HOW RICH IS RICH? PLACING CONSTRAINTS ON THE ABUNDANCE OF SPINEL IN THE PINK SPINEL ANORTHOSITE LITHOLOGY ON THE MOON THROUGH SPACE WEATHERING.
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Introduction: A previously unknown lunar rock was recently recognized in the Moon Mineralogy Mapper (M^3) visible to near-infrared (VNIR) reflectance spectra. The rock type is rich in Mg-Al spinel (~30%) and plagioclase and contains less than 5% mafic silicate minerals (olivine and pyroxene) [1,2]. The identification of this pink spinel anorthosite (PSA) at the Moscoviense basin [1-3] has sparked new interest in lunar spinel [e.g. 4-7]. [2] suggested that these PSA deposits might be an important component of the lunar crust. However, Mg-Al spinel is rare in the Apollo and meteorite sample collections (only up to a few wt%), and occurs mostly in troctolites and troctolitic cataclastites [8-10].

In this study, we are conducting a series of experiments (petrologic and space weathering) to investigate whether deposits of spinel identified by remote sensing are in high concentration (e.g. 30%) or whether the concentrations of spinel in these deposits are more like lunar samples, which contain only a few wt%.

To examine the possibility of an impact-melt origin for PSA, [6] conducted 1-bar crystallization experiments on rock compositions similar to pink spinel troctolite 65785. The VNIR spectral reflectance analyses of the low-temperature experiments yield absorption features similar to those of the PSA lithology detected at Moscoviense Basin (Fig. 1) [6].

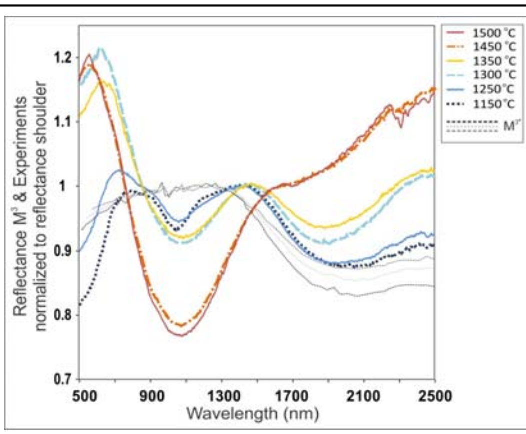

Fig. 1: *Reflectance spectra of the AT-65785 experimental run products (1500 ºC to 1150 ºC, thick colored, dotted, and solid lines) compared to M^3 spectra of PSA detected at Moscoviense basin (thin dotted black, grey, light grey lines) relative to featureless soil [2]; from [6].*

The experimental run products at these temperatures contain ~5 wt% spinel, which suggests that the spinel-rich deposits detected by M^3 might not be as spinel-rich as previously thought [6]. However, the effect of space weathering on spinel is unknown and could significantly alter its spectral properties including potential weakening of its diagnostic 2-µm absorption feature. Thus, weathered lunar rocks could contain more spinel than a comparison with the unweathered experimental charges would suggest [6].

In this study, we have initiated space weathering experiments on 1) pure pink spinel, 2) spinel-anorthite mixtures, and 3) the low temperature experimental run products from [6] in order to evaluate the influence of space weathering on the absorption strength of spinel. The results can be used to place constraints on the spinel abundance in the PSA lithology and can be used as ground truth for further VNIR spectral analyzes of lunar lithologies.

Method: Space weathering experiments are carried out at the University of Hawaii. [11] along with [12] laid the foundation that pulsed lasers could reproduce the pulse heating of materials similar to micrometeorite impacts. Laser pulse-heating experiments have been shown to reproduce components of micrometeorite space weathering. [13] showed that the size and location of the space weathering derived submicroscopic iron (SMFe) (or "nanophase" Fe0) identified in the rims of irradiated samples were similar to those observed in Apollo soils [e.g., 14]. The experimental apparatus at the University Hawaii is similar to [15], where dust impacts are simulated with a pulsed laser beam produced by a Continuum Surelite I-20 Nd:YAG laser (1064 nm, 20 Hz pulse rate, 6-8 ns pulse width). Laser spot size on the sample is 0.250 mm with an incident energy of 30 mJ. Irradiation is done in a vacuum between 10^{-6} and 10^{-7} torr, enabling the weathering to be performed in a reducing environment sufficiently comparable to that found on the lunar surface. The ~7 ns pulse duration is comparable to the timescale of dust impacts [15]. The samples are weathered up to 40 min (48,000 laser pulses) in order to match the reduced albedo, visible continuum slope, and reduced spectral contrast of san carlos olivine [13], which is representative of ~5E8 yrs. of exposure to the space environment.

Laser irradiation weathering experiments are conducted on uncompressed, powdered samples (<150 µm grain size). VNIR reflectance spectra are acquired incrementally after each laser weathering experiment, which lasts in duration of 5 min or 6,000 shots.

Sample: Pink Mg-Al spinel from Myanmar is used in the weathering experiments. These spinel are low in

FeO (ranging from 0.1-0.6wt%) and Cr_2O_3 (~2 wt%) (Table 1) and are close in composition to the spinel from the experimental run products by [6] (FeO = 5.3wt%; Cr_2O_3 = 2.1 wt%) and the calculated pink spinel composition of the PSA suggested by [2,7] (FeO = < 5wt%). Experimental charges are from [6] and contain spinel, anorthite, olivine, and glass. The spinel-anorthite mixtures contain different proportions of spinel ranging from pure anorthite to 70% anorthite. Plagioclase is from Stillwater with an anorthite component of An74 and contains ~0.6 wt% FeO [16].

Table 1: *Average analyses of pink spinel from Myanmar and Apollo 17 spinel [17].*

Oxides (wt%)	Av. spinel (n=20)	Apollo 70002,7
SiO_2	0.01	-
TiO_2	0.19	-
Al_2O_3	68.21	64.52
V_2O_3	0.35	-
Cr_2O_3	2.01	4.31
FeO	0.15	5.66
MnO	0.01	-
MgO	28.17	24.23
CoO	0.01	-
NiO	0.01	-
Total	99.12	98.72

Results: Figure 2 shows our first time-dependent weathering experiment on pure pink spinel. The 522 nm and 2-µm absorption bands are still apparent after 25 min of weathering. In fact, the 2-µm absorption band in particular is essentially unchanged. However, the near-IR (700-1400 nm) region of the absorption exhibits substantial changes, becoming darker and more sloped with increased laser exposure.

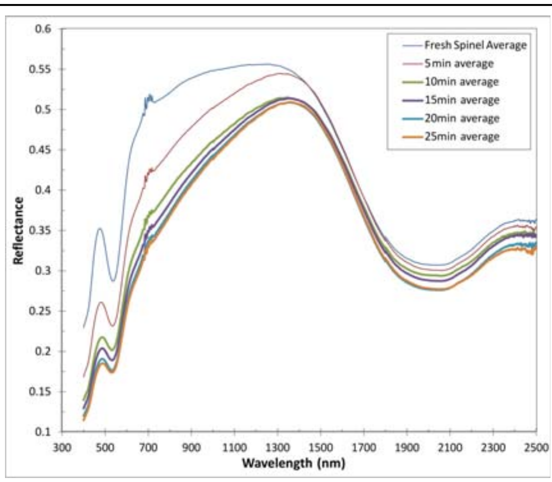

Fig. 2: *Weathering effect on the absorption features of pink spinel over time.*

Discussion and Implications: The spinel in PSA has no detectable absorption feature near 1-µm but exhibits a strong absorption centered near 2-µm [2]. This is very similar to the reflectance spectra from the Myanmar pink spinel of this study. Based on the changes in the absorption features in our pure spinel experiments, it seems that space weathering will only change/weaken the 700-1400 nm absorption region significantly whereas the characteristic 2-µm spinel absorption feature is not strongly influenced. If this was true, then a few % spinel in the PSA could be sufficient enough to produce the spectra detected by M^3. However, the spinel in our experiments are very low in FeO (Table 1). In addition, our preliminary spinel-anorthite mixture experiments show that at least 10% spinel is necessary in order to detect a spinel signature. Future experiments on pure spinel with a wider compositional range in FeO, additional mixture of pure anorthite-spinel, and weathering the experimental run products from [6] will reveal how much spinel is indeed necessary to produce weathered reflectance spectra comparable to the M^3 spectra of the PSA. This will help us place constraints on the abundance of spinel in the PSA.

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