Athabasca Valles, Mars: How important was erosion by lava?

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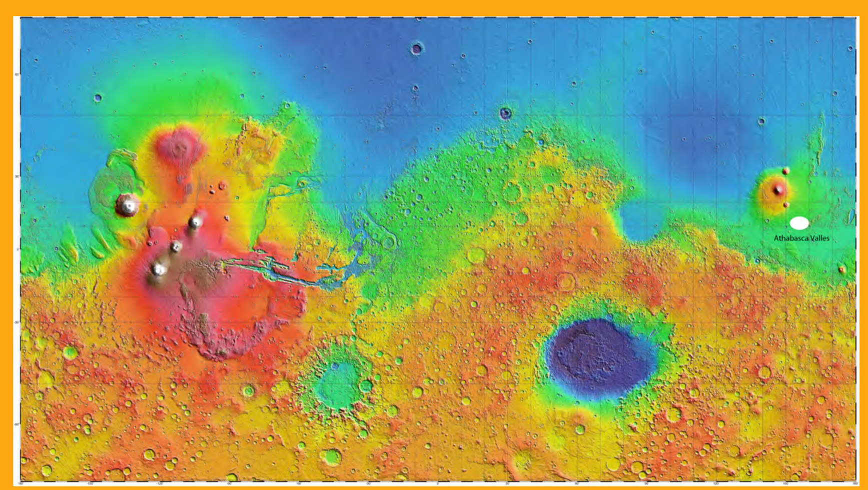


Figure 1. MOLA image of the surface of Mars. The small white ellipse on the right indicates the location of Athabasca Valles.

Athabasca Valles

Athabasca Valles is a young 300-km-long outflow channel located in north-central Elysium Planitia (Figure 1).

A thin lava flow drapes the channel.

Ice and hydrovolcanic (rootless) cones

Hydrovolcanic cones are found near channels margins, and likely formed as a result of interactions between hot lavas and ice in the substrate (Figure 4).

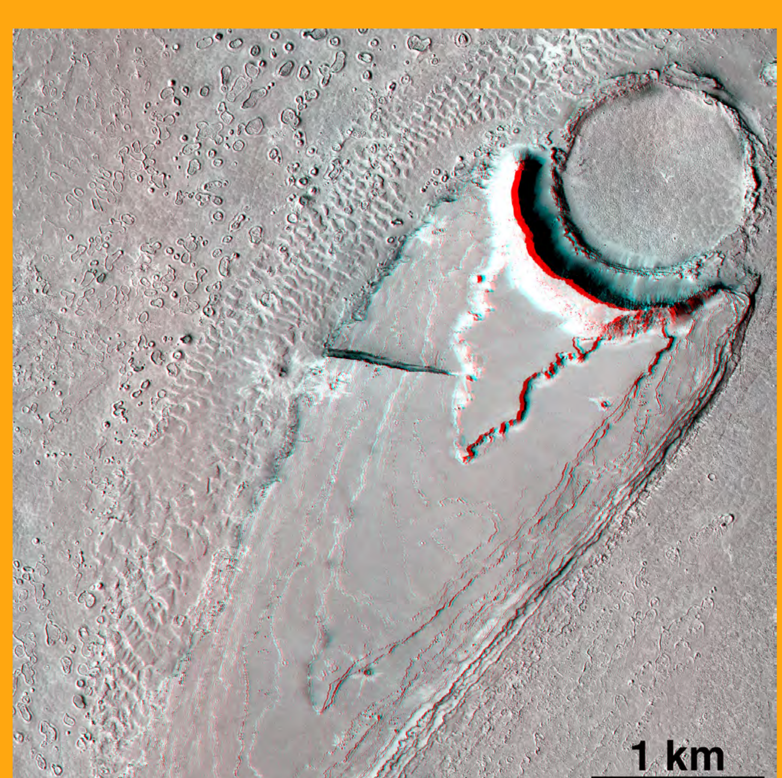


Figure 4. Section of HIRISE image PSP_002661_1985 of the Athabasca Valles main channel, showing rootless cones on the upper left.

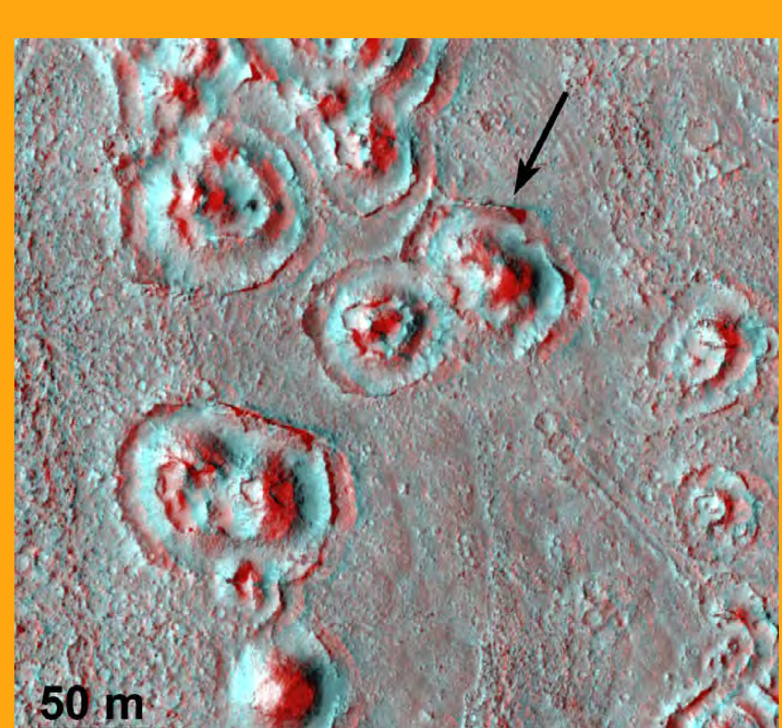


Figure 5. HIRISE stereo image pair PSP_001540_1890 and PSP_002371_1890, showing rootless cones. Arrow points at a thin plate that broke in response to the loading of the lava surface by the growth of a hydrovolcanic cone.

A flow of turbulent lava at Proximal Athabasca

Erosion by lava may involve some combination of thermal erosion (i.e., melting of the substrate) and mechanical erosion (i.e., physical removal of the substrate without melting). Here, we explore the role played by thermal erosion by turbulent lavas in eroding the substrate over the upper 50-75 km of the central Athabasca channel.

Thermal erosion is likely to play an important role for high-temperature, low-viscosity lavas, which are likely to flow turbulently. Flow emplacement occurred over a few weeks, and estimated flow thicknesses of 20 -30 m lead to total flow volumes of 5000-7500 km^3 for the entire 1400-km-long flow (Jaeger et al. 2010).

Depths of 80-100 m were reached at peak flow in the center of the channel. The channel width is 30-50 km, and its average slope is about 0.04 degrees.

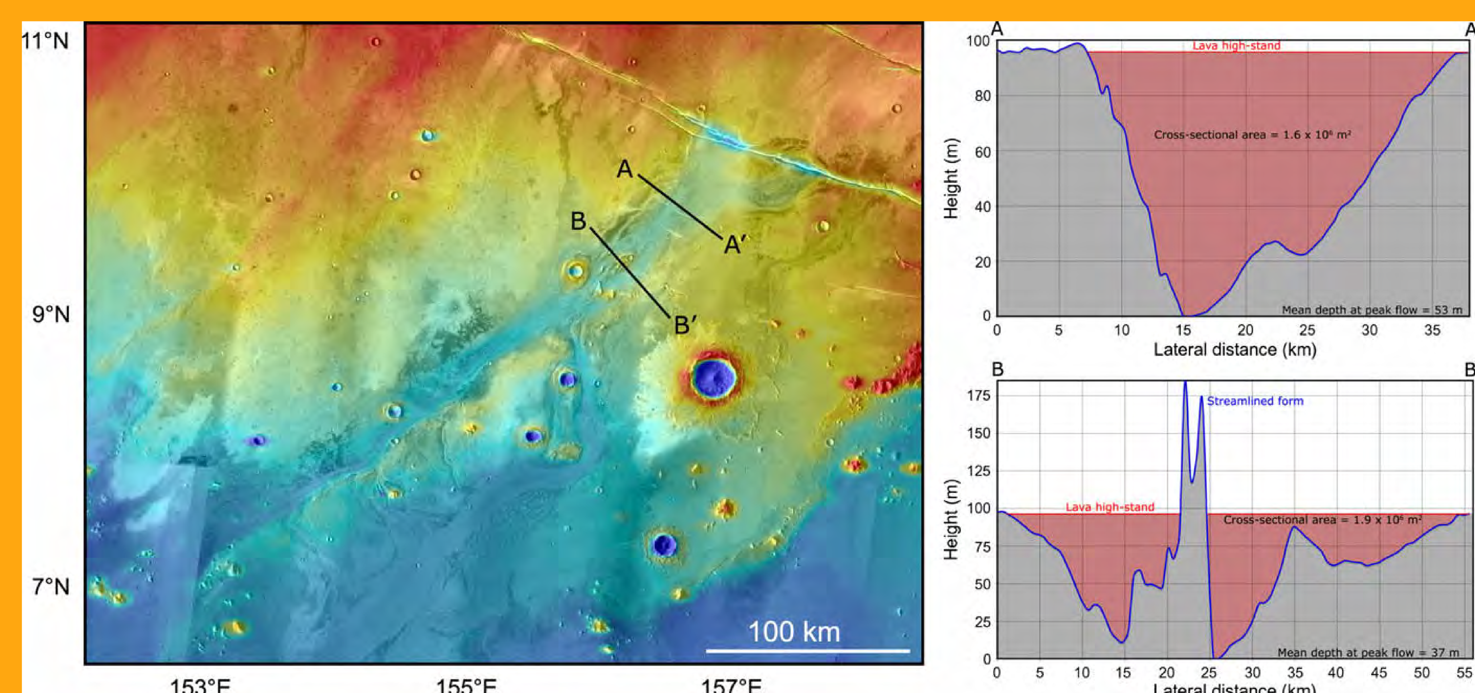


Figure 2. 2 MOLA profiles by Jaeger et al (2010), used to estimate the depth and cross-sectional area of proximal Athabasca Valles. In the graphs to the right, the substrate is represented in gray and the lava, at its highest stand, in red.

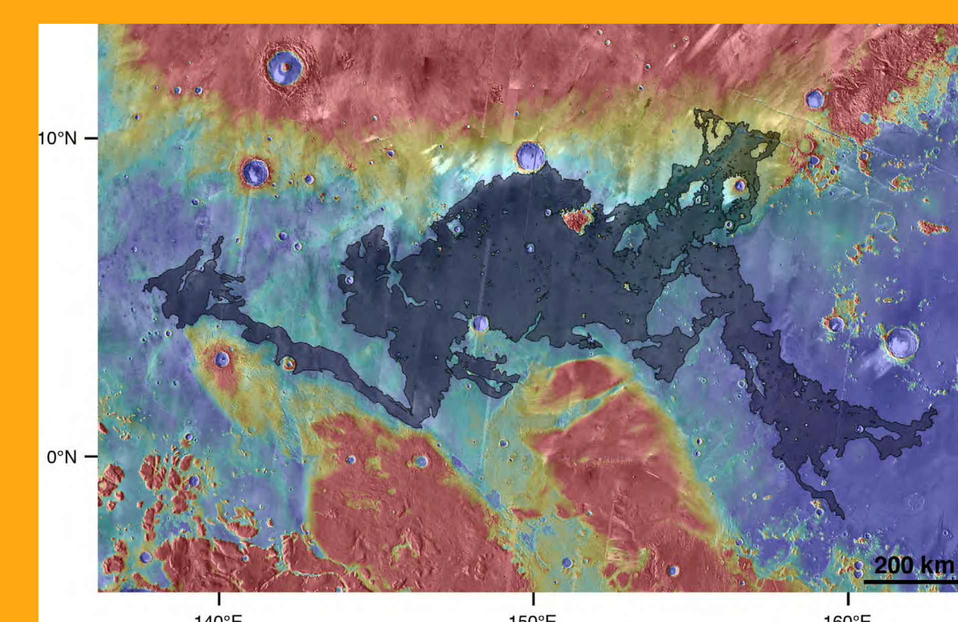


Figure 3. Areal extent of the Athabasca lava flow, as mapped from MRO data. The flow empties into the plains, reaching 1400 km in total length (from Jaeger et al. 2010).

Thermal erosion by lava at proximal Athabasca

We adapted the Williams et al. (1998) model of thermal erosion by lava to the Athabasca Valles scenario and calculated erosion rates and depths with time, as a function of distance from the source. The flow is one-dimensional (in the x direction) with thermal erosion in the z direction. The lava temperature decreases as the flow moves downstream and flow thickness, h, increases as velocity, v, decreases.

Flow thickness is used as proxy for flow rate (that is conserved). 3-D flow rates are obtained by multiplying h and v by width w. From these, we derive an estimate of the duration of the flow by using the available range of flow volumes (Jaeger et al. 2010).

The model accounts for the presence of water ice within the substrate, and calculates the energy required to heat up the ground to the vaporization temperature, and vaporize the water for an assumed volume fraction of water ice in the substrate (ice is melted first, followed by the rock).

Key eruption parameters

Estimate of eruption duration is approximate since effusion rate is expected to vary with time. Values are plausible average values for the main effusive event.

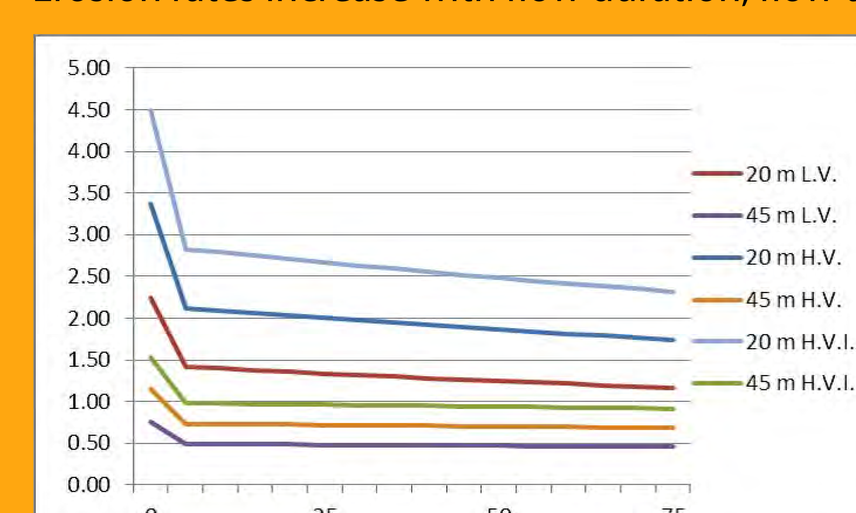
r_h	u	μ_{75}	Re_{75}	Q	t_a	t_b
m	m/s	Pa s	#	km^3/s	days	days
20	3.4	16.8	2.2×10^4	2.6×10^{-3}	21.9	32.9
25	3.9	15.2	3.6×10^4	3.8×10^{-3}	15.1	22.7
35	4.9	13.7	7.0×10^4	6.7×10^{-3}	8.6	12.9
45	5.8	12.9	1.1×10^5	1.0×10^{-2}	5.7	8.5
55	6.6	12.5	1.6×10^5	1.4×10^{-2}	4.1	6.1
68	7.6	12.2	2.4×10^5	2.0×10^{-2}	2.9	4.3

r_h Hydraulic radius,
u Flow velocity,
u_{75} Bulk viscosity 75 km from source,
Re_{75} Reynolds number 75 km from source,
Q Effusion rate,
t_a Flow duration, if V = 5000 km^3,
t_b Flow duration if V = 7500 km^3.

Table 1. Key parameters as a function of flow rates and thickness for an eruption temperature of 1523 K and a 39-km-wide channel.

Erosion rates and depths

Erosion rates increase with flow duration, flow thickness, and substrate ice.



20 m Flow thickness
45 m Flow thickness
L.V. Lower V = 5000 km^3
H.V. Higher V = 7500 km^3
H.V.I. Higher V + 25% substrate H_2O.

Figure 6. Erosion depth in meters (y-axis) plotted against distance from lava source in kilometers (x-axis).

Crust formation

A thicker crust forms as the flow cools.

31 cm thick 20-m-thick flow 75 km from source

17 cm thick 68-m-thick flow 75 km from source

These values are lower than those found for terrestrial pahoehoe flows (Keszthelyi and Denlinger, 1996).

Figure 7. THEMIS sees evidence of crust formation on this portion of the Athabasca lava flow. The crust is brittle and breaks in slabs.

"Lava rafts" are smoother and coated with finer-grain material. In between lie channels of dark, rough lava.
Mars Odyssey/Themis credit

Summary and Conclusions

The Athabasca Valles lava flow was likely emplaced over a period of ony a few to several weeks (Jaeger et al. 2010).

Inferred total flow volumes and thicknesses are used to constrain erosion rates and depths by turbulent lava at 50-75 km from the lava source.

For flow thicknesses of 20-25 m, the duration of the eruption varies between 15 and 33 days.

The lava substrate is eroded to a depth that is never larger than a few meters, due to the short duration of the flow which prevents thermal erosion from playing a key role.

We will investigate the role played by mechanical erosion, which could produce larger erosion rates and depths than those associated wih thermal erosion.

Acknowledgments

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References

Jaeger W. L. et al. (2010) Icarus, 205, 230-243.
Keszthelyi L. and Denlinger R. (1996) Bull. Volcanol., 58, 5-18.
Williams D. A. et al. (1998) J.G.R., 103, B11, 27533-27549.