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Geologically recent gully–polygon relationships on Mars: Insights from the Antarctic Dry Valleys on the roles of permafrost, microclimates, and water sources for surface flow

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ABSTRACT

We describe the morphology and spatial relationships between composite-wedge polygons and Mars-like gullies (consisting of alcoves, channels, and fans) in the hyper-arid Antarctic Dry Valleys (ADV), as a basis for understanding possible origins for martian gullies that also occur in association with polygonally patterned ground. Gullies in the ADV arise in part from the melting of atmospherically-derived, wind-blown snow trapped in polygon troughs. Snowmelt that yields surface flow can occur during peak southern hemisphere summer daytime insolation conditions. Ice-cemented permafrost provides an impermeable substrate over which meltwater flows, but does not significantly contribute to meltwater generation. Relationships between contraction crack polygons and sedimentary fans at the distal ends of gullies show deposition of fan material in polygon troughs, and dissection of fans by expanding polygon troughs. These observations suggest the continuous presence of meters-thick ice-cemented permafrost beneath ADV gullies. We document strong morphological similarities between gullies and polygons on Mars and those observed in the ADV Inland Mixed microclimate zone. On the basis of this morphological comparison, we propose an analogous, top–down melting model for the initiation and evolution of martian gullies that occur on polygonally-patterned, mantled surfaces.

1. Introduction

Gullies on Mars are a class of geologically young features, initially interpreted to have formed by surficial flow of released groundwater (Malin and Edgett, 2000, 2001; Mellon and Phillips, 2001), and which may still be active (Malin et al., 2006). Martian gullies are geomorphic features composed of a recessed alcove, one or more sinuous channels, and a depositional fan or apron (Malin and Edgett, 2000). Alternative hypotheses for the source of gully-carving fluids include obliquity-driven melting of near-surface ground ice (Costard et al., 2002), melting of dust-rich snow deposits (Christensen, 2003), and melting of atmospherically emplaced frost and/or snow (Hecht, 2002; Dickson et al., 2007a; Head et al., 2007; Dickson and Head, 2008; Williams et al., 2008). Complementing gully formation models, recent GCM results (Forget et al., 2007) predict the deposition and potential for melt of up to 25 mm/yr of water ice at martian northern midlatitudes (∼30–50° N) during obliquity conditions modeled to have occurred within the past 10 My (and potentially within the past <1 My; Laskar et al., 2004). Other workers have proposed that gullies can form by dry avalanche processes alone (Treiman, 2003; Pelletier et al., 2008).

Concurrent with advances in understanding of gully processes on Mars, modeling and observational studies have documented the distribution and origin of various types of martian thermal contraction crack polygons (Mellon, 1997; Mangold, 2005; Levy et al., 2008a). Despite the observation of polygonally patterned ground in gullied terrains on Mars and Earth (Malin and Edgett, 2000, 2001; Bridges and Lackner, 2006), and an increasing awareness of the importance of polygonally patterned permafrost in the development of terrestrial polar fluvial systems (Fortier et al., 2007; Levy et al., 2007a; Levy et al., 2008b), there has been little analysis of the interactions between thermal contraction crack polygons and gullies on Mars.

In this contribution, we explore interactions between gullies and polygons in the Mars-like Antarctic Dry Valleys (Marchant and Head, 2007), and then assess similarities and differences with features observed on Mars. We first summarize recent research on the spatial distribution, formation, and modification of gullies and polygons in selected regions of the Antarctic Dry Valleys (ADV). In the next section we show how gully development on polygonally patterned ADV surfaces affects gully morphology and enhances water-flow processes. Further, we show how the morphology of

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