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Transient atmospheric effects of the landing of the Mars Science Laboratory rover: The emission and dissipation of dust and carbazic acid

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Abstract

Imaging during and after the landing of the Mars Science Laboratory (MSL) rover in 2012 provides a means to examine two transitory phenomena for the first time: the settling of the plume of material raised by the powered terminal descent, and the possible dispersal of 140 kg of hydrazine into the atmosphere as fine-grained solid carbazic acid. The peri-landing images, acquired by the Mars Descent Imager (MARDI) and the rover hazard cameras (Hazcams), allow the first comparison of post-landing geological assessment of surface deflation with the plume itself. Examination of the Hazcam images acquired over a period of 4011 s shows that only a small fraction (350–1000 kg) of the total mass of fine-grained surface material displaced by the landing (4000 kg) remained in the atmosphere for this duration. Furthermore, a large component of this dust occurs as particles for which the characteristic optical radius is 20–60 μm, preventing them from being substantially mixed with the atmospheric column by eddy diffusion. Examination of the MARDI record over 225 s post-landing reveals a rapidly settling component that comprised approximately 1800–2400 kg and had a larger particle size with an optical radius of 360–470 μm. The possible release of hydrazine by the sky crane stage also may have created particles of carbazic acid that would, analogous to the dust, spread through eddy diffusivity and settle to the ground. Peri-landing Hazcam images of the plume created during sky crane destruction constrains the particle radius to be either less than 23 μm or greater than 400 μm. When combined with a Lagrangian model of the atmosphere, such particle sizes suggest that the carbazic acid was either deposited very near the sky

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crane crash site, or was widely dispersed as small particles which would have been quickly photodissociated to volatile ammonia and carbon dioxide. Surfaces visited by the MSL rover, Curiosity, would have received at most <0.2 ppb of carbazic acid and levels of sky crane related organics would have fallen well below the detection threshold of the Sample Analysis at Mars (SAM) instruments within 4–6 sols, well before the rover acquired its first samples over 60 sols into the mission.

Keywords: Mars; Atmosphere; Dust settling; UV photolysis; Surface–atmosphere interactions

1. Introduction

As the Mars Science Laboratory (MSL) and its instrument payload (Grotzinger et al., 2012) descended towards the northern floor of Gale crater on August 6, 2012 prior to its 15:03:09 Local Mean Solar Time touchdown (Vasavada et al., 2014), a carefully choreographed, preplanned sequence of events occurred. First, the heat shield was jettisoned just below 10 km altitude. This allowed the Mars Descent Imager (MARDI) camera to obtain its first views of the surface. Next, the parachute and back shell were cut away from the sky crane and rover tandem. From this point onward, the sky crane and the Curiosity rover were falling freely until ignition of the sky crane descent engines. The sky crane system (Steltzner et al., 2010) slowed the descent of the rover and lowered it gently to the surface; then, by design, the sky crane flew away and crashed.

The descent engines of the sky crane caused sufficient energy to be applied to the surface that scour marks exposing bedrock were evident on the surface after the departure of the vehicle and a change in the albedo of the surface was noted from orbit (Fig. 1). This albedo change, approximately 100 m in radius, is the result of the removal of a veneer of dust on the surface by the landing engines. While some of the particles lofted were large, many of the particles would have been much smaller and would therefore have required significant time to settle from the atmosphere. Based on pre-landing experience with Viking thrusters (Hutton et al., 1980) and analysis of the thruster system for MSL (Mehta et al., 2013), such scouring was anticipated and material from depths of a few centimeters may have been mobilized.

As such, this perturbation of the local atmosphere and surface by the rover landing event offers a unique opportunity to investigate the particles that make up the near surface, which were lofted by impingement of the sky crane thrusters and made available for optical analysis, and to examine models of the deposition of dust and larger particles back onto the surface. Key to this analysis is the documentation provided by two imaging sources. First, the

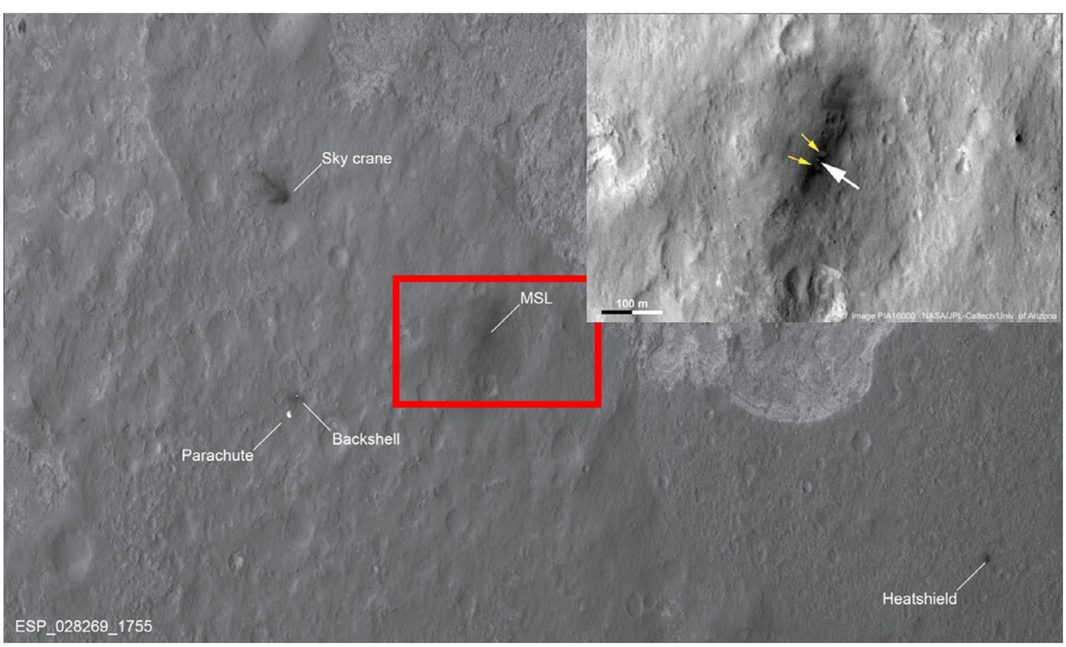

Fig. 1. Annotated HiRISE image showing the relative position of the rover, the sky crane, heat shield and parachute/back shell. Note that the disturbed area around the landing site extends approximately 100 m in each direction and is symmetric at this scale. Inset: a zoom-in on the rover landing site shows a zone of greater albedo change aligned with the landing jets. The white arrow shows the location of the rover, and the yellow arrows show the location of the areas that were strongly scoured by the rocket jets. HiRISE image products are available at: http://uahirise.org/releases/msl-descent.php. Image Credits: NASA/JPL-Caltech/University of Arizon. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)