the partial preservation of the ice-rich deposit by armoring of the surface or superposition of ejecta (Kadish and Head, 2011).

4. Interpretations and 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 (Table 1). Pedestal volumes substantially exceed crater volumes (Table 1). In our preferred interpretation, this surface layer (now largely removed) resulted from climate variations that drove accumulation of meter-thick ice deposits. Evidence for the cyclical deposition of such icy layers during the late Amazonian is well documented (Forget et al., 2006; Head et al., 2005; Kreslavsky and Head, 2000; Mustard et al., 2001; Schon et al., 2009) and has been interpreted as a series of ice ages (Head et al., 2003; Schorghofer, 2007). Climate modeling studies (e.g., Forget et al., 2006; Levrard et al., 2004; Madeleine et al., 2009, and Mischna et al., 2003) have suggested that equatorial deposition preceded mid-latitude mantling events in the late Amazonian and our observations provide the first geological support for this scenario of recent equatorial ice associated with obliquity variations.

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 (Fig. 4A). 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 (Fig. 4B) 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 (2008). An atmospheric blast effect as described by Wrobel et al. (2006) or another non-ballistic ejecta armoring mechanism (e.g., Schultz and Mustard (2004)), which appears necessary to explain larger fully-perched pedestal craters (e.g., Kadish et al., 2009), is not necessary to explain the more modest pedestal extents observed here (Table 1) due to the possible armoring effect of sub-ice excavated ejecta (e.g., Kadish and Head, 2011).

When was the icy layer deposited and when did the pedestal craters form? We cannot know for certain, because there could be successive periods of deposition and removal during which normal craters were formed. Our morphological observations (Figs. 2 and 3) and chronological constraints (Fig. 4), however, in conjunction with the obliquity history calculated by Laskar et al. (2004), provide a framework for considering hypotheses. One possibility is that the pedestal craters could have formed during the most recent ~0.4–2.1 Ma ice age (Head et al., 2003). However, we suggest that formation is more likely to have preceded this most recent ice age and occurred during a period of higher mean obliquity prior to 5 Ma, during which obliquity excursions often approached 45° (Fig. 5). These older more extreme obliquity conditions are consistent with global climate modeling results of equatorial ice deposits at 45° obliquity (e.g., Forget et al., 2006). Additionally, the longer succeeding time interval is consistent with the destruction and removal of the intercrater material by sublimation and eolian erosion during subsequent history (<5 Ma).

Global climate modeling studies reveal that high obliquity conditions (~45°) are required to construct the large tropical mountain glaciers associated with the Tharsis Montes (Forget et al., 2006). The geological records of these significant tropical mountain glaciers (Fig. 1), for which climate models indicate sufficient ice deposition at high obliquity (Forget et al., 2006), are substantially older (~65 Ma and older, Shean et al., 2007) than more recent obliquity peaks (Fig. 5). Reconnaissance of the Arsia Mons fan-shaped deposit reveals small-scale pedestal craters in Mars Reconnaissance Orbiter Context Camera (Malin et al., 2007) images (Fig. 6) similar to those documented at Daedalia Planum (Fig. 3). These craters (Fig. 6) are superposed on the ridged facies of the fan-shaped deposit (interpreted as drop moraines; Head and Marchant (2003); Shean et al. (2007)). We interpret these craters as geological evidence that less voluminous quantities of ice have been present in the Tharsis region substantially more recently than indicated by the underlying Amazonian deposits of the large tropical mountain glaciers (Head and Marchant, 2003; Kadish et al., 2008a; Milkovich et al., 2006; Shean et al., 2005, 2007). For these larger (~100-m diameter) pedestal

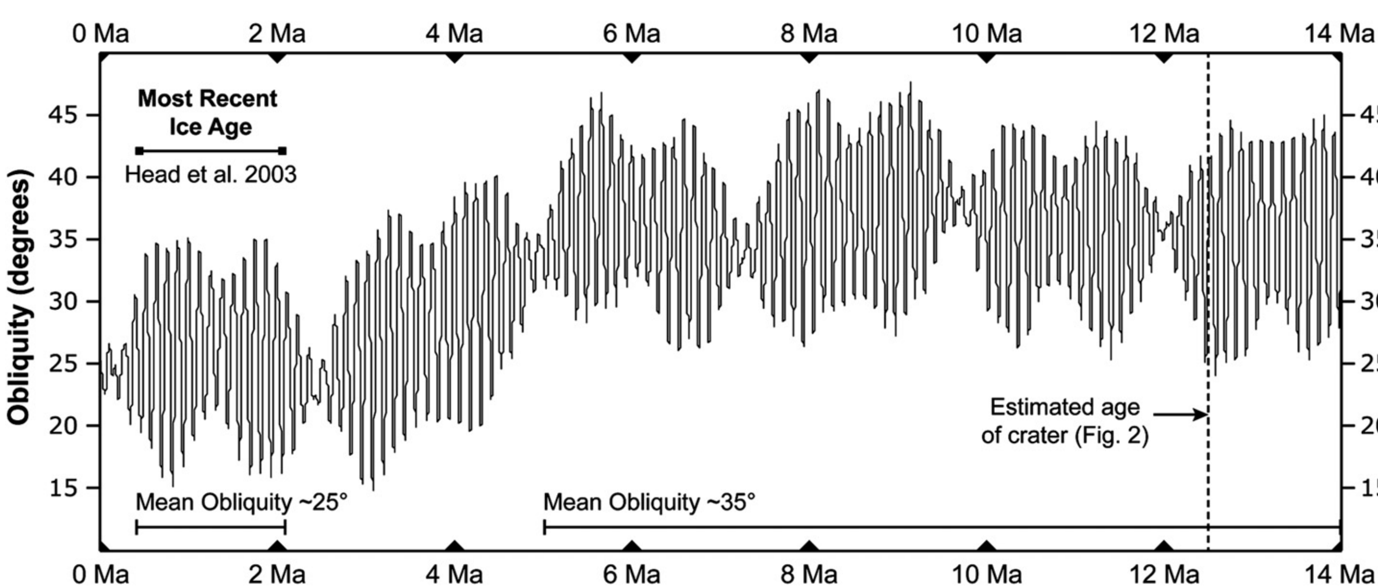

Fig. 5. Mars recent obliquity (Laskar et al., 2004). Enhanced obliquity variations, 0.4 Ma to 2.1 Ma characterize what has been interpreted as Mars' most recent "ice age" (Head et al., 2003). In our interpretation, the pedestal crater substrate was deposited during the period of higher obliquity prior to 5 Ma.