PHOBOS ENVIRONMENT MODEL AND REGOLITH SIMULANT FOR MMX MISSION. H. Miyamoto[1], T. Niihara[2], K. Wada[3], K. Ogawa[4], N. Baresi[5], P. Abell[6], E. Asphaug[7], D. Britt[8], G. Dodbiba[1], T. Fujita[1], K. Fukui[1], M. Grott[9], K. Hashiba[1], R. Hemmi[1], P. Hong[1], T. Imada[5], H. Kikuchi[1], P. Michel[10], K. Mogi[1], T. Nakamura[11], [1]Dept Systems innovation, Univ Tokyo, Tokyo 113-8656, Japan, hm@sys.t.u-tokyo.ac.jp, [2]UMUT, Univ Tokyo, Japan, [3]PERC, Chiba Inst Tech, Japan, [4]Dept Planetology, Kobe Univ, Japan, [5]JAXA, Japan, [6]JSC, NASA, TX, [7]LPL, Univ Arizona, AZ, [8]Dept Physics, UCF, FL, [9]German Aerospace Center (DLR), Berlin, Germany, [10]Université Côté d'Azur, Observatoire de la Côte d'Azur, CNRS, Lagrange Laboratory, Nice, France, [11]Tohoku Univ, Japan

Introduction: Phobos and Deimos, the two moons of Mars, are considered to be scientifically important and potential human mission's target [e.g., 1,2]. Martian Moons eXplorer (MMX) is the JAXA's mission to explore Phobos (and/or Deimos), which is scheduled to be launched in 2024. The main spacecraft of MMX will perform in-situ observations of both Phobos and Deimos, land on one of them (most likely, Phobos), and bring samples back to Earth. Small landing modules may be included in the mission as for the Hayabusa-2 mission.

The designs of both the landing and sampling devices depend largely on the surface conditions of the target body and on how this surface reacts to an external action in the low gravity conditions of the target. Thus, the Landing Operation Working Team (LOWT) of MMX, which is composed of both scientists and engineers, is studying Phobos' surface based on previous observations and theoretical/experimental considerations. Though engineering motivation initiated this activity, the results will be extremely useful for scientific purposes.

Environment of Phobos for a lander: The general characteristics of Phobos, such as dimensions, mass, and orbital parameters, have been intensively studied through analyses of previous missions and terrestrial observations, whose summaries can be found in [e.g., 3, 4]. Photomosaics, maps, and numerical shape models have been built by several authors [e.g., 5]. Different from asteroids of the same size-range, the orbital dynamics and gravitational heterogeneity of Phobos are particularly complex due to the unique combination of small mass-ratio and short distance between Mars and Phobos, which affect the gravity environments and particle behaviors near Phobos as discussed by [e.g., 6, 7].

Even so, the availability of reliable numerical models allows us to estimate many important characteristics of Phobos. Slope angles can be caluculated to be mostly lower than 40 degrees with plenty of <10 degrees slope areas (for the area of about $10^4 m^2$, which comes from the resolution of the shape model). This indicates that, in terms of landing hazard, the surface roughness can be considered to be represented mainly by craters and boulders.

Surface roughness: The MMX lander will be about 2.1m in width and may require the surface roughness to be smaller than 40cm at a landing site. Unfortunately, data from past missions have been obtained with a too low resolution to evaluate the landing hazard. Thus, we theoretically develop a DTM based image analyses as follows.

First, we carefully studied one of the highest-resolution images of Phobos, which show numerous boulders and craters. Boulders smaller than several meters are difficult to identify even in the highest resolution images. Therefore, we picked up all positive relief as boulder candidates, which are composed of bright pixels (in the sunny side) immediately next to dark pixels (in the shadow side). Similarly, we mapped out both craters and crater candidates. The densities of craters and boulders vary significantly. For example, one region has $240/km^2$ confirmed boulders (and $2{,}718/km^2$ boulders including unconfirmed candidates) and 318 confirmed craters (1,439 craters including unconfirmed candidates), while another region has 45 (207) boulders and 260 (610) craters. We use the worst case (area with the largest number densities of craters and boulders) to develop the artificial DTM.

We then extrapolate the size-frequency distributions of boulders to those as small as 35cm by artificially adding boulders, whose locations are randomly selected onto the DTM. We analyse the roughness of the area and find that about >5% of 20m x 20m regions have a roughness <40cm. Considering that this result is based on the worst case, we believe that we will have a high enough probability to find a smooth enough place to land on Phobos.

Composition of Phobos regolith: The composition of Phobos regolith is still not constrained unabiguously. Reflectance spectrum of Phobos is generally featureless and very dark, and at least two (blue and red) units are identified. They are most commonly interpreted as materials similar to P- and D-type asteroids [8], whose low albedo likely indicates the presence of organic compounds. On the other hand, theoretical studies of formations of Phobos and Deimos favor the giant-impact hypothesis and suggest that about 50% of the materials forming Phobos originate from Mars [9]. The darkness and the featureless spectra could be explained by shock-darkened silicates as reported by [10].

The uncertainty of the material properties covering the surface of Phobos partially comes from the interpretation of subtle absorptions and the featureless general trend of the spectrum. Our approach to remove the subjective interpretation is as follows: we compiled and resampled reflectance spectra of 369 asteroids and 741 meteorites from mostly the Relab database [13]. We performed principal component and cluster analyses by using 16 standard schemes to calculate the relative distance of reflectance spectra. The results indicate that (1) the spectral characteristics of both the blue and red units are not that different from each other and (2) their reflectance spectra characteristics are mostly similar to those of Tagish lake and CM2 chondrites.

This result can suggest that Tagish lake and CM2 chondrites could be analogue materials of Phobos in the following sense: if Phobos is a gravitationaly captured asteroid, the origin of Phobos is basically an asteroid similar to the parent bodies of those meteorites, while if the giant-impact hypothesis is correct, Phobos is composed of both Mars and impactor fragments (and perhaps impactor fragments dominate the spectral characteristics).

Structure of Phobos regolith: Mechanical properties of the surface soil, such as the bearing capacity, the bulk frictional coefficient, and other parameters controling granular material behaviors, are among the most essential parameters for designing a lander/sampler, and also for a good scientific understanding of surface processes working on Phobos and of its surface history. However, mechanical properties of Phobos regolith are poorly constrained due mostly to the difficulty in estimating the particle sizes, particle size-distributions, the packing density of the regolith and other frictional parameters. Nevertheless, thermal inertia values (25.2-84.0 MKS for most regions, and 168 MKS for specific regions) indicate that the average particle diameter is expected to be <2mm in most regions. Assuming the thermal inertia is 55 MKS, the most probable values for particle diameter and porosity are <1mm and >53% from analyses based on [11]. Other useful information comes from Earth-based radar observations as discussed by [12], as well as typical regolith particles on the Moon and Itokawa, where regolith maturation processes are probably similar to those on Phobos.

Accounting for these considerations, we assume that the regolith structure of Phobos has at least three layers; (1) a thin uppermost layer (<3cm in depth) of micron-scale dusts accumulated at exteremly low density, (2) a 10cm- to 3m-depth regolith layer with particles accumulated at relatively higher porosity, and (3) a >10m-depth regolith layer with lower porosity.

Univ Tokyo (UT) Phobos simulant: Even when the chemical compositions and size distributions of a soil are known, many mechanical properties of this soil are still difficult to estimate. These values can be estimated by using Tagish lake and CM2 meteorites as analogues, but this is difficult due to their limited availability. Alternatively, we prefer to estimate them by using a simulant of Phobos soil.

We developed two types of simulants such as a Tagish Lake-based simulant (UTPS-TB; Univ Tokyo Phobos Simulant, Tagish lake based; Fig) and mixtures of UTPS-TB and mars-like materials as powders of dunite/basalts (UTPS-IB; Univ Tokyo Phobos Simulant, impact hypotheis based). As for the UTPS-TB, we crushed Mg-rich phyllosilicates (asbestos-free serpentine), Mg-rich olivine, Magnetite, Fe-Ca-Mg carbonates, Fe-Ni sulfides into very fine particles, which are mixed with carbone nanoparticles and polymer organic materials. Then we mix them under wet condition and then dried them completely, the initial liquid content being adjusted to control the compressible strength. The reported compressible strength of Tagish lake varies from 0.7 MPa and larger, so we typically arranged the compressible strength to be as large as about 1MPa.

We have developed more than 100 kg of both simulants and prepared source materials for 10 tons of simulant, which is planned to be processed in this year. We are planning to measure/perform basic experiments based on simulants through international collaborations.

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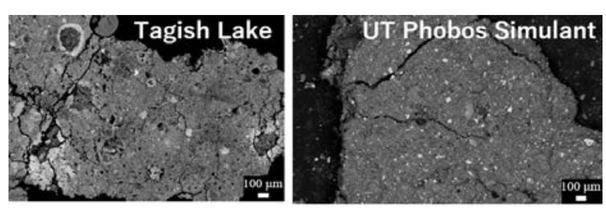

Fig: SEM (back-scattered electron) image of Tagish lake (left) and UT Phobos Simulant (UTPS-TB).