SPECTRAL VARIABILITY IN NATURALLY WEATHERED ROCK SURFACES AND IMPLICATIONS FOR MARS. S. A. Curtis*[1], M. S. Rice[1], M. D. Kraft[1], S. R. Mulcahy[1], K. E. Lapo[1], L. E. Duflot[1], [1]Western Washington University, Geology Department, 516 High St, Bellingham, WA 98225, *curtiss9@wwu.edu

Introduction: Rock weathering products are important clues for understanding past environmental conditions on Mars. They can be identified using reflectance spectroscopy because the formation of new minerals and textures on a rock surface will change its spectral signature. Previous studies demonstrate that the spectral signature of coated rock surfaces can vary with viewing geometry (the angle between incident and emitted light); however, these photometric effects have not been extensively characterized for naturally weathered rocks. Our goal in this study is to quantify how both weathering and viewing geometry affect visible to near-infrared (VNIR) reflectance spectra of dunites and andesites - end member compositions - so that we can better interpret VNIR data from orbital and *in-situ* Mars missions. We compared weathered surface compositions and textures to their unweathered rock interiors using powder X-ray diffraction (XRD) and scanning electron microscopy (SEM) and energy dispersive spectroscopy (EDS). We used surface color and texture at the hand sample scale to categorize the amount of weathering for each sample; grain size decreases and color shifts to orange/brown with progressive alteration in both dunites and andesites.

We used Western Washington University's hemispheric spectrogoniometer [1] to collect reflectance spectroscopy data from natural and cut surfaces on the samples at several geometries covering the full scattering hemisphere. Improving our understanding of how weathering changes the spectral signature of terrestrial samples can then be applied to Martian rocks to make inferences about their original compositions and environmental conditions that formed any weathering products present.

Here we compare our laboratory spectral measurements directly to spectra of olivine-rich rocks observed by Perseverance's Mastcam-Z in Jezero crater. Mastcam-Z is a pair of zoom-enabled cameras with broadband red/green/blue and narrowband filters covering 440-1020 nm [2]. Within the South Séítah region, Mastcam-Z has documented layered rocks that have been mapped from orbit as olivine-bearing [3], and which have been confirmed by Perseverance's *in-situ* instruments (PIXL and SHERLOC) to contain olivine and pyroxenes with some alteration to carbonates, silica phases, and salts [4]. These include the "Bastide" and "Brac" outcrops, where fresh rock faces are exposed in the "Garde" and "Dourbes" and "Pont_du_loup" observations from sols 207, 255 and 268, respectively.

Dunites: A suite of weathered dunite samples, collected at Twin Sisters Mountain in western Washington State, acts as spectroscopic analogs for the olivine-rich rocks Perseverance is encountering on Mars. The samples have a mix of tan, orange, and dark brown weathered surfaces with less-altered green interiors. They are ultramafic in composition: mostly olivine (Fo_{90}) with some augite and diopside [5], along with small (≤2 mm) chromite crystals. We conducted a semi-qualitative analysis of sample compositions with SEM-EDS and found serpentine in fractures within the rocks. Clay minerals and Fe-oxides are present on some weathered surfaces. We separated the clay-sized fraction of the alteration material and used XRD of oriented clay mounts to confirm the presence of serpentine group minerals (likely chrysotile) and a potential kaolin group or chlorite group mineral. XRD of glycolated clays confirmed the absence of expanding clay minerals.

Reflectance spectra show hydration in most samples (Fig. 1) regardless of the amount of weathered material present on exterior surfaces. Samples with weathering rinds have spectral signatures consistent with mixtures of clay minerals, ferric oxides, and serpentine. The teal spectrum is distinct, with its narrow 1400 nm feature, wider 1900 nm band, and 2100 nm feature that are all distinctive of serpentine and set it apart from the other five samples.

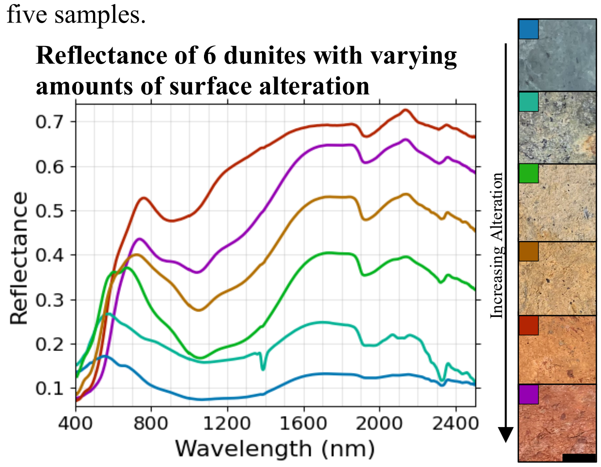

Figure 1: Reflectance spectroscopy data from 6 dunite samples in a lab standard viewing geometry (i=30, e=0, az=0). Visible range peaks shift to longer wavelengths and average reflectance magnitudes increase with alteration. The blue line is from a relatively unaltered sample interior; the rest are naturally weathered surfaces. The black scale bar is 2 mm.

Comparison to Mars: We convolved the hyperspectral terrestrial data to multi-spectral Mastcam-Z wavelengths for comparison. Within the visible range, peaks shift to redder wavelengths with increasing alteration. Spectra from olivine-rich Séítah rocks have similar shapes and peak locations to the moderately altered dunites (Fig. 2). Additionally, the band depth at 528 nm (an Fe^{3+} feature) is similar between the Martian and weathered terrestrial samples.

Andesites: Andesites collected from Mt. Baker in western Washington are included as an end member composition. The least altered samples are light gray with visible feldspar crystals; more weathered samples are orange, red, and/or brown. We used SEM-EDS to determine initial semi-qualitative compositions of the samples. Interiors are made up of feldspar and pyroxenes with small amounts of iron-titanium oxides. In addition to feldspar and pyroxene, weathered surfaces have darker areas in hand sample that appear to be amphibole or mica. There are also areas that contain Mn and Ba: elements associated with rock varnish.

Terrestrial dunite spectra compared to olivine-rich rocks in Jezero crater

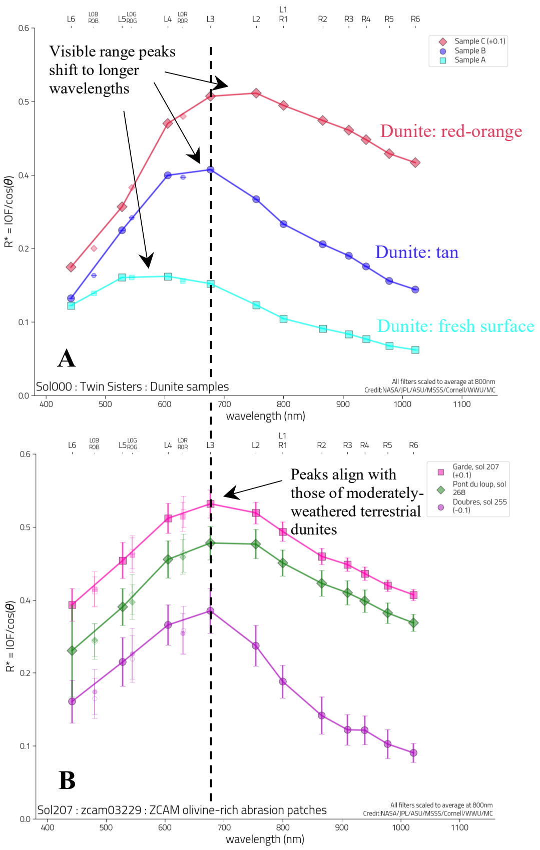

Figure 2: (A) Reflectance from 442-1022 nm for 3 Twin Sisters dunite samples (geometry: i=30, e=0, az=0). Here the dunite data is convolved to Mastcam-Z wavelengths for comparison to (B) olivine-rich rocks found in Jezero crater on Mars. Mastcam-Z spectra are from abraded surfaces in observations at Garde (sol 207, zcam03229), Dourbes (sol 255, zcam03252) and Pont_du_loup (sol 268, zcam03259).

Viewing Geometry: Measuring reflectance across the full hemisphere reveals variation in scattering behavior among the dunite samples. The more weathered dunites have more backscattering behavior. Additionally, increasing amounts of alteration correlate with fewer wavelength-dependent spectral variations with viewing geometry (Fig. 3). The locations of key composition diagnostic features are consistent regardless of viewing geometry. Initial andesite spectra on the other hand show forward scattering behavior for all samples.

Conclusions: Within the 400-1100 nm range, we find that reflectance peaks shift to longer wavelengths for weathered dunites. Spectra from Séítah rocks included here show similar characteristics to spectra from moderately weathered terrestrial dunites. Spectrogoniometry shows that key spectral features for mineral identification can change in magnitude with viewing geometry, but weathered samples show less spectral variation with viewing geometry than unweathered samples. In our ongoing work, we will combine the compositional observations presented here with quantitative characterizations of surface texture [6] to interrogate their combined influence on weathered rocks' spectra and scattering behavior.

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References: [1] Rice, M. S. et al., 2022, LPSC, *this issue*. [2] Bell, J. F. et al., 2021, *Space Sci. Rev.* 217, 1, 1-40. [3] Horgan, B. N. et al., 2020. *Icarus* 339. [4] Hickman-Lewis, K. et al., 2022, LPSC, *this issue.* [5] Ragan, D.M., 1963, *American Journal of Science* vol.261, p.549-565. [6] Duflot, L. E. et al., 2022, LPSC, *this issue*.

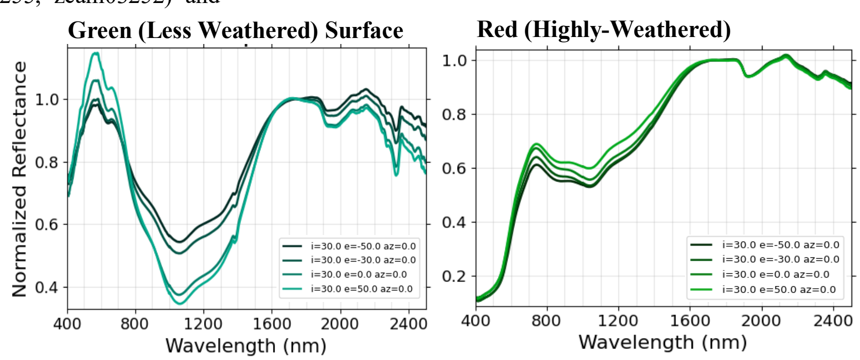

Figure 3: Two dunite samples with reflectance spectra taken at four different viewing geometries and normalized to 1750 nm. The less weathered sample shows more variation in reflectance with viewing geometry than the heavily weathered sample.