SPECTRAL & PHOTOMETRIC BEHAVIOR OF ANALOG COATED HAWAIIAN BASALT & APPLICATIONS TO SURFACE SPECTRA OF MARS. S. A. Theuer*[1], M. S. Rice[1], K. Lapo[1] M. D. Kraft[1], E. A. Cloutis[2], D. Applin[2], [1]Western Washington University (516 High St, Bellingham, WA 98225, USA, *theuers@wwu.edu) [2]University of Winnipeg

Introduction: Silica precipitates are widespread on Mars [e.g., 1] and spectra consistent with silica-coated basalts have been interpreted from orbital data [e.g., 2]; these provide valuable clues about past surface processes and paleoenvironments. However, our ability to identify and distinguish coatings from underlying lithologies on Mars is complicated by the influence of viewing geometry, surface texture, coating thickness, and nonlinear spectral mixing on visible to near-infrared (VNIR) reflectance spectra [e.g., 3, 4]. Studying the VNIR properties of terrestrial analog samples can help to constrain these factors.

Previous work has identified coated basalt samples from Hawaii as reasonable analogs for coatings detected on Mars [e.g., 5, 6]. Silica-rich and Fe/Ti-enriched coatings have observed on these samples and a number of formation mechanisms proposed [e.g., 5, 6]. But further work is needed to characterize the spectral and photometric behavior of these natural coatings. This work describes additional coated Hawaiian basalt samples and better constrains the photometric and spectral effects of natural coatings on VNIR spectra of analog basalts. Understanding how these coating affect the spectra of these naturally weathered analog rocks is critical to our ability to identify rock coatings on Mars, constrain their compositions, and interpret their formation environments.

Methods: Four types of coated basalt samples collected from the Mauna Iki, Kau Desert, and Puna Coast Trails in Hawaii Volcanoes National Park were analyzed: lightly coated (referred as "less coated"), blue coated, yellow coated, and red coated. An initial dataset of VNIR spectra at backscattering (i=50, e=30, a=0), standard (i=30, e=0, a=0), and forward scattering (i=50, e=-30, a=0) geometries was collected using Western Washington University's TANAGER spectrogoniometer [7]. A small diameter probe spectrometer was used to collect spectra from ~2 mm surface spots displaying the most brightly colored coatings, mixed colored coatings (yellow/blue), and less or uncoated spots. Coating composition, texture, and distribution were qualitatively analyzed using a reflected light microscope and Scanning Electron Microscope (SEM) with energy dispersive spectroscopy (EDS) elemental maps and backscattered electron (BSE) imaging.

Spectrogoniometry: All sample spectra exhibit reflectance peaks between wavelengths of 460 and 745 nm (Figure 1). Blue coated sample spectra display a reflectance peak at ~460 nm, yellow coated spectra at ~670 nm, less coated spectra at ~710 nm, and red coated spectra at ~745 nm wavelengths. The NIR spectral slope is relatively negative in backscattering geometries and more positive in forward scattering geometries across all samples. All sample spectra exhibit forward-scattering behavior (Figure 1). A weak 1900 nm absorption band and a 475 nm shoulder were both present across all samples and viewing geometries.

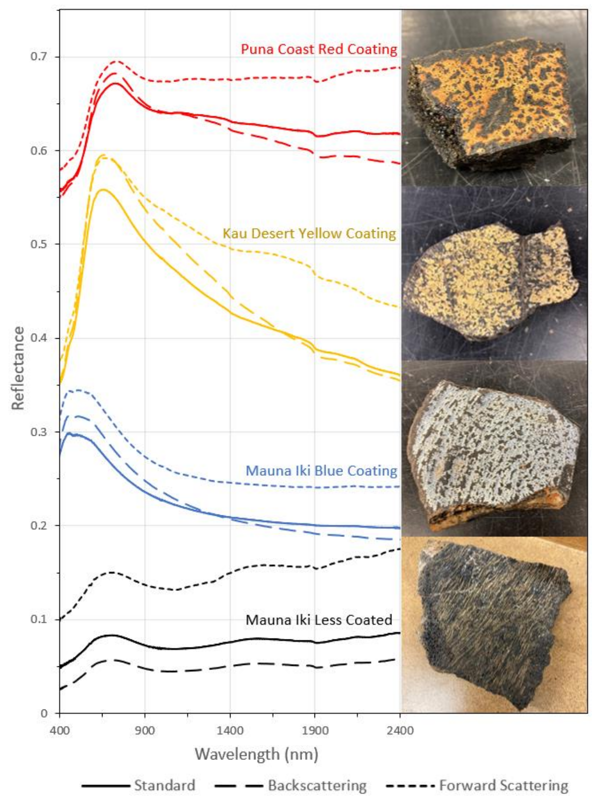

Figure 1: VNIR goniometer spectra of samples at standard geometry (i=30, e=0, a=0), back scattering geometry (i=50, e=30, a=0), and forward scattering geometry (i=50, e=-30, a=0). Spectra are offset for clarity (blue coating +0.16, yellow coating +0.27, red coating +0.5).

Microscopy & Spectral Characterization: Targeted spectra were collected using a small diameter probe to investigate end-member surface compositions (Figure 2). Reflectance peaks within spectra of the most brightly coated spots occur at 400 nm for the blue coated sample and 615 nm for the less coated sample. The reflectance peaks of the most brightly coated spots on the red and yellow samples do not differ in wavelength from those observed in spectrogoniometer spectra. The 475 nm shoulder feature was absent from the spectra of the most brightly blue spots on the blue coated sample.

Spectra collected from less coated spots on the blue, yellow, and red samples exhibit low reflectance and near horizontal shapes, with small reflectance peaks at ~600 nm.

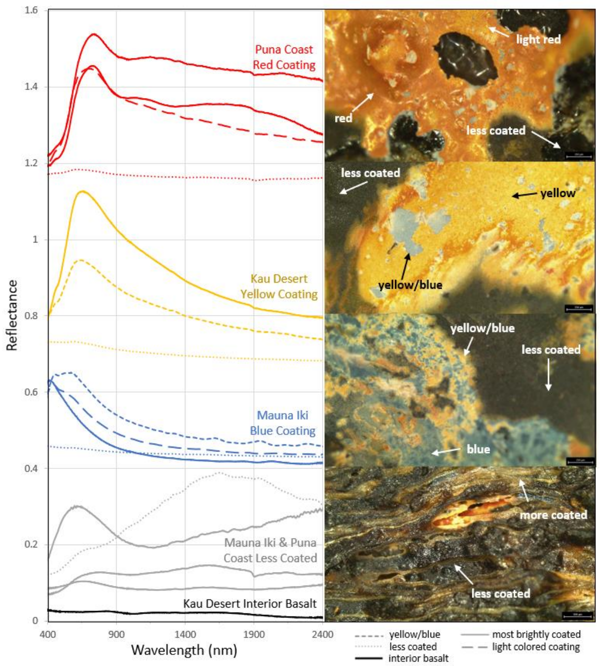

Figure 2: Targeted small diameter probe VNIR end-member spectra with annotated microscopy images of samples. Specta are offset for clarity (interior basalt -0.05, blue coating +0.4, yellow coating +0.65, red coating +1.1).

SEM Analysis: Two distinct coating types were observed in BSE images and EDS maps: a Si-rich coating (blue coating) and a Fe/Ti-enriched coating (yellow and red coatings) (Figure 3). Yellow and red coatings are both enriched in Fe and Ti, with relatively more Ti in yellow coating and Fe in red coating. Dark surfaces across samples are also minorly enriched in Si and/or Fe/Ti compared to interior basalt. Blue coatings are topographically the lowest and are sometimes capped by a yellow coating. Red coatings overlay blue and yellow coatings, as well as dark substrate. Blue, yellow, and red coatings in varying amounts were observed on all sample types. Analysis of a piece of interior basalt from the Kau Desert yellow coated sample showed evidence of basaltic glass with olivine, pyroxene, and plagioclase crystals.

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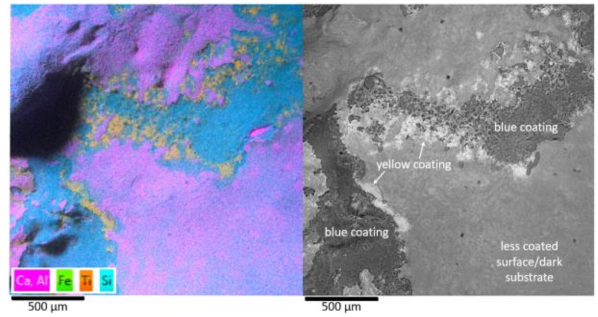

Figure 3: Mauna Iki Blue Coated sample EDS chemical map and BSE image labeled with coating types. Blue coating is capped by yellow coating.

Discussion: The 475 nm shoulder suggests the presence of ferric oxides in samples while the 1900 nm absorption feature may indicate a hydration band. The 1000 nm feature is indicative of underlying mafic mineralogy. Overall, spectral shape, absorption features, and SEM data are consistent with varying amounts of hydrated silica coatings (some enriched in Fe and Ti oxides) overlying glassy basalt. This aligns with previous work identifying two distinct coating types: an amorphous Si coating and a capping Fe/Ti enriched coating [5, 6], though the relationship between these coatings and their formation mechanism(s) invite further analysis. SEM analysis supports some degree of alteration of dark surfaces relative to interior basalt. The change in NIR slope from positive in forward scattering to negative in backscattering geometries is consistent with trends observed by [8], who studied photometric effects of synthetic ferric coatings on basalt slabs. The natural Hawaiian coatings exhibit the same behavior of increasing transparency at longer wavelengths in the backscattering geometry.

Conclusions and Further Work: Notable photometric effects were observed across coating types, particularly related to NIR spectral slope. Coatings significantly impacted the ability to identify underlying basalt in samples with greater amounts of hydrated silica coating present. Additional work will explore coating textures, composition, thickness, and further constrain photometric effects across more extreme geometries and how these factors influence our ability to identify mineralogy. We will also compare the spectra of these samples to multispectral data collected by the Mastcam-Z instrument on the Perseverance Rover and to CRISM orbiter data. This will help illustrate how spectral and photometric behavior of coatings may impact spectral data from Mars and influence our ability to interpret underlying lithologies.

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