Icarus xxx (2015) xxx–xxx

Contents lists available at ScienceDirect

Icarus

journal homepage: www.journals.elsevier.com/icarus

Observations of an aeolian landscape: From surface to orbit in Gale Crater

Mackenzie Day *, Gary Kocurek

2275 Speedway Stop C9000, Department of Geological Sciences, Jackson School of Geosciences, University of Texas at Austin, Austin, TX 78712, USA

ARTICLE INFO

Article history:
Received 8 June 2015
Revised 16 September 2015
Accepted 29 September 2015
Available online xxxx

Keywords:
Aeolian processes
Mars, surface
Cratering

ABSTRACT

Landscapes derived solely from aeolian processes are rare on Earth because of the dominance of subaqueous processes. In contrast, aeolian-derived landscapes should typify Mars because of the absence of liquid water, the long exposure times of surfaces, and the presence of wind as the default geomorphic agent. Using the full range of available orbital and Mars Science Laboratory rover *Curiosity* images, wind-formed features in Gale Crater were cataloged and analyzed in order to characterize the aeolian landscape and to derive the evolution of the crater wind regime over time. Inferred wind directions show a dominance of regional northerly winds over geologic time-scales, but a dominance of topography-driven katabatic winds in modern times. Landscapes in Gale Crater show a preponderance of aeolian features at all spatial scales. Interpreted processes forming these features include first-cycle aeolian abrasion of bedrock, pervasive deflation, organization of available sand into bedforms, abundant cratering, and gravity-driven wasting, all of which occur over a background of slow physical weathering. The observed landscapes are proposed to represent a spectrum of progressive surface denudation from fractured bedrock, to retreating bedrock-capped mesas, to remnant hills capped by bedrock rubble, to desert pavement plains. This model of landscape evolution provides the mechanism by which northerly winds acting over ~3 Ga excavated tens of thousands of cubic kilometers of material from the once sediment-filled crater, thus carving the intra-crater moat and exhuming Mount Sharp (Aeolis Mons). The current crater surface is relatively sand-starved, indicating that potential sediment deflation from the crater is greater than sediment production, and that most exhumation of Mount Sharp occurred in the ancient geologic past.

1. Introduction

On Earth, landscapes evolve through the interplay between tectonics, and water-dominated erosion and deposition. In contrast, Mars has generally been regarded as the most aeolian-dominated planet in the Solar System (e.g., Sagan and Bagnold, 1975; Arvidson et al., 1979; Greeley et al., 1999). On Earth, landscapes fashioned solely by wind action are rare. For example, although extensive aeolian dune fields blanket the modern Sahara Desert of North Africa, even a cursory examination of this landscape reveals uplands marked by erosional dendritic fluvial networks, and lowlands marked by mid-Holocene lakes and fluvial systems (e.g., Bouchette et al., 2010). Uniquely aeolian erosional and depositional features such as yardangs and dunes are well known, but sand dunes are nearly universally sourced by contemporaneous or earlier wet period fluvial systems (Kocurek and Lancaster, 1999), and yardangs are typically fashioned from lacustrine deposits (Wang et al., 2011). Similarly, although the Dry Valley of Antarctica displays a rich variety of cold-climate aeolian features (Gillies et al., 2013), the fundamental fabric of the landscape is glacial-dominated. While fluvial-dominated and glacial-dominated processes and their landscapes are well described and modeled, with the paucity of aeolian-dominated Earth landscapes, there is no comparable body of work describing landscapes that evolve where wind is the prime or sole geomorphic agent. Resurfacing by aqueous processes and tectonism on Earth precludes the formation of aeolian landscapes over geologic spans of time.

On Mars, landscapes and strata formed in fluvial, deltaic and lacustrine environments are well known from the most ancient martian surfaces. However, beginning with global climatic change at ~3.5 Ga (Bibring et al., 2006), aeolian processes have increasingly dominated. In the absence of liquid water at the surface, wind emerges as the "default" global geomorphic agent, with more localized geomorphic change caused by impacts, ice, and gravity-driven slope retreat, all imprinting over a background of very slow physical weathering. Mars, therefore, may be the best natural laboratory in which to delineate the attributes of an aeolian

* Corresponding author.
E-mail address: mdday@utexas.edu (M. Day).

http://dx.doi.org/10.1016/j.icarus.2015.09.042
0019-1035/

landscape. In this study we use satellite and surface images to explore the extent to which the landscape of Gale Crater is aeolian-dominated, thus helping to define the attributes of such a system. The collection of aeolian features associated with Gale Crater also serves to reconstruct the history of the wind regime over orders of magnitude of time.

2. Gale Crater study area and data set

The impact that formed Gale Crater is estimated to have occurred ~3.6–3.8 byr ago (Thomson et al., 2011; Le Deit et al., 2013). At 155 km in diameter, Gale Crater sits just south of the dichotomy boundary near Aeolis Mensae (Fig. 1) (Wray, 2013). The interior of Gale is dominated by the central mound Mount Sharp (Aeolis Mons), which stands roughly 5 km high, or three times the depth of the Grand Canyon. The mound and surrounding features have been extensively mapped (e.g., Anderson and Bell, 2010; Hobbs et al., 2010; Thomson et al., 2011) and are similar to other intra-crater mounds found across Mars (Grotzinger and Milliken, 2012).

In association with the ongoing Mars Science Laboratory (MSL) mission, an unprecedented number of images have become available for the study of Gale Crater. To date, the rover *Curiosity* has spent over 1000 martian sols traversing the floor of Gale, taking images at resolutions down to 15 μm/px (Edgett et al., 2012). Using the full range of available scales, for this study features were first mapped in orbital images using a High Resolution Stereo Camera (HRSC) basemap, overlain with higher resolution Context Camera (CTX) and High Resolution Imaging Science Experiment (HiRISE) images. Resolution ranged from 25 cm/px in HiRISE coverage, to ~10 m/px in HRSC. Surface images were then used to sample aeolian features along the *Curiosity* rover traverse from Bradbury Landing to Pahrump Hills (sols 1–960). Sampling every 200–300 m, Navigation Camera (Navcam) mosaics were used to document aeolian features in the landscape. Mast Camera (Mastcam), and Mars Hand Lens Imager (MAHLI) images were used to support identification and characterization of the aeolian features discussed below.

3. Non-aeolian activity in Gale Crater

Gale Crater is fundamentally an impact crater. Smaller-scale cratering blankets the crater interior (Le Deit et al., 2013), disrupting the morphology of aqueous and aeolian features alike.

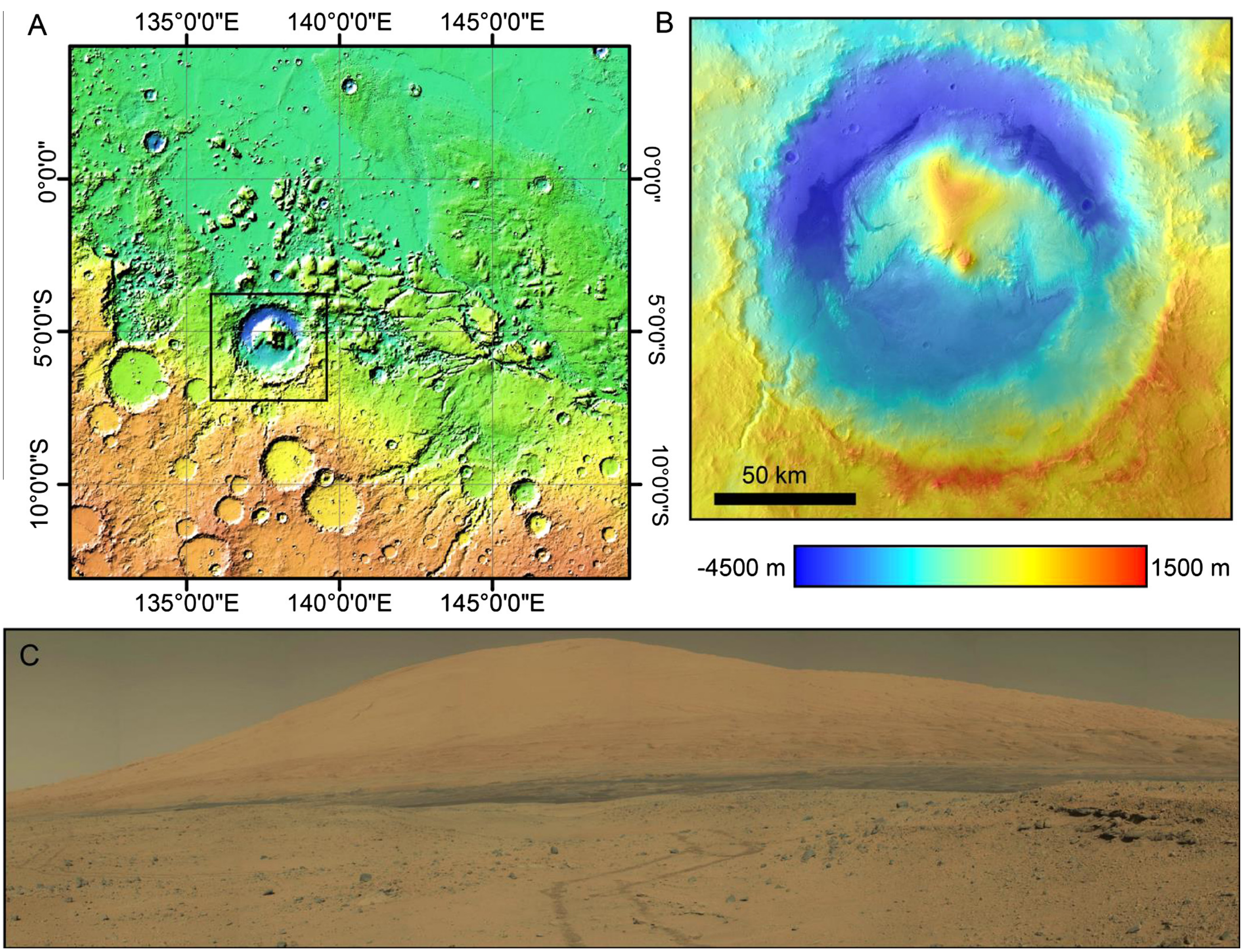

Fig. 1. Gale Crater context. A. Mars Orbiter Laser Altimeter (MOLA) colorized elevation map showing context of Gale Crater (boxed). Note the change from high elevation in the south to low elevation in the north associated with the global topographic dichotomy. B. Gale Crater shown with HRSC-derived DEM superimposed on HRSC visual basemap. The crater interior is dominated by Mount Sharp (Aeolis Mons). C. Mount Sharp as seen from the surface by *Curiosity*. Foreground wheel tracks are 30 cm wide, and the total relief on the mound is ~5 km (sol 530, Mastcam mosaic starting at frame 0530ML0021050000203319E01_DRCX; all MSL data can be accessed through the JPL PDS archive). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Please cite this article in press as: Day, M., Kocurek, G. Observations of an aeolian landscape: From surface to orbit in Gale Crater. Icarus (2015), http://dx.doi.org/10.1016/j.icarus.2015.09.042