UNIQUE FAN-SHAPED LANDFORMS IN MOJAVE CRATER, XANTHE TERRA, MARS.

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Setting and Fan Characteristics: Mojave Crater is an ~60 km-diameter impact crater centered at 7.6° N, 33.0° W in Xanthe Terra that is relatively fresh-appearing with multi-lobate eject blanket, terraced crater walls and a central peak (Figure 1). The crater is superposed on outflow channel floor between Tiu and Simud Valles. Unique fan-shaped landforms are observed associated with massifs on the Mojave Crater walls. These fans share many morophologic attributes in common with terrestrial alluvial fans including a semi-conical form, branching tributary network, distributary channels and incised channels [1].

Typically, the fans coalesce to form an apron with radial length of ~500 m (Figure 2). Light-toned branching and rejoining channels form a braided distributary network on the dark fan surface. The fan margin is commonly a linear break in slope, although a few examples of lobate fan margins have been identified. Headward of the fan apex, some of the tributary branching networks are dense, with channels visible down to the resolution limit and highly ordered systems (at least third order) (Figure 3). The first-order tributaries originate at local topographic highs.

Figure 1B illustrates the spatial distribution of fans in Mojave Crater. Although these fans are prevalent in Mojave Crater, they are not present on all slopes (Figure 3). Fans are associated with massifs on the crater walls and proximal to the crater rim but are noticeably absent in the central peak region. Likewise, no fan-shaped landforms or evidence of dissection have been observed on the ejecta blanket. These fan-shaped landforms are unique to this crater and have not been observed elsewhere on Mars in >75,000 MOC NA images covering ~3% of the martian surface, including craters at a range of sizes (meters to hundreds of kilometers).

Relative Timing: Crater counts on the circum-Chryse outflow channels yield an age of Late Hesperian [2] and provide a relative age for Mojave Crater of Late Hesperian or Amazonian. Some of the fans have small (<200 m diameter) circular depressions on their surface that have raised rims but lack an ejecta blanket or rays (Figure 2). Evidently, the Mojave Crater fans did not form so recently as to remain craterless. In a few cases (~5), tributary or distributary channels appear to traverse around or across circular depressions (Figure 4). These landforms could be interpreted as degraded secondary craters and would suggest fan formation or modification events of sufficient duration to produce the observed degree of dissection. However, the origin of these circular depressions is ambiguous; thus, the time-scales required for generating the Mojave fans remains ill constrained based on the cratering record.

Cross-cutting relationships on and between fans is evidence for sequential fan formation. Fans aggraded on top of pre-existing fans resulting in abandoned and truncated fan surfaces (Figure 2). Figure 5 shows distributary channels that were buried by emplacement of a superceding fan. Additional evidence for multiple-phase fan development is the presence of incised channels (Figure 6). Some incised channels merge with the fan surface at the intersection point (Figure 6a), while other incised channels traverse the entire length of a pre-existing fan and have an associated triangular-shaped deposit at its distal end (Figure 6b). While some evidence suggests multiple episodes of fan formation, it is possible different networks and fans developed sequentially over a relatively short event.

Fan Formation: How did these fan-like forms develop? The high degree of dissection indicated by the distal channel density and the topographically-controlled bifurcating pattern of channels headward of the fan and on the fan surface argues for a surface-constrained fluid erosional process rather than channelized, dry mass movement. Although incised channels and braided distributary networks could result from secondary modification of fans by surface runoff, the highly-ordered, branching tributary network strongly suggests a component of surface runoff in the primary fan formation process. The lobate margins of a few fans may reflect a different complimentary formation mechanism involving a more viscous medium such as a debris flow. Collectively, these landforms have attributes consistent with surface overland flow of fluids and formation of fans by water and gravity-driven alluvial sedimentation.

This naturally leads to the question of the fluid source. Either atmospheric or groundwater fed surface runoff could produce the observed relationships. (It is worth noting that aquifers for a groundwater source were likely (re)charged via precipitation.) The non0uniform distribution of fans on Mojave Crater wall slopes and lack of dissection on the surrounding terrain may be easier to explain with a groundwater source than atmospheric precipitation that typically results in a more uniform pattern of dissection. However, it is the presence of first-order tributaries originating at the apex of narrow ridges (e.g. Figure 3) that leads us to conclude that precipitation was directly involved in the formation of these landforms. Given that these fans are spatially confined to this specific crater, we do not believe a regional climate-induced process produced the precipitation. The unique occurrence of these landforms indicates a unique origin. One possibility, explored below, is a genetic link between the impact event that formed Mojave Crater and the generation of these fan-shaped landforms.

Fan formation may have been associated with the impact event that liberated sequestered volatiles in the subsurface. This would be consistent with the geologic setting: a crater formed on an outflow channel floor where it is widely believed that catastrophic floodwaters once flowed. Assuming the bulk of the fans are developed from fluid-flow or fluid-abetted (e.g. debris flows) processes, the size of the fans and associated drainage basin can be used to crudely and conservatively estimate the minimum amount of precipitation required to form these landforms: meters to tens of meters depending on the sediment concentration in the primary fan-formation flows. The geologic evidence does not constrain the duration or number of precipitation events required to form the fans. We believe the precipitation occurred during or shortly after the impact event. While the impact model best fits our collective observations, further investigation is needed to determine if this mechanism can produce sufficient precipitation and generate the spatial distribution of the fans.

The Mojave Crater fans contribute to our evolving understanding of martian fluvial history. These unique and isolated landforms suggest localized atmospheric precipitation and overland flow of fluids during an epoch of martian history that had been believed to be relatively dry. Furthermore, this is the first geologic evidence on Mars supporting a link between impact crater events and resulting, albeit local, climate change.

References: [1] Williams, R. M. E. et al., 2004, *LPSC XXXV*, #1415 [2] Tanaka, K. L, 1997, *JGR, 102*, E2, 4131-4149.

Figure Captions:

Figure 1: A) 1/128° digital elevation map (DEM) illustrating the regional setting of Mojave Crater on outflow channel material between Tiu and Simud Valles in Xanthe Terra. B) Sketch map of the spatial distribution of fan landforms (red) in Mojave Crater are shown over an MOC red wide angle (WA) image with high-resolution MOC narrow angle (NA) images superimposed. To date, approximately 70% of the crater has been imaged by high resolution MOC NA images. The black circle is the approximate location of the crater rim. These unique fan-shape landforms are found adjacent to slopes of all orientations within the crater basin and proximal to the crater rim, however they are absent in the central peak complex and the ejecta blanket.

Figure 2: False-color portion of image R07-01504 illustrates coalesced fans on the west wall of the crater. Light-toned linear feature (white arrows) which may be a channel that cross-cuts or the distal margin of a fan that post-dates formation of the abandoned fan marked by yellow arrow. Black arrows point to secondary impact craters on fan surface. Illumination is from top.

Figure 3: Portion of image R14-02615 illustrates the dense, highly-ordered tributary network. The first-order channels originate at local topographic highs including the arcuate ridge in the middle-center of the image. No channels or associated fan-shaped deposits are present on the northwestern slope. Boxed region is enlarged at right. Illumination is from lower left.

Figure 4: Circular depressions that appear to be traversed by channels. For both MOC NA images cut-outs, scale bar is 100 m and north is to the upper right. Candidate dissected craters are observed on A) the fan surface (R07-01987) and B) in the drainage basin (R17-01337).

Figure 5: Portion of MOC NA image R07-01337 with light-toned tributary channels (white arrows) have been buried by successive fans (black arrows). Illumination is from the left.

Figure 6: Examples of incised channels (white arrows) include A) one where the incised channel floor merges with the fan surface (intersection point) mid-fan (R12-01744) and B) one that traverses the entire length of the fan and terminates at a small, triangular-shaped deposit (black arrow) at the toe of the pre-existing fan (R14-00032).

Figure 1

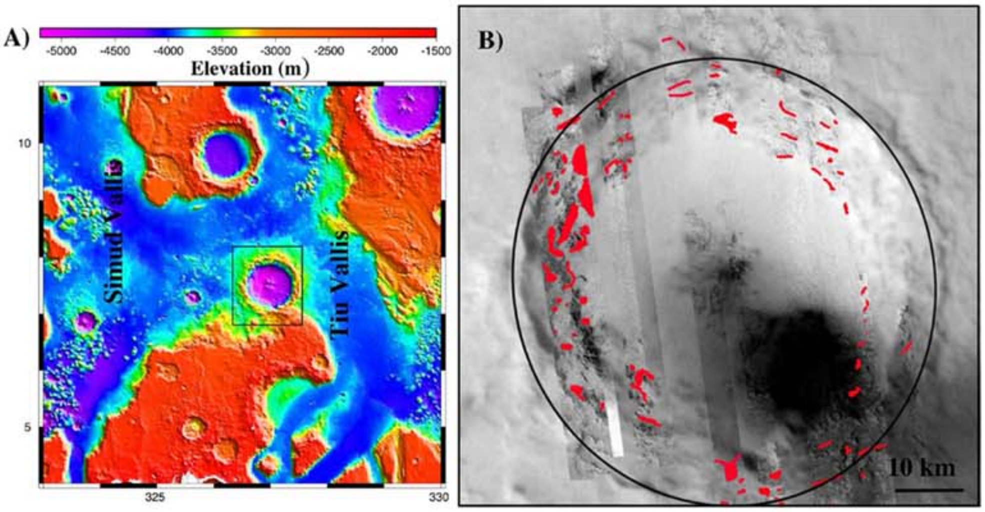

Figure 2

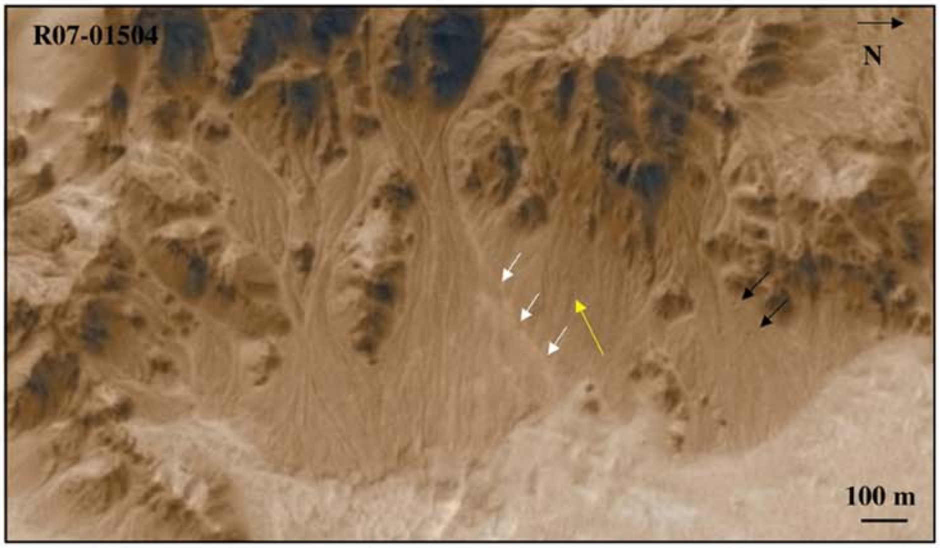

Figure 3

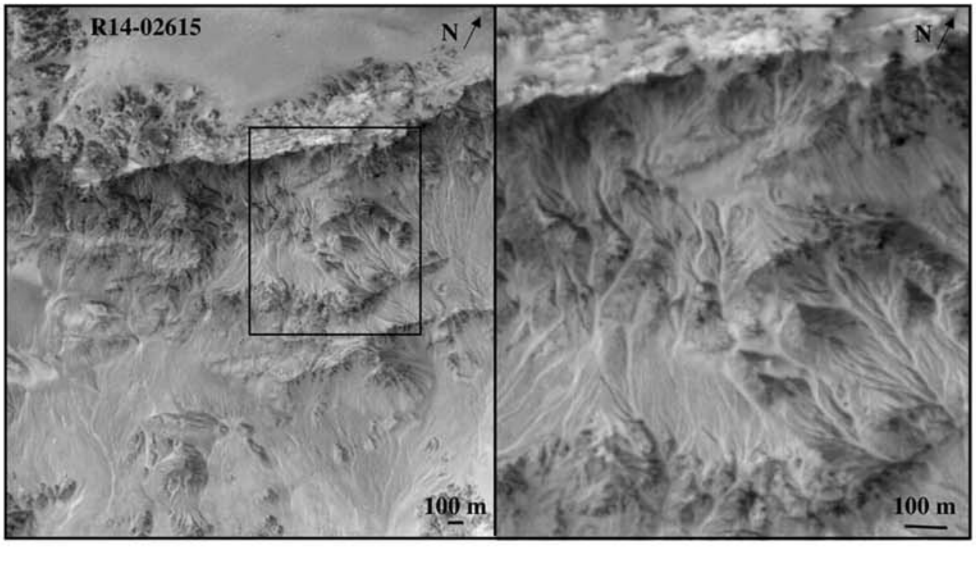

Figure 5 (Right)

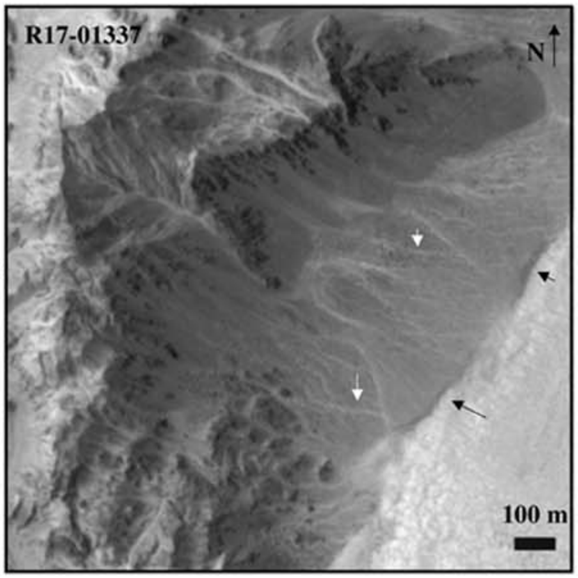

Figure 4 (Below)

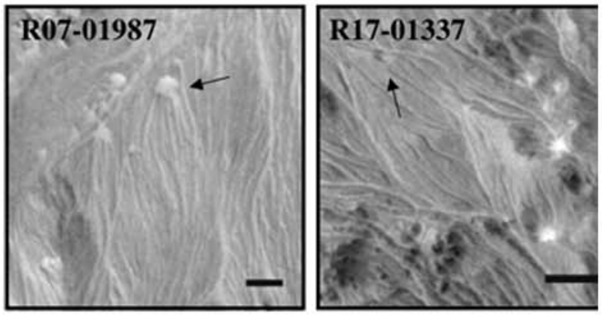

Figure 6