Mars satellite sample return mission and its sciences

（火星衛星サンプルリターンミッションとその科学）

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ABSTRACT

The Mars satellite sample return mission is being planned as the next strategic middle class mission of ISAS. This mission aims to clarify the origin of the two martian satellites through in-situ high-resolution remote sensing and precise analysis of returned samples from Phobos with shedding light on delivery processes of volatile-rich primitive material that formed around or beyond the snow line of the early solar system. These observations and analyses, as well as unique observations of Mars and its surrounding space from orbits near the satellites, will also provide clues to decode the evolutionary processes that occurred on the martian surface environment and the satellites' surfaces.

A sample return mission to the martian satellites has been rapidly crystallized as the next strategic middle class space mission of ISAS. This mission is planned to approach the Mars system, not yet successfully reached by our country, by extending the heritage of asteroid sample return missions that have brought a unique advantage to Japanese space exploration. Mars has been recognized as a main target of future Japanese space exploration because its Earth-like surface environment provides us irreplaceable research field about the origin and evolution of habitable environments in the solar system. The Mars satellite sample return mission is positioned as a key step toward future successive Mars exploration programs to be promoted in our country.

This mission primarily aims to clarify the origin of the two martian satellites through in-situ high-resolution remote sensing and precise analysis of returned samples from Phobos with shedding light on delivery processes of volatile-rich primitive material that formed around or beyond the snow line in the early solar system. These observations and analyses, as well as the unique observations of Mars and its surrounding space from orbit near the satellites, will also provide clues to decode the evolutionary processes that occurred on the satellites' surfaces as well as on the martian surface environment.

From the two Mars moons, Phobos is selected as the sampling target mainly because of its relatively abundant information on surface physical state and expected mixing of late impact ejecta from Mars in regolith. Regolith samples more than 10 grams from a site well-characterized by remote sensing will firmly tell us the origin of Phobos with independent evidence collected from in-situ observations. By referring to the new detailed knowledge acquired for Phobos, the origin of the other satellite Deimos will be constrained from in-situ observation data that characterize building materials and geologic structures of Deimos.

Origin of the two Mars moons is still an enigma. The available surface reflectance spectra of them are similar to those of D-type asteroids, suggesting their capture origin from the outermost population of the main asteroid belt. Their bulk densities significantly lower than that of typical rock, suggestive of significant porosity and/or ice fraction in their interiors, are consistent with primitive chondritic bodies. On the other hand, both bodies have near-circular orbits above the equator of Mars. Such an orbit is difficult to reconcile with the capture origin, but favors the formation from a circum-planetary disk created by a giant impact.

The composition of a satellite depends on its origin. If giant impact origin is the case, each satellite should be composed from igneous type rocks produced by impact shock heating. In this case, they are likely depleted in volatile species such as water, organics, and potassium due to impact heating. Depletion of Fe is also expected because impact ejecta from the crust and mantle of proto-Mars probably constitutes a certain fraction of building materials of the satellite. If capture origin is the case, the satellite likely preserves chemical and mineralogical compositions similar to volatile-rich primitive meteorites because of the cold environment of Mars system and of least internal heating of such small satellite. Therefore, chemistry and mineralogy of returned samples are useful to clarify the satellite origin. The oxygen and chromium isotopic compositions of returned samples are another possible clue to identify source material of the satellite because they are known to be different among solar system bodies and meteorite groups.

In-situ observations are also important to constrain the origin of both satellites. Major element ratios such as Fe/Si and Fe/Ca are possible observables from near-satellite orbit. If abundant structural water and/or organics are identified on fresh outcrops or boulders in high-resolution reflectance spectra, captured origin becomes very favorable. The presence of interior ice is also expected if they are captured asteroids originated from the outermost population of the main asteroid belt. Such an ice-rich body may have heterogeneous density profile due to partial sublimation and also still release a small flux of water vapor. Thus measurements of interior density and as well as flux of water-related gas species are clue to diagnose the internal ice.

Mars orbits in the outermost region of the inner solar system, where may be regarded as the gateway of volatile-rich primitive solid bodies that formed near or beyond the snow line of the early solar system. Both satellites may record the formation and transport processes of such bodies that delivered source materials for atmosphere, ocean, and life. If they are revealed to be captured primitive asteroids, returned samples may also tell us their original location, time scale of orbital evolution, and cosmochemical processes in the early solar system. If giant impact origin is conversely confirmed, the satellites are probably composed from imperfect mixture of materials originated from impactor(s) and the crust and mantle of proto-Mars. Returned samples would provide constraints for the source region of the impactor as well as the initial condition of Mars evolution. Application of isotopic chronology would reveal the timing of capture or giant impact, which would shed light on the scattering processes of small bodies due to the orbital migration of giant planets suggested for the early solar system.

The martian satellites also record accumulated influences from influx of various types of external materials such as small bodies, dusts, solar wind, outflow gases from Mars, and so on. In-situ observations and sample analyses will also provide constraints on the long-term fluxes and compositions of these materials at their orbits and its consequences to the geological evolution of the satellites' surfaces at multiple spatial scales from the entire moon to each regolith grain. These knowledges are valuable to estimate the influence of external material fluxes to the evolution of the Mars surface environment. The inner satellite Phobos may also contain a small amount of ejecta from large impact craters produced on Mars after the moon formation. If such materials are found from returned samples, they might provide geochemical constraints for the evolution of the Martian surface environment.

Since Phobos and Deimos have equatorial orbits above Mars, it is valuable to make observations of the circum-Mars space environment and the Mars atmosphere from the vicinity of these satellites. Gas and ion flux measurements around these satellites may reveal the influence of gas flux to the satellite surface material as well as the outflow rate of the Martian upper atmosphere. Successive full disk imaging of Mars from the high-altitude, equatorial orbit at multiple wavelengths may provide unique data to clarify the global transport of water vapor and dust in the Martian atmosphere. This has advantage in capturing the atmospheric dynamics more effectively than observations by previous Mars orbiters with low-altitude polar orbits at fixed local time. New observations of circum-Mars space and the Mars atmosphere would provide basic knowledge to understand the long-term evolution of the martian water that have been partitioned among surface reservoirs and continuously lost to space.

This mission covers broad scientific areas and its planning has just begun. We hope that many researchers, especially of young generations, will participate this attractive mission.