DECADAL SCIENCE FROM MARS SAMPLE RETURN: THE IMPORTANCE OF SAMPLING IN-PLACE NILI PLANUM NOACHIAN STRATA ACCESSIBLE OUTSIDE JEZERO CRATER FOR PRIORITY PLANETARY SCIENCE QUESTIONS.

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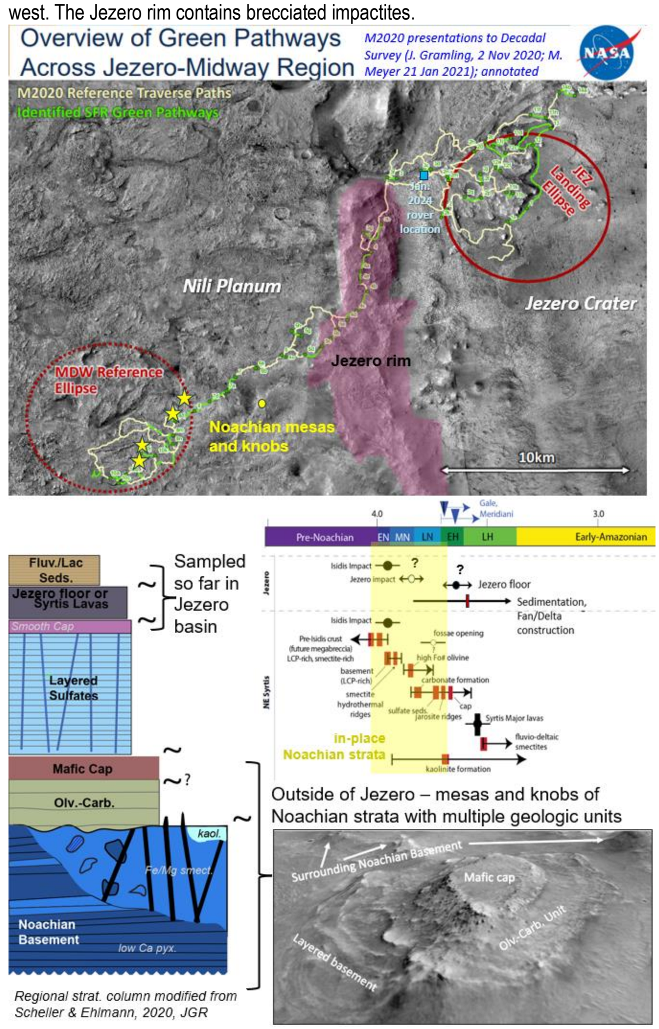
Figure 1. MSR Jezero-Midway traverse and sample locations presented to the Decadal survey ([3], annotated to add place names, delineate rim and Noachian strata locations) along with the regional stratigraphy and timeline for unit/landform emplacement. Samples so far [5] capture the upper regional stratigraphy, a time interval (likely <100,000yrs) around the late Noachian-early Hesperian boundary. Stratigraphically lower strata that sample multiple millions of years earlier in Mars history, in the Mid/Early Noachian lie outside of Jezero's rim in eroded terrains to the west. The Jezero rim contains brecciated impactites.



Introduction: The last two Decadal Surveys have prioritized a multi-mission Mars sample return (MSR) program because of the anticipated merit of in situ exploration coupled with return of a carefully selected sample cache [1, 2]. MSR addresses multiple high priority science questions identified by the Decadal Survey related to planetary evolution and the search for life, advances national objectives in space exploration and technological innovation, and is an important joint endeavor with European Space Agency partners. Consequently, [2] recommended "*completion of Mars Sample Return as soon as is practicably possible with no increase or decrease in its current scope*" and provided decision rules about how to avoid scope change amid MSR cost growth or in a budget-constrained environment, such as has become the case for FY24-FY25.

A crucial aspect of MSR scope is the planned traverse of the Perseverance rover from the Jezero crater impact basin across the crater rim to in-place Noachian strata of Nili Planum en route to the "Midway" locality (Fig. 1). This mission profile was recommended following the community landing site workshop process, matured by the Mars-2020 team, and presented as the baseline MSR concept to the Decadal Survey that defined the scope of the anticipated MSR science return [3].

The quality of specific rocks sampled dictates the ultimate science return of the MSR endeavor (Fig. 2). As noted by decades of community reports [e.g., 4], rocks formed by diverse processes enable addressing a breadth of science questions. Equally essential are the geologic context and timescale(s) spanned of sampled materials. In-place bedrock and, specifically, the ability to relate it to globally/regionally significant geologic features are crucial for time-ordering processes and extrapolating from local events to planetary-scale evolutionary changes. Units tied to major features will anchor the chronology of Mars and impact bombardment flux with specific radiometric dates. By contrast, samples in restricted basins (e.g., Jezero) or local breccia (e.g., Jezero rim) do not enable extrapolation from a local geologic history to major trajectories in planetary evolution—even with superb, detailed analyses—simply because crucial geologic context is lacking.

Given that collection of in-place Noachian strata entails the planned traverse of ~20-km (~40-km round-trip), we review critical questions in planetary science that can be uniquely addressed only by sampling in-place Noachian strata of Nili Planum (Fig. 2).

Decadal Priority Questions Addressable Only with Outside Jezero, In-Place Noachian Strata: *What was the timing of impacts in the inner solar system? What is the absolute timing of the climatic and volcanic history of Mars? (Q4)* The chronology of Mars is presently a function of crater production and chronology models, scaled from the Moon, which have uncertainties

Figure 2. Cache quality enables answering Priority Science Questions, highlighted by the Decadal Survey. Colors indicate MSR science baseline Decadal survey assessment (yellow=modest contribution; green shades=breakthrough to transformative); dots indicate where the ability to answer questions is enabled by in place Noachian rocks from the MSR baseline (questions provided in [2]; derived sub-questions in this abstract)

Mission Name	Priority Science Questions											
	1	2	3	4	5	6	7	8	9	10	11	12
Mars Sample Return				•	•	•				•	•	

of at least hundreds of Ma [6,7]. Ages of Mars samples from landforms that are regionally significant and related to dateable surfaces (e.g., pre-Isidis crust, the Isidis basin, the regional olivine carbonate unit, and the mafic capping unit) are required to anchor the chronology and gain data on impact flux. The Isidis basin is a well-established global chrono-stratigraphic marker [8]. By contrast, Jezero crater, formed around the Noachian-Hesperian boundary but with timing fairly uncertain relative to other Martian geologic features due to lack of reliable dateable surfaces to constrain the ages of Jezero or its floor [9]. Absolute ages will be determined in volcanic rocks and mineral precipitates in Jezero basin returned samples [5], but their relationship to other Mars units lacks context for interpretation. Collecting and dating samples of Nili Planum strata with melt rock from Isidis and pre-Isidis breccia blocks [10] is critical. These rocks are stratigraphically beneath the Jezero rim, exposed by erosion without the Jezero impact's confounding effects.

What was the nature of early volcanism and interior evolution? (Q5) Nili Planum Noachian strata record a major compositional transition observed globally [11,12] from Noachian low-Ca pyroxene to Hesperian high-Ca pyroxene rocks, inferred to record secular changes in mantle evolution [13]. A unique, regional-scale circum-Isidis olivine unit records processes related to large basin-scale impacts that are not fully understood but may be related to heatflow and volcanism after large impacts [14-16]. Jezero lavas may be related as well, but the geologic context is not certain. Further, the early/mid-Noachian strata and breccia blocks capture a period where the magnetic field strength of Mars is predicted to wane: interrogation of in place strata allows collecting oriented samples for understanding these key transitions [17].

What is the nature of the Noachian crust-forming processes? How did the widespread clay minerals form? (Q5, Q6) There is debate whether the early/mid-Noachian crust seen from orbit is volcanic [18] or pyroclastic/sedimentary [19] and whether clay minerals formed by surface weathering, groundwater hydrothermalism, igneous processes, or impact metamorphism [20-23]. Distinguishing between these hypotheses addresses the fundamental nature of planetary processes on Mars during its first billion years and is only knowable by interrogating in situ strata of Noachian crust from that period.

What were the aqueous geochemical environments and cycles in the Noachian? Why and how did Mars climate change profoundly? (Q6, Q10) Sampling fluid/gas inclusions and mineral-hosted isotopes in Nili Planum rocks will enable determining Noachian fluid/atmosphere chemistry, isotopic records, and geochemical cycles, allowing testing models of Martian climate drivers (e.g., atmospheric gases) and models of volatile loss to space vs loss to the crust [24-29]. Jezero basin rocks are from later habitable times while rim rocks are a mix of ages with overprinting from the impact process. Sampling early/mid-Noachian strata, enables investigating Mars in its most habitable, geologically active, and least understood period.

Was the Martian subsurface habitable/inhabited? (Q10, Q11) Lacustrine strata have been sampled to search for life by Mars-2020 so far. Rocks from subsurface Noachian aquifers are in-place in Nili Planum strata. Given the growing evidence of terrestrial subsurface ecosystems and the fact that obliquity-driven fluctuations meant the Mars surface environment was less stable than Earth [30], the prioritization of the search for life in the subsurface is recommended by the National Academies [31].

Conclusions. A mission sampling fluvial-lacustrine and local Jezero lavas from the early Hesperian and in-place early/mid-Noachian stratigraphy will collect samples of quality (diversity, context, timing) that justify the enormous MSR investment and make substantial progress toward addressing the most important outstanding questions in planetary science. The baseline science scope presented to the Decadal survey [2] should be maintained; costs and program schedule should be handled according to the decision rules. Sampling in-place Noachian strata that span Mars' early history uniquely enables answering important evolutionary questions about Mars' geologic and atmospheric history in the context of other terrestrial planets, in our solar system and beyond.

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