Thermorheological Modeling of Channelized Lava Flows on Earth and Mars

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Introduction

Prior quantitative modeling of individual lava flows on Mars could easily be hindered because of poor image spatial resolution, the lack of required data or most commonly the obscuration of flow-scale morphology by mantling of dust, sand and other flows [1, 2]. Here, we focus on the younger volcanic region south of Arsia Mons, which includes numerous channelizes flows (Fig. 1). These flows have been studied for their age relationships and unique thermophysical properties [3-6]. A newly-funded NASA Solar System Workings (SSW) project will extend these studies by modeling the eruptive conditions at the time of their formation using a terrestrial thermorheological model (PyFLOWGO) [7]. It will be constrained first at a Mars analog site, Tolbachik volcano (Kamchatka) flow field formed during the 2012-2013 eruption, and then applied to the Arisa flows. The overarching goal of this project is to test and refine this well-developed flow model to quantify the properties of the Arsia flows including the range of eruption rates and down flow variations in viscosity, crystal content and velocity. One of the initial refinements to the PyFLOWGO model involves changing the radiative cooling calculation from use of a singular emissivity to one that uses two components representing the molten fraction and the cooling crust.

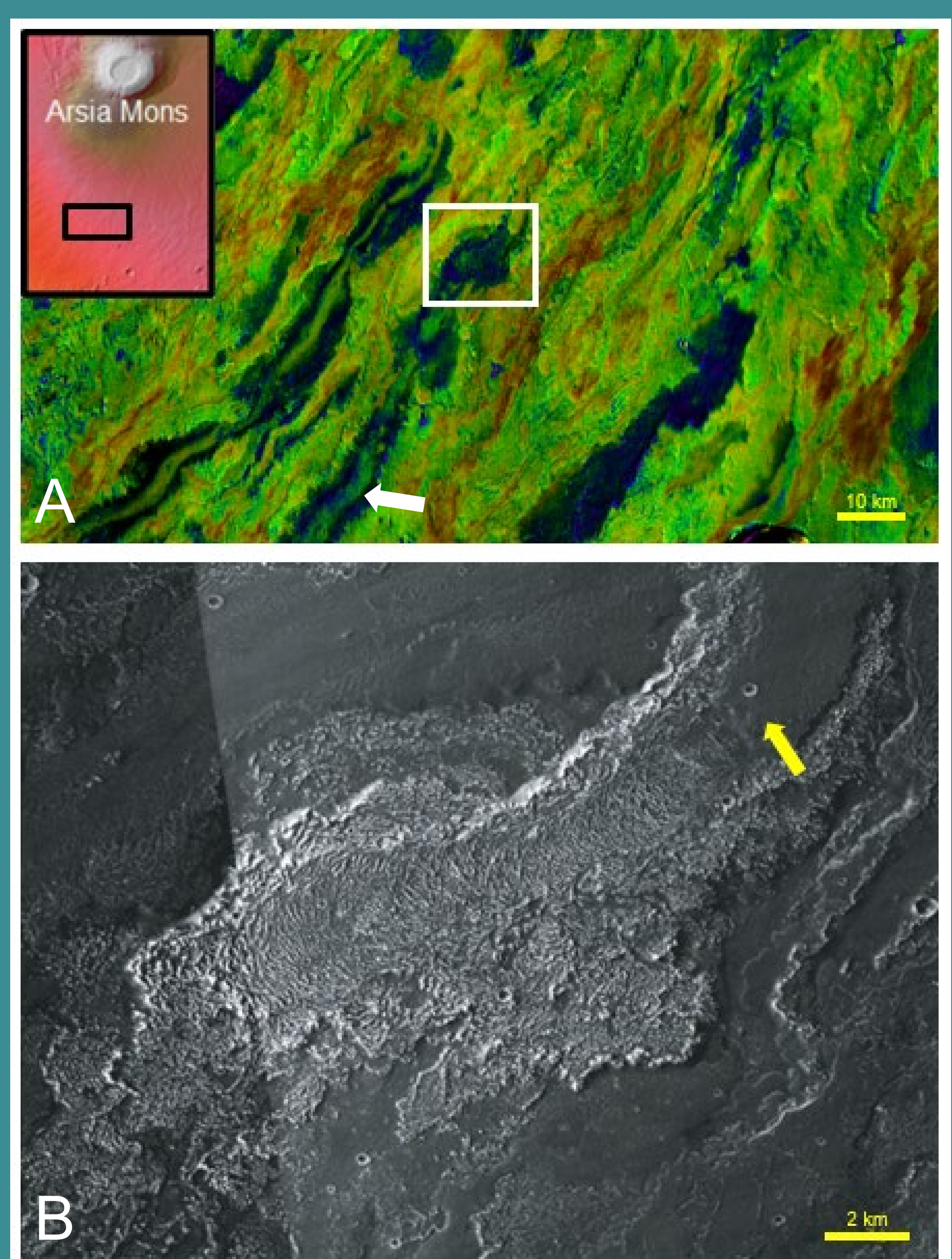

Figure 1: Individual flows in the Arsia Mons flow field with inset showing the location of (A). **(A)** THEMIS nighttime IR (colorized) draped over daytime IR showing a wide distribution of flow morphologies and surface temperatures (warmer colors indicate rocky and less mantled surfaces). The white box denotes the area shown in (B) and the white arrow shows a typical channelized rugged flow. **(B)** CTX image mosaic of the upper portion of the same flow showing a central channel, flow folds, levees, and lower albedo, smoother flows surrounding and at times, pirating the central channels of the blockier flows (yellow arrow) [5].

Initial Mars Site

- The initial proposed study area is the SW Arsia Mons flow field located at 238.3° W, 22.3° S (Fig. 1).
- Many of the flows in this region are blocky and channelized, with morphologies similar to Hawaiian a'a lava [3].
  - Most flows have no identifiable vent locations.
- The SW Arsia Mons flow field may represent one of the last stages of active volcanism on Mars [3].
  - Crater counts show some flows to be ~ 100 Ma [3].
- Instruments that will be central to our initial analysis are HiRISE, CTX, THEMIS and MOLA.

Terrestrial Analog/Model Testing

- The Tolbachik Volcanic complex is located on the Kamachatka Peninsula, Russia [8].
- The last eruption was in November 2012 and continued until September 2013 (Fig. 2).
  - The resulting flow fields covered ~ 30 km^2 [9].
  - Large subaerial (>10 km) channelized flows were produced such as the modeled Leningradskoye flow (Fig. 3).
- Extraordinary coverage of the entire eruption sequence was acquired by both high spatial resolution (e.g., ASTER, ALI, Hyperion) and high temporal resolution (MODIS, AVHRR) sensors.
  - These data coupled with the entirely subaerial erupted lava volume offers a unique target for refining the input parameters to PyFLOWGO (e.g., channel width, crust cover, temperature).
  - The first of these refinements (two-component emissivity for the lava + the crust) has been examined [9].

Figure 2: Aerial views of the Leningradskoye flow's open channel emplaced during the first week of the 2012-2013 eruption. The channel in the main photo is ~10m wide downstream of the confluence and covered by ~ 40% cooler crust. View to the east toward the fissure (approximately 2km in the background). Inset photograph was taken on the same day of the same channel ~ 2km further downstream. Flow is now covered by ~ 70% crust. Photographs courtesy of the Institute of Volcanology and Seismology (IVS), FEB RAS, KVERT [8].

Preliminary Results

Initial testing on the Tolbachik lava flows used a refinement to PyFLOWGO by adding a two-component emissivity cooling model [8]. Results show a better fit to the final flow length as a function of the fraction of crust (Fig. 4). With further refinement to the other input parameters we will be able to constrain PyFLOWGO to the best fit of the orbital data over the entire flow field's evolution.

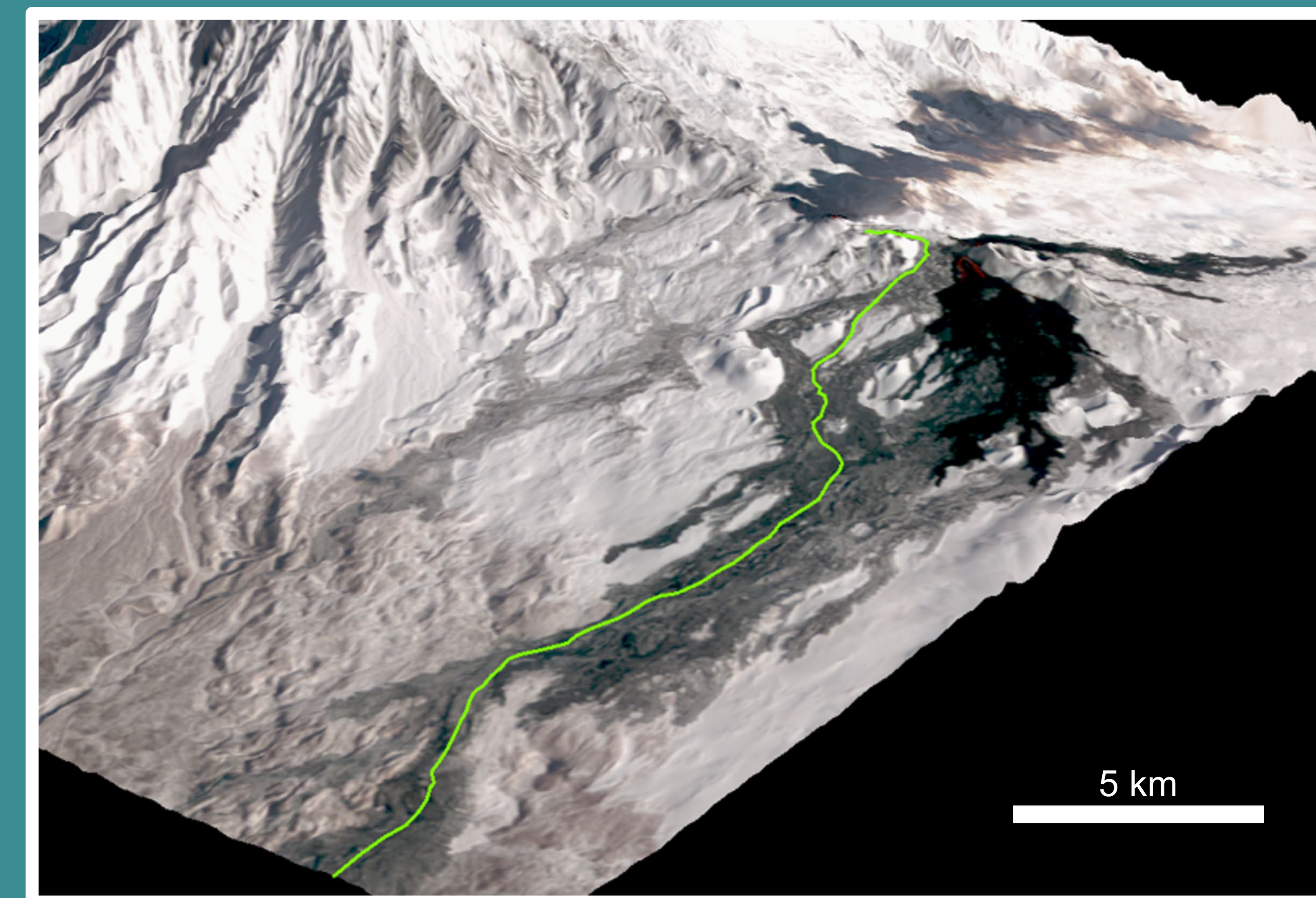

Figure 3: Fifteen meter orbital ASTER data acquired on 2 March 2013 draped over the ASTER-derived 30 m DEM acquired on 28 Feb 2013. The active channel at the time of emplacement (1 Dec 2012) was traced, exported as a vector and shown here in green [8]. These data serve as some of the many inputs to the model testing criteria (Fig. 4).

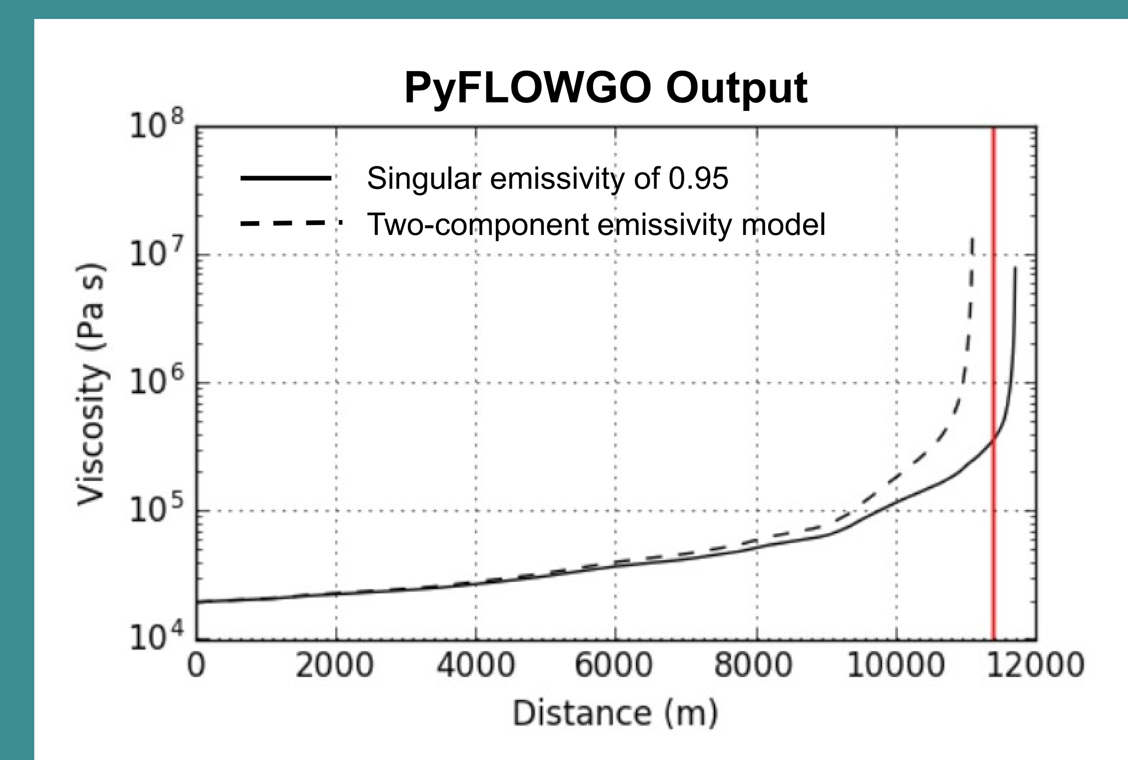

Figure 4: PyFLOWGO modeled viscosity variation for the Leningradskoye lava flow (see Fig. 2). Flow is assumed to stop as the modeled viscosity increases exponentially. The vertical red line represents the measured flow length on 1 Dec 2012 [8]. Note that the 2-component emissivity model produces a more accurate result.

Future Work

Work on this project will consist of three tasks:

(1) Image-based modeling: to assess the accuracy of the PyFLOWGO model for replicating the final length of the 2012-2013 Tolbachik flows.

(2) Field-based data collection: to measure specific flow dimensions, morphology and topography that could not be derived (or derived in sufficient detail) from the spatial resolution of the orbital data.

(3) Mars application: to the blocky, channelized flows SW of Arsia Mons that share similar morphologies to those at Tolbachik.

Investigating this flow field, with a refined thermorheological model, will provide further insight into the final stages of active Mars volcanism. The results will also be applicable to other terrestrial and Martian flows as well as those emplaced in very different environments such as Venus [10].

References

[1] Johnson, J.R. et al. (2002) *JGR, 107*. [2] Ruff, S.W. and Christensen, P.R. (2002) *JGR, 107, 5127*. [3] Berman, D.C. and Crown, D.A. (2018) *LPSC abstract*. [4] Simurda, C.M. et al. (2016) *LPSC XLVII*. [5] Crown, D.A. and Ramsey, M.S. (2016) *J. Volcanol. Geotherm. Res.* [6] Ramsey, M.S. et al. (2012) *LPSC XLIII abstract*. [7] Chevrel, O.M. et al. (2018) *Computers & Geosciences,11*. [8] Fedotov, S.A. et al. (1991) *Active Volcanoes of Kamchatka, vol. 1*. [9] Ramsey, M.S. et al. (2018) *Annals of Geophysics*. [10] Ashley, K.T. and Ramsey, M.S. (2018) *Earth Planet. Sci. Lett.*