Summary: Phobos and Deimos, Mars’ two moons, are associated with significant planetary protection knowledge gaps for human missions, that may be filled by a low cost robotic reconnaissance mission focused on elucidating their origin and volatile content.

Introduction: Phobos and Deimos are currently considered to be potentially worthwhile destinations for early human missions to Mars orbit, and possibly in the context of longer term human Mars exploration strategies as well [1] (Fig. 1). Until recently, it was widely considered that planetary protection (PP) concerns associated with the exploration of Phobos and Deimos would be fundamentally no different from those associated with the exploration of primitive NEAs [2], as the preponderance of scientific evidence suggested that 1) there was never liquid water on Phobos and Deimos, except possibly very early in their history; 2) there is no metabolically useful energy source except near their heavily irradiated surface; 3) there was likely never sufficient organic matter on or in these bodies to support life within the zone where metabolically useful energy is available, because of space radiation; 4) subsequent to the disappearance of liquid water, these bodies have not been subjected to extreme temperatures (i.e., > 160°C), except near the irradiated surface zone as a result of impacts; 5) there is, and was, sufficient irradiation for biological sterilization of terrestrial life form near the surface; and 6) there has likely been a natural influx to Earth, via meteorites, of material equivalent to a sample returned from the target body.

However, two recent developments relating to the origin of Phobos and Deimos are prompting a revisit of PP assessments for these bodies:

Giant Impact Hypothesis. In addition to the two classical hypotheses concerning the origin of Phobos and Deimos (namely that they might be captured small bodies from the outer main belt, or remnants of Mars’ formation), a third hypothesis is now commonly cited: that they might be reaccreted Mars Impact ejecta. The latter includes the possibility that Phobos and/or Deimos formed less than 0.5 Ga ago, and are made of Martian crustal material ejected from Mars’s near-surface environment by a large impact. Given the possibility of this scenario (if not its plausibility: giant impacts are unlikely in recent times), it can no longer be said with the same confidence that there is a preponderance of evidence for the six inferences listed above.

Extinct Comet Hypothesis. As a variant of the “captured small body from the outer main belt” hypothesis, it has long been suggested that Phobos and/or Deimos might be captured comet nuclei. (now inactive or extinct). Consistent with this idea, some grooves on Phobos (those resembling crater chains, or catenae) are interpreted as fissures lined with vents through which volatiles were once outgassed [3] (Fig. 2).

While the grooves on Phobos could have an entirely different origin, recent outgassing activity detected around D-type NEA 3552 Don Quixote revives the extinct comet hypothesis for Phobos and Deimos. The key facts and observations are as follows:
a) All 3 are D-type objects: Phobos, Deimos, and NEA 3552 Don Quixote all present, to first order, a D-type spectrum, i.e., they are very dark and very red in the visible and near-IR.

b) D-types are rare in the inner solar system: Only 36 NEAs are known to be of D-type, i.e. only 1.5% of NEAs whose spectral type has been determined.

c) Phobos & Deimos are exceptionally large as inner solar system small bodies: If Phobos and Deimos were to be included in the NEO population, they would rank #3 and #5 in size, respectively;

d) NEA 3552 Don Quixote is exceptionally large as well. Don Quixote would rank #4 in size, i.e., it is intermediate in size between Phobos and Deimos (Fig. 3). Thus, although D-type objects are rare among NEAs, three of the five largest small bodies in the inner solar system have a D-type spectrum;

e) NEA 3552 Don Quixote is a comet nucleus. Ever since Don Quixote’s discovery, it has been suggested that it might be an extinct comet, as it revolves around the sun on a highly inclined (30°), Jupiter and Mars-crossing orbit, and is spectrally akin to small bodies found in the outer main belt and beyond. In early 2014, however, 3552 Don Quixote was observed to display comet-like activity, with a coma and tail associated with CO₂ emission [4]. Rather than being extinct, it is a moderately active comet nucleus.

Thus, given that Phobos and Deimos are similar to 3552 Don Quixote in both size and spectral type (albedo and color), and these have uncommon values among inner solar system small bodies (they are large objects and of spectral type D), the hypothesis that Phobos and Deimos might be captured comet nuclei that are now extinct or largely inactive merits serious consideration. Their low bulk densities, which is generally attributed to an interior with macroscopic porosity, is also consistent with a volatile-rich interior. If a volatile-rich interior is a likely possibility, then PP assessments of Phobos and Deimos would need be to revised.

While surface and near-surface materials on Phobos and Deimos are likely to be depleted in volatiles as a result of diffusive exposure to space and impact processing, the deeper interior might remain volatile rich. As new technologies (such as plasma drilling [5] (Fig. 4)) designed to access and sample the deeper interior of planetary bodies, including airless small bodies, are now emerging, human exploration will likely not remain confined to sampling surface and near-surface materials, but will likely include interacting with deeper interior materials on Phobos and Deimos, including potential volatiles.

Figure 3: Deimos (top left), NEA 3552 Don Quixote (bottom left), NEA Itokawa (top right), and Phobos (bottom right), to scale. (NASA & JAXA).

Figure 4: Plasma drilling opens the possibility for human explorers to access and sample, the deeper interior of small bodies such as Phobos or Deimos (Zaptec).

Conclusion: The volatile content, and therefore the origin and evolution, of Phobos and Deimos, are major PP knowledge gaps for future human missions to these bodies. To better constrain PP requirements associated with their exploration, a robotic reconnaissance mission to Phobos and Deimos focused on investigating their origin and assessing their volatile content is recommended. Short-term options include low-cost and low-risk Discovery class missions such as PADME (Phobos And Deimos & Mars Environment) [6].


Acknowledgment: This study was supported by NASA HEOMD (Doug Craig’s office).