PYROXENE MINERALOGIES OF NEAR-EARTH VESTOIDS. T. H. Burbine[1], P. C. Buchanan[2], Tenzin Dolkar[3], and R. P. Binzel[4], [1]Departments of Geology and Physics & Astronomy, Bates College, Lewiston, ME 04240, USA, tburbine@bates.edu, [2]Kilgore College, Kilgore, TX 75662, USA, [3]Mount Holyoke College, South Hadley, MA 01075, USA, [4]Department of Earth, Atmospheric, and Planetary Sciences, Massachusetts Institute of Technology, Cambridge, MA 02139, USA.

Introduction: For any near-Earth asteroid (NEA) on a possible collision course with Earth, a number of factors must be determined to evaluate the object's potential hazard. One of these factors is the object's mineralogy, which can be used to estimate the density and, therefore, the mass of the object. This work discusses how to determine the mineralogies of NEAs that have reflectance spectra similar to howardites, eucrites, and diogenites (HEDs).

Among near-Earth asteroids, we have identified seven HED-like, pyroxene-dominated objects (3908 Nyx, 4055 Magellan, (5604) 1992 FE, (6611) 1993 VW, (52750) 1998 KK17, (88188) 2000 XH44, 2005 WX) using spectra acquired during the MIT-UH-IRTF Joint Campaign for NEO Spectral Reconnaissance. The average pyroxene mineralogies of these seven asteroids are estimated through the application of two techniques that derive pyroxene mineralogies from an object's Band I and II centers. All band centers are corrected for the effects of the low surface temperatures of asteroids. We show in detail the steps needed to calculate the pyroxene mineralogies of asteroids and the uncertainties in the calculations. We hope to identify possible meteoritic analogs for near-Earth V-type asteroids, which we speculatively call "Vestoids" because of their possible relationship to Vesta.

Data: All objects (Figure 1) were observed using SpeX, a medium-resolution near-infrared spectrograph [1] on the NASA Infrared Telescope Facility (IRTF) located on Mauna Kea. Appropriate solar analog standard stars were used to produce the final reflectance spectra, normalized to unity at 0.55 μm. Asteroid (88188) 2000 XH44 was observed on two different dates with the second set of observations having higher signal-to-noise. Only the 2000 XH44 spectrum with the higher signal-to-noise is plotted in Figure 1. Visible data are available for four of the objects.

All objects (Figure 1) have the characteristic pyroxene absorption features typical of HEDs. All objects have strong pyroxene bands centered near ~0.94 μm and ~1.95 μm. The objects with visible spectra all have very strong UV (ultraviolet) features.

Pyroxene Mineralogies: To calculate pyroxene mineralogies, band centers must be determined. Band I centers for the asteroid spectra with visible data were calculated using the method of Storm et al. [2]. Only SpeX data were fit. A linear slope that was derived from a straight line tangent to the two reflectance peaks on each side of Band I was divided out. For asteroids without visible data, no slope was divided out and only the Band I minima were calculated for those objects. No linear slopes were divided out to calculate Band II centers since none of the objects appeared to be significantly sloped over this wavelength region and it is unclear if the bands extend far past 2.5 μm. We believe our calculated Band II minima are equivalent to the Band II centers.

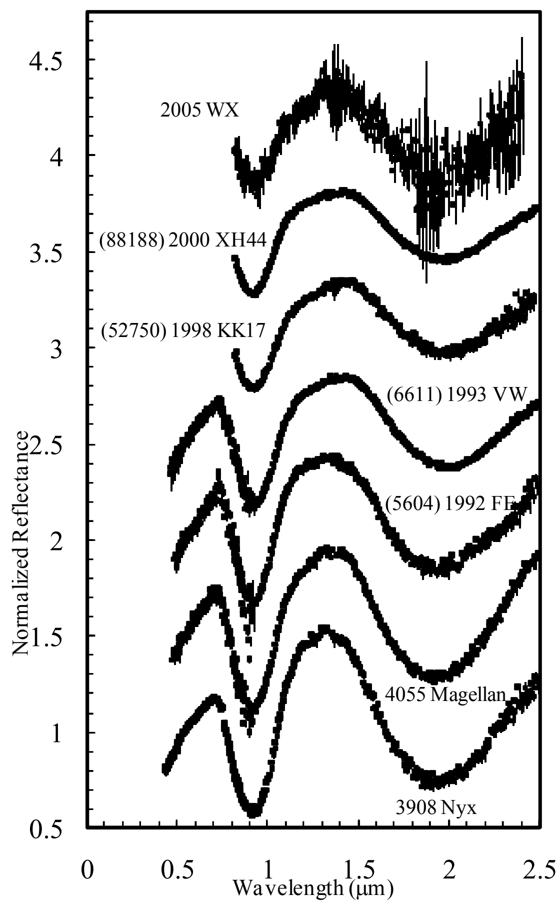

Figure 1. Normalized reflectance spectra of the NEAs. Spectra are offset in reflectance. Error bars are one sigma.

A second-degree polynomial was fit over the bottom third of each band and the band center (or minimum) was determined. Each reflectance value was randomly resampled using a Gaussian distribution for the observational error and then fit using another second-degree polynomial. Each spectrum was resampled ninety-nine times. The derived one-hundred band centers were then averaged to calculate an average band center (or minimum) and a sample standard deviation.

Band centers move to shorter wavelengths as the temperature of the surface decreases [3]. The temperature (T) (Kelvin) of an asteroid can be estimated from the equation

$$T = [(1-A)L_o/16\eta\varepsilon\sigma\pi r^2]^{1/4}$$

where A is the asteroid albedo, L_o is the solar luminosity (3.827×10^{26} W), η is the beaming factor (assumed to be unity), ε is the asteroid's infrared emissivity (assumed to be 0.9), σ is the Stefan-Boltzman constant (5.67×10^{-8} J s^{-1} m^{-2} K^{-4}), and r is the asteroid's distance from the Sun in meters. If the albedo has not been measured for an object, we use the albedo (0.31) of 4055 Magellan, which is intermediate between the albedos of (5604) 1992 FE (0.48) and 3908 Nyx (0.16).

To perform the temperature corrections, we use the results of Moroz et al. [3] who measured the movement of the band centers for two pyroxenes, which they call bronzite and enstatite, at temperatures of 293, 173, and 80 K. The corrections are very small for Band I (typically +0.001 um) and slightly larger for Band II (typically +0.01 um).

To calculate the pyroxene mineralogies of Vestoids, formulas derived by Gaffey et al. [4] from the analysis of a wide variety of pyroxene spectra, primarily terrestrial, at room temperature were used. These formulas calculate the molar contents of ferrosilite (Fs) and wollastonite (Wo), with uncertainties, from band centers determined from their reflectance spectra.

We also use formulas for determining Fs and Wo contents that were derived by Burbine et al. [5] using data from thirteen HEDs with high-quality reflectance spectra measured at room temperature and with calculated average pyroxene compositions. The importance of using independent sets of formulas to derive mineralogies is that we will have more confidence in the results if both sets of formulas derive similar mineralogies.

For objects without visible spectra, it is impossible to know the exact spectral slope since the reflectance peak near 0.7 µm cannot be exactly identified. We use the trend found for the distribution of band centers for HEDs to try to estimate the best correction, which can be as large as +0.01 µm. All of the asteroids fall within the band center ranges for eucrites and howardites. None of the asteroids fall within the range for diogenites.

Results: Mineralogies for these NEAs were derived using the Gaffey et al. [4] formulas and the Burbine et al. [5] formulas. The derived Wo contents using the different formulas are almost exactly the same with differences only as large as 1 mol%. The derived Fs contents using the different formulas have larger differences that range from 3 to 8 mol%. Both the Gaffey et al. [4] formulas and the Burbine et al. [5] formulas give calculated pyroxene mineralogies that are within the other set of formulas' given uncertainties.

All of these observed near-Earth V-type asteroids have pyroxene mineralogies (Fs and Wo contents) consistent with eucrites or howardites. If Vesta is the parent body of most HEDs then these similarities in pyroxene mineralogies between these NEAs and HEDs would support a possible relationship between Vesta and these NEAs, supporting their labeling as "Vestoids". However, we can not rule out that these NEAs did not originate from Vesta.

None of the possible "Vestoids" have both Fs and Wo contents consistent with diogenites. The lack of identified mineralogies similar to diogenites in the near-Earth population suggests that it may be difficult to produce large (km-sized or larger) bodies that only contain diogenitic material If these bodies originated from Vesta, the observational evidence suggests that km-sized material that is excavated from greater depths (e.g., diogenitic material) tends to be successfully liberated only in mixtures with upper layers. Intact large fragments consisting almost solely of material from the deep interior appear to be relatively rare.

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