RHEOLOGICAL PROPERTIES OF EMPLACED LOBATE LAVA FLOWS ON SYRIA PLANUM, MARS

Baptista, A. R.[1,2]; N. Mangold [2]; V. Ansan [2]; F. Costard [2]; P. Masson [2]; P. Lognonné [1]; G. Neukum [3] and HRSC team

[1] Équipe d'Études Spatiales et Planétologie, Institut de Physique du Globe de Paris, France, [2] Université Paris XI, 91405 Orsay cedex, France, [3] Inst. für Geologische Wissenschaften, Freie Universität Berlin, Malteserstr. 74-100, 12249 Berlin, Germany.

(baptista@ipgp.jussieu.fr)

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. Concretly, the properperties of the lava flows emplaced on Syria Planum, and their relation with the surrounded volcanic strutures [3] requires to be studied in detail to understand its relationships with Tharsis bulge complex history.

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 0,2º, although in some few cases, on places with superposition of lavas, it can exceed 1º. This results in volumes of individual lava flows ranging from 100 and 500 km³.

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 10-7 m² s⁻¹, 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 m³s⁻¹ to 6075 m³s⁻¹, and the mean value is 3300 m³s⁻¹. 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 km³ to 500 km³ 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 ms⁻²), *θ* is the slope, *μ* the viscosity and *ρ* is the density (we assumed 2800 kg m⁻³).
We attempt an estimation of the viscosity ranging from a minimum of 6, 89 x 105 Pa.s and a maximum of 4, 23 x 106Pa.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 x 102 to 1,4 x 107 Pa.s, e.g., [14], [18]. So, the Syria Planum lavas are consistent with this range.

Yield stress:
To determine the yield stress σs 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, θ, the slope, and w, the width of the flow, and also assuming a density flow value equivalent to terrestrial basalt (2800 Kg m⁻³) e.g., [14].

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

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

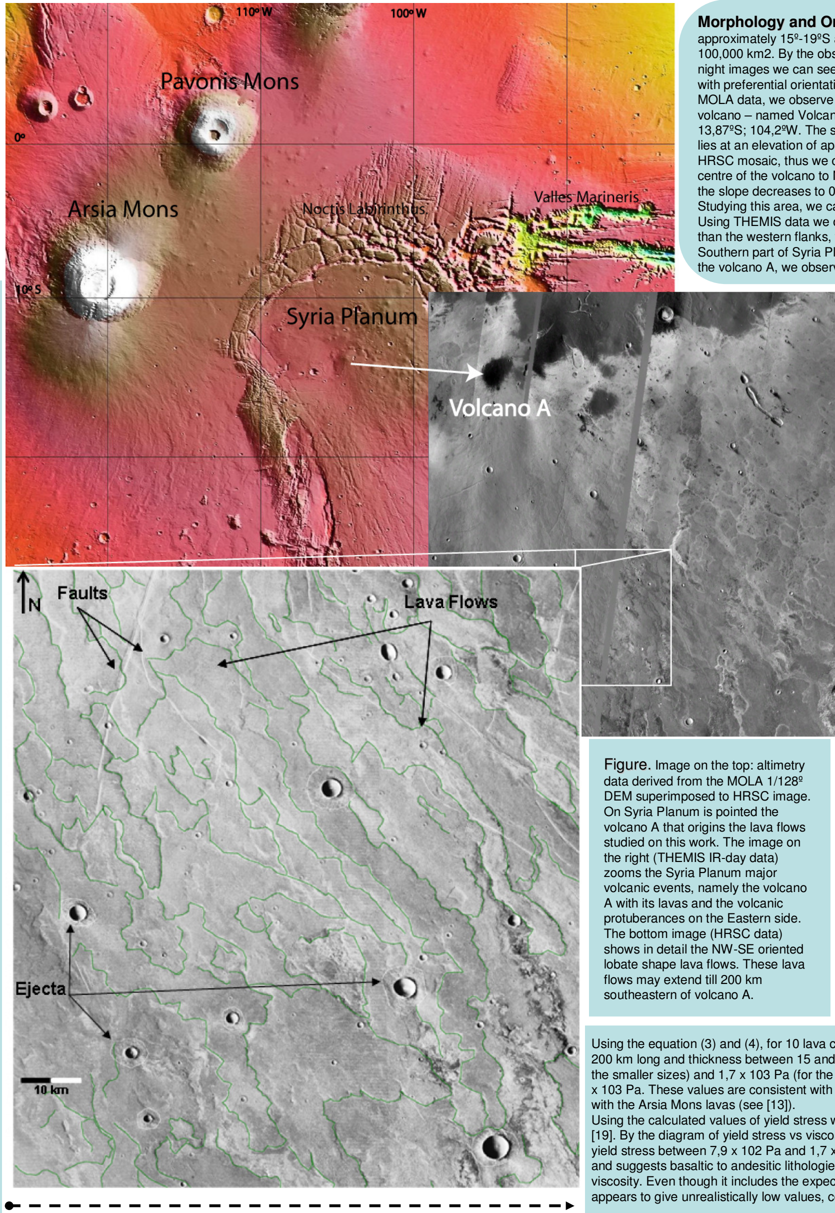

Figure. Image on the top: altimetry data derived from the MOLA 1/128º DEM superimposed to HRSC image. On Syria Planum is pointed the volcano A that origins the lava flows studied on this work. The image on the right (THEMIS IR-day data) zooms the Syria Planum major volcanic events, namely the volcano 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.

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 x 102 Pa (for the smaller sizes) and 1,7 x 103 Pa (for the larger sizes) and the all mean value of yield stress is 1,2 x 103 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 x 102 Pa and 1,7 x 103 Pa implies viscosities > 20 Pa.s and < 106 Pa.s, 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.

Morphology and Origin: The extensive field of lava flows, identified between approximately 15º-19ºS and 105º - 102ºW, covers an area of approximately 100,000 km2. 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 13,87ºS; 104,2ºW. 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 1,4º while from the centre to SSE the slope decreases to 0,7º 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.

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.

References:

[1] Plescia, J.B. (1981) *Icarus, 45*, 586-60.[2] Hodges, C.A., and H.J. Moore (1994) *Atlas of volcanic landforms on Mars, U.S. Govt. Printing Office*. [3] Baptista, A. R.; N. Mangold; V. Ansan; L. Dupeyrat; F. Costard; P. Masson; P. Lognonne; G. Neukum (2007) *JGR, submitted.* [4] Christensen, P.R. (2003) *American Geophysical Union, Fall Meeting, P32B-01*. [5] Masson, P. (1980) *Moon and the Planets, 22*, 211-219. [6]Tanaka, K. L.; P. A. Davis (1988) *JGR, 93*, 14893-14917. [7] Head, J.W. III; Ivanov, M.A; Hiesinger, H.; Kreslavky M ;Thomas B.; Pratt, S. (2000) *XXXI LPSC*, Abstract 1750. [8] Sakimoto, S.E.H. (2003) *6th International Conf. Mars*, Abstract 3197. [9] Tanaka, K. L.; P.A. Davis (1988) *JGR, 93,* 14893-14917. [10] Sakimoto S.E.; Greg, T.K.; Hughes, S.; Weren, S. (2004), *American Geophysical Union, Fall Meeting 2004*, Abstract #V32A-02. [11] Webb, B.; Head, J.W. III; Korz, K.B.; Pratt, B. (2001) *LPSC XXXII*, Abstract 1145. [12] Wilson, L.; Head, J.W. III (1994) *Reviews of Geophysics, 32, no. 3*, p. 221-263. [13] Warner, N.H.; Gregg, T. (2003) *JGR, 108*, pp. 1-1. [14] Hiesinger, H.; J.W. Head; G. Neukum and HRSC Co-Investigator Team (2005) *XXXVI LPSC*, Abstract 1727. [15] Gregg, T.; Fink, J. (1996) *JGR, 101*, p. 16891-16900. [16] Sakimoto, S. Crisp, J.; Baloga, S. (1997, *JGR, 102*, p. 6597-6614.[17] Wilson, L.; Head, J.W. III(1983) *Nature. vol. 302*, p. 663-669. [18] Wilson, L. (2001) *JGR, 106*, p. 1423-1434. [19] Vaucher, J.; Baratoux, D.; Pinet, P.; Mangold, N.; Ceuleneer, G.; Gregoire, M.; Daydou, Y.; Chevrel, S.; Neukum, G.; HRSC Co-Investigator team (2006) *XXXVII LPSC*, Abstract 1851.