In light of these findings and their conflict with the standard dust model, we have modified a doubling-and-adding code [8] to reanalyze the Mariner 9 IRIS spectra of Mars atmospheric dust as well as Viking IRTM EPF sequences in the 7-, 9-, and 20-µm channels. The code is capable of accurate emission/absorption/scattering radiative transfer calculations over the 5–30-µm wavelength region for variable dust composition and particle size inputs, and incorporates both the Viking IRTM channel weightings and the Mariner 9 IRIS wavelength resolution for direct comparisons to these datasets. We adopt atmospheric temperature profiles according to the algorithm of Martin [3] in the case of the Viking IRTM comparisons, and obtained Mariner 9 IRIS temperature retrievals from the 15-µm CO_2 band (as well as IRIS spectra of dusty periods, courtesy of J. Pearl and W. McMillan) for the case of the IRIS comparisons. We consider palagonite as the primary alternative to the montmorillonite composition of Mars atmospheric dust, based on several considerations. Palagonite absorbs in the ultraviolet and visible wavelength region due to its Fe content. Palagonite is also, in principal, consistent with the observed lack of clays on the Mars surface. Furthermore, palagonite does not display strong, structured absorption near 20 µm as does montmorillonite (in conflict with the IRIS observations). We were provided optical constants for a particular specimen of Hawaiian palagonite by T. Roush for the 5–30-µm wavelength of Hawaiian palagonite by T. Roush for the 5–30-µm wavelength region, and derived 0.3–5.0-µm constants for the same sample from Clark et al. [9].

We summarize the conclusions of our study as follows: (1) The Viking EPF visible and 9-µm sequences yield a visible-to-IR dust extinction ratio of ~2, consistent with the analysis of Martin [3]. This provides the first coincident, contemporaneous measurement of the visible-to-IR opacity ratio for Mars atmospheric dust. (2) Palagonite dust with a 1.2-µm cross-section weighted mean radius (mode radius = 0.15 µm) leads to visible single-scattering albedos consistent with their observed values at ultraviolet and visible wavelengths. Hence a single component composition for Mars atmospheric dust can explain all the existing observations of the dust within their uncertainties. (3) Such palagonite dust also leads to a much improved fit to the IRIS observations near 20-µm wavelengths. However, the particular sample of palagonite modeled does not fit the 8–9-µm region. (4) The ratio of 9- and 20-µm absorption for the palagonite or montmorillonite composition is very different for a 1.2- vs. a 2.5-µm mean cross-section weighted particle radius. (5) Palagonite dust with the 1.2-µm cross-section weighted mean radius also yields a visible-to-IR extinction ratio of 2, consistent with the measurements of this ratio, as well as the Phobos near-IR extinction observations. (6) A montmorillonite composition would require much smaller particle sizes than palagonite to obtain the same visible-to-IR opacity ratio. Hence a montmorillonite composition is much harder to accommodate with the observed visible-to-IR extinction ratio of Mars atmospheric dust.

We propose that a palagonite composition with particle sizes roughly one-half that of the Toon et al. [1] determination provide a much improved model to Mars atmospheric dust. Since palagonite is a common weathering product of terrestrial basalts, it would not be unreasonable for palagonite to be a major surface component for Mars. The lack of even a minor component of Al-rich clays on the surface of Mars [7] could be consistent with a palagonite composition for Mars dust if the conditions for basalt weathering on Mars were sufficiently anhydrous [10]. Variations in palagonite composition could also lead to the inability of the modeled palagonite to

fit the details of the 9-µm absorption indicated by the IRIS observations [11].

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S11 -91 ABS. ONLY

MAGMATIC VOLATILES AND THE WEATHERING OF MARS. B. C. Clark, Planetary Sciences Lab, Mail Stop B0560, Martin Marietta, Denver CO 80201, USA.

The sources for volatiles on Mars have been the subject of many hypotheses for exogenous influences including late accretion of volatile-enriched material, impact devolatilization to create massive early atmospheres, and even major bombardment by comets. However, the inventory of chemically active volatiles observable at the contemporary surface of Mars is consistent with domination by endogenous, subsequent planetary processes, viz., persistent magmatic outgassing.

Volcanism on Mars has been widespread in both space and time [1]. Notwithstanding important specific differences between the mantles of Earth and Mars, the geochemical similarities are such that the suite of gases emitted from martian volcanic activity should include H_2O, CO_2, S-containing gases (e.g., H_2S and/or SO_2), and Cl-containing gases (e.g., Cl_2 and/or HCl). Both H_2O and CO_2 exist in the atmosphere of Mars. Both are also present as surface condensates. However, spectroscopic observations of the martian atmosphere clearly show that the S- and Cl-containing gases are severely depleted, with upper limits of $\leq 10^{-7}$ the abundance of CO_2 [2]. Likewise, there is no evidence of polar condensates of compounds of these elements as there is for CO_2 and H_2O. Within the soil, on the other hand, there has been direct measurement of incorporated H_2O [3] and abundant compounds containing S and Cl [4]. Barring some as yet implausible geochemical sequestering process, the S/Cl ratio of about 6:1 in martian soils implies a limit of 5% on the contribution of matter of solarlike composition (e.g., carbonaceous chondrite or cometary material) to these volatiles [5]. Hence, exogenous sources are minor or not yet observed.

From analysis of elemental trends in martian soils, it has been recently shown that a simple two-component model can satisfy the Viking *in situ* measurements [6]. Component A includes Si and most or all the Al, Ca, Ti, and Fe. Component B, taken as $16 \pm 3\%$ by weight of the total, contains S and most or all the Cl and Mg. These results constrain several models of martian soil mineralogy but are consistent with a mixture of silicates (such as Fe-rich clays and accessory minerals [7]) and soluble salts [8]. The overall element profile is notably like shergottites [9,10], with significant incorporation of chemically reactive atmospheric gases from magmatic degassing.

Estimates for the total magma generated after crustal formation and the terminal stages of heavy bombardment have recently been updated. Although some 60× lower than the current areal rate of

extrusive lava resurfacing on Earth [1], the martian total is nonetheless equivalent to the release of ≥ 500 g/cm² averaged over the planet for every 0.1% (wt/wt) of volatile species released from magma. Quantitatively, this is sufficient to make up as much as 5% of the fine-grained regolith weathering product to a mean depth of 100 m. This reservoir of fine-grained material can be readily mobilized globally by episodic dust storms. With the relative absence of soil-consolidation factors, such as reworking by liquid water, tectonically driven metamorphism, and burial processes that are ubiquitous on Earth, survival of some material over significant portions of geologic time on Mars may have been possible. As fines are repeatedly transported over the surface, they have experienced weathering regimes from various geologic settings and epochs. Mixed fines could represent a planetwide sampling of the physical and chemical products from various surface, near-surface, and impactor materials.

Excess acidity in the fines can occur due to the preponderance of acidic volcanic emissions. Some minerals will be more susceptible to weathering than others, but reaction rates vary enormously as a function of temperature [11] and H_2O availability. Initial weathering rinds will typically form barriers to further conversion of source material. Resistant units such as rocks and bedrock outcrops would be subjected to a balance between surficial chemical weathering and physical removal by eolian abrasion. Because of saltation heights and wind-shadowing effects, three-dimensional geochemical gradients of weathering may be found on exposed surfaces on boulders such as those observed at the Viking 1 lander site.

Although carbonates and nitrates are widely expected in the martian regolith, current evidence is lacking or weak. Reworked fines may have been chemically scrubbed of any weathering product of either class of compounds since it has been demonstrated experimentally that volcanic SO_2 gas can undergo rapid heterogeneous-phase displacement reactions with susceptible solid substrates, even under simulated dry and cold martian conditions [12], to release CO_2 and NO_x back to the atmosphere.

On the other hand, magmas release additional volatiles that would not be recyclable because of their lower vapor pressures and/or chemical stability. A variety of data relevant to volatility would imply that weathering products may be highly enriched in elements such as Na, Cu, Zn, As, Se, Br, Rb, Cd, In, Sn, Sb, Hg, Tl, Pb, and Bi compared to rock compositions [13]. Many of the compounds formed by these elements may be soluble in H_2O, as data indicate for the S- and Cl-bearing compounds in martian fines, and hence be subject to transport processes that create duricrust and soil peds. The occurrences and distributions of these elements could provide key evidence of weathering history and magmatic degassing.

Where alteration products have been exposed to bulk liquid water, chemical sediment deposits with evaporite sequences should be found on Mars. Quasistable liquid brine pools might also have resulted. However, if the dominant soluble anion on Mars is SO_4^{2-}, then most strong freezing-point depressant salts would not be available for contemporaneous brine. Even if formed, subzero brines would have restricted mobility, because of high viscosity and reduced chemical activity of H_2O molecules compared to pure water.

Although it is widely believed that the missing H_2O is buried in the regolith as physical deposits of permafrost ice, it cannot be ruled out that significant portions, perhaps most, of this inventory has been incorporated into secondary minerals. A pervasive drawdown of atmospheric volatiles would result from chemical reaction with

abraded and comminuted surface materials and may be central to probing the climatological evolution of Mars.

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THERMAL AND HYDRAULIC CONSIDERATIONS REGARDING THE FATE OF WATER DISCHARGED BY THE OUTFLOW CHANNELS TO THE MARTIAN NORTHERN PLAINS.   S. M. Clifford, Lunar and Planetary Institute, Houston TX 77058, USA.

The identification of possible shorelines in the martian northern plains suggests that the water discharged by the circum-Chryse outflow channels may have led to the formation of transient seas, or possibly even an ocean, covering as much as one-third of the planet. Speculations regarding the possible fate of this water have included local ponding and reinfiltration into the crust; freezing, sublimation, and eventual cold-trapping at higher latitudes; or the *in situ* survival of this now frozen water to the present day—perhaps aided by burial beneath a protective cover of eolian sediment or lavas. Although neither cold-trapping at higher latitudes nor the subsequent freezing and burial of flood waters can be ruled out, thermal and hydraulic considerations effectively eliminate the possibility that any significant reassimilation of this water by local infiltration has occurred given climatic conditions resembling those of today.

The arguments against the local infiltration of flood water into the northern plains are two-fold. First, given the climatic and geothermal conditions that are thought to have prevailed on Mars during the Late Hesperian (the period of peak outflow channel activity in the northern plains), the thickness of the cryosphere in Chryse Planitia is likely to have exceeded 1 km. As discussed by Clifford [1], a necessary precondition for the widespread occurrence of groundwater is that the thermodynamic sink represented by the cryosphere must already be saturated with ice. For this reason, the ice-saturated cryosphere acts as an impermeable barrier that effectively precludes the local resupply of subpermafrost groundwater by the infiltration of water discharged to the surface by catastrophic floods. Note that the problem of local infiltration is not significantly improved even if the cryosphere were initially dry, for as water attempts to infiltrate the cold, dry crust, it will quickly freeze, creating a seal that prevents any further infiltration from the ponded water above.

The second argument against the local infiltration of flood water into the northern plains is based on hydraulic considerations. As discussed by Carr [2] and Clifford [1], repeated impacts have likely brecciated the martian crust down to a depth of roughly 10 km. Given a value of permeability no greater than that inferred for the top 10 km of the Earth's crust ($\sim 10^{-2}$ darcies [1,3]), a timescale of