FROM GRAINS TO BOULDERS: MORPHOLOGICAL ANALYSIS OF THE BONESTELL CRATER ALLUVIAL FANS USING ORBITAL DIRECTIONAL INFRARED SPECTROSCOPY

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Introduction:

The depositional styles and sedimentary characteristics of Martian alluvial fans provide valuable records of past fluvial activity, offering insights into surficial processes, water volumes, transport energy, and potential climatic conditions [1-3]. Whereas terrestrial studies typically analyze these aspects using detailed in-situ stratigraphic examination, the limited coverage of high resolution orbital image data and ground-based observations pose challenges to investigating Martian fans. However, by leveraging correlations between thermophysical properties and surface physical characteristics, we model the spatial distribution of surface unit coverage, sub-meter features, and induration state of the fans within Bonestell Crater.

Situated within Acidalia Planitia, Bonestell Crater features relatively young, well-preserved alluvial fans with incised channels and a symmetrical scarp edge, suggesting significant fluvial modification. Unlike older fan structures, Bonestell's fans display steeper slopes and less well-defined catchments, hinting at shorter-lived fan activity and potentially correlating with crater formation processes and localized hydrological systems [4].

Methods:

This study combines new Routine Off-nadir Targeted Observations (ROTO) THEMIS thermal infrared (TIR) data with existing THEMIS-derived quantitative thermal inertia (TI) data [4] and high-resolution visible image data (CTX and HiRISE) to analyze the fan surfaces. THEMIS ROTO data were acquired in 2023 at emission angles from -34° to +33° shortly before Martian sunset. These data underwent standard processing and atmospheric correction [5]. TI values along the fan were extracted from the THEMIS quantitative global mosaic [4], and the KRC thermophysical model [6] was then used to predict the distribution of distinct TI units. Retrieved TIR emission spectra of the selected fan were modeled to determine the abundance of dust mixed laterally with higher TI material [7]. This comprehensive approach is designed to determine the current state of the fans and their formation by pairing thermal inertia, thermal spectroscopy, and image analysis.

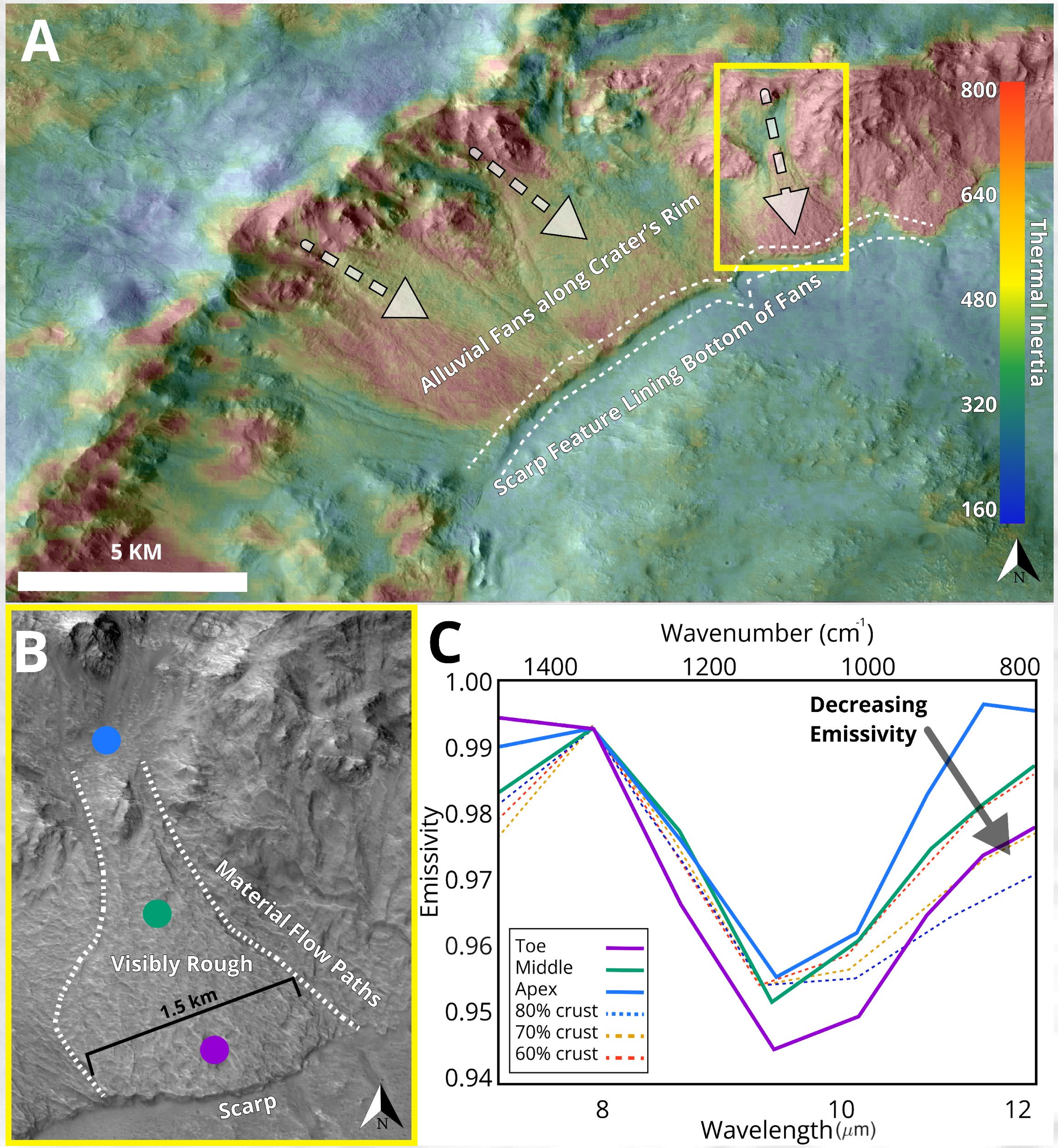

Fig 1. (A) CTX image (F04_037413_2225_XN_42N030W) of Bonestell Crater's north rim combined with colorized THEMIS TI showing the alluvial fan units. A 51% increase in TI from apex to toe is seen for most fans. **(B)** HiRISE image of the fan analyzed, which shows the surface texture and location of TIR spectra (dots). **(C)** Retrieved THEMIS TIR spectra (solid lines) from the ROTO data compared to the KRC modeled synthetic spectra (dashed lines). Decreasing emissivity (increasing negative spectral slope from shorter to longer wavelengths) occurs from the apex to the toe. KRC modeling of 70-80% indurated material plus 20-30% dust best fit the ROTO data.

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Results:

A clear progression is observed from the fan apex to the toe, with increasing thermal inertia (TI) and temperature (Fig. 1A), more distinct surface roughness down fan (Fig. 1B), and increasingly negatively sloped spectra (Fig. 1C). The observed TIR spectra and brightness temperatures retrieved from the ROTO data are best matched by a synthetic spectral mixture of moderate TI (indurated) material (800 TIU) and low TI dust (75 TIU).

Interpretations:

- The fan apex shows near-isothermal conditions with a TI of approximately ≈ 350 TIU, suggestive of coarse sand [8].
- The fan toe is modeled as an areal mixture of 70-80% indurated material plus 20-30% fine dust [8,9].
- There is an increase in cementation down fan, indicating possible increasing groundwater influence proportional to elevation.
- The down fan increase in spectral slope suggests sub-pixel anisothermality due to increased abundance of the higher TI component mixed with dust.

Conclusions:

The TI, spectral gradients, and HiRISE image data collectively reveal significant post-emplacement cementation and weathering within Bonestell Crater's alluvial fans. The sensitivity of the ROTO data TIR spectra to the meter-scale reflects an increase in induration (not block size). Coupled with the absence of dendritic channels, this suggests a groundwater-driven processes, particularly at lower elevations [10]. The formation of scarp-fronted fans here may imply deposition in standing water, into a glaciated crater floor, or may arise from post-depositional aeolian erosion [11]. Further modeling and compositional analyses are planned to separate these hypothesis and provide constraints on the timing and location of potential water reservoirs.