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Kilometer-thick ice accumulation and glaciation in the northern mid-latitudes of Mars: Evidence for crater-filling events in the Late Amazonian at the Phlegra Montes

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ABSTRACT

Amazonian non-polar ice deposits on Mars record periods and events when the climate differed substantially from that of today. Particularly evident are examples of ice-rich deposits in the martian mid-latitudes (lobate debris aprons, lineated valley fill, and concentric crater fill). Uncertain, however, is the amount of ice remaining in these deposits today, and the thickness of ice that might have existed when they formed. Here, we use HRSC, CTX and HiRISE imagery and MOLA topographic data to document an occurrence of concentric crater fill within which the past minimum volume of ice can be constrained. An ~8 km impact crater is superposed on the rim of a ~32 km impact crater near the contact between the Phlegra Montes and the Vastitas Borealis Formation in the northern mid-latitudes of Mars. We find evidence for flow from the larger crater into the perched smaller crater that indicates an earlier period of significant ice accumulation and glaciation within this double crater. Lobate ridges observed outside of the perched younger crater suggest that ice filled and overtopped the crater rim, providing minimum estimates of ice thickness and volume within the system. Glacial ice must have been at least ~1000 m thick to overtop the rims of both craters and induce gravitational flow onto the surrounding plains, with a minimum volume of ice of ~750 km^3. This is the first volumetric measurement of this kind on Mars for concentric crater fill craters, and the thickness is comparable to that measured in a lineated valley fill glacial system along the dichotomy boundary at a similar latitude. We also document late-stage episodes of more localized glacial flow that include ridges on valley walls that we interpret as late-stage glacial high-stands, and concentric crater fill (CCF) that characterizes most of the present-day crater floor. Similar deposits in a crater ~60 km to the northeast suggest that such episodes were at least regional in nature. This sequence provides evidence for significant spin-axis/orbital parameter-driven shifts in the Late Amazonian climate of Mars and suggests that regional ice sheets may have existed in the mid-latitudes of Mars within the last several hundred million years.

1. Introduction

Global mapping of the surface of Mars using Viking Orbiter data revealed a suite of enigmatic Late Amazonian landforms in the mid-latitudes of each hemisphere, including lineated valley fill (LVF), lobate debris aprons (LDA) and concentric crater fill (CCF) (Squyres, 1978, 1979). Morphology indicative of viscous flow and the latitude-dependence of these features implicated ice-related processes in their formation (Squyres, 1979; Lucchitta, 1981), and it was proposed that small amounts of water vapor condensing within pore space mobilized dry material to produce the observed landforms (Squyres, 1978; Lucchitta, 1984).

As higher resolution data have been obtained, these features have been studied in detail not available at the time of their discovery, adding insight into their formation and providing implications for the Late Amazonian climate within which they formed (Pierce and Crown, 2003; Head et al., 2005; Li et al., 2005; Head et al., 2006a,b; Dickson et al., 2008; Holt et al., 2008; Head et al., 2010-this issue; Plaut et al., 2009). Regional mapping using the High Resolution Stereo Camera (HRSC [Neukum et al., 2004; Gwinner et al., 2005; Scholten et al., 2005]) on Mars Express (MEX), together with other complementary data sets, has revealed valleys along the dichotomy boundary that show evidence for integrated networks of LVF (Head et al., 2005; Head et al., 2006a,b), consistent with the flow of glacial ice. Measurements using the SHAllow RADar instrument (SHARAD) on the Mars Reconnaissance Orbiter (MRO) of LDAs in each hemisphere detected subsurface reflections, with the LDAs having dielectric properties consistent with an ice-dominated composition on contemporary Mars (Holt et al., 2008; Plaut et al., 2009). Dickson et al. (2008) used HRSC elevation data to document an LVF lobe with an upslope profile that has been stranded within a box canyon at the contact of Coloe Fossae and Protonilus Mensae along the dichotomy boundary, with measurements of downwasting suggesting a previous ice thickness of at least ~920 m. While networks of LVF (Head et al., 2005; Head et al., 2006a,b) and ice-rich LDAs (Pierce and Crown, 2003; Head et al., 2005; Li et al., 2005; Holt et al., 2008; Plaut et al., 2009) are observed in each

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