EXPLORATION OF CARBONATE-RICH ROCKS IN THE MARGIN UNIT BY THE PERSEVERANCE ROVER IN JEZERO CRATER.

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Introduction: In situ investigations by the Perseverance rover in Jezero crater have revealed a complex and long aqueous history, including possible early serpentinization of and late salt addition to igneous rocks [1] and a well-preserved delta-fan [2,3]. Perseverance is now exploring the Margin unit (MU), a region along the western rim of the crater with strong orbital carbonate signatures [4]. Prior to arrival, hypotheses for the origin of the MU included igneous and fluvial processes [5,6], but the concentration of carbonate within a narrow range of elevations is also consistent with shorezone deposition of authigenic lacustrine carbonate [5,7]. Lacustrine carbonates would be a compelling target for sample return due to their recognized biosignature preservation potential [8]. Here we provide an overview of the Mars 2020 Margin Campaign, key initial results, and a working model for the geologic history of the unit.

Campaign Overview: The Margin Campaign aims to determine emplacement processes, alteration history, geologic relationships, biosignature preservation potential, and paleoenvironment of the MU [9]. These goals support the selection of rock cores for potential return to Earth by Mars Sample Return [10]. Perseverance approached the MU from the fan top at Mandu Wall, the lowest point encountered in the MU. The first abrasion (Amherst Point) and sample collection (Pelican Point) were conducted at the Hans Amundsen Memorial Workspace. The rover turned north to Turquoise Bay, a topographic high with strong orbital carbonate signatures, for a second abrasion (Bills Bay) and sample (Lefroy Bay). The rover then conducted a remote sensing survey of Gnaraloo Bay to investigate contacts between the MU and the delta-fan. Perseverance is currently driving west across the MU, where an abrasion (Crystal Geyser) and sample (Comet Geyser) were acquired at Bunsen Peak. The next major investigation is at Bright Angel, where light-toned layered materials within Neretva Vallis may underlie the MU.

Initial Results: Observations so far suggest that the MU includes at least some clastic rocks and is carbonate-rich, in which carbonate occurs both as pore-filling cements and discrete grains. We identified a transition in the properties of the MU ~400m west of the edge of the fan-delta and refer to "eastern" and "western" regions of the MU relative to this zone [11,12].

Morphology: Mastcam-Z images (Fig. 1) show that the MU is composed of dark granular layers [13,14]. Filled fractures sometimes cut across layers, suggesting late diagenetic alteration. The eastern MU is dominated by relatively flat terrain broken into large polygons (Fig 1c), showing layers of variable thickness (<1-40 cm). The western MU shows a sharp increase in overall slope upward toward the crater rim, as well as increased roughness, in the form of rolling linear hills oriented perpendicular to Neretva Vallis (Fig. 1b) and narrow ridges oriented parallel to Neretva Vallis, both a few meters in height. While the western MU lacks clear sedimentary structures, it shows more textural diversity, and is variably composed of packages of rubbly and recessive outcrops, sets of thin layers, and resistant and seemingly structureless thick layers [11,14].

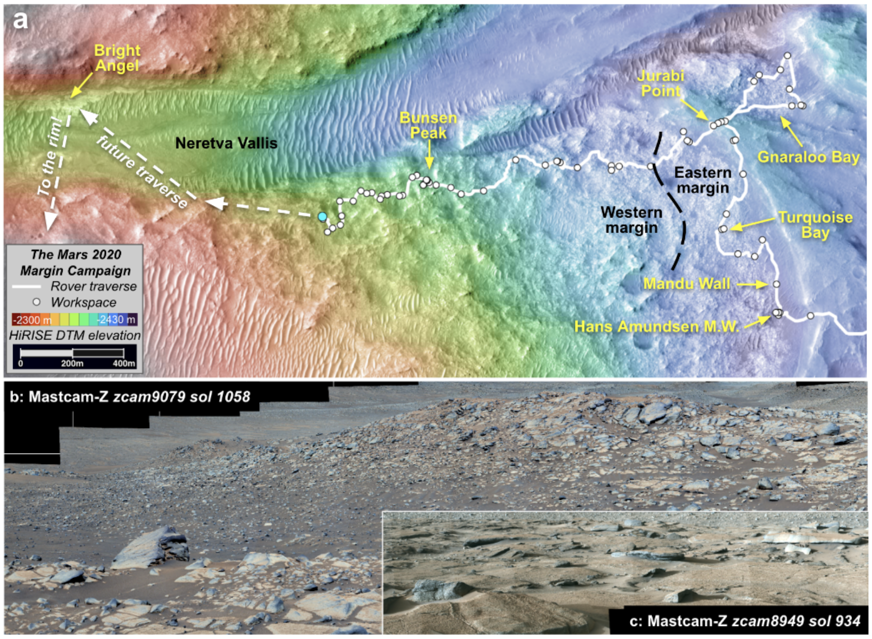

Figure 1: *(a) Perseverance strategic traverse in the Margin unit, key regions of interest, and progress to date. (b) Western margin unit at Bunsen Peak and (c) eastern margin unit at Turquoise Bay in enhanced color from Mastcam-Z.*

Structure: RIMFAX ground penetrating radar and surface outcrops show that the MU underlies the fan/delta [15,16]. Layers in the eastern MU form packages that are horizontal to sub-horizontal or dipping either rimward or basinward, sometimes with sharp truncate [11,15-17]. The layer dips are shallow (6-15°), and no steeply dipping cross-beds have been identified. In contrast, layer packages in the western MU show a consistent basinward dip (6-20°). The dipping packages appear to correspond to strong RIMFAX reflectors, which are continuous over several tens of meters. Across the MU, RIMFAX profiles also commonly show potential trough, hummock, and clinoform structures [16].

Composition: Mastcam-Z and SuperCam reflectance spectra and LIBS chemistry show similar composition throughout the MU, with variable olivine and pyroxene, Fe/Mg-carbonate, hydrated silica, and phyllosilicates, [12-14]. The degree of alteration may be correlated with texture, as more resistant targets may contain more silica/carbonate than rubbly/recessive targets [14].

Abrasion patches in the eastern MU show putative clasts including diverse dark to light-toned sand-sized grains [13,18]. PIXL XRF and SHERLOC Raman spectra identify grains of olivine and grains of carbonate, with more rare pyroxene, feldspar, and silica, and cements that are largely composed of carbonate and hydrated silica with some phyllosilicates [19,20].

Proximity science observations from Bunsen Peak in the western MU show a highly altered rock with mm-scale carbonate masses, which sometimes include olivine or serpentine cores, but also occur without these cores [19,20]. The grains are embedded in a silica-dominated matrix, but are often rimmed by amorphous or microcrystalline phyllosilicates including serpentine-group minerals. We have seen no evidence for non-diffracting glassy zones or scoriaceous textures suggestive of a pyroclastic, but the level of mineralization makes the primary textures difficult to discern.

Interpretive framework: *Origin of the grains:* Primary silicate grains in the MU are likely igneous crystals, and are similar to the mm-scale olivine grains of the Seitah cumulate [21] and inferred within the regional olivine-bearing unit [22-23]. While carbonate grains with olivine/serpentine cores likely formed via carbonation of olivine grains, grains without these cores may have precipitated from water. Both types are present in all abrasions and with unaltered olivine grains in the eastern MU [19-20], suggesting a combination of alteration, precipitation, and detrital origins.

Depositional processes: Eastern MU abrasions show subrounded primary and secondary mineral grains that are consistent with a well-sorted sandstone [18]. The distribution of the MU along the rim could be consistent with alluvium, and some subsurface radar features across the MU appear consistent with fluvial accretion and erosion [17]. However, it is difficult to explain the rimward-dipping strata and well-sorted sandstones observed in the eastern MU in a purely alluvial or fluvial scenario. In addition, no high-angle cross-beds or wind ripple laminae expected for aeolian settings have been observed [11]. In contrast, lacustrine beach bars can form truncated and well-sorted sandstone beds dipping both toward and away from the basin [11]. Thus, along with the distribution of the MU along the western crater rim, a shorezone depositional environment seems the most likely for the eastern MU, potentially with local fluvial/aeolian modification.

Interpreting the primary textures and depositional setting of the western MU is challenging due to the mineralization of the Crystal Geyser abrasion and the lack of clearly exposed sedimentary structures. Early precipitation of carbonate cements within strandline sands in alkaline lagoons can form massive dipping planar layers (beachrock) [24], but this is not a unique interpretation of this facies. Planar dipping layers of mm-size olivine grains were also previously observed in the Seitah igneous cumulate on the crater floor, and some types of pyroclastic deposits can be crystal-dominated and produce well-sorted and planar dipping layers (e.g., eruption of large, crystal rich magma bodies and/or the tail end of smaller dilute pyroclastic density currents).

Diagenetic history: The MU shows evidence for aqueous carbonate precipitation, carbonation of olivine/serpentine grains, silicification, and late diagenetic addition of carbonate and sulfate. While carbonate is present throughout the margin, silica is heterogeneous at the cm to m scale. Many early and late diagenetic processes could produce carbonation and silicification, including weathering, hydrothermalism, and cementation.

Conclusion: The stratigraphy, composition, and distribution of the eastern MU seem to be most consistent with a lacustrine shorezone deposit, in which at least some of the carbonate formed due to contemporaneous low energy reworking and cementation of subaqueous or pore-filling precipitates. The western MU may reflect the continuation of processes in the eastern MU or alteration of a pre-existing igneous unit.

References: [1] Farley et al. (2022) *Science 377*. [2] Mangold et al. (2021) *Science 374* 711-717. [3] Stack et al. (2024) *JGRP 129*. [4] Ehlmann et al. (2008) *Science 322* 1828-1832. [5] Horgan et al. (2020) *Icarus 339* 113526. [6] Tarnas et al. (2021) *JGR 126*. [7] Zastrow & Glotch (2022) *GRL 48*. [8] Farley et al. (2020) *SSR 216* 1-41. [9] Horgan et al. (2024) *55th LPSC* #2624. [10] Randazzo et al., this vol. [11] Jones et al., this vol. [12] Clave et al., this vol. [13] Garczynski et al., this vol. [14] Ravanis et al., this vol. [15] Barnes et al., this vol. [16] Russell et al., this vol. [17] Cardarelli et al., this vol. [18] Williams et al., *55th LPSC* #1288. [19] Hurowitz et al., *55th LPSC* #2541. [20] Sinclair et al., this vol. [21] Liu et al. (2022) *Science 377* 1513-1519. [22] Kremer et al. (2019) *Geology 47* 677-681. [23] Ruff et al. (2022) *Icarus 380* 114974.