ALLUVIAL FANS AS A RECORD OF LATE PRECIPITATION ON MARS: J. A. Grant[1] and S. A. Wilson[1], [1]Center for Earth and Planetary Studies, National Air and Space Museum, Smithsonian Institution, 6th at Independence SW, Washington, DC, 20560, grantj@si.edu.

Introduction: Alluvial fans are semi-conical deposits of sediment emplaced where streams transition from steeper confined valleys to unconfined, relatively flatter terrain (e.g., [1]). Fan deposits record information regarding weathering processes that produce an inventory of regolith for transport and reflect the frequency and intensity of discharge from upstream basins (e.g., [2]). As such, the occurrence and morphometry of alluvial fans on Earth are indicative of climate (e.g., [3]). On Mars, alluvial fans are widespread [4-11] and their age and morphology also provide insight into the amount and style of runoff and climate in which they formed (e.g., [4, 8]).

Fan Morphometry: The characteristics of alluvial fans within large craters in southern Margaritifer Terra (MT) [6], Gale crater [11], and elsewhere on Mars [9] hold clues related to the conditions and timing of deposition. For example, fans in MT typically display well developed alcoves and their surfaces preserve distributary channels standing ~10-15 m in relief (via inversion of topography) [4-6]. Fan surfaces are characterized by slopes of 1–2 degrees [4] and are of intermediate brightness in THEMIS nighttime thermal images. HiRISE images reveal fairly uniform and block-free surfaces, which together with the efficient eolian erosion responsible for the inverted distributary ridges, requires a significant fine component of sand and silt. The *in situ* breakdown of coarser sediments on the fans to create the fine component is not consistent with the differential erosion creating the inverted distributary ridges, so the fine-grained nature of the near-surface fan sediments likely reflects the original depositional inventory. The relatively uniform fan slopes (where measured) and lack of fan head trenches indicate their current form reflects deposition related to precipitation (perhaps with minor orographic enhancement in some craters) causing relatively low-to-moderate discharge under uniform climate [8].

Fan Ages: Sediments exposed in the alluvial fans record only the final phase of deposition and therefore does not preclude earlier fluvial activity. Crater statistics help constrain the timing of the final deposition and were compiled using CraterTools in ArcGIS [12] and Craterstats software to derive relative and absolute ages [13] based on the chronology function of [14] and production function of [15]. Statistics were also plotted using the variable diameter bin-size method of [16] and yielded similar ages. As summarized in [6], cumulative plots for the fans in MT have best fit isochrons ranging from 1.5 to 2.5 Ga (average 1.9 +/- 0.5 Ga). These statistics suggest the alluvial fans formed in the Amazonian or near the Hesperian-Amazonian boundary. Although less certain, statistics for the Peace Vallis and other fans in Gale crater may also be consistent with late activity [11].

Possible Sources of Water for Late Activity: The late activity responsible for the current expression of the fans could relate to either regional-scale or synoptic sources of rain or snow. Local precipitation could be driven by the impact-induced release of volatiles [17-19], with runoff resulting in deposition on fans in nearby craters. The broad distribution of fans studied in MT and their apparently common age, however, argues against local water sources [6]. Nevertheless, Hale and Holden craters are relatively young, nearby, large craters whose formation was evaluated as possible local sources of water.

The 125×150 km diameter Hale crater (36°S, 324°E) formed between the Early to middle Amazonian [20] and Hesperian-Amazonian boundary [21]. However, fans in MT are 700-800 km from Hale, there is little correlation between Hale and the azimuth to craters containing fan deposits (as might be expected for a relatively local source of water under prevailing winds), and many craters nearer Hale lack fans [6].

The ~150 km diameter Holden crater (26°S, 326°E) is middle-to-late Hesperian in age [22]. Like at Hale, however, craters bearing fans are up to hundreds of km away and at a range of azimuths from Holden. Additionally, there are six degraded craters around Holden's rim, some which are fluvially modified. The time required to accumulate these craters, which were then degraded, suggests a gap in time between the formation of Holden and final deposition on nearby fans. This is supported by depositional relationships between fans in Holden that show evidence for multiple periods of activity after the crater formed [8]. These observations, together with the regional distribution of the fans, favor a synoptic source of water for late fan activity.

Synoptic precipitation (rain or snow) as a source of water for late fan activity may be consistent with late water-driven erosion inferred to have occurred elsewhere on Mars (e.g., [23-32]). In addition, [4] suggest that other fans on Mars were possibly contemporaneous with those in MT.

A Model for Late Fan Activity: A possible synoptic source of water responsible for late runoff and deposition on fans includes precipitation derived from redistribution of water from outflow channel discharge (e.g., [27, 28, 33]) back into the highlands [34]. The distribution and appearance of fans within some craters and the apparently fine-grained nature of the sediments comprising fan surfaces provide additional clues about the form and intensity of precipitation.

For example, there is limited correlation between fan occurrence and physical characteristics of the bounding craters, such as floor elevation and wall relief, and an absence of channels heading on fan surfaces or central peaks [8]. This suggests precipitation was insufficient to generate widespread runoff and required concentration to enable erosion and transport of an inventory of fine sediments out of source alcoves. Repeated, but limited snowfall could be concentrated by the wind into pre-existing impact produced topography and pre-existing alcoves where it would be largely protected from sunlight [4, 8]. By contrast, snow not concentrated and protected in this manner would either evaporate or melt and mostly infiltrate.

Accumulated snow within rim depressions and (or) pre-existing alcoves would be in contact with rocks such that repeated intervals of freezing and thawing would facilitate physical weathering to produce an inventory of fines [35]. On Earth, freeze-thaw cycles often occur annually or over shorter time scales [36-37] and can result in "hydro fracturing," frost shattering, and (or) the granular disintegration of rocks [37]. This process produces significant gravel and finer materials in some lithologies (e.g., sedimentary or coarse granular igneous [36, 38]). On Mars, annual or even longer freeze-thaw cycles in highly fractured/disrupted rocks around the interior rims of impact craters could yield similar results in some lithologies. A possible influence by lithology necessary to produce mostly fines by this mechanism could contribute to the preferential development of alcoves and fans in some craters.

The accumulation and later melting of snow could occur annually and (or) may be accentuated by orbital variations over longer periods. In either case, however, melting must occur gradually and result in fairly uniform, but limited runoff capable of carrying fine sediment onto the fan surfaces.

Regardless of the source(s) of water responsible for deposition on alluvial fans and water-driven activity elsewhere, the potentially habitable environments they record occurred relatively late in Martian history [39] and may not have been isolated (e.g., [40]). These results support the contention that habitable conditions persisted at least locally on Mars well after the Noachian [41].

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