

USING THERMAL INERTIA AND SHORT-WAVE INFRARED SPECTROSCOPY TO CHARACTERIZE LITHIFIED BEDFORMS ON MARS

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Introduction: Lithified bedforms, also called paleobedforms, are becoming increasingly identified across Mars. These features often appear similar in morphology to modern dunes but may host traits, such as superimposed impact craters, which are commonly associated with lithified material [1, 2].

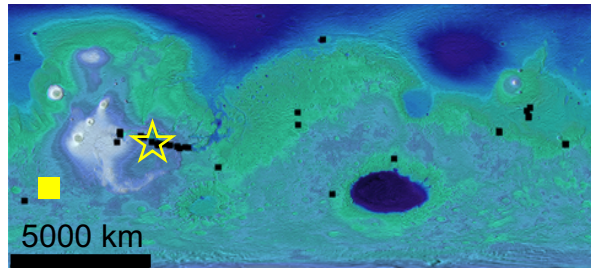


Figure 1: Colorized MOLA elevation map (white and green as high elevation, purple as low elevation) of Mars indicates best candidates of lithified bedforms as black squares. The yellow square marks Terra Sirenum, the location of Figure 2. The yellow star marks the location of Melas Chasma, discussed in *Results*.

These features are inferred to have first formed as active dunes or ripples and then be partially indurated, possibly along with burial, allowing the features to preserve their dune-morphology for at least thousands, if not millions, of years [1]. Understanding the specific circumstances of this preservation mechanism will provide insight into environmental conditions on Mars. We aim to constrain the mechanisms responsible for preserving the dune-like surface geometry of paleobedforms by leveraging their thermophysical and compositional traits.

Methods: Thermal inertia (TI) was derived with the KRC model [3] using surface brightness temperatures from Mars Odyssey's Thermal Emission Imaging System (THEMIS; [4]). Data were carefully selected from warm seasons to provide the lowest Noise Equivalent Δ Temperature (NEAT; reciprocal of signal-to-noise ratio) of the THEMIS instrument. Nighttime images (0300-0600 local solar time) and observations with low atmospheric dust opacity (<0.7) were chosen to reduce solar illumination effects and atmospheric influences in the model. Composition was determined by using spectral data from the Compact Reconnaissance Imaging Spectrometer for Mars (CRISM; [7]).

Thermophysical Analysis: TI is a material property commonly used to study how heat is conducted and dissipated throughout a surface.

It is represented as: $I = \sqrt{\kappa \rho c}$, where κ is thermal conductivity, ρ is density, and c is specific heat [8]. Thermal conductivity is the dominant factor influencing the TI of a geological surface. This is because for the different geological materials (e.g., on Earth as well as Mars), density and specific heat only vary by a few factors, whereas thermal conductivity can vary by orders of magnitude [9, 10].

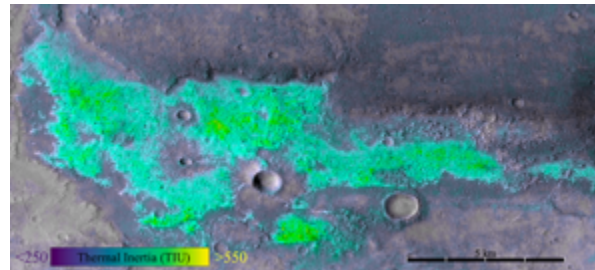


Figure 2: Colorized TI overlay on CTX visible imagery of Terra Sirenum. Notice the raised TI of the paleobedforms compared to its surrounding terrain.

Thermal inertia will be used in this work to determine the grain size distribution of paleobedforms. This is possible based on the strong power-law relationship between thermal conductivity – which can be converted to TI – and grain size [11], thus giving an idea of the degree of bedform lithification.

Compositional Analysis: Composition was evaluated using CRISM spectral data after applying standard atmospheric corrections [12].

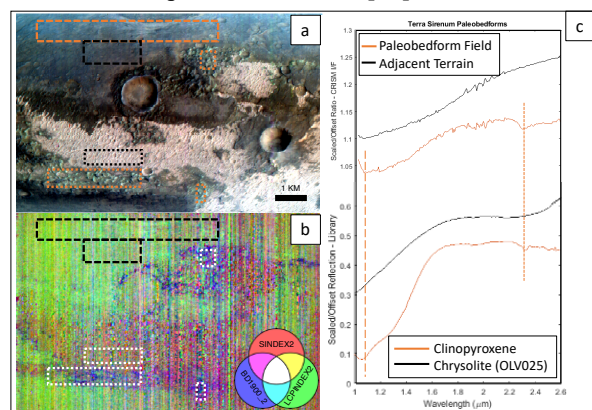


Figure 3: (A) CRISM imagery with ROIs colored to match the spectra in c, top (B) A parameter map where magenta indicates polyhydrated sulfates and green indicates low-calcium pyroxene. (C) Top: CRISM spectra, Bottom: laboratory spectra [13]. Fits are plotted in the same color as the corresponding CRISM spectra.

Full-Resolution Targeting (FRT) images were used when available. Lower resolution data such as MSW (Multispectral Window) and HSP (Hyperspectral Mapping) were inspected in locations with no FRT coverage, but these data typically provided ambiguous interpretations.

Unique spectral signatures were enhanced by ratioing regions of interest (Figure 3; white boxes) with bland regions (Figure 3; black boxes) within the same detector columns. Ratioing reduces the effect of dust and atmosphere within a scene and can emphasize minerals of interest.

Results: The TI of 52 paleobedform fields (Figure 1) were derived using KRC. Average TI was (250 ± 100 TIU), with minimum values of 35 TIU (corresponding to dusty regions identified with bland CRISM data and albedo maps) and maximum values of 400 TIU.

Figure 3 depicts the composition of a paleobedform field in Terra Sirenum. Compositional analysis reveals paleobedforms are most likely a pyroxene-rich basalt. In Melas Chasma [1; yellow star in Figure 1] and Terra Sirenum the terrain surrounding these fields have strong hydrated sulfate features at 1.9 and 2.3 μm , respectively.

Discussion: The low TI values of the studied paleobedforms are not significantly higher than that of modern aeolian dunes [1], which could imply thin dust coverings on material of varying lithification. However, in areas where distinct mineral species were detected through CRISM – as in Melas Chasma [1] and Terra Sirenum – significant dust covering is much less likely. Such low values most likely imply weak lithification and/or sandy materials [14]. One explanation for such low thermal inertia values is the cementing agents responsible for preservation (e.g., through groundwater upwelling [1]) have since been removed on large scales through weathering and erosion. Fracturing and mass-wasting of many paleobedforms, for example in Melas Chasma [1], support this notion. Cementation through groundwater upwelling is further supported by the detection of chloride signatures in Terra Sirenum which were believed to form through precipitation of ground and/or surface water [15].

Previous studies found modern wind directions to match those of paleobedforms in Melas Chasma [1]. The study also estimated how long paleobedforms could persist under current, aeolian abrasion rates. They estimate present-day rates would fully destroy a partially eroded paleobedform on a timescale of 10^3 - 10^6 years. While this could constrain upper paleobedform ages, the continued existence of the weakly lithified paleobedforms could also suggest abrasion rates have not fluctuated since their formation, which could have been much more than 10^3 - 10^6 years ago [1]. This prolonged surface stability further implies the regional climate of paleobedform fields has remained similar to present-day conditions.

Future Work: Modelling thermal inertia from surfaces composed of various grain sizes is very challenging. The complex thermal response from such surfaces produces diurnal and seasonal variation that would not be present in a homogeneous surface [14]. Therefore, if the thermal inertia changes over the course of the day, the thermal response is being affected by a mixture of grain sizes within the surface. Figure 4 shows the thermal inertia for paleobedforms in Terra Sirenum is higher pre-sunrise than it is pre-sunset, implying a heterogeneous material. Further mixture modelling is currently being performed to identify the most likely mixture scenario.

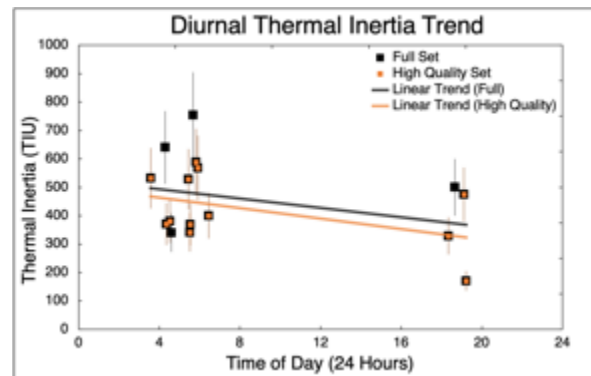


Figure 4: Each dot represents the modelled TI from a single THEMIS observation in Terra Sirenum. (Black) All available THEMIS images meeting the minimum observational requirements. (Orange) THEMIS observations of the warmest seasons from the full set to reduce NEAT.

Additionally, possible candidate paleobedforms in Gale crater identified by the *Curiosity* rover [16] will provide high-resolution ground truthing following the methods of [8]. The Ground Temperature Sensor from the Rover Environmental Monitoring Station aboard the *Curiosity* rover collects *in situ* surface temperatures [17] that can be used as input parameters in KRC to derive TI, thus providing a ground check on the accuracy of orbital methods.

References: [1] Chojnacki et al. (2020) *JGR Planets* 125(9); [2] Edgett and Malin (2000) *JGR: Planets* 105(1); [3] Kieffer (2013) *JGR Planets* 118(3); [4] Christensen et al. 2009 *AGU Meeting*; [7] Murchie et al. (2007) *JGR Planets* 112(5); [8] Edwards et al., (2009) *JGR Planets*, 114(11); [9] Piqueux & Christensen (2009b) *JGR Planets*, 114(9); [10] Piqueux & Christensen (2011) *JGR Planets*, 116(7); [11] Presley & Christensen (1997b) *JGR Planets*, 102(3); [12] McGuire et al. (2009) *Planetary and Space Science*, 57(7); [13] Mustard & Pieters (1989) *JGR Solid Earth*, 94(10); [14] Piqueux & Christensen (2009a) *JGR Planets*, 114(9); [15] Osterloo et al. (2008) *Science* 319(5870); [16] Bryk et al. (2019) *LPSC Meeting LPI* 2132; [17] Hamilton et al. 2014 *JGR Planets*, 119(4)