PERSPECTIVES: MARTIAN CLIMATE

A Message from Warmer Times

Matthew P. Golombek

When the Sojourner rover crawled over the Pathfinder landing site on Mars last year, the images returned "indicated that the site had changed little from when it was created by catastrophic floods some 1.8 billion years (Ga) ago (1, 2). This observation provides quantitative constraints on the rate of change at the landing site since that time. The Pathfinder data, taken together with those from the recent Global Surveyor mission and from Viking missions, suggest an early warmer and wetter environment with vastly different erosion rates and a major climatic change on Mars between then and now.

The Pathfinder mission was the first to obtain direct data at a small scale. Remote sensing from Viking spacecraft has provided images of the area where Pathfinder landed (JUL), at a scale of a kilometer or greater. Comparison of these images, such as the image of the Ephrata Fan of the Channelled Scabland (IJU), with an Earth analog suggests that this region on Mars is covered by streamlined hills; a ridge-like, rough rocky surface; perched, overlapping, and partially rounded tabular rocks; and a surface analogous to cataclysmically deposited fans on Earth. These features are consistent with the ones observed by Pathfinder and indicate that the site has altered little since it formed about 3.6 to 1.8 Ga ago (1, 3, 4).

Erosional features such as an exposed former soil horizon, sculpted wind tails, dunes, and other ripple-like lag deposits (IJU) (see figure), and vestigial (stones worn by wind-blown sands) are abundant at the Pathfinder landing site, suggesting that the site has undergone net deflation or loss of material (2, 6). The 5- to 7-cm-thick redder band along the base of several rocks, interpreted to be a deflated soil horizon, and the sculpted erosional wind tails behind rocks that are less than 1.5 cm high (2, 6) suggest extremely low deflation rates, of around 0.01 to 0.08 nanometers (1 nm = 10^-9 m) per year. The ripple-like features and at least some of the dunes, such as Mermaid Dune, appear to be composed of poorly sorted material beneath an armor veneer of dark gray granules, as could be seen in the trenches created by the rover [JUL]. These have been interpreted as lag deposits (7), also indicative of net erosion or deflation of the landing site. The presence of fluted and grooved rocks also argues for erosion by discontinuous flow [JUL] of crystalline sand-size particles carried by the wind (8). In contrast, wind-driven deposition at the Pathfinder site is limited to a few dunes, including a bar-shaped (IJU)-shaped feature imaged by the rover that strongly argues for formation from salting [JUL] sand-size grains (6).

Taken together, these rate estimates for the different features at the Pathfinder site severely limit the overall erosion or deflation of materials to less than 0.1 nm per year (or m/Ga) over the past 3.5 to 1.8 Ga. The rim heights of small craters at the site are similar to those expected for fresh Martian craters. This places similar (<1 m/year), albeit less precise, constraints on erosion rates at the Pathfinder (9) and the Viking 1 (IJU) landing sites (10) and suggests that a old and dry environment, similar to today's, has prevailed since that time (IJU).

A variety of observations by Pathfinder indicate that the earlier Martian climate was warmer and wetter than today's desiccating environment. Rounded pebbles and cobbles (7), evidence for abundant sand-size particles (6), and possible conglomerates (7) at the Pathfinder landing site suggest an early fluvial environment with relatively abundant liquid water. Airborne dust particles collected by the Pathfinder magnetic targets further support this hypothesis (IJU). The particles are composite silicates containing a highly magnetic material interpreted to be maghemite. This mineral may have freeze-dried as a stain of crustal material that had previously leached iron from crustal materials in an active hydrologic cycle. Pathfinder detected sand-size particles at the landing site, whereas none could be seen in lower resolution Viking images. The Pathfinder data suggest that sand-size particles may be abundant on Mars, a conclusion (IJU) consistent with recent Mars orbiter camera high-resolution images (IJU) returned by Mars Global Surveyor (12). On Earth, sand typically forms via water-dominated weathering, erosional and depositional processes that mechanically break down rocks into smaller fragments (13), which may be another indicator of a warmer and wetter past on Mars.

The suggestion that the early Martian environment was warmer and wetter is not new (see, for example, (14)). Valley networks (at least one of which, Nanedi Valles, shows a central fluvial channel in high-resolution MOC (IJU) images, presumably formed by running water) and associated dry lake beds (14); possible shore lines, beaches, and terraces indicating a northern ocean (15); and rimless, degraded craters in ancient heavily cratered terrain (16, 17) have all been described in Viking orbiter images and used to argue for a warmer and wetter past in which liquid water was an integral part of the environment. Erosion rates calculated from changes in crater number and shape formed at x to y years before present (JUL) are 3 to 5 orders of magnitude higher (0.1 to 10 m/year) than those calculated for more recent times, and are comparable to those in some alpine and periglacial environments on Earth (16, 18).

Our knowledge of the Martian surface layer developed from remote sensing observations, image analysis, and observations at the three landing sites (JUL) agrees with the very slow erosion rates described above and suggests that since the Hesperian (IJU), a surface layer with a thickness of up to several tens of meters has been redistributed around Mars (19). This layer likely consists of sand- and dust-sized particles that are collected and transported by the wind (20). Dust can be deposited and
removed at much greater rates than sand
over short time periods [11,20]. For example, deposition of dust on Pathfinder's sol-
lar panels during the 3 months of the mis-
sion has been estimated at roughly 20
µm/year (7, 21). But this value cannot
represent long-term averages, as such high
rates would result in the accumulation of
meters of dust within a comparatively
short span of a million years. However,
there seem to be other areas that are not
sinks for this material. For example, Amazonia Planitia's thermal inertia, radar,
and imaging properties suggest that this is
an area with dust accumulations several
meters in thickness (19). The large region
of sand dunes surrounding the polar cap
may be another sink (20). In contrast, ar-
eas such as the Pathfinder landing site ap-
pear to have been swept clean or even de-
flated. These [21,22] short-term rates of
deposition and removal and longer term
redistribution rates in Late Hesperian and
Amazonian time [22] are on the order of
nanometers per year, comparable in mag-
nitude to erosion rates in the
Noachian [23].

All these data seem to point to a sig-
nificant climatic change at some time in
the past, but when this occurred is not
tightly constrained because of the uncer-
tainties in the proposed crater density time
scales [24] (5). All three landings were in
areas of Early Amazonian to Middle Hes-
perian age [25] and thus document the
present-day dry, desiccating environment
since 3.1 to 3.7 Ga. In contrast, valley
networks appear to be dominantly >3.5 to
3.8 Ga in age (I-4). The impact degrada-
tion of many valley networks further sug-
gests that they may have formed at the tail
end of heavy bombardment about 3.9 Ga
(22). Future missions to Mars, especially
in areas that are sinks for dust material,
should give further clues about past cli-
mate change on Mars [26].

References and Notes
2. P. H. Smith et al., ibid, p. 1758.
9. Big and Little craters [29] in view of the lander
[30] have rim heights of 40 m and 5.2 m, respec-
tively, similar to the expected heights (56 m and 6
m) for fresh Martian craters with diameters of 1.5 km
and 0.15 km. [31, 32] The differences between the
measured and expected heights of these craters are
not statistically distinct, given the measured disper-
sion of fresh Martian crater rim heights. There may
thus have been no erosion of their rims. If the craters
are not significantly younger than the surface, this
limits erosion at the Pathfinder site to <1 mm/year.
Although higher erosion rates are possible if the cra-
ters are much younger than the surface, they are not
argued for by the freshness of the craters [33].
10. R. Arvidson, E. Guinan, S. Lee, Nature 278, 533
(1979).
12. M. C. Malin et al., ibid 279, 1681 [1998].
and I. J. Smalley, Am. Sci. 60, 286 (1972); F. J. Pett-
john, P. E. Potter, R. Siever, Sand and Sandstone
(Springer-Verlag, NY, 1987).
1996).
16. R. A. Craddock and T. A. Maxwell, ibid, p. 3453; —,
A. D. Howard, ibid, 102, 13321 (1997).
17. N. G. Barlow, ibid, 100, 23307 (1995); J. A. Grant and
19. P. R. Christensen and H. J. Moore, In Mars, H. H. Kie-
ffer et al., Eds. (Univ. Ariz. Press, CITY, 1992), pp. 686-
729.
730-766.
22. V. R. Baker and J. B. Partridge, J. Geophys. Res. 91,
3561 (1986).
23. I thank B. Bridges, R. Craddock, R. Greeley, and T.
Parker for helpful suggestions and comments and J.
Maki for exceptional image processing of the figure.
This work was carried out at the Jet Propulsion Lab-
atory, California Institute of Technology under con-
tact with NASA.

When Mars was wet, Mosaic of the Mars Path-
finder landing site and the Sojourner Rover ac-
quired in the late afternoon of sol 2 [32]. The
low sun emphasizes the bright wind tails be-
hind rocks such as Barnacle Bill and others im-
mediately to the left of the rover. The sculpted
areas to the right of the rover are interpreted
as large rock fragments [33]. The impact
process of the figure.

I thank B. Bridges, R. Craddock, R. Greeley, and T.
Parker for helpful suggestions and comments and J.
Maki for exceptional image processing of the figure.
This work was carried out at the Jet Propulsion Lab-