THE ROLE OF SUBSURFACE VOLATILES IN THE FORMATIONAL HISTORY OF NOCTIS LABYRINTHUS, MARS. Corbin L. Kling (clkling@ncsu.edu)[1], Paul K. Byrne[1], and Karl W. Wegmann[1], [1]Department of Marine, Earth, and Atmospheric Sciences, North Carolina State University, Raleigh, NC, 27695.

Introduction: Noctis Labyrinthus on Mars boasts many interesting geomorphological signatures indicating a complex history (**Figure 1**). Situated between the Tharsis Rise and Valles Marineris, Noctis is understudied compared with its more famous neighboring regions. Noctis Labyrinthus itself contains abundant normal faults, pit craters, and deep troughs. The area was first mapped in 1977 on Mariner imagery [**1**], and interpreted as akin to the East African Rift system with respect to the large amount of faulting and the orientations of those faults. The formational history of Noctis Labyrinthus, however, is still debated, with explanations for its deep troughs ranging from lava tube collapse [**2**] to groundwater release through faulting pathways and psuedokarst [**3, 4**]. There is no widespread evidence for a large amount of liquid water once having flowed through Noctis Labyrinthus—such as major outflow channels and tear-drop-shaped island remnants—but a few fluvial-like channels are situated on the eastern margin close to Valles Marineris that have short runouts and do not appear to cross cut between different troughs, which could be indicative of a more complex fluvial system. Here, we present a comprehensive assessment of the geomorphology of Noctis Labyrinthus, and offer a formational history that incorporates these disparate features and points to volatile sublimation as a major contributor to regional topographic evolution.

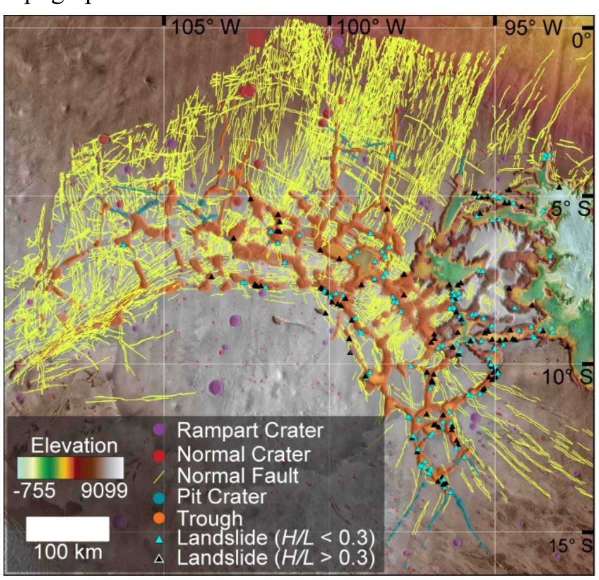

Figure 1. *Map of Noctis Labyrinthus, Mars. MOLA–HRSC DEM overlaid on Themis Daytime IR. All pertinent geomorphological features are shown.*

Landforms of Noctis Labyrinthus: The region contains abundant normal faults, pit craters (collapse pits with circular to elliptical/elongate shapes), and rampart craters (impact craters with morphologies indicating volatiles were mobilized in the ejecta) surrounding the deep troughs (**Figure 1**). The troughs contain many landforms indicating mass wasting processes and hint at the presence of ice. Landslides dominate trough slopes, whereas periglacial landforms are common along troughs floors.

The occurrence of landslides and periglacial features in the large troughs of Noctis provide useful information regarding the final stages of formation, and potentially give clues to what process(es) contributed to the initial development, of these troughs. For example, scaling relations for rampart craters located around Noctis Labyrinthus can place bounds on the depth to a volatile layer that could have contributed to the growth of the troughs. If a volatile-rich layer were exposed to the atmosphere, that material could sublimate or melt to create additional void space for collapse. Landslide height-to-runout length (*H*/*L*) ratios can further be used to determine the extent to which a fluid agent might have been involved in mass wasting.

Methods: For this project, we used Context Camera (CTX) images [**7**] to identify landforms of interest, and the Themis Daytime IR mosaic [**8**] and the MOLA–HRSC Combined Global digital elevation model (DEM) [**9**] for mapping and topographic analyses.

Landforms interpreted as periglacial were identified on the basis of the morphological properties for thermokarst presented by, for example, ref. [**3**]. All craters ≥250 m in diameter were mapped using CraterTools for ArcGIS™ [**10**]. The global database of Martian landslides from [**5, 6**], including *H*/*L* data, was used to identify the point locations of the landslides present within Noctis Labyrinthus.

Pit craters were mapped in a polygon shapefile. For each pit, the major and minor axes and depth were measured in separate shapefiles and combined for further morphometric analyses. Normal faults were mapped using a polyline shapefile, with vertices being placed along the base of the scarp denoting the fault displacement. Troughs were mapped using polygon shapefiles, with the vertices being placed at the top of the trough walls.

Mapping Results:

Landslides: There are 231 landslides within the Noctis Labyrinthus region as identified by the global dataset of ref. [5]. Landslide spatial density increases from west to east as the troughs get wider and deeper and open up towards Valles Marineris. The landslides have an average *H/L* ratio of 0.27; although *H/L* ratios do not unequivocally indicate whether a given landslide was fluidized [5, 6, 11], values below 0.30 may indicate fluidization, as commonly observed on Earth.

Pit Craters: There are 250 pit craters located within Noctis Labyrinthus. The pits occur on the periphery of the large trough structures making up the labyrinth, with only one pit located inside a trough. Most (>70%) of the pits have associated normal faults bounding either or both sides of the pit chain, suggesting that there is an extensional tectonic component to the formation of the pits. Pits at Noctis Labyrinthus are of order 10s to 1000s m in both diameter and depth.

Periglacial landforms: We find that numerous examples of periglacial landforms including interpreted ice wedge polygons, solifluction lobes, and thermokarst are present within the troughs of Noctis Labyrinthus. Examples of each type of landform are sited at 5.64°S, 263.64°E, 6.07°S, 258.74°E, and 7.01°S, 261.14°E, respectively. These features are cross cut by landslides in most places, indicating that the periglacial activity is older than the landslides. The presence of these landforms strongly suggests some role played by ground ice in shaping Noctis Labyrinthus.

Rampart Craters: All craters ≥250 m in diameter in the region were mapped, yielding a total of 831. Each crater was assessed for rampart ejecta morphology (e.g., after [13, 14]) and designated as such in the shapefile. Of the 831 total craters we mapped, 77 have clear rampart morphology, with a further 50 having potential rampart morphology (which we do not consider further here). Using depth–diameter relationship scaling [e.g., 12, 13], and under the assumption that the rampart morphology reflects mobilization of a volatile in the crust, we determined the depth to such volatile(s) using scaling relationships for ejecta blankets given by ref. [14, 15] (where ejecta comes from the top 1/3 of the depth of the crater). We find that rampart craters are present with diameters as small as ~750 m, indicating some volatile component in the subsurface at depths of as little as ~250 m when those craters were formed.

Discussion and Outlook: Abundant normal faulting and pit craters are evident around the periphery of Noctis Labyrinthus, but are mostly absent from the bigger, central troughs. We take this spatial distribution of tectonic structures to indicate that pits and normal faults developed first in the region, before being cross-cut and destroyed by later, further growth of the troughs.

On the basis of our mapping results, we suggest that, early in the history of Noctis Labyrinthus, normal faults developed in response to localized or regional extension, that then led to pit crater generation as unconsolidated material drained into dilational normal faults (i.e., extensional faults with some amount of Mode I opening) [16]. Some pit craters grew to a sufficient depth to intersect volatile-rich layers, allowing those volatiles to escape due to sublimation, in turn driving further collapse and coalescence of the pits to form the large troughs (especially if coupled with continued crustal extension). Such growth of initial tectonic depressions, aided by subsequent volatile exposure and loss via sublimation, could explain the absence of pit craters and faults within the troughs, as well as the presence of secondary mass-wasting products (e.g., landslides) therein. Using scaling relations for the rampart craters, we find that such a volatile layer could be situated as shallow as ~250 m in the crust there.

Possible causal volatiles include H_2O or CO_2. An H_2O ice cryosphere may be situated at depths of less than 5 km today [17]. This ice may have been at even shallower depths in the past, depending on climatic conditions at Noctis Labyrinthus and within the troughs. The periglacial landforms imply that a substantial amount of volatiles were trapped or remained within the troughs, with seasonal melting or sublimation responsible for the features we see there today, e.g., ice-wedge polygons, thermokarst, etc. The contribution of volatiles to the formation of Noctis Labyrinthus supports the hypothesis of a hydro/cryosphere being present at equatorial regions of Mars beyond the Late Hesperian, the age of the volcanic flows that make up the surface of Noctis Labyrinthus.

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