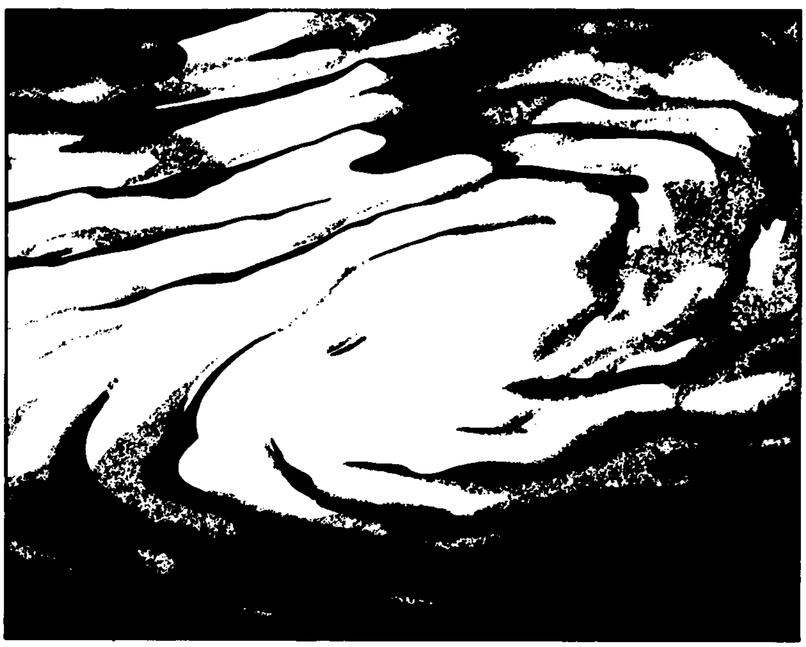
NASW-4066

SCIENTIFIC RESULTS OF THE NASA-SPONSORED STUDY PROJECT ON MARS: EVOLUTION OF ITS CLIMATE AND ATMOSPHERE



MECA

(NASA-CR-184652) SCIENTIFIC RESULTS OF THE NASA-SPONSORED STUDY PROJECT ON MARS: EVOLUTION OF ITS CLIMATE AND ATMOSPHERE (NASA) 36 p CSCL 03B
N89-15059
Unclas
G3/91 0170241

LPI Technical Report Number 88-09

LUNAR AND PLANETARY INSTITUTE 3303 NASA ROAD 1 HOUSTON, TEXAS 77058

SCIENTIFIC RESULTS OF THE NASA-SPONSORED STUDY PROJECT ON MARS: EVOLUTION OF ITS CLIMATE AND ATMOSPHERE

Stephen M. Clifford
Lunar and Planetary Institute
3303 NASA Road 1
Houston, TX 77058

Ronald Greeley
Department of Geology
Arizona State University
Tempe, AZ 85287

Robert M. Haberle
Mail Code 245-3
NASA Ames Research Center
Moffet Field, CA 94035

Lunar and Planetary Institute 3303 NASA Road One Houston, Texas 77058-4399

LPI Technical Report Number 88-09

Compiled in 1988 by the
LUNAR AND PLANETARY INSTITUTE

The Institute is operated by Universities Space Research Association under Contract NASW-4066 with the National Aeronautics and Space Administration.

This report may be cited as:
Clifford S. M., Greeley R., and Haberle R. M. (1988) *Scientific Results of the NASA-Sponsored Study Project on Mars: Evolution of its Climate and Atmosphere.* LPI Tech. Rpt. 88-09. Lunar and Planetary Institute, Houston. 33 pp.

Papers in this report may be cited as:
Author A. A. (1988) Title of paper. In *Scientific Results of the NASA-Sponsored Study Project on Mars: Evolution of its Climate and Atmosphere* (S.M. Clifford, R. Greeley, and R. M. Haberle), pp. xx–yy. LPI Tech Rpt. 88-09. Lunar and Planetary Institute, Houston.

This report is distributed by:

ORDER DEPARTMENT
Lunar and Planetary Institute
3303 NASA Road One
Houston, TX 77058-4399

Mail order requestors will be invoiced for the cost of shipping and handling.

Contents

Project Summary

The principal scientific finding of the MECA study project is that Mars had a substantially "wetter" early history than previously thought. This realization is derived from several lines of evidence, including various geological arguments and geochemical models based on the composition of the SNC meteorites (which many investigators believe may be samples of Mars).

The research suggests that Mars has outgassed the equivalent of a global ocean of water 0.5–1.0 km deep. Previous estimates, based on the low measured abundance of atmospheric rare gas, suggested an inventory as small as 10–100 m. The discrepancy between these estimates is resolved if consideration is given to the various loss processes that may have affected the early atmosphere, such as hydrodynamic escape and atmospheric erosion by large impacts.

Where does the surviving water reside? The only visible reservoirs are the martian polar caps and atmosphere, but their combined inventories fall far short of the suspected total. The "missing" water may be stored within the impact-generated regolith. Geologically reasonable estimates of the regolith's total pore volume indicate that it may be sufficient to store a global ocean of water as much as 1.5 km deep.

The presence of integrated networks of small valleys throughout the planet's ancient cratered terrain suggests that the early martian climate may have differed markedly from that of today. Calculations indicate that an atmosphere of 1–5 bars of carbon dioxide would raise temperatures high enough to permit the flow of liquid water over the martian surface. Such conditions may have characterized the first half billion years of the planet's climatic history, only to end as weathering processes depleted the atmospheric inventory of carbon dioxide faster than it could be replenished by global volcanism. If the early climate of Mars was indeed warm and wet, it clearly reopens the possibility that the planet may have evolved indigenous life.

The diurnal, seasonal, and longer-term cycles of atmospheric water, carbon dioxide, and dust were also addressed during the MECA project. Evidence of the cyclical nature of the martian climate is visible in the layered stratigraphy of the perennial polar caps. This record is believed to reflect obliquity-driven changes in the formation of the seasonal carbon dioxide frost caps and the intensity of global dust storms. Complicating our understanding of this process is the recent discovery that the albedo of the seasonal caps is insolation dependent, a behavior that appears to explain why the current southern seasonal cap is able to survive throughout the southern summer.

As an experiment in the management of a complex scientific program, MECA must be considered a success. Of particular note were the various MECA workshops, which brought together scientists of diverse backgrounds to discuss issues of common interest. The cross-discipline education and cooperative efforts that resulted from these meetings were major factors in the success of the program. Because many important issues in Mars climate research remain unresolved, we strongly recommended that a mechanism be established to continue this program of focused workshops. Given the success of this approach, we believe that the investigation of other complex problems in planetary science would benefit from the MECA model of science management.

Science Report

INTRODUCTION

Mars has long fascinated scientists and the public. As a result, it has been the target of a number of ambitious spacecraft missions, the most recent being that of Vikings 1 and 2 in 1976. Following an initial period of intensive study, it became clear by the late 1970s that the Viking data could still yield important clues about the nature and evolution of Mars. In recognition of this potential, NASA established the Mars Data Analysis Program (MDAP) in 1979 to coordinate the funding and direction of Mars research. The first major investigation supported by MDAP was a focused three-year study project on the origin and evolution of martian volatiles. The project, entitled "Mars: Evolution of its Climate and Atmosphere" (MECA), was initiated in 1984 under the direction of the Lunar and Planetary Institute.

In many respects, MECA was an experiment in science management. It combined elements of both a project approach and an approach involving research by independent investigators. From the project perspective, specific goals and objectives were defined, with administrative and logistical support provided through a central organization, the Lunar and Planetary Institute. However, investigators were funded individually and operated independently within the context of the study. To insure broad-based involvement, participation in the study project was open to all investigators who had research interests in the volatile and climate history of Mars, regardless of funding source.

At the first meeting of the project, held in the spring of 1984, a science steering committee was elected and general guidelines for the project were defined. Three broad areas of study were identified: (1) the bulk chemical composition and outgassing history of Mars, (2) surface processes and climate history, and (3) seasonal cycles. Within each area key questions were identified to provide a focus for research. A program of workshops was then organized to provide cohesion to the project and ensure that the project's objectives would be addressed (Table 1). The results and ideas stimulated by this approach opened avenues of research that were unforeseen at the project's outset.

In this report, we review the scientific highlights of the MECA study project and discuss some of the important issues in martian climate research that remain unresolved.

TABLE 1. MECA workshops.

Name of Workshop	Date
Water on Mars	December 1984
Dust on Mars I	February 1985
Clouds on Mars I	April 1985
Evolution of the Martian Atmosphere	August 1985
Dust on Mars II	February 1986
Special Session on Martian Geomorphology and Its Relation to Subsurface Volatiles at LPSC XVII	March 1986
MECA Symposium on Mars: The Evolution of Its Climate and Atmosphere	July 1986
Atmospheric H_2O Observations of the Earth and Mars	September 1986
Clouds on Mars II	June 1987
Polar Processes on Mars	May 1988
Dust on Mars III	September 1988

WATER ON MARS

The principal conclusion of the MECA study project is that Mars had a substantially "wetter" history than previously thought. Although this conclusion is not accepted by all investigators, strong evidence has been rallied from several independent lines of study, including various geological arguments and geochemical considerations.

Geological Evidence for Abundant Water

With an atmospheric surface pressure of 6.1 mbar and a mean equatorial temperature of 220 K, the present martian climate precludes the stable flow of liquid water on the surface. However, there is evidence that a far different climate may have existed in the past. Integrated networks of small valleys, which resemble terrestrial runoff channels, dissect the planet's ancient (~4 b.y. old) heavily cratered terrain, an indication that the early climate may have differed markedly from that of today.

As discussed by *Carr* (1986), the clearest evidence of past water is provided by the outflow channels, which are broad, scoured depressions hundreds of kilometers long that

PRECEDING PAGE BLANK NOT FILMED

exhibit braided and streamlined forms within their beds. Most outflow channels originate within the cratered highlands just north of the great equatorial canyon system of Valles Marineris. The channels emerge abruptly from areas of collapsed and disrupted terrain, the apparent result of a massive and catastrophic release of groundwater. Carr estimates that the volume of water required to carve the channels was equivalent to a global ocean some 50 m deep. Channel ages, inferred from the density of superposed craters, indicate several episodes of flooding; the oldest postdate most of the valley networks, while the youngest apparently formed within the last 1 to 2 b.y.

There is little evidence of the fate of the water that eroded the channels. Initial examination of Mariner 9 and Viking images failed to reveal any indication of catchment areas. Their absence was attributed to the rapid vaporization of flood waters under conditions of low atmospheric pressure. However, the assumption that the flood waters were short-lived has been challenged recently by the discovery of possible remnants of ancient shorelines and sedimentary deposits in the low-lying northern plains. The evidence, derived from analysis of Viking images, suggests that large lakes and possibly even a shallow sea may have developed at the confluence of the major channels (*Jöns*, 1984; *Scott and Tanaka*, 1986; *Parker et al.*, 1987; *Greeley and Guest*, 1987).

Ancient shorelines and sedimentary deposits are not the only evidence that sizable bodies of water may have once existed on Mars. Horizontal, layered deposits up to 5 km thick are found in several branches of Valles Marineris. *McCauley* (1978) argued that these deposits are lake sediments that accumulated during an early epoch. *Nedell et al.* (1987) developed this idea further, suggesting that the lakes were formed when extensive groundwater seepage filled several of the enclosed canyons.

Given the evidence of past water and the desiccated appearance of Mars today, the question arises: Where has all the water gone? Spacecraft measurements of the hydrogen escape flux from the martian atmosphere (*Anderson and Hord*, 1971) and kinetic theory calculations (*Walker*, 1977) indicate that Mars has lost ~3 m of water by photodissociation and exospheric escape over the course of its geological history. Thus, most of the planet's initial inventory of water should still reside in one of three reservoirs: the atmosphere, the perennial polar caps, or the regolith. The inventories of the first two reservoirs are readily assessed. Data obtained by the Viking Mars Atmospheric Water Detectors (MAWD) revealed that if all the water vapor present in the martian atmosphere were to condense on the surface it would form a global layer only 15 microns thick (*Farmer et al.*, 1977). Similarly, the dimensions of the perennial polar caps are consistent with a quantity of water no greater than a global ocean several tens of meters deep. The total size of these two reservoirs falls significantly short of the planetary inventory inferred from the abundant geomorphic evidence of past fluvial and periglacial activity (*Carr*, 1986). This evidence suggests that a considerable amount of water now resides within the regolith.

How much water can the martian regolith hold? As on the Moon, the intense bombardment phase of early martian geologic history is thought to have resulted in the production of a blocky, porous megaregolith that extends to considerable depth (*Fanale*, 1976; *Carr*, 1979). Studies of the seismic characteristics of the lunar crust suggest that it is brecciated to a depth of about 20 km. Gravitationally scaling this result to Mars suggests that the martian crust may retain significant porosity to a depth of 10 km and may possess a total pore volume sufficient to store a global layer of water 0.5–1.5 km deep (*Clifford*, 1987a).

The possibility that the regolith represents a sizable volatile reservoir is supported by a long list of martian landforms whose morphology has been attributed to the presence of subsurface water (*Rossbacher and Judson*, 1981; *Carr*, 1986). Many of these features resemble cold-climate features found on Earth; however, in other instances the morphologies appear unique to Mars. Of particular interest are rampart craters. Unlike craters found on the Moon, Mercury, and other bodies of the solar system, the ejecta surrounding many martian craters appears to have been emplaced in part as a ground-hugging fluidized flow. This fluidized appearance has led many investigators to conclude that rampart crater ejecta morphology originates from an impact into a water- or ice-rich crust (*Carr et al.*, 1977; *Gault and Greeley*, 1978; *Mouginis-Mark*, 1987); however, laboratory cratering experiments indicate that interactions with the atmosphere may also play a role (*Schultz and Gault*, 1979). If the water impact interpretation is correct, then the number and distribution of rampart craters indicates that the inventory of subsurface water on Mars, at the time of impact, was substantial.

Geological estimates of the amount of water that Mars has degassed have varied over a wide range. By mapping the extent and thickness of the planet's volcanic units, *Greeley* (1987) has estimated that about 46 m of water may have been released by volcanism alone, given lava volatile contents comparable to Earth's. *Carr* (1986) has taken a different approach. Based on his estimate of the volume of water required to erode the outflow channels and the likely extent of its original source area, he estimates a global inventory of water in excess of 500 m, assuming the source region was representative of the rest of the planet.

Mars Volatile Inventory: Geochemical Considerations

Most early attempts at estimating the volatile inventory of Mars were based on comparisons of the relative abundance of various atmospheric constituents (e.g., the noble gases, carbon, and nitrogen) with the corresponding values found on Earth. These comparisons were made in the belief that they provided an accurate indication of the relative extent of outgassing that Mars had experienced. However, the inventory of water predicted by these models was invariably small (100 m or less) and clearly at odds with the geological evidence. This conflict may at last be reconciled as a result of knowledge gained from an unlikely source: the Shergotty, Nakhla, and Chassigny (SNC) meteorites.

The SNCs are a group of eight stony meteorites that share at least two unique characteristics: a remarkably youthful crystallization age (~1.3 b.y.) and an embedded gas component that provides persuasive evidence of their origin. Based on age alone, the SNCs have attracted considerable attention, for they are half as old as the next youngest extraterrestrial sample found to date. Such recent crystallization requires a parent body that was geologically active for far longer than might be reasonably expected of the Moon or any asteroid. This consideration narrows the field of dynamically reasonable candidates to just one: Mars (*Wasson and Wetherill*, 1979; *Wood and Ashwal*, 1981).

Virtual confirmation that Mars is the parent body of the SNC meteorites has come from the analysis of gas trapped within their shock-induced melt. The gas has an isotopic composition that is strikingly similar to the atmospheric samples analyzed by the Viking Landers (*Bogard*, 1982; *Pepin*, 1987). This similarity extends to an observed enrichment in ^{15}N, a compositional characteristic that is otherwise unique to Mars (*Becker and Pepin*, 1984).

As probable samples of Mars, the SNCs provide clues to the planet's bulk composition and geochemical history (*Dreibus and Wanke*, 1985; *McSween*, 1985). When normalized to the abundances of such refractory elements as Si and La, the SNC meteorites are found to be several times richer in the moderately volatile elements (e.g., Na, K, and Br) than is generally inferred for Earth (*Dreibus and Wänke*, 1985). This finding provides further support for the belief that Mars is a volatile-rich planet.

Although a high volatile inventory appears difficult to reconcile with the low measured abundance of atmospheric rare gas, the discrepancy is readily explained if the martian atmosphere experienced a substantial mass loss early in its history. There are at least three processes by which such a loss may have occurred: hydrodynamic escape, atmospheric erosion by energetic impacts, and loss via the solar wind.

Hydrodynamic escape, or the rapid thermally-driven loss of hydrogen from a planetary atmosphere, was probably most effective during the first few hundred million years of solar system history, when the atmospheres of the terrestrial planets may have still possessed a significant solar component and when the sun's ultraviolet output was 1–2 orders of magnitude greater than it is today. One consequence of a vigorous flow of escaping hydrogen would be the enhanced loss of other light atmospheric constituents. As a result, an atmosphere that has undergone this process should exhibit a noticeable mass-fractionation of the lighter species; this is precisely what is observed in the present-day noble gas pattern of Mars (*Hunten et al.*, 1987; *Pepin*, 1987).

At least two other processes may have contributed to the depletion of a dense early atmosphere. Calculations by *Watkins and Lewis* (1985) suggest that large impacts may have blasted a significant portion of the early atmosphere off into space. This process would have been particularly effective during the heavy bombardment period, when large impacting bodies were still prevalent in the solar system. The depletion of the atmosphere was probably further enhanced by the interaction of the solar wind with the martian ionosphere. Particle velocities within the resulting plasma flow likely exceeded the 5 km s^{-1} escape velocity of Mars. Calculations indicate that this process alone could have reduced a dense early atmosphere to its present state in as little as a billion years (*Perez-de-Tejada*, 1987).

Thus, lines of geological evidence and geochemical models based on the composition of the SNC meteorites suggest that a substantial amount of water was present on Mars thoughout much of its early history. The apparent discrepancy between this large inventory and the low measured abundance of atmospheric rare gas is readily explained if consideration is given to the various loss processes that are likely to have affected the early atmosphere.

EVOLUTION OF THE CLIMATE

There are at least two schools of thought regarding the climatic conditions that prevailed on Mars at the time of valley network formation. The first is based on the idea that the networks resulted from precipitation and surface runoff (e.g., *Masursky et al.*, 1977), a model that requires atmospheric pressures and surface temperatures far higher than those of today. Such conditions are possible if Mars had an early "greenhouse" environment. Estimates of the amount of carbon dioxide necessary to maintain surface temperatures above freezing range from 1 to 5 bars (*Postawko and Kuhn*, 1986; *Kasting*, 1987). Although this is two to three orders of magnitude greater than the present atmosphere, it is well within current estimates of the planet's total volatile budget (*Pepin*, 1986).

For the atmospheric inventory of carbon dioxide to decline from an initial value of several bars to its present level of 6.1 mbar implies a significant depletion process. Although atmospheric erosion may have played a role, an alternative explanation is that atmospheric carbon dioxide reacted with the regolith and liquid water to form carbonate rocks (*Kahn*, 1985; *Pollack et al.*, 1987). The further development of the regolith by repeated impacts and weathering would have created an additional sink via adsorption (*Fanale et al.*, 1986). These processes may have ultimately modified the climate to the point where liquid water was no longer stable at the surface. Proponents of this model suggest that this transition occurred about 4 b.y. ago, marking the end of valley network formation.

The second school of thought suggests that the early climate did not differ substantially from that of today. Advocates of this view find no compelling reason to invoke a warmer, wetter period to explain the origin of the valley networks. Rather, they cite evidence that the primary mechanism of small valley formation was groundwater sapping (*Pieri*, 1980; *Brakenridge et al.*, 1985; *Baker and Partridge*, 1986), a process that does not require that liquid water exist in equilibrium with the atmosphere. If this analysis is correct, then small valleys could develop even under current climatic conditions (*Carr*, 1983; *Brakenridge et al.*, 1985).

Yet if the early climate were similar to the present one, why are valley networks found almost exclusively in the oldest terrains? Several explanations are possible. First, it has been observed that many small valleys originate on or near the rims of large craters. This association led *Brakenridge et al.* (1985) to suggest a genetic relationship whereby the impact melt produced during the formation of large craters resulted in the establishment of local hydrothermal systems within the surrounding ice-rich crust; the discharge from these systems then formed the valleys. Because only large impacts would have produced sufficient melt to establish the necessary hydrothermal activity, the decline in valley network formation might then simply reflect a decline in the number of large impactors.

Another possibility has been proposed by *Jakosky and Carr* (1985). They note that prior to the formation of the Tharsis volcanic complex, the obliquity of Mars periodically reached values as high as 45°. During these times, large quantities of water ice may have sublimed from the perennial polar caps. As the resulting vapor was transported toward the equator, cold nighttime temperatures could have led to saturation and snowfall at low latitudes, creating a snowpack that grew until the obliquity once again declined. *Clow* (1987) has shown that the absorption of sunlight within such a snowpack could lead to transient melting, even at pressures and temperatures only slightly in excess of those of today. The meltwater so produced may have then eroded the valleys.

An interesting aspect of this proposal is that it is self-terminating. With the formation of Tharsis, the maximum obliquity of Mars declined to 35°, a figure too small to generate the high polar sublimation rates and low-latitude snowpack ascribed to the pre-Tharsis climate. Although the exact timing is not well constrained, present estimates indicate that the age of the Tharsis complex is about 3.5 b.y.

Finally, recent geological mapping by *Masursky et al.* (1987) indicates that some small valleys may be considerably younger than previously thought, although it is unclear whether these valleys are volcanic or fluvial in origin. If subsequent investigation establishes that the valleys are indeed fluvial, then either our understanding of the middle course of martian climatic history, or the process involved in valley network formation, will likely need revision.

Geomorphic Evidence of the Current Climate

Although there is considerable uncertainty regarding the conditions that characterized the early martian climate, there is little debate that Mars has been cold throughout its recent history. Climatic models indicate that surface temperatures have probably not varied significantly from the current average of 220 K at the equator and 160 K at the poles. Atmospheric surface pressures have probably also been low, with obliquity-driven polar insolation changes causing oscillations between 0.1 to 15 mbar, a variation that reflects differences in the amount of carbon dioxide adsorbed in the regolith and stored as ice in the seasonal polar caps (*Fanale et al.*, 1982).

An important characteristic of the current climate is that between the latitudes of ±35°, mean annual temperatures exceed the frost point. Consequently, ground ice in this region is unstable and will eventually sublime away (*Clifford and Hillel*, 1983; *Fanale et al.*, 1986). The vapor that results from the sublimation of equatorial ground ice is ultimately cold trapped at higher latitudes, thus enriching the ground ice content of the temperate and polar regolith.

Evidence that the distribution of ground ice conforms to this theoretical expectation has been presented by *Squyres and Carr* (1986). They note that while crater rims, scarps, and ridges are all sharply defined at equatorial latitudes, these features exhibit more rounded and subdued profiles closer to the poles. Squyres and Carr propose that this "softened" appearance is the result of ice-enhanced creep, and they further note that the absence of softened terrain near the equator is consistent with the theoretical prediction that this latitude band is ice free.

THE SEASONAL CYCLES OF CARBON DIOXIDE, WATER, AND DUST

The rotational axis of Mars is currently inclined by 25°; thus the planet experiences seasonal change. In late fall, the reduction in insolation at high latitudes is sufficient to cause carbon dioxide to condense from the atmosphere. Surface pressure variations monitored by the Viking Landers indicate that as much as a fifth of the planet's atmosphere freezes out during winter, forming a seasonal polar cap that extends toward the equator as far as 40° latitude. By midspring, the measured rise in surface pressure indicates that virtually all of the carbon dioxide has returned to the atmosphere.

Because northern winter occurs very near perihelion, the seasonal cycle of carbon dioxide is not symmetric between the poles. As a consequence of its shorter season, the northern carbon dioxide cap is smaller than its southern counterpart. In addition, while the northern seasonal cap disappears entirely during summer, a remnant of the southern seasonal cap persists throughout the year. This year-round survival of carbon dioxide has been attributed to a polar cap albedo that is significantly higher in southern spring than observed during the equivalent season in the north (*Paige and Ingersoll*, 1985). A possible explanation for this disparity is that major dust storms on Mars occur at a time when the northern cap is forming, making it inherently dustier than its southern counterpart. However, the Viking mission found that global dust storms did not occur every year, and that the seasonal variation of atmospheric pressure showed little variability. This insensitivity of the carbon dioxide cycle to atmospheric dustiness may be related to the greater insolation of southern spring, which may cause dust grains entrained in the seasonal deposit to become hot and sink into the frost, producing a dramatic increase in the seasonal cap's surficial reflectivity (*Paige and Kieffer*, 1986).

There is a clear link between the seasonal cycle of carbon dioxide and the corresponding cycles for dust and water. When the seasonal cap sublimes in southern spring, the high mass flow from the cap and the sharp temperature contrast across the cap boundary often results in the generation of local dust storms. Closer to perihelion, larger storms frequently occur at the subsolar point. The actual manner in which dust is initially raised by these storms is unknown, but several mechanisms have been proposed. These mechanisms include impact ejection of dust particles by saltating sand grains, the entrainment of dust clumps or aggregates by low-speed surface winds, and dust fountaining due to the rapid desorption of carbon dioxide (*Huguenin et al.*, 1986) or water (*Greeley and Leach*, 1979) from the regolith. Dust devils, discovered recently on Viking Orbiter images by *Thomas and Gierasch* (1985), may be another mechanism for raising dust into the atmosphere.

Perihelion dust storms frequently grow to global proportions. Two examples of this occurred during the first year observed by the Viking mission. However, while global dust storms may dominate the planet one year, they can be absent the next. This interannual variability may be linked to the dust cycle itself. For example, the transport of dust into the northern hemisphere during the winter of one year may ultimately weaken the Hadley circulation in the following year (*Haberle*, 1986).

Pollack et al. (1979) have suggested that the fate of atmospheric dust is intimately tied to the formation of the seasonal polar caps. They propose that airborne dust particles serve as nucleation centers for the condensation of water ice. As either hemisphere enters the fall season, the suspended particles receive an additional coating of frozen carbon dioxide. This coating of carbon dioxide makes the particles heavy enough to precipitate from the atmosphere, contributing to the formation of the seasonal polar caps. In the spring, the carbon dioxide sublimes away; however, at high latitudes, it leaves behind a residual deposit of water ice and dust that adds to the perennial caps. Insolation changes, due to axial precession and periodic variations in obliquity and orbital eccentricity, may alter the mixing ratio of ice to dust in the annual depositional layer. Such a scenario appears to explain the origin of the numerous horizontal layers that comprise the stratigraphy of both caps (*Toon et al.*, 1980). This model of polar deposition has a potential problem, however. As noted by *Jakosky and Martin* (1987), Viking infrared observations, made at times of peak dust storm activity, indicate that the temperature of the polar atmosphere above the lowermost scale height often exceeds the frost point of carbon dioxide. Clearly, such an observation is difficult to reconcile with the condensation mechanism of *Pollack et al.* (1979). As a result, the process of polar deposition remains an active area of theoretical investigation.

Mariner 9 radio occultation data indicates that the polar deposits may be anywhere from 1–6 km thick (*Dzurisin and Blasius*, 1975). If the larger estimates are accurate, calculations suggest that the deposits may be thick enough to undergo geothermal melting at their base (*Clifford*, 1987b). In the north the deposits cover an area ~1000 km across, while in the south they have a diameter of approximately 1500 km. Because few craters with diameters greater than 300 m are visible within the deposits, they are believed to be relatively young (~10^8 years; *Plaut et al.*, 1988). Interestingly, elsewhere on the planet there are a number of older, but morphologically similar, deposits. Though they now appear devoid of ice, *Schultz and Lutz* (1988) have argued that these deposits may be evidence that the location of the poles has migrated over time due to changes in the planet's moment of inertia. Such changes may have resulted from the filling of impact basins by flood basalts and the development of the Tharsis volcanic complex.

Models of the martian atmospheric circulation have been constructed to study the transport processes involved in the formation of the polar deposits. Since much of the redistribution of dust is thought to occur during northern winter, most of the research has focused on the circulation at this time of year. Constraining the models are Viking observations showing a substantial warming of the polar atmosphere during the second global dust storm of 1977 (*Martin and Kieffer*, 1979). The fact that the warming occurs well into the polar night indicates that it must be due to atmospheric dynamics, although the precise mechanism remains unclear. Early calculations with an inviscid zonally symmetric model were unable to reproduce the warming (*Haberle et al.*, 1982). More recently, however, *Magalhaes* (1987) and *Barnes and Hollingsworth* (1987) have been able to reproduce some of its features, although the mechanisms they invoke are fundamentally different. Magalhaes, for example, retains zonal symmetry but invokes viscous mixing, while Barnes and Hollingsworth employ a planetary wave mechanism similar to that involved in the sudden warming of the Earth's stratosphere.

In each of these approaches, suspended dust particles play a key role by altering the thermal drive for atmospheric motions. *Pollack et al.* (1987) have begun to investigate this interaction with the aid of a general circulation model. Their first results show that the presence of atmospheric dust has a substantial effect: strengthening and expanding the Hadley circulation, enhancing the thermal tides, and changing the character of the midlatitude storms. One interesting result of their calculations is the steady increase in low-level winds (at the latitudes where dust storms originate) as the total dust in the atmosphere increases. However, if wind speeds continue to increase, what stops the dust-raising process? One possibility is that by increasing the atmospheric stability, dust in the atmosphere suppresses the turbulence that mixes momentum down to the surface. Calculations with a boundary layer model tailored for Mars have shown this to be the case, suggesting that a direct reduction in wind speeds is not necessary to shut off the dust-raising process (*Haberle*, 1987).

Water, like dust and carbon dioxide, is cycled seasonally between its reservoirs. Measurements from both Earth-based instruments and the Viking MAWD experiment have shown that the distribution of atmospheric water vapor varies both seasonally and latitudinally. This variability is thought to result from a combination of atmospheric transport and exchange with surface and subsurface reservoirs (*Jakosky*, 1985). The most likely reservoirs are surface ice deposits and water adsorbed within the regolith. However, because of their similar response to solar insolation and because of the uncertain role of atmospheric transport, the relative contributions of these two sources are difficult to determine.

Nevertheless, it is known that the residual north polar cap is composed of water ice and that it acts as a source of vapor during the summer (*Kieffer et al.*, 1976; *Farmer et al.*, 1976). However, is the residual cap the only source of water at this season? Recent modeling calculations by *Haberle and Jakosky* (1987) suggest that it is not. If it were, then the resulting vapor would have to be transported to lower latitudes rather quickly; otherwise, the polar regions would be saturated and covered with clouds, a condition that is not observed. Furthermore, calculations show that the high latitude circulation is too weak to move water very far from the cap. Other sources of water must therefore exist.

On an annual and zonally averaged basis, there is a gradient in atmospheric water vapor abundance from north to south. The cause of this asymmetry has been the subject of some debate. *Jakosky* (1983) has argued that the gradient is a reflection of the different composition of the remnant caps and that it implies a net north-to-south transport. However, asymmetries in global circulation patterns due to dust storms (*Davies*, 1981) or the seasonal mass flux of carbon dioxide to and from the caps (*James*, 1986) can also set up a gradient in water vapor with no net transport. Thus, the mass balance of the caps remains an open issue.

SUMMARY

The view of Mars that has evolved during the MECA study project is far different from that which existed shortly after the Viking mission. Mars is now recognized as a wetter and more complicated planet than previously thought; however, many questions about its evolution still remain:

How much water did Mars inherit from the solar nebula, and how much of this was ultimately outgassed? Was there an additional late-stage input from comets and meteorites? What was the primordial composition of the atmosphere and to what extent was it affected by hydrodynamic escape and impact erosion? What conditions gave rise to the valley networks? How much confidence is there in the identification of various martian landforms as indicators of subsurface volatiles? What variables affect the current annual cycles of carbon dioxide, water, and dust? How have these cycles varied with time? These are just a few of the many questions that investigators have only begun to address.

Some answers may be provided by the further analysis of data already in hand; this is the approach of the three-year study project that succeeds MECA, entitled "Mars: Evolution of Volcanism, Tectonism, and Volatiles." New data anticipated from Mars Observer (the next U.S. Mars mission, scheduled for launch in 1992) will be of critical importance. But ultimately our ability to answer many of the outstanding questions concerning the martian climate is contingent on the missions that follow Mars Observer. These will likely include rover investigations of the polar layered terrains, canyons, volcanos, outflow channels, and valley networks; the establishment of a global meteorological network to monitor the present climate; seismic and electrical investigations to determine the current state and distribution of subsurface volatiles; and the return of samples to Earth to allow researchers to bring to bear the full spectrum of modern analytical techniques to the investigation of martian mineralogy, geochemistry, and volatiles.

As an experiment in the management of a major science program, MECA must be viewed as a success. Besides meeting its scientific goals, the study project clearly demonstrated the benefits of an interdisciplinary approach to the investigation of a complex and multifaceted topic. The success of this strategy was particularly evident during the study project's various workshops, where terrestrial and planetary scientists were often brought together from seemingly disparate fields. Yet out of these meetings came discussions and collaborations that often produced significant advances in our understanding of the martian atmosphere and climate. The fruit of this effort is likely to benefit Mars research for many years to come.

REFERENCES

Anderson D. E. and Hord C. W. (1971) Mariner 6 and 7 ultraviolet spectrometer experiment: Analysis of hydrogen Lyman-alpha data. *J. Geophys. Res.*, *76*, 6666–6673.

Baker V. R. and Partridge J. B. (1986) Small martian valleys: Pristine and degraded morphology. *J. Geophys. Res.*, *91*, 3561–3572.

Barnes J. B. and Hollingsworth J. L. (1987) Dynamical modeling of a planetary wave mechanism for a martian polar warming. *Icarus*, *71*, 313–334.

Becker R. H. and Pepin R. O. (1984) The case for a martian origin of the shergottites: Nitrogen and noble gases in EETA 79001. *Earth Planet. Sci. Lett.*, *69*, 225–252.

Bogard D. D. (1982) Trapped noble gases in the EETA shergottite. *Meteoritics*, *17*, 185–186.

Brakenridge G. R., Newsom H. E., and Baker V. R. (1985) Ancient hot springs on Mars: Origins and paleoenvironmental significance of small martian valleys. *Geology*, *13*, 859–862.

Carr M. H. (1979) Formation of martian flood features by release of water from confined aquifers. *J. Geophys. Res.*, *84*, 2995–3007.

Carr M. H. (1983) Stability of streams and lakes on Mars. *Icarus*, *56*, 476–495.

Carr M. H. (1986) Mars: A water-rich planet? *Icarus*, *68*, 187–216.

Carr M. H., Crumpler L. S., Cutts L. A., Greeley R., Guest J. E., and Masursky H. (1977) Martian impact craters and the emplacement of ejecta by surface flow. *J. Geophys. Res.*, *82*, 4055–4065.

Clifford S. M. (1987a) Mars: Crustal pore volume, cryospheric depth, and the global occurrence of groundwater. In *MECA Symposium on Mars: Evolution of its Climate and Atmosphere* (V. Baker, M. Carr, F. Fanale, R. Greeley, R. Haberle, C. Leovy, and T. Maxwell, eds.), pp. 32–34. LPI Tech. Rpt. 87-01, Lunar and Planetary Institute, Houston.

Clifford S. M. (1987b) Polar basal melting on Mars. *J. Geophys. Res.*, *92*, 9135–9152.

Clifford S. M., and Hillel D. (1983) The stability of ground ice in the equatorial region of Mars. *J. Geophys. Res.*, *88*, 2456–2474.

Clow G. D. (1987) Generation of liquid water on Mars through the melting of a dusty snowpack. *Icarus, 72,* 95–127.

Davies D. W. (1981) The Mars water cycle. *Icarus, 45,* 398–414.

Dreibus G. and Wänke H. (1985) Mars, a volatile-rich planet. *Meteoritics, 20,* 367–381.

Dzurisin D. and Blasius K. R. (1975) Topography of the polar layered deposits of Mars. *J. Geophys. Res., 80,* 3286–3306.

Fanale F. P. (1976) Martian volatiles: Their degassing history and geochemical fate. *Icarus, 28,* 179–202.

Fanale F. P., Salvail J. R., Branerdt W. B., and Saunders R. S. (1982) Mars: The regolith atmosphere cap system and climate change. *Icarus, 50,* 381–407.

Fanale F. P., Salvial J. R., Zent A. P., and Postawko S. E. (1986) Global distribution and migration of subsurface ice on Mars. *Icarus, 67,* 1–18.

Farmer C. B., Davies D. W., and LaPorte D. D. (1976) Northern summer ice cap—Water vapor observations from Viking 2. *Science, 194,* 1339–1340.

Farmer C. B., Davies D. W., Holland A. L., LaPorte D. D., and Downs P. E. (1977) Mars: Water vapor observations from the Viking Orbiters. *J. Geophys. Res., 82,* 4225–4248.

Gault D. E. and Greeley R. (1978) Exploratory experiments of impact craters formed in viscous-liquid targets: Analogs for martian rampart craters? *Icarus, 34,* 486–495.

Greeley R. (1987) Release of juvenile water on Mars: Estimated amounts and timing associated with volcanism. *Science, 236,* 1653–1654.

Greeley R. and Guest J. E. (1987) Geologic map of the eastern equatorial region of Mars. *U.S. Geol. Surv. Misc. Inv. Map I-1802B.*

Greeley R. and Leach R. (1979) "Steam" injection of dust on Mars: Laboratory simulations. *NASA TM-80339,* pp. 304–307.

Haberle R. M. (1986) Interannual variability of great dust storms on Mars. *Science, 234,* 459–461.

Haberle R. M. (1987) The influence of dust on the structure of the diurnally varying boundary layer on Mars. *Bull. Amer. Astron. Soc., 19,* 815.

Haberle R. M. and Jakosky B. M. (1987) Transport of water from the residual north polar cap on Mars. In *Lunar and Planetary Science XVIII,* p. 378. Lunar and Planetary Institute, Houston.

Haberle R. M., Leovy C. B., and Pollack J. B. (1982) Some effects of global dust storms on the atmospheric circulation of Mars. *Icarus, 51,* 322–367.

Huguenin R. L., Harris S. L., and Carter R. (1986) Injection of dust into the martian atmosphere: Evidence from the Viking gas exchange experiment. *Icarus, 68,* 99–119.

Hunten D. M., Pepin R. O., and Walker J. C. G. (1987) Mass fractionation in hydrodynamic escape. *Icarus, 69,* 532–549.

Jakosky B. M. (1983) The role of seasonal reservoirs in the Mars water cycle II: Coupled models of the regolith, the polar caps, and atmospheric transport. *Icarus, 55,* 19–39.

Jakosky B. M. (1985) The seasonal cycle of water on Mars. *Space Sci. Rev., 41,* 131–200.

Jakosky B. M. and Carr M. H. (1985) Possible precipitation of ice at low latitudes of Mars during periods of high obliquity. *Nature, 315,* 559–561.

Jakosky B. M. and Martin T. Z. (1987) Mars: North polar atmospheric warming during dust storms. *Icarus, 72,* 528-534.

James P. B. (1986) The martian hydrologic cycle: Effects of carbon dioxide mass flux on global water distribution. *Icarus, 64,* 249–264.

Jöns H. P. (1984) Sedimentary basins and mud flows in the northern lowlands of Mars. In *Lunar and Planetary Science XV,* p. 417. Lunar and Planetary Institute, Houston.

Kahn R. (1985) The evolution of carbon dioxide on Mars. *Icarus, 62,* 175–190.

Kasting J. F. (1987) Climatic effects of enhanced carbon dioxide levels in Mars' early atmosphere. In MECA *Symposium on Mars: Evolution of its Climate and Atmosphere* (V. Baker, Michael Carr, F. Fanale, R. Greeley, R. Haberle, C. Leovy, and T. Maxwell, eds.), pp. 64–66. LPI Tech. Rpt. 87-01, Lunar and Planetary Institute, Houston.

Kieffer H. H., Chase S. C., Jr., Martin T. Z., Miner E. D., and Palluconi F. D. (1976) Martian north pole summer temperatures: Dirty water ice. *Science, 194,* 1341–1344.

Magalhaes J. A. (1987) The martian Hadley circulation: Comparison of "viscous" model predictions to observations. *Icarus, 70,* 442–468.

Martin T. Z. and Kieffer H. H. (1979) Thermal infrared properties of the martian atmosphere. 2. The 15 μm band measurements. *J. Geophys. Res., 84,* 2830–2842.

Masursky H., Boyce J. M., Dial A. L., Schaber G. G., and Strobell M. E. (1977) Formation of martian channels. *J. Geophys. Res., 82,* 4016–4028.

Masursky H., Chapman M. G., Davis P. A., Dial A. L., Jr., and Strobell M. E. (1987) Martian terrains. *NASA TM-89810,* pp. 545–547.

McCauley J. F. (1978) Geologic map of the Coprates quadrangle of Mars. *U.S. Geol. Surv. Misc. Inv. Map I-879.*

McSween H. Y., Jr. (1985) SNC meteorites: Clues to martian petrologic evolution? *Rev. Geophys., 23,* 391–416.

Mouginis-Mark P. J. (1987) Water or ice in the martian regolith? Clues from rampart craters seen at very high resolution. *Icarus, 71,* 269–286.

Nedell S. S., Squyres S. W., and Anderson D. W. (1987) Origin and evolution of the layered deposits in the Valles Marineris, Mars. *Icarus, 70,* 409–441.

Paige D. A. and Ingersoll A. P. (1985) Annual heat balance of the martian polar caps: Viking observations. *Science, 228,* 1160–1168.

Paige D. A. and Kieffer H. H. (1986) Nonlinear frost albedo feedback on Mars: Observations and models. In *Workshop on the Evolution of the Martian Atmosphere* (M. Carr, P. James, C. Leovy, R. Pepin, and J. Pollack, eds.), pp. 33–34. LPI Tech Rpt. 86-07, Lunar and Planetary Institute, Houston.

Parker T. J., Schneeberger D. M., Pieri D. C., and Saunders R. S. (1987) Geomorphic evidence for ancient seas on Mars. In MECA *Symposium on Mars: Evolution of its Climate and Atmosphere* (V. Baker, M. Carr, F. Fanale, R. Greeley, R. Haberle, C. Leovy, and T. Maxwell, eds.), pp. 96–98. LPI Tech. Rpt. 87-01, Lunar and Planetary Institute, Houston.

Pepin R. O. (1986) Volatile inventory of Mars. In *Lunar and Planetary Science XVII,* pp. 656–657. Lunar and Planetary Institute, Houston.

Pepin R. O. (1987) Volatile inventories of the terrestrial planets. *Rev. Geophys., 25,* 293–296.

Perez-de-Tejada H. (1980) Plasma flow in the Mars magnetosphere. *J. Geophys. Res., 92,* 4713–4718.

Pieri D. C. (1980) Martian valleys: Morphology, distribution, age, and origin. *Science, 210,* 895–897.

Plaut J. J., Kahn R., Guiness E. A., and Arvidson R. E. (1988) Accumulation of sedimentary debris in the south polar region of Mars and implications for climate history. *Icarus,* in press.

Pollack J. B., Colburn D., Flasar F. M., Kahn R., Carlston C. E., and Pidek D. (1979) Properties and effects of dust particles suspended in the martian atmosphere. *J. Geophys. Res., 84,* 2929–2945.

Pollack J. B., Kasting J., and Richardson S. (1987) Partitioning of carbon dioxide between the atmosphere and lithosphere on early Mars. In *MECA Symposium on Mars: Evolution of its Climate and Atmosphere* (V. Baker, M. Carr, F. Fanale, R. Greeley, R. Haberle, C. Leovy, and T. Maxwell, eds.), pp. 104–105. LPI Tech. Rpt. 87-01, Lunar and Planetary Institute, Houston.

Postawko S. E. and Kuhn W. R. (1986) Effect of the greenhouse gases (CO_2, H_2O, SO_2) on martian paleoclimate. *J. Geophys. Res., 91,* 431–438.

Rossbacher L. A. and Judson S. (1981) Ground ice on Mars: Inventory, distribution, and resulting landforms. *Icarus, 45,* 39–59.

Schultz P. H. and Gault D. E.(1979) Atmospheric effects on Martian ejecta emplacement. *J. Geophys. Res., 84,* 7669–7687.

Schultz P. H. and Lutz A. B. (1988) Polar wandering on Mars. *Icarus, 73,* 91–141.

Scott D. H. and Tanaka K. L. (1986) Geologic map of the western equatorial region of Mars. *U.S. Geol. Surv. Misc. Inv. Map I-1802A.*

Squyres S. W. and Carr M. H. (1986) Geomorphic evidence for the distribution of ground ice on Mars. *Science, 231,* 249–252.

Thomas P. and Gierasch P. (1980) Dust devils on Mars. *Science, 230,* 175–177.

Toon O. B., Pollack J. B., Ward W., Burns J. A., and Bilski K. (1980) The astronomical theory of climate change on Mars. *Icarus, 44,* 552–607.

Walker J. C. G. (1977) *Evolution of the Atmosphere.* Macmillan Co., New York. 318 pp.

Wasson J. T. and Wetherill G. W. (1979) Dynamical, chemical and isotopic evidence regarding the formation locations of asteroids and meteorites. In *Asteroids* (T. Gehrels, ed.), pp. 926–974. Univ. of Arizona Press, Tucson.

Watkins H. and Lewis J. S. (1985) Loss of volatiles from Mars as the result of energetic impacts. In *Workshop on Water on Mars* (S. Clifford, ed.), pp. 93–95. LPI Tech. Rpt. 85-03, Lunar and Planetary Institute, Houston.

Wood C. A. and Ashwal L. D. (1981) SNC meteorites: Igneous rocks from Mars? *Proc. Lunar Planet. Sci. 12B,* pp. 1359–1375.

Appendix 1. Origin of MECA

The Mars Data Analysis Program (MDAP) was initiated in FY–79 to provide support for the post-Viking analysis of Mars data. It was recognized by the scientific community that the amount of high-quality data acquired during the Primary and Extended Viking Mission (from June 1976 to August 1980) constituted a national resource, but that adequate support for continued analysis was not available from the existing Research and Analysis Program.

TABLE A1. *Ad hoc* Mars Science Working Group, assembled March 11, 1982 to define science goals for a Mars data analysis program.

Members	Affiliation
R. Greeley, Chairman	Arizona State University
J. Boyce, ex officio	NASA Headquarters
M. Malin	Arizona State University
R. Batson	U.S. Geological Survey
S. Saunders	Jet Propulsion Laboratory
S. Squyres	Cornell University
E. Shoemaker	U.S. Geological Survey
L. Wilkening	University of Arizona
V. Baker	University of Arizona
M. Carr	U.S. Geological Survey
J. Pollack	NASA Ames Research Center
A. Albee	Jet Propulsion Laboratory
F. Fanale	University of Hawaii
D. Wilhelms	U.S. Geological Survey
D. Wise	University of Massachusetts
H. Kieffer	U.S. Geological Survey

An *ad hoc* Mars Working Group (Table A1) of planetary scientists met in 1981 and defined the key science questions for Mars that could be addressed with the available data. Representatives of the working group then met with NASA administrators and presented their findings. Four major scientific questions were identified for continued study of Mars:

1. What is the volatile history of Mars?
2. What is the climatic history of Mars and how have lithosphere/atmosphere/hydrosphere interactions affected the evolution of the martian surface?
3. What is the volcano-tectonic history of Mars?
4. What are the major components of the atmospheric circulation and what processes are responsible for major atmospheric phenomena?

Because of limited resources, the restructured Mars Data Analysis Program was unable to support research to address all of these questions concurrently. Rather, the approach was to address problems dealing with atmosphere and climate first, and to defer the volcanic-tectonic research topics to a later time.

A Space Science and Applications Notice entitled "The Volatile Evolution and Climate History of Mars" was released May 25, 1983. Proposals were received and reviewed later that year. As stated in the notice:

> *Plans for administering this study involve not only focusing the effort [science], but also introducing a novel method of coordinating the individual research tasks which are selected. The approach involves the establishment of a working group consisting of all investigators whose proposals are accepted and, through occasional meetings of the group, the coordination of the research efforts.*
>
> *The organized approach is not intended to coerce any of the participants to redirect their research, but rather to take advantage of the collective wisdom of the participants to guide the study, to identify important areas of research not addressed by proposals, and to encourage voluntary responses to the identified needs.*

Thus, in addition to having scientific goals, the program was also an experiment in science management that, in many respects, combined elements of a mission-oriented project while retaining the principal investigator's individual goals and responsibilities.

An organizational meeting of funded investigators and associates was held in March 1984 to refine the science objectives and to decide how to move forward on the three-year program. A steering committee was elected (Table A2) and science questions were posed around three issues for Mars: (1) seasonal cycles, (2) surface processes/climate history, and (3) bulk chemical composition and outgassing history (Table A3).

PRECEDING PAGE BLANK NOT FILMED

TABLE A2. MECA Science Steering Committee.

Member	Affiliation	Area
Ronald Greeley	Arizona State University	Chairperson
Michael Carr	U.S. Geological Survey	Surface Processes
Fraser Fanale	University of Hawaii	Climate Change
Robert Haberle	NASA Ames Research Center	Seasonal Cycles
Robert Pepin	University of Minnesota	Bulk Chemistry
Peter Schultz	Lunar and Planetary Institute	Project Scientist (to 1984)
Stephen Clifford	Lunar and Planetary Institute	Project Scientist (1984 to 1988)
Joseph Boyce	NASA Headquarters	Ex Officio
Kevin Burke	Lunar and Planetary Institute	Ex Officio
Pam Jones	Lunar and Planetary Institute	Project Administrator

TABLE A3. Major MECA study questions.

Season Cycles

- What are the physical processes that control the present seasonal cycles of dust, water, and carbon dioxide?
- How do the seasonal cycles change from year to year?
- How can models of the seasonal cycles be extended to long-term variations?

Surface Processes and Climate History

- What are the causative *agents* of climate change on Mars?
- How have the *abundances* of surface volatiles changed with time?
- What are the major volatile *reservoirs*, and how have they changed with time?
- What has been the *climatic history* of Mars and how has it been affected by the agents, abundances, and reservoirs?
- What observations and modeling will help resolve the above questions?

Bulk Chemical Composition and Outgassing History

- What is the range of possible absolute and relative abundances of the initial Mars volatile inventory?
- What evidence exists that the planet has undergone significant oxidation? Is the oxidation only on the surface? Are there plans to try to measure martian atmospheric D/H? Has the composition of degassed volatiles changed with styles of volcanism in time and space (inputs from climate history/ surface morphology)?
- What does the present atmosphere tell us about integrated outgassing modified by "loss processes" to the regolith and to space over martian geologic time? Implications of isotopic signatures ($^{15}N/^{14}N$, $^{129}Xe/^{132}Xe$, $^{40}Ar/^{36}Ar$)?

It was decided that the study project [named "Mars: Evolution of Its Climate and Atmosphere" (MECA)] would be open to all investigators who had a potnetial contribution, regardless of funding. A letter of invitation was mailed to more than 3500 individuals on the LPI distribution list. Eventual membership for the project grew to about 130 (see Appendix 2). Newsletters were issued regularly to keep the study group, NASA, and the community abreast of MECA activities. Figure A1 shows the relationship among NASA, the Working Group, and the Lunar and Planetary Institute.

The scientific program of MECA was conducted through a series of symposia, special sessions, and workshops. For each of these activities, an organizing committee was formed to develop the program, solicit participants, and prepare summaries of the program. All activities were supported through LPI for logistics, including mailing and preparation of abstract volumes and technical reports.

Appendix 2. MECA Membership List

Vincent J. Abreau
SPRL
2455 Hayward
Ann Arbor, MI 48105

Mario H. Acuna
Mail Stop 695.0
NASA Goddard Space Flight Center
Greenbelt, MD 20771

Arden L. Albee
Division of Geological and Planetary Science
Caltech
Pasadena, CA 91125

David W. Andersen
Department of Geology
San Jose State University
San Jose, CA 95192

Duwayne M. Anderson
East Bizzell Hall, Room 305
Texas A & M University
College Station, TX 77843-1112

James R. Arnold
Department of Chemistry, B-017
University of California, San Diego
La Jolla, CA 92093

Raymond E. Arvidson
McDonnell Center for the Space Sciences
Washington University
St. Louis, MO 63130

Victor R. Baker
Department of Geosciences
University of Arizona
Tucson, AZ 85721

Amos Banin
Mail Stop 239-12
NASA Ames Research Center
Moffett Field, CA 94035

Jeffrey R. Barnes
Department of Atmospheric Sciences
Oregon State University
Corvallis, OR 97331

Bruce Barraclough
Institute of Geophysics and Planetary Physics
University of California, Los Angeles
Los Angeles, CA 90024

Joseph Boyce
Mail Code EL4
NASA Headquarters
Washington, DC 20546

G. Robert Brakenridge
Department of Geological Sciences
Wright State University
Dayton, OH 45435

Geoffrey Briggs
Mail Code EL
NASA Headquarters
Washington, DC 20546

Henry Brinton
Mail Code EL
NASA Headquarters
Washington, DC 20546

Kevin Burke
Lunar and Planetary Institute
3303 NASA Road One
Houston, TX 77058

Robert W. Carlson
Mail Stop 183-301
Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, CA 91109

Michael H. Carr
U.S. Geological Survey
345 Middlefield Road
Menlo Park, CA 94025

Patrick Cassen
Mail Stop 245-3
NASA Ames Research Center
Moffett Field, CA 94025

Peter Cattermole
Beaumont Building
University of Sheffield
Brookhill
Sheffield S3 7HF England

Philip R. Christensen
Department of Geology
Arizona State University
Tempe, AZ 85287

Todd Clancy
Laboratory for Atmospheric and Space Physics
Campus Box 392
University of Colorado
Boulder, CO 80309

Stephen Clifford
Lunar and Planetary Institute
3303 NASA Road One
Houston, TX 77058

Gary D. Clow
U.S. Geological Survey
345 Middlefield Road
Menlo Park, CA 94025

David Colburn
Mail Stop 245-3
NASA Ames Research Center
Moffett Field, CA 94035

Lelia Coyne
Department of Geology
San Jose State University
San Jose, CA 95192

D. Crerar
Department of Geology and Geophysical Science
Princeton University
Princeton, NJ 08544

G. E. Danielson
Division of Geological and Planetary Science
170-25
Caltech
Pasadena, CA 91125

Richard Durham
Department of Space Physics and Astronomy
P. O. Box 1892
Rice University
Houston, TX 77251

Thanasis E. Economou
Laboratory for Astrophysics and Space Research
Enrico Fermi Institute
University of Chicago
Chicago, IL 60637

Charles Elachi
Mail Stop 183-701
Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, CA 91109

L. W. Esposito
Laboratory for Atmospheric and Space Physics
Campus Box 392
University of Colorado
Boulder, CO 80309

Fraser P. Fanale
Planetary Geosciences Division
Hawaii Institute of Geophysics
2525 Correa Road
Honolulu, HI 96822

Stuart Gaffin
Department of Applied Science
New York University
New York, NY 10003

Everett K. Gibson, Jr.
Mail Code SN4
NASA Johnson Space Center
Houston, TX 77058

Kenneth A. Goettel
Geophysical Laboratory
Carnegie Institute of Washington
2801 Upton St. NW
Washington, DC 20008

James Gooding
Mail Code SN2
NASA Johnson Space Center
Houston, TX 77058

Ronald Greeley
Department of Geology
Arizona State University
Tempe, AZ 85287

Edward A. Guinness
McDonnell Center for the Space Sciences
Washington University
St. Louis, MO 63130

Robert M. Haberle
Mail Code 245-3
NASA Ames Research Center
Moffett Field, CA 94035

R. B. Hargraves
Department of Geology and Geophysical Science
Princeton University
Princeton, NJ 08544

Paul B. Hays
Department of Atmospheric and Oceanic Science
University of Michigan, North Campus
Ann Arbor, MI 48109

James Head
Department of Geological Sciences
Brown University
Providence, RI 02912

Kenneth Herkenhoff
Division of Geological and Planetary Science
170-25
Caltech
Pasadena, CA 91125

Paul C. Hess
Department of Geological Sciences
Brown University
Providence, RI 02912

Martin I. Hoffert
Department of Applied Science
New York University
Washington Square
New York, NY 10003

John R. Holloway
Chemistry Department
Arizona State University
Tempe, AZ 85287

Robert L. Huguenin
Remote Sensing Center
302 Hasbrouck Laboratory
University of Massachusetts
Amherst, MA 01003

Andrew P. Ingersoll
Division of Geological and Planetary Science
170-25
Caltech
Pasadena, CA 91125

Bruce M. Jakosky
Laboratory for Atmospheric and Space Physics
University of Colorado
Boulder, CO 80309

Philip B. James
Physics Department
University of Missouri, St. Louis
St. Louis, MO 63121

Fred Jaquin
Space Sciences Building
Cornell University
Ithaca, NY 14853

Heinz-Peter Jöns
Technische Universitat Claustha
Sven-Hedin Str. 19
3000 Hannover 51
F. R. Germany

Ralph Kahn
Department of Earth and Planetary Science
Campus Box 1169
Washington University
St. Louis, MO 63130

Jim Kasting
Mail Stop 245-3
NASA Ames Research Center
Moffett Field, CA 94035

Hugh H. Keiffer
U.S. Geological Survey
2255 North Gemini Drive
Flagstaff, AZ 86001

William R. Kuhn
Department of Atmospheric and Oceanic Science
University of Michigan, North Campus
Ann Arbor, MI 48109

Steve Lee
Department of Geology
Arizona State University
Tempe, AZ 85287

Conway Leovy
Mail Code AK-40
University of Washington
Seattle, WA 98195

John S. Lewis
Planetary Sciences Department
University of Arizona
Tucson, AZ 85721

Sanjay S. Limaye
Space Science and Engineering Center
University of Wisconsin, Madison
1225 W. Dayton Street
Madison, WI 53706

Baerbel K. Lucchitta
U.S. Geological Survey
Branch of Astrogeology
2255 North Gemini Drive
Flagstaff, AZ 86001

Michael Malin
Department of Geology
Arizona State University
Tempe, AZ 85287

Hal G. Marshall
Laboratory for Atmospheric Research
College of Engineering
Washington State University
Pullman, WA 99164-2730

Leonard Martin
Lowell Observatory
Box 1269
Flagstaff, AZ 86002

Terry Z. Martin
Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, CA 91109

John V. Martonchik
Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, CA 91109

Harold Masursky
U.S. Geological Survey
2255 North Gemini Drive
Flagstaff, AZ 86001

Daniel J. McCleese
Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, CA 91109

Thomas B. McCord
Planetary Geosciences Division
Hawaii Institute of Geophysics
2525 Correa Road
Honolulu, HI 96822

Michael B. McElroy
Pierce Hall, Room 100E
Harvard University
Cambridge, MA 02138

Albert E. Metzger
Mail Stop 183-501
Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, CA 91109

Carleton B. Moore
Center for Meteorite Studies
Arizona State University
Tempe, AZ 85287

Henry J. Moore
U.S. Geological Survey
345 Middlefield Road
Menlo Park, CA 94025

Jeff Moore
Geology Department
Arizona State University
Tempe, AZ 85287

Richard V. Morris
Mail Code SN4
NASA Johnson Space Center
Houston, TX 77058

Bruce Moskowitz
Department of Geology and Geophysical Science
Princeton University
Princeton, NJ 08544

Peter Mouginis-Mark
Planetary Geosciences Division
Hawaii Institute of Geophysics
2525 Correa Road
Honolulu, HI 96822

Duane O. Muhleman
Division of Geological and Planetary Science
170-25
Caltech
Pasadena, CA 91125

Michael J. Mumma
Mail Stop 693.0
NASA Goddard Space Flight Center
Greenbelt, MD 20771

Bruce Murray
Division of Geological and Planetary Science
170-25
Caltech
Pasadena, CA 91125

Tobias Owen
Astronomy Program
Department of Earth and Space Science
State University of New York, Stony Brook
Stony Brook, NY 11794

David A. Paige
Division of Geological and Planetary Science
170-25
Caltech
Pasadena, CA 91125

Frank Palluconi
Mail Stop 183-501
Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, CA 91109

Tim Parker
Mail Stop 183-501
Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, CA 91109

Robert O. Pepin
School of Physics and Astronomy
University of Minnesota
Minneapolis, MN 55455

Gordon H. Pettingill
54-618
Massachusetts Institute of Technology
Cambridge, MA 02139

Roger Phillips
Department of Geological Sciences
Southern Methodist University
Dallas, TX 75275

David C. Pieri
Mail Stop 183-501
Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, CA 91109

Richard J. Pike
U.S. Geological Survey
345 Middlefield Road
Menlo Park, CA 94025

James B. Pollack
Mail Stop 245-3
NASA Ames Research Center
Moffett Field, CA 94035

Jessica Posey Dowty
Department of Geology and Geophysical Science
Princeton University
Princeton, NJ 08544

Susan Postawko
Planetary Geosciences Division
Hawaii Institute of Geophysics
2525 Correa Road
Honolulu, HI 96822

William Quaide
Mail Code EL4
NASA Headquarters
Washington, DC 20546

Colin Reid
Beaumont Building
University of Sheffield
Brookhill
Sheffield S3 7HF England

Lisa Rossbacher
Earth Science Department
California State Polytechnic University
3801 West Temple Avenue
Pomona, CA 91768

Ladislav E. Roth
Mail Stop 183-701
Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, CA 91109

Christopher T. Russell
Institute of Geophysics and Planetary Physics
University of California, Los Angeles
Los Angeles, CA 90024

Malcolm J. Rutherford
Department of Geological Sciences
Brown University
Providence, RI 02912

Carl Sagan
Laboratory for Planetary Studies
Cornell University
Space Sciences Building
Ithaca, NY 14853-0355

Steve Saunders
Mail Stop 183-501
Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, CA 91109

Thomas W. Scattergood
Mail Stop 239-12
NASA Ames Research Center
Moffett Field, CA 94035

F. Peter Schloerb
Astronomy Department
Graduate Tower B
University of Massachusetts
Amherst, MA 01003

Peter Schultz
Department of Geological Sciences
Brown University
Providence, RI 02912

David Scott
Mail Code EL4
NASA Headquarters
Washington, DC 20546

Robert B. Singer
Planetary Geosciences Division
Hawaii Institute of Geophysics
2525 Correa Road
Honolulu, HI 96822

James A. Slavin
Mail Stop 169-506
Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, CA 91109

L. A. Soderblom
U.S. Geological Survey
2255 North Gemini Drive
Flagstaff, AZ 86001

Steven W. Squyres
Mail Stop 245-3
NASA Ames Research Center
Moffett Field, CA 94035

A. Ian Stewart
Department of Astrogeophysics
University of Colorado
Boulder, CO 80302

Robert Steinbacher
Mail Stop 180-402
Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, CA 91109

Carol Stoker
National Center for Atmospheric Research
P.O. Box 3000
Boulder, CO 80307

Hans E. Suess
Department of Chemistry, B-017
University of California, San Diego
La Jolla, CA 92093

James E. Tillman
Department of Atmospheric Sciences
Mail Stop AK-40
University of Washington
Seattle, WA 98195

Owen B. Toon
Mail Stop 245-3
NASA Ames Research Center
Moffett Field, CA 94035

Marsha R. Torr
Center for Atmospheric and Space Sciences
Utah State University, UMC41
Logan, UT 84322

G. Leonard Tyler
Center for Radar Astronomy
Stanford University
Stanford, CA 94305

Jose R. Valentin
Mail Stop 245-3
NASA Ames Research Center
Moffett Field, CA 94035

Michael Velbel
Department of Geological Sciences
Michigan State University
East Lansing, MI 48824-1115

Tyler Volk
Department of Applied Science
New York University
26 Stuyvesant Street
New York, NY 10003

Hampton Watkins
P.O. Box 2370
Cambridge, MA 02238

Robert A. West
Mail Stop 183-301
Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, CA 91109

Don E. Wilhelms
U.S. Geological Survey
345 Middlefield Road
Menlo Park, CA 94025

Sherman Wu
U.S. Geological Survey
2255 North Gemini Drive
Flagstaff, AZ 86001

John Yatteau
Pierce Hall, Room 100E
Harvard University
Cambridge, MA 02138

Aaron P. Zent
Planetary Geosciences Division
Hawaii Institute of Geophysics
2525 Correa Road
Honolulu, HI 96822

Jim Zimbelman
Lunar and Planetary Institute
3303 NASA Road One
Houston, TX 77058

Richard W. Zurek
Mail Stop T-1166
Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, CA 91109

Appendix 3. MECA Bibliography

What follows is a compilation of papers and abstracts authored by participants in the MECA program during the period 1984–1988. Notably absent from this listing are abstracts from the last two MECA workshops: Polar Processes on Mars (to be issued as a NASA Technical Memorandum) and Dust on Mars III (to be published as an LPI Technical Report), neither of which had gone to press by the time this summary was ready for publication. While every effort has been made to ensure that this bibliography is otherwise complete, a few abstracts and papers have undoubtedly slipped through the cracks. This possibility should be kept in mind when using the bibliography for research purposes.

Special thanks are due Mildred Dickey, who spent countless hours inputting and revising this bibliography, and to Stephen Tellier, of the Institute's Library Information Center, who compiled and maintains the Lunar and Planetary Bibliography Database from which many of these citations were originally obtained.

Symbol notation: "†" MECA Principal Investigator, "*" Member MECA Study Group.

Agresti D. G., Morris R. V.[†], Newcomb J. A., and Lauer H. V., Jr. (1986) Spectral properties of selected soils from the dry valleys of Antarctica. In *Lunar and Planetary Science XVII*, pp. 3–4. Lunar and Planetary Institute, Houston.

Agresti D. G., Newcomb J. A., and Morris R. V.[†] (1987) Mossbauer study of ultramicrocrystalline hematite. In *Lunar and Planetary Science XVIII*, pp. 7–8. Lunar and Planetary Institute, Houston.

Ahrens T. J. (1986) Accretional constraints on Mars volatile budget. In *MECA Workshop on the Evolution of the Martian Atmosphere* (M. Carr, P. James, C. Leovy, R. Pepin, and J. Pollack, eds.), pp. 9–10. LPI Tech. Rpt. 86-07, Lunar and Planetary Institute, Houston.

Anderson D. M.[†] (1985) The present water cycle on Mars: Some thermodynamic considerations. In *Workshop on Water on Mars*, (S. Clifford, ed.), pp. 9–11. LPI Tech. Rpt. 85-03, Lunar and Planetary Institute, Houston.

Anderson D. M.[†] and Brandstrom G. W. (1987) Evidence for glaciation in Elysium. In *MECA Symposium on Mars: Evolution of its Climate and Atmosphere*, (V. Baker, M. Carr, F. Fanale, R. Greeley, R. Haberle, C. Leovy, and T. Maxwell, eds.), pp. 15–17. LPI Tech. Rpt. 87-01, Lunar and Planetary Institute, Houston.

Anderson D. M.[†] (1988) Water in the Martian regolith. In *Workshop on Atmospheric H_2O Observations of Earth and Mars*. LPI Tech. Rpt., in press, Lunar and Planetary Institute, Houston.

Arvidson R. E.[†] (1986) On the rate of formation of sedimentary debris on Mars. In *MECA Workshop on Dust on Mars II* (S. Lee, ed.), p. 9. LPI Tech. Rpt. 86-09, Lunar and Planetary Institute, Houston.

Arvidson R. E.[†] and Kahn R. (1985) The relative rates of aeolian and tectonic processes on Venus and Mars. In *Lunar and Planetary Science XVI*, pp. 17–18. Lunar and Planetary Institute, Houston.

Baker V. R.[†] (1984) Problems in the paleohydrologic and hydroclimatologic interpretation of valley networks. In *Workshop on Water on Mars* (S. Clifford, ed.), pp. 4–5. LPI Tech. Rpt. 85-03, Lunar and Planetary Institute, Houston.

Baker V. R.[†] (1984) Fluvial erosion of impact craters: Earth and Mars. *NASA TM-86246*, pp. 175–177.

Baker V. R.[†] (1985) Models of fluvial activity on Mars. In *Models in Geomorphology* (M. Woldenber, ed.), pp. 287-312. Allen & Unwin, Boston.

Baker V. R.[†] (1985) Paleohydrologic implications of valley networks on Mars. *NASA TM-87563*, pp. 313–315.

Baker V. R.[†] (1986) Evolution of small valley networks in the heavily cratered terrains of Mars. *NASA TM-88383*, pp. 271–273.

Baker V. R.[†] (1986) Evolution of valleys dissecting volcanoes on Mars and Earth. *NASA TM-88383*, pp. 414–416.

Baker V. R.[†] and Gulick V. C. (1987) Fluvial valleys on Martian volcanoes. *NASA TM-89810*, pp. 294–296.

Baker V. R.[†] and Gulick V. C. (1987) Valley development on Hawaiian volcanoes. *NASA TM-89810*, pp. 297–299.

Baker V. R.[†] and Kochel F. R. C. (1984) Valley network development by spring sapping. *Geol. Soc. Amer. Abst. with Prog.*, *16*, 435.

Baker V. R.[†] and O'Connor J. E. (1986) Flow modeling of cataclysmic flood discharges. *NASA TM-88383*, pp. 274-276.

Baker V. R.[†] and Partridge J. B. (1984) Morphometry of small valley networks on Mars. In *Lunar and Planetary Science XV*, pp. 23–24. Lunar and Planetary Institute.

Baker V. R.[†] and Partridge J. B. (1984) Pristine and degraded segments of small valley networks on Mars. In *Lunar and Planetary Science XV*, pp. 25–26. Lunar and Planetary Institute, Houston.

Baker V. R.[†] and Partridge J. B. (1986) Small Martian valleys: Pristine and degraded morphology. *J. Geophys. Res.*, *91*, 3561–3572.

Banin A.[†] (1986) Constraining Mars-dust mineralogy on the basis of Viking biology simulations and Mars spectral reflectance. In *MECA Workshop on Dust on Mars II* (S. Lee, ed.), pp. 10–11. LPI Tech. Rpt. 86-09. Lunar and Planetary Institute, Houston.

Banin A.[*], Margulies L., and Chen Y. (1984) Iron-montmorillonite: Spectral analogy to Mars soil. In *Lunar and Planetary Science XV*, pp. 31–32. Lunar and Planetary Institute, Houston.

Banin A.[†], Margulies L., and Chen Y. (1985) Iron-montmorillonite: A spectral analog of Martian soil. *Proc. Lunar Planet. Sci. Conf. 15th*, in *J. Geophys. Res.*, 90, C771–C774.

Barnes J. R.[†] (1984) Linear baroclinic instability in the Martian atmosphere. *J. Atmos. Sci.*, *41*, 1536–1550.

Barnes J. R.[†] (1985) Transient baroclinic eddies in the atmospheres of Mars and Earth. *IAMAP/IAPSO Joint Assembly Abstracts*, p. 95.

Barnes J. R.[†] and Hollingsworth J. L. (1985) Dynamical modeling of a Martian polar warming. *Bull. Amer. Astron. Soc.*, *17*, 733.

Barnes J. R.[†] and Hollingsworth J. L. (1986) Implications of a polar warming for dust transport into the north polar region of Mars. In *Workshop on Dust on Mars II* (S. Lee, ed.) pp. 12-13. LPI Tech. Rpt. 86-09, Lunar and Planetary Institute, Houston.

Barnes J. R.[†] and Hollingsworth J. L. (1987) Numerical simulations of dust transport into northern high latitudes during a Martian polar warming. In *MECA Symposium on Mars: Evolution of its Climate and Atmosphere* (V. Baker, M. Carr, F. Fanale, R. Greeley, R. Haberle, C. Leovy, and T. Maxwell, eds.), pp. 18–19. LPI Tech. Rpt. 87-01, Lunar and Planetary Institute, Houston.

Barnes J. R.[†] and Hollingsworth J. L. (1987) Dynamical modeling of a planetary wave mechanism for a martian polar warming. *Icarus, 71*, 313–334.

Barnes J. R.[†] and Hollingsworth J. L. (1988) Transport of Mars atmospheric water into high northern latitudes during a polar warming. In *Workshop on Atmospheric H_2O Observations of Earth and Mars*. LPI Tech. Rpt., in press, Lunar and Planetary Institute, Houston.

Becker R. H. and Pepin R. O.[†] (1984) The case for a martian origin of the shergottites: Nitrogen and noble gases in EETA 79001. *Earth Planet. Sci. Lett.*, 69, 225–242.

Becker R. H. and Pepin R. O.[†] (1985) Nitrogen and light noble gases in the Shergotty meteorite. In *Lunar and Planetary Science XVI, Supplement A*, pp. 1–2. Lunar and Planetary Institute, Houston.

Brakenridge G. R.[†] (1987) Small valley networks and the past and present distribution of subsurface volatiles, Aeolis Quadrangle, Mars. In MECA *Special Session at LPSC XVII: Martian Geomorphology and its Relation to Subsurface Volatiles* (S. Clifford, L. A. Rossbacher, and J. R. Zimbelman, eds.), pp. 12–13. LPI Tech. Rpt. 87-02, Lunar and Planetary Institute, Houston.

Brakenridge G. R.[†], Newson H. E., and Baker V. R.[†] (1985) Ancient hot springs on Mars: Origin and paleoevironmental significance of martian valleys. *Geology, 13*, 859–862.

Brakenridge G. R.[†], Newson H. E., and Baker V. R.[†] (1985) Hot springs on Mars: Origins and paleoenvironmental significance of small martian valleys. *Geol. Soc. Amer. Abst. with Prog., 17*, 530.

Brandenburg J. E. (1987) The paleo-ocean of Mars. In MECA *Symposium on Mars: Evolution of its Climate and Atmosphere* (V. Baker, M. Carr, F. Fanale, R. Greeley, R. Haberle, C. Leovy, and T. Maxwell, eds.), pp. 20–22. LPI Tech. Rpt. 87-01, Lunar and Planetary Institute, Houston.

Bruckenthal E. A. and Singer R. B.[†] (1987) Spectral effects of dehydration of phyllosilicates. In *Lunar and Planetary Science XVIII*, pp. 135–136. Lunar and Planetary Institute, Houston.

Calvin W. M., Jakosky B. M.[†], and Christensen P. R.[*] (1987) A model of diffuse radar scattering from martian surface rocks. *NASA TM-89810*, pp. 245–247.

Carr M. H.[†] (1984) Freezing of martian streams under different climatic conditions. *NASA TM-86246*, pp. 185–186.

Carr M. H. (1984) Formation of martian valley networks as a consequence of large impacts. In *Lunar and Planetary Science XV*, pp. 131–132. Lunar and Planetary Institute, Houston.

Carr M. H.[†] (1986) Water on Mars: History and current distribution. *Proc. XXVI COSPAR*, 149.

Carr M. H.[†] (1986) Climatic implications of martian channels. In *Workshop on the Evolution of the Martian Atmosphere* (M. Carr, P. James, C. Leovy, R. Pepin, and J. Pollack, eds.), pp. 11–12. LPI Tech. Rpt. 86-07, Lunar and Planetary Institute, Houston.

Carr M. H.[†] (1986) Mars: A water-rich planet? *Icarus*, 68, 187–216.

Carr M. H.[†] (1987) Water on Mars. *Nature, 326*, 30–35.

Carr M. H.[†] (1987) Mars: A water-rich planet. In MECA *Symposium on Mars: Evolution of its Climate and Atmosphere* (V. Baker, M. Carr, F. Fanale, R. Greeley, R. Haberle, C. Leovy, and T. Maxwell, eds.), pp. 23–25. LPI Tech. Rpt. 87-01, Lunar and Planetary Institute, Houston.

Carr M. H.[†] (1987) Martian volcanism: A review. In MECA *Symposium on Mars: Evolution of its Climate and Atmosphere* (V. Baker, M. Carr, F. Fanale, R. Greeley, R. Haberle, C. Leovy, and T. Maxwell, eds.), pp. 29–31. LPI Tech. Rpt. 87-01, Lunar and Planetary Institute, Houston.

Carr M. H.[†] (1987) The inventory and distribution of water on Mars. *Advances in Space Research, 7*, 85–94.

Carr M. H.[†] (1987) The Martian surface. *Rev. Geophys., 25*, 285–292.

Carr M. H.[†], Leovy C. B.[*], and Pepin R. O.[†], eds. (1985) *Workshop on the Evolution of the Martian Atmosphere*. LPI Tech. Rpt. 86-07, Lunar and Planetary Institute, Houston. 52 pp.

Carroll M. R. and Rutherford M. J.[*] (1985) Sulfide and sulfate saturation in hydrous silicate melts. *Proc. Lunar Planet. Sci. Conf. 15th*, in *J. Geophys. Res.*, 90, C601–C612.

Chen R. C. (1988) The effect of global-scale divergent circulation of the atmospheric water vapor transport and maintenance. In *Workshop on Atmospheric H_2O Observations of Earth and Mars*. LPI Tech. Rpt., Lunar and Planetary Institute, Houston, in press.

Christensen P. R.[*] (1984) The origin of regional dust deposits on Mars. In *Lunar and Planetary Science* XV, pp. 148–149. Lunar and Planetary Institute, Houston.

Christensen P. R.[*] (1984) Thermal emissivity of the martian surface: Evidence for compositional variations. In *Lunar and Planetary Science* XV, pp. 150–151. Lunar and Planetary Institute, Houston.

Christensen P. R.[*] (1985) The origin of regional dust deposits on Mars. *NASA TM-87563*, pp. 295–296.

Christensen P. R.[*] (1985) Regional dust deposits on Mars: Origin, age, and geologic history. In *Workshop on Dust on Mars* (S. Lee, ed.), pp. 1-2. LPI Tech. Rpt. 85-02, Lunar and Planetary Institute, Houston.

Christensen P. R.[*] (1986) Albedo variations of the martian surface and atmosphere. *EOS Trans. AGU, 67*, 301.

Christensen P. R.[*] (1986) Dust deposition and erosion on Mars: Cyclic development of regional deposits. In *Workshop on Dust on Mars II* (S. Lee, ed.), pp. 14–16. LPI Tech. Rpt. 86-09, Lunar and Planetary Institute, Houston.

Christensen P. R.[*] (1986) Regional dust deposits on Mars: Origin, age, and geologic history. *NASA TM-88383*, pp. 237–238.

Christensen P. R.[*] (1986) Regional dust deposits on Mars: Physical properties, age and history. *J. Geophys. Res., 91*, 3533–3546.

Christensen P. R.[*] (1986) Seasonal variability of martian surface albedos: Implications for yearly dust deposition and removal. In *Lunar and Planetary Science* XVII, pp. 121–122. Lunar and Planetary Institute, Houston.

Christensen P. R.[*] (1986) Surface albedo variations on Mars: Implications for yearly dust deposition and removal. In *Workshop on Dust on Mars II* (S. Lee, ed.), pp. 17–19. LPI Tech. Rpt. 86-09, Lunar and Planetary Institute, Houston.

Christensen P. R.[*] (1987) Variations of martian surface albedo: Evidence for yearly dust deposition and removal. *NASA TM-89810*, pp. 167–169.

Christensen P. R.[*] (1987) Global albedo variations on Mars: Implications for active aeolian transport, deposition, and erosion. Submitted to *J. Geophys. Res.*

Christensen P. R.[*] and Zurek R. W.[†] (1984) Martian north polar hazes and surface ice: Results from the Viking Survey/Completion Mission. *J. Geophys. Res.*, 89, 4587–4596.

Christensen P. R.[*] and Zurek R. W.[†] (1984) Martian north polar hazes and surface ice: Results from the Viking Survey/completion mission. *J. Geophys. Res.*, 89, 4587–4596.

Christensen P. R. and Zurek R. W.[†] (1984) Mars water-ice clouds. In *Workshop on Water on Mars* (S. Clifford, ed.), pp. 14–16. LPI Tech. Rpt. 85-03, Lunar and Planetary Institute, Houston.

Christensen P. R.[*], Kieffer H. H., and Chase S. (1985) Determination of martian surface composition by thermal infrared spectral observation. In *Lunar and Planetary Science XVI*, pp. 125–126. Lunar and Planetary Institute, Houston.

Christensen P. R.[*], Jaramillo L., and Greeley R.[†] (1985) Water-ice clouds on Mars: Location and seasonal variation. *NASA TM-87563*, pp. 389–390.

Christensen P. R.[*], Zurek R. W.[†], and Greeley R.[†] (1986) Mars water-ice clouds. *NASA TM-88383*, pp. 512–514.

Christensen P. R.[*], Zurek R. W.[†], and Jaramillo L. L. (1986) Seasonal and diurnal variability of Mars water-ice clouds. In *Lunar and Planetary Science XVII*, pp. 123–124. Lunar and Planetary Institute, Houston.

Christensen P. R.[*], Zurek R. W.[†], and Jaramillo L. L. (1988) Seasonal and diurnal variability of Mars water-ice clouds. In *Workshop on Atmospheric H_2O Observations of Earth and Mars*. LPI Tech. Rpt., Lunar and Planetary Institute, Houston, in press.

Christiansen E. H.[*] and Hopler J. A. (1987) Geomorphic evidence for subsurface volatile reservoirs in the Elysium region of Mars. In MECA *Special Session at LPSC XVII: Martian Geomorphology and its Relation to Subsurface Volatiles* (S. Clifford, L. A. Rossbacher, and J. R. Zimbelman, eds.), pp. 14–15. LPI Tech. Rpt. 87-02, Lunar and Planetary Institute, Houston.

Clark B. C. (1987) Comets, volcanism, the salt rich regolith and cycling of volatiles on Mars. In MECA *Symposium on Mars: Evolution of its Climate and Atmosphere* (V. Baker, M. Carr, F. Fanale, R. Greeley, R. Haberle, C. Leovy, and T. Maxwell, eds.), pp. 29–31. LPI Tech. Rpt. 87-01, Lunar and Planetary Institute, Houston.

Clark B. C.[*] (1987) Comets, volcanism, the salt-rich regolith, and cycling of volatiles on Mars. *Icarus, 71*, 250-256.

Clifford S. M.[*] (1984) Do the martian polar caps have equilibrium profiles? *EOS Trans. AGU, 56*, 979.

Clifford S. M.[*], ed. (1985) *Workshop on Water on Mars*. LPI Tech. Rpt. 85-03, Lunar and Planetary Institute, Houston. 105 pp.

Clifford S. M.[*] (1985) Mars: Groundwater mound development in response to polar basal melting. In *Workshop on Water on Mars* (S. Clifford, ed.), pp. 17–19. LPI Tech. Rpt. 85-03, Lunar and Planetary Institute, Houston.

Clifford S. M.[*] (1985) Mars: Permeability requirements for a global groundwater system driven by polar basal melting. In *Workshop on Water on Mars* (S. Clifford, ed.), pp. 20–22. LPI Tech. Rpt. 85-03, Lunar and Planetary Institute, Houston.

Clifford S. M.[*] (1986) Mars: Where has all the water gone? *Sky & Telescope, 72*, 20.

Clifford S. M.[*] (1987) Polar basal melting on Mars. *J. Geophys. Res., 92*, 9135–9152.

Clifford S. M.[*] (1987) Theoretical equilibrium profiles of the martian perennial polar caps. In *Lunar and Planetary Science XVIII*, pp. 189–190. Lunar and Planetary Institute, Houston.

Clifford S. M.[*] (1987) Mars: Crustal pore volume, cryospheric depth, and the global occurrence of groundwater. In MECA *Symposium on Mars: Evolution of its Climate and Atmosphere* (V. Baker, M. Carr, F. Fanale, R. Greeley, R. Haberle, C. Leovy, and T. Maxwell, eds.), pp. 32–34. LPI Tech. Rpt. 87-01, Lunar and Planetary Institute, Houston.

Clifford S. M.[*] (1988) The interpretation of data from the Viking Mars Atmospheric Water Detectors (MAWD): Some points for discussion. In *Workshop on Atmospheric H_2O Observations of Earth and Mars*. LPI Tech. Rpt., Lunar and Planetary Institute, Houston, in press.

Clifford S. M.[*] and Bartels C. J. (1985) MARSTHERM: A FORTRAN 77 finite-difference thermal model available for general distribution. *Bull. Amer. Astron. Soc., 17*, 738.

Clifford S. M.[*] and Bartels C. J. (1986) The Mars Thermal Model (MARSTHERM): A FORTRAN 77 finite-difference thermal model designed for general distribution. In *Lunar and Planetary Science XVII*, pp. 142–143. Lunar and Planetary Institute, Houston.

Clifford S. M.[*] and Fanale F. P.[†] (1985) The thermal conductivity of the martian crust. In *Lunar and Planetary Science XVI*, pp. 144–145. Lunar and Planetary Institute, Houston.

Clifford S. M.[*] and Haberle R. M.[†], eds. (1988) *Workshop on Atmospheric H_2O Observations of the Earth and Mars*. LPI Tech. Rpt., Lunar and Planetary Institute, Houston, in press.

Clifford S. M.[*] and Hillel D. (1986) Knudsen diffusion: The effect of small pore size and low gas pressure on gaseous transport in soil. *Soil Sci., 141*, 289–299.

Clifford S. M.[*] and Huguenin R. L.[†] (1988) Regolith water vapor sources on Mars: A historical bibliography. In *Workshop on Atmospheric H_2O Observations of the Earth and Mars*. LPI Tech. Rpt., Lunar and Planetary Institute, Houston, in press.

Clifford S. M.[*], Rossbacher L. A.[*], and Zimbelman J. R.[*], eds. (1987) *MECA Special Session at LPSC XVII: Martian Geomorphology and its Relation to Subsurface Volatiles*. LPI Tech. Rpt. 87-02, Lunar and Planetary Institute, Houston. 51 pp.

Clow G. D.[*] (1984) Use of planetary boundary layer model for martian paleoclimates. In *Lunar and Planetary Science XV*, pp. 176–177. Lunar and Planetary Institute, Houston.

Clow G. D.[*] (1985) Radiation-dominated snowmelt on Mars. In *Workshop on Water on Mars* (S. Clifford, ed.), pp. 23–24. LPI Tech. Rpt. 85-03, Lunar and Planetary Institute, Houston.

Clow G. D.[†] (1987) Generation of liquid water on Mars through the melting of a dusty snowpack. *Icarus, 72*, 95–127.

Colburn D. S.[*], Pollack J.[*], and Haberle R. M.[†] (1986) Influence of dust on water condensation at Mars. In MECA *Workshop on Dust on Mars II* (S. Lee, ed.) pp. 20–22. LPI Tech. Rpt. 86-09, Lunar and Planetary Institute, Houston.

Colburn D. S.[*], Pollack J.[*], and Haberle R. M.[†] (1988) Factors governing water condensation in the martian atmosphere. In *Workshop on Atmospheric H_2O Observations of Earth and Mars*. LPI Tech. Rpt., Lunar and Planetary Institute, Houston, in press.

Costard F. and Dollfus A. (1987) Ice lenses on Mars. In MECA *Special Session at LPSC XVII: Martian Geomorphology and its Relation to Subsurface Volatiles* (S. Clifford, L. A. Rossbacher, and J. R. Zimbelman, eds.), pp. 16–17. LPI Tech. Rpt. 87-02, Lunar and Planetary Institute, Houston.

Dale-Bannister M., Arvidson R.[†], Singer R.[†], and Bruckenthal E. A. (1985) Observed upper limits for clay minerals on Mars. In *Lunar and Planetary Science XVI*, pp. 787–788. Lunar and Planetary Institute, Houston.

Dale-Bannister M., Arvidson R.[†], Singer R.[†], and Bruckenthal E. (1985) The search for igneous minerals at the Viking Lander Sites. In *Lunar and Planetary Science XVI*, pp. 161–162. Lunar and Planetary Institute, Houston.

DeHon R. A. (1987) Ring furrows: Inversion of topography in martian highland terrains. *Icarus, 71*, 287–297.

Donner L. J. (1988) Cumulus convection and the terrestrial water-vapor distribution. In *Workshop on Atmospheric H_2O Observations of Earth and Mars*. LPI Tech. Rpt., Lunar and Planetary Institute, Houston, in press.

Drake D. M., Feldman W. C., Reedy R. C., and Jakosky B. M.[†] (1987) Neutron mode of the Mars Observer Gamma Ray Spectrometer. In *Lunar and Planetary Science XVIII*, pp. 244–245. Lunar and Planetary Institute, Houston.

Drake D. M., Muhleman D. O.[†], Berge G. L., and Jakosky B. M.[†] (1987) Martian neutron albedo spectra. Submitted to *J. Geophys. Res.*

Dreibus G. and Wänke H.[†] (1985) Mars, a volatile-rich planet. *Meteoritics, 20*, 367–381.

Dreibus G. and Wänke H.[†] (1986) Comparison of Cl/Br and Br/I ratios in terrestrial samples and SNC meteorites. In MECA *Workshop on the Evolution of the Martian Atmosphere* (M. Carr, P. James, C. Leovy, R. Pepin, and J. Pollack, eds.), pp. 13–14. LPI Tech. Rpt. 86-07, Lunar and Planetary Institute, Houston.

Dreibus G. and Wänke H.[†] (1987) Volatiles on Earth and Mars: A comparison. *Icarus, 71*, 225–240.

Duxbury E. and Clifford S. M.[*] (1987) Minimum rampart crater onset diameters in the equatorial region of Mars. *EOS Trans. AGU, 68*, 344.

Elfstrom A. and Rossbacher L.[*] (1985) Erosional remnants in the Baldakatj area, Lapland, northern Sweden: A terrestrial analog for martian landforms. *Geografiska Annaler, 67*, 167–176.

Evans L. G. and Squyres S. W.[†] (1987) Investigation of martian volatiles via gamma-ray spectroscopy. *J. Geophys. Res., 92*, 9153–9167.

Fanale F. P.[†], Salvail J. R., Zent A. P.[*], and Postawko S. E.[*] (1984) Mars: Astronomical effects on regolith H_2O state. *Bull. Amer. Astron. Soc.*, *16*, 674.

Fanale F. P.[†], Salvail J. R., Zent A. P.[*], and Postawko S. E.[*] (1984) Mars: Long term changes in the state and distribution of H_2O. In *Workshop on Water on Mars* (S. Clifford, ed.), p. 25. LPI Tech. Rpt. 85-03, Lunar and Planetary Institute, Houston.

Fanale F. P.[†], Salvail J. R., Zent A. P.[*], and Postawko S. E.[*] (1985) Mars: Long term changes in the state and distribution of H_2O. In *Ices in the Solar System* (J. Klinger, D. Benest, A. Dollfus, and R. Smoluchowski, eds.), pp. 535–564. D. Reidel, Dordrecht.

Fanale F. P.[†], Salvail J. R., Zent A. P.[*], and Postawko S. E.[*] (1985) Global distribution and migration of subsurface ice on Mars. In *Lunar and Planetary Science XVI*, p. 231. Lunar and Planetary Institute, Houston.

Fanale F. P.[†], Postawko S. E.[*], Zent A. P.[*], and Salvail J. R. (1986) Is regolith adsorption the explanation for the transition from early to present Mars climate? In *MECA Symposium on Mars: Evolution of its Climate and Atmosphere* (V. Baker, M. Carr, F. Fanale, R. Greeley, R. Haberle, C. Leovy, and T. Maxwell, eds.), pp. 21–22. LPI Tech. Rpt. 87-01, Lunar and Planetary Institute, Houston.

Fanale F. P.[†], Salvail J. R., Zent A. P.[*], and Postawko S. E.[*] (1986) Global distribution and migration of subsurface ice on Mars. *Icarus*, *67*, 1–18.

Fanale F. P.[†], Postawko S. E.[*], Zent A. P.[*], and Salvail J. R. (1987) The role of regolith adsorption in the transition from early to late Mars climate. *NASA TM-89810*, pp. 161–164.

Frey H. (1987) Pseudocracters as indicators of ground ice on Mars. In *MECA Special Session at LPSC XVII: Martian Geomorphology and its Relation to Subsurface Volatiles* (S. Clifford, L. A. Rossbacher, and J. R. Zimbelman, eds.), pp. 18–19. LPI Tech. Rpt. 87-02, Lunar and Planetary Institute, Houston.

Garvin J. G., Ulaby F. T., Smith D. E., Frey H. V., Solomon S., and Zwally H. J. (1987) Martian surface physical properties to be derived by radar altimeter on the Mars Observer Spacecraft. In *MECA Symposium on Mars, Evolution of its Climate and Atmosphere* (V. Baker, M. Carr, F. Fanale, R. Greeley, R. Haberle, C. Leovy, and T. Maxwell, eds.), pp. 37–39. LPI Tech. Rpt. 87-01, Lunar and Planetary Institute, Houston.

Gibson E. K.[*], Jr. (1985) Sources and sinks of present day water within the martian regolith: Evidence from a terrestrial analog of Martian weathering processes—the dry valleys of Antarctica. In *Workshop on Water on Mars* (S. Clifford, ed.) pp. 26–28. LPI Tech. Rpt. 85-03, Lunar and Planetary Institute, Houston.

Goettel K. A.[*] (1986) Rigorous constraints on the bulk composition and volatile inventory of Mars. In *MECA Workshop on the Evolution of the Martian Atmosphere* (M. Carr, P. James, C. Leovy, R. Pepin, and J. Pollack, eds.), pp.15–16. LPI Tech. Rpt. 86-07, Lunar and Planetary Institute, Houston.

Gooding J. L.[*] (1984) Do igneous rocks fall from Mars and beyond? *Geotimes*, *29*, 29–30.

Gooding J. L. (1985) Water and ice in the martian regolith: Dependence of stabilities on regolith mineralogy. In *Workshop on Water on Mars* (S. Clifford, ed.), pp. 29–31. LPI Tech. Rpt. 85-03, Lunar and Planetary Institute, Houston.

Gooding J. L.[†] (1986) Martian dust particles as condensation nuclei: A preliminary assessment of mineralogical factors. *Icarus*, *66*, 56–74.

Gooding J. L.[†] (1986) Martian weathering products: Response to climate changes and effects on volatile inventories. In *MECA Workshop on the Evolution of the Martian Atmosphere* (M. Carr, P. James, C. Leovy, R. Pepin, and J. Pollack, eds.), pp. 17–18. LPI Tech. Rpt. 86-07, Lunar and Planetary Institute, Houston.

Gooding J. L.[†] (1986) Condensation of frosts on martian dust particles. In *MECA Workshop on Dust on Mars II* (S. Lee, ed.), pp. 23–25. LPI Tech. Rpt. 86-09, Lunar and Planetary Institute, Houston.

Gooding J. L.[*] (1987) Are SNCs smoked or salted? *Geotimes*, *32*, 10–11.

Gooding J. L.[*] (1987) Undercooled water in basaltic regoliths and implications for fluidized debris flows on Mars. *Icarus*, *72*, 519–527.

Gooding J. L.[†] (1987) Water-ice in the martian regolith: Experimental investigation of lithologic effects. In *MECA Special Session at LPSC XVII: Martian Geomorphology and its Relation to Subsurface Volatiles* (S. M. Clifford, L. A. Rossbacher, and J. R. Zimbelman, eds.), pp. 20–21. LPI Tech. Rpt. 87-02, Lunar and Planetary Institute, Houston.

Gooding J. L.[*] (1987) Non-equilibrium freezing of water-ice in sandy basaltic regoliths and implications for fluidized debris flows on Mars. *NASA TM-89810*, pp. 305–306.

Gooding J. L.[†] (1988) Possible significance of H_2O-ice in the martian atmospheric water cycle. In *Workshop on Atmospheric H_2O Observations of Earth and Mars*. LPI Tech. Rpt., in press, Lunar and Planetary Institute, Houston.

Gooding J. L.[*] and Muenow D. W. (1986) Martian volatiles in shergottite EETA 79001: New evidence from oxidized sulfur and sulfur-rich aluminosilicates. *Geochim. Cosmochim. Acta*, *50*, 1049–1059.

Gooding J. L.[*] and Wentworth S. J. (1987) Calcium carbonate and calcium sulfate in martian meteorite EETA79001. *NASA TM-89810*, pp. 158–159.

Greeley R.[†] (1986) Aeolian activity as a planetary process. In *Physics of Desertification*, (F. El-Baz and M.H.A. Hassan, eds.), pp. 159–190.

Greeley R.[†] (1986) Dust storms on Mars: Mechanisms for dust-raising. *NASA TM-88383*, pp. 242–244.

Greeley R.[†] (1986) Toward an understanding of the martian dust cycle. In *Workshop on Dust on Mars II* (S. Lee, ed.), pp. 22–24. LPI Tech. Rpt. 86-09, Lunar and Planetary Institute, Houston.

Greeley R.[†] (1986) Martian dust: The case for "parna." In *Workshop on Dust on Mars II* (S. Lee, ed.), pp. 25–27. LPI Tech. Rpt. 86-09, Lunar and Planetary Institute, Houston.

Greeley R.[†] (1986) Water on Mars: Amounts and timing released in association with volcanism. *EOS Trans. AGU*, *67*, 1074.

Greeley R.[†] (1987) The martian dust cycle: A proposed model. In *MECA Symposium on Mars: Evolution of its Climate and Atmosphere* (V. Baker, M. Carr, F. Fanale, R. Greeley, R. Haberle, C. Leovy, and T. Maxwell, eds.), pp. 43–45. LPI Tech. Rpt. 87-01, Lunar and Planetary Institute, Houston.

Greeley R.[†] (1987) Release of magmatic water on Mars: Estimated timing and volumes.In *MECA Symposium on Mars: Evolution of its Climate and Atmosphere* (V. Baker, M. Carr, F. Fanale, R. Greeley, R. Haberle, C. Leovy, and T. Maxwell, eds.), pp. 40–43. LPI Tech. Rpt. 87-01, Lunar and Planetary Institute, Houston.

Greeley R.[†] (1987) Release of juvenile water on Mars: Estimated amounts and timing associated with volcanism. *Science*, *236*, 1653–1654.

Greeley R.[†], Williams S., White B. R., Pollack J.[†], Marshall J., and Krinsley D. (1984) Abrasion by aeolian particles: Earth and Mars. *NASA-CR-3788*, p. 50.

Greeley R.[†], Williams S. H., White B. R., Pollack J., and Marshall J. R. (1985) Wind abrasion on Earth and Mars. In *Models in Geomorphology* (M. Woldenberg, ed.), pp. 373–422. Allen and Unwin, Boston.

Guinness E. A.[*], Leff C. E., and Arvidson R. E.[†] (1985) On the latitudinal distribution of debris in the northern hemisphere of Mars. In *Workshop on Water on Mars* (S. Clifford, ed.), pp. 32–34. LPI Tech. Rpt. 85-03, Lunar and Planetary Institute, Houston.

Guinness E. A.[*], Arvidson R. E.[†], Dale-Bannister M. A., Singer R.[†], and Bruckenthal E. A. (1987) On the spectral reflectance properties of materials exposed at the Viking landing sites. *J. Geophys. Res.*, *92*, 575–587.

Gulick V. C. and Baker V. R.[†] (1986) Evolution of valley networks on Mars: The Hawaiian analog. *Geol. Soc. Amer. Abst. with Prog.*, *18*, 623.

Gulick V. C. and Baker V. R.[†] (1987) Origin and evolution of valleys on martian volcanoes: The Hawaiian analog. In *Lunar and Planetary Science XVIII*, pp. 376–377. Lunar and Planetary Institute, Houston.

Haberle R. M.† (1985) Hidden carbon dioxide on Mars. *Nature, 318,* 599–600.

Haberle R. M.† (1986) Interannual variability of great dust storms on Mars. *Science, 234,* 459–461.

Haberle R. M.† (1986) The development of global dust storms: The role of the mean meridional circulation. In MECA *Workshop on Dust on Mars II* (S. Lee, ed.), pp. 32–33. LPI Tech. Rpt. 86-09, Lunar and Planetary Institute, Houston.

Haberle R. M.† (1986) The climate of Mars. *Sci. Amer., 254,* 54–62.

Haberle R. M.† (1987) Interannual variability of global dust storms on Mars. In *MECA Symposium on Mars: Evolution of its Climate and Atmosphere* (V. Baker, M. Carr, F. Fanale, R. Greeley, R. Haberle, C. Leovy, and T. Maxwell, eds.), p. 46. LPI Tech. Rpt. 87-01, Lunar and Planetary Institute, Houston.

Haberle R. M.† (1988) On the vertical distribution of water vapor in the martian tropics. In *Workshop on Atmospheric H_2O Observations of Earth and Mars.* LPI Tech. Rpt., in press, Lunar and Planetary Institute, Houston.

Haberle R. M.† and Herdtle T. (1985) Numerical simulation of the current water cycle on Mars. In *Workshop on Water on Mars* (S. Clifford, ed.), p. 35. LPI Tech. Rpt. 85-03, Lunar and Planetary Institute, Houston.

Haberle R. M.† and Jakosky B. M.† (1987) Transport of water from the residual north polar cap on Mars. In *Lunar and Planetary Science XVIII,* pp. 378–379. Lunar and Planetary Institute, Houston.

Hale-Erlich W. S. (1987) Implications for substrate volatile distributions on Mars from complex crater morphology and morphometry. In MECA *Special Session at LPSC XVII: Martian Geomorphology and its Relation to Subsurface Volatiles* (S. M. Clifford, L. A. Rossbacher, and J. R. Zimbelman, eds.), pp. 22–23. LPI Tech. Rpt. 87-02, Lunar and Planetary Institute, Houston.

Harris S. L. and Huguenin R. L.† (1987) Chemical frost weathering of olivine: Experimental study and implications. In MECA *Symposium on Mars: Evolution of its Climate and Atmosphere* (V. Baker, M. Carr, F. Fanale, R. Greeley, R. Haberle, C. Leovy, and T. Maxwell, eds.), pp. 47–49. LPI Tech. Rpt. 87-01, Lunar and Planetary Institute, Houston.

Hart H. M. and Jakosky B. M.† (1985) Stability and composition of condensate at the Viking Lander 2 site on Mars. In *Workshop on Water on Mars* (S. Clifford, ed.), pp. 36–37. LPI Tech. Rpt. 85-03, Lunar and Planetary Institute, Houston.

Hart H. M. and Jakosky B. M.† (1986) Composition and stability of the condensate observed at the Viking Lander 2 site on Mars. *Icarus,* 66, 134–142.

Hart H. M. and Jakosky B. M.† (1987) Vertical distribution of water vapor in the atmosphere of Mars: Error analysis and preliminary results. In *Lunar and Planetary Science XVIII,* pp. 387–388. Lunar and Planetary Institute, Houston.

Herkenhoff K.* (1986) Dust scattering at the martian terminator during the Mariner 9 Mission. In MECA *Workshop on Dust on Mars* (S. Lee, ed.), pp. 34–36. LPI Tech. Rpt. 86-09, Lunar and Planetary Institute, Houston.

Horner V. M. and Greeley R.† (1987) Effects of elevation and plains thicknesses on martian crater ejecta morphologies for the ridged plains. In MECA *Special Session at LPSC XVII: Martian Geomorphology and its Relation to Subsurface Volatiles* (S. M. Clifford, L. A. Rossbacher, and J. R. Zimbelman, eds.), pp. 24–25. LPI Tech. Rpt. 87-02, Lunar and Planetary Institute, Houston.

Horner V. M. and Greeley R.† (1987) Effects of elevation and ridged plains thickness on martian crater ejecta morphology. *J. Geophys. Res., 92,* 561–569.

Horner V. M. and Zimbelman J. R.* (1986) Viking IRTM studies of the Crater Curier. In *Lunar and Planetary Science XVII,* pp. 360–361. Lunar and Planetary Institute, Houston.

Huguenin R. L.† (1985) Mars: Mineralogical constraints on volatile evolution. In *Workshop on Water on Mars* (S. Clifford, ed.), pp. 38–40. LPI Tech. Rpt. 85-03, Lunar and Planetary Institute, Houston.

Huguenin R. L.† (1987) Mars low albedo regions: Possible map of near-surface H_2O. In MECA *Symposium on Mars: Evolution of its Climate and Atmosphere* (V. Baker, M. Carr, F. Fanale, R. Greeley, R. Haberle, C. Leovy, and T. Maxwell, eds.), pp. 50–52. LPI Tech. Rpt. 87-01, Lunar and Planetary Institute, Houston.

Huguenin R. L.† (1987) Photochemical weathering and contemporary volatile loss on Mars. In MECA *Symposium on Mars: Evolution of its Climate and Atmosphere* (V. Baker, M. Carr, F. Fanale, R. Greeley, R. Haberle, C. Leovy, and T. Maxwell, eds.), pp. 53–56. LPI Tech. Rpt. 87-01, Lunar and Planetary Institute, Houston.

Huguenin R. L.† (1987) The silicate component of martian dust. *Icarus, 70,* 162–188.

Huguenin R. L.† and Harris S. L. (1986) Accreted H_2O inventory on Mars. In MECA *Workshop on the Evolution of the Martian Atmosphere* (M. Carr, P. James, C. Leovy, R. Pepin, and J. Pollack, eds.), pp. 19–22. LPI Tech. Rpt. 86-07, Lunar and Planetary Institute, Houston.

Huguenin R. L.†, Harris S., and Carter R. (1985) Freeze/thaw injection of dust into the martian atmosphere. In *Lunar and Planetary Science XVI,* pp. 376-377. Lunar and Planetary Institute, Houston.

Huguenin R. L.†, Harris S. L., and Carter R. (1986) Injection of dust into the martian atmosphere: Evidence from the Viking gas exchange experiment. *Icarus, 68,* 99–119.

Hunt G. E. and James P.† (1985) Martian cloud systems: Current knowledge and future observations. *Adv. in Space Res., 5,* 93–99.

Hunten D. M., Pepin R. O.†, and Walker J. C. G. (1987) Mass-fractionation in hydrodynamic escape. *Icarus, 69,* 532–549.

Iversen J. D. and Greeley R.† (1984) Martian crater dark streak lengths: Explanation from wind tunnel experiments. *Icarus, 58,* 358–362.

Iwasaki K., Saito Y., and Akabane T. (1987) Interannual differences in the regressions of the polar caps of Mars. In MECA *Symposium on Mars: Evolution of its Climate and Atmosphere* (V. Baker, M. Carr, F. Fanale, R. Greeley, R. Haberle, C. Leovy, and T. Maxwell, eds.), pp. 57–59. LPI Tech. Rpt. 87-01, Lunar and Planetary Institute, Houston.

Jakosky B. M.† (1984) The seasonal cycle of water on Mars. *EOS Trans. AGU, 65,* 979.

Jakosky B. M.† (1985) The seasonal cycle of water on Mars. *Space Sci. Rev., 41,* 131–200.

Jakosky B. M.† (1985) Thermal properties of martian fines. In *Workshop on Dust on Mars* (S. Lee, ed.), p. 6. LPI Tech. Rpt. 85-02, Lunar and Planetary Institute, Houston.

Jakosky B. M.† (1986) On Mars: Remote sensing examines surface. *Geotimes, 31,* 28–30.

Jakosky B. M.† (1986) On the thermal properties of the martian fines. *Icarus,* 66, 117–124.

Jakosky B. M.† (1986) Remote sensing examines surface. *Geotimes, 31,* 28–30.

Jakosky B. M.† (1987) Sublimation of water from the residual north polar cap on Mars. In *Lunar and Planetary Science XVIII,* p. 455. Lunar and Planetary Institute, Houston.

Jakosky B. M.† (1987) Surface-atmosphere interactions on Mars. *Internat. Union Geod. Geophys., I* 95.

Jakosky B. M.† (1988) The behavior of water vapor in the Mars atmosphere. In *Workshop on Atmospheric H_2O Observations of Earth and Mars.* LPI Tech. Rpt., in press, Lunar and Planetary Institute, Houston.

Jakosky B. M.† and Barker E. S. (1984) Comparison of ground-based and Viking Orbiter measurements of martian water vapor: Variability of the seasonal cycle. *Icarus, 57,* 322–334.

Jakosky B. M.† and Carr M. H.† (1984) Mars at high obliquity: Possible precipitation of ice at low latitudes. *Bull. Amer. Astron. Soc., 16,* 673.

Jakosky B. M.[†] and Carr M. H.[†] (1985) Possible precipitation of ice at low latitudes of Mars during periods of high obliquity. *Nature, 315,* 559-561.

Jakosky B. M.[†] and Christensen P. R.[*] (1984) Duricrusts on Mars: Evidence from thermal, radio, and radar data. In *Lunar and Planetary Science XV,* pp. 397-398. Lunar and Planetary Institute, Houston.

Jakosky B. M.[†] and Christensen P. R.[*] (1985) Interpretation of remote-sensing observations of Mars. In *Lunar and Planetary Science XVI,* pp. 392–393. Lunar and Planetary Institute, Houston.

Jakosky B. M.[†] and Christensen P. R.[*] (1985) Global duricrust on Mars: Analysis of remote sensing data. In *Workshop on Dust on Mars* (S. Lee, ed.), p. 7. LPI Tech. Rpt. 85-02, Lunar and Planetary Institute, Houston.

Jakosky B. M.[†] and Christensen P. R.[*] (1986) Are the Viking Lander sites representative of the surface of Mars? In MECA *Workshop on Dust on Mars II* (S. Lee, ed.), pp. 37–38. LPI Tech. Rpt. 86-09, Lunar and Planetary Institute, Houston.

Jakosky B. M.[†] and Christensen P. R.[*] (1986) Are the Viking landing sites representative of the surface of Mars? *Icarus, 66,* 125–133.

Jakosky B. M.[†] and Christensen P. R.[*] (1986) Global duricrust on Mars: Analysis of remote sensing data. *J. Geophys. Res., 91,* 3547–3560.

Jakosky B. M.[†] and Christensen P. R.[*] (1986) Thermal properties of the martian surface. *EOS Trans. AGU, 16,* 301.

Jakosky B. M.[†] and Lindner B. L. (1984) Mars atmospheric photochemistry, surface reactions, and climate change. In *Lunar and Planetary Science XV,* 399–400. Lunar and Planetary Institute, Houston.

Jakosky B. M.[†] and Martin T. Z.[*] (1987) Mars: North-Polar atmospheric warming during dust storms. *Icarus, 72,* 528–534.

Jakosky B. M.[†], LaPointe M. R., and Zurek R. W.[†] (1987) The observed day-to-day variability of Mars water vapor. In MECA *Symposium on Mars: Evolution of its Climate and Atmosphere* (V. Baker, M. Carr, F. Fanale, R. Greeley, R. Haberle, C. Leovy, and T. Maxwell, eds.), p. 60. LPI Tech. Rpt. 87-01, Lunar and Planetary Institute, Houston.

Jakosky B. M.[†], Thomas G. E., Rusch D. W., Barth C. A., Lawrence G. M., Olivero J. J., Clancy R. T., Sanders R. W., and Knapp B. G. (1988) Solar mesosphere explorer observations of stratospheric and mesospheric water vapor. In *Workshop on Atmospheric H_2O Observations of Earth and Mars.* LPI Tech. Rpt., in press, Lunar and Planetary Institute, Houston.

Jakosky B. M.[†], Zurek R. W.[†], and LaPointe M. R. (1988) The observed day-to-day variability of Mars atmospheric water vapor. *Icarus, 73,* 80–90.

James P. B.[†] (1984) Martian local dust storms. In *Recent Advances in Planetary Meteorology* (G.E. Hunt, ed.), pp. 85–99. Cambridge Univ. Press, Cambridge.

James P. B. (1985) Hydrologic cycle on Mars: Effects of CO_2 mass flux on global water distribution. In *Workshop on Water on Mars* (S. Clifford, ed.), p. 44. LPI Tech. Rpt. 85-03, Lunar and Planetary Institute, Houston.

James P. B.[†] (1986) The martian hydrologic cycle: Effects of CO_2 mass flux on global water distribution. *Icarus, 64,* 249–264.

James P. B.[†] (1987) The direction of water transport on Mars: A possible pumping mechanism. In MECA *Symposium on Mars: Evolution of its Climate and Atmosphere* (V. Baker, M. Carr, F. Fanale, R. Greeley, R. Haberle, C. Leovy, and T. Maxwell, eds.), pp. 62–63. LPI Tech. Rpt. 87-01, Lunar and Planetary Institute, Houston.

James P. B.[†] and Martin L. J.[*] (1986) Interannual variability in Mars south polar recessions and possible correlations with major dust storms. In MECA *Workshop on Dust on Mars II* (S. Lee, ed.), pp. 29–40. LPI Tech. Rpt. 86-09, Lunar and Planetary Institute, Houston.

James P. B.[†] and Martin L. J.[*] (1988) Circumpolar hoods and clouds and their relation to the martian H_2O cycle. In *Workshop on Atmospheric H_2O Observations of Earth and Mars.* LPI Tech. Rpt., in press, Lunar and Planetary Institute, Houston.

James P. B.[†], Pierce M., and Martin L. J.[*] (1987) Martian north polar cap and circumpolar clouds: 1975-1980 telescopic observations. *Icarus, 71,* 306–312.

James P. B.[†], Malolepszy K. M., and Martin L. J.[*] (1988) Interannual variability of Mars south polar cap. *Icarus, 71,* 298–305.

Jaquin F.[*] (1986) The vertical distribution of aerosols during the growth phase of a global dust storm. In MECA *Workshop on Dust on Mars II* (S. Lee, ed.), p. 41. LPI Tech. Rpt. 86-09, Lunar and Planetary Institute, Houston.

Jaquin F.[*] (1988) Very high elevation water ice clouds on Mars: Their morphology and temporal behavior. In *Workshop on Atmospheric H_2O Observations of Earth and Mars.* LPI Tech. Rpt., in press, Lunar and Planetary Institute, Houston.

Jaquin F.[*], Gierasch P., and Kahn R.[*] (1986) The vertical structure of limb hazes in the martian atmosphere. *Icarus, 68,* 442–461.

Jöns H.-P.[*] (1984) Orcus Patera and its surroundings: A squeezed zone between two Mega-Aureoles? In *Lunar and Planetary Science XV,* pp. 415–416. Lunar and Planetary Institute, Houston.

Jöns H.-P.[*] (1984) Sedimentary basins and mud flows in the northern lowlands of Mars. In *Lunar and Planetary Science XV,* pp. 417–418. Lunar and Planetary Institute, Houston.

Jöns H.-P.[*] (1985) Late sedimentation and late sediments in the northern lowlands on Mars. In *Lunar and Planetary Science XVI,* pp. 414–415. Lunar and Planetary Institute, Houston.

Jöns H.-P.[*] (1987) Arcuate ground undulations, gelifluxion-like features and "front tori" in the northern lowlands on Mars—What do they indicate? In MECA *Special Session at LPSC XVII: Martian Geomorphology and its Relation to Subsurface Volatiles* (S. M. Clifford, L. A. Rossbacher, and J. R. Zimbelman, eds.), pp. 26–27. LPI Tech. Rpt. 87-02, Lunar and Planetary Institute, Houston.

Kahn R.[*] (1984) The spatial and seasonal distribution of Martian clouds and some meteorological implications. *J. Geophys. Res., 98,* 6671–6688.

Kahn R.[*] (1985) Observational constraints on the global-scale wind systems of Mars. In *Workshop on Water on Mars* (S. Clifford, ed.), pp. 45–47. LPI Tech. Rpt. 85-03, Lunar and Planetary Institute, Houston.

Kahn R.[*] (1985) The evolution of CO_2 on Mars. *Icarus, 62,* 175–190.

Kahn R.[*] (1986) The evolution of CO_2 on Mars. In MECA *Workshop on the Evolution of the Martian Atmosphere* (M. Carr, P. James, C. Leovy, R. Pepin, and J. Pollack, eds.), p. 23. LPI Tech. Rpt. 86-07, Lunar and Planetary Institute, Houston.

Kahn R.[*] (1986) The varying properties of Martian aerosols. In MECA *Workshop on Dust on Mars II* (S. Lee, ed.), p. 42. LPI Tech. Rpt. 86-09, Lunar and Planetary Institute, Houston.

Kahn R.[*], Guiness E.[*], and Arvidson R.[†] (1986) Loss of fine-scale surface texture in Viking Orbiter images and implications for the inferred distribution of debris mantles. *Icarus, 66,* 22–38.

Kahn R.[*], Guinness E.[*], and Arvidson R.[†] (1986) Loss of fine-scale surface texture in Viking Orbiter images due to atmospheric obscuration, and a reassessment of latitudinal debris mantling on Mars. In MECA *Workshop on the Evolution of the Martian Atmosphere* (M. Carr, P. James, C. Leovy, R. Pepin, and J. Pollack, eds.), pp. 24–25. LPI Tech. Rpt. 86-07, Lunar and Planetary Institute, Houston.

Kargel J.S. (1987) Morphologic variations of martian rampart crater ejecta and their dependencies and implications. In MECA *Special Session at LPSC XVII: Martian Geomorphology and its Relation to Subsurface Volatiles* (S. M. Clifford, L. A. Rossbacher, and J. R. Zimbelman, eds.), pp. 28–29. LPI Tech. Rpt. 87-02, Lunar and Planetary Institute, Houston.

Kasting J. F.[*] (1987) Climatic effects of enhanced CO_2 levels in Mars early atmosphere. In MECA *Symposium on Mars: Evolution of its Climate and Atmosphere* (V. Baker, M. Carr, F. Fanale, R. Greeley, R. Haberle, C. Leovy, and T. Maxwell, eds.), pp. 64–66. LPI Tech. Rpt. 87-01, Lunar and Planetary Institute, Houston.

Kasting J. E.[*] and Toon O.[*] (1987) Climate evolution on the terrestrial planets. In *Proceedings of the Conference on Origin and Evolution of Planetary and Satellite Atmospheres*, March 10-14. Univ. of Ariz. Press, Arizona.

Kasting J. F.[*], Toon O., and Pollack J. B.[*] (1988) How climate evolved on the terrestrial planets. *Sci. Amer., 258*, 90–97.

Kieffer H. H.[†] and Paige D. A.[*] (1987) Influence of polar-cap albedo on past and current martian climate. In *MECA Symposium on Mars: Evolution of its Climate and Atmosphere* (V. Baker, M. Carr. F. Fanale, R. Greeley, R. Haberle, C. Leovy, and T. Maxwell, eds.), pp. 69–70. LPI Tech. Rpt. 87-01, Lunar and Planetary Institute, Houston.

Kochel R. C. and Howard A. D. (1985) Groundwater sapping and ancient valley networks on Mars. In *Workshop on Water on Mars* (S. Clifford, ed.), pp. 48–50. LPI Tech. Rpt. 85-03, Lunar and Planetary Institute, Houston.

Kochel R. C. and Piper J. O. (1987) Morphology of large valleys on Hawaii: Implications for groundwater sapping and comparisons to Martian valleys. In *MECA Special Session at LPSC XVII: Martian Geomorphology and its Relation to Subsurface Volatiles* (S. M. Clifford, L. A. Rossbacher, and J. R. Zimbelman, eds.), pp. 30–31. LPI Tech. Rpt. 87-02, Lunar and Planetary Institute, Houston.

Krinsley D. and Greeley R.[†] (1985) Individual particles and martian aeolian action—a review. *Sedimentary Geology, 47*, 167–189.

Laul J. C., Smith M. R., Wänke H.[*], Jagoutz E., Dreibus G., Palme H., Spettel B., Burghele A., Lipschutz M. E., and Verkouteren R. M. (1985) Chemical systematics of Shergotty. In *Lunar and Planetary Science XVI*, pp. 17–18. Lunar and Planetary Institute, Houston.

Laul J. C., Smith M. R., Wänke H.[*], Jagoutz E., Dreibus G., Palme H., Spettel B., Burghele A., Lipschutz M. E., and Verkouteren R. M. (1986) Chemical systematics of the Shergotty meteorite and the composition of its parent body (Mars). *Geochim. Cosmochim. Acta, 50*, 909–926.

Lee S. W.[*] (1984) Albedo features in the Solis Planum/Sinai Planum region of Mars: Seasonal and secular changes. *Bull. Am. Astron. Soc., 16*, 672.

Lee S. W.[*] (1984) Mars: Eolian dust transport at high altitudes and low pressures. *Geol. Soc. Amer. Abst. with Prog., 16*, 573.

Lee S. W.[*] (1984) Mars: Wind streak production as related to obstacle type and size. *Icarus, 58*, 339–357.

Lee S. W.[*] (1985) Influence of atmospheric dust loading and water vapor content on settling velocities of martian dust/ice grains: Preliminary results. In *Workshop on Water on Mars* (S. Lee, ed.), pp. 51–52. LPI Tech. Rpt. 85-02, Lunar and Planetary Institute, Houston.

Lee S. W.[*] (1985) Seasonal and secular variation of the Solis Lacus albedo feature: Relation to the martian dust-transport cycle. In *Lunar and Planetary Science XVI*, pp. 483–484. Lunar and Planetary Institute, Houston.

Lee S. W.[*] (1985) Aeolian dust transport at high altitudes and low pressures on Mars. In *Workshop on Dust on Mars* (S. Lee, ed.), pp. 8–9. LPI Tech. Rpt. 85-02, Lunar and Planetary Institute, Houston.

Lee S. W.[*], ed. (1985) *Workshop on Dust on Mars* LPI Tech. Rpt. 85-02, Lunar and Planetary Institute, Houston. 23 pp.

Lee S. W.[*] (1985) IRTM Observations of Syrtis Major: An area of active aeolian transport. *Bull. Amer. Astron. Soc., 17*, 736–737.

Lee S. W.[*] (1986) IRTM thermal and albedo observations of Syrtis Major. In *Lunar and Planetary Science XVII*, pp. 470–471. Lunar and Planetary Institute, Houston.

Lee S. W.[*] (1986) Viking observations of regional sources and sinks of dust on Mars. In MECA *Workshop on Dust on Mars II* (S. Lee, ed.), pp. 44–45. LPI Tech. Rpt. 86-09, Lunar and Planetary Institute, Houston.

Lee S. W.[*], ed. (1986) *MECA Workshop on Dust on Mars II*. LPI Tech. Rpt. 86-09, Lunar and Planetary Institute, Houston. 79 pp.

Lee S. W.[*] (1986) Regional sources and sinks of dust on Mars: Viking observations of Cerberus, Solis Planum, and Syrtis Major. In MECA *Symposium on Mars: Evolution of its Climate and Atmosphere* (V. Baker, M. Carr, F. Fanale, R. Greeley, R. Haberle, C. Leovy, and T. Maxwell, eds.), pp. 57–58. LPI Tech. Rpt. 87-01, Lunar and Planetary Institute, Houston.

Lee S. W.[*] (1986) Dust transport at high altitudes and low pressures on Mars: Aeolian activity on the Tharsis Montes. *NASA TM-88383*, pp. 251–253.

Lee S. W.[*] (1987) Regional sources and sinks of dust on Mars: Viking observations of Cerberus, Solis Planum, and Syrtis Major. In *NASA TM-89810*, pp. 259–260.

Leovy C. B.[*] (1985) The general circulation of Mars: Models and observations, Advances. In *Issues in Atmospheric and Oceanic Modeling, Part A: Climate Dynamics* (S.K. Manabe, ed.), *Advances in Geophys., 28A*, pp. 327–346. Academic, New York.

Leovy C. B.[*] (1986) Martian dust storms and climate change. In MECA *Workshop on the Evolution of the Martian Atmosphere* (M. Carr, P. James, C. Leovy, R. Pepin, and J. Pollack, eds.), pp. 26–27. LPI Tech. Rpt. 86-07, Lunar and Planetary Institute, Houston.

Leovy C. B. (1987) Planetary atmospheres. *Rev. Geophys., 25*, 297–303.

Leovy C. B.[*], Tillman J. E.[*], Guest W. R., and Barnes J. R.[*] (1985) Interannual variability of martian weather. In *Recent Developments in Planetary Meteorology* (G. E. Hunt, ed.), pp. 69–84. Cambridge Univ. Press, Cambridge.

Leovy C. B.[*], Hitchman M., and McCleese D.[*] (1988) Flux of water vapors in the terrestrial stratosphere and in the martian atmosphere. In *Workshop on Atmospheric H_2O Observations of Earth and Mars*. LPI Tech. Rpt., in press, Lunar and Planetary Institute, Houston.

Leshin L. A. and Zimbelman J. R.[*] (1986) Thermal inertias for the Elysium and Aeolis quadrangles of Mars. In *Lunar and Planetary Science XVII*, pp. 474-475. Lunar and Planetary Institute, Houston.

Lewis J. S.[†] and Watkins G. H.[*] (1986) Early volatile element inventories on Mars. In MECA *Workshop on the Evolution of the Martian Atmosphere* (M. Carr, P. James, C. Leovy, R. Pepin, and J. Pollack, eds.), p. 28. LPI Tech. Rpt. 86-07, Lunar and Planetary Institute, Houston.

Lindner B. L. and Jakosky B. M.[†] (1985) Martian atmospheric photochemistry and composition during periods of low obliquity. *J. Geophys. Res., 90*, 3435–3440.

Lucchitta B. K.[*] (1984) Ice and debris in the fretted terrain, Mars. *Proc. Lunar Planet. Sci. Conf. 14th*, in *J. Geophys. Res., 89*, B409–B418.

Lucchitta B. K.[*] (1984) A late climatic change on Mars. In *Lunar and Planetary Science XV*, pp. 493–494. Lunar and Planetary Institute, Houston.

Lucchitta B. K.[*] (1984) Small-scale polygons on Mars. *NASA TM-86246*, pp. 205–207.

Lucchitta B. K.[*] (1984) Permafrost on Mars and Earth. In *27th International Geological Congress*, 8, August 4–14. Moscow.

Lucchitta B. K.[*] (1984) Valles Marineris basin beds: A complex story. NASA TM-87563, pp. 506-508.

Lucchitta B. K.[*] (1985) Groundwater in the equatorial region of Mars: Evidence from landslides. In *Workshop on Water on Mars* (S. Clifford, ed.), pp. 53–55. LPI Tech. Rpt. 85-03, Lunar and Planetary Institute, Houston.

Lucchitta B. K.[*] (1985) Geomorphologic evidence for ground ice on Mars. In *Ices in the Solar System* (J. Klinger, D. Benest, A. Dollfus, and R. Smoluchowski, eds.), pp. 583–604. D. Reidel, Dordrecht.

Lucchitta B. K.[*] (1985) Ice-laden debris in outflow channels and northern lowland plains, Mars. *Geol. Soc. Amer. Abst. with Prog., 17*, 647.

Lucchitta B. K.[*] (1987) Water and ice on Mars: Evidence from Valles Marineris. In MECA *Symposium on Mars: Evolution of its Climate and Atmosphere* (V. Baker, M. Carr, F. Fanale, R. Greeley, R. Haberle, C. Leovy, and T. Maxwell, eds.), pp. 73–75. LPI Tech. Rpt. 87-01, Lunar and Planetary Institute, Houston.

Lucchitta B. K.[*] (1987) Ice-formed landscapes on Mars. *Inter-Nord, Int. Journal of Arctic and Nordic Studies*, in press.

Lucchitta B. K.[*] (1987) Valles Marineris, Mars: Wet debris flows and ground ice. *Icarus, 72*, 411–429.

Lucchitta B. K.[*], Ferguson H. M., and Summers C. A. (1986) Northern sinks on Mars(?). In *Lunar and Planetary Science XVII*, pp. 498-499. Lunar and Planetary Institute, Houston.

Lucchitta B. K.[*], Ferguson H. M., and Summers C. A. (1986) Sedimentary deposits in the northern lowland plains, Mars. *Proc. Lunar Planet. Sci. Conf. 17th*, in *J. Geophys. Res.*, *91*, E166-E174.

Lucchitta B. K.[*], Ferguson H. M., and Summers C. A. (1986) An ancient ocean on Mars? *NASA TM-88383*, pp. 450-453.

Lumme K. and James P. B.[†] (1984) Some photometric properties of the martian south polar cap during the 1971 apparition. *Icarus*, *58*, 363-377.

Marshall H. G.[*], Walker J. C. G., and Kuhn W. R.[†] (1985) Cloud properties in past martian climates. In *Workshop on Water on Mars* (S. Clifford, ed.), p. 56. LPI Tech. Rpt. 85-03, Lunar and Planetary Institute, Houston.

Martin L. J.[*] (1984) Clearing the martian air: The troubled history of dust storms. *Icarus*, *57*, 317-321.

Martin L. J.[*] and James P. B.[†] (1985) The possible role of water in the recession of Mars polar caps. In *Workshop on Water on Mars* (S. Clifford, ed.), p. 56. LPI Tech. Rpt. 85-03, Lunar and Planetary Institute, Houston.

Martin L. J.[*] and James P. B.[†] (1986) Major dust storm activity and variations in the recessions of Mars south polar cap. In *MECA Workshop on the Evolution of the Martian Atmosphere* (M. Carr, P. James, C. Leovy, R. Pepin, and J. Pollack, eds.), pp. 29-30. LPI Tech. Rpt. 86-07, Lunar and Planetary Institute, Houston.

Martin L. J.[*] and James P. B.[†] (1986) Dust clouds of a different nature. In *MECA Workshop on Dust on Mars II* (S. Lee, ed.), pp. 46-47. LPI Tech. Rpt. 86-09, Lunar and Planetary Institute, Houston.

Martin L. J.[*] and James P.[†] (1987) The great dust storm of 1986(?). In *MECA Symposium on Mars: Evolution of its Climate and Atmosphere* (V. Baker, M. Carr, F. Fanale, R. Greeley, R. Haberle, C. Leovy, and T. Maxwell, eds.), pp. 76-77. LPI Tech. Rpt. 87-01, Lunar and Planetary Institute, Houston.

Martin T. Z.[*] (1986) Infrared opacity of dust from Mars atmosphere. In *MECA Workshop on Dust on Mars II* (S. Lee, ed.), pp. 48-49. LPI Tech. Rpt. 86-09, Lunar and Planetary Institute, Houston.

Martin T. Z.[*] (1986) Thermal infrared opacity of the Mars atmosphere. *Icarus*, *66*, 1-21.

Martin T. Z.[*] and Kieffer H. H.[†] (1985) Improved access to martian infrared radiometry/spectroscopy datasets. In *Lunar and Planetary Science XVI*, p. 523. Lunar and Planetary Institute, Houston.

Masursky H.[*] (1986) Ages of rocks and channels in prospective martian landing sites of Mangala Vallies region. In *Lunar and Planetary Science XVII*, pp. 520-521. Lunar and Planetary Institute, Houston.

McCleese D. J.[*] and Schofield J. T. (1988) Measurement of the vertical profile of water vapor abundance in the martian atmosphere from Mars Observer. In *Workshop on Atmospheric H_2O Observations of Earth and Mars*. LPI Tech. Rpt., in press, Lunar and Planetary Institute, Houston.

McCleese D. J.[*] and West R. A.[*] (1986) Observations of dust from Mars Observer. In *MECA Workshop on Dust on Mars II* (S. Lee, ed.), pp. 50-52. LPI Tech. Rpt. 86-09, Lunar and Planetary Institute, Houston.

McKay C. P., Clow G. D.[*], Wharton R. A., and Squyres S. W.[*] (1985) Thickness of ice on perennially frozen lakes. *Nature*, *313*, 561-562.

McSween H. Y., Jr. (1985) SNC meteorites: Clues to martian petrologic evolution? *Rev. Geophys.*, *23*, 391-416.

Michelangeli D. V., Zurek R. W.[†], and Elson L. S. (1987) Barotropic instability of midlatitude zonal jets on Mars, Earth and Venus. *J. Atmospheric Sci.*, *44*, 2031-2041.

Miller J. S., Marshall J. R., and Greeley R.[†] (1987) Wind ripples in low density atmospheres. *NASA TM-89810*, pp. 268-270.

Moore H. J.[†] (1985) Sublimation rates required for steady-state glaciers, Mars. In *Workshop on Water on Mars* (S. Clifford, ed.), pp. 59-61. LPI Tech. Rpt. 85-03, Lunar and Planetary Institute, Houston.

Moore H. J.[†] (1985) Local dust storm of SOL 1742, Mars. In *Lunar and Planetary Science XVI*, 571-572. Lunar and Planetary Institute, Houston.

Moore H. J.[†] (1986) The martian dust storm of SOL 1742. *Proc. Lunar Planet. Sci. Conf. 16th*, in *J. Geophys. Res.*, 90, D163-D174.

Moore H. J.[†] (1986) Martian miniature slope failures, Mutch Memorial Station. In *MECA Workshop on Dust on Mars II* (S. Lee, ed.), pp. 53-55. LPI Tech. Rpt. 86-09, Lunar and Planetary Institute, Houston.

Moore H. J.[†] and Davis P. A. (1987) Ablation of martian glacier. In *MECA Symposium on Mars: Evolution of its Climate and Atmosphere* (V. Baker, M. Carr, F. Fanale, R. Greeley, R. Haberle, C. Leovy, and T. Maxwell, eds.), pp. 78-80. LPI Tech. Rpt. 87-01, Lunar and Planetary Institute, Houston.

Morris R. V.[†] (1985) Determination of optical penetration depths from reflectance and transmittance measurements on albite powders. In *Lunar and Planetary Science XVI*, pp. 581-582. Lunar and Planetary Institute, Houston.

Morris R. V.[†] and Lauer H. V., Jr. (1984) Spectral properties of annealed $(Fe_xAl_{1-x})_2O_3$ gels with applications to Mars. In *Lunar and Planetary Science XV*, pp. 571-572. Lunar and Planetary Institute, Houston.

Morris R. V.[†] and Mendell W. W. (1984) Scattering coefficients and optical penetration depths for powders of San Carlos olivine. In *Lunar and Planetary Science XV*, pp. 573-574. Lunar and Planetary Institute, Houston.

Morris R. V.[†], Lauer H. V., Jr., Lawson C. A., Gibson E. K., Jr.[†], Nace G. A., and Stewart C. (1985) Spectral and other physicochemical properties of submicron powders of hematite (α-Fe_2O_3), maghemite (γ-Fe_2O_3), magnetite (Fe_3O_4), goethite (α-FeOOH), and lepidocrocite (γ-FeOOH). *J. Geophys. Res.*, 90, 3126-3144.

Morris R. V.[†], Lauer H. V., Jr., Agresti D. G., and Newcomb J.A. (1986) Spectral properties of "dust" produced in the dry valleys of Antarctica: A martian analogue? In *MECA Workshop on Dust on Mars II* (S. Lee, ed.), pp. 56-57. LPI Tech. Rpt. 86-09, Lunar and Planetary Institute, Houston.

Morris R. V.[†], Lauer H. V., Jr., Murali A. V., Agresti D. G., and Newcomb J. A. (1987) Ultramicrocrystalline hematite: Properties and occurrence on the martian surface. In *Lunar and Planetary Science XVIII*, pp. 668-669. Lunar and Planetary Institute, Houston.

Morris R. V.[†], Agresti D. G., Lauer H. V., Jr., Newcomb J. A., and Murali A. V. (1987) Ultramicrocrystalline hematite: Properties and occurrence on Mars and the Earth. Submitted to *J. Geophys. Res.*

Mouginis-Mark P. J. (1985) Volcano/ground ice interactions in Elysium Planitia, Mars. *Icarus*, *64*, 265-285.

Mouginis-Mark P. J.[*] (1985) Identification of lava flow-permafrost interactions on Mars. In *Lunar and Planetary Science XVI*, pp. 591-592. Lunar and Planetary Institute, Houston.

Mouginis-Mark P. J.[*] (1987) Ice or liquid water in the Martian regolith? Morphologic indicators from rampart craters. In *MECA Symposium on Mars: Evolution of its Climate and Atmosphere* (V. Baker, M. Carr, F. Fanale, R. Greeley, R. Haberle, C. Leovy, and T. Maxwell, eds.), pp. 81-83. LPI Tech. Rpt. 87-01, Lunar and Planetary Institute, Houston.

Mouginis-Mark P. J.[*] (1987) Water or ice in the Martian regolith?: Clues from rampart craters seen at very high resolution. *Icarus*, *71*, 268-286.

Mouginis-Mark P. J.[*] (1987) Martian rampart craters: Morphologic clues for the physical state of the target at time of impact. *NASA TM-89810*, pp. 420-422.

Mouginis-Mark P. J.[*] and Zimbelman J. R.[*] (1987) Channels on Alba Patera, Mars: Evidence for polygenic eruptions. In *Lunar and Planetary Science XVII*, pp. 672-673. Lunar and Planetary Institute, Houston.

Mouginis-Mark P. J.[*], Wilson L., Head J. W., Brown S. H., Hall J. L., and Sullivan K. D. (1984) Elysium Planitia, Mars: Regional geology, volcanology, and evidence for volcano-ground ice interactions. *Earth, Moon, and Planets*, 30, 149-173.

Muenow D. W. and Gooding J. L.[*] (1985) "Martian" volatiles in shergottite EETA 79001: Possible significance of secondary minerals. In *Lunar and*

Planetary Science XVI, pp. 593–594. Lunar and Planetary Institute, Houston.

Muhleman D. O., Clancy R. T., Schloerb F. P., Riley L., and Wilson W. G. (1985) Mapping of the water vapor distribution on Mars; a microwave spectrometer and radiometer for MG/CO. In *Workshop on Water on Mars* (S. Clifford, ed.), pp. 62–63. LPI Tech. Rpt. 85-03, Lunar and Planetary Institute, Houston.

Murphy J., Leovy C.*, and Tillman J.* (1987) Seasonal wind variations in the martian subtropics. In MECA *Symposium on Mars: Evolution of its Climate and Atmosphere* (V. Baker, M. Carr, F. Fanale, R. Greeley, R. Haberle, C. Leovy, and T. Maxwell, eds.), p. 84. LPI Tech. Rpt. 87-01, Lunar and Planetary Institute, Houston.

Murray B. C.*, Herkenhoff K. E.*, and Landry B. M. (1985) Frost variations within the south polar residual cap of Mars. *Bull. Amer. Astron. Soc., 17*, 734.

Narumi Y. (1987) Optical thickness of the Olympus cloud. In MECA *Symposium on Mars: Evolution of its Climate and Atmosphere* (V. Baker, M. Carr, F. Fanale, R. Greeley, R. Haberle, C. Leovy, and T. Maxwell, eds.), pp. 85–87. LPI Tech. Rpt. 87-01, Lunar and Planetary Institute, Houston.

Nedell S. S. and Squyres S. W.* (1985) Geology of the layered deposits in the Valles Marineris. In *Workshop on Water on Mars* (S. Clifford, ed.), pp. 64–65. LPI Tech. Rpt. 85-03, Lunar and Planetary Institute, Houston.

Nedell S. S. and Squyres S. W.* (1987) Formation of the layered deposits in the Valles Marineris, Mars. In MECA *Symposium on Mars: Evolution of its Climate and Atmosphere* (V. Baker, M. Carr, F. Fanale, R. Greeley, R. Haberle, C. Leovy, and T. Maxwell, eds.), pp. 88–90. LPI Tech. Rpt. 87-01, Lunar and Planetary Institute, Houston.

Nedell S. S., Squyres S. W.*, and Anderson D. W.* (1987) Origin and evolution of the layered deposits in the Valles Marineris, Mars. *Icarus, 70*, 409–441.

Newsom H. E. and Graup G. (1987) The role of fluidization in the emplacement and alteration of the suevite impact melt deposit at the Ries Crater, West Germany. In MECA *Special Session at LPSC XVII: Martian Geomorphology and its Relation to Subsurface Volatiles* (S. M. Clifford, L. A. Rossbacher, and J. R. Zimbelman, eds.), pp. 34–35. LPI Tech. Rpt. 87-02, Lunar and Planetary Institute, Houston.

Olivero J. J. (1988) Measurement of H_2O in the terrestrial mesosphere and implications for extra-terrestrial sources. In *Workshop on Atmospheric H_2O Observations of Earth and Mars*. LPI Tech. Rpt., in press, Lunar and Planetary Institute, Houston.

Owen T.* (1986) Update of the Anders-Owen model for martian volatiles. In MECA *Workshop on the Evolution of the Martian Atmosphere* (M. Carr, P. James, C. Leovy, R. Pepin, and J. Pollack, ed.), pp. 31–32. LPI Tech. Rpt. 86-07, Lunar and Planetary Institute, Houston.

Owen T.* (1987) Could icy impacts reconcile Venus with Earth and Mars? In MECA *Symposium on Mars: Evolution of its Climate and Atmosphere* (V. Baker, M. Carr, F. Fanale, R. Greeley, R. Haberle, C. Leovy, and T. Maxwell, eds.), p. 91. LPI Tech. Rpt. 87-01, Lunar and Planetary Institute, Houston.

Page T. (1987) Seismic exploration for water on Mars. In MECA *Symposium on Mars: Evolution of its Climate and Atmosphere* (V. Baker, M. Carr, F. Fanale, R. Greeley, R. Haberle, C. Leovy, and T. Maxwell, eds.), p. 92. LPI Tech. Rpt. 87-01, Lunar and Planetary Institute, Houston.

Paige D. A.* (1986) Dust in the spring season polar atmospheres: A north-south comparison. In MECA *Workshop on Dust on Mars II* (S. Lee, ed.), pp. 58–60. LPI Tech. Rpt. 86-09, Lunar and Planetary Institute, Houston.

Paige D. A.* and Ingersoll A. P.* (1985) Annual heat balance of martian polar caps: Viking observations. *Science, 228*, 1160–1168.

Paige D. A.* and Kieffer H. H.† (1986) Non-linear frost albedo feedback on Mars: Observations and models. In MECA *Workshop on the Evolution of the Martian Atmosphere* (M. Carr, P. James, C. Leovy, R. Pepin, and J. Pollack, eds.), pp. 33–34. LPI Tech. Rpt. 86-07, Lunar and Planetary Institute, Houston.

Paige D. A.* and Kieffer H. H.† (1987) The thermal properties of martian surface materials of high latitudes: Possible evidence for permafrost. In MECA *Symposium on Mars: Evolution of its Climate and Atmosphere* (V. Baker, M. Carr, F. Fanale, R. Greeley, R. Haberle, C. Leovy, and T. Maxwell, eds), pp. 93–95. LPI Tech. Rpt. 87-01, Lunar and Planetary Institute, Houston.

Paige D. A.*, Herkenhoff K. E.*, and Murray B. C.* (1987) Mariner 9 observations of the south residual polar cap of Mars: Evidence for residual CO_2 frost, in preparation.

Pallaconi F. D.* and Albee A. L.* (1985) The Mars Geoscience/Climatology Observer (MGCO) Mission. In *Workshop on Mars* (S. Clifford, ed.), p. 66. LPI Tech. Rpt. 85-03, Lunar and Planetary Institute, Houston.

Parker T. J.* and Schneeberger D. M. (1986) Longitudinal depth profile for Nirgal Vallis. *NASA TM-88383*, pp. 465–467.

Parker T. J.*, Pieri D.*, and Saunders R.* (1986) Morphology and distribution of sinuous ridges in central and southern Argyre. *NASA TM-88383*, pp. 468–470.

Parker T. J.*, Schneeberger D. M., Pieri D. C.*, and Saunders R. S.* (1987) Geomorphic evidence for ancient seas on Mars. In MECA *Symposium on Mars: Evolution of its Climate and Atmosphere* (V. Baker, M. Carr, F. Fanale, R. Greeley, R. Haberle, C. Leovy, and T. Maxwell, eds.), pp. 96–98. LPI Tech. Rpt. 87-01, Lunar and Planetary Institute, Houston.

Parker T. J.*, Schneeberger D. M., Pieri D. C.*, and Saunders R. S.* (1987) Curvilinear ridges and related features in southwest Cydonia Mensae, Mars. *NASA TM-89810*, pp. 502–504.

Parker T. J.*, Schneeberger D. M., Pieri D. C.*, and Saunders R. S.* (1987) Geomorphic evidence for ancient seas in west Deuteronilus Mensae, Mars—I: Regional geomorphology. *NASA TM-89810*, pp. 319–321.

Parker T. J.*, Schneeberger D. M., Pieri D. C.*, and Saunders R. S.* (1987) Geomorphic evidence for ancient seas in west Deuteronilus Mensae, Mars—II: From very high resolution Viking Orbiter images. *NASA TM-89810*, pp. 322–324.

Pepin R. O.* (1985) Evidence of martian origins. *Nature, 317*, 473–475.

Pepin R. O.* (1987) Volatile inventory of Mars. In MECA *Special Session at LPSC XVII: Martian Geomorphology and its Relation to Subsurface Volatiles* (S. M. Clifford, L. A. Rossbacher, and J. R. Zimbelman, eds.), pp. 36–37. LPI Tech. Rpt. 87-02, Lunar and Planetary Institute, Houston.

Pepin R. O.* (1987) Volatile inventory of Mars-II: Primordial sources and fractionating processes. In MECA *Symposium on Mars: Evolution of its Climate and Atmosphere* (V. Baker, M. Carr, F. Fanale, R. Greeley, R. Haberle, C. Leovy, T. Maxwell, eds.), pp. 99–101. LPI Tech. Rpt. 87-01, Lunar and Planetary Institute, Houston.

Pepin R. O.* (1987) Volatile inventories of the terrestrial planets. *Rev. Geophys., 25*, 293–296.

Pepin R. O.* and Becker R. H. (1984) Galactic-cosmic-ray exposure histories of the Antarctic shergottite EETA 79001. In *Lunar and Planetary Science XV*, pp. 637–638. Lunar and Planetary Institute, Houston.

Peterfreund A. R. (1985) Local dust storms and global opacity on Mars as detected by the Viking IRTM. In *Workshop on Dust on Mars* (S. Lee, ed.), pp. 10–14. LPI Tech. Rpt. 85-02, Lunar and Planetary Institute, Houston.

Philip J. R. (1988) Atmospheric heat engines, and H_2O in the martian regolith. In *Workshop on Atmospheric H_2O Observations of Earth and Mars*. LPI Tech. Rpt., in press, Lunar and Planetary Institute, Houston.

Phillips R. J.* (1987) Martian tectonics: A review. In MECA *Symposium on Mars: Evolution of its Climate and Atmosphere* (V. Baker, M. Carr, F. Fanale, R. Greeley, R. Haberle, C. Leovy, and T. Maxwell, eds.), pp. 102–103. LPI Tech. Rpt. 87-01, Lunar and Planetary Institute, Houston.

Plaut J. J., Kahn R.*, Guinness E. A.*, Arvidson R. E.† (1988) Accumulation of sedimentary debris in the south polar region of Mars and implications for climate history. *Icarus*, in press.

Pollack J. B.* (1986) Longevity of a dense carbon dioxide atmosphere on Mars. In *MECA Workshop on the Evolution of the Martian Atmosphere* (M. Carr, P. James, C. Leovy, R. Pepin, and J. Pollack, eds.), p. 37. LPI Tech. Rpt. 86-07, Lunar and Planetary Institute, Houston.

Pollack J. B.*, Haberle R. M.†, White J., and Bilski K. (1985) New GCM simulations of transport into the polar regions. In *Workshop on Water on Mars* (S. Clifford, ed.), p. 67. LPI Tech. Rpt. 85-03, Lunar and Planetary Institute, Houston.

Pollack J. B.*, Haberle R. M.†, Barnes J.*, Schlesinger M., Zurek R.†, Leovy C.*, White J., Schaeffer J., and Bilski K. (1986) Influence of dust on the general circulation of the martian atmosphere. In MECA *Workshop on Dust on Mars II* (S. Lee, ed.), pp. 61–62. LPI Tech. Rpt. 86-09, Lunar and Planetary Institute, Houston.

Pollack J. B.*, Kasting J.*, and Richardson S. (1987) Partitioning of carbon dioxide between the atmosphere and lithosphere on early Mars. In *MECA Symposium on Mars: Evolution of its Climate and Atmosphere* (V. Baker, M. Carr, F. Fanale, R. Greeley, R. Haberle, C. Leovy, and T. Maxwell, eds.), pp. 104–105. LPI Tech. Rpt. 87-01, Lunar and Planetary Institute, Houston.

Pollack J. B.*, Kasting J. F.*, Richardson S. M., and Poliakoff K. (1987) The case for a wet, warm climate on early Mars. *NASA TM-89810*, p. 160.

Pollack J. B.*, Kasting J. F.*, Richardson S. M., and Poliakoff K. (1987) The case for a warm, dense CO_2 atmosphere on early Mars. *Icarus, 71*, 203–224.

Posey-Dowty J.*, Tanenbaum L.B., Moskowitz B. M.*, Crerar D. A., and Hargraves R.† (1985) Controls on precipitation of various iron oxides and hydroxides: Relevance to Mars. In *Workshop on Water on Mars* (S. Clifford, ed.), pp. 68–70. LPI Tech. Rpt. 85-03, Lunar and Planetary Institute, Houston.

Posey-Dowty J.*, Moskowitz B.*, Crerar D., Hargraves R., Tanenbaum L., and Dowty E. (1986) Iron oxide and hydroxide precipitation from ferrous solution and its relevance to martian surface mineralogy. *Icarus*, 66, 105–116.

Postawko S. E.* and Kuhn W. R.* (1984) Sulfur dioxide and martian temperature. *EOS Trans. AGU, 65*, 980.

Postawko S. E.* and Kuhn W. R.* (1985) Sulfur dixoide and martian surface temperature. In *Lunar and Planetary Science XVI*, pp. 673–674. Lunar and Planetary Institute, Houston.

Postawko S. E.* and Kuhn W. R.* (1986) Effect of greenhouse gases (CO_2, H_2O, SO_2) on martian paleoclimate. *Proc. Lunar Planet. Sci. Conf. 16th*, in *J. Geophys. Res., 91*, D431–D438.

Postawko S. E.* and Mouginis-Mark P.* (1987) Possible origin of some channels on Alba Patera, Mars. *NASA TM-89810*, pp. 303–304.

Rao A. S. P. (1987) Implications of isotopic signatures of noble gases for the origin and evolution of terrestrial atmospheres. In MECA *Symposium on Mars: Evolution of its Climate and Atmosphere* (V. Baker, M. Carr, F. Fanale, R. Greeley, R. Haberle, C. Leovy, and T. Maxwell, eds.), pp. 106–108. LPI Tech. Rpt. 87-01, Lunar and Planetary Institute, Houston.

Rhodes D. D. and Rossbacher L. A.* (1985) The surface of Mars. In *Himmel och Jord: Ymer* (Yearbook, Swedish Geographical Society), *105*, 7–29.

Rossbacher L. A.* (1984) Curvilinear ground on Mars: The search for terrestrial analogs. In *Abstracts of the 27th International Geological Congress, 7*, 303–304.

Rossbacher L. A.* (1985) The problem of scale in planetary megageomorphology: Global megageomorphology. *NASA Conference Publication 2312*, pp. 76–78.

Rossbacher L. A.* (1985) Terrestrial analog studies for Martian patterned ground. *NASA TM-87563*, pp. 329–331.

Rossbacher L. A.* (1985) Ground ice models for the distribution and evolution of curvilinear landforms on Mars. In *Models in Geomorphology* (M. Woldenberg, ed.), pp. 343-372. Allen and Unwin, Boston.

Rossbacher L. A.* (1985) Quantitative analysis of Martian polygonal ground. In *Lunar and Planetary Science XVI*, pp. 710–711. Lunar and Planetary Institute, Houston.

Rossbacher L. A.* (1986) Ground patterns on Earth and Mars. In *Lunar and Planetary Science XVII*, pp. 726–728. Lunar and Planetary Institute, Houston.

Rossbacher L. A.* (1987) Ground patterns on Earth and Mars. In MECA *Special Session at LPSC XVII: Martian Geomorphology and its Relation to Subsurface Volatiles* (S. M. Clifford, L. A. Rossbacher, and J. R. Zimbelman, eds.), pp. 38–39. LPI Tech. Rpt. 87-02, Lunar and Planetary Institute, Houston.

Rossbacher L. A.* (1987) The G-scale and planetary megageomorphology: How big is it really? In MECA *Special Session at LPSC XVII: Martian Geomorphology and its Relation to Subsurface Volatiles* (S. M. Clifford, L. A. Rossbacher, and J. R. Zimbelman, eds.), pp. 40–41. LPI Tech. Rpt. 87-02, Lunar and Planetary Institute, Houston.

Rossbacher L. A.* and Rhodes D. D. (1987) Planetary analogs for geomorphic features produced by catastrophic flooding. In *Catastrophic Flooding* (L. Mayer and D. Nash, eds.), pp. 289–304. *Binghamton Symposium in Geomorphology: International Series, 18.*

Roth L. E.* and Saunders R. S.* (1984) Microwave reflectivity of the multi-layer models of the martian surface. In *Lunar and Planetary Science XV*, pp. 693–694. Lunar and Planetary Institute, Houston.

Roth L. E.*, Saunders R. S.*, and Schubert G. (1984) Radar and the detection of liquid water on Mars. In *Workshop on Water on Mars* (S. Clifford, ed.), p. 63. LPI Tech. Rpt. 85-03, Lunar and Planetary Institute, Houston.

Roth L. E.*, Saunders R. S.*, and Schubert G. (1985) Mars: Seasonally variable radar reflectivity. In *Lunar and Planetary Science XVI*, pp. 712–713. Lunar and Planetary Institute, Houston.

Roth L. E.*, Saunders R. S.*, and Schubert G. (1986) Mars: Seasonally variable radar reflectivity II. In *Lunar and Planetary Science XVII*, p. 730. Lunar and Planetary Institute, Houston.

Roth L. E.*, Saunders R. S.*, and Thompson T. W. (1986) Radar reflectivity of a variable dust cover. In MECA *Workshop on Dust on Mars II* (S. Lee, ed.), pp. 63–65. LPI Tech. Rpt. 86-09, Lunar and Planetary Institute, Houston.

Roth L. E.*, Saunders R. S., and Thompson T. W. (1987) Modification styles of the martian impact craters. In *Lunar and Planetary Science XVIII*, pp. 852–853. Lunar and Planetary Institute, Houston.

Roth L. E.*, Saunders R. S.*, and Thompson T. W. (1987) Mars: Seasonally variable radar reflectivity. *NASA TM-89810*, pp. 248–250.

Roush T. L. and Singer R.† (1985) Carbonates on Mars: Searching the Mariner 6 and 7 IRS Measurements. In *Lunar and Planetary Science XVI*, pp. 714–715. Lunar and Planetary Institute, Houston.

Roush T. L., Singer R.†, and McCord T.* (1986) The spectral reflectance of mafic silicates and phyllosilicates from 0.6–4.6 μm. *EOS Trans. AGU, 67*, 1271.

Roush T. L., Singer R.†, and McCord T. (1987) Reflectance spectra of selected phyllosilicates from 0.6–4.6 μm. In *Lunar and Planetary Science XVIII*, pp. 858–859. Lunar and Planetary Institute, Houston.

Roush T. L., Singer R.†, and McCord T. (1987) The spectral reflectance, 0.6–4.3 μm, of particulate mineral-water ice mixtures. In *Lunar and Planetary Science XVIII*, pp. 856–857. Lunar and Planetary Institute, Houston.

Rudy D. J., Muhleman D. O., Berge G. L., Jakosky B. M.†, and Christensen P. R.* (1987) Mars: VLA observations of the northern hemisphere and the north polar region at wavelengths of 2 and 6 cm. *Icarus, 71*, 159–177.

Rusch D. W., Jakosky B. M.†, Clancy R. T.*, Barth C. A., Stewart A. I. F.*, Lawrence G. M., McClintock W. E., and Paxton L. J. (1986) The Mars atmosphere spectrometer for Mars Observer. In MECA

Workshop on Dust on Mars II (S. Lee, ed.), pp. 66–68. LPI Tech. Rpt. 86-09, Lunar and Planetary Institute, Houston.

Rutherford M. J.[*] and Carroll M. R. (1985) The influence of H_2O on volcanic degassing of aerosol forming elements S, Cl, and F. In *Workshop on Water on Mars* (S. Clifford, ed.), pp. 74–75. LPI Tech. Rpt. 85-03, Lunar and Planetary Institute, Houston.

Saunders R. S.[*] and Blewett D. T. (1987) Mars north polar dunes: Possible formation from low-density sediment aggregates. *Solar System Res., 21,* 113–117.

Saunders R. S.[*] and Parker T. J.[*] (1986) Distribution possible sources of dune-like material at the martian poles. *NASA TM-88383,* pp. 260–262.

Saunders R. S.[*], Parker T. J.[*], Stephens J., Laue E. G., and Fanale F. P.[†] (1985) Sediment-water deposition and erosion in the martian polar regions. In *Workshop on Water on Mars* (S. Clifford, ed.), pp. 76–78. LPI Tech. Rpt. 85-03, Lunar and Planetary Institute, Houston.

Saunders R. S.[*], Parker T. J.[*], Stephens J., Laue E. G., and Fanale F. P.[†] (1985) Transformation of polar ice sublimate residue into Martian circumpolar sand. *NASA TM-87563,* pp. 300–302.

Saunders R. S.[*], Parker T. J.[*], Stephens J., Laue E. G., and Fanale F. P.[†] (1985) Filamentary sublimation residues from dispersions of siliceous particles in ice. In *Lunar and Planetary Science XVI,* pp. 730–731. Lunar and Planetary Institute, Houston.

Saunders R. S.[*], Fanale F. P.[†], Parker T. J.[*], Stephens J., and Sutton S., (1986) Properties of filamentary sublimation residues from dispersions of clay in ice. *Icarus,* 66, 94–104.

Schultz P. H.[*] (1985) Polar wandering on Mars and the distribution of water-ice through time. In *Workshop on Water on Mars* (S. Clifford, ed.), pp. 79–81. LPI Tech. Rpt. 85-03, Lunar and Planetary Institute, Houston.

Schultz P. H.[*] (1985) Polar wandering on Mars. *Sci. Amer., 253,* 94–102.

Schultz P. H.[*] (1986) The martian atmosphere before and after the Argyre impact. In MECA *Workshop on the Evolution of the Martian Atmosphere* (M. Carr, P. James, C. Leovy, R. Pepin, and J. Pollack, eds.), pp. 38–39. LPI Tech. Rpt. 86-07, Lunar and Planetary Institute, Houston.

Schultz P. H.[*] (1987) Crater ejecta morphology and the presence of water on Mars. In MECA *Symposium on Mars: Evolution of its Climate and Atmosphere* (V. Baker, M. Carr, F. Fanale, R. Greeley, R. Haberle, C. Leovy, and T. Maxwell, eds.), pp. 109–111. LPI Tech. Rpt. 87-01, Lunar and Planetary Institute, Houston.

Schultz P. H.[*] (1987) Crater ejecta morphology and the presence of water on Mars. *NASA TM-89810,* pp. 423–425.

Schultz P. H.[*] and Britt D. (1987) Early changes in gradation styles and rates on Mars. In MECA *Special Session at LPSC XVII: Martian Geomorphology and its Relation to Subsurface Volatiles* (S. M. Clifford, L. A. Rossbacher, and J. R. Zimbelman, eds.), pp. 42–43. LPI Tech. Rpt. 87-02, Lunar and Planetary Institute, Houston.

Schultz P. H.[*] and Gault D. E. (1984) On the formation of contiguous ramparts around martian impact craters. In *Lunar and Planetary Science* XV, pp. 732–733. Lunar and Planetary Institute, Houston.

Schultz P. H.[*] and Lutz A. (1988) Polar wandering of Mars. *Icarus, 73,* 91–141.

Schultz P. H.[*] and Rogers J. (1984) Evolution of erosional styles of martian impact basins. In *Lunar and Planetary Science* XV, pp. 734–735. Lunar and Planetary Institute, Houston.

Schultz P. H.[*] and Simon J. F. (1985) Mangala Valles outflow region: Characterization of the source and associated terrains. In *Lunar and Planetary Science* XVI, pp. 779–780. Lunar and Planetary Institute, Houston.

Schultz P. H.[*], Rogers J., and Haber S. (1985) Erosion of martian impact basins and the changing water cycle. In *Workshop on Water on Mars* (S. Clifford, ed.), pp. 82–84. LPI Tech. Rpt. 85-03, Lunar and Planetary Institute, Houston.

Schultz P. H.[*], Simon J., and Clifford S. M.[*] (1985) Ice-embedded unconformable deposits as a possible source for outflow channels. In *Lunar and Planetary Science* XVI, 744–745. Lunar and Planetary Institute, Houston.

Simon J. F., Jr. and Schultz P. H.[*] (1985) Mangala Valles outflow region: Characterization of the source and associated terrains. In *Lunar and Planetary Science* XVI, pp. 779–780. Lunar and Planetary Institute, Houston.

Singer R.[†] (1985) Spectroscopic observation of Mars. *Adv. Space Res.,* 59–68.

Singer R.[†], Owensby P. D., and Clark R. N. (1984) First direct detection of clay minerals on Mars. *Bull. Amer. Astron. Soc., 16.,* pp. 679–680.

Singer R.[†], Cloutis E., Roush R. L., Mouginis-Mark P. J.[*], Hawke B. R., and Christensen P. R.[*] (1984) Multispectral analysis of the Kasei Valles—Lunae Planum region of Mars. In *Lunar and Planetary Science* XV, pp. 794–795. Lunar and Planetary Institute, Houston.

Singer R.[†], Owensby P. D., and Clark R. N. (1985) Observed upper limits for clay minerals on Mars. In *Lunar and Planetary Science XVI,* pp. 787–788. Lunar and Planetary Institute, Houston.

Singer R.[†], Owensby P. D., and Clark R. N. (1985) Direct detection of minor clay mineralogy on Mars. In MECA *Workshop on Water on Mars.* (S. Clifford, ed.), pp. 85–87. LPI Tech. Rpt. 85-03, Lunar and Planetary Institute, Houston.

Singer R.[†], Bruckenthal E. A., Roush T. L., and Lucey P. G. (1986) Mars: Spatially resolved spectrophotometry from 2.2–4.2 μm. *Bull. Amer. Astron. Soc., 18,* p. 806.

Singer R.[†], Roush E. A., Roush T. L., and Lucey P. G. (1987) Mars: Spatially resolved spectrophotometry from 2.2–4.2 μm, in preparation.

Singer S. F.[†] (1987) Phobos and Deimos: A base for sampling the martian past. In MECA *Symposium on Mars: Evolution of its Climate and Atmosphere* (V. Baker, M. Carr, F. Fanale, R. Greeley, R. Haberle, C. Leovy, and T. Maxwell, eds.), p. 112. LPI Tech. Rpt. 87-01, Lunar and Planetary Institute, Houston.

Spencer J. R. and Croft S. K. (1986) Valles Marineris as karst: Feasibility and implications for martian atmospheric evolution. In MECA *Workshop on the Evolution of the Martian Atmosphere* (M. Carr, P. James, C. Leovy, R. Pepin, and J. Pollack, eds.), pp. 40–41. LPI Tech. Rpt. 86-07, Lunar and Planetary Institute, Houston.

Squyres S. W.[*] (1984) The history of water on Mars. *Ann. Rev. Earth Planet. Sci., 12,* 83.

Squyres S. W.[*] (1985) The problem of water on Mars. In *Lunar Bases and Space Activities in the 21st Century* (W. Mendell, ed.), pp. 817–823. Lunar and Planetary Institute, Houston.

Squyres S. W.[*] and Carr M. H.[†] (1984) Distribution of ground ice features on Mars. *EOS Trans. AGU, 65,* 979.

Squyres S. W.[*] and Carr M. H.[†] (1985) The distribution of ground ice features on Mars. In *Workshop on Water on Mars* (S. Clifford, ed.), pp. 88–89. LPI Tech. Rpt. 85-03, Lunar and Planetary Institute, Houston.

Squyres S. W.[*] and Carr M. H.[†] (1986) Geomorphic evidence for the distribution of ground ice on Mars. *Science, 231,* 249–252.

Squyres S. W.[*] and Evans L. G. (1986) Investigation of martian volatiles via gamma-ray spectroscopy. *Bull. Amer. Astron. Soc., 18,* 807.

Squyres S. W.[*] and Evans L. G. (1987) Investigation of martian H_2O and CO_2 via gamma-ray spectroscopy. *NASA TM-89810,* pp. 184–186.

Squyres S. W.[*] and Moosman A. C. (1984) Numerical simulation of volcano-ground ice interaction on Mars. In *Lunar and Planetary Science* XV, pp. 816–817. Lunar and Planetary Institute, Houston.

Squyres S. W.[*], Wilhelms D. E.[*], and Moosman A. C. (1985) Large-scale volcano-ground ice interactions on Mars. *Bull. Amer. Astron. Soc., 17,* 735.

Squyres S. W.[*], Wilhelms D. E.[*], and Moosman A. C. (1987) Large-scale volcano-ground ice interactions on Mars. *Icarus, 70,* 385–408.

Stephens J., Parker T. J.[*], Saunders R. S.[*], Laue E. G., and Fanale F. P.[†] (1985) Properties of filamentary sublimation residues from dispersions of clay in ice. *NASA TM-87563,* pp. 440–442.

Summers C. A. and Lucchitta B. K.[*] (1986) Polygonal ground in the northern hemisphere of Mars. *NASA TM-88383*, pp. 488–490.

Tanaka K. L.[*] (1985) Ice-lubricated gravity spreading of Olympus Mons aureole deposits. *Icarus, 62*, 191–206.

Tanaka K. L.[*] and Scott D. H.[*] (1987) The youngest channel system on Mars. In *MECA Special Session at LPSC XVII: Martian Geomorphology and its Relation to Subsurface Volatiles* (S. M. Clifford, L. A. Rossbacher, and J. R. Zimbelman, eds.), pp. 44–45. LPI Tech. Rpt. 87-02, Lunar and Planetary Institute, Houston.

Thomas P. (1985) Dust streaks and related phenomena: Photometry and mapping. In *Workshop on Dust on Mars* (S. Lee, ed.), pp. 15–17. LPI Tech. Rpt. 85-02, Lunar and Planetary Institute, Houston.

Thompson T. W., Jurgens R. F., Roth L.[*], and Robinett L. (1986) Possible Goldstone radar observations of Mars: 1986 and 1988 oppositions. In *MECA Workshop on Dust on Mars II* (S. Lee, ed.), pp. 69–71. LPI Tech. Rpt. 86-09, Lunar and Planetary Institute, Houston.

Tillman J. E.[*] (1984) The Viking Mission to Mars. *Proceedings of the National Prime Users Group Conference*, pp. 92–101, Orlando, FL.

Tillman J. E.[*] (1985) Martian meteorology and dust storms from Viking observations. In *The Case for Mars II, Science and Technology, 62* (C.P. McKay ed.), pp. 333–342. American Astronautical Society.

Tillman J. E.[*] (1986) Martian atmospheric dust processes over three years as inferred from Lander meteorology measurements. In *MECA Workshop on Dust on Mars II* (S. Lee, ed.), p. 72. LPI Tech. Rpt. 86-09, Lunar and Planetary Institute, Houston.

Tillman J. E.[*] (1987) Mars global atmospheric oscillations: Transients and dust storm relations. In *MECA Symposium on Mars: Evolution of its Climate and Atmosphere* (V. Baker, M. Carr, F. Fanale, R. Greeley, R. Haberle, C. Leovy, and T. Maxwell, eds.), p. 113. LPI Tech. Rpt. 87-01, Lunar and Planetary Institute, Houston.

Tyler A. L. and Hunten D. M. (1987) Vertical O_3 distribution as a diagnostic for eddy diffusion profile. In *MECA Symposium on Mars: Evolution of its Climate and Atmosphere* (V. Baker, M. Carr, F. Fanale, R. Greeley, R. Haberle, C. Leovy, and T. Maxwell, eds.), pp. 114–116. LPI Tech. Rpt. 87-01, Lunar and Planetary Institute, Houston.

Walker J. C. G. (1986) Early evolution of the terrestrial atmosphere. In *MECA Workshop on the Evolution of the Martian Atmosphere* (M. Carr, P. James, C. Leovy, R. Pepin, and J. Pollack, eds.), p. 42. LPI Tech. Rpt. 86-07, Lunar and Planetary Institute, Houston.

Wänke H.[*] (1987) Chemistry and accretion of Earth and Mars. *Bull. De La Societe Geologique De France, 3*, 13–19, Lunar and Planetary Institute, Houston.

Wänke H.[*] and Dreibus G. (1984) Chemistry and accretion of Earth and Mars. In *Lunar and Planetary Science* XV, pp. 884–885. Lunar and Planetary Institute, Houston.

Wänke H.[*] and Dreibus G. (1985) The degree of oxidation and the abundance of volatile elements on Mars. In *Lunar and Planetary Science XVI*, pp. 28–29. Lunar and Planetary Institute, Houston.

Wänke H.[*] and Dreibus G. (1985) Volatiles on Mars. In *Workshop on Water on Mars* (S. Clifford, ed.), pp. 90–92. LPI Tech. Rpt. 85-03, Lunar and Planetary Institute, Houston.

Wänke H.[*] and Dreibus G. (1986) Can a high abundance of moderately volatile and even some highly volatile elements on Mars be reconciled with its low abundance of primordial rare gases? In MECA *Workshop on the Evolution of the Martian Atmosphere* (M. Carr, P. James, C. Leovy, R. Pepin, and J. Pollack, eds.), pp. 43–45. LPI Tech. Rpt. 86-07, Lunar and Planetary Institute, Houston.

Wänke H.[*] and Dreibus G. (1987) Water on Mars. In MECA *Symposium on Mars: Evolution of its Climate and Atmosphere* (V. Baker, M. Carr, F. Fanale, R. Greeley, R. Haberle, C. Leovy, and T. Maxwell, eds.), pp. 117–119. LPI Tech. Rpt. 87-01, Lunar and Planetary Institute, Houston.

Warren P. H. (1987) Mars regolith versus SNC meteorites: Evidence for abundant crustal carbonates? In MECA *Symposium on Mars: Evolution of its Climate and Atmosphere* (V. Baker, M. Carr, F. Fanale, R. Greeley, R. Haberle, C. Leovy, and T. Maxwell, eds.), pp. 120–122. LPI Tech. Rpt. 87-01, Lunar and Planetary Institute, Houston.

Watkins H.[*] and Lewis J. S.[†] (1985) Loss of volatiles from Mars as the result of energetic impacts. In *Workshop on Water on Mars* (S. Clifford, ed.), pp. 93–95. LPI Tech. Rpt. 85-03, Lunar and Planetary Institute, Houston.

Watkins G. H.[*] and Lewis J. S.[†] (1986) Evolution of the atmosphere of Mars as the result of asteroidal and cometary impacts. In *MECA Workshop on the Evolution of the Martian Atmosphere* (M. Carr, P. James, C. Leovy, R. Pepin, and J. Pollack, eds.), pp. 46–47. LPI Tech. Rpt. 86-07, Lunar and Planetary Institute, Houston.

Weins R. C., Becker R. H., and Pepin R. O.[*] (1986) The case for a martian origin of the shergottites, II. Trapped and indigenous gas components in EETA 79001 glass. In *Earth Planet. Sci. Lett., 77*, 149–158.

Wilhelms D. E.[*] (1986) Lava-ice interactions on Mars. In *Lunar and Planetary Science* XVII, pp. 946–947. Lunar and Planetary Institute, Houston.

Wilhelms D. E.[*] and Baldwin R. J. (1986) Relation between gullying and crater degradation in the martian uplands. In *Lunar and Planetary Science XVII*, pp. 948–949. Lunar and Planetary Institute, Houston.

Wilhelms D. E.[*] and Hayden C. J. (1986) Areas of gullied terrain and possible volcanic deposits in the martian uplands. In *Lunar and Planetary Science* XVII, pp. 950–951. Lunar and Planetary Institute, Houston.

Wilhelms D. E.[*] and Squyres S. W.[*] (1985) Lava-ice interaction along Mars upland-lowland scarp. *EOS Trans.* AGU, 66, 946.

Williams S. H. and Greeley R.[†] (1986) Wind erosion on Mars: Impairment by poor saltation cloud development. In *Lunar and Planetary Science* XVII, pp. 952–953. Lunar and Planetary Institute, Houston.

Williams S. H. and Greeley R.[†] (1987) Mass transport by aeolian saltation on Earth, Mars and Venus: The effects of saltation cloud development and choking. *NASA TM-89810*, pp. 274–275.

Wu S. S. C. (1985) Mars topographic maps. In *Workshop on Water on Mars* (S. Clifford, ed.), pp. 96–97. LPI Tech. Rpt. 85-03, Lunar and Planetary Institute, Houston.

Yatteau J. H. and McElroy M.[*] (1985) Mars: Effect of water vapor abundance on atmospheric oxidation state. In *Workshop on Water on Mars* (S. Clifford, ed.), p. 98. LPI Tech. Rpt. 85-03, Lunar and Planetary Institute, Houston.

Yatteau J. H. and McElroy M.[*] (1986) Mars: Atmospheric escape of major volatiles. In MECA *Workshop on the Evolution of the Martian Atmosphere* (M. Carr, P. James, C. Leovy, R. Pepin, and J. Pollack, eds.), p. 48. LPI Tech. Rpt. 86-07, Lunar and Planetary Institute, Houston.

Zahnle K. J. and Kasting J. F.[*] (1986) Mass fractionation during transonic escape and implications for loss of water from Mars and Venus. *Icarus*, 68, 462–480.

Zent A. P.[*] and Fanale F. P.[†] (1985) Possible Mars brines: Kinetics and chemistry. *Bull. Amer. Astron. Soc., 17*, 734.

Zent A. P.[*] and Fanale F. P.[†] (1985) Solis Lacus brines: Possible chemistry and kinetics. In *Lunar and Planetary Science* XVI, pp. 930–931. Lunar and Planetary Institute, Houston.

Zent A. P.[*] and Fanale F. P.[†] (1986) Possible Mars brines: Equilibrium and kinetic considerations. *Proc. Lunar Planet. Sci. Conf. 16th*, in *J. Geophys. Res.*, 91, D439–D445.

Zent A. P.[*] and Fanale F. P.[†] (1986) Adsorption of H_2O and CO_2 on Mauna Kea palagonites. In *Lunar and Planetary Science XVII*, p. 962. Lunar and Planetary Institute, Houston.

Zent A. P.[*] and Fanale F. P.[†] (1986) Mars: A quantitative estimate of total H_2O exchange between the regolith and the atmosphere/cap system over obliquity timescales. In MECA *Workshop on the Evolution of the Martian Atmosphere* (M. Carr, P. James, C. Leovy, R. Pepin, and J. Pollack, eds.), pp. 49–50. LPI Tech. Rpt. 86-07, Lunar and Planetary Institute, Houston.

Zent A. P.[*], Fanale F. P.[†], and Salvail J. R. (1984) Seasonal cycles of diffusion and phase partitioning of water within the Martian regolith. *Bull. Amer. Astron. Soc.*, 16, 674.

Zent A. P.[*], Fanale F. P.[†], and Salvail J. R. (1985) Short term water cycles within the Mars regolith. In *Workshop on Water on Mar* (S. Clifford, ed.), pp. 99–101. LPI Tech. Rpt. 85-03, Lunar and Planetary Institute, Houston.

Zent A. P.[*], Fanale F. P.[†], Salvail J. R., and Postawko S. E.[*] (1986) Distribution and state of H_2O in the high latitude shallow subsurface of Mars. *Icarus, 67,* 19–36.

Zent A. P.[*], Fanale F. P.[†], and Postawko S. E.[*] (1987) Adsorption on the martian regolith: Specific surface area and missing CO_2. In MECA *Symposium on Mars: Evolution of Its Climate and Atmosphere* (V. Baker, M. Carr, F. Fanale, R. Greeley, R. Haberle, C. Leovy, and T. Maxwell, eds.), pp. 123–125. LPI Tech. Rpt. 87-01, Lunar and Planetary Institute, Houston.

Zent A. P.[*], Fanale F. P.[†], and Postawko S. E.[*] (1987) Mars: Detection of regolith H_2O sources from space. In *Lunar and Planetary Science XVIII,* pp. 1120–1121. Lunar and Planetary Institute, Houston.

Zent A. P.[*], Fanale F. P.[†], and Postawko S. E.[*] (1987) CO_2: Adsorption on palagonite and the martian regolith. *NASA TM-89810,* pp. 181–183.

Zent A. P.[*], Fanale F. P.[†], and Postawko S. E.[*] (1987) Carbon dioxide: Adsorption on palagonite and partitioning in the martian regolith. *Icarus, 71,* 241–249.

Zent A. P.[*], Fanale F. P.[†], and Postawko S. E.[*] (1988) Atmospheric H_2O and the search for martian brines. In *Workshop on Atmospheric H_2O Observations of Earth and Mars.* LPI Tech. Rpt., in press, Lunar and Planetary Institute, Houston.

Zimbelman J. R.[*] (1985) Surface properties of Ascraeus Mons: Dust deposits on a Tharsis volcano. In *Workshop on Dust on Mars* (S. Lee, ed.), pp. 14–16. LPI Tech. Rpt. 85-02, Lunar and Planetary Institute, Houston.

Zimbelman J. R.[*] (1986) Physical properties of aeolian features in the Elysium-Amazonis region of Mars. In *Workshop on Dust on Mars II* (S. Lee, ed.), pp. 73–75. LPI Tech. Rpt. 86-09, Lunar and Planetary Institute, Houston.

Zimbelman J. R.[*] (1986) Spatial resolution and the geologic interpretation of martian morphology. In *Lunar and Planetary Science XVII,* pp. 63–964. Lunar and Planetary Insitute, Houston.

Zimbelman J. R.[*] (1986) Surface properties of the Pettit wind streak on Mars: Implications for sediment transport. *Icarus, 66,* 83–93.

Zimbelman J. R.[*] (1986) On the Red Planet: Does landscape show subsurface volatiles? *Geotimes, 31,* 18–20.

Zimbelman J. R.[*] (1987) Thermal properties of channels in the Aeolis quadrangle: Topographic traps for aeolian materials. In MECA *Symposium on Mars: Evolution of Its Climate and Atmosphere* (V. Baker, M. Carr, F. Fanale, R. Greeley, R. Haberle, C. Leovy, and T. Maxwell, eds.), pp. 126–128. LPI Tech. Rpt. 87-01, Lunar and Planetary Institute, Houston.

Zimbelman J. R.[*] (1987) Spatial resolution and the geologic interpretation of martian morphology: Implications for subsurface volatiles. *Icarus, 71,* 257–267.

Zimbelman J. R.[*] (1987) Old channels on Mars spark new ideas. *Geotimes, 32,* 13–14.

Zimbelman J. R.[*] (1987) Martian geomorphology and subsurface volatiles discussed at LPSC XVII. In MECA *Special Session at LPSC XVII: Martian Geomorphology and its Relation to Subsurface Volatiles* (S. M. Clifford, L. A. Rossbacher, and J. R. Zimbelman, eds.), pp. 5–7. LPI Tech. Rpt. 87-02, Lunar and Planetary Institute, Houston.

Zimbelman J. R.[*] (1987) New information on puzzling channels. *Geotimes, 32,* 13–14.

Zimbelman J. R.[*] and Leshin L. A. (1986) Comparisons between high resolution thermal inertias and Mars consortium data for the Elysium and Aeolis quadrangles of Mars. In *Lunar and Planetary Science XVII,* pp. 965–966. Lunar and Planetary Institute, Houston.

Zimbelman J. R.[*] and Leshin L. A. (1987) A geologic evaluation of thermal properties for the Elysium and Aeolis quadrangles of Mars. *Proc. Lunar Planet. Sci. Conf. 17th,* in *J. Geophys. Res.. 92.* E588–E596.

Zurek R. W.[†] and Christensen P. R.[*] (1983) Mars north polar hazes: Estimating opacity and temperature with a δ-Eddington Code. *Bull. Amer. Astron. Soc., 15,* 847–848.

Zurek R. W.[†] (1985) Surface winds inferred from models of the planetary-scale circulation. In *Workshop on Dust on Mars* (S. Lee, ed.), p. 23. LPI Tech. Rpt. 85-02, Lunar and Planetary Institute, Houston.

Zurek R. W.[†] (1986) Atmospheric tidal forcing of the zonal mean circulation: The martian dusty atmosphere. *J. Atmos. Sci., 43,* 652–670.

Zurek R. W.[†] (1988) The interannual variability of atmospheric water vapor on Mars. In *Workshop on Atmospheric H_2O Observations of Earth and Mars.* LPI Tech. Rpt., in press, Lunar and Planetary Institute, Houston.

Zurek R. W.[†] (1988) The martian atmospheric water cycle as viewed from a terrestrial perspective. In *Workshop on Atmospheric H_2O Observations of Earth and Mars.* LPI Tech. Rpt., in press, Lunar and Planetary Institute, Houston.

Zurek R. W.[†] and Haberle R. M.[†] (1986) Cross-equatorial transport during a martian great dust storm. In MECA *Workshop on Dust on Mars II* (S. Lee, ed.), p. 79. LPI Tech. Rpt. 86-09, Lunar and Planetary Institute, Houston.