Effects of varying obliquity on Martian sublimation thermokarst landforms

Colin M. Dundas

Astrogeology Science Center, U.S. Geological Survey, 2255 N. Gemini Dr., Flagstaff, AZ 86001, USA

ARTICLE INFO

Article history:
Received 16 May 2016
Revised 23 August 2016
Accepted 30 August 2016
Available online 31 August 2016

Keywords:
Mars, surface
Mars, climate
Geological processes
Ices

ABSTRACT

Scalloped depressions in the Martian mid-latitudes are likely formed by sublimation of ice-rich ground. The stability of subsurface ice changes with the planetary obliquity, generally becoming less stable at lower axial tilt. As a result, the relative rates of sublimation and creep change over time. A landscape evolution model shows that these variations produce internal structure in scalloped depressions, commonly in the form of arcuate ridges, which emerge as depressions resume growth after pausing or slowing. In other scenarios, the formation of internal structure is minimal. Significant uncertainties in past climate and model parameters permit a range of scenarios. Ridges observed in some Martian scalloped depressions could date from obliquity lows or periods of low ice stability occurring ~5 Ma, suggesting that the pits are young features and may be actively evolving.

Published by Elsevier Inc.

1. Introduction

The distribution of ice on Mars is strongly sensitive to the planetary climate. At one extreme, stacks of thin layers make up the polar layered deposits and record variations in the deposition of ice and dust over time (e.g., Byrne, 2009). At lower latitudes, ice comes and goes as the climate changes (Mellon and Jakosky, 1995; Chamberlain and Boynton, 2007), resulting in a landscape shaped by this repeated emplacement and removal. However, the details of past climates are not known well, and must be inferred from the traces they have left on the modern surface.

Scalloped depressions (“scallops”; Fig. 1) are commonly found on Mars in the Utopia Planitia region and around Amphitrites and Peneus Paterae south of Hellas Planitia (e.g., Costard and Kargel, 1995; Plescia, 2003; Morgenstern et al., 2007; Lefort et al., 2009, 2010; Séjourné et al., 2011, 2012; Soare et al., 2007, 2008, 2011; Ulrich et al., 2010, 2012; Zanetti et al., 2010). They are typically meters to decameters deep, and range in size from hundred-meter-scale to merged structures spanning kilometers. Most workers attribute these pits to sublimation-thermokarst processes under a variety of evolution scenarios, while others have proposed origins as thermokarst lakes. Such origins imply that their formation, evolution, and morphology are potentially useful recorders of climate history, if they can be interpreted correctly.

One morphology of particular interest is the occurrence of arcuate ridges in certain scalloped depressions (Fig. 1), which are found in many pits in Utopia (e.g., Soare et al., 2007; Lefort et al., 2009), but not in the Amphitrites/Peneus Paterae region (Lefort et al., 2010). Lefort et al. (2009) argued that the ridges arise from several intervals of sublimation and erosion, while Séjourné et al. (2011) proposed that they are exposed shallowly-dipping layers. Soare et al. (2007, 2008) suggested an origin as shoreline features, but Lefort et al. (2010) pointed out that these ridges are not level and that scallops occur on slopes that make lake formation improbable.

Dundas et al. (2015) used a landscape evolution model to demonstrate that sublimation under the current Martian climate can produce landforms similar to simple scalloped depressions. Here I apply this model with a varying climate in order to understand how this modifies landform evolution.

2. Model

This work uses the sublimation-thermokarst model described in Dundas et al. (2015), hereafter referred to as Paper I. The basis of the model is insolation-driven sublimation of excess ground ice, dependent on slope and aspect, combined with diffusive mass movement of dry regolith. The diffusive mass movement is due to surface creep of the dry lag, which may be caused by factors like thermal cycling, frost loading and sublimation, or seismic shaking. The subsurface initially comprises a surface layer of ice-free regolith above excess ice with low regolith content, and pore-filling ice can develop within the lag during periods of net deposition. Aggradation always fills the pores just above the ice table, although in reality more diffuse deposition can occur, as discussed in Paper...
1. This may influence the details of landform evolution but is unlikely to alter the general behavior. The lookup tables for ice loss were generated for a latitude of 50°N, a thermal inertia of 300 J m⁻² K⁻¹ s⁻¹/2 and albedo of 0.13, reasonable values for the northern plains. Because the model is optimized for computational efficiency, the precise equilibrium ice depths are not as accurate as in some other models, but the uncertainties due to this factor are likely less than the uncertainties in past climate conditions.

Unlike Paper 1, the simulations described in this work use time-varying climate conditions. This is implemented via time variation of the lookup tables used to model sublimation, which are derived from a thermal model and depend on the ice depth, mean atmospheric water content, and the obliquity and orbit of Mars. Melting never occurs in the climate scenario considered here; only the rate and distribution of sublimation varies. The model steps between lookup tables generated for a range of conditions in order to model a variable climate.

Mars’ obliquity, eccentricity and longitude of perihelion all vary and influence the stability of ground ice (Mellon and Jakosky, 1995; Chamberlain and Boynton, 2007). However, generating lookup tables for all combinations of these variables experienced in recent history is computationally expensive. This paper focuses on the effect of obliquity, for two reasons. First, obliquity has the most significant effect on mean surface temperature at most latitudes, other than a narrow zone near 60° latitude (Schorghofer, 2008), and has the strongest effect on the distribution of stable ground ice (Chamberlain and Boynton, 2007). Second, the relative evolution of surfaces with different orientations and ice depths controls the morphology of sublimation landforms. Eccentricity and the timing of perihelion affect the distance to the sun as a function of season, but obliquity controls the solar zenith angle. The zenith angle is more relevant for determining the relative heating of different slopes and aspects. Therefore, this paper examines only the variation of obliquity, assuming a circular orbit. The mean annual atmospheric water vapor content follows the zero-eccentricity-orbit values of Chamberlain and Boynton (2007). The lookup table changes every 2.5° of obliquity, so I interpolate values intermediate to their estimates (spaced 5°) using the logarithm of the water vapor content. Obliquity variations follow Laskar et al. (2004) (Fig. 2), but the general conclusions below are not sensitive to the details of this evolution.

In order to simplify the climate variations (the details of which are subject to significant uncertainty), some factors are not considered. The model does not include surface ice deposition, which is predicted to occur at high obliquity (e.g., Forget et al., 2006; Madeleine et al., 2009, 2014). I discuss the effects of this assumption below. Atmospheric pressure is also held constant in the model, although in reality it does vary over time.

There are several other important parameters in the model. Paper 1 used a nominal regolith diffusivity of 10⁻⁴ m² s⁻¹, but considered this likely to be an upper bound. In baseline cases here I used a value of 3 × 10⁻⁵ m² s⁻¹, which may still be high; use of too-low regolith diffusivity values can lead to numerical instabilities as discussed in Paper 1. For comparison, Golombok et al. (2014) estimated a value of 10⁻⁶ m² s⁻¹ for Meridiano Planum, although mid-latitude geomorphic evolution is likely faster. Though the regolith diffusivity value is constant in time in the model, it may vary in reality. However, the strength or even the direction of the effect as a function of obliquity are unknown. I also examine different values of the diffusion coefficient for water vapor as it sublimates through the regolith, namely 3 × 10⁻⁴ m² s⁻¹.

The standard model domain for these model runs is 200 m in the east-west dimension and 500 m north-south, with periodic boundary conditions. The elongated domain accommodates growth along the north-south axis. For most model runs the scallop did not reach the edge of the domain. The spatial resolution was 0.5 m, and higher resolution runs gave negligible differences in trial cases. Scallop growth in each run is initiated by removal of a shallow spherical cap of regolith tangent to the top of the ice table, destabilizing ground ice by reducing the lag thickness. This initiating
دریافت فوری
متن کامل مقاله
امکان دانلود نسخه تمام متن مقالات انگلیسی
امکان دانلود نسخه ترجمه شده مقالات
پذیرش سفارش ترجمه تخصصی
امکان جستجو در آرشیو جامعی از صدها موضوع و هزاران مقاله
امکان دانلود رایگان ۲ صفحه اول هر مقاله
امکان پرداخت اینترنتی با کلیه کارت های عضو شتاب
دانلود فوری مقاله پس از پرداخت آنلاین
پشتیبانی کامل خرید با بهره مندی از سیستم هوشمند رهگیری سفارشات