

**RHEOLOGICAL PROPERTIES OF EMPLACED LOBATE LAVA FLOWS ON SYRIA PLANUM, MARS.**  
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**Introduction:** Mars exhibits an immense variety of volcanic landforms. The four most prominent shield volcanoes, Ascraeus, Pavonis, Arsia and Olympus Mons, are located on the Tharsis province. Large volcanic edifices also occur in Elysium region, about 4.500 Km west of Olympus Montes, although with significant contrasts in structure, composition and eruptive style from those of the Tharsis province. The extensive lava flows associated with both the Tharsis and Elysium shields suggested that numerous smaller volcanic landforms of various types should also exist [1], [2].

Our study is focused on the Syria Planum region (Figure 1), a region where no specific volcanic style was observed from the Viking imagery. The High Resolution Stereoscopic Camera (HRSC) of the MEx (Mars Express) mission allows us to identify and characterize them at a high resolution (up to 10m/pix) and large coverage ideal for volcanic systems. Our study identifies, describes and characterizes the volcanic lava flows of this region. Concretely, the properties of the lava flows emplaced on Syria Planum, and their relation with the surrounded volcanic structures [3] requires to be studied in detail to understand its relationships with Tharsis bulge complex history.

**Data:** We used high resolution images from the HRSC instrument, orbits 2021, 2032 and 2055, with 15 m/pixel resolution, and overlaid on altimetry MOLA (Mars Orbital Laser Altimeter – Mars Global Surveyor mission) data, with 128 pixel/degree resolution, to construct a local crossover-corrected topography grid. A suite of tools under a GIS were used to measure local slope, height, volume, width and length of the lava flows. In addition, we used THEMIS (Thermal Emission Imaging system), IR-day and IR-night 100m/pixel images [4]. The THEMIS data permit to obtain measurements of the surfaces brightness temperature and allows defining each structure of the volcanoes, degree of degradation of the surface, which means an increased knowledge for morphologic correlations.

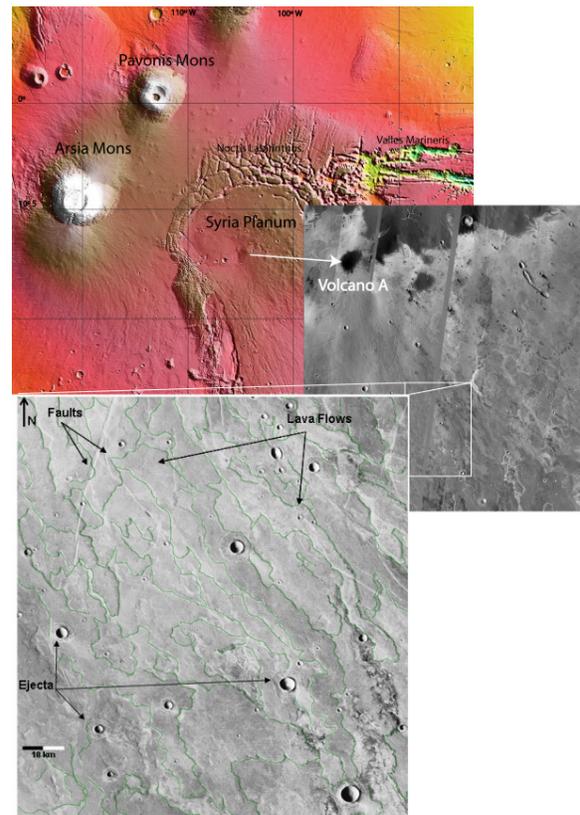


Figure 1. Image on the top: altimetry data derived from the MOLA 1/128° DEM superimposed to HRSC image. On Syria Planum is pointed the volcano A that origins the lava flows studied on this work. The image on the right (THEMIS IR-day data) zooms the Syria Planum major volcanic events, namely the volcano A with its lavas and the volcanic protuberances on the Eastern side. The bottom image (HRSC data) shows in detail the NW-SE oriented lobate shape lava flows. These lava flows may extend till 200 km southeastern of volcano A.

**Characterization:** Syria Planum has an extension of about 450 by 700 km and centered at 12°S, 104°W. Syria Planum is a broad plateau with little topography separated from the large Tharsis Montes by Noctis Labyrinthus on the North and Northwest and Claritas Fossae on the West [5], [6], [7]. Within this tectono-volcanic Syria Planum province, we can observe possi-

ble small edifices, usually named protuberances due to the lack of good imagery to certify the volcanic origin e.g., [2], [8]. It is also observed radial volcanic flow patterns, e.g., [9], isolated vents, volcanic eruptions along tube and vent-fed flows e.g., [10], [11].

The structures observed on Syria Planum can be mainly described by three main morpho-structural units: (1) in the northern and eastern side, nearly circular shape that resemble small volcanoes and appears as protuberances on MOLA data; (2) in the western and central part, extensive lobate shaped lava flows; (3) in the southern part, a highly fractured terrains displaying graben-like structures.

This study is focused on the unit 2, where, to the west of 100°W longitude, we can observe the passage to several lava flows that show elongated shapes and that cover an extensive area. The emplacement of voluminous lobate and elongated lava flows are observed in several hundreds of km extension on Syria Planum between 5400 and 6800 m altitude. These lava flows erupted from the NW of Syria Planum as it is shown by their NW to SE orientation observed in HRSC images. On the southernmost part, the lava flows of unit 2 appear till altitudes close to 5400 m, where extensive graben patterns are observed.

In addition to these units we observe that a few grabens also cross the unit 1 and 2. Ovoid depressions apparently resulting from a collapsed surface exists on the top west and east at the external margins of unit 1 and 2. A large number of impact craters are also visible from a few tens to meters to 10 km diameter.

**Morphology and Origin:** The extensive field of lava flows, identified between approximately 15°-19°S and 105° - 102°W, covers an area of approximately 100,000 km<sup>2</sup>. By the observation of HRSC images and THEMIS IR-day and IR-night images we can see that these lava flows have an elongate and lobate shape, with preferential orientation NW to SE, as the regional slope. Using THEMIS and MOLA data, we observe that these lava flows have erupted from an isolated volcano – named Volcano A - on the northeast of Syria Planum, and centered at 13,87°S; 104,2°W. The summit cone of the volcano A has about 40 km large and it lies at an elevation of approximately 6700m. This volcano is located out of the HRSC mosaic, thus we can not detail its morphology at the highest scale. From the centre of the volcano to NNW the slope is about 1,4° while from the centre to SSE the slope decreases to 0,7° to the side where the lava flows extend.

Studying this area, we can determine evidences for post-flow tectonic deformation. Using THEMIS data we observe that the flanks facing east are highly smoother than the western flanks, where the slope is much more accentuated. On the Southern part of Syria

Planum, and from an extension of some hundreds kms SE of the volcano A, we observe that the lava flows partially cover a field of grabens.

#### **Rheological Properties:**

*Dimensions:* From the tenths lava flows observed, we isolated 10, where channels- or tube- flows are mostly present, and its rheology study was made.

The size of the observed lava flows varies from some tenths km to about 200km, and the mean length is about 150km. Their width varies from 5km to 15km, with the mean value 9,4km. The levees flow has a mean width of 5km. The thickness of the lava flow varies from 15m to 70m, and the mean value is 34,5m. The average slopes of the studied flows is approximate to 0,2°, although in some few cases, on places with superposition of lavas, it can exceed 1°. This results in volumes of individual lava flows ranging from 100 and 500 km<sup>3</sup>.

[12] refer that the thermal constrains will be the factor for the maximum length of a flow by a given volume or mass effusion rate.

*Effusion Rate:* The effusion rate of this system, or its volume flow rate, can be determined using the Gretz dimensionless number (Gz) e.g., [13], [14]. The Gretz number assumes laminar flow and relates the heat lost by diffusion in a flow to the heat lost by advection along its length [15].

$$Q = \frac{G_z k x w}{b} \quad (1)$$

Where k is the thermal diffusivity, we used 3.0 x 10<sup>-7</sup> m<sup>2</sup> s<sup>-1</sup>, a constant value for both Martian and terrestrial lavas e.g., [15], [13], x is the flow length (m), w is the width of the flow (m) and b is the thickness of the flow (m). As a result, we find that effusion rates range from 990 m<sup>3</sup>s<sup>-1</sup> to 6075 m<sup>3</sup>s<sup>-1</sup>, and the mean value is 3300 m<sup>3</sup>s<sup>-1</sup>. These values are in the same array as the ones determined for Arsia Mons [13].

#### *Emplacement Time:*

Regarding the effusion rates and determining volumes of individual lava flows ranging from 100 km<sup>3</sup> to 500 km<sup>3</sup> of lava, we calculated that the time necessary to emplace these flows is a minimum of 350 days and a maximum of 1750 days.

#### *Viscosity:*

The viscosity can be determined using a model obtained from a steady laminar isothermal gravity-driven Newtonian flow, with no slip at the base and no shear stress at the top surface [16]. We assume the assumption of a Newtonian fluid, even though the lavas have a Bingham rheology e.g., [13] once this method provided more realistic values, not as high as other methods e.g., [13], [17]. This flow system can be resolved in a rectangular flow solution - equation (2) - where flow

depth and flow width are comparable, and thus where channel wall effects are irrelevant.

$$\frac{Q}{w} = \frac{b^3 \rho g' \sin(\theta)}{3\mu} \quad (2)$$

$Q$  is the volume flow rate (i.e. eruption rate),  $w$  is full flow width (in sheet flow),  $b$  is the flow depth in a Newtonian channel and sheet flow,  $g'$  is the adjust made for the acceleration of gravity on Mars ( $3,73 \text{ ms}^{-2}$ ),  $\theta$  is the slope,  $\mu$  the viscosity and  $\rho$  is the density (we assumed  $2800 \text{ kg m}^{-3}$ ).

We attempt an estimation of the viscosity ranging from a minimum of  $6,89 \times 10^5 \text{ Pa.s}$  and a maximum of  $4,23 \times 10^6 \text{ Pa.s}$  (depending on the previous determined values of effusion rate). These values are in agreement with several other viscosities determination of Martian lavas e.g., [13], [14].

On Earth, the terrestrial basalts and andesites have viscosities from  $1,4 \times 10^2$  to  $1,4 \times 10^7 \text{ Pa.s}$ , e.g., [14], [18]. So, the Syria Planum lavas are consistent with this range.

#### Yield stress:

To determine the yield stress  $\sigma_s$  we assumed that lavas follows have a Bingham fluid rheology (that differs from the Newtonian fluid by the existence of this threshold). The yield stress may be estimated from the combination of the three parameters,  $b$ , the flow depth,  $\theta$ , the slope, and  $w$ , the width of the flow, and also assuming a density flow value equivalent to terrestrial basalt ( $2800 \text{ Kg m}^{-3}$ ) e.g., [14].

$$\sigma_s = \rho g b^2 / w \quad (3)$$

$$\sigma_s = \rho g b \sin \theta \quad (4)$$

Using the equation (3) and (4), for 10 lava channels of Syria Planum, with sizes between 100 and 200 km long and thickness between 15 and 70 m, we obtain mean values between  $7,9 \times 10^2 \text{ Pa}$  (for the smaller sizes) and  $1,7 \times 10^3 \text{ Pa}$  (for the larger sizes) and the all mean value is  $1,2 \times 10^3 \text{ Pa}$ . These values are consistent with the terrestrial basaltic and andesitic lava flows and also with the Arsia Mons lavas (see [13]).

Using the calculated values of yield stress we can also determine the viscosity of the lavas e.g., [12], [19]. By the diagram of yield stress vs viscosity, obtained from Earth, Mars, Io and Moon lavas [19], a yield stress between  $7,9 \times 10^2 \text{ Pa}$  and  $1,7 \times 10^3 \text{ Pa}$  implies viscosities  $> 20 \text{ Pa}$  and  $< 10^6 \text{ Pa}$ , and suggests basaltic to andesitic lithologies. This method implies a wider interval for the lava flows viscosity. Even though it includes the expected values from equation (2), it seems that this method appears to give unrealistically low values, considering the morphology of the observed lavas.

**Conclusions:** HRSC images combined with MOLA and THEMIS data permit to better understand some geophysical processes, structures and processes on the surface of Mars. The Syria Planum region reveals a pattern of volcanic features singular in the context of the Martian tectonics and volcanism.

On the basis of our investigation, we conclude that these lavas flows are likely to be basaltic to andesitic in composition, and show similarities with the big shields of Tharsis, mostly with Arsia Mons lava flows.

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