The stratigraphy at northeast Syrtis Major [Figure 1] provides a unique temporally-constrained record of changing hydrological conditions during the Noachian–Hesperian transition on early Mars [2]. The stratigraphy, bracketed by the mid-Noachian Isidis Basin-forming impact and mid-Hesperian Syrtis Major lavas [4], contains layered sulfates superposed atop Noachian basement units altered to carbonates and clays. The sulfate unit is recessive and layered at meter-scale, with some areas containing boxwork polygonal ridges. It is capped by lava flows contiguous with the Syrtis Major volcanic province.

The upward progression from alkaline to acidic aqueous environments (and ultimately to capping lavas with no evidence of pervasive alteration) is characteristic of the planet’s first billion years [e.g. 1, 5]. An understanding of the depositional environment and alteration history of the layered sulfate unit can help trace the evolution of the early Martian surface environment. We assess detailed structural, mineralogical, and morphological observations of the layered sulfates against a range of possible formation mechanisms (e.g. lava flow, ash fall, lacustrine deposition). The layered sulfates were likely deposited as bedded sediments gently draping the Noachian basement, and underwent diagenetic volume-loss fracturing and acid-sulfate alteration.

A localized deposit: The extent of the layered sulfates is mapped using HiRISE, CTX, and HRSC imagery and derived elevation models [Figure 1]. Morphologic mapping is refined with CRISM mineral identifications and thermal inertia data. Based on the elevation of bounding surfaces, the layered sulfates are up to ~400 m thick, tapering laterally to the northwest and southeast towards the edges of the study area.

Figure 1: Regional overview of layered sulfates assembled from morphology, mineralogy, and thermal inertia. The study area is centered on 75°E, 15°N.

Figure 2: Bedding orientations (95% CI in dip–dip azimuth space, using method from [6]) measured on HiRISE stereo pair ESP_021612_1975/ESP_021757_1975. (a) Superposition of the Syrtis Major lavas atop a slope of layered sulfates and a dipping basement pediment. (b) Sulfates in the north part of the image dip southward beneath a flat lava flow. (c) In the southern part of the image, layered sulfates dip ~8° southwest beneath south-dipping lava flow, creating an angular unconformity.
This, along with the lack of similar units elsewhere in Isidis Basin, suggests localized deposition or preferential shielding from erosion within the study area.

**Draping deposition:** A new method for error analysis of bedding-orientation measurements [6] is used to interpret the depositional form of the layered sulfates. Dips are <10° over the entire study area, but dip directions are variable, with low angle changes in bedding evident at several-km scale. Dips greater than ~5° often loosely correspond to dipping basement paleotopography, suggesting deposition on a tilted surface.

Figure 2 shows a stratigraphy with layered sulfates beneath the capping Syrtis major lavas. Bedding orientations in the sulfate are consistent at ~4 km scale, but change at the northern part of the image. In both areas, bedding is distinct from the dip of the Syrtis Major lavas, showing a significant angular unconformity that marks an erosional hiatus prior to lava emplacement.

**Volume-loss fracturing and alteration:** Polygonal ridges at ~500 m scale (Figure 1) are key markers of alteration history of the layered sulfates. These ridges dominantly intersect at right angles but have no preferred orientation, and are often subvertical. In some areas, localized bedding-orientation variability (up to ~5°) coincides with boxwork domains. These features are characteristic of volume-loss fracturing without a regional stress field, analogous to 3D polygonal faulting on Earth [3]. Dewatering of saturated sediments during diagenesis is a likely model for fracture formation.

CRISM detections of jarosite along fracture traces, along with isopachous fills visible from HiRISE imagery, show that these volume loss-fractures were mineralized by acid-sulfate fluids. Variable penetration of fluids leads to a wide range of fracture expression and erosional resistance. Fracture fills grade into a bright-toned alteration halo beneath the capping Syrtis Major lavas (Figure 2a), underscoring the association of fluid mineralization with the overriding lava flows.

**Conclusion:** The layered sulfates at northeast Syrtis major represent a significant sedimentary package that was both deposited and significantly eroded during the Noachian–Hesperian transition, prior to capping by Syrtis major lavas. The sedimentary origin suggested by the rhythmic bedding and recessive erosional character is confirmed by the

![Diagram](2932.pdf)

Figure 3: A model emplacement history for the layered sulfates, emphasizing the separability of sedimentation, volume-loss fracturing, and fluid alteration. The relative order of fracturing and lava flows is uncertain; volume-loss could occur in response to, or after, lava emplacement. In this alternative scenario, the panels (2,3,4) would be reordered (3,2,4).

Flat to gently draping layering and pattern of volume-loss fracturing. The regional layering style and pattern of volume-loss fractures is characteristic of basin deposition. After deposition, the deposits underwent a multistage history of volume loss and fluid mineralization. Overall, the layered sulfates show a significant presence of water at the surface of Mars during the Noachian–Hesperian transition.