VADUZ, AN UNUSUAL FRESH IMPACT CRATER ON MARS: EVIDENCE FOR IMPACT INTO A RECENT ICE-RICH MANTLE.

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Introduction: Has the migration and emplacement of volatiles during recent ice ages on Mars (since 5 Ma) taken place solely by vapor diffusion and ice deposition into preexisting regolith pore space [1] or has surface deposition of ice, snow, and dust also created mantling layers? Indeed, several workers have described evidence for a recent ice-rich, latitude-dependent mantle, meters to tens of meters thick, currently preserved under a sublimation lag [2-5].

Impact crater morphologies attributed to ice-rich units include pedestal craters (Pd) [6] and excess ejecta craters (EEC) [7]. Both Pd and EEC are elevated above their surroundings, likely due to local preservation of an underlying ice-rich unit that has been regionally removed [e.g., 6-8]. Whereas the crater cavities of Pd are entirely perched [8], EEC excavate below the background surface [7]. The armoring mechanism involved in Pd and EEC is debated [see 8].

In this analysis, we document a very fresh midlatitude impact crater (Fig. 1), Vaduz, whose associated deposits provide insight into the nature, distribution, and timing of ice-rich mantles as well as the impact-related mechanisms for armoring these mantles.

Observations: Located at ~38.2°N, 15.8°E, just west of Mamers Valles near the dichotomy boundary, Vaduz is a 1.85 km diameter impact crater with several distinctive facies (Fig. 1). It appears extremely fresh, with very few superposed craters, and there is also no evidence of related secondary craters out to a search distance of ~40 R (radii from the rim crest). The crater has minimal infilling and a sharp rim crest.

Six geomorphic units are associated with Vaduz and overlie the background Hesperian ridged plains (Hr) [9] (Figs. 1,2). From the center outward, these are *crater interior* (CI), *crater rim* (CR), *lobate facies* (LF), *smooth facies* (SF), *radial facies* (RF), and *knobby terrain* (KT). We use "crater facies" to denote the *lobate*, *smooth*, and *radial facies* collectively.

Prominent, elongate projections of the radially-textured *radial facies* (RF; Fig. 1) extend outward semicontinuously up to ~15 R *Knobby terrain* (KT; Fig. 1) commonly fringes RF and, in places, extends in tongues well beyond it. KT is composed of polygonal to rounded knobs that range from equidimensional to elongate in planform and are both sparsely and densely distributed. Knobs appear flat-topped and are frequently centrally pitted. They are usually ~25-60 m wide, and may be smaller, but features <~25 m are poorly resolved in Context Imager data.

The surface of the *radial facies* (RF) is generally ~10-25 m above adjacent Hr in Mars Orbiter Laser Altimeter (MOLA) profile and High Resolution Stereo Camera (HRSC) digital terrain model (DTM) data (Fig. 2). Where *knobby terrain* (KT) fringes RF, it is always lower than RF and slopes away from it.

Analysis and Interpretation: Morphologically, Vaduz appears very young; crater counts suggest an age of a few million years. The extreme ~15 R extent of the *radial facies* projections is highly unusual. The presence of *knobby terrain* adjacent to, and lower than, the crater facies strongly suggests that it underlies the crater facies. MOLA profile and HRSC DTM data indicate that the crater facies and knobby substrate form a deposit ~10-25 m thick that overlies the Hesperian ridged plains.

To determine whether this knobby substrate is impact-related or a preimpact relict, we used a method very similar to that used by Black and Stewart [7] to identify craters with apparently excess ejecta. They compared the volume of material above the preimpact surface, including both ejected and uplifted material, to the volume of the crater cavity below that surface: V_{Above}/V_{Cavity}. The preimpact surface was interpolated from background terrain points near the crater using Delaunay triangulation within the HMars program. They found a mean V_{Above}/V_{Cavity} of 0.99 ± 0.41 for 572 fresh craters and identified ten craters with ratios ≥2.5 as excess ejecta craters (EEC).

Using the same general method within ArcGIS, 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 MOLA, HRSC DTM, and HRSC DTM-MOLA hybrid data, respectively. The hybrid was created by inserting a paraboloidal cavity, fit to MOLA shot data, into the HRSC DTM. These values clearly indicate that Vaduz is an excess ejecta crater (EEC) and suggest that the crater facies are emplaced on a relict substrate over ten meters thick that has been regionally removed.

The inferred stratigraphic position of the *knobby terrain* (KT) suggests that it is part of this relict substrate. KT also lacks textures and morphologies typical of ejecta and occurs regionally up to ~41 km from Vaduz, consistent with a nonejecta origin. In fact, its polygonal to rounded knobs resemble thermal contraction crack polygons, which are associated with icy substrates [e.g., 10-13]. A mechanism for centrally pitting polygons has already been suggested [14].

An ice-rich mantle can also explain the lack of secondary craters. Because the typical depth of the largest secondaries for craters the size of Vaduz is ~10 m [15-16], they would have been erased when the underlying unit was removed.

The almost complete regional disappearance of this ice-rich mantle suggests that the unit was not regolith with minor pore ice but rather a very ice-rich deposit, as was recently excavated by five impacts at higher midlatitudes [17]. The disappearance is consistent with the retreat of near-surface ice stability to higher latitudes in the last several hundred thousand years [1-3]. Because the latitude-dependent mantle described by Head et al. [2] is similarly interpreted to have formed in a recent ice age, it is likely similar to this former ice-rich unit.

In excess ejecta craters (EEC), the perched surface is composed of ejecta [7], but pedestal craters (Pd) are perched on circular plateaus that extend well beyond the ejecta [8]. An airblast/thermal pulse model [18] could explain the extent and circularity of these pedestals [8]. 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.

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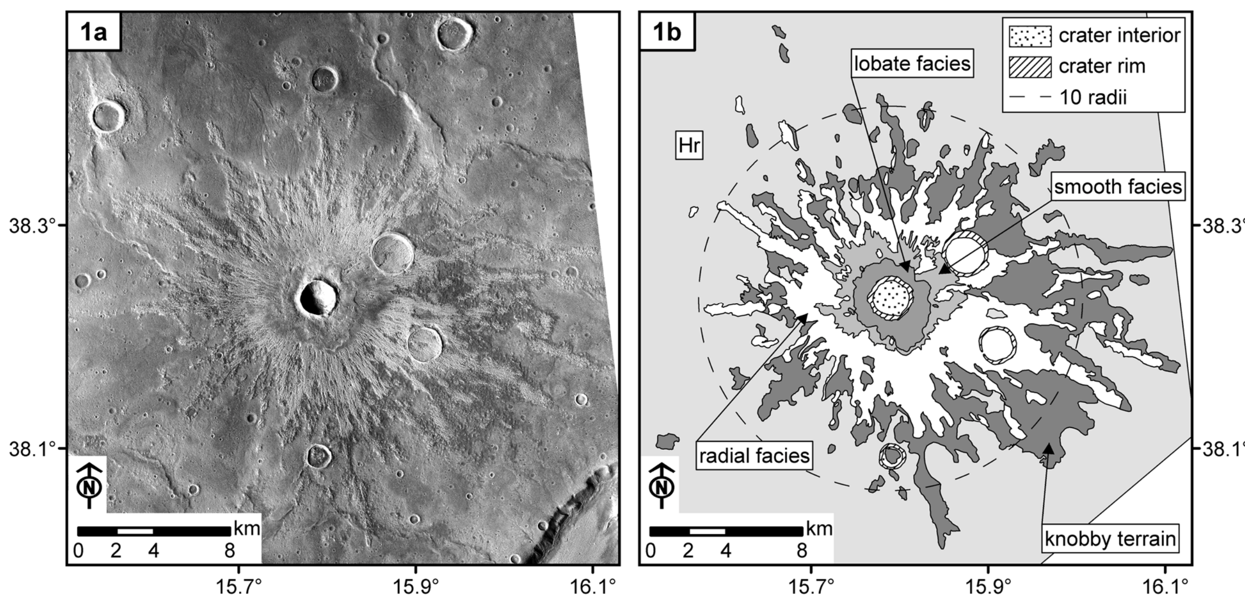

Figure 1. Vaduz, a very fresh, 1.85 km diameter impact crater centered at ~38.2°N, 15.8°E. a) Portion of CTX image P15_007057_2179. A portion of Mamers Valles is seen in the lower right corner. b) Geomorphic map, with map units labeled. Dashed circle indicates 10 radii radius from the rim crest.

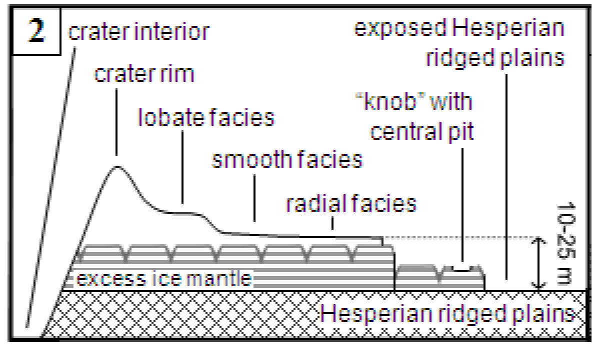

Figure 2. Diagrammatic cross-section of Vaduz illustrating the inferred relationship of geologic units (Fig. 1) and topography. The excess ice mantle is interpreted to have once extended regionally but has since retreated by sublimation. The knobs are interpreted to be thermal contraction crack polygons.