A GEOLOGIC RECORD OF THE FIRST BILLION YEARS OF MARS HISTORYAT THE MARS 2020 LANDING SITE . John F. Mustard[1], Michael S. Bramble, Christopher H. Kremer, Jesse D. Tarnas, Alyssa Pascuzzo and James W. Head[1] [1]Department of Earth, Environmental and Planetary Sciences, Box 1846, Brown University, Providence, RI 02912 (John_Mustard@Brown.edu

Introduction: The Mars 2020 rover will land in the Jezero crater near the outcrops of an ancient deltaic deposit in February 2021. The rover will investigate this ancient habitable site while collecting well-characterized samples to create a returnable cache [1]. The well preserved and accessible delta in Jezero presents an exceptional opportunity to investigate a Noachian-aged hydrological system with excellent biosignature preservation potential [2]. While this delta, formed in an open-basin lake [23], will likely be the immediate terrain targeted for sampling, the Jezero crater sits in an exceptionally well-exposed region that exhibits a record of the first billion years of Mars evolution [28]. The geologic targets for this record exist outside the rim of Jezero which is well within the capabilities of the 2020 rover. This is an unprecedented opportunity to create a scientifically compelling cache of rock cores that record major events of the first billion years of Solar System evolution. The surprising geologic diversity makes the Mars 2020 landing site a compelling target [2, 3, 28].

The Jezero crater region sits at the intersection of Isidis impact basin and Syrtis Major volcanic province (Fig. 1). The region exhibits a well-ordered stratigraphy of geologic units spanning Noachian to Early Hesperian times [3, 4]. Geologic units can be definitively associated with the Isidis basin-forming impact (≈3.9 Ga) in the form of mega breccia [26, 27, 28]. The composition and textures of the blocks in the megabreccia range widely and include pristine igneous lithologies, aqueously altered rocks, and layered (sedimentary?) blocks of Noachian crust that pre-date the Isidis-forming impact [4, 28]. Unaltered mafic igneous blocks dominated by low-Ca pyroxene (e.g. pigeonite) 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 may record crustal formation processes dating back to the magma ocean or Noachian intrusions into the crust (e.g. [4]) or Noachian/Pre- Noachian volcanism.

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]. Quantitative geochemical modeling [6] hypothesize this transition could be explained by a slower cooling rate than the Earth with a much higher Urey number (ratio of heat production to loss) for Mars.

Establishing an absolute chronology for Mars is important for placing key planetary evolution events in the context of Solar System evolution. A major outstanding solar system evolution question 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 systems in crystalline igneous rocks exposed by Isidis and possible melts generated during the event would likely contain isotopic signals of the impact. Returned samples from these rock would provide a key data point for understanding basin forming processes on Mars and in the Solar System. Furthermore the Isidis basin impacted onto the rim of the hypothesized Borealis Basin [7]. Given this proximity there is a possibility that some ages 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 in the rocks exposed in the plateau outside Jezero. A remnant martian magnetic field observed in Noachian-aged crust (mostly in the southern highlands [8]) has also been 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. Crystalline igneous samples collected in geologic context by Mars 2020 will contain an invaluable record of the magnetic field of another solar system body to address significant planetary evolution questions of the evolution of particularly of a Mars-sized body. Such samples could be used to test, for example thermal evolution models of Mars that predict a convecting core and geodynamo extending from 4.55 Ga to sometime after 4 Ga [10, 11].

A major outstanding question for Mars is how and when did Noachian-aged phyllosilcate- bearing crust become so extensively altered? Since the pioneering discovery that Noachian crust is extensively aqueously altered, while Hersperian rocks are much less likely to be altered (or not at all!) the questions of how this observation fits into models of water and climate history have prevailed [12]. While there is little doubt that aqueous alteration has occurred in many different geologic contexts over a broad span of geologic time, the question of Noachian crustal alteration seeks to understand the origins of the pervasive alteration so readily exposed in scarps, impact central peaks, walls and eject, and exhumed landscapes in Noachian crust.

The leading hypotheses can be aligned along four themes:

(1) Low-grade hydrothermal to diagenetic alteration in the shallow crust (e.g. [13]). Geothermal heat flow provides a steady source of heat to keep the shallow crust between 100- 300°C. In the presence of abundant groundwater basaltic rocks are altered to assemblages containing Fe/Mg smectite clays (saponite) and mix layer chlorite-smectite [14, 15].

(2) Surface and near- surface weathering was very active in the the Noachian leading to active leaching and aluminous clay alteration [13]. Deposits formed during periods of surface weathering would be mixed into the crust via impact gardening and mixing over 100s of millions of year, perhaps recorded in the layered megabreccia blocks observed in NE Syrtis [28].

(3) Impact generated hydrothermal alteration occurred frequently when impacts formed in water rich crust [e.g. 17]. There is the potential for these low-grade hydrothermal systems to have lasted thousands or years and locally altered the crust similarly. 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 H_2O-CO_2 steam atmosphere [18]. This atmosphere would have enormous potential to alter the upper 10 km of basaltic crust to the assemblages commonly seen today [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 five are not exclusive hypotheses, and simultaneous and/or sequential processes involving these types of alteration are entirely possible.

Throughout the region northeast of Syrtis Major is an olivine-rich deposit that is variably altered to carbonate [20]. Four hypotheses have been advanced to explain its origin: (1) Impact melt [3], (2) volcanism [21], (3) basin-related spherules [24] and (4) Volcanic tephra [22]. It temporally postdates the Isidis impact event and is found to drape the crater rim of the Jezero impact crater. The process of carbonation is particularly important for understanding climate and habitability at the time of alteration.

One of the enduring mysteries on Mars is the composition of the early atmosphere and nature of Noachian climate [25]. The geologic record for the late Noachian is rich in morphologic and mineralogic evidence for abundant water flowing on the surface. The detailed isotopic signatures of the atmosphere and surface atmosphere interactions will be recorded in phyllosilicates and volcanic and impact glasses.

Conclusion: The geologic units accessible to Mars 2020 in the Jezero delta, floor deposits, crater rim and the adjacent region of NE Syrtis contain rocks effected by many of the important evolutionary events in the evolution of Mars and the Solar System. The sample cache from Mars 2020 will be transformative for planetary science.

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