A GEOLOGIC RECORD OF THE FIRST BILLION YEARS OF MARS HISTORY. John F. Mustard[1] 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: A compelling record of the first billion years of Mars geologic evolution is spectacularly presented in a compact region at the intersection of Isidis impact basin and Syrtis Major volcanic province (Fig. 1). In this well-exposed region is a well-ordered stratigraphy of geologic units spanning 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 and aqueously altered Noachian crust that pre-date the Isidis event. The rich collection of well defined units spanning ≈500 Myr of time in a compact region is attractive for the collection of samples. Detailed analyses of samples from these terrains would provide a window into the first billion years of Mars and the solar system evolution.

In this abstract we put the well exposed units in a larger geologic context of Mars evolution and implications for understanding of Solar System evolution. Mars is small planet, likely a planetesimal that was not swept up by larger planets. Yet its surprising geologic diversity makes it a compelling target.

The NE Syrtis region (Figure 1) sits within the Isidis impact basin between the first and second rings. The Isidis event would have excavated deeply into the crust and laid bare a deep crustal section composed of breccia blocks from a variety of depths. Today, spectacular breccia from sub-meter to km in size are well exposed wherever erosion has removed post-Isidis cover. The composition and textures of the blocks range widely [3]. 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]. 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.

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 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 systems 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. Furthermore the Isidis basin impacted onto the rim of the hypothesized Borealis Basin [7]. Given this proximity there is a possibility that some 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 in the NE Syrtis region. 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 is a significant planetary evolution question,, particularly for a planet the size of Mars. Thermal evolution models of Mars predict a convecting core and geodynamo extending from 4.55 Ga (or possibly delayed by several hundred Myr) to sometime after 4 Ga [10, 11]. Carefully selected samples from the megabreccia blocks would strongly constrain these processes.

How and when did Noachian-aged phyllosilcate-bearing crust become so extensively altered? Since the pioneering discovery that Noachian crust is extensively altered but not Hesperian and younger crust [12], how and when this alteration occurred has been widely debated. 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 address 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 energy to keep the shallow crust between 100-300°C. In the presence of abundant groundwater this would alter basaltic crust (consisting of olivine, pyroxene and plagioclase) to the commonly observed assemblages of Fe/Mg smectite clays (saponite) and mix layer chlorite-smectite [14, 15]. (2) Surface and near-surface weathering played a large role in developing the Noachian alteration [13]. While subsurface alteration is likely in this hypothesis, there is evidence for more alumino-phyllosilicates (evidence for leaching in a surface weathering environment) than generally accepted. 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 such as observed in NE Syrtis [3] 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. 17]. There is the potential for these systems to have lasted thousands or 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 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 alterd 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 widespread 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 is tightly bound temporally between the Isidis impact event and opening of Nili Fossae troughs. The process of carbonation is particularly intriguing for its implications for climate and habitability.

One of the enduring mysteries on Mars is the composition of the early atmosphere and nature of Noachian climate [25]. 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 as mapped by [23] stratigraphies of aluminum phyllosilicates over Fe/Mg phyllosilicates [16] indicative of leaching by water of stratigraphic sections). The detailed isotopic signatures of the atmosphere and surface atmosphere interactions will be recorded in phyllosilicates and volcanic and impact glasses.

Conclusion; The range of significant geologic processes and events in NE Syrtis and their location in a well structured stratigraphy touches on many of the important evolutionary events in the evolution of Mars and the Solar System.

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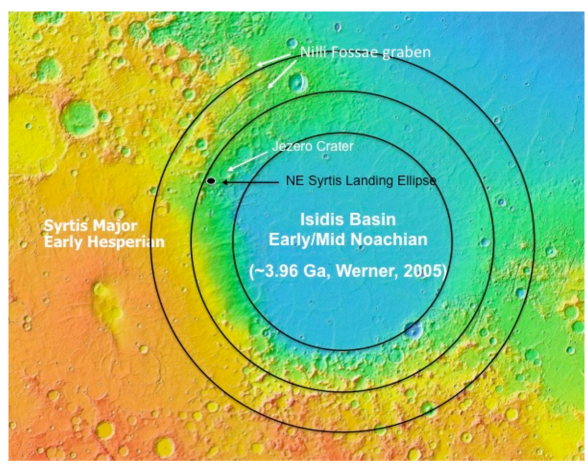

Figure 1. Location of the NE Syrtis landing Ellipse where a detailed record of the first 500 Myr of Mars evolution may be obtained.