Remote-sensing techniques for mapping desert pavements

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SUMMARY:

Desert terrain is commonly rocky and darkened by a mineral coating known as rock varnish, a precipitate of silica with admixture of illite clay and Fe & Mn oxides. Desert pavements are the best developed such surfaces, in which a single layer of clasts shields a layer of aeolian silt/clay. These surfaces are attractive to drive on when dry. However, vehicles easily disrupt the "pavement," exposing the silt below to erosion, and when wet the silt layer turns to impassable mud. Recognizing the stage of a desert surface in its evolution to pavement is thus important for trafficability models.

The varnish is one way to estimate relative age, since it grows over time. With remote sensing, spatial integration is straightforward, but basic studies need to be completed before exploitation is possible. In this study, different approaches were taken, and two are reported here.

Modeling absorption: do varnished clasts behave like nonlinear mixtures of varnish and substrate, or linear mixtures?

Oblique images: what spectral characteristics can be exploited in oblique imaging from cameras in a tactical setting?

Young, thin coats can be modeled as nonlinear mixtures, permitting coating depth to be estimated. Thicker coats are best modeled as "checkerboard" models of opaque varnish and unvarnished substrate. Both can be exploited to devise a relative age scheme.

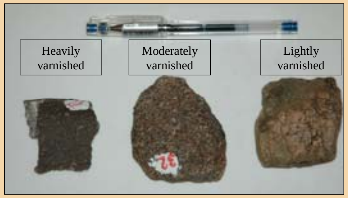
Clasts on an older (QG_2) alluvial fan, Trail Canyon, Death Valley, CA, are covered by rock varnish. The coating thickens with time and is composed of silica contaminated with clay and Fe/Mn oxides. Looking east.

Desert pavement showing silt layer exposed in soil pit 20 cm across.

CH53 at Rhino in the dust of its own rotor wash

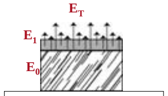
Pavement surfaces become dust sources after damage. When wet they become muddy and impassable.

- Clasts are generally smooth on top surface. Usually of silicate compositions.
- Dark varnish preferentially fills in pits. Even for heavily varnished rocks, 'topographically high' features can be unvarnished. Varnish can be discontinuous on sub-mm to cm horizontal scale. Thickness rarely exceeds 100 μm.
- Consists of multiple depositional layers. Matrix is an amorphous silica, colored by MnO, with ~ 10-20% illite dominating TIR spectrum.



Spectral modeling

The mineralogical composition of varnish is different from the substrate. Varnish consists of silica, clay, and metal oxides. The silicate components are active in the thermal infrared (8-14 μm); the metals are active in the visible/near-infrared (0.4-1.4 μm). Varnish begins as small, scaly deposits in pits on rock surfaces. With time, it thickens and the scales grow to meet and cover more of the surface. Two processes are involved: 1) nonlinear due to absorption in the thickening varnish, followed by reflection from the substrate back through the varnish (left); and 2) linear or additive mixtures of opaque varnished and unvarnished substrate (right).



Varnished rock

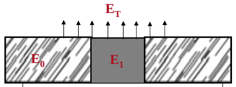
E_T, the energy emitted is a **Non-Linear** combination from the rock substrate and clay-rich varnish.

$E_T = E_o T_c + E_1(1-T_c)$ (non-scattering)

where $T_c = (1-R_1)(1-R_2)e^{-kx}/(1-A)$,

$A = R_1 R_2 e^{-2kx}$, $R = [(n-1)^2+k^2]/[(n+1)^2+k^2]$.

'x', 'n', 'k' are varnish thickness, and the indices of refraction for each material.



Mixed rock and clay soil

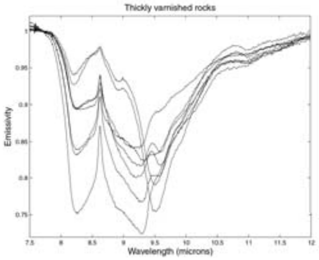
E_T, the energy emitted is a **Linear** combination from the rock and soil.

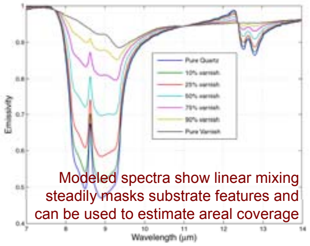
$E_T = E_o f_0 + E_1(1-f_0)$

'f_o' is the fractional area covered by the bare rock.

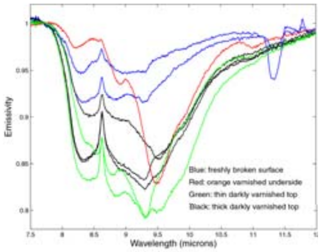
These models predict different spectra from varnished surfaces as they age.

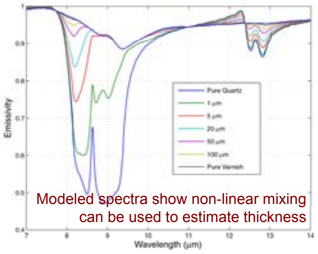
Laboratory and Model Spectra of Varnished Rocks





Modeled spectra show linear mixing steadily masks substrate features and can be used to estimate areal coverage



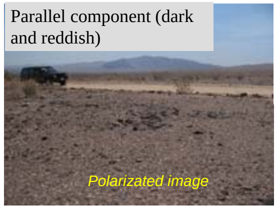


Modeled spectra show non-linear mixing can be used to estimate thickness

A combination of linear and non-linear models can be used to estimate total varnish "cover," but this was not implemented.

Oblique imaging

In tactical settings, imaging must often be stand-off and oblique. This often reduces spectral contrast because of Fresnel reflections, but it increases polarization. Varnished surfaces are smooth and reflect well: can their degree of polarization also be used to estimate varnish cover, this time in the VNIR instead of the TIR?

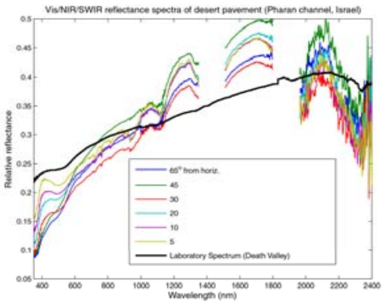


Parallel component (dark and reddish)

Polarizated image

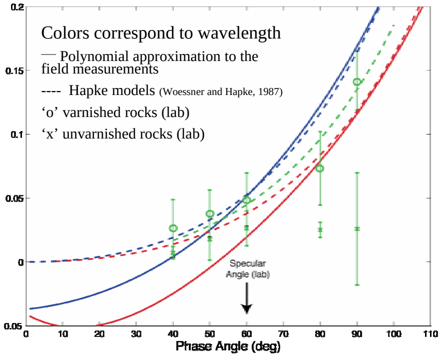
Perpendicular component (bright and blueish)

Polarized image

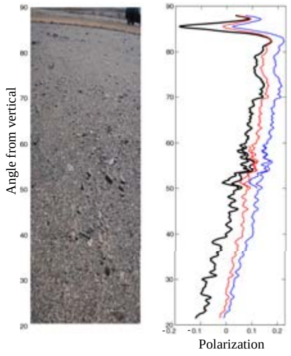


VNIR spectra of varnished pavements at different look angles show mainly lightening and some loss of spectral contrast as the look angle increases (oblique imaging). Spectral analysis is feasible even in oblique images; however, varnish is not distinctive in the VNIR.

"Explaining" the polarization



Including color with polarization



Combining color and polarization:

$$P_c = \frac{(R_B\_perp - R_R\_par)}{(R_B\_perp + R_R\_par)}$$

Color polarization (P_c)

1. Specular reflection is ~ independent of wavelength and thus emphasizes the blueness of natural objects that are otherwise red.
2. Combining blueness and polarization emphases the differences between natural surfaces that polarize and those that do not.
3. Caution: water and sky.

Sponsors

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