THE MINERALOGY OF MIDDLE- AND OUTER-BELT VESTOIDS. T. H. Burbine[1], P. C. Buchanan[2] and R. P. Binzel[3], [1]Department of Astronomy, Mount Holyoke College, 50 College Street, South Hadley, MA 01075, USA (tburbine@mtholyoke.edu), [2]Kilgore College, 1100 Broadway, Kilgore, TX 75662, USA (pbuchanan@kilgore.edu), [3]Department of Earth, Atmospheric, and Planetary Sciences, Massachusetts Institute of Technology, Cambridge, MA 02139, USA (rpb@mit.edu).

Introduction: Asteroid 4 Vesta is commonly thought to have a basaltic crust due to its spectral similarity in the visible and near-infrared to the HED meteorites (howardites, eucrites, and diogenites) [1,2]. Vesta is located in the inner main-belt with a semi-major axis (a) of 2.36 AU and is one of the few asteroids that can be persuasively linked to a group of meteorites [3].

HEDs are a clan of achondritic meteorites that have continuous variations in mineralogy and chemistry [4]. Eucrites are composed primarily of anorthitic plagioclase and low-Ca pyroxene with augite exsolution lamellae, whereas diogenites are predominately magnesian orthopyroxene. Howardites are polymict breccias containing fragments of both lithologies and are the primary evidence that almost all HEDs are derived from one parent body. Oxygen isotopes [5,6] also are consistent with almost all HEDs originating on the same parent body.

Pyroxenes have distinctive absorption features [7] that are centered near 0.9 and 1.9 µm and are due to the presence of Fe^{2+} in pyroxenes. Reflectance spectra of Vesta, Vestoids [8,9], and HEDs all have these distinctive features, which move to longer wavelengths for increasing contents of Fe^{2+} and/or Ca^{2+} in pyroxenes. It is important to note that although most polymict HED breccias contain a wide variety of pyroxenes, the resulting reflectance spectrum of each of these breccias has a single Band I minimum and a single Band II minimum. Hence, the average pyroxene composition of a breccia controls the positions of these minima.

Vesta is the largest body (~500 km in diameter) in an asteroid family. A large number of these objects in the Vesta family have spectra similar to HEDs and are commonly called Vestoids. Vestoids are also found outside the Vesta family. Almost all of the inner-belt Vestoids are thought to be fragments of Vesta.

Vestoids have also been identified past the 3:1 resonance (~2.5 AU). Asteroids in this resonance have very unstable orbits and it appears very difficult for objects to cross this resonance [10]. For example, the first one identified was outer-belt 1459 Magnya [11], which has a semi-major axis of 3.14 AU. It is dynamically difficult [12] to derive Magnya from Vesta. Magnya has an estimated diameter of ~17 km [13]. Other identified Vestoids include 7472 Kumakiri (a=3.01 AU) [14], 10537 1991 RY16 (a=2.85 AU) [14], 21238 1995 WV7 (a=2.54 AU) [15,16], and 40521 1999 RL5 (a=2.53 AU) [10].

Roig et al. [10] have calculated that some of the middle-belt Vestoids could be fragments of Vesta. The calculated probability is a function of the size of the object since a larger size reduces the efficiency of the Yarkovsky effect. Roig et al. [10] found that there is a low probability (~1%) that 21238 1995 WV7 (~5 km in diameter) is a fragment of Vesta; however, 40521 1999 RL5 (~3 km in diameter) has a much higher probability to be related to Vesta due to its slightly smaller estimated diameter.

In this study, near-infrared spectra of two of these middle- and outer-belt Vestoids, 1459 Magnya and 21238 1995 WV7, are analyzed. Our goal is to determine whether the average pyroxene mineralogies of these objects are consistent with HEDs. Could they be fragments of the HED parent body?

Observations: Both 1459 Magnya and 21238 1995 WV7 were observed using SpeX. SpeX is a medium-resolution near-infrared spectrograph [17], which is used on the NASA Infrared Telescope Facility (IRTF) located on Mauna Kea. A Magnya near-infrared spectrum was previously obtained and analyzed by Hardersen et al. [10]. Appropriate standard stars were used to produce the final spectra.

Results: Spectra of Magnya and 1995 WV7 are plotted in Figure 1. Both objects have the characteristic absorption features of Vestoids. The most notable difference in the two spectra is that the Band II minimum of 1995 WV7 is at a much shorter wavelength than the Band II of Magnya.

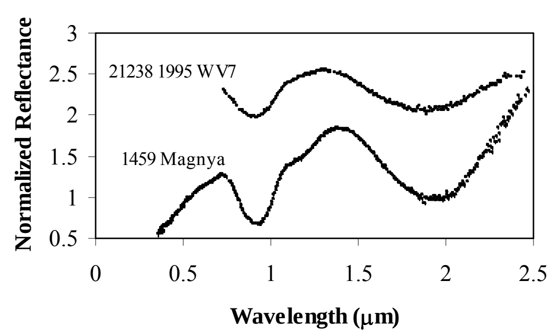

Figure 1. Reflectance spectra of 1459 Magnya and 21238 1995 WV7. The spectra are offset in reflectance.

Analysis: The Band I and Band II of each spectrum were fit to determine band centers. The reddened continua of the Band I and II of the Magnya spectrum and Band I of the 1995 WV7 spectrum were first divided out. As recommended by Storm et al. [18], we then fit a 2nd order polynomial over one-third of each band to determine the band centers. Error bars were only estimated, but will be calculated later using the method of Storm et al. [18].

The Band I center for Magnya is calculated to be 0.93±0.01 μm whereas its Band II center is at 1.96±0.02 μm. Within these estimated error bars, these band centers are the same as those calculated for Magnya by Hardersen et al. [9]. The Band I center for 1995 WV7 is calculated to be 0.93±0.01 μm whereas its Band II center is at 1.89±0.02 μm.

To calculate the pyroxene mineralogies of these objects using the formulas of Gaffey et al. [19] or Burbine et al. [20], the band positions must be corrected for the temperatures on asteroids [21,22]. The surface temperature for Magnya when it was observed is calculated to be ~130 K while 1995 WV7 is slightly warmer (~150 K) if both objects have Magnya's albedo (0.37) [13]. From the work of Moroz et al. [22] on the reflectance spectra of pyroxenes at low temperatures, only the Band II center appears significantly shifted for asteroid temperatures. To correct for the low temperatures, we added 0.02-0.03 μm to the Band II center position of each asteroid. The temperature-adjusted Band II center for Magnya was ~1.98-1.99 (±0.02) μm and the Band II center for 1995 WV7 was 1.91-1.92 (±0.02) μm.

Using the Gaffey et al. [19] formulas on our temperature-corrected band centers, we calculated average pyroxene mineralogies of $Fs_{47\text{-}50\pm5}Wo_{9\pm4}$ for Magnya and $Fs_{29\text{-}31\pm5}Wo_{9\pm4}$ for 1995 WV7. Using updated Burbine et al. [20] formulas, we calculated average pyroxene mineralogies of $Fs_{41\text{-}42\pm3}Wo_{9\pm1}$ for Magnya and $Fs_{33\text{-}34\pm3}Wo_{6\pm1}$ for 1995 WV7 for these band center positions. Our calculated Fs content for Magnya is higher than that calculated by Hardersen et al. [9] due to our Band II center position being at a slightly higher wavelength (but within error bars) and our use of a larger temperature correction. Even with all these uncertainties, Magnya's average pyroxene mineralogy appears more Fe-rich than 1995 WV7's.

Different types of HEDs have distinct ranges of average pyroxene compositions: noncumulate eucrites ($Wo_{9\text{-}15}Fs_{43\text{-}55}$), cumulate eucrites ($Wo_{6\text{-}10}Fs_{30\text{-}44}$), diogenites ($Wo_{1\text{-}3}Fs_{20\text{-}30}$) [4,23,24,25,26]. Howardites, being mixtures of eucrites and diogenites, have a broad range of average pyroxene compositions that extends through much of the eucrite and cumulate eucrite ranges. Comparison of the above calculated compositions indicates that average pyroxene composition of Magnya is consistent with a eucrite. The Gaffey et al. [19] formulas suggest that it may be a noncumulate eucrite, whereas the Burbine et al. [20] formulas suggest it may be a cumulate eucrite.

For 1995 WV7, the Gaffey et al. [19] formulas produce average pyroxene compositions with Wo contents that are higher than diogenite pyroxenes; Fs contents are intermediate between the compositions of diogenite and cumulate eucrite pyroxenes. The Burbine et al. [20] formulas produce average pyroxene compositions for WV7 that are consistent with a cumulate eucrite. It is also possible that both of these asteroids have surfaces composed of polymict breccias similar to howardites. Hence, considering all of the uncertainties, both asteroids have average pyroxene compositions consistent with HEDs. Magnya appears to be evidence that other HED-like bodies formed in the belt, while 1995 WV7 could be a fragment of Vesta.

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