A STRATIGRAPHIC SECTION THAT TRAVERSES THE NOACHIAN-HESPERIAN CAPTURING DIVERSE HABITABLE ENVIRONMENTS. 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 evolution of distinct eras on Mars defined by specific hydrous mineral phases as proposed by [1] provides a broad framework for assessing the nature of habitable environments and the interaction of water with the crust and surface through time. If processes on early Mars that resulted in alteration mineralogies dominated by phyllosilicate were followed by processes resulting in sulfate and other evaporite minerals during the middle period of Mars' then it will be critical to identify and understand regions of the crust that record these transitions. These localities will capture a fundamental reorganization of aqueous processes on a planetary scale. The region of the western Isidis Basin that transitions to the volcanic deposits of Syrtis Major Planum that we refer to as North East Syrtis (NE Syrtis) is an extraordinarily well preserved stratigraphic section that has datable and in place rock units that traverse this critical time stratigraphic boundary.

The key martian geologic processes recorded here are directly related to understanding fundamental processes of impact basin formation, large volcanic provinces and aqueous alteration on ancient Mars, including the most important environmental transition in Mars geologic history.

Site stratigraphy and mineralogy: The Isidis basin is the last and best-preserved of Mars' impact basins (~3.96 Ga, [2]). In this region at the contact between Syrtis Major lavas and the Isidis basin there is a clear stratigraphy of Hesperian lava emplaced on Noachian-aged interior deposits. 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 [3]. The likely volatile-rich deposit was the Vastitas Borealis Formation (VBF) [4] that was present at the time of the lava flow emplacement.

The region of interest sits close to an inner ring of the Isidis Basin and as such was likely within the transient crater during basin formation. This excavated a deep section of Martian crust that is exposed in a number of areas [5] as the lowest stratigraphic unit. It is characterized by a generally smooth texture with frequent linear ridges that are resistant to erosion. Overall the unit is apparently weak as impact craters are poorly retained. Breccia blocks on a range of scales are also commonly observed. The dominant spectral signature is one of Fe/Mg phyllosilicates, but some of the breccia blocks show distinct mafic signatures dominated by low-Ca pyroxene.

Resting directly on this phyllosilicate-bearing basement is a compositionally distinct but somewhat enigmatic unit. It generally lies in local topographic lows, though it is observed to drape underlying topography defined by the basement. In some places the spectroscopic signature is definitively olivine-bearing [5, 6], while others the olivine signatures are supplemented by absorptions diagnostic of magnesite [7]. In a few regions serpentine is also detected in association with olivine [8]. In the study region this unit is almost exclusively magnesite-bearing. Where well exposed it typically shows an irregular polygonal fracturing on the scale of meters. The olivine-magnesite unit is commonly capped by a medium-toned spectrally bland unit that preserves impact craters. The thickness of the two units is on the order of several 10s of meters. There are two hypotheses for the origin of the olivine-rich unit and its mafic cap: a) as impact melt from the Isidis basin forming event [5, 6] and b) as volcanic flow [8]. For the alteration of the olivine-bearing unit there are two hypotheses: (1) hydrothermal activity associated with the emplacement of the ultramafic unit and (2) low-temperature, near surface alteration during later Hesperian aqueous activity [7, 9].

Above the olivine/magnesite unit and its mafic cap is a unit that forms steep walls and is apparently layered. The origin of the layering is a subject of ongoing research but may include sedimentary and impact processes. There is a rich and diverse mineralogy associated with this layered unit that sits apparently stratigraphically above the olivine-magnesite unit and below the volcanics of Syrtis Major. (Figure 2) The lavas of Syrtis Major are olivine-basalts [10, 11] that were emplaced over an extended period in the Hesperian [12]. The lavas exhibit a steep sided plateau morphology at this contact with the Isidis Basin floor. Topography and morphology here imply volcano-ice interactions [3]. The lavas are in contact with a unit that exhibits layering that could be sedimentary or may be impact ejecta. Exposed in the steep walls beneath the lava and in the layered material is 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 1). These minerals provide evidence for possible hydrothermal alteration resulting from the volcano-ice interactions, including precipitation of minerals from acidic waters circulating within the volcanic unit. The relationship of the sulfate mineral deposits with the volcanic emplacement is a subject of ongoing research: did the sulfate minerals form as a result of the volcanic processes, prior to the volcanic deposits, or at a later date?

Distributed throughout the region are outcrops that contain the spectral signatures of kaolinite. This is sig-

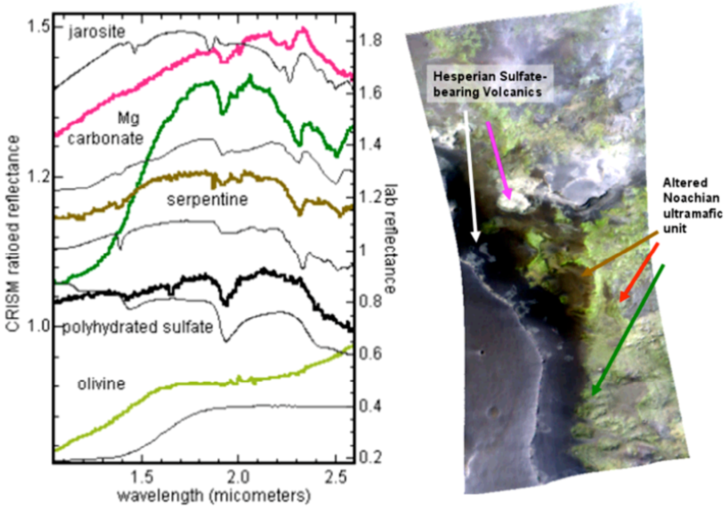

Figure 2: CRISM image HRL0000B8C2 from the northeast group of CRISM images showing sulfate-bearing Hesperian volcanic strata (white, purple) eroding to expose an altered Noachian ultramafic unit beneath (green, yellow). CRISM spectra (thick) indicate polyhydrated sulfates and jarosite in the Hesperian 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.

nificant because of the possible role of water in leaching the rocks and forming kaolinite. Recent work has shown that fluvial activity was persistent in the study region [13]. Previous work has shown numerous channels were carved in the Noachian basement, including the system that fed the Jezero closed basin lake and its system of deltas [14]. We also recognize a number of specific channels that are present on the lavas of Syrtis Major that indicate water flowed across the volcanics and into the this region. Based on topography and morphology and tracing the path of water across the landscape the water would have pooled in the region that has the highest concentration of magnesite and kaolinite.

The regional geologic context is well defined by recent publications [5, 6, 9, 13, 15]. 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 [3]. Fluvial activity persisted throughout from the time of the Isidis Basin formation to time of the Hesperian volcanism [11, 16, 17], including fluvial channels that have been carved into the surface of Syrtis Major.

This region thus captures the major era of mineral evolution from phyllosilicate formation recorded in the Noachian basement to the period of sulfate formation. Importantly it appears that the mineral deposits are present in the geologic units in which they formed, and there are clear time stratigraphic markers. What is particularly significant is the sulfate-bearing volcanics. If these indeed represent the result of volcano-ice interactions, they would be definitive evidence for a hydrothermal system and its associated deposits. The abundance of fluvial features in the region also argues for a possibly abundance subsurface water. If there had been the development of a martian biota, this region has the necessary components that may have led to the entombment of biosignatures in an active hydrothermal system.

Conclusions and Implications: In this region of Mars the transition from an early, phyllosilicate formation era to a later sulfate formation era is well recorded in distinct geologic units of defined character. The units here represent bedrock, altered in situ where both reactants and products are retained. 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. NE Syrtis offers the unique opportunity to investigate extensive hydrothermal mineral deposits, of high importance for organic preservation [16]. 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. We will be analyzing the available MRO, MEx, etc. data to better constrain the geologic relationships, stratigraphy and timing in this region on Mars and refining our understanding as a potential future landing site.

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