GULLIES WITH CHANGING APPEARANCE ON MARS: REGIONAL CHARACTERISTICS AND GEOLOGICAL SETTING.

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Introduction: Remarkably, two gullies on Mars have been observed to change significantly in appearance by brightening between observations taken over a period of only a few years [1]. This discovery has been interpreted to mean that these small gullies must have been active in the recent past [1], though it remains possible that the cause of the brightening may be due to some other process. This provides new impetus to understand the how gullies form on Mars, a process that has remained controversial (in part because of gullies wide range of morphological expression). The most widely advocated models fall into two classes: groundwater discharge [e.g., 2-5] or melting of ice or snow [e.g., 6,7]. Here we describe contextual characteristics of the brightened gullies in Terra Sirenum and Centauri Montes [1], and discuss what this might imply for their formation via groundwater or snowmelt if they are active at the present day.

Centauri Montes: The 'active' gully is on a southeastern portion of the interior wall of an oblong (8 km x 6.6 km) crater, located at ~96.8 E, -38.4 N, with rim elevation of -2150 m (Fig. 1). Along with the available MOC data, the region containing the Centauri Montes feature has been imaged by HRSC in three orbits (38, 506, and 2510), all after the brightening became evident in MOC data [1]. Though the feature itself is unresolvable in the HRSC data, these provide a valuable context for understanding the MOC observations.

The active feature is one of the smallest gully features in the crater, and unlike the well-expressed gullies on the crater's north and northeast wall it has no clear source region and only a small possible depositional apron. The gullies found here are on steep slopes (>~20º), consistent with other observations in this latitude band [8]. The slope of the interior crater wall is where the active feature is found is ~22-23º. Where steep slopes are present, gullies are also common on nearby crater and valley walls.

Large lobate flow features are common on inner-massif surfaces in the Centauri Montes region (Fig. 1). This feature class on Mars has been interpreted as debris-covered (or rock) glaciers [9,10,11], where the mobility of material is enhanced by a significant (but unknown) ice fraction. These lobate flow features are at least hundreds of meters thick. Recent GCM work has discovered a plausible source for the ice deposition that led to these lobate flows: water vapor is preferentially transported into this region due to focusing by the deep Hellas basin during periods of high obliquity, causing snow or ice deposition [12, see especially Fig. 4].

These lobate flow features surround the crater which contains the brightened gully to its north and east. The crater seems likely to have formed with the lobate flow features already present, since its ejecta appears to have caused deflation of the flow's surface (resulting in pitting and 'wavy' texture found within one crater diameter of the crater rim; Fig. 1). This implies that the crater ejecta interacted with a pre-existing volatile-rich surface. Similar deflation around craters is found in other potentially ice-rich regions (e.g., Deuteronilus Mensae).

Terra Sirenum: The active gully is located on the western wall of a 5-km crater at ~-161.7 E, -36.3 N. The crater rim elevation is ~3000 m, which is an unusually high elevation for a Martian gully, at least in this latitude band [8]. The peak slope near the active feature is ~21º. There are other small gully features in the crater, but these are all rather poorly-developed compared to many gullies on Mars, including the larger gullies in the Centauri Montes' crater. The data coverage at the location of the Terra Sirenum active feature itself is somewhat poorer than for Centauri Montes, so it is necessary to rely on nearby images to understand its geological context.

In both the 'active' gully crater and in the crater found on the nearby MOC image R13-04515, the walls are mantled by 'pasted-on' material. There is also highly degraded lineated or ridged material on crater floors of both the 'active gully' crater and the crater in R13-04515. The association between both pasted-on terrain [7] and ridged crater fill material with gullies is a common one for gullies [e.g., 13]. Both of these units are thought to be potentially ice-rich, perhaps deposited during periods of mantling of the surface at latitudes >30º [14]. Advocates of the snowmelt formation model point to the pasted-on material as a possible source for gullies [7].

Temperature and Pressure: The maximum surface temperatures observed in the Centauri region in the summer are at least ~280 K (on sun-facing, steep slopes, e.g., THEMIS IR images I17334004 and I17359002). Likewise, THEMIS IR summertime temperatures in the 'active' gully crater itself in Terra Sirenum (I07983006) reach a maximum brightness temperature of 297 K. Although this is on eastern side of the crater lit by the afternoon sun (opposite from the brightened gully), presumably the western rim experiences similar peak temperatures during the morning.

These observed peak temperature in both the Centauri Montes and Terra Sirenum are well above the melting temperature of water (at least at the surface). Indeed, this is expected, since both brightened gullies are at latitudes (~36 and ~38º S) close to where the peak summertime temperatures are found on Mars [e.g., 15]; temperatures likely reach >300 K with favorable illumination geometries. Though the amount of the subsurface that will reach the melting temperature is limited to the thermal skin depth of a few cms or less, if ice were available in this near-surface region when high temperatures are reached, the temperature regime is sufficient for melting to occur today.

However, the elevation of the Terra Sirenum brightened gully is a major limitation on possible surface melting. At 3000 m above the datum, the atmospheric pressure should never be above the triple point pressure for water in the present Martian climate [e.g. 15, Fig 4]. Only in the Centauri Montes case is there both sufficient atmospheric pressure and temperature to produce liquid water at the surface, as was recognized before the changing gullies were discovered [15]. This condition is reached relatively rarely on Mars in the present day (though the locations identified by Haberle et al. [15] are somewhat conservative, since temperatures can be enhanced by slope effects, as emphasized by Hecht [16]).

Implications: In many respects, the Centauri Montes are an optimal location for present-day gullying, because (1) water ice deposition appears to have been focused in this region (at least in the past [12], perhaps also today?), (2) temperatures get very warm on the surface, (3) pressures are greater than the H_2O triple point, and (4) the impact crater where 'brightened' gully is found appears to be surrounded by material (hundreds of meters thick) that might still be ice-rich. The gully-containing impact crater appears to have formed when ice-rich material was already in place in its surroundings; it is easy to imagine this could generate anomalously warm temperatures in the subsurface that could persist until today (and help trigger subsurface melting to supply groundwater into the crater). Thus, in the case of Centauri Montes, both surface melting and groundwater models are plausible mechanisms for explaining why a gully might be active today.

In Terra Sirenum, the peak temperature in the surface environment is high in the summertime, and there is some evidence for 'pasted-on' terrain, thought to potentially result from deposition of a volatile-rich mantle [14]. However, there are no special reasons why we would expect enhanced ice deposition in the Terra Sirenum region, and the present surface pressure is too low to support melting. Groundwater models [2-5] that have been proposed may bring water to the surface well out of equilibrium with the surface environment, and this sort of explanation may be the easiest explanation for recent activity in Terra Sirenum.

Scenarios consistent with these observations include: (1) If both gullies brightened due to flow of liquid water across the surface and the same process is responsible in both cases, groundwater discharge is a possible explanation. If this is the case, we need to understand the subsurface conditions that make these locations favorable for groundwater discharge to occur today (e.g., saline springs [5]).

(2) Alternatively, the recent flow of liquid water at the two locations might be due to different mechanisms. The range of formation models [2-7] presented for gullying on Mars are not exclusive. The warm peak temperature, high atmospheric pressure, and plausible source of ice in Centauri Montes makes meltwater production there a likely option, even if it unlikely to occur today in Terra Sirenum. Analogs in the Antarctic Dry Valleys are providing insight into gully formation by top-down melting in a range of microenvironments [17].

(3) It remains possible that the observed changes in the gullies was not a result of recent flow of liquid water on the surface. Other mechanisms to explain the brightening still need to be fully explored, and further high resolution observations also need to be obtained to fully constrain the relevant processes.

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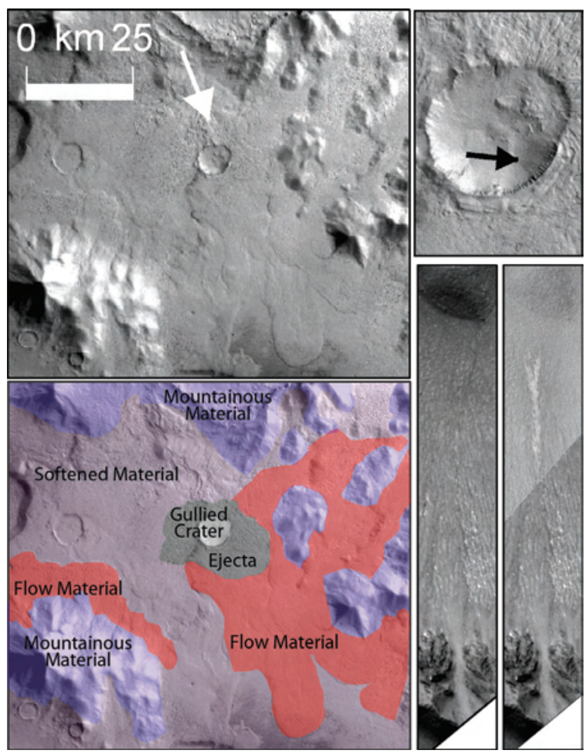

Figure 1. Regional context (HRSC orbit 2510) for the Centauri Montes crater with the 'brightened' gully (at lower right; MOC images M04-04175 and S10-00142 [see 1]).