Thermophysical Modeling of Recent Lava Flows in Daedalia Planum, Mars

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Introduction

Mantling by eolian material (i.e., dust and sand) hinders thermal infrared investigations of the Martian surface. However, recent studies suggest that rather than a continuous layer of dust/sand on the surface, checkboard mixing of larger lava outcrops mixed with fine-grained material (dust or sand) in low-lying regions may also occur [1]. Therefore, it is critical to identify the degree of mantling and/or mixing of fine-grained particles and lava outcrops on the surface. To achieve this goal, thermal properties can be used to identify particle and block size distribution due to the grain-size dependence of thermal conductivity [2]. Since the detection of coarse grained particles can be obscured by fine-grained particles, low thermal inertia regions, like Daedalia Planum, may be explained by a mixture of coarse plus fine-grained material rather than a continuous layer of fines [1]. In this research, multiple datasets, with both high spatial and spectral resolutions, are used to identify possible mixing relationships on the flow.

Location

Daedalia Planum contains one of the main flow aprons originating from the SW flank of Arsia Mons (fig.1), the southernmost Tharsis shield volcano [3-4]. These flows have a predominately basaltic composition [5]. The study area was selected for its coverage by multiple datasets, extensive lava flow fields, and flow mapping [6-8]. The extent of thermophysical variation in the flow field suggests the presence of different roughness distributions or linear mixing of fine-grained material (predominantly sand in this area) and lava outcrops.

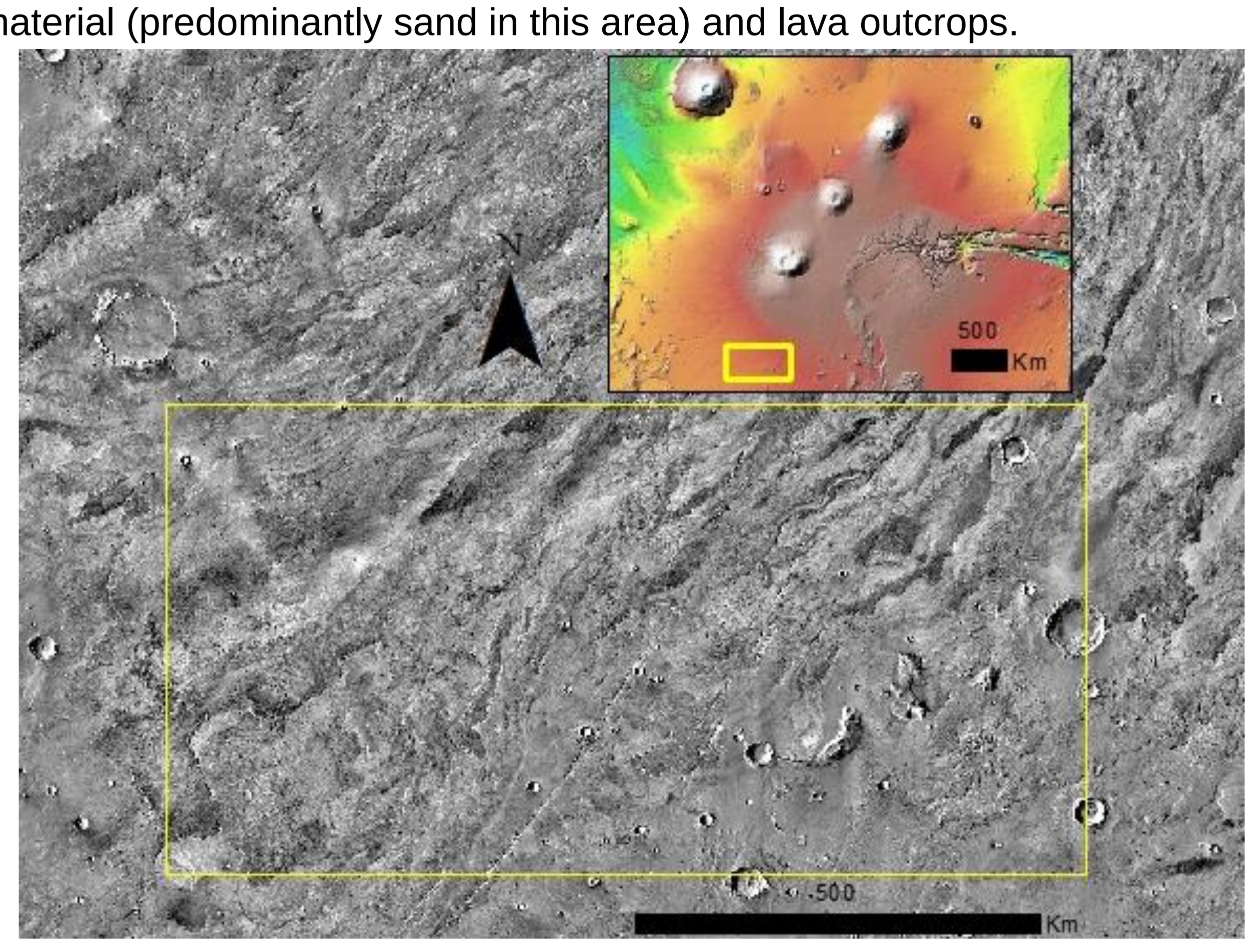


Fig.1. THEMIS IR day brightness temperature mosaic of the study area (yellow rectangle) in Daedalia Planum [9]. MOLA color map inset shows the location of the Tharsis study.

Datasets

Lava Flow Boundaries and Surface Textures

- MRO ConTeXt Camera (CTX)
- MRO High Resolution Imaging Science Experiment (HiRISE)

Thermophysical Properties

- Thermal Emission Imaging System (THEMIS) IR Brightness Temperature Day and Night
- THEMIS Derived Thermal Inertia (TI)
- Thermal Emission Spectrometer (TES) Dust Cover Index

CTX and HiRISE images were used to visually identify flow boundaries, flow superposition relationships, and characterize surface morphology. Flows were identified as having either rugged (bright in the visible) or smooth (dark in the visible) surfaces (figs.3,4) [6-8]. For the thermophysical analysis of these flows, thermal inertia (TI) derived from THEMIS IR night data were compared with THEMIS IR day and night brightness temperature data to determine the thermophysical response of the flows over a diurnal cycle (fig.5) [10-11].

Methods

Over 1250 regions of interest (ROIs) [500m x 500m] were defined to assess the variability of TI and brightness temperature between 48 individual flows (fig.2). To investigate the thermophysical characteristic of the flows, statistical analysis (including ANOVA) of the ROI data was performed and four categories were defined based on day and night THEMIS IR brightness temperature data (table 1). Finally, the THEMIS defined category, TI, and flow type defined by Crown et al. 2015 [8] were compared to identify potentially unmantled exposures.

Category	IR Day Temperature	IR Night Temperature
A	High	High
B	High	Low
C	Low	High
D	Low	Low

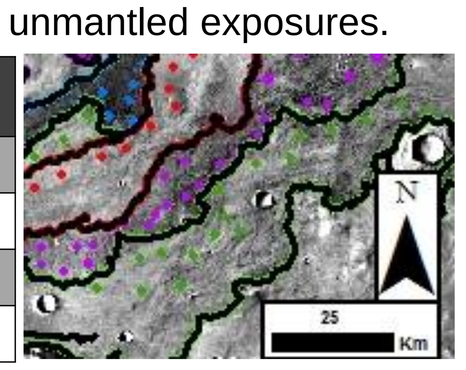


Table 1. Definition of the four categories identified using THEMIS-derived day and night brightness temperature data. **Fig.2.** Example of ROI placement along the flows using category coloration on THEMIS day brightness temperature mosaic [9].

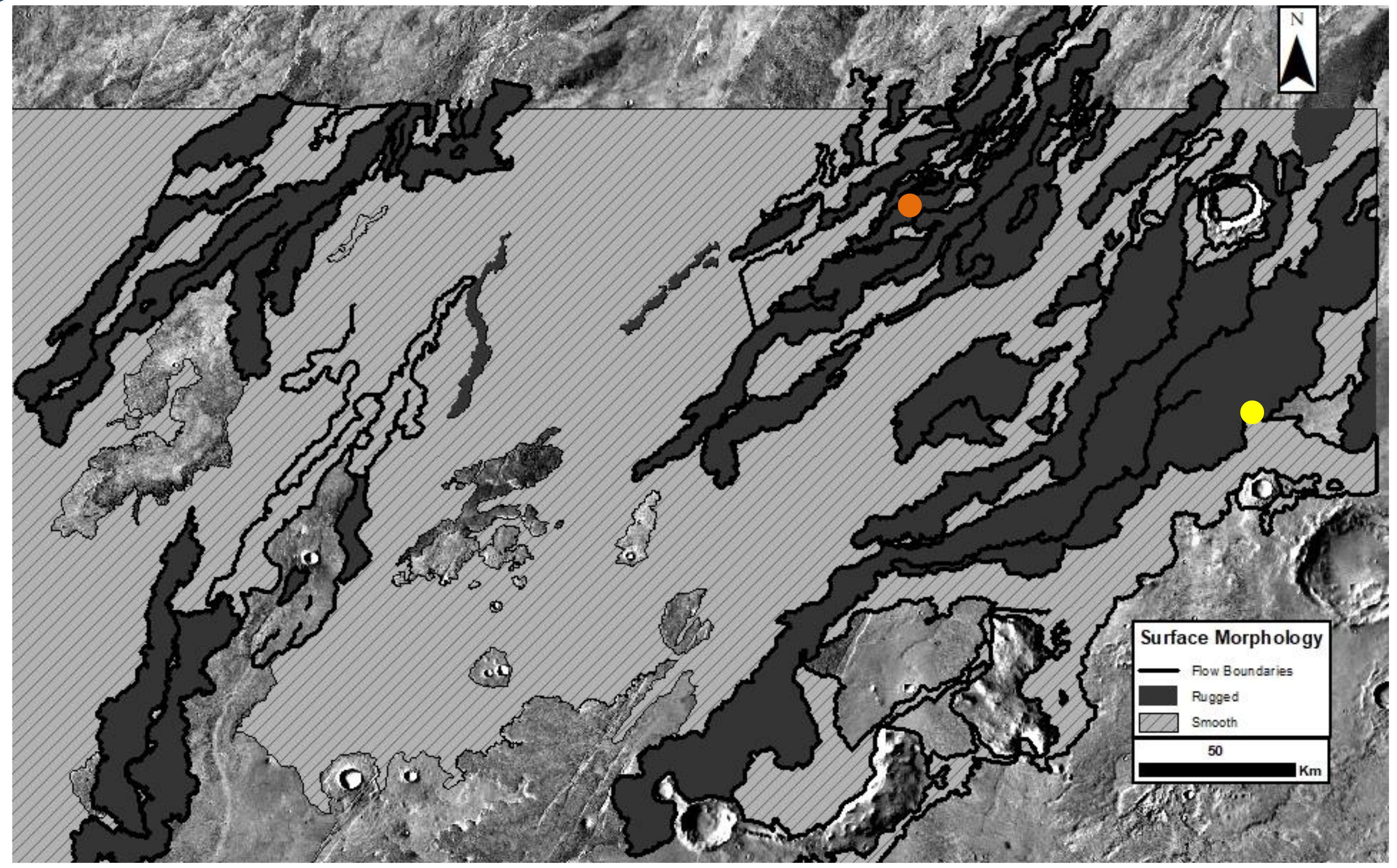


Fig.3. Crown et al. [2015] flow boundaries with surface morphologies (rugged and smooth) [6-8] overlain on THEMIS IR daytime brightness temperature mosaic of Daedalia Planum [9]. Colored dots correspond to the locations of fig.4 CTX images.

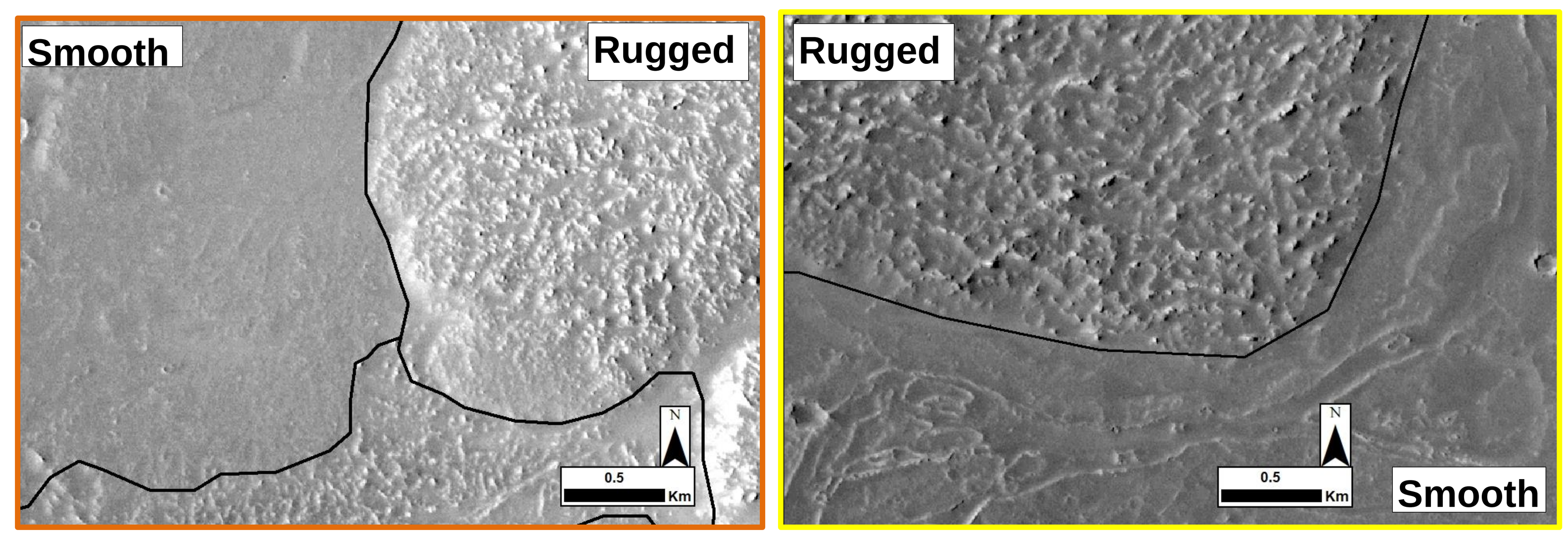


Fig.4. CTX images displaying distinct surface morphologies with labels of the identified type. The locations are marked on fig.3 as colored dots..

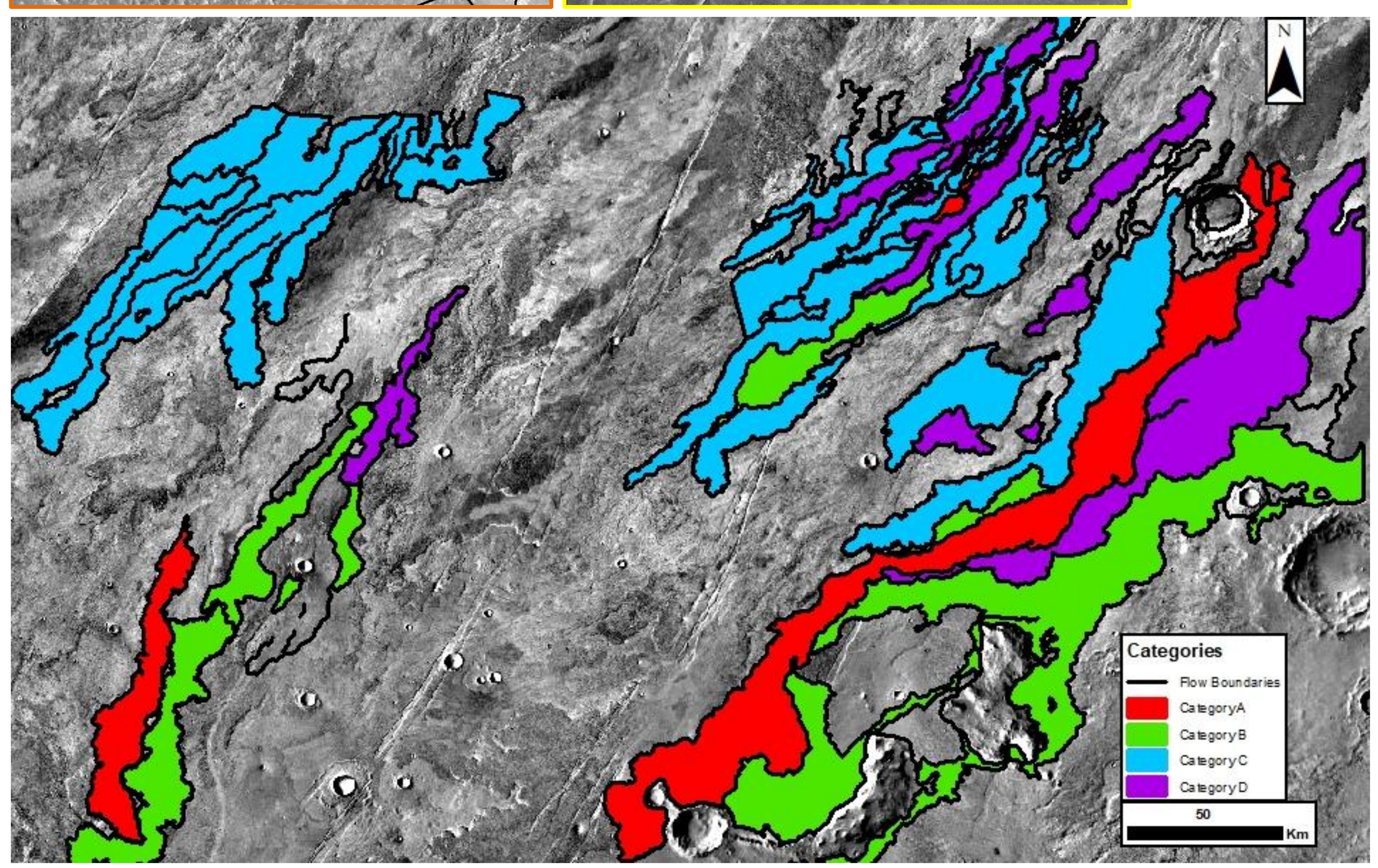


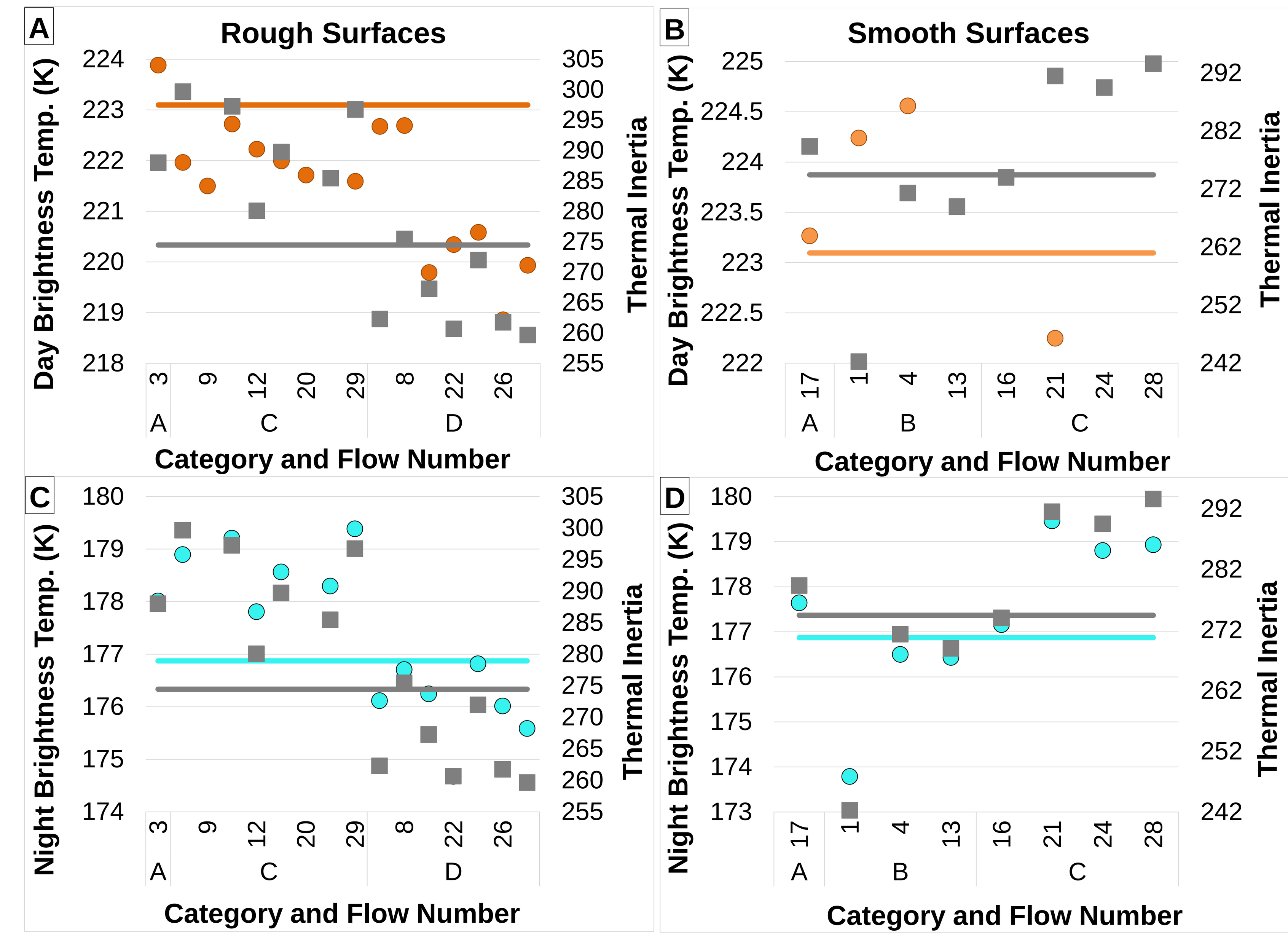
Fig.5. Lava flows with colors corresponding to the flow categories in table 1 overlain on the THEMIS IR day brightness temperature mosaic [9] and flow boundaries [6-8].

Results

Roughly 30% of smooth flows are identified as category B and display the characteristics of a mantled surface. With high day and low night brightness temperatures, the surface displays a low TI value suggesting that these smooth flows have a continuously mantled surface (figs.6b,6d). Meanwhile, smooth flows identified as category C with higher TI values likely display a thinner dust layer and potentially exposed outcrops. Alternatively, over 88% of rough surface flows display low day brightness temperatures (either category C or D). Of these flows, over 53% have low day and high night brightness temperatures (category C) producing higher TI values (figs.6a,6c). These category C rough flows likely represent a 'checkerboard mixing' surface with larger outcrops rising above low-lying regions filled with sand. This result is supported by the presence of ripples in HiRISE images of rough surfaces.

Category	Total # of Flows	% of Smooth Flows	% of Rough Flows
A	3	7.69 %	5.71 %
B	6	30.77 %	5.71 %
C	27	53.85 %	57.15 %
D	12	7.69 %	31.43 %

Table 2. Statistical results of the relationship between thermophysical response (defined using the categories) and surface morphologies (rugged or smooth) [8].



Figs.6A-D. Average TI (grey squares) for a flow plotted with (A-B) daytime brightness temperatures (orange circles) and (C-D) nighttime brightness temperatures (blue circles). Data was separated by surface morphology (rough vs. smooth). Average brightness temperature and TI responses for the area are displayed as horizontal lines with the corresponding color. The following THEMIS stamps were used: Daytime (I52274005) and nighttime and TI (I18321003).

Summary and Future Work

Analyses of surface thermophysical properties and flow morphology reveal that individual flows in Daedalia Planum respond differently to diurnal heating, suggesting that the area is not completely (or uniformly) covered by dust and fine-grained particles. The results provide important information about the eolian effects on the surface by suggesting that sand accumulates in the low lying regions of rough lava flow surfaces rather than uniformly. Furthermore, the identification of flows with potentially exposed lava outcrops now enables TI modeling to determine the percentage of rock plus fines that would produce the calculated TI values for the category C and D lava flows. This will ultimately determine whether or not it is possible to deconvolve the signature of only large outcrops. These results will constrain any changes in the down-flow composition and ultimately the emplacement process over time. Such an approach will also be applicable to other lava flow regions on Mars.

Acknowledgements

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References

[1] Putzig and Mellon. (2007) Icarus. 191, 68-94. [2] Presley M.A. and P.R. Christensen (1997) JGR, 102, E3, 6551-6566. [3] Crumpler L.S. et al. (1996) Geol. Soc. Spec. Publ., 110, 725-744. [4] Lang N.P. et al. (2009) J. Volc. And Geotherm. Res., 185, 103-115. [5] Ruff S.W. et al. (2002) *JGR, 107*, 5127. *[6] Crown D.A. and M.S. Ramsey (2016) J. Volc. Geotherm. Res., doi:10.1016/j.jvolgeores.2016.07.008. [7] Crown D.A. et al. (2014) AGU, Fall, abs. P41B-3906. [8] Crown D.A. et al. (2015) LPSC, XLVI, abs. #1439. [9] Edward C.S. et al., (2010) JGR, 116, E10008. [10] Fergason R.L. et al. (2004) JGR, 111, E12004. [11] Christensen P.R. et al. (2001) JGR, 106, 823, 871. [12] Kieffer, H.H. (2013) JGR 118, 451-470.*