SPECTRAL EFFECTS OF ROASTING OLIVINE IN H_2 AT HIGH TEMPERATURES AS A LUNAR SPACE WEATHERING SIMULATION. R. J. Hopkins[1], T. D. Glotch[1], T. Catalano[1], and H. Nekvasil[1]. [1]Department of Geosciences, Stony Brook University reed.hopkins@stonybrook.edu

Introduction: Space weathering refers to a set of alteration processes that occur on surfaces directly exposed to the space environment, and has been studied extensively on airless bodies such as the Moon, asteroids, and Mercury [1]. In this study, we focus specifically on lunar space weathering, and how to simulate the optical effects of space weathering in the laboratory. Space weathering on the Moon occurs primarily through two processes: micrometeoroid bombardment and solar wind sputtering and implantation [1]. These two processes gradually alter any fresh lunar material exposed on the surface. There is a significant difference in the visible to near-infrared (VNIR) spectra of unaltered lunar materials and space weathered materials [2]. Space weathered materials experience reddening and darkening in the VNIR, as well as a significant decrease in the band depths of absorption features. The cause of these spectral changes is the formation of nanophase Fe particles, which are often ^{0}Fe, but can have a range of oxidation states [3]. An increase in the number of these particles increases the deviations from unaltered spectra [4]. The size of these nanophase iron particles is also a factor in the changes to the spectra. Smaller particles (<40nm) cause both darkening and reddening, while larger particles (>40nm) cause only darkening [4, 5].

Roasting olivine at high temperatures can create surficial nanophase iron particles, and can have a major effect on its spectral features [6]. We roasted olivine at various high temperatures for different amounts of time under a reducing hydrogen atmosphere to create experimentally space-weathered materials with different nanophase iron size-frequency distributions. We then compared scanning electron microscope (SEM) images of the samples with VNIR spectra to characterize how the size and distribution of nanophase iron effects the spectrum of olivine.

Methods: The starting material we used in this study was San Carlos olivine (Fo90). We ground the olivine using an agate mortar and pestle, and then separated the olivine into three grain sizes with a combination of dry sieving and gravity separation. The three resulting grain size ranges were <10 μm, 63-90 μm, and 125-250 μm. We separated the olivine from these three size ranges into 1-gram aliquots. Each aliquot was roasted in a H_2 atmosphere at a specific temperature for either 5, 15, or 30 minutes. The roasting temperatures were 750, 800, 850, and 900 °C. We then analyzed the roasted samples with VNIR spectroscopy and SEM secondary electron imaging. We used an ASD Fieldspec3 Max spectrometer with 30˚ incidence and 0˚ emission angles for VNIR spectroscopic measurements. Each spectrum used in the analysis is an average of 12 spectra taken from 4 orientations each turned 90˚. SEM secondary electron imaging was completed at the Thermomechanical & Imaging Nanoscale Characterization (ThINC) facility at Stony Brook University using a ZEISS Crossbeam 340 Focused Ion Beam – Scanning Electron Microscope.

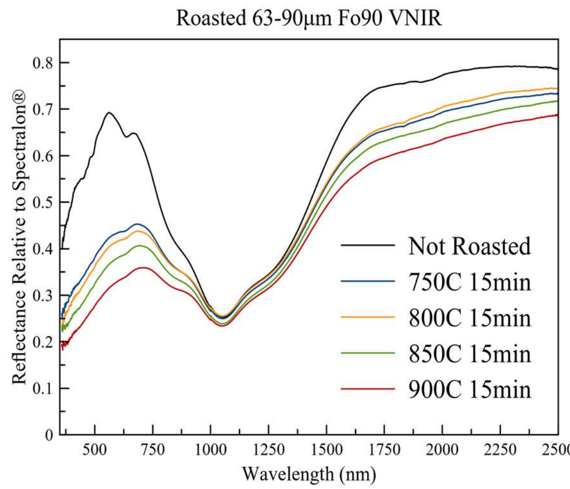

Figure 1. Reflectance spectra of four roasted olivine samples compared to unroasted olivine. Olivine grain size is 63-90 μm. Samples were roasted at 750, 800, 850, and 900 °C for 15 minutes. Each spectrum is an average of 12 spectra taken from 4 orientations. All spectra are corrected for Spectralon®.

Results: VNIR spectra of four of the samples roasted for 15 minutes are shown in Figure 1, along with the unroasted olivine of the same grain size (63-90 μm) for reference. All four roasted samples are significantly darker at all wavelengths compared to the unroasted olivine. The overall darkening of the four roasted samples also generally increases with increasing temperature. However, the difference in overall reflectance between the sample roasted at 750 ˚C and 800 ˚C is minimal, and the reflectance of the 800 ˚C sample is actually slightly higher than the 750 ˚C sample at longer wavelengths. This difference was reproduced on multiple integrated spectra of different aliquots of the same samples. This may indicate some temperature threshold to induce increased darkening at longer wavelengths, but more spectra are needed to test this.

As expected, the band depth of absorption features is greatly reduced for the roasted samples.

Temperature (˚C)	Band Depth (ΔR)
Unroasted	0.428
750	0.270
800	0.257
850	0.243
900	0.205

Table 1. Band depth of the 1050nm absorption of 63-90μm olivine in the unroasted sample and four samples roasted for 15 minutes.

The band depths of the 1050 nm absorption in olivine for the unroasted and four roasted samples are shown in Table 1. All four roasted samples have a lowered band depth compared to the unroasted olivine. There is also a systematic decrease in band depth when increasing temperature from 750 ˚C to 900 ˚C.

The decrease in reflectance of the roasted samples is more significant at shorter wavelengths. From previous studies of nanophase iron [4], this spectral reddening should indicate an abundance of smaller (<40 nm) sized nanophase iron particles. SEM secondary electron images of the roasted samples (Figure 2A-D) show these metallic iron droplets on the surfaces of the olivine grains. While quantitative analysis of these images is needed, the trends between the images appear well correlated with the differences in the VNIR spectra of the four roasted samples. The size of the nanophase iron particles appears to be on the scale of nanometers to tens of nanometers. However, much smaller particles may not be resolved. The abundance of these particles noticeably increases from the 750 ˚C sample (Fig. 2A) to the 900 ˚C sample (Fig. 2D), while the sizes of these particles appear relatively constant with increasing temperature.

Conclusions: The increase in abundance of the nanophase iron particles on the surfaces of the roasted olivine grains with increasing temperature appears well correlated with the band depth decrease, darkening, and reddening seen in the VNIR spectra of the samples. These data can be useful for quantifiably understanding natural space weathering of lunar materials. Further studies will also characterize these samples with mid-infrared, Raman, and ultraviolet spectroscopies.

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References: [1] Pieters C. M. and Noble S. K. (2016) *JGR: Planets. 121,* 1865-1884. [2] Adams J. B. and McCord T. B. (1970) *Proc. Apollo 11 Lunar Sci. Conf., 3,* 1937-1945. [3] Burgess K. D. and Stroud R. M. (2018) *JGR: Planets. 123,* 2022-2037. [4] Noble S. K. et al. (2007) *Icarus, 192,* 629-642. [5] Lucey P. G. and Noble S. K. (2008) *Icarus, 197,* 348-353. [6] Allen C. C. et al. (1993) *Icarus, 104,* 291-300.

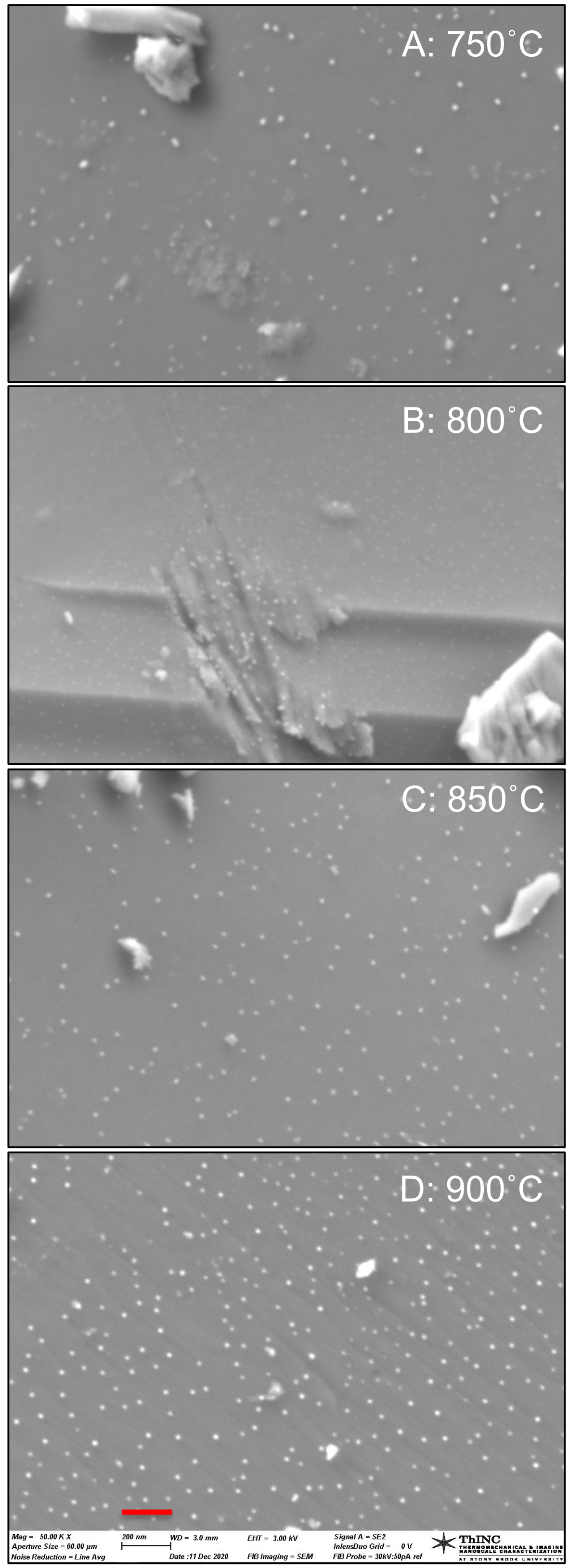

Figure 2. Secondary electron images of the four roasted 63-90μm olivine samples. Scale bar (red) is 200 nm and is the same across images. Magnification is 50,000x.