High-velocity impact experiments on porous gypsum simulating C-type asteroids: In-situ measurements of post shock temperature around impact crater

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Carbonaceous chondrites (CCs) have the minerals showing the evidence of aqueous alternation at the temperature higher than 150 °C and the possible heating origin is supposed to be the decay heat of a short-period radioactive nuclide, ^{26}Al. If so, C-type asteroids should be formed within 10^6 years after solar system formation, but the conclusive evidence has not been obtained yet. It is recently proposed that the other possible heating origin of aqueous alternation in CCs is the impact heating. The porosity of a C-type asteroid, Mathilde, is estimated to be ~50% [Veverka et al., 1999] and when a body collides on such a porous asteroid, the wide area surrounding the crater can be heated effectively by post shock heating [Rubin, 2005]. However, to confirm that the heating origin of aqueous alternation is a post shock heating, it is necessary to examine the initial shock temperature distribution on the bottom of impact crater, the dependence of the distance from the impact point on the maximum temperature and the duration of post shock temperature, and the relationship between these parameters and impact conditions and to reveal the impact conditions at which an impactor can heat the target body at higher than 150 °C. In this study, we carried out high-velocity impact cratering experiments using the porous materials simulating C-type asteroids and measured the post shock temperature directly to examine the temperature history around the impact crater.

We used porous gypsum targets simulating porous C-type asteroids having the size of 7 x 7 x 3 cm with the porosity of 50%. The temperature was measured using five chromel-alumel thermocouples setting inside the target at the constant interval (0.5 or 1 cm) from the impact point. The temperature measured by the thermocouples was recorded by a data logger with the frequency of 100 kHz and the temperature resolution of ±0.1 °C. Two types of projectiles, a polycarbonate sphere with the diameter of 4.7 mm and an aluminum sphere with the diameter of 2 mm were accelerated at 1 to 5 km/s. The target was set in the vacuum chamber evacuated below 20 Pa to prevent the thermal conduction of the remaining air in the chamber. The collisional phenomena were observed using a high-speed digital video camera with the frame rate of 10^5 fps.

After the impact, the maximum temperature, T_{max}, decreased with the increase of distance from the impact point. On the other hand, the duration between the impact time and the peak time showing the maximum temperature, t_{max}, and the duration between the peak time and the arrival time when the temperature falls to the half of maximum temperature, t_{half}, increased with the increase of distance from the impact point. At 1.2 cm from the impact point, the T_{max} increased with the increase of impact velocity, while both t_{max} and t_{half} were almost consistent: t_{max} was about 20-40 seconds and t_{half} was about 40-70 seconds at 1.2 cm, respectively.

In this study, two kinds of projectiles were used so next, we examined the relationship between the difference in temperature between the maximum temperature and that before the impact, ΔT_{max}, and the distance from the impact point normalized by the crater radius, x/R. As a result, the ΔT_{max} increased with the increase of impact velocity at same x/R; for example, at x/R=3, the ΔT_{max} was 1 °C at 1 km/s while it was 15 °C at 5 km/s. The ΔT_{max} had a power law relation to the x/R, and the power was almost consistent, -5.0 to -7.0, except for 1 km/s. The power at 1 km/s was -2.3.

Finally, we assumed that the power law relation mentioned above does not change with surface gravity (that is, microgravity of C-type asteroids), and calculated the normalized distance x/R at which the maximum temperature can reach 150 °C. As a result, the x/R at the temperature of 150 °C was almost consistent, 1.0-1.5, at the impact velocity higher than 1.7 km/s. This x/R value means the aqueous alternation can occur in the volume from the crater wall to the distance from the crater bottom which is 1.5 times larger than the crater radius. At 1 km/s, the x/R at the temperature of 150 °C was 0.4 and this means that the aqueous alternation can not occur.

[References] Veverka et al. (1999), Icarus 140, 3; Rubin (2005), Sci. Am. 292, 80.

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