REMOTE THERMOPHYSICAL OBSERVATIONS OF TERRESTRIAL INVERTED RELIEF FEATURES.

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Introduction: Inverted channels and sinuous ridges are well studied sedimentary features on Earth, and with the discovery of inverted relief features on Mars, these features are now being considered as analogs for their putative Martian counterparts [1, 2, 3]. On Earth and Mars, the inverted topography of these features indicates they are composed of well-cemented, relatively large clast-size materials or are capped by lava flows that are resistant to erosion. Previous studies [4] have shown that, on Earth, the technique of using a simple day-night temperature difference image (ΔT) can be used to reveal surface (top ~10 cm) heterogeneities in particle size and degree of induration. We examine ASTER-derived (Advanced Spaceborne Thermal Emission and Reflection Radiometer) ΔT images from locations in eastern-central Oman near Barzaman and southeastern Utah near Green River and compare documented surface grain sizes and degree of induration [5, 3]. The relationships between ΔT observed from orbit and ground-truth measurements of the inverted features show that thermal imaging can provide insight into weathering histories of inverted surface features.

Inverted channels on Earth: Inferred inverted channels have been identified at a number of sites on Mars, with a range of depositional environments from stream networks [6] to alluvial fans [7] to deltaic systems (e*.g.,* Eberswalde) [8]. As a potential analog to these features, we examine inverted topography interpreted as paleochannels in an alluvial fan in east central Oman near Barzaman [5] and previously studied inverted sinuous ridges in southeastern Utah [3]. Terresterial analog sites were selected in arid environments where vegetative cover is minimal.

The inverted channel deposits near Barzaman, Oman are part of a large multi-phase alluvial fan system that may date from the Pliocene. Individual channels are traceable for over 20 km (darker toned features in Figures 1 and 2a). The channels themselves are mantled by a monolayer of varnished, cobble- and gravel-sized quartz particles up to 20 cm in diameter, that are undergoing extensive mechanical weathering (*e.g.,* aeolian abrasion) to smaller size particles. All that remains is a thin gravel mantle underlain by 10-20 cm of clast-free silty sand [5] while surrounding surfaces are composed of calcite-cemented clay-rich duricrust (lighter toned features in Figures 1 and 2a). The gravel mantling has had an armoring effect, protecting underlying calcite-cemented duricrust from erosion and causing these channel deposits to become positive features rising up 20 meters above the surrounding landscape.

Inverted sinuous ridges southwest of Green River, Utah, are much older (Lower Cretaceous) than the paleochannel deposits in Oman [9]. These lithified channel deposits differ in origin from the well-cemented deposits in Oman. Surfaces of the inverted ridges are composed of resistant, silica and/or calcite-cemented sandstone and conglomerate that are being exposed as surrounding, weaker mudstones are eroded. This erosion creates ridges that extend for up to 8 km and rise 10's of meters above the landscape. The uppermost surfaces are varnished.

Methods: ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) orbital day and night surface temperature images (to provide diurnal ΔT), are co-registered and subtracted for each fan [4, 10]. The change in temperature (ΔT) of a pixel from the coldest to the warmest times of day is used as a proxy for the relative TI of the surface. Although Apparent Thermal Inertia (ATI) [11], which is a function of both the albedo and ΔT is more commonly used on Earth, we have found that differences in illumination of lit and unlit sides of the inverted features results in spurious values of ATI. ASTER was chosen for its similarity in spectral and spatial resolution to THEMIS, which will facilitate future comparisons to Martian alluvial fans. For Mars, we correlate THEMIS band 9 brightness temperatures with a lookup table for the best fitting season, time of day, latitude, surface pressure, dust opacity and albedo to arrive at an optimal TI [12].

Results: Inverted channels in Oman appear as darker toned linear features in both Figure 1 and Figure 3a. On the Oman fan ΔT's of inverted channels are generally higher (relatively lower TI) than their surroundings (Figure 3b), indicating a smaller grain size or less indurated material in the top ~10 cm of the surface. These results are consistent with previous observations of channel gravel disintegration at the surface and the indurated character of the calcrete-cemented duricrust surfaces [5].

Low albedo features in Figure 3 (*top*) are sinuous ridges in Green River, UT. Sinuous ridges show lower ΔT values (relatively higher TI) in Figure 3b than their surroundings indicating a larger grain size or a more heavily indurated surface. A previous ground study of these features [1] indicates surfaces are well cemented, with little fine-grained sediment at their surfaces. The surface material surrounding these inverted channels is primarily mudstone. These factors contribute to the lower ΔT values of the sinuous ridges in Figure 3 (*bottom*).

Conclusions: Inverted relief features on the alluvial fan in Terra Tyrrhena, Mars are lower in TI and are elevated in silica content [7]. On Earth, increased silica content can be the due to the development of clay-mineralogies within weathered, desert varnished surfaces [13]. Results from our terrestrial study in Oman indicate inverted channel surfaces with higher ΔT (relatively low TI) have undergone mechanical weathering processes resulting in grain-size reduction relative to surrounding surface materials. In Green River, UT, the inverted channels are well-indurated at the surface, and have a low ΔT (relatively high TI). Although Green River, UT inverted channels are varnished, they are not characterized by grain-size reduction due to aeolian abrasion or rock disintegration. We have shown that thermal images of terrestrial inverted relief features have a range of thermophysical expressions (relatively low TI in Oman and relatively high TI in Utah). In both terrestrial cases, materials surrounding the inverted channels are well consolidated (indurated calcrete-cemented duricrust in Oman and mudstone in Utah), suggesting differences in ΔT are due to the degree of surface weathering on the inverted channels themselves. Previous terrestrial studies [14] have also shown that heavily varnished surfaces appear as higher ΔT (lower relatively TI surfaces) in Death Valley, CA. On Mars, quantitative TI values can be used to compare inverted channels to the TIs of their surrounding materials. When used in combination with visible to near-infrared spectral data (*e.g.,* to identify increased silica content) [7] or ground-based measurements [1,5], thermal images can provide another method of assessing surface weathering conditions and mapping units. Continued study of THEMIS thermal images of inverted relief features will help determine if thermophysical properties can help discern surface weathering processes.

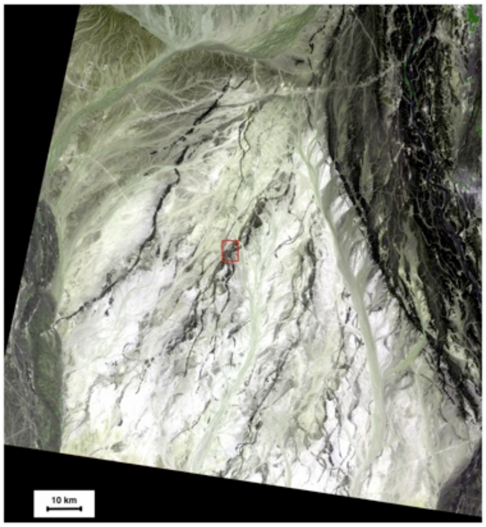

Figure 1: ASTER-derived visible RGB image for the alluvial fan near Barzaman, Oman. Darker-toned features are inverted channels capped with highly weathered gravel and sand Lighter-toned surfaces are calcite-cemented duricrust. Zoom box shows location of Figures 3a and 3b.

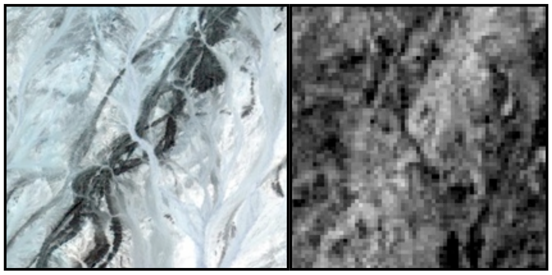

Figure 2: a) Visible RGB ASTER image, subset from Figure 1 (see zoom box). Inverted channels appear as low albedo features. Note the cross-cutting relationship of light toned calcareous well-cemented deposits, across darker-toned inverted channels in the center of the image. b) ASTER derived ΔT image showing high ΔT (lower relative TI) inverted channel materials.

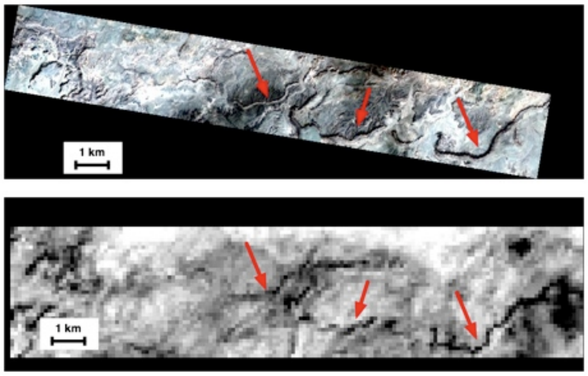

Figure 3: (*top*) Visible RGB ASTER image of the Green River, UT inverted channels region. The darker-toned channels in the visible image are labeled with arrows. (*bottom*) ASTER derived ΔT image showing low ΔT (higher relative TI) inverted channels labeled with arrows.

References: [1] Williams et al. (2007) UGA Pub. 36 [2] Burr et al. (2009) Icarus 200 [3] Williams et al. (2009) Geomorphology 107 [4] Hardgrove et al. (2009) EPSL 285 [5] Maizels et al. (1987) GSA Spec. Pub. 35 [6] Mangold et al., (2004) Science 305 [7] Williams et al. (2010) LPSC 41 [8] Malin and Edgett (2003) Science 302 [9] Lorenz et al. (2006) AAPG Bull. 9 [10] Abrams, M., Int'l J. Remote Sens*ing, 21*, 2000 [11] Gupta, R.P., Remote Sensing Geology, 199, and refs therein [12] Putzig N. E. and Mellon M. T. (2007) *Icarus, 191,* 68-94. [13] Potter and Rossman, (1977) Science 196 [14] Hardgrove et al. (2009) PSS *in press*