WORKSHOP ON THE EVOLUTION OF THE MARTIAN ATMOSPHERE

MSATT

Mars Surface and Atmosphere Through Time

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WORKSHOP ON
THE EVOLUTION OF THE MARTIAN ATMOSPHERE

Edited by
J. G. Luhmann
B. M. Jakosky

Held at
Kona, Hawaii
June 29–July 1, 1992

Sponsored by
Lunar and Planetary Institute
The MSATT Study Group

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

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Program

Monday, June 29, 1992

8:30 a.m. – 11:30 a.m.

Welcoming Remarks
Janet Luhmann and Bruce Jakosky

INVITED OVERVIEW TALKS

Chair: Janet Luhmann

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Carr M. H.
Water Inventories on Earth and Mars: Clues to Atmosphere Formation

Jakosky B. M.
Volatile Evolution on Mars over Geologic Time

2:30 p.m. – 6:00 p.m.

ORIGINAL INVENTORY AND EARLY HISTORY OF VOLATILES I

Chair: Robert Haberle

Walter F. M.
The Young Sun and the Protoplanetary Environment

Zahnle K.
How Mars Lost Its Atmosphere

Fegley B. Jr.
Chemical Models of Volcanic Outgassing on Mars

Schaefer M. W.
Volcanic Recycling of Carbonate Deposits on Mars

Craddock R. A. Maxwell T. A.
Nature and Evolution of the Early Martian Atmosphere: Evidence from Highland Crater Populations

Flynn G. J.
Time Variation of the Meteoritic Contribution to the Atmosphere of Mars

Kasting J. F.
A Reduced Atmosphere for Early Mars?

Tuesday, June 30, 1992

8:00 a.m. – 11:30 a.m.

ORIGINAL INVENTORY AND EARLY HISTORY OF VOLATILES II

Chair: Martha Schaefer

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A Photochemical Model for NH_3 in an Early Martian Atmosphere

Wänke H. Dreibus G. Jagoutz E. Mukhin L. M.
The Role of SO_2 on Mars and on the Primordial Oxygen Isotope Composition of Water on Earth and Mars

McKay C. P. Davis W. L.
Liquid Water Habitats on Early Mars

Chamberlain J. W. Schmunk R. B.
A Two-Dimensional Climate Model for Early Mars

Haberle R. M. Pollack J. B. Murphy J. R. Schaeffer J. Lee H.
High Pressure Experiments with a Mars General Circulation Model

Fox J. L.
The Production and Escape of Nitrogen Atoms on Mars

Luhmann J. G. Zhang M. H. G. Johnson R. E. Bougher S. W. Nagy A. F.
History of Oxygen and Carbon Escape from the Martian Atmosphere

2:30 p.m. – 6:00 p.m.

CLUES TO THE PAST, AND PRESENT CONSTRAINTS

Chair: James Bell III

Jakosky B. M.
Mars Volatile Evolution: Implications of the Recent Measurement of ^{17}O in Water from the SNC Meteorites

Pollack J. B. Haberle R. M. Murphy J. R. Schaeffer J. Lee H.
Astronomical Variation Experiments with a Mars General Circulation Model

Jakosky B. M. Henderson B. G. Mellon M. T.
The Mars Water Cycle at Other Epochs: History of the Polar Caps and Layered Terrain

Nair H. Allen M. Yung Y. L. Clancy R. T.
Martian Atmospheric Chemistry During the Time of Low Water Abundance

Postawko S. Fanale F.
Regional Climatic Effects of Atmospheric SO_2 on Mars

Kossacki K. Leliwa-Kopystynski J.
Influences of CO_2 Sublimation Condensation Processes on the Long-term Evolution of the Martian Atmosphere

Wednesday, July 1, 1992

8:00 a.m. – 11:30 a.m.

CLUES TO THE PAST, AND PRESENT CONSTRAINTS II

Chair: James Kasting

Burns R. G.
Oxygen in the Martian Atmosphere: Regulation of P_{O2} by the Deposition of Iron Formations on Mars

Wright I. P. Hartmetz C. P. Pillinger C. T.
Martian Surficial Carbon – Constraints from Isotopic Measurements of Shock-Produced Glass in EET A79001

Zent A. P. Roush T. L.
Spectral Identification of Chemisorbed CO_2 and Application to Mars Analog Materials

Anbar A. D. Allen M. Nair H. Leu M.-T. Yung Y. L.
The Impact of Temperature Dependent CO_2 Cross Section Measurements: A Role for Heterogeneous Chemistry in the Atmosphere of Mars?

Martin L. J.
Using the Historical Record to Determine Dust Sources

Bell J. F. III Crisp D.
Surface vs. Atmospheric Origin of 2.1 – 2.5 μm Absorption Features in the Martian Spectrum

Santee M. Crisp D.
The Thermal Structure, Dust Loading, and Meridional Transport in the Martian Atmosphere During Late Southern Summer

Justus C. G. James B. F.
Mars Global Reference Atmosphere Model (Mars-GRAM)

2:30 p.m. – 6:00 p.m.

FUTURE MEASUREMENTS AND MEASUREMENT OBJECTIVES

Chairs: Janet Luhmann and Bruce Jakosky

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An Ion Mass Spectrometer for Measuring Isotopic Abundances and Loss Rate of O, C and H in Mars' Upper Atmosphere

Feldman W. C. Boynton W. V. Jakosky B. M. Mellon M. T.
Redistribution of Subsurface Neutrons Caused by Ground Ice on Mars

Discussion: *Led by Janet Luhmann and Bruce Jakosky*

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Workshop Summary

J. G. Luhmann and B. M. Jakosky
Conveners

An MSATT workshop on the evolution of the martian atmosphere was held June 29—July 1, 1992 in Kona, Hawaii. Thirty-three papers based on the state of our knowledge prior to the anticipated new results from Mars Observer were presented. Because of the nature of the subject, the scope of the papers covered a broad disciplinary range encompassing astronomy and solar physics, geology and geophysics, climatology, atmospheric science, aeronomy, and space physics. The 42 participants heard about topics from the evolution of solar-type stars [1] to candidate instrumentation for measuring escape to space on yet-unscheduled future missions [2]. The diverse expertise within the group of attendees greatly enhanced the amount of cross-fertilization and the educational aspects of the meeting.

Some of the major issues pertinent to Mars atmosphere evolution include the sources and makeup of the "original inventory" [3,4]; the likelihood and effects of an early hydrodynamic escape phase [5,6] or massive impact(s) either delivering or eroding volatiles; the existence of an early "greenhouse" phase and the causative atmospheric constituent(s) [7-11]; whether carbonates or other mineralogical deposits containing a substantial fraction of the original atmosphere are still present on the surface and in the crust [12-14]; and our general ability to interpret the presently available "clues" to the past. The latter include isotope abundances (principally of the noble gases and H, C, N, and O) derived from a number of sources [15], the properties of the SNC meteorites [16], surface features [10,17,18], groundbased observations [12], laboratory experiments [13], and related measurements from previous spacecraft mission (Mariners, Vikings, and Phobos 2). Modeling studies [7-9,19-23] provide means of extending these observations and their interpretations into the past.

The workshop included critical discussions of the currently reigning dogmas in the field. In particular, it was considered that while the interpretation of isotope fractionation is fairly straightforward in the case of $^{14}N/^{15}N$ [22], it is fraught with potential pitfalls in many other cases. For example, the D/H ratio can be temporarily altered by the impact delivery of volatiles, while the C and O isotopes are affected by exchange with the surface. In the case of the fractionations of the rare gases, it is agreed that they probably indicate early and massive escape, but for the most part it is not certain whether hydrodynamic escape is the only credible candidate mechanism. Minor species have also been continuously delivered by the solar wind [5] and in meteorites and interplanetary dust (e.g., [24]). Some participants noted that isotope abundance measurements derived from both the bulk atmosphere at Mars and at other planets (particularly Venus and Jupiter) are the keys to making significant progress in the use of this type of evidence.

With regard to the SNC meteorites [16], the outstanding issue is clearly whether they are indeed representative samples of martian regolith. If they are, their composition indicates that the mantle of Mars was dry when they were released ~ 1.5 Ga ago. While some participants felt some confidence concerning the martian origin of SNCs, a "wait-and-see" attitude in advance of a sample return was generally held. All agreed that traditional sample return should be a primary Mars mission goal. However, even mineralogical experiments on the surface on a mission such as MESUR would immensely improve our ability to both interpret the SNC "samples" and to understand the history of Mars.

Surface features have perhaps offered the most convincing evidence of a past thick atmosphere and warm climate of Mars (e.g., [17,23]). Although hypotheses have been advanced proposing liquid SO_2 as a possible alternative to water in producing the striking out-flow channel features (e.g., [3]), the generally held view of the channels favors water. Whether they represent a single period of erosion prior to 3.5 Ga ago or include more recent episodic events is still debatable. The existence of glaciers, lakes, and oceans is regarded as more speculative at this time [25]. It was pointed out that mineralogical experiments on a MESUR lander at a proposed lake bed or beach site would be of considerable value in settling this issue. Craters provide clues relating to both the history of impacts and erosion, but there is more to be exploited than has been to date. In particular, the extent to which crater erosion is water related as opposed to wind related can in principle be used to "date" the periods of climate change (e.g., [18]). Moreover, laboratory experiments could be used to help determine whether the craters produced during the period(s) of thick atmosphere should look different from those produced during the period(s) of thin atmosphere. Wind erosion features and processes, including dust storms (e.g., [26]), will be studied extensively by Mars Observer experiments, thereby resolving this question to some extent.

The appearance of the polar caps and their cycle deserve separate mention because of their status as the solid "reservoirs" for the atmosphere. Apparently, these caps are major players in the climate system due to their ability to store much larger quantities of volatiles than can be held in the atmosphere at any single time. The ability of the water in the polar caps to exchange with the atmosphere and mix between the two poles on timescales of up to 10 m.y. was noted [27]. More detailed modeling of the seasonal cycle on these same timescales suggests that the formation of polar caps at other epochs is governed to a large extent by the role of atmospheric radiation due to dust [19]. Atmospheric heat transport also plays a role in the stability of the polar caps during periods of higher atmospheric pressure [9,28]. On shorter timescales, the requirement for heterogeneous atmospheric chemistry was questioned based on new determinations of photochemical cross sections [29]. These results also allow assessment of the interannual variations in atmospheric chemistry forced by possible variations in the water abundance of the atmosphere [30]. In general, the water cycle of Mars is still an area of active research that should be helped by results from Mars Observer.

The main difficulties in interpreting groundbased spectroscopic observations seem to center on the removal of telluric and solar backgrounds. In particular, it was shown that observations such as the previously inferred existence of surface carbonates, including scapolite, must be questioned [12]. On the other hand, the presence of OH groups (e.g., [30]) in the atmosphere of Mars and of ferric oxides on the surface [31] are not disputed because of the data made available by the Viking landers. Hubble Space Telescope and Mars Observer should eventually provide freedom from at least the telluric contamination of groundbased spectroscopic observations. Along the same lines, laboratory experiments can help with the interpretation of the complex spectra that are obtained only if they are tightly controlled [13].

Of course, the consensus was that if progress is to be made, emphasis should be attached to making specific *in situ* measurements in the future. Observations provided by earlier spacecraft, especially Viking, were critical in their importance and yet very limited. Phobos 2 instruments provided a tantalizing first look at some previously underrated evolutionary processes such as ion scavenging by the solar wind. Enthusiastic support was expressed for both the impending Mars Observer measurements pertaining to questions such as the water content of the crust (e.g., [32], as well as for pertinent instrumentation on the MESUR landers (especially tools for mineralogical analyses such as α, p, x spectrometers, seismometers, and pH probes). Other pertinent experiments, not currently planned by NASA and perhaps best carried out on an orbiter, are "aeronomical" experiments such as the measurement of ion density and composition profiles and escaping ion and neutral components of the atmosphere (e.g., [2]). The Mars 94 and Planet B missions have the potential to make important contributions in these areas. Measurements of isotope abundances at other planets, especially at Venus and Jupiter, are likely to be of some value in our efforts to understand the isotope history puzzle. Galileo probe measurements may help in this regard.

Finally, modeling exercises were recognized for their ability to fill in the interpretational gaps and for their potential to delve into the past. The problem of maintaining an early greenhouse in the face of CO_2 condensation (clouds) is the source of one of the current controversies sparked by climate modeling [7,9]. Was Mars warm and wet, or cold and dry? Did methane or ammonia provide the greenhouse [8]? Was the greenhouse episodic [10]? Also, what were the effects of the martian orbit eccentricity and Mars' obliquity variations over time [19]? The contemporary loss processes of nonthermal escape and ion scavenging processes can be extrapolated backward [22,23], but as in the other models, these require an understanding of the early Sun's output [1]. In this case, histories of both visible and ionizing (EUV) wavelengths are needed, as well as a description of the evolution of the solar wind. Finally, models of the earliest periods of evolution such as those invoking hydrodynamic escape must explain not only the current state of the Mars atmosphere, but also the states of the atmospheres of all of the terrestrial planets [5,6].

In summary, the Kona workshop highlighted once more the fact that the problem of Mars atmosphere evolution is best addressed with multidisciplinary and multimethod modeling and experimental efforts. In many areas, only direct information from Mars will lead to progress. It will be exciting to see how our current views of the scenarios for evolution change as new data are supplied by HST, the Mars Observer, and hopefully by the MESUR missions. In the meantime, several other MSATT workshops will focus in more detail on some of the specific questions raised in Kona.

References: Abstracts appearing in LPI Contribution No. 787, *Papers Presented to the Workshop on the Evolution of the Martian Atmosphere.*

[1] Walter F. M., The Young Sun and the Protoplanetary Environment. [2] Elphic R. C., Barraclough B. L., McComas D. J., and Nordholt J. E., An Ion Mass Spectrometer for Measuring Isotopic Abundances and Loss Rate of O, C and H in Mars' Upper Atmosphere. [3] Wänke H., Dreibus G., Jagoutz E., and Mukhin L. M., The Role of SO_2 on Mars and on the Primordial Oxygen Isotope Composition of Water on Earth and Mars. [4] Fegley B. Jr., Chemical Models of Volcanic Outgassing on Mars. [5] Pepin R. O., The Early Martian Atmosphere. [6] Zahnle K., How Mars Lost Its Atmosphere. [7] Kasting J. F., A Reduced Atmosphere for Early Mars? [8] Brown L. L. and Kasting J. F., A Photochemical Model for NH_3 in an Early Martian Atmosphere. [9] Haberle R. M., Pollack J. B., Murphy J. R., Schaeffer J., and Lee H., High Pressure Experiments with a Mars General Circulation Model. [10] Schaefer M. W., Volcanic Recycling of Carbonate Deposits on Mars. [11] Postawko S. and Fanale F., Regional Climatic Effects of Atmospheric SO_2 on Mars. [12] Bell J. F. III and Crisp D., Surface vs. Atmospheric Origin of $2.1-2.5$ μm Absorption Features in the Martian Spectrum. [14] Kossacki K. and Leliwa-Kopystynski J., Influences of CO_2 Sublimation Condensation Processes on the Long-term Evolution of the Martian Atmosphere. [15] Jakosky B. M., Mars Volatile Evolution: Implications of the Recent Measurement of ^{17}O in Water from the SNC Meteorites. [16] Wright I. P., Hartmetz C. P., and Pillinger C. T., Martian Surficial Carbon—Constraints from Isotopic Measurements of Shock-Produced Glass in EET A79001. [17] Carr M. H., Water Inventories on Earth and Mars: Clues to Atmosphere Formation. [18] Craddock R. A. and Maxwell T. A., Nature and Evolution of the Early Martian Atmosphere: Evidence from Highland Crater Populations. [19] Pollack J. B., Haberle R. M., Murphy J. R., Schaeffer J., and Lee H., Astronomical Variation Experiments with a Mars General Circulation Model. [20] Santee M. and Crisp D., The Thermal Structure, Dust Loading, and Meridional Transport in the Martian Atmosphere During Late Southern Summer. [21] Justus C. G. and James B. F., Mars Global Reference Atmosphere Model (Mars-GRAM).

[22] Fox J. L., The Production and Escape of Nitrogen Atoms on Mars. [23] Luhmann J. G., Zhang M. H. G., Johnson R. E., Bougher S. W., and Nagy A. F., History of Oxygen and Carbon Escape from the Martian Atmosphere. [24] Flynn G. J., Time Variation of the Meteoritic Contribution to the Atmosphere of Mars. [25] McKay C. P. and Davis W. L., Liquid Water Habitats on Early Mars. [26] Chamberlain J. W. and Schmunk R. B., A Two-Dimensional Climate Model for Early Mars. [27] Martin L. J., Using the Historical Record to Determine Dust Sources. [28] Jakosky B. M., Henderson B. G., and Mellon M. T., The Mars Water Cycle at Other Epochs: History of the Polar Caps and Layered Terrain. [29] Anbar A. D., Allen M., Nair H., Leu M.-T., and Yung Y. L., The Impact of Temperature Dependent CO_2 Cross Section Measurements: A Role for Heterogeneous Chemistry in the Atmosphere of Mars? [30] Nair H., Allen M., Yung Y. L., and Clancy R. T., Martian Atmospheric Chemistry During the Time of Low Water Abundance. [31] Burns R. G., Oxygen in the Martian Atmosphere: Regulation of P_{O2} by the Deposition of Iron Formations on Mars. [32] Feldman W. C., Boynton W. V., Jakosky B. M., and Mellon M. T., Redistribution of Subsurface Neutrons Caused by Ground Ice on Mars.

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