IMPACT EXPERIMENTS ON SNOW: THE EFFECT OF SINTERING ON THE FORMATION OF CRATER. Masahiko Arakawa, Graduate School of Environmental Studies, Nagoya University (Chikusa-ku, Furo-cho, Nagoya, 464-8601, Japan: arak@eps.nagoya-u.ac.jp)

Introduction: Recent planetary explorations for small bodies revealed that they have large craters compared to their seizes. These small bodies could be a mixture of silicates and ices. The important mechanism to give the strength in porous small bodies could be a sintering of the dusts. Sirono and Yamamoto (1997) studied the porosity evolution by sintering and the thermal history in small icy bodies for the implication to comets [1]. They showed that the mechanical structure of the strength developed by sintering in the process of the thermal evolution. Therefore, we studied the contribution of sintering to the mechanical strength of icy bodies and the effect of sintering on the formation of impact craters made on snow.

Experimental method: Impact experiments on snow were conducted to make clear the formation mechanism of crater and the disruption mechanism of the sintered porous materials [2,3,4]. The target was made of ice particles with the size of about 500 microns. The ice particles were put in a cylindrical container with the diameter of 13.5cm and the height of 10cm for the cratering experiments. The target porosity was between 35 % to 45 % and the target was set in a cold room for sintering from 3 minutes to 60 hours. We used the projectile made of ice and snow with the porosity of about 30%. The projectile was a cylinder with the diameter of 7mm and launched by a He-gas gun at the impact velocity less than 150 m/s. Every impact experiment was conducted in a large cold room at the temperature of -5 to –18°C. In order to compare these results obtained by low velocity impacts with the craters formed by high velocity impacts, the craterig experiments were conducted by using a two stage light gas gun set in a cold room. The nylon projectile was launched at the velocity from 2 to 3 km/s and it was impacted on the snow target with the porosity of about 40%, which was sintered for 24 hrs at -10°C. The crater found on the recovered target was measured and the thin section near the crater area was made to analyze the melting region.

Results: In the low velocity impact experiments made by snow and ice projectile, we have found that the crater size clearly increased with increasing the impact velocities at -10°C. The snow projectile was recovered intact at the impact velocity lower than 70m/s, but it was broken completely at the velocity higher than 70m/s and the relic of impact point was observed as ring-like structure. At lower temperatures, the crater size became larger at the same impact velocity. In contrast, the crater size became smaller at higher temperatures. The relationship between the crater volume (V_{cr}) and the projectile kinetic energy (E_k) was fit by power law equations for each temperature and projectile. The power law index derived from the fitting for each data was about 0.5 irrespective of the temperatures. The V_c of the lower temperatures becomes larger at the same E_k because of the effect of sintering. The V_{cr} at –18°C is noted to be three times larger than that at –5°C (Fig.1).

In the high velocity impact experiments made by nyron projectiles, the recovered crater had a spherical

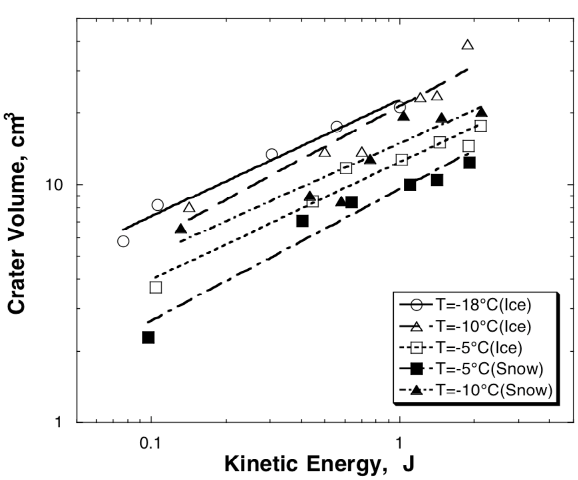

Fig.1 Crater volume vs. Kinetic energy of the projectiles

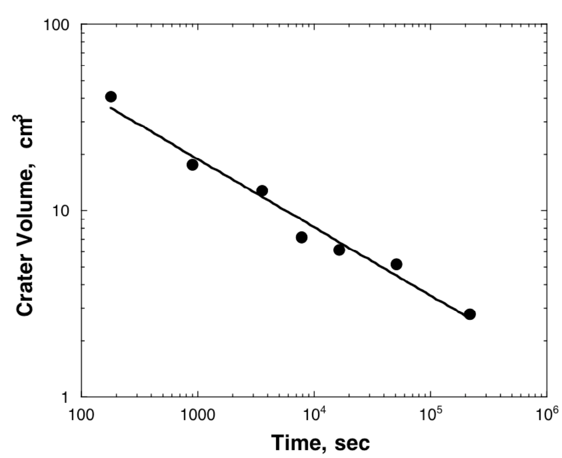

Fig.2 Crater volumes made on the snow with different degree of sintering

pit and a concentric spall area surrounding the pit. The pit radius was about 10mm and the center of the pit was about 9mm below the surface. The wall of the spherical pit was covered with a thin ice layer about the thickness of 0.5mm, which was observed in the thin section under a microscope. This ice layer could be a refrozen snow target melted by the impact. This melt evidence and the spall area observed aroud the pit were characteristics of the high velocity impact. We never observed them in the low velocity impacts.

We also found that the crater size simply decreased with time from 3min. to 60 hrs. at –10°C. Figure 2 shows the crater volume for the targets sintered at different duration. The target was sintered at –10°C, and the crater was formed at the impact velocity of 100m/s. The crater volume decreases with increasing sintering duration. The empirical relationship between V_{cr} and t_{s} is as follows,

$$V_{\mathrm{cr}}[\mathrm{cm}^3] = 236 \cdot t_{\mathrm{s}}^{-0.37}[\mathrm{sec}]. \quad (1)$$

Because the target strength should increase with increasing the duration by sintering, we can expect that the above power law relationship can be explained by the strength variation with time.

In order to measure the mechanical strength of sintered snow at -10°C, the impact test by dropping the metal weight was conducted and the impact acceleration of the weight was measured to evaluate the snow dynamic strength. We define the snow dynamic strength by the maximum stress. We recognize that the strength (Y) increases with the duration according to the following power law relationship,

$$Y[\mathrm{kPa}] = 5.75 \cdot t_s^{0.28}[\mathrm{sec}]. \quad (2)$$

Now we can rewrite the equation (1) by using equation (2) to represent the strength dependence of the crater volume.

$$V_{cr}[\mathrm{cm}^3] = 1852 \cdot Y^{-1.3}[\mathrm{kPa}]. \quad (3)$$

The above empirical equation shows the effect of strength on the crater formation. The important property discovered in this experiment is that the volume is inversely proportional to the material strength for the porous sintered target.

Discussion: According to a simple theoretical consideration on the impact crater formed on weak targets, we propose a scaling parameter of P_0/Y for the scaling law of a sintered snow, where P_0 is an initial impact pressure, and Y is a strength of sintered snow. All of our resuts shown in Fig.1 were reanalyzed to plot them by using P_0/Y and a crater volume normalized by the projectile volume. Figure 3 shows the relationship between the normalized crater volume and P_0/Y for all of our results with different tempetratures and projectiles. The difference among the results observed in Fig.1 was reduced and all of the data were fit by one line described by the following equation,

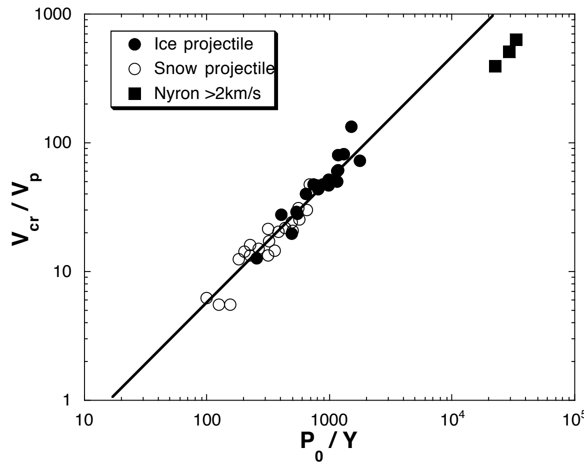

Fig.3 Normalize crater volume vs. Normalized impact pressure for snow targets with the porosity of 40% impacted at the velocity from 10m/s to 3km/s.

$$V_{cr}/V_p = 0.07(P_0/Y)^{0.95}, \quad (4)$$

where V_{p} is a projectile volume. This equation can be suitable for the data obtained by not only snow projectiles but also ice projectiles. We also pot the results derived from the high velocity impact. They are slightly lower than the fitted line: the craterig efficiency was less than that derived from the low velocity impacts. This difference might be caused by the impact melting because the impact energy was consumed by the latent heat to reduce the crater volume.

References: [1]Sirono and Yamamoto (1997) *Planet. Space. Sci.*, *45*, 827-834. [2] Arakawa et al. (2002) *Icarus*, 158, 516-531. [3] Arakawa and Tomizuka (2004) *Icarus*, 170, 193-201. [4] Burchell et al. (2005) *Icarus*, 179, 274-288.