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Formation of cycloidal dust devil tracks by redeposition of coarse sands in southern Peru: Implications for Mars

Dennis Reiss [a,*], Michael I. Zimmerman [b,c], David C. Lewellen [d]

[a] *Institut für Planetologie, Westfälische Wilhelms-Universität Münster, Wilhelm-Klemm-Str. 10, 48149 Münster, Germany*
[b] *NASA/Goddard Space Flight Center, Greenbelt, MD 20771, USA*
[c] *The Johns Hopkins University Applied Physics Laboratory, Laurel, MD, USA*
[d] *West Virginia University, Morgantown, WV, USA*

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ABSTRACT

Aeolian processes are the most active processes modifying the surface of Mars under present day climatic conditions. Besides wind streak changes and dune and ripple migrations, active dust devils occur frequently leaving numerous tracks on the Martian surface. These dust devil tracks (DDTs) are characterized by albedo changes with respect to their surroundings and are suggested to be caused by erosion of dust exposing coarser grained material. Here we show that DDTs with a cycloidal pattern analyzed in situ in southern Peru are formed by erosion of very coarse sands at the outer margins and its subsequent annular deposition in the central parts of dust devils. Field observations are supported by large-eddy simulations using typical dust devil parameters resembling the cycloidal morphology of the DDTs. Cycloidal DDTs observed on Mars resembling the Peruvian DDTs suggest an equivalent formation mechanism. Our results imply that the formation of DDTs on Mars are not solely due to dust erosion but also depositional processes and dust devils are strong enough to redistribute coarser grained material such as sands; hence they might contribute to the modification of the present day Martian landscape.

1. Introduction

Dust devils are dust laden vortices formed by heating and rising of near surface air due to insolation. They occur on Earth and Mars (Balme and Greeley, 2006) and contribute to dust entrainment into the atmosphere on both planets. On Mars, dust devils are frequently observed (e.g., Thomas and Gierasch, 1985; Metzger et al., 1999; Greeley et al. 2006; 2010; Cantor et al., 2006; Stanzel et al., 2008; Towner, 2009; Reiss et al., 2011a) and potentially play a key role in maintaining and replenishing the background dust opacity of the atmosphere (Whelley and Greeley, 2008). The passage of dust devils across the surface often leaves tracks of decreased albedo (Grant and Schultz, 1987; Malin and Edgett, 2001). The formation of dust devil tracks (DDTs) can significantly lower the surface albedo of larger regions (Geissler, 2005) which affects large-scale weather patterns and recent climate change on Mars (Fenton et al., 2007). On Earth, DDTs are rarely observed in satellite imagery (Rossi and Marinangeli, 2004; Neakrase et al. 2008; 2012; Reiss et al., 2010; Hesse, 2012) and in situ studies have so far only been performed in China (Reiss et al., 2010; 2011b). These studies showed that passages of active dust devils remove a thin, top layer of fine-grained material ($<\sim 63$ μm), darkening the underlying coarse sands (0.5–1 mm) (Reiss et al., 2010). This erosional process changes the photometric properties of the surface causing an albedo difference within the track relative to the surroundings (dark track and bright surroundings) (Reiss et al., 2010). This process is consistent with the formation mechanism proposed for DDTs on Mars based on in situ studies by the Mars Exploration Rover (MER) Spirit (Greeley et al., 2005).

Observed DDTs in southern Peru (Hesse, 2012) show a different morphology than usual continuous, low albedo DDTs on Earth and Mars. They have a low albedo cycloidal pattern which is in some areas accompanied by bright margins (Hesse, 2012). These low albedo cycloidal DDTs accompanied by bright lateral areas are still visible after 5 years (long-lived), whereas DDTs without bright lateral areas disappear in less than six months (short-lived) (Hesse, 2012). Based on satellite imagery, the long-lived tracks were suggested to be due to coarse surface materials exposed within the dark, cycloidal central track and fallout of sand-sized material along the bright margins, whereas the formation of shorter-lived DDTs was ascribed to erosion of fine dust exposing coarser sand-sized material (Hesse, 2012) equivalent to the previously described formation mechanism (Greeley et al., 2005; Reiss et al., 2010). The longevity of the DDTs was explained by the higher erosion resistance of the finer sands in the bright lateral areas of the tracks (Hesse, 2012). We will show that these proposed

* Corresponding author.

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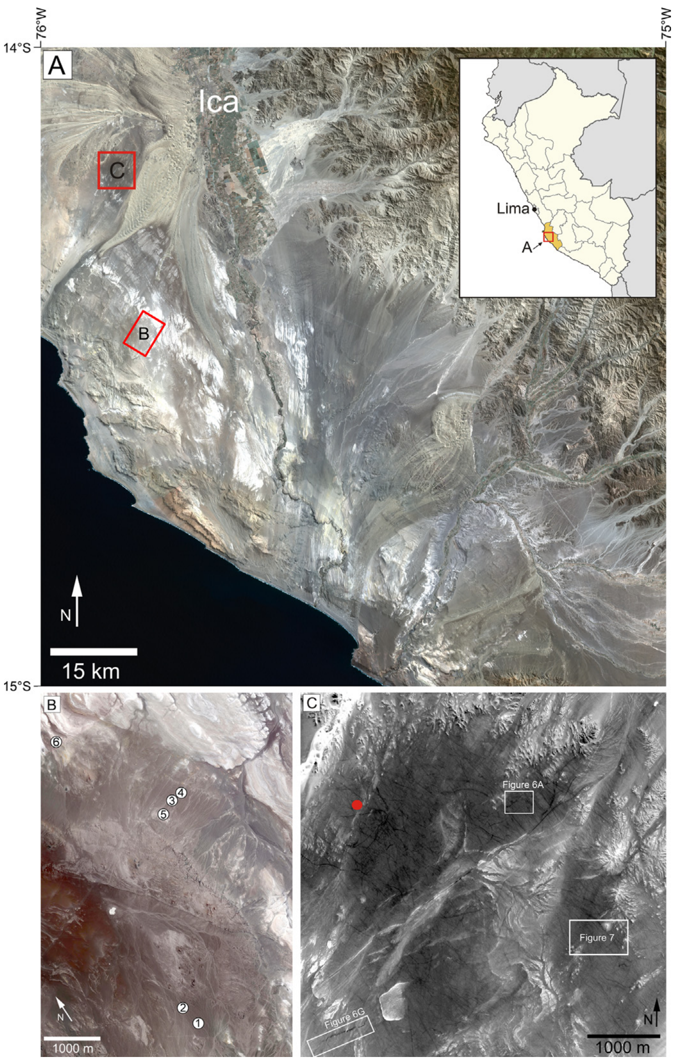

Fig. 1. (A) Context image for the study regions in southern Peru (Landsat 7 RGB image). Red frames show the position of the study area 1 southwest of the city of Ica and study area 2 west of the city of Ica. (B) Study area 1 (Quickbird 2 image from 14 March 2010 accessed through Google Earth). White dots with track numbers show the positions of the investigated DDTs. These image numbers correspond to the shown DDTs in the Figs. 2 and 3. (C) Study area 2 (Quickbird 2 image from 08 May 2010 accessed through Google Earth). White frames show the locations of Figs. 6A and G, and Fig. 7. Red dot marks the location of the analyzed DDT in Fig. 6B and the location of the soil sample (Fig. 8). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

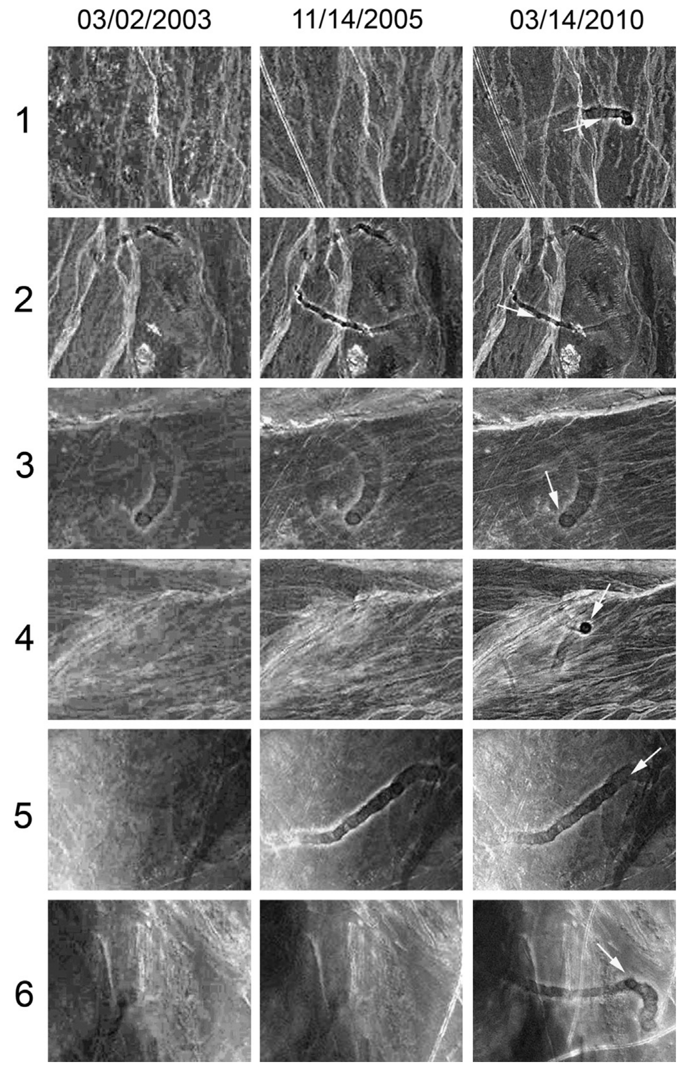

Fig. 2. Chronological sequence of high resolution satellite imagery of the investigated DDTs (see Fig. 1 for location of DDTs as indicated by their numbers). All images are 125 m in width and 100 m in height. Satellite images from 2 March 2003 were acquired by Quickbird 2 (∼ 65 cm/pxl) and accessed through Google Earth, from 14 November 2005 acquired by Quickbird 2 (∼ 65 cm/pxl) and accessed through Bing Maps, and from 14 March 2010 acquired by GeoEye-1 (∼ 50 cm/pxl) and accessed through Google Earth. Location and direction from where field photos (see Fig. 3) were taken are indicated by white arrows in the imagery from 14 March 2010. (A–C) Track 1 at 14.471°S and 75.842°W is first visible in the image acquired on 14 March 2010. (D–F) Track 2 (lower one) at 14.467°S and 75.844°W is first visible in the image acquired on 14 November 2005. Note that the upper track which was not investigated during the field survey is visible since 2 March 2003. (G–I) Track 3 at 14.438°S and 75.827°W is first visible on 2 March 2003. (J–L) Track 4 at 14.437°S and 75.825°W is first visible on 14 March 2010. (M–O) Track 5 at 14.439°S and 75.829°W is first visible on 14 November 2005. (P–R) Track 6 at 14.420°S and 75.838°W is first visible on 14 March 2010.

formation mechanisms for the Peruvian DDTs and the hypothesis for the longevity of bright lateral DDTs (Hesse, 2012) are not valid.

2. Study areas

Long- and short-lived DDTs were analyzed in southern Peru (Fig. 1). The first study area for analyzing long-lived DDTs is located southwest of the city of Ica at 14.45°S and 75.84°W. The long-lived dust devil tracks discovered by Hesse (2012) occur 70 km southeast of our study region. They were not analyzed because they lie within an area under protection of the UNESCO world heritage sites (Nascza lines). However, the long-lived dust devil tracks in our area show the same morphologic characteristics and always occur on the same ground surface of Quaternary alluvial plains (based on geologic maps and satellite imagery) to those described by Hesse (2012). The second study area for analyzing short-lived DDTs is located west of the city of Ica at 14.19°S and 75.88°W. This area was previously described to contain short-lived DDTs (Hesse, 2012).

3. Results

3.1. Long-lived DDTs

The alluvial fan surface where the long-lived DDTs are found can be classified as a desert pavement. Grain size analysis (all grain size analyses have been done after the classification of Wenthworth, 1922) shows that the upper surface layer is dominated by very coarse sand grains (1–2 mm) (Fig. 5). Aeolian landforms such as ripples cannot be found indicating a stable surface