WORKSHOP ON

DUST ON MARS

MECA

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WORKSHOP ON

DUST ON MARS

Edited by
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Contents

Summary

I. Workshop Goals

A MECA workshop, "Dust on Mars," was sponsored by NASA through the Lunar and Planetary Institute and hosted by Arizona State University on February 4-5, 1985. This workshop was organized to stimulate and coordinate research on the properties of martian dust, its distribution on the planet, and the processes affecting its yearly deposition, erosion, and transport. A great deal of research has been carried out to understand local, regional, and global aspects of the martian dust transport cycle, with the goal being definition of the currently active processes and their relation to those operating over the long term. To date, however, most individual research projects have centered around interpretation of single data sets (visual images, IRTM, radar, etc.), and these many efforts have not been coordinated. Many of the details of short and long term dust-related processes, as inferred from the various single data sets, are still not agreed upon. It was the intent of this workshop to encourage the informal exchange of ideas among several researchers currently investigating various aspects of the problem and to instigate cooperative efforts to synthesize the individual approaches into a unified understanding of the present seasonal and yearly martian sediment transport cycles.

II. Discussion of Current Research

During the first portion of the workshop, each of the eight participants led a discussion on some aspects of his dust-related research. These discussions are summarized below; for further details, refer to the associated abstract(s).

R. Zurek discussed the ability of planetary-scale circulation models to predict the strength and pattern of martian surface winds. Models including large-scale topography indicate an enhancement of near-surface winds over high regions such as Tharsis. Tidal models show peak near-surface winds to occur in the subtropics, particularly so at present in the southern hemisphere. These large-scale models provide important boundary conditions for detailed modeling of more localized wind systems. Future combination of observations and theory holds great potential for enhancement of both global circulation models and our understanding of martian æolian processes.

R. Greeley discussed possible mechanisms for raising dust from the surface of Mars. Among these are dust fountaining due to rapid outgassing of absorbed CO_2 or water, clumping of dust into larger, more easily moved particles, dust entrainment by impact of saltating grains, and raising of particles during passage of dust devils. Wind tunnel studies of these processes were outlined, and the possibility of changing the albedo of a dusty surface through wind-induced changes in surface texture was discussed. The studies conducted to date suggest a framework for future experimental programs to examine in detail the range of processes discussed here.

A. Peterfreund reported on his IRTM-based analysis of local dust storms and global atmospheric opacity. Of particular interest is the observation that local dust clouds have a wide range of thermal and visual characteristics, suggesting that local surface materials play a significant role in determining the characteristics of local storms. Extrapolating from the Viking observations, it is estimated that about one hundred local dust storms occur during a given martian year; most local events decay over the course of several days, considerably faster than the decay of the major or global storms. Further observations of the albedo and photometry of local dust clouds will be needed to determine the variability of local and regional dust sources and whether these sources provide significant input to the dust loading during major or global storms.

B. Jakosky commented on remote-sensing evidence (including radar cross-section, radio thermal emission, thermal inertia, and models of rock abundance) for a spatially variable global duricrust on Mars. In general, high thermal inertia surfaces would result from a well-developed crust, while low thermal inertia regions would exhibit a poorly developed crust. He also reported on a theoretical study of thermal properties of particles both smaller and larger than the 50–800 micron-size range for which laboratory measurements have been made under martian conditions. These results are useful for inferring the average size of particles covering areas for which thermal inertias have been determined. Future laboratory and theoretical studies will be needed to further constrain interpretations of surface properties from the application of these various remote-sensing data sets.

P. Christensen presented evidence, based on IRTM data, for regional dust deposits on Mars. The major deposits, located in Tharsis, Elysium, and Arabia, are characterized by relatively low thermal inertias and high albedos. The thermal inertia values, radar signatures, degree of visible mantling, and modeled sparse exposure of rocks constrain the net accumulation of dust in these regions as being between 0.1 and 2 meters thick. Deposit ages of 10^5 to 10^6 years are consistent with such thicknesses and possible rates of dust accumulation, as well as suggesting a link to cyclic variations in the magnitude and location of maximum wind velocities related to Mars' orbital variations. Redistribution of these deposits over such geologically short time scales implies that the upper few meters over much of the martian surface have been continually reworked. Future work should entail examination of the processes involved in redistribution of such deposits, in particular the details of erosion mechanisms; models of large-scale dust transport should also be incorporated into atmospheric circulation models.

P. Thomas discussed his photometric studies of bright and dark wind streaks, and the resulting estimates of the amounts of dust being cycled through streaks. He also suggested that "martian dust" may be multi-component in nature; in terrestrial samples, similar dust compositions exhibit a change of more than a factor of two in albedo, depending on the actual particle size. Viking Orbiter observations of numerous columnar and fan-shaped clouds, thought to be dust devils, were outlined; photometric studies and thermal modeling of such clouds may provide important constraints on conditions leading to injection of dust into the martian atmosphere. These observations illustrate the wealth of information yet to be gained by detailed examination of the Viking Orbiter imaging data set; in particular, little photometric analysis of the images has been completed to date.

J. Zimbelman reviewed the results of his research into the surface properties of Ascraeus Mons. Based on photo-interpretation and studies of the visual reflectance and thermal properties of the region, the surface is inferred to be mantled with from several centimeters (near the summit) to more than 15 meters (near the base) of fine material. The effective particle size increases from <50 microns near the summit to about 100 microns near the base. Estimated deposition rates under present conditions would yield mantle ages of at least 1500 years. These results point out the desirability of completing detailed local studies using several data sets; future work should involve determining the applicability of such local studies to understanding the surface properties at larger (regional) scales.

S. Lee described Viking Orbiter observations of short-term and seasonal variability in the large-scale albedo features found on the flanks of the Tharsis volcanoes. These features have been inferred to result from rapid redistribution of bright dust by downslope winds, even at the high elevations and low atmospheric pressures obtained near the summits of the volcanoes. Given the apparent efficacy of dust transport exhibited in these albedo features, the residence time of bright dust on the Tharsis volcanoes appears to be less than one martian year. Future examination of other areas will be needed to determine how typical æolian processes occurring on the volcanoes are of those active elsewhere, and how representative the observed activity is of that occurring over much longer time scales.

III. Suggested Future Work

Both the above discussions and the work of other researchers make it obvious that æolian transport of dust is readily achieved under present conditions on Mars; such activity may occur over the entire range of surface elevations and atmospheric pressures exhibited on the planet. A wide variety of processes may be involved in raising dust from the surface. There are indications of possible source and sink regions for dust, and evidence for regional differences in the properties of the particles comprising "martian dust." However, it is obvious that many of the details related to dust properties and movement remain to be investigated.

Following an in-depth discussion of the questions posed or left unaddressed by the research completed to date, several experimental, observational, and theoretical research projects were defined to be completed both jointly and individually by the workshop participants over the course of the next year. These projects all relate to the questions:

How many components of dust are there on Mars, and what are their properties?
How is dust ejected from the surface into the atmosphere?
How do the sources and sinks of dust vary with time?

All of the above projects proposed to address these questions fall within the scope of on-going research by the individuals involved. In addition to general investigations, several specific areas of Mars were chosen for detailed study: Tharsis (in particular Arsia and Ascraeus Mons), Solis Planum, Syrtis Major, Arabia, and the complex deposits and streaks in and around Petit Crater.

A second workshop will be held in about one year to report on the results of the projects outlined above. Recognizing the interest of the planetary sciences community concerning the "martian dust cycle," the workshop participants recommend that a MECA topical conference on this subject be organized early in 1986 to encourage participation by the entire community.

ABSTRACTS

REGIONAL DUST DEPOSITS ON MARS: ORIGIN, AGE, AND GEOLOGIC HISTORY;
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Major dust storms on Mars play an important role in the deposition and removal of fine dust material. Thermal, radar, and visual remote sensing observations provide important constraints on the martian regolith which have been used to determine the location and physical properties of regional dust deposits (Christensen, 1985). These deposits are located in three northern equatorial regions, Tharsis (-20°S to 50°N, 60° to 190°W), Arabia (-5°S to 30°N, 300° to 360°W), and Elysium (10° to 30°N, 210° to 225°W). They are covered by fine (~2-40 μm), bright (albedo > 0.27) particles, with fewer exposed rocks and coarse deposits than found elsewhere. Dust is currently deposited uniformly throughout the equatorial region at a rate of ~40 μm/global storm as determined from the total dust loading observed in the 1977 global storm (Pollack et al., 1979). Over geologic time the rate of accumulation may vary from 0 to 250 μm/year due to changes in atmospheric conditions produced by orbital variations (Ward, 1974). These estimates are based on the fact that for very low atmospheric density no dust may be moved, while at high atmospheric density dust storms may be continuously generated. At present, however, there appears to be a decay phase of several months between major storms, so that even at peak dust activity, only 10 storms may be generated each year.

Dust storm fallout is subsequently removed from dark regions following global storms as evidenced by: 1) higher dust content over dark regions during clear periods, 2) post-storm darkening of dark regions, 3) removal of dust at the Viking Lander 1 site, and 4) the historical persistence of classic dark features. Non-removal of dust from low-I, bright regions results in a net accumulation of dust in these areas. The thickness of these current dust deposits is 0.1 to 2 meters. The thermal inertia places a lower limit of ~0.1 m on the thickness of these deposits, while the sparse but ubiquitous presence of exposed rocks and the degree of visible mantling indicate that the thickness is less than 5 meters. Dual-polarization radar observations of a very rough texture in Tharsis (Harmon et al., 1980) are consistent with this model, with a ~2 m thick dust layer burying most of the surface rocks but permitting radar sampling of the rough sub-surface.

Based on their thickness and rate of accumulation, the age of these deposits is 10^5-10^6 years, suggesting a cyclic process of deposition and removal. One possible cause may be cyclic variations in the magnitude and location of maximum wind velocities related to variations in Mars' orbit. At present, perihelion and maximum wind velocities occur in the south whereas regional dust deposits occur in the north, suggesting net transport from south to north. Orbital parameters oscillate with periods ranging from 5×10^4 to 10^6 years. The agreement between these periods and the dust deposit age suggests a possible link. At different stages in orbit evolution, maximum wind velocities will occur in the north, with subsequent erosion and redistribution of the accumulated fines.

Several mechanisms exist for the subsequent erosion of the regional dust deposits. Perhaps the most effective may be "dust-devil" activity. There is some observational evidence for vortices at the Viking Lander sites which produced a factor of 2 to 3 enhancement in wind velocities (Ryan and Lucich, 1983). Because vortices form due to convection in an atmosphere with a superadiabatic lapse rate, they should be more common during periods of maximum solar heating. Thus, this process will be most effective over low inertia regions at times of perihelion summer. This is exactly the time when the regional dust deposits may be eroded.

The presence and history of regional dust deposits on Mars provide some direct evidence for cyclic processes of deposition outside the polar regions. They therefore support models of cyclic variations in martian climate over geologic time. In addition, the occurrence of these deposits and the model for their evolution suggest that the upper few meters over much of the martian surface is young and is being continually reworked.

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DUST STORMS ON MARS: MECHANISMS FOR DUST-RAISING

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"Dust" is generally defined as solid particles $\leq$60 μm in diameter carried by the wind in suspension (1,2). Estimates for particle sizes in martian dust storms yield values of <0.2 to >30 μm in diameter (3). Thus, dust storms on both Earth and Mars involve principally silt- and clay-size particles. Estimates of fluid "threshold" wind speeds for particles of this size show that markedly higher winds are required for progressively smaller particles, which is attributed both to aerodynamic effects and to various interparticle forces such as cohesion. However, once threshold is attained, very low winds can keep dust aloft. Because threshold scales inversely with atmospheric density, the winds required to move "dust" on Mars are exceedingly high; for example, minimum winds required to move 10 μm grains exceed the speed of sound (4) and are far higher than winds measured (or expected) on Mars. Thus, mechanisms other than simple fluid threshold have been proposed for raising dust on Mars. These include a) dust fountaining by desorbed CO_2 (5) and H_2O (6,7); b) dust devils (8); c) presence of "triggering" particles (9); and d) "clumping" of fine grains to produce particles of larger, more easily moved sizes (aggregates, chunks of duricrust, etc.). These mechanisms are reviewed and experiments are described to assess their potential for dust-raising on Mars.

Dust-fountaining. Johnson et al. (5) conducted experiments involving 1-10 μm silica particles in a CO_2 atmosphere which was cooled until CO_2 was absorbed into the particles; the system was then heated so that desorption occurred. The surface initially formed a crust which acted as a "barrier," causing buildup of subsurface gas pressure until the crust ruptured; the gas jets injected dust above the surface several cm. The authors suggested that similar processes on Mars could inject very fine particles into the atmosphere where they could be carried aloft by relatively gentle winds.

A similar mechanism could occur involving water; Huguenin et al. (6) suggested that some of the "blue clouds" observed on Mars could be water vapor released to the atmosphere. Exploratory experiments were conducted (7) to study the effects of water vaporization on the movement of dust. Experiments were performed in both a bell jar and in a wind tunnel using a range of particle compositions and sizes (10 to 1000 μm). In bell jar tests, as the atmospheric pressure was reduced below 10 mb (temperature ~24°C) absorbed water vaporized and ejected particles by one of two processes: 1) vent holes and fissures developed in the surface, followed by a fountainlike spray of particles as high as 20 cm above the surface, or 2) violent "eruptions" occurred in a boiling fashion; the smaller the grain size, the more violent the eruption. Some activity increased with depth of particle bed, with 20 cm high fountains occurring for beds 10 cm deep; some activity was also observed in beds as shallow as 1 mm. The amount of absorbed water also affected activity, with ejection occurring with water contents as low as 0.75% by weight. Similar effects were observed in tests conducted in the wind tunnel. However, in some experiments the particle bed remained stable until a low velocity wind passed over the surface at which time injection was "triggered." Although there is no clear explanation for this effect, the triggering could be related to slight differences in pressure resulting from the wind. In some cases, desorption of water did not eject dust, but caused the surface to crack. Erosion began as the wind picked up crust-like sections of the particles; the wind speed of ~25 m/s was substantially lower than threshold for undisturbed particles. Evidently, the fissures sufficiently roughened the surface to lower the threshold speed.

Dust devils. Dust devils are local cyclonic winds that result from atmospheric instabilities. They have been suggested as a dust-raising mechanism on Mars, an idea enhanced by the recent discovery of possible dust devils in Viking Orbiter images (10). Field studies of dust devils on Earth (11,12) show that a wide range of particle size can be raised even when unidirectional winds are very gentle. Laboratory experiments (13) suggest that the entrainment mechanism for raising particles via dust devils is markedly different than for a uniform wind boundary-layer case. In dust devils, the primary factor may be the difference in pressure between the top and bottom of the particle layer; in cyclonic motion, the size and density of the particles seem to have little importance in threshold and even the very small grains are easily raised.

Presence of "Triggering" particles. Numerous authors have suggested that dust could be entrained by saltation impact of larger (e.g., "sand"), more easily moved grains (7,9,14). In order to assess this mechanism, wind tunnel experiments were run (15) involving basaltic particles (<40 μm) that were impacted by saltating sand grains (120 μm diameter). Although some basaltic "dust" was entrained upon impact by the sand, the effect was minimal. Additional experiments are planned in which the test bed will consist of a mixture of particle sizes.

Dust "clumps". Any means that could increase the effective diameter of dust particles could lower the threshold necessary for entrainment. Aggregation of small particles by electrostatic bonding occurs in dust storms (16) and volcanic eruptions (17) on Earth and has been proposed for Mars (18). Wind tunnel experiments (15) show that threshold winds for aggregates of basaltic silt are ~25% lower than the same non-aggregated silt grains. Even though the aggregates are very fragile and do not survive saltation impact, the "soils" are sufficiently rough that clumps are more easily picked up by the wind. Disrupted crusts developed on deposits of fine grains may also produce clumps that are more easily entrained by low winds. Gillette (19) notes significantly lower threshold values for silt and clay on Earth where crusts on the deposits have been disturbed. For application to Mars, duricrust and "cloddy" soils have been described; disturbance by events such as the slumping in drift deposits at "Big Joe" could provide local surface roughness which would lower the effective threshold wind speed for martian dust.

The four mechanisms described above appear viable for raising of fine (<60 μm) particles on Mars. However, additional testing is required, including: 1) determination of the limits for dust-fountaining on Mars via desorption of volatiles, 2) assessment of dust devils at low atmospheric densities for dust entrainment, 3) threshold experiments using mixed particle sizes under martian conditions, and 4) assessment of the physical properties of various aggregates, clumps, and crusts on Mars.

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Thermal properties of martian fines. Bruce M. Jakosky (Laboratory for Atmospheric and Space Physics, University of Colorado, Boulder, CO 80309).

Laboratory measurements of the thermal properties of fines under martian pressure and temperature conditions are available only for particles between about 50 and 800 µm diameter. This range corresponds to thermal inertias between about 3 and 8 x 10^{-3} cal/cm^2 - s$^{1/2}$ - K, as compared to the observed range of thermal inertia on Mars of about 1-20 x 10^{-3}. Extension to smaller and larger particles has been made based on theoretical grounds and on laboratory measurements at non-Mars-like conditions. In both cases (small and large particles), gas conductivity dominates the total conductivity. For small particles (pore size less than gas mean free path, ~ 5 µm), conductivity is linear with particle size, such that a thermal inertia of 3 x 10^{-3} corresponds to particles of ~ 30 µm diameter and an inertia of 1 x 10^{-3} corresponds to particles of ~ 3 µm diameter at 6 mbar. There is some uncertainty, however, due to the unknown role of the solid-solid conductivity of small particles and of the possible variations due to packing or previous adsorption history; particles corresponding to each inertia may be as much as an order of magnitude smaller. For large particles (pore size much larger than mean free path, but smaller than the diurnal thermal skin depth of rock), gas conductivity is independent of pore size, and the bulk thermal conductivity depends only on porosity. Based on laboratory measurements at larger pressure, an inertia of 10 x 10^{-3} is thus appropriate for 1mm $\lesssim$ d $\lesssim$ 5 cm. Larger thermal inertia values must correspond either to d $\gtrsim$ 5 cm or to the presence of a bonded surface of greater conductivity. There is a great need for laboratory measurements of the properties of small and larger particles under Mars-like conditions.

Global Duricrust on Mars: Analysis of Remote Sensing Data. Bruce M. Jakosky (Laboratory for Atmospheric and Space Physics, University of Colorado, Boulder, CO 80309) and Philip R. Christensen (Department of Geology, Arizona State University, Tempe, AZ 85281).

Global remote-sensing data for Mars are analyzed to obtain a simple, self-consistent model for the surface. The data sets include radar cross-section at several wavelengths, radio whole-disk thermal emission rotational curves at two wavelengths, a global thermal inertia map, deviations of diurnal temperatures from those of a homogeneous model, and thermal spectral estimates of rock abundance and of the thermal inertia of the fine component of the surface. The most constraining of the data sets are the rock abundance map and the correlation of thermal inertia with 70-cm radar cross-section; these require the rock abundance to not vary significantly from place to place, and require the density and thermal inertia of the fines to vary in a consistent manner, respectively. The simplest model which can explain all of the data involves a global case-hardened crust ("duricrust") which varies spatially in its degree of formation. In general, low thermal inertia regions have a poorly-developed crust and high-inertia regions have a well-developed crust; there are, however, regions that consist of coarse particles, which do not fit into this model (e.g., Chryse). This model is consistent with the ages of, and aeolian mechanisms for developing, low-inertia regions. The duricrust is thought to form via the mobilization of salt ions within a layer of water adsorbed within the regolith, and its formation may be associated with the 10^5- and 10^6-year timescale for exchange of water between the regolith and atmosphere.

AEOLIAN DUST TRANSPORT AT HIGH ALTITUDES AND LOW PRESSURES ON MARS;
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Some of the most distinct and time variable albedo features on the surface of Mars are associated with the Tharsis shield volcanoes (Arsia, Pavonis, Ascraeus, and Olympus Mons), occurring at the highest elevations and lowest atmospheric pressures on the planet. Viking images have revealed well-developed dark collars encircling the flanks of these constructs, reaching the summits (elevations of up to 26 km and sub-millibar pressures) and extending 400 km or more down the flanks. These features have been attributed to coalescing dark wind streaks trending downhill [1,2], and as such provide dramatic evidence for the efficacy of slope winds as agents of aeolian dust transport.

Modelling of the sedimentation rates at various elevations on the volcanoes indicates the observed short-term changes in the dark collars are consistent with regular deposition from the atmospheric dust load contained in a stably stratified near-surface air mass during early morning. The deposited dust is subsequently redistributed by nightly slope wind activity (produced by the combination of long, steep slopes and large diurnal temperature excursions [3,4] found on the volcanoes). Seasonal variations in the albedo features are explained by large increases in the sedimentation rate due to enhanced dust loading during major dust storm activity, again followed by rapid removal of surface dust by slope winds.

On a yearly basis, the dark collars are generally repeatable in form and position; they appear to have persisted throughout the span of the available spacecraft and ground-based observations. Given the evidence for rapid redistribution of surface dust, the residence time of dust on the Tharsis volcanoes appears to be much less than one martian year.

These observations leave several questions open for discussion:

1) How can dust be so readily raised from surfaces at such low pressures without either winds of several hundred m/s or the ready availability of sand-sized particles to act as a "saltation trigger" [5,6], neither of which conditions probably occur on the volcanoes?

2) Interpretation of photogeology [7] and IRTM data [8] indicate the volcanoes may be mantled to a depth of several meters, while interpretation of variability of albedo features (presented here) indicate these surfaces are swept relatively clean of dust on short time scales. Are these various interpretations mutually exclusive, or can they prove consistent by inclusion of other data sets (radar, photometry, laboratory simulations, etc.)? Can the observed levels of aeolian activity be used to constrain the ages and formation mechanisms of such surface deposits?

3) Is the cycling of dust through the Tharsis region unique to that area, or does such a process explain the production of many of the classical dark albedo features observed elsewhere on Mars?

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LOCAL DUST STORMS AND GLOBAL OPACITY ON MARS AS DETECTED BY THE VIKING IRTM. A.R. Peterfreund, 21 High Point Dr., Amherst, MA 01002 and Department of Geology, Arizona State University, Tempe, AZ 85287

Viking Infrared Thermal Mapper (IRTM) observations of the atmosphere and surface of Mars were used to identify local dust storms that occurred during the four years of coverage. A search routine, based on the relative opacity of the atmosphere at different wavelengths (7 and 9 μm) determined the relative opacity of the atmosphere, τ_9, as a function of time, and identified local anomalies as discrete local dust clouds (1).

Average global opacities are similar in relative intensity, to opacities derived from the Viking Lander camera, the Orbiter camera, and other derivations of opacity using the IRTM data. The time-history of τ_9 reveals basic characteristics about the annual dust-loading of the martian atmosphere (see Fig. 1).

1) The atmosphere of Mars was not observed to be dust-free during the Viking mission, and may not achieve a "clear" state during the current climatic epoch.

2) Global opacity is at a minimum during the northern hemisphere spring and summer and at a maximum during southern spring and summer, the seasons during which most local and major dust storms occur. This is strongly correlated with total insolation received at Mars as a function of time of year and distance from the sun.

3) On an annual basis, the initial increase in global opacity ($\sim L_s = 135°$) that marks the onset of the dust storm season is associated with local dust storms that originate along the retreating south polar cap soon after recession begins.

4) Effects of major dust storms on the global opacity vary depending on

the intensity and latitudinal extent of the storm. Initial build-up in opacity occurs over 2 weeks, decay begins immediately thereafter. The decay in opacity from the major 1977 dust storms followed two distinct patterns. The decay of the first storm and the latter part of second followed similar patterns. In contrast, the initial decay phase of the second and more intensive storms, showed a more rapid clearing.

5) Global opacities derived from the second martian year of IRTM observations show a similar pattern of dust activity, the exception of the occurrence of major storms. At L_s 205°, the time of year of the first 1977 major dust storm, no major storm appears to be in progress. Unfortunately during the second martian year, IRTM observations were not obtained during the period a major storm would most likely have occurred.

The record of local (<1000 km diameter) dust storm activity, based on the 31 clouds identified by this search and combined with observations from the Viking Orbiter VIS experiments and those made by Earth-based astronomers, documents recurrent characteristics of the local clouds:

1) Local dust clouds occur throughout the year and at almost all latitudes. However, the majority of these storms occur in the southern hemisphere ± 90° L_s from perihelion (see Fig. 2).

2) Two major classes of local dust clouds, that account for approximately 70% of all local dust clouds, are: a) those associated with thermal winds generated along the edge of the receding south polar cap, and b) mid- and low-latitude storms associated with peak surface heating near the sub-solar point.

3) Local dust clouds were observed during the waning stages of the major dust storms as early as 20° L_s after the peak in atmospheric opacity.

4) Local dust clouds have a wide range of thermal and visual

characteristics suggesting that local surface materials have a significant role in defining the character of the local clouds.

5) Based on the Viking Orbiter observations, it is estimated that approximately one hundred local dust storms occur in a given martian year.

6) Common local dust storm localities in the southern hemisphere include: the region form Noctis Labyrinthus to Thaumasia Fossae, Argyre, Noachis-Hellespontus, Hellas, and the edge of the south polar cap. Common local dust storm sites in the northern hemisphere include: Chryse, Isidis-Syrtis Major, Cerberus, and Acidalia.

7) Local dust storms originate in regions that are characterized by moderate thermal inertia (consistent with a sand-rich surface) and a broad range of albedos.

Reference: (1) A.R. Peterfreund (1985) Ph.D. dissertation, A.S.U.

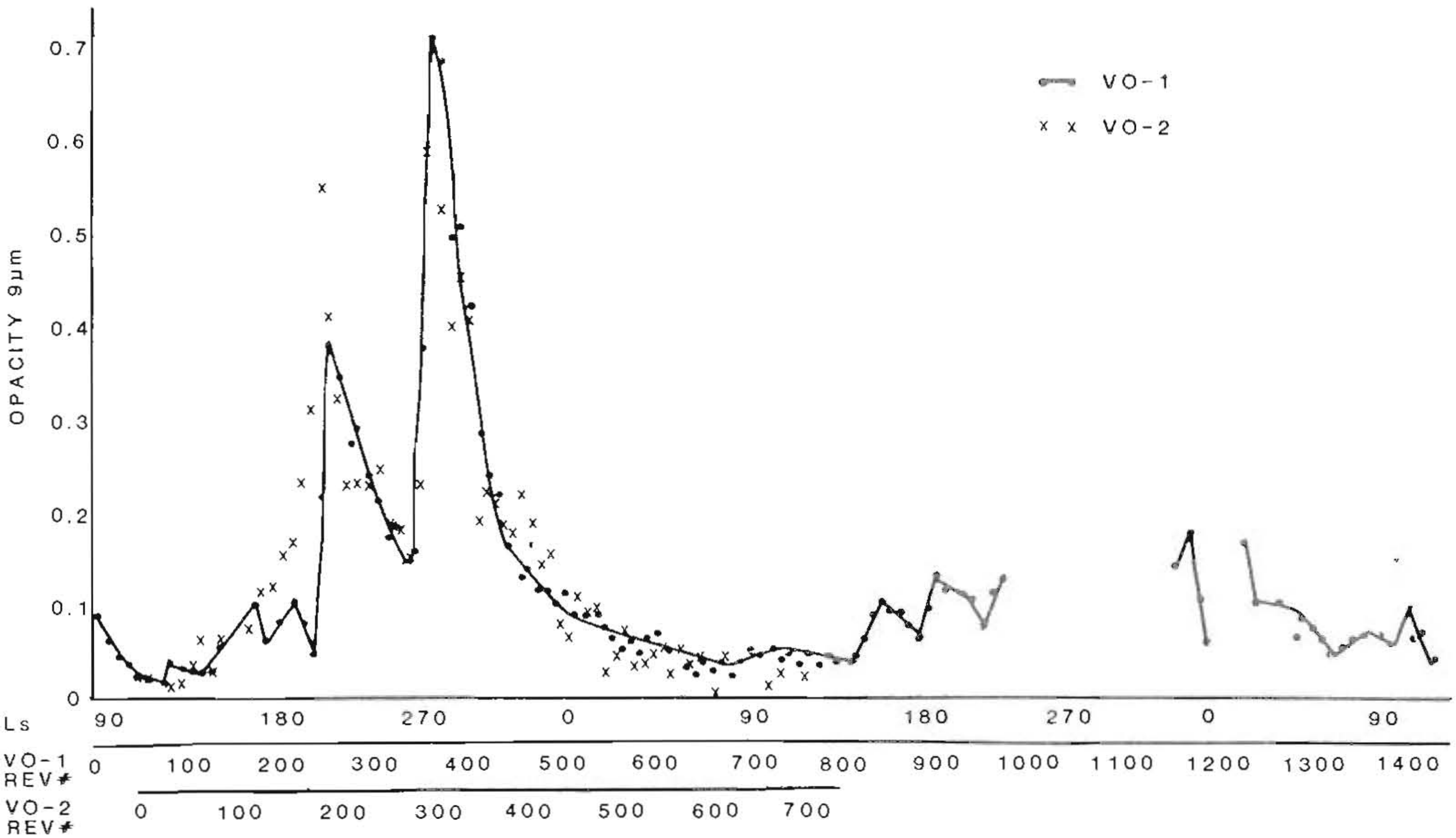

Figure 1 Relative opacity of the martian atmosphere during the Viking Mission. The opacities, τ_9, are derived from IRTM observations obtained within periods of ten revolutions. Plotted separately are τ_9 derived from VO-1 and VO-2 observations. A line connects the VO-1 data. Offsets between the two data sets are due to variations in the coverage by the separate orbiters.

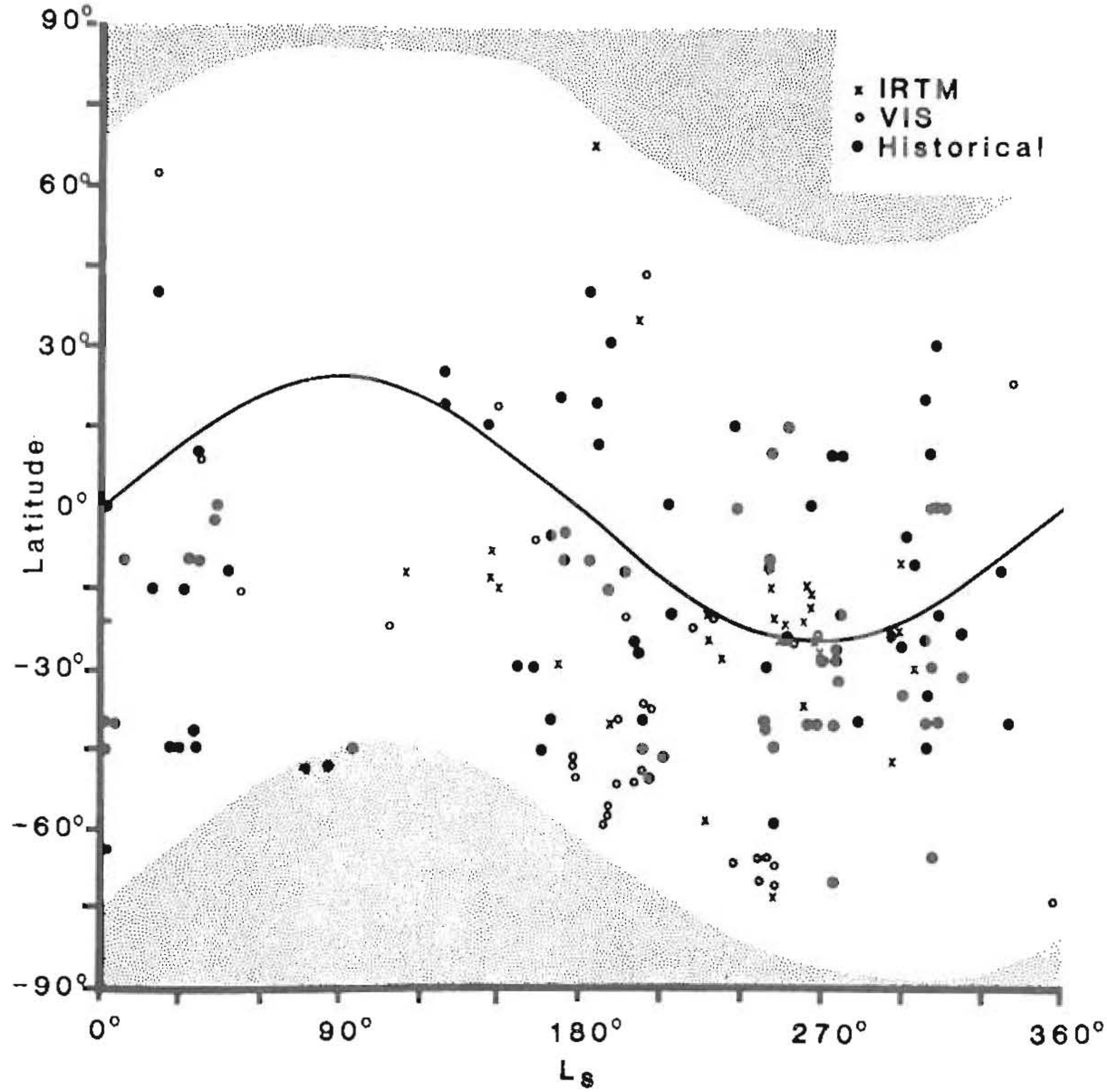

Figure 2 Latitudinal distribution of local dust clouds as a function of L. The local dust storms are those identified from IRTM, VIS and Earth-based observations. The solid line represents the sub-solar latitude and the shaded areas indicate the maximum extent of the polar caps.

Dust Streaks and Related Phenomena: Photometry and Mapping

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Imaging data provide the basis for global maps of erosional and depositional dust streaks on Mars, as well as for local studies of the conditions of deposition or entrainment of dust. Here we note the status and potential use of the global data set as well as progress of work on two "local" phenomena: linear streaks and dust devils.

1. Global Streak Data: The types, position, orientation, and size are available for about 11000 depositional and erosional dust streaks (Thomas et al., 1984). Although information on the time variation of streaks is restricted to a few areas (see Lee, 1984) these have been of great diagnostic value in assigning seasonal characteristics to some types of streaks. The global data set is particularly useful in studying the circulation associated with deposition or erosion of dust. Current work includes division of the data set by topography (elevations and slopes from the several data sets on Mars topography) to allow better modelling of surface wind stress patterns resulting from either global or local wind systems. Photometry of bright and dark streaks has given some rough estimates of the amounts of dust which may be stored or cycled in the streaks (Thomas et al., 1984).

2. Linear Streaks. Regional linear streaks are long, narrow streaks that occur in sets of nearly parallel members and attain lengths of nearly 400 km. Linear streaks longer than 50 km occur in only three areas of Mars: Amazonis Planitia, Acidalia Planitia, and

southwest of Mare Erythraeum. All areas are 23-38° latitude, relatively smooth, and have only slight regional slopes.

Nearly all high resolution data of these streaks are of the Amazonis group. These streaks are generally 100-400 km long and 2-10 km wide, spaced 12-18 km apart. The streaks are not perfectly parallel, and at least two sets of different orientation cross each other. There are no visible source obstacles. In Argyre and Acidalia nearby dark, crater-related streaks are parallel to the linear streak trends and suggest formation by east winds. In Amazonis there are bright linear streaks which follow a slightly different trend from the dark linear streaks. The bright streaks may originate at a series of low scarps, in which case they also formed during east winds. The streaks are time variable. The Amazonis dark streaks were stable from $L_s = 37°$ to $L_s = 159°$. Between $L_s = 159°$ and $L_s = 32°$ the streaks were erased and two or more new sets formed. The streaks were stable through $L_s = 80°$. In Argyre at $L_s = 101°$ there were no streaks. At $L_s = 16°$ the streaks were well formed; at $L_s = 32°$ they were reduced in extent.

The primary characteristics of the streaks that must be explained are the restricted latitude occurrence, the long nearly parallel forms, their probable formation by easterly winds, and the consistent pattern of lines convex to the equator. These streaks pose problems in both general circulation and the local conditions of dust entrainment.

3. Possible dust devils on Mars. Columnar to fan-shaped clouds that extend up to 6 km from the martian surface have been found in an area 33-43°N, 140-155°W; others may exist at 37°N, 192°W (a complete search of all Viking frames was made). The clouds were observed from L_S = 122-124°, and 139°, at 14 to 15 hrs local time. Heights from shadow measurements are 0.5 to 6 km; most of the 94 observed clouds are 2-3 km high. Some are nearly vertical, others have tilts of up to 30°. Optical depths of the clouds appear to be on the order of 0.3-0.5. We are presently doing photometry of the clouds and shadows to constrain their possible dust contents and their shapes; thermal modelling of conditions which may produce the clouds is being done by P. Gierasch. If these features are indeed analogous to terrestrial "dust devils", then they may provide crucial information on conditions that lead to injection of dust into the martian atmosphere.

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SURFACE PROPERTIES OF ASCRAEUS MONS: DUST DEPOSITS ON A THARSIS VOLCANO

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Ascraeus Mons (11^{o}N, 104.5^{o}W) is the northernmost of the Tharsis Montes shield volcanoes. Remote sensing data collected at several wavelengths were analyzed in order to relate the surface properties (such as albedo, thermal inertia, and surface roughness) to the geologic history of the volcano (1). The results are discussed here in relation to the abundance of fine-grained material (dust) on the volcano.

OBSERVATIONS

Photointerpretation. Photographs 401B01-24 (22 m/pixel) show the surface morphology of Ascraeus Mons from the summit caldera complex to near the contact between the shield base and the surrounding Tharsis plains. Flow fronts and leveed channels are abundant and clearly visible near the summit of the volcano but all surface relief is increasingly subdued with decreasing elevation. The areal density of craters < 270 m in diameter also decreases with decreasing elevation; summit area craters are well defined with sharp rims but both subdued and sharp-rimmed craters are visible at low elevation.

Visual reflectance. Photographs 696A41,45, and 47 (822 m/pixel, taken through violet, green, and red filters, respectively) were used to produce a color photograph of Ascraeus Mons. Summit area albedos are very uniform (0.05 and 0.16 at violet and red wavelengths) when the photometric effects of the volcano slopes are taken into account. A zone of lower albedo surrounds the summit area below an elevation of approximately 19 km (0.05 and 0.14 at violet and red wavelengths). Atmospheric haze obscures the surface and increases the apparent albedo below an elevation of approximately 13 km.

Thermal infrared. Four IRTM sequences with spatial resolutions of 11 to 31 km^2 cross Ascraeus Mons at or near its summit. Elevation-dependent corrections were applied to the calculated thermal inertias to account for atmospheric radiation and the gas-pressure-dependence of thermal inerita in porous materials. Summit area thermal inertias of 2.0 to 2.5 (10^{-3} cal cm^{-2} $sec^{-1/2}$ K^{-1}) are comparable to or larger than the thermal inertias for the Tharsis plains that surround the volcano. The uppermost caldera walls are the only terrain unit with distinguishable thermal inertias (I = 4.5); all flow-related terrains have equivalent thermal inertias, even where individual flows can be spatially resolved. Flank thermal inertias increase with decreasing elevation but they return to summit area values at the shield-plains contact. Differences between temperatures measured at 11 and 20 μm wavelengths indicate that spatially unresolved high thermal inertia materials (I = 30) cover > 20% of the summit surface area but < 10% of the shield surface at low elevations. Temperatures measured in all of the IRTM thermal bands indicate the presence of suspended dust in the atmosphere, even above the summit, but there is no evidence of water vapor clouds (using the results from ref. 2,3). Fourteen moderate resolution IRTM sequences (810 to 4840 km^2) indicate that the thermal inertias are radially symmetric about the summit and that the results from the four high resolution sequences are appicable to the entire volcano edifice.

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Radar. Few radar returns have been received from the Tharsis region for either continuous-wave (4) or delay-Doppler (5,6) methods of observation and and no returns were received from groundtracks that passed directly over the Ascraeus Mons shield (4). These analyses dealt with the quasi-specular portion of the radar signal but radar data from the Tharsis region are dominated by the diffuse component of the radar signal (7). A localized feature of enhanced diffuse radar signal may be associated with Ascraeus Mons but Ceraunius Fossae and Syria Planum are also potential source areas for the feature (7).

INTERPRETATIONS

The thermal inertias can be related to an effective particle size for an idealized surface consisting of only one particle size (8); < 50 μm for the summit area, increasing to 100 μm near the base of the volcano. The increase in size may be related to an increase in the abundance of sand-sized particles, perhaps including aggregates of clay-sized particles (9). Sand-sized materials would be most easily set in motion by the wind (10) and it is difficult to initiate aeolian activity in silt or clay-sized particles without the presence of sand to dislodge the fine particles from the surface (11). The wavelength dependence of the summit area albedos parallels the reflectance spectra of Arabia, interpreted to be the result of dust deposits (12), but Ascraeus Mons is consistently darker than Arabia. Fine-grained dust is probably areally predominant on the surface of Ascraeus Mons but darker (larger or more competent) materials are also present.

The thickness of the surface deposits can be broadly constrained from the different data sets. Visible relief indicates that surface deposits in the summit area are probably << 15 m in thickness while at the base of the volcano the deposits are probably > 15 m in thickness and may be > 45 m at some locations (1). The presence of both subdued and sharp-rimmed craters at lower elevations indicates that the degradation of surface relief is not due to atmospheric obscuration of surface details. The low thermal inertia of the summit area requires that at least 2 cm of the fine-grained materials be present (13). The diffuse component of the radar signal is most likely due to scattering by objects comparable in size to the 13 cm wavelength of the radar (7). Either the radar signal penetrates the fine-grained material responsible for the thermal inertia or the scattering occurs from areally less abundant objects at or near the surface (e.g. rocks).

Both a volcanic and an aeolian origin are possible for the surface properties but several considerations make a volcanic origin appear less likely. The lack of correlation between flow features and the thermal data indicates that flow textures apparently do not contribute significantly to the observed thermal inertia (consistent with the presence of material deposited over the orginal flow surface). From this observation it follows that the thermal variations on the flank of the volcano are related to the surface materials on the volcano and not the flow surfaces.

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The degradation of surface relief indicates increasing deposit thickness with decreasing elevation; this relationship is opposite to what might be expected for a pyroclastic source near the summit of the volcano. The radial symmetry of the thermal inertias around the summit caldera is also difficult to justify with a pyroclastic source away from the volcano. Finally, there is no morphologic evidence of potential source vents which could be responsible for m-thick deposits around the base of the volcano.

Estimates of deposition rates for settling of dust (suspended in the atmosphere) onto the summit and base of the Tharsis volcanoes (14) are consistent with the observed thickness distribution on Ascraeus Mons. The 2 cm minimum thickness for fine-grained materials in the summit area can be combined with the calculated dust deposition rate to indicate that at least 1500 years of average dust deposition are needed to produce the observed thermal inertias. Albedo variations are observed to occur on the Tharsis Montes and Olympus Mons over timescales of days to weeks (14) so that dust erosion (or remobilization) must accompany the dust deposition; the thermal inertias probably represent dust accumulations through many thousands of years. Future work should involve comparison of the surface properites for all of the large shield volcanoes to the Ascraeus Mons results.

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SURFACE WINDS INFERRED FROM MODELS OF THE PLANETARY-SCALE CIRCULATION

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Winds at the surface of Mars are strongly dependent on the nearly inviscid flow at the top of the planetary boundary layer. Various models have been developed to describe the planetary-scale components of these near-surface winds; the most advanced of these models include the thermal and mechanical effects of the sizeable, continental-scale martian orography (Zurek, 1976; Webster, 1977; Pollack et al., 1981). These models indicate that, in the relatively dust-free atmosphere, near-surface winds are enhanced over high areas (e.g., Tharsis, Noachis-Arabia). In addition, the diurnally varying component of the near-surface wind is strongest over subtropical latitudes (15°-30°) with somewhat stronger winds occurring in the summer hemisphere. These models do not adequately simulate mesoscale wind systems, such as slope winds or mountain lee waves. They also focus on the steady, rather than transient (i.e., nonperiodic or rapidly varying), components of the wind fields. However, these models of the large-scale circulation can be used to indicate general areas of high, near-surface wind and could provide boundary conditions for detailed modelling of more localized winds.

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