

**PLANETARY PROTECTION ISSUES: A PHOBOS CASE STUDY.** K. Kurosawa<sup>1</sup>, H. Genda<sup>2</sup>, R. Hyodo<sup>2</sup>, A. Yamagishi<sup>3,4</sup>, and K. Fujita<sup>4</sup>, <sup>1</sup>Planetary Exploration Research Center, Chiba Institute of Technology (2-17-1, Tsudanuma, Narashino, Chiba 275-0016, Japan, [kosuke.kurosawa@perc.it-chiba.ac.jp](mailto:kosuke.kurosawa@perc.it-chiba.ac.jp)), <sup>2</sup>Earth-Life Science Institute, Tokyo Institute of Tech., Japan, <sup>3</sup>Dept. of Applied Life Sci., Tokyo Univ. of Pharmacy and Life Sci. Japan, <sup>4</sup>ISAS/JAXA, Japan.

**Introduction:** Recently, JAXA announced that the next target for a sample return mission is either of Phobos or Deimos. The presences of Martian meteorites strongly suggest that Martian rocks have been transported to its moons through the history [e.g., 1]. Since there is a possibility that organisms might exist on Mars, “microbial rocks” might be transported from Mars to the moons. Consequently, the transport processes is attracted an attention in the context of planetary protection issues [e.g., 2-5].

In this study, we investigated the transport processes from Mars to Phobos driven by impacts using our best knowledge. Then, the microbial contamination probability of collected samples from Phobos  $P_s$  is derived by statistical analyses. Note that We employed “the Requirement-10 (REQ-10)” criterion defined by COSPAR. The Earth-return missions from the target body with  $P_s < 10^{-6}$  are classified into “Unrestricted Earth return”.

**Assumptions:** We assumed that some kind of microbes have lived on Mars with the similar density of the microorganism living at terrestrial Mars analogs, where are the areas in the Antarctic permafrost. Since the microbe density at different areas exhibit a large data scatter depending on temperature and arid conditions [6], a Gaussian with the average of  $10^{7.5}$  cells/kg was assumed as the probability density function (PDF) of potential microbe density on Mars  $n_{\text{Mars}}$ .

We focused on the Zunil-forming impact on Mars as the origin of the microbial contamination of the Martian moons. The Zunil is the youngest ray crater with a diameter larger than 10 km [7]. A lower limit of the formation age has been estimated to be 0.1 Myr [e.g., 7].

**Supporting data:** We used the recent data about the sterilization of various kind of microbes taken by the group named “SterLim” [4, 5]. They have extensively studied the sterilization of the microbes by different types of experiments, including impacts and radiation. We constructed an impact sterilization model [6] based on the SterLim impact tests [5]. We assumed that the microbe density on Phobos after the transport decrease with time. The time constant  $TC$  of the exponential decay at a given depth under the radiation environment has been reported by the SterLim radiation tests [5].

**Fundamental processes:** Here, we describe the processes considered in this study. A full description will be appeared in [6, 8, 9]

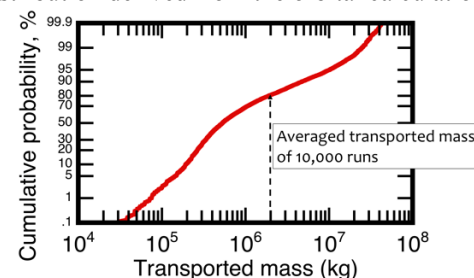
**Launch:** Hypervelocity material ejection during the Zunil-forming impact event was addressed by a three-

dimensional smoothed-particle-hydrodynamics (SPH) code [9, 10]. Since the actual temperature rise in the ejected Mars rocks has been still under debates [e.g., 11, 12], the survival rate during the launch  $\alpha$  was assumed to be 0.1 for a conservative estimate.

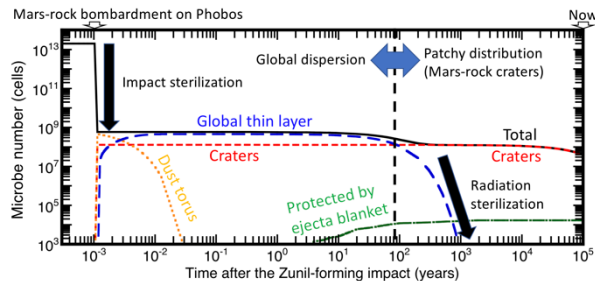
**Penetration of the atmosphere:** We conducted aerodynamic analyses to investigate the minimum diameter of the Mars rocks required for penetrating of the atmosphere, resulting in that it is 10 cm as well as the previous estimate [13]. We also confirmed that the effects of the sterilization due to aerodynamic heating can be neglected.

**Orbital evolution:** To address the fraction of the Mars rocks reaching Phobos and their velocity and angle distributions, we conducted 10,000 orbital calculations [8]. The impact conditions, such as the projectile diameter, impact velocity and angle, were randomly extracted from the plausible distributions [14-16]. The parameter set was chosen to reproduce the diameter of the Zunil. The ejecta velocity distributions derived from the SPH simulations were used as the initial conditions. All the ejecta particles were launched at the current location of the Zunil. The phase angles of Phobos at the time were randomly chosen. Figure 1 shows the cumulative probability of the transported mass to Phobos. The averaged value is estimated to be  $2.0 \times 10^6$  kg. Consequently, the averaged number of the potentially-transported microbes to Phobos is estimated to be  $2.0 \times 10^{13}$  cells when we assumed  $n_{\text{Mars}} = 10^8$  cells.

**Impact sterilization:** The orbital calculations showed that the impact velocity  $v_{\text{imp}}$  onto the Phobos surface of the most part of the Mars rocks exceeds 1 km/s, suggesting that shock heating during collisions leads to a significant sterilization. The averaged survival rate during impacts  $\xi_{\text{ave}}$  can be obtained as  $2.9 \times 10^{-5}$  by a convolution of the impact sterilization model with the  $v_{\text{imp}}$  distribution derived from the orbital calculations.



**Figure 1.** Cumulative probability of the transported mass calculated from the 10,000 orbital calculations.



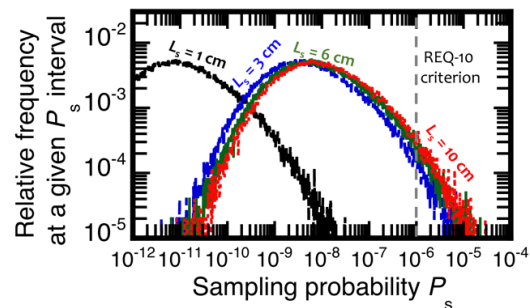
**Figure 2.** Time variation of the microbe number.

**Implantation of microbes to the regolith:** The collision of a Mars rock with the regolith on Phobos at  $> 1$  km/s inevitably leads to a crater formation. A typical size of Mars-rock craters is estimated to be  $\sim 10$  m by the  $\pi$ -group scaling laws [17]. A part of impactor is expected to be retained at the volume lying at the crater floor, which is referred to as “collapsed lens”. The averaged retained fraction of the projectile in the Mars-rock craters  $\psi_{ave}$  is estimated to be 20% based on the  $\theta_{imp}$  distribution from the orbital calculations and the results of the oblique impact experiments by [18], where  $\theta_{imp}$  is the impact angles of the Mars rocks. The averaged mixing ratio of Mars rocks to the collapsed lenses  $\beta_{ave}$  is estimated to be  $\sim 10$  ppm, suggesting that the averaged microbe density in the collapsed lenses just after the implantation becomes  $3.1 \times 10^{-3}$  cells/kg. The averaged thickness of the collapsed lenses is roughly estimated to be  $\sim 1$  m.

**Global dispersion:** The major fraction of the Mars rocks (80%) would fly away from the Mars-rock craters and disperse globally [e.g., 2]. According to the radiation-sterilization model, the microbes deposited on the uppermost surface suffer a rapid extinction within  $\sim 2,000$  years.

**Radiation-induced sterilization:** The microbes embedded in the collapsed lenses would cause the microbial contamination of the collected samples by space crafts because the required time for an extinction due to radiation at the subsurface is much longer than that at the uppermost surface. Nevertheless, the sterilization due to radiation gradually proceeds even at the subsurface. We calculated the survival rate at the present in a given volume down to a selected depth  $\eta(t, H)$  using the radiation-sterilization model, where  $t$  and  $H$  are the time after the Zuni formation and the depth from the surface.

**Time variation and spatial distribution:** Figure 2 shows the time variation of the survived microbes. We found that the total number of the survived microbes up to the present is estimated to be only 2 ppm of the initial and that the microbe concentration is expected to be patchy in the horizontal direction due to stochastic impacts and be heterogeneous in the vertical one due to the depth-dependent radiation-induced sterilization.



**Figure 3.** Probability density function of the microbial contamination probability.

**Contamination probability and Conclusions:** In Figure 2, we clearly show that the survived microbes are concentrated in the Mars-rock craters. The full description of  $P_s$  from a given sampling depth  $L_s$  is given by,

$$P_s = n_{\text{Mars}} \alpha \beta_{\text{ave}} \zeta_{\text{ave}} \psi_{\text{ave}} \eta(t, H=L_s) P_{\text{crater}} M_s \quad (1)$$

where  $P_{\text{crater}}$ , and  $M_s$  are the access probability to the Mars-rock craters, and the sampling mass, respectively. Figure 3 shows the PDF of  $P_s$  at  $t = 0.1$  Myr and  $M_s = 30$  g. To derive the PDF of  $P_s$ , we considered the PDFs of the input parameters in Eq. (1) using a Monte Carlo technique. We found that  $P_s$  could be ranged from  $10^{-11}$  to  $10^{-5}$  and that the most likelihood value of  $P_s$  is around  $10^{-8}$  expect that the sampling depth  $L_s$  is shallower than 2 cm. The sample collection from Phobos could satisfy the REQ-10 criterion with 99% confidence level even when we consider the case of  $M_s = 30$  g and  $L_s = 10$  cm.

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