REFLECTANCE AND MÖSSBAUER SPECTROSCOPY OF SYNTHETIC PYROXENES: II. CHARACTERIZING THE COOLING HISTORIES OF HEDS USING REFLECTANCE SPECTROSCOPY.

R.L. Klima[1], C.M. Pieters[1] and M.D. Dyar[2], [1]Department of Geological Sciences, Brown University, Providence RI 02912 Rachel_Klima@Brown.edu; [2]Department of Astronomy, Mount Holyoke College, South Hadley, MA 01075.

Introduction: The relative strength of the 1.2 µm band in synthetic and natural pyroxene NIR spectra has been shown to be directly related to the amount of Fe^{2+} in the M1 sites measured by Mössbauer spectroscopy [1,2]. The M1 intensity ratio, defined as the strength of the 1.2 µm band relative to the combined strengths of the 1.2 and 2 µm bands, has been derived for the spectra of 51 howardite, eucrite and diogenite (HED) meteorites in order to evaluate how well the M1 intensity ratio can be used to differentiate between slowly and rapidly cooled natural pyroxene-bearing rocks. Diogenites and cumulate eucrites exhibit the lowest M1 intensity ratios, consistent with their formation as slowly-cooled cumulates. Basaltic eucrites exhibit a large range of M1 intensity ratios, all of which are consistently higher than those of the diogenites and cumulate eucrites [2]. In this work, we integrate Mössbauer measurements of select HED meteorites with reflectance data for those samples to validate the inferred cooling histories. We also analyze the HED Mössbauer data in the context of an extensive suite of synthetic pyroxenes that have been measured at a series of temperatures to allow determination of the recoil-free fraction and true site occupancy, as explained in greater detail in our companion paper [3].

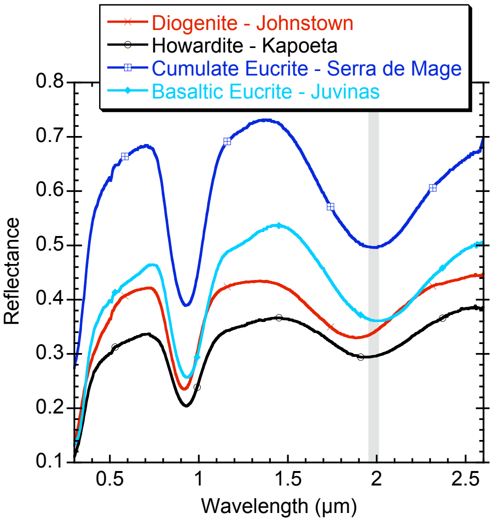

Fig. 1. Comparison of typical HED meteorite spectra.

Background: The HED meteorites, thought to originate on the asteroid 4 Vesta, can be broadly subdivided into basaltic and cumulate rocks. Diogenites are cumulates, consisting primarily of orthopyroxene with some finely exsolved augite (~10's of nm wide lamellae) [e.g. 4]. Eucrites contain plagioclase and low-Ca pyroxene, and may be either cumulate or basaltic [e.g. 4]. Howardites are physical mixtures of these lithologies. In general, HEDs are spectrally dominated by pyroxene, as are the asteroid 4 Vesta and other 'V' type asteroids.

Several examples of HED spectra are presented in Fig. 1. Diogenites and basaltic eucrites can be distinguished spectrally from one another on the basis of the position of the 2 µm band, which moves to longer wavelengths with the addition of Ca and Fe^{2+} (both of which are higher in eucrites than in diogenites). However, for HEDs of similar bulk composition but different cooling history, such as the more Mg-rich basaltic eucrites and more Fe-rich cumulate eucrites, the 2 µm band is insufficient to distinguish between the spectra, as illustrated in Fig. 2. The relative strengths of the 1.2 µm and 2 µm bands also vary among the HEDs. Diogenites exhibit the weakest 1.2 µm bands relative to the 2 µm bands, while eucrites generally exhibit stronger 1.2 µm bands.

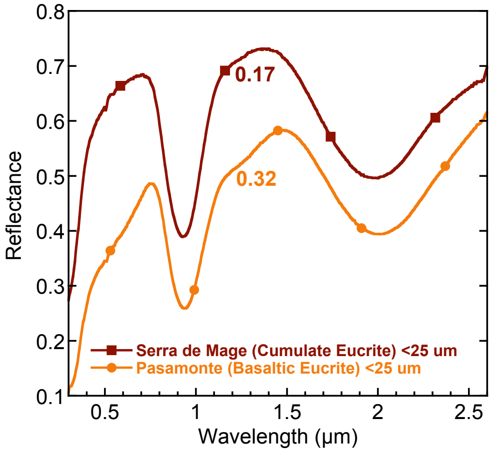

Fig 2. Spectra of two eucrites, Serra de Mage and Pasamonte, with comparable 1 µm and 2 µm band positions. Despite their similar bulk composition, the strength of the 1.2 µm M1 band is significantly stronger in Pasamonte than in Serra de Mage (adapted from [2]).

Spectroscopic methods: Near-infrared reflectance spectra were measured at the NASA/Keck RELAB at Brown University from 0.3-2.6 µm. Reflectance spectra were modeled using the modified Gaussian model (MGM) which can be used to deconvolve a spectrum into a continuum slope and individual bands that correspond to crystal field absorptions associated with the M1 and M2 sites [5]. An example of an MGM deconvolution of a reflectance spectrum and the paired Mössbauer spectrum is presented in Fig. 3. The meteorite spectra from the RELAB database have been classified broadly as eucrites, howardites, or diogenites. The petrology of some of the meteorites has not been described formally, and the eucrites are not classified into basaltic or cumulate subgroups in the database. Only eucrites that have been formally described as cumulates have been grouped as such for this analysis.

Mössbauer spectra of the synthetic pyroxenes were measured at Mount Holyoke College. 40 pyroxenes selected to span the full range of the pyroxene quadrilateral, have been measured over a series of temperatures ranging from 295K to 4K. Fits of these spectra at each temperature allow calculation of the recoil-free fraction, which can then be used to accurately determine the site occupancy of the pyroxene. Specific methods for collection and analysis of Mössbauer spectra are provided in greater detail in [3]. Mössbauer spectra of Johnstown and other selected HEDs will be presented.

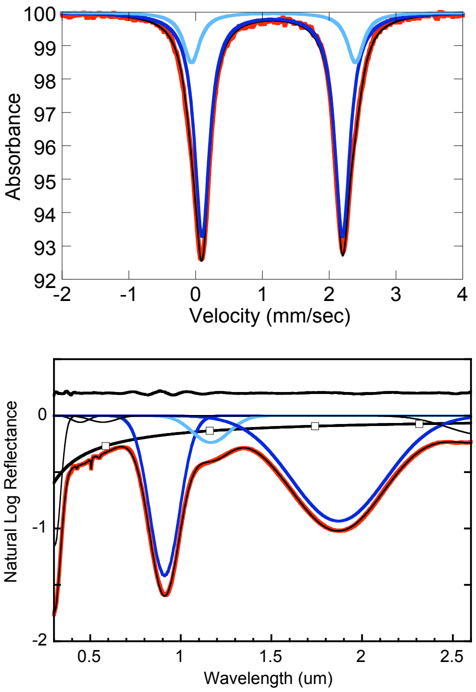

Fig. 3. Example deconvolution of paired Mössbauer and near-infrared reflectance spectra for a synthetic pyroxene (En80Fs20). The bands/doublets associated with the M2 site are colored in dark blue, and those associated with the M1 site are colored in light blue. Data are shown in red and the modeled fit is shown as a thin black line.

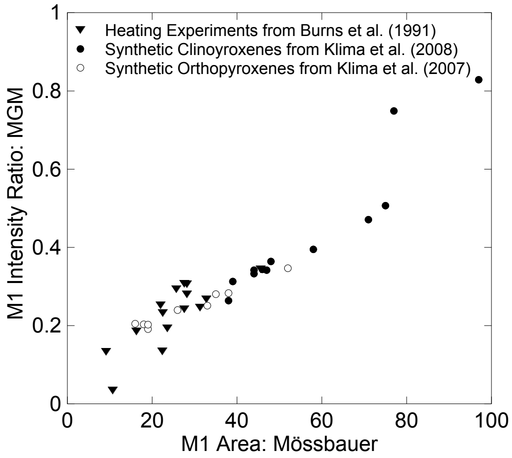

Fig. 4. Comparison of M1 area ratio derived from reflectance spectra with the M1 Mössbauer area (adapted from [2]).

Preliminary results and ongoing work: Shown in Fig. 4 is a preliminary scatter plot of the relationship between the area of the MGM derived M1 intensity ratio [1.2μm band intensity/(1.2μm + 2μm band intensities)] to the M1 Mössbauer area. Calculations of recoil-free fraction are underway for the 40 synthetic pyroxenes, and will be used to revise this relationship to reflect the actual M1 site population for the pyroxenes. For natural pyroxenes, the recoil-free fraction determined for the synthetic pyroxene of most similar composition will be used to estimate the true site occupancy.

Implications: Integrated Mössbauer and near-infrared studies of synthetic pyroxenes are providing a fundamental framework for assessing the site occupancy of pyroxenes. For pyroxene-dominated surfaces such as that of Vesta or the V-type asteroids, deconvolution of reflectance spectra offers the prospect of characterizing site occupancy, and thereby thermal history, remotely.

Acknowledgments: We are extremely grateful to Don Lindsley and Al Turnock for providing us the synthetic pyroxene samples. We thank Taki Hiroi for his dedication and care in measuring these samples in RELAB and Eli Sklute and Jerry Marchand for their help in running the Mössbauer spectra. Partial support for this project was provided by UCLA subcontract 2090GFC198 of NASA grant NNM05AA86C and grants NNX07AP41G, NNG06GJ31G, EAR-0439161 and NNG06G130G.

References: [1] Burns R.G., Besancon J. and Pratt S. (1991) *NASA #N92-10823*, Washington, DC, 253-255. [2] Klima R.L. et al. (2008) *MAPS* in press. [3] Dyar M.D. et al. (2008) *LPSC XXXIX*, this volume. [4] Mittlefehldt, D. (1998) in *Planetary Materials*, Washington, DC, pages. [5] Sunshine J. M. et al. (1990) *JGR, 95*, 6955-66.