

GULLY FORMATION ON THE CENTRAL PEAK OF LYOT CRATER: IMPLICATIONS FOR A LATE PALEO MICROCLIMATE. Virginia C. Gulick and Natalie G. Glines, SETI Institute/NASA-ARC, NASA Ames research Center, MS 239-20, Moffett Field, CA 94035 (vgulick@seti.org).

Introduction: The role liquid water played in gully formation in Mars' recent geological history continues to be actively debated. Numerous global studies have mapped the distribution and morphologies of the gullies (for recent reviews see [1, 21]). The global diversity of gully morphologies led many to conclude multiple formation processes were responsible for their origin with no one mechanism being broadly preferred. To better understand the relative importance of various possible gully formation and modification processes, we have been conducting detailed morphologic/morphometric studies of gullies in various environmental settings on Mars using HiRISE and CTX images and DTMs. Studied gully locations include: Palikir Crater [12, 13, 14], Corozal Crater [18], Moni Crater [19, 20], the central peak of Lyot crater [3, 4], western rim of Sisyphi Cavi, Hale Crater [2], the central pit and western rim of Asimov Crater [15], and the Kaiser and Matara dunes [17].

Here, we report our recent gully studies on Lyot's central peak [3] and our detailed mapping of adjacent landforms, which we find are consistent with persistent freeze/thaw processes operating over several hundred years or more [5, 6]. We propose that a local atmospheric hydrologic cycle associated with an evaporating ice-covered paleolake, snow accumulation, and subsequent melting on the adjacent central peak region was responsible for the formation of these gully systems.

Potential Thermokarst Landforms and Paleolake in Lyot Crater's Central Peak Region: Based on our recent mapping of Lyot Crater's central peak region, we have identified flat-floored, circular-to-oblong depressions, connected by channels [5, 6, 3]. We find these potential thermokarst landforms are similar morphologically to beaded streams on Earth. The bead and channel systems flow southwards towards the lowest elevation region (~ -7 km) in the northern hemisphere. The gullies which preferentially form on the western side of the central peak also mostly flow towards this region (Figure 1). Beaded streams and other associated landforms terminate at ~ -6.8 km elevation, which we suggest delineates a paleolake margin which formed during a period of higher obliquity. In this scenario, winds blowing over an ice-covered lake towards the peak region could evaporate/sublimate sufficient water vapor to deposit snow at a cold trap on the western central peak slopes at ~ 1.7 to 2 km higher elevation (Figure 2). This snow could have melted seasonally. Assuming T_s of 265 K on the floor of Lyot Crater, snow could accumulate at 2 km higher in elevation on the central peak over a similar area at rates of over a meter/year of equivalent water [9]. Estimated snowfield sublimation rates on the central peak are on order of 10s of cm/year.

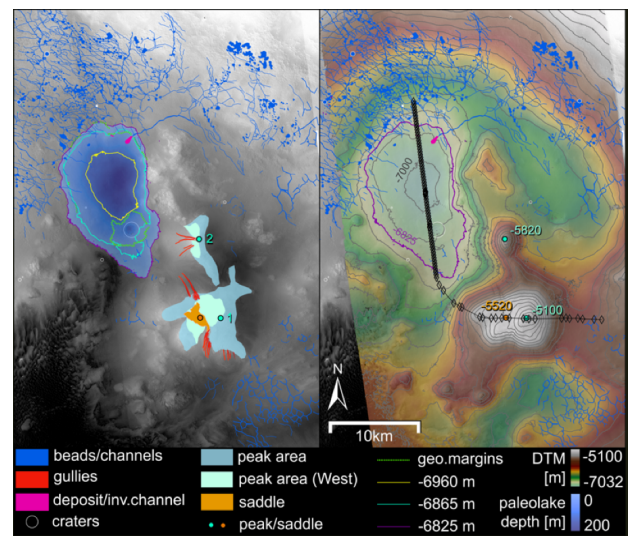


Figure 1: Left: Map showing locations of gullies, potential snow pack, peak area, potential paleolake levels, thermokarst channels, depressions (beaded streams) and other channel forms. Right: CTX DTM colorized elevation map over CTX mosaic showing transect location. (CTX DTM 100 m contours tied to MOLA). (Gulick et al. 2018).

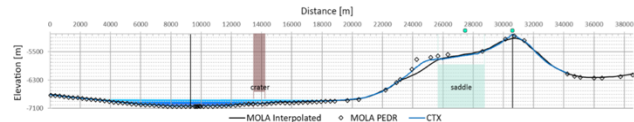


Figure 2: Elevation profile of transect in right panel through potential paleolake and across central peak.

Could liquid water have ever been stable enough to flow on the surface of Lyot crater? Haberle et al. [11] addressed water stability on Mars and stated that liquid water need not be stable with respect to evaporation, but only with respect to boiling and freezing. They pointed out, that liquid water is generally not stable on Mars or Earth with respect to evaporation, as the lower limit of liquid water stability is defined by the freezing curve and is independent of ambient pressures. Furthermore, the boiling point is the temperature at which the saturation vapor pressure equals the total external pressure, *regardless of the external pressure source*. They estimated that the T and P range in which liquid water could exist on Mars is between the triple point of water at 273 K and 6 mbar and 283 K and ~ 12 mbar. Within this range, the total pressure can be supplied by CO_2 , and water vapor need not be present to stabilize liquid water against boiling.

TES P_s are ~ 9 to ~ 11 mbar, and TES T_s range up to ~ 276 K over the central peak of Lyot Crater, while THEMIS T_s ranged up to ~ 265 K. Liquid water on the floor

of Lyot crater is thus stable against boiling. In fact, we find that nearly 90% of TES P_s values exceed 10 mbar in Lyot’s central peak region [3].

A paleo micro-climate on the western slope of Lyot Crater’s central peak region? The gullies on the central peak of Lyot Crater are intriguing because they formed on an Amazonian age isolated topographic high and therefore may provide a better understanding of Mars’ more recent paleoclimatic history. The central peak region of Lyot Crater has a unique micro-environment where surface pressures are ~10.5 mbar and seasonal surface temperatures approach the melting point of water, which put it in proximity to the favorable zone where similar to Earth, water evaporates but doesn’t boil. This environment would be conducive for liquid water seasonally during periods of slightly higher obliquity or possibly even currently if liquid water were present.

The gullies on Lyot Crater’s central peak form integrated tributary systems on overall slopes between ~17-22 degrees with apron apex slopes < 14 degrees. Given these low slopes, a fluid (water) would have been required to erode the slopes to form gullies and transport material to emplace material in the apron deposits. Distributary channels formed on the aprons which blend in gradually with the surrounding terrain. These characteristics are consistent with fluvial processes (Table 1).

Table 1: Compatibility of Lyot Crater Gully Morphologic Characteristics with a Formation by Fluvial, Debris Flow, and Dry Flow processes.

Lyot Crater Gully Characteristics	Fluvial/H ₂ O dominated	Debris Flows (~20-50% H ₂ O)	Dry Flows
Alcoves cut into bedrock	Yes	Yes	Unconsolidated Alcoves only
Alcove slopes: ~20° - 22°	Yes	No	No
Complex tributaries	Yes	No	No
Exploits fractures	Yes	Not generally	No
Erodes through bedrock	Yes	Not generally	No
Channel Slopes: ~12° -17°	Yes	No	No
Concave Long profiles	Yes	No	No
V-shaped X-sections	Yes	No	No
Point bars/cut banks	Yes	No?	No
Sinuuous	Yes	Yes	Yes?
Knickpoints in long profile	Yes	No	No
Distributary channels on apron	Yes	No	No
Apron apex slopes: ~10° - 14°	Yes	No	No
Apron margins blend in gradually with surrounding terrain	Yes	No	No
Apron volumes ~10% - 40% of gully volumes	Yes	No	No

The system of thermokarst-like depressions and troughs that are morphologically similar to terrestrial beaded streams terminate at ~ -6800 m into the low elevation region adjacent to the gullied slopes of the central peak. Terrestrial beaded streams form as a result of seasonal freeze/thaw processes operating over several hundred years. If these landforms are indeed beaded streams, then water must have flowed on the surface seasonally. The formation of the small pristine crater in this region with a lobate ejecta blanket is consistent with the subsurface containing liquid water or ice.

The presence of gullies only on the western side of the central peak suggests orographic processes may have been important to gully formation (Figure 3). We have estimated

sublimation/evaporation rates that would be associated with an ice-covered paleolake in this region (Figure 4). We estimate that several tens of centimeters per year could accumulate on the central peak, from dry winds (~10 m/s) blowing across a sublimating ice-covered paleolake onto the western central peak region. Seasonal melting from such a snowpack would be sufficient to form the gullies on the central peak of Lyot Crater. Modest changes towards higher obliquities may have been sufficient to initiate this microclimatic hydrologic cycle.

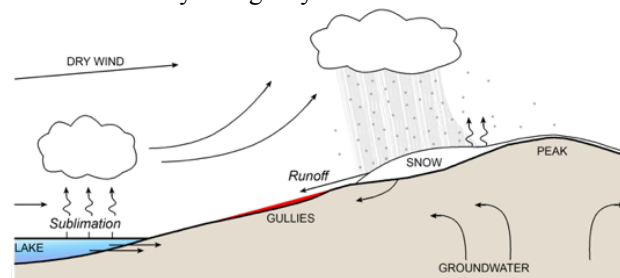


Figure 3: Conceptual model of the paleo micro-climate on the western slope Lyot Crater's central peak region.

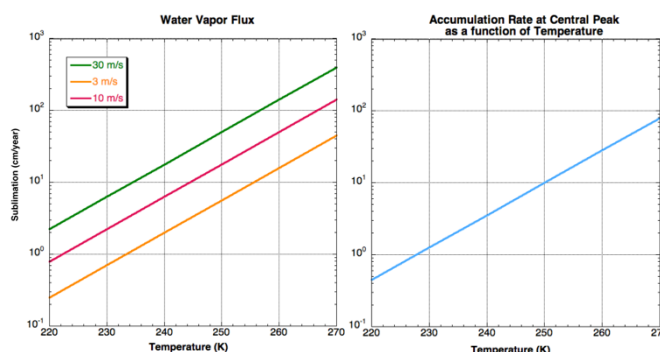


Figure 4a) Water vapor flux as a function of wind speed and surface temperature (after Moore et al. 1995) yield sublimation rates from a frozen paleolake as a function of temperature. b) Snow accumulation results from the difference in sublimation between the body of water and snowfield. Larger elevation differences and warmer T produce greater net snow accumulation (after Gulick et al. 1997).

We are continuing to explore this potential water source and the possibility for other potential paleo microclimates elsewhere on Mars. This mechanism if correct would also have important astrobiological and paleoclimatic implications for late Mars geologic history.

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References: [1] Harrison et al. 2015, Icarus 252. [2] Gulick et al. 2017 LPSC #1970. [3] Gulick et al. 2018 GSL, SP 467. [4] Hart S.D. et al. (2010) LPSC #2662; Hart et al. 2009 LPSC #2349. [5] Glines & Gulick 2018 LPSC #2955. [6] Glines & Gulick 2018, Late Mars Workshop, [7] Kolb et al. 2010, Icarus 208. [8] Gulick et al. 1997, Icarus. [9] Gulick 2001, Geomorphology. [10] Gulick et al. 2014, 8th Mars Conf. [11] Haberle et al. 2001, JGR 106. [12] Narlesky & Gulick 2014, #2870. [13] Hamid & Gulick 2018. LPSC #2644. [14] Luu et al. 2018. LPSC #2650. [15] Paladino et al. 2018. LPSC #2889. [16] Corrigan et al. 2017. LPSC # 2876. [17] Glines & Gulick 2018. LPSC #2825. [18] Hernandez et al. 2014. LPSC #1198 [19] Glines & Gulick 2014. LPSC #2926. [20] Glines et al. 2016. LPSC #2464. [21] Hobbs et al 2017. Geomorphology 295.