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The ages of pedestal craters on Mars: Evidence for a late-Amazonian extended period of episodic emplacement of decameters-thick mid-latitude ice deposits

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A B S T R A C T

There is significant geomorphologic evidence for the past presence of longitudinally widespread, latitudinally zoned deposits composed of ice-rich material at the northern and southern mid latitudes on Mars (lobate debris aprons, lineated valley fill, concentric crater fill, pedestal craters, etc.). Among these features, pedestal craters (Pd) are impact craters interpreted to have produced a protective layer on top of decameters-thick ice deposits now missing in intercrater regions. The time during which these various deposits were present is still highly debated. To address this question we have analyzed the distribution and characteristics of pedestal craters; here, we use a population of 2287 pedestal craters (Pd) to derive a crater retention age for the entire population, obtaining a minimum timescale of formation of ~90 Myr. Given that the ice-rich deposit has not been continuously present for this duration, the timescale of formation is necessarily longer than ~100 Myr. We then compiled impact crater size-frequency distribution dates for 50 individual pedestal craters in both hemispheres to further assess the frequency distribution of individual ages. We calculated pedestal crater ages that ranged from ~1 Myr to ~3.6 Gyr, with a median of ~140 Myr. In addition, 70% of the pedestal ages are less than 250 Myr. During the 150 Myr period between 25 Ma and 175 Ma, we found at least one pedestal age every 15 Myr. This suggests that the ice-rich paleodeposit accumulated frequently during that time period. We then applied these results to the relationship between obliquity and latitudinal ice stability to suggest some constraints on the obliquity history of Mars over the past 200 Myr. Atmospheric general circulation models indicate that ice stability over long periods in the mid latitudes is favored by moderate mean obliquities in the ~35° range. Models of spin-axis/orbital parameter evolution predict that the average obliquity of Mars is ~38°. Our data represent specific observational evidence that ice-rich deposits accumulated frequently during the past 200 Myr, supporting the prediction that Mars was characterized by this obliquity range during an extensive part of that time period. Using these results as a foundation, the dating of other non-polar ice deposits will permit the specific obliquity history to be derived and lead to an assessment of volatile transport paths in the climate history of Mars.

1. Introduction

The nature of recent climate change on Mars is becoming better understood as evidence mounts for a variety of Amazonian-aged ice-rich surface features at mid and low latitudes (e.g., Head and Marchant, 2008). The current dominance of polar ice caps on Mars as the major water ice reservoir (Haberle et al., 2003, Phillips et al., 2008), with minimal quantities of surface ice at mid and low latitudes, suggests a significant change in the distribution and exchange of volatiles over the past few hundred Myr (Head et al., 2003, 2005, 2010; Head and Marchant, 2003), and that the current climate environment is likely to be somewhat anomalous (e.g., Head et al., 2011).

In an effort to improve the current understanding of the Late-Amazonian climate change and the location of surface ice deposits and reservoirs, we have undertaken geomorphological analyses of pedestal craters (Pd) (impact craters interpreted to have produced a protective layer on top of decameters-thick ice deposits now missing in intercrater regions; (Fig. 1(A)) to assess the distribution and characteristics of a class of non-polar ice-related deposits (e.g., Kadish et al., 2008a, 2009, 2010; Kadish and Head, 2011a, 2011b). Kadish et al. (2009) analyzed 2696 pedestal craters and found that they were concentrated poleward of ~33°N and ~40°S latitudes (Fig. 1(B)), Kadish et al. (2010) measured the heights of 2300

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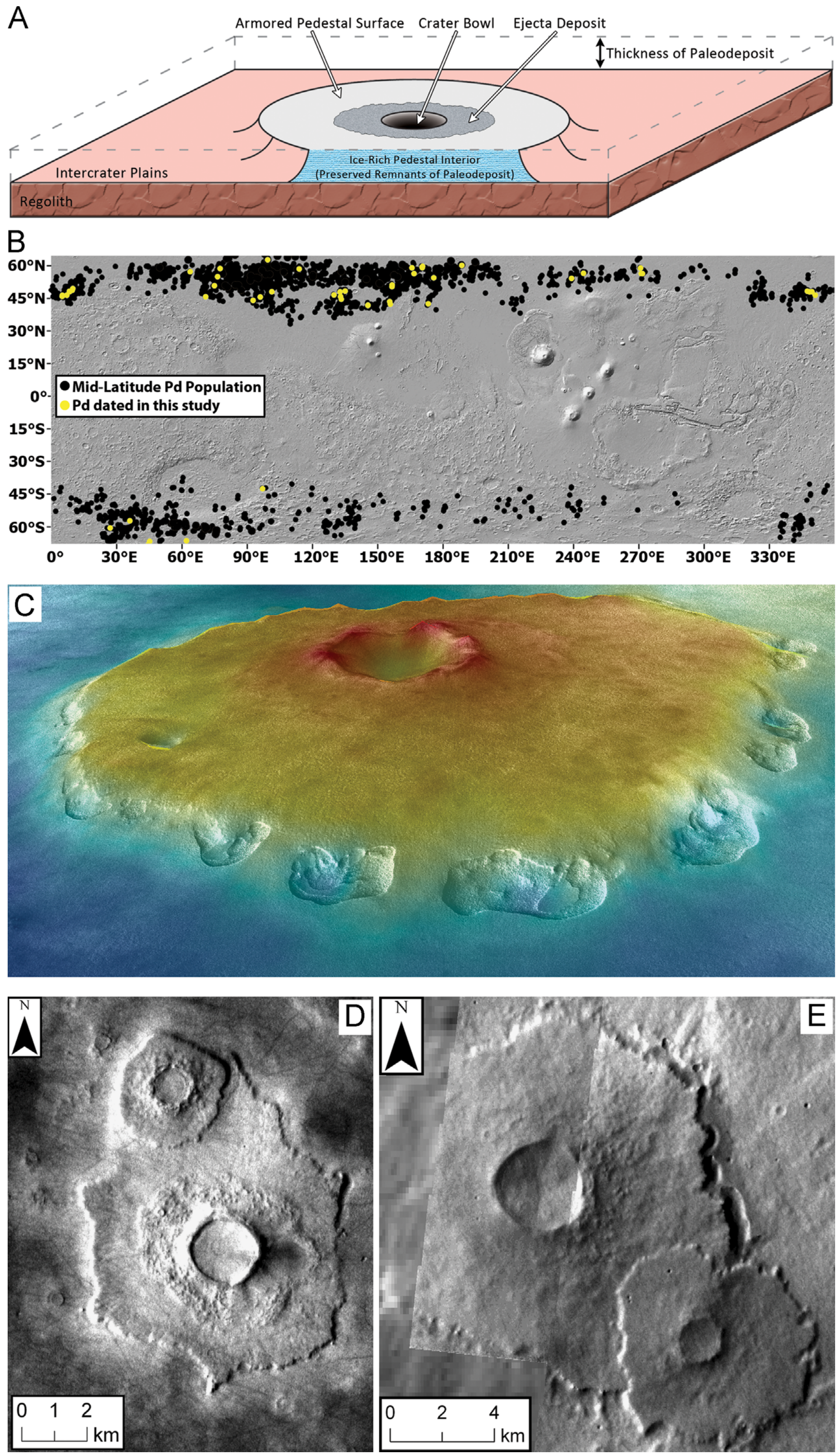

Fig. 1. A synthesis of pedestal crater characteristics, distribution and interpretation. (A) A 3D perspective sketch of a pedestal crater highlighting the limited distribution of ejecta on the pedestal surface, the significance of the pedestal height, and the ice-rich material that composes the pedestal. (B) The distribution of pedestal craters as mapped by Kadish et al. (2009), and the subpopulation of pedestal surfaces dated in this study. The pedestals selected for age dating were based on available HiRISE and CTX coverage, and are thus not a random sample. See Table 1 for a specific listing of dated craters, ages and related information. (C) A perspective view (VE = 10x) of a pedestal crater in Utopia Planitia with marginal pits in its outward-facing scarp (CTX image P01_001555_2430 with MOLA altimetry data). The 3.9-km-in-diameter crater is elevated ~100 m above the surrounding plains. The pits, which are ~1–3 km in length and 20 m deep, result from the sublimation of ice from the volatile-rich material underlying the indurated surface of the pedestal crater and do not extend down into the substrate below the pedestal. (D) A subscene of V21415004 (57.1°N, 78.5°E). This example shows the limited extent of the rough-textured ejecta deposit superposed on the smooth pedestal surface; the pedestal surface has a greater radial extent than the ejecta deposit in all directions. A small marginal pit exists on its eastern scarp. (E) A mosaic of V18046009 and V18358008 (61.0°S, 71.0°E). The larger crater has marginal pits along its eastern perimeter. The smaller crater is draped over this scarp, truncating one of the pits.