CLIMATE CHANGE ON MARS INFERRED FROM EROSION RATES AT THE MARS PATHFINDER LANDING SITE. M. P. Golombek and N. T. Bridges, Jet Propulsion Laboratory, Pasadena, CA 91109

Introduction: The observation that the Mars Pathfinder landing site probably looks very similar to when it was deposited by catastrophic floods some 1.8-3.5 Ga [1, 2] allows quantitative constraints to be placed on the rate of change at the landing site since that time. When combined with interpretations of data recently returned by the Mars Pathfinder and Global Surveyor missions and perspectives drawn from 20 years of analysis and interpretation of Viking data, these observations and inferences suggest an early warmer and wetter environment with vastly different erosion rates and a major climatic change on Mars.

Landing Site: Remote sensing data generally at a scale greater than ~1 km and an Earth analog correctly predicted the Pathfinder site would be a rocky plain composed of materials deposited by catastrophic floods [1]. The surface is composed of subangular to subrounded pebbles, cobbles, and boulders, and generally resembles a surface produced by catastrophic floods, such as the Ephrata Fan in the Channeled Scabland of Washington State [1]. From the lander, the Twin Peaks look like streamlined islands and rocks in the Rock Garden may be imbricated or inclined blocks generally tilted in the direction of flow [2]. The general similarity to analogous surfaces on Earth as suggested in orbiter remote sensing data argue that the site has undergone minor alteration [3] since it formed in Late Hesperian/Early Amazonian time [4] (estimated to be 1.8-3.5 Ga [5]).

Aeolian Features and Environment: The abundance of erosional features such as an exhumed former soil horizon, sculpted wind tails, duneforms and other ripple-like lag deposits, and ventifacts all suggest the site has undergone net deflation or loss of material [2, 6]. A 5-7 cm thick redder band along the base of several rocks appears to be a former soil horizon that has been deflated or exhumed. The sculpted shape of numerous wind tails behind rocks and pebbles also suggests they are predominantly erosional as opposed to the bulbous shape expected of wind tails formed by deposition [6]. Ripple-like pebble features at the site and at least some of the dunes, such as Mermaid Dune, are interpreted to be lag deposits [7] indicative of net erosion or deflation of the landing site. The presence of ventifacts, or fluted and grooved rocks also argues for erosion by saltating crystalline sand-size particles entrained in the wind [8]. All of these features suggest that the landing area has been dominantly scoured by the winds and thus is a zone of net deflation or erosion and removal of surface fines.

In contrast, aeolian depositional features at the Pathfinder site are limited to a few duneforms, including a barcan-shaped feature [6] that likely resulted from redistribution of predominantly locally derived sand-size material. The ventifacts probably formed soon after the catastrophic flood, which likely introduced a large, fresh supply of sand-size particles distributed across the rocky plain. The orientation of the ventifacts, northeast-southwest oriented dunes within Big Crater, and possibly eroded northwest sector of small crater rims all suggest the strongest winds were oriented southeast-northwest during this time [8, 9]. Later strong winds from the northeast to the southwest, completed the deflation of the surface, deposited sand-size material in dunes and ultimately trapped these dunes in lows.

Deflation Rates: The inferred depth of deflation at the site can be used to estimate the deflation rates since the surface formed some 1.8-3.5 Ga, which provides an estimate of the efficiency of erosional processes on Mars in Amazonian time. The 5-7 cm thick deflated soil horizon and the 3 cm thick wind tails suggest extremely low (0.01-0.04 nm/yr) deflation rates. Crater rim heights seen from the lander are similar to those expected for fresh Martian craters, placing similar, albeit less precise constraints on erosion rates. Big and Little craters in view of the lander have rim heights of 40 m and 5.2 m, respectively, which are similar to the expected heights (56 m and 6 m) for fresh Martian craters with diameters of 1.5 km and 0.15 km [10]. The differences between the measured and expected heights of these craters are not statistically distinct [10], so there may 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 nm/yr, which is the same result determined from crater rim heights at the Viking 1 landing site [11]. Higher erosion rates are permissible if the craters are much younger than the surface, but the existence of dunes inside Big Crater apparently formed in the older, northwest-southeast wind direction argues against this. These observations and calculations severely limit the erosion or deflation of materials at the Pathfinder and Viking 1 landing sites to <1 nm/yr and more likely <0.1 nm/yr or mm/Ma or m/Ga in the past 1.8-3.5 Ga at the Pathfinder site and suggests that a cold and dry environment, similar to today's, has prevailed since that time.

These deflation rates are long term averages and the actual time during which the deflation occurred is not known. It could be argued that the site has undergone repeated burial and exhumation, with the observed deflation occurring during the most recent cycle. In this scenario, burial by possible migrating dunes or other sediments would be removed by later winds. We consider this scenario unlikely because sand dunes are isolated masses of sand size particles that would not leave wind tails or soil horizons. In addition, without some cementing agent, such as water, it is not clear how a dust layer could be deposited that would preferentially stick to the lower horizons of rocks, suggesting that the soil horizon dates back to the floods and that the derived erosion rates are reasonable long term averages.

Early Warmer/Wetter Environment: In contrast to the desiccating environment of today, a variety of observations by Pathfinder support an earlier climate that was warmer and wetter. Rounded pebbles and cobbles [7], evidence for abundant sand-size particles [6], and possible conglomerates [7] observed at the Pathfinder landing site suggest an early fluvial environment that was warmer and wetter than today, perhaps with liquid water in equilibrium with the environment. Airborne dust particles collected by the Pathfinder magnetic targets further support this hypothesis [12]. The particles are composite silicates with a highly magnetic mineral preferentially interpreted to be maghemite that may have freeze dried as a stain or cement from liquid water that previously leached iron from crustal materials in an active hydrologic cycle. Trapped dunes, likely composed of sand size particles, are found at the Pathfinder landing site and appear abundant elsewhere on Mars both at the scale of Viking and Global Surveyor images [13]. Sand on Earth typically forms via fluvial processes that mechanically break down rocks into smaller fragments [14], which may be another indicator of a warmer and wetter past. The suggestion that the early Martian environment was warmer and wetter is not new [e.g., 15]. Valley networks (at least one of which, has a central fluvial channel formed by running water in high resolution MOC images) and associated dry lake beds [15], possible strand lines, beaches and terraces inferring a northern ocean [16], and rimless, degraded craters in ancient heavily cratered terrain [17, 18] have all been described in Viking Orbiter images and used to argue for a warmer and wetter past in which liquid water was stable with the environment. Erosion rates calculated from changes in Noachian age crater number and shape are 3-5 orders of magnitude higher (0.1-10 micron/yr) [17, 19] than those calculated for more recent times abd are comparable to slowly eroding environments on Earth.

Martian Surface Layer: Our knowledge of the Martian surface layer developed from remote sensing observations, image analysis and observations at the three landing sites agrees with the very slow erosion rates described above and suggest that since the Hesperian a surface layer of order meters to up to several tens of meters thick has been redistributed around Mars [20]. This layer likely consists of sand and dust size particles that are entrained and moved by the wind [21]. Dust can be deposited and removed at much greater rates over short time periods. For example, deposition of dust on Pathfinder's solar panels during the 3 month mission has been estimated at roughly 20 mm/yr [22], which cannot represent long term averages as such rates would result in meters thick accumulations of dust within a comparatively short span of a million years. Other areas may be net sinks for aeolian material such as areas like Amazonis Planitia, whose thermal inertia, radar and imaging properties suggest an area with meters thick accumulations of dust [20] or the north polar erg, a large region of sand dunes surrounding the polar cap [21]. Other areas such as the Pathfinder landing site appear to have been swept clean or even deflated.

Climate Change: Constraints on when the suggested climate change occurred are not tightly bound due to uncertainties in the proposed crater density time scales [5]. All three landers are on units of Early Amazonian to Middle Hesperian age and thus document the present day dry, desiccating environment since 3.1-3.7 Ga. Valley Networks appear to be dominantly Noachian in age [15], which places them at >3.5-3.8 Ga. The impact degradation of many valley networks further suggests that they may have formed at the tail end of heavy bombardment around 3.9 Ga [23].

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