SEARCH FOR RE-IMPACT SITE OF STICKNEY EJECTA ON PHOBOS.

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Introduction: Ejecta from impact craters on small bodies of the solar system such as smaller asteroids, satellites, and comets plays a significant role in the surface formations such as the erosion, retention, and distribution of regolith. Owing several missions have succeeded to obtain high-resolution images of small bodies, the geological features including boulders, mass movements, various degraded craters, and color variations have been observed [1]. Because ejecta from younger or deeper impact craters is considered to well preserve the original information of the small body, investigating the re-impact positions of the ejecta particles is important implications for its origin and evolutionary history. Besides, such studies will be greatly useful in future missions, especially when selecting a landing site.

Martian Moons eXploration (MMX) is ISAS/JAXA mission to explore Martian two moons, Phobos and Deimos [2]. MMX is planning to collect the surface materials of a Martian moon and bring them return to the earth. The mission objective is to provide key information to determine the origin, evolutionary history, and progress our understanding Mars system formation.

The largest crater of the Martian moons is Stickney crater on Phobos. The diameter and depth is 9 and 1.2 km, respectively. The deeper material from the surface is relatively fresher compared to the original surface material, because it is hard to affect space weathering and mass transfer between the moons and Mars [3]. Thus, we focus on the re-impact site of ejecta from Stickney crater.

Method: While a lot of our simulation conditions refer to Thomas (1998) [4], some are implemented in different ways: (1) launch and impact conditions are calculated using the update shape model, (2) ejecta velocities are randomly generated, and (3) the original surface is defined from the rim of Stickney crater.

The different orbital radius (R_{Ph}) is set to 2.76, 3.04, 3.34, 3.67, 4.88 and 6.49 Mars radius (R_M), because Phobos has been losing altitude due to the tidal force of Mars. With respect to the inertial coordinate system on Mars, the Phobos' default Cartesian position is given as $-R_{Ph}$, 0, 0. Although Phobos has a slight orbital eccentricity and inclination to Mars' equator, the initial velocity vector of Phobos and the inclination are supposed to be $\left(0, -\sqrt{GM_M/R_{Ph}}, 0\right)$ and zero in the simulations.

The initial conditions of ejecta particles as follows. The total number of particles is set to 5000 for each simulation. To set initial positions of particles, the reference plane on which particles set initially is defined by calculating the plane vector from three positions on the crater rim. Although the reference plane should be strictly regarded as the original surface [5], we use the former plane due to significant effects on the results. The surface of Phobos is approximated by 99,846 vertices aggregated from the Gaskell shape model [6]. Using Small Body Mapping Tool [7], the central coordinates of Stickney crater (x, y, z) (km) is set to (7.998, -9.407, -0.235) in the Phobos-fixed frame. Regarding the shapes of the rim of Stickney as a circle with a diameter of 9 km. Launching velocities are assumed to be decreased by a power law [8], and 0.86 crater radius velocity is 1.5 m/s in a nominal case [4]. We define the initial particle's distance from the center of a crater through the reference plane as X_0 and determine it from the following equation:

$$X_0 = 0.86R\left(\frac{v_e}{1.5}\right)^{-1/2.1}$$

where R is the crater radius, and v_e is a launching velocity. Particles are placed at equal intervals on the circle with the radius of X_0 in increments of 1 degree.

Considering the randomly generated ejecta velocities is useful for detecting crater ejecta-blanket boundaries on asteroid 433 Eros [9]. We vary launching speed randomly, using values ranging from 1.5 to 10 m/s. The upper limit of launching speed used in these simulations is approximately within the escape velocity for particles with the aforementioned launching angles (8 m/s). Based on the dimensional analysis, the normalized volume of ejecta with a velocity greater than a given velocity and normalized ejecta velocity is predicted to be the following condition:

$$\frac{V}{R^3} = C\left(\frac{v_e}{\sqrt{gR}}\right)^{\alpha}$$

where C and α are a constant value and number and g is the gravity of Phobos. In this work, we adapt α as -1.22 of the fitting results to the data [10]. The particle launching angle (θ_l) is defined as the angle from the reference plane and set to 45°, or 35.4°, which is used in numerical computations on Deimos [3] in each simulation.

The fate of ejecta launched from Phobos is influenced by the Mars tidal force, the tiny gravity of Phobos, and the rotation of Phobos [11]. Thus, we assumed that the mass and size of particles are zero, and neglect particle-particle collisions. The calculations are performed with the inertial reference frame having the center of Mars at the origin. We compute positions of particles by using the N-body simulations. To calculate the ballistic trajectory of ejecta particles, we assume Phobos and Mars are point masses. The time step in the simulation is 1 s. The ending time of each simulation is 5 x 10^4 s.

The shape of Phobos is largely influenced by detecting the impact positions on the surface of Phobos [4]. We originally define the candidate collision positions between Phobos and a moving particle in a step-by-step simulation in the following conditions,

$$\overrightarrow{v_k} \cdot \overrightarrow{n_l} < 0$$

$$\overrightarrow{|P_k Q_l|} < 0.05$$

where v_k and P_k are the kth velocity vector and position of a particle respectively, and n_l and Q_l are the lth vertex normal vector and polygon vertex on the shape model. The value of 0.05 in the formulation is set from the average distance between the vertices (50 m). When a particle satisfies this condition, and the distance between a particle and a vertex of the shape model be at the minimum, the vertical point is assumed to be the re-impact position.

Results and Discussions: The colliding positions are more widely scattered in the longitude direction than in the latitude direction. More particles launched from Stickney's rim collide with Phobos with the increasing distance from Mars. When the orbital distance is small, the launched particles tend to collide widely with the eastern region to Stickney crater. When the orbital radius is larger than 3.67 R_M, the west-east asymmetry is not clear. Comparing the distributed patterns of the ejection angle 35.4° with that of the angle 45°, a significant difference could not appear. These tendencies are almost similar to the previous study [4].

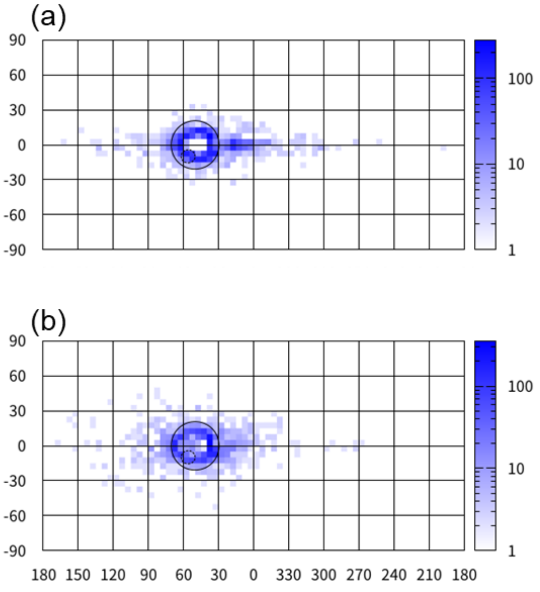

Figure 1. Ejecta re-impact simulation for particles launched from Stickney crater at the different orbital radius (a) 3.34, and (b) 6.49 R_M.

We find that the launched particles from Stickney re-impact frequently in the following range (0° < longitude < 30° and -10° < latitude < 10°) at any orbital radius (Figure 1). The distributed bitterns are similar to the east blue unit region [4]. Although the results are almost consistent with the previous study in the low orbital radius, a certain amount of the ejecta particles from Stickney re-impact to the east even at the high orbital radius beyond the synchronous radius (~6 R_M), which is slightly different from the previous result [4]. This may be due to the assumption that the shape of Stickney crater is regarded as a circle, and the original surface is estimated from the existing plane of Stickney's rim in our simulation.

Materials around the ray craters in the region may contain the more inner information of Phobos than any other regions. The region is considered to be scientifically suitable landing sites.

Conclusion: We investigate the re-impact site of ejecta materials from Stickney crater whose velocities are generated randomly using the shape model and changing the orbital radius. We find that the ejecta particles from Stickney re-impact the eastern region to Stickney frequently not only in low Mars orbit but also around the synchronous radius. The region in the following range (0° < longitude < 30° and -10° < latitude < 10°) is considered to concentrate the Stickney material, which may involve the deeper materials under the original surface of Phobos.

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