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PHYSICAL PROPERTIES OF LAVA FLOWS ON THE SOUTHWEST FLANK OF TYRRHENA PATERA, MARS

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Tyrrhena Patera (22°S, 253.5°W), a large, low-relief volcano located in the ancient southern highlands of Mars, is one of four highland paterae thought to be structurally associated with the Hellas basin [1-3]. The highland paterae are Hesperian in age [4] and among the oldest central vent volcanoes on Mars. The morphology and distribution of units in the eroded shield of Tyrrhena Patera are consistent with the emplacement of pyroclastic flows [5]. A large flank flow unit extending from Tyrrhena Patera to the SW contains well-defined lava flow lobes and leveed channels (Figure 1) [5-6]. This flank flow unit is the first definitive evidence of effusive volcanic activity associated with the highland paterae and may include the best preserved lava flows observed in the southern hemisphere of Mars.

A large volcano-tectonic channel, similar in morphology to lunar sinuous rilles, connects the flank flow unit to the summit caldera of Tyrrhena Patera, which is interpreted to be filled with late-stage lavas [5]. The flank flow unit extends ~1000 km from the summit toward the Hellas basin. The flow unit averages ~185 km in width (max. = ~275 km) and embays the older, eroded shield units. Numerous wrinkle ridges are contained within the unit and exhibit NW-SE (Hellas-concentric) and NE-SW (Hellas-radial) trends [6]. The NW-SE trending ridges post-date flow emplacement and the NE-SW ridges are comtemporaneous with or older than the flows [7].

The flank flow unit is characterized by a series of SW-trending flow lobes, with average widths of ~2-15 km and lengths of ~10-120 km (Table 1). Most are single lobate flows with sinuous, lobate scarps defining their margins. Some individual lobes feed other lobes near their termini. In several locations, a complex of flows is evident with one or two large lobes and several smaller lobes branching from the same region. Many flows can be traced upstream to NE-SW trending wrinkle ridges; some appear to emanate from ridges or to have sources adjacent to ridges, implying that the ridges serve as feeder dikes or delineate fractures along which magma rose to the surface.

On the flanks of Tyrrhena Patera, the volcano-tectonic channel changes in character from a linear depression to a leveed, channelized flow. Discontinuous segments of this channelized flow can be observed at distances as great as 650 km from Tyrrhena's summit, where a ~1.3 km wide channel extends from a partially collapsed segment. Other regions of partial collapse also suggest that this feature was at one time a continous conduit for lava, analogous to a terrestrial lava tube. Segments of this channelized flow have been covered by later lava flows within the flank flow unit, and flows emanating from individual segments indicate that it also partially buried itself.

This extensive channelized flow and the large lava flows of the flank flow unit, which are morphologically different from flows in the Tharsis region, can be used to constrain the differences in volcanic style between the younger northern plains and the ancient, cratered highlands. Standard rheologic models have been used to estimate effusion rates [8], yield strengths [9], and viscosities [10], assuming the mapped flows were emplaced as single lobes (Table 1). Because accurate flow thicknesses are not available, calculations for idealized 10- and 100-m thick flows are shown. The regional slope of 0.25° is assumed for the calculations [5]. Inferred viscosities of ~10^4 Pa S for 10-m thick flows are significantly less than estimates for lavas in the Tharsis region (including Olympus Mons) [11-13], whereas viscosities of 100-m thick flows (~10^8 Pa S) are comparable to estimates for Tharsis flows. Yield strength estimates for Tyrrhena flows (~10^2 Pa for 10-m thick and ~10^4 Pa for 100-m thick flows) are also less than estimates for Tharsis and Alba Patera flows [12-14]. Effusion rate estimates for Tyrrhena flows (~10^3 m^3/sec for 10-m thick and ~10^2 m^3/sec for 100-m thick flows) fall at the minimum end of the range previously determined for Tharsis and Alba Patera lavas [12-15]. If the Tyrrhena flows are 10's of meters thick, the calculations indicate a general trend to higher viscosities and yield strengths from Tyrrhena Patera to Alba Patera to the

Tharsis volcanoes, which suggests a temporal evolution of the nature of martian magmas. In the future, thickness estimates and further applications of physical models for flow emplacement will better constrain these trends.

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Table 1. Rheologic and Eruptive Properties of Tyrrhena Patera Lava Flows

Flow	Length (km)	Average Width (km)	Effusion Rate (m3/sec) d = 10 m	Effusion Rate (m3/sec) d = 100 m	Yield Strength Pa d = 10 m	Yield Strength Pa d = 100 m	Viscosity Pa S d = 10 m	Viscosity Pa S d = 100 m
1	69.4	10.1	1.3E+04	1.3E+03	1.0E+02	1.0E+04	1.2E+04	1.2E+08
2	90.5	10.5	1.7E+04	1.7E+03	9.6E+01	9.6E+03	8.9E+03	8.9E+07
3	74.5	9.0	1.2E+04	1.2E+03	1.1E+02	1.1E+04	1.1E+04	1.1E+08
4	32.3	11.1	6.4E+03	6.4E+02	9.0E+01	9.0E+03	2.5E+04	2.5E+08
5	34.2	6.0	3.7E+03	3.7E+02	1.7E+02	1.7E+04	2.4E+04	2.4E+08
6	43.7	14.4	1.1E+04	1.1E+03	7.0E+01	7.0E+03	1.9E+04	1.9E+08
7	22.0	8.0	3.2E+03	3.2E+02	1.3E+02	1.3E+04	3.7E+04	3.7E+08
8		7.3			1.4E+02	1.4E+04		
9		5.5			1.8E+02	1.8E+04		
10		8.8			1.1E+02	1.1E+04		
11	32.6	4.5	2.6E+03	2.6E+02	2.2E+02	2.2E+04	2.5E+04	2.5E+08
12	25.9	5.9	2.7E+03	2.7E+02	1.7E+02	1.7E+04	3.1E+04	3.1E+08
13	117.4	11.9	2.5E+04	2.5E+03	8.4E+01	8.4E+03	6.9E+03	6.9E+07
14	100.5	7.0	1.3E+04	1.3E+03	1.4E+02	1.4E+04	8.1E+03	8.1E+07
15	13.1	2.1	5.0E+02	5.0E+01	4.7E+02	4.7E+04	6.2E+04	6.2E+08
16	93.4	8.7	1.5E+04	1.5E+03	1.2E+02	1.2E+04	8.7E+03	8.7E+07
17	22.7	2.8	1.2E+03	1.2E+02	3.5E+02	3.5E+04	3.6E+04	3.6E+08
18	21.1	3.3	1.3E+03	1.3E+02	3.0E+02	3.0E+04	3.8E+04	3.8E+08
19	51.3	7.2	6.7E+03	6.7E+02	1.4E+02	1.4E+04	1.6E+04	1.6E+08
20	38.1	4.7	3.2E+03	3.2E+02	2.1E+02	2.1E+04	2.1E+04	2.1E+08
21	55.4	6.0	6.0E+03	6.0E+02	1.7E+02	1.7E+04	1.5E+04	1.5E+08
22	23.2	5.4	2.3E+03	2.3E+02	1.9E+02	1.9E+04	3.5E+04	3.5E+08
23	652.1	2.5	3.0E+04	3.0E+03	4.0E+02	4.0E+04	1.2E+03	1.2E+07

Effusion Rate: $Q = (G_z \kappa x)(w/d)$

Yield Strength: $\tau_o = \rho g d^2/w$

Viscosity: $\eta = \rho g d^2 \sin\alpha / 3u$

x = flow length
w = average flow width
d = flow thickness
κ = thermal diffusivity = 6×10^{-7} m^2/sec
G_z = Graetz number = 300 (when flow stops)
g = gravitational acceleration = 3.71 m^2/sec

ρ = density = 2700 kg/m^3
α = slope = 0.25°
u = flow velocity = Q/wd

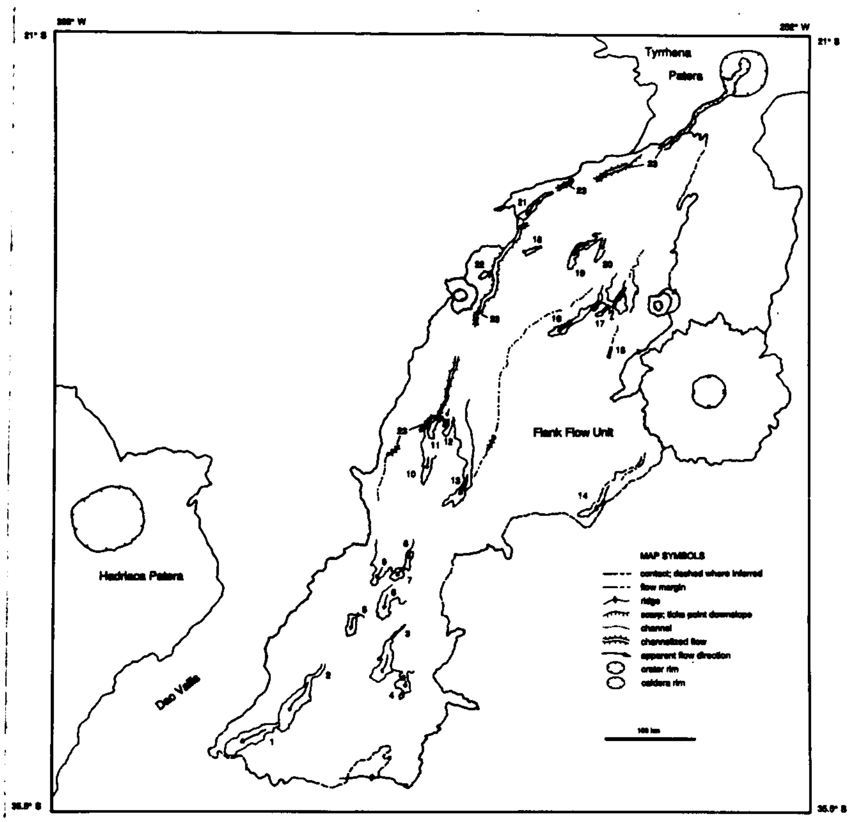

Figure 1. Simplified sketch map of the southwest flank flow unit of Tyrrhena Patera showing the distribution of lava flow lobes. The boundaries of Hadriaca Patera and the Tyrrhena Patera basal shield unit [5] are also indicated. Numbers are keyed to Table 1. Flows were mapped from images with ~90 - 230 m/pixel resolution.