# Study of the lava flow under the Marius Hills Hole on the Moon by analogy on the Earth

*Tsutomu Honda[1]

1. Vulcano-speleological Society

**1.Introduction:**The purpose of this study is to estimate the scenario and temperature at the lava tube formation assumed in the lava flow in the lava river (Rilles-A) in the Marius Hills on the Moon by comparing the lava flows related to lava tube formation on the Earth. In Newtonian fluids, the flow changes from laminar to turbulent flow when the Reynolds number(Re) exceeds about 2000, whether it is a flow in a circular pipe or an inclined surface gravity flow [1)]. Though,lava flow is considered to be a Bingham fluid. Bingham number(B) and Hedstrom number(He) indicate the degree of Bingham properties, and it is known that the transition Reynolds number from laminar to turbulent flow increases as He increases [1,2)]. Here, by focusing on Re, B, and He of lava flow, the scenario of lava tube[3)] formation assumed in the Rilles-A were estimated.
**2.Examination of the earth's lava flow:**Tables 1 (a), (b) and (c) show the in-situ measured values such as temperature, lava thickness, viscosity coefficient, yield strength, etc. are shown for Miharayama 1951 lava flow ($SiO_2$: 52-53 wt%) [4)], Mauna Loa 1984 lava flow ($SiO_2$: 52 wt%) [5)], Tolbatik 2013 lava flow ($SiO_2$: 52wt%) [6)] Each flow shows a low Reynolds number. In the Mauna Loa example, temperature and fluid properties including yield strength and estimated B, He are shown over long distances. As the temperature decreases along the flow, the fluid property value increases significantly. These flows are all in the laminar region from the outlet to the downstream by creating the lava tubes. The lava tube on the earth is formed in a laminar region.
**3. Examination of lava flow in the lava river Rilles-A of Marius Hills on the Moon:**To know B, He, and Re of the Rilles-A lava flow of Marius Hill, the lava flow thickness, viscosity coefficient, yield strength, gravity acceleration, lava density, lava flow velocity, and slope angle are required. The lava flow thickness is assumed as 17m which is tube height below Marius Hills Hole in the Rilles-A. The yield strength 131Pa[7)] was used as fixed value. Viscosity coefficient was assumed in the range from 5 Pa.s to 16000 Pa.s. The flow velocity was calculated by the formula [8)] of free surface gravity flow and parallel plate gravity flow with an inclination angle of 0.31 °as laminar flow. Tables 1 (d) and 1 (e) show B, Re, and He based on the obtained flow velocity. The free surface gravity flow is in the transition region with a viscosity coefficient of 100 Pa.s, and shows laminar flow at 3000 Pa.s, The parallel plate gravity flow shows laminar flow at 100 Pa.s. The temperature dependent viscosity coefficient of lunar lava is summarized in Chevrel et al (2014) [9)] for lava of various chemical compositions. Although the chemical composition of Marius Hill is unknown, 100Pa.s to 3000Pa.s for high-titanium lava (sample 15555) shown in Fig. 3 of Cukierman et al (1973) [10)] corresponds to lava temperature 1050-1000℃ as shown in Table 1 (d) (e). For a lava with a low titanium content (sample 68502), 100Pa.s to 3000Pa.s may correspond to a higher lava temperature of 1200-1100°C. Since the lava tube is thought not to be formed by the turbulent mixing effect avoiding the tube ceiling formation, a scenario where the laminar lava flow forms a lava tube seems to be reasonable
**4. Summary:**A possible scenario of lava tube formation in the Rilles-A is assumed as follows;(1) the lava is in a turbulent state in the vicinity of the eruption point when the lava is hot (low viscosity coefficient, low yield strength), (2) the temperature decreases along the flow direction (viscosity coefficient and yield value increase), and the transition from turbulent to laminar flow occurs together with formation of lava tube. The estimated lava tube formation temperature may be around 1000-1200℃ depending on the lava chemical composition. Future study needs accumulation and examination of data base with synthetic sample experiment for viscosity coefficient,yield strength based on the chemical composition of lunar lava

as a function of temperature(Ishibashi[11])measured both for Fuji1707 lava).

**References:see abstract of Japanese version**

Keywords: lava tube, viscosity, yield strength, lava flow, lunar pit

表１．地球上の玄武岩溶岩流と月・マリウス丘のリルAの溶岩流の傾斜表面重力流の比較検討

| (a)三原山1951年溶岩流測定の位置[4] | 溶岩温度[4] | 流速[4] | 溶岩深さ[4] | 降伏値 | 粘性係数[4] | 密度 | 傾斜角度[4] | ビンガム数:B | レイノルズ数:Re | ヘドストロム数:He |
|---|---|---|---|---|---|---|---|---|---|---|
| I | 1125℃ | 1.02±0.08 m/sec | 0.31 m | - | 560 Pa.s | (2500 $Kg/m^3$) | 35° | - | 1.41 | - |
| II | 1108℃ | 0.35±0.04 m/sec | 0.5 m | - | 1800 Pa.s | (2500 $Kg/m^3$) | 27° | - | 0.24 | - |
| III | 1083℃ | 0.15±0.03 m/sec | 0.77 m | - | 7100 Pa.s | (2500 $Kg/m^3$) | 16° | - | 0.04 | - |
| VI | 1038℃ | 0.08±0.02 m/sec | 1.3 m | - | 23000 Pa.s | (2500 $Kg/m^3$) | 11° | - | 0.01 | - |

| (b)マウナウル1987年溶岩流測定の位置[5] | 参考溶岩温度[5] | 流速[5] | 溶岩深さ[5] | 降伏値[5] | 粘性係数[5] | 密度[5] | 傾斜角度[5] | ビンガム数:B | レイノルズ数:Re | ヘドストロム数:He |
|---|---|---|---|---|---|---|---|---|---|---|
| 火口から3km | 1140±3℃(火口) | 5.3 m/sec | 4 m | 150 Pa | 1134 Pa.s | 1000 $Kg/m^3$ | 5.6° | 0.099 | 18.7 | 1.86 |
| 火口から8km上段 | 1135±5℃(火口から10km) | 1.6 m/sec | 5 m | 970 Pa | 3014 Pa.s | 1700 $Kg/m^3$ | 3.75° | 1.005 | 4.5 | 4.54 |
| 火口から8km下段 | 1135±5℃(火口から10km) | 1 m/sec | 6 m | 891 Pa | 2885 Pa.s | 1700 $Kg/m^3$ | 2° | 1.853 | 3.5 | 6.55 |
| 火口から15km | 1086-1126℃(火口から12km以上) | 0.34 m/sec | 9.3 m | 3200 Pa | 81110 Pa.s | 2400 $Kg/m^3$ | 3.3° | 1.079 | 0.09 | 0.10 |

| (c)トルバチク2013年溶岩流測定の位置[6] | 溶岩温度[6] | 流速[6] | 溶岩深さ[6] | 降伏値 | 粘性係数[6] | 密度[6] | 傾斜角度[6] | ビンガム数:B | レイノルズ数:Re | ヘドストロム数:He |
|---|---|---|---|---|---|---|---|---|---|---|
| 火口から2.4km | 1069℃～1082℃ | 0.008 m/sec | 3.5 m | - | 1800000 Pa.s | 2500 $Kg/m^3$ | 8° | - | $3.89 \times 10^{-4}$ | - |

| (d)月マリウス丘溶岩流(表面流れ)の位置 | 推定溶岩温度(試料15555から推定) | 推定流速(層流として計算) | 溶岩深さ[7] | 設定降伏値[7] | 推定粘性係数 | 密度 | 傾斜角度[7] | ビンガム数:B | レイノルズ数:Re | ヘドストロム数:He |
|---|---|---|---|---|---|---|---|---|---|---|
| 縦孔下 | 不明(900℃) | 0.08 m/sec | 17m | 131 Pa | 16000 Pa.s | 2500 $Kg/m^3$ | 0.31° | 1.68 | 0.22 | 0.37 |
| 縦孔下 | 不明(1000℃) | 0.44 m/sec | 17m | 131 Pa | 3000 Pa.s | 2500 $Kg/m^3$ | 0.31° | 1.68 | 6.26 | 10.5 |
| 縦孔下 | 不明(1050℃) | 13.3 m/sec | 17m | 131 Pa | 100 Pa.s | 2500 $Kg/m^3$ | 0.31° | 1.68 | 5634 | 9464 |
| 縦孔下 | 不明(1100℃) | 44.2 m/sec | 17m | 131 Pa | 30 Pa.s | 2500 $Kg/m^3$ | 0.31° | 1.68 | $6.3 \times 10^4$ | $1.05 \times 10^5$ |
| 縦孔下 | 不明(1200℃) | 265 m/sec | 17m | 131 Pa | 5 Pa.s | 2500 $Kg/m^3$ | 0.31° | 1.68 | $2.3 \times 10^6$ | $3.79 \times 10^6$ |

| (e)月マリウス丘溶岩流(並行平板間)の位置 | 推定溶岩温度(試料15555から推定) | 推定流速(層流として計算) | 溶岩深さ[7] | 設定降伏値[7] | 推定粘性係数 | 密度 | 傾斜角度[7] | ビンガム数:B | レイノルズ数:Re | ヘドストロム数:He |
|---|---|---|---|---|---|---|---|---|---|---|
| 縦孔下 | 不明(900℃) | 0.02 m/sec | 17m | 131 Pa | 16000 Pa.s | 2500 $Kg/m^3$ | 0.31° | 6.72 | 0.06 | 0.37 |
| 縦孔下 | 不明(1000℃) | 0.11 m/sec | 17m | 131 Pa | 3000 Pa.s | 2500 $Kg/m^3$ | 0.31° | 6.72 | 1.56 | 10.5 |
| 縦孔下 | 不明(1050℃) | 3.31 m/sec | 17m | 131 Pa | 100 Pa.s | 2500 $Kg/m^3$ | 0.31° | 6.72 | 1408 | 9464 |
| 縦孔下 | 不明(1100℃) | 11.1 m/sec | 17m | 131 Pa | 30 Pa.s | 2500 $Kg/m^3$ | 0.31° | 6.72 | $1.56 \times 10^4$ | $1.05 \times 10^5$ |
| 縦孔下 | 不明(1200℃) | 66.3 m/sec | 17m | 131 Pa | 5 Pa.s | 2500 $Kg/m^3$ | 0.31° | 6.72 | $5.6 \times 10^5$ | $3.79 \times 10^6$ |