

THE FORMING PROCESSES OF THARSIS MONTES, MARS. J. Y. Moon¹, C. B. Lee² and S. J. Park³,
¹Department of Geography, College of Social Sciences, Seoul National University, Daehak-dong, Gwangak-gu, Seoul, Republic of Korea. mjy1102@naver.com, ²chaboklee@hotmail.com, ³catena@snu.ac.kr.

Introduction: More than 60% of martian surface is covered with volcanic materials and their distribution and morphologies are various [1]. Tharsis Montes which are centered on Tharsis region are Arsia Mons, Pavonis Mons and Ascraeus Mons aligned from southwest to northeast (Figure 1). They have attracted scientists with similar morphology, common evolutionary history [2], [3] and latest record of volcanic activity [4]. Most interestingly, there are contrasting results about their age. Early studies indicated decreasing surface ages towards the northeast [2], [5], [6], whereas recent studies indicated decreasing ages towards the southwest [4], [7], [8]. These forming order can present surface age directly, however, forming processes can not be understood without distinctive forming events which leave topographical features [9]. Nevertheless, there are still lack of comprehensive analyses. Thus we tried to consider morphology and chronology together for understanding forming processes of Tharsis Montes.

Research purpose: This study aims to synthesize the result of morphological and chronological analysis for estimating general forming processes of Tharsis Montes. First, we set hypotheses that there have been different eruption events and the characteristics of erupted materials are also different. For verifying those hypotheses, morphological analyses were used. Finally, the results of analyses were considered with surface age of volcanoes to estimate forming processes.

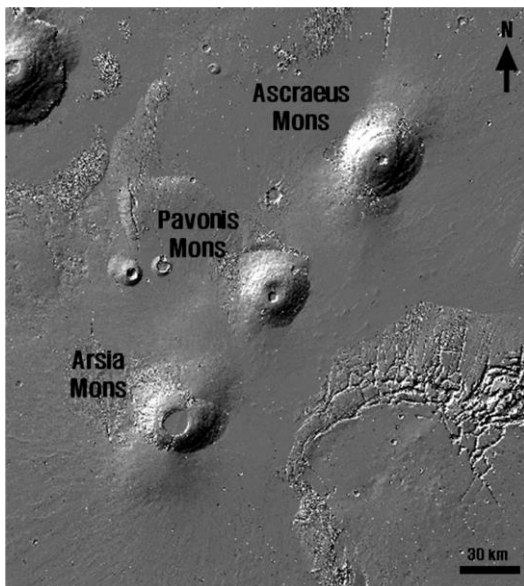


Figure 1. MOLA DEM shaded relief map of Tharsis Montes.

Methods: The hypotheses are related with eruption style and properties of erupted materials. Eruption style is represented in the overall shape of morphology of volcanic body and crater. Erupted materials have various characteristics, however, it is possible to find out the difference of viscosity and type of lava by morphology, roughness analysis and rheological analysis of lava flow. Thus we applied four methodologies to verify the hypotheses. MOLA DEM and THEMIS images were used for analyses.

Morphometry of volcanic edifice. It is the way to understand the morphology of volcanoes numerically. We set the boundary of volcanic edifice [10] and organized properties [11], [12], [13].

Caldera formation. It is common way to figure out the formation of caldera using DEM and high resolution images [2], [14]. We used MOLA DEM to find out the width, depth and area of caldera and THEMIS images adjunctively.

Roughness of volcanic flank. We calculated RMS (Root-mean-square) height and RMS slope [13], [15]. The result of roughness, however, is limited to understand the general terrain roughness and the difference of viscosity, because MOLA DEM has not enough resolution to distinguish the type of erupted materials.

Rheology of lava flow. Lava flow makes distinctive topographies and those traces give us information of the type and viscosity of lava [16], [17]. To figure out morphology of lava flows, we chose 6 lava flows (2 lava flows for each volcano). With the morphological properties of lava flows, we obtained yield strength, effusion rate and viscosity of lava flows.

Results: There are four results and they are summarized in Table 1. Each result was examined to specify the hypotheses in Discussion.

Morphometry of volcanic edifice. Ascraeus Mons is the tallest volcano within Tharsis Montes with the elevation of 18.2km and volcano height of 13.4km. Furthermore, it is also steepest with the flank slope of 5.62° and largest with the volume of 9.4×10^{11} . On the contrary, Pavonis Mons is the smallest volcano, and its slope is most gentle. Arsia Mons is the middle at the size and steepness. Relative size of crater is largest at Arsia Mons with the ratio of 0.34. Those results show that Tharsis Montes are shield volcanoes. However, the viscosity of erupted materials is different because of the difference in slope [18]. Indeed, their eruption style is also varied following the size of craters.

Caldera formation. Arsia Mons has single caldera which is largest but most shallow. Pavonis Mons has large and small calderas, and Ascraeus Mons has 5 overlapped calderas. Common feature among the calderas is that the youngest one is deepest and at the center. With the formation of caldera, it is able to understand the formation of magma chamber as well as the eruption style.

Roughness of volcanic flank. Surface of volcano is roughest at Ascraeus Mons with RMS height of 4.3km and RMS slope of 5.39° . Pavonis Mons has smoothest surface with RMS height of 2.5km and slope of 3.75° . Arsia Mons is the middle of them with RMS height of 3.1km and slope of 4.97° . Result of roughness also indicates there is difference in viscosity.

Rheology of lava flow. Yield strength of Arsia Mons is the highest with 6.1×10^3 Pa. Pavonis Mons has smallest yield strength with 8.1×10^2 Pa and Ascraeus Mons shows 2.8×10^3 Pa. Pavonis Mons, however, has highest effusion rate. Most viscous lava flow is Arsia Mons with 2.5×10^7 , and the lava flow of Pavonis Mons has smallest viscosity with 4.8×10^5 . Those results mean the viscosity of lava flow is different, and make us identify the type of lava from the range of yield strength.

Discussion: Our hypotheses were already verified from the results. However, it is need to specify the hypotheses, so that we suggest more elaborated hypotheses.

It is assumed that viscosity of erupted materials is highest at Ascraeus Mons and lowest at Pavonis Mons according to the morphometry and roughness analysis. Because viscosity is one of the most effective factor on the slope of volcano [18]. Or it could be formed steep and huge volcanic body by continuous eruption. Shape of caldera shows the characteristics of magma chamber, thus magma chamber of Arsia Mons is presumed to be most wide and shallow and that of Pavonis Mons is deepest. However, if they have magma chamber individually, shade of caldera rather implicates the eruption style. According to this, there was more explosive eruption at Arsia Mons than other volcanoes. Erupted lavas of Tharsis Montes are suggested to be basalt in accordance with the result of yield strength, whereas presumed to be dacite by viscosity. Unfortunately, the result of viscosity from analysis of lava flow rheology was not matched with the result of morphometry and roughness analysis. This is interpreted as that lava flows which were chosen are located not in the boundary of volcanic edifices, but outside of them.

Conclusion: We tried to estimate general forming processes of Tharsis Montes by synthesizing the result of morphology and chronology. Finally, we suggest two scenarios by matching hypotheses with 2 chronology

results. First, if Tharsis Montes have been developed from south to north, viscosity should be decreasing during the formation of Pavonis Mons, and then increasing during the eruption of Ascraeus Mons. Or Ascraeus Mons could be grown by continuous eruption. Intensity of explosive eruption has been decreasing gradually, and resurfacing of caldera floor has been also decreasing. On the other hand, if Tharsis Montes have been formed from north to south, viscosity should be decreasing during the formation of Pavonis Mons, then increasing during the eruption of Arsia Mons. Or Arsia Mons also could be developed by continuous eruption. However, the intensity of explosive eruption has been increasing with the activity of resurfacing conversely. Unfortunately, highest viscosity of lava at Arsia Mons is difficult to interpret on both scenarios.

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Table 1. Major results of analyses of Tharsis Montes

Parameters	Arsia	Pavonis	Ascraeus
Height(km)	9.0	7.7	13.4
Slope($^\circ$)	4.98	4.02	5.62
Volume(km ³)	8.0×10^{11}	5.0×10^{11}	9.4×10^{11}
Basal area(km ²)	10.6×10^7	8.3×10^7	10.8×10^7
No. of calderas	1	2	5
Caldera width(km)	126	87	55
Caldera depth(km)	1.7	4.9	3.9
RMS height(km)	3.1	2.5	4.3
RMS slope($^\circ$)	4.97	3.75	5.39
Lava viscosity	2.5×10^7	4.8×10^5	3.3×10^6