ROCK ABRASION ON MARS: CLUES FROM THE PATHFINDER AND VIKING LANDING SITES.

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Introduction

A significant discovery of the Mars Pathfinder (MPF) mission was that many rocks exhibit characteristics of ventifacts, rocks that have been sculpted by saltating particles [1-3]. Diagnostic features identifying the rocks as ventifacts are elongated pits, flutes, and grooves (collectively referred to as "flutes", unless noted otherwise). Faceted rocks or rock portions, circular pits, rills, and possibly polished rock surfaces are also seen and could be due to aeolian abrasion. Many of these features were initially identified in rover images, where spatial resolution generally exceeded that of the IMP (Imager for Mars Pathfinder) camera. These images had two major limitations: 1) Only a limited number of rocks were viewed by the rover, biasing flute statistics, and 2) The higher resolution obtained by the rover images and the lack of such pictures at the Viking landing sites hampered comparisons of rock morphologies between the Pathfinder and Viking sites. To avoid this problem, rock morphology and ventifact statistics have been examined using new "super-resolution" IMP and Viking Lander images. Analyses of these images show that 1) Flutes are seen on about 50% or more of the rocks in the near field at the MPF site, 2) The orientation of these flutes is similar to that for flutes identified in rover images, and 3) Ventifacts are significantly more abundant at the Pathfinder landing site than at the two Viking Landing sites, where rocks have undergone only a limited amount of aeolian abrasion. This is most likely due to the ruggedness of the Pathfinder site and a greater supply of abrading particles available shortly after the Ares and Tiu Valles outflow channel floods.

The Pathfinder and Viking Landing Sites

The Pathfinder and Viking landing sites are broadly similar, but exhibit important differences. Rock abundances are about 15% at all three sites [4-6]. The soils of the sites consist of drift and more consolidated, soil-like deposits [7]. A few Viking rocks are perched on pedestals of soil, suggesting aeolian scour on the rocks' undersides, as has been observed in terrestrial deserts [8]. Some possible ventifacts in the form of faceted rocks, flutes, and circular to elongated pits are suggested [8-11]. The ventifact-like forms and scouring at the Viking Landing sites imply that aeolian abrasion has modified these surfaces. In contrast, the Pathfinder site contains abundant ventifacts, with 50% or more of the rocks having undergone significant aeolian abrasion [1,2]. The ventifact features are most commonly in the form of flutes. At least one rock, Yogi, lies on a soil pedestal, which could have formed from aeolion scour. There is evidence for sand-sized particles at the Pathfinder landing site in the form of barchan dunes [3], a possible basaltic sand or granule armor on Mermaid Dune [7], and larger-scale dunes visible in MOC images of the landing site. The Pathfinder site is within a depositional flood plain, where abundant sediment would be expected after flood deposition, prior to removal by the wind. In contrast, VL1 is located at the more distal margins of a flood plain whereas VL2 resides within knobby plains unaffected by large-scale fluvial activity [12,13].

Methods

Based on previous analyses of rover images, the width of most flutes at the Pathfinder landing site is less than 2 cm [2]. With IMP's resolution of 1 mrad/pixel and recognizing that flute widths must subtend at least ~10 pixels to be easily identified, only flutes within about 2 m of the lander can be discerned. To increase the detail of flutes visible in nominal resolution IMP images and to extend the range over which the flutes can be identified, "super-resolution" images were studied. To produce these images, multiple IMP frames of the same scene with sub-pixel offsets were co-added [14,15]. The resolution of these images is approximately three times that of nominal IMP images. These super-resolution images were used to identify flutes, after which the 3-D location of the flute endpoints were located in nominal resolution stereo IMP images using the JPL-developed "Showstereo" program. The positions of the flute endpoints was then converted to trend and plunge.

To determine if ventifacts were more abundant at the Pathfinder landing site than at the Viking sites, IMP images were compared to Viking lander frames. This approach avoided the bias inherent in using close-up rover images, which were not available for the Viking sites. IMP's nominal resolution of 1 mrad/pixel is less than Viking's 0.7 mrad/pixel [16]. Therefore, super-resolution IMP images were degraded to Viking's resolution in order to produce comparable resolution images at all three landing sites. At the present time, super-resolution Viking images are being made and compared to un-degraded super-resolution IMP images to identify additional ventifacts in both data sets.

Results

The distribution of flute orientations visible in super-resolution images is shown in Figure 1. Flutes were found on 19 rocks, of which 2 lie in the NE quadrant and 17 in the SW quadrant. All the rocks have radial positions relative to IMP within (14 rocks) or close to (3 rocks) the range of modern directions indicated by wind tails, wind streaks, and the General Circulation Model [3,17,18]. If the flute distribution were random, then it would be expected that flute statistics would be biased to orientations radial from the IMP camera, in this case the NE and SW quadrants. If the flutes were produced by the present wind regime, the clustering would be expected to be even greater within these quadrants. However, of the 35 flutes measured so far in IMP images, 25 (71%) are actually within the NW and SE quadrants. This is indicative of winds blowing SE to NW or NW to SE.

The abundance of ventifacts at the Pathfinder landing can be gauged by examining Figure 2. Shown is a super-resolution IMP image of the western part of the landing site compared to Viking-scale super-resolution and nominal IMP resolution images. Preliminary studies have examined the landing site at Viking-scale resolution through an azimuth range of 190° to 275°. Although representing less than a quarter of the entire site panorama, many ventifacts are found. Flutes are apparent on 19 rocks, including multiple flutes on Geordi (at least 3), Half Dome (≥ 8), Garrak (≥ 3), Mohawk (≥ 2), Grommit (≥ 9), and an unnamed rock (≥ 4). Grooves are also apparent on Flat Top and Flute Top. Other ventifact forms may be present, but to be conservative, are not identified. About 50% of the rocks visible in super-resolution IMP images in the near field are ventifacts.

The multiple flutes and grooves visible at the Pathfinder site contrast with the rock textures at the Viking sites. Although some elongated pits are visible, even the best examples lack long flutes like those at the Pathfinder site [8,10,11]. These observations strongly suggest that ventifacts are more abundant at the Pathfinder landing site than at the Viking sites.

Discussion

The identification of a predominance of SE-NW flute trends in the IMP images agrees with the flute trends identified in rover images [1,2] and strongly suggests that ventifacts at the Pathfinder landing site formed under a wind regime different from that of today. The observations of rock morphology at the Viking sites gives insight into how the Pathfinder ventifacts formed. All three landing sites are about the same age and are therefore expected to have undergone similar weathering events over time. This is especially true for MPF and VL1, which are only ~800 km apart and have similar weather conditions [19]. It is unlikely that the rocks at the MPF site are more susceptible to abrasion than rocks at the Viking sites, for ventifacts form on all major rock types and pitted rocks, which are common at the Viking sites, would be expected to evolve into ventifacts if conditions were appropriate, just as pitted rocks on Earth do [20].

Rather, the rock size distribution and the availability of sand-sized particles are probably responsible for the presence, characteristics, and orientation of ventifacts at the Pathfinder site. The MPF site is more rugged and contains more tall rocks than the Viking sites [17]. Grains saltating at greater heights should be entrained in higher velocity winds for a longer time than grains at lower heights, increasing their momentum and ability to abrade rock surfaces [20]. A supply of abrading particles is an important factor controlling aeolian transport and the formation of ventifacts on Earth [20,21]. A large supply of sand-sized particles capable of abrasion was probably deposited at the mouths of the Ares/Tiu channels, which formed in the late Hesperian to early Amazonian (1.8-3.5 Ga). Because wind directions at this time were probably different than winds of today and because any sand supply should be reduced or become exhausted over time, abrasion by flood sediments is consistent with the discrepancy in wind directions derived from flutes versus those from wind tails, wind streaks, and the general circulation model. This hypothesis also explains the relative lack of ventifacts seen at the Viking sites, where a putative ancient source of sediment is lacking. Ongoing and future studies of ventifacts at the three Martian landing sites should yield additional important information on weathering processes and climate change on Mars.

[1] N.T. Bridges et al., *Lun. Planet. Sci. XXIX*, 1530, 1998. [2] N.T. Bridges et al., *J. Geophys. Res.*, in press, 1999. [3] R. Greeley et al., *J. Geophys. Res.*, in press, 1999. [4] M.P. Golombek et al., *Science, 278*, 1758-1765, 1997. [5] H.J. Moore and B.M. Jakosky, *Icarus, 81*, 164-184, 1989. [6] J.E. Baron et al., *J. Geophys. Res., 103*, 22,695-22,712, 1998. [7] Rover Team, *Science, 278*, 1765-1768, 1997. [8] J.F. McCauley et al., *J. Geophys. Res., 84*, 8222-8232, 1979. [9] A.B. Binder et al., *J. Geophys. Res., 82*, 4439-4451, 1977. [10] Mutch et al., *J. Geophys. Res., 82*, 4452-4467, 1977. [11] Viking Lander Team, *The Martian Landscape, NASA Spec. Publ., SP-425*, 160 pp., 1978. [12] D.H. Scott and K.L. Tanaka, *Geol. Map West. Eq. Mars, USGS Misc. Invest. Ser. Map I-1802-A*, 1986. [13] R. Greeley and J.E. Guest, *Geol. Map East. Eq. Mars, USGS Misc. Invest. Ser. Map I-1802-B*, 1987. [14] T.J. Parker, *Lunar Planet. Sci. XXIX*, 1817, 1998. [15] T.J. Parker, *Fall AGU Meeting, Abstract 5470*, 1998. [16] P.H. Smith et al., *J. Geophys. Res., 102*, 4003-4025, 1997. [17] P.H. Smith et al., *Science, 278*, 1758-1765, 1997. [18] J.B. Pollack et al., *J. Atmos. Sci., 38*, 3, 1981. [19] J.T. Schofield et al., *Science, 278*, 1752-1758, 1997. [20] R. Greeley and J.D. Iversen, ***Wind as a Geological Process***, 333 pp., Cambridge Univ. Press, New York, 1985. [21] S.H. Williams and J.A. Lee, *J. Arid Environ., 30*, 153-160, 1995.

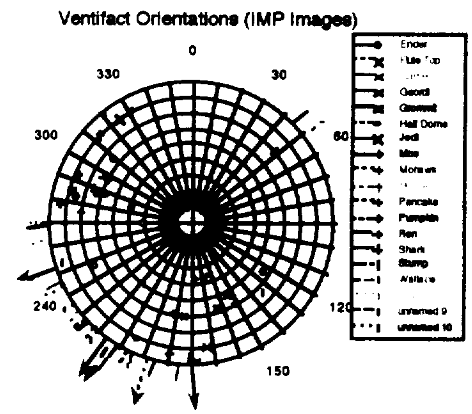

Figure 1: Orientations of flutes seen in IMP images. In this polar projection, flute azimuth in the up-plunge direction is shown as the radial coordinate, with plunge being the circumferential coordinate. Lines projecting outward from the edge of the plot show rock azimuth as viewed by IMP. These lines and the associated symbols for each rock are shown in the legend. Solid arrows are minimum, average, and maximum values of local wind tail directions [3,17]. Arrow with large dashes represents the average trend of wind streaks as seen in orbital images [3,17]. Arrow with small dashes is the predominant wind direction predicted by the general circulation model [3,17,18].

Figure 2: Examples of ventifacts seen at the Pathfinder landing site in nominal IMP resolution (left), super-resolution scaled to Viking Lander camera resolution (middle), and un-degraded super-resolution (right). These rocks are located to the west of the lander. Ventifacts are identified by arrows in the middle frame.