PHOBOS AND DEIMOS: A POSSIBLE COMET CONNECTION. Pascal Lee1,2,3, 1Mars Institute, 2SETI Institute, 3NASA Ames Research Center, Moffett Field, CA 94035-1000, USA, pascal.lee@marsinstitute.net

Summary: Phobos and Deimos are closely similar in size and spectrum to 3552 Don Quixote, an unusual near-Earth asteroid (NEA) that has turned out to be a comet. If Phobos and/or Deimos are captured small bodies (or made of materials from captured small bodies) from the outer solar system, might Don Quixote represent an earlier stage of what Phobos and Deimos once were?

Introduction: The origin of Phobos (L~ 27 km) and Deimos (L ~ 15 km) remains an enigma. There are three prevailing hypotheses: H1) they are captured small bodies from the outer main belt or beyond; H2) they are remnants of Mars’ formation; H3) they are reaccreted Mars impact ejecta. There are dynamical difficulties associated with each one of these hypotheses, one common to all being the relatively short dynamical lifetime of Phobos inside Mars’ synchronous orbit. It is also not clear if Phobos and Deimos share the same origin. The two martian moons present similarities, but are also distinct. While both have low densities and dominantly D-type (dark red) spectra, there are differences between the two on both accounts: Deimos’ density (1.471±0.166 g/cm³) is lower than Phobos’s (1.876 g/cm³). Also, while Deimos is uniformly dark red, Phobos presents two spectral units: a “Redder Unit” (similar to Deimos) dominating most of Phobos (> 65%), and a “Bluer Unit” (red also, but significantly less so than Deimos) of more limited surface extent (< 35%). It has been suggested that the “Redder Unit” on Phobos might be an exogenous veneer of D-type-like material imported from Deimos, with the “true” Phobos being better characterized by its “Bluer Unit”. Morphologically, Phobos is more visibly cratered and rugged than Deimos, and presents conspicuous networks of “grooves” which Deimos lacks entirely. Deimos has more subdued topography and a smoother surface.

Remarkable Characteristics: Aside from these bodies being the moons of Mars, the following characteristics of Phobos and Deimos make them remarkable small bodies when considering their current heliocentric location:

Large Small Bodies. Phobos and Deimos are relatively large small bodies compared to the Near-Earth Object (NEO) population. If counted among NEOs, Phobos would rank #3 in size, and Deimos #5. NEAs 433 Eros (L~34 km) and 1036 Ganymed (D~33 km) rank #1 and #2, respectively, while NEA 3552 Don Quixote (D~18 km) would rank #4. Thus, there is only one NEA that is intermediate in size between Phobos and Deimos: 3552 Don Quixote.

Figure 1: Phobos (center) and Deimos (far right) compared in size and spectral type to the three largest NEAs: 1036 Ganymed, 433 Eros, and 3552 Don Quixote. Phobos, Deimos, and Don Quixote are in a remarkable group of large and D-type small bodies, an otherwise rare spectral type among NEOs.

Rare, D-Type Spectrum. Deimos has a D-type spectrum, and most of Phobos as well, i.e., they are both very dark and very red. That these two inner solar system small bodies have D-type spectra is remarkable, because most D-type asteroids are found in the outer main belt and beyond, and among Jupiter Trojans. D-Types are rare among NEAs. Only ~1.5 % of NEAs are D-type. Given this scarcity, Phobos and Deimos are in a spectral minority when compared to the NEO population. NEA 3552 Don Quixote stands out in the same way: it too, is a D-type object.

Volatile-Rich Bodies D-Type Spectrum. While it remains unclear if D-type asteroids are generally rich in volatiles (e.g., in water and organics), the visible and near-IR spectra of Phobos and Deimos, and indeed that of all D-type asteroids, are best matched by the Tagish Lake meteorite, an unusual carbonaceous chondrite particularly rich in water and organics.

One interpretation of the above observations, consistent with hypothesis H1, is that Phobos, Deimos, and 3552 Don Quixote might all be members of a rare type of body in the inner solar system: large, volatile-rich, D-type objects that originated in outer main belt or beyond.

3552 Don Quixote. NEA 3552 Don Quixote was discovered by P. Wild at Zimmerwald Observatory, Switzerland, on 26 Sep 1983. It is a Jupiter and Mars orbit crosser, with an orbital inclination of 31.210°. These orbital characteristics suggested early that it might be an (extinct) comet. The cometary nature of Don Quixote was confirmed in 2014, when it was observed to be an active comet outgassing CO₂ and other volatiles [Mommert et al 2014].

Phobos, Deimos and the Comet Connection. Given the above considerations, might Phobos and Deimos have a connection to comets? Might 3552 Don Quixote represent an earlier stage of Phobos and/or Deimos, or of the objects that their materials were once part of, prior to their capture in Mars orbit?
Conclusion: Although the possibility that Phobos and/or Deimos are cometary remnants may seem unlikely, that possibility remains part of the current trade space and cannot be excluded with available data. Phobos and Deimos are morphologically very different from active cometary nuclei imaged to date, but the evolutions that comet nuclei and their materials would experience in Mars orbit following capture might be expected to produce significantly evolved morphologies. Assuming a CM chondrite-like composition for their rock fraction, the current densities of Phobos and Deimos suggest that they might contain up to 37% and 55% water by volume. If true, this would represent a significant resource for ISRU in Mars orbit and have considerable implications for shaping future human Mars exploration architectures. The main caveats to the comet connection hypothesis presented here are that capture remains dynamically difficult (be it of a comet or a passing asteroid), and Phobos might not be a “true” D-type object as its “Redder Unit” might have been imported from Deimos. It is also unclear if volatiles would actually survive ~4.5 GY in Mars orbit even if initially buried deep inside Phobos and Deimos given likely structural fracturing features such as the grooves networks on Phobos.