**Lava Coils on Mars: Modeling Using Wax Analog Experiments.**

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**Introduction:** HiRISE images from Mars have shown 5-30m coils in channelized lava flows in the Athabasca Region that have different morphology than terrestrial coils (Fig. 1). It is inferred that the rifting of solid plates of lava crust with fluid lava beneath provides the mechanism for martian coil formation. However, this emplacement mechanism has not been directly observed. By understanding martian coil formation, we can better understand lava properties and historical conditions during eruptions on Mars.

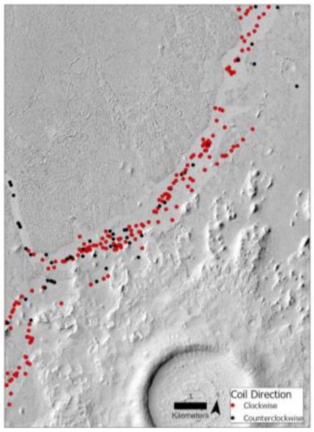


Fig. 1. Plate-ridge morphology in Athabasca Valles, Mars, with location of coils marked; red is clockwise orientation, black is counter clockwise orientation.

Athabasca Valles is characterized by platy-ridge morphology and distinct lava coils that are believed to be primary volcanic structures [1]. Platy-ridge morphology forms as lava with a solid crust is disrupted and rifted by a surge in lava flow rate; lava remains fluid beneath the flow and upwells between the sheared plates [2]. It has been proposed that the unsteady nature of Athabasca Valles' flow caused the cooled surficial crust of the lava to rupture periodically, with the hardened crustal material rafted laterally as new material was exposed in near channel axis [1]. The cumulative shear from the lateral spreading motion of the hardened crust and down-channel flow of the fluid lava created coils in the centermost flow unit [1].

Martian coils have a different morphology than terrestrial coils. Terrestrial coils have a ropy texture [3] whereas martian coils are curvilinear features. Terrestrial coils are formed by lava with high mobility, a plastic crust with a molten interior, and is undergoing shear [3].

**Methods:** Following [1], we used HiRISE image PSP_007250_1840 to systematically map coils and plate morphology at Athabasca Vallesincluding measuring coil size, rotation direction, centrality, and number of arms. The plates were classified based on morphology: rough, which was pre-rifted surface; wrinkly, which is a secondary plate that has undergone ductile deformation; and elephant-skin, which is the youngest and most central zone and holds most of the coils.

We used wax analog experiments to test coil emplacement with varied flume angle, shear direction, and plate geometry. Melted wax was poured into a flume and capped by particle boards with varying edges on top (Fig. 2). After wax was released, the boards were rifted perpendicular or oblique to the flow direction to mimic primary plate rifting in platy-ridge flows.

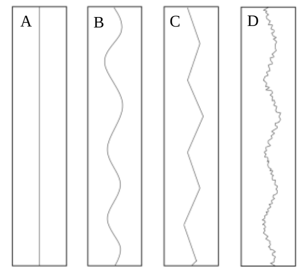


Fig. 2. Plate geometries: A) straight, B) curved, C) jagged, and D) extra jagged.

The system was also modeled using GPlates, an open source software for reconstruction of continental plates and plate motion [4]. GPlates was used to create multiple rifting models based on plate geometry to recreate potential rifting scenarios at Athabasca Valles.

**Results:** *Mapping.* Of the 245 coils identified in the HiRISE imagery, I rated 141 as confident selection due to resolution limits. There was a near-even split between the number of arms per coils (52% 1-arm, 48% 2-arm). Most of the coils were formed in the elephant skin plate and were designated as central (72%). The average coil diameter was 16.9 m (min 4.81, max 57.5).

*Wax experiments.* Eighy-four wax coils were formed in analog experiments. The majority were single arm (89%), counterclockwise (60%), and central (80%). The average size was 6.25 mm (min 0.5, max 25). Most coils formed with slope (77%) and oblique rifting (54%); board geometry did not have a control on coil formation.

*Gplates Modelling.* Athabascan plate motion was evaluating 3 GPlates models: east-west, north-south with rotation, and north-south. The east-west model fits geometrically; however, there is a lot of space that should be primary lava crust. In the north-south with rotation model, moving plates in the were obstructed by non-moving plates. The north-south model fit well geometrically and rifting direction fit with lineation directions measured in HiRISE imagery (192° for model, 195° for Mars).

**Discussion:** *Mapping and GPlates Modelling.* Past work [1] identified 269 coils between 5 and 30 m diameter; we, however, identified 245 coils between 4.8 and 58m. The discrepancy between total coils is mostly due to differences in interpretation of small craters as too small for classification and larger circular features as ring mountain landforms. Past work [1] suggested a northerly rifting model based on plate geometries and coil direction; we support their findings. Coil orientation correlates with shear, suggesting a north-south rifting direction; clockwise oriented coils reflect right-lateral shear and counterclockwise coils record left-lateral shear.

Athabasca Valles has morphology similar to platy-ridge lava flows. The similar morphology to the Laki Flow, Iceland, suggests similar mode of formation. The platy-ridge morphology at Laki was formed via surges in eruption rate that disrupted a solidified lava crust [2]. The three plate morphologies at Athabasca show two rifting events: the first broke apart the rough primary plates exposing molten interior that formed a thin crust. This secondary skin was then stretched into the wrinkly crust until it broke and exposed lava between the plates, forming the elephant skin crust.

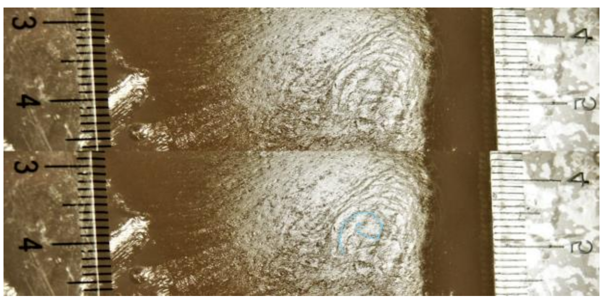

Fig. 3. Single wax coil formed in experiment with 1-degree angle, straight plats and oblique shear. Wax coils tend to be one-armed and do not form raised surface.

*Wax experiments.* Wax experiments with rifting formed smooth to wrinkly crust with shear zones, which are necessary for KHI and coil formation [1]. Rotation occurred during shearing and formed wax coils (Fig. 3). However, they were not as distinct as Athabascan coils; they tended to from as single arm coils and did not form in chains. Wax coils ropy textures and raised surfaces associated with terrestrial coils.

Wax flow and shear are necessary for coil formation. Experiments without down-channel flow did not create coils; increased fluid flow towards the center of the flume creates a differential speed in the flow that is forms eddies as the plates are rifting. Plate geometry did not have a large control on coil formation; only a small portion of the wax interacts with board edges. Coil formation depends most on rifting and wax temperature. Plate shear allowed hot wax to upwell between plates and then be fluidly deformed. High temperature wax did not form secondary crust that is deformed and preserved coils; low temperature wax had secondary crust that was too thick and was not deformable by fluid flow beneath. Lava flows without a secondary crust would not preserve transient coils. If the lava's crust is too thick, it would not be deformable and capable of creating coils.

Martian lava coils exhibit a different morphology than terrestrial coils. Martian flows have high velocity, lower viscosity, and thinner solid crusts due to cooling primarily due to radiation [5]. This allows fluid flowing beneath the crust to ductilely deform.

*Implications for emplacement of Athabasca Valles.* Athabasca Valles was likely emplaced as a platy-ridge lava flow. An initial solid crust was disrupted by a surge in the eruption rate. This exposed fluid lava that formed a thin crust from radiative cooling and was stretched by continued plate shear. This secondary crust broke apart, allowing lava to upwell again. This hot lava formed a thin plastic crust that was able to be rotated and deformed. Continued cooling solidified the lava and preserved martian lava coils.

**Conclusions:** HiRISE imagery of martian lava flows reveal coil structures that have a different morphology than terrestrial coils. Formation of martian-style lava coils was tested through wax analog experiments. Wax coils formed through tests with fluid flow and plate shear. GPlates modeling show a dominantly north-south rifting direction of primary lava plates.

Based on our models, we believe that Athabasca Valles was emplaced as a platy-ridge lava flow. The rifting of primary plates allowed fluid lava to well up between plates. This lava underwent radiative cooling and formed a thin plastic crust that was able to be deformed. The first stage of rifting formed the wrinkly crust and the second stage formed the elephant-skin crust. Coils formed during this stage were destroyed or deformed beyond recognition during subsequent rifting. The thin lava crust was able to be deformed through differential speed within the low viscosity flow, creating martian style lava coils.

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**References:** [1] Ryan A. J. and Christensen P. R. (2012) *AAAS, 336*, 449-452. [2] Kesthelyi L. et al. (2000) *JGR, 105*, E6, 15,027-15,049. [3] Lonsdale P. (1976) *Geology, 5*, 147-152. [4] Müller R. D. et al. (2018) *GGG. 19.* [5] Jaeger, W.L. et al. (2010) *Icarus, 205(1)*, 230-243.