NEW INSIGHTS INTO THE EXTENSIVE INVERTED FEATURES WITHIN GALE CRATER, MARS.

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Introduction: Gale crater is understood to contain sedimentary deposits of fluvial, alluvial, and lacustrine origin which have been detailed by investigations of both orbital data and in-situ rover data. The potential for conditions favorable to colder, glacial-like environments within the region has been previously discussed [1-3] with potential glacial geomorphic indicators identified [2]; however, no direct observations of glacial modification or deposition have been characterized in-situ so far.

New imagery and interpretations reveal numerous geomorphic features newly recognized as indicators of past glacial processes in the Gale crater region. Elongated, linear structures previously identified as fluvial inverted channels are hypothesized to represent glacial eskers. Other newly documented glacial features observed within the region [4] include: U-shaped valleys, cirques, arêtes, and scoured and breached crater rims. These features were formed before the Late Amazonian fluvial period [5] observed within the crater.

Glacial eskers: When a glacier of sufficient thickness accumulates, and if melting of the ice occurs, water may be transported by gravity on both the surface and base of the glacier. Water flowing at the base may carve tunnels in the ice as flow paths for meltwater. This fluid will carry sediments as bed load and suspended load from the local watershed and from below the glacier itself; the sorting within these flows is poor, containing grain sizes ranging from glacial flour to boulder size. Some of the sediment will form relatively static inverted features that will aggrade within the ice tunnel. These geologically preserved structures, known as eskers (Figure 1), are observed on the Earth where they can extend up to hundreds of km and comprise features distinguishing them from other inverted forms.

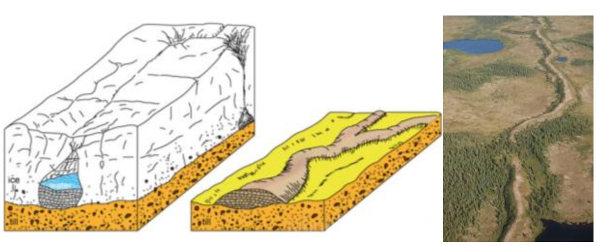

Figure 1. Left: Schematic illustrating the formation and deposition of an esker (image credit: Dr. John Bluemle). Right: Esker remnant from Manitoba, Canada.

Observations: A combination of orbital and in-situ observations provide evidence for possible glacial modification within and around Gale crater.

Gale crater watershed. The large area which drains into Gale crater through the Peace Vallis channel, known as the Peace Vallis watershed, is calculated to have an area ~1500 km^2 [6] with a complex surface-process history [4]. It contains many parallel and relatively linear inverted geomorphic features that observed on near-flat surfaces (Figure 2). These features are best explained as products of glacial processes.

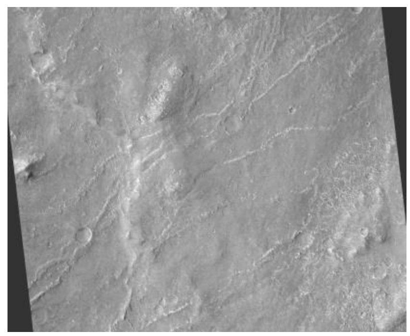

Figure 2. HiRISE view of a swarm of sub-parallel inverted features within the Gale crater watershed. Image is ~5 km across.

One inverted feature in the watershed flows along the rim of the crater and enters the crater at the east side of the Peace Vallis alcove, topographically higher than the current Peace Vallis channel. Newly captured HiRISE imagery (Figure 3 left) shows a segmented, linear form typical of eskers. This feature eventually leads into the crater floor where it has been previously noted as a potential esker form (Figure 3 right) [2].

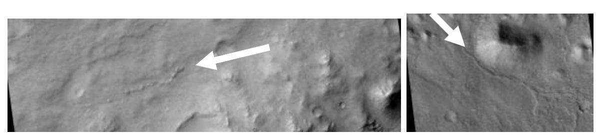

Figure 3. Right: HiRISE view of an inverted feature above Gale crater in the Peace Vallis alcove with the arrow indicating flow direction. Image is ~5 km across. Left: HiRISE view of the same feature flowing into Gale crater. Both images are scaled to ~5 km width.

NE inner-rim bajada. The sloping bajada structure (Figure 4 left) which stretches along the inner-rim of the NE section of Gale crater has numerous inverted features on the individual fan structures. Compared to inverted features on other fan surfaces of Mars, these are relatively linear and appear to have not formed in a typical sinuous fluvial environment. At the distal end of the bajada, linear inverted forms can lead into areas with deposits of highly sinuous forms (Figure 4 right). These areas may represent glacial outwash plains and/or other purely fluvial structures.

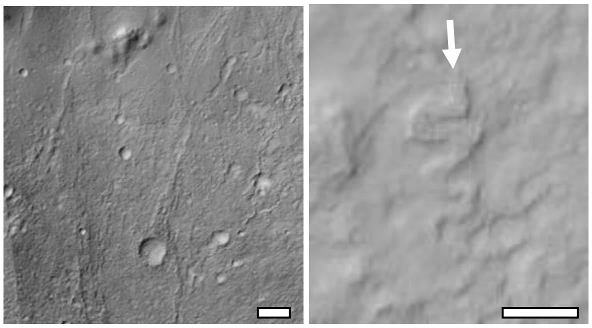

Figure 4. Left: CTX view of a section of the Gale crater inner-rim bajada displaying extensive, linear inverted features of likely glacial origin (scale bar 1 km). Right: HiRISE view of a highly sinuous inverted channel on the floor of Gale crater of likely fluvial origin (scale bar 150 m).

Peace Vallis fan. The inverted structures of the Peace Vallis fan system (e.g. Figure 5) appear significantly different than other fluvially/alluvially inverted channels on Earth and on Mars [9]. This inverted network is less sinuous than other analogous structures. The fan system is located north of the Mars Science Laboratory rover and has been the subject of past, ground-level observations by the ChemCam RMI [7,8]. Figure 6 (top, ~17 km distance to center of image) displays a large inverted structure which is segmented and highly linear. This feature is interpreted as an esker. Figure 6 (bottom, ~9 km distance to center) shows a section of the extensive network of linear, inverted features which outcrop at the western toe of the fan. These features are remnants of the early fan or lacustrine sediments.

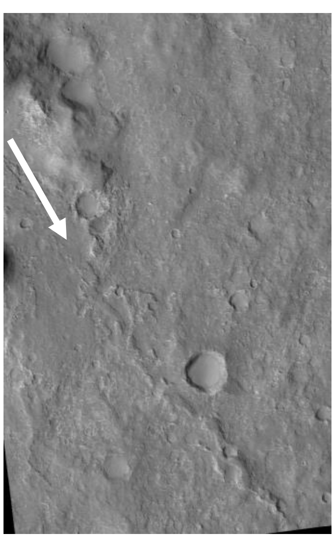

Figure 5. Linear inverted feature on Peace Vallis fan older BF (bedded and fractured) unit. Note the discontinuous nature due to cratering. This feature does not originate within a fluvial channel. Image is ~2.5 km across.

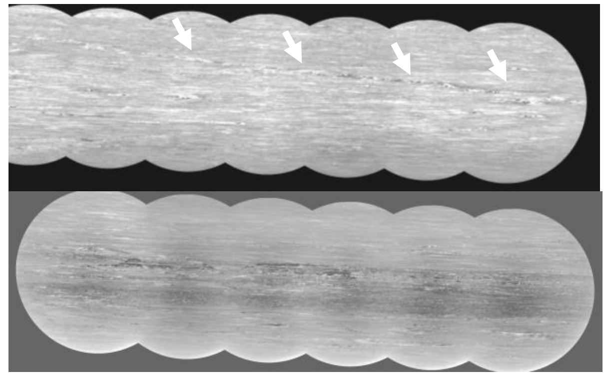

Figure 6. ChemCam RMI of the Peace Vallis fan showing low-sinuosity, inverted features associated with the older BF (bedded and fractured) unit. Top: (CCAM03998) Largest inverted feature on the fan running from the top-left to the middle-center of the image. Bottom: (CCAM02241) Inverted features at the toe of the fan.

Discussion: Inverted features within the Gale crater region have been described by previous studies as fluvial/alluvial sedimentary geomorphic features [9,10]. Fluvially-deposited inverted features are present in other localities on Mars: Jezero delta, Eberswalde delta, and many other crater fan-deltas. At these locations, inverted features are sinuous and anastomosing. Some inverted features inside Gale are distinctly different, being linear/non-sinuous. This difference is also noted at analogue sites on Earth like the Green River basin sinuous ridges. Eskers, like those recorded in Canada from previous glacial periods, more closely resemble the features seen in the Gale crater region.

Geomorphic evidence of glaciation on Mars is well documented from the poles to the mid-latitudes in both hemispheres, but glaciation near the equator has until now been enigmatic. Future work will look to quantify the sinuosity and slope of the Gale crater inverted features with newly acquired imagery and orbital data to confirm the possible glacial origin.

Conclusion: The extensive inverted features within and around the Gale crater area have been previously considered as fluvial in origin. A new hypothesis for a glacial origin helps to illustrate the differences between the linear inverted features described in this abstract and more sinuous fluvial inverted features on Mars.

References: [1] Le Deit L. et al. (2013) JGR Planets, V 118, 2439-2472. [2] Fairén *Planetary and Space Sci.* (2014), 93, 101-118. [3] E. S. Kite (2013) *Icarus* 223.1, 181-210. [4] Newsom H. E. (2020) LPSC LI, This Conference. [5] Scuderi L. A. (2019) LPSC L, Abstract # 2714. [6] Newsom H. E. (2019) Mars 9, Abstract # 6119. [7] Gallegos (2018) LPSC XLIX, Abstract # 2965. [8] Gallegos (2019) LPSC L, Abstract # 2841. [9] Palucis (2014) JGR: Planets, 119.4, 705-728. [10] Grant (2014) GRL, 41.4, 1142-1149.