LATE AQUEOUS ACTIVITY ON MARS: EVIDENCE FROM SOUTHERN MARGARITIFER TERRA AND GALE CRATER.

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Introduction: Much of the aqueous activity on Mars occurred relatively early in the planet's history and, with the exception of some outflow channel formation, is widely accepted to have slowed by around the time of the Noachian-to-Hesperian transition [e.g., 1-3]. Nevertheless, some aqueous activity persisted into the Hesperian and Amazonian [e.g., 4-11] at a time in Martian history when conditions were less favorable. Here we focus on alluvial fans within craters in two widely separated locations, southern Margaritifer Terra and Gale crater (Fig. 1), in order to constrain the magnitude and timing of late alluvial activity and implications for late climate on Mars.

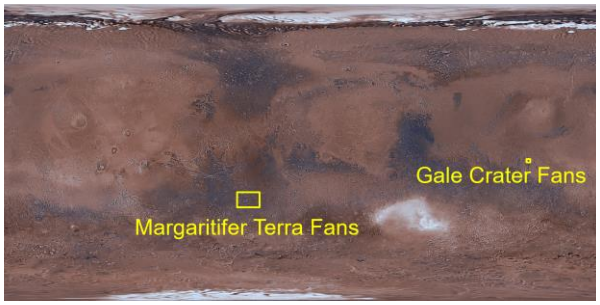

Figure 1. Map of Mars showing the location of alluvial fans studied in Margaritifer Terra and Gale Crater. NASA/Jet Propulsion Lab/USGS.

Overview of Alluvial Fans: Alluvial fans within craters are fairly widespread across mid and low latitudes of Mars [11, 12] and fans within Margaritifer Terra and Gale crater (Fig. 1) share many common morphometric characteristics. For example, fans in both locales superpose broader surfaces within their host craters and clearly embay adjacent rougher and often relatively brighter-toned surfaces (Fig. 2). In Gale crater, the smoother, upper portion of the Peace Vallis fan transitions downslope to a rougher, relatively brighter, alluvial deposit (Fig. 3).

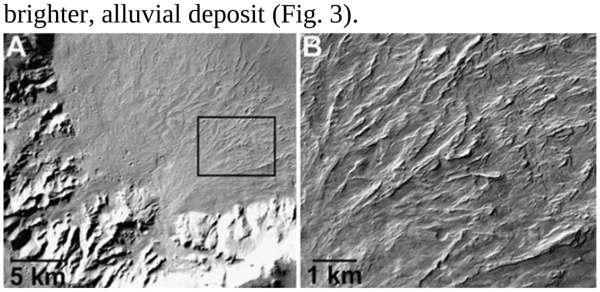

Figure 2. A) Alluvial fans on the southern wall of an unnamed crater in Margaritifer Terra. **B**) Fans embay surrounding surfaces and express relict distributaries as inverted relief due to meters of deflation on adjacent surfaces (see box in A for context). CTX B01_009999_1519_ XI_28S027W (5.2 m pixel scale). Modified from Fig. 2A-B in [8]. North is up.

At least portions of the fans typically preserve relatively small-scale morphology as compared to adjacent surfaces (e.g., the upper portion of the Peace Vallis fan, Fig. 3) and they often slope uniformly at only a few degrees towards the bounding crater floor. The fans preserve distributary channels (up to 100s of m wide and kms long) that currently stand meters in relief as a result of later, limited erosional lowering of finer-grained, adjacent surfaces (Figs. 2-3 [12]). Fan margins display little evidence of significant erosional modification (e.g., isolated remnants) and sometimes occur as outward facing slopes.

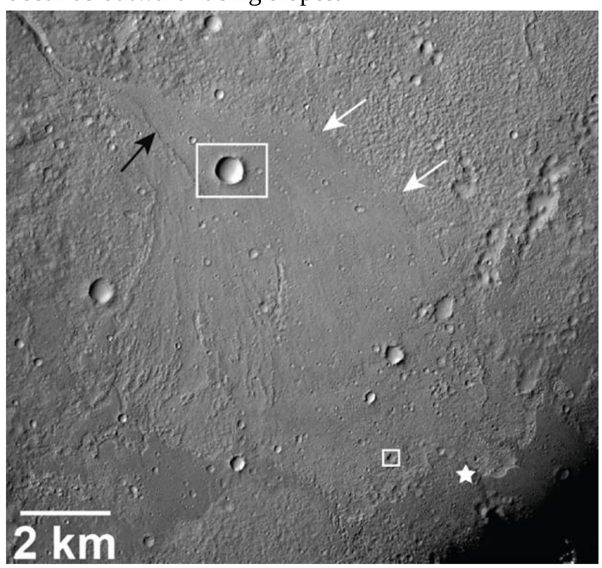

Figure 3. Peace Vallis alluvial fan in Gale crater with outward facing eastern margin (white arrows) and inverted relict distributary channels standing in relief (e.g., black arrow) due to minor deflation of adjacent finer-grained fan surface. Large box marks a ~750 m-diameter crater embayed by alluvium on the uphill side of the smoother upper fan. Small box denotes a more degraded crater typical of the lower fan. Star marks Curiosity landing site. CTX merged orthophoto [13]. Modified from Fig. 1B in [9]. North is up.

Timing of Alluvial Fan Activity: The size-frequency of craters preserved on the alluvial fans helps to constrain the timing of latest activity. Careful mapping and the combination of similar morphological units into larger cumulative areas (e.g., in Gale crater) helped to minimize potential uncertainties associated with statistics drawn from small geologic surfaces [7-9]. As summarized from [7-9], interpreted ages for the fans in Gale crater and Margaritifer Terra range from around the time of the Amazonian-Hesperian boundary and well into the Amazonian [7-9]. Cumulative crater statistics for individual fans in Margaritifer Terra yield interpreted ages ranging from around 1.0 Ga to 2.5 Ga, whereas the interpreted age drawn from statistics of the combined area of all of those fans (covering 11,000 km^2) yields an interpreted absolute age of ~2.0 Ga (for craters >375 m-diameter) [7, 8]. Cumulative crater statistics for the combined area of fan surfaces in Gale crater (covering 429 km^2) yield an interpreted absolute age of ~1.3 (±0.10) Ga (for craters >0.17 m-diameter) [9]. Incremental statistics yield results consistent with those drawn from the cumulative statistics.

The range in interpreted ages for fans in Margaritifer Terra and Gale crater could reflect the relatively low fidelity of counts made on young, small surfaces of some of the fans and/or could reflect variable timing of activity in separated craters/locations over one or more periods of time fairly late in Martian history. Nevertheless, the consistently young ages coupled with the well-preserved fan morphology and superposing character [7-9, 11] all point to occurrence of late alluvial activity in widely separate locations on the planet.

Magnitude of Late Activity: Fan deposition may have occurred over an extended time related to a variety of water sources [7, 14, 15] and contributions during late activity appear relatively small. For example, estimates of the thickness of the sediments forming the generally smooth, upper Peace Vallis fan are only ~10-20 meters [15, 16], consistent with their partially embayment, but not burial, of a large pre-existing crater (Fig. 3). And fans flanking the northern wall of Holden crater in Margaritifer Terra were locally excavated by an impact crater that was subsequently partially infilled by later activity. Hence, late activity associated with these fans may have been of fairly limited magnitude.

Implications for the Source of Late Water: The wide distribution of these fans, coupled with the likelihood that other alluvial fans on Mars also experienced late activity [11], indicate a synoptic, late source of water was likely required (in the form of rain or snow). Possible sources include water debouched into the northern lowlands during late outflow channel formation [2, 17, 18] or atmospheric injection of water released during/after large, late-occurring impacts [e.g., 15]. Release of water by such mechanisms could have reinvigorated a global hydrologic cycle for a time that would have included water redistribution as precipitation into the highlands [19]. Under this scenario, synoptic precipitation accumulating as a snowpack in pre-existing rim alcoves/depressions could be protected from sunlight and facilitate *in situ* weathering. Subsequent gradual melting and limited runoff, occurring annually and (or) over longer periods (e.g., accentuated by orbital variations) could transport the resultant sediment onto the fans. Collectively, these data indicate that aqueous and potentially habitable environments occurred at least occasionally during the Hesperian and into the Amazonian.

Figure 4. Evidence for multiple stages of fan formation in Holden crater [8]. Arrow indicates crater wall excavated into older fan that was later filled by younger alluvium. HiRISE ESP_012676_1545 (52 cm pixel scale). Modified from Fig. 6B in [8]. North is up.

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