DUST DEVIL VORTICES AT THE ARES VALLIS MPF LANDING SITE

S.M. METZGER, Desert Research Institute, Quaternary Sciences Center, 7010 Dandini Blvd., Reno NV, 89512, metzger@scs.unr.edu

INTRODUCTION Mars Pathfinder (MPF) landed near the outlet of the Ares Vallis outflow channel into the Chryse Planitia depositional plain. Based on terrestrial field studies of dust devil vortices [1,2], the identification of dust devils on Mars [3,4,5], various predictions regarding regional surface geology in Ares Vallis [6,7,8], and the repeated passage of pressure and wind shift excursions over the Pathfinder ASIMET mast [9], it is reasonable to expect observable dust devil activity and resultant geomorphic effects at the MPF landing site. With the exception of a single sun-sensor occultation event (M. Golombek, GSA presentation, 1997), however, dust devil columns are not readily apparent in the MPF images. Why?

Although the contribution of dust devils to the global aeolian sediment transport system is not yet articulated, it is potentially considerable [10, 11]. Their ability to entrain fine material from crusted as well as unconsolidated surfaces, even when forced-convection wind speeds are below threshold [12,13], could explain much of the dust activity on Mars.

DUST DEVIL VORTICES Dust devils are localized vortical air columns which form when insolation bearing upon an arid surface results in an unstable hot layer of ground-level air that generates rotating thermal plumes [15]. Sinclair [15] found that dust devils typically auto-initiate as a vortex on calm days when gentle winds were not sufficient to disperse the hot ground-level air. Hallett and Hoffer [16] proposed that dust devil vortices could form when gusts spun off eddy vortices in their wake, especially when flowing across a topographically irregular surface; once initiated, thermal plumes would sustain the vortex [1]. Dust devil columns may extend up to several km in height whereupon the particulates can be transported great distances by winds above the planetary boundary layer.

Ryan and Lucich [3] interpreted Viking Lander data to infer at least 4 vortices had developed. Thomas and Gierasch [4] identified ~100 dust devils, using Viking Orbiter images. Dust column heights reached 1 to 6 km above the Martian surface with maximum reported widths of several km. They calculated that the average dust devil was lofting 3×10^3 kg of dust (10 μm). An on-going survey of Martian dust devils recorded in Viking Orbiter imagery has tallied over 200 examples to date in the n. hemisphere [5]. Although MPF arrived in the middle of Summer when the regional winds were gentle [14], numerous local dust storms have been observed in the Chryse basin at this season [17,18,19].

TERRESTRIAL ANALOG STUDIES Terrestrial investigations were conducted in Eldorado Valley, Nevada, a closed playa basin flanked by ridges of basalt and granitic gneiss. A state-wide survey failed to reveal a single Nevada basin or valley where dust column vortices did not develop at some time. The largest columns attained widths of 100 m and over 2 km height. Many lasted for tens of minutes and traveled several kilometers. Dust devils would form under wind conditions that ranged from calm to sustained winds of 8 m/s, gusting to 16 m/s (measured at 2 m). Rotational velocities in several dust devil vortices exceeded 25 m/s, vertical velocities achieved 10 m/s (measured at 2 m height). When a defined center developed in a tubular column dust devil, vortex-center air pressures were often lower than ambient by 7.0 mbar (0.8 % of ambient).

Dust devils rarely formed on the proximal alluvial plain (2% of total occurrences; % defined on geomorphic surface type, as opposed to areal extent). The medial plain was highly productive (57%) while the basin's center playa was moderately so (16%). Intense dust-free vortices were observed at several locations across Eldorado Valley which did not develop dust columns.

A vacuum collection technique determined the availability of loose sand (2.0 mm - 106 μm) and fines (< 106 μm) on the surface. The primary conclusion is that sand, and fine silt and clay are available on all surfaces across the valley. The surficial material found on the proximal alluvial plain (sand 4.1 g m^{-2}, fines 1.7 g m^{-2}) was far less that that of the medial (sand 36.4 g m^{-2}, fines 12.0 g m^{-2}) and distal (sand 20.1 g m^{-2}, fines 6.8 g m^{-2}) areas. There was at least 4 g m^{-2} of sand on the playa available to act as abrasive tools during a strong wind event.

Although in most cases the mean rock dimensions in Eldorado Valley are smaller than those described at the Viking [20] and MPF lander sites, numerous dust devil-active areas in the terrestrial study site had rocky surfaces that match the Martian surfaces quantitatively and visually. In particular, Golombek and Rapp [8] calculate the Ares Vallis region to have a rock abundance of 20% whereas the terrestrial medial alluvial fan has a rock abundance of 19% and experiences a high level of dust devil activity (57%).

Surface strength is described in terms of its resistance to penetration and torque. Whereas the medial alluvial plain had little penetration and torque strength (0.80 kg cm^{-2} and 0.09 kg cm^{-2}, respectively), the playa was strongly crusted with resultantly high penetration and torque strength (2.66 kg cm^{-2} and 0.28 kg cm^{-2}, respectively). Regardless, dust devils were common and large over both surfaces.

The saltation friction speed threshold (u_{*t}) and surface aerodynamic roughness length (z_0) were determined using a portable field wind tunnel ("WT U*t" and "WT Zo" respectively). A profiling meteorology mast determined surface aerodynamic roughness lengths ("MetMast zo") for the same locations as the wind tunnel but included influences, such as vegetation and local topographic factors, than the tunnel could not handle. The playa u_{*t} is lowest at 0.66 m s^{-1} but only 16% of the dust devils form there. The next lowest u_{*t} (0.84 m s^{-1}) occurs on the medial alluvial plain where the majority of dust devils form (57%). The distal alluvial plain produces a moderate number of dust devils (25%) yet it has a high saltation friction speed threshold and aerodynamic roughness lengths (WT u_{*t} 1.40 m s^{-1}, WT z_0 0.0042 m, and MetMast z_0 0.2890 m).

All the sites had some quantity of sand and silt/clay "fines". The sand appears to provide either a mechanism to splash the dust off the surface via impact ejection or to abrade dust free from a cohesive crust. Additionally, highly porous sand may provide a reservoir of "over-pressured" air once a low-pressure vortex moves briskly across it. This could result in rapid outgassing which in turn greatly reduces the Bernoulli effect wind speeds necessary to entrain soil particles. Strongly bonded crusts, such as some portions of the playa, are not obvious sources of entrainable dust. They may only shed fines when exposed to intense saltation abrasion. Similarly, surfaces with considerable rock coverage are also not obvious sources of entrainable dust. The very presence of those rocks may provide a dust source, however. Goossens [21] demonstrated that dust accumulates several tens of times greater on rocky surfaces than on rock-free surfaces but that less than 20% of such dust is stabilized and retained, 80% is resuspended or washed away. Furthermore, although rocks are usually assumed to increase the surface's frictional drag on the boundary-layer wind and lower the shear stress which can be applied to the bed, it may also locally focus wind energy between large rocks or initiate turbulent gusts and eddies with velocities considerably above average regional wind speeds. Thus, in the absence of vegetation, all but the very rockiest of surfaces are likely to experience significant aeolian transport.

CONDITIONS AT THE ARES VALLIS LANDING SITE Viking orbiter Infrared Thermal Mapper (IRTM) data has been analyzed by Edgett and Christensen [6] to predict the extent of rocks, sand and dust throughout the Ares Vallis region. They report that albedo is intermediate, thermal inertia is intermediate-to-high and rock abundance is high (18-25%). These characteristics make the Ares Vallis site slightly rockier than the Viking 1 lander site and closer in rock abundance to the Viking 2 lander site. They stress the high probability that the region is covered by a heterogeneous mixture of rocks, sand and fines, as are the Viking lander sites. Haldemann et al [7] report on earth-based radar surveys across the MPF landing ellipse. They find the site to be similar to the Viking 1 landing area in the degree and spatial scales of surface roughness elements. Using these remote sensing reports, evaluation of the near-field rock abundances at the Viking lander sites and various terrestrial studies, Golombek and Rapp [8] calculated that Ares Vallis region rock abundances will not exceed ~20% and interpret the landing location to be a heterogeneous mixture of rocks and finer materials, similar to that seen by Viking. After touchdown, MPF images validated these estimates.

The Ares Vallis site and the Viking 1 landing site are both located in the Chryse Planitia basin. Frictional wind velocities (u_*) in the Viking-observed Dust Storm of Sol 1742 were estimated at 2.2-4.0 m/s (which at the sensor boom would translate to 40-50 m/s). Moore [22] calculates that the storm's erosion results could have taken as little as a few tens of seconds to achieve. Indeed, such a brief yet intense period of erosion is a good description of the dust devil process. Ryan and Lucich [3] interpreted meteorology data to infer that several dust devil vortices had passed over the Viking landers.

MPF results included the near daily passage of thermal vortices over the meteorology mast (9). These involved radical swings in wind direction and speed as well as pressure drop spikes of 50 microbars (approximately 0.7 % of ambient pressure). On one such event, a sensor recorded a dip in light intensity (M. Golombek, GSA presentation, 1997); otherwise, no dust columns have been recognized to date in horizon imagery (although only one image series was specifically targeted to do so).

CONCLUSIONS The MPF site has the appropriate rock, sand, and silt abundances to enhance temporary dust storage, initiate eddies, and provide abrasive tools to dislodge encrusted dust. Mid-day heating of the fan surface, aided by low albedo rock surface weathering products was clearly sufficient to promote the formation of thermal vortices with pressure structures equal to terrestrial dust devils. The apparent lack of predicted dust devil columns [2] may therefore be partly attributable to highly bonded crusts, "sieve deposits" that reduced soil porosity (and with it the soil atmosphere reservoir), weak local winds that were unable to trigger eddy vortices, and perhaps an imaging strategy less optimal for a dust devil search. None the less, when numerous thermal vortices sweep across a single sensor array on a daily basis, providing a variety of particle lift and entrainment mechanisms, they are very likely to be playing a substantial role in the dynamic global dust transport system on Mars.

References [1] Metzger & Lancaster, 1995, EOS 76, F66. [2] Metzger & Lancaster, 1996, LPSC 27, 873. [3] Ryan & Lucich, 1983, JGR 88, 11005. [4] Thomas & Gierasch, 1985, Sci 230, 175. [5] Wennmacher et al, 1996, LPSC 27, 1417. [6] Edgett & Christensen, JGR Planets MPF, 1997. [7] Haldemann et al, JGR Planets MPF, 1997. [8] Golombek & Rapp, JGR Planets MPF, 1997. [9] Murphy et al, AGU Fall Mtng, 1997. [10] Gierasch & Goody, 1973, JAtmosSci 30, 169. [11] Kahn et al , 1992, *in* Mars, 1017. [11] Ryan & Carroll, 1970, JGR 75, 531. [13] Gillette et al, 1980, JGR 85, 5621. [14] Greeley et al, 1993, JGR 98, 3183. [15] Sinclair, 1966, UofAZ Dissert. [16] Hallett & Hoffer, 1971, Weather 26, 247. [17] Peterfreund, 1985, ASU PhD Dissert. [18] Beish & Parker, 1990, JGR 95,14657. [19] Martin & Zurek, 1995, JGR 98, 3221. [20] Moore et al, 1979, JGR 84, 8365. [21] Goossens, 1995, Sed 42, 391. [22] Moore, 1985, JGR 90, D163.