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

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Introduction: Subsurface ice is thought to be related to the formation of a number of geomorphologic features on Mars, including layered ejecta craters, thermokarst features, chaotic terrain, patterned ground, pingos, lineated valley fill, concentric crater fill, and lobate debris aprons [1-7], confirmed by radar results suggesting the presence of massive ice underneath a talus layer in some of these features [8,9]. Lobate debris aprons are masses of debris extending from topographic highs that form distinct lobate masses with sharp margins, analogous to terrestrial rock glaciers, ice-lubricated debris flows, or debris-covered glaciers. Terrestrial rock glaciers are thought to form by downslope flow of massive ice lenses (as in a debris-covered glacier) or via permafrost creep when ice and rock debris are intimately mixed. This flow forms textures in the surface debris that can be observed from both satellite and ground-based imagery. In addition to surface textures, rock debris sorting and packing vary across the feature due to flow should produce variations in the thermophysical character of the feature.

Background: The term "rock glacier" [10] in terrestrial geomorphology 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. Field studies suggest that the upper few meters of debris in an active rock glacier are free of ice [11-14]. 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. Such variations have been noted in thermal inertia images of lobate debris aprons derived from nighttime thermal infrared data from the Thermal Emission Imaging System (THEMIS) [18,19]. Similar variations are observed in thermal infrared images of terrestrial rock glaciers from the Advanced Spaceborne Thermal Emission and Reflectance Radiometer (ASTER), which is similar in spectral and spatial resolutions to THEMIS [20,21]. Although difficult to see due to the smaller scale of terrestrial features, variations in thermophysical properties appear to reflect the relationship of ice and rock within the debris (intermixed rock and ice vs. massive ice covered by debris) [22].

Ground-Based Analysis: Lone Mountain (Big Sky, MT) has a number of mostly inactive rock glaciers [23]. Although most are not easily accessible, one relict feature on the east slope extends into a ski resort (Figure 1), where its surface morphology helps form a freestyle slope during the ski season. 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.

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° x 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 [24]. Visible panoramas with similar geometry as the thermal images were acquired using a GigaPan® robotic camera mount.

Detailed examination of the surface character of the eastern Lone Mountain rock glacier was accomplished via a series of traverses. Photographs of surface debris were acquired along the top of the feature along with GPS coordinates. The results of these traverses can be compared with the thermal images to determine what surface characteristics are likely responsible for observed thermophysical variations.

Preliminary Results: Thermal images of this inactive rock glacier indicate variations in thermophysical character of the feature that are likely related to multiple physical processes. Observed variations (Fig. 2) appear related to changes in albedo (exposure of fresh vs. weathered surfaces), slope, packing state and particle size, and possibly hydration state and lichen cover.

Conclusions: The initial analysis of the thermophysical expressions of a relict terrestrial rock glacier suggests that there may be a relationship between the observed variations and the type of downslope ice movement responsible for forming the feature. Detailed examination of these results should help differentiate between thermophysical variations caused by surface cover (weathering, lichen) and those more intimately related to flow processes.

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Figure 1: ASTER VNIR reflectance false color (left) and apparent thermal inertia (right) images of Lone Mountain, (MT). The rock glacier examined in this study is outlined in red. Although variations in apparent thermal inertia are observed on terrestrial rock glaciers, these are too small for variations to be visible at ASTER resolution.

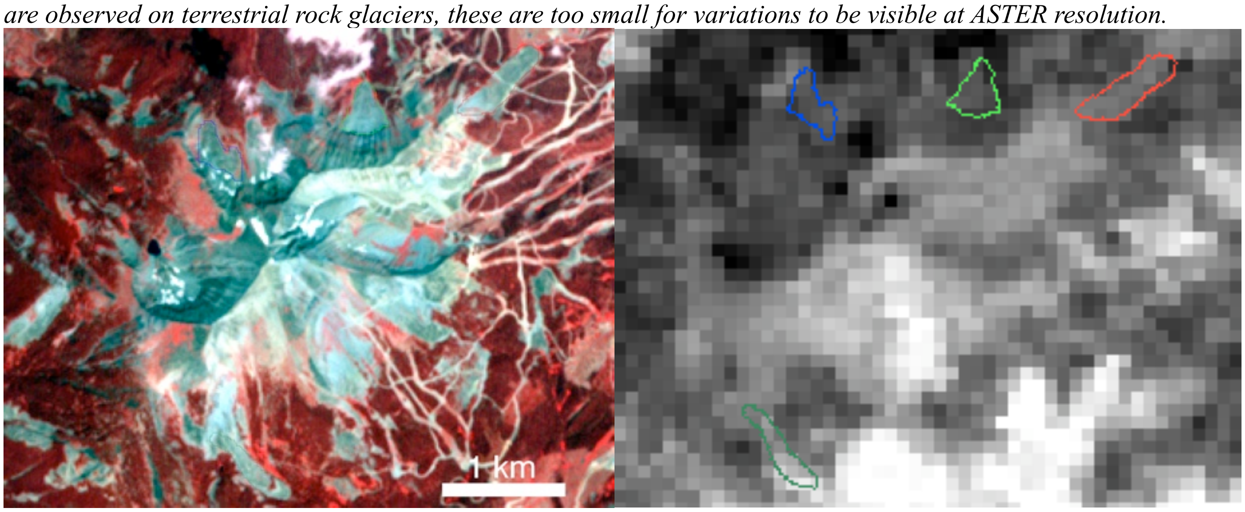

Figure 2: Photo with RGB composite of ground-based thermal images: areas in red warmed relatively quickly (low thermal inertia), while those with high green values have more moderate thermal inertia and those with high blue values have the highest thermal inertia. The inactive rock glacier appears mostly cyan, but exhibits variations in color that are likely related to changes in particle size and packing (note differences from the source to the toe).