EXPERIMENTAL SPACE WEATHERING OF SYNTHETIC SPINELS. P. J. Isaacson[1], J. J. Gillis-Davis[1], C. Jackson[2], T. C. Prissel[2], S. Parman[2], K. Donaldson Hanna[3], L. Cheek[2,4], [1]HIGP/SOEST, University of Hawaii, Honolulu HI (isaacson@higp.hawaii.edu), [2]Brown Univ, [3]Oxford Univ., [4]Univ. of MD.

Introduction: Spinels have recently been identified as a major rock-forming mineral, in isolated but broadly-distributed areas across the lunar surface that are typically associated with large impact basins and/or mare basalts [1-5]. In these detections, which are identified as both Mg-Al and Fe- or Cr-rich spinels (depending on the interpretation), the spinel is interpreted as being associated with no detectable other mafic silicates, and mixed with an unknown proportion of plagioclase feldspar. Spinel is not uncommon in lunar samples, but is always observed in association with other mafic minerals [6-9]. As such, these recent detections of spinel-rich materials are considered to be a "new" rock type, and suggest the existence of a previously unrecognized facet to the magmatic evolution of the moon and modification of the crust. A series of formation hypotheses have since been forwarded for spinel anorthosite [9-12]. Evaluating these hypotheses requires a detailed understanding for how the spectrum of spinel is affected by changes in chemical and physical parameters, including space weathering.

Space weathering and spinel. Space weathering is the process by which airless solar system bodies are altered by exposure to the space environment, including the solar wind and micrometeorite bombardment [13]. The consensus of numerous studies [e.g., 13-19] is that space weathering has pronounced effects on vis/NIR (VNIR) spectra collected from airless bodies, which include, particularly for the Moon: reduced albedo, development of a red (increasing reflectance with wavelength) continuum, and suppressed absorption bands in comparison to spectra of unweathered materials of similar composition and mineralogy. These effects are driven primarily by the formation of vapor-deposited layers bearing nanophase metallic iron (SMFe or $npFe^0$) on sample grains [13, 17-19]. Space weathering complicates most efforts to determine composition through VNIR spectral analysis of airless body surfaces, even in cases where the effect of space weathering is somewhat understood, such as in the case of lunar soils [14-16].

Recently, several of the authors have synthesized a series of spinel samples at lunar-like oxygen fugacities (~IW-1) covering a range of compositions thought to be relevant or potentially analogous to the recent detections [20]. These samples will provide constraints on the composition and mode of the spinels detected on the lunar surface. However, the effects of space weathering on spinel are effectively unstudied, such that its effect on the VNIR spectra of spinels is not constrained. Lacking this constraint, VNIR analysis of spinel-bearing deposits on the lunar surface can at best provide crude estimates of spinel abundance and compositions. We seek to quantify the effects of space weathering on lunar analog spinels to improve petrogenetic constrains on spinel anorthosite.

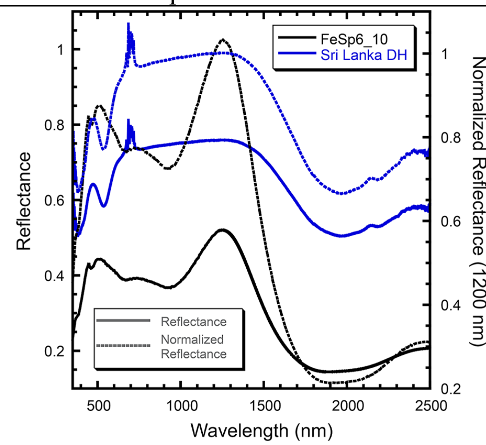

Figure 1: VNIR reflectance properties of Mg-Al spinel endmembers used for space weathering experiments. The FeSp6_10 spectrum was measured in the Brown Univ. RELAB, and the Sri Lanka DH spectrum with the ASD spectrometer at the Univ. of Hawaii.

Methods and Samples: We are conducting experimental space weathering of the synthetic spinel samples described previously. The experiments are performed in the laser space weathering laboratory at the University of Hawaii, which uses a 1064 nm Nd:YAG laser to irradiate samples that are contained in a vacuum chamber. This arrangement simulates the vaporization under reducing conditions that occurs during micrometeorite bombardment of airless body surfaces (i.e., space weathering). VNIR spectral reflectance measurements of the unweathered and weathered samples are acquired with an ASD FieldSpec 4 spectrometer, and will also be acquired at the Brown University RELAB [21]. In the present work, we present results from weathering experiments conducted on two Mg-Al spinel samples, 1) a synthetic sample with intermediate FeO abundance and 2) a terrestrial sample with very low FeO abundance, both of which are reasonable analogs to the lunar Mg-Al spinel detections (the lunar spinel detections are thought to be relatively FeO poor [2]). Spectra of the unweathered endmembers are presented in Fig. 1, in reflectance and reflectance normalized at 1200 nm (dashed lines). The two endmembers have notably different spectral properties, owing primarily to their differing FeO contents. Both samples exhibit the diagnostic spinel 2 μm absorption [22], although FeSp6_10 exhibits a more pronounced 2 μm absorption as well as significant absorptions in the visible to 1000 nm region, both attributable to its higher FeO content. Sri Lanka DH has no absorption near 1000 nm, likely due to its lack of significant FeO, and exhibits a weak absorption near ~600 nm. We are not confident in interpreting this visible feature, but suspect it may be attributable to octahedral Cr^{3+} [22]. The origin of the sharp features near 700 and >~2000 nm in the Sri Lanka DH spectra are unknown, but we suspect a calibration artifact. The compositions of these samples, determined by electron microprobe analysis, is summarized in Table 1 (normalized to 100% totals). In future work, we will conduct comparable weathering experiments on spinel samples covering a broader range of compositions [e.g., 20].

Table 1: Composition of spinel samples, normalized to 100% totals. Colors correspond to plots in Fig. 1 and 2.

Oxide	FeSp6_10	Sri Lanka DH
Al_2O_3	67.63	71.30
Cr_2O_3	0.01	0.14
MgO	20.98	28.34
FeO	11.20	0.15

Results: Here we present VNIR reflectance spectra for space weathering experiments conducted on the two samples listed in Table 1 and shown in Fig. 1. Results of the weathering experiments are illustrated in Fig. 2. For enhanced clarity, Fig. 2 only shows spectra after normalization to a common wavelength (1200 nm). Thus, changes in absolute albedo are not seen, but both samples exhibit minor reductions in albedo after irradiation. As illustrated in Fig. 2, the principal effect of the irradiation is the development of a red-sloped continuum across the visible to 1000 nm region (the shorter wavelengths become darker relative to the longer wavelengths), an effect that is consistent between the samples. The Sri Lanka DH sample also appears to exhibit some minor weakening of the 2 μm absorption feature.

Discussion: The principal optical effect of the weathering experiments conducted on these samples appears to be the development or enhancement of a red-sloped continuum across the visible to ~1000 nm region. Most importantly, this indicates that space weathering (and likely the associated formation of a vapor-deposited layer with a nano-scale phase) is occurring in these samples. Confirmation of the formation and nature of the nanophase materials would require fine-scale analyses such as transmission electron microscopy (TEM). The development of a red-sloped continuum (and possible suppression of the 2 μm feature) in the nearly Fe-free sample (Sri Lanka DH) may suggest that the nanophase material is not Fe^0, although this is pure speculation without further analyses. Confirmation of the suppression of the 2 μm absorption feature requires further analyses on low-Fe samples, to determine a) if this effect is real and b) if there is a compositional dependence (e.g., if the band is suppressed in proportion to the sample's Fe content). A compositional dependence of this potential effect is a strong possibility, due to the saturation of the 2 μm feature (in most cases) above ~5% FeO [22].

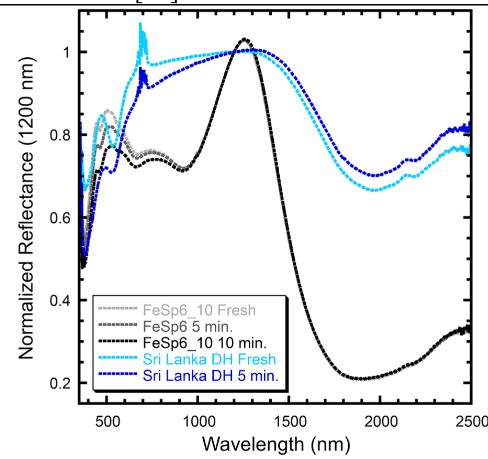

Figure 2: VNIR reflectance properties of fresh and weathered spinel samples. Darker colors (black, blue) indicate **more weathered** samples. Only the normalized spectra are shown, for clarity. The principal optical effect is an increase in continuum slope (reddening) across the visible, although minor darkening is also observed in the reflectance (not shown) results.

Future work: Future work will involve space weathering experiments on a more extensive suite of spinel samples, covering a range of FeO and potentially Cr_2O_3 abundances, as well as TEM analyses of the space weathering products to confirm the presence and nature of any nanophase materials in vapor-deposited rims on the sample grains.

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