IDENTIFICATION OF SEDIMENTARY PROCESSES ON ALLUVIAL FANS USING AERIAL THERMAL IMAGES AND GROUND TRUTH C. J. Hardgrove[1], J. E. Moersch[1] and S. C. Whisner[2], [1]University of Tennessee, Department of Earth and Planetary Sciences, Knoxville, TN 37923 (chardgro@utk.edu), [2]Bloomsburg University of Pennsylvania, Department of Geology, Bloomsburg, PA, 17815.

Introduction: We have previously demonstrated the viability of using thermal infrared images for mapping surface grain size distributions on terrestrial alluvial fans [1, 2, 3]. For a well characterized alluvial fan in Owens Valley, CA we have used a quantitative analysis between aerial thermal images and ground-based grain size counts as well as a qualitative analysis between our thermal images and a published surface feature map [1]. Here, we combine aerial thermal images with field-based ground truth observations to study sedimentary processes on a wide assortment of fans in both Owens Valley and Death Valley, CA. High-resolution thermal infrared mapping, sensitive to the grain size of the top ~10 cm, in conjunction with visible images, provides insight into the processes that have acted on the surfaces of alluvial fans that is not available using visible images alone. Several sedimentary processes both build and rework the surfaces of alluvial fans, acting to sort grains by their size. Although the particle size distribution at the surface of most alluvial fans is the result of secondary weathering processes, remnant fluvial or debris-flow deposits still present at the surface can be revealed by thermal imaging. By understanding the thermal signatures of sedimentary deposits on terrestrial alluvial fans, we can utilize similar thermal infrared data sets to study proposed Martian alluvial fans [4, 5, 6]. To our knowledge, this study is the first thermal infrared survey of terrestrial alluvial fans.

Methods: Individual daytime and pre-dawn thermal images of the target alluvial fans were taken from a light aircraft to give an overhead perspective similar to that seen from orbit, but at higher spatial resolution. We selected times of day during which surfaces of different thermal inertias had the greatest separation in temperature - 3:30 to 5:00 AM local time for pre-dawn images (also a time when topographic effects are muted [7]) and 11:00 to 12:30 AM local time for daytime images (images have high signal to noise). Visible images were acquired during the same 24-hour period from the same airborne vantage points as the thermal images by using an aviation GPS navigation unit. Sophisticated multivariable analytical models for the diurnal thermal behavior of terrestrial surfaces have been developed (e.g., Watson, 2000), but here we make the simplifying assumption that thermal inertia is inversely proportional to the change in surface temperature between the pre-dawn and daytime images, which is referred to as ΔT [8]. As demonstrated in our earlier work, this approximation is adequate for revealing surface thermophysical heterogeneities associated with differences in particle size and/or varying degrees of induration in the scene. The resulting ΔT image shows the spatial distribution of relative particle sizes (or, in some areas of high thermal inertia, areas of induration). We note, however, that this simplification only allows for derivation of relative thermal inertia values not absolute thermal inertia values.

Data: *Death Valley Alluvial Fans*: A ΔT map for the eastern side of Death Valley south of Badwater is presented in Figure 1. Figure 1 has the same pixel-stretch applied across the whole image, emphasizing the differences in grain size across multiple fans in the valley. The ΔT values on each fan increase from north to south, demonstrating the general decrease in average particle size to the south. Ground truth of these fans verified this trend in particle size from an average grain size of ~boulders at Badwater to an average grain size of ~cobbles at Coffin Canyon. Due to a steady decrease in fan slope from north to south from ~6 degrees at Badwater to ~2 degrees at Coffin Canyon, we suggest this effect is topographically controlled, leading to larger particle sizes being distributed on the more steeply sloped fans. Field observations on the ground indicate that reworked debris flows tend to dominate the surfaces of fans to the north, while fluvial processes tend to dominate the fan surfaces to the south. This is best evidenced by a large incised channel in the southernmost Coffin Canyon alluvial fan.

Coffin Canyon Alluvial Fan: The Coffin Canyon fan is the southernmost fan on the thermal map in Figure 1. A re-stretched rendition of this fan (Figure 2a) reveals evidence of several sedimentary processes that could not be clearly identified with visible images alone. In the mid- to upper-fan regions, field observations on the ground showed low ΔT (colored red and yellow in Figure 2a) features representing the oldest areas of the fan, which are typically remnant coarse-grained debris flow surfaces. We have verified on the ground that the northern and central regions are composed of these remnant debris flows (cobble to boulder sized, Figure 2b) which are lined by finer-grained channel fill material. The channel fill is loose and composed of sand to pebble sized grains, however, in some areas the channels have exposed indurated mud. The large incised channel in the southern region of the fan shows an interesting thermophysical signature. The thermal image reveals that this channel contains coarser grains (colored green) than the material on the outside of the channel (colored blue). Ground truth of this area showed that within the channel there are relatively coarse grains (pebble to cobble sized) as well as indurated mud, while outside the channel there are wide areas of fine-grained loose material (Figure 2c). The presence of wide expanses of finer grains presumably made it easier for the channel in the southern portion of the fan to become incised. Subsequent clast-rich and -poor debris flows have utilized the incised channel and deposited coarse-grained material and indurated mud. Ground based evidence supported this hypothesis through observations of cross-cutting relationships of the channel and the surrounding material. The margins of the fan (dark blue in color) are characterized by very fine-grained sand and pebble deposits which are located at a break in slope. Further to the west, low ΔT features (red) correspond to basin-related salt deposits.

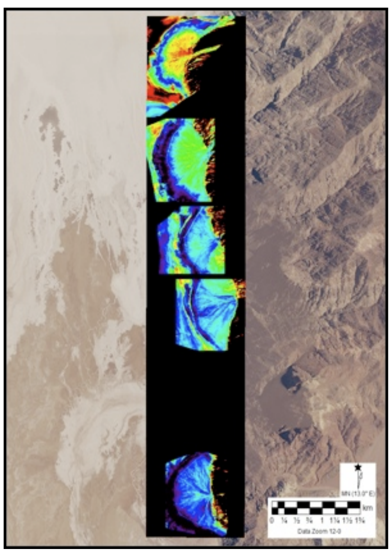

Figure 1: ΔT map of alluvial fans on the east side of Death Valley near Badwater Basin. Warm colors indicate areas of high thermal inertia (inferred from lower ΔT values), with larger grain size distributions while cooler colors indicate areas of low thermal inertia (inferred from higher ΔT values) with smaller grain size distributions.

Dolomite Alluvial Fan. We have acquired thermal images for four alluvial fans in Owens Valley, CA. On the Dolomite Fan, evidence of recent debris-flow processes dominate the top surface of the fan, while field mapping of other fans in Owens Valley has only revealed remnant (older, degraded) debris flows. The Dolomite Fan displays debris flow levees (Figure 3b), clast-rich (Figure 3c) and -poor debris flows, and remnant debris flow lobes, which all have thermophysical signatures in Figure 3a. A detailed comparison of the aerial thermal images and ground truth for the Dolomite Fan is presented in Hardgrove et al (*in press*) [1].

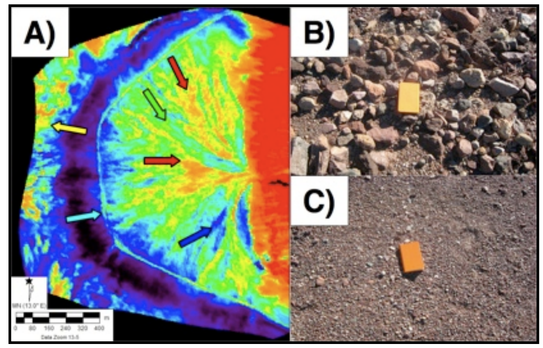

Figure 2: a) ΔT map (~ 2 m/pixel) of Coffin Canyon Fan. Red arrows show the location of older fan surfaces and remnant, coarse-grained debris flows. Green arrow shows the location of fine-grained channel fill (colored light blue) with exposed indurated mud (colored green). Blue arrow shows the location of very fine-grained material on the margins of the main incised channel. Light blue arrow shows the location of the break in slope. Yellow arrow denotes location of basin-related salt deposits. b) Grain size distribution in location of remnant debris flow near red arrow. c) Grain size distribution on incised channel walls near blue arrow

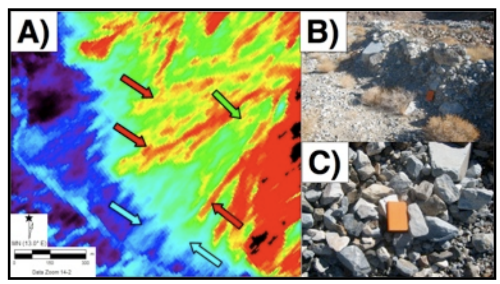

Figure 3: a) ΔT map (~ 2 m/pixel) of Dolomite alluvial fan. Red arrows marks location of debris flow lobes. Green arrow marks location of remnant debris flow levees. Light blue arrows marks location of clast-poor debris flows. b) Debris flow levee near green arrow c) Grain size distribution of debris flow lobe near red arrow.

Conclusions: We have shown that aerial thermal imaging can be used to remotely identify a host of sedimentary processes on alluvial fans, such as clast-rich and clast-poor debris flows, remnant debris flows, debris flow levees, and channelized fluvial deposits which are difficult to discern in visible images alone. In combination with visible imaging and ground-based mapping techniques, aerial thermal images are an excellent tool for the study of sedimentary processes on alluvial fans in both terrestrial or planetary environments.

References: [1] Hardgrove C. et al, (2009) *EPSL* (*in press*), [2] Hardgrove C. et al, (2008) *Eos Trans. AGU, 89(53), Fall Meet. Suppl.* #H33A-0985, [3] Hardgrove C. et al, (2008) *LPSC* XXXIX, #1226., [4] Moore J. and Howard A. (2003) *JGR, 110*, [5] Malin M. and Edgett K. (2003) *Science, 302*, [6] Kraal, E. (2008) *Icarus, 194* [7] Gupta.R. (2003) Remote Sensing Geology, [8] Watson. K. (2000) *Rem. Sens. Env. 72*