NEUTRON ABSORPTION MEASUREMENTS CONSTRAIN EUCRITE-DIOGENITE MIXING IN VESTA'S REGOLITH.
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Introduction: The NASA Dawn Mission's Gamma Ray and Neutron Detector (GRaND) [1] acquired mapping data during 5 months in a polar, low altitude mapping orbit (LAMO) with ~460-km mean radius around main-belt asteroid Vesta (264-km mean radius) [2]. Neutrons and gamma rays are produced by galactic cosmic ray interactions and by the decay of natural radioelements (K, Th, U), providing information about the elemental composition of Vesta's regolith to depths of a few decimeters beneath the surface. From the data acquired in LAMO, maps of vestan neutron and gamma ray signatures were determined with a spatial resolution of ~300 km full-width-at-half-maximum (FWHM), comparable in scale to the Rheasilvia impact basin (~500 km diameter). The data from Vesta encounter are available from the NASA Planetary Data System.

Based on an analysis of gamma-ray spectra, Vesta's global-average regolith composition was found to be consistent with the Howardite, Eucrite, and Diogenite (HED) meteorites, reinforcing the HED-Vesta connection [2-7]. Further, an analysis of epithermal neutrons revealed variations in the abundance of hydrogen on Vesta's surface, reaching values up to 400 μg/g [2]. The association of high concentrations of hydrogen with equatorial, low-albedo surface regions indicated exogenic delivery of hydrogen by the infall of carbonaceous chondrite (CC) materials. This finding was buttressed by the presence of minimally-altered CC clasts in howardites, with inferred bulk hydrogen abundances similar to that found by GRaND, and by studies using data from Dawn's Framing Camera (FC) and VIR instruments [8-10]. In addition, from an analysis of neutron absorption, spatial-variations in the abundance of elements other than hydrogen were detected [2].

Ongoing mapping studies with GRaND data include the determination Fe abundances from the 7.6 MeV ^{56}Fe capture gamma ray [11]; atomic mass (<A>) from fast neutrons [12]; and compositional variations from high energy gamma rays [13]. Here, we present preliminary results for mapping the bulk neutron absorption cross section of Vesta's regolith using thermal- and epithermal-neutron counting data. We show that neutron absorption is sensitive to the proportion of eucrite to diogenite in Vesta's regolith.

Neutron Absorption: Energetic neutrons produced by the interaction of galactic cosmic rays are moderated by collisions with nuclei within the vestan regolith. Below about 1 MeV, billiard-ball (elastic) collisions are dominant. Since neutrons have about the same mass as a proton, they lose energy rapidly in planetary materials that contain hydrogen. As a result, the leakage flux of epithermal neutrons decreases sharply with increasing hydrogen content. The cross section for neutron absorption (e.g. by radiative capture) generally varies inversely with neutron speed. Thus, the flux of neutrons below about 1 eV is highly sensitive to the presence of elements that have high thermal neutron absorption cross sections. For vestan materials, epithermal neutron measurements depend on hydrogen content; whereas, thermal neutrons are sensitive to both hydrogen content and neutron absorption [1,2].

The macroscopic absorption cross section for a material (expressed as cm^2/g) is given by a weighted-sum of elemental atom densities, where the weights are the microscopic neutron absorption cross sections for each element [1]. Microscopic cross sections are highly variable (ranging from 2×10^{-4} barns for O to 4.6×10^{4} barns for Gd for 0.025 eV neutrons). The macroscopic thermal absorption cross section for lunar materials has a wide dynamic range, from about 30- to 130×10^{-4} cm^2/g [14]. The dominant contributors to this variation are Fe, Ti and REE (primarily Gd). The range for HED materials is smaller (about 50- to 75×10^{-4} cm^2/g), with variations dominated by Fe, Ca, Al, Ti, and Mg.

For the HEDs, neutron absorption is indicative of petrology. Eucrites contain Fe-rich, Ca-poor pyroxene, pigeonite and Ca-rich plagioclase; whereas, diogenites primarily consist of magnesium-rich orthopyroxenes. Lower abundances of Fe along with the absence of plagioclase (Ca and Al) in diogenite results in lower absorption cross sections for diogenites than eucrites. For howardites and polymict eucrites, thought to be representative of Vesta's regolith, we found that the absorption cross section is correlated with the percentage of eucritic materials (POEM) [15] (Fig. 1).

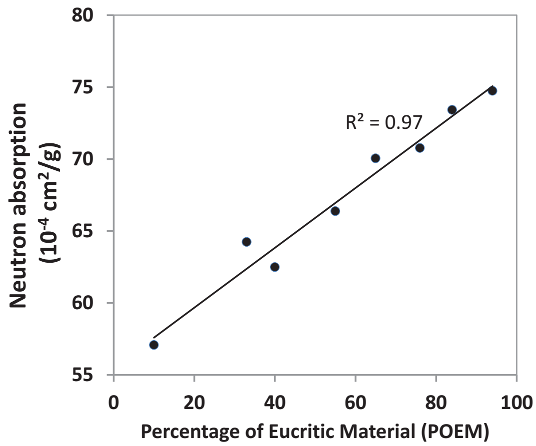

Figure 1. Variation of the macroscopic thermal neutron absorption cross section (0.025 eV) for selected howardites and polymict breccias as a function of eucrite content. (The balance is diogenite.) Abundance data for 48 elements were used to calculate the absorption cross section for each material [15,16].

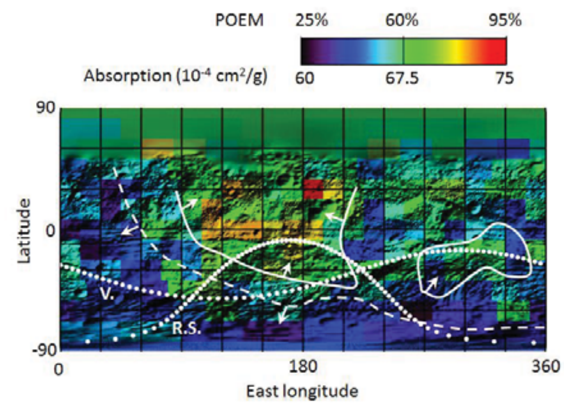

Figure 2. Map of the macroscopic neutron absorption cross section of Vesta's regolith. The scale bar also indicates the percentage of eucritic materials (POEM) (Fig. 1). Boundaries of the Rheasilvia (R.S.) and Veneneia (V.) are indicated by dotted lines. Regions mapped as diogenite-rich by FC/VIR are indicated by the dashed line. Regions mapped as eucrite-rich by FC/VIR are indicated by solid lines.

Analysis: Epithermal neutrons were measured by GRaND's boron-loaded plastic (BLP) scintillator. A weighted sum of thermal and epithermal neutrons was measured by GRaND's LiG scintillator. Deviations of measured BLP and LiG counting rates from a fiducial, linear trend were interpreted as variations in neutron absorption (cf. Fig. 4 of [2]). The deviations in counting rate were converted to absorption units using a correlation (r = 0.98) between modeled counting rates and thermal neutron absorption and assuming the mean H-free composition of the vestan surface was given by a representative howardite composition.

Results: The range of Vesta's macroscopic absorption cross section is consistent with that of howardite (Figs. 1 and 2). The observed variation is over three times lower than that of the Moon. The GRaND data indicate that the Rheasilvia basin has relatively low neutron absorption, consistent with diogenite-rich lithologies. In addition, diogenitic material, likely ejected by the impact that formed Rheasilvia, follows a lane extending northward from the basin across the equator in the western hemisphere of Vesta. Materials rich in eucrite (high absorption) are found within a broad, low-albedo equatorial region, with the highest abundances of hydrogen [2]. These observations are consistent with measurements of pyroxene band-depths and –centers by FC and VIR [6,7].

Conclusions: The neutron absorption map indicates that the Rheasilvia impact exposed and globally-distributed lower crustal materials over large portions of Vesta's surface. The nonuniform distribution of diogenite-rich material may have resulted from an oblique impact. High concentrations of basaltic material are found in older regions where CC material has accumulated [2].

Future Work: Although our preliminary results have been interpreted in terms of eucrite-diogenite mixing, it may also be possible to identify regions rich in cumulate eucrites. For example, spectral reflectance measurements are not sensitive to plagioclase content, making it difficult to discriminate between cumulates and basalts; however, cumulate eucrites have lower absorption than the basalts due to low Fe content. Thus, low absorption regions that are pyroxene-rich would indicate the presence of cumulate eucrites.

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