pography is more enduring are that in the polar regions the surface processes are well supplied with mobile material and are sustained for a much larger fraction of the time.

A scenario for the evolution of the north polar region. Our preliminary study of the north polar region geology leaves us with uncertainties and ambiguities concerning the events that have taken place there. Some of this confusion may well be resolved by future analyses of the imaging data. The scenario that is outlined in Table 1 is not a unique one—it may not even be the one that is most in harmony with the data—but it does offer a credible framework for the observations against which further observations and theoretical models may be tested.

Two distinct types of climate change are implied by this scenario. Climate changes of type 1 are associated with the fine-scale layering and are clearly cyclical with a relatively short and apparently regular period. They seem to involve fairly limited excursions in environmental conditions affecting, apparently, the rate of deposition. Climate changes of type 2, of which two episodes, at least, have been recognized so far, occur on a much longer time scale, perhaps two or even three orders of magnitude longer than that of type 1 changes. Type 2 climatic changes do not necessarily have a uniform duration or a regular period, and they seem to involve radical excursions in environmental conditions from a depositional regime to an erosional regime.

There is no evidence that changes in the polar climate have any connection with climatic changes postulated in connection with channel formation on Mars (*17*). The polar climatic changes indicated are probably much more subtle than the massive temperature and pressure changes required for fluvial activity in the equatorial regions. The martian channels are also reported to be extremely old (*18*) whereas erosion in the polar regions is clearly very recent. We cannot, however, exclude the possibility that accumulation of the layered deposits was contemporary with channel formation, but even if that were so, the erosion of the deposits postdated it. The layered deposits may nevertheless play an important role in the volatile history of Mars. Much of the water inferred to have been released from the planet's interior since its formation (*19*) could have been codeposited in the form of ice with dust in the polar regions.

Paradoxically, the events that are least certain in the history of the polar region are those that are closest to the present. The relationship of the layered units to the polar caps is not understood. Neither is the origin of the dune fields. The searchlight features that transect major topographic features without a change in direction are also a puzzle. We don't know whether the polar region is presently experiencing a depositional or erosional cycle. We cannot exclude the possibility that the evolution of the polar region is now controlled by a climatic regime quite distinct from those that have existed previously. If we are fortunate enough to recover higher-resolution imagery after the spacecraft passes the solar occultation period of superior conjunction, we may obtain insights into some of these tantalizing problems.

JAMES A. CUTTS, KARL R. BLASIUS
Planetary Science Institute, Science Applications, Inc., Pasadena, California 91101

GEOFFREY A. BRIGGS
Jet Propulsion Laboratory, Pasadena, California 91103

MICHAEL H. CARR
Branch of Astrogeology, U.S. Geological Survey, Menlo Park, California 94025

RONALD GREELEY
University of Santa Clara, Santa Clara, California 95053, and *NASA Ames Research Center, Moffett Field, California 94305*

HAROLD MASURSKY
Branch of Astrogeology, U.S. Geological Survey, Flagstaff, Arizona 86001

References and Notes

1. B. C. Murray, L. A. Soderblom, J. A. Cutts, R. P. Sharp, D. J. Milton, R. B. Leighton, *Icarus* **17**, 328 (1972).
2. J. A. Cutts, *J. Geophys. Res.* **78**, 4231 (1973).
3. ———, *ibid.*, p. 4211.
4. D. Dzurisin and K. R. Blasius, *ibid.* **80**, 3286 (1975).
5. B. C. Murray, W. R. Ward, S. C. Yeung, *Science* **180**, 638 (1973).
6. L. A. Soderblom, M. C. Malin, J. A. Cutts, I C. Murray, *Icarus* **78**, 4197 (1973).
7. The Viking visual imaging system consists (two high-resolution, slow-scan television fran ing cameras. Conceptually similar to the Mar ner camera systems used in previous Mars, Me cury, and Venus missions, the visual imagin system incorporates improvements designed t increase both spatial resolution and coverage Each camera employs a 475-mm diffraction-lin ited telescope and a 37-mm-diameter vidicon the central region of which is scanned with raster format of 1056 lines by 1182 samples an produces a 1.54° by 1.69° field of view. Th optical axes of the cameras are offset by 1.38° Cameras are shuttered alternately, which result in contiguous swaths of images 80 km wide, wit resolution better than 100 m near periapsis. Si color filters are available to restrict the imag spectral bandpass to limited portions of the cam eras' near-visual response characteristics. The camera systems are described in detail by J. B Wellman, F. P. Landauer, D. D. Norris, and T E. Thorpe (*J. Spacecr. Rockets*, in press).
8. H. H. Kieffer, S. C. Chase, Jr., T. Z. Martin, F. J. Palluconi, E. D. Miner, *Science* **194**, 1341 (1976).
9. All images published here are oriented with the north approximately toward the top of the frame and with the illumination directed from the bottom of the frame. Unless otherwise noted, the dimensions of individual frames lie in the range 60 to 100 km. Most images used have been filtered to display detail in both ice-covered and ice-free areas. Consequently, in many cases the brightness of an area in the processed image is not a reliable indicator of the presence or absence of ice cover.
10. The crustlike material observed by the Viking landers has recently been termed "duricrust," which avoids the implication of genesis that accompanied the earlier use of the term "caliche."
11. J. A. Cutts and R. S. U. Smith, *Icarus* **78**, 4139 (1973).
12. P. Toulmin III, B. C. Clark, A. K. Baird, K. Keil, H. J. Rose, Jr., *Science* **194**, 81 (1976).
13. G. A. Briggs, *Icarus* **23**, 167 (1974).
14. R. L. Huguenin, *Science* **192**, 138 (1976).
15. L. A. Soderblom, C. D. Condit, R. A. West, B. M. Herman, T. J. Kriedler, *Icarus* **22**, 239 (1974).
16. C. Sagan *et al.*, *J. Geophys. Res.* **78**, 4199 (1973).
17. C. Sagan, O. B. Toon, P. J. Geirasch, *Science* **181**, 1045 (1973).
18. M. C. Malin, *J. Geophys. Res.* **81**, 4825 (1976).
19. T. Owen and K. Biemann, *Science* **193**, 801 (1976).
20. The Viking 2 reconnaissance of the north polar region of Mars has benefitted from the dedicated efforts of large numbers of individuals. Among members of the orbiter imaging team and staff we thank especially K. Klaasen, T. E. Thorpe, R. Tyner, and J. B. Wellman for their untiring support of the polar photography effort. Financial support for the work of team members was provided by NASA through the Viking Project Office and the Office of Planetary Geology (R.G.).

16 November 1976

Mars Dynamics, Atmospheric and Surface Properties: Determination from Viking Tracking Data

Abstract. *Approximately 3 months of radio tracking data from the Viking landers have been analyzed to determine the lander locations, the orientation of the spin axis of Mars, and a first estimate from Viking data of the planet's spin rate. Preliminary results have also been obtained for atmospheric parameters and radii at occultation points and for properties of the surface in the vicinity of lander 1.*

The objectives of the Viking radio science investigations are to use the data from the tracking and communication systems on the orbiters and landers for scientific studies of Mars and its environment, to study properties of the solar system, and to perform tests of general relativity (*1*). Preliminary results from three of the investigations, lander tracking analyses, the occultation experiment, and the surface properties experiment, are reported here.

Lander tracking analyses. In a previous report (*2*), we presented preliminary results for the Viking lander 1 (VL1) position and for the orientation of the martian spin axis, on the basis of an analysis of the first few days of radio tracking data from VL1. Here we present preliminary results from an analysis of combined VL1 and VL2 radio tracking data in a simultaneous solution for nine parameters: three coordinates for each lander, two spin-axis orientation components, and a first estimate from Viking data of the spin rate of Mars. The data used for this analysis extend over intervals of (i) 81 sols (a sol is a martian day) for VL1, with an average of 25 Doppler points per sol and a total of 16 range points, and (ii) 35 sols for VL2, with an average of 15 Doppler points per sol and a total of 28 range points.

Several of the parameters, particularly the latitudes and radii of the landers, are best determined from ranging data and are highly sensitive to even small errors in our knowledge of the distance between Earth and Mars and of the charged particle environment. Therefore, dual-frequency orbiter radio tracking data were used (*3*) to correct the lander range points for these effects.

The results obtained for the areocentric latitudes, longitudes, and radii for VL1 and VL2, respectively, are 22.272° ± 0.006°N, 47.94° ± 0.2°W, and 3389.38 ± 0.08 km; and 47.669° ± 0.006°N, 225.71° ± 0.2°W, and 3381.88 ± 0.22 km. The corresponding aerographic latitudes are 22.483°N and 47.968°N. The sidereal rotation rate of Mars is determined to be 350.891986° ± 0.000012° per day. For the epoch of 1950.0, the values for the right ascension α_0 and the declination δ_0 of the martian spin axis, referred to Earth's mean equator and equinox of 1950.0 are

$$\alpha_0(1950.0) = 317.340° \pm 0.006°$$
$$\delta_0(1950.0) = 52.710° \pm 0.004°$$

Such accuracy in the determination of the spin-axis orientation from only a few months of data implies that an extended set of lander tracking data might allow detection of spin-axis motion. The martian spin rate given above corresponds to a rotational period of 24 hours, 37 minutes, 22.663 seconds ± 0.004 seconds, which is about 8 msec longer than the value of de Vaucouleurs *et al.* (*4*). We previously noted (*2*) that any adjustment in martian spin rate would affect the values of the lander longitudes.

To understand this change, note that the lander longitudes are determined with respect to the vernal equinox, but are referred to a prime meridian, which passes through the crater Airy-0 (*4, 5*) and which is implicitly defined (*4*, p. 4402) to be at a right ascension of 4.376° at 0 hours ephemeris time on 27 November 1971 as determined from the Mariner 9 data (*4, 5*). The cumulative effect, over the 5 years since 1971, of lengthening the martian rotation period displaces the prime meridian westward for the mid-1976 epoch and thus shifts the lander longitudes by about 0.06° eastward with respect to the unadjusted spin rate values. The uncertainties presented for lander longitudes are principally caused by the approximately 10-km uncertainty (*4, 5*) in the areocentric location of crater Airy-0, and thus in the prime meridian at the 1971 epoch. Because our corresponding uncertainties in the right ascensions of the landers with respect to the vernal equinox are only about 0.002°, any appreciable improvement in the accuracy of the lander longitudes will require more accurate knowledge of the areocentric location of crater Airy-0.

Occultation experiment. During the interval between 6 October and 1 November 1976, the Viking orbiter 1 was occulted daily by Mars, thus providing data on martian atmospheric and ionospheric properties and radii at the occultation points. We have analyzed the Doppler frequency data obtained from the closed loop receiver systems during the first four ingress events. The measurements were made in the two-way tracking mode at Deep Space Station 43 in Canberra, Australia. The data are noisy because of phase scintillations introduced by the solar corona as the signals pass close to the sun; in fact, the Sun-Earth-Mars angle was only about 13° in early October.

The martian atmosphere was probed in the Vastitas Borealis region at latitudes ranging from 63° to 69°N and longitudes from 60° to 121°W. The observations yielded atmospheric pressures and temperatures near the surface ranging from 6.5 to 7.5 mbar and 210° to 180°K. The observed radii at the points where the signals grazed the planetary surface ranged from 3377 to 3376 km, respectively. The uncertainties in this preliminary analysis are about ± 0.5 mbar, ± 10°K, and ± 1 km, somewhat larger than the uncertainties quoted in previous occultation experiments.

No ionization was detected in the martian atmosphere during the first four ingress measurements, because the data were noisy and because they were obtained on the night side, at local times ranging from 2200 to 0200 hours, where the electron density is known to be low. For example, earlier measurements with Mariner 4 conducted near 60°N latitude in the late summer season at about 2340 hours during minimum solar activity gave an upper limit for the peak night-side electron density of 10^4 cm^{-3} (*6*). The upper limit derived from the current measurements is of the order of 3×10^4 electrons per cubic centimeter.

Surface properties experiment. The surface properties experiment is predicated on the fact that the electromagnetic signals radiated by the lander antenna at 400 Mhz reach the orbiter both directly and after reflection from the martian terrain as the orbiter rises and sets with respect to the lander. The fading pattern of the signal intensity received at the orbiter therefore contains information on the reflection coefficient of the terrain and hence on the relative dielectric constant ϵ_r and the conductivity σ in the vicinity of the lander. The data for the experiment consist of measurements on the orbiter of the amplitude of the lander-orbiter radio link signals as a function of the elevation angle of the orbiter as seen by the lander.

The data collected with the lander-orbiter link are of good quality and show that surfacing reflections are above the threshold of detectability, with a peak-to-peak relative intensity of several decibels in the fading envelopes for most sols. Reduction of the observations for the first several sols on the lander 1–orbiter 1 link has led to the preliminary conclusion that ϵ_r is 3.5 ± 0.5, and σ is between 10^{-3} and 10^{-5} mho/m in the vicinity of lander 1. These values of ϵ_r and σ are similar to those for pumice or tuff.

W. H. MICHAEL, JR.
A. P. MAYO
W. T. BLACKSHEAR
R. H. TOLSON
NASA Langley Research Center, Hampton, Virginia 23665
G. M. KELLY
Analytical Mechanics Associates, Inc., Hampton, Virginia 23665
J. P. BRENKLE
D. L. CAIN
G. FJELDBO
D. N. SWEETNAM
Jet Propulsion Laboratory, California Institute of Technology, Pasadena 91103
R. B. GOLDSTEIN
P. E. MACNEIL
R. D. REASENBERG
I. I. SHAPIRO
Massachusetts Institute of Technology, Cambridge 02139
T. I. S. BOAK, III
M. D. GROSSI
C. H. TANG
Raytheon Company, Sudbury, Massachusetts 01776

References and Notes

1. W. H. Michael, Jr., D. L. Cain, G. Fjeldbo, G. S. Levy, J. G. Davies, M. D. Grossi, I. I. Shapiro, G. L. Tyler, *Icarus* **16**, 57 (1972).
2. W. H. Michael, Jr., R. H. Tolson, A. P. Mayo, W. T. Blackshear, G. M. Kelly, D. L. Cain, J. P. Brenkle, I. I. Shapiro, R. D. Reasenberg, *Science* **193**, 803 (1976).
3. W. T. Blackshear, R. H. Tolson, G. M. Day, *J. Spacecr. Rockets* **10**, 284 (1973).
4. G. de Vaucouleurs, M. E. Davies, F. M. Sturms, Jr., *J. Geophys. Res.* **78**, 4395 (1973).
5. M. E. Davies and D. W. G. Arthur, *ibid.*, p. 4355.
6. G. Fjeldbo and V. R. Eshleman, *Planet. Space Sci.* **16**, 1035 (1968).
7. We thank T. A. Komarek, J. T. Findlay, E. J. Christensen, C. E. Hildebrand, H. R. Kowitz, and other members of the Viking flight team for assistance and support. Financially supported by the National Aeronautics and Space Administration.

15 November 1976

Mars: Northern Summer Ice Cap—Water Vapor Observations from Viking 2

Abstract. *Observations of the latitude dependence of water vapor made from the Viking 2 orbiter show peak abundances in the latitude band 70° to 80° north in the northern midsummer season (planetocentric longitude ~ 108°). Total column abundances in the polar regions require near-surface atmospheric temperatures in excess of 200°K, and are incompatible with the survival of a frozen carbon dioxide cap at martian pressures. The remnant (or residual) north polar cap, and the outlying patches of ice at lower latitudes, are thus predominantly water ice, whose thickness can be estimated to be between 1 meter and 1 kilometer.*

Over the past several years the subject of the fate of martian volatiles has received much attention. In particular, the question of whether the present thin CO_2 atmosphere with its purported small abundance of water vapor is the result of considerably less degassing than has occurred on the earth, or whether the planet has degassed to a similar extent and the volatiles are stored in the regolith material, has been debated at some length. Much of the background to this argument is summarized by Murray and Malin (*1*). It has been suggested that the bulk (CO_2) atmosphere is stabilized against variations in insolation by the presence of a reservoir of solid CO_2 located within the large residual northern polar cap.

We report here observations of the atmospheric water vapor at extreme northern latitudes, taken from the Viking 2 orbiter, within a few weeks of the northern summer solstice. The total vertical column vapor abundances poleward of 70°N latitude are the largest seen anywhere on the planet to date, and imply near-surface atmospheric temperatures in the polar region which are incompatible with the survival of a CO_2 ice cap. The remnant pole cap seen in the television images, and the outlying patches of ice covering the surface at lower latitudes, are thus predominantly water ice.

Observations. During the first 2 weeks after orbit insertion of the Viking 2 spacecraft (7 August 1976), observations were made by the Mars atmospheric water detector (MAWD) in support of the landing site selection procedure for the Viking 2 lander (*2*). These observations provided the first opportunity during the mission to view the extreme northern latitudes. Throughout the site selection and certification process, Viking 2 was in asynchronous orbit with a period of 27.4 hours, providing a survey of the northern hemisphere by drifting westward at a rate of 40° per revolution. During this phase of the orbiter's activities, MAWD made observations of two types on each of revs 7 through 15: the first of these were constant-longitude swaths from the polar region to about 20°N (the local time chosen for these swaths was approximately 1400 hours); the second set of observations comprised scans of constant latitude along the region 40° to 50°N, a total longitude coverage of about 80° being obtained on each revolution. In this way a complete survey of the nominal landing site latitude was obtained, each point being covered at several local times of day. Taken as a whole, these observations provided an adequate first-order description of the water vapor over the northern hemisphere in terms of its dependence on latitude, local time, and topography at this season (that is, about one martian month past the northern summer solstice).

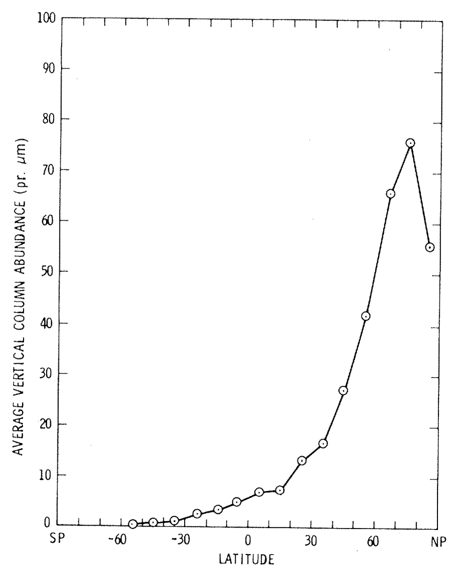

Fig. 1. Latitude distribution of water vapor at 180°W longitude. The column abundances are averaged over 10° of latitude and are taken from observations made between 1200 and 1400 hours local time. The season is northern summer (planetocentric longitude ~ 108°).

On rev 7, the constant-longitude swath scanned the 180°W meridian. The latitude dependence of vertical abundance derived from this sequence, averaged over 10° of latitude, is shown in Fig. 1. Individual measurements contributing to the averages plotted in Fig. 1 have an uncertainty (1 standard deviation) of 10 to 15 percent, depending on the local surface albedo; the corresponding uncertainty in the mean abundance for each latitude band (derived from some 10 to 20 individual records) is ± 4 percent. Included in Fig. 1 are the midday averages determined from the southern hemisphere mapping (*3*) carried out from the Viking 1 orbiter during approximately the same time period; the latter measurements overlap those from the Viking 2 orbiter at 20°N, and the composite result illustrates the strong latitude dependence of the vapor from the extreme winter latitudes—less than 1 precipitable micrometer (pr μm)—to the edge of the summer cap, covering a range of abundances of almost three orders of magnitude. There is a marked increase at about 40°N, the maximum being reached in the polar region at 70° to 80°N. Similar distributions were observed at each of the longitudes scanned, although the values were somewhat smaller than those at 180°W.

As a result of the large abundances observed in the polar region during the initial site certification phase, a set of box scans coupled with an imaging sequence was inserted on rev 22. This was done in order to obtain more detailed data for the polar latitudes before any major change in the atmospheric or surface conditions in that region occurred (*4*). Figure 2 shows the mosaic of seven television images taken on rev 22; water vapor scans were taken before, during, and after the imaging sequence, and hence cover a larger range of longitudes in the vicinity of the cap. In general terms, the data show large areas, coin-