DECAMETER-SCALE PEDESTAL CRATERS IN THE TROPICS OF MARS: EVIDENCE FOR THE RECENT PRESENCE OF VERY YOUNG REGIONAL ICE DEPOSITS IN THARSIS.

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Introduction: Global climate models predict that ice will be deposited in tropical regions during obliquity excursions from the current mean obliquity of ~25° to ~35°, but no geological evidence for such deposits has been reported. We document the presence of very small (decameter scale) pedestal craters in the tropics of Mars (the Daedalia Planum-Tharsis region) that are superposed on an impact crater dated to ~12.5 million years ago [1]. The characteristics, abundance, and distribution of these small pedestal craters provide geological evidence that meters-thick ice accumulations existed in the tropical Tharsis region of Mars in the last few million years when mean obliquity was ~35° (~5-15 Ma) before it transitioned to a mean of ~25° (~0-3 Ma). A reconnaissance survey reveals similar small pedestal crater examples superposed on the older Amazonian Arsia Mons tropical mountain glacier deposit, suggesting that ice can accumulate in these tropical regions without initiating large-scale glacial conditions. These results support the predictions of general circulation models that ice can migrate to the equatorial regions during periods of moderate obliquity and then serve as a source for mid-latitude deposits.

Origins of Latitude-dependent Mantle Ice: Geological evidence has suggested that the higher amplitude obliquity of the past few million years caused ice stability conditions to migrate equatorward, and resulted in the deposition of a dust-ice mixture as a broad circum-polar high latitude mantle during periods of high obliquity [2,3,4]. In contrast, atmospheric general circulation models suggest that during periods of higher obliquity (mean obliquity ~25° and high amplitude variation) ice migrates directly to equatorial regions and then works its way back to the mid to high latitudes to be deposited in a more stable environment [5]. In a similar manner, mid-latitude glaciation is best explained in Mars general circulation models if mean obliquity is ~35° and the source of ice is at the equator, not at the poles [6]. However, direct evidence of the presence of large quantities of ice that could serve as equatorial sources in the recent geologic past has not yet been documented.

Tropical Decameter-scale Pedestal Craters: We discovered a population of very small (decameter-sized) pedestal craters in the tropics of Mars, superposed on ejecta from a 5.3-km diameter crater that formed about 12-13 million years ago. While km-scale mid-latitude pedestal craters are likely to have formed over Amazonian climate epochs of ~100 Myr duration [7], because of their substantially smaller size, the newly observed pedestal craters examined here are sensitive to meters-scale substrates (now substantially removed) that are of keen interest because of their potential relation to late Amazonian climate conditions and volatile transport pathways. Here we present evidence that these small pedestal craters formed when a meters-thick layer of ice was present in the tropics of Mars in the last few million years. These features provide the first observational evidence that an ice reservoir existed in the tropics in the very recent geological history of Mars.

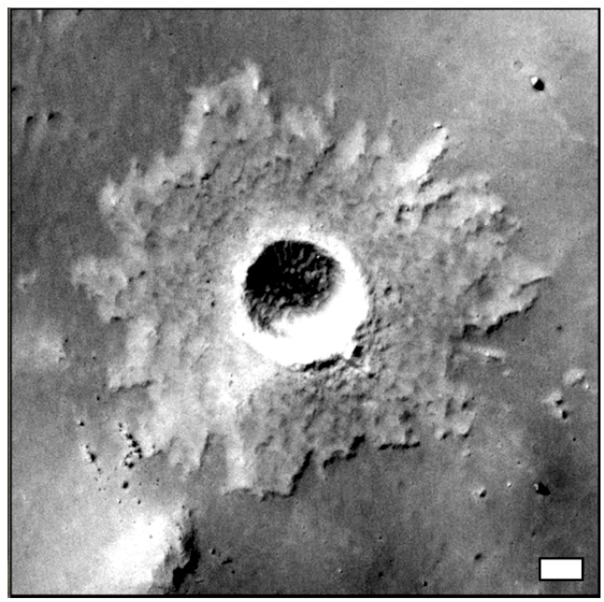

Figure 1: Example decameter-scale pedestal crater observed in the Daedalia Planum region (23° S, 230° E). The scale bar is 10 meters and north is oriented up. Crater measurements are reported in [1]. Portion of HiRISE: PSP_007735_1570.

Unambiguous examples of decameter-scale pedestal craters (Fig. 1) are observed ranging in diameter from 7.9 meters to 29.5 meters with pedestals extending from 1.9 to 3.2 crater radii beyond the rim crest. Shadow measurements were used to estimate crater depths and pedestal thicknesses. Given a pedestal thickness of one to several meters, the crater depths (1.6 – 4.6 m) suggest that these craters have excavated through the pedestal substrate and into the underlying material. The pedestals range from symmetric about the crater to more asymmetric, but the morphology of the pedestal margins does not suggest strong control by a prevailing wind regime. Pedestal boundary scarps are commonly sharp and well defined, to locally more rounded. Pedestal surfaces appear smooth or modestly stippled. Elevated rim crests are common [1].

Chronological Constraints: The regional terrain underlying the pedestal craters is comprised of Amazonian lava flows emerging from the Arsia Mons region of the Tharsis rise. Locally, the pedestal craters sit on top of the northern flank of an ejecta deposit of a young 5.3 km-diameter crater. The crater size-frequency distribution observed on this deposit suggests a best-fit age of ~12.5 Ma calculated using craters with diameters larger than 8 m. An apparent deficit of craters less than approximately 10 meters in diameter occurs compared to the isochrons of Hartmann [2005]. This may be attributable in part to the difficulty identifying small impact craters in relatively rough and pitted regions of the deposit. Small craters could also have been removed or filled by the emplacement and removal of the layer responsible for the ~8-30 m diameter pedestal craters. Degraded and partially filled craters are also observed, which is consistent with the removal of a surface layer. On the basis of the ~12.5 Ma age of the underlying ejecta deposit and the superposition of the pedestal craters deposition of the pedestal substrate and formation of the pedestal craters by preferential removal of the intercrater material must post-date the ~12.5 Ma ejecta deposit.

Could the pedestal craters be substantially younger than this age? The extremely small surface areas of the pedestals considered here prevent their analysis using conventional crater retention age techniques to count superposed craters and derive ages as has been done for larger pedestal craters [8]. However, the crater-size frequency distribution represented by the population of pedestal craters themselves provides information on the timescale of their formation, but does not constrain the exact temporal occurrence of this period. These data suggest that the pedestal craters formed during an interval or intervals that post-dated the ~12.5 Ma ejecta unit and collectively lasted at least 600 kyr, the "age" represented by the portion of superposed impact craters that are pedestal craters. Of course, the pedestal craters could have formed over a singular ~600-kyr period, or over a set of shorter, recurring intervals when episodic ice deposits were present.

Conclusions: The decameter-scale craters (Fig. 3) analyzed here are morphologically similar to much larger pedestal craters documented at higher mid-latitudes. Pedestal heights are consistent with a surface layer a few meters thick. Crater depths indicate penetration through this surface layer and excavation of underlying material. Pedestal volumes substantially exceed crater volumes. In our preferred interpretation, this surface layer (now largely removed) resulted from climate variations that drove accumulation of meters-thick ice deposits. Evidence for the cyclical deposition of such icy layers during the late Amazonian is well documented [e.g., 3,4].

We propose that ejecta of the decameter-scale craters derived from underlying material provided the armoring mechanism to preserve a portion of the mantling layer. In our model, deposition of this icy and dusty mantling layer occurred on the ejecta deposit that we estimate as ~12.5 Myr old. The impact craters that occurred then penetrated through the icy surface layer. These craters excavated underlying material onto the surface layer. The surface layer endured for at least 600,000 years in one or more episodes to accumulate the morphologically distinct craters that are observed. Ejecta of the craters protected the underlying surface layer from sublimation, dissection, and eolian erosion, which have stripped away the surface layer in the intercrater areas. In this fashion our model is similar to the model of excess ejecta crater formation proposed by Black and Stewart [9].

These newly identified small pedestal craters imply a greater equatorial extent of surficial ice deposits in the equatorial and mid-latitudes during latest Amazonian climate variations than previously known from geological observations. These pedestal craters imply that surficial ice-rich mantling deposits were present in the tropics during the previous ~12.5 Ma and have since eroded back to the armored pedestal craters. The observations expand the latitude range over which such deposits are known to have occurred and constrain their deposition to the latest Amazonian. These deposits represent a plausible source for recent detections of shallow ice at low mid-latitudes [e.g., 10]. Finally, these results support the predictions of general circulation models that ice migrated to the equatorial regions during recent periods of enhanced obliquity and from there served as a source for mid-latitude ice-rich mantling deposits.

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