THE EFFECT OF TEMPERATURE ON THE REFLECTANCE SPECTRA OF PYROXENE AND A HIGHLANDS ANALOG WEATHERED BY LASER IRRADIATION. L. M. Corley[1], J. J. Gillis-Davis[1], P. G. Lucey[1], and D. Trang[1], [1]Hawai'i Institute of Geophysics and Planetology, University of Hawai'i at Mānoa, 1680 East-West Road, Honolulu, HI 96822, USA (lmc44@hawaii.edu).

Introduction: The Lunar Orbiter Laser Altimeter (LOLA) measures higher albedo at 1,064 nm in permanently shadowed regions (PSRs), relative to average mature highlands, and as a trend of higher albedo with lower temperatures [1–3]. On the basis that space weathering lowers reflectance [4], reduced space weathering has been hypothesized to cause the relatively higher albedo at 1,064 nm in the polar regions [1, 2]. Decreased space weathering could occur because the low temperatures of the polar regions and PSRs may affect the volume of impact melt and vaporization produced, and the subsequent development of submicroscopic iron (SMFe). If reduced space weathering is responsible for PSR albedo, PSRs may contain between 50% and 80% the abundance of nanophase iron (~10 nm) of mature lunar soil [2].

To test for temperature-dependent effects of space weathering, we compare spectra of materials weathered by laser irradiation at low temperature (85 K) with spectra of the same materials laser irradiated at room temperature (295 K). We performed laser irradiation experiments on orthopyroxene and a highlands analog, and measured the ultraviolet to near-infrared (UVVIS to NIR) reflectance, paying specific attention to 1,064 nm. If temperature does influence space weathering processes, reduced space weathering would be expected to occur even at equatorial regions during lunar nighttime, where temperatures fall below 100 K [5]. In addition, reduced space weathering would affect the poles of Mercury, where PSRs are as cold as 50 K [6].

Methods: Samples were powdered (<75 µm) orthopyroxene ($Wo_1En_{69}Fs_{30}$) and a highlands analog composed of 85% Stillwater plagioclase (An_{80}), 10% orthopyroxene, and 5% San Carlos olivine (Fo_{90}). One-half g of each sample was irradiated with a 1,064-nm pulsed laser. The pulse energy was 30 mJ and pulse length was 5–7 nsec at 20 Hz, which simulates µm-sized micrometeorite impacts. The laser was rastered across the surface of the sample at 30-sec intervals, waiting 1 min between intervals to allow the temperature to recover. Samples were in a thermally controlled vacuum chamber that can be cooled to liquid nitrogen temperatures. Experiments were performed at 85 K and 295 K, under vacuum pressure of 10^{-5} to 10^{-7} mbar.

Spectral changes were measured as a function of temperature and total irradiation time. Reflectance spectra of all samples were taken at ambient temperature outside the thermal chamber with an Analytical Spectral Devices FieldSpec 4 spectrometer, which measures reflectance from the UVVIS to NIR (0.35-2.5 µm). Although the temperature at which the reflectance of minerals is measured has an effect on reflectance properties [7], space weathering has been shown to mask these effects [8]. Spectra were acquired with 30° incidence and 0° emission angles, and reflectance was measured relative to Spectralon standards. Hapke radiative transfer modeling [4] with modifications for SMFe by [9] provided estimates for the abundance of microphase iron (~1µm), which darkens spectra, and smaller nanophase iron (~10 nm), which darkens and reddens spectra.

Results: All of the irradiated orthopyroxene samples exhibit darkening, reddening, and subdued absorption bands characteristic of space weathering. The orthopyroxene irradiated at 85 K is brighter overall than the sample irradiated at 295 K and is 8% brighter at 1,064 nm (Fig. 1a). The 85 K irradiated orthopyroxene also exhibits less reddening than the orthopyroxene irradiated at 295 K (Fig. 1b). Based on the radiative transfer modeling estimates, the orthopyroxene irradiated at 85 K contains 69% the abundance of microphase iron and 79% the abundance of nanophase iron of orthopyroxene irradiated at 295 K (Fig. 2).

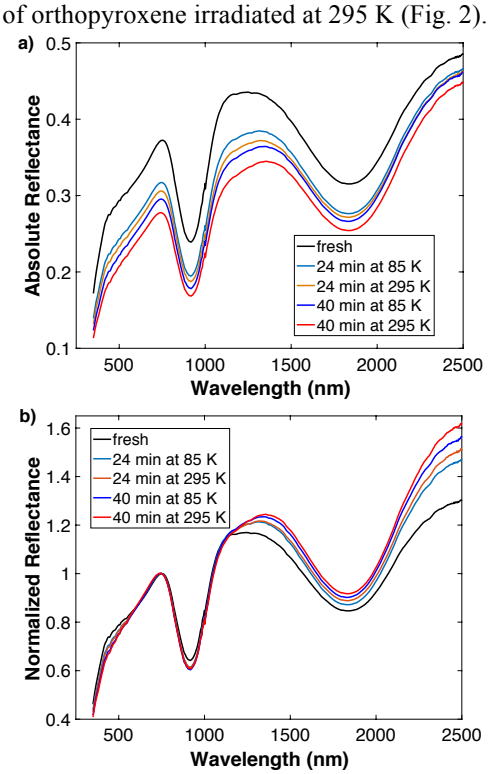

Figure 1: Absolute reflectance (a) and reflectance normalized to 750 nm (b) of fresh and irradiated orthopyroxene.

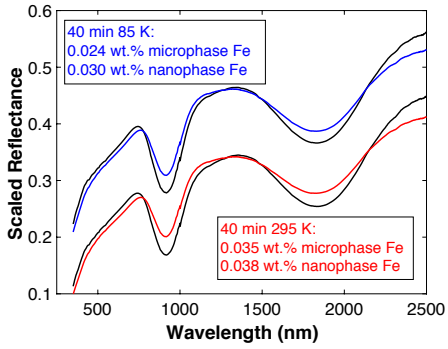

Figure 2: Scaled reflectance showing the fits of the model to orthopyroxene samples irradiated at 85 K and 295 K. The 85 K spectra are offset by 0.1 relative to the 295 K spectra.

Laser irradiation of the highlands analog at 85 K yielded only a 0.2% increase in brightness at 1,064 nm compared to irradiation at 295 K (Fig. 3a). We consider this to be insignificant because the standard deviation of our measurements of the reflectance standards is 0.5%. However, the 85 K sample did exhibit slightly reduced reddening in the near-infrared compared to the 295 K sample (Fig. 3b).

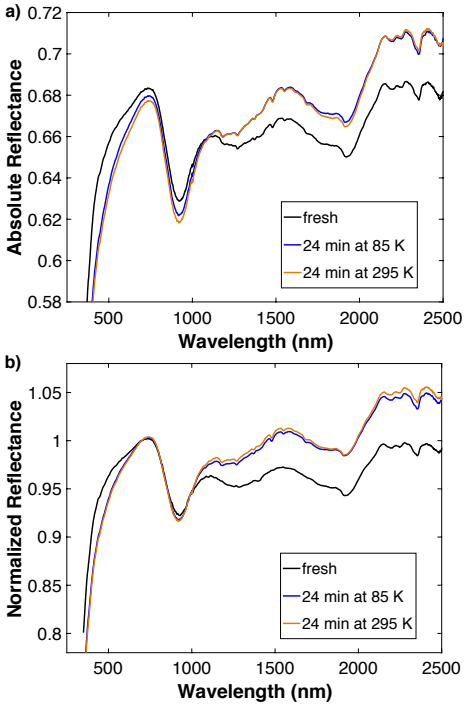

Figure 3: Absolute reflectance (a) and reflectance normalized to 700 nm (b) of fresh and irradiated highlands analog.

Discussion: Laser irradiation of the orthopyroxene at 85 K and 295 K suggests that temperature influences space weathering processes. The 8% greater reflectance at 1,064 nm for the 85 K orthopyroxene is comparable to results from previous experiments on olivine, which showed a 5% greater reflectance at 1,064 nm [10]. A brightness increase of this magnitude is consistent with the observed trend between temperature and LOLA albedo [3].

Estimates from radiative transfer modeling of the orthopyroxene spectra indicate that the orthopyroxene irradiated at 85 K contains 79% the abundance of nanophase iron of the orthopyroxene irradiated at 295 K. This reduction in nanophase iron abundance is comparable to the prediction by [2] that suggested that if only differences in nanophase iron abundances are responsible for the LOLA albedo anomaly of PSRs, then PSRs have between 50% and 80% the abundance of nanophase iron in mature lunar regolith.

Unlike orthopyroxene, laser irradiation of the highlands analog did not produce significant temperature dependent spectral differences. We attribute this mineral dependent observation to the lower irradiation time and a decrease in the production of SMFe. We will confirm this hypothesis with transmission electron microscopy (TEM). Principal component analysis indicates that samples from our experiments only begin to transition from immature to submature [11]. Thus, we predict that in order to observe the spectral effects of temperature on space weathering, the highlands analog requires significantly longer irradiation time.

Conclusions and Future Work: Previous work hypothesized that reduced space weathering contributes to higher albedo measured by LOLA at the polar regions [1, 2]. Our results demonstrate that low temperatures, comparable to those of PSRs, influence the space weathering process and decrease the production of SMFe. In addition to decreased SMFe abundance, the presence of ice [1, 2] likely also contributes to the LOLA albedo anomaly of PSRs. Nonetheless, reduced space weathering may also contribute to the trend of higher albedo with decreasing temperature measured by LOLA. These temperature-dependent space weathering effects should be detectable with latitude on a given body (i.e. equator vs. poles of the Moon and Mercury) and as a function of solar distance (i.e. Mercury compared to asteroids). To confirm the decrease in production of SMFe, we will use TEM to directly compare the thickness of amorphous rims and the size and abundance of SMFe produced at 85 K and 295 K.

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