# MINERALOGY FROM MARS-2020: UPDATES TO THE REGIONAL GEOLOGICAL HISTORY OF JEZERO CRATER, ITS WATERSHED, AND A FRAMEWORK FOR PERSEVERANCE EXPLORATION.

B. L. Ehlmann[1], J. Bell III[2], A. Brown[3], B. Horgan[4], J.A. Hurowitz[5] , P. Kelemen[6], N. Mangold[7], L. Mayhew[8], C. Quantin[9], W. Rapin[10], J. Razzell Hollis[11], E. Scheller[1], D. Shuster[12], K. Stack[11], V. Sun[11], J. Tarnas[11], A. Treiman[13], [1]Caltech [2]Arizona State Univ., [3]Plancius Research, MD, [4]Purdue University, [5]Stony Brook Univ., [6]Columbia Univ., [7]LPG, CNRS, Univ Nantes, [8]Univ. Colorado, [9]ENS, CNRS, Univ Lyon, [10]IRAP-OMP, CNRS-UPS, Toulouse, [11]JPL-Caltech, [12]Univ. California Berkeley, [13]Lunar & Planetary Institute

**Introduction:** The Perseverance rover's landing site, Jezero crater, lies west of the Isidis basin and north of the basaltic lava plains of the large Hesperian Syrtis Major volcanic province. The Jezero watershed dissects cratered Noachian terrains comprised of significant, compositionally distinct geological formations (Fig. 1). The regional stratigraphy includes one of Mars' two largest phyllosilicate-bearing terrains [1], Mars' most olivine-enriched and only regionally widespread carbonate-bearing deposit [2,3], along with a number of enigmatic capping units that are relatively "spectrally" bland but of varying silicate polymerization in infrared-data (Fig. 1) [4]. The distinctiveness of these formations from orbital data—and only partial information on their composition—has driven multiple hypotheses for their origins and emplacement histories.

Here we integrate initial data from Mars-2020 to update the regional context for rover exploration and describe how grain-scale SHERLOC's Deep-UV Raman [5] and PIXL's x-ray fluorescence [6] along with remote sensing data from Mastcam-Z [7] and SuperCam [8] will reveal insights on the origin and timing of the regional formations. With its first measurements of mineralogy and chemistry, Mars-2020 Perseverance will provide key compositional constraints that update our understanding of these orbitally-defined formations, arbitrate among hypotheses for their origins, and thereby augment our understanding of the regional geologic history of the Jezero crater landing site. Petrologic measurements of texture with composition are ideal, but most of the formations will likely not be examined in place during the prime mission. Rather, they will be interrogated indirectly via analyses of the composition of detrital materials within the Jezero crater basin: float rocks, grains in sedimentary rocks, soils, and sands. We describe the key open questions and likely progress from detrital phases. Table 1 summarizes key mineral data that arbitrate between origins.

**Inferred Mineralogy and Key Questions:**

*Basement formation:* This lowermost formation comprises multiple distinctive units that formed before or contemporaneous with the Isidis impact [9] (Fig. 1). Low Ca-pyroxene units: few dozens of km$^2$ exposures are found in plains, upper reaches of plateaus, and megabreccia. Infrared spectra, which show a broad absorption centered at <1.9 µm, imply that the pyroxene is highly magnesian, En>50, Wo<20. Initially proposed to be early Noachian lavas [10], the units' distribution may also be related to the Isidis impact, as differentiated products of the melt sheet or large breccias of lower crust or upper mantle [9]. The presence/absence of

Figure 1. (left) Regional stratigraphy of Jezero-Nili Planum-NE Syrtis adapted from [9] (right) Timeline of geologic history and estimated emplacement ages

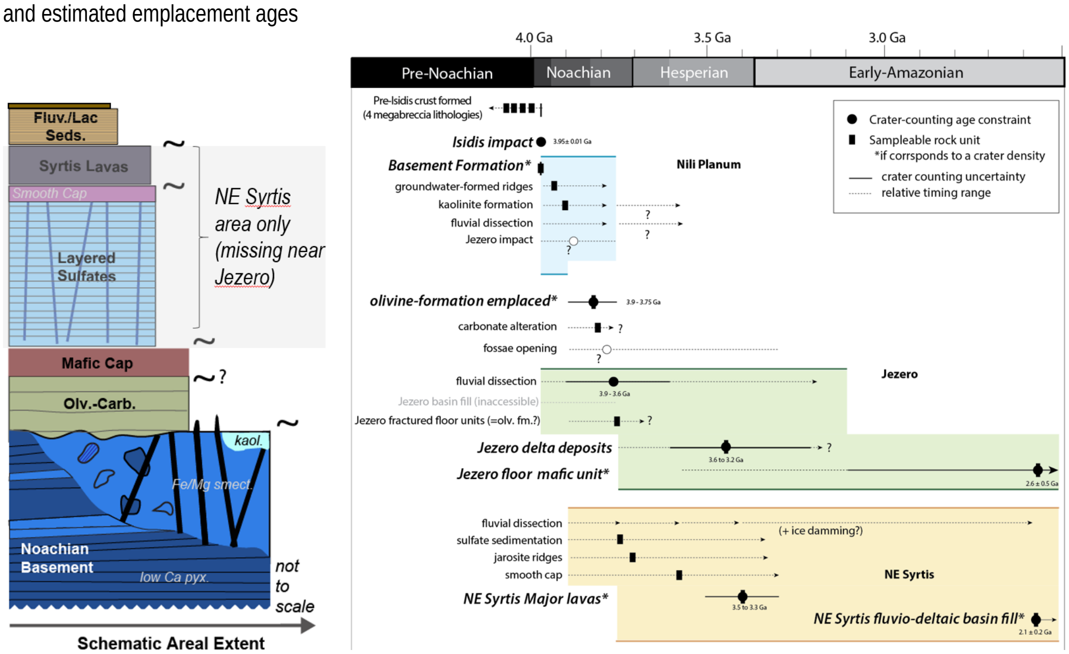

Table 1. Key indicator phase minerals for in situ examination by Mars-2020 that would change regional geologic histories

| Formation | Phases ID'd from orbit | Hypothesized Origins | Diagnostic Potential Add'l Phases |
|---|---|---|---|
| Basement formation* | Low-Ca pyroxene (En>50, Wo<20)<br>Plagioclase, other pyroxenes modeled in spectral umixing | •Primitive volcanics<br>•Impact melt sheet/breccia<br>•Lower crust/upper mantle | Maskelynite/Shocked minerals: impact pressures<br>Glasses: impact melt products<br>Garnet: mantle/deep origin |
| | Fe/Mg phyllosilicates<br>Quartz hypothesized in ridges | •Surface weathering<br>•Hydrothermal/groundwater alteration | Amphiboles: high temperature alteration (>~300C)<br>Chlorite, prehnite, talc, zeolites: elevated T, low $pCO_2$ alteration<br>Fe(III) dicot. smectites: near-surface, oxidizing alteration |
| Olivine- and Carbonate-enriched formation# | Olivine, variable Fo# up to Fo90 modeled<br>Plagioclase, other pyroxenes modeled in spectral umixing (w/ ~20wt% olivine) | •Layered igneous intrusion<br>•Mantle cumulates<br>•High-T primitive lavas<br>•Volcanic ash | Fo>70 olivine: mantle or high T lava origin<br>Cr-spinel: ultramafic rock, likely intrusive<br>Garnet: mantle/deep origin<br>Fe(II or III) oxides: chemistry during alteration |
| | Mg(Fe)-carbonate, silica,<br>Fe/Mg phyllosilicate<br>Olivine, plag, pyx modeled in spectral umixing | •Surface-weathered olivine-enriched volcanics<br>•Hydrothermal serpentinization | Serpentine: low aSiO2 and low O2 reactions in the subsurface<br>Talc, brucite: low grade metamorphic activity |
| Cap unit(s)# | Plagioclase, pyroxene, glass | •Ash<br>•Volcanics<br>•Sandstones | Glasses, if ash or volcanic<br>Secondary minerals (varied) from weathering/diagenesis |

*will be accessed via detrital grains in sediments #possible for in situ outcrop analysis of intra-Jezero sedimentary rock unit occurrences

shocked phases or glasses in sands or float rocks will signal the relative importance of impact processes. Detection of high pressure phases like garnet would point to a deep crust / mantle origin. Clay units: Massive and layered lower stratigraphic units and megabreccia enriched in Fe/Mg phyllosilicates extend >100,000 km$^2$ [11-13]. The phase is abundant (20-30% of the unit[15]); its NIR spectral absorptions at 1.4, 1.9, 2.3 µm imply a composition between nontronite and saponite [13] or possibly talc [14]. Unresolved is whether phyllosilicates formed via near-surface weathering/diagenesis or via post-impact hydrothermal activity, or both. Diagnostic detrital phases might provide key insight, e.g. higher temperature minerals (amphibole, talc, chlorite), minerals formed from alkaline waters like zeolites, and the redox state of Fe in clays and oxides [16].

*Olivine- and carbonate- enriched formation:* Olivine-enriched terrains (>20-30 wt%) are found circumferential to the Isidis basin [12]. While most olivine on Mars is modeled to be $Fo_{30}$-$Fo_{70}$ [17], this is one of the few locations (along with Argyre and Hellas basins) where >$Fo_{75}$ olivine has been reported [18]. Originally proposed to be an intrusive like the Bushveld complex on Earth [2], subsequent studies of its geomorphic context found that the olivine is associated with layered fractured rocks, which suggested lava flows [19], mantle cumulates from the Isidis impact [12, 20], or volcanic ash [21]. While some of the olivine is in bedrock, most is in regional dunes [22-23]. The Fo# of these grains will be crucial for establishing origin. If present, phases like garnets and spinels could suggest a deep crust/mantle origin.

The olivine-enriched unit is variability altered [11, 23] to Mg-carbonate and Fe,Mg phyllosilicate [3, 13] with some silica [24]. The presence of talc, brucite, or serpentine within this unit could be key for signaling formation by subsurface hydrothermalism/ serpentinization [14,25,26] or near-surface weathering [3]. These phases may be found in detrital products or it is possible the olivine-carbonate unit within Jezero is identical to that outside, permitting in situ study [27].

*Cap rock unit(s):* Varied silicate mafic cap rocks that lack signatures of olivine, carbonate, or any hydrous phases are found atop the Jezero delta, floor units, and much of the Nili Planum stratigraphy [4, 27]. For these units, too little is known for detrital grains to be fruitfully examined and attributed to cap rocks but float rock or in situ measurements of capping materials in Jezero will provide the first clues to the regional units.

**Conclusions:** In situ mineralogy of detrital material provides a key means to advance understanding of the regional geologic history and guide future sample choices by addressing key questions: (1) does the Jezero watershed contain samples of mantle rock, either in the low-Ca pyroxene or olivine-enriched units?, (2) are there elevated temperature alteration phases, e.g., in the clay unit or carbonate unit, indicating hydrothermal systems?, (3) to what extent are impact-originated phases preserved, holding a time-record of Noachian bombardment? (4) To what extent has aqueous chemical weathering occurred regionally over the last ~3 billion years? Many first clues will be found in the float rocks, sands, soils, and sedimentary rocks of Jezero crater.

Acknowledgments: Thanks to the entire Mars-2020 team for enabling collection of these data. B.L.E. is supported by Co-I funding from Mastcam-Z and SHERLOC via the Mars-2020 project.

References: [1] Poulet et al., 2005 Nature [2] Hoefen et al., 2003, Science [3] Ehlmann et al., 2008, Science [4] Amador & Bandfield, 2016 [5] Beegle et al., this conf [6] Allwood et al., this conf [7] Bell et al., this conf [8] Wiens et al., this conf [9] Scheller & Ehlmann, 2020, JGR [10] Mustard et al., 2005, Science [11] Mangold et al, 2007, JGR [12] Mustard et al, 2009, JGR [13] Ehlmann et al, 2009, JGR [14] Viviano et al. 2013, JGR [15] Michalski et al., 2010, Icarus [16] Catalano, 2011, JGR [17] Brown et al., 2020, Icarus [18] Koeppen & Hamilton, 2008, JGR [19] Hamilton & Christensen, 2005, Geology [20] Mustard et al., 2007, JGR [21] Kremer et al., 2019, Geology [22] Edwards & Ehlmann, 2015, Geology [23] Mandon et al., 2020, Icarus [24] Tarnas et al., 2019, GRL [25] Brown et al., 2010, Astrobio [26] Ehlmann & Mustard, 2012, GRL [27] Stack et al., 2020, SSR