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

EARLY MARS: HOW WARM AND HOW WET?

Edited by

S. Squyres and J. Kasting

Held in
Breckenridge, Colorado

July 26–28, 1993

Sponsored by
MSATT Study Group
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Preface

In 1992 the MSATT program conducted a workshop on modeling of the martian climate. At that workshop it became clear that a serious problem had arisen concerning the early climate of Mars. Based on the evidence for small-scale fluvial activity, the view had been widely held that early in its history Mars had a climate that was much warmer and wetter than today's. However, most plausible recent climate models have fallen far short of the warm temperatures often inferred from the geologic evidence. Moreover, recent geophysical work has suggested that early geothermal warming may also have played a significant role in allowing fluvial activity. In order to address the issue of just how warm and how wet early Mars was, a workshop was convened in July of 1993, in Breckenridge, Colorado. The results of the workshop are reported here.

Contents

Program

Monday, July 26, 1993

8:00 a.m. *Registration*

8:45–9:45 a.m.

OVERVIEW OF MARS' EARLY EVOLUTION

8:45 a.m. *Early Mars: Warmed from Without or Within*
S. W. Squyres*

9:15 a.m. *Possible Solutions to the Problem of Channel Formation on Early Mars*
J. F. Kasting*

9:45 a.m. *Break*

10:00 a.m.–12:30 p.m.

VOLATILE INVENTORIES AND ATMOSPHERIC EVOLUTION

10:00 a.m. *Wet Inside and Out?: Constraints on Water in the Martian Mantle and on Outgassed Water, Based on Melt Inclusions in SNC Meteorites*
H. Y. McSween Jr.* and R. P. Harvey

10:30 a.m. *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

11:00 a.m. *Evolution of the Martian Atmosphere*
R. O. Pepin*

11:30 a.m. *Requirements for the Early Atmosphere of Mars from the Nitrogen Isotope Ratios*
J. L. Fox*

12:00 p.m. *Adjourn*

7:00–9:00 p.m.

CLIMATE/GEOCHEMICAL/PHOTOCHEMICAL MODELING

7:00 p.m. *A Model for the Evolution of CO_2 on Mars*
R. M. Haberle*, D. Tyler, C. P. McKay, and W. L. Davis

* Indicates speaker

7:30 p.m. *Early Mars: The Inextricable Link Between Internal and External Influences on Valley Network Formation*
S. E. Postawko* and F. P. Fanale

8:00 p.m. *The Young Sun and Photochemistry of the Primitive Martian Atmosphere*
H. Nair*, M. F. Gerstell, and Y. L. Yung

8:30 p.m. *A Carbon Dioxide/Methane Greenhouse Atmosphere on Early Mars*
L. L. Brown* and J. F. Kasting

9:00 p.m. *Mars and the Early Sun*
D. Whitmire*, L. R. Doyle, R. T. Reynolds, and P. G. Whitman

9:30 p.m. *Adjourn*

Tuesday, July 27, 1993
9:00 a.m.–12:30 p.m.

MARTIAN HYDROLOGY AND VALLEY SYSTEM FORMATION

9:00 a.m. *The Changes on Mars at the End of Heavy Bombardment*
M. H. Carr*

9:30 a.m. *Evolution of the Global Water Cycle on Mars: The Geological Evidence*
V. R. Baker* and V. C. Gulick

10:00 a.m. *Fluvial Valleys in the Heavily Cratered Terrains of Mars: Evidence for Paleoclimatic Change?*
V. C. Gulick* and V. R. Baker

10:30 a.m. *Break*

11:00 a.m. *The Hydrologic Response of Mars to the Onset of a Colder Climate and to the Thermal Evolution of Its Early Crust*
S. M. Clifford*

11:30 a.m. *Briny Lakes on Early Mars? Terrestrial Intracrater Playas and Martian Candidates*
P. Lee*

12:00 p.m. *Adjourn*

7:00–9:30 p.m.

CLUES FROM MARTIAN GEOMORPHOLOGY

7:00 p.m.	*Early Mars: A Regional Assessment of Denudation Chronology* T. A. Maxwell* and R. A. Craddock
7:30 p.m.	*The Early Martian Environment: Clues from the Cratered Highlands and the Precambrian Earth* R. A. Craddock* and T. A. Maxwell
8:00 p.m.	*Ancient Martian Valley Genesis and Paleoclimatic Inference: The Present as a Key to the Past* G. R. Brakenridge*
8:30 p.m.	*Mars: Noachian Hydrology by Its Statistics and Topology* N. A. Cabrol* and E. A. Grin
9:00 p.m.	*The Martian Valley Networks: Origin By Niveo-Fluvial Processes* J. Rice*
9:30 p.m.	*Adjourn*

Wednesday, July 28, 1993
9:00—10:00 a.m.

CHEMICAL WEATHERING AND CLIMATE

9:00 a.m.	*An Attempt to Comprehend Martian Weathering Conditions Through the Analysis of Terrestrial Palagonite Samples* C. Douglas*, I. P. Wright, J. B. Bell, R. V. Morris, D. C. Golden, and C. T. Pillinger
9:30 a.m.	*Oxidation of Dissolved Iron Under Warmer, Wetter Conditions on Mars: Transitions to Present-Day Arid Environments* R. G. Burns*
10:00 a.m.	*Break*
10:30 a.m.	*Discussion*
12:30 p.m.	*Adjourn*

Summary of Technical Sessions

It is clear that conditions on Mars during the Noachian Period (which extended from the beginning of Mars' geologic record to something like 3.9 b.y. ago) were significantly different than they are today. As on the other planets, the rate of meteoritic bombardment was far higher than it is at present; this is shown clearly by the densely cratered nature of Noachian terrains. But there were other differences as well. Some are only inferred, while for others we have clear evidence. The nature of these differences, and what they imply about broader topics of planetary evolution, were the primary subjects of the workshop.

The atmosphere of Mars during the Noachian was probably substantially more dense than the present atmosphere of 7 mbar of CO_2. Just how dense it was is a subject of some debate. Processes that fed it during this period include volcanic outgassing and infall of volatile-rich meteorites. Processes that destroyed it may have included hydrodynamic and thermal escape, solar wind erosion, impact erosion, and chemical processes at the surface such as carbonate formation. The balance among these various processes has been a topic of much recent work and was vigorously discussed at the workshop. While the atmospheric pressure during the Noachian is unknown, there is a consensus that pressures of up to a few bars are plausible. If this was the case, then carbonate formation during or after the Noachian must have been important. Other sinks could remove hundreds of millibars of CO_2 from the atmosphere, but removal of a few bars would require that a substantial carbonate reservoir currently be present on Mars.

Probably another important characteristic of the Noachian was a much higher geothermal heat flow. Detailed models of the accretion and early thermal evolution of Mars, as well as isotopic evidence from SNC meteorites believed to come from Mars, provide persuasive evidence for very early core formation, a hot early mantle, and a high early heat flow. This recognition that Mars probably began its history hot has been one of the major developments in martian geophysics over the last several years. The mean global heat flow during the Noachian is also very uncertain, but a value 3.9 b.y. ago of about 5 × the present one (which is typically estimated at about 45–50 mW/m^2) is plausible. Whatever the global mean heat flow was at that time, it is certain that local values in areas of enhanced geothermal activity were significantly higher still.

Given these very different environmental conditions, it is natural to expect that geomorphic processes during the Noachian were different as well, and it is clear that they were. The most obvious difference is that the rate of formation of valley systems was far higher during the Noachian than it has been during any other period of martian history. Valley systems are small, quasidendritic drainage networks found primarily in the ancient cratered highlands of Mars. Typical valley widths are 1–2 km, and lengths extend up to several hundred kilometers. The valleys were almost certainly carved by liquid water flowing at low discharges in small channels. These valley systems have long provided the primary physical evidence suggesting that conditions on Mars were different early in the planet's history.

There is other morphologic evidence as well. Careful comparison of the depths and rim heights of Noachian craters with post-Noachian craters shows clearly that the rate of crater degradation (lowering of crater rims and raising of crater floors) was far higher in the Noachian than it has been since then. Such degradation is certainly attributable in part to erosion and deposition, though other processes (such as volcanic infilling) could also have played a role.

There is general agreement that there has been enough H_2O on Mars for us to accept that water was the fluid that carved the valley systems. However, the details of their formation are unclear. In particular, there are two key obviously linked questions that remain unresolved: Did conditions during the Noachian allow precipitation? And does the geomorphic evidence from the Noachian require precipitation?

If the climate of Mars was warm enough during the Noachian to allow precipitation, then an enhanced greenhouse effect enabled by a denser atmosphere is required. However, temperatures anywhere close to the melting point of water may be difficult to achieve with a dense early CO_2 atmosphere on Mars. Earlier models predicted substantial greenhouse warming for an atmosphere of a few bars of CO_2. However, more recent models that include the effects of CO_2 condensation and cloud formation suggest that such an atmosphere is capable of raising the martian surface temperature by at most several tens of degrees. For the conventional view of solar evolution (which suggests a luminosity about 75% the present value during the Noachian), such a greenhouse does not appear capable of producing mean surface temperatures in excess of ~230 K.

There are two other factors that could conceivably contribute further climatic warming, but both are highly uncertain. One is the possibility that the early Sun was substantially more luminous than predicted by conventional models; this would require a much higher rate of solar mass loss during the Sun's early history than is usually accepted. The other is the possibility that substantial quantities of methane, another very effective greenhouse gas, were present in the martian atmosphere. Without either of these effects, however, the best recent work suggests that climatic warming to temperatures above 273 K during the Noachian was not possible.

There also is no general agreement as to whether the geomorphic evidence actually requires precipitation. Some researchers point to the ubiquitous nature of the valley systems in old heavily cratered terrain on Mars, and to the fact that some valley heads extend right to the crests of drainage divides. From these characteristics they infer that precipitation and runoff must have taken place. Others note that the morphology of many valley systems is more consistent with sapping than runoff, and that the highest drainage densities on Mars are substantially lower than those in even arid regions on Earth. From these characteristics, they infer that the valleys formed by sapping of subsurface liquid, and that precipitation was not required. There is also disagreement as to whether the early high rates of crater degradation require precipitation, or whether they are just a consequence of higher early rates of sapping, eolian transport, volcanism, and so forth.

There are geomorphic points on which there is agreement. There are some valley systems for which all workers agree that sapping is a satisfactory explanation, without the need to invoke precipitation and runoff. It is also clear that many valley systems are too extensive to have formed by the single discharge of an aquifer, i.e., that some type of aquifer recharge is required. Several different processes, including precipitation and hydrothermal convection (enabled by the early high heat flow), have been examined closely as recharge mechanisms. Both of these appear to be more than adequate to do the job. The basic difficulties are that dissimilar processes can produce similar final landforms, and that many processes may have operated on these valleys, including ones that have substantially obscured the evidence for the primary genetic process.

A final issue that was considered at the workshop was identification of directions for future work. Important areas where further progress should be possible include these:

- Use geochemical data from Mars Observer or a follow-on mission to search for martian carbonates.
- Use imaging data from Mars Observer or a follow-on mission to search for further morphologic evidence requiring Noachian precipitation.
- Improve models of the contribution of methane to the martian greenhouse.
- Further investigate the prospects for a more luminous early Sun.
- Model the climatic effects of the very high and rapidly varying obliquities that are suggested by recent dynamical modeling.
- Improve climate models to include the optical properties of CO_2 clouds.
- Continue investigation of terrestrial analog terrains and processes.

Note added in proof: In light of the failure of Mars Observer, a top priority should be a reflight of the instruments to obtain the data that otherwise will not be acquired.

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