SCIENCE EXPLORATION ARCHITECTURE FOR PHOBOS AND DEIMOS: ARE THE MOONS OF MARS IN THE CRITICAL PATHWAY OF HUMAN EXPLORATION OF MARS? Ken R. Ramsley, Michael S. Bramble, James P. Cassanelli, Ariel N. Deutsch, Ashley M. Horan, Erica R. Jawin, Lauren M. Jozwiak, Hannah H. Kaplan, Connor F. Lynch, Alyssa C. Pascuzzo, Ross W. K. Potter, Le Qiao, David K. Weiss, James W. Head. Department of Earth, Environmental and Planetary Sciences, Brown University, Providence, RI 02908 USA.

Introduction: As NASA plans to send humans to Mars in the 2030's [1], it is vital to gain a further understanding of the role of the martian moons, Phobos and Deimos. These bodies may facilitate the later exploration of Mars, either through the exploitation of in-situ resources, through the incremental development of technologies tested in the martian system, or by providing radiation protection. It is crucial that a mission architecture be developed to serve as a roadmap for the exploration of Mars' moons focusing on the questions: What is the origin of Phobos/Deimos? Are Phobos/Deimos in the critical pathway for human exploration of Mars?

Mission Framework: We have developed a framework of scientific questions to assess prior to sending humans to the moons of Mars (Fig. 1). In order to determine if Phobos/Deimos are in the critical pathway for human exploration of Mars, their near-surface physical and chemical characteristics must be understood. A comprehensive understanding of these properties is best achieved by establishing the origin of Phobos/Deimos.

Therefore, the key question that initially drives this framework is: What is the origin of Phobos/Deimos? To date, several formation models have been proposed, including: co-accretion with Mars [2], ejecta from a giant impact with Mars [3], and capture of a foreign body, potentially sourced from the asteroid belt [4]. Each formation model has distinct implications for the utility of Phobos/Deimos in the human exploration of Mars.

We recommend an initial orbital + landed mission to address our key question, prior to investing resources in the development of technologies for humans to operate in such low-gravity environments. This mission will investigate the physical and compositional characteristics of both moons (Fig. 1 Stage I) in conjunction with a landed mission (Stage II) to determine how these moons formed. If the formation can still not be resolved with this initial orbital + landed mission and an additional lander could determine the origin, we remain in Stage II and send another lander. If the results of these missions indicate that Phobos/Deimos have utility for human exploration, our program will continue with subsequent missions to determine the role of Phobos/Deimos in human exploration of Mars (Stage III). These missions will ultimately determine whether humans can successfully operate on the surface of the moons [5, 6]. We outline a suite of tasks that human explorers can accomplish on the moons of Mars (Stage IV).

Mission Design and Payload: The mission design has been proposed in several steps, consisting of various orbital and landed components, detailed in Fig. 1. The specific nature and instrument payload of these missions are described below.

Orbital + Landed Components. The first mission to visit Phobos/Deimos will be an orbiter (Stage I) + lander (Stage II) designed to provide initial geological, geochemical, and geophysical assessments for an understanding of the origin of the moons. The specific suite of instruments onboard the orbiter will include a laser altimeter, high-resolution camera, and spectrometer in order to produce global maps of topography, composition, and near-surface gravity. In addition, regolith samples will be returned via methods similar to those of the Hayabusa 2 spacecraft [7]. Small spacecraft/rover hybrids [8] with similar instrumentation will explore the surface at a higher resolution, while also providing orbital ground truthing. The mission will build upon previous proposals, especially those detailing missions that visit both Phobos and Deimos and return samples to Earth [e.g., 9]. The results of this mission feed forward into the scientific mission framework (Fig. 1), while future landed missions (e.g., Stages II and III) may be required to address additional strategic knowledge gaps.

Landed Components. The specification and scope of subsequent landed missions depend on the results from the prior orbital + landed mission. In general, the landed missions (Stages II and III) have the broad objective of classifying the characteristics of Phobos/Deimos at a higher spatial scale. The lander payload aims to characterize the physical and mechanical properties of the regolith and near-surface, and provide ground-based geophysical measurements. Lastly, to assess the possibility and practicality of sending humans to Phobos/Deimos, proposed regions for human exploration will be characterized in high fidelity (Stage IV).

Conclusions: As there are still many unknowns surrounding the nature and origin of the moons of Mars, further robotic missions are required to characterize these bodies, a critical step in assessing whether human exploration of Phobos/Deimos is in the critical pathway for human exploration of Mars. We also note that programmatic logic may dictate sending humans to Phobos/Deimos, in which case this mission framework is critical when structuring a human precursor mission.

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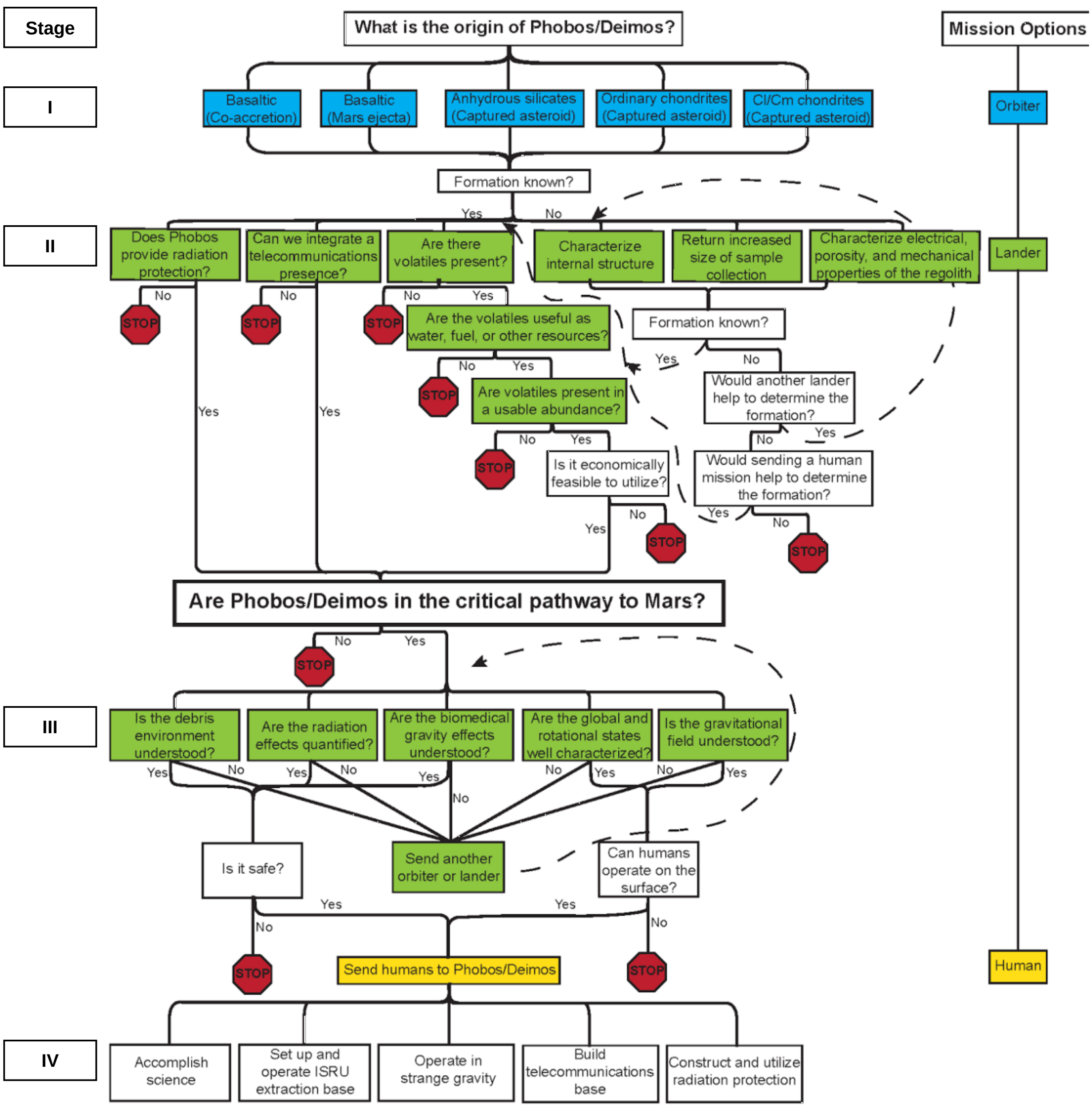

Fig. 1. Flow chart that illustrates the mission framework of exploration of Phobos/Deimos. This framework will determine if the moons of Mars are in the critical pathway for human exploration of Mars. Stop signs suggest that either Phobos/Deimos do not lie in the critical pathway, or that the answer cannot be determined. However, science and engineering goals can still be attained from the various missions proposed in the text.