globally map elemental abundances to depths of about 1m while Dawn is in a low altitude, circular polar mapping orbit [11]. The objective of this study is to determine GRaND's ability to test the HED model and to distinguish other compositions that might be exposed on Vesta's surface. For the planned low altitude mapping orbit (LAMO), we expect that GRaND will provide, at a minimum, global and regional [field-of-view (FOV) <20% of the surface] abundances of Fe, Si, and Mg along with neutron transport parameters (additionally sensitive, for example, to Ca and Al) needed to determine the proportions of plagioclase and pyroxene (basalts vs. ultramafics) in Vesta's crust and mantle. Like all planetary nuclear spectrometers, GRaND's sensitivity to elements is selective, dependent on instrument design, elemental composition, and the details of radiation production and transport, including nuclear reaction cross sections, which are variable. Consequently, the elements detected at Vesta will be different from those measured by previous missions to the Moon and Mars. In addition, GRaND's ability to sense elements and spatially-resolve distinct surface units depends on operational parameters, including proximity, pointing and acquisition time. Because strong spin-orbit resonances are expected, achieving close proximity to Vesta may be challenging [12]. Low enough altitudes are desired such that Vesta's enigmatic south polar basin fills as much of GRaND's FOV as possible. Here, we demonstrate GRaND's capability to sense compositional variations from the planned LAMO at 460km radius (>70d @ 80% duty cycle) and for a shorter-duration (e.g., 50d), 410 km orbit, which may be considered once Dawn has mapped Vesta's gravity field. The details of this work will appear in a forthcoming instrument paper and prospective study.

Virtual Vesta: We have developed an end-to-end model of data acquisition by GRaND at Vesta that generates a realistic time series of gamma ray and neutron counting data that can be analyzed to map the composition of a "virtual" Vesta. The model was created to guide the planning of science operations and to aid in the development of analytical methods. The model includes spacecraft ephemeris data from dynamical simulations, which reveal substantial variations in orbital radius for LAMO (e.g., Fig. 1). The radiation output and orbital-transport model includes the Vesta numerical shape model [13] and a heterogeneous chemical map based on recent HST observations [3] (between 50°S and 20°N latitude), which was modeled using whole-rock meteorite compositions [7]. Inner and outer regions are included in the south polar basin to represent, for example, an olivine-rich central region surrounded by olivine-diogenite. Variations in K abundance were incorporated into regions in the northern hemisphere. The instrument response model, which was calibrated during Dawn's close fly by of Mars [14], enabled an accurate model of counting rates, pulse height spectra, and uncertainties used in the simulations (Fig. 1).

Results: Simulated neutron counting data were corrected for solid angle and binned onto equal area maps. Counting rates from the nadir-pointing phoswich were converted to the flux of incident thermal and epithermal neutrons via a linear transformation. The fast neutron flux was determined from the boron-loaded plastic double pulse signature. The flux maps were smoothed with a high-resolution filter that fills in missing data. The resulting maps were subjected to spatial deconvolution. Surface bulk neutron transport parameters, including neutron number density, effective atomic mass (A*), and the ratio (Δ) of the macroscopic neutrons absorption (Σ_a) to effective scattering cross section ($\xi\Sigma_s$), were determined from reconstructed fluxes [15,16]. The parameters A*, Σ_a, and $\xi\Sigma_s$ are weighted sums of elemental abundances that have different sensitivities to major rock types. The Δ–A* diagram (Fig. 2) can be used to differentiate the HED compostions and mixtures of diogenite with olivine. Both orbital scenarios are sensitive to the presence of diogenite and olivine-rich materials. Improved sensitivity is achieved at the lower altitude, despite the shorter stay time.

Corrected gamma ray spectra for the BGO sensor were binned onto coarse, equal-area squares and subjected to spectral unmixing [17] to determine the abundance of major and radioactive elements. Elements with the highest precision were Fe, Mg, and Si, and an Mg/Si-Fe/Si diagram was found to strongly separate the olivine-diogenites from the HEDs. The analysis showed that material with >0.1 wt.% K can be detected and quantified even if the material only covers 50% of the surface within the FOV, which is well below the maximum value reported by Barrat [8] of 2 wt.%.

These encouraging results motivate ongoing work, including the determination of regional composition by forward modeling using VIR/FC mineral maps, determining HED end-member mixing ratios directly from the gamma/neutron data, and using thermal neutron absorption to constrain plagioclase abundance.

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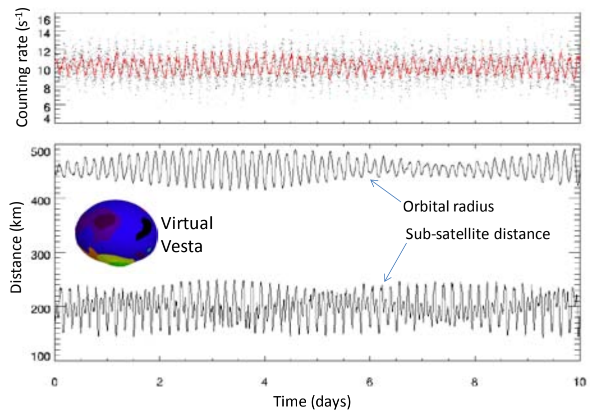

Figure 1. Simulated orbital ephemeris data for 10 days of LAMO (460 km mean radius). Mean (red) and sampled (dots) counting rates for the $^{10}B(n,\alpha)$ reaction in boron-loaded plastic are shown for the nadir-pointing phoswich.

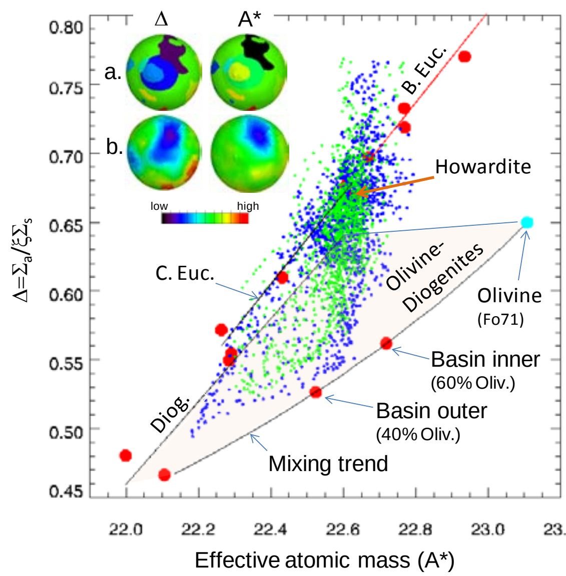

Figure 2. Elemental mixing diagram. Neutron parameters Δ and A* are described in the text. A* was determined by linear correlation with fast neutrons based on eucrite data, resulting in a slight bias for olivine-diogenites, which follow a different trend. The solid red circles are for the compositions assigned to regions on virtual Vesta. Lines indicate the range of values from the whole-rock meteoritic data for diogenite (Diog.), cumulate eucrite (C. Euc.), and basaltic eucrite (B. Euc.). The trend for mixing an end-member diogenite composition with olivine is shown. The trend, which delineates a boundary of the olivine-diogenite set, is non-linear due to the power law relationship between the neutron counting data and Δ. The green points are 5° equal-area map values determined by spatial deconvolution from simulated counting data from the nominal, 460km orbit. The dark-blue points were determined for the lowered, 410km orbit. Reference (a) and reconstructed (b) maps of the southern hemisphere are compared for the 410km orbit (inset).