Experimental study of high-speed rock ejecta reaching the escape velocity of planetary bodies

*Keita Nomura[1], Akiko Nakamura[1], Sunao Hasegawa[2]

1. Graduate School of Science, Kobe University, 2. Japan Aerospace Exploration Agency

The MMX, a sample return mission from the Martian satellite Phobos is planned in the 2020s, and it is expected to find out the origin of the Martian satellites and the evolution process of the Martian system.

On the surface of the satellites, it is considered that the Martian materials excavated and ejected with high velocity by meteoroid impact exist [1]. The relationship between the size and the velocity of the ejecta is important to constrain the estimation of the ejecta amount with ejection velocities higher than 4 km/s to reach Phobos from Mars.

Previous studies of size and velocity of the impact ejecta include model calculation [2][3], secondary crater analysis of the Moon and Mars [4], and laboratory experiments [5]. However, secondary crater analysis cannot, in principle, reveal ejecta that exceed the escape velocity of the planetary body. Also in laboratory experiments, the size-velocity data of ejecta above 1 km/s are limited, and it is difficult to obtain information on ejecta which is faster than the reaching speed to Phobos from high-speed camera images.

We conducted impact experiments aiming to investigate ejecta with a speed exceeding the reaching velocity from Mars to Phobos. We adopted a new method of capturing ejecta impacting secondary target surface with high-speed cameras. We used a two-stage light gas-gun at the Institute of Space and Astronautical Science. The impactors were aluminum and alumina spheres with a diameter of 3 mm and impact velocities about 7 km/s, and targets were basalt blocks. The impact angle was fixed at vertical and oblique with 45°from the horizontal direction of the target. Glass plates as secondary targets were placed at the location where the ejecta passes. First, we calculated the velocity from the flight time and distance between the primary and the secondary targets, and the size from diameter of the craters formed on the secondary targets by applying the scaling law for the glass plate target. The location of the secondary target was varied from experiment to experiment, in order to obtain datasets in different ejection angles.

So far, we showed that data have been obtained for 100 m/s to 7 km/s for vertical impact and 5 to 12 km/s for oblique impact, and that the velocity and size of small ejecta particles with a diameter of about 1/400 of projectile diameter (10 μm size) can be estimated by this method (Nomura et al., in The Japanese Society for Planetary Science 2020 Autumn Meeting). In order to investigate the faster materials ejected by 45°oblique impact, we conducted experiments to capture the ejecta released at different angles by adjusting the location of the secondary target. As a result, we succeeded in capturing ejecta with velocities of 14 km/s, which is about twice as the impact velocity of the projectile. We confirmed ejecta smaller than few micrometer size based on the optical microscope images and electron microscope images of the secondary targets. However, the spatial resolution of the high-speed cameras used for the observation of the secondary targets is not high enough. Therefore, we have not investigated the small ejecta, which means the data obtained in this study are biased toward large fragments. In addition, the inhomogeneous radial ray-like pattern of the ejecta by the oblique impact which we presented previously was also clearly observed in recent experiments. The fragment size distribution had a similar profile regardless of the ejection velocity, and the fragment with higher ejection velocity tends to be small.

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