**Introduction:** The physical properties of rocks and sediments on Mars (e.g. grain size, porosity, vescularity, cementation quality, or degree of fracturing) have the potential to provide insight into past geologic surface processes and the origins of geologic materials. Mars Odyssey THEMIS continues to provide overlapping surface temperature ($T_{surf}$) observations at multiple times of day and year, now totaling nearly 18 years (~10 MY) of data. This data allows for better thermal, and therefore physical, characterization of geologic materials through the proxy property of thermal inertia ($I$) [1, 2].

Orbitally-derived $I$ values are usually given as apparent $I$ values using a single night-time temperature measurement. Apparent $I$ assumes that a surface is physically uniform laterally at observation resolution and to depth. However, dust, sediment, and loose rock cover, along with layering in bedrock and surface induration have been observed [3]; changing apparent $I$ values of the same surface over daily and yearly cycles corroborate this [4,5].

We seek to characterize the nature of physical heterogeneity in select locations on the Martian surface. For this work, we focus on unique surfaces at the Gale, Gusev, and Jezero crater landing sites, identified through previous rover observations in the case of Gale and Gusev, and through geologic mapping in the case of Jezero [6]. A better understanding of sediment and rock properties will provide constraints on the formation of bedrock on Mars as well as diagenetic and surface transport processes that have occurred.

**Methods:** Within each geologic unit of interest, small ($<$1 km$^2$) locations are selected based on minimal apparent surface complexity in HiRISE images and also the availability of overlapping 10-band THEMIS observations at both the pre-sunrise (3-6 AM local time) and the post-sunset (6-8 PM local time) windows. At these times the surface thermal contrast is greatest and albedo effects on $T_{surf}$ are minimized. We calculate $T_{surf}$ based on THEMIS band 3 (7.93 μm) radiance images, where surface emissivity is close to unity and atmospheric CO$_2$ has less effect on $T_{surf}$ calculations. Along with THEMIS thermal radiance values, visible albedo values derived from THEMIS VIS images are extracted. We exclude images that have infrared atmospheric dust opacity (TAUD-IR) values that are greater than 0.5 as well as any $T_{surf}$ that is lower than 160 K, where subpixel mixing of CO$_2$ frost may be occurring. TAUD values are retrieved as a function of location and season, from the database produced by [7].

We use the KRC thermal model [8] with spatial and temporal inputs from all remaining THEMIS observations to generate predicted $T_{surf}$ in a variety of scenarios of surficial heterogeneity for comparison with the measured THEMIS $T_{surf}$ to find a scenario of best fit. Currently, KRC permits up to two vertical layers as inputs. Lateral mixing is calculated assuming linear mixing of thermal radiances. In total there are 2257 physical configurations that we use for comparison: 2076 vertical scenarios in which we capture (a) variable sediment size cover and thickness over ranges of bedrock $I_s$ (400-2000 t/μm), and (b) duricrust or desert pavement scenarios where a higher $I$ material is layered over a lower one (all vertical scenarios with the top layer in equal proportions of the seasonal thermal skin depth); 158 lateral mixing scenarios in which we mix all sediment sizes with all bedrock types laterally within pixels in proportions of 25/75, 50/50, and 75/25; and finally 24 physically homogeneous scenarios ranging from dust to the most competent bedrock or water ice.

To determine best-fit models, we compare RMS differences between measured and modeled $T_{surf}$. Scores are calculated separately for pre-sunrise and post-sunset observations and then combined, since physical heterogeneity affects $T_{surf}$ in these two windows of time differently. Lowest RMS scores indicate model scenarios that are the closest fits. We also use leave-one-out cross-validation to evaluate how the exclusion of single THEMIS observations affect the best-fit combinations of higher and a frequency-of-use metric that can be used to determine the most likely scenarios based on available data. The geologic units of study we present here are from past, current, and future rover landing sites and are listed in Table 1 and shown in HiRISE imagery in Figure 1.

**Jezero Crater:**

Volcanic floor unit. Within the volcanic floor unit, as mapped by [6], there appears to be differential sediment cover from both VIS and IR imaging. Our results also suggest this. Our sample location closest to the Jezero delta (VFU1) shows best-fits consistent with thick (55 mm) deposits of 400 μm sand (Fig. 2a). However, moving away...
from the delta into the floor of the crater (VFU4) this same unit looks to have thermal contribution from laterally scattered finer deposits (possibly dust and sand mixed) and a higher I material, possibly representing the actual bedrock constituting the volcanic unit (Fig 2b). The higher I end-member shows values that fall more within vesicular or pyroclastic basalts (~600-1200 tui), as opposed to denser, more effusive basalts (predicted to be >2000 tui [9]). The thicker (55 mm) sediment covering without surf ace bedrock contribution proximal to the delta may be derived from the breakdown of the delta itself, whereas distal, thinner sediments toward the center of the crater may be a combination of transported delta sediment and wind-borne dust.

Light-toned floor unit. The best-fit scenarios selected are non-unique for the light-toned unit. However, VIS imagery suggests the light-toned rock is heavily fractured and covered by patches of sediment. The fine sand laterally mixed with bedrock of 900-1100 tui, represented by the green dots in Fig 2c, matches most closely with what has been imaged by HiRISE.

Western delta deposits. The western delta best-fit scenarios are spread between dust and medium sand for the lower I material and low to moderate values for the higher I material Fig 2d). It is possible that the two-component material scenarios do not adequately capture what is likely a multi-component physical mixture of materials. Further, there may be both vertical layering and lateral mixing of physically different materials in that multi-component system. However, based on our results, we can conclude that the delta is not likely to be made of very competent rocks. The fact that other units may have sediment cover derived from the delta also suggests that it is weathered relatively easily.

Gusev Crater:

Plains unit. The plains unit on the floor of Gusev Crater is consistent with fine sand (200 μm) below a thin covering of higher I material (Fig 3a). This would suggest that the upper few mm of sand have been inducted in the location that we tested, and this agrees with observations made by the Spirit rover during both driving and digging [10].

Columbia Hills rocks. The thermal results we have obtained from sampling the Columbia Hills rocks suggest a thick cover of 400 μm sand, but also contribution from a high I (1800-2000 tui) bedrock layer below (Fig 3b). I values this high can suggest competent rocks, or infilling of vesicle or fracture space by sediment, which increases the solid conductivity of the rock.

![Figure 3: Bubble plots displaying best-fit scenarios from leave-one-out results from Gusev Crater geologic units.](image)

Gale Crater:

Bagnold Dunes. Some of the Bagnold Dunes thermal results are consistent with thick (> 64 mm) deposits of 400-500 μm sand, which is corroborated by [10] in their rover-based observations ([11] reports 425 μm sand). However, there are several non-unique scenarios selected both by RMS fits and the leave-one-out method as possible fits that do not match what has been observed both by HiRISE and from the ground. It is unlikely that we would be able to detect bedrock below these dunes on thermal skin depth scales.

Adjacent rocks. The rocky surface that we sampled has two possible scenarios: (1) a lateral surface mixture of fine sands with higher I rock, or (2) vertical layering of fine-medium sands over a lower I rock (Fig 4b). Visual imagery seems to favor the first possibility, given that lateral mixing is apparent in the photos. Rocks in this area have been shown by the Curiosity rover to be both resistant to physical weathering and also to have been eroded in the past by wind abrasion [12].

![Figure 4: Bubble plots displaying best-fit scenarios from leave-one-out results from Gale Crater geologic units.](image)

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