IMPACT CRATERING EXPERIMENTS TO TARGETS WITH CAVITY: APPLICATION TO CAVE SKYLIGHT ON MARS. T. Michikami[1], S. Miura[1], J. Haruyama[2], and P. S. Lykawka[3], [1]Fukushima National College of Technology, Iwaki, Fukushima 970-8034, Japan., (mitikami@fukushima-nct.ac.jp), [2]Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency, [3]Graduate School of Science, Kobe University, Japan.

Introduction: Recently, NASA's Mars Odyssey spacecraft has discovered seven candidate skylight entrances into a subterranean cavern system on Mars [1]. The seven caves are located near a massive Martian volcano, Arisa Mons, which may have an abundance of subsurface void spaces [2,3]. Subterranean caverns represent a potential environment for future manned missions. That is, human activities and industrial operations could be carried out, protected from various natural hazards that occur at the surface, such as cosmic rays radiation, meteorites and micrometeorites impacts, and impact crater ejecta. Thus, it is important to investigate the structure and origin of these caverns for the future exploitation on Mars. However, the extent and structure of subterranean caverns are not precisely known due to the difficulty in finding these caves in the observational fields.

Natural caverns are commonly observed on the Earth in the form of “lava tubes”, which are the drained conduits of underground lava rivers. Terrestrial lava tubes typically possess a few meters of height and width; cross-sectional dimensions in excess of 10 m are rare. The length of lava tubes on Earth may reach 10 to 20 km, but most lava tubes are only 1-2 km long. The caverns are considered to exist also on the Moon and the Mars in the form of lava tubes. On lower gravity, lava tube caves can be larger than on Earth. On the Mars typical height and width are a few hundred meters [4]. The heigth and width on the Moon are typically hundreds of meters [4]. Lava tube caverns would have roofs tens of meters thick (roughly 40 m on the Moon, and perhaps 20 m on Mars) [4]. Therefore, the discovered seven skylights might be the collapsed roofs of lava tube.

The Martian skylight entrances have sizes of 100 to 250 meters. However, it is not clear how deep they are, because their floors have not been seen yet. Besides, these entrances lack an elevated rim, ejecta deposits associated with impact craters. Thus, the structure and origin of all candidate skylight entrances are not well understood. Cushing et al. [1] suggested that the entrances are not of impact origin, not patches of dark surface material, and are likely skylight openings into subsurface cavernous spaces. Nevertheless, when a crater is formed on the surface with a cavity in the interior, the outline of the crater may acquire a characteristic shape owing to the cavity. That is, these craters may not have an elevated rim and ejecta deposits even if they are produced by impact cratering. In this paper, we performed impact cratering experiments to investigate the scenario described above. Firstly, we produced targets with cavities in the interior, and then performed impacts on the surface of the targets. In summary, we intend to constrain the formation of skylight entrances into subterranean caverns based on the results of impact cratering experiments.

Experimental procedures and Results: We produced cylindrical target blocks with diameter and height of 15 cm and 6 cm, respectively. The targets were made of cementing 'Toyoura' sand with mean particle diameter of 0.2 mm. The bulk density and the compressive strength of the target are 1550 kg/m^3 and ~3 MPa, respectively. This compressive strength is similar to that estimated for the lava tube (or cavern) ceiling (e.g. [4]). The targets underground was hollowed as shown in Fig.1. We produced targets with various roof thicknesses (T_R) and a cavity width of 8 cm (T_C=8cm). According to Oberbeck et al. [5], the ratio of roof thickness (T_R) to typical lava tube cross sections (T_C) ranges from 0.125 to 0.25 on Earth. We used the same ranges for the targets in our experiments.

Impact experiments were carried out using a two-stage light-gas gun at ISAS, JAXA (The Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency). Nylon sphere projectiles with 7 mm diameter (mass 0.213 g) were shot perpendicularly into the target surface at nominal velocity 1.2 km/s. The targets were enclosed in a target holder with one face exposed to the impact. The whole system was mounted in a vacuum impact chamber with acrylic resin windows. The ambient pressure in the chamber was less than 200 Pa. For the targets with cavity widths of 2 cm and without cavities, the experiments were carried out three times in order to confirm reproducibility. The reproducibility of our experiments was good.

Figure 2 illustrates examples of obtained craters, and how crater shapes vary with roof thickness (T_R). The leftmost photo of Fig. 2 indicates the results for the target with smallest roof thickness (T_R=1cm). A relatively large hole is seen. Worth noting, this shape resembles the shapes of skylight entrances observed on Mars. This result suggests that the Martian skylight caves are produced by impact cratering.

In general, the crater areas can be divided into two distinct zones. The inner zone at the central pit is highly fractured, while the outer zone has a wide and shallow surface. In our experiments, the hole on the target having relatively thin roofs (T_R < 3cm) appears to be the inner zone. The sizes of the hole appear to decrease with increasing the roof thickness. On the other hand, for targets having relatively thick roofs (T_R ≥ 3cm), particular zones cannot be distinguished around the crater area.

Figure 3 shows the outer diameter and depth of obtained craters. As the roof thickness increases, the crater diameter remains almost constant. In the targets without holes, crater depth is nearly constant regardless of roof thickness. We believe that the holes depend on the crater formation at the rear surface of the target. In our experiments, craters at rear surface are not seen in the targets with large roof thickness (T_R ≥ 4cm). The rear crater diameters are considerably larger than front crater ones, except for the target with the smallest roof thickness (T_R=1cm). Lastly, the holes were produced when both the front and rear craters were connected.

Discussion: In the skylight caves on Mars, a relatively large crater would have caused more structural damage than the cumulative effects of many small craters. However, it is difficult to assert the influence of impact cratering frequency on the shape of the holes because impact cratering is a stochastic process. Further research is necessary.

As shown in Fig. 3, a hole is produced when the roof thickness is less than half of the crater diameter. We tried to apply this result to the craters of a few hundreds meters in size on the Moon and on Mars. Uncollapsed roofs of lava tubes on the Moon display impact craters with diameters typically of a few tens of meters. No crater over 100m has been found [6]. This is consistent with our results because typical roof thickness on the Moon is 40 m. In the same way, the roof thickness on Mars must be less than 50 or 120 m because the seven Martian cave entrance sizes range from 100 to 250 meters. Furthermore, because cave entrances larger than a few km have not been observed on Mars, lava tubes with roof thickness larger than several 100m probably do not exist.

Conclusion: Impact cratering experiments to targets with cavity were carried out in order to constrain the formation of skylight entrance into subterranean caverns on Mars. The results of our experiments suggest that crater diameters are almost constant regardless of roof thickness. Craters are seen at rear surface when roof thickness is less than 4 cm. Besides, rear craters are larger than front craters. Holes were obtained when the front and rear craters were connected in targets with small roof thickness. A relatively large hole is seen in the target with the smallest roof thickness (T_R=1cm). For instance, the shape of the holes is similar to those of skylight entrances observed on Mars. Therefore, the cave skylights on Mars are probably produced by impact cratering on relatively thin surfaces.

References: [1] Cushing, G. E. et al. (2007) LPSC *XXXVIII*, Abstract#1371. [2] Ferrill, D. A. et al. (2003) LPSC *XXXIV*, Abstract#2050. [3]Wyrick, D. et al. (2004) *JGR*, 109(E6). [4] Walden, B.E. et al. (1998) Workshop on *ISRU*, 16-17. [5] Oberbeck, V. R. et al. (1969) *Mod. Geol*., 1, 75-80. [6] Horz, F. et al. (1985) LPSC *XXI*, 405-412.

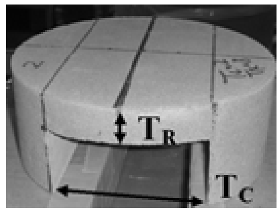
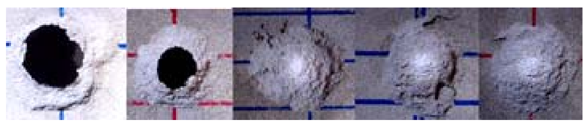


Figure 1: This photo shows a target with roof thickness (T_R) 2 cm and cavity width (T_C) 8 cm.



T_R=1cm, T_R=2cm, T_R=3cm, T_R=4cm, T_R=6cm

Figure 2: Typical obtained crater shapes on the front surface of the targets.

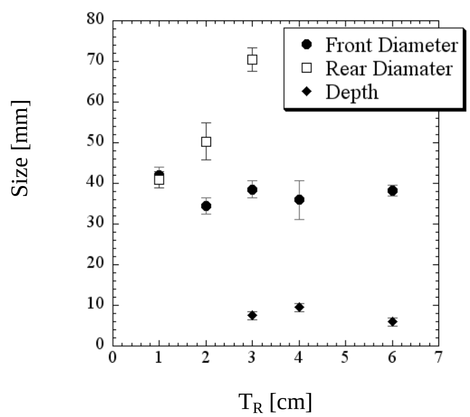


Figure 3: The (outer) diameters and depths of the craters, acquired from the images shown in Fig. 2. The targets with T_R=1 and 2 cm have a hole.