

DOES SPECTROSCOPY PROVIDE EVIDENCE FOR WIDESPREAD PARTIAL MELTING OF ASTEROIDS? I. MAFIC MINERAL ABUNDANCES. C. M. Corrigan¹, T. J. McCoy², J.M. Sunshine³, S.J. Bus⁴ and A. Gale² ¹Johns Hopkins University Applied Physics Laboratory, 11100 Johns Hopkins Road, Laurel MD 20723, USA, (cari.corrigan@jhuapl.edu); ²Dept. of Mineral Sciences, National Museum of Natural History, Smithsonian Institution, Washington, DC 20560; ³Department of Astronomy, University of Maryland, College Park, MD, 20742; ⁴Institute for Astronomy, University of Hawaii, Hilo, HI, 96720.

Introduction: In contrast to the detailed chemical, petrologic and isotopic studies that are conducted on meteorite samples to decipher the origins of their asteroidal parent bodies, our ability to remotely analyze asteroids is considerably more limited. From a compositional perspective, our major tool has been and will remain reflectance spectroscopy. Diagnostic absorption features near 1 and 2 μm can be used to infer the relative abundances and compositions of transition metal-bearing silicates, notably olivine and pyroxene. These studies have been applied to hundreds of asteroids to date and been used to infer the origin and evolution of specific parent bodies, largely by comparison to an extensive database of spectral reflectance of meteorites [1,2]. A significant hindrance to linking meteorite and asteroid data is the scale of observation, which can reach nm-scale in meteorites and is hemispherical in asteroids. Small-scale variations in surface mineralogy are often diluted in hemispherically averaged spectra, making it almost impossible to decipher whether regional processes may have taken place, as well as making the linkage between meteorite types and asteroids more difficult.

Asteroid 433 Eros was visited by the NEAR-Shoemaker spacecraft more than five years ago. Controversy still exists as to whether or not 433 Eros exhibits signs of partial melting [3,4], and [4] concluded that in order to improve laboratory calibrations, additional synthetic mineral spectra need to be obtained. A serious problem in deciphering the composition and mineral abundances for a complex body like 433 Eros is the fact that it itself is a complex, polymineralic mixture. Both ordinary chondrites and primitive achondrites (those that formed by partial melting) typically contain olivine, low-Ca pyroxene (LCP), high-Ca pyroxene (HCP), plagioclase (plag), Fe,Ni metal, troilite, phosphates, and chromite. Among these, the first four all exhibit diagnostic absorption features and complex, realistic mixtures of these minerals pose a significant challenge to our data interpretation techniques. A variety of methods have been used to overcome these difficulties.

To circumvent these problems and the effects of space weathering, which increases the spectral slope and reduces the strength of absorptions [5], asteroid spectroscopists have widely applied techniques utiliz-

ing band area parameters. These techniques have been applied to a range of asteroids to infer their mineralogy and mineral compositions [6,7]. To fully exploit this technique requires not just precise derivation of band centers and band area ratios (a subject of some dispute among asteroid spectroscopists in its own right), but calibrations of the influence of mineral abundances and mineral compositions in complex, polymineralic mixtures. These calibrations that are lacking in the community, though many workers [1,2,6-12] have made significant strides toward remedying this situation.

Methods: Toward the goal of creating a better understanding of the link between meteorite/mineral spectra and asteroidal spectra, we [13] have created mixtures of varying proportions (designed to mimic ordinary chondrites) of olivine, low-Ca pyroxene, and plagioclase, specifically San Carlos olivine, Kakanui augite, hypersthene from the Johnstown diogenite and Lake County plagioclase. These minerals are exceptionally well characterized [14] and have been distributed as microprobe standards by the Smithsonian Institution. Spectra of 40 mineral mixtures were obtained at Brown University's RELAB using the bidirectional spectrometer ($<45 \mu\text{m}$ grain size, 5 nm resolution, $e=30^\circ$, $i=0^\circ$). We began with olivine-low-Ca pyroxene mixtures, similar to those of [6]. Although an unrealistically simple case, these mixtures are required for direct comparison of derived spectral features to those of earlier workers. More realistic mixtures of olivine plus an 85:15 mixture of low-Ca pyroxene:high-Ca pyroxene (similar to that observed in ordinary chondrites) with and without plagioclase (in the range of abundances 5-20%; again similar to that observed in ordinary chondrites) were produced. Each mixture is designed to introduce slightly greater mineralogical complexity and, by extension, difficulty in deconvolution. These new powder mixtures will expand the library of spectra that can be applied by the scientific community to investigations involving asteroid/meteorite links.

Discussion: Initial attempts to compare spectra from these powders to previous studies led us to plot actual olivine/olivine+pyroxene ratios vs. those derived using the BAR method of [6](Fig.1). The diagonal 1:1 line, which would indicate a perfect determina-

tion of olivine content, provides a relatively good fit for ol-lcp mixtures. It is possible that another, shallower line could be derived to provide slightly better fit, especially in the high-olivine region of interest, though, as the Ol-LCP points actually seem to define a curve, no variations that we attempted were much of an improvement overall. The current line provides a decent fit, certainly within a $\pm 5\%$ margin of error. The addition of HCP into the mineral mixtures, however, decreased the goodness of the fit, especially the 50:50 LCP:HCP mixture, and at low olivine contents.

Figure 2 shows these same mixtures plotted onto Fig. 1F of [7]. The solid black line in this figure represents Ol-LCP mixtures. Note that the low-olivine (20%) points are on the highest BAR end of the plot. As expected from Figure 1, our Ol-LCP powder mixtures fit this line well. Adding HCP drives compositional points toward lower BAR and higher Band I center wavelengths. Adding plagioclase appears to have the same effect.

Ordinary chondrite (OC) compositions plot within the blue parallelogram on Fig.1 ($\pm 5\%$) and within the boot-shaped region of Fig. 2. Within the OC region of Fig. 1, there are two points (at $\sim 60\%$ ol) – one Ol-50:50 LCP:HCP mixture and one Ol-85:15 LCP:HCP. In Fig. 2, however, at least four mixtures plot within the OC region. This would suggest that using the method of [7] would conclude that significantly more unknown compositions were ordinary chondrites than that of [6], and that the method may need to be reviewed, particularly for composition with high proportions of HCP to LCP.

In that light, what is “close enough” in identifying the type of a planetary body? It is arguable that determining compositions within 5% is acceptable when just labeling a body as an ordinary chondrite, though it is fairly clear that these methods will not allow us to determine the ordinary chondrite type for a body (H,L or LL). As to whether or not mineral abundances can be determined well enough outside of the margin of error to say, for example, that something is *not* an OC, the composition of the unknown needs to be significantly different than that of an OC. When adding HCP, for example, it is obvious that a significant proportion needs to be added to a mixture before it can definitively be distinguished from other mixtures. That said, it is clear that in the presence of olivine, using HCP for tracking geologic processes (i.e. partial melting) provides a significant challenge.

Part of the issue with these types of methods, is, undoubtedly, that we are trying to solve multi-component problems in 1 or 2-dimensional space. It remains that a more multi-dimensional method of de-

termining the identity of unknown bodies based on compositional information needs to be developed.

References: [1] Gaffey et al., (2002) *Asteroids III*, 183. [2] Burbine et al. (2002) *Asteroids III*, 653. [3] Foley et al. (2005) *LPS XXXVI* #2017. [4] McFadden et al. (2005) *LPS XXXVI* #1561. [5] Clark et al. (2002) *Asteroids III*, 653. [6] Cloutis et al. (1986) *JGR* 91, 11,641. [7] Gaffey et al. (1993) *Icarus* 106, 573. [8] Adams (1974) *JGR* 79, 4829. [9] Cloutis & Gaffey (1991) *JGR* 96, 22,809. [10] McFadden et al. (2001) *MAPS* 36, 1711. [11] McFadden & Gaffey (1978) *Met.* 13, 556. [12] Singer et al. (1981) *JGR* 86, 7967. [13] McCoy et al., this vol. [14] Jarosewich et al. (1980) *Geost. News.* 4, 43.

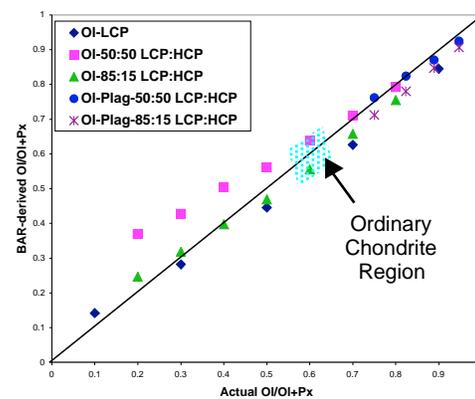


Figure 1. BAR-derived olivine/olivine+pyroxene vs. Actual olivine/olivine+pyroxene of various powder mixtures. Blue region denotes that of ordinary chondrite composition.

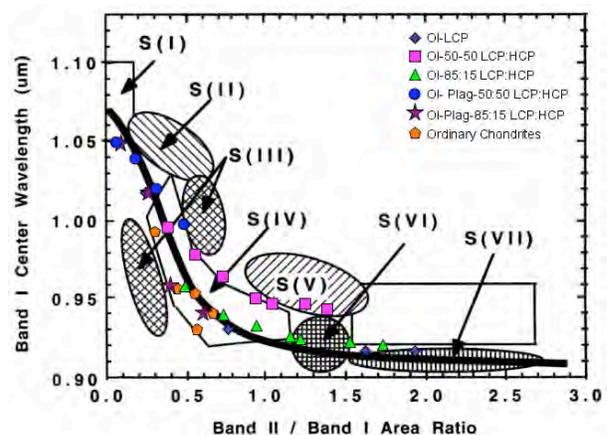


Figure 2. Band I Center wavelength vs. Band II/Band I Area Ratios of mineral mixtures plotted onto Figure 1F of [7].