

Estimation of lava tube cave height below the vertical hole from the surface topography of the Moon

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[Introduction] The inclination($\sin \alpha$) and slope angle(α) of the near surface of the vertical hole and the rille, where the cavity of the lava tube cave is assumed to be under it, can be obtained from the LROC Quick Map⁽¹⁾ made from the data of the US LRO. Marius Hills Hole (MHH), Mare Tranquillitatis Hole (MTH), Mare Ingenii Hole (MIH)⁽²⁻⁵⁾ discovered by Haruyama et al., furthermore Lacus Mortis vertical holes^(6,7), Rille structure discovered by Chandrayaan-1⁽⁸⁾, and Sinus Iridum Pit⁽⁹⁾ were examined. For the case where the direction of flow of the lava is unknown, the direction showing the angle at which the highest inclination angle of the surrounding is adopted. The cavity height is obtained from the lava (Bingham fluid) flow limit condition $H = nfb / (\rho g \sin \alpha)$ in the tube⁽¹⁰⁻¹²⁾, where for $n = 4$, H is a tube height with circular section, for $n = 3$, H is a tube height with finite width rectangular cross section, for $n = 2$, H is a tube height with infinite width rectangular section. Here, the gravitational acceleration $g = 1.62 \text{ m / sec}^2$, the lava density $\rho = 2500 \text{ kg / m}^3$, and the yield strength values $fb = 100 \text{ Pa}$ and 200 Pa ⁽¹³⁾.

[Marius Hills Hole (MHH)] MHH has a diameter of 57 m \times 48 m, a depth of 48 m, a ceiling thickness of 31 m, and a cavity height of 17 m. The inclination angle of the rille surface in the vicinity where MHH exists is considered to be in the range of 0.28 degree to 0.69 degree and the tube height was obtained with the lava yield strength value 100 Pa to 200 Pa. For a finite width rectangular section tube, the height is 15.4 m at 100 Pa, which is close to the cavity height of 17 m of MHH.

[Mare Tranquillitatis Hole (MTH)] MTH has a diameter of 99 m \times 84 m, a depth of 107 m, a ceiling thickness of 47 m, and a cave cavity height of 60 m. The inclination angle in the highest direction near MTH was 0.62 degree. A finite width rectangular section tube height is 6.7 m to 13.5 m at 100 Pa to 200 Pa, which is smaller than the cavity height 60 m. The actual angle of the inclination of the tube may be lower.

[Mare Ingenii Hole (MIH)] MIH has a diameter of 103 m \times 66 m and a depth of 37 - 63 m. As the highest inclination angle is 0.21 degree around MIH, the finite width rectangular cross section tube height is estimated as 20 to 40 m at 100 Pa to 200 Pa. As the vertical hole depth is 37 to 63 m, so the ceiling thickness is considered to be about 20 m.

[Pit of Lacus Mortis] Lacus Mortis's pit has a diameter of 60 m \times 100 m and a depth of 114 m. The highest inclination angle around the pit is 1.2 degrees. So, the finite width rectangular cross section tube height is estimated as 3.7 m - 7.4 m at 100 Pa - 200 Pa. As the vertical hole depth is 114 m, so the ceiling thickness seems to be quite thick.

[Rille discovered by Chandrayaan - 1] The inclination angle of the undamaged portion in the central part of the rille is 0.93 degree. The height of the finite width rectangular cross section tube height is estimated as 4.6 m to 9.2 m at 100 Pa to 200 Pa. Considering that the rille depth at both ends of the undamaged portion is 8 m to 17 m, the ceiling thickness is considered to be extremely thin if there is a cavity under the undeflected ceiling of the rille.

[Pit of Sinus Iridum] Sinus Iridum Pit has a diameter of 70 m \times 30 m and a depth of 20 m. The maximum inclination angle around the Sinus Iridum Pit is 0.83 degree. The height of the finite width rectangular section tube is estimated as 5.1 m to 10.2 m at 100 Pa to 200 Pa. The ceiling thickness will be on the order of 10 to 15 meters.

[Conclusion] Table 1 shows a summary of estimates of cavity heights of possible lava tube caves under the holes or pits and rilles. Lava tube cave height was estimated from the LROC Quick Map by measuring the slope of the surface. However, due to the possible lunar crustal deformation after tube formation, there is a possibility that the used slope angle may be different from the actual slope angle of the lava tube below the surface. The estimated cavity height is only a rough estimate and it is expected to be demonstrated by further detailed examination and exploration.

References: see japanese version.

Keywords: Moon, pit, lava tube

表 1 縦孔/Rille下に想定される溶岩チューブ洞窟の空洞高さの推定値

縦孔/Rille	降伏値: fb	傾斜率: $\sin \alpha$	傾斜角度: α	円形断面チューブ高さ: $H=4fb/(\rho g \sin \alpha)$	有限幅矩形断面 チューブ高さ: $H=3fb/(\rho g \sin \alpha)$	無限幅矩形断面 チューブ高さ: $H=2fb/(\rho g \sin \alpha)$
Marius Hills Hole(MHH) 直径57mx48m,深さ48m, 天井厚さ31m, 空洞高さ17m	100Pa	0.0128	0.78°	7.7m	5.8m	3.9m
	200Pa	0.0128	0.78°	15.4m	11.6m	7.7m
	100Pa	0.0048	0.28°	20.6m	15.4m	10.3m
	200Pa	0.0048	0.28°	41.2m	30.9m	20.6m
Mare Tranquillitatis Hole (MTH) 直径99mx84m,深さ47m, 深さ107m,天井厚さ47m, 空洞高さ60m	100Pa	0.0110	0.62°	9.0m	6.7m	4.5m
	200Pa	0.0110	0.62°	18.0m	13.5m	9.0m
Mare Ingenii Hole(MIH) 直径103mx66m, 深さ37m~63m	100Pa	0.0037	0.21°	26.7m	20m	13.3m
	200Pa	0.0037	0.21°	53.4m	40m	26.7m
Lacus Mortis Pit 直径60mx100m, 深さ114m	100Pa	0.0201	1.2°	4.9m	3.7m	2.5m
	200Pa	0.0201	1.2°	9.8m	7.4m	4.9m
Rille found by Chandrayaan-I 深さ8m~17m	100Pa	0.0162	0.93°	6.1m	4.6m	3.1m
	200Pa	0.0162	0.93°	12.2m	9.2m	6.2m
Sinus Iridum Pit 直径70mx30m, 深さ20m	100Pa	0.0145	0.83°	6.8m	5.1m	3.4m
	200Pa	0.0145	0.83°	13.6m	10.2m	6.8m