Origin and evolution of Mars to be explored by MMX

（火星衛星探査から迫る火星の起源と進化）

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ABSTRACT

The Martian Moons eXplorer (MMX) mission has been planned as the next strategic middle class mission of ISAS. The primary objective of this mission is to clarify the origin of the two martian satellites through in-situ high-resolution remote sensing of these bodies and precise analysis of returned samples from Phobos. This exploration will also provide unique constraints on the formation and differentiation processes of the parent planet Mars.

In the last year's this symposium, we introduced a summary of scientific objectives of the MMX mission, which was provisionally named the Mars satellite sample return mission [1]. The mission objectives have been kept preserved until now, while we also have made efforts to polish up the scientific values of this mission. Here we present a tentative report on the potential and significance of this mission to approach the origin and evolution of Mars.

Among the solar system bodies, Mars has the surface environment most resemble to the Earth's one, each of which has atmosphere and liquid water activity. As represented by the heavily cratered surface, Mars preserves ancient geologic units abundant in records of the evolution of atmosphere and hydrosphere over the planet's history: such early geologic records, including those about the era of origin of life, were largely lost from the Earth. Due to these significance, Mars is being the most frequent target of deep space missions.

Precise remote sensing mapping of the martian surface and landing explorations over the past decades have revealed the water history of Mars in more detail: Mars probably had an ocean with neutral to weakly alkaline water composition before ~3.5 Ga likely sustained by the greenhouse effect of thicker atmosphere, and then gradually lost water from the surface associated with global cooling, surface oxidation, transient volcanic gas supply, and atmospheric escape [2]. On one hand, it still remains an open question how Mars originally acquired water and atmosphere, mainly because of the obliteration of geologic records older than ~4Ga by heavy bombardment [3].

Recently, precise ^{182}Hf-^{182}W chronometry of martian meteorites reveals that Mars rapidly grew and differentiated into core-mantle structure [4]. The enhanced ^{182}W/^{184}W ratio found in martian meteorites indicates that Mars reached at least the half of its present mass within about 1-3 My after the formation of the oldest calcium-aluminum rich inclusion in primitive meteorites. Such rapid growth of Mars is consistent with the oligarchic growth scenario for the planet formation [5]. In this scenario, planetesimals in the proto-planetary gas disk are first accreted to several tens of proto-planets with lunar to martian sizes in the terrestrial planet region within the time scale of order of Myr. After that, protoplanets experienced occasional mutual collisions, so-called giant impact, to form Earth-size planets over several tens of Myr. From its size and orbital location near the outer edge of the terrestrial planet region, Mars has been suggested to be the survivor of a proto-planet that avoided any giant impact. The Hf-W chronometry strongly supports this view [6]. Therefore, Mars potentially has clues to issues how the terrestrial planets grew in an early stage and how the proto-planets differentiate into core, mantle, and atmosphere.

The MMX mission may give us a unique opportunity to approach those issues. As introduced in our last year's report [1], there are two major hypotheses for the origin of martian moons: one is the capture of volatile-rich primitive asteroids and another is the giant impact that sprayed out impact ejecta to agglomerate into satellites [7]. The first mission objective of MMX is to clarify the moons' origin, as stated above, by identifying the composition of materials constituting these bodies from in-situ remote sensing and return sample analysis [1]. Here the term "composition" includes elemental, mineralogical, chemical, and isotopic ones. As a byproduct of their survey, we may address the origin and very early physical state of Mars

If the capture hypothesis is correct, the martian moons are remnants of Mars-forming planetesimals and can serve as an anchor to estimate the material properties of Mars building blocks. Even if the moons' compositions are significantly deviated from the constraints for the bulk Mars composition, the transport dynamics deduced from the MMX mission should improve our understanding of the formation processes and building blocks of Mars. In particular, possible acquisition of constraints on the volatile delivery to Mars is important because these are difficult to be deduced only from the observations of Mars which has experienced differentiation and volatile escape to space. Once the processes and composition of material supply are estimated, theoretical modeling can be made for the atmosphere formation along with the core-mantle differentiation on growing Mars [8].

In general, moon formation by asteroid capture needs some dissipation of orbital energy around a planet. Otherwise a body approaching to a planet will escape from the planetary gravitational well. A possible dissipation mechanism is an action of gas drag induced by an expanded proto-atmosphere. In order to explain the smallness of eccentricities and inclinations of the martian moons' orbits, it is favored that the proto-atmosphere was expanded over several times the planetary radius and rotating to form a circum-planetary disk like structure. If the atmosphere formation modelling reproduces such structure, it strengthens the martian system formation scenario. Moreover, gas drag capture might leave some traces in the moons' materials and bulk structure.

Recently, an attractive giant impact model for the martian moons' formation is proposed [9]. In this model, impact ejecta uplifted into circum-martian orbits is mainly accreted into a massive satellite at a low orbit. Note that the favored mass of impactor for this model is several % of the Mars mass, which is smaller than the lunar mass and meets the estimated mass of an impactor which might produce the northern lowland of Mars. The massive satellite gravitationally enhances random velocities of ejected pieces remaining in higher orbits and promotes them to collide and agglomerate into a few small moons. The massive satellite eventually falls back to Mars due to tidal interaction with the parent planet, leaving two small moons near the present orbits of Phobos and Deimos.

If this model is correct, the timing of the giant impact may be determined from the chronometry of returned samples. This would arouse reinterpretation of the Martian geologic chronology related to possible huge impact basins including the northern lowland. The impact age as well as the cratering record on Mars may also provide clues to understand the large scale orbital evolution of planetary embryos, asteroids and comets that have been suggested to be affected by the orbital migration of giant planets [10].

In the numerical simulations of giant impact and subsequent ejecta accretion [9], the remaining moons are constituted from a mixture of nearly equal proportion of impactor and proto-Mars. In addition, most of ejected materials experience relatively weak impact-induced heating, avoiding severe homogenization due to melting and vaporization before agglomeration. This is consistent with the low bulk densities of the two martian moons compared to an intact rock, suggesting a loose aggregate structure of the moons.

It may therefore be possible to estimate the material properties of impactor and proto-Mars, separately, from returned regolith samples which are likely an admixture of fragments of moon building blocks. Its results would be essentially the first constraints for the physico-chemical state of proto-Mars as well as for the material supply to Mars. These constraints are clues to understand the earliest martian surface environment where chemical evolution potentially toward life was expectedly proceeding.

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