

A COMPARISON OF THE VISIBLE AND NEAR INFRARED REFLECTANCE OF HYDROVOLCANIC PALAGONITE TUFFS AND MARTIAN WEATHERED SOILS

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The visible and near infrared reflectance of martian weathered soils, abundant in the bright regions, have been shown to resemble certain examples of the X-ray amorphous mineraloid palagonite (e.g., [1,2]). To date, most comparisons between terrestrial palagonites and martian telescopic spectra have been done using palagonites that were formed under ambient semi-arid weathering conditions on Hawaiian volcanoes such as Mauna Kea [1,2]. Here we examine palagonites associated with the tephra deposits that make up tuff rings and tuff cones. Tuff rings and tuff cones result from hydrovolcanic activity, defined as the interaction of magmas (in this instance, of basaltic composition) with surface or near-surface water [3]. Tuff rings and tuff cones can contain variable amounts of country rock and juvenile crystals, but their primary constituent is fine grained sideromelane (basaltic glass). Sideromelane alters to palagonite. Unlike the aforementioned Hawaiian palagonites, the alteration of sideromelane to palagonite seems to occur relatively rapidly in tuff cones, on the order of days to months [3,4]. In comparing the spectra of hydrovolcanically produced palagonites with telescopic spectra of Mars, one is struck by their similarity in the VNIR and dissimilarity in the SWIR.

Figures 1 and 2 present overlays of several palagonite tuff sample spectra with bright region spectra. The palagonite tuff samples come from the Cerro Colorado tuff cone located in the Pinacate volcanic field of Sonora, Mexico and from the Pavant Butte tuff cone of Millard County, Utah. The Mars bright region spectrum in Figure 1 is an average of 8 spectra from Arabia collected during the 1988 opposition [5]. The spectrum in Figure 2 is an average of 3 bright region spectra (Aeolis, S. Elysium, and Amenthes) collected during the 1978 opposition [6]; the data shortwards of 0.7 μm are an average of bright region spectra collected in 1969 [7]. All spectra are scaled to 1.0 at 0.79 μm .

There is a very good correspondence between the position and slope of the UV/Vis Fe^{3+} absorption edge of the Cerro Colorado sample CC-2c and that of the Arabia spectrum. Differences that can be noted include the presence of a distinct 0.48 μm band in the tuff cone spectra and its absence in the Arabia spectrum. This absorption can be ascribed to the ${}^6\text{A}_1 \rightarrow ({}^4\text{E}, {}^4\text{A}_1)$ electronic transition of the Fe^{3+} ion [8], possibly occurring in the tuff sample due to poorly- to well-crystalline goethite and perhaps nontronite. To date, this feature has not been observed in telescopic spectra of Mars. There is also a shoulder in the tuff cone spectra centered at 0.68 μm which can be attributed to the ${}^6\text{A}_1 \rightarrow {}^4\text{T}_2$ Fe^{3+} transition [8]. There is a weak indication of this feature in the Arabia spectrum [5] and this absorption has been noted in other telescopic spectra (e.g. [1,7,9]).

There is a disparity between Arabia (1978 and 1988) and most of the 1969-1978 bright region spectra in the 1 μm region. The Arabia spectrum trends downward in a fashion consistent with a reflectance minimum near 0.98 μm . This is close to the "1 μm " band center for the PB-2b sample at 0.974 μm [4]. In contrast, the 1978 bright region average shows a band minimum near the 0.93 μm band center of the CC-2c sample. Farrand and Singer [4] noted that differences in the "1 μm " band center of palagonite tuffs are related to the degree of oxidation of the constituent sideromelane. In the CC-2c sample, the sideromelane is nearly completely altered to palagonite; thus the "1 μm " band center is more reminiscent of a ferric oxide phase such as a goethite. In the PB-2b sample, there still exist remnants of Fe^{2+} bearing sideromelane, thus its "1 μm " band center is skewed to longer wavelengths.

What is occurring on the scale of individual pyroclasts in the palagonite tuffs might also be happening on the surface of Mars. That is to say that most bright regions observed in 1978 and before probably have a more uniform coating or soil layer of nearly completely altered palagonitic material than does Arabia. This tendency of Arabia to exhibit traits intermediate between light and dark regions was discussed by McCord et al. [6]. Those authors noted that Arabia probably has more exposed dark materials than other bright regions or perhaps a larger component of Fe^{2+} bearing grains (pyroxenes or sideromelane fragments) admixed in its soils. Recent interpretations of reflectance spectra from the Phobos ISM instrument support this evidence for compositional variety among martian weathered soils [10].

Beyond about 1.2 μm , the resemblance between the palagonite tuff and the martian bright region spectra ends. The continua of the palagonite tuff spectra are convex in the SWIR, punctuated at 1.4 and 1.9 μm by strong OH and H_2O absorptions and a strong fall-off in reflectance approaching the water and OH absorptions centered near 3.0 μm . In contrast, the average bright region spectrum is relatively flat beyond 1.2 μm with a strong

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atmospheric CO₂ band at 2 μ m, and weaker CO₂ absorptions near 1.45 and 1.62 μ m. A weak but important absorption feature near 2.36 μ m was first noted in telescopic data for Mars [6, 11]. Clark et al. [12] have observed and analyzed this feature in greater detail, and conclude that it is due in part to martian atmospheric CO, but with good evidence for a surface mineral absorption as well, suggested by them to be scapolite.

The palagonite tuff spectra display a distinct absorption at 2.29 μ m which is tentatively assigned to a combination overtone of the Fe-OH bending fundamental within the smectite clay mineral nontronite. Nontronite, perhaps admixed with poorly crystalline goethite, could also be responsible for the 0.48 μ m and 0.68 μ m features in the palagonite tuff spectra. Clark et al. [13] observed a 2.29 μ m absorption in Hellespontica that was consistent with the nontronite band, but otherwise a 2.29 μ m feature with band parameters consistent with nontronite has not been seen on Mars [1, 11].

The dissimilarity of palagonite tuff and martian telescopic spectra longwards of 1.2 μ m can be attributed in large part to what is probably a greater degree of crystallinity within the terrestrial tuffs than within the martian soils. The southwestern palagonite tuffs formed in semi-arid environments but with abundant ground water and, in the case of Pavant Butte, in a standing lake. At one time conditions on Mars may have been conducive to the formation of this variety of palagonite. However, over most of its history Mars has been considerably drier. Thus, models for palagonite formation on Mars involving semi-arid ambient weathering, or other alteration involving low temperatures and minimal water, seem more appropriate for explaining the ubiquitous weathered soils.

[1] Singer, R.B., *J. Geophys. Res.*, 87, 10,159-10,168, 1982; [2] Evans, D.L. and J.B. Adams, *Proc. Lunar Planet. Sci. Conf. 10th*, 1829-1834, 1979; [3] Wohletz, K.H. and M.F. Sheridan, *Am. J. Sci.*, 283, 385-413, 1983; [4] Farrand, W.H. and R.B. Singer, *J. Geophys. Res.*, 97, 17,393-17,408, 1992; [5] Singer, R.B. et al., *Lunar Planet. Sci. Conf. 11th*, 1154-1155, 1990; [6] McCord, T.B., et al., *J. Geophys. Res.*, 87, 3021-3032, 1982; [7] McCord et. al., *Icarus*, 31, 25-39, 1977; [8] Morris, R.V. et al., *J. Geophys. Res.*, 90, 3126-3144, 1985; [9] Bell, J.F. III, et al., *J. Geophys. Res.*, 95, 14447-14461, 1990; [10] Murchie et al, *LPI Tech. Report 92-04*, 23-25, 1992; [11] Singer et al., *Lunar Planet. Sci. Conf.*, 16th, 787-788, 1985; [12] Clark, R.N. et al., *J. Geophys. Res.*, 95, 14463-14480, 1990.

