Identification of lava flow temperature by lava tube cave structure of Mt.Etna

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[Introduction]

Like Mt.Fuji, there are many lava tube caves formed in the past on Mt.Etna. An attempt was made to identify the lava flow temperature during the formation of a lava tube by using the yield strength obtained from the height of the lava tube cave at Mt.Etna. The viscosity coefficient of the lava flow was also estimated from the identified temperature.

[Lava yield strength obtained from lava tube cave]

Table 1 shows a list of major lava tube caves at Mt.Etna[1)] along with their length, cavity height, and slope angle. Considering the tube cave as the drain of lava from the inside of the tube, the yield strength can be obtained from the flow limit condition [2)] in the inclined tube:

$f_B = H(\rho g \sin\alpha) / 4$ ·····(eq-1)

where f_B is the yield value, H is the cavity height, ρ is the lava density, g is the gravitational acceleration, and α is the slope angle. The yield strength of the cave obtained from (eq-1) is shown in the rightmost column of Table 1. The yield strength is in the range of $1.6x10^4$~$1.1x10^5$ dyne/cm^2($1.6x10^3$~$1.1x10^4$Pa).

[Temperature change of yield value and viscosity of Etna volcano]

Mt.Etna is the only example where temperature-dependent curves of yield strength and viscous coefficient have been obtained by actual measurement of lava flow[3,4,5)]. The fitting equation from that data can be obtained as follows,

$\log_{10} f_B = 35.1836-0.0289\theta$, ·····(eq-2)

θ is the temperature in degrees Celsius and the yield strength f_B is dyne / cm^2

$\log_{10}\eta_B = 24.0469-0.0175\theta$, ·····(eq-3)

θ is the temperature in degrees Celsius and the viscosity coefficient η_B is poise

The lava tube cave formation temperature is in the range of 1044℃~1073℃ judging from the yield strength-temperature curve (eq-2) according to the yield strength $1.6x10^4$~$1.1x10^5$ dyne/cm^2($1.6x10^3$~$1.1x10^4$Pa)obtained from the cave. According to the viscosity coefficient -temperature curve (eq-3), the lava viscosity coefficient with respect to the temperature is in the range of $1.9x10^5$~$6.2x10^5$ poise($1.9x10^4$~$6.2x10^4$ Pa.s). It should be noted that the temperature of 1056~1067℃ obtained from the yield strength of $2.4x10^3$~$4.8x10^3$Pa and the viscosity coefficient of $2.6x10^4$~$4.0x10^4$Pa.s obtained for the Cutrona cave formed in the 1991-1993 lava flow, are close to the measured temperature 1020 ~ 1080 ℃ and the viscosity coefficient $0.8x10^4$~$1.9x10^4$Pa.s, which were measured in the lava flow at an altitude of 2000m at Serra Pirciata by Calvari et al [6)]

[Conclusion]

It is possible to identify the lava temperature at the time of lava tube cave formation by obtaining the yield strength from the cave by obtaining the temperature change dependence curve of the lava yield value in advance. Moreover, the viscosity coefficient can be obtained from the temperature dependence curve of the lava viscosity coefficient by the temperature. Therefore, it is considered that this method can be used to identify the temperature and viscosity coefficient of lava flow during the formation of a lava tube cave whose temperature has not been measured in the past.

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表１ エトナ火山の溶岩チューブ洞窟に関する形状データと得られた降伏値, 温度, 粘性係数
（形状データは文献 1)の測量図よりチューブ形状部分から読み取っている）

洞窟名 Name of lava tube cave	長さ Cave length	高低差 Cave elevation range	傾斜度 Slope angle α	空洞高さ Cave height H	流動限界条件(eq-1)から得られる降伏値 Yield strength f_B	回帰式(eq-2)からの温度 Temperature	回帰式(eq-3)からの粘性係数 Viscosity η_B
Cutrona Cave (1991~1993 lava flow)	404m	60m	8.5°	2m~4m	$2.4x10^4$ ~$4.8x10^4$dyne/cm^2 ($2.4x10^3$ ~$4.8x10^3$Pa)	1056~1067°C	$2.6x10^5$~$4.0x10^5$poise ($2.6x10^4$~$4.0x10^4$ Pa.s)
La Fenice Cave (1792-1793 lava flow)	80m	15m	10.8°	1m~3m	$1.5x10^4$~$4.5x10^4$ dyne/cm^2 ($1.5x10^3$~$4.5x10^3$Pa)	1057~1073°C	1.9 $x10^5$~$3.8x10^5$poise (1.9 $x10^4$~$3.8x10^4$Pa.s)
Serracozzo Cave (1971 lava flow)	280m	60m	12.4°	3m~6m	$5.3x10^4$~$1.1x10^5$dyne/cm^2 ($5.3x10^3$~$1.1x10^4$Pa)	1044~1054°C	$4.3x10^5$~$6.2x10^5$poise ($4.3x10^4$~$6.2x10^4$Pa.s)
Tre Livelli Cave (1792-1793 lava flow)	1000m	260m	15.1°	~5m	$1.1x10^5$dyne/cm^2 ($1.1x10^4$Pa)	1045°C	$6.2x10^5$poise ($6.2x10^4$Pa.s)
KTM Cave (1792-1793 lava flow)	533m	94m	10.2°	~5m	$7.2x10^4$dyne/cm^2 ($7.2x10^3$Pa)	1051°C	$5.0x10^5$poise ($5.0x10^4$Pa.s)
Cassone Cave (1792-1793 lava flow)	246m	25m	5.9°	~6m	$5.0x10^4$dyne/cm^2 ($5.0x10^3$Pa)	1055°C	$4.1x10^5$poise ($4.1x10^4$ Pa.s)
Intraleo Cave (uncertain dating)	80m	4m	2.9°	~5m	$1.6x10^4$dyne/cm^2 ($1.6x10^3$Pa)	1073°C	$1.9x10^5$poise ($1.9x10^4$ Pa.s)
Abisso di Monte Nero Cave(1923 lava flow)	612m	38m	3.6°	~10m	$3.8x10^4$dyne/cm^2 ($3.8x10^3$Pa)	1059°C	$3.5x10^5$poise ($3.5x10^4$Pa.s)

