

CRITICAL GEOLOGIC RECORD OF THE FIRST BILLION YEARS OF MARS HISTORY ACCESSIBLE BY PERSEVERANCE FOR MARS SAMPLE RETURN. J. F. Mustard,¹ ¹Affiliation ¹Department of Earth, Environmental and Planetary Sciences, Box 1846, Brown University, Providence, RI 02912 (John_Mustard@Brown.edu).

Introduction: The first billion years of Mars' evolution is beautifully exposed in a compact region at the intersection of Isidis impact basin and Syrtis Major volcanic province (Fig. 1). The well-ordered stratigraphy of geologic units spans Noachian to Early Hesperian times [1]. Geologic units can be definitively associated with the Isidis basin-forming impact (≈ 3.9 Ga, [2]) as well as pristine igneous, aqueously altered and sedimentary Noachian crust that pre-date the Isidis event. The rich collection of well-defined units spanning ≈ 500 Myr in a compact region is ideal for the collection of samples. The *Perseverance* rover is actively exploring the Jezero crater collecting samples for return to Earth [26, 28]. Detailed analyses of samples from this region would provide unprecedented insight into the first billion years of Mars and the Solar System [28] but the current cache on *Perseverance* would not.

Jezero Crater, within the Nili Planum region, (Figure 1) sits between the first and second rings of the Isidis impact basin. Isidis deeply excavated the crust and laid bare a deep crustal section now represented in breccia blocks [3]. Spectacular breccia from sub-meter to km in size are well exposed throughout the region and are accessible to *Perseverance*'s extended sampling plan. Unaltered mafic igneous blocks dominated by low-Ca pyroxene are relatively common along with less common olivine- and high-Ca rich lithologies. These crystalline igneous rocks are a window into early magmatic processes. The blocks likely contain a record of the Isidis Impact and may record crustal formation processes dating back to the magma ocean (e.g. [4]).

There is a well-documented transition in igneous mafic composition on Mars from Low-Ca pyroxene-enriched rocks in Noachian terrain to widespread high-Ca, low-Ca, olivine volcanism in Hesperian volcanic provinces [e.g. 5, 6]. From quantitative geochemical modeling, [6] hypothesize a slower cooling rate than the Earth and a much higher Urey number (ratio of heat production to loss) for Mars. Acquiring samples that capture this transition in igneous process would revolutionize our understanding of planetary evolution.

Establishing an absolute chronology for Mars is important for placing key planetary evolution events in the context of Solar System evolution. A major outstanding question is the existence, or not, of a period of heavy bombardment ≈ 500 Myr after accretion of the terrestrial planets. Except for the Moon, we have no definitive dates for basins formed in the Solar System.

Radiometric clocks in crystalline igneous rocks exposed by Isidis would likely have been reset and thus contain evidence of the impact providing a key data point for understanding basin forming processes in the Solar System. Isidis basin impacted onto the rim of the hypothesized Borealis Basin [7]. Given this proximity there is a possibility that some breccia block fragments may have been reset by the Borealis basin as well.

The nature of Mars' magnetic field is an important planetary evolution question that can be investigated in the context of the rocks exposed on the rim and outside Jezero crater. A remnant Martian magnetic field has been observed in Noachian-aged crust, mostly in the southern highlands [8] that was also detected in Martian meteorite ALH84001 [9]. The lack of a recorded magnetic field in and around the large impact basins (Hellas, Isidis, Argyre) is cited as evidence that the magnetic dynamo had ceased by the time of basin formation. The strength and persistence of a magnetic field for a planet the size of Mars is a significant planetary science question. Thermal evolution models of Mars predict a convecting core and geodynamo extending from 4.55 Ga to sometime after 4 Ga [10, 11]. Samples from the megabreccia blocks would strongly constrain these processes. How and when did Noachian-

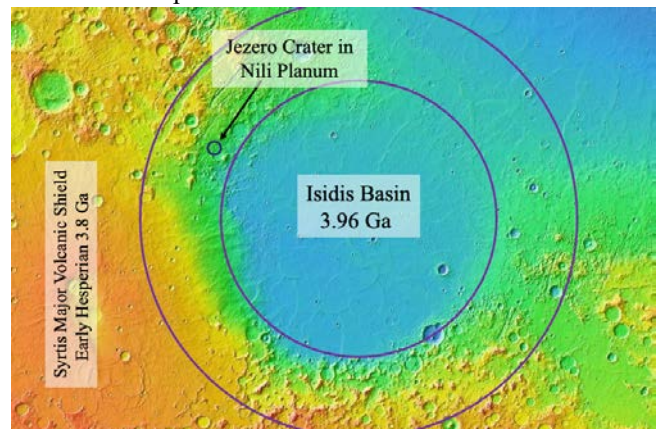


Figure 1. Location of the Jezero crater and Nili Planum.

aged phyllosilicate-bearing crust become so extensively altered? Since the pioneering discovery that Noachian crust is extensively altered but not Hesperian and younger crust [12], this question has been widely debated, but remains unanswered. Aqueous alteration has occurred in many different geologic contexts over a broad span of geologic time, the question of Noachian crustal alteration seeks to address the pervasive

alteration so readily exposed in scarps, impact central peaks, walls and eject, and exhumed landscapes in Noachian crust [14, 20]. The leading hypotheses can be aligned along four themes. (1) Low-grade hydrothermal to diagenetic alteration in the shallow crust [13]. (2) Surface and near- surface weathering played a large role in developing the Noachian alteration [16]. Deposits formed during periods of surface weathering would be mixed into the crust via impact gardening and mixing over 100s of millions of year. Layered megabreccia blocks [3, 27] may contain evidence of these periods in time when water was stable on the surface. (3) Impact generated hydrothermal alteration is likely to have occurred when impacts formed in water rich crust [e.g.



Figure 2. Notional extended traverse to sample crater rim and beyond from Gupta et al MSR planning workshop. Sampling target areas is key to building the cache for all science.

17, 21]. There is the potential for these systems to have lasted thousands of years and locally altered the crust similarly to low-grade hydrothermal processes. Over 500 Myrs, the accumulation of these deposits would contribute significantly to the Noachian record of alteration. (4) Following accretion, Mars may have been shrouded in a dense, super critical H₂O-CO₂ steam atmosphere [18]. This atmosphere would have altered the upper 10 km of basaltic crust to the assemblages commonly seen today [14, 20]. Modeling the following 500 Myr of impacts and volcanism results in a spatially and vertically heterogeneous mélange of unaltered and altered mafic-ultramafic crust, similar to what is observed today in Noachian crust [19]. (5) Large basin impacts could produce both hot spherule layers and abundant hot rainfall for decades to centuries [24]. This could provide both wide- spread olivine-rich layers and hot and water-rich environments necessary for extensive alteration. These are not exclusive hypotheses, and processes involving all types of alteration are entirely possible

Throughout the region northeast of Syrtis Major, the Perseverance workspace and Nili Planum is an olivine-rich deposit that is variably altered to carbonate [22]. Four hypotheses have been advanced to explain the origin of the olivine-bearing unit: (1) Impact melt [3], (2) volcanism [21], (3) basin-related spherules [24] and

(4) Volcanic tephra [22]. It is tightly bound temporally between the Isidis impact event and opening of Nili Fossae troughs [3]. The process of carbonation is particularly intriguing for its implications for climate and habitability.

The composition of the early atmosphere and nature of Noachian climate [25] is a huge question. The geologic record for late Noachian is rich in morphologic and mineralogic evidence for abundant water flowing on the surface (e.g. open basin lakes [23], stratigraphy of Al-phyllosilicates over Fe/Mg phyllosilicates [16] indicative of leaching by water). Detailed isotopic signatures of the atmosphere and surface atmosphere interactions will be recorded in phyllosilicates and volcanic and impact glasses.

Perseverance's Cache and Future Sampling. The suite of samples currently in the cache will only touch on a subset of the top science questions outline in this abstract possible with Mars Sample Return. To build a sample set that will truly revolutionize our knowledge of Mars, Perseverance MUST leave the crater and explore the rim of Jezero and beyond to Nili Planum. Sampling the sites shown in Figure 2 will create a cache that can address all the questions outlined here and specified in the Decadal Survey [28]

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