TERRESTRIAL ROCK VARNISH: A KEY TO UNDERSTANDING THE SURFACE COMPOSITION OF MARS. J. G. Ward[1], L. E. Kirkland[2], D. Keller[1], and R. April[1]; [1]Colgate University, jward@mail.colgate.edu, dkeller@mail.colgate.edu; rapril@mail.colgate.edu; [2]Lunar and Planetary Institute, kirkland@lpi.usra.edu.

Summary: The thermal infrared spectral signatures of two weathered terrestrial basalts were studied to better understand spectral signatures measured of weathered surfaces on Mars. Here we examine whether thermal infrared spectra (5-25 µm) may be used to differentiate between a desert varnish and a glassy, silicate cooling rind. Our preliminary results indicate the spectral signatures of both poorly ordered silicates are so similar that it may require a different method or wavelength range to differentiate between the two.

Background: An important goal of remote sensing studies of Mars is to determine the surface composition, enabling scientists to better understand the past environmental conditions and plate tectonic history of Mars and to locate deposits of interesting minerals as a factor for landing site selection. For example, thermal infrared signatures recorded by the 1996 Thermal Emission Spectrometer (TES, 6-50 µm) may be used to examine the surface composition. TES spectral signatures are interpreted by comparison to laboratory spectra of known materials. Accurate interpretations require a full understanding of the spectral signatures of all the materials that may be present. Since it is reasonable to consider whether the surface of Mars may include silicates with a glassy cooling rind or a desert varnish, we desire to examine the signatures of these materials.

Terrestrial desert varnish, generally less than 50 µm thick, consists of small particles [1] comprising mostly clays surrounded by oxides of iron and manganese [2, 3]. The small particles are cemented together so that they appear to an infrared spectrometer as if they are large particles, which produces a strong spectral band contrast. This also gives varnish its shiny appearance.

On Earth rock varnish may have a microbial origin [3]. Clays are transported from an external source and deposited on the rocks [4, 5]. Manganese-concentrating bacteria, which bloom during wet periods, oxidize the manganese in the rock. These oxides cause the clay to adhere to the rock surface, producing varnish [5]. Raymond *et al*. [1] found manganese-rich stromatolites in rock varnish, which reinforces the idea that manganese-oxidizing bacteria are involved in varnish formation. Krinsley *et al*. [6] suggested a varnish formation model that involves biomineralization and diagenesis.

If the surface layer composition matches that of the bulk composition, and in particular if the surface layer shows no manganese enrichment, then we use this as evidence that the surface layer is a cooling rind rather than a desert varnish. Thus a surface characterization allows us to differentiate between a varnish and a cooling rind. This distinction is important for Martian surface studies, since the presence of a varnish may indicate that aeolian and possibly biotic mechanisms were involved in clay or other mineral deposition and cementation [4, 5], while glassy rinds would form as a result of the rapid cooling of a basalt.

Surface characterization: The samples were cut perpendicular to the coatings, and therefore the thin sections observed contained both the inner core of the bulk rock and segments of the outer coating. Samples are from the SP Crater, near Flagstaff, Arizona and Black Mesa, near Las Vegas, Nevada. Samples were analyzed using x-ray diffraction (XRD), scanning electron microscopy (SEM), and energy dispersive spectrometry (EDS).

SP Crater: The SP Crater sample is a vesicular basalt, with fine-grained crystals and large vesicles up to 0.5 cm in diameter occurring throughout. The bulk rock is dark gray, with small (<0.25 cm) plagioclase grains and a glassy surface coating ~10 µm thick. The rock coating is more weathered and pitted than the bulk rock. When viewed as a back-scattered image the coating has a brighter surface, due to the presence of more elements with higher atomic numbers, as compared to the bulk rock. Collection of an x-ray energy spectrum for a region exhibiting a glassy coating shows the aluminum-rich silicate nature of this rock. Iron and manganese, whose presence would be expected for a dark varnish (e.g. [5, 1]) are notably absent.

Black Mesa: The Black Mesa sample is more fine-grained and contains smaller vesicles (all <0.25 cm) than the SP Crater sample. Some plagioclase grains are visible. A thin section was analyzed using the SEM/EDS. The ~15 µm thick rock coating was identified by the "brighter" and "weathered/pitted" features it exhibited when the thin section was viewed using back-scattered electrons (Figure 1). The spectrum collected for a varnished region shows a substantial amount of manganese and iron. These manganese and iron peaks indicate the presence of a varnish [5, 1]. Other coated regions of this thin section revealed similar results.

Discussion: The SP Crater sample surface layer lacks manganese and strong iron signatures, suggesting that this layer is a glassy rind rather than a desert varnish. In contrast, the presence of manganese and iron oxides in the Black Mesa sample coating indicates that it is varnished (Figure 1). The SP Crater and Black Mesa samples are of similar basaltic composition as indicated by XRD analysis. Their x-ray diffractograms were comparable, as both samples were found to contain diopside and plagioclase. The vesicle and grain sizes were the main differences observed, but these differences would not likely be the cause of varnish forming on one rock and not on the other. Both samples showed varying coating thickness, with the SP Crater rind averaging ~10 µm and the Black Mesa varnish averaging ~15-40 µm.

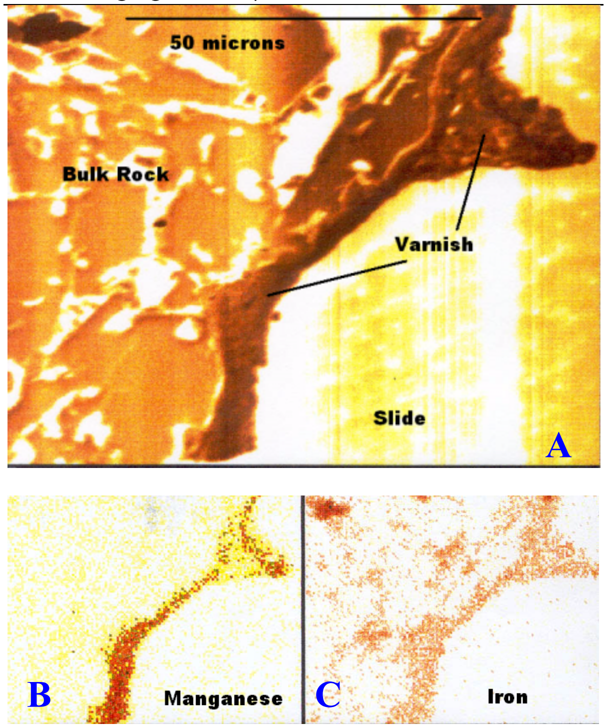

Figure 1: Image A shows the Black Mesa back-scattered SEM in false color. It is the negative image, so that dark regions actually appear bright on the SEM. Image B shows the manganese map and Image C the iron map for Image A.

The SP Crater coating in the thin section did not show the presence of manganese or a substantial amount of iron. No compositional changes were observed between the SP Crater bulk rock and its coating, with the only difference being the glassier look of the coating. These results indicate that the Flagstaff sample may instead be a glassy cooling rind, evidenced by the amorphous nature of its coating when viewed both optically and with the SEM/EDS. However, the Black Mesa varnished regions observed vary greatly in their abundance of manganese, which implies that the amount of manganese throughout a particular varnished sample may vary, and only one SP Crater thin section has thus far been studied. While our preliminary conclusion is that the SP Crater sample contains a glassy rind rather than a varnish, more samples and coated regions need to be examined before this conclusion can be firmly stated.

Spectral implications: Figure 2 shows the thermal infrared spectrum for the SP Crater bulk rock and weathered surface, and the Black Mesa weathered surface. The varnish and glassy rind spectra are very similar, especially in the 9 µm region, where a strong V-shaped absorption band occurs due to the poorly ordered arrangement of the crystals/glass. The only noticeable difference between the two spectra is a feature near 8.3 µm present only in the varnish, which may result from the transparency of the silicate near the Christiansen peak [7]. It should be noted that these spectra indicate coatings ~10-40 µm thick may dominate the measured thermal infrared signature.

From these data one may conclude that glassy rinds and varnish appear very similar in the thermal infrared region examined (2.5-25 µm). In addition, spectral uniqueness is also a function of the spectral resolution, with lower spectral resolution causing a loss of characteristic spectral detail. The similar appearance may make them practically indistinguishable, although the 8.3 µm feature warrants additional study. The strong similarity may pose a challenge to thermal infrared remote sensing research of Mars. What one may perceive as a glassy basalt may actually be a glassy cooling rind, or it might be a rock varnish or vice versa, or it is possible for a combination to be present. Methods other than thermal infrared spectroscopy may be necessary to differentiate between these possibilities.

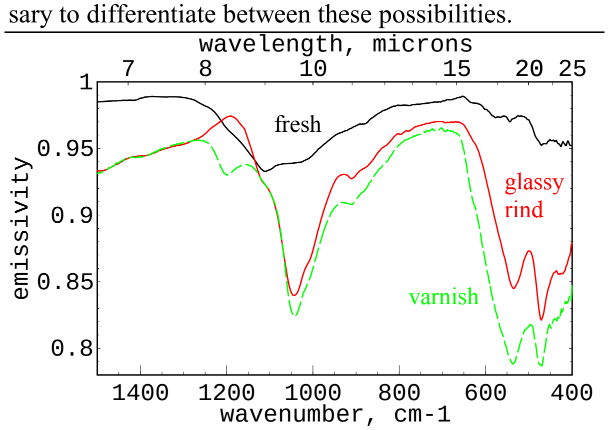

Figure 2: The black (upper) spectrum shows the fresh SP Crater, the red spectrum the SP Crater glassy rind, and the green spectrum the Black Mesa desert varnish spectrum. Biconical reflectance spectra measured by Paul Adams (The Aerospace Corporation), converted to approximate emissivity using 1-reflectance.

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Acknowledgements: We thank William Peck, John Salisbury, and Paul Adams for their thoughtful comments, and Paul Adams for measuring spectra for this project.