passive descent subsystem (no active guidance or control), and landing system based on air vessels (no active propulsion). Further in-depth studies and critical analyses on such potentially critical areas as the descent and landing systems would consolidate and validate work already performed in supporting technology and the MARSNET phase A study. The feasibility of the concept has been adequately demonstrated to the present level, but further studies should be performed in the relevant critical technological areas.

Mission Scenario: The delivery of the three ESA MARSNET semihard landers could be performed by moderate- to high-performance expendable launch vehicles, such as Delta-II, Ariane-4, and Proton. The phase A study evaluated the two major mission scenarios for the transfer, delivery to Mars, and targeting of nominally three and possibly four probe/landers, which would then enter the martian atmosphere, descend, and land on the surface. Surface operations, during which a number of challenging and significant scientific investigations would be performed, is planned for a nominal duration of one martian year. The two major mission design scenarios are both based on a Delta-II 7925 expendable launch vehicle, but either could be performed with a similar class of expendable launch vehicle.

The MARSNET reference baseline mission design was that of the multiprobe carrier scenario, in which all landers are accommodated on one common cruise spacecraft (Mariner Mark-II class). The three entry modules could be launched toward Mars in appropriate reference launch windows (2001, 2003) and subsequent launch opportunities. The carrier spacecraft would then deliver and target the stations for atmospheric entry. The descent in the martian atmosphere would last for about 10 min. The distribution of the three MARSNET stations would take place from an approach hyperbola. The MARSNET probe/landers are targeted and separated sequentially during the Mars approach phase. All targeting maneuvers are performed by the cruise spacecraft. After separation, the entry probes containing the landers are passive with respect to communications until after landing.

The alternative was that of the single-probe carrier scenario, in which each lander is carried to Mars by a separate cruise module. Separation of the different cruise spacecraft modules from their launch accomodation structure will be at the time of separation from the launcher upper stage. After completion of the interplanetary cruise an unguided ballistic entry into the martian atmosphere from an hyperbolic approach has been chosen as the preferred solution for the final delivery of the landers. Each lander is contained in a blunt nosed sphere-cone aeroshell and thus uses passive aerobraking techniques with rigid decelerators to effect entry. During descent, further deceleration is achieved through the use of a two-parachute descent system, which stabilizes the descent module during the different phases and reduces the impact velocities to the design range catered for in the MARSNET design.

International Cooperation: NASA is also actively studying a network mission to Mars called MESUR (Mars Environmental SURvey). An existing understanding of future cooperation between the two agencies could develop into a joint ESA/NASA global Mars Network Mission, where ESA could provide, nominally, three surface stations (MARSNET) and NASA a number of additional ones (MESUR), therefore complementing each other in terms of scientific investigations and landing sites. A joint collaborative global Mars Network Mission is ideally suited to an appropriate division of effort and sharing of scientific return between the partners in the

collaboration. Such a mission offers potentially high benefits to both the European and U.S. scientific communities.

Conclusions: The scientific exploration of Mars will give us new insights into the physical and chemical processes that took place in the primordial solar nebula, since the chemical composition of a planet depends on its location in the nebula during condensation. Most importantly, however, the study of Mars will deepen our understanding of the evolution of planets, including the Earth. Comparative planetology will thus provide significant clues for assessing current environmental challenges facing our planet.

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MARS ATMOSPHERIC DUST PROPERTIES: A SYNTHESIS OF MARINER 9, VIKING, AND PHOBOS OBSERVATIONS.   R. T. Clancy[1], S. W. Lee[1], and G. R. Gladstone[2], [1]Laboratory for Atmospheric and Space Physics, University of Colorado, Boulder CO 80309, USA, [2]Southwest Research Institute, P.O. Drawer 28510, 6220 Culebra, San Antonio TX 78228, USA.

The longstanding model of Mars atmospheric dust, as derived by Toon et al. [1] on the basis of Mariner 9 IRIS observations and by Pollack et al. [2] on the basis of Viking lander observations, is characterized by a montmorillonite-like composition and a cross-section weighted mean radius of 2.5 μm (mode radius ≈ 0.4 μm). The basis for this model was an analysis of Mariner 9 IRIS infrared (IR) spectra (5–50 μm) of the 1971 global dust storm, performed by Toon et al. [1]. Subsequently, Pollack et al. [2] analyzed Viking lander observations of visible (0.4–0.9 μm) sky brightness and transmission during the 1977 global dust storms. These observations were intrepreted as confirmation of the Toon et al. model of Mars atmospheric dust, with two important modifications. A nonspherical shape of the dust particles and an additional visible/ultraviolet absorbing component of dust were required to match these Viking lander observations. Pollack et al. suggested that a several percent component of magnetite in the Mars atmospheric dust could provide the observed visible absorption by the dust, since montmorillonite does not absorb visible or ultraviolet light efficiently.

Since these key studies, a number of important measurements ranging from analysis of Viking 9-μm dust opacities [3] to Phobos near-IR extinction observations of Mars dust have been obtained. Zurek [5] pointed out that the visible-to-IR dust opacity ratio obtained from the Viking studies (~2) was not consistent with the ratio predicted by the standard dust model of [1] (~1). Clancy and Lee [6] analyzed Viking IRTM emission-phase-function (EPF) sequences, which suggested smaller absorption (visible single scattering albedo near 0.92 vs. a value of 0.86 from Pollack et al.) and larger backscattering (single scattering assymetry parameter of 0.55 vs. the 0.79 from Pollack et al.) for Mars atmospheric dust. Phobos solar occultation measurements of dust extinction at wavelengths of 0.75–3.15 μm indicated particle sizes closer to 1 μm at 20 km altitude [4]. Most recently, Clark [7] interpreted groundbased near-IR spectra of Mars surface reflectance to place a very low limit (<1%) on the amount of montmorillonite-like clay materials.

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 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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MAGMATIC VOLATILES AND THE WEATHERING OF MARS.

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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 ± 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 60x lower than the current areal rate of