CAN FORMULAS DERIVED FROM PYROXENE AND/OR HED REFLECTANCE SPECTRA BE USED TO DETERMINE THE MINERALOGIES OF V-TYPE NEAS? T. H. Burbine[1], P. C. Buchanan[2], R. L. Klima[3], and R. P. Binzel[4], [1]Department of Astronomy, Mount Holyoke College, South Hadley, MA 01075, USA (tburbine@mtholyoke.edu), [2]Department of Geology, Kilgore College, Kilgore, TX 75662, USA, [3]Johns Hopkins University Applied Physics Laboratory, Laurel, MD 20723, USA, [4]Department of Earth, Atmospheric, and Planetary Sciences, Massachusetts Institute of Technology, Cambridge, MA 02139, USA.

Introduction: The band centers for pyroxenes are known to be a function of their mineralogies. To derive equations for determining pyroxene compositions, reflectance spectra need to be obtained for compositionally well-characterized pyroxenes. Gaffey et al. [1] derived a series of equations using spectral data for pyroxenes with known mineralogies. Burbine et al. [2] used the spectra of thirteen HEDs (howardites, eucrites, diogenites) with measured bulk pyroxene compositions to derive formulas for determining the mineralogies of V-type (HED-like) asteroids.

Recently, Klima [3] and Klima et al. [4,5,6] did a spectral and mineralogical study of synthetically-produced pyroxenes. This study will test whether pyroxene and/or HED reflectance spectra of well-characterized samples can be used to determine the mineralogies of V-type near-Earth asteroids.

Data: The pyroxenes used in this study were synthesized by Donald Lindsley and coworkers. The powders were crushed manually and sieved to less than 45 μm and also greater than 45 μm grain size fractions for further analysis. The less than 45 μm size fraction was used for visible/near-infrared and Mössbauer spectroscopy. The visible/near-infrared spectra were taken at the KECK/NASA Reflectance Experiment Laboratory (RELAB) at Brown University. The greater than 45 μm size fraction was used to prepare grain mounts for electron microprobe analysis.

The Band I and II centers and uncertainties for the pyroxene spectra were calculated using a specially written MATLAB™ program. The only spectra that were used in this analysis were those that had calculated Band I and Band II centers that fell on a relatively straight line in a plot of Band I versus Band II center and also were electron microprobed. To try to determine if these pyroxene spectra can be used to determine the mineralogies of asteroids, the calculated pyroxene band centers and their mineralogies will be compared to the band centers and bulk pyroxene mineralogies of the HEDs studied by Burbine et al. [2].

Analysis: We plotted the band centers for the pyroxenes and HEDs versus their Fs and Wo contents. As can be seen in a plot of Band I center versus Fs content (**Figure 1**), the HEDs do not overlap well the $Wo_{>0}$ pyroxenes even though the HED pyroxenes have bulk $Wo_{2\text{-}14}$ contents.. The HEDs tend to fall above the $Wo_{>0}$ pyroxenes. Other plots of band centers versus Fs and Wo contents, respectively, show similar trends.

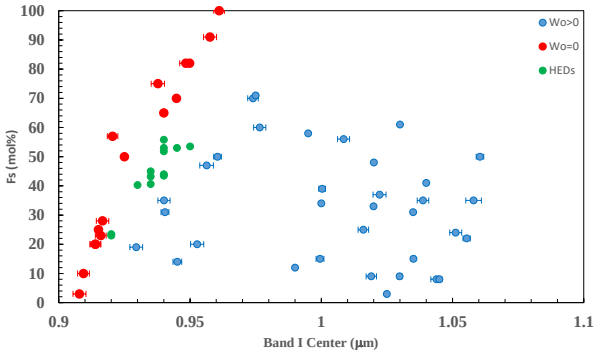

Figure 1. Plot of Band I center versus Fs content (mol%) for synthetic pyroxenes and HEDs.

The reason that any fit through $Wo_{>0}$ pyroxene data does not appear able to reliably predict the mineralogies of HED meteorites is that HEDs contain a wide variety of pyroxenes that have differing optical constants. Therefore, the spectral properties of one pyroxene with a particular mineralogy may not be equivalent to the spectral properties of a material containing a variety of pyroxenes with the same average bulk mineralogy as that one pyroxene. We argue that formulas for deriving mineralogies should be derived from meteoritic spectra with measured bulk compositions since this material will best reflect asteroidal compositions.

Four linear formulas have been derived to determine the bulk pyroxene mineralogies (Fs and Wo molar contents) of the HEDs. The formulas are

Fs (mol%)(±4) = 1119.4*Band I Center (μm) - 1004.1,
Wo (mol%)(±1) = 436.31*Band I Center (μm) - 398.33,
Fs (mol%)(±3) = 223.15*Band II Center (μm) -398.91,
and
Wo (mol%)(±1) = 85.342*Band II Center (μm) – 159.21.

These newly derived formulas are different than the previously derived formulas of Burbine et al. [2] even though the same HED reflectance spectra are used. This is due to using different fitting techniques for the band centers, which results in slightly different values.

The advantage of using the Band I formulas is that the Band I band center is the least affected by asteroi-

dal temperatures with estimated temperature corrections of ~+0.001 μm [2]. Almost all meteorite spectra are only measured at room temperature. Therefore, the band centers that are significantly affected by temperature must be shifted to where the center would be at room temperature. The Band II center is affected to a larger extent at asteroidal temperatures with estimated temperature corrections of +0.01 to +0.02 μm [2].

Pyroxene mineralogies were determined for twelve V-type NEAs that were observed as part of the MIT-UH-IRTF Joint Campaign for NEO Spectral Reconnaissance. Band centers and errors were calculated. The average bulk pyroxene mineralogies for the V-types derived from the Band I center are given in **Table 1**. If you take the derived mineralogies at face value, Akhenaten has a composition similar to diogenites due to its magnesian, low bulk Wo content similar to Johnstown or Tatahouine. Midas, 1996 EN, and 2000 SP_{43} are all relatively Fe-rich and seem to be most similar to Bouvante or PCA 82502. The other V-type NEAs seem to be most similar to polymict breccias (polymict eucrites or howardites). We note that discriminating between the howardites and polymict eucrites is a bit more difficult because there is a good bit of overlap in composition. However, Nyx, Magellan, 1992 FE, and 2000 XH_{44} are more like howardites because they are lower in Fs and Wo, which would indicate more of a low-Ca, magnesian diogenitic component. An analogous meteorite would be EET 87503. NEAs 1993 VW, 1994 LX, 2003 YG_{118}, and 2001 YE_4 are richer in Fe and Wo, which suggests that they might be more like polymict eucrites with less of a low-Ca, magnesian diogenitic component. Analogous meteorites would be EETA79005 or LEW 87004.

Table 1. Interpreted V-type asteroid mineralogies. Optimistic and pessimistic interpretations are given.

	Optimistic		**Pessimistic**
Asteroid Name	Fs	Wo	
(1981) Midas	55	14	eucrite
(3908) Nyx	42	9	polymict eucrite/howardite
(4055) Magellan	37	7	polymict eucrite/howardite
(5604) 1992 FE	37	7	polymict eucrite/howardite
(6611) 1993 VW	43	10	polymict eucrite/howardite
(7889) 1994 LX	43	10	polymict eucrite/howardite
(8566) 1996 EN	55	15	eucrite
(88188) 2000 XH_{44}	37	7	polymict eucrite/howardite
(253841) 2003 YG_{118}	45	11	polymict eucrite/howardite
(297418) 2000 SP_{43}	53	14	eucrite
(326290) Akhenaten	22	2	howardite/diogenite
(480883) 2001 YE_4	44	10	polymict eucrite/howardite

A more pessimistic (and probably more realistic) interpretation (**Table 1**) would be that Akhenaten has a howardite or diogenite surface composition. Midas, 1996 EN, and 2000 SP_{43} are most similar to some type of eucrite. Nyx, Magellan, 1992 FE, 1993 VW, 1994 LX, 2000 XH_{44}, 2003 YG_{118}, and 2001 YE_4 are either polymict eucrites or howardites. Without any ground truth ((a sample from a characterized body), these general meteoritic interpretations are the most defendable using the derived formulas. However, if the same specific meteoritic interpretation was concluded using a second technique, more specific interpretations would be much more easily justified. For example, Batista et al. [7] found that the best spectral matches for Nyx, Magellan, 1992 FE, and 1993 WW were howardites.

Conclusions: We have tested whether the reflectance spectra of synthetic pyroxenes and/or HEDs with known compositions can be used to determine the pyroxene mineralogies of V-type NEAs. Our conclusions:

1) Band centers from the reflectance spectra of synthetic pyroxenes with known compositions cannot be used to derive equations for determining accurate pyroxene compositions of V-type asteroids.

2) Band centers from the reflectance spectra of HEDs with known bulk pyroxene compositions can potentially be used to derive equations for deriving the pyroxene compositions of V-type asteroids.

3) Formulas for determining mineralogies should be derived again if the fitting technique used to determine band centers is different at all in the new study. Each different fitting technique most likely will calculate slightly different band centers.

4) Formulas using the Band I center appear best for determining asteroid pyroxene compositions for V-type asteroids due to the current difficulty in doing accurate temperature corrections to the Band II center.

5) Specific meteoritic interpretations are difficult to justify without the use of a second technique to validate the interpreted mineralogies of the asteroids.

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