Icarus 271 (2016) 360–374

Contents lists available at ScienceDirect

Icarus

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

Thermal and microstructural properties of fine-grained material at the Viking Lander 1 site

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ARTICLE INFO

Article history:
Received 13 September 2015
Revised 27 January 2016
Accepted 4 February 2016
Available online 23 February 2016

Keywords:
Mars
Atmospheres
Dynamics
Geophysics
Regoliths

ABSTRACT

As Viking Lander 1 touched down on Mars one of its footpads fully penetrated a patch of loose fine-grained drift material. The surrounding landing site, as observed by VL-1, was found to exhibit a complex terrain consisting of a crusted surface with an assortment of rocks, large dune-like drifts and smaller patches of drift material. We use a temperature sensor attached to the buried footpad and covered in fine-grained material to determine the thermal properties of drift material at the VL-1 site. The thermal properties are used to investigate the microstructure of the drift material and understand its relevance to surface-atmosphere interactions.

We obtained a thermal inertia value of 103 ± 22 tiu. This value is in the upper range of previous thermal inertia estimates of martian dust as measured from orbit and is significantly lower than the regional thermal inertia of the VL-1 site, of around 283 tiu, obtained from orbit. We estimate a thermal inertia of around 263 ± 29 tiu for the duricrust at the VL-1 site. It was noted the patch of fine-grained regolith around the footpad was about 20–30 K warmer compared to similar material beyond the thermal influence of the lander.

An effective diameter of 8 ± 5 μm was calculated for the particles in the drift material. This is larger than atmospheric dust and large compared to previous estimates of the drift material particle diameter. We interpret our results as the presence of a range of particle sizes, <8 μm, in the drift material with the thermal properties being controlled by a small amount of large particles (~8 μm) and its cohesion being controlled by a large amount of smaller particles. The bulk of the particles in the drift material are therefore likely comparable in size to that of atmospheric dust. The possibility of larger particles being locked into a fine-grained material has implications for understanding the mobilisation of wind blown materials on Mars.

1. Introduction

The structure and microstructure of a planetary surface provides important clues to the geological processes acting on it. Thermal property measurements of the martian surface, from orbit, is a way to indirectly assess the regolith microstructure, the horizontal structure and the stratigraphy of the shallow subsurface (Christensen, 1986, 1988; Edgett and Christensen, 1991; Golombek et al., 2012, 1999; Jakosky and Christensen, 1986; Kieffer et al., 1977; Nowicki and Christensen, 2007; Putzig et al., 2005). Ground-based remote sensing of surface thermal properties by the MER and MSL rovers have provided detailed structural information for interpreting the local environments (Martínez et al., 2014; Spanovich et al., 2006). Thermally and physically well characterised surface and subsurface materials are also beneficial for near-surface atmospheric and/or subsurface exploration such as with the MetNet mission, a penetrator delivered meteorological network for Mars (Harri et al., 2015, 2007).

The first spacecraft to make in-situ temperature measurements in the martian regolith was Viking Lander 1 (VL-1). These were utilised for supporting surface property investigations by Moore and Jakosky (1989). Moore and Jakosky (1989) comprehensively characterised and assessed the site using interactions of the lander parts with the surface materials, imaging and selected results from other experiments. Moore and Jakosky (1989) describes the

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http://dx.doi.org/10.1016/j.icarus.2016.02.012

Fig. 1. A morning view looking south-east across the VL-1 sample field. The loose fine-grained patch, sampled by the landers instruments and the subject of this study, is apparent occupying the bottom left part of the image extending a few metres from the lander. More distant dune-like drifts are visible in the upper left part of the image near the horizon. Covering the middle and right of the image is the rock-strewn crusted blocky material. VL-1's footpad #2 is located at the extreme left of the image. Next to it is the meteorological boom and the sampler. Image: NASA/JPL.

surface as being covered with so called blocky material, rocks, large dune-like drifts and smaller patches of drift material. See Fig. 1 for a view of the VL-1 site from the lander. The blocky material was found to be the strongest material while the drift material was found to be very loose. The size of particles in the blocky material is not known but the material is mechanically consistent with a cemented fine-grained material. The average diameter of particles in the fine-grained material, next to the lander, was calculated to be somewhere between 0.14 and 9 μm using indirect methods.

Surface properties derived from the lander's sample site have been synthesised with images from beyond the lander's sample field resulting in an ongoing assessment of the local geology (Arvidson et al., 1989; Binder et al., 1977; Craddock et al., 1997; Moore and Jakosky, 1989; Mutch et al., 1976; Parker et al., 1999; Sharp and Malin, 1984). The accepted view of the dune-like drifts consisting of fine-grained particles was challenged by Sharp and Malin (1984) who presented evidence supporting the presence of sand. There has been a long-term debate in the literature since Viking regarding the nature of sand-sized grains and their role in explaining various observations such as the paradox that dust appears to be more easily mobilised than sand when the opposite is predicted. For example, Sagan et al. (1977) suggested strong sand-sized particles may saltate and disintegrate on impact with the surface producing the small-scale fine-grained wind blown deposits associated with rocks at the VL-1 site. Sullivan et al. (2008), who also includes a brief review of particle mobility on Mars and the related debate, suggests weakly bound sand-sized dust aggregates observed by the Spirit rover may disintegrate once airborne and be a source of atmospheric dust.

In this paper we analyse the VL-1 footpad temperature sensor measurements, described in Section 2, by first accounting for the shadows and thermal influence from the lander with models described in Section 3. In Section 4 we derive the thermal properties of the regolith covering the temperature sensors by fitting our regolith model to the measurements which in turn enables us to comment on its microstructural properties in Section 5. We restrict ourselves to an assessment of the patch of drift material next to the lander's footpad #2 that can be seen in the lower left portion of Fig. 1. The appendix describes the thermal and structural model of VL-1.

2. In-situ temperature measurements of the martian regolith

VL-1 lander touched down on the martian surface on 20th July 1976 during the northern hemisphere summer at an aerocentric longitude of $Ls = 97°$ (Soffen and Snyder, 1976). The landing location was eventually pinpointed when the HiRISE camera on Mars Reconnaissance Orbiter spotted the lander on the surface (Parker et al., 2007) about 5.9 km north east of the location 22.483 °N 47.968° W (aerocentric coordinates) predicted by Morris and Jones (1980).

VL-1's footpad #2 penetrated 16.5 cm into a patch of loose fine grained material and was completely buried (Moore et al., 1977). Mounted on the rim of the footpad was a temperature sensor that was originally designed for atmospheric measurements during the descent (Seiff and Kirk, 1977) consisting of multiple fine wire thermocouples directly exposed to the environment. The sensors survived the impact of landing intact (Moore et al., 1977) and continued to make measurements. Footpad #2 was located at the front-left corner of the lander and at its north-east point on Mars. The sensor sampled subsurface temperatures every 40 Smin with some sols sampled every second or less. Data ceases on sol 2245 when the last downlink from VL-1 was received. The data we use is formally archived from sol 1008 (Tillman and William, 1996) on the NASA Planetary Data System (PDS). The previous sols were generated in edited and summarised format and are not available on the PDS.

The VL-1 footpad temperature sensor (Seiff, 1976), shown in Figs. 2 and 3, is capable of measuring temperatures over a range of 100 to 400 K and has an accuracy of ± 1.3 K. The sensor head consists of three fine-wire thermocouple elements connected in series with each one mounted between two supporting rods. Each thermocouple element comprises of three thermocouples connected in parallel for redundancy. The footpad sensor design is based on results from a similar sensor flown on the Planetary Atmosphere Experiments Test (PAET) vehicle (Seiff et al., 1973). Three thermocouple elements are used to build up the output range without using amplification. As each sensor element is identical we assume that the sensor is measuring the average temperature of the three sensor elements.

A series of images were acquired to determine to what extent the sensor was covered in surface material (Moore et al., 1977). Fig. 2 shows a series of images, unpublished in the literature, downloaded from the PDS. The top of the sensor housing is exposed in the images and the sensors are buried with the sensor supports and are not visible. The sensor supports can be seen in Fig. 2(d) on a temperature sensor mounted on the Viking Lander proof test article. During the development of the Viking mission, this copy of the Lander was used to test structural integrity. While the two other Viking Landers were on Mars, this vehicle was used to test lander behavior and responses to commands. It was transferred from NASA to the National Air and Space Museum in 1979. Moore (1987) reports that the three sensors were buried at a depth