THREE DISTINCT HABITABLE ENVIRONMENTS DEFINED BY AQUEOUS ALTERATION TRAVERSING THE ALKALINE-ACIDIC TRANSITION. J. F. Mustard[1] and B. L. Ehlmann[1], [1]Department of Geological Sciences, Box 1846, Brown University, Providence, RI 02912 John_Mustard@brown.edu.

Introduction: The stratigraphy of Hesperian-aged Syrtis Major volcanic flows superposing Noachian rocks within the Isidis Basin provides a unique and compelling suite of habitable environment targets for MSL. Three distinctive aqueous environments are preserved in discrete bedrock units characterized by Fe/Mg phyllosilicate, carbonate, and sulfate minerals in stratigraphic section. The units can be placed in a well-defined regional stratigraphic framework and span an interval of time from the mid-Noachian to mid-Hesperian. Unit alteration mineralogy indicates the nature of water-rock interaction varied systematically with time from near-surface fluvial to hydrothermal and from alkaline to acidic. At this low elevation site (-2.5 to -2.0 km) (Table 1, Fig. 1), there is the potential for both in-ellipse and go-to science directly related to understanding fundamental processes of impact basin formation, large-scale volcanism and aqueous alteration on ancient Mars, including the most important environmental transition in Mars geologic history.

Table 1: Site Characteristics

Site Name	NE Syrtis Acidic-Alkaline transition
Ellipse Center	76.9°E, 16.7°N
Elevation	-2.6 km (reference ellipse: #1)
Prime Science Targets	• Altered (carbonate, serpentine) and unaltered Noachian ultramafic rock [Highest Priority] • Jarosite, polyhydrated sulfate deposits • Fe/Mg phyllosilicate deposits • Al phyllosilicate deposits • "Unaltered" Hesperian Syrtis lavas • Fluvial Channels [Lowest Priority]
Distance of Science Targets from Ellipse Center	• Ultramafic unit (carb., serp., olv.): ?km • Sulfate deposits: ?km • Phyllosilicate deposits: ?km • Syrtis lavas: ? km <30km in all cases, but cannot determine definitively with data in hand. While targeted, ellipses have not yet been imaged by CRISM

Site stratigraphy and mineralogy: The Isidis basin is the last and best-preserved of Mars' impact basins (~3.96 Ga, [1]). In Northeast Syrtis, there is a clear stratigraphy of Hesperian lava emplaced on Noachian-aged interior deposits of the Isidis Basin. The steep-sided, sinuous, and branched morphology of the lava flow boundaries has been cited as evidence for emplacement of the lava into a volatile-rich deposit [2]. The likely volatile-rich deposit was the Vastitas Borealis Formation (VBF) [3] that was present at the time of the lava flow emplacement.

The mineralogy of this region is incredibly rich (Figure 2) and the type localities of a number of key minerals are found at this site (e.g. carbonate, serpentine; [4]). The CRISM image HRL0000B8C2 (Figure 2) is one example. In this one image are found polyhydrated sulfate, jarosite, Mg-carbonate and serpentine as well as mafic and ultramafic rocks. Fe/Mg smectite clays are recognized in many of the other observations in this region. This region lies in the watershed of Jezero crater [5, 6], proposed as an MSL landing site but rejected on the basis of rocks in the landing ellipse.

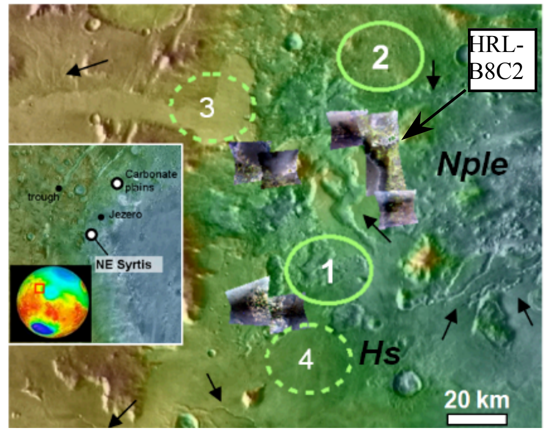

Figure 1: Location of candidate landing ellipses, west of the Isidis basin at the northern contact between the Hesperian Syrtis Major lava flows (Hs) and the Noachian terrain around Nili Fossae (Nple). Arrows indicate fluvial channels. The phyllosilicates, sulfates, and carbonates of interest are found in all three areas imaged by CRISM in the border region. Ellipses have been targeted for imaging.

The Hesperian lavas at the contact are distinctly altered, containing a rich diversity of sulfate minerals. We have identified large, tens-of meter scale exposures of polyhydrated sulfate and jarosite in the exposed volcanic strata (Figure 2). These minerals provide evidence for hydrothermal alteration resulting from the volcano-ice interactions, including precipitation of minerals from acidic waters circulating within the volcanic unit.

The youngest rock units (VBF, volcanic flows) rest on Noachian-aged basement rocks on the interior of the Isidis Basin [4, 7]. These rocks are rich in Fe/Mg smecitite clays, a defining characteristic of Mars' early crust [8]. The Noachain terrains here contain a distinctive ultramafic, olivine-rich late Noachian stratigraphic horizon [7, 9, 10]. In places the ultramafic rocks are altered exhibiting the characteristic signatures of Mg-carbonate [11] and serpentine [4]. Two endmember hypotheses exist for the formation of these units: (1) hydrothermal activity associated with the emplacement of the ultramafic unit and (2) low-temperature, near surface alteration during later Hesperian aqueous activity [4, 11].

The regional geologic context is well defined by recent publications [4, 7, 10, 12]. Immediately following or concurrent with the formation of the Isidis Basin, the ultramafic unit was emplaced. A major period of gradation ensued, concurrent at least in its latest phases with the creation of fossae concentric to Isidis. Hesperian lavas of Syrtis Major were deposited atop the Noachian units and reached the floor within the Isidis basin and interacted with the VBF [2]. Fluvial activity persisted throughout from the time of the Isidis Basin formation to time of the Hesperian volcanism [7, 12, 13]. A tremendous stratigraphy is thus captured in this proposed landing site, from the era of phyllosilicate formation to the period of sulfate formation, with clearly defined geologic context. Significant for the habitability goals of MSL is the preservation of phyllosilicates in the geologic environment of formation, carbonate-bearing rocks in stratigraphic context, and hydrothermal deposits of volcano-ice interactions in stratigraphic context. The benefits of elemental, mineralogic, and isotopic characterization of clays, carbonates, and sulfates from successive periods of Mars history are substantial. Each specific environment has the potential to dramatically increase our understanding of the habitability potential of Mars as it evolved through time.

Biological preservation potential: The aqueous mineral-bearing strata at NE Syrtis are each distinct in age, primary mineralogy, particular geologic setting, and consequently the biological processes that may be recorded in each unit differ. Notably, the deposits here are quite different in character from the fluvio-lacustrine or pedogenic sediments at other candidate MSL landing sites. The units here represent bedrock, altered in situ where both reactants and products are accessible to the rover instrument suite. In particular, NE Syrtis offers the unique opportunity to investigate extensive hydrothermal mineral deposits. These have been identified as of highest importance for organic preservation [14]. In fact, two hydrothermal episodes are probably represented at NE Syrtis. First, the ultramafic rocks of the Noachian olivine-rich unit in some places have the distinctive spectral signature of serpentine, a marker mineral for hydrothermal activity under highly reducing alkaline conditions that are energetically favorable for chemosynthetic organisms such as methanogens [e.g. 15]. Second, sulfate-silica spring deposits from terrestrial volcanic hydrothermal systems (e.g. Iceland, Yellowstone) entomb rich microbial communities of organisms with diverse metabolisms and may be similar to the sulfate-bearing deposits exposed within the volcanic rock here. In searching for evidence of the earliest Mars life, it is appropriate to note the nature of the earliest Earth life—thermophilic and chemosynthetic—and guide exploration efforts toward terrestrial planets' earliest habitats, hydrothermal environments.

Engineering criteria: The low elevation (-2.5 to -2.0 km) of the Northeast Syrtis Acidic-Alkaline Transition site landing ellipse would be favorable for MSL EDL systems. More MRO data remain to be acquired before full assessment of engineering criteria is possible. Ellipse #4 would be go-to for the targets of highest scientific importance but was previously studied and deemed safe during MSL Landing Site Workshop II proceedings (NE Syrtis). CRISM and HiRISE data at the preferred sites (#1, #2) with best in-ellipse science potential (based on morphologic correlation) were not acquired prior to MRO entering safe mode. MOLA slope maps at <1 km scale show all ellipses likely satisfy criteria, although ellipse #1 has terrain of comparable roughness to the existing MSL site in Eberswalde. CTX coverage of the region is already complete, and acquisition of two CRISM and HiRISE images will allow more complete assessment of both safety and in-ellipse science. The proposers would work with the landing site selection engineering team to ensure best targeting of MRO resources.

References: (1) Werner, 2005, Ph.D. thesis, Freie Universität Berlin. (2) Ivanov & Head, 2003, *JGR* 108 (3) Tanaka, K., (2002) (4) Ehlmann et al., 2009, *JGR* 114 (5) Fassett, C. and J. Head, 2005 (6) Ehlmann et al., 2009, *Nature Geosci.* 1 (7) Mustard et al., in press, *JGR*, doi:10.1029/2009JE0033497 (8) Bibring et al., 2006, *Science* 312 (9) Hamilton & Christensen, 2005, *Geology* 33 (10) Mustard et al., 2007, *JGR* 112 (11) Ehlmann et al., 2008, *Science* 322 (12) Mangold et al., 2007, *JGR* 112 (13) Mangold et al., 2008, *Plan. Space Sci*., 2008 (14) Farmer and DesMarais, 1999, *JGR* 104, (15) Schulte et al., 2006, *Astrobiology* 6.

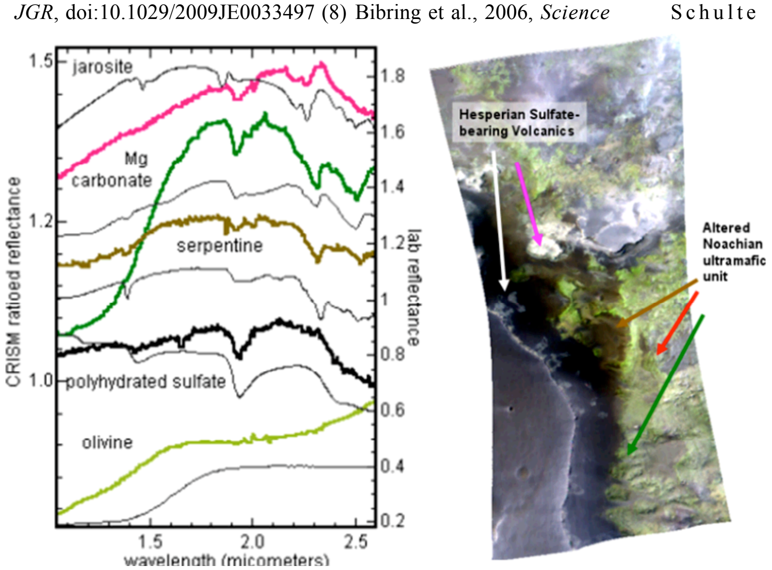

Figure 2: Example CRISM image HRL0000B8C2 from the northeast group of CRISM images showing sulfate-bearing Hesperian volcanic strata (white, purple) eroding to expose an altered Noachian ultramafic unit beneath (green, yellow). CRISM spectra (thick) indicate polyhydrated sulfates and jarosite in the Hesperian terrains (white) and serpentine, carbonate, and olivine in the Noachian terrains (green, yellow). Similar mineralogy/stratigraphy is observed in all CRISM images. In the other groups of images, Fe/Mg smectites and sometimes kaolinite are also present.