DOES SPECTROSCOPY PROVIDE EVIDENCE FOR WIDESPREAD PARTIAL MELTING OF ASTEROIDS?: II. PYROXENE COMPOSITIONS. T.J. McCoy[1], C.M. Corrigan[2], J.M. Sunshine[3], S.J. Bus[4] and A. Gale[1] [1]Dept. of Mineral Sciences, National Museum of Natural History, Smithsonian Institution, Washington, DC 20560-0119 USA (mccoyt@si.edu), [2] Johns Hopkins University Applied Physics Laboratory, Laurel MD 20723, USA [3]Department of Astronomy, University of Maryland, College Park, MD, 20742, [4]Institute for Astronomy, University of Hawaii, Hilo, HI, 96720.

Introduction: The advent of high-qualtiy spectral data from instruments like SpeX at the NASA Infrared Telescope Facility (IRTF) [1], coupled with the return of geologic, geochemical and spectroscopic data from missions to asteroids 433 Eros [2] and 25143 Itokawa [3,4], allow us to move beyond classification to explore the geologic histories of asteroids. Not surprisingly, the richness of data for Eros and Itokawa have produced divergent intepretations of their origins. In particular, debate has centered on whether these two asteroids are composed of material mineralogically and chemically similar to ordinary chondrites but altered at the surface by interaction with the space environment or whether these two asteroids have experienced limited partial melting [5].

Partial melting of metal-bearing ordinary chondrites produces predictable geochemical and mineralogical trends as Fe,Ni-FeS and FeO-rich, plagioclase-pyroxene-rich basaltic melts are segregated from an olivine-rich, pyroxene-bearing residue [6]. Those advocating for a surface-altered chondritic composition point to chondritic ol/px ratios [7] and chondritic ratios of, e.g., Fe/Si, Al/Si, Mg/Si, and Cr/Fe [8-9] as evidence supporting this hypothesis, while acknowledging that the fractionated S/Si ratio must result from volatilization of S found in sulfides [8]. Advocates for partial melting point to the fractionated S/Si ratio as evidence of Fe,Ni-FeS melt mobility and reflectance spectra with 2 micron band centers interpreted as pointing to a high-FeO pyroxene, partial melt component [10-12]. The spectroscopically-inferred data (ol/px; pyroxene composition) can be applied to a wide variety of asteroids and has been used to imply widespread partial melting among asteroids [e.g., 10-12].

In this abstract, we examine the robustness of the spectrally-derived pyroxene compositions as a measure of partial melting.

Methodology: We have examined spectral parameters (band area ratio, band II center) from spectra of 433 Eros (our data) and 25143 Itokawa [13] collected using the SpeX instrument at the IRTF, as well as spectral parameters and known compositions of L and LL chondrites and synthetic mixtures of two pyroxenes (high- and low-Ca) ± olivine and plagioclase collected at Brown University's RELAB facility.

Results: A method for determining the average Fs and Wo composition of pyroxenes was proposed by [14] based on data of [15]. Figure 1 presents the data of [15], in which measured band II centers were plotted against measured Fs concentration. [15] applied four bins to their data based on the Wo concentration (<11, 11-30, 30-45, >45). [14] applied linear fits to these data, producing four lines that would yield the average Fs concentration, given an independent determination of Wo concentration based on the band I center corrected for the presence of olivine. This methodology has been widely applied to asteroid spectra [e.g., 11], typically yielding an average of $Fs_{\sim 40-45}$. We derived average pyroxene Fs compositions of Fs_{40} for Eros and Fs_{43} for Itokawa from our determination of band II centers from SpeX data using the calibration of [14]. This FeO-enriched pyroxene composition is comparable to eucrites and could be taken as an indicator of partial melting. It is important to note that band area ratios for these same asteroids typically point to olivine/(olivine+pyroxene) ratios (0.7-0.8) similar to those derived for ordinary chondrites.

To test the robustness of this method, we first examined pure low-Ca (hypersthene from Johnstown diogenite) and high-Ca (Kakanui augite) pyroxene and mixtures of 85:15 and 50:50 low-Ca:high-Ca pyroxene. The calibrations of [14] are reasonably successful at determining the average Fs of the low-Ca pyroxene and the 85:15 mixture, although it overestimates the average Fs of the high-Ca pyroxene (Fs_{17} calculated vs. Fs_{11} measured) and the 50:50 mixture (Fs_{31} calculated vs. Fs_{17} actual), calling into question the validity of the technique

More relevant to ordinary chondrite-like mineralogies are mixtures of 60-80% olivine, 5-20% plagioclase and 5-20% pyroxene, where the pyroxene was a mixture of 85:15 low-Ca:high-Ca pyroxene. Determined band II centers (1.92-1.94 μm, increasing with increasing olivine concentration) yielded calculated average Fs_{30-37}, while the actual pyroxene composition is Fs_{22}. It is interesting to note that the band II center shifts to longer wavelengths not as a function of pyroxene composition, but solely due to the addition of olivine, probably resulting from a change in the lower inflection point for the 2 μm band. An overestimation of the pyroxene average Fs is also observed for L and LL ordinary chondrites, where derived band II centers (1.94-1.99 μm) imply pyroxene compositions of Fs_{36-}

$_{41}$, markedly greater than actually measured in these meteorites (Fs$_{\sim 20-22}$).

Discussion: In light of these observations, we suggest that the calibrations of [14] overestimate the average Fs composition of pyroxenes for asteroids. In fact, the overestimation (8-20 mol% Fs) masks our ability to distinguish chondritic pyroxene compositions from those of a partial melt. We suggest that band II center position reflects a mixture of high- and low-Ca pyroxene and that pyroxene compositions of Fs$_{\sim 20-22}$ are more appropriate for Eros and Itokawa. Indeed, such compositions are derived if the calibration suggested by [14] for compositions of Wo$_{30-45}$ are extrapolated to lower Wo values. This fit (indicated in green below) essentially serves as a mixing line between low-Ca and high-Ca pyroxene and yields surprisingly good fits to both our mineral mixtures and ordinary chondrites. A similar mixing approach was applied initially to data for 433 Eros by [7]. We suggest that in cases where the ol/px ratio is consistent with a chondritic mineralogy, the use of this mixing trend is more appropriate. A consequence of this result is that it removes one of the prime lines of evidence supporting partial melting among asteroids and yields a pyroxene composition entirely consistent with an ordinary chondrite composition, consistent with both mineralogical (e.g., ol/px) and geochemical data (where it exists). Finally, we note that realistic errors on these determinations remain on the order of ±5% in Fs, as suggested by [14]. Further, any derived mixing line would yield a steep slope and have limited fidelity in determining Fs composition even over a wide range in band II center. Given the limited range of Fs compositions within ordinary chondrites (Fs$_{15-25}$), it is unrealistic to think that we can use the derived compositions to distinguish among H, L and LL ordinary chondrites.

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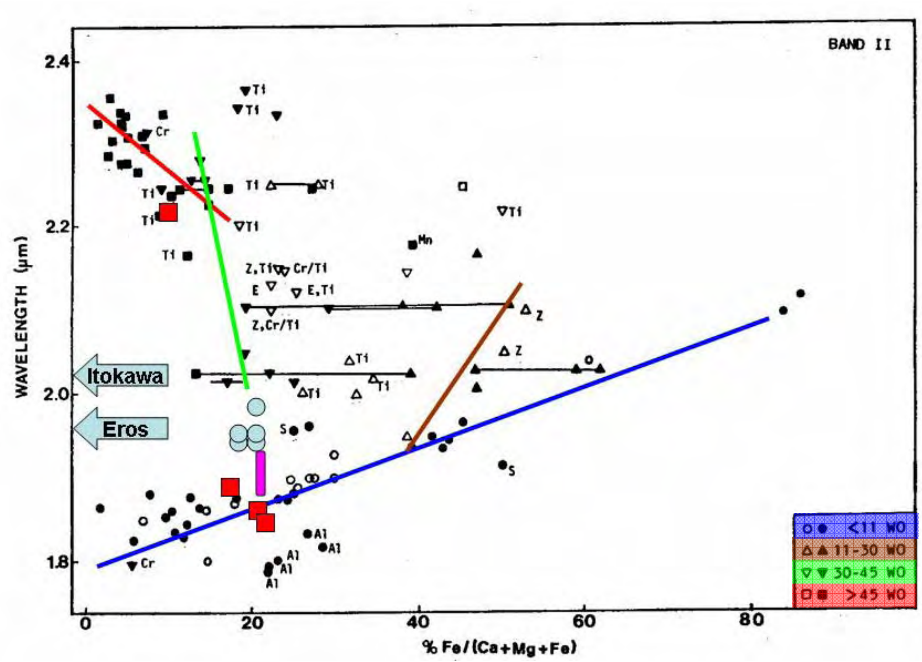

Figure 1. Plot of Fs composition (% Fe/(Ca+Mg+Fe) vs. 2 μm band (band II) center after [15]. Background points are for spectrally and compositionally characterized pyroxenes. Colored lines are calibrations from [14] and are applicable to a restricted range of pyroxene Wo compositions (%Ca/(Ca+Mg+Fe)) with colors matching those in the key. Red squares are high- and low-Ca pyroxenes and mixtures of the two. Pink rectangle are values for ol-plag-pyroxene mixtures with an 85:15 mixture of pyroxene. Blue-gray circles are values for L and LL chondrites. Arrows indicate measured band II centers for SpeX spectra of asteroids Eros and Itokawa.