MARS ROVER ROCK MEASUREMENTS IN DUSTY ENVIRONMENTS: LESSONS FROM COATED ROCKS IN THE SOUTHWESTERN UNITED STATES.

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Introduction

The Athena payload on the 2001 Mars Surveyor Program Rover will include: stereo camera and emission spectrometer for remote sensing; Mössbauer, Alpha-proton X-ray Spectrometer (APXS), microscope imager, perhaps a Raman Spectrometer for in-situ study of rocks and soils; and a coring and cache system. Viking and Pathfinder results demonstrate that aeolian deposits are abundant on Mars, as discrete dunes, drifts and layers, and as dust coatings draped on rocks. Further, rocks appear to have been smoothed and coated by fine-grained materials with optical properties similar to those for Martian aerosols, e.g., micrometer sized grains with single scattering albedos close to 0.80 **[1]**. Thus, both remote sensing and in-situ measurements of rocks will necessarily include components due to dust and coatings. In an attempt to gain experience in operating and making measurements under such circumstances, we have pursued rover field trials and laboratory measurements for surface rocks in arid, dusty environments that prevail in the southwestern United States **[2]**. In this paper, we concentrate on observations for the Silver Lake and Lavic Lake regions in the Mojave Desert, California, particularly the optical properties of coatings on rocks collected from these areas.

Description of Study Sites and Surface Coatings

Silver Lake playa is located north of Baker in the Mojave Desert of California (figure 1), and is bounded to the west by the Soda Mountains. This range contains both varnished rocks (Precambrian metasedimentary rocks, Lower Cambrian quartzite units, and Pre-Tertiary plutonics which range in composition from gabbro to granite) and uncoated Lower Permian and Cambrian/Precambrian carbonates. Lavic Lake playa is adjacent to the Pisgah and Sunshine Volcanic Fields in the Mojave Desert of southern California (figure 1). The flows in both fields are comprised of a'a basalt covered with an aeolian accretion mantle and desert pavement. Cobbles that comprise the pavement are coated with desert varnish.

Desert varnish is a thin (<50 µm), amorphous film composed of clay mineralogy (typically mixed layer illite-montmorillonite and occasionally kaolinite) and hydrous, manganese and iron oxides. The constituents of varnish are derived from sources external to the rock (airborne dust and suspended components in solution) which are chemically fixed to the rock surface by a biologic agent [**3**]. Field observations indicate that the formation of desert varnish is favored on a stable substrate. Thick varnish coatings are observed on rocks which spall to reveal massive stable surfaces, such as basalts. In general, thin, patchy desert varnish is found on rocks which tend to break down by granular disintegration (e.g. granite). The sparse, thin varnish coatings on smooth rocks, like quartzite, suggests that small-scale surface roughness is a necessary criteria for varnish-forming organisms [**3**]. No desert varnish was observed on carbonate rocks at our field areas since these rocks undergo rapid dissolution as evidenced by their sharp, pitted surfaces.

Absorbance Spectra of Desert Varnish

To investigate the optical properties of desert varnish, thin sections of a varnished dacite porphyry specimen from an alluvial fan on the Sunshine Flow were cut perpendicular to the varnished surface. A microscope was used to align the specimen and a knife-edge aperture masked the image to isolate the varnish component for transmission observations using a Bomem DA3. The measured absorbance, A, is given by the following equation:

$$A = -\log_{10}(I/I_o)$$

where I is the measured radiance through the sample and I_o is the measured initial radiance, both as a function of wavelength The resulting absorbance spectra indicate that varnish is opaque in the visible due to the presence of manganese and iron oxides (figure 2). Several absorption bands were identified and are consistent with the clay constituent of varnish: broad features centered at ~2.9 µm and 6.1µm due to molecular water, a sharp peak at 2.75 µm due to vibrations in the hydroxyl ion, and a symmetric Si-O stretch producing a broad band centered at 9.2 µm.

Skin depth is inversely proportional to absorbance and is defined as the distance light travels for a 1/e attenuation in radiance. Derived values for skin depth indicate low values (18 ± 1 µm) in the visible which confirms the opaque nature of varnish in this wavelength region. In the thermal infrared, skin depth values were ~30 ± 7 µm, which are approaching the maximum varnish thickness observed on the sample (~50 µm).

Remote Sensing of Varnished Rocks

A Landsat Thematic Mapper (TM) false-color composite image of Silver Lake, with bands 2 (0.52 – 0.60 µm), 4 (0.76 – 0.90 µm), 7 (2.08 – 2.35 µm) mapped as blue, green and red respectively, illustrates the opaque nature of desert varnish in visible wavelengths. The quartzite and plutonic suites are both dark, indicating the presence of varnish coatings. The skin depth of varnish in the visible, ~18µm, implies that for surface coating on the order of 50 µm thick, reflected light from a varnished surface is significantly attenuated before it can reach the detector. This explains the opaque appearance of varnished rocks in the 2,4,7 false-color TM image. However, in a Thermal Infrared Multispectral Scanner (TIMS) false color image of Silver Lake with decorrelation stretched bands 1 (8.2 – 8.6 µm), 3 (9.0 – 9.4 µm), 5 (10.2 – 11.2 µm) mapped as blue, green and red, it is easy to distinguish felsic from mafic units. The quartzite unit has a bright red color while the plutonic suite is bluish-green.

The reason these units are easily discriminated in the thermal infrared is related to the areal extent, thickness, and optical properties of desert varnish. The composition of the rock affects the manner in which it weathers which subsequently affects the thickness and continuity of varnish coatings developed. As noted earlier, mafic rocks typically break down in a manner which exposes massive surfaces which are ideal sites for thick varnish to develop. On the other hand, felsic rocks weather to smaller, friable fragments, which are often smooth. These unstable surfaces are not suitable to desert varnish formation and the resulting patinas are thin and discontinuous.

To understand how desert varnish modifies the thermal infrared spectra of the underlying rock, one must determine the emissivity signature of desert varnish. In the thermal infrared region of the absorbance spectra for desert varnish, the Si-O stretch produces a broad asymmetric band which has a steep rise from ~7 µm, peaks at 9.2 µm and has a shallow tail at longer wavelengths (figure 2). Such strong absorptions correspond to high absorption coefficients, high real and imaginary components of the index of refraction and strong reflections called Restrahlen bands. By Kirchoff's Law, these Restrahlen bands correspond to emissivity lows. Thus, the peak emissivity for desert varnish would be in band 1 and rocks with this type of surface coating would appear blue in a TIMS 1,3,5 false-color image. Interestingly, the optical properties of desert varnish are similar to mafic rocks, which characteristically have low emissivities in TIMS bands 3 and 5 **[4]**. Felsic rocks, which typically have patchy desert varnish coatings, have emissivity signatures governed by the rock substrate. In the case of the quartzite unit at Silver Lake, peak emissivity in band 5 results in a bright red color for this unit in a TIMS 1,3,5 false-color composite. Thus, a combination of thin, discontinuous varnish on felsic rocks and the similarities in optical properties of desert varnish with mafic rocks in the thermal infrared enables the discrimination of felsic and mafic rocks in the thermal infrared.

Future Work

A prototype for the 2001 Mars rover Athena payload (FIDO: Field Integration Data and Operations) is scheduled for field testing using multispectral imaging, infrared and Mössbauer Spectroscopy and potentially Raman Spectroscopy at Silver Lake, CA, in December 1998/January 1999 (figure 1). One of the goals of this field exercise will be to measure the spectral properties of surface coatings and to use this data to understand how surface coatings modify the spectra of the underlying rock.

References: **[1]** Guinness, E. A., Arvidson, R. E. and Clark, I. H. D. (1997) *JGR*, **102**, 28,687-28,703. **[2]** Israel, E. J., Arvidson, R. E., Wang, A., Pasteris, J. D., and Jolliff, B. L, (1997) *JGR*, **102**, 28705-28716. **[3]** Dorn, R. I. And Oberlander, T. M. (1982) *Progress in Physical Geography*, **6**, 317-367. **[4]** Rivard, B. and Petroy, S. B., (1993) *IEEE Transactions on Geoscience and Remote Sensing.* **31, no. 1,** 284-290. **[5]** Grose, L. T. (1959) *GSA Bull.*, **80**, 1509-1548.

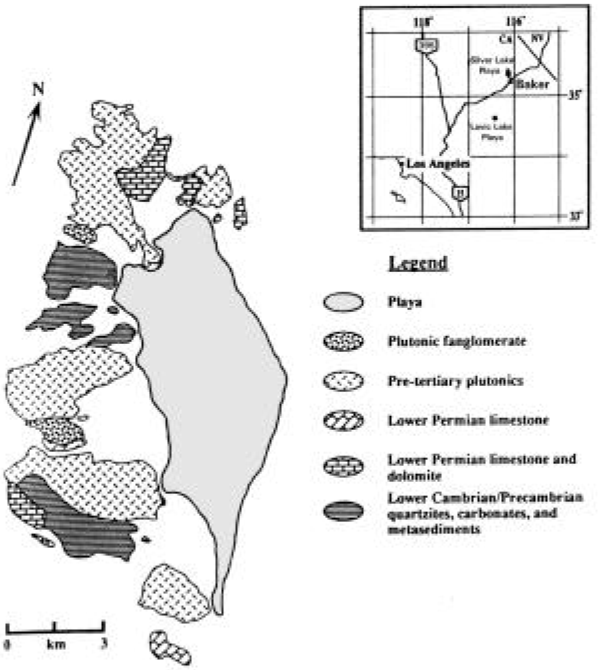

Figure 1: Geologic map of Silver Lake, CA, based on work done by **[5]**. Inset shows location of Silver Lake and Lavic Lake, CA. Figure from **[4]**.

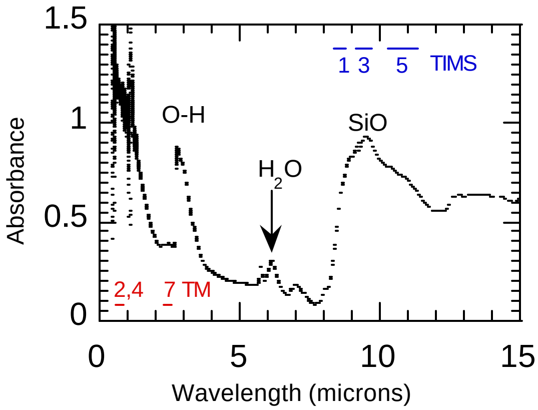

Figure 2: Absorbance spectra of desert varnish. Absorbance bands are consistent with the clay, managanese and iron oxide composition of desert varnish. The wavelength regions for Landsat TM are labeled in red while the TIMS bands are labeled in blue.