A RELICT GLACIER NEAR MARS' EQUATOR: EVIDENCE FOR RECENT GLACIATION AND VOLCANISM IN EASTERN NOCTIS LABYRINTHUS. Pascal Lee[1,2,3], Sourabh Shubham[4], and John W. Schutt[2]. [1]Mars Institute, [2]SETI Institute, [3]NASA Ames Research Center, [4]University of Maryland. Email: pascal.lee@marsinstitute.net.

Summary: A light-toned deposit (LTD) in Eastern Noctis Labyrinthus presents distinctive morphologic characteristics of a glacier. Although the glacier is likely relict, the preservation of fine-scale glacial features opens the possibility that H_2O ice might still be preserved beneath LTD material. Recent equatorial glaciation, volcanism, and volcano-ice interaction on Mars are implied.

Introduction: The broad, topographically depressed region on Mars between Valles Marineris (VM) and Noctis Labyrinthus (NL), north of Oudemans crater, presents great geologic diversity and a complex aqueous, volcanic, and glacial evolutionary history [e.g., 1-3]. This unnamed region, provisionally designated *Noctis Landing*, has been proposed as a candidate landing site and exploration zone (LS/EZ) for human missions to the surface of Mars [4,5] **(Fig.1).** *Noctis Landing* is attractive to explore as it enables access, towards the East, to VM and its extensive record of Martian geologic history to search for signs of past life, and towards the West, to NL, the Tharsis volcanoes beyond, and their many lava caves, to search for extant life [4].

Hydrated minerals are present in *Noctis Landing* in a wide variety of forms among the many light-toned deposits (LTDs) in the area [2,6]. H_2O ice fog has also been interpreted as a common occurrence in VM/NL [7,8]. However, there is as yet no evidence in this region of H_2O ice in surface or near-surface materials in the current epoch. This is not surprising, as H_2O ice would not be thermodynamically stable if exposed directly to current annual atmospheric P, T conditions in Mars' equatorial regions.

We report here morphologic features characteristic of a glacier presented by a LTD at 7°33' S, 93°14'W in Eastern Noctis Labyrinthus, 160 km NW of Oudemans crater **(Figs 1+2).**

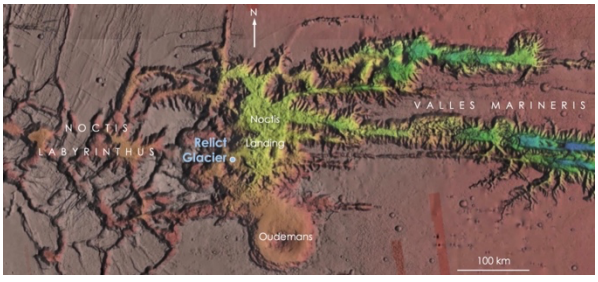

Figure 1: "Relict Glacier" Location Map *(Mars QuickMap).*

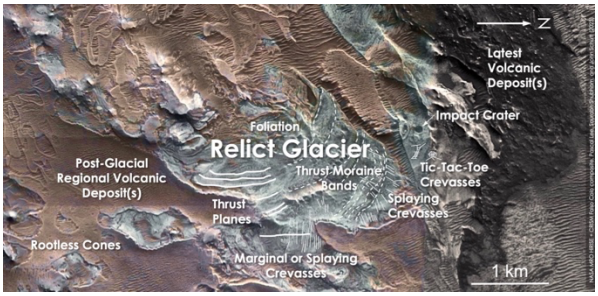

Figure 2: "Relict Glacier" in Eastern Noctis Labyrinthus. *This 2-4 km wide light-toned deposit (LTD) (gray), exposed through breaks in overlying surface volcanics and sand (red and black), presents a lobate structure, fracture patterns, banding, foliation, and surface textures characteristic of glaciers, glacial flow, and ablation. (False color composite NASA MRO HiRISE+CRISM).*

Observations: Analysis of MGS MOC and MRO CTX and HiRISE imaging data reveals an LTD area in which light-toned material is exposed through breaks created in the apparent collapse and partial removal of an overlying surface crust. The main collapse zone is tongue shaped **(Fig. 3).** The surface crust in the main collapse zone presents fields of sand dunes, whereas the LTD is relatively sand-free.

The main exposure of the LTD presents a number of fine-scale (meters to 10s of meters) dark and light sets of thin lineations (5-25 m wide) and curvilinear bands (20-200 m wide). The lineations are locally subparallel and equally spaced (5-50 m apart), and form a a radial pattern on the LTD near the tip of the tongue-shaped collapse area. The banding pattern, while overall arcuate and traceable across much of the width of the collapse zone, shows local kinks and areas of thinning and broadening. Band boundaries are also observed to intersect the sides of the tongue at curving, asymptotic angles. The LTD surface also shows locally roughly circular, concentric lineation patterns ~100-150 m across, as well as wedge-shaped intersecting fracture patterns which dice up the LTD surface into angular blocks ~20-50 m across. The main LTD and nearby satellite LTD exposures also show, in places, in particular away from the tip of the tongue, "disturbed" terrain (term used in original HiRISE image captions) exhibiting distinct flow and banding patterns ~10-300 m wide, often with high-relief, ~10-150 m tall, boundaries.

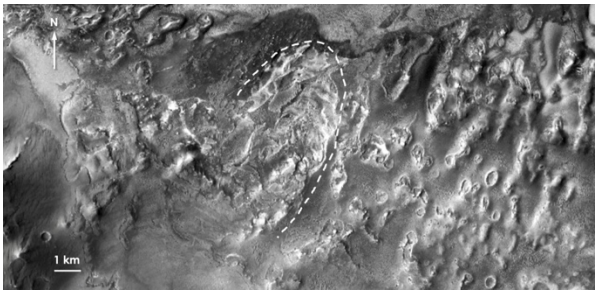

Figure 3: "Relict Glacier" Context Image. *Hachured line outlines tongue-shaped main surface crust collapse area revealing underlying LTD material. The main LTD exposure shown in Fig.2 is near tip of the tongue. (NASA MRO CTX).*

Glacier Interpretation: The above *combination* of morphologic and structural features and relationships are characteristic of glaciers on Earth and on Mars. The tongue-shaped collapse zone and partial exposure of underlying LTD material is interpreted to mark the location of a relict glacier tongue approximately 2-4 km wide and at least 6 km long. The glacier's direction of flow was toward the NE. Large scale banding across the width of the glacier and asymptotic angles near the edge of the tongue are interpreted as thrust moraine bands and their associated thrust planes **(Figs. 2+4).** Disturbed terrain described above reflects complex glacial flow patterns, resulting in shearing and foliation features. Elevated flow and fold boundaries may be the result of differential erosion, although recessional moraine deposits might also be present.

Lineation sets shown in **Figs. 2 and 4** are interpreted as networks of ice marginal and splaying crevasses, the latter showing their distinctive radially fanning geometry. Circular concentric and dicing lineation patterns in **Figs. 2 and 5** are interpreted as circular and tic tac toe crevasse fields, respectively.

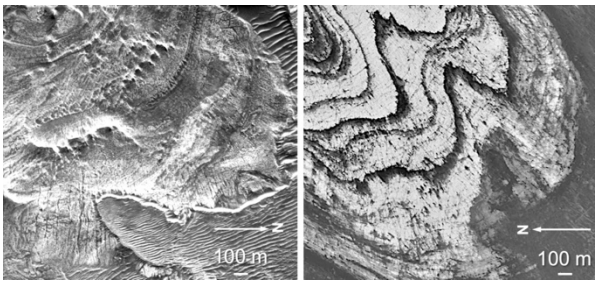

Figure 4: "Relict Glacier" Bands and Lineations vs Terrestrial Analog. Left: *"Relict Glacier" tip displays distinctive lineation sets and banding interpreted as splaying crevasses and foliated thrust moraine bands, resp. (NASA MRO HiRISE).* ***Right:*** *Frontal area of an outlet glacier, Vatnajökull Ice Cap, Iceland, with features analogous in form and in scale (Google Earth).*

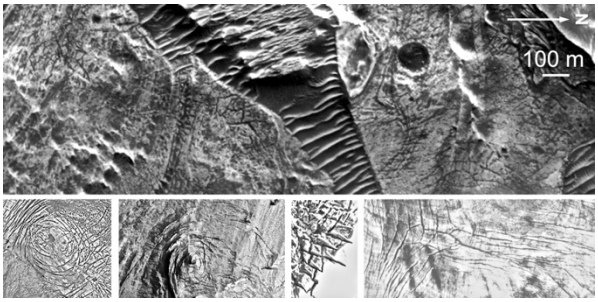

Figure 5: "Relict Glacier" Circular and Intersecting Fractures vs Terrestrial Analogs. Top: *Circular fractures (upper left) and intersecting fractures (center & right) on "Relict Glacier" (NASA MRO HiRISE).* ***Bottom:*** *Circular crevasses (left images) and tic tac toe crevasses (right images) on the Pasterze Glacier, Austria. (Google Earth).*

Age, Evolution, and H_2O Ice Survival: The LTD and overlying volcanic deposits are likely recent, i.e., Amazonian [9], given the sparsity of impact craters and the preservation of fine-scaled glacier features.

MRO CRISM data do not show H_2O ice in association with this LTD, but hydrated and hydroxylated sulfates. These sulfates were likely produced in volcano-H_2O interactions, possibly from ash or pyroclastic deposits resting on, and reacting with, glacier ice [10]. Over time, with the eventual loss of much or all of the ice, the volcanic crust collapsed and partially eroded away, exposing a LTD deposit with the underlying glacier's morphologic signatures still preserved. Two possible current states are hypothesized: 1) All the H_2O ice is gone, but the LTD deposit has formed a veneer preserving the glacier's morphology in relict form down to its finer details, such as crevasse fields; 2) Some H_2O ice is still there, but is blanketed by LTD material which insulates it thermally and diffusively, as with ancient ice islands in Altiplano salars [11].

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