MARS: PAST, PRESENT, AND FUTURE—
RESULTS FROM THE MSATT PROGRAM

Edited by

R. M. Haberle

Convened by

The MSATT Steering Committee

Held at
Houston, Texas

November 15–17, 1993

Sponsored by
Mars Surface and Atmosphere Through Time (MSATT) Study Group
Lunar and Planetary Institute

Lunar and Planetary Institute 3600 Bay Area Boulevard Houston TX 77058-1113

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Program

Monday morning, November 15, 1993

8:30 a.m. *Introduction and Overview*
R. M. Haberle

9:00–10:00 a.m.

ATMOSPHERIC DUST AND COMPOSITION
Chair: S. W. Lee

Might It Be Possible to Predict the Onset of Major Martian Dust Storms?
L. J. Martin*, P. B. James, and R. W. Zurek

Mars Atmospheric Dust Properties: A Synthesis of Mariner 9, Viking, and Phobos Observations
R. T. Clancy*, S. W. Lee, and G. R. Gladstone

The Wavelength Dependence of Martian Atmospheric Dust Radiative Properties
J. B. Pollack, M. E. Ockert-Bell*, R. Arvidson, and M. Shepard

Groundbased Monitoring of Martian Atmospheric Opacity
K. E. Herkenhoff* and L. J. Martin

Studies of Atmospheric Dust from Viking IR Thermal Mapper Data
T. Z. Martin*

Temporal and Spatial Mapping of Atmospheric Dust Opacity and Surface Albedo on Mars
S. W. Lee*, R. T. Clancy, G. R. Gladstone, and T. Z. Martin

Polar Sediment Accumulation: The Role of Surface Winds at the Two Poles
P. C. Thomas* and P. J. Gierasch

How Well was Total Ozone Abundance Inferred with Mariner 9?
B. L. Lindner*

* Indicates speaker

10:00–11:00 a.m. *Posters*

11:00–12:00 p.m. *Discussion*

Monday afternoon, November 15, 1993

1:30–3:00 p.m.

CLIMATE EVOLUTION
Chair: R. M. Haberle

Escape of Mars Atmospheric Carbon Through Time by Photochemical Means
J. G. Luhmann*, J. Kim, and A. F. Nagy

Mars Atmospheric Loss and Isotopic Fractionation by Solar-Wind-Induced Sputtering and Photochemical Escape
B. M. Jakosky*, R. O. Pepin, R. E. Johnson, and J. L. Fox

A Model for the Evolution of CO_2 on Mars
R. M. Haberle*, D. Tyler, C. P. McKay, and W. L. Davis

Obliquity Variation in a Mars Climate Evolution Model
D. Tyler* and R. M. Haberle

The Effect of Polar Caps on Obliquity
B. L. Lindner*

The Distribution of Martian Ground Ice at Other Epochs
M. T. Mellon* and B. M. Jakosky

IRTM Brightness Temperature Maps of the Martian South Polar Region During the Polar Night: The Cold Spots Don't Move
D. A. Paige*, D. Crisp, M. L. Santee, and M. I. Richardson

Controls on the CO_2 Seasonal Cycle
J. B. Pollack*, F. Forget, R. M. Haberle, J. Schaeffer, and H. Lee

The Influence of Thermal Inertia on Mars' Seasonal Pressure Variation and the Effect of the "Weather" Component
S. E. Wood* and D. A. Paige

Stationary Eddies in the Mars General Circulation as Simulated by the NASA Ames GCM
J. R. Barnes*, J. B. Pollack, and R. M. Haberle

Eddy Transport of Water Vapor in the Martian Atmosphere
J. R. Murphy* and R. M. Haberle

Numerical Simulation of Thermally Induced Near-Surface Flows Over Martian Terrain
T. R. Parish* and A. D. Howard

3:00–4:30 p.m. *Posters*

4:30–5:30 p.m. *Discussion*

Tuesday morning, November 16, 1993
8:30–9:45 a.m.

VOLATILES, SNCs, AND GEOCHEMISTRY
Chair: J. H. Jones

Magmatic Volatiles and the Weathering of Mars
B. C. Clark*

SNC Meteorites and Their Implications for Reservoirs of Martian Volatiles
J. H. Jones*

The Martian Sources of the SNC Meteorites (Two, Not One), and What Can and Can't Be Learned from the SNC Meteorites
A. Treiman*

Carbonates, Sulfates, Phosphates, Nitrates, and Organic Materials—Their Association in a Martian Meteorite
I. P. Wright*, M. M. Grady, and C. T. Pillinger

Carbonate Formation on Mars: Latest Experiments
S. K. Stephens*, D. J. Stevenson, G. R. Rossman, and L. F. Keyser

Simultaneous Laboratory Measurements of CO_2 and H_2O Adsorption on Palagonite: Implications for the Martian Climate and Volatile Reservoir
A. P. Zent* and R. Quinn

The pH of Mars
R. C. Plumb, J. L. Bishop*, and J. O. Edwards

Deposition Rates of Oxidized Iron on Mars
R. G. Burns*

The Mineralogic Evolution of the Martian Surface Through Time: Implications from Chemical Reaction-Path Modeling Studies
G. S. Plumlee*, W. I. Ridley, J. D. De Braal, and M. H. Reed

9:45–11:00 a.m. *Posters*

11:00–12:00 p.m. *Discussion*

Tuesday afternoon, November 15, 1993

1:30–2:45 p.m.

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Chair: R. G. Burns

Martian Spectral Units Derived from ISM Imaging Spectrometer Data
S. Murchie*, J. Mustard, and R. Saylor

Evidence for Ultramafic Lavas on Syrtis Major
D. P. Reyes* and P. R. Christensen

Ferric Sulfate Montmorillonites as Mars Soil Analogs
J. L. Bishop* , C. M. Pieters, and R. G. Burns

The Importance of Environmental Conditions in Reflectance Spectroscopy of Laboratory Analogs for Mars Surface Materials
J. Bishop*, S. Murchie, S. Pratt, J. Mustard, and C. Pieters

Mineralogical Diversity (Spectral Reflectance and Mössbauer Data) for Compositionally Similar Impact Melt Rocks from Manicouagan Crater, Canada
R. V. Morris*, J. F. Bell III, D. C. Golden, and H. V. Lauer

Thermal Emission Measurements (5–25 μm) of Hawaiian Palagonitic Soils with Implications for Mars
J. F. Bell III* and T. L. Roush

Dielectric Properties of Mars' Surface: Proposed Measurement on a Mars Lander
S. Ulamec* and R. Grard

MARSNET: A European Network of Stations on the Surface of Mars
A. F. Chicarro*

2:45–4:00 p.m. *Posters*

4:00–5:00 p.m. *Discussion*

Wednesday morning, November 17, 1993
8:30–10:00 a.m.

SURFACE GEOLOGY
Chair: K. L. Tanaka

Geologic Controls of Erosion and Sedimentation on Mars
K. L. Tanaka*, J. M. Dohm, and M. H. Carr

Constraints on the Martian Cratering Rate Imposed by the SNC Meteorites and Vallis Marineris Layered Deposits
J. Brandenburg*

Depth-Diameter Ratios for Martian Impact Craters: Implications for Target Properties and Episodes of Degradation
N. G. Barlow*

Global Color Views of Mars
A. S. McEwen*, L. A. Soderblom, T. L. Becker, E. M. Lee, and R. M. Batson

Regional Sedimentological Variations Among Dark Crater Floor Features: Toward a Model for Modern Eolian Sand Distribution on Mars
K. S. Edgett* and P. R. Christensen

Temporal Changes in the Geographic Distribution, Elevation, and Potential Origin of the Martian Outflow Channels
S. Tribe* and S. M. Clifford

Apron Heights Around "Stepped Massifs" in the Cydonia Mensae Region: Do They Record the Local Paleobathymetry of "Oceanus Borealis"?
T. J. Parker* and D. S. Gorsline

Martian Deltas: Morphology and Distribution
J. W. Rice Jr.* and D. H. Scott

Thermal and Hydrologic Considerations Regarding the Fate of Water Discharged by the Outflow Channels to the Martian Northern Plains
S. M. Clifford*

The Northern Plains MSATT Meeting, and a Call for a Field-Oriented Successor to MSATT
J. S. Kargel*

10:00–11:30 a.m. *Posters*

11:30–12:30 p.m. *Discussion*

12:30 p.m. *Adjourn*

PRINT-ONLY ABSTRACTS

Thermal Studies of Martian Channels and Valleys Using Termoskan Data: New Results
B. H. Betts and B. C. Murray

Aerosols Scattering and Near-Infrared Observations of the Martian Surface
S. Erard

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Summary of Technical Sessions

The final MSATT workshop was held at the Lunar and Planetary Institute on November 15–17, 1993. The workshop, entitled "Mars: Past, Present, and Future—Results from the MSATT Program," brought together the entire MSATT community to assess the progress made during the program's three-year lifetime. Fifty papers were presented that addressed subjects ranging from current atmospheric and surface processes to the long-term geologic history of the planet.

The meeting had a unique format in which each session consisted of three parts: an oral part, a poster part, and a discussion part. During the oral part of the session, participants were asked to deliver a short discussion of their work, which served as an advertisement for their posters. This gave all presenters an opportunity to address the entire community and then follow up with more detailed discussion during the poster part of the session. After the posters, participants reconvened for a general discussion, which often featured some lively debate. This format turned out to be very successful in that it fostered interactions between researchers of differing backgrounds, which, of course, was the hallmark of the MSATT program.

The atmosphere and climate were the subject of the first day, and dust—its properties and behavior—dominated the morning's presentations. While it is now known that major martian dust storms do not occur each year, as was previously believed, the cause of this interannual variability is not known. There is some observational evidence suggesting that activity along the northwest rim of the Hellas Basin generally precedes major dust storms (Martin et al.), but it suffers from the statistics of small numbers. However, there was general agreement that Hellas is currently experiencing net erosion, which is consistent with its role as a major supplier of atmospheric dust. Continued groundbased monitoring of atmospheric dust (Herkenoff and Martin) would help extend the record of these spectacular events, which are evidently capable of lofting enormous quantities of dust into the atmosphere (Martin).

The presence of dust in the atmosphere has several important consequences. First, it can significantly alter the thermal drive for the circulation, so knowlege of its physical properties is critical. The size and composition of suspended dust particles have been widely debated, but reanalysis of existing data (Clancy et al.) and further analysis of Viking lander images (Pollack et al.) seem to be converging on particles in the 1–2-µm range possibly composed of palagonite, a basaltic weathering product. Second, dust in the atmosphere complicates the analysis of time-varying surface albedo features (Lee et al.) and estimates of ozone column abundances (Linder). Exactly how to account for this effect remains elusive, since it requires an accurate knowledge of the properties and distribution of the suspended particles.

Evolution of the martian atmosphere and climate system was the subject of a number of papers. If Mars did have a more massive CO_2 atmosphere early in its history, then where is it now? As much as 500 mbar may have escaped out the top of the atmosphere via sputtering of reentering O^+ pick-up ions and dissociative recombination of CO^+ (Luhmann et al.), but loss of this amount of CO_2 is not consistent with the observed weak fractionation of stable carbon isotopes unless there is a comparable amount of exchangeable CO_2 stored in near-surface reservoirs (Jakosky et al.). CO_2 could also have been incorporated into carbonate rocks or stored in the regolith and polar caps (Haberle et al.; Zent). But all the models presented contained enough uncertainties that it was not possible to rule anything out. Weathering rates (Stephens et al.), solar evolution (Luhmann et al.), and obliquity variations (Tyler and Haberle; Lindner) were just some of the areas where the uncertainties are great.

Turning to the current climate system, there were a number of papers that dealt with polar processes. The three-plus years of surface pressure measurements from Viking provide important constraints for models of the CO_2 cycle. The observed fluctuations are dominated by the condensation and sublimation of CO_2 at the poles, but weather systems can make a significant contribution as well (Pollack et al.). Furthermore, the thermal inertia of the surface can have a similar effect on the condensation process itself (Wood and Paige). These are new and important results since they have implications for the number and location of future landers. Also new is the growing body of evidence for the existence of CO_2 ice clouds in the south polar region during winter (Paige et al.). These clouds could play an important role in the polar heat budget, and in the ability of the atmosphere to scavenge dust and water to the surface.

Models of the circulation and climate continue to improve, and several were presented at the workshop. During summer, for example, water subliming from the residual cap is transported equatorward, but how much and how far are uncertain. A full three-dimensional general circulation model has been used to study this issue (Murphy and Haberle). A more focused three-dimensional model has been used to study local patterns in the north polar region (Parish and Howard). This latter kind of model could be useful in helping to understand the origin and evolution of the circumpolar dune fields, which provide markers of the local circulation (Thomas and Gierasch). A model for studying the stability of water ice at or below the surface was also presented (Mellon and Jakosky).

On Tuesday, workshop topics shifted to volatiles, SNCs, geochemistry, and mineralogy. In the morning session, a variety of topics were addressed during the oral presentations: B. Clark argued for the presence of sulfates in martian soils; J. Jones gave a number of reasons for why the martian mantle is likely to be dry and not a good source for water; A. Treiman compared and contrasted the various SNC meteorites and concluded that they were probably ejected from Mars by more than one impact event; I. Wright suggested there was more than one reservoir for nitrogen on Mars since the isotopic composition of N in SNCs does not match that of the martian atmosphere; S. Stephens summarized the results of his experiments for producing carbonates by the low-temperature weathering of silicates; A. Zent described current experiments to measure the adsorption capacity of palagonite for H_2O and CO_2; J. Bishop described Plumb's experiments to determine the pH of martian soil; R. Burns presented a summary of what is known about the rates of Fe^{2+} oxidation, with applications to martian soils; and G. Plumblee presented thermodynamic calculations used to model weathering and alteration processes on Mars.

After the poster session there was an extended discussion of how the isotopic data from SNC meteorites could be reconciled with models of isotopic fractionation by atmospheric escape mechanisms. Hydrogen appears to be hugely fractionated, and Ar is modestly fractionated. However, within the ability to measure, O and C may not be fractionated at all. One solution to this problem may be that the massive CO_2 and silicate reservoirs on Mars buffer the isotopic compositions of O and C, but not of H or Ar. No resolution to the overall problem was achieved by the discussion. In particular, it was noted that the mechanisms for H loss were only capable of removing a few tens of meters of water, whereas the SNC data and the observations of widespread fluvial activity on Mars seem to require the loss of hundreds of meters of water. This glaring discrepancy requires explanation.

In another extended discussion, there was much debate on how many cratering events are necessary to eject the SNC meteorites and deliver them to Earth. The discussion was polarized between choices of one crater or several. The SNC cosmic ray exposure ages cluster in three groups, so this appears to be the maximum number of craters necessary. If so, all ejection events occurred in the last 10 m.y. Differences in composition and petrology between the cosmic ray exposure groups seem to argue that different martian terrains were sampled, implying spatial separation of the parent craters. The competing hypothesis is that only one crater is necessary, since several impacts, each capable of ejecting material from Mars in the last 10 m.y., seem unlikely. The one-crater hypothesis assumes a very large crater (~100 km?), and thus may overcome the concern that geologic diversity of the impacted terrain is required.

Partly at issue is whether the observed average cratering rates are meaningful on short timescales. Conceivably, the average rate could be achieved by very large spikes in impactor fluxes separated by long, quiescent hiatuses. These important questions have implications far beyond the issue of SNC meteorites and their source craters. Unfortunately, there is currently no database to test the various cratering hypotheses.

After lunch workshop participants reconvened to focus on the mineralogy of martian soils. Mineral identification of the martian surface continues to be strongly influenced by spectroscopic measurements in the near-infrared region. Telescopic and spacecraft observations, together with laboratory studies of materials believed to simulate phases in the martian regolith, have been the source of the spectral data. Results from the Phobos 2 Imaging Spectrometer for Mars (ISM) reveal a variety of soil units in equatorial regions, ranging from normal bright albedo regions dominated by hematite (band at 0.86 µm) and hydroxysilicates (band at 2.2 µm), to dark albedo regions containing pyroxenes (band near 2 µm). However, anomalous regions characterized by the very strong water band at 3 µm, together with variable band depths at 2.2 µm and ranges of ferric band centers extending from 0.89–0.92 µm, indicate heterogeneity in the layered materials. The occurrence of pyroxenitic komatiites in low-albedo areas of the Syrtis Major region was suggested on the basis of pyroxene compositions inferred from ISM data; however, it was noted that such compositions are not diagnostic of ultramafic lavas.

Spectroscopic analyses have shown that ferric-doped smectites prepared in the laboratory exhibit important similarities to the martian soils. Compared with the ferrihydrite-montmorillonite assemblages previously studied, montmorillonites doped with ferric sulfate have stronger ferric bands near 0.9 µm, more intense features at 1.96 and 3 µm, and match more closely the telescopic reflectance spectra of Mars in the visible-near infrared region. However, environmental conditions influence the reflectance spectra of laboratory analogs. Intensities of features due to molecular water (near 1.4, 1.9, and 3 µm) in the spectra of clays, palagonites, and hydrated minerals are particularly sensitive to the moisture environment of the samples. Compared to ferrihydrite-montmorillonite and other cation-exchanged montmorillonites, ferric sulfate-doped montmorillonites retain structurally bound water under environmental conditions simulating the surface of Mars.

Variability of band centers in the 0.86–1.0 µm region may also be explained by hematite-pyroxene assemblages formed by meteoritic impacts under oxidizing conditions on Mars. This inference stems from spectroscopic investigations of terrestrial impact melt rocks from the Manicouagan Crater in Canada. Mössbauer spectral data have revealed variable hematite-pyroxene proportions in highly oxidized, moderately oxidized, and slightly oxidized samples of the Manicou-agan impact melt rocks. Reflectance spectra of the moderately oxidized samples containing comparable amounts of hematite and pyroxene bear close resemblance to remotely sensed spectra of the martian surface.

Spectroscopic data in the mid- and near-infrared region may provide additional information for characterizing the mineralogy, crystallinity, and rock types of the martian surface. Thermal emission spectrometer measurements of Hawaiian palagonitic soils at 5–25 µm exhibit complex and variable emissivity spectra at these wavelengths, which may be due to differences in particle size, crystallinity, and mineral proportions in coarse and fine samples. Much research is warranted in this area if future spacecraft missions carry a Thermal Emission Spectrometer.

Considerable discussion ensued about the uniqueness of band centers near 0.9 μm for identifying pyroxenes, pyroxene-hematite assemblages, ferric sulfate exchanged clays, and other ferric minerals on Mars. Improved resolution of bands near 2 μm in reflectance spectra is necessary to better characterize pyroxene compositions, hydrated minerals, and hydroxyl-bearing clay silicates in the martian regolith. There was consensus that carbonates have been identified in the mid-infrared spectra of Mars, whereas spectroscopic characterization of sulfate-bearing minerals and confirmation of scapolite in the martian regolith remain elusive.

The final day of the workshop focused on surface geology, and two key issues were discussed at length. First, what has been the crater flux and absolute-age chronology of Mars? J. Brandenburg reviewed how Mars chronologies were dependent upon relative cratering flux with the Moon, and that the radioisotopic ages of the SNC meteorites were indicative of a Mars with a young mean surface age (or high crater flux). However, others were generally skeptical of this suggestion. All agreed that the crater flux for Mars is not well determined, and it was hoped that the empirically calculated crater fluxes would become more accurate as the database on Mars-crossing asteroids and comets increases. An intriguing aspect of crater flux mentioned by W. Hartmann was the possible signature of atmospheric density in the cratering record. Clusters of craters hundreds of meters across are fairly common across the martian surface, as was confirmed by N. Barlow and K. Tanaka. These clusters indicate break-up of smaller bolides. A study of the distribution of these clusters across the martian surface, as well as the distribution of smaller craters (<1–2 km across), may provide evidence that could be used to calculate paleodensity of the planet's atmosphere.

The other topic for discussion was the eolian geology of the Hellas region. As L. Martin pointed out on the first day of the workshop, this is a key area to understand because it has been observed to be the source region of several major martian dust storms. K. Tanaka pointed out that he and G. Leonard have mapped extensive (>106 km^2), deeply etched deposits in Hellas Basin that they have interpreted as made up largely of dust. This deposit includes linear ridges interpreted to be yardangs, as well as reticulate ridge patterns that appear to be dunes. Saltation by dune sand may be one way to erode dust and generate storms.

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