EVIDENCE OF COMPLEX ICE-VOLCANO INTERACTIONS IN THE TRANSITION ZONE BETWEEN ELYSIUM RISE AND UTOPIA BASIN. G. B. M. Pedersen[1,2] and J. W. Head[3], [1]Nordic Volcanological Center, Institute of Earth Sciences, University of Iceland, Sturlugata 7, 101 Reykjavík, Iceland. [2]Department of Earth Sciences, University of Aarhus, Hoegh-Guldberggade 2, 8000 Aarhus C, Denmark (grobirkefeldt@gmail.com). [3]Dept. of Geological Sciences, Brown Univ., Providence, RI 02912, USA.

Introduction: Landforms resulting from ice-volcano interactions on Mars are of great interest because of their potential to provide important information about the presence and distribution of volatiles through martian geologic history. A variety of magma-H_2O interactions, including both intrusive and extrusive magmatic activity, have been proposed [e.g., 1-6] and a comprehensive review concludes that magma-H_2O interactions on Mars have been widespread through space and time [7].

We here report on morphologic evidence of a complex succession of ice-volcano interactions and reconsider the emplacement properties of volcanoclastic outflow deposit under martian conditions as well as their implications for subsequent volcanic activity and degradation.

Geologic setting: The study area encompasses the northwestern part of the Elysium Rise, the western part of Galaxias Chaos and its transition into Utopia Planitia, spanning from 138°-145°E; 31°N-40°N (Fig. 1). A variety of ice-volcano interactions have been proposed to have taken place in the region. Of special interest are the outflow deposits originating from the NW flank of Elysium Rise and extending more than a thousand kilometers into Utopia Basin. They are of Early Amazonian age [8] and have been interpreted as evidence for mega-lahars due to their lobate morphology, well-defined snout and close association with channels; this has led to hypotheses that heat from volcanic activity melted ground ice and thereby mobilized surface and subsurface material [1, 4, 8-11]. Studies by [12] supported the mega-lahar hypothesis by observations of dendritic ridges along the margin of the flow deposits interpreted to result from dewatering of the mega-lahars. Calculations by [4] suggested that melted ground ice is not sufficient to account for the enormous volumes of lahar deposits, thus requiring a groundwater source. It was therefore suggested that dike emplacement would disrupt the cryosphere and tap an underlying confined groundwater system, which during drainage would form mega-lahars by incorporation of erupted and existing surrounding materials.

Morphology and Distribution: Various units have been interpreted to relate to volcano-ice interactions and include: smooth flow, SF (~45,400 km^2), channel deposit, CD (~1,890 km^2), flood plain deposit, FPD (~13,730 km^2), terrace deposit, TD (~4,200 km^2), knobby unit, KU (~8,550 km^2), wavy unit, WU (~4,900 km^2), trough unit, TU (~4,000 km^2), ridges and fractures.

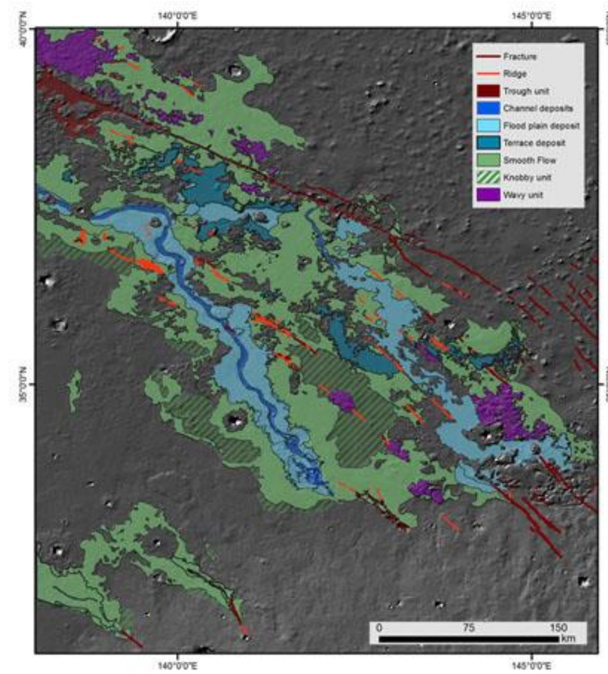

Figure 1. Study area and distribution of SF, CD, FPD, TD, KU, WU, TU, ridges and fractures.

SF is the most extensive deposit with diagnostic steep, lobate flow fronts with upward convex snouts, variable thickness (10-100 m), enclosed depressions pits and hollows, crenulated rims and internal fractures. Distinct crater morphologies are observed resembling ring-mold craters (RMCs) [13,14], thermally distinct craters [15] and ice-cauldron–like features [16].

CD, FPD and TD are recognizable by their very flat, smooth appearance and normal impact craters. Both FPD and TD display flow-like textured albedo variations, while CD is associated with very characteristic tear-drop shaped islands.

KU is characterized by its knobby surface and its gradual stratigraphic relationship with SF and *WU* consists of 17 irregular elongated low sloping edifices trending NW-SE, 130-250 m high with wavy-smooth-surface, normal craters and an irregular outline with raised rims.

Discussion and Conclusion: We interpret these relationships to represent widespread evidence of repeated, complex ice-volcano interactions in the transition zone between Elysium Rise and Utopia Planitia based on morphological and stratigraphical observations of SF, CD, FPD, TD, KU, WU, TU, ridges and fractures: All units are stratigraphically closely related and are interpreted to be volcaniclastic outflow deposits (SF, CD, FPD and TD), degraded outflow deposits (KU) and landforms originating from volcanic intrusions (WU, TU, ridges and fractures).

Unlike previous interpretations of mega-lahar deposits, we interpret SF to be the frozen, distal parts of lahar flows because of the distinct morphological properties of the unit (smooth, lobate flow fronts with upward convex snouts, unusual crater morphologies, raised rim fractures and localized flow fronts indicating rheomorphism), which is unlike CD, FPD, and TD (which display fluvial morphologies). Thus, we hypothesize that lahar emplacement under martian conditions may result in a double-layered deposit consisting of an ice-rich core with an ice-poor surface layer (Fig. 2). The top layer develops as a raft of material as a result of inverse particle segregation during the flow analogues to terrestrial lahar flows. However, because of the cold martian conditions only the water in the central parts of the flow drains (and produces landforms such as CD, FPD and TD), whereas the water in the distal parts of the lahar deposit freeze up rather than sublimates due to the insulating properties of the top layer. We moreover suggest that post-emplacement processes modified SF due to subsequent volatile loss in the ice-rich core resulting in deflation and retreat of SF explaining the raised rim fractures along the edges of the SF deposit as well as isolated SF–islands (Fig. 3). Based on stratigraphic relationships we find it very likely that such volatile losses were a consequence of volcanic intrusions within SF, which helps to explain previous interpretations of Galaxias Mons as a möberg ridge [1] as well as dikes and associated ice-cauldron-like depressions within SF [14]. Instead of möberg formation under an ice sheet [1] we alternatively suggest that Galaxias Mons, along with other deposits mapped as wavy units, are volcanic edifices emplaced into ice-rich lahar deposits mapped as SF, confirming previous [17] suggestions of intrusions into a mixed units of rock and ice.

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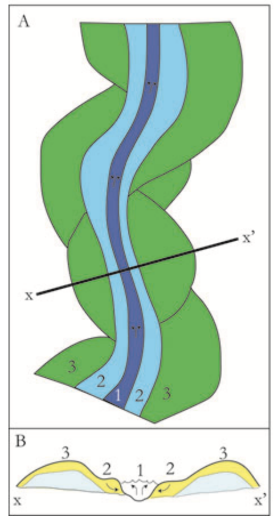

Figure 2. Sketch of lahar deposition where (A) shows a plan view and (B) display a cross section at x-x' and no. 1 marks the medial channel (channel deposit, CD), no. 2 marks the flood plain deposit (FPD) and no. 3 is lobes of smooth flow (SF).

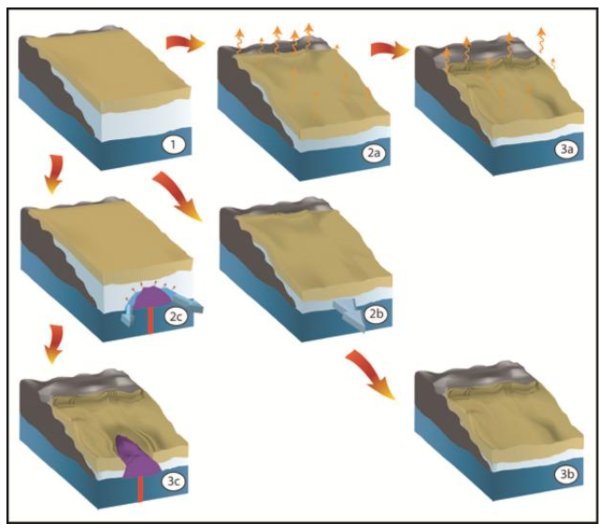

Figure 3. Three possible models for raised rim fracture formation along the edges of SF (smooth flow). SF is shown as a two layered deposit with an ice-rich core (white) and ice-poor plug (beige) and is emplaced on top of a horizontal layer (dark blue) thinning towards some hilly terrain (gray). Deflation of the ice-rich core can occur either by: (A) sublimation through the plug shortly after emplacement before the particles have settled (2a-3a) (B) drainage of some of the water from the central core shortly after emplacement (2b-3b) (C) volcanic intrusion into a frozen SF unit melting substantial amount of ice within the SF deposit that after drainage deflates and crack the SF deposit.