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Aeolian processes as drivers of landform evolution at the South Pole of Mars

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ABSTRACT

We combine observations of surface morphology, topography, subsurface stratigraphy, and near surface clouds with mesoscale simulations of south polar winds and temperature to investigate processes governing the evolution of spiral troughs on the South Pole of Mars. In general we find that the south polar troughs are cyclic steps that all formed during an erosional period, contrary to the troughs at the North Pole, which are constructional features. The Shallow Radar instrument (SHARAD) onboard Mars Reconnaissance Orbiter detects subsurface stratigraphy indicating relatively recent accumulation that occurred post trough formation in many locations. Using optical instruments, especially the Thermal Emission Imaging System (THEMIS), we find low altitude trough clouds in over 500 images spanning 6 Mars years. The locations of detected clouds correspond to where recent accumulation is detected by SHARAD, and offers clues about surface evolution. The clouds migrate by season, moving poleward from 71° S at ~L_s 200° until L_s 318°, when the last cloud is detected. Our atmospheric simulations find that the fastest winds on the pole are found roughly near the external boundary of the seasonal CO_2 ice cap. Thus, we find that the migration of clouds (and katabatic jumps) corresponds spatially to the retreat of the CO_2 seasonal ice as detected by Titus (2005) and that trough morphology, through recent accumulation, is integrally related to this seasonal retreat.

1. Introduction

Polar layered deposits (PLD) on Mars are primarily composed of water ice and dust (Grima et al., 2009; Fishbaugh et al., 2010; Hvidberg et al., 2012). The PLD together comprise the majority of surface ice on Mars, each rising above the surrounding terrain ~3 km, and are together comparable in volume to the Greenland ice sheet on Earth (Smith et al., 2001a). The north PLD (NPLD) and south PLD (SPLD) undergo seasonal variability, especially between winter (when CO_2 ice frost covers the polar regions) and summer (when the CO_2 ice has sublimed) (Kieffer et al., 2000; Kieffer and Titus, 2001; Byrne, 2009).

The surfaces of the PLD have enigmatic medium scale features, including chasmae larger than the grand canyon on Earth (Fishbaugh and Head, 2001; Farrell et al., 2008) and deep spiral depressions with 20–50 km wavelengths (Cutts, 1973; Howard et al., 1982; Smith et al., 2013) (Fig. 1). On the SPLD specifically, other features are found, including scallops with similar cross section to the spiral troughs but much smaller in breadth (Howard, 2000; Grima et al., 2011) and the aptly-named wirebrush terrain (Kolb and Tanaka, 2006). These features, resulting from erosional and depositional patterns of ice, are potentially a key to understanding the history of the PLD and the water cycle on Mars.

Various processes have been invoked to explain observations associated with each PLD feature: basal melting (Clifford, 1987; Fishbaugh and Head, 2002), tectonics (Grima et al., 2011), viscous ice flow (Fisher, 1993, 2000), and brittle deformation (Murray et al., 2001), among others. Recent evidence on the NPLD has shown that the spiral troughs and Chasma Boreale likely formed within a constructional setting, with winds and atmospheric deposition likely playing the major roles (Holt et al., 2010; Smith and Holt, 2010; Smith et al., 2013). Observations of low altitude clouds and atmospheric modeling (Smith et al., 2013), surface morphology (Howard, 2000), in addition to radar stratigraphy (Smith and Holt, 2010) demonstrate that ice is transported across the NPLD by wind to form and modify these features; however, no studies have provided the same detailed combination of techniques to address the SPLD.

Here, we provide evidence that SPLD features, like those on the NPLD, are the result of persistent katabatic winds that contain katabatic jumps. In particular, we find that the SPLD spiral troughs belong to a set of morphological features called cyclic steps, which form because of fast winds and repeated katabatic jumps (Smith et al., 2013). Unlike on the NPLD, the SPLD troughs formed within a regime that has experienced more erosion than deposition, especially during the early stages. Our evidence includes topographic profiles, subsurface stratigraphy with

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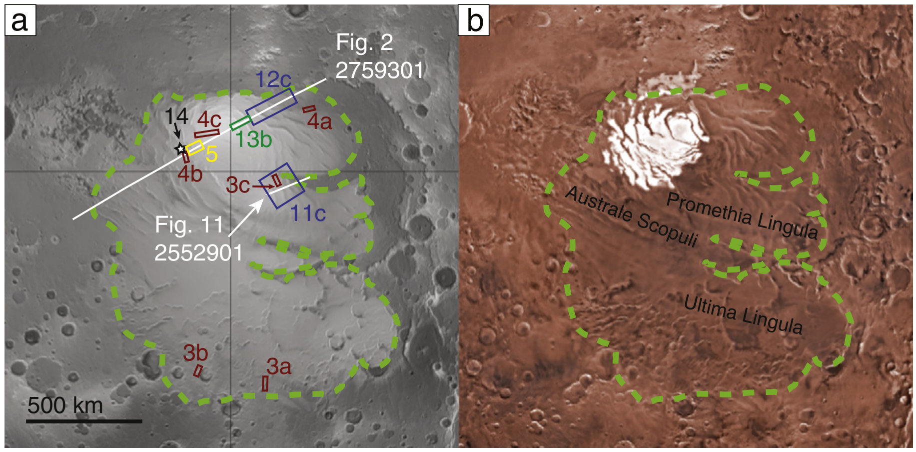

Fig. 1. SPLD surface and locations of the following figures. a) SPLD hillshade map. Ground tracks of SHARAD radargrams and footprints of optical imagery for future figures are listed with numbers. b) Viking color mosaic of SPLD with labeled geographic names. Residual CO_2 ice cap remains white through the Martian year, but the rest of the ice cap is covered by red dust in spring and summer. Large chasmae, spiral troughs, and scallops are visible. Green dashed lines delineate the approximate extent of the SPLD ice deposits.

the shallow radar instrument (SHARAD), and optical data that images the surface and atmospheric phenomena (i.e. clouds).

As a supplement to these observations, we employ a cap-wide high-resolution mesoscale atmospheric model on the SPLD. Global and regional (mesoscale) climate models have been developed for many years to predict circulation and clouds in the Martian atmosphere. In particular, NPLD features related to winds have been studied in detail (Massé et al., 2012; Brothers et al., 2013; Smith et al., 2013), yet few studies have attempted to relate the landforms on the SPLD to modeled winds (Koutnik et al., 2005).

As a reference we adopt a nomenclature of trough orientation based on elevation rather than one based on orientation. Trough high sides are always topographically higher than the low sides (Fig. 2). Descriptions based on orientation, such as "poleward" or "equatorward," are insufficient because troughs in some regions are oriented east-west, so these characterizations break down. Furthermore, the terrain of each trough varies by location, so characterizations of morphology or stratigraphic exposure are fundamentally limited to the individual trough being examined. The high/low side topographic description has the advantage of being consistent across all troughs.

In Section 2 we provide a background for the rest of the paper. Section 3 introduces the methods utilized in this study, including optical observations detecting near surface clouds, radar observations of subsurface structure, and atmospheric modeling of surface temperature and near surface winds. In Section 4 we describe cloud detections, specifically spatial and temporal variability. Section 5 provides results of atmospheric simulations of an individual day and throughout the season. Modeled winds are compared temporally to cloud detections. In Section 6, we use SHARAD to associate the spatial detection of clouds with recent accumulation. Section 7 discusses these correlations and significance, and Section 8 provides some concluding remarks.

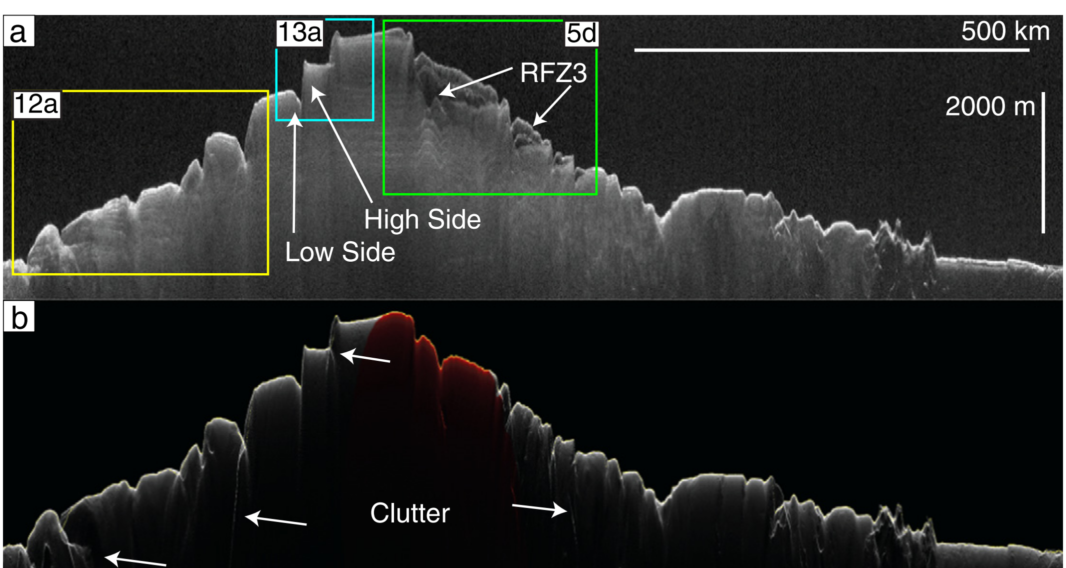

Fig. 2. SHARAD observation and clutter simulation 2579301. a) Troughs are topographically asymmetric. High side slopes generally face toward the equator and are always higher in elevation than low side slopes. Low side slopes generally face toward the pole. RFZ_3 unit has been interpreted as being massive CO_2 ice (Phillips et al., 2011). b) Clutter is from surface reflectors and provides no information about the subsurface. Boxes with numbers are later figures.