THERMOPHYSICAL PATTERNS IN TERRESTRIAL ALLUVIAL FANS FOR APPLICATION TO THE STUDY OF MARTIAN SEDIMENTARY FEATURES. C. Hardgrove[1], S. C. Whisner[1], and J. E. Moersch[1]
[1]University of Tennessee (chardgro@utk.edu)

Introduction: Alluvial fans are a class of depositional features that exist on Earth and have been proposed to exist on Mars [*e.g.,* 1]. They form in areas where subaerial runoff surfaces transition from relatively steep slopes with confined flow to shallow slopes with unconfined flow. Spatial distribution of grain sizes on alluvial fans varies with the sediment/water ratio and catchement lithology, so an understanding of the distribution of grain sizes in Martian fans may provide insight into the history of water on that planet. Our hypothesis is that alluvial fans of different depositional styles have distinct thermophysical "signatures", due primarily to grain size variations, and therefore, should be identifiable by imaging instruments that are sensitive to infrared emission, given sufficient spatial resolution. By comparing satellite thermal infrared images to ground based diurnal thermal infrared image sequences, we can determine what, if any, patterns are consistant between fans of differing depositional styles.

Blair and McPherson distinguish two endmember categories of alluvial fans based on the dominant mode of flow: fluvial-dominated and debris-flow-dominated [2]. For fans in which both types of flow operate, debris flow tends to dominate in the upper portions, and fluvial flow dominates in the lower portions, probably because of the greater mobility of fluvial flows [1], [3]. Fan grain-size distributions are complicated, but there is a nominal trend toward larger grains (sometimes called "fanglomerates") in the upper fan, intermediate grain sizes in the midfan, and smaller grains in the distal fan, or fanbase [4]. Upper fan grain sizes can be as large as boulder-sized, and distal fan grain sizes can be sand-sized or smaller [5]. There are, however, exceptions to this trend, as it has been noted that in some debris-flow dominated fans, the coarsest clasts are found at the foot of the fan, with backfilling by fines up-slope [2]. The type of grain size distribution found in fans is probably related to both the sediment source and the mode of deposition. Some authors have argued for a correlation between fan type and climate [6] although more recently this association has been called into question [2].

Typically, there is a single main channel at the apex of the fan, which divides into a radial pattern of wide, multiple-branching distributaries down-slope [5]. In fluvial-dominated fans, these channels are often braided. Some fans have other features that might be expected to display a spatial-thermophysical expression, such as longitudinal gravel bars, transverse bars, sheetflood deposits, and sieve deposits [5, 7]. The primary goal of the work described here is to determine whether patterns in the spatial distribution of grain size that are diagnostic – or at least suggestive – of different fan-forming processes are evident in thermal infrared images of different styles of terrestrial alluvial fans.

Methods: Nine alluvial fans have been studied in the Death Valley and Owens Valley, CA region. These fans were chosen for their relatively dry climate, lack of vegetation, accessibility, availability of vantage points, and spatial extent in satellite imagery. ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) orbital day-time reflectance (as a proxy for albedo) and day and night surface temperature images (to provide diurnal ΔT), are co-registered and converted to an Apparent Thermal Inertia (ATI) image [8, 9] for each fan. The ATI value of a pixel in each image is given by the ratio of the co-albedo ($1 - A$) of the pixel to the change in temperature (ΔT) of the pixel from the coldest to the warmest times of the day. ASTER was chosen for its similarity in spectral and spatial resolution to THEMIS, which will facilitate future comparisons to Martian alluvial fans [10, 11].

To determine if the patterns seen from orbit are also seen from the ground, a FLIR Systems ThermaCam S45 thermal infrared camera was stationed at each fan to acquire a "hypertemporal image cube" by the methods outlined in Moersch *et al*., [12]. A "hypertemporal image cube" is simply a time-lapse series of images acquired at a rate faster than the characteristic timescale of thermal variations in the scene over the course of at least one diurnal cycle. These images are stacked into a single data product for analysis. The advantage of the hypertemporal cube is that it may be subjected to many of the same statistical analysis techniques that are used in hyperspectral cubes to separate and map compositions. For example, factors that play a significant role in controlling the variability of diurnal temperature response should be isolated into separate image planes by a principle component rotation of the dataset.

Example alluvial fans from this study: Two fans of interest in our study are the Warm Springs and Anvil Springs fans, both at the foot of the Panamint Mountains on the western side of Death Valley, CA (Figure 1). *Blair* showed that these fans have evolved under similar climatic, tectonic and geomorphic conditions [13]. They also have similar areas and slopes, however, the fans have different source lithologies, leading to a change in the porosity of their catchement basin. The result of this difference is that the Anvil Springs

fan formed from fluvial processes while the Warm Springs fan formed from debris-flow processes [13].

Two other alluvial fans that will be extensively studied are the Coffin Canyon fan in Death Valley, which has a mix of debris-flow and fluvially dominated deposits, and the Owens Valley fan (Figure 2), which represents primarily debris-flow dominated deposition [14].

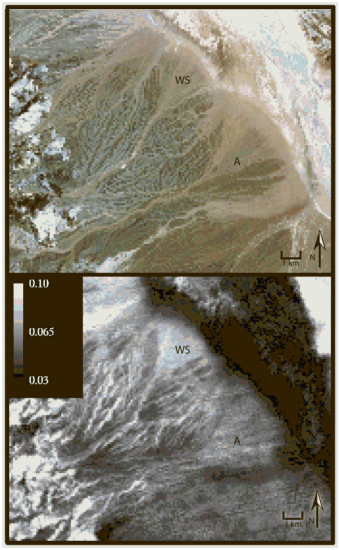

Figure 1: *Top:* Color ASTER image of the Warm Springs (WS) and Anvil Springs (A) fans degraded to ASTER thermal resolution. *Bottom:* ATI image of the Warm Springs (WS) and Anvil Springs (A) fans. Bright pixels represent higher values of ATI, while dark pixels represent lower values of ATI.

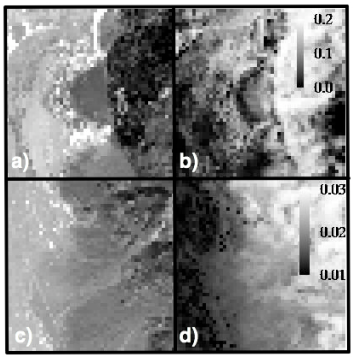

Figure 2: *a)* and *b)* Effective albedo image derived from ASTER RGB channels and ATI images, respectively, of the Coffin Canyon fan. *c)* and *d)* Effective albedo image derived from ASTER RGB channels and ATI images, respectively, of debris-flow dominated Owens Valley fan.

FLIR Hypertemporal Image Cubes: Ground-based hypertemporal image cubes spanning approximately 25 hours were acquired at the Coffin Canyon and Owens Valley fans. Pre-dawn temperature images and *N*-dimensional clustering methods accentuate thermophysical differences, as shown in Figure 3.

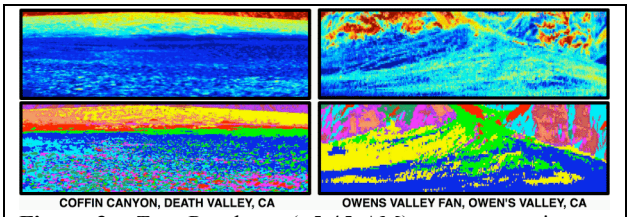

Figure 3: *Top:* Pre-dawn (~5:45 AM) temperature images of fluvially-dominated Coffin Canyon fan (*left*) and debris-flow dominated Owens Valley fan (*right*). In these temperature images, red indicates warmer temperatures or material with higher thermal inertia, while blue indicates cooler temperatures or material with lower thermal inertia. *Bottom: N*-dimensional cluster analysis results for Coffin Canyon (*left*) and Owens Valley fan (*right*). Class image colors represent statistical classes, and correspond to regions with statistically similar diurnal temperature curves.

Discussion: Preliminary analyses show significant differences between the thermophysical patterns of fluvial- and debris-flow dominated alluvial fans. Debris-flow fans show more longitudinal features in thermophysical images, representative of levees, gullies, or lobate features common in debris-flow fans. Using georeferenced ATI maps, ground truth transects were conducted at the Coffin Canyon and Owens Valley fans. In general, we found the average grain size of particles increases with proximity to the fanhead for both depositional styles, however, in the Owens Valley fan, large grain size clasts are more prevalent in the medial regions of the fan. These large particles are associated with levees or debris-flow lobes, which are primarily longitudinal features. These channels and levees can be seen in ASTER effective albedo and ATI images (as high ATI pixels) of the Owens Valley fan (Figure 2), and are even more readily identified in the pre-dawn thermal camera image (yellow pixels) and its associated *n*-dimensional classification image (green class). Similarly, lobes or levees may be responsible for the high values of ATI in the medial portions of the Warm Springs fan (Figure 1). Further analyses will expand the database of fans and ground truth data, as well as correct for atmospheric and slope effects.

References: [1] Moore, J.M., and Howard A., (2005) *JGR*, 110. [2] Blair, T.C., and McPherson J.G., (1994) *Geomorph. of Desert Environ*. [3] Hooke, R.L.B., (1967) *Journal of Geology*, *75*. [4] Moore, J.M., and Howard A., (2005) *JGR*, 110. [4] Boggs. S., J., (2001) *Principles of Sedimentology and Stratigraphy*. [5] Blissenbach, E., (1954) *Bulletin of the Geological Societry of America*, *65*. [6] Bull, W.B., and A.P. Schick, (1979) *Quat. Res.*, *11*. [7] Stanistreet, I.G., and McCarthy T.S., (1993) *Sed. Geo.*, *85*. [8] Price, C. (1977) *JGR*, 82. [9] Gupta, R.P. (2003) Remote Sensing Geology, 199, and refs therein. [10] Abrams, M., *Int'l J. Remote Sensing, 21*, 2000. [11] Christensen, P. et al. (2004) *Space Sci Rev.*, *110*. [12] Moersch, J.E., (2007) *7th International Conference on Mars*. [13] Blair T., (1999) *Sedimentology,* 46. [14] Blair T., (1998) *Journal of Sedimentary Research*, 68.