DETERMINING VESTOID PYROXENE MINERALOGIES. T. H. Burbine[1,2], P. C Buchanan[3], M. J. Jercinovic[4], and R. C. Greenwood[5], [1]Department of Astronomy, Mount Holyoke College, 50 College Street, South Hadley, MA 01075, USA (tburbine@mtholyoke.edu), [2]Planetary Science Institute, 1700 East Fort Lowell, Suite 106, Tucson, AZ 85719, USA, [3]Department of Geology, Kilgore College, Kilgore, TX 75662, USA, [4]Department of Geosciences, University of Massachusetts, Amherst, MA 01003, USA, [5]The Open University, Walton Hall, Milton Keynes MK7 6AA, UK.

Introduction: One of the most studied bodies in the Solar System is (4) Vesta. Vesta is one of the largest bodies in the asteroid belt and has long been known to be spectrally similar to the HED (howardite, eucrite, diogenite) meteorites. Vesta was one of the targets of the Dawn mission, which spectrally and chemically mapped its surface. Numerous bodies (Vestoids) in the Vesta family and throughout the inner asteroid belt (< 2.5 au) have reflectance spectra (**Figure 1**) similar to HEDs; together Vesta and the Vestoids have been classified as V-types. The large impact basin located at Vesta's south pole has long been thought to be the source of Vestoids [1]. However, Vestoids have been identified far from Vesta in the middle and outer asteroid belt [2], implying that other basaltic asteroids formed besides Vesta.

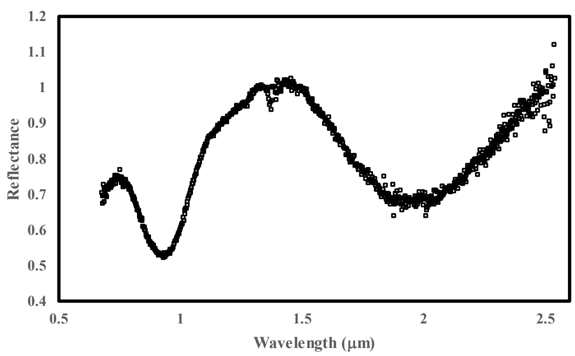

Figure 1. Reflectance spectrum of Vestoid (3715) Štohl from Hardersen et al. [3]. Band I is located at ~0.9 μm and Band II is located at ~1.9 μm.

Burbine et al. [4] developed new formulas for determining Vestoid bulk pyroxene mineralogies from their band center positions. These formulas were used to estimate the bulk pyroxene mineralogies of a number of Vestoid near-Earth asteroids (NEAs). The formulas were derived from HED spectra with well-measured bulk pyroxene compositions. These formulas found a linear relationship between the Band I and Band II centers and the average bulk Fs and Wo contents of the HEDs. Burbine et al. [5] found that HED pyroxene mineralogies could be determined with a ±4 mol% uncertainty for the Fs content and a ±2 mol% uncertainty for the Wo content.

We will determine bulk pyroxene mineralogies of main-belt Vestoid spectra to determine their best meteoritic analogs. We will look at compositional trends among the Vestoids to try to better understand the mineralogy of Vesta.

Data: We have analyzed publicly available main-belt spectra for forty-nine V-type bodies (including Vesta) that had wavelength coverage in the visible and near-infrared. The estimated diameters of the inner-belt Vestoids are ~3-10 km. Some objects had multiple spectra. The near-infrared reflectance spectra were all taken using SpeX at the IRTF. V-type asteroids had visible spectra spliced to their near-infrared spectra when necessary so the reflectance peak located at ~0.7-0.8 μm would be part of each analyzed spectrum.

Analysis: Band centers and one-sigma errors were calculated with the same procedure used in Burbine et al. [4]. To determine peak positions, fourth-order polynomials were first fit over the ~0.7, ~1.5, and ~2.5 μm maxima. Linear continua over Bands I and II were then divided out using the maxima as tangent points. The bottom one-third of Band I was then fit with a fourth-order polynomial and the bottom one-third of Band II was fit with a second-order polynomial. The wavelength positions of the band minima were then determined. All reflectance values for the asteroid spectra were then randomly resampled using a Gaussian distribution based on the one-sigma uncertainty for each reflectance value. Each resampling produces a new spectrum, which is then fit. This resampling was then done 99,999 times for each band. A mean band minimum and a standard deviation for each band center was then determined.

Main-belt asteroids will have surface temperatures much lower than room temperature. Pyroxene band positions are known to move to shorter wavelengths with decreasing temperature. Since the Burbine et al. [4] formulas were derived from room-temperature HED spectra, the typical procedure is to apply a temperature correction to each asteroid band center position. The temperature correction formulas are taken from Reddy et al. [6]. Different temperature corrections are used for eucrite/howardite and diogenite material, respectively.

Asteroids are modeled as grey bodies, which have emissivities that cause them to deviate from being ideal black bodies. The mean effective surface temperature is assumed to be a function of the object's distance from the Sun, its Bond albedo, and its emissivity. The emissivity of each asteroid is assumed to be 0.9. To calculate the asteroid temperatures, we will use Bond albedos of 0.20 for Vesta and 0.15 for other V-type bodies since the phase integrals for most Vestoids are unknown.

A temperature correction is applied to each asteroid band center. The eucrite/howardite temperature correction is applied to all the Vestoid band centers since none of the Vestoids had band centers consistent with just diogenitic material. The temperature corrections are approximately +0.007 µm for Band I and +0.02 µm for Band II.

From our analysis of HED spectra, diogenites tend to dominate predicted pyroxene contents that are less than ~$Fs_{28}Wo_4$. Howardites tend to dominate predicted pyroxene contents from ~$Fs_{33\text{-}41}Wo_{6\text{-}9}$. Noncumulate eucrites tend to dominate predicted pyroxene contents that are greater than ~$Fs_{46}Wo_{11}$. Howardites and diogenites tend to overlap for predicted pyroxene contents of ~$Fs_{28\text{-}33}Wo_{4\text{-}6}$ and eucrites and howardites tend to overlap for predicted pyroxene contents of ~$Fs_{41\text{-}46}Wo_{9\text{-}11}$. There is considerable overlap among the different eucrite subtypes, which does not appear to allow any specific eucritic characterizations to be made.

Results: Band I and Band II centers, respectively, were calculated from seventy-one V-type reflectance spectra taken of forty-nine bodies. Fs and Wo contents were then calculated from the band centers. Sixteen bodies had multiple spectra and their pyroxene mineralogies were calculated by averaging the Fs and Wo contents calculated from their individual spectra.

Figure 2 plots the band centers of the HEDs and V-types. The distribution for the temperature-corrected V-type band centers tends to fall slightly below the HED distribution. This slight offset argues that the temperature corrections might not be large enough. Our relatively simplistic temperature calculation may be overestimating the asteroid surface temperatures. Our calculated Fs and Wo contents would then be lower limits. The two spectra that plot far from the HED distribution are one of the three observations of (2168) Swope (which plots below the HED distribution) and the observation of (10537) 1991 RY_{16} (which plots to the right). Asteroid 1991 RY_{16} is located far from Vesta in the outer main-belt and its spectrum has been interpreted as having an olivine component [7], which would increase its Band I center value. Asteroid 1991 RY_{16} is thought to be a fragment of a parent body in the outer part of the asteroid belt that was partially or fully differentiated.

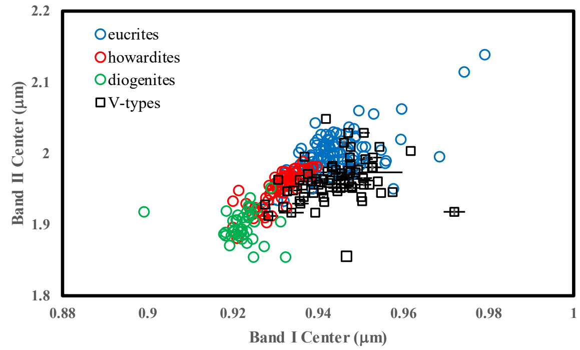

Figure 2. Plot of band centers of HEDs and V-type asteroids. The V-type band center values are corrected for temperature.

Excluding 1991 RY_{16}, we find that 52% of the V-types had Fs and Wo contents consistent with eucrites, 33% with eucrites/howardites, 13% with howardites, and 2% with diogenites/howardites. The scarcity of diogenitic Vestoids indicates that it may be extremely difficult to excavate km-sized diogenitic material from Vesta. Many researchers [3,8,9] have previously noticed the scarcity of diogenitic bodies among main-belt asteroids. Burbine et al. [10] found that diogenitic asteroids were rare among near-Earth objects. Dawn observations also find that diogenitic material is much less abundant on the surface of Vesta than eucritic and howardite material [11].

Conclusions: Formulas for determining Fs and Wo contents from band centers are a valuable tool for determining the mineralogies of Vestoids. Diogenitic Vestoids appear to be very rare in the asteroid belt.

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