LABORATORY SPECTROSCOPY TO ASSESS THE ORIGIN OF THE MARTIAN MOONS. S.M. Potin[1], E.A. Cloutis[1], M.R.M. Izawa[2], [1]Centre for Terrestrial and Planetary Exploration (C-TAPE), University of Winnipeg, 515 Portage Avenue, Winnipeg, Manitoba, Canada, R3B 2E9 (sandra.potin63@gmail.com); [2]Institute for Planetary Materials, Okayama University–Misasa, Misasa, Japan.

Introduction: The Martian moons, Phobos and Deimos, have been orbited by several space missions [1, 2, 3, 4] and are the next targets of the future JAXA sample return mission Martian Moons eXploration (MMX)[5], but the origin of the formation of the two bodies remain uncertain. Several theories have been suggested, but none manages to fully reconcile or explain their composition and current orbits.

Here we analyse the spectral reflectance properties and associated compositions of several potential analogue samples available for analysis in the laboratory that may provide insights into the origin and composition of Phobos simulant, and several processes modifying the reflectance spectrum of a surface.

Previous spectroscopic observations: The Martian moons Phobos and Deimos present a low albedo with an absolute reflectance of ~0.05 in the visible, a red-sloped spectrum, and absolute reflectance of ~0.15 in the near infrared [10, 11,12]. While not all observational spectra of Phobos are in agreement, most show a broad but shallow absorption band centered near 0.65µm [1, 6, 7, 8], consistent with phases such as metallic iron and some Fe^{2+}-Fe^{3+}-bearing phyllosilicates, a faint 1µm absorption feature varying in strength across the surface [9, 10] consistent with materials such as mafic silicates, Fe^{2+}-bearing phyllosilicates, and magnetite. No observations showed a significant 3µm band, which would be a sign of hydrated minerals on the surface [11] (Fig. 1)

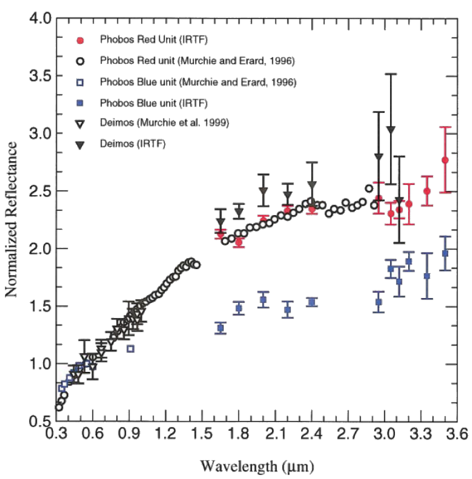

Fig. 1: Normalized reflectance spectra of Phobos and Deimos. Data from [10, 11, 12]

It has been suggested that the low albedo and lack of hydration shown in the spectra of Phobos match those of the D-type asteroids initially found in the outer Asteroid Belt.

Possible formation scenarios: Two major different scenarios have been suggested for the formation of Phobos and Deimos, each with their evidences and limits.

Gravitational capture: The spectroscopic similarities between Phobos, Deimos and the D- and T-types asteroids suggests the ejection of Phobos and Deimos from the outer parts of the Asteroid Belt, which were then captured by Mars [12, 13, 14, 15]. This scenario is supported by gravitational models of the early Solar System [16] but fails to explain the near-circular and near-equatorial orbits of Phobos and Deimos, as gravitational capture tends to result in highly-elliptical orbits in a near-heliocentric plane.

Accretion from a Martian debris disk: The orbits of Phobos and Deimos are consistent with the bodies being formed by accretion from a debris disk, resulting from the impact onto Mars of a large bolide [17, 18, 19, 20]. The low bulk density of the moons also support this theory, and their composition could match the impactor's, which could differ from Mars. However, this scenario implies a debris disk extending at a great distance from Mars, and an intensive alteration of the surfaces of Phobos and Deimos so that their original composition is beyond recognition. It was also suggested the accretion of the moons from a disk left over after the formation of Mars [21, 22]. This can explain the near-circular and near-equatorial orbits of Phobos and Deimos, but the two bodies should present a composition similar to Mars, which is inconsistent with the observations.

None of the suggested scenarios explain the spectroscopic features of Phobos and Deimos and their orbits at the same time. Thus, we need further investigations of the various processes altering the surfaces of these small bodies and modifying the reflectance spectra by removing the absorption features for example.

Possible Phobos analogues: We suggest several types of possible Phobos analogues (Fig. 2).

Basaltic and lunar materials: Basalt samples show absorption features around 1 and 2 µm, while this bands usually occur at longer wavelengths in the case of glassy or poorly crystallized samples. Apollo lunar regolith presents a low reflectance value, typically under 5%, but also the two olivine and pyroxene absorption bands in the 1 and 2 µm regions.

Organics materials: These samples are characterized by a reflectance value of a few percent in the visible range, while their red slope seems to be controlled by the nature of the organic compounds. Spectral slopes and shape of organic-bearing geological materials are highly variable, and only a few organic phases (e.g., anthraxolite) exhibit reflectance spectra consistent with Phobos. These phases are largely organic-rich, high in C and low in H.

Meteorites: Carbonaceous chondrites have been proposed as spectral analogues for Phobos for their absorptions bands around 0.7, 1 and 2µm, but most do not match the monotonic red slope observed on Phobos. However, the reflectance spectra of Tagish Lake and Wisconsin Range 91600 (WIS 91600), two ungrouped and aqueously altered chondrites, match the red slope and lack of deep absorption features of Phobos, but in the visible-near infrared range only. Moreover, most carbonaceous chondrites show a clear absorption feature around 2.7-3µm, sign of hydrated minerals, which does not appear in the reflectance spectra measured on Phobos.

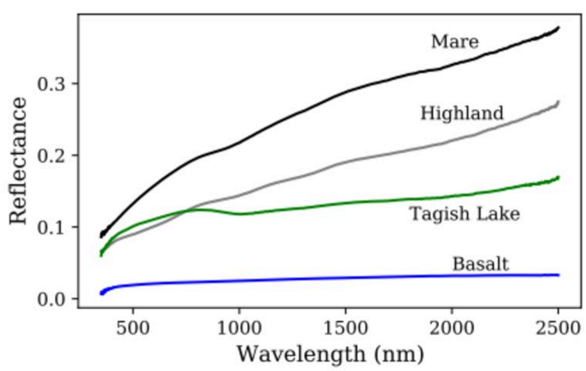

Fig. 2: Visible Near Infrared reflectance spectra of lunar (Grey: Mare; Black: Highland), basalt (blue) samples and the meteorite Tagish Lake (green).

Alteration processes: Planetary surfaces are subject to several processes altering their structure and composition, thus modifying the information we receive from them. The surface can be desiccated due to the high vacuum [23], exhibit indicators of stress from impact shocks, such as amorphization [24], and metamorphism resulting from space weathering. For example, micrometeroroid impacts can lead to the formation of fine-grained metallic iron on their surfaces [25].

Conclusion: The origin of Phobos is still unknown and no sample has been found to be a satisfactory analogue of this surface. We are investigating several samples, beside the most proposed Tagish Lake meteorite, such as various basaltic/silica-rich glassy materials, and various alteration processes to assess and better constrain the composition of Phobos and its formation scenario.

Acknowledgements: This study was supported with grants from the Natural Sciences and Engineering Research Council, the Canadian Space Agency, the Canada Foundation for Innovation, the Manitoba Research Innovation Fund, and the University of Winnipeg.

References: [1] Fraeman et al. (2012) JGR, 117, E00J15. [2] Avanesov et al. (1989) Nature, 341, pp 585-587. [3] Avanesov et al. (1991) Plant. Space Science, 39, pp 281-296. [4] Gendrin et al. (2005) JGR, E4, E04014. [5] Kuramoto K., et al (2018) EPSC abs., EPSC2018–1036. [6] Fraeman et al. (2014), Icarus, 299, pp 196–205. [7] Murchi et al. (2008) LPSC Abstracts, pp 1434. [8] Pajola et al. (2012), MNRAS, 427, pp 3230-3243. [9] Bibring et al. (1990), LPSC Abstracts, pp 461-471. [10] Murchie and Erard (1996) Icarus, 123, pp 63-86. [11] Rivkin et al. (2002) Icarus, 156, pp 64-75. [12] Murchie et al. (1999) JGR, 104, pp 9069–9080. [13] Glotch et al. (2018) JGR, 123, pp 2467-2484. [14] Pajola et al. (2012) MNRAS, 427, pp 3230-3243. [15] Pajola et al. (2013) ApJ, 777, pp 127-133. [16] Tsiganis et al. (2005) Nature, 435, pp 459–461. [17] Rosenblatt et al. (2012) Icarus, 222, pp 806-815. [18] Rosenblatt et al. (2016), Nat. Geo., 9, pp 581. [19] Craddock et al. (2011), Icarus, 211, pp 1150-1161. [20] Canup et al. (2018), LPSC Abstract, pp 2598. [21] Burns et al. (1992) Mars, pp 1283. [22] Giuranna et al. (2011), PSS, 59, pp 1308-1325. [23] Potin et al. (2020), Icarus, 348, pp 113826. [24] Tomioka et al. (2007) MAPS, 42, pp 19-30. [25] Clark et al. (2002), Asteroid III, pp 585-599.