Rotationally-resolved Compositional Study of Asteroid (4) Vesta's Southern Hemisphere: Implications for the DAWN mission.

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Introduction: Vesta is the largest basaltic asteroid that remains mostly intact today and can be considered as a model for the early stages of planetary differentiation. Vesta has been postulated (e.g., 1, 2 and 3) as the parent body of the HED (howardite, eucrite, and diogenite) meteorites based on their similar near-infrared (NIR) spectra. A small cluster of asteroids (D <10 km) has been identified [4] that extends from Vesta's current location in the main belt to the 3:1 resonance (from where fragments can be rapidly transferred to Earth-crossing orbits). These asteroids share the same spectral and mineralogical characteristics as Vesta. Based on the observational and dynamical evidence, it is now generally accepted that Vesta is the parent body of most HED meteorites.

HED meteorites differ from each other primarily based on their pyroxene composition and their pyroxene to plagioclase feldspar ratio. These ratios were later estimated to be 3:1 for howardites, 1:1 for eucrites, and 30:1 for diogenites [5,6]. The Fe content in low-Ca pyroxene in HEDs increases from diogenites (Fs_{20-33}), to cumulate eucrites (Fs_{32-46}), to basaltic eucrites (Fs_{54-60}). Eucrites are surface lava flows or subsurface cumulate layers, while diogenites are samples from deeper regions that cooled slowly. Howardites are brecciated mixtures of eucrites and diogenites and thus have intermediate characteristics.

The NASA Dawn mission is currently on its way to Vesta and is expected to rendezvous in July 2011 for a 9-month orbital characterization mission. Earth-based spectral observations remain the only viable method for surface mineralogical characterization of Vesta prior to the arrival of Dawn. Using ground-based rotationally resolved spectral observations, [7] was able to show that Vesta's surface has distinct hemispheric compositional heterogeneity. These hemispheric heterogeneities have been linked to albedo variations on the surface of Vesta by [8] using HST images and shape model by [9].

However, compositional maps of Vesta were created [7,8] using observations based on a narrow range of sub-Earth latitudes (16º N to 22º N); so a large fraction of the asteroid's southern hemisphere was not observed. In 2007, HST observations were made [10, 11, 12] when the asteroid's sub-Earth latitude was 18º S; and included the large South Pole impact crater. Here we present preliminary results of our rotationally-resolved spectral study of Vesta's southern hemisphere from 2007. Rotationally-resolved broad band filter data from 1996 opposition of Vesta has also been analyzed to complement the spectroscopic data.

Observation/Data Reduction: Near-IR (0.7-2.5 μm) spectral observations of asteroid (4) Vesta were made using the low-resolution SpeX instrument on the NASA IRTF between May 24 and June 1, 2007. The object's sub-Earth latitude during this period ranged from 17.48º S to 16.16º S at a phase angle between 3.6-5.0º and covered between 104º to 323º in Vesta's longitude (0º longitude at Olbers). Near-IR spectral data were independently processed using two different software packages, i.e. SpecPR [13] and Spextool [14]. The resulting final average spectra were identical irrespective of the data reduction protocol employed.

Spectral band parameters (band centers and band area ratio, BAR) were calculated using SpecPR. Band centers were corrected for temperature-induced spectral effects using methods described in Burbine et al. (2009). The resulting temperature-corrected band centers for both data sets are shown in Table 1.

Broad band differential CCD photometric color data was obtained using the Bochum 24" telescope at ESO, La Silla, Chile, during April 1996. The data was obtained using a set of five interference filters covering the spectral range between 0.45-0.95 μm. To detect rotational spectral variability, color indexes were calculated relative to 0.55 μm filter.

Results: The results presented here are preliminary and further analysis is ongoing.

Hemispherical Differences: Figure 1 shows the average near-IR spectrum of Vesta's northern and southern hemispheres. The average northern hemisphere spectrum (red) is from [7] and was obtained at sub-Earth latitude 21º N. The southern hemisphere spectrum is from 2007 opposition at sub-Earth latitude 17º S. Both spectra are normalized to unity at 1.4 μm. Spectral band parameters for northern vs. southern hemisphere averages were calculated to quantify broad mineralogical differences and are show in Table 1. Band I center, depth and BAR for the southern hemisphere data differ from those of northern hemisphere.

Band II center and depth for both hemispheres are within the uncertainties (±0.01 µm) quoted. It has been suggested [7] that the decrease in Band I center with little change in Band II center could be due to a decrease in wollastonite (Ca) content without a corresponding decrease ferrosilite (Fe) content as show in Figure 11 of [7].

This was explained by invoking crystal site preferences in the pyroxene structure where Ca^{2+} will have preference over Fe^{2+} when portioning into M(2) site [7]. In calcic or Fe-rich pyroxenes some of the Fe^{2+} goes into the M(1) site producing a characteristic weak absorption band at 1.2 µm as seen in eucrites. This weak feature is seen in southern hemisphere spectrum in Figure 1. This feature was studied in HEDs and synthetic pyroxenes, and the strength of this feature was attributed to cooling rate of eucrites [15].

Band I depth difference between N and S hemispheres could be due to a range of observational and compositional effects. Phase angle at the time of observation affects band depth where increasing phase angle increases band depth [16]. A ~3.5% change was noted [7] in Band I depth on Vesta as the phase angle went from 4.3º to 17.5º (Avg. 10.9º). Based on this, Vesta's band depth changes ~2.7%/10º change in phase angle. Southern hemisphere observations of Vesta in 2007 were obtained when the phase angle was between 3.7-5.0º (Avg. 4.3º) and the Band I depth is 32±1%.

If phase angle alone affected the Band I depth then Vesta's southern hemisphere Band I depth should be 30±1%. While this value is within the uncertainties of the measured Band I depth, minor contribution due to composition can not be ruled out. A 7% change was noted Band I depth with rotation and attribute this to compositional variations [7]. This change in band depth is confirmed by the broad band color data from ESO where depth of low-resolution visible spectrum peaks between 0.40-0.50 rotation phase. Apart from phase angle and composition; particle size, opaque phases, space weathering, detector response at shorter wavelengths, and atmospheric dispersion can affect band depth.

Mean pyroxene chemistry for the two hemispheric spectra was calculated using two independent methods by [17, 18]. Based on this the mean pyroxene chemistry for northern hemisphere is $Fs_{36\text{-}38\pm4}$ $Wo_{8\text{-}11\pm3}$ and southern hemisphere is $Fs_{36\pm4}$ $Wo_{7\text{-}8\pm3}$.

Future work: We are completing the analysis of rotationally-resolved spectral data. Preliminary analysis suggests significant spectral variations on hemispherical scale as first suggested by [7]. Our current goal is to rule out systematic and user-induced errors in the data reduction and analysis process before final interpretation of the data. Results of these efforts including the search for olivine in the South Pole crater will be studied.

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Table 1. Temperature-corrected spectral band parameters of northern and southern hemispheric average spectra of Vesta.

Location	Band I Center	Band I Depth	Band II Center	Band II Depth	BAR
Errors >	±0.005	±0.5	±0.01	±1	±0.1
Units	µm	%	µm	%	-
North	0.935	30	1.938	25	2.2
South	0.929	32	1.938	24	1.9

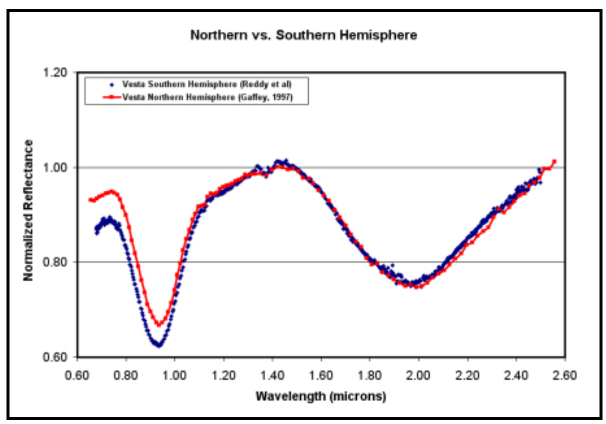

Figure 1. Average hemispherical spectra of Vesta's northern (red) Gaffey, 1997) and southern (blue) hemispheres (this work).