WATER-LAIN SULFATES AND EPISODIC FLUVIAL SEDIMENTATION AND EROSION SPANNING THE MIDDLE NOACHIAN TO EARLY AMAZONIAN, NORTHEAST SYRTIS MAJOR

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Introduction: The first billion years of Mars history is characterized by a significant environmental transition and drying of the surface environment [e.g. 1, 6]. The stratigraphy at northeast Syrtis Major captures this transition in a stratigraphy temporally constrained by the early-Noachian Isidis Basin-forming impact [11] and mid-Hesperian Syrtis Major lavas [4]. Clay-, then carbonate-, then sulfate-/jarosite-bearing units transition to comparatively unaltered Syrtis Major lavas, tracking changing hydrological conditions during the Noachian–Hesperian transition on early Mars [2].

Here we focus on the units stratigraphically above the well-studied clay- and carbonate-bearing units, extended mission targets for the Mars 2020 mission. Our detailed geologic mapping and structural analysis [Figure 1] of the sulfates and their cap units suggests several cycles of water-driven sedimentation and erosion at the rim of Isidis Basin, both pre- and post-dating the Hesperian Syrtis Major lava flows [Figure 2]. These events suggest a long record of surface waters at NE Syrtis.

Results - A History of Water Interaction:

Water-lain sulfate sediments. First, the layered sulfates were deposited as a package of bedded sediments, gently draping the basement and decreasing in elevation towards the interior of Isidis Basin. The deposit consists of thick stacks of parallel meter-scale beds that dip up to 7-10° with no preferred direction. Bed orientations are generally consistent at several-km scale, but smaller-scale orientation variations are associated with boxwork polygonal domains. The deposit is up to 500 m thick and unconformable with the basement. It thins over and embays basement highs, with a maximum elevation of -1600 m [7]. The scale, thin bedding and nonzero depositional dips of the layered sulfates suggest formation by sedimentation within a deep, water-filled basin. The layered sulfates are confined to a ~150 km segment of the Isidis Basin rim, and modeling of probable projections of the deposit reveal that at least ~760 km³ of layered sulfates (of a likely volume of ~1200 km³ within the study area) have been eroded.

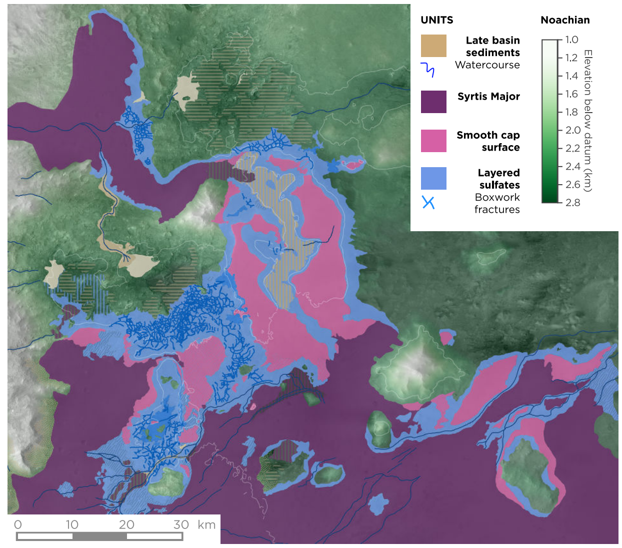

Figure 1: *Geologic map of NE Syrtis Major, showing the layered sulfates, capping units, and late fluvial features. The study area is centered on 75°E, 15°N.*

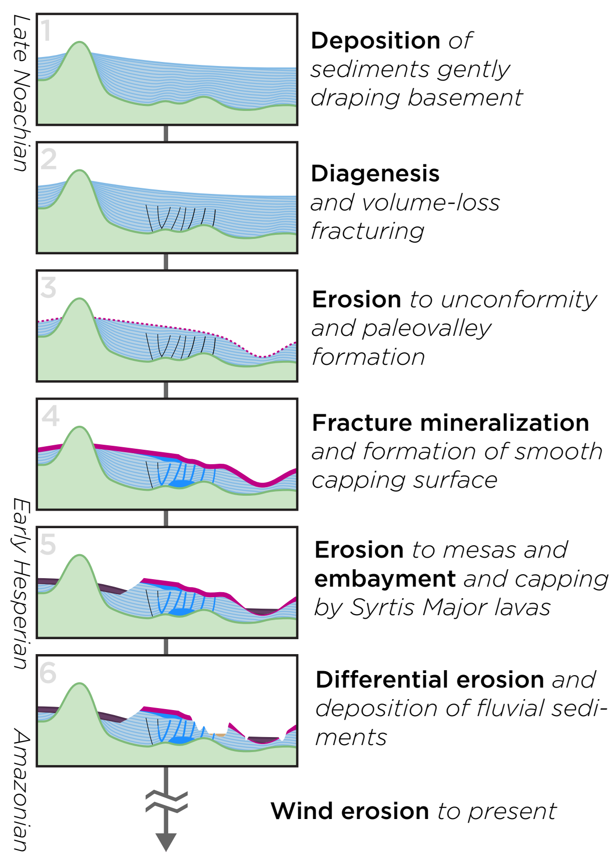

Figure 2: *A schematic emplacement history for the layered sulfates.*

Fracturing and fluid mineralization. Some of the layered sulfates contain large (500 m long, 200 m high) boxwork polygonal ridges. These landforms were generated by initial polygonal faulting driven by volume loss, followed by later mineralization from fluids that precipitated jarosite, and then erosion to form resistant ridges [7, 2]. Using the assumptions and methods of [8], we estimate that interaction with > 515 km³ of water was required for the formation of the ~860 km of mineralized boxwork.

Episodic deposition and fluvial erosion. In some areas, the layered sulfates are overlain by a smooth mafic capping unit, rather than the Syrtis lavas as was interpreted by [2]. This cap unit is ~10-30 m thick, resistant to erosion, and has low thermal inertia. Its character and separability from the Syrtis Major lavas suggest at least two independent erosional episodes [Figure 3]: (1) it cuts across bedding in the layered sulfate, suggesting erosion of the layered sulfates to create an unconformity surface prior to cap unit formation [7] and (2) the sulfates beneath are cut into mesas by valley-forming erosion after cap unit formation.

Distal flows of the Syrtis Major volcanic province then capped and embayed preexisting paleotopography within the layered sulfates. A flow that entered from the west ("I-80" valley [3]) appears to have been channelized along the pre-existing *Valley A* [Figure 1]. The lavas flow between mesas of the layered sulfates in the southeast part of the study area. After this phase, much of the layered sulfate deposit was eroded, exposing isolated deep basins.

Fluvial incision. A final set of fluvial features occur atop the Syrtis Major lavas, carving and modifying deep basins in the study area. Sedimentary deposits from this episode include inscribed fluvial channels, small deltas, and inverted channel deposits <1 km wide. Flat-lying (dips <1.5º) indurated layered deposits occur on basin floors, suggesting a shallow lacustrine origin. These deposits date to the Early Amazonian, with crater-counting ages of 1.3 Ga [9]. The channel deposits link to canyons cut into the Noachian basement, layered sulfates, and the capping Syrtis Major lavas and correlate in timing to outflow features mapped further south on the Syrtis Major lavas by [5].

During this stage, the interior of *Valley A* was mantled with a unit that covers the valley floor and drapes its sides [Figure 3]. This "draping valley fill" is of uncertain origin but emphasizes the incision of valleys into the layered sulfates prior to late-stage fluvial activity. The delta and basin-filling deposits within the study area occur near an open contour of −2300 m elevation, suggesting that these features formed at a similar base level.

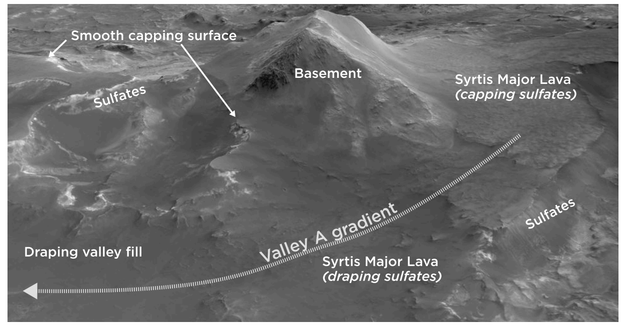

Figure 3: *Relationship between the Syrtis Major lava flow, smooth capping surface, and paleovalley-filling features in a key location.*

Implications: Overall, the upper stratigraphy of NE Syrtis Major was built by a history of aqueous interaction: (1) the deposition of the layered sulfates, (2) groundwater mineralization of fractures, (3) erosion to an unconformity and emplacement of the smooth capping surface, (4) paleovalley incision and embayment by Syrtis Major lavas, (5) erosion of sulfates to uncover deep basins, and (6) superposed fluvial and lacustrine features.

Several phases of aggradation, groundwater interaction, and erosion postdate the clay- and carbonate-bearing crustal exposures of NE Syrtis. Deposition and alteration of the layered sulfates requires large volumes of surface water and groundwater during the Noachian–Hesperian transition. The extensive erosion and superposed fluvial features demonstrate that surface water was at least episodically present into the Late Hesperian–Early Amazonian. The succession of unconfined sediments at the rim of Isidis Basin suggests either a basin-filling ice sheet [10] or global ocean as a necessary boundary condition for the observed depositional history.

References: [1] J.-P. Bibring et al., *Science* 312.5772 (2006). [2] B. L. Ehlmann and J. F. Mustard, *GRL* 39.11 (2012). [3] R. P. Harvey and J. Griswold, *LPSC*, vol. 41, 2010. [4] H. Hiesinger and J. W. Head, *JGR* 109.E1 (2004). [5] N. Mangold et al., *JGR* 112.E8 (2007). [6] S. L. Murchie et al., *JGR* 114 (2009). [7] D. P. Quinn and B. L. Ehlmann, *LPSC*, vol. 48, 2017. [8] K. L. Siebach and J. P. Grotzinger, *JGR: Planets* 119 (2014). [9] J. Skok and J. Mustard, *LPSC*, vol. 45, 2014. [10] O. Souček et al., *EPSL* 426.August (2015). [11] S. C. Werner, *Icarus* 195.1 (2008).