What do the >3.8 Ga rocks studied so far at Jezero crater tell us about the past climate of Mars?

Quantin-Nataf C.[1], Dehouck E.[1], N. Mangold[2], Mandon L.[3], Clave E[4], Royer C.[5], Beck P.[3], Forni O.[6] Bedford C.[7], Mayhew L.[8], Ravanis E.[9], Poulet F.[5] , J. Johnson [10], Cousin A.[6], Wiens R.[7], J. L. Simon[11] and K. Stack-Morgan [12]
(1)LGL-TPE, France, (2) LPGN, France, (3) IPAG, Grenoble, France, (4) DLR, Germany, (5) IAS, France, (6) IRAP, France, (7) Purdue University, USA , (8)University of Colorado, USA, (9) *University of Hawaii, USA, (10) Johns Hopkins University (11) NASA Johnson Space Center, Houston, USA, (12) JPL, USA.*

Introduction: Since February 2021, the Mars 2020 rover *Perseverance* has been exploring Jezero crater to characterize the geology, assess the potential for rocks to record ancient habitable environments and/or preserve biosignatures, and collect a suite of scientifically compelling samples for return to Earth [1]. From 2021 to 2024, Perseverance explored the interior of Jezero, and consequently the geological units post-dating its formation. These units include, from the oldest to the youngest: volcanic crater floor unit (Maaaz and Seitah), the "Margin unit", a unit composed of olivine, clays and carbonates, and a younger fluvio-deltaic sedimentary complex (See [3] this issue). In September 2024, Perseverance started the ascent of the Jezero crater rim where the Mars' most ancient crust (Pre-Jezero and even pre-Isidis basin crust) is exposed.

In this contribution, we focus on the geological units pre-dating the fluvio-deltaic complex encountered by Perseverance and are discussing the implication for the ancient Martian climate.

Geological context as seen from orbit: From the oldest to the youngest rocks (Figure 1), the rocks exposed in Jezero comprise:

-The Noachian basement. In the region around Jezero, the Noachian basement has been described from orbital data [3]. It is composed of layers altered into smectite clays, of megabreccia bearing layers including a large variety of megablocks attributed to a reworking of the pre-Isidis Noachian crust [3]. And locally, the Noachian basement is capped by surficial Al-rich phyllosilicate horizons, possibly related to intense surface weathering [3, 4]

-The regional olivine- and carbonate-rich unit: over several thousands of square kilometers around Jezero, an olivine- and carbonate-rich unit has been described from orbital data as draping the Noachian basement in the region [5]. Within Jezero, the Margin unit is in the same stratigraphic position and displays a similar composition to the regional olivine- and carbonate-rich unit, but it's mode of emplacement is still debated [6]. The regional unit has been dated via Crater counting at 3.8 Ga [5].

Figure 1 : Left : Simplified stratigraphic column of the rocks exposed in Jezero. Right: Simplified geological map and traverse of Perseverance from Sol 1 to 1542.

Dataset: The SuperCam instrument onboard Perseverance uses a suite of techniques, including passive spectroscopy in the 0.40-0.85 µm (VIS) and 1.3-2.6µm (IR) wavelength ranges, Raman spectroscopy, Laser Induced Breakdown Spectroscopy (LIBS) and a camera (RMI; Remote Micro-Imager) providing high resolution context images [7,8]. In this contribution, we use an extensive, mostly the IR data set to review the diversity of the alteration encountered by Perseverance in the geological units older than 3.8 Ga that pre-date the fluvio-deltaic and mafic volcanic crater fill (Maaz Unit).

Results:

Investigated in situ, the rocks of the Margin unit reveal large grains of olivine highly altered mainly into carbonate, silica, and phyllosilicates (see blue spectrum of figure 3 as an example of a natural surface target within the Margin unit).

The rocks exposed in the crater rim are more diverse and show different degrees of alteration. Within the megabreccia complex at the top of the Crater rim (Location named Shallow Bay), Perseverance identified a megablock of serpentinite (yellow spectrum in figure 3) just next to a megablock composed mainly of unaltered pyroxene (green spectrum), indicating that the alteration conditions within the Martian crust before the Isidis impact were heterogeneous. A thick sequence of basaltic layers (Location named Witch Hazel Hill) exposed the western basal part of the crater rim shows very limited signs of alteration (orange spectrum). Finally, at the base of the rim, a distinct unit with strong phyllosilicate signature (red spectrum) is observed. Several float rocks, yet to be observed in place, show strong Al-

phyllosilicate signature implying intense leaching (light green spectrum, Figure 2).

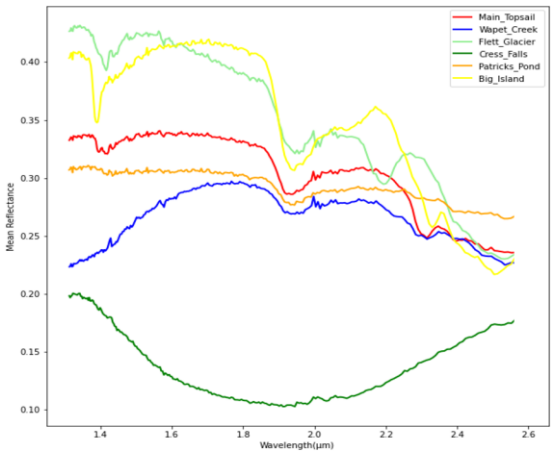

Figure 2 : Mean IR spectra of a selection of targets. In red : a clay rich targe (base of the crater rim)s; in blue : a mixture of olivine, clays and carbonates (typical of Margin Unit); in light green : a kaolinite rich target (float rocks); in green, a non-altered pyroxenite (Crater rim); in orange : a weakly altered basaltic rock (Crater rim); in yellow : a serpentinite (Crater rim).

Discussion:

If one assumes that the Margin unit is part of the regional olivine- and carbonate-rich unit, a surficial unit widespread in the region, its alteration implies surface environments favorable to alteration of olivine into phyllosilicates and carbonates. It implies also carbon rich fluid circulation and a widespread process of sequestration of carbon. These events would be 3.8 Ga or younger. Older than that, the conditions seem to have been very diverse. There are evidence of intense hydrothermal processes altering ultramafic rocks possibly dating from before the Isidis impact, possibly at depth but without co-formation of carbonate, which rules out the circulation of deep CO_2 rich fluids. There is also evidence of unaltered rocks among the Isidis-related megablocks. It means that such rocks have been preserved from significant water-rock interactions before the emplacement of the megabreccia unit, but also that the block has not been altered afterwards by either hydrothermal or meteoric fluids. On the other hand, the kaolinite-bearing float rocks are evidence for intense weathering conditions, but the exact context and timing of this event cannot be constrained by the rover as this type of rocks has yet to be observed in place. The sequence of weakly altered basaltic layers in the pre-Noachian exposures suggests surficial relatively cold and/or dry conditions preventing intense rock alteration, although it is also possible that rapid burial of these layers protected them from surface alteration. Finally, the strongly altered unit observed at the base of the rim is probably composed of pyroxene partially altered into Fe/Mg phyllosilicate, and indicates conditions more favorable to alteration.

Conclusion

In summary, a large variety of conditions seems to have prevailed during ancient times of Mars possibly pointing toward intermittent water-related alteration. Interestingly, carbonate seems to be restricted to <3.8 Ga rocks. Whether this is due to a preservation bias or to their conditions of formation remains to be revealed.

During its extended mission, Perseverance will continue to explore the ancient geological record exposed in Jezero crater rim and in the future, rocks in the surrounding Nili Planum, with the goal to advance the understanding of ancient environmental conditions of Mars.

References: [1]Farley et al., 2020; [2]Mangold et al., this conference; [3] Scheller and Ehlmann, 2021, [4] Gaudin et al., Icarus, 2011[5] Mandon et al., 2020; [6] Horgan et al., 2020; [7] Wiens, et al., 2021 ; [8] Maurice et al., , 2021