

PALAGONITIC MARS: A BASALT CENTRIC VIEW OF SURFACE COMPOSITION AND AQUEOUS ALTERATION.

R. V. Morris¹, T. G. Graff², D. W. Ming¹, J. F. Bell III³, L. Le⁴, S. A. Mertzman⁵, P. R. Christensen², ¹NASA Johnson Space Center, Houston, TX 77058 (richard.v.morris@nasa.gov), ²Dept. of Geol. Sci., Arizona State University, Tempe, AZ 85287, ³Dept. of Astronomy, Cornell University, Ithaca, NY 14853, ⁴Lockheed Martin, Houston, TX 77058, ⁵Dept. of Geosci., Franklin and Marshall College, Lancaster, PA 17604.

Introduction: Palagonitic tephra from certain areas on Mauna Kea Volcano (Hawaii) are well-established spectral and magnetic analogues of high-albedo regions on Mars [e.g., 1-6]. By definition [7], palagonite is “a yellow or orange isotropic mineraloid formed by hydration and devitrification of basaltic glass.” The yellow to orange pigment is nanometer-sized ferric oxide particles (np-Ox) dispersed throughout the hydrated basaltic glass matrix [4-6]. The hydration state of the np-Ox particles and the matrix is not known, but the best Martian spectral analogues contain allophane-like materials and not crystalline phyllosilicates [6]. Martian low-albedo regions are also characterized by a palagonite-like ferric absorption edge, but, unlike the high-albedo regions, they also show evidence for absorption by ferrous iron.

Thermal emission spectra (TES) obtained by the Mars Global Surveyor Thermal Emission Spectrometer suggest that basaltic (surface Type 1) and andesitic (surface Type 2) volcanic compositions preferentially occur in southern (Syrtis Major) and northern (Acidalia) hemispheres, respectively [8-10]. The absence of a ferric-bearing component in the modeling of TES spectra is in apparent conflict with VNIR spectra of Martian dark regions, as discussed above. However, the andesitic spectra have also been interpreted as oxidized basalt using phyllosilicates instead of high-SiO₂ glass as endmembers in the spectral deconvolution of surface Type 2 TES spectra [11].

We show here that laboratory VNIR and TES spectra of rinds on basaltic rocks are spectral endmembers that provide a consistent explanation for both VNIR and TES data of Martian dark regions.

Samples and Methods: Basaltic rock HWMK124, which was collected at an elevation of ~4000 m on Mauna Kea Volcano (Hawaii), has a brown rind over the entire exterior surface. Two thick sections containing the rind and adjacent rock were made from small slabs cut normal to the exterior surface. One rind appeared tough and coherent (Type 1 rind) and the other more porous (Type 2 rind). A 500-1000 μm size fraction was prepared from interior rock by grinding and wet sieving (ethanol). Previous results on this rock are reported by [12, 13]. Analytical methods are described by [e.g., 5, 14], except for microprobe analyses which were done using a Cameca SX100 Electron Microprobe.

Results: Major element concentrations are shown in Table 1. Although HWMK124 is basaltic in bulk composition, the rinds are enriched in SiO₂. The oxide totals for the two rinds are considerable less than 100%, presumably because of water and pore space. The Type-2 rind is enriched in Fe₂O₃ and Al₂O₃ and depleted in SiO₂ in relative to the Type 1 rind. This trend is observed for Mauna Kea palagonitic tephra, and it implies that the Type 2 rind has undergone a higher degree of aqueous leaching than the Type 1 rind. From XRD powder diffraction patterns, the crystalline phases in bulk rock are plagioclase feldspar, olivine, pyroxene, ilmenite, and minor quartz.

Element maps for selected major elements are shown in Figure 1. The rinds (20-50 μm thick) are clearly demarcated by the high-SiO₂ regions. The glassy, amorphous nature of the rind is indicated by the absence of mineral inclusions. The cracks and incipient spalling of a rind segment (arrows) are manifestations of the higher porosity of the Type-2 rind. For both rinds, the SiO₂

concentration decreases right at the exterior surface, consistent with aqueous leaching subsequent to rind formation. The depleted zone is thicker in Type-2 rind, which is consistent with its lower measured SiO₂ concentration (Table 1).

Table 1. Major element concentrations in wt.%.

	Bulk Interior [§]	Type 1 Rind	Type 2 Rind
SiO ₂	48.30	66.72	61.98
TiO ₂	3.27	0.94	1.19
Al ₂ O ₃	13.45	9.54	10.72
Fe ₂ O ₃ T	14.72	4.42	5.53
MgO	5.86	0.87	0.69
CaO	10.70	0.92	0.97
Na ₂ O	2.69	0.20	0.22
K ₂ O	0.75	0.27	0.35
P ₂ O ₅	0.40	0.34	0.44
Total	100.46	84.30	82.18

[§]LOI = 0.76%, FeO = 11.62%, and Fe₂O₃ = 1.81%

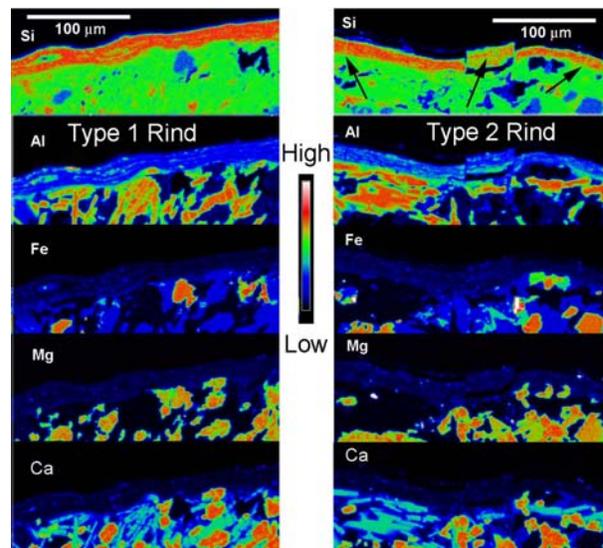


Figure 1. Major element maps for Type 1 and Type 2 rinds.

Figure 2a shows VNIR spectra for the rinds and the size fraction (500-1000 μm) derived from interior rock. The size fraction spectrum is nearly flat with a minimum near 1020 nm from Fe²⁺ in olivine. The spectra for both rinds are virtually identical and are characterized by a ferric absorption edge (~350-760 nm) resulting from nanophase ferric oxide particles [e.g., 4,5] and an olivine band near 1020 nm. Significant ally, the rind does not obscure the Fe²⁺ spectral feature.

The corresponding TES spectra (Figure 2b) show that the spectra for the size fraction of (unaltered) interior rock and the Type-1 rind are essentially identical in the range ~1300-200 cm⁻¹. That is, with respect to detection of unaltered rock material, the Type-1 rind is essentially transparent. The Type-2 rind, however, essentially blocks detection of underlying rock. This difference in behavior is not understood, but the opacity of the Type-2 rind may be related to its higher porosity and weaker coupling to underlying rock.

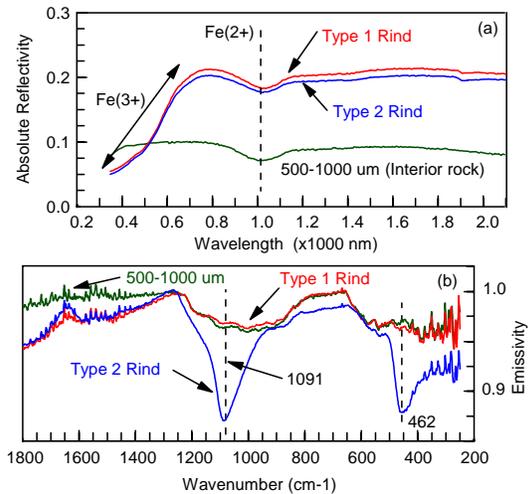


Figure 2. VNIR (a) and TES (b) spectra for Type 1 and 2 rinds.

The general shape of the Type-2 rind spectrum (reststrahlen bands near 1091 and 462 cm^{-1}) is similar to that for other amorphous or poorly-crystalline materials (e.g., allophane, glass, and opal-CT), and the absence of a band near 530 cm^{-1} implies crystalline phyllosilicates are not present [e.g., 13]. The feature at 1091 cm^{-1} is the “B” feature described by [15-17] for Mauna Loa and Kilauea basaltic rocks. The TES spectra for the Type-2 rind and the high-SiO₂ (obsidian) endmember used to model Mars surface Type 2 are nearly equivalent.

Applications to Mars: In Figure 3 we compare VNIR and TES spectra for martian surface Type 1 and Type 2 regions and for Type 1 and Type 2 rinds for basaltic rock HWMK124. For VNIR spectra (Figure 3a), the two rind spectra are essentially the same and so are the two surface spectra. The ferric absorption edges for both rind and surface are essentially identical, but their Fe³⁺ mineralogy is different, and evidenced by the $\sim 1020\text{ nm}$ minimum (olivine) for the rock and $\sim 950\text{ nm}$ minimum (pyroxene) for the martian surface. That is, both rock and planet are characterized by weathered surfaces for which the spectral signature of the ferrous component can be detected.

As just discussed, the VNIR evidence is that surface Types 1 and 2 are both covered with weathered surface materials, or are at least aerial mixtures of weathered and not weathered surface units. The analyses of [8-10], however, imply that both regions are unaltered surface units, with surface Types 1 and 2 being basaltic and andesitic, respectively. Part of this conflict is resolved if we accept the analysis of [11] that the surface Type 2 can be interpreted with a phyllosilicate (instead of high-SiO₂ glass) endmember. These seemingly contradictory results are possible because the spectral region where the phyllosilicates and high-SiO₂ glass can be distinguished ($\sim 532\text{ cm}^{-1}$) is excluded for surface modeling by atmospheric CO₂ [e.g., 8]. The spectrum for the Type 2 rind can also be used as an endmember, allowing surface Type 2 to be a weathered surface that has no phyllosilicates. Thus, there is no conflict between VNIR and TES results for surface Type 2 if the surface is weathered and Type 2 rinds are present.

The apparent conflict for surface Type 1 is resolved if the surface is weathered and Type 1 rinds are present. This is possible because Type 1 rinds are transparent in TES spectra, giving the appearance of an unaltered surface when it is actually altered. We suggest that palagonitic material is favored over phyllosilicates for the weathered martian surface because of the absence of

strong phyllosilicate H₂O/OH features near 1400 and 1900 nm [e.g., 18, 19] and the presence of a ferric absorption edge.

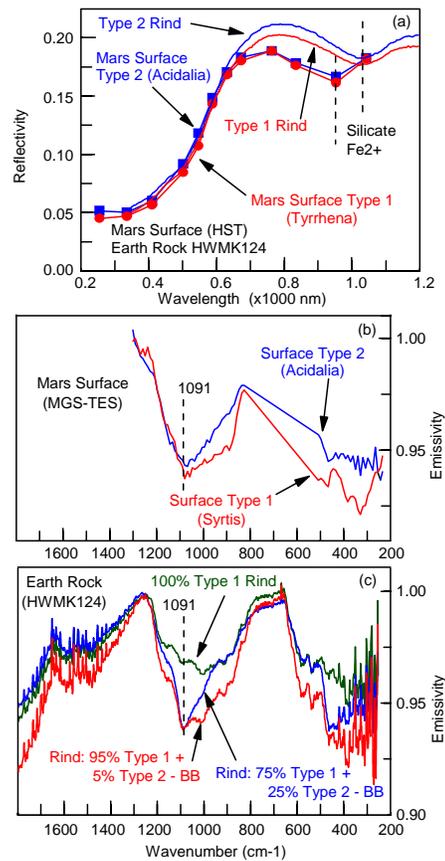


Figure 3. VNIR (a) and TES (b, c) spectra for Mars and for rinds on basaltic rock HWMK124.

Figures 3b,c show that the TES spectra for Type 1 and 2 rinds can be used with linear mixing to approximate the martian surface Type 1 and 2 spectra. The martian surface spectra [8] are shown in Figure 3b. Spectra for pure Type 1 rind and linear mixtures of 95% Type 1 rind + 5% Type 2 rind and 75% Type 1 rind + 25% Type 2 rind are shown in Figure 3c. The mixture spectra were adjusted with a blackbody component to make their emissivity the same at $\sim 1091\text{ cm}^{-1}$. The linear mixtures with 95% and 75% Type 1 rind approximate the shape of martian surface Types 1 and 2, respectively. This simple example shows that Mars can be entirely basaltic in composition and be weathered everywhere without the presence of phyllosilicates.

References: [1] Evans and Adams (1979) *PLPSC*, 10, 1829. [2] Singer (1982) *JGR*, 87, 10159. [3] Morris et al. (1990) *JGR*, 95, 14427. [4] Morris et al. (1993) *GCA*, 57, 4597. [5] Morris et al. (2000) *JGR*, 105, 1757. [6] Morris et al. (2001) *JGR*, 106, 5057. [7] Bates and Jackson (1984) *Dict. Geol. Terms*, Doubleday, NY. [8] Bandfield et al. (2000) *Science*, 287, 1626. [9] Christensen et al. (2001) *JGR*, 106, 23823. [10] Hamilton et al. (2001) *JGR*, 106, 14733. [11] Wyatt and McSween (2002) *Nature*, 417, 263. [12] Morris et al. (2003), *LPSC34*, #1874. [13] Morris et al, *Sixth International Conference on Mars*, Abstract #3211, 2003. [14] Ruff S. W. et al. (1997) *JGR*, 102, 14899. [15] Kahle et al. (1988) *JGR*, 93, 15,239. [16] Kahle et al. (1995) *Mauna Loa Revealed*, Geophys. Monograph 92, 145. [17] Crisp and Bartholomew (1992) *JGR*, 97, 14,691. [18] Mustard et al. (1997), *JGR*, 102, 25605. [19] Murchie et al. (1993) *Icarus*, 105, 454-468.