

HIGH-SILICA ROCK COATINGS: TES SURFACE-TYPE 2 AND CHEMICAL WEATHERING ON MARS. M. D. Kraft, J. R. Michalski and T. G. Sharp, Department of Geological Sciences, Arizona State University, Tempe, AZ 85287-1404; mdkraft@asu.edu.

Introduction: Knowledge of chemical weathering processes on Mars is important for understanding the geologic history of Martian soils and dust and the global history of water. We are investigating high-silica rock coatings as a potential product of aqueous weathering on Mars [1]. Silica coatings may be responsible for certain global-scale observations made by the Thermal Emission Spectrometer (TES). Using terrestrial silica coatings as an analog, we suggest that the essential conditions required for silica coating formation may exist on Mars. Here, we discuss a basic mechanism of silica-coating formation on Martian rocks how these coating might impact spacecraft observations of Mars.

Silica rock coatings on Earth: Silica coatings are accretions of amorphous silica on rock surfaces. They are similar to rock (desert) varnish in that coatings are formed from exogenous material that is pasted onto the rock surface and, thus, differ from weathering rinds, in which the chemistry and mineralogy of the rock changes in situ in response to aqueous attack. An excellent overview of the subject of silica rock coatings can be found in R. Dorn's book, *Rock Coatings*, in a chapter on "silica glaze" [2]. Silica coatings form in a broad range of environments, including warm deserts, fore-glacial areas, and the cold deserts of Antarctica [2]. Silica coatings vary widely in their chemistry and mineralogy. Dorn defines silica glaze subtypes based on the relative amounts of SiO_2 , Al_2O_3 , and Fe_2O_3 —the principal chemical constituents of silica coatings—and the amount of detrital material embedded in the coatings. Silica coatings are composed mainly of amorphous silica, but Al_2O_3 can comprise 10s of percent by weight, and Fe_2O_3 nearly 10 wt% [2].

Formation of silica rock coatings has been most closely studied for arid regions of Hawaii [3,4]. There, silica is dissolved from tephra and dust that is in contact with rocks. The silica is transported in aqueous solution to rock surfaces and precipitated. Late-stage precipitates (e.g., salts) may also form but are destroyed by later wetting events. Small amounts of water are needed to form silica coatings in this way; excessive water destabilizes silica's ability to bond to rock surfaces [2]. In a general sense, two things are needed to form high-silica coatings: (1) silicate material that is susceptible to chemical breakdown and in contact with rock surfaces, and (2) small amounts of liquid water.

Silica rock coatings on Mars: There is abundant rock-dust interaction at the Martian surface and a portion of the dust may be silicates susceptible to aqueous dissolution. Also, small amounts of liquid water may have been available at the Martian surface. Thus, the conditions requisite to form silica coatings appear possible and high-silica rock coatings may have formed on Mars [2].

Weathering of Martian fines. Atmospheric dust regularly coats Martian rocks. To form silica coatings, silica must be dissolved from dust particles, transported to a rock or particle surfaces, and precipitated. For this to happen, the dust must contain silicate particles that are out of thermodynamic equilibrium and susceptible to chemical weathering. Although the origin and mineralogy of Martian dust is poorly constrained, it is reasonable to expect that it would contain primary silicate phases that would be susceptible to aqueous weathering. The dust is likely to have input of basaltic minerals—olivine, pyroxene, plagioclase, basaltic glass—from comminution of mafic rocks by impacts or physical abrasion, as well as some pyroclastic influx of basaltic tephra [5]. Some of these phases, particularly glasses, would be susceptible to weathering reactions.

Well-substantiated chemical alteration products are found in Martian soils and dust. These include Fe(III)-oxides or oxyhydroxides [6], carbonates [7], and chloride and sulfate salts inferred from lander chemical measurements [8]. These authogenic materials may have become concentrated in Martian fines by physical breakdown of weathering rinds or more extensive aqueous deposits. Alternatively, these minerals may be concentrated in fines because that is where they formed. Because of their greatly enhanced surface area, fine-grained materials would be highly susceptible to aqueous attack compared to rocks or sands, especially if alteration occurred under a low water-rock ratio. Additionally, wind-transported fines could have relocated to regions of the Martian surface that were amenable to chemical weathering. With continued eolian cycling fines, fresh fine-grained materials could be transported to these regions where weathering processes operate. During 100s-of-My of combined eolian and chemical reworking, Martian fines may have become not only uniformly mixed [9], but uniformly weathered.

Occurrence of water. The occurrence of silica coatings, if they exist on Mars, should be closely tied to the occurrence of water. The regions of Mars that we suggest have silica-coated rocks—the areas mapped as surface-type 2 (ST2) with TES data [10]—occur primarily at mid-to-high latitudes. The occurrence of liquid water films on Mars is modeled to have a latitudinal dependence [11]. Observations of the Martian surface layer show latitudinally dependent features. Features identified in latitudinally dependent terrains suggest that water ice has occupied near-surface soil pore space at mid-latitudes [12]. The Mars Odyssey Neutron Spectrometer results show subsurface ice at higher latitudes [13]. Recently formed gulleys, which are likely formed by water, are found in mid-latitude regions [14]. Putative snow packs are seen above 30° latitude [15]. Collectively, these

features, as well as others that show a latitudinal dependence, indicate the presence of water, and occur poleward of 30° latitude in both hemispheres [16]. (The approximate latitudinal extent of the unaltered, basaltic TES surface-type 1, ST1, is 0-30° [17]). It is in these areas, where water ice occurs, that liquid water would most likely form. The gulleys indicate that liquid water, in fact, does form in these regions, at least periodically. It is doubtful that enough liquid water would have been present to extensively weather rocks. However, small amounts of liquid water could have been available to weather fine particulates and mobilize silica [18].

Formation. Martian fines contain weatherable silicate materials and mid-to-high-latitude regions of Mars likely have had liquid water available to facilitate weathering and chemical transport. In our model, transient liquid water at dust-rock (or dust-sand) interfaces could dissolve silica from dust particles, transport the silica to rock surfaces, and precipitate silica to form a coating. Dissolution of silica would be coupled with other weathering reactions, such as Fe oxidation and carbonate formation. Cycling dust and repeating this process, silica coatings would be constructed over time.

Silica coatings and TES: TES ST2 spectra may result from high-silica rock coatings adhered to basaltic rocks. In order to test this hypothesis, we have performed laboratory experiments to determine the effects that silica coatings have on thermal emission spectra of basaltic rock [1]. We coated polished slabs of basalt with silica by applying a mist of colloidal silica solution to the basalt surface and allowing it to evaporate. Coatings were built up by repeating this process and we produced several samples with silica coatings of different thicknesses. We then acquired thermal emission spectra of the silica-coated basalt slabs at 2 cm⁻¹ resolution over the 200-2000 cm⁻¹ range. The results show that the coatings of pure silica that we used cannot explain TES ST2 spectra because the silica absorption occurs at too short a wavelength. However, coatings dominated by silica but containing other constituents (e.g., coatings of aluminous opal) may have absorption features consistent with TES ST2 and would be chemically more similar to silica coatings found on Earth.

Two results for thermal emission spectroscopy of silica coated rocks are important for TES observations of Mars. First, small amounts of high-silica material occurring as a rock coating could produce ST2 surfaces. Coatings of pure silica ~7-10-μm thick effectively mask the underlying basaltic substrate in thermal emission spectra. We estimate that silica-dominated coatings ~1-μm-thick could result in the ST2 spectrum. Such thin coatings could be formed by aqueous release of small amounts of silica from Martian dust. Thin silica coatings on Mars would be consistent with a weathering regime characterized by exceedingly low amounts of liquid water and/or exceedingly slow kinetics.

Second, coating material and basaltic substrate combine nonlinearly in emission spectra. In our silica-coating hypothesis for ST2, we assume that the substrate rocks of ST2 are mineralogically and spectrally the same as ST1 rocks, meaning that the differences between the two results only from a surface coating on ST2 rocks. Thus, this nonlinearity of spectral mixing is important because TES surface-type 2 is not a linear combination of surface-type 1 and a high-silica material. ST2 may, therefore, be a high-silica-coated ST1 surface. However, further study is needed to understand whether this nonlinearity is entirely consistent with rock coatings of impure, aluminous silica.

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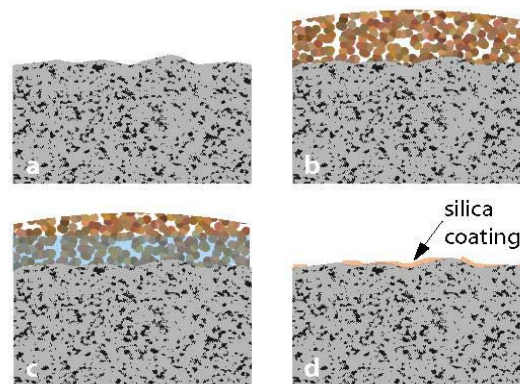


Figure 1. Formation of high-silica rock coatings on Mars. (a) Exposure of rock surface; (b) Deposition of dust onto rock surface; (c) Thin films of liquid water form between dust grains along the dust-rock interface. Silicate dust particles are aqueously altered, including Fe oxidation, and silica dissolution and mobilization; (d) Silica is deposited onto the rock surface. Repeating this process will construct a silica-rich coating over time.