**Introduction:** The Perseverance Rover of M2020 [1] spent ~400 sols on the Jezero Crater Western Fan, traversing ~8 km in ~100 drives between Sols 439-909. The fan traverse can be partitioned into 4 general divisions: the horizontal layers of the Fan Front, a Transition region to the upper fan, the Curvilinear outcrops, and Blocky materials, including topographic lobes with interspersed occasional light-toned exposures. Prior, Perseverance had traversed ~12 km over crater floor surfaces from its landing site. The RIMFAX ground penetrating radar [2] has been making sounding measurements every 10 cm for almost the entire traverse [3].

All parts of the fan listed above exhibit radar characteristics distinguishing them from one another. Additionally, all of them differ significantly from typical crater floor characteristics. We present a RIMFAX overview of all sections of the fan with discussion on implications for depositional environment and geological evolution. RIMFAX subsurface GPR results have significantly augmented and illuminated more traditional rover surface observations, in a fundamentally new way over previous Mars rover missions.

Previous works have used Rimfax data to investigate the Maaz formation of the crater floor [4,5], the transition to Seitah [4], and the contact of fan with the crater floor [6], in which the fan was proven to be younger than the crater floor. This contact is sharp and dipping ~12° NNE at Cape Nukshak, where buried sedimentary layers of the fan have been deposited on an erosional surface truncating layers within Seitah. In contrast, the contact is fairly horizontal beneath Hawksbill Gap, with what appears to be Seitah below and the near-horizontal layers of the Shenandoah formation above (with a short, complicated section at the toe of the fan, where it may directly overlie Maaz [17]).

In examining the fan with RIMFAX, we focus particularly on the complementary, wide-open question of the relationship of the fan with its neighboring deposits, the “Margin Unit”, at the fan’s upper extent [e.g., 7-10]. The relative superposition of fan with the Margin (which arcs along the whole western crater rim, over a significant elevation span) is obviously key to their relative age relationship and the broader geologic context of the fan in the overall crater setting. What underlies the majority of the fan, and if the upper Margin is connected (physically and/or genetically) to the lower-elevation, crater-interiorwards Seitah, are also of interest and addressed with RIMFAX.

**Results:** We present the main Rimfax features along much of the on-fan rover traverse, from crater floor to Margin Unit, in complement with [3]. Note that these observations up the fan will construct a succession of units and materials representative of what lies along the exact rover path. This could exhibit similarities and differences from stratigraphic columns developed by other authors incorporating off-track observations and/or representing idealized or composite stratigraphies of the fan or subsections thereof [e.g., 11-14]. The stack of Shenandoah formation layers exposed in the Fan Front up to Hogwallow Flats are nearly horizontal, and are revealed to extend in planar-like fashion 10s of meters into the hillside. This confirms the topographic gradient was likely very low during deposition. Relief along the interfaces, which would reflect non-uniform deposition and/or erosion, is also minimal.

In contrast, Shenandoah Rockytop and higher Transition materials slope downwards towards the fan edge, indicating a different episode and depositional environment of emplacement (Fig. 1). More irregular, higher-relief interfaces suggest deposition and/or erosion may not have been as spatially uniform.

Within the curvilinear Tenby Formation, steep dips and truncations of layer-set boundaries are apparent in select profile sections, allowing the intricate relationships of curvilinear surface sets to be extended to the subsurface. Typical configurations include bent step-like and asymmetric-V intersections. There are signatures in nearest-surface radar data likely derived from the interlayering of individual curvilinear beds, though likely not representing the beds 1:1.

Beneath the horizontal Emerald Creek outcrop (high in the Tenby Formation), radar data shows a broad trough defined by very high relief radar features. This roughness is likely the expression of highly inclined layers truncated into an irregular surface, as is visible at the surface nearby. This suggests that the inclined layers were eroded (forming the trough) before deposition of Emerald Creek (filling the trough), which has implications for the relationships of layer-packets within the curvilinear deposits.

Above this point, through much of the Blocky Unit, significant sections of the subsurface appear relatively featureless in Rimfax data, with relatively high, yet noisy, signal. This signature likely arises from above-surface scattering (or clutter) off the innumerable boulders sitting on/in the fine regolith, which characterizes the surface here (evident from orbit and confirmed from the rover’s
perspective). Unfortunately, the dense presence of these rocks on the surface around the rover often have the effect of ‘masking’ any subsurface details (though it’s likely the near-surface is boulder-rich and thus highly scattering as well).

Intriguingly, in local low areas amongst lobes and expanses of the Blocky Unit, are limited exposures of light-toned, fractured bedrock. In orbital CRISM band-depth maps, these often appear as small areas of strong carbonate indicators [7], more similar to the Margin or Seitah than the surrounding Upper Fan. RIMFAX penetration at these isolated, relatively smooth outcrops is better than in the boulders, revealing near-horizontal to gently sloping reflectors (Fig. 2). Because they are bounded by lobes and other bouldery terrain, these reflectors can’t be traced laterally very far from the outcrops.

Between placing wheels on the Margin Unit and the Hans Amundsen Workspace, two significant observations of the Margin were quickly clear from strong, continuous reflectors in the RIMFAX data: that it is composed of multiple, planar, sub-parallel ESE-dipping layers, and that it dives beneath the blocky lobe representing the western edge of the fan that the rover had just descended [3,10]. The Margin Unit is thus older, making the fan the youngest of the 3 main terrain divisions (the crater floor being the third) traversed in Jezero so far.

**Discussion:** As it turns out, the subsurface at the above inter-lobe outcrops (e.g., Dream Lake, Willow Park) appears similar to the ~SE-dipping layers characterizing the contiguous Margin along its eastern edge (ie, the entirety of Mandu Wall, to where the rover deviated towards Turquoise Lake). Based on similarities in elevation trends (absolute and relative to neighboring higher blocky fan lobes), surface outcrop appearance (smooth, low relief, light tone, size and shape of paver-like rocks, fracturing), orbital carbonate indications, and RIMFAX subsurface reflectors (character and orientation), we suggest these bedrock exposures may be windows to the Margin through the surrounding, intervening, otherwise covering material of lobes and Blocky Unit.

One geographic implication is that the Margin Unit extends and underlies the fan up to at least 0.5 km to the East. An analysis of surface images throughout the Blocky Unit, including at and near these window outcrops, also places them at the base of the regional stratigraphic column, possibly correlated with the Margin Unit [13].

This interpretation of the Dream Lake and Willow Park outcrops has significant contextual implications for interpretations of rock abrasions (Thunderbolt Peak and Gabletop Mountain, respectively) and other composition data gleaned from them. Namely that these measurements should perhaps be considered within the suite of Marginal Unit observations, together comprising variation within the materials of the Margin and its derived emplacement/alteration history (as opposed to being considered in contrast to the Margin Unit, e.g., along with Blocky Unit and other materials in their much more immediate surroundings). Current analysis of “pure” mineral identifications in PIXEL data of these abrasions currently suggests enough similarities with the Margin to allow for this possibility, though not uniquely [15]. Associations with rover-based carbonate abundances are under study [e.g., 16].

Both the regularity of Margin Unit layering (given the rough, structureless appearance of the surface from orbit) and the low subsurface radar loss were surprising, more prominent than any Rimfax had encountered in the crater until then. This high penetration and low loss is particularly noteworthy as a contrast between Marginal Unit and Seitah, suggesting that their primary materials, alteration history, and/or degree of fracturing likely differ.


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**Figure 1.** Rimfax traverse of upper Shenandoah formation, from Hogwallow Flats (green), through Rockytop (red & orange), into Transition region.

**Figure 2.** Rimfax traverse from Willow Park (left), a light-toned, fractured window outcrop within the Blocky Unit, up across rocky fan lobes, and down onto Margin Unit to Hans Amundsen (right).