DEPOSITIONAL HISTORY OF THE UPPER SEQUENCE OF THE WESTERN FAN: EVIDENCE FOR LATE-STAGE FLUVIAL AND POTENTIAL IGNEOUS ACTIVITY, JEZERO CRATER, MARS

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Introduction: Within Jezero crater, a 45 km diameter Noachian-aged crater on Mars, the Upper Fan group (UFg) stratigraphy records the youngest interval of sediment deposition via aqueous activity on the western fan. From orbital images, the UFg surface is characterized by ridges interpreted to be associated with channels [1-2] that can be group based on orientation into distinct elongate and fan-shaped deposits [3]. UFg deposits primarily consist of a sandstone to granule conglomerate facies covered by a lithified boulder conglomerate or dense accumulations of loose boulders along the surface. The coarse-grained nature of UFg deposits and the unconformable contact with the underlying fan stratigraphy suggest that the UFg represents a higher-energy shift from the relatively longer-lived, lower-energy aqueous systems interpreted in underlying fan stratigraphy [4-6]. The Mars 2020 *Perseverance* rover encountered the main exposures of the UFg deposits beginning on Sol 755 and has been continuously collecting data along its northwestward traverse across the fan, enabling reconciliation of orbitally-derived geomorphology with in-situ observations from the rover and *Ingenuity* helicopter.

This work represents a combined assessment of the geomorphology and the sedimentology and stratigraphy of the UFg in order to establish its depositional and emplacement history. Determining the origins of the Upper Fan sequence will clarify how, when, and in what order aqueous environments evolved through time within Jezero crater (e.g. crater infill, overflow, breach, and lake level drop; [1]). Finally, this work will provide critical context for the three rock samples within the UFg sample suite.

Methods: Mapping of UFg deposits was done at the 1:5,000 scale using a 25 cm/pixel High Resolution Imaging Science Experiment (HiRISE) basemap and a 1 m/pixel HiRISE digital terrain model [7].

Observations and measurements of outcrop-scale features, including outcrop thicknesses and boulder sizes, were primarily made from Mastcam-Z images [8], helicopter images [9], Navigation camera (Navcam) images [10], and Supercam Remote Micro-Imager (RMI) images [11]. Grain-scale textures and additional context were primarily observed in RMI and Wide Angle Topographic Sensor for Operations and eNgineering (Watson) images [12].

Results and depositional interpretations:

Orbiter image analysis and mapping: From HiRISE images, fan-shaped and elongate deposits were differentiated on the UFg surface based on common ridge orientations as well as morphologic and tonal differences. Based on cross-cutting relationships and other morphologic features (e.g. Belva crater), deposits can be placed in a relative timeline. It is unclear whether the Neretva Vallis channel extension formed before or after UFg deposits. In one scenario, the channel cross-cuts mapped deposits and therefore post-dates the UFg deposition, implying an even younger interval of high-energy aqueous activity. In the second scenario, channel formation predates the deposits, which emanate from the channel.

Rover and helicopter image observations: Observations from Mastcam-Z and helicopter images corroborate hypotheses based on orbital data that the UFg is unconformable with underlying Tenby and Shenandoah formation stratigraphy (Fig. 1a-b).

One notable finding is that the mapped deposits appear to consist primarily of a planar-stratified sandstone and granule conglomerate facies known as the Otis Peak formation (Fig. 1b). The Otis Peak formation shows sparse occurrences of trough-cross stratification (Fig. 1c). The sedimentary structures and grain size range lend support to a fluvial interpretation for this formation. The minimum flow depths and velocities requiring for transport of the sand- to granule-size fraction are cm- and cm/s-scale, respectively, indicating a shallow river system [13 and references therein].

There are two primary boulder populations overlying the Otis Peak formation: (1) rounded to well-rounded boulders that are massive and lithified within a boulder conglomerate (Fig. 1a), and non-lithified boulder accumulations that comprise ridges (Fig. 1d); and (2) angular boulders that exhibit variable ventifacts (Fig. 1b & e) and, in some exposures, appear to derive from the degradation of a more coherent capping unit (Fig. 1f). Compositionally, the majority of boulders exhibit olivine-rich signatures with a secondary population of pyroxene-rich boulders [14 & 15]. The rounded boulder population (Fig. 1a & d) is interpreted to represent deposition in a fluvial system, requiring minimum flow depths of 3.3-4.9 m and velocities of 3.1-

4.1 m/s [eq. from 16]. Compositional [14 & 15], morphologic, and textural evidence suggests that the more angular boulder population (Fig. 1b & e) represents erosion from a more massive igneous capping unit (Fig. 1f).

Model for Upper Fan group formation: Based on mapping and rover-scale observations, the following sequence of events is proposed for UFg formation: (1) Fluvial deposition of the Otis Peak formation occurs over underlying fluvial, deltaic, and lacustrine fan units of the Tenby and Shenandoah formations. Deposits may have formed as alluvial fan lobes that are later cross-cut by the Neretva Vallis channel, or, more likely, based on spatial distribution and orientation relative to Neretva Vallis, as splay deposits that emanate from the channel. (2) Subsequently, an igneous unit is emplaced, capping the Otis Peak formation. (3) Following emplacement, the igneous unit erodes into massive deposits and angular boulders. (4) Where they occur, boulders act to preserve underlying fan stratigraphy. At some point along this timeline, fluvial deposition of the boulder conglomerate population occurs.

Implications: The Upper Fan group records a diverse depositional and emplacement history. This history includes late-stage fluvial activity ranging from rivers characterized by more shallow flow depths (Otis Peak formation) to deeper and high-velocity river systems capable of transporting boulders (boulder conglomerate). Unconformable contacts throughout the UFg suggest that this fluvial activity was decoupled from the aqueous systems of the underlying Shenandoah and Tenby formations [4 & 6]. A second population of boulders that derives from degradation of an igneous unit implies late-stage volcanic activity not previously identified on the fan, and likely a hiatus in fluvial crater fill activity. Boulders of the UFg preserve underlying stratigraphy, implying that their distribution dictates the present-day shape of the Jezero crater western fan.

Acknowledgements: Thank you to the Mars 2020 science and engineering operations teams.

References: [1] Goudge, T.A., et al, (2018), *Icarus* [2] Schon et al. (2012), *PSS* [3] Sun & Stack (2020), *USGS* [4] Ives et al. (2023), *AGU fall mtg*. [5] Mangold et al. (2021), *Science* [6] Stack et al. (2023), *LPSC* [7] Calef et al. HiRISE basemap. [8] Bell III et al. (2022), *Sci. Adv.* [9] Balaram et al. (2021), *SSR* [10] Maki et al. (2020), *SSR* [11] Maurice et al. (2021) *SSR* [12] Bhartia et al. (2021), *SSR* [13] Williams et al. (2013), *Science* [14] Vaughan et al., *LPSC this mtg.* [15] Beyssac et al., *LPSC this mtg.* [16] Palucis & Lamb (2017), *GRL*

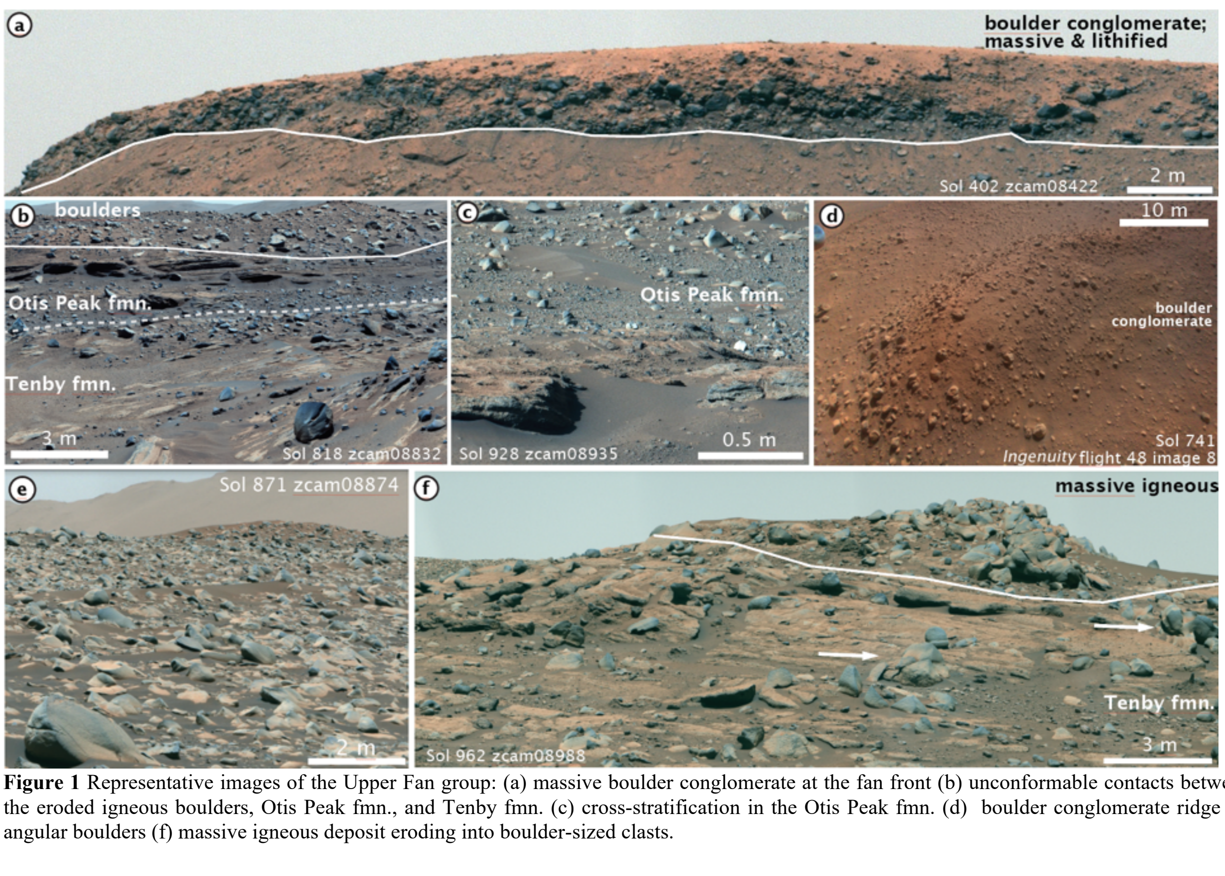

Figure 1 Representative images of the Upper Fan group: (a) massive boulder conglomerate at the fan front (b) unconformable contacts between the eroded igneous boulders, Otis Peak fmn., and Tenby fmn. (c) cross-stratification in the Otis Peak fmn. (d) boulder conglomerate ridge (e) angular boulders (f) massive igneous deposit eroding into boulder-sized clasts.