DETERMINING VESTOID MINERALOGIES USING HEDS AS A GUIDE. 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]Planetary and Space Sciences, The Open University, Walton Hall, Milton Keynes MK7 6AA, UK.

Introduction: Numerous bodies (Vestoids) in the Vesta family and throughout the inner asteroid belt have reflectance spectra similar to HEDs (howardites, eucrites, diogenites). HED and Vestoid spectra are dominated by pyroxene absorption bands. The large impact basin located at Vesta's South Pole (**Figure 1**) is thought to be the source of most Vestoids [1]. Some Vestoids have also been identified far from Vesta in the middle and outer part of the main belt [2].

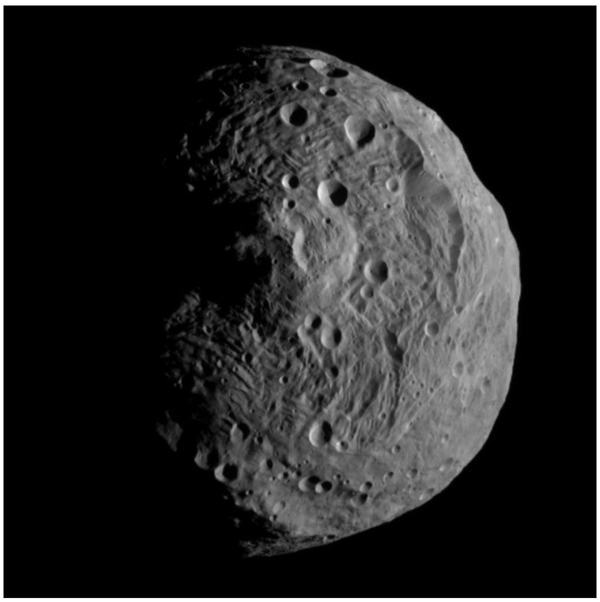

Figure 1. Dawn image of Vesta's South Pole. Image credit: NASA/JPL-Caltech/UCLA/MPS/DLR/IDA.

HEDs formed as a result of igneous processes, with many samples showing evidence of subsequent metamorphism and/or brecciation. Over 2,000 HED specimens have so far been identified and these can be subdivided into a number of subtypes depending on composition and/or texture. Most HEDs appear to have originated on one body, which is generally assumed to be (4) Vesta. However, a few eucrites have oxygen isotopic compositions significantly different from the main HED group [3]. Meteorites classified as HEDs probably originate from a number of different parent bodies [3]. The potential number of distinct parent body sources for HED and HED-like meteorites is estimated to be between 5 and 11 [3].

To determine the surface mineralogy of asteroids from Earth, reflectance spectra must be analyzed. There have been a large number of high-wavelength-resolution near-infrared spectral observations of Vestoids due to the advent of SpeX at the NASA IRTF (Infrared Telescope Facility).

A number of techniques have been used to estimate the mineralogies of Vesta and the Vestoids from their reflectance spectra. One method uses the positions of the centers of the HED absorption bands, which are functions of the composition of the pyroxenes. The pyroxenes in eucrites tend to be more Fe- and Ca-rich than those in diogenites, which results in the Band I and Band II centers being at longer wavelengths for eucritic spectra compared to diogenitic spectra.

Burbine et al. [4] derived four formulas for determining the bulk pyroxene compositions of HEDs. Two of the formulas use the Band I center to predict the Fs (ferrosilite) and Wo (wollastonite) contents, respectively, and two of the formulas use the Band II center to predict the Fs and Wo contents, respectively.

We will test the Burbine et al. [4] formulas to see how well these equations determine the bulk pyroxene mineralogies of HEDs. Our aim is to derive better uncertainties for the calculated pyroxene compositions and to assess how well we can link Vestoids back to Vesta.

New Analyses: To explicitly test how well these formulas determine bulk pyroxene mineralogies of HEDs and gain insight on analyzing the HED spectra, we first requested from the Meteorite Working Group three small (~50 mg) chips for spectral measurements and thin sections for electron microprobe (EPMA) analysis. The meteorites were polymict eucrite ALHA76005, howardite GRO 95574, and diogenite LAP 03630. These meteorites all have a weathering grade of A. Each chip was powdered to a grain size fraction of 25-125 µm. The powdered samples had their spectral reflectances measured at the Keck/NASA Reflectance Experiment Laboratory (RELAB). We note that the LAP 03630 spectrum, which had its reflectance measured from a relatively small sample, had a number of slight absorption features in the visible and at ~2.3 µm. These features may be due to terrestrial weathering and/or contamination from the plastic vial.

However, these features do not appear to affect the calculated band center positions.

Element mapping and quantitative analysis were done using the Cameca SXfive-Tactis electron probe micro-analyzer at the University of Massachusetts-Amherst with Cameca's Peaksight 6.4 control and automation software. The measured bulk pyroxene compositions are consistent with previous analyses.

Since only three HEDs were microprobed, no relevant statistics could be calculated. However, even with a controlled study, the predicted bulk pyroxene compositions for the HEDs sometimes significantly vary from the measured bulk pyroxene compositions with differences larger than the uncertainties given in Burbine et al. [4]. One possible explanation for these discrepancies is the heterogeneous nature of many eucrites and howardites. An approximately 10-100 mg sample used for a reflectance measurement may have a slight to significantly different bulk composition than a thin section of the same meteorite.

Testing of Formulas: To test how well the formulas work, we downloaded over 200 HED spectra from the RELAB database. Some meteorites had multiple spectra. We calculated band centers from the spectra, used the formulas to determine their Fs and Wo contents, and then determined their predicted bulk pyroxene compositions. For spectra without uncertainties, we assumed that all the reflectance uncertainties are 0.005. We removed any spectra from the dataset that had anomalous band centers compared to most HEDs. We ended up with 217 spectra in our study.

To test the Burbine et al. [4] formulas, we estimated average pyroxene compositions for as many HEDs with spectra as possible. The HEDs either had a published bulk pyroxene composition or enough analyses that we could calculate a meaningful bulk average.

We found 99 of the 217 HED reflectance spectra had corresponding bulk pyroxene compositions. We compared the bulk pyroxene compositions calculated using the formulas with the estimated bulk pyroxene composition of each HED. A small number of the calculated bulk pyroxene compositions from the formulas were physically impossible because they either resulted in negative Wo contents or total Fs and Wo contents greater than a 100.

We found that the best estimates of the Fs and Wo contents were calculated by averaging the Fs and Wo values, respectively, calculated from the Band I and the Band II formulas. The average absolute value of the differences between average Fs and Wo values estimated from the meteorite spectra and those actually measured were ±3.7 mol% for the Fs content and ±2.1 mol% for the Wo content. Rounding these numbers results in a ±4 mol% uncertainty for the Fs content and a ±2 mol% uncertainty for the Wo content.

Of the 217 total HED spectra, 33% were howardites, 48% were eucrites, and 19% were diogenites. Of the eucrites, 14% were classified as brecciated, 4% as cumulate, 4% as Mg-rich, 19% as monomict,, 42% as polymict, 13% as unbrecciated, and 4% just as eucrites with no subtype.

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

From our analysis of HED spectra, we found that the meteorite data supports classifying Vestoids using band centers as either a eucrite, a eucrite/howardite, a howardite, a howardite/diogenite, or a diogenite on the basis of predicted pyroxene compositions.

Conclusions: Using a vast array of meteorite spectra with known bulk pyroxene mineralogies, we have tested the Burbine et al. [4] formulas to see how well they could work on Vestoid spectra. For HEDs, we found that we can estimate the Fs content to an uncertainty of ±4 mol% and the Wo content to an uncertainty of ±2 mol%. These uncertainties in the bulk pyroxene mineralogies will be a lower limit for Vestoids due to the lower temperatures on the asteroid surfaces and possible processes such as space weathering. These equations coupled with other types of modeling (e.g., radiative transfer, Modified Gaussian) may be the best way for determining Vestoid mineralogies.

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