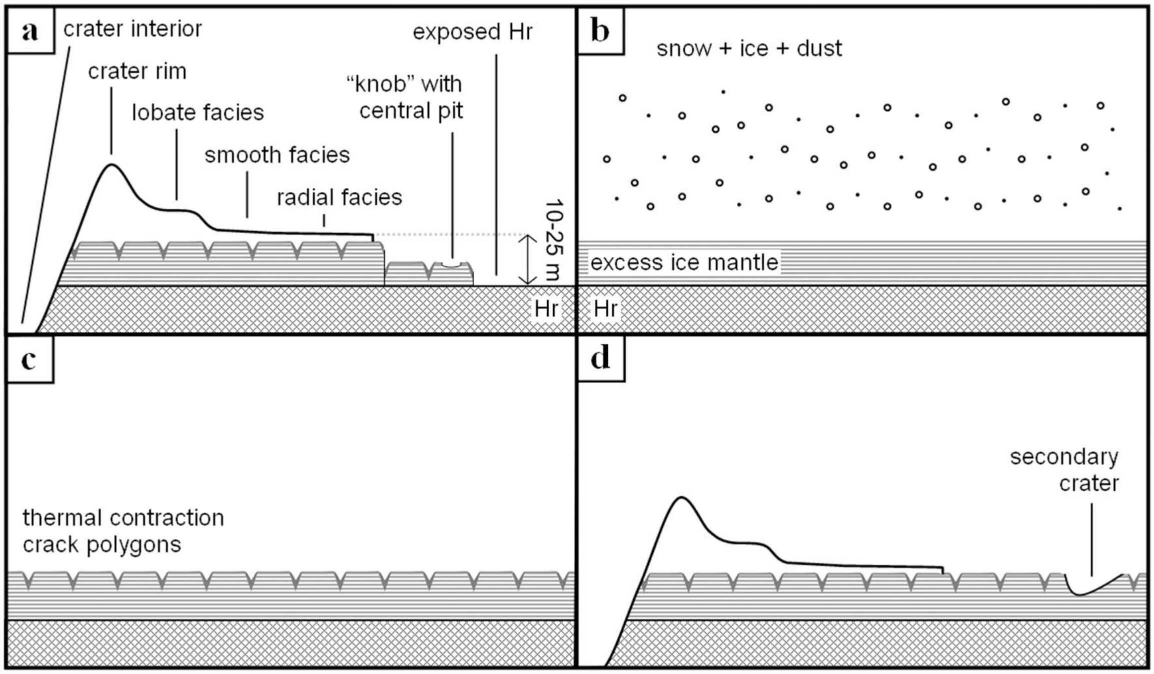


**Figure 3.** Diagrammatic cross-sections illustrating the relationship of geologic units (Figure 1) and topography. (a) Cross-section of Vaduz and surrounding terrain showing current crater morphology and inferred stratigraphy. Proposed sequence of formation is illustrated in Figures 3b–3d. (b) During a recent high obliquity period, atmospheric precipitation of snow and codeposition of ice and dust emplaced a layered excess ice mantle over ten meters thick. (c) Thermal contraction crack polygons formed and matured on this mantle. (d) An impact emplaced the crater facies and possibly secondary craters, but any secondary craters would have been too shallow to excavate below the mantle. Later, a return to lower obliquity prompted removal of the mantle by sublimation, except where it was armored by proximal crater facies, forming the observed 10–25 m *radial facies* scarp and erasing secondary craters (Figure 3a). Not to scale.

rather a very ice-rich deposit, as was recently observed to have been excavated by five impacts at higher midlatitudes [*Byrne et al.*, 2009]. The presence of such extensive excess ice and its preservation for millions of years favor atmospheric precipitation of ice/snow and dust over equilibrium vapor diffusion in regolith.

[20] What is the nature of the armoring mechanism? The crater cavities of excess ejecta craters (EEC), including Vaduz, are largely below the background surface, indicating that these impacts penetrated through the surficial ice-rich unit to excavate mostly silicate rock [*Black and Stewart*, 2008]. This ejected material forms their associated facies and seems to insulate the substrate, as described by *Black and Stewart* [2008]. In contrast, pedestal craters (Pd), formed by impacts that do not typically excavate below the background surface, likely do not penetrate through the ice-rich layer. *Kadish et al.* [2009] review several proposed Pd armoring mechanisms, including an airblast/thermal pulse process [*Wrobel et al.*, 2006] that could explain the great extent of the pedestal beyond the ejecta and the extreme circularity of pedestals [see *Kadish et al.*, 2009]. Because this model is driven by energy transferred from an impact-induced vapor cloud, it may be that EEC, which excavate mostly silicate material, produce less significant vapor and thus are characterized by ejecta-related armoring, whereas Pd excavate only the ice-rich substrate and produce robust vapor clouds, favoring an airblast/thermal pulse mechanism. Although consistent with our observations, we acknowledge that this dual process model is only one possible interpretation.

## 4. Conclusions

[21] A very fresh, 1.85 km diameter impact crater in the midlatitudes of Mars (38°N) named Vaduz exhibits distinctive crater-related facies extending up to ~15 radii from the rim crest and perched >10 m above the adjacent plains. *Knobby terrain* fringing and underlying the crater facies is interpreted as degraded thermal contraction crack polygons, consistent with an ice-rich mantle buried by ejecta. The *knobby terrain* rapidly degrades, then disappears, away from the margins of the ejecta; this is interpreted to signal the progressive degradation and loss of the ice-rich substrate following the time of impact (estimated to be a few million years ago). The almost complete disappearance of this ice-rich unit, and consequent lowering of regional topography by over ten meters, suggests that the ice-rich unit was formed by climate-related deposition of snow, ice, and dust during recent periods of high obliquity, rather than by vapor diffusion into regolith pore space. The onset of the current lower-amplitude obliquity period, and the attendant poleward retreat of the mantling unit, is the most likely cause of the regional loss of the ice-rich layer.

[22] We propose the following tentative relationship between crater morphology and the armoring mechanism that protects near-surface volatile deposits: 1) Pedestal cra-