Lava coils on Mars: Modeling using wax analog experiments

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Lava Coils observed at Athabasca Valles

Martian lava coils, hereafter called panulae after the Latin word for coil, were observed in the Athabasca Valles, in platy-ridge flows by Ryan and Christensen (2012). They have a distinct morphology from terrestrial coils.

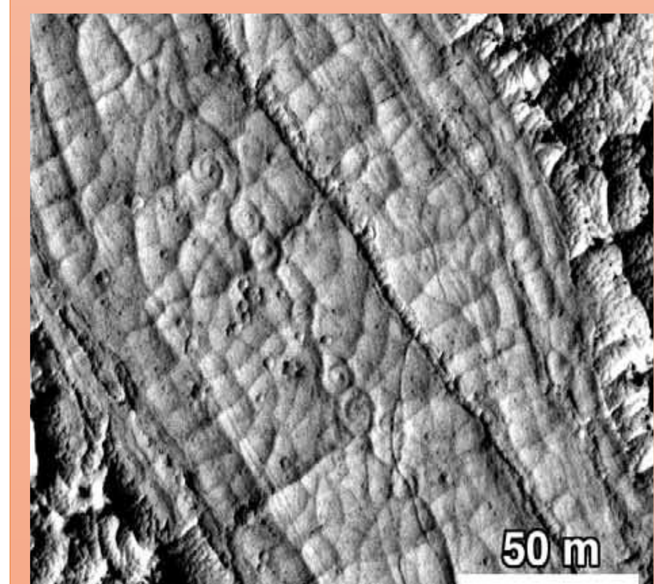

Fig. 1. Panulae form in secondary plate morphologies. Ryan and Christensen (2012) are hypothesized to form through Kelvin-Helmholtz instability. From Ryan and Christensen, 2012.

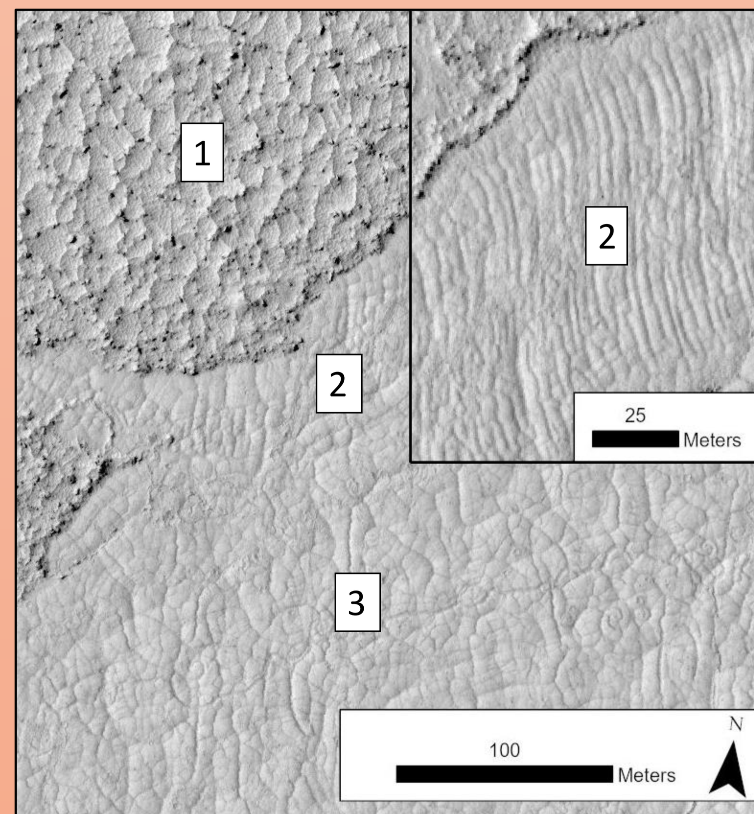

Fig. 2. Platy-ridge morphology at Athabasca Valles. 1) Primary plate that formed an initial crust on a stagnant flow that rifted thorugh a surge in the eruption rate. 2) Wrinkly skin plate, with stretch lineations, 3) coil bearing elephant skin plate. HiRISE image PSP_007250_1840

Literature on lava coils in Hawaii, a common analog for Martian volcanism, shows a different style, caused by squeeze ups.

Fig. 3. Example of a squeeze-up coil shape (~2m) at Mauna Ulu, Hawaii Volcanoes National Park. Note the different morphology. Photo by S. Nawotniak.

Wax analog experiments

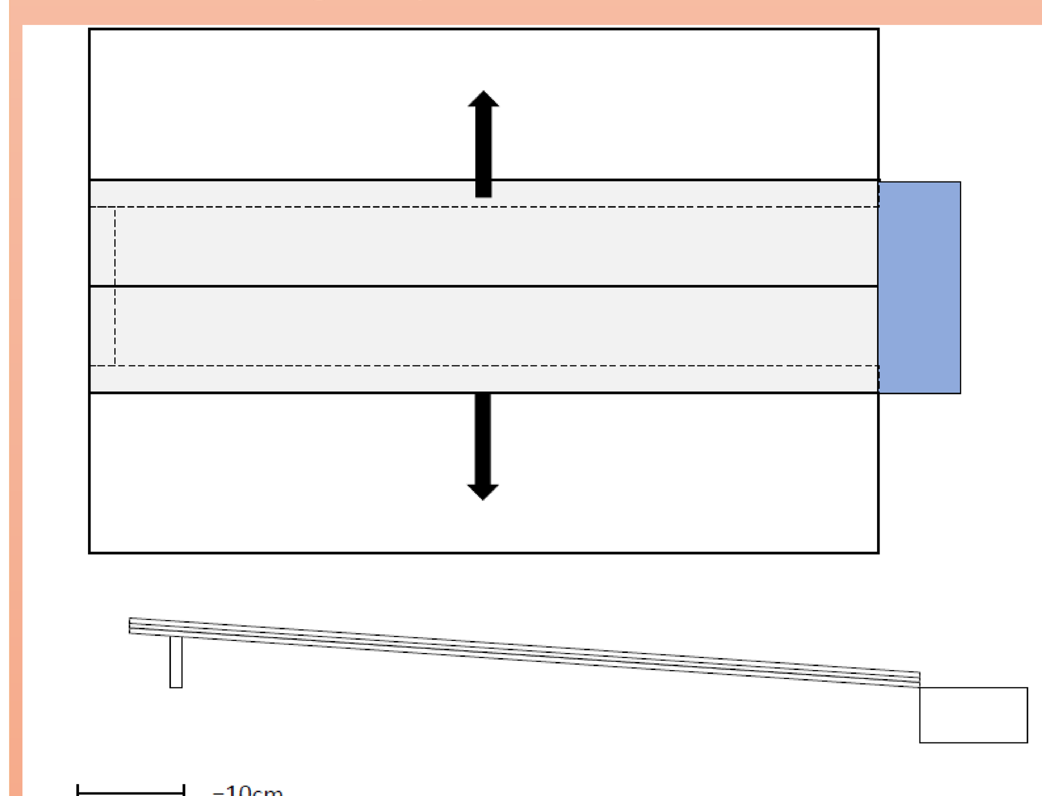

Fig. 4. Schematic of flume. A) Top-down view; the gray is the sheared plates which mimic rifting primary plates in platy-ridge flows, blue is a bucket to collect wax after it flows of the flume. B) Perpendicular view; slope of flume is 5°.

Experimental Parameters				
Slope	0	0.5	1	5
Rift Direction	Perpendicular		Oblique	
Plate Geometry	Straight	Curved	Jagged	Extra Jagged

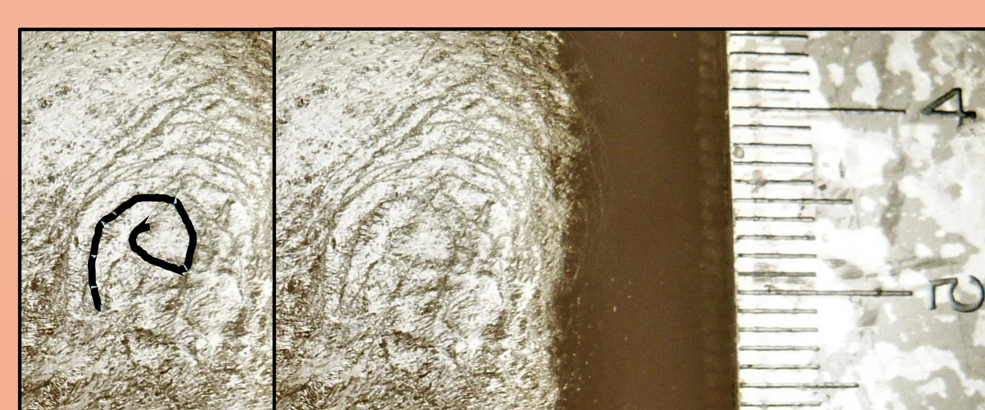

Fig. 5. A single arm wax coil. Coils formed in experiments that had a secondary crust form and was deformable through fluid flow beneath. Shear direction and plate geometry did not have a control on likelihood of coil formation. The strongest control was wax temperature; too cool and the primary crust would not break, too hot and no secondary crusts would form.

GPlates Modeling

GPlates is an open source software used to reconstruct plate geometries and model rifting Multiple models were created to test viability of different rifting scenarios (Müller et al., 2018).

Methods:
- Multiple rifting scenarios based on plate geometry and morphological features
  - North-South Rifting
  - East-West Rifting
  - Northwest-Southeast Rifting with plate rotation

How did the lava plates rift?
- East-West and Northwest-Southeast rifting models were unfeasible
- North-South modeling fit best
  - Fit well and no obstructions to block reconstructed plate locations
  - Fits with direction of stretching lineations and coil direction

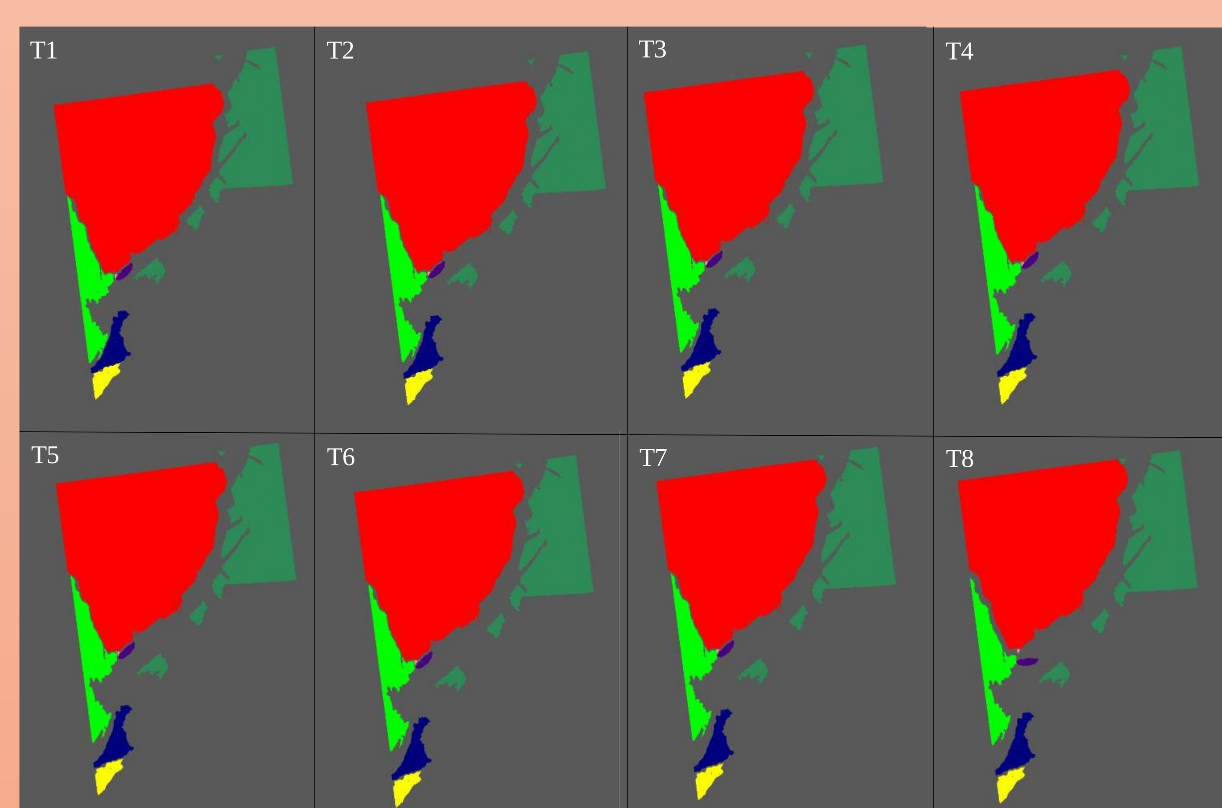

Fig. 6. North-south rifting model of the primary lava plates. Reconstructions were based on geometry. Flowlines were generated to compare to lineation direction in wrinkly plates.

Mapping

Methods
- Plates based on morphology
- Coils

Mapped 247 coils
- Majority clockwise, center of channel
- Even split between coil arms
- Majority occur in elephant-skin plate
- Lineations 12 ± 6

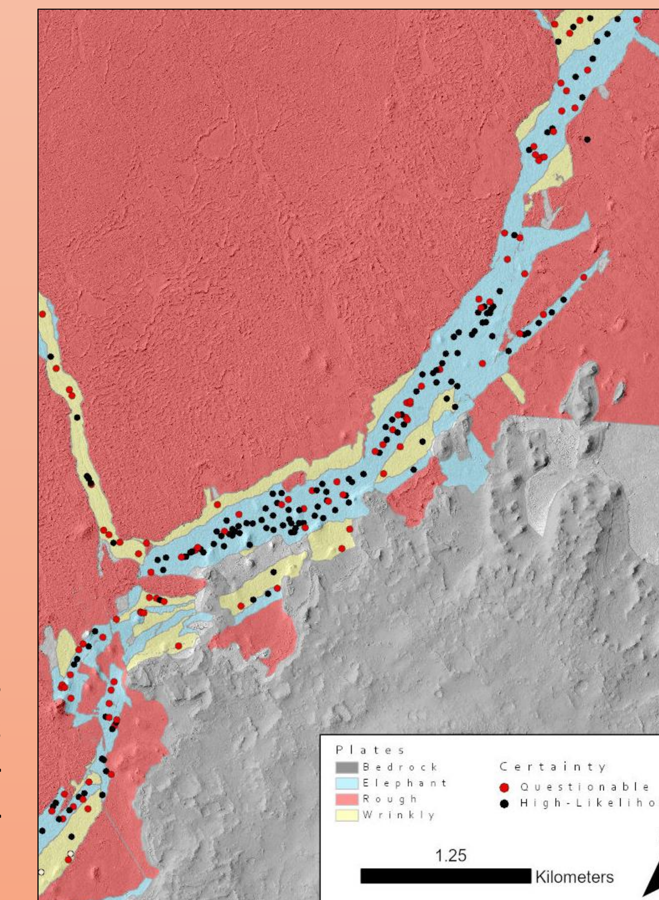

Fig. 7. Plate morphologies and coils mapped at Athabasca Valles. Coils predominantly formed in the interior of the elephant-skin plate. Scale bar is 1.25km.

	Wax		Mars	
Total Coils	94		243	
Size	6.25-25mm, Avg. 6.25		9.62-114.9m, Avg. 33.88	
Direction (Clockwise, Counterclockwise)	33	50	185	58
Centrality (Edge, Central)	17	67	67	176
Number of Arms (1, 2)	85	9	126	116

Discussion

Implications for Emplacement of Athabasca Valles

Fig. 8. Emplacement of platy-ridge morphology. A surficial crust is broken apart through a surge in eruption rate, allowing solid-lava plates to raft and interstitial magma to upwell between the plates (Kesthelyi et al., 2004)

Style of Rotation

- Kelvin Helmholtz Instability (KHI)
  - Formed through shear flow between fluids of different velocity and/or density (Fritts et al., 2014)
- Von Karmen Street
  - Vortices shed from obstructions (Buresti, 1998)
  - Form clockwise-counterclockwise pairs (Buresti, 1998)
- Analogous to Spiraling Garnet

Fig. 10. Von Karman Street behind a cylinder. Vortices form as billows as double-chains with alternating orientation.

Panulae on Earth?

Kesthelyi et al., 2004

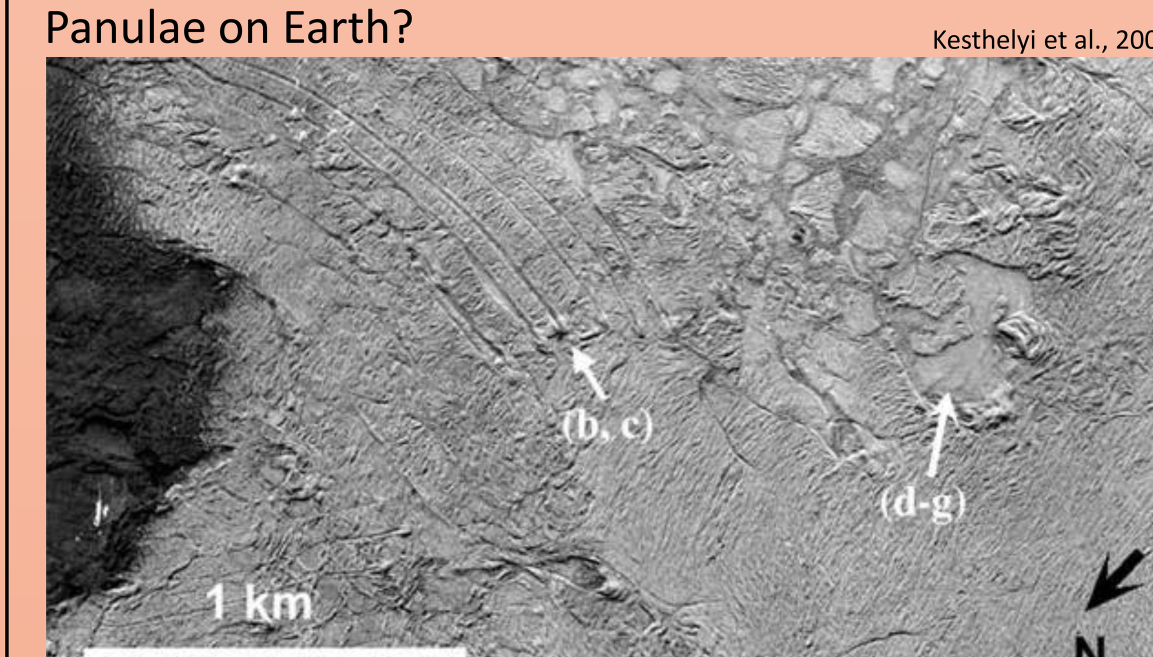

Fig. 9. Platy ridge morphology on the Laki Flow Field. Though the Laki Flow has similar morphology as Athabasca Valles, panulae are unlikely due to differences in terrestrial and martian volcanism and cooling conditions.

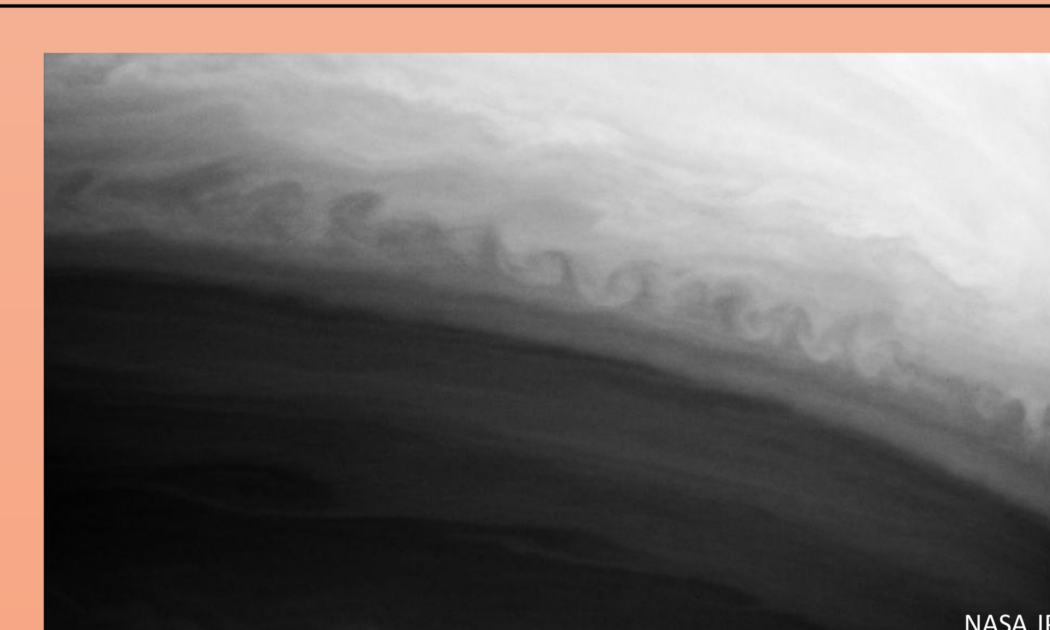

Fig. 11. KHI billows on Saturn. Vortices form in fluids with shear caused by differing velocity or density.

Conclusion

Panulae formed through rifting
- Requires fluid flow and thin deformable crust
- Direction correlates to rifting direction

Panulae have different morphology than terrestrial coils
- Different mode of formation
- Different emplacement dynamics

Platy-ridge morphology at Athabasca Valles
- Quiet flow
- Surge in eruption rate
- Solid crust breaks
- Expose fluid lava between plates

Future Work

Continue wax analog experiments
- Uneven bottom surface
- Obstructions in channel
- Continues supply
- PEG wax

EddyJ analysis

References & Acknowledgements

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Buresti, G., 1998, Vortex shedding from bluff bodies, *in* Riera, J.D., Davenport, A.G., Eds., "Wind Effects and Structures", Balkena, Rotterdam, p. 61-95.

Cashman, K.V., Kerr, R.C., Griffiths, R.W., 2006, A laboratory model of surface crust formation and disruption on lava flows through non-uniform channels: Bulletin of Volcanology, vol. 68, p. 753-770.

Fritts, D.C., Baumgarten, G., Wan, K., Werns, J., and Lund, T., 2014, Quantifying Kelvin-Helmholtz instability dynamics observed in noctilucent clouds: 2. Modeling and interpretation of observations: Journal of Geophysical Research: Atmospheres, vol. 119. P. 9359-9375.

Kesthelyi, L., McEwen, A.S., and Thordarson, T., 204, Icelandic analogs to Martian flood lavas: Geochemsitry, Geophysics, Geosystems, vol. 5, no. 11.

Müller, R. D., Cannon, J., Qin, X., Watson, R. J., Gurnis, M., Williams, S., et al.,2018. Gplates: Building a virtual Earth through deep time. Geochemistry, Geophysics, Geosystems, 19.

Ryan, A.J. and Christensen, P.R., 2012, Coils and Polygonal Crust in the Athabasca Valles Region, Mars, as Evidence for a Volcanic History: AAAS, vol. 336, p. 449- 452.