Possible existence of lava tube cave under Marius Hills Hole of the Moon

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[Introduction]
The vertical pit, Marius Hills Hole (MHH), found by Haruyama has several lava layers in it' s cross-section(Robinson). From a mean thickness of lava flow layers in the cross section, the yield strength of the lava is estimated by using the critical condition of free Bingham fluid flow on the inclined surface. The lava tube cave height is then estimated by the critical condition of flow between the two plates or in the circular tube and compared with the actually observed height by Haruyama and Robinson. The possible cave width by using a simple beam model from the ceiling thickness is also estimated
[Hydrodynamic model for Bingham fluid]
The lava flow model on the inclined surface with angle α is used as shown in Fig.1, where ρ is density, g is gravity, H is lava thickness and f_B yield strength of lava as Bingham fluid.
The flow critical condition of the lava is expressed as $H=nf_B/(\rho\ g \sin\ \alpha)$. The case for n=1,lava flows on the slope surface with a free surface, the case for n=2, lava flows between infinite width parallel plates and the case for n=4, lava flows in the circular tube (Hulme). Then,n will be between 2 and 4 for a flow in a rectangular cross sectional tube. We assumed that lava tube cave in the moon is formed as a drained flow in the circular tube or in between the parallel plates and compared with actual observation.
[Estimation of the lava yield strength and the lava tube cave height]
The depth of the MHH is 48m (Haruyama) and the cave height under MHH is 17m (Robinson), therefore the thickness of the ceiling is 31m as shown in Fig.2. The 31m thick ceiling of MHH is composed by 4 m-12 m of stratified lava layer with an average of 6 m thickness (Robinson). This average thickness H=6m is used here for the lava flow critical condition in the case of n=1 in the Rille- A. The slope angle of 0.31 deg (Greeley) , gravity g=162 cm/s^2 and density ρ=2.5g/cm^3, give an estimated value of 1314 $dyne/cm^2$. Consequently for n=4,H is 24m, for n=2,H is12m. As the actual cave height is 17m, so n will be between 2 and 4 with a flow in the rectangular cross-sectional tube.
[Estimation of the lava tube cave width]
It's possible to presume the cave width sustained without the ceiling's falling down for the ceiling thickness 31m by using a simple beam model with ℓ : cave width, S: tensile strength of lava, S=6.9×10^7 $dyne/cm^2$ (Oberbeck) and the d: ceiling thickness, For a concentrated load model (Oberbeck) , $\ell = ((4/3)\ Sd/\ \rho,\ g)^{1/2}$ =313m. For a distributed load model (Honda), $\ell = (2Sd/\ \rho g)^{1/2}$= 327m. If the ceiling has an arch shape, the load becomes even compressive, so the cave probably becomes wider. The flow critical condition of the lava flow in the rectangular cross section tube of hollow height 17m and width 327m will be between n=2 and n=4.
[Conclusions]
The estimated value of the lava tube cave height from this consideration is in accordance with the actual measurement. It seems that a lava tube cave of rectangular cross section with height of 17m and width of 327m exists under MHH with high possibility. The hollow detection in the MHH neighborhood by gravity measurement by Sood also suggests the existence of lava tube cave. More in-depth study and future exploration are highly expected.
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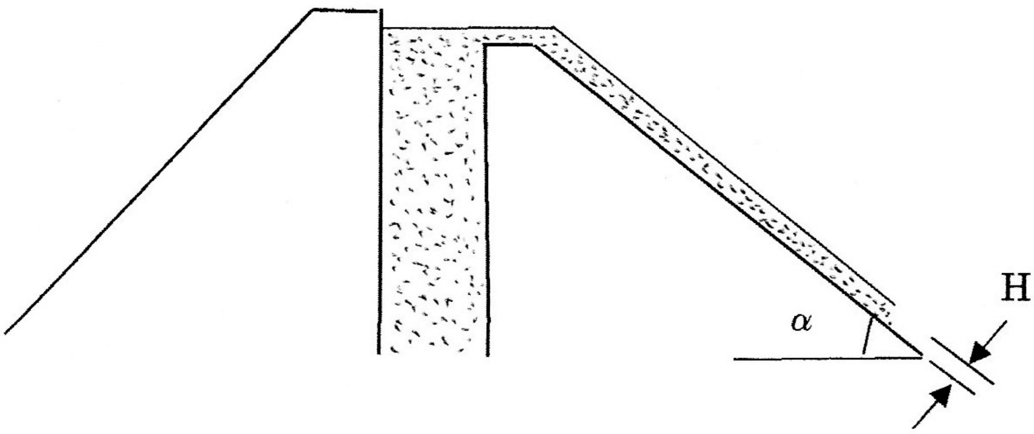

Fig.1 Critical thickness of the lava flow: $H=nf_B/(\rho g \sin\alpha)$
n=1:Free surface flow, n=2:Flow between parallel plates,
n=4:Flow in circular tube

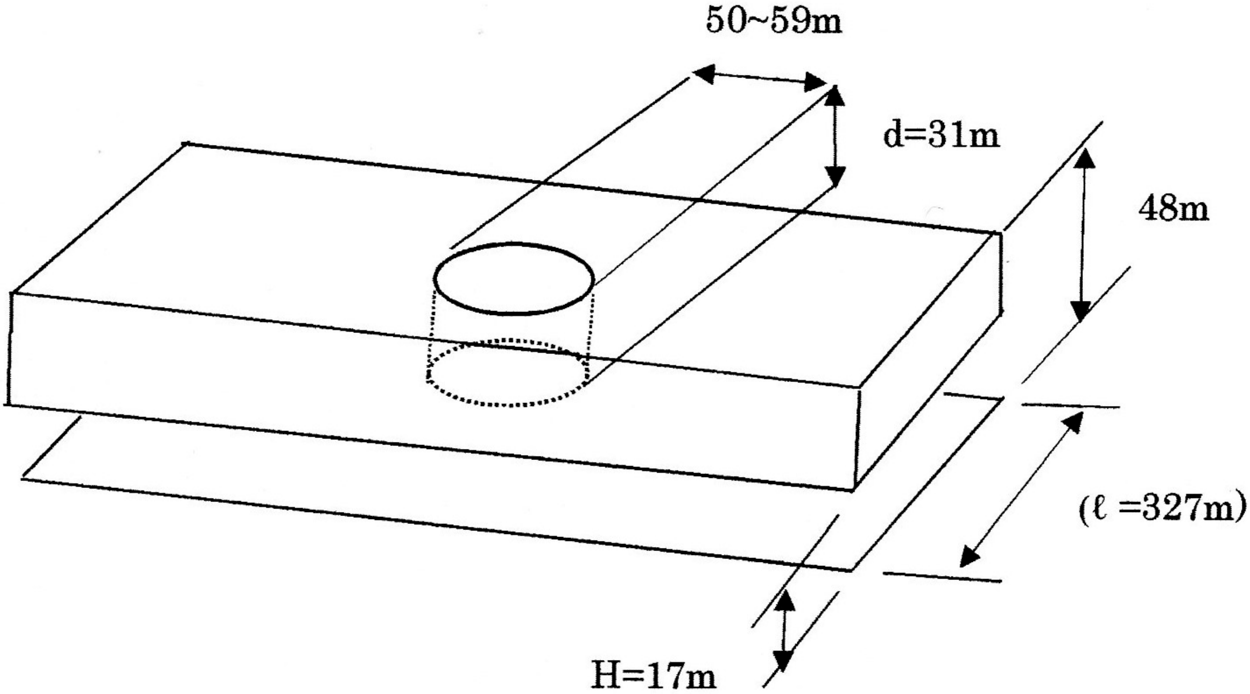

Fig.2 Schematic configuration of Marius Hills Hole