SEDIMENTOLOGY AND STRATIGRAPHY OF THE LOWER DELTA SEQUENCE, JEZERO CRATER, MARS.

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Introduction: In April 2022, the Mars 2020 *Perseverance* rover arrived at the base of the ancient delta in Jezero crater after completing the first year of its mission exploring and sampling aqueously altered igneous rocks of the present-day crater floor [1]. Perseverance then spent ~200 sols exploring the lower ~25 m of rock exposed within the eastern scarp of the Jezero delta [2], a sedimentary sequence informally named the 'Shenandoah' formation. This study describes the sedimentology and stratigraphy of the Shenandoah formation explored by *Perseverance* at two sections—'Cape Nukshak' and 'Hawksbill Gap'—including a description, interpretation, and depositional framework for the facies that comprise it.

Sedimentary Facies: Using observations acquired during the traverses of Cape Nukshak and Hawksbill Gap from Navcam, Hazcam, Mastcam-Z, SuperCam RMI, and SHERLOC WATSON and ACI cameras, facies were distinguished on the basis of grain size, sedimentary structures, and bedding style (Fig. 1). Geochemistry and mineralogy, as observed primarily by PIXL, SHERLOC, and SuperCam, were used to distinguish facies in several instances where composition was the defining characteristic.

Thick-bedded Pebbly Sandstone: This facies is comprised of apparently planar cm to dm-scale structureless beds of matrix-supported poor to moderately-sorted coarse to very coarse sandstone with intermittent dark, pebble-sized clasts and vugs. Erosion-resistant beds appear better-sorted and coarser grained than those that weather recessively.

Interpretation: This facies is interpreted to represent high density, relatively high energy flows alternating with upper flow regime bedload transport.

Planar Thin-Bedded Coarse Sandstone and Granule Conglomerate: This facies is comprised of tabular, thin beds (1-8 cm thick) of medium to very coarse-grained sandstone sometimes alternating with thin beds of granule conglomerate. Rare low angle cross-stratification is observed, but planar bedding dominates. Clasts within coarser-grained beds are sub-rounded to sub-angular, with some clast imbrication observed. Rare larger clasts up to 20 cm are observed, though most are ~3 cm in diameter or less. Thicker beds appear normally graded.

Interpretation: This facies represents high density, upper flow regime bedload deposition with tractional reworking. Normal grading suggests waning flows.

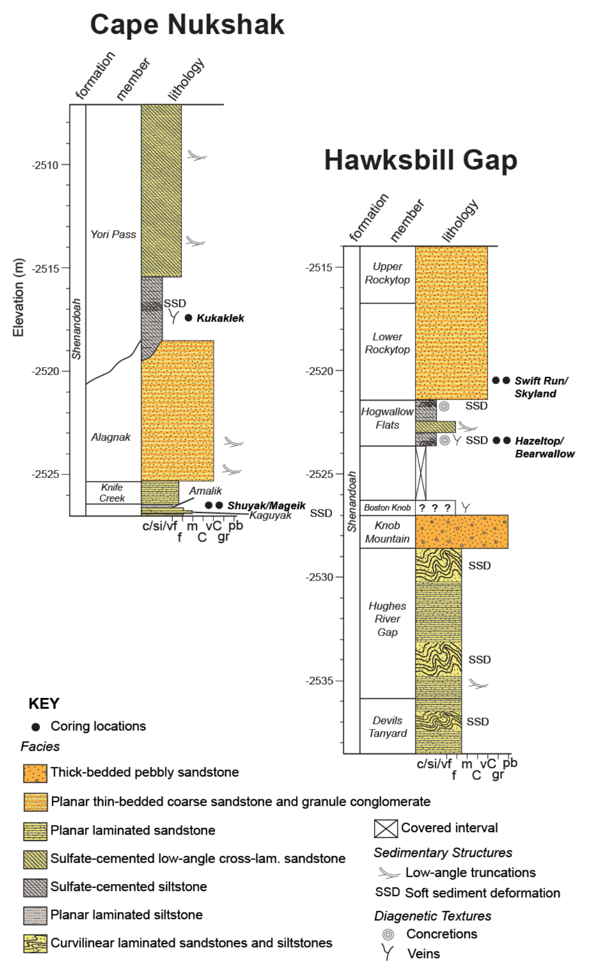

Figure 1. Stratigraphic columns for the Cape Nukshak and Hawksbill Gap sections of the Jezero delta front.

Planar Laminated Sandstone. This facies is dominated by mm-scale planar laminations (1-2 mm thick) with rare low-angle truncated laminae. Laminations are traceable laterally at least several meters and are comprised predominantly of poorly to moderately sorted fine to medium sandstone.

Interpretation: The planar laminations within this facies could represent upper flow regime plane bed deposition; settling from suspension is also being considered. Truncated laminae are consistent with scour and fill geometries.

Sulfate-cemented Low-angle Cross Laminated Sandstone: This facies is comprised of platy, thin mm-scale laminae that form shallow dm-scale troughs. Grain size information for this facies is limited, but its platy-weathering texture and lack of observable larger clasts suggest sand-sized grains. This facies is distinguished by the presence of ~20-30 wt % Fe/Mg sulfate.

Interpretation: This facies is interpreted to represent lower flow regime deposition of three-dimensional bedforms. Primary aqueous precipitate versus late diagenetic origins for the sulfate are under consideration [3,4].

Sulfate-cemented Siltstone: This facies is comprised predominantly of moderately to well-sorted coarse silt-sized grains. Planar, mm-scale laminations are observed, but can transition laterally into intervals that appear massive or exhibit contorted, deformed laminae. This facies is distinguished by its 20-30 wt% Fe/Mg sulfate composition.

Interpretation: This facies is interpreted to represent settling from suspension given its fine grain size and lack of sedimentary textures. Primary aqueous precipitate versus late diagenetic origins for the sulfate are under consideration [3,4].

Planar Laminated Siltstone: This facies includes rhythmic planar thin laminations (<1 cm thick) comprised of silt. Individually laminae fine upward, consistent with normal grading.

Interpretation: The planar laminated siltstone facies is interpreted to represent settling out of suspension in a low energy environment.

Curvilinear Laminated Siltstones and Sandstones: This facies appears fine-grained (siltstone to fine sandstone) with deformed, contorted curvilinear laminations and thin beds.

Interpretation: This facies is interpreted to represent soft sediment deformation resulting from instabilities due to density contrast between underlying and overlying sediment, or downslope movement or slumping.

Discussion: The sedimentary facies observed at Cape Nukshak and Hawksbill Gap (up to the level of upper Yori Pass and Rockytop) represent a largely sand-dominated sequence in which planar lamination and bedding and soft sediment deformation are common (Fig. 1). Throughout much of the section, bedform geometries with the migration of ripples or dunes is notably absent; exceptions include the middle interval of Hogwallow Flats and the Alagnak outcrop (Fig. 1). Mud cracks, fluvial channels, or other indicators of subaerial exposure have not been conclusively identified in the lower 25 m of the Shenandoah formation.

The facies observed at Hawksbill Gap and Cape Nukshak are consistent with subaqueous deposition by a series of broadly unconfined hyperpycnal flows in a distal deltaic setting [5], with intermittent settling from suspension during periods of quiescence or via hypopycnal plumes. In this context, the broad, convex up, planar bedded sand lenses at Rockytop and Alagnak would be interpreted as turbidite lobes observed in their distal reaches or off axis from their main distributary channels [6].

Also under consideration is an interpretation for this sequence as one or more distal crevasse splay complexes. Such distal splay complexes could share similarities in facies and facies associations with those observed in distal deltaic turbidite sequences, and can be challenging to recognize in outcrop [7]. Furthermore, the depositional environments and processes expected for a lacustrine basin and a persistent floodplain setting would be similar. However, we have not yet observed the diagnostic overlying and underlying fine-grained deposits expected in between splay deposition, the distal thinning and fining trend away from the associated channel belt characteristic of splay sequences, nor the massive sandstones that dominate such sequences, that would uniquely favor a crevasse splay origin [7].

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