PATHFINDER LANDING SITE: ALTERNATIVES TO CATASTROPHIC FLOODS AND AN ANTARCTIC ICE-FLOW ANALOG FOR OUTFLOW CHANNELS ON MARS. B.K. Lucchitta, U.S. Geological Survey, 2255 N. Gemini Drive, Flagstaff, AZ 86001. E-mail: blucchitta@flagmail.wr.usgs.gov

Introduction

The Pathfinder spacecraft landed successfully at the mouth of the outflow channels Ares and Tiu Valles, returning a wealth of information about the surrounding landscape [1]. One goal of the mission was to ascertain that catastrophic floods formed the outflow channels, the prevailing hypothesis for their origin [2]. The follow-up reports on the mission [1,3] proclaim that observations are "consistent" with an origin by catastrophic flood; no alternative mechanisms for channel origin are considered. Thus, the impression is given that the problem of channel origin has been solved. Yet none of the observations are diagnostic of origin by catastrophic floods. Other origins are possible but have been ignored, for instance origin as liquefaction mudflows [4,5], debris flows [6,7], mass flows [8], or ice flows [9,10]. Here I will examine landing site observations that have been used to infer origin by catastrophic flooding [1,3] and suggest alternative origins. Finally, I will highlight some new observations from Antarctica that make an ice-flow mechanism plausible for the origin of some of the outflow channels.

Landing site observations

The following observations were used as evidence that catastrophic floods shaped the landing site. <u>The rocky surface is consistent with being a depositional plain.</u> Pre-mission analyses of rock distributions were conducted by Golombek and Rapp [11] for various landscapes, including catastrophic-flood plains, alluvial fans, an eroded volcanic surface, and the Viking 1 and 2 landing sites. Curves of cumulative number of rocks versus rock diameter and of cumulative fraction of area covered by rocks versus rock diameter were generated for the various areas. The curves dominantly reflected rock fragmentation laws from fracturing of rocks due to weathering or transport [11]; they were less diagnostic for processes of emplacement of rocks. Even though the Mars Pathfinder curves are similar to those of catastrophic-flood deposits, they more closely resemble those of an ancient alluvial fan. The results are consistent with rock emplacement in a depositional environment, but they do not indicate that catastrophic floods formed the Pathfinder landscape. <u>Large rocks (>0.5 m) appear tabular and semirounded.</u> Images showing the surface of the Ephrata Fan of the Channeled Scabland of Washington State, a deposit of catastrophic flooding (Fig 6 in Rice and Edgett [12]) show many more rounded boulders than seen at the Pathfinder site. Also, cross-sectional outcrops of catastrophic-flood deposits are loaded with rounded cobbles and boulders. The semirounded boulders at the Pathfinder site are not very abundant; those that occur could have formed in debris flows or glaciers, or in any other mass movement with corrosive ability. <u>Rocks in the Rock Garden may be imbricated blocks generally tilted in the direction of flow.</u> Imbrication can be expected in any material transported by a fluid. The minor possible imbrication observed could have formed equally well by debris or ice flows. <u>Rocks appear perched.</u> Some of the perched appearance may be due to the acknowledged local deflation in the area of 5 to 7 cm [3]. Perched rocks are common on glacial moraines.

<u>The Twin Peaks appear to be streamlined hills in lander images. A gentle ridge trends northeast from the hills.</u> On Earth, streamlined hills of the dimensions seen on martian images are more commonly formed by flowing ice (drumlins) than by floods, as are long ridgelike tails behind obstacles (drumlinoid forms). Given the right material, streamlined forms can also be formed by wind (yardangs). The streamlined, flood-eroded hills in the Channeled Scabland are composed of easily erodible loess [13]. The Twin Peaks, one of which may show layering, could be composed of basalt, consistent with surface material covering many plains on Mars, or of older mass-flow deposits [8]. Streamlining would require larger discharges than those of the Channeled Scabland floods to accomplish erosion of these materials, which are more resistant than loess, but estimated discharges for the landing site are not that large (see below). <u>Boulder trains on the twin hills resemble landforms found in the lee of obstacles in large terrestrial floods.</u> Boulder trains also occur on alluvial fans and are common downslope from outcrops on steep slopes, especially in a periglacial environment. They are also associated with glacial deposits. <u>The northern Twin Peak is banded with possible terraces.</u> The use of the word terraces implies river or flood activity. Yet the banding could equally well be layers, as the Ares and Tiu Valles are carved into highland plateaus that are locally surfaced by basalts [14]. The light color could well be drift deposited on benches. The abrupt termination of the layers on the upstream side of the hill is consistent with erosion by glaciers at the stoss side of drumlins, and the banding could be glacial grooves. The vertical stripe on the southern Twin Peak could be sand from kame deposits. However, these suggestions are very speculative.

<u>The Pathfinder site has a pronounced ridge-and-trough texture, with amplitudes as high as 5 m and 15 to 25 m crest-to-crest.</u> Ridges in flow directions are found in landslides, debris flows, and glacial flutes. For instance, flutes at the base of Antarctic ice streams in till are about 8 m in relief [15], similar to the relief at the landing site. However, the Antarctic grooves are wider than those at the Pathfinder site. <u>Ridges and trough trends comparable</u>

with the large-scale Tiu and Ares flow directions are modestly expressed. Debris flow and ice flow would also give a texture in the main flow direction. In addition, the fairly disordered topography showing enclosed depressions [1, Plate 4] resembles a morainal surface more than a fluvial one.

Flow velocities at the landing site are computed to have been about 8 m/s and the flow depth 10 to 20 m. These values are inferred from the size of the largest boulders transported and from the local topographic slope [16,17,18]. Smith et al. [3] admit that these depths and velocities do not agree with those commonly used or computed for catastrophic floods on Mars and that they are more like those of large floods in Iceland and Washington State. This velocity is 3 to 10 times less than that generally inferred for floods on Mars. Yet, a 15-km-long tail behind a hill only 30 km south of the site (Far Knob) suggests that floods in the landing area were just as energetic as martian floods elsewhere. Discharges at the landing site are estimated to have been between 10^6 and 10^7 m^3/s in the immediate vicinity of the lander. These values are estimated from the generally small size of the inferred bed load at the landing site. Again, Smith et al. [3] state that these values are one to two orders of magnitude smaller than previous estimates for floods in Ares Valles [19]. The discrepancy is explained by proposing that deposition at the landing site reflects a waning phase of flooding resulting in late-stage deposition [3], comparable, for instance, to what can be observed in floods in Iceland [20]. The landing site surface characteristics are also likened to those of the Ephrata Fan of the Channeled Scabland, a plain of deposition from catastrophic flooding. However, there is no clear evidence that the landing site is indeed located in a basin of deposition, as shown by the tail behind Far Knob. Landforms in the landing-site region suggested to Komatsu and Baker [19] that flood power was expected to be very high. What is clear is that the landing site characteristics do **not** match those expected for a deposit from a catastrophic megaflood.

In conclusion, the Pathfinder landing site characteristics may be consistent with an origin by catastrophic flooding, but none of the observations are diagnostic. An origin by debris flows or by rock-laden ice flows is just as likely. Considering that ice flow is a possibility, I present below some new data from Antarctica that support the ice-flow idea.

Antarctic ice-flow analog

It is commonly accepted that some form of ice flow occurred in the fretted channels [10,21,22], but the influence of ice flow on landscape development in the outflow channels is generally relegated to a minor, subordinate role [23,24]. An exception is the hypothesis by Lucchitta et al. [9] and Lucchitta [10] that suggests that ice sculpture in the outflow channels may have played a major role. The following observations from Antarctica support this contention. Sounding of the sea floor in front of the Ross Ice Shelf in Antarctica recently revealed large persistent patterns of longitudinal megaflutes and drumlinoid forms [25], which bear remarkable resemblance to longitudinal grooves and highly elongated streamlined islands on the floors of martian outflow channels. The flutes are interpreted to have formed at the base of ice streams during the last glacial advance [25]. The Antarctic ice streams are thought to slide over longitudinally grooved, deforming till, where much of the movement is within the till [15]. The till is saturated with water at high pore pressures that nearly supports all of the weight of the ice [15,26]. A similar mechanism of sliding may have operated at the base of outflow channels on Mars. It could have permitted the movement of rock-laden debris that may have crept through the outflow channels (like the fretted channels) at some stage in their early development, or it could have aided flow of ice derived from cleaner water erupted from springs or flowing from lakes.

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