The Sub-Meter Surface Roughness of Martian Basaltic Lava Flows

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Introduction:

Characterizing the morphology of volcanic terrains from orbital data is important for understanding eruption dynamics over time and vital if ground validation is not possible [1-4]. However, orbital instruments commonly have spatial scales in the tens to hundreds of meters, much greater than the degree of surface change observed between different lava flow morphologies and compositions. Surface roughness is one important characteristic of flow morphology and lava emplacement conditions. Where this roughness falls below the spatial resolution of thermal infrared (TIR) instrument data, it produces negatively sloped emissivity spectra at longer wavelengths. It arises either from an incorrect assumption of a uniform surface temperature and/or an incorrect choice of the maximum emissivity during temperature-emissivity separation of the radiance data [5,6]. This negative spectral slope is accentuated further in off-nadir data due to the increased areal percentage of shadows or change in the relative surface cover percentage within the FOV [7,8]. The resulting spectral slopes are distinct, with magnitudes proportional to the degree of temperature mixing [5,6]. This study utilizes Thermal Emission Imaging System (THEMIS) TIR data acquired during Routine Off-Nadir Targeted Observations (ROTO) of the Mars Odyssey spacecraft to derive Root Mean Square (RMS) surface slopes at scales currently only achievable by ground-based methods.

Methods:

The ROTO triplet data used in this study were acquired in September 2017 centered at 237.62°E and - 23.26°N with solar incidence angles between 50°- 89° and emission angles between 1°- 28°. Standard THEMIS processing and atmospheric correction was performed on all images [7]. The retrieved emissivity shows distinct spectral slopes (Fig. 1) that were modeled by combining the KRC thermal model [8] with a Surface Slope Model (SSM) [9] to produce simulated radiance data at different RMS slope values. The spectral emission features of averaged TES low and high albedo regions, resampled at THEMIS spectral resolution, were added to the model-produced blackbody radiance spectra prior to temperature-emissivity separation to mimic the surface data more accurately.

Forward-modeling of the spectral slopes was also performed using a two-component TI mixing model using combinations of low TI (50 TIU) representing dust with either a duricrust at 400 TIU or rock at 1250 TIU. TI values consistent with Martian sand were also modeled but did not produce spectra slopes consistent with the observed magnitude.

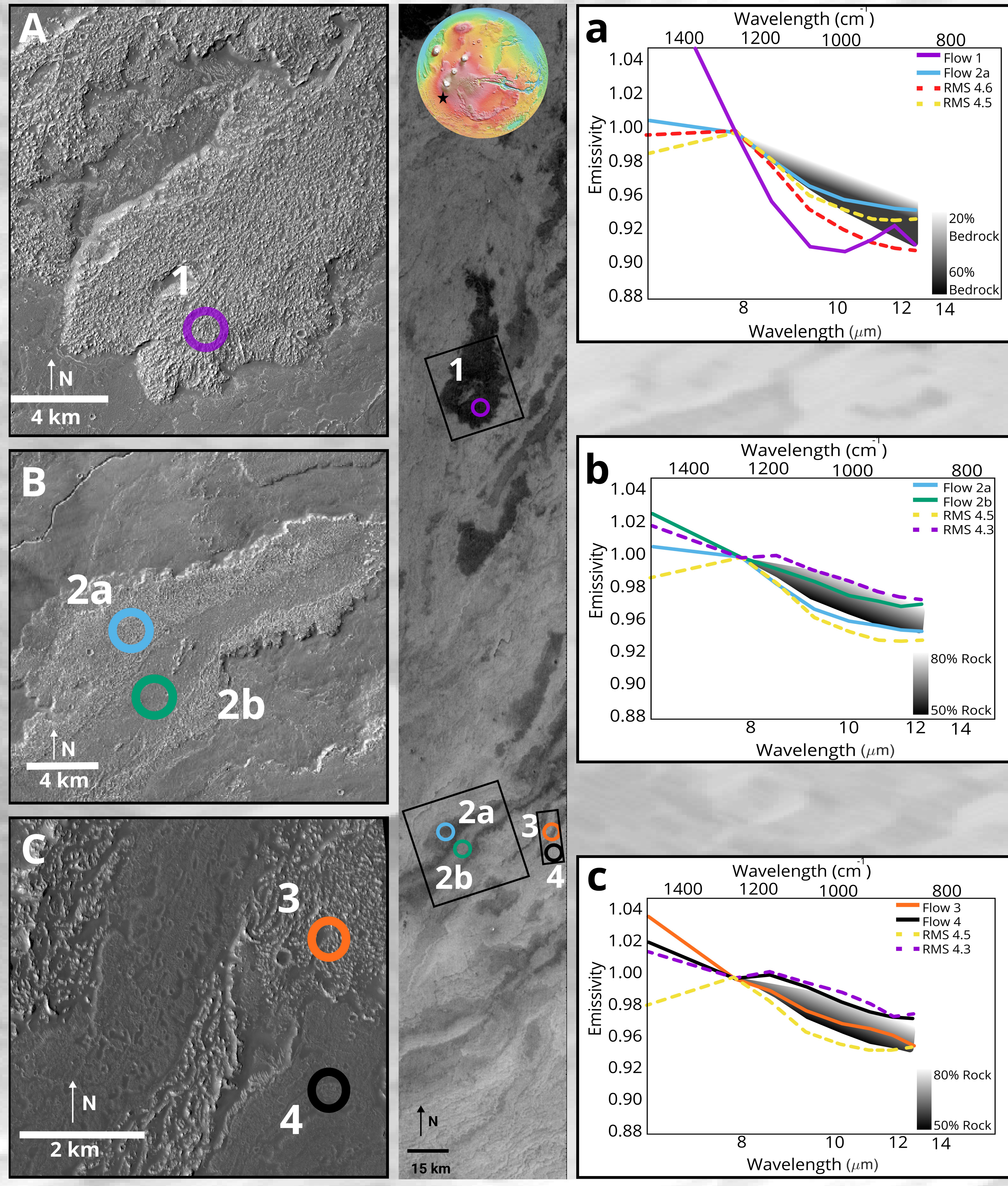

Fig 1. (center) THEMIS daytime ROTO stamp I68222002 identifying the four flows studied with circles indicating the approximate ROI location used to retrieve the modeled emissivity spectra. (A) CTX image K03_054414_1587_XN_21S122W showing the location of a colder flow surface (Flow 1). (B) CTX image F16_041940_1570_XN_23S122W showing the location of a different colder flow surface (Flow 2a) and its warmer central channel (Flow 2b). (C) HiRISE stamp ESP_038419_1570 showing locations of a third colder flow (Flow 3) and an adjacent warmer flow surface (Flow 4). (a, b, c) Emission spectra for each flow ROI showing the modeled RMS slope and rock abundance.

References:

[1] Byrnes and Crown (2002), JGR: Planets, 107(E10), 9-1. [2] Shepard et al., (2001), JGR: Planets, 106(E12), 32777-32795. [3] Tolometti, G. D., et al. (2020), Planetary and Space Science, 190: 104991. [4] Voigt et al. (2021), Bul. of Volc., 83.12, 1-14. [5] Bandfield J.L. and Edwards C.S., (2007), Icarus, 193, 139-157. [6] Bandfield J.L., 2009, Icarus, 202:2, 414-428. [7] Bandfield et al., (2004), JGR: Planets, 109, E10008. [8] Kieffer, H.H., (2013), JGR: Planets, 118, 451– 470. [9] Crown D.A. and Ramsey M.S., (2017), J. Volc. 342, 13-28.

Results:

Two distinct flow types are seen in this ROTO image set: colder and warmer daytime temperatures [10].

Colder Flows:

- Individual lobate flows (Flow 1) or levees along large, channelized flows (Flows 2a & 3)
- Slightly higher TI and larger magnitude spectral slopes than the warmer flows
  - *caused by increased temperature mixing and/or potentially rougher surfaces*
- In TI space, synthetic spectral slopes matching the colder flows indicate a surface containing 50/50 low (50 TIU) and high (600 TIU) TI material
  - *the exception is Flow 1 which requires a 60/40 mixture with a higher (1250 TIU) TI end-member*

Warmer Flows:

- Found at both lobate flow structures (Flow 4) and central channel material (Flow 2b)
  - *similar roughness and/or mixture of TI units*
- Synthetic spectral slopes modeled by the SSM indicate a surface with RMS slopes of 4.3 to 4.5 at the 10 cm scale, slightly lower than the colder flows (4.5° - 4.6°)

Discussion:

- Greater magnitude spectral slopes indicate an increase in anisothermality caused by either a:
  - *variability in the magnitude of surface roughness (RMS slope)*
  - *differences in surface cover of thermophysically distinct units (rock + dust, bedrock + dust)*
- HiRISE and CTX image data show distinct surface textures between the colder and warmer flows
- Colder flows exhibit a higher RMS slope and/or greater mixture of thermally distinct surface units than the warmer flows
- Thermal mixing is most likely a combination of surface roughness variability and TI differences
- Colder flows represent high TI, rough surfaces that trap fine material thus creating a larger temperature contrast
- Warmer flows represent smoother surfaces with a greater degree of mantling by fine material

Conclusions:

ROTO data from the THEMIS instrument retrieves sub-pixel anisothermality caused by surface roughness and/or differences in surface thermophysical units. This is demonstrated by the presence of negatively sloped TIR emission spectra. Different temperature surfaces display varying degrees of spectral slopes that, upon modeling, enable RMS slope and rock abundance retrievals. This is consistent with the morphology seen in the image data, however TIR spectra are sensitive to much smaller spatial scales [5]. Additional work is needed to validate the SSM and compare the results to terrestrial values of a'a, pahoehoe, and other transitional textures.