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Present-day seasonal gully activity in a south polar pit (Sisyphi Cavi) on Mars

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ABSTRACT

The large amount of multi-temporal high-resolution images acquired in the last few years offers the opportunity to identify morphological changes associated with recent geologic activity on the surface of Mars. In this study we focus on a single gully in Sisyphi Cavi, located in the south polar region at 1.44°E and 68.54°S. The gully incises the gullied equator-facing slope of an isolated polar pit within an infilled impact crater. It is important to notice that the following investigations describe the activity and modifications of an existing gully and not the formation of the gully itself. High-resolution image data analyses show new deposits at the terminus of the gully channel and on the gully apron within spring (after solar longitudes of 236°) of martian years (MY) 29 and 31. Our morphological investigations show that the identified new deposits were formed by dark flows through the entire gully deposited on top of the apron between solar longitudes (L_S) ~218° and ~226°. Thermal data show a temperature increase between L_S ~218° and ~226°. Near-infrared spectral data show relatively constant band strengths of CO_2 ice and H_2O ice in this time range. After the formation of the dark flows (after L_S ~226°), temperatures increase rapidly from ~180 K to >~270 K at L_S ~250°. At this time, spectral data indicate that all volatiles on the surface sublimated. However, an earlier beginning of sublimation when the dark flows were observed (between L_S ~218° and ~226°) is likely, due to the fact that the instruments can only show the last phase of sublimation (decrease of volatile band strengths). Spectral modeling shows that from winter to mid-spring, the surface of the studied area is covered by translucent CO_2 slab-ice contaminated by minor amounts of H_2O ice and dust. Furthermore, our spectral modeling indicates that the dark material most likely flows on top of the CO_2 slab-ice cover. Three different scenarios were proposed to explain the identified dark flows, including (1) flows supported by liquid H_2O, (2) flows supported by CO_2 gas, and (3) dry flows. On the basis of our study we find that scenario (1) is unlikely because of the very low temperatures. While scenario (2) is consistent with the observed beginning of CO_2 ice sublimation in the study area, it is unlikely because of the limitation of the activity to only one gully compared to surrounding gullies that share the same morphologies, slope angles, and volatile contents. Also with scenario (3), dry flows, the activity of only one gully is difficult to explain. Thus, we propose a mixture of scenario (2 and 3), dry flows supported by the ongoing sublimation of CO_2 ice within the gully, to be the most plausible scenario, when the observed active gully comprises different source material than the surrounding gullies, i.e., a higher content of probably sand-sized material from outcrops located in the alcove.

1. Introduction

Gullies on Mars were first detected by Malin and Edgett (2000) in high-resolution Mars Orbiter Camera-Near Angle (MOC-NA) imagery. In this work, gullies showing the typical morphology of an alcove, channel, and apron (Malin and Edgett, 2000) are described by the term "classical gullies". Classical gullies might be formed by subsurface water release (e.g., Malin and Edgett, 2000), CO_2-based liquid or gas supported flows (e.g., Musselwhite et al., 2001), melting of near-surface H_2O ice (e.g., Costard et al., 2002; Reiss et al., 2009; Jouannic et al., 2012) or surface snow (Christensen, 2003; Head et al., 2008), or by dry granular flows (Treiman, 2003; Shinbrot et al., 2004).

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The global distribution of gullies is limited to mid- and high-latitudes poleward of ~30° in both hemispheres with an orientation of gullies on mostly poleward-facing slopes (e.g., Malin and Edgett, 2000; Balme et al., 2006) shifting to a predominantly equatorward orientation between ~44°S and 64°S (e.g., Heldmann and Mellon, 2004; Aston et al., 2011; Raack et al., 2012a). In the northern hemisphere, Heldmann et al. (2007) and Kneissl et al. (2010) observed a predominantly equatorward orientation of gullies. The strong latitude-dependence of gullies and their assemblage with viscous flow features and the dust–ice mantle (Milliken et al., 2003) suggest a climatic influence on their formation, possibly caused by obliquity changes in the recent past (Head et al., 2003). Hoffman (2002) investigated gullies in the southern polar region (Sisyphi Cavi), adjacent to our study region. He estimated that gullies within Sisyphi Cavi are young (~20 ka to ~20 Ma) and were formed in spring by CO_2-gas lubricated flows.

Dickson and Head (2009) estimated that gullies were active in the last several millions of years (Ma) by an episodic melting of an atmospherically emplaced snow/ice cover during spin-axis orbital variations of Mars. Investigations by Reiss et al. (2004) and Schon et al. (2009) show gully ages of less than ~3 Ma and ~1.25 Ma, respectively. Raack et al. (2012a) investigated gullies in the Argyre Basin with a general age of <~20 Ma and an even younger generation of gullies with ages of about <500 ka.

Multi-temporal high-resolution image datasets of the last martian years (MY) offer the possibility to identify present-day seasonal modifications of gullies on Mars. For instance, bright sedimentary deposits at gully sites formed within the last decade imply current activity (Malin et al., 2006). These deposits show morphological attributes expected from liquid water flow (Malin et al., 2006; Heldmann et al., 2010), but they might also be consistent with dry flows (Pelletier et al., 2008; Kolb et al., 2010) or frosted granular flows, being lubricated by vaporization of CO_2 frost and possibly small amounts of H_2O frost (Hugenholtz, 2008).

A large variety of currently active mass movement features occur on dune slopes on Mars (e.g., Diniega et al., 2010; Reiss et al., 2010). These mass movement features do not share all morphological attributes and thus are morphological different to the classical gullies on Mars. Nevertheless, the same processes might trigger their present-day activity resulting in observable modifications of classical gullies.

Investigations of classical gullies (Dundas et al., 2010) show that present-day activity occurs in a latitude range between ~29°S and 54°S in 10 different regions on Mars, possibly involving CO_2 frost (Dundas et al., 2010). Interestingly, all these regions with present-day gully activity are located in latitude bands where H_2O and CO_2 frosts are seasonally stable (Vincendon et al., 2010a, 2010b). Activity of classical gullies in the last martian years in the southern polar regions and also in specific location presented in this work were detected by Dundas et al. (2012) and Raack et al. (2012b), however, it remains unclear how the activity was initiated. Dundas et al. (2012) and Raack et al. (2012b) narrowed the activity down to southern early spring and mid-spring, respectively. Generally, all seasonal activity of gullies occurred when defrosting, CO_2 ice sublimation or sublimation/melting of H_2O ice (brines) on the surface took place (Dundas et al., 2012).

Defrosting dark spots on large dark dunes were analyzed by several authors (e.g., Cantor et al., 2002; Piqueux et al., 2003; Kieffer et al., 2006; Appel et al., 2010). These dark spots are likely formed by basal sublimation of CO_2 ice followed by degassing of CO_2 gas through cracks within the translucent CO_2 ice slab, carrying darker sand and dust from the surface aloft to form dark spots on top of the slab ice (e.g., Piqueux et al., 2003; Kieffer et al., 2006).

Another model describes the formation of dark spots and the resulting dark flows on dunes in the northern polar region by basal melting of H_2O ice and subsequent seeping to the surface (Appel et al., 2010). Dark flows emanating from dark spots down the dune were also observed by, e.g., Kereszturi et al. (2009, 2010, 2011), Gardin et al. (2010), and Hansen et al. (2011, 2012). The formation of the dark flows is not yet understood. A proposed mechanism is the formation through the involvement of H_2O (Appel et al., 2010; Kereszturi et al., 2009, 2011) or brines (Kereszturi et al., 2010). Hansen et al. (2011, 2012) favored a formation through the involvement of CO_2, while Gardin et al. (2010) proposed avalanches of a mixture of sand, dust, and sublimating CO_2 ice above a frosted surface as the formation mechanism for the dark flows.

The most abundant volatiles on Mars are CO_2 and H_2O, which can be found in the atmosphere and in higher amounts as ices in the north and south perennial polar caps (e.g., Kieffer et al., 1976; Brown et al., 2010, 2012; Schmidt et al., 2010; Appéré et al., 2011) or in isolated and protected regions like impact craters (Brown et al., 2008). The seasonal changes in insolation result in a global volatile cycle characterized by waxing and waning of the seasonal polar caps due to seasonal deposition and sublimation of CO_2 and H_2O ices (e.g., James et al., 1992; Jakosky and Haberle, 1992). These seasonal processes might also lead to landform changes in the circumpolar regions on Mars (e.g., Christensen et al., 1998; Piqueux et al., 2003). The southern residual polar cap consists of a ~3700 m thick reservoir of H_2O ice and is covered the entire year by meters-thick CO_2 ice with contaminations of H_2O ice (e.g., Bibring et al., 2004a; Langevin et al., 2007). Completely CO_2-free H_2O ice was spectrally detected by Bibring et al. (2004a) during southern summer at the scarps around the residual polar cap and in regions tens of kilometers away from the CO_2 ice residual cap. Based on theoretical considerations, Farmer and Doms (1979) and Schorghofer and Aharonson (2005) suggested that a water ice layer can form down to ~30° latitude in both hemispheres. Recently, using near-infrared data, surface seasonal water ice has been detected on poleward slopes down to 13°S (Carrozzo et al., 2009; Vincendon et al., 2010a). Furthermore, evidence for near-surface perennial H_2O ice was obtained down to 25° latitude in the southern hemisphere (Vincendon et al., 2010b).

Here we report on seasonal modifications of a classical gully on a slope in the south polar pitted region named Sisyphi Cavi (71.5°S and 355°E). This region was selected because of the extensive coverage with high-resolution image data. With a multi-temporal survey of high-resolution images, temperature, and spectral data, we address the following main questions: (1) Which morphologic changes of the gully can be observed within the last martian years? (2) What is the time range (season) for the formation of new morphologic changes of the gully? (3) What material forms the morphologic changes? (4) What mechanism(s) triggers the formation of these new morphologic changes?

2. Study region

We have performed a survey of 130 HiRISE images acquired in the last four martian years (MY) in Sisyphi Cavi over a large area centered on 355°E and 71.5°S (Fig. 1). Fig. 1 shows a Mars Orbiter Laser Altimeter (MOLA) shaded relief model superposed by a MOLA digital terrain model. The black rectangles represent footprints of available HiRISE images; the red box represents the region with the gully showing morphologic changes (Fig. 2a). Almost half of the images cannot be used for our investigations because 41 images show no gullies and another 10 images are lacking multi-temporal coverage of at least two images. Most of the images used in this study were acquired during spring and summer.

The highest concentration of multi-temporal HiRISE images (36 images) is located at 1.3°E and 68.5°S (red square in Fig. 1, corresponding to Fig. 2a), thus, we will focus our study on this region. The study region comprises a polar pit with numerous gullies on