SURFACE TEMPERATURES FROM MARS TO EARTH AND BACK: DEVELOPING NEW INTERPRETATIONS OF THERMAL INERTIA FROM GROUND TRUTH EXPERIMENTS.

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Introduction:

Recent thermophysical observations from rovers and landers have begun to reshape our understanding of the physical controls on thermal inertia relevant to Mars. Despite extensive satellite thermal infrared imaging of the planet, there is an insufficient number of ground-truths, and therefore a wide range of observed thermal trends in Martian sediments have remained difficult to interpret, with numerous non-unique solutions for a given thermal inertia (TI) [1]. Observations from MSL and other surface assets, however, hint that individual depositional settings appear to lead to the development of unique combinations of physical properties, mineralogy, and thermal inertia, which can be used together for more confident interpretation than with any single property alone [2–6].

The Mars Science Laboratory (MSL) mission has captured repetitive diurnal temperature observations of a wide range of surface materials over numerous sols. Units include fluviolacustrine environments, interbedded clays, cemented sulfates, active sand dunes, paleobedforms, and volcanic terrains, and Mars 2020 appears to be encountering a similarly diverse suite of deposits. In this work, we compiled *in situ* measurements from Mars to compare thermal properties of sedimentary deposits to an array of other remotely observable physical and compositional traits that we are testing for correlation.

To build a larger and even more detailed database, we have also collected paired thermophysical, spectral, compositional, and morphological data at multiple analog sites on Earth [7], representing a comparable suite of surface materials to those observed on Mars. We developed a new model that enables thermophysical results from Earth to be extrapolated to Mars [7]. Together, data from Mars and Earth expose an improved route to interpreting remotely-retrieved thermal data for Mars' surface.

Methods:

Thermal Inertia: is a material property controlling the rate of heating or cooling in response to an energy flux, and it is a function of thermal conductivity, density, and heat capacity. For geologic materials, higher TIs (≳600 $Jm^{-2}K^{-1}s^{-1/2}$) are associated with cemented surfaces and bedrock, while unconsolidated sediments show lower TIs. We assembled results from Mars missions, including Phoenix [8], Pathfinder [9,10], Viking I & II [9,10], MER [9,11], MSL [3–5], InSight [12,13], and Mars 2020 [14,15] in tandem with compositional data, deposit morphology, and depositional interpretations (e.g., [16]).

To expand the number of data points, we also studied basaltic sediments at field sites on Earth, where we derived TI and/or dry bulk thermal conductivity using multiple approaches (Fig. 1). Where feasible, a transient plane source probe (Thermtest TPS-EFF) was used to make direct *in situ* TI measurements. It was a challenge, however, to achieve reliable readings for the majority of sampling sites, since the instrument requires homogenous surface contact and fine grain sizes (≲150 µm), and the majority of natural sites that were analyzed were more variable and coarser-grained. A transient line source thermal conductivity probe (Thermtest TLS-100) proved somewhat better suited to the sites we studied, but the tool retrieves thermal conductivity rather than TI, and grain sizes that were too fine yielded poor results due to clumping and vapor diffusion.

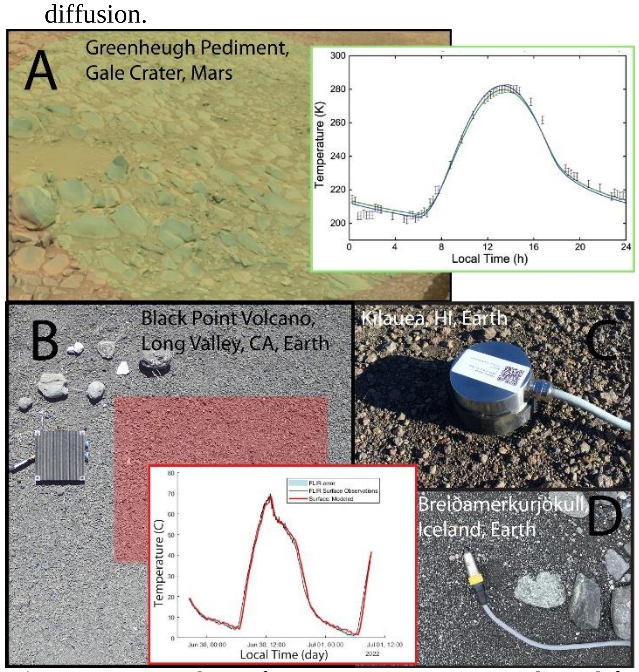

Figure 1: *Example surface temperature retrievals and fits for (A) Mars from MSL Sol 3418-3419 observations [7] and (B) Earth from June, 2022. (C) TPS-EFF placement. (D) TLS-100 placement.*

Our least disruptive tool for retrieving TI, and the approach most similar to that used by MSL, InSight, and Mars 2020, was to capture surface temperatures in time series using infrared imagery. Paired with energy flux data from a weather station, temperatures were then used to provide best fit models of bulk dry thermal conductivity [7]. Ultimately, thermal conductivity was translated from Earth to Mars using estimates of respective gas conductivities and a mixing model.

Grain properties and density: Martian grain sizes (Fig. 2) were taken from direct observations cited in literature or newly estimated from fine-scale imagery (e.g., the Mars Hand Lens Imager). Earth sediment samples were collected from each observed unit. Samples were sieved, weighed, and imaged under a microscope. Grain size distributions were parameterized from median (Fig. 2), spread, and skewness. Roundness and disc-rod index was averaged from 20 randomly selected grains in each sub-sample.

In order to calculate the natural density of the near surface soils, known volumes of material were collected using a metal cylinder and spatula. Larger sample volumes were calculated by measuring water displacement.

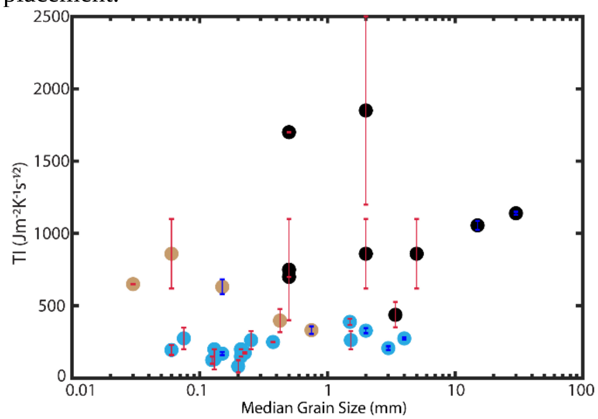

Figure 2: *Preliminary TI vs median grain size data using results gathered from multiple ground truth sources on Mars (e.g., MSL, InSight, MER - points with red errorbars), and multiple field campaigns on Earth (points with blue errorbars). Black dots: lithified, Beige: loosely consolidated, Cyan: unconsolidated.*

Spectroscopy: Characteristic VNIR reflectance spectra (350-2500 nm) of sieved subsamples and individual cobbles were captured using a Malvern Panalytical ASD FieldSpec. The same sample subsets were also measured for their thermal emission spectra (Fig. 3) using a Thermo Scientific Nicolet iS50R FTIR over 15-27,000 cm^{-1} (370-6667 nm). Samples were heated to 90°C and spectra were calibrated using 60 and 100 °C black bodies. For both reflectance and emission, distinguishing spectral features were parametrized from band depths.

Composition: To determine bulk mineral phases with greater certainty than VNIR and IR spectra alone, powdered subsamples were analyzed using a Rigaku MiniFlex 6G Benchtop X-ray Diffractometer (XRD). Another set of powdered subsamples was analyzed for chemical index of alteration (CIA) using a Cameca MBX Electron Microprobe (EMPA).

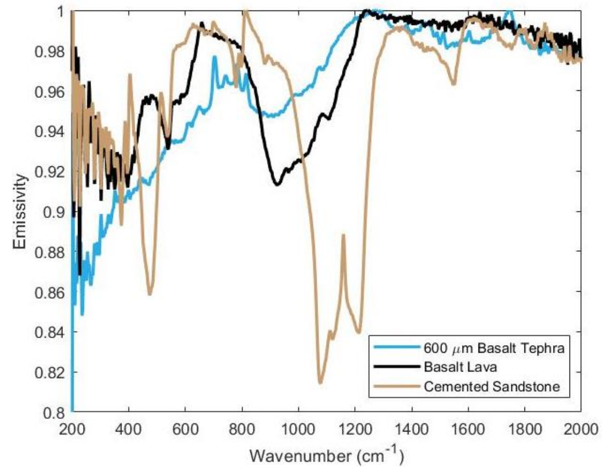

Figure 3: *Emission spectra of basaltic tephra, lava, and cemented sandstone samples from Woodhouse Mesa, AZ.*

Preliminary Results and Future Work:

Correlation Analysis: We are building a library of paired *in situ* thermophysical, spectral, compositional, and morphological measurements taken for Mars and Mars-analog sediments. Each of the measured sample traits are being assessed for correlation using principal components analysis and clustering, with the goal of using TI as a predictor for depositional origin.

Preliminary results indicate distinct regimes of parameterized traits for different major sediment sources (e.g., eroded lava, aeolian reworked tephra, fluviolacustrine cements). We plan to test these correlations using imaging datasets at previously well-studied sites (e.g., [1]) before applying results to study regions of uncertain depositional origins on Mars.

Acknowledgements:
This work is funded by the NASA FINESST Program (PLANET20-0138), MSL Participating Scientist Program (21-MSLPSP21-0062), and a NASA PSTAR grant (17-PSTAR17_2-0044). Mars data was accessed from cited works and the Planetary Data System.

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