SPECTRAL EFFECTS OF REGOLITH POROSITY IN THE MID-INFRARED - PYROXENE.

A. C. Martin[1,2], J. P. Emery[2], M. Loeffler[2,3] [1]Department of Physics, University of Central Florida, Orlando, FL 32816 (Audrey.martin@ucf.edu), [2]Department of Astronomy and Planetary Science, Northern Arizona University, Flagstaff, AZ 86011, [3]Center for Materials Interfaces in Research and Applications, Northern Arizona University, Flagstaff, AZ, 86011

Introduction: The regolith porosity on airless bodies in the Solar System has a known effect on remotely acquired spectra in the mid-infrared (MIR; 5–35 μm). Previous experiments quantifying this effect have focused on olivines. Here we report systematic laboratory experiments designed to quantify the effect of regolith porosity on the MIR spectra of pyroxene, an important rock forming mineral on Earth, the Moon, and throughout the Solar System.

A large fraction of the primitive asteroid population are P- and D-type asteroids, which are spectrally featureless in the visible and near-infrared (VNIR; 0.5 – 2.5 μm), but show spectral features indicative of anhydrous silicates in the MIR. Previous laboratory studies [1,2] highlight the use of MIR pyroxene spectra in identifying Mg# (i.e., Mg/(Mg + Fe)). Being able to extract the Mg# of pyroxenes via remote sensing has profound implications for understanding the formation region of that primitive body [3,4].

One aspect that can potentially complicate the use of the MIR to extract the composition of a given pyroxene-rich asteroid is that the position of many absorption features may also depend on the porosity of the asteroid's regolith. Recently we have shown that changing the porosity of olivine powders, a somewhat simpler silicate than pyroxene, can cause many of these MIR features to shift in position [5]. Here, we turn our attention to the spectral effect of porosity on the MIR of pyroxene powders.

Sample Measurement: For this work, we purchased the following seven natural pyroxenes from Mineralogical Research Company and borrowed one sample from the American Museum of Natural History: enstatite, two diopsides, two hedenbergites, aegirine, augite, and a fayalite + enstatite mixture. Mineralogy was verified and Mg# was determined with a Cameca SX-100 Electron Microprobe (EMP). We removed non-pyroxene phases identified in EMP results.

We mixed samples in three particle size fractions (0-20 μm, 20-45 μm, and 45-63 μm) with potassium bromide (KBr) of the same particle size fraction. KBr is transparent in the MIR, so we use it as a regolith porosity proxy. All pyroxene powder samples were mixed with KBr in ratios from 0% to 90% by weight, in 10 wt.% intervals.

Once samples were prepared we took MIR measurements with a Thermo-Nicolet IS50 Fourier transform infrared (FTIR) spectrometer, under ambient temperature and pressure conditions, using the PIKE Technologies EasiDiff diffuse reflectance accessory. The reflected intensity of the sample is an average of 200 scans between 4000 and 400 cm^{-1} at 4 cm^{-1} spectral resolution. Finally, we used Kirchhoff's law (Emissivity = 1- Reflectance) to convert to emissivity. The spectra of enstatite is shown in Figure 1.

Spectral Analysis: For an agnostic approach, we identify maxima (or peaks; P) and minima (or dips; D) in the spectra, as well as characterize the broad 10-μm plateau feature, using a feature-finding routine developed in our previous work [5]. Key spectral parameters that we extract to help us quantify the effect of regolith porosity are features' position, width, and spectral contrast, the latter of which is defined as the height (or depth) of a feature above (or below) the continuum.

Results and Discussion: In our previous work [5], we found that increasing the regolith porosity of olivine sample mixtures resulted in spectral features that are characteristic of both surface scattering (dominant at low regolith porosities) and volume scattering (dominant at high regolith porosities), leading us to conclude that the olivine spectra gradually transitioned between surface and volume scattering regimes as regolith porosity increased. We also found that this transition depends on particle size fraction - samples with smaller particle sizes more readily transition into volume scattering when regolith porosity is increased. All these trends are also observed in our pyroxene samples. Evidence of scattering regime transition include: decreasing spectral contrast of the Christiansen Feature (CF) and growth of the 10-μm plateau with increasing regolith porosity.

An additional line of evidence that the pyroxene spectra transition from surface to volume scattering is the similarity between pyroxene spectra presented here and spectra known to be in the surface or volume scattering regimes. For example, reflectance spectra in the surface scattering regime from [1, 6], and minerals from the Johns Hopkins University (JHU) spectral library are more similar to our low regolith porosity spectra, while spectra from [2, 7], as well as emission spectra from the Berlin Emissivity Database (BED) are much better spectral analogs to our high porosity spectra.

Applications to small bodies: We compared our laboratory spectra, as well as spectra of amorphous enstatite, to asteroid (624) Hektor. We note, our laboratory reflectance spectra, taken under ambient conditions, and emissivity spectra of an airless body, should be prudently compared because environmental effects can potentially alter resulting spectra. However, there are many features consistent with spectra taken under vacuum conditions, which can be used for compositional analysis of asteroid surfaces.

By cautiously comparing Hektor's MIR spectrum to modeled mixtures of crystalline and amorphous enstatite as well as to a high regolith porosity enstatite spectrum. We found that the existence of a 10-µm plateau on an optically thick surface, such as an asteroid, can be indicative of both high porosity regolith and amorphous silicates, and we estimate the regolith porosity of Hektor's surface to be >80%, consistent with [5].

Future work: We recognize that, although olivine and pyroxene are common minerals found on many extraterrestrial surfaces, it is unlikely for a surface to be comprised entirely of these two silicate constituents. Thus, in future studies, we plan to explore how the porosity affects the MIR spectra of phyllosilicates and mixtures of additional minerals.

Acknowledgments: We would like to acknowledge that this work was primarily done in Northern Arizona, at the base of the San Francisco Peaks, on homelands sacred to Native Americans through the region. Additional work was done in Eastern Tennessee, on the traditional land of the Tsalagi and Tsoyaha people. This work is supported by the National Aeronautics and Space Administration's Science Mission Directorate Research and Analysis Solar System Workings program NH19ZDA001N.

References: [1] Hamilton V. (2000) *JGR* 105, 9701-9716. [2] Chihara H. et al. (2002) *A&A* 391, 267–273. [3] Gail H.P. (2004) *A&A* 413, 571-591. [4] Henning T. (2010) *A&A* 48, 21-46. [5] Martin A. C. et al. (2022) *Icarus* 378. [6] Lane M. D. et al. (2011) *JGR* 116. [7] Koike C. et al. (2000) *A&A* 363, 1115-1122.

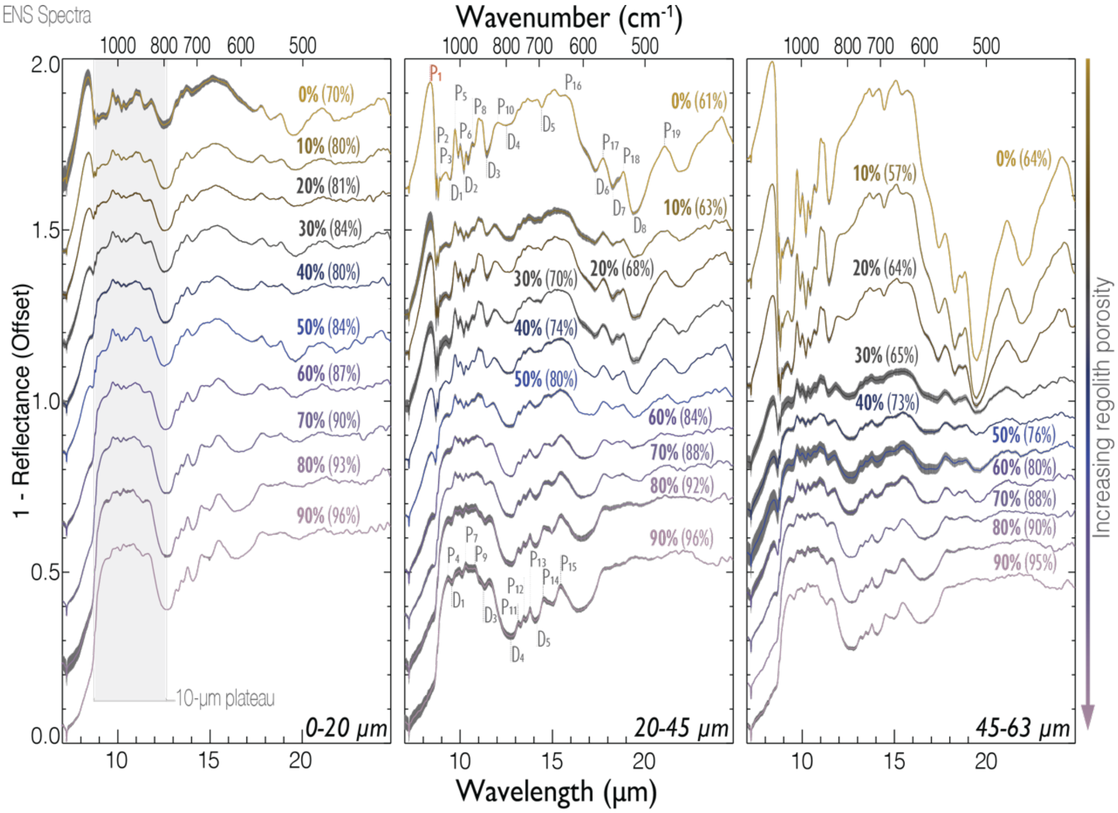

Figure 1 Spectra of enstatite powder mixed with increasing wt.% of KBr (from top to bottom). Gray region around the spectral curve represents standard deviation between each measurement. Bold percentages listed for each spectra represent the weight percent of KBr, while the percentages in parentheses are total simulated porosity (units of vol.%). From left to right the panels show 0-20, 20-45, and 45-63 µm particle size fractions. Spectra have been vertically offset for clarity and features are labeled in the 20–45 µm panel. The approximate 10-µm plateau region is shaded slightly in the 0-20 µm plot.