A RHEOLOGICAL, MATHEMATICAL AND STATISTICAL COMPARISON OF LUNAR RILLES AND TERRESTRIAL LAVA TUBES. Sonit Sisolekar[1], Raymond Duraiswami[1], Aristle Monterio[1] . [1]Department of Geology, Savitribai Phule Pune University, Pune - 411007 India

Introduction: The rheological characteristics of lunar lava flows are yet to be fully understood. Mathematical analysis of lunar rilles (LRs) can be helpful in deriving these. This study compared the dimensions and other rheological parameters of lunar and terrestrial lava tubes. There were some successful attempts at finding the reason behind the huge dimensions of lunar rilles, and the existence of lava channels/tubes as rilles. It was concluded that the eruption temperatures of lunar lavas were relatively very high, allowing them to flow for longer distances; the low atmospheric pressure and gravity led to more inflation, and thus to deeper and wider flows.

Data and Methods: In this study, the data from Hurwitz et. al. [1] was used to study the lunar rilles; while the ASU (Arizona State University) worldwide lava-tube database revealed the dimensions of terrestrial lava-tubes. The dimensions and floor-slope were used to find out various parameters like viscosity, effusion rate, etc. using various equations [2], [3], [4], [5], [6] and [7]. The results are given in Table 1.

Results and Discussion:

1] It was observed that the length, width and depth of lunar rilles is very high as compared to the lava-tubes on Earth. The length of lunar rilles, for instance, was 85-88 times more than terrestrial ones. This may indicate 2 things - a) The lunar lavas were hotter than terrestrial lavas; and b) The total mass of lava erupted was much more than on the Earth. To check this, the SiO2 and MgO contents were compared. It is known that higher the SiO2 content and lower the MgO content, the lower is the temperature of the lava. It was found that average SiO2 was lower (45.4 wt%) and average MgO higher (9.24 wt%) on the Moon [8] [9]. This implies that lunar lava was hotter and took a longer time to cool, thus leading to the formation of longer lava flows.

2] It was evident through calculations that the basal stress in case of lunar rilles is 50% more than that of terrestrial lava-tubes. This leads to 2 inferences: a) the basal stress is higher because the flow depth is higher on the Moon; and b) lunar lava-tubes have more erosive power: their huge basal stress indicates high substrate erosion, and loss of energy in displacing substrate debris. Thus, the lava flows/channels form rilles later on.

3] Average total lava mass of the lunar rilles is observed to be 4764 times that of terrestrial ones. This is the parameter which differs the most between the lunar rilles and the terrestrial lava-tubes.

4] Average aspect ratio (AR) of the lunar rilles is observed to be 4.2 times that of terrestrial ones. This implies that inflation happens more vigorously in case of lunar lava flows. Since atmospheric pressure and gravity is less on the Moon, the lava flows are relatively free to inflate to a larger extent. Thus, it can be inferred from the above explanations that AR is a function of both atmospheric pressure and gravity. This also explains why vesicularity is significantly negligible in lunar basalt as observed in the samples from Apollo missions. Due to less atmospheric pressure at the time of eruption, the degassing of volatiles took place immediately and lost to the dissipating lunar atmosphere.

5] Average yield strength of the lunar rilles is observed to be half that of terrestrial ones. This means that the lunar lavas were less viscous compared to the terrestrial lavas. This reconfirms that the lunar lavas were hotter at the time of eruption, thereby having lesser yield strength. In addition, the low stress may signify that they are less vesicular, since it is often associated with high viscosity and/or yield strength.

6] The viscosity was calculated to check the validity of the above argument and was found to be 460 times less on the Moon, indicating the argument to be valid. This could suggest that the lunar magmas didn't experience heat loss and assimilation of the wall rock in the magmatic plumbing system or while ascending the crust. One possible explanation could be due to the fact that the Moon's crust is definitely very thin when compared to that of the Earth.

7] When 'total lava-tube mass'(mlt) is plotted against 'erupted mass'(me), the trend-slope is found to be higher in the graph for the LRs (Figure 1). in comparison to lava tubes on Earth (Figure 2). This implies that, compared to the Earth, the lunar rilles consist of a huge portion of the total erupted mass of lava. In other words, the LRs are more efficiently formed than terrestrial lava-tubes.

References: [1] Hurwitz et al. (2013) Planet. Space Sci., 79–80, 1-38. [2] Moore (1987) USGS Prof Paper 1350:1569-1588. [3] Cattermole (1996) J Wiley & Sons, London. [4] Sparks et al. (1976) Geology 4: 269-271. [5] Hulme (1974) Geophys. J R Astr Soc 39: 361-383. [6] Pinkerton and Wilson (1994) Bull Volcanol 56: 108-120. [7] Chester e al. (1985) Chapman and hall, London 187-227. [8] Taylor and Stuart (1975)

Pergamon Press, New York. [9] Philpotts and Ague (2009) Cambridge University Press.

Table 1. Basic statistics of various parameters of lunar LRs and terrestrial lava-tubes, and their comparison.

PARAMETRES		Dimensions			Slope	de (equivalent (	Time	Velocity
unit		length	width	depth	deg	m^2	hours	m/s
EARTH(E)	AVERAGE	777.31	9.88	4.67	9.44	2.36	364.23	0.08
	Maximum	65500	200	20	30	4	833.33	5.24
	Minimum	3	0.91	0.6	0.3	0.63	20.67	0.00006
	Standard Deviation	3053.24	41.98	12.18	78.6	1.16	301.68	0.22
MOON(M)	AVERAGE	66758.43	628.69	70.54	0.35	3.34	59899831.95	0.0000198
	Maximum	565680	4270	534.36	1.4	3.85	78987496.71	0.00073
	Minimum	2130	160	4.22	0.01	2.57	35278567.5	0.00000078
	Standard Deviation	86442.88	573.73	78.71	0.33	0.26	9230918.53	0.000026
Average (moon) / Average (earth) [AE/AM ratio]		85.88	63.65	15.12	0.04	1.41	2740.93	0.00024

		Mass Flux	Basal Stress	Lava-Tube Mass	Aspect Ratio	Yeild Strength	Viscosity	Wb (levee width)	E (Effusion rate)	m_e
		kg/s	kg/m/s	kg	dimensionless ra	N/m^2	kg/m/s	m	m	Celcius
EARTH(E)	AVERAGE	115477.36	10142.81	3509916287	2.12	88381.5	1.57257E+24	10.53144498	30.24219712	483577644.7
	Maximum	12140352	74823.21	421540000000	10	956052.72	4.36974E+25	82.7533439	739.1112911	11456225012
	Minimum	4.46	695.23	35181.73	1.52	1327.85	2.43709E+15	0.6750832833	0.03758263382	962959.1176
	Standard Deviation	3130636.19	12060.88	108763574838	3.45	78681.18	8.80175E+23	11.83264683	15.91410138	249444998.1
MOON(M)	AVERAGE	5519.96	15268.34	16721706764931	12.69	41512.28	3.4228E+21	16.15454884	2.032568243	1799050858679
	Maximum	13795.21	17121.99	1.11857E+15	50.77	343504.8	0.01884927684	248.8406598	124.7833847	1.14028E+15
	Minimum	9.77	73.16	44697049920	3.6	418.4	46065680.88	0.07665000117	0.003524044167	44833339641
	Standard Deviation	25406.36	30978.59	80380705745556	7.46	57887.96	3.45529E+22	32.58471913	9.301740871	8396265309795
Average (moon) / Average (earth) [AE/AM ratio]		0.048	1.51	4764.13	5.99	0.51	0.0022	1.53	0.07	37202.94

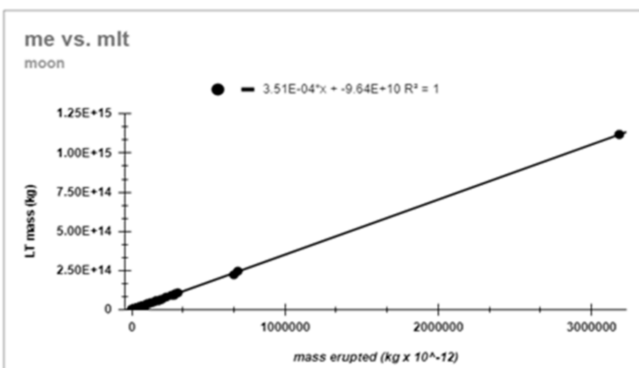

Figure 1. Lava-tube mass [LT mass] against erupted mass, for lunar rilles (n=190 rilles). The relation is found to be:

$m_{lt} = 0.000351\, m_e - (9.64 \times 10^{10})$

$R^2 = 1$

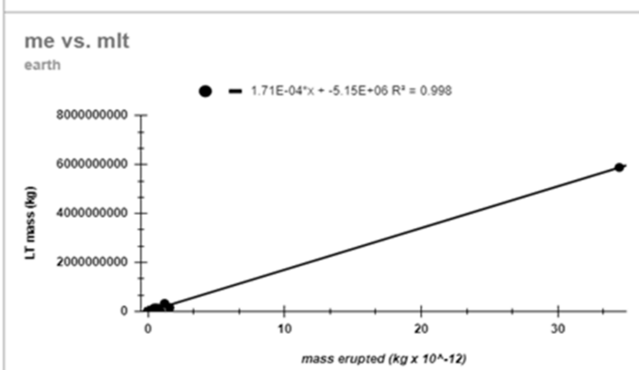

Figure 2. Lava-tube mass [LT mass] against erupted mass, for terrestrial lava-tubes (n=30 lava-tubes). The relation is found to be:

$m_{lt} = 0.000171\, m_e - 5150000$

$R^2 = 0.998 = (\sim 1)$