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Science exploration architecture for Phobos and Deimos: The role of Phobos and Deimos in the future exploration of Mars

Ariel N. Deutsch [a,*], James W. Head [a], Kenneth R. Ramsley [b], Carle M. Pieters [a], Ross W.K. Potter [a], Ashley M. Palumbo [a], Michael S. Bramble [a], James P. Cassanelli [a], Erica R. Jawin [a], Lauren M. Jozwiak [a], Hannah H. Kaplan [a], Connor F. Lynch [a], Alyssa C. Pascuzzo [a], Le Qiao [a,c], David K. Weiss [a]

[a] *Department of Earth, Environmental and Planetary Sciences, Brown University, Providence, RI 02912, USA*
[b] *School of Engineering, Brown University, Providence, RI 02912, USA*
[c] *Planetary Science Institute, China University of Geosciences, Wuhan, Hubei 430074, China*

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Abstract

Phobos and Deimos are the only natural satellites of the terrestrial planets, other than our Moon. Despite decades of revolutionary Mars exploration and plans to send humans to the surface of Mars in the 2030's, there are many strategic knowledge gaps regarding the moons of Mars, specifically regarding the origin and evolution of these bodies. Addressing those knowledge gaps is itself important, while it can also be seen that Phobos and Deimos are positioned to support martian surface operations as a staging point for future human exploration. Here, we present a science exploration architecture that seeks to address the role of Phobos and Deimos in the future exploration of Mars. Phobos and Deimos are potentially valuable destinations, providing a wealth of science return, as well as telecommunications capabilities, resource utilization, radiation protection, transportation and operations infrastructure, and may have an influence on the path of the martian exploration program. A human mission to the moons of Mars would maintain programmatic focus and public support, while serving as a catalyst for a successful human mission to the surface of Mars.

Keywords: Phobos; Deimos; Mars; Human exploration; Mission architecture

1. Introduction

As NASA plans to send humans to Mars in the 2030's (https://www.nasa.gov/content/nasas-journey-to-mars; e.g., Head et al., 2015), it is vital to gain a further understanding of the role of the martian moons, Phobos and Deimos, in this next stage of planetary exploration. These bodies may facilitate later exploration of Mars, through exploitation of *in situ* resources, by providing radiation protection, or through contributions to the continuity of the martian program. It is crucial that a mission architecture is developed to serve as a roadmap for the exploration of Mars' moons focusing on the questions: "What is the origin of Phobos and Deimos?" and "What is the role of Phobos and Deimos in the future exploration of Mars?".

Besides our Moon, Phobos and Deimos are the only known natural satellites of the terrestrial planets. We seek to understand why our Moon is different than the martian moons, and what their presence tells us about the moonless Mercury and Venus. Understanding these satellites can help us understand the origin and evolution of the

* Corresponding author.
E-mail address: Ariel_Deutsch@brown.edu (A.N. Deutsch).

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martian system. To date, the origins of Phobos and Deimos are still unknown. The hypothesized formation theories have specific and distinct implications for the possibilities of finding pristine martian crust, primitive material, or volatiles (e.g., Murchie et al., 2014). Depending on their composition, these moons could greatly facilitate Mars exploration (e.g., Oberst et al., 2014) (Table 1).

There are many strategic knowledge gaps concerning Phobos and Deimos science. Here we design a mission architecture that can, first, answer the fundamental scientific questions of the martian moons and, second, assess to what extent Phobos and Deimos can facilitate the later human exploration of Mars. This facilitation could occur in many ways (as discussed in-depth in Section 3), therefore it is crucial to develop a framework to serve as a roadmap before sending missions to Phobos and Deimos.

The major initial question driving our framework has a scientific motivation: "What is the origin of Phobos and Deimos?" The second question driving our framework asks how stopping at one or both moons could complement a human exploration program to Mars: "What is the role of Phobos and Deimos in the future exploration of Mars?"

To address the above questions, we outline major gaps remaining in Phobos and Deimos science that motivate future missions to the moons of Mars. We present a science exploration architecture consisting of orbiter, lander, and human exploration stages and discuss a framework designed to assess the role of Phobos and Deimos in the future exploration of Mars, specifically determining how these bodies might aid in the Mars program.

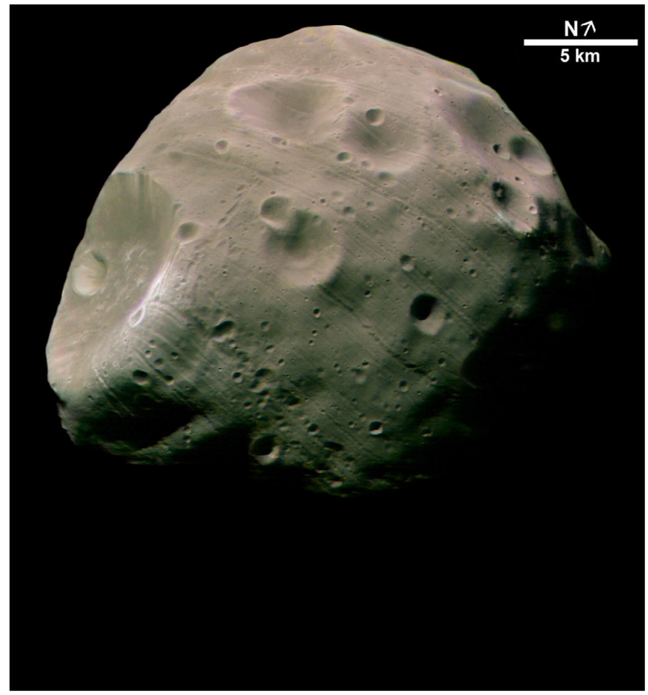

Fig. 1. Mars-facing side of Phobos, highlighting the linear grooves across the surface of the moon and Stickney crater in the left of the image. Image acquired by the High Resolution Stereo Camera from the Mars Express spacecraft on 22 August 2004. Pixel resolution of ~7 m. Image credit: ESA/DLR/FUB.

2. Strategic knowledge gaps in Phobos and Deimos science

Many unanswered questions regarding the formation and evolution of Phobos (Fig. 1) and Deimos exist today (e.g., Basilevsky et al., 2014; Murchie et al., 2014). Here we discuss the major gaps in the understanding of the origin and evolution of Phobos and Deimos that motivate the need for future exploration.

2.1. Origin

Many formation hypotheses have been suggested for the origin of Phobos and Deimos. One hypothesis is that these moons are captured asteroid belt objects, consistent with compositional data and optical and spectral properties of Phobos and Deimos (e.g., Fraeman et al., 2012, 2014; Pajola et al., 2013; Pieters et al., 2014). Specifically, the low albedos, low densities, and spectral similarities of the moons to D-type asteroids are consistent with capture of outer solar system objects that are composed of primitive, carbonaceous material (Hartmann, 1990; Burns, 1992). Additionally, Phobos and Deimos have near-identical surfaces, so if they are captured, then they either are of the same original composition, or they are unrelated and have undergone extensive space weathering to produce near-identical surfaces (Murchie et al., 2014). The process of permanent capture, however, requires sufficient energy loss and has proven to be difficult to explain dynamically. Both Burns (1978) and Pollack et al. (1979) described qualitatively a possible method by which to capture a single object by aerodynamic drag in a circumplanetary envelope around Mars. Dynamical models that explore this phenomenon produce a Phobos spiraling toward Mars and a retreating Deimos (Hunten, 1979; Sasaki, 1990). While the physical properties of the moons suggest that they may be dark carbonaceous asteroids that were captured by Mars (e.g. Fraeman et al., 2012, 2014; Pajola et al., 2013; Pieters et al., 2014), the predicted orbital evolution due to the tides of the martian system suggests that the

Table 1
Formation models of Phobos and Deimos and implications for water and carbon content.

Origin model	Water content (wt%)	Carbon content
Co-accretion	~1 (moderate) Sarafian et al. (2014)	Low Murchie et al. (2014)
Capture	2–60+ (high–very high) Murchie et al. (2014); Lee et al. (2017)	High Murchie et al. (2014)
Mars impact	≤0.015 (low) Truong and Lee (2017)	Low Murchie et al. (2014)

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