GROUND-BASED THERMAL ANALYSIS OF A TERRESTRIAL ROCK GLACIER AS AN ANALOG TO MARTIAN LOBATE DEBRIS APRONS

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Introduction

A number of periglacial features have been identified on Mars, including concentric crater fill, lineated valley fill, pingos, and lobate debris aprons. [e.g. 1,2]; the presence of massive ice has been confirmed in some lobate debris aprons via spacecraft radar [3,4]. These debris aprons are geomorphic features that extend from local topographic highs and have a distinct lobate form and relatively steep margins [e.g. 5-7]. Some lobate debris aprons display visible surface lineations approximately parallel to the downslope direction and/or traverse ridge and furrow structures towards the feature toe. In the thermal infrared, many debris aprons exhibit observable variations in thermophysical properties similar to features observed in visible images, such as downslope parallel lineations and curvilinear variations near apron toes [7,8]. These apron properties suggest formation by fluid or plastic flow, and are similar in morphology to terrestrial rock glaciers, debris-covered glaciers, and protalus ramparts.

Rock Glaciers. The term 'rock glacier' [10] in the terrestrial literature refers to a steep-margined spatulate mass of debris, sourced from nearby mountain slopes, that flows downslope due to the presence of ice within the debris. Active features have margins with slopes steeper than the angle of repose; inactive rock glaciers have slopes that have degraded to angles at or below the angle of repose. Surface morphologies often exhibit flow features like ridges and furrows [11-14]. Possible formation mechanisms for these features include flow of an intimate mixture of rock and ice or flowing glacial ice covered by a thick layer of debris. Flow occurs both by slow downslope creep and faster catastrophic mass movement events [15-17]. Sorting of surface debris by flow forms features such as lineations parallel to flow direction and compressional ridge and furrow structures. This produces particle size and packing variations that contribute to variations in thermal inertia, which produce variations in temperature than can be observed in thermal infrared datasets.

Method

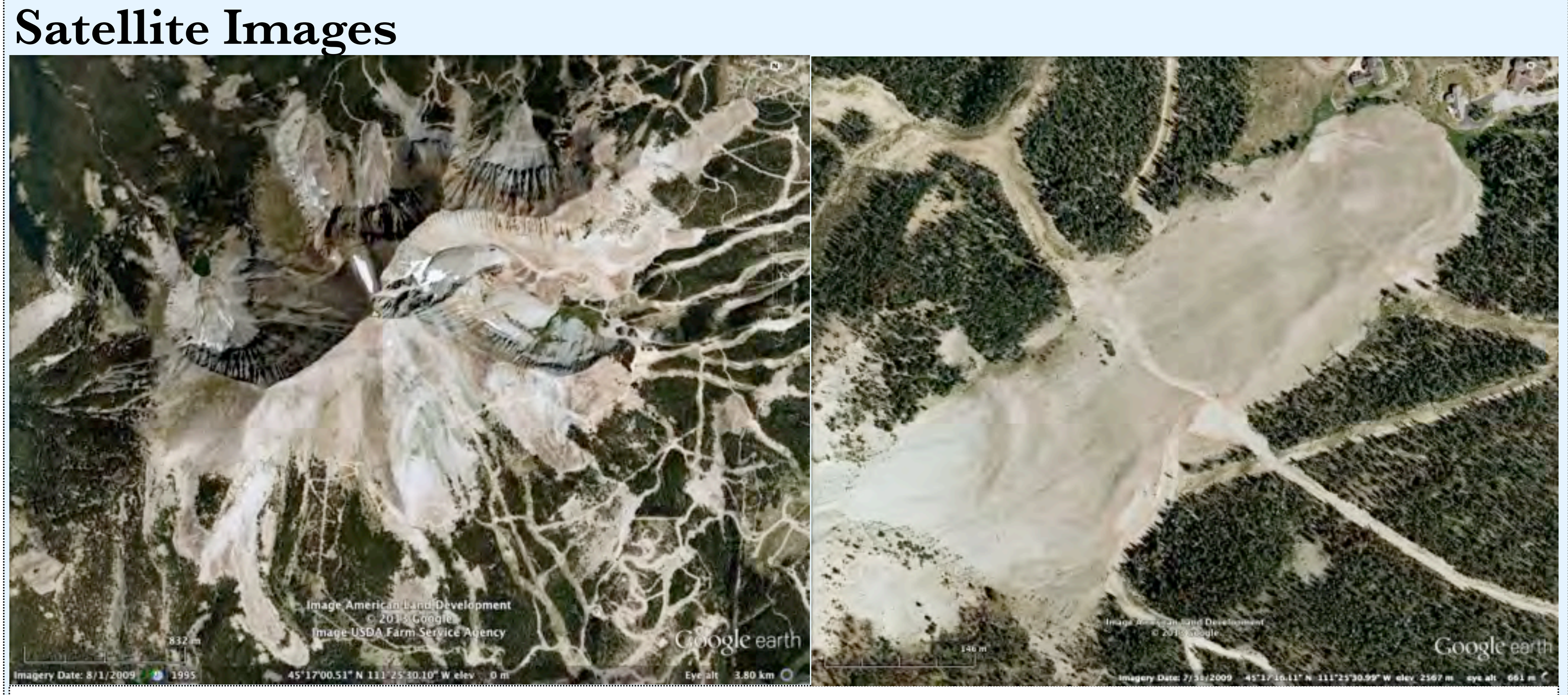
Satellite images of the field location from the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) were examined to determine if thermophysical variations were visible on the surface of the eastern Lone Mountain rock glacier. ASTER visible/near-infrared (VNIR) images have 3 wavelength bands (0.5 - 0.86 µm) and a spatial resolution of 15 m/pixel, while thermal infrared (TIR) images have 5 bands (8.125 - 11.65 µm) at 90 m/pixel [18]. These specifications are similar to those of the THEMIS instrument aboard Mars Odyssey, which has 5 bands at 18 m/pixel in the visible (VIS) and 8 bands at 100 m/pixel in the TIR [19]. Relative changes in surface thermophysical properties were examined using apparent thermal inertia (ATI), which is related to the surface albedo and the day-night temperature difference [20,21], as Earth's atmosphere makes the thermal modeling necessary to determine absolute thermal inertia values complex.

Thermal imaging of this relict feature was completed using a FLIR Systems ThermaCam S45, which operates in the 7.5-13 µm telluric transmissivity window and has a temperature accuracy of 2K. The camera has a field of regard of 24° × 18° and produces 320x240 pixel images. A series of images were acquired over a period of time to examine changes in temperature, which were then arranged to produce a image "cube" with temperature along the z-axis. Data were acquired during sunset and sunrise, where the change in surface temperature due to changing solar input will be greatest. Ideally, a full diurnal curve would be best for calculating thermal inertia, but observations at dusk/dawn are typically used to estimate thermal inertia based on these short term changes: similar datasets have been used to examine variations in sediment on alluvial fans [22].

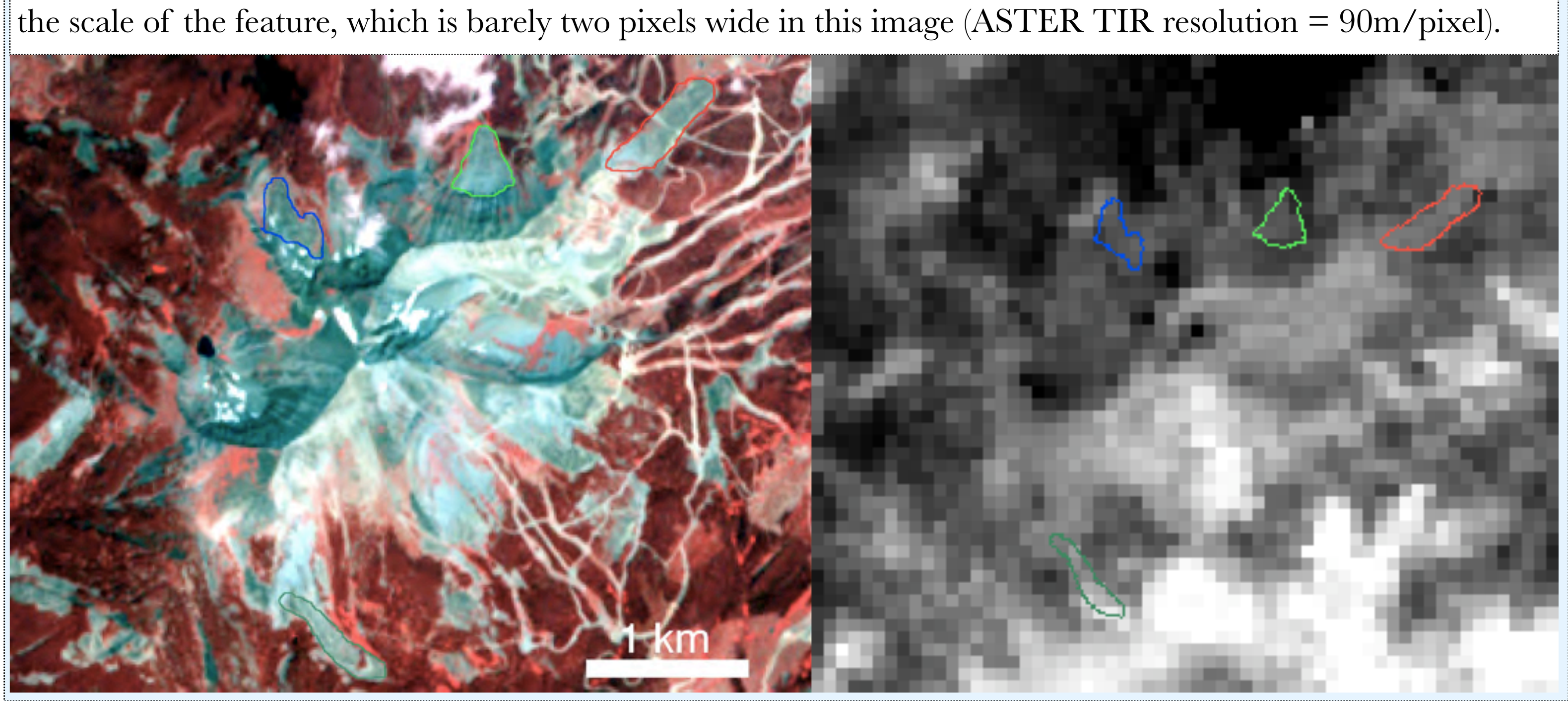
Visible panoramas (some with similar geometry as the thermal images) were acquired using a GigaPan® robotic camera mount with a point and shoot digital camera. The GigaPan mount takes photos with the camera at each point in a grid based on user inputs (upper left corner, lower right corner, and image field of view). Images are stitched together using software designed for use with the GigaPan and can be zoomed to see details at the resolution limit of the camera.

Examination of the surface topography of the eastern Lone Mountain rock glacier was accomplished via a series of GPS traverses, which were interpolated to form an elevation grid. The results from the gridded dataset were compared with field pans to determine if slopes seemed reasonable.

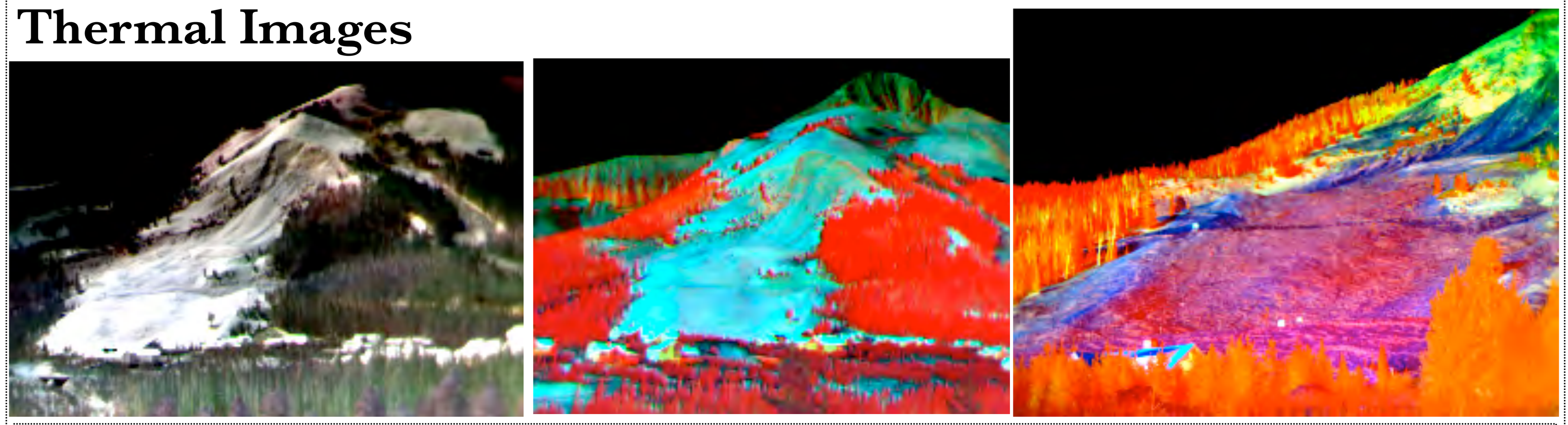
Satellite Images



Lone Mountain (Big Sky, MT; 111°25'W, 45°17'N) has multiple rock glaciers, most inactive [23]. Although most are not easily accessible, one relict feature on the east slope extends into a ski resort, where its surface morphology helps form a freestyle slope during the ski season (see Google Earth images above, with a close-up of the rock glacier examined by this study on the right). The rock debris consists mostly of local volcanic materials (dacite/andesite) with a small contribution from sedimentary units (sandstones). The middle portion of the rock glacier is accessible from ski slopes, while the toe is reachable by road where it extends into an area of ski cabins. The rock glacier examined in this study is outlined in red on the false color ASTER image (below left) and apparent thermal inertia image (below right). The lack of variation in the ATI image is likely due to the scale of the feature, which is barely two pixels wide in this image (ASTER TIR resolution = 90m/pixel).

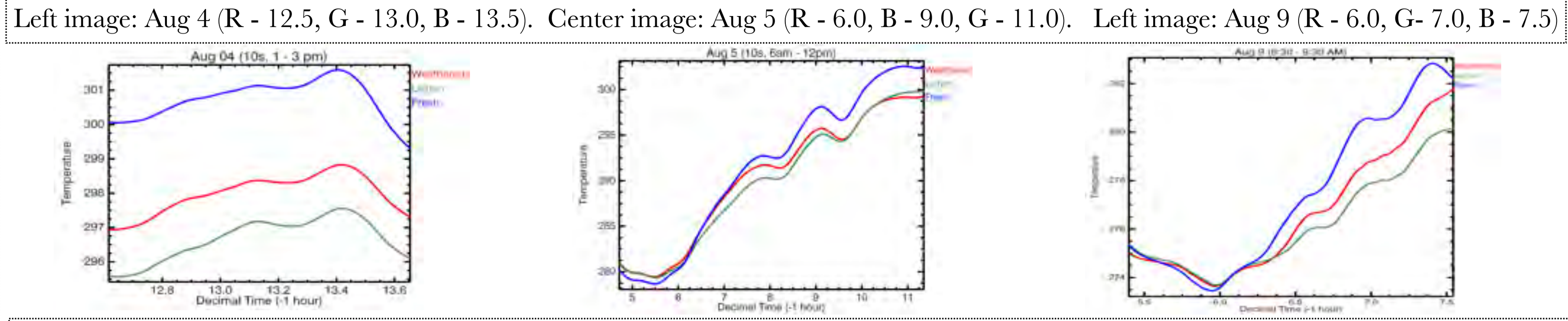


Thermal Images

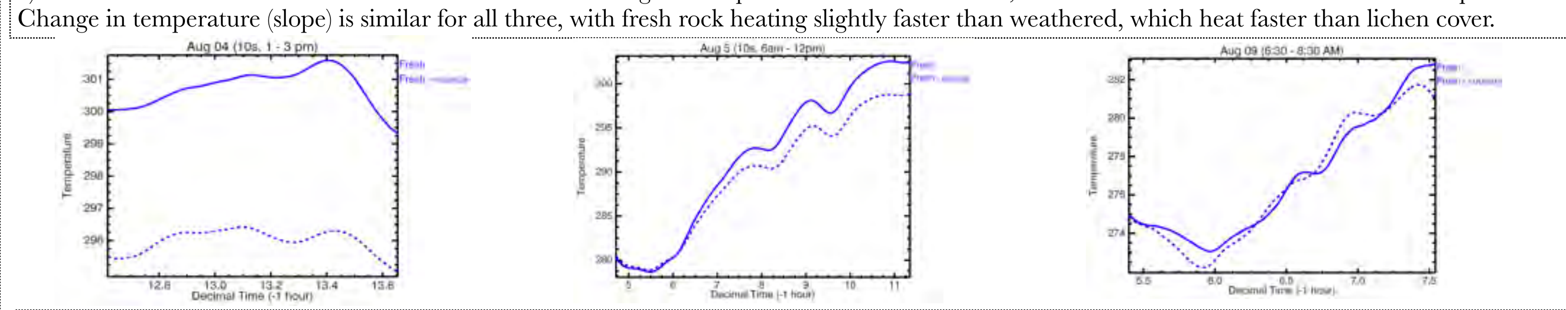


Images derived from thermal image cubes, created by placing the temperature image from a different timestamp in the RGB channels to illustrate variations in time. Corresponding temperature vs. time curves are below: actual local time is 1 hour ahead of image values.

Left image: Aug 4 (R - 12.5, G - 13.0, B - 13.5). Center image: Aug 5 (R - 6.0, B - 9.0, G - 11.0). Left image: Aug 9 (R - 6.0, G- 7.0, B - 7.5)



a) Effect of surface character: fresh rock surfaces have higher temperatures than weathered, and lichen-covered areas the lowest temperatures. Change in temperature (slope) is similar for all three, with fresh rock heating slightly faster than weathered, which heat faster than lichen cover.



b) A comparison of thermal image results for fresh surfaces on different slopes. Fresh material near the toe of the rock glacier reaches higher temperatures at a slightly faster rate than material exposed near the source. Orientation of the source slope towards the east suggests it would heat faster in the morning than the flat toe; other factors such as packing density or underlying bedrock may be responsible for the observed differences.

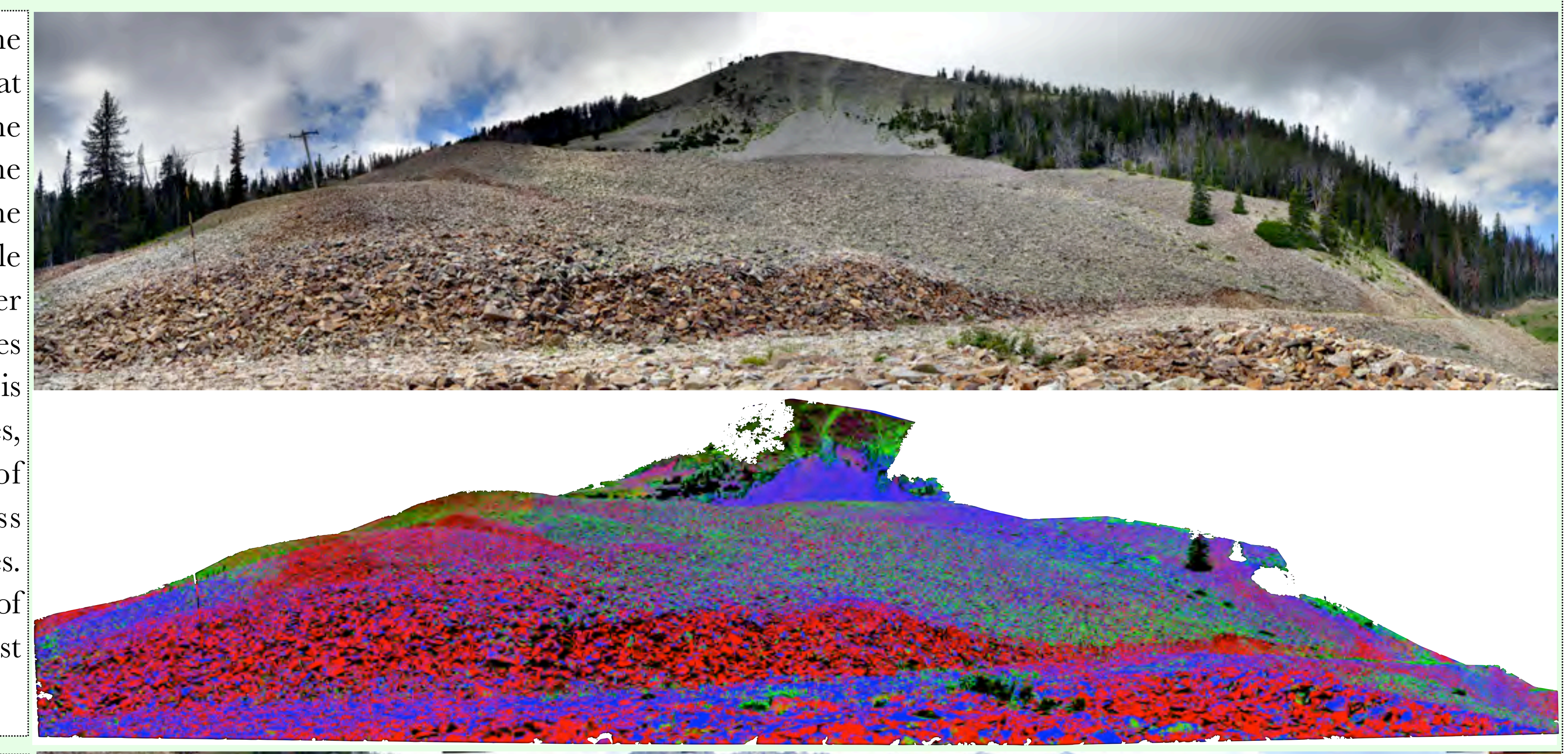
Visible Images

Field photos and panoramas of the eastern Lone Mountain rock glacier with associated image classifications. For each panorama, a maximum likelihood classification was performed on the portion of the image containing the rock glacier. Training ROIs were created for five classes (weathered surfaces, lichen, fresh rock surfaces, vegetation, and shadows). In the classification images below, red areas indicate weathered rock surfaces, green lichen covered rocks, and blue fresh rock surfaces (black pixels are classified as either vegetation or shadow).

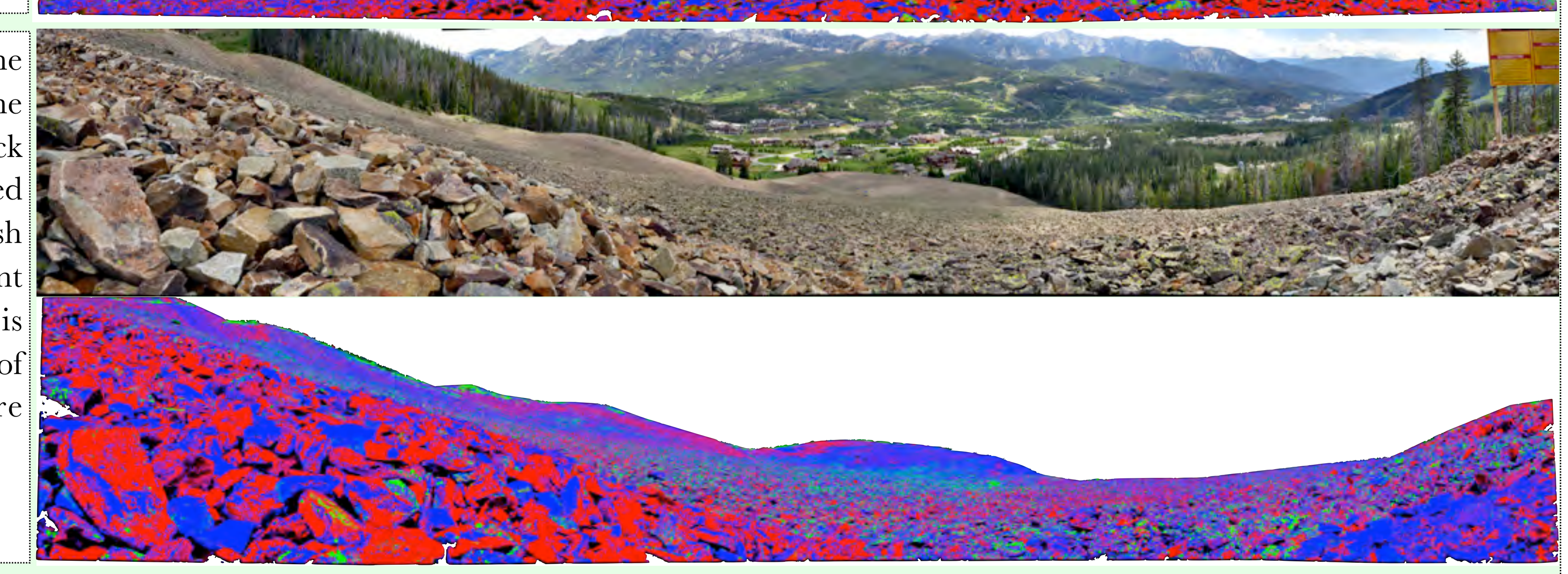
Above: field photos indicate green lichen cover is more common on flat slopes with less along steep edges.

Below: GigaPan (left) and thermal camera

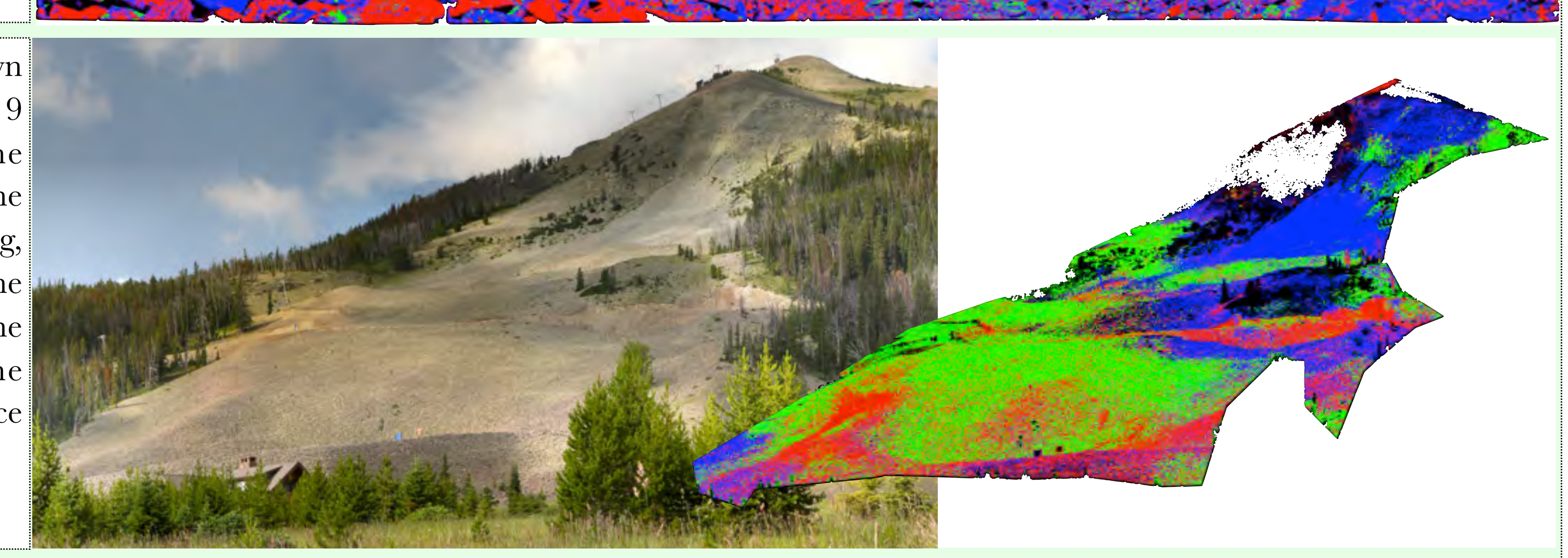
a) Panorama looking towards the source from the access road that cuts approximately through the middle (see satellite images to the left for location). Material in the "road cut" is weathered, while rocks in the path show fresher surfaces. Lichen cover dominates the middle of the feature and is less prevalent on steeper slopes, possibly due to ponding of surface water and/or mass wasting of debris from slopes. Source material (below the top of the mountain) has the freshest surfaces, as is expected.



b) Panorama looking towards the rock glacier toe, taken from the access road. Much of the rock debris in this area exhibits a red weathering rind, with some fresh faces representing more recent fractures. Lichen coverage is densest towards the middle of the feature, although more difficult to see in this view.



c) Panorama acquired with dawn thermal imaging on August 9 (similar line of sight). The material towards the toe of the glacier exhibits more weathering, with more lichen cover in the center of the toe than on the compressional ridges at the margin. Debris near the source appears freshest.



Results

- Thermal field images of this inactive rock glacier indicate variations in thermophysical character of the feature that are likely related to multiple physical processes. Observed variations appear related to changes in alteration state (fresh vs. Weathered), lichen cover and possibly packing state and particle size.
- Comparison between visible field panoramas and thermal images suggests a correlation between surface temperature and the amount of weathering of the surface. This may be in part due to changes in albedo between fresh and weathered surfaces, but fresh surfaces appear brighter than weathered in field photos (which suggests a higher albedo and subsequent slower heating). This may be due to a change in albedo that is not apparent in images, but more likely it represents a change in thermophysical properties of the material as it weathers. The alteration minerals may have different thermal properties or the surface character may affect short term heating.
- Lichen cover, considered an indication of inactivity, is prevalent on this feature on flatter slopes. The lichen cover has a different thermal response than rocks and must be considered when examining thermal images of inactive terrestrial rock glaciers.
- There is some indication of variations in thermophysical properties due to changes in packing density or underlying surface materials that should be explored.

Conclusions

Thermal field imaging of an inactive rock glacier on Lone Mountain (MT) indicates that thermophysical variations visible in thermal data are related to identifiable surface characteristics, such as amount of weathering and lichen-cover. Although these relationships are not simple, the results from this study suggest that field imaging can provide a useful analog to Mars datasets, especially when the terrestrial features are smaller than can be resolved in satellite datasets (as is the case here). Future work might rely on additional datasets to help understand complex relationships such as thermophysical variations due to changes in packing state and alteration rinds as well as the differences between the thermophysical properties of inactive and active features.

References

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