MSATT NEWSLETTER

Mars Surface and Atmosphere Through Time

Number 1 *July 1991*

The MSATT logo incorporates Viking images of the southern hemisphere limb of Mars, depicting the surface and atmosphere in early and late winter (NASA Photos 53A65 and 79B06).

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WELCOME TO MSATT

Robert M. Haberle, NASA Ames Research Center
Chair, MSATT Steering Committee

This newsletter marks the kickoff of MSATT (Mars Surface and Atmosphere Through Time), a three-year NASA-sponsored LPI study project whose goals are to better understand the processes that have modified the martian surface and atmosphere through time. MSATT is the third in a series of focused study projects, the first two of which were MEVTV (Mars: Evolution of Volcanism, Tectonism, and Volatiles), which ran from 1986 to 1989, and MECA (Mars: Evolution of its Climate and Atmosphere), which ran from 1983 to 1986.

Both MEVTV and MECA were highly successful projects and much of that success can be attributed to the manner in which they functioned. By guiding the research through periodic topical workshops, these programs fostered collaborations and interactions between scientists of widely differing backgrounds. As a result, an interdisciplinary approach to solving key Mars science questions was developed that accelerated progress and increased productivity. This will also be the approach taken for MSATT since, even more than its predecessors, MSATT's goals cross many disciplines. Briefly stated, those goals address the following questions: (1) What is the current state of the martian surface and atmosphere, and by what processes do they interact? (2) What is the chemistry and mineralogy of martian soils and rocks, and how have they changed over time? (3) What was the composition and climate of the early martian atmosphere, and how has it evolved to its present state? (4) What is the long-term geologic history of Mars, and what role have erosional and depositional processes played in that history?

MSATT was to begin addressing these questions in March of 1990, but funding problems delayed its inception for a year. During that time several meetings were held to discuss how the program would function. Given the proven success of MEVTV and MECA, there seemed little reason to change the basic plan. Thus, MSATT will function through a working group and a steering committee. The working group will consist of the program's 31 funded investigators, who will carry out research as approved in their proposals. However, participation in MSATT is open to all interested researchers through a study group. Members of the MSATT Study Group will be kept abreast of the project's activities through the MSATT Newsletter and periodical mailings. Those interested in joining the study group should contact the LPI's Program Services Department, whose main function is to provide logistical and administrative support.

The steering committee, which was selected by the working group, will provide guidance to the Program Services Department on science goals and workshop topics. Given the broad interdisciplinary nature of MSATT and the desire to foster working group interactions, the steering committee decided that the first workshop should be open to the entire community. The smaller and more focused workshops would then follow. Limited funds are available to support these workshops, five or six of which are expected to be held

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Welcome to MSATT *continued*

during the project's three-year lifetime. Proposals for the smaller workshops should be submitted to the steering committee through the Program Services Department. Guidelines for workshop proposals are given in the article on page 5 of this newsletter.

Journal publication will be the principal means of reporting MSATT results. Workshop programs and LPI technical reports will also be part of the reporting process and, where appropriate, special issues and timely review articles will be encouraged.

In summary, MSATT promises to be an exciting project and I look forward to your participation. With the launch of Mars Observer but a year away, now is a good time for a research program dedicated to the red planet. On behalf of the steering committee, welcome to MSATT! ♂

OBSERVATIONS OF MARS USING HUBBLE SPACE TELESCOPE

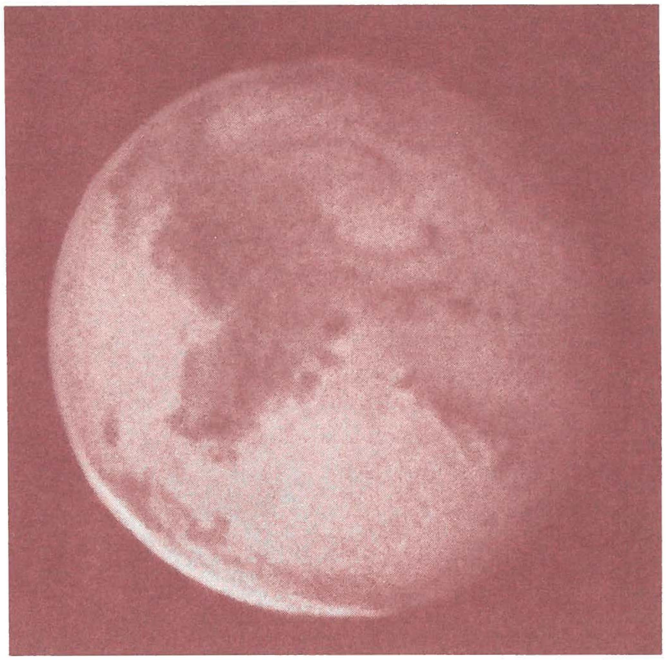
Philip B. James, University of Toledo
R. Todd Clancy and Steven W. Lee, University of Colorado
Ralph Kahn and Richard Zurek, Jet Propulsion Laboratory
Leonard Martin, Lowell Observatory
Robert Singer, University of Arizona

The lack of a continuous record of martian meteorology or of volatile cycles on Mars for extended periods of several martian years seriously hinders efforts to understand the physics of the martian atmosphere-surface system. Spacecraft observations are limited to only a few isolated time periods, and the Earth-based record is limited by the relatively short periods surrounding oppositions when telescopic observations can yield useful data. Our incomplete knowledge of the temporal distribution of major dust storm events on Mars is the best-known consequence of the lack of such a record, but the situation is much the same for seasonal variability in the behavior of surface condensates in the polar regions and for the behaviors of clouds in different years.

To test one possible technique for remedying this situation, we have embarked on a three-year program of Mars observations using the Hubble Space Telescope (HST). Current policy prohibits pointing the telescope closer than 50° to the Sun. Although this restriction eliminates 45% of the 780-day synodic cycle from possible observation, it is still a great improvement over the 2 to 5 months of each cycle (depending on the orbital geometry of the two planets at opposition) that can profitably be used for Earth-based observations. During the initial phase of the project we have imaged Mars five times in a variety of spectral bands, starting in December 1990, when Mars was roughly 16.5" in size, to May 1991, when Mars's angular size was 4.8", near the minimum for the synodic cycle. The sub-Earth point resolution, using prelaunch expectations for optical performance, would have ranged from about 50 km to about 175 km during this period; thus, even when Mars is at its smallest angular size, HST would consistently provide resolution similar to that typically obtained using Earth-based telescopes during favorable oppositions. The well-known spherical aberration present in HST's primary mirror has degraded the resolution of the raw HST images to that of average Earth-based views. However, computer deconvolution of the images using observed or simulated stellar point-spread functions restores most of the missing detail to images of extended solar system objects. The Mars images taken to date have been deconvolved using a version of the Richardson-Lucy algorithm supplied by the Space Telescope Science Institute.

Preliminary analysis of the images obtained by HST during the five observation sequences has rewarded our optimism. Even at 4.8", details of the albedo boundaries on the surface are clearly resolvable. The images taken in May, when L_s equaled 60°, clearly reveal the multicomponent "W" clouds in the Tharsis-Valles Marineris region as well as clouds associated with Elysium Mons. These images also show the north polar surface cap, which is tilted Earthward during this season. The potential scientific value of these images augurs well for the investigation of the 1992 "classic dust storm" season, which will begin following the emergence of Mars from the 50° exclusion zone; the images obtained at this time will be of similar scale to those obtained in May.

Several scientific investigations are presently being conducted using the HST images, which were acquired using narrow-band pass filters at 889 nm, 673 nm, 588 nm, and 502 nm and wide-band pass filters at 413 nm, 336 nm, and 230 nm. Integration times were, for all but the last filter, about 1 second; a roughly 2-minute exposure was necessary at 230 nm, requiring a scan of the target to compensate for proper motion. The investigations include study of the albedo variations on the surface of the planet in the region of Syrtis Major, unit mapping of spectral reflectances in the wavelength bands mentioned above, determination of optical depths due to aerosols and condensates, study of the properties of condensate clouds and hoods, comparison of surface and atmospheric features observed by HST to the historical database of terrestrial observations at the same season, observation of the size and shape of surface polar caps, and investigation of surface and atmospheric phenom-



This image of Mars was recorded on December 13, 1990 by NASA's Hubble Space Telescope. The dark region protruding to the north (lower lefthand corner) is Syrtis Major.

ena revealed by Wide-Field/Planetary Camera (WFPC) imaging in the ultraviolet portion of the spectrum and by spectral maps derived from Faint Object Spectrograph (FOS) scans of the planet.

The ultraviolet imaging capabilities of HST provide a unique opportunity to study the surface and atmosphere of Mars in this relatively unexploited wavelength region. In particular, the strong ozone absorption near 230 nm makes it possible to map ozone concentration through differencing the 230- and 336-nm images. Preliminary use of this method reveals strong ozone absorption in the north polar region during late winter, as expected from the low water-vapor content in the atmosphere at that time, and reveals other interesting correlations with various topographic and surface features. The differencing technique will be verified and calibrated using spectral scans of the planet in the ultraviolet portion of the spectrum using the FOS; the latter data have been inspected to verify that the signal-to-noise ratio is as expected, but detailed analysis of those data has not yet been undertaken.

Preliminary data analysis has already established that the deconvolved images of Mars will be sufficient to attain the scientific objectives of the program. It has also indicated that this technique has the capability of providing regular monitoring of the planet except during periods when Mars is too close to the Sun. Hubble Space Telescope's Cycle 2 will encompass a major portion of the next dust storm season, and frequent monitoring of the planet will be conducted during that period. That cycle will also afford the opportunity of revisiting the same seasons imaged during the last few months in order to search for existence and causes of variability. Cycle 2 will provide monitoring of Mars leading into the Mars Observer Mission. We hope that, using the new instrumentation to be installed on HST in 1993, it will be possible to make observations that will complement the experiments to be conducted on the Mars Observer Mission. ♂

MARS ENVIRONMENTAL SURVEY MISSION

Stephen W. Squyres, Cornell University

For some time it has been recognized that the next logical step in the exploration of Mars after the Mars Observer mission is the deployment of a network of numerous landers on the martian surface. A mission of this sort will enable achievement of two classes of scientific objectives that cannot be met by any other means: (1) objectives that require the simultaneous operation of a number of globally distributed surface stations, primary examples of which are a global seismic network and a global network of meteorological stations; and (2) objectives that require sampling of a large number of globally distributed sites, for example, geochemical sampling, high-resolution surface imaging, and measurement of atmospheric structure along entry profiles. Particular emphasis would be placed on hard-to-reach sites (polar deposits, rugged volcano flanks, etc.) that would be difficult or impossible to investigate by other means.

In order to meet objectives like these, global distribution of landers is necessary, so trajectories and vehicle designs must be chosen that can reach nearly all points on the martian surface and can survive once they get there. Simultaneous operation of many stations for long periods is needed, so the landers must be capable of long life. The landers must be simple and rugged; simple so that many of them can be sent for a reasonable cost, and rugged so they can survive a wide range of landing and environmental conditions.

Over the past year, a specific mission design has been found that meets these requirements: the Mars Environmental Survey (MESUR) mission. MESUR is presently under study at NASA Ames Research Center, and the mission will be considered late this summer for inclusion in NASA's queue of new mission candidates. The study is being led by Scott Hubbard of Ames, with science guidance

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Mars Environmental Mission *continued*

from the MESUR Science Definition Team, chaired by Steve Squyres of Cornell.

The MESUR approach involves as many as 20 lightweight stations distributed over the surface of Mars. They would be launched in the late 1990s on medium-lift (Delta-class) launch vehicles. Launches would take place over as many as three launch opportunities at intervals of about two years. Four small stations would be launched on each vehicle, and each would fly independently to Mars. After atmospheric entry, the stations would descend by parachute and make a semihard landing. Power would be provided by radioisotope thermal generators (RTGs). The lander itself weighs 65 kg, including 8 kg of scientific instruments. The entire probe, including parachute, heat shield, and cruise stage, weighs 150 kg. The stations will be designed to survive long enough that the full network will be in place and operational for at least one Mars year. Communications to Earth will be via a simple relay orbiter, with low-rate direct-to-Earth communication possible as a backup. All latitudes and longitudes on the planet will be available for landing, and landing accuracy is expected to be better than 50 km.

The following instruments are under consideration as a strawman scientific payload for the MESUR landers:

Seismometer: A single, three-axis seismometer with a sensitivity of 10^{-10} g, bandwidth of 25 s to 20 Hz, and a capability for data compression and programmable event detection.

Meteorology package: A set of meteorological instruments consisting of a pressure sensor, wind sensor, temperature sensor, sky radiometer, and humidity sensor.

Alpha/proton/X-ray spectrometer: An instrument consisting of an alpha particle source and detectors for backscattered alpha particles, protons, and X-rays. The alpha-p-x spectrometer will determine elemental chemistry of surface materials for most major elements except hydrogen.

Thermal analyzer: Either a differential scanning calorimeter or differential thermal analyzer for investigation of the low-temperature mineralogy of martian soils.

Evolved gas analyzer: Either a gas chromatograph or a solid-state water analyzer that samples the gas evolved from the thermal analyzer as it is heated; will also be used for investigation of the low-temperature mineralogy of soils.

Descent imager: An imaging system that acquires monochromatic nested images of the martian surface as the lander descends toward the surface.

Surface imager: A panoramic camera that acquires high-resolution multiband images of the scene surrounding the surface station after landing.

Atmospheric structure experiment: Instrumentation to measure atmospheric temperature, atmospheric pressure, and vehicle acceleration during entry into the martian atmosphere and descent to the surface.

The seismometers and compositional instruments will be placed in direct contact with the martian surface, while the surface imager and meteorology package will be deployed above the lander on 1-m booms. With this payload and a large number of widely distributed surface stations, it is expected that MESUR will lead to considerable improvements in our understanding of Mars, providing the first detailed look at a large number of surface sites.

For more information on MESUR, contact Scott Hubbard at NASA Ames Research Center (415-604-5697) or Steve Squyres at Cornell University (607-255-3508). ♂

NEWSLETTER CONTRIBUTIONS

In an effort to keep the study group informed about the latest meetings, activities, and other news relevant to MSATT's goals and Mars in general, contributions to the MSATT Newsletter are cordially invited. Contributions should be brief and written in newsletter style. Submissions may be either typewritten or transmitted as standard ASCII text files either over the telephone or by sending a standard diskette (along with a hard copy of the article) to MSATT Newsletter, LPI Publications Services, 3303 NASA Road 1, Houston TX 77058-4399. The deadline for contributions to the next issue of the MSATT Newsletter is **November 25, 1991.**

To send contributions via electronic mail, your modem should be set to either 300 or 1200 baud; to reach the LPI VAX dial 713-486-8214 or 9782. The username is "MAILBOX," the password is "LPI" (after each entry hit RETURN). When the prompt "$" appears on your screen, type "MAIL." All contributions should be addressed to "SCHURAYTZ." When you complete your message hit CTRL-Z and then type "EXIT" in response to the prompt ">." When the symbol "$" returns to your screen, type "LOG" and then hang up. For electronic mail, any PC or terminal will theoretically work; however, best compatibility is achieved by using or emulating a DEC terminal. Questions regarding electronic transmission should be directed to Lorraine Fisher, LPI Computer Center, at 713-486-2194. ♂

SPECIAL SESSION HELD AT SPRING AGU

Janet G. Luhmann, University of California, Los Angeles
Bruce M. Jakosky, University of Colorado

An AGU Special Session on "Mars Atmospheric Sciences" was featured at this spring's American Geophysical Union Meeting in Baltimore, Maryland, held the week of May 28-31, 1991 (see *Eos Trans. AGU*, *72*, April 23, 1991). The session, which was co-organized by B. Jakosky and J. Luhmann, included five invited and four contributed presentations. Many of these papers dealt with aspects of paleoclimate and atmosphere evolution. In particular, J. Kasting (in a paper coauthored with T. P. Ackerman) discussed the recent finding that it is probably incorrect to invoke the greenhouse effect caused by an early, dense CO_2 atmosphere to explain the presence of ancient water channels on the martian surface. These authors find that under the conditions presumed to exist at early Mars (solar system age $\leq$1 b.y.), CO_2 in fact condenses in the upper troposphere and stratosphere, thereby significantly altering radiative transfer to the point where a "greenhouse" would not be produced. They conclude that another explanation, such as the presence of an alternative "greenhouse gas," must be found if such a process is indeed responsible for the water channels.

A. Vickery presented the latest results on the theory of early impact erosion of the atmosphere of Mars. Since impacting bodies can be a source of atmospheric gases as well as a means by which they are removed, detailed numerical models are required to determine the conditions for which substantial material is ejected for a given projectile. The effects of impacts also depend on the local gravitational well. Current models indicate that impacts may have been a major factor in atmosphere removal at early Mars, but there are significant uncertainties associated with the limited knowledge of the history of bombardment in the early solar system at the orbit of Mars.

The history of Mars's volatile budget was the topic of a paper given by B. Jakosky, who described the need to understand the interconnected processes of both escape to space and interaction with the surface in order to account for the current H_2O and CO_2 reservoirs. For the former, models of both photochemically driven escape and processes related to the solar wind interaction are necessary. On the subject of interaction with the surface, B. Fegley focused attention on the circulation of Mars volatiles through the polar caps and on new experimental work being done on the consequences of the penetration of the atmosphere by solar UV radiation, which produces surface photochemical reactions not possible at either Venus or Earth because of their thicker atmospheres. S. Bougher described the latest global models of the circulation of Mars's upper atmosphere, including the effects of dust storms on atmosphere dynamics. While it is not yet clear how the evolution of the atmosphere is affected by the dynamics of the mesosphere and thermosphere, it is nonetheless useful to know the response of that part of the system to various factors. For example, atmosphere escape due to dissociative recombination processes can be altered if the upper atmosphere is significantly affected by dust storms.

Contributed papers added breadth to the session, ranging from descriptions of further work on the solar wind interaction (papers by M. H. G. Zhang et al. and H. Perez-de-Tejada) to details concerning surface chemistry and Mars obliquity that relate to the understanding of how Mars's atmosphere works (papers by M. T. Leu et al. and D. P. Rubincam). Many of these same topics will be the subject of more intensive discussions in the upcoming MSATT workshop in the fall of this year. ♂

GUIDELINES FOR SUBMITTING WORKSHOP PROPOSALS

The MSATT Steering Committee welcomes suggestions for future workshop topics from all interested researchers, including but not limited to MSATT Principal Investigators. If you would like to suggest a topic for a focused workshop that is germane to the goals of the MSATT Project, submit your proposal for consideration by the steering committee through the LPI's Program Services Department (PSD). Below are some workshop guidelines to keep in mind when preparing your proposal.

Workshop proposals should identify the prospective conveners and include the scientific rationale, goals, and potential participants of the workshop, as well as meeting location, tentative dates, and budgetary information.

Upon approval of a workshop proposal by the steering committee, the manager of the PSD is notified, and the workshop is developed in accordance with NASA and LPI requirements. The conveners also select the members of the program committee at this time.

When these preliminary steps have been completed, a PSD Meeting Coordinator is assigned to the workshop. This person will work closely with the conveners to coordinate all meeting-related support, including the preparation and distribution of circulars and publicity information, locating and

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Guidelines for Workshop *continued*

contracting with meeting facilities, establishing and collecting fees, payment of meeting-related expenses, etc.

The LPI Publications Services Department provides consultation for and preparation of published meeting products. Discussions with the Managing Editor to establish the publications desired and the constraints and deadlines necessary to provide them should occur as soon as the workshop has been scheduled. A premeeting abstract volume and a postmeeting LPI Technical Report are the normal published products associated with workshops.

In most circumstances, about $3K is made available for supported meeting travel. These funds are normally reserved for those investigators not funded by the program. Support for program committee travel for committee meetings or workshop attendance is not provided except in very rare circumstances.

A registration fee is collected to cover expenses that cannot be paid out of contract funds (i.e., refreshments, etc.). This fee is estimated as a "break-even" amount, based on the total estimated costs divided by the total number of estimated paid participants.

As reservations for meeting space need to be made and confirmed well in advance, a proposal should be approved approximately eight months prior to the actual date of the workshop. This timing is flexible based on the needs, size, and complexity of the meeting. However, proposals should be submitted so as to allow adequate time for evaluation by the steering committee.

Send proposals to:

MSATT Workshop Proposals
Lunar and Planetary Institute
Program Services Department
3303 NASA Road 1
Houston TX 77058-4399

For additional information write to the address above or telephone 713-486-2150. ♂

FIRST MSATT WORKSHOP SCHEDULED

The first workshop of the MSATT Study Project, aptly titled "Workshop on the Martian Surface and Atmosphere Through Time," will be held September 23-25, 1991, in Boulder, Colorado. The purpose of this workshop is to begin to explore the interdisciplinary nature of and define the relationships between aspects of Mars science involving evolution of the surface, atmosphere, upper atmosphere, volatiles, and climate. The scope of the workshop is broad enough to include all MSATT participants and will focus attention on the crux of each of four research problems of the project:

- The present state of the surface and atmosphere and the nature of ongoing processes that can affect their evolution or mutual interactions.
- The geochemistry and mineralogy of the surface at present or in past epochs.
- The history of geologic processes that either had an affect on or are indicators of the interactions between the surface and atmosphere.
- The evolution of the atmosphere and volatile system as a whole, including loss to space, interactions with the surface and climate history.

In order to maintain a dynamic workshop atmosphere, each session will begin with invited talks that will be review, tutorial, or inflammatory in nature. Much of the workshop will be devoted to formal discussion periods, with designated discussion leaders to keep things lively by posing key questions and eliciting comments from participants. All contributed papers will be presented as posters. A significant fraction of the meeting time will be devoted to the poster sessions to ensure that participants have ample opportunity for viewing the posters and interacting with the presenters.

The tentative program includes the following topics and invited speakers:

Current geological processes	*R. Greeley*
Current surface properties	*P. Christensen*
Current atmospheric properties	*R. Zurek*
Current atmospheric chemical processes	*Y. Yung*
Surface-atmosphere interactions—Volatiles	*A. Zent*
Mineralogy of the surface	*R. Singer*
Geochemistry of the surface	*B. Clark*
Atmospheric evolution—Interactions with the surface	*B. Fegley*
Atmospheric evolution—Loss to space	*J. Luhmann*
Long-term geological processes	*K. Tanaka*
Oceans and ice-related geological evolution	*V. Baker*
Short- and long-term climate change	*J. Pollack*

The deadline for abstracts of contributed papers is July 26. Authors will be given an opportunity immediately following the workshop to revise their abstracts for inclusion in the LPI Technical Report.

The program committee includes co-conveners Robert Haberle (NASA Ames Research Center) and Bruce Jakosky (University of Colorado) and committee members Kenneth Tanaka (U.S. Geological Survey, Flagstaff) and Amos Banin (NASA Ames Research Center and Hebrew University).

For further information on the scientific content of the workshop, contact either co-convener:

Robert M. Haberle
Mail Stop 245-3
NASA Ames Research Center
Moffett Field CA 94035
Phone: 415-604-5491

Bruce M. Jakosky
LASP/Campus Box 392
University of Colorado
Boulder CO 80309-0392
Phone: 303-492-8002

For information on logistics or workshop registration, contact:

Cathy Fischer
Meeting Coordinator
Lunar and Planetary Institute
3303 NASA Road 1
Houston TX 77058
Phone: 713-486-2177
FAX: 713-486-2160

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Ben Schuraytz, Editor 713-486-2187
Publications Services Dept. 713-486-2143

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MARS REPRINTS/PREPRINTS

A Mars reprint/preprint announcement service, started during the MECA Study Project, will be continued as part of the MSATT Study Project. Any paper whose scope is encompassed by the research objectives of the MSATT Study Project, and whose authorship includes at least one member of the MSATT Study Group, is a candidate for inclusion. Preprint and reprint information should be submitted by the author, and titles will be added to the list of publications. Additions should be limited to recent articles (1988 or later). Requests for copies should be addressed to the senior author.

Burns R. G. (1988) Gossans on Mars. *Proc. Lunar Planet. Sci. Conf. 18th*, pp. 713-721.

Burns R. G. (1989) Spectral mineralogy of terrestrial planets: Scanning their surfaces remotely. *Mineral. Mag., 53*, 135-151.

Burns R. G. and Fisher D. S. (1990) Evolution of sulfide mineralization on Mars. *J. Geophys. Res., 95*, 14169-14173.

Edgett K. S. (1991) The ejecta deposit of the ancient basin Herschel: An example of a generally unrecognized martian sedimentological unit. *Proc. Lunar Planet. Sci., Vol. 21*, pp. 657-667.

Frey H. V., Doudnikoff C. E., and Mongeon A. M. (1991) Are Noachian-age ridged plains (Nplr) actually Early Hesperian in age? *Proc. Lunar Planet. Sci., Vol. 21*, pp. 635-644.

Golombek M. P., Plescia J. B., and Franklin B. J. (1991) Faulting and folding in the formation of planetary wrinkle ridges. *Proc. Lunar Planet. Sci., Vol. 21*, pp. 679-693.

Longhi J. (1991) Complex magmatic processes on Mars: Inferences from the SNC meteorites. *Proc. Lunar Planet. Sci., Vol. 21*, pp. 695-709.

Mouginis-Mark P. J., Wilson L., and Zimbelman J. R. (1988) Polygenic eruptions on Alba Patera, Mars. *Bull. Volcanol., 50*, 361-379.

Scott D. H. and Chapman M. G. (1991) Mars Elysium Basin: Geologic/volumetric analysis of a young lake and exobiologic implications. *Proc. Lunar Planet. Sci., Vol. 21*, pp. 669-677.

Scott D. H. and Underwood J. R. Jr. (1991) Mottled terrain: A continuing martian enigma. *Proc. Lunar Planet. Sci., Vol. 21*, pp. 627-634.

Solomon S. C. and Head J. W. (1990) Heterogeneities in the thickness of the elastic lithosphere of Mars: Constraints on heat flow and internal dynamics. *J. Geophys. Res., 95*, 11073-11083.

Zimbelman J. R. and Craddock R. A. (1991) An evaluation of probable bedrock exposure in the Sinus Meridiani region of the martian highlands. *Proc. Lunar Planet. Sci., Vol. 21*, pp. 645-655.

Zimbelman J. R., Solomon S. C., and Sharpton V. L. (1991) The evolution of volcanism, tectonics, and volatiles on Mars: An overview of recent progress. *Proc. Lunar Planet. Sci., Vol. 21*, pp. 613-626. ♂

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