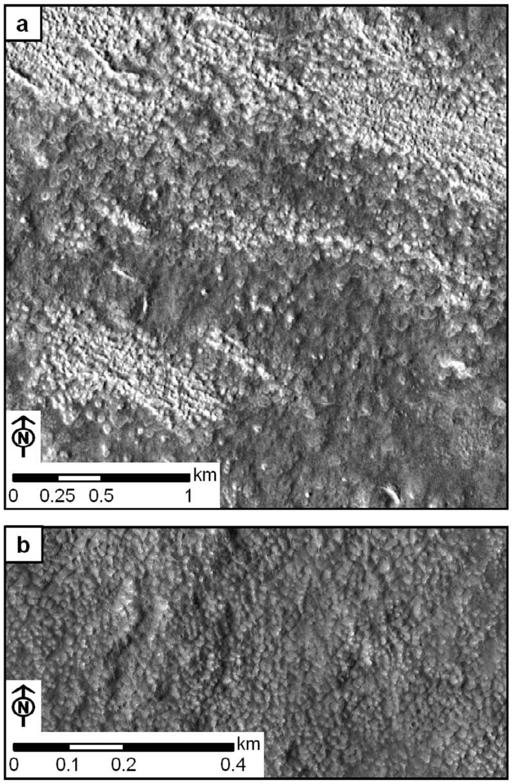

Figure 2. Comparison of the *knobby terrain* of Vaduz with degraded polygonal terrain elsewhere on Mars. Note the strong morphologic similarity. (a) *Knobby terrain* knobs, generally with summit pits, outcrop between an enclave (lower left) and a tongue (upper right) of *radial facies* distinctly exhibiting radial, curvilinear ridges; the crater center is to the northwest. Portion of CTX image P15_007057_2179. (b) Degraded thermal contraction crack polygons in Noachis Terra at ~43.6°S, 0.0°. Portion of High Resolution Imaging Science Experiment image PSP_003818_1360.

DTM-MOLA hybrid. Given the small size of Vaduz, the HRSC DTM is likely more representative than the lower spatial resolution MOLA data, but MOLA data suggest a significantly deeper crater cavity. To allow for this possibility, we fit a paraboloid, centered at the centroid of the *crater interior*, to the MOLA profile data in the crater cavity and inserted this paraboloidal cavity into the HRSC DTM to produce an HRSC DTM-MOLA hybrid.

[14] We found V_{Above}/V_{Cavity} values of 20.6, 16.4, and 3.2, corresponding to average excess thicknesses of 25.8 m, 16.1 m, and 11.2 m, for the MOLA data, HRSC DTM, and HRSC DTM-MOLA hybrid, respectively. These values clearly indicate that Vaduz is an excess ejecta crater (EEC), and it is the smallest EEC yet identified. Because uplifted material and ejecta bulking cannot explain the high V_{above}/V_{cavity} of EEC [*Black and Stewart*, 2008], we conclude that the crater facies are emplaced on a relict substrate over ten meters thick that has been regionally removed (Figure 3).

[15] The common fringing of *radial facies* (RF) with *knobby terrain* (KT) and the position of KT topographically below RF suggest that KT is part of this relict substrate. KT also lacks crater-radial and crater-concentric textures, is unlike common ejecta morphologies, and occurs regionally up to ~41 km from Vaduz, consistent with a nonejecta origin. Additionally, its polygonal to rounded knobs resemble thermal contraction crack polygons (Figure 2), which occur in Mars-like areas on Earth [e.g., *Marchant et al.*, 2002] and widely on Mars and are associated with icy substrates [*Marchant and Head*, 2007; *Levy et al.*, 2006, 2010]. Although polygons are usually <25–40 m wide [*Mangold*, 2005; *Levy et al.*, 2010], they reach widths of 50–300 m in some areas of Mars, suggesting micro- and/or paleoclimates allow for wider polygons [*Mangold*, 2005].

[16] The central pitting of many knobs suggests that they vary radially in their properties. Indeed, sublimation polygons such as those seen on Earth [*Marchant et al.*, 2002] have ice-rich centers topped with fine-grained sublimation lag but marginal sand-wedge troughs [e.g., *Levy et al.*, 2010]. Summit pits could form when wind deflates the fine-grained center. Sublimation could also be more efficient through the relatively thin polygon summit lag than through the thicker trough sediments [*Levy et al.*, 2009]. Both mechanisms could also work together.

[17] Could the presence of a regional ice-rich mantle also explain the lack of secondary craters? Typically, the largest secondary craters have diameters <~5% of that of the primary crater [*Schultz and Singer*, 1980], or ~92 m in this case. Because the depth/diameter ratio for martian secondary craters of that size is ~0.11 [*McEwen et al.*, 2005], secondaries associated with Vaduz would have been ≤~10 m deep and thus would have been erased when the underlying unit was removed (Figure 3d). Notably, double-layer ejecta craters also generally lack secondary craters [*Boyce and Mouginis-Mark*, 2006]. Because these craters are similarly found in the midlatitudes and share some morphologic characteristics with Vaduz, it is possible that proposed explanations for their lack of secondary craters also apply to Vaduz, including entrainment and/or crushing of ejected blocks by a high-velocity outflow or fragmentation of ejected blocks due to water in the target material [*Boyce and Mouginis-Mark*, 2006].

[18] The young age of the crater requires its relict substrate to have been present regionally a few million years ago. Obliquity excursions sufficient to stabilize ice at the latitude of Vaduz have punctuated the climate of Mars since ~5 Ma [*Mellon and Jakosky*, 1995; *Laskar et al.*, 2004]. The ice- and dust-rich latitude-dependent mantle described by *Head et al.* [2003] also is interpreted to have formed in this regime, specifically during the most recent glacial period of ~0.4–2.1 Ma. On the basis of these observations, we interpret the relict substrate to be similar in nature to the latitude-dependent mantle deposit. Currently, and for the last several hundred thousand years, the amplitude of obliquity oscillations has decreased, causing near-surface ice stability conditions to retreat to higher latitudes [*Mellon and Jakosky*, 1995; *Head et al.*, 2003; *Laskar et al.*, 2004]. Under these conditions, unarmored surface ice deposits would sublimate and migrate poleward.

[19] The evidence presented here strongly suggests that an ice-rich deposit over ten meters thick covered the region a few million years ago. The significant topography (generally more than ten meters) associated with the remaining *knobby facies* is evidence that the material forming the substrate was removed from the unarmored surrounding areas; this removal supports the interpretation that the material was not regolith with minor vapor diffusion emplaced pore ice but