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Phobos sample return mission: Prediction of Phobos composition from a giant impact and implications for the MMX/JAXA mission

P. Rosenblatt (1), R. Hyodo (2), J.-P. Bibring (3), H. Genda (2), Charnoz S. (4,5) and Pignatale F.C. (4)
(1) Royal Observatory of Belgium, Brussels, Belgium (rosenb@oma.be / Fax: +32 2 374 98 22), (2) Earth and Life Science Institute (TIT), Tokyo, Japan, (3) Institut d'Astrophysique Spatiale, Paris, France, (4) Institut de Physique du Globe, Paris, France, (5) Université Paris Diderot, Paris, France.

Abstract

We present computations of possible mineralogical composition of material formed in a post-impact debris disk around Mars. The goal of this study is to predict potential minerals condensed in a circum-Martian disk from which Phobos and Deimos might be formed. The results of this study could be used as guidelines for both the remote sensing of Phobos surface and the analyses of samples from Phobos that will be returned to Earth by the JAXA Mars Moon eXplorer (MMX) mission, due to launch in 2024.

1. Introduction

The origin of the Martian moons is still strongly debated. Are they captured asteroids -owing to their spectra reminding those of D-type asteroids [1] - or did they form after a giant impact in the way our own Moon formed [2]? In order to answer this important question with respect to the early dynamics of the solar system, the JAXA has recently decided to send a spacecraft (MMX, Mars Moons Explorer) that should return Phobos samples on Earth in 2027 or 2029. One of the prime objectives of MMX is to decipher the origin of Phobos, which is in great part recorded in its composition. The payload of the mission is thus focused on the characterization of the surface composition of Phobos with a Gamma-spectrometer for elemental composition and an Infra-red spectrometer for mineralogical composition. They will be complemented by in-depth analyses of returned samples, including the determination of the isotopic composition. All these observations will be key for testing and constraining the scenario of origin. Is the composition of Phobos similar to those of asteroids? Could the composition of Phobos be accounted for by condensation of material in a circum-Mars accretion disk? What is the age of Phobos material? In addition to the returned samples, the instruments onboard MMX are well suited for answering those questions. The near-IR spectro-imager instrument, MacrOmega (CNES) onboard MMX, will provide us with images and spectra at high spatial resolution in the wavelength band of 0.5-3.8 microns that will allow the identification of the igneous and altered minerals as well as of potential volatile phases (aqueous and carbonaceous) at the surface of Phobos. It will allow for characterizing the material Phobos is made of and to compare it with Mars material (a mixture of both Mars and impactor material are indeed expected in the accretion disk [2,3]). In addition to mineralogy, the gamma spectrometer aboard MMX will allow to measure elementary atomic composition. Due to the high temperature during the impact event some devolatilisation of the most abundant volatile species (like Zn, or K) may indeed be expected.

We present here new high-resolution simulations of the formation of Phobos in a giant collision scenario. By computing the temperature and pressure of the post-impact debris disk made of a mix of Mars and impactor material [3], we compute the condensation sequence of the first minerals in the condition of the Phobos accretion. It provides a new theoritical framework to interpret the future observations of the MMx mission.

2. The condensation sequence in the circum-Mars debris disk

We perform numerical simulations of the disk-formation just after the giant collision using Smooth Particles Hydrodynamics (SPH) code. We assume this collision has formed the Borealis basin giving constraints on the energy of the impact, i.e. a less energetic impact than in the case of the formation of the Earth's Moon [3]. We add equation of state allowing for computation of temperature and pressure increase in the disk due to the energy released during the collision [3]. We also track for the particles originating from Mars and from the impactor in order to get the repartition of the two kind of material expected to be present on the circum-Martian disk. Then, using temperature, pressure variations in the disk (i.e. tracking cooling of the disk) as well as initial material repartition (Mars vs impactor), we compute the condensation sequences in order to get the series of minerals that can be formed in this circum-Martian disk. Starting from different initial compositions of the impactor (from carbonaceous to silicates), we, thus, assume thermodynamic equilibrium and use the Gibbs free energy minimisation technique [4] to solve for the stable phases. The resulting mineralogies are taken as proxies for the building block of Phobos. Thermodynamic equilibrium has been extensively used in the past for the study of the chemistry in several astrophysical environments from the Solar Nebula and meteorites [5,6,7] to stars' dusty envelopes [8] and exoplanets' composition [9], providing a reliable and powerful tool.

3. Summary and Conclusions

The MMx mission will be a milestone in the exploration of Mars and for constraining the formation processes of satellites in the inner Solar System. The Martian case indeed constitutes a unique witness of the dynamical processes, which have driven the early evolution of the solar system, responsible for the diversity of planetary worlds revealed by the space exploration of the solar system. The composition of Phobos is likely to preserve key records of its origin, through its mineralogical, elemental and isotopic composition. Instruments aboard the MMX mission will allow to characterize this composition and so to provide strong constraints on the origin of the Martian moons, currently considered through two 'end members' scenarios: Is Phobos of primitive composition like for asteroids or is Phobos composed of some material (Mars and impactor material mixture) expected in the giant collision scenario?

This paper presents new computations of the sequence of minerals one might expect from a Phobos formation triggered by a giant impact on Mars.

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