MARS PATHFINDER LANDING SITE: REGIONAL GEOLOGY AND MASS-FLOW INTERPRETATION. K. L. Tanaka, U.S. Geological Survey, 2255 N. Gemini Dr., Flagstaff, AZ, 86001, ktanaka@flagmail.wr.usgs.gov

Introduction. The spectacular images returned by Mars Pathfinder reveal a landing site that has become quite familiar to the science community and public at large. Rocks, ridges and swales, distant hills, and reddish soils characterize the landscape. The Pathfinder mission team has suggested that the landing site setting and landscape are consistent with a deposit formed by catastrophic flooding and later modified by impact cratering, weathering, and eolian processes [1-2].

However, others have suggested different mechanisms for sedimentary transport and emplacement of the deposit on which Pathfinder landed, including ice flow [3] and mass (debris) flows [4]. Here, I review and discuss regional geologic constraints based on detailed stratigraphic mapping of the Chryse basin deposits as a framework for interpreting the local geology of the Pathfinder landing site (PLS).

Stratigraphic approach. Mapping of the Chryse Planitia region at local to global scales based on Viking images has, until recently, largely resulted in geomorphic rather than stratigraphic units [e.g., 5-6]. These earlier studies failed to discover key unit contacts, and therefore have limited value in addressing the origin and extent of sedimentary units in the basin and in reconstructing the basin's geologic history. Rather, they merely outline areas dominated by morphologic traits thought to represent material units, but some of the traits may be repeated for different deposits.

Recently, I began remapping the northern plains of Mars, including the Chryse region, using where possible a stratigraphic approach [4, 7]. I have been successful in identifying several stratigraphic units by tracing unit contacts defined by distinctive embayment and overlap features. However, as is common in martian geologic mapping, the contacts appear gradational or obscure in places due to their original nature, secondary modification, or available image quality.

Regional geologic history. My preliminary stratigraphic mapping of Chryse basin [4] shows a succession of at least five broad plains units, separated in some cases by pendant bars, terraces, and longitudinal ridges largely indicative of erosional events. The units and features and their stratigraphic relations form the basis for the following discussion of the geologic history (from oldest to youngest) in the vicinity of the Pathfinder landing site (PLS):

Unit HNr. The oldest plains unit in Chryse basin is the Late Noachian to Early Hesperian [4] ridged plains material (unit HNr), possibly made up of lava flows or early sedimentary deposits. The unit covers much of western Chryse Planitia and may form some of the streamlined bars in southeastern Chryse. The remaining plains units, according to crater counts [6], are Late Hesperian to Early Amazonian.

Unit AHc_1. Along the eastern edge of Ares Vallis, the first of the younger plains units emplaced in Chryse Planitia (unit AHc_1) is mostly featureless except for scattered wrinkle ridges and knobs. The unit is dissected by Ares Vallis, whose floor is characterized by longitudinal grooves. The floor may consist of unit AHc_1 or ridged plains material (unit HNr).

Unit AHc_2. Remnants of another plains deposit (unit AHc_2) can be found overlying the longitudinal bedforms within lower Ares Vallis and forming degraded bars in east-central Chryse Planitia north of PLS. The highly degraded state of this unit, which includes pits and irregular scarps, may be due to thermokarst, suggesting that the unit was initially ice-rich. Its streamlined bars north of PLS indicate that the material was dissected by erosional agents emanating from Simud and Tiu Valles.

Unit AHc_3. A thin plains unit (unit AHc_3) apparently buried lower parts of Chryse Planitia, particularly whereever unit AHc_2 had been eroded away. In places, this unit has observable bounding scarps apparently formed by viscous flow. Additionally, the unit includes possible sedimentary (mud) volcanoes southwest of PLS [4, 8]. My further reassessment of this unit indicates that it may be more widespread than previously mapped, perhaps covering part of northwestern Chryse Planitia.

Unit AHa. Material of unit AHc_3 is partly buried by another flow deposit that covers much of Acidalia Planitia (unit AHa), having flowed southward into northern Chryse. This unit may have originated from the vicinity of Acidalia Mensa (47°N, 24°W), more than 1,000 km north of the southern margin of the unit. Alternatively, the unit is an extension of unit AHc_3 that has backflowed over itself [4].

Landing-site geology. PLS occurs on unit AHc_3, which appears to bury the longitudinal ridges and grooves of lower Ares Vallis; however, a marginal scarp for unit AHc_3 south of PLS cannot by discerned in the ~40 m/pixel Viking images of this area to prove this relation. However, north of PLS, subtle marginal scarps and ridges of unit AHc_3 do appear to embay the edges of high-standing remnants of unit AHc_2 and the south edge of Wabash crater north of PLS. These observations are consistent with emplacement of unit AHc_3 by mass flow. If unit AHc_3 had been deposited by catastrophic flooding, it could be expected that a huge, temporary lake formed in Chryse Planitia, which would have produced paleoshoreline features along its margin; however, no such features are seen [9]. Unit AHc_3 appears to originate hundreds of kilometers south of PLS within the broad, interconnected Simud and Tiu Valles system.

The longitudinal grooves on the floor of Ares Vallis south of PLS probably predate the geologic event that ultimately resulted in the emplacement of unit AHc_3. The uncertainty in their relative age rests on whether or not the outcrops of unit AHc_2 in lower Ares Vallis truly correlate with those embayed by unit AHc_3 farther north. If it turned out that the grooves were associated with unit AHc_3, they have both catastrophic flood and glacial analogies on Earth [3, 10]. Roller vortices have been cited to cause such grooving. Theoretical considerations of roller vortex development in geologic agents for upper Tiu Vallis suggest that such vortices could have formed within debris flows having velocities of 10^{-2} to 10^{2} m/s [11]. However, pure-water flows would require unrealistically low velocities of less than 10^{-6} m/s to generate them [11].

About 300 km north of PLS, unusual curvilinear ridges occur within subtle troughs that have been interpreted as pressure features within ice streams [12] or some sort of deformation along the margin of a mass-flow deposit [4]. This mechanism may be analogous to the ice-stream mechanism but by ice-rich frozen debris moving over unfrozen, viscous material. Because these occur within unit AHa, they are not necessarily related to the emplacement of unit AHc_3, unless the backflow interpretation is correct. If the deformed material were made up mainly of ice, the ice should have largely sublimated by now, producing a thermokarst terrain. Since the material appears well preserved, any contained ice should have been mainly interstitial within a sedimentary matrix.

Emplacement of boulders at PLS. Pathfinder imaged near-field rocks up to meter-size superposed on rolling topography and distant hills (the Twin Peaks) showing possible boulder trains [2]. Rock-size distributions heavily laden with large cobbles and boulders with various degrees of rounding and preferred orientation can be produced by a variety of sedimentary processes, including floods, mass (debris) flows, and ice flows [3]. Mass and ice flows can raft large boulders because of the strength and density of the debris or ice, and therefore appear to be plausible mechanisms for depositing the rocks at PLS as long as they had sufficient mobility to travel down the lengths of the outflow channels and across Chryse Planitia.

Floods can also move boulders if the stream energy and bed shear stress are sufficiently high. At PLS, considerable uncertainty exists in constraining the parameters involved in calculating the bed shear stress, such as slope and hydraulic cross section. However, Komatsu and Baker [13] placed an upper limit of 1 m for rocks that could have been moved by flooding through a narrow section of upper Ares Vallis. Because lower reaches of Ares Vallis are wider and presumably flatter, the clast size that could have been transported by a flood would have been reduced. Finally, where Ares (and other outflow channels) opens up into Chryse Planitia, transportable clast size would decrease further. Therefore, it appears unlikely that floods were responsible for emplacement of boulders at PLS.

Conclusion. Preliminary examination of the landscape and rock distribution at PLS does not unequivocally determine how the material at the site was emplaced. However, regional geologic mapping indicates that PLS occurs on a flow unit (unit AHc_3) that has not been heavily degraded by possible thermokarst, although another nearby deposit (unit AHc_2) may have been degraded in that way. Longitudinal grooves and ridge and trough features that occur nearby appear to form in older plains material (unit HNr or AHc_1) that likely is unrelated to the PLS deposit. Stream energy generated by catastrophic floods entering Chryse basin should have dissipated to the point where they would have been unable to transport boulders of the size seen at PLS. A mass (debris) flow interpretation for the material at PLS, therefore, appears most consistent with the regional geologic reconstruction of Chryse basin.

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