**PRESERVATION OF ANCIENT ICE IN TROPICAL MOUNTAIN GLACIER DEPOSITS ON MARS:**
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**Introduction:** Analysis new data for the extensive fan-shaped deposits on the NW flanks of the equatorial Tharsis Montes (Fig. 1) provides compelling evidence that they represent the remnants of tropical mountain glaciers (TMG) dating from the Late Amazonian [1-5]. The distinct geomorphology of the deposits, together with updated terrestrial analogs for glaciation under martian hyper-arid, extremely cold conditions [6], show that the tropical mountain glaciers were cold-based. Global climate models show that when obliquity reaches 45 degrees, water-rich air ascends the flanks of Tharsis, encounters the NW flanks of the Tharsis volcanoes, undergoes upwelling and adiabatic cooling, precipitating snow on the northwest flanks [7]. Models of accumulation and glacial flow show that this scenario can produce tropical mountain glaciers [8].

On Earth, when glaciers retreat, ablation can result in an increase of debris on top of the glacier (sublimation till); this deposit can significantly decrease the sublimation rate and protect the buried ice from further loss of ice, preserving it for long periods [9-10]; in the Antarctic Dry Valleys, ice buried below sublimation till may be as old as 8 million years [11]. Is there any evidence of similar remnant ice in the tropical mountain glaciers on Mars?

**Description and interpretation:** Arsia and Pavonis TMG deposits (Fig. 1) consist of three basic facies, ridged (R), knobby (K) and smooth (S) [1-5]. The proximal smooth facies consists of lobate, relatively smooth-textured deposits interpreted as the remnants of individual cold-based glacial lobes (alpine-like glaciers), emplaced in the waning stages of glaciation [3]. Debris-covered cold-based glaciers build up a protective sublimation till derived from supraglacial and englacial debris. As glacial conditions wane, ice is often preserved longest in the distal portions, where the insulating effect of the till is greatest, producing thick arcuate lobes. Similar arcuate lobe configurations are seen at Arsia and Pavonis (Fig. 1). Could these lobes, morphologically and environmentally similar to those seen on Earth, still contain remnant glacial ice from the Late Amazonian glaciation [10] many tens of millions of years ago? Analysis of high-resolution image and altimetry data reveal several crater-like depressions in the smooth facies at Arsia (Fig. 2) and Pavonis (Fig 3). These features are shallower than fresh impact craters of similar diameters and show significant evidence of having undergone viscous relaxation. They have several zones (Figs. 2-3): An inner hummocky, but often oyster-shell-like floor with outward-facing scarps; an intermediate zone beyond the apparent crater rim of concentric ridges and troughs; a narrow zone of closely-spaced fractures; and an outer zone of hummocks oriented along the regional trend of the lobe, sometimes with superposed secondary craters (Fig. 2c, d). These resemble (Fig. 3d) viscously relaxed craters in laboratory experiments [12]. The sequence of evolution visualized for these craters is shown in Fig. 4.

In summary, TMG deposits on Mars record ancient climates when planetary spin-axis obliquity was in excess of 45°, and polar volatiles were mobilized and transferred equatorward. We interpret the set of unusual impact craters superposed on these deposits (Figs. 2-3) to indicate that the impact penetrated a veneer of sublimation till and excavated buried remnant glacial ice, subsequently undergoing viscous relaxation. Remaining deposits may be hundreds of meters thick. The deposits are Late Amazonian in age and the remnant ice may preserve records of ancient atmospheric gas content and microbiota, as is seen in terrestrial glacial ice [13].

**References:** 1) J. Head and D. Marchant, *Geology*, 31, 641, 2003; 2) D. Shean et al., *JGR*, 110, 05001, 2005; 3) D. Shean et al., *JGR*, 112, E03004, 2007; 4) S. Milkovich et al., *Icarus*, 181, 388, 2006; 5) S. Kadish et al., *Icarus*, in revision, 2007; 6) D. Marchant and J. Head, *Icarus*, 192, 187, 2007; 7) F. Forget, et al.. *Science*, 311, 368, 2006; 8) J. Fastook et al., *LPSC 37*, #1794, 2006; 9) D. Kowalewski et al., *Ant. Sci.*, 18, 421, 2006; 10) J. Helbert et al, *LPSC 37*, #1371, 2006; 11) D. Marchant et al., ISAES, 54, 2007; 12) R. Scott (1967) *Icarus*, 7, 139. 13) K. Bidle et al., *PNAS*, 104, 13455, 2007; 14) A. Kress and J. Head, *LPSC 39*, #1273, 2008; 15) A. Kress et al., *LPSC 39*, #1293, 2008.

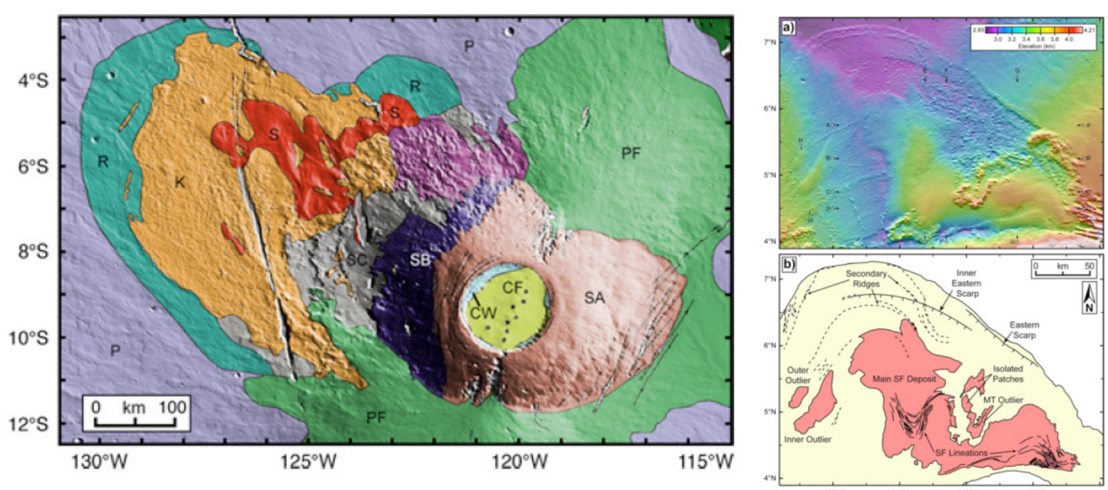
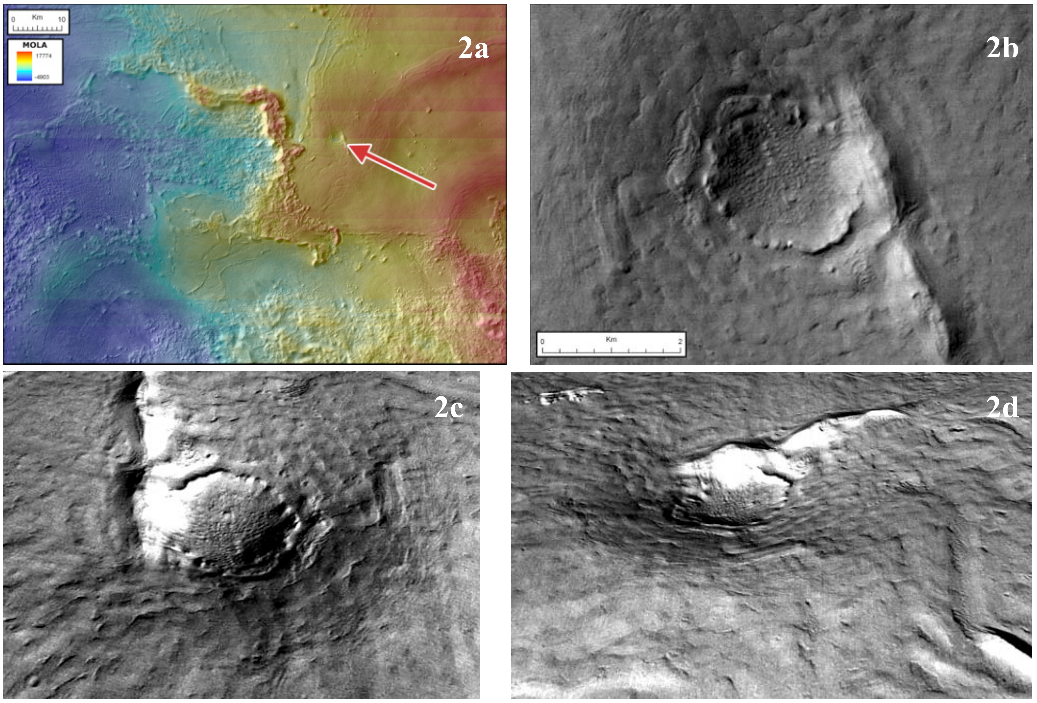



**Fig. 1.** Geologic units and facies in Arsia Mons (left) [1,3] and Pavonis Mons (right) [2].



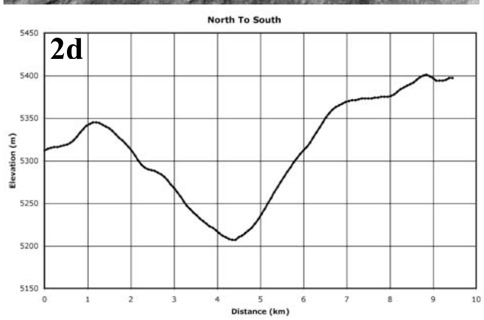
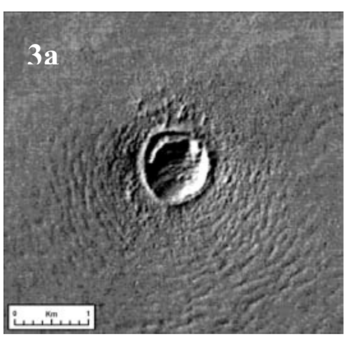




Fig. 2. Arsia Mons: Impact into remnant smooth facies and resulting crater modification, viscous relaxation. a) Location of crater in the smooth facies (red arrow); b-d) Vertical/perspective views of modified and relaxed crater; e) N-S MOLA altimetric profile.



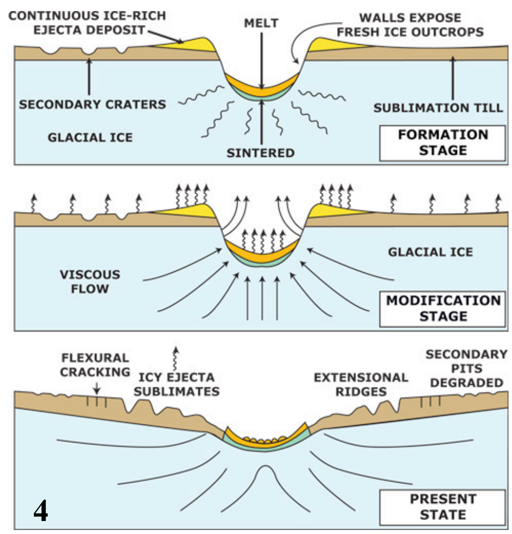




Fig. 4: Reconstruction of the crater formation and modification stage leading to the present configuration. Three processes are important: 1) initial response to impact into an ice substrate [14-15], 2) sublimation of blocky icy ejecta and crater wall material, and 3) viscous relaxation of subsurface ice.

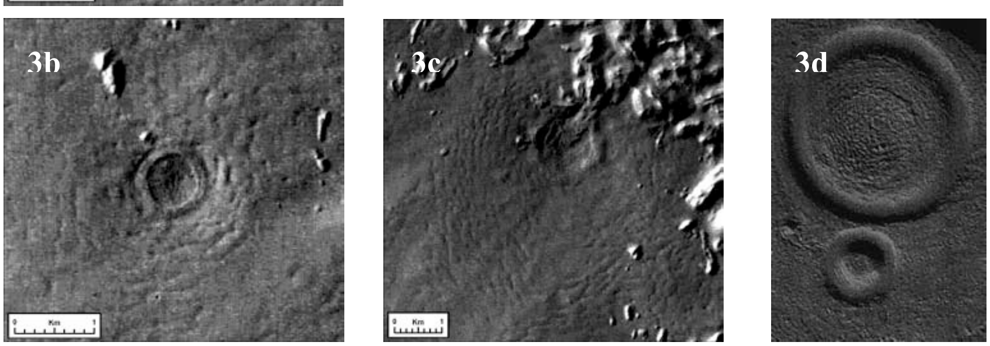



Fig. 3. Pavonis Mons: a-c) Relaxed impact craters on the Pavonis smooth facies. d) Viscously relaxed craters in laboratory experiments [12].