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The fate of the impact-debris produced by a Borealis-forming impact

Ryuki Hyodo and Hidenori Genda
Earth-Life Science Institute, Tokyo Institute of Technology, Japan (hyodo@elsi.jp)

Abstract

Mars is expected to have experienced a giant impact that forms the Borealis basin – thought to be the largest and oldest Martian impact basin. It is also suggested that the same impact can form a circumplanetary impact-debris disk from which Martian moons, Phobos and Deimos, accrete. Here, we perform high-resolution smoothed particle hydrodynamics (SPH) giant impact simulations that form the Borealis basin and investigate the fate of the Mars-originated impact-debris that escape from the Martian system. We show that a part of the debris originated from Martian mantle can potentially be the source of the Mars' trojans and the rare A-type asteroids. Our results also indicate that the impact-debris can hit pre-existing asteroids with impact velocities much larger than ~5 km/s which would record a reset of ^{40}Ar-^{39}Ar age and/or impact melts.

1. Olivine-rich small bodies

The rare asteroids, called A-type asteroids, orbit within the Hungarian region (~7% of the total mass) and within the main asteroid belt region (~0.4%). They have olivine-rich spectral features [1]. Their origin is still unclear even though some could be mantle materials fragmented and ejected by a catastrophic impact of a differentiated primordial asteroid [2]. It is also recently reported that seven out of the nine known Martian Trojans, called the Eureka family, show olivine-rich spectral features [3]. Olivine is a major mineral of the Martian upper mantle with ~60 wt% [4,5]. Also, at the surface of Martian grabens, such as Nili Fossae, an olivine-rich signature is detected [6,7]. It is suggested that a giant impact could be responsible for the origin of these rare olivine-rich small bodies [3]. Here, we investigate the fate of the impact debris in details.

2. The fate of the impact debris

2.1. Giant impact simulations

We performed high-resolution smoothed particle hydrodynamics (SPH) giant impact simulations that produce the Borealis basin and Martian-moons forming debris disks (typical impact parameters: impactor mass of ~0.03 Mars mass, impact velocity of ~6 km/s and impact angle of 45 degrees) [e.g. 8,9]. The total number of SPH particles in the simulation is N=3×10^5 or 3×10^6. The initial entropy of Mars and the impactor is set to be 2000 J K^{-1} kg^{-1}, which corresponds to ~680 K at the surface of Mars (see more details in Hyodo & Genda 2018, ApJL [10]).

Here, we focus on the SPH particles that are not gravitationally bound to Mars after the impact (particles that escape from Mars gravity). Then, using the data of the escaping particles obtained from our SPH simulations, we calculated Sun-centered orbits of the ejected particles (semimajor axis, eccentricity and inclination).

2.2. Escaping debris from Mars

The canonical impact (impactor mass of ~0.03 mass of Mars, impact velocity of ~6 km/s and impact angle of 45 degrees without pre-impact Martian spin) produces the escaping debris whose total mass (that originated from Mars and from impactor) is ~1% of Mars mass. ~20wt.% of the total debris comes from Mars and the rest comes from the impactor. ~50wt.% of Martian debris originates from Martian mantle (between ~50km and ~200km in depth from the surface of Mars)[10]. During the impact, the debris is shocked and temperature increases. Our simulations show that the resultant temperature of the debris is ranged between ~1000K and 4000K with a peak of around ~2000K [10].

2.3. Composition of impact debris

Assuming the Mg# (=Mg/(Mg+Fe) in mol) of bulk silicate Mars of ~75% [11] and thus $(Mg_{0.75}, Fe_{0.25})SiO_4$ olivine solid solution as a major mineral of the Martian upper mantle, solidus and liquidus temperatures are about ~1850 K and ~2000 K [12]. Then, using our SPH simulations, we found that ~10% of escaping Martian mantle debris does not melt but ~70% of the debris completely melts [10]. In the case of partial melting (2000K), ~20% of the Martian mantle debris avoids melting and thus they would preserve their primitive mineralogy. Hence, the un-melted Martian mantle material (olivine-rich material) is estimated to be about ~2% of the total ejected mass ($\sim 1.7\times10^{20}$ kg). This mass is much larger than those of current A-type asteroids found in the Hungarian region ($\sim 2.8\times10^{15}$ kg [1]) and the current main asteroid belt ($\sim 8.9\times10^{18}$ kg; [1]).

2.4. Orbits of the impact debris

The orbits of the ejected particles are distributed between ~0.5-3.0 AU with eccentricity up to ~0.6 and inclination up to ~0.3 radian [10]. Detailed studies on the long-term evolution of the debris are required for future works but the initial orbits of the debris, at least, show that they can easily reach the asteroid belt region and thus un-melted Martian mantle material (a maximum of ~2% of the total debris mass) is potentially expected to settle into stable orbits as rare A-type asteroids found in the Hungarian and main asteroid belt regions.

We also expect that the debris hit the pre-existing asteroids with impact velocity much larger than ~5 km/s [10]. The nominal collision velocity between existing asteroid is ~5 km/s [13]. Such high velocity collision between the debris and pre-existing asteroids may record a reset of ^{40}Ar–^{39}Ar age and/or impact melts [14] and thus the timing of the giant impact on Mars may be recorded in some chondrite.

3. Discussion and summary

All these physical and chemical theoretical predictions would be useful for testing the giant impact hypothesis on Mars. Our results present the initial conditions for the long-term evolution of the debris. Not all but a fraction of the impact-debris could be implanted in asteroid region or/and as Martian trojan. Other fraction of the debris could be accreted by other terrestrial planets or/and could be scattered by planetary perturbation. N-body simulations would be useful to study such long-term evolution of the debris. Also, future observations and planetary explorations including a sample return mission would be important.

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References

[1] DeMeo, F. E., & Carry, B. 2013, Icar, 226, 723 [2] Sanchez, J. A., Reddy, V., Kelley, M. S., et al. 2014, Icar, 228, 288 [3] Polishook, D., Jacobson, S. A., Morbidelli, A., & Aharonson, O. 2017, NatAs, 1, 0179 [4] Bertka, C. M., & Fei, Y. 1997, JGR, 102, 5251 [5] Zuber, M. T. 2001, Natur, 412, 220 [6] Hoefen, T. M., Clark, R. N., Bandfield, J. L., et al. 2003, Sci, 302, 627 [7] Mustard, J. F., Ehlmann, B. L., Murchie, S. L., et al. 2009, Geophys. Res., 114, E00D12 [8] Marinova, M. M., Aharonson, O., & Asphaug, E. 2008, Natur, 453, 1216 [9] Hyodo, R., Genda, H., Charnoz, S., & Rosenblatt, P. 2017, ApJ, 845, 125 [10] Hyodo & Genda 2018, ApJL, 856, 2 [11] Elkins-Tanton, L. T., Parmentier, E. M., & Hess, P. C. 2003, M&PS, 38, 1753 [12] Bowen, N. L., & Schairer, J. F. 1935, AmJS, 29, 151 [13] Bottke, W. F., Nolan, M. C., Greenberg, R., & Kolvoord, R. A. 1994, Icarus, 107, 255 [14] Kurosawa, K., & Genda, H. 2018, GeoRL, 45, 620