CONNECTING THE SURFACE MORPHOLOGY OF ALLUVIAL FANS TO PRECIPITATION AND CLIMATE: THE ATACAMA DESERT AS AN ANALOG FOR MARS.

Erin R. Kraal[1]
[1]Kutztown University (Department of Physical Sciences, Kutztown, PA 19530, kraal@kutztown.edu)

Introduction: Although alluvial fans were not widely identified on Mars until the availability of higher resolution surface images in the late 1990's, they are now recognized to be widespread and relatively common geomorphic landforms [1, 2]. Spacecraft data provide excellent (and increasingly high resolution) global coverage of the current Martian surface morphology as well as exhumed ancient landforms. This has permitted both focused studies on specific areas as well as comparisons of alluvial fan deposits globally and regionally [e.g. 3, 4, 5]. Researchers have also used fan shape (topographic profiles) to estimate long-term formation time scales [6, 7]. Many of these previous studies have focused on connecting the formation and evolution of alluvial fans to Martian climate history to help illuminate the timing, duration, and distribution of precipitation.

Recently, the Mars Science Laboratory (MSL) Rover has imaged what may be the first grain size sample of a Martian alluvial fan system. This permits investigation of another link between alluvial fans and the climate history of Mars. Standard sediment transport calculations can estimate the flow depth and velocity from transported particle sizes and regional slope (along with some other variables); depth and velocity estimates provide a snapshot of the flow conditions responsible for transporting the observed surface grains. Ultimately, the goal is to connect flow conditions estimated from the rover images (grain size and distribution) and space craft data (slope/topography) to the climate and precipitation conditions necessary to produce that type of flow. However, even on Earth with extensive data (field, remote sensing, laboratory) and several types of climate information (both collected and simulated data), this comparison can be challenging. Here I compare transport on Martian alluvial fan systems to a terrestrial study that links surface transport on alluvial fans to climate.

Terrestrial Analog: The alluvial fans in the Atacama Desert of Chile provide an excellent analog for Martian alluvial fans because of the lack of vegetation, excellent preservation, and hyper-arid conditions (average precipitation of ~2 mm/year). Using surface grain sizes and precipitation and drainage basin modeling, a recent study compared flow competency on three small alluvial fans near Antofagasta, Chile to a suite of regional climate data in an effort to understand the frequency and magnitude of surface flow events [8]. A similar approach could be used to connect the increasingly high-resolution alluvial fan (i. e. surface grain size and local slopes) data to climate on Mars.

For a given drainage basin, the transported grain size offers an estimate of the flow conditions required to transport that grain. The question then becomes how much precipitation must fall on the catchment to produce the flow required for grain transport. Catchment characteristics (shape, size, topography, substrate) are important factors in determining the required precipitation rate. Finally, the estimated precipitation rate can be linked to meteorological data (either observational or modeled) to identify the frequency of events that activate the surface.

Sediment Transport. MSL landed in Gale Crater near the base of an alluvial fan originating from Peace Vallis [see 9 for overview]. On Sept 2, 2012 the Mast Camera imaged an outcrop called 'Link' (PIA16188). This image shows rounded clasts of approximately gravel size eroding out of a conglomerate. The rounded nature of the eroding particles indicates original fluvial transport and the D95 grain size as measured from the image is between 0.75 and 1 cm. Assuming standard fluid and rock (basalt) densities (1000 kg/m^3 and 3000 kg/m^3, respectively) and a regional slope of 1° - 2° (from MOLA Gridded slope data), the estimated flow depth required to transport the observed gravel sized particles is between 0.4 m and 1.2 m (see method overview in [8]). Using a friction factor calibrated for Martian gravels the required flow velocity ranges from 0.8 – 1.4 m/s [10]. Discharge estimates will require complete channel dimensions (i.e. widths) - these are not currently discernable in available data. In the case of the terrestrial analogue (Atacama Desert, Chile) ,alluvial fan surfaces were activated by even shallower flows (~0.15 m depth) associated with modest discharges of ~0.1 m^3/s.

Connection to precipitation. As water falls in a basin, the characteristics of the basin and the precipitation delivery rate determine whether water infiltrates or flows overland as channel discharge. For example, the Atacama alluvial fan study found that short-lived, intense precipitation events (on the order of 1 to 3 hours, >4 mm/hr) could produce surface flow capable of activating the channels [8]. These modest precipitation rates are comparable to results from the Mars Regional Atmospheric Modeling System in a study of localized precipitation near possible lakes on Mars that found precipitation rates of ~6 mm/hour of water equivalent – though the water was delivered as snow [11].

Links to Climate. Comparison of precipitation rates derived from surface grain analyses to a suite of observed and simulated climate records for the Atacama Desert suggested that these small alluvial fan channels activate approximately every 3-7 years, likely capturing an El Nino/La Nina signal [8].

Conclusion. As the available Martian surface dataset continues to grow, we can expect to employ many new and more detailed techniques to understand the flow conditions required to form and modify Martian alluvial fans. However, linking the morphology of Martian alluvial fans to global climate will require climate simulations that resolve precipitation at high temporal (i. e. hourly) and spatial (i.e. catchment scale) resolutions. In turn, as we improve our process/formation modeling and analysis of Martian alluvial fans, we can use the sediment-derived estimates of storm magnitude and duration as 'proxy data' to verify simulations of Martian paleoclimate.

References: [1] Moore, J. M. and Howard, A., (2005), JGR doi:10.1029/2004JE002352. [2] Kraal, E. R. et al, (2010), Icarus doi:10.1016/j.icarus.2007.09.028 [3] Grant, J. A. and Wilson, S. A. (2011), GRL dio: 10.1029/2011GL046844. [4] Howard et al. (2005), JGR doi:10.1029/2005JE002459. [5] Mangold et al. (2012), JGR doi: 10.1029/2011JE004005. [6] Armitage, et al. (2011), GRL doi:10.1029/2011GL048907. [7] Jerolmack et al. (2004), GRL doi: 10.1029/2004GL021326. [8] Haug et al. (2010) Geomorphology, p184-196. [9] Anderson, R. B. and Bell, J. F. (2010), Mars, p 76-128. [10] Kleinhans (2005), JGR doi:10.1029/2005JE002521. [11] Kite, E. S., et al (2011) JGR doi:10.1029/2010JE003783

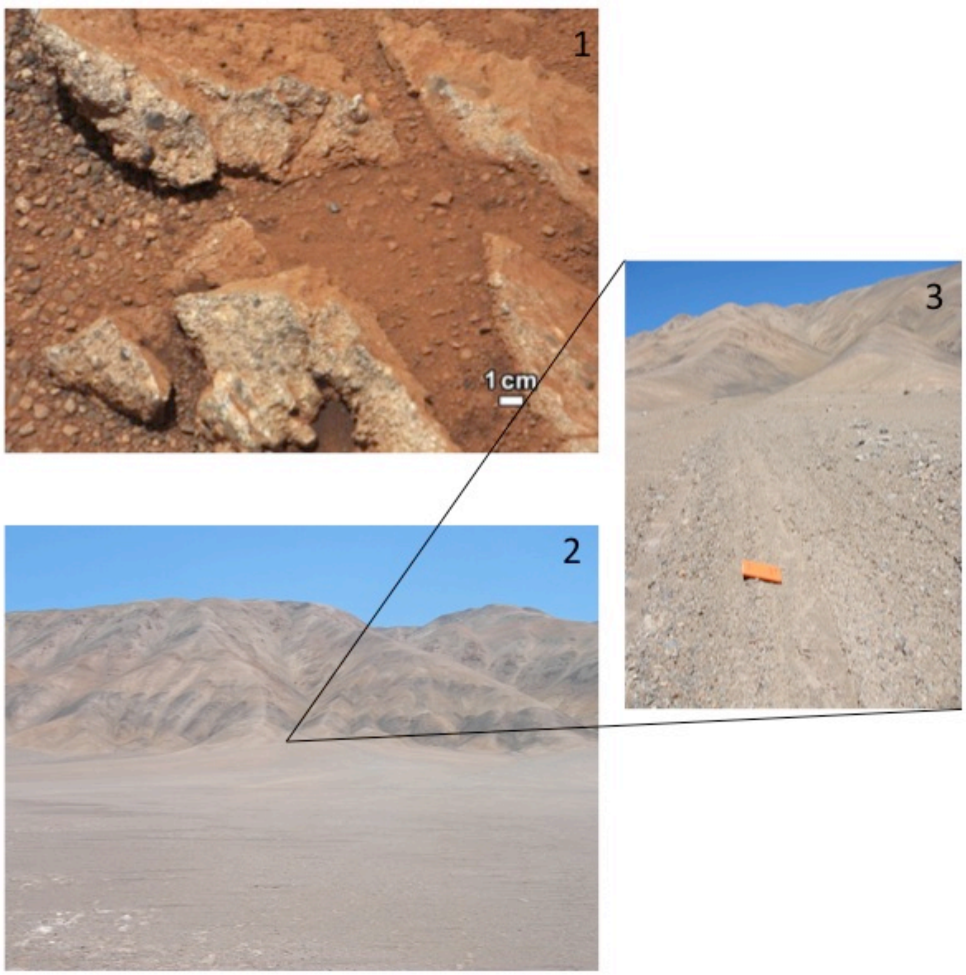

Figure 1: Image of Link Rock outcrop showing rounded gravel clasts taken by MSL. Image PIA16188, Credit: NASA/JPL-CalTech/MSSS **Figure 2 and 3**: Alluvial fans in the Atacama Desert, Chile. Fig 2 shows the catchment and fan apron. Area of fan and catchment is ~3x104 m2 with a slope of 0.252 m/m. Fig 3 is a close up of clast transport in the recently activated channel, grain size on the fan apron is 202 mm (D95) and 26.7 mm (mean). Flow magnitude and frequency is described in [8].