CHARACTERIZING THE EFFECTS OF VIEWING GEOMETRY ON THE REFLECTANCE SPECTRA OF ROCK COATINGS. M. S. Rice¹ and J. F. Bell III², ³California Institute of Technology, Pasadena, CA, mrice@caltech.edu, ⁴Arizona State University, Tempe, AZ.

Introduction: Understanding the spectra of rock coatings as functions of viewing geometry is important for interpreting remote sensing observations of planetary surfaces, specifically for the interpretation of multispectral data from the Mars Exploration Rover (MER) Pancam and other past (Imager for Mars Pathfinder, Phoenix Surface Stereo Imager), current (Mars Science Laboratory Mastcam) and future surface-based Mars imaging studies. To our knowledge, a comprehensive study of the visible to near-infrared (Vis-NIR) spectral behavior of ferric and silica rock coatings of varying compositions, thicknesses, and phase angles has not yet been performed. Here we present results of an initial laboratory study of the effects viewing geometry (forward-scattering vs. backscattering) on a variety of coated rock surfaces.

Background: The presence of fine-grained coatings on Martian surface materials are known to cause significant masking effects on the remote sensing and in-situ spectroscopic investigations of the Martian surface. Ferric coatings have been shown to become more transparent with wavelength in laboratory studies [e.g., 2-3], allowing darker mafic substrates to spectrally dominate at longer wavelengths. Fischer and Pieters [4] also showed that some ferric coatings will exhibit wavelength-dependent spectral properties that are a function of the illumination and viewing geometries. These phenomena result in a negative spectral slope in the near-infrared, like that which has been observed from orbit for the Gusev Plains by the Mars Express Observatoire pour la Minéralogie, l’Eau, les Glaces, et l’Activité (OMEGA) spectrometer [5]. Silica coatings on Hawaiian basalts also obscure the spectra of their substrates and exhibit negative NIR spectral slopes [e.g., 6-7]. The effects of viewing geometry on the spectra of such natural silica coatings, however, are poorly understood.

Relevance to MER/Pancam and MSL/Mastcam: One of the most striking discoveries of the Spirit mission has been the presence of near-pure hydrated silica in a subsurface soil called Gertrude Weise near the putative pyroclastic feature known as Home Plate [8]. The soil and nearby silica-rich outcrops are spectrally distinct from other Gusev crater materials in Vis-NIR wavelengths: a strong spectral downturn from 934 to 1009 nm characterizes Pancam spectra of all known hydrated silica targets [9], which is due to the $2\nu_1 + \nu_3$ H$_2$O combination band and/or the $3\nu$ OH overtone centered near 960-1000 nm [1]. The silica-rich materials are characterized by “flat” near-infrared (NIR) spectra from 864 to 934 nm, which allows the narrow hydration band to be distinguished from broad absorptions near 1000 nm in the spectra of iron-bearing minerals. Using criteria based on these parameters, Rice et al. [1] defined a Pancam “hydration signature” that characterizes the spectra of the hydrated minerals to which the instrument is sensitive (including hydrated silica, some hydrated Mg- and Ca-sulfates, water ice, and some carbonates). This Pancam hydration signature has since been used to interpret the mineralogy of other potentially hydrated surface targets at both Gusev crater and Meridians Planum [e.g., 10-12]. Recently, the Pancam hydration signature has also been adapted to Mars Science Laboratory (MSL) Mastcam filter data [e.g., 13].

The utility of the Pancam hydration signature is currently limited, however, by poorly-understood NIR slope effects at high phase angles. The Pancam spectra of some rock surfaces can mimic the hydration signature when tilted away from the rover’s line of sight and/or when viewed at very low Sun elevations [1]. To avoid these “false detections,” the Pancam hydration signature is typically only used to identify potentially hydrated materials in observations made at low (~0°-30°) incidence (i) and emission (e) angles. The contributing factors to the negative 934 to 1009 nm spectral slope of these rock surfaces have not yet been fully identified, and here we propose to test one hypothesis for the observed Pancam phenomenon: the negative NIR spectral slope arises from fine-grained rock coatings viewed at high phase angles.

Methods: We acquired Vis-NIR spectra (350-2500 nm) of 18 natural Hawaiian basalts and two natural andesites coated with varying amounts of silica, ferric iron, sulfur and titanium. Reflectance spectra were measured with an Analytical Spectral Devices (ASD) FieldSpec Pro HR spectrometer at Arizona State University. For each sample, spectra were acquired at a forward-scattering viewing geometry ($i=40°, e=30°$, with the light source and detector on opposite sides of the surface normal) and a more backscattering geometry ($i=30°, e=0°$). Sample spectra were measured relative to a SpectraRite® standard and corrected for minor (<2%) irregularities in absolute reflectance and for small occasional offsets at 1000 and 1830 nm where detector changes occur [e.g., 14]. Collimating lenses were used in front of the ASD probe and light source to ensure that a fully-illuminated portion of a representative and relatively uniform coating material
occupied the full field of view.

Results: Based on the main absorption features present, the Vis-NIR spectra of these coatings are dominated by silica and iron oxides to varying degrees. The silica-bearing coatings exhibit bands at ~1400 nm and ~1900 nm, indicating hydration, but the $2v_1 + v_3$ H$_2$O combination band near 960-1000 nm observed by Pancam in the hydrated silica materials at Gusev crater [1] is apparently too weak to be resolved in these coatings and/or is masked by broad Fe$^{3+}$ absorptions.

The continuum slope of all measured samples becomes more negative past ~1000 nm in the forward-scattering orientation. Fig. 1 shows example spectra of coated basalt and andesite rock samples, and the NIR spectral variations between the forward-scattering and more backscattering geometries is apparent. However, none of the coating spectra yet collected reproduce the specific negative slope from 937 to 1009 nm observed by Pancam.

Discussion: We interpret the observed changes to NIR slope as wavelength-dependent spectral properties that are a function of viewing geometry, as has been proposed for ferric coatings in previous studies [e.g., 2-4]. However, while Fischer and Pieters [4] had reported more negative NIR slopes in the spectra of ferric coatings in backscattering geometries, we observe more negative slopes in the forward-scattering orientation. This disagreement may be attributed to differences in coating thickness, composition and/or surface texture between our natural silica-rich coating samples and the synthetic ferric coatings used in their study.

This initial work underscores the importance of quantifying the dependence of the NIR slope on viewing geometry, and suggests that measurements at higher phase angles may reproduce and better constrain the specific effects observed by Pancam. Our next steps will be to perform a systematic laboratory study of the Vis-NIR spectral properties of these samples across a wider range of incidence and emission angles (every 10° from 0-70°) and at a variety of out-of-plane phase angles.


![Figure 1](image_url)

Figure 1. Spectra of a coated natural Hawaiian basalt sample (left) and a coated natural andesite (right) at two viewing geometries: forward-scattering ($i=40°$, $e=-30°$; gray line) and back-scattering ($i=0°$, $e=30°$; black line). Coatings contain varying amounts of silica, ferric iron, sulfur and titanium. Spectra are normalized to 1 at their maximum values. Vertical dashed line indicates the band center of Pancam’s 1009 nm filter. Note that the NIR continuum slope of all measured samples becomes more negative in the forward-scattering orientation.