Sedimentary units accessible in the NE Syrtis extended mission area and recent findings on the history of surface water in the broader region

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This study

Layered sulfates

Noachian basement

Study area

Syrtis Major lavas

Proposed Mars 2020 landing ellipses

Jezero

Midway

NE Syrtis

Layered sulfates

Schematic Areal Extent

not to scale
Layered sulfates
- Thick sedimentary unit
- Acidic style of aqueous alteration (distinct from Noachian basement units)
- Depositional timing bracketed by units of known Noachian and Hesperian age

Syrtis Major lavas
- No signatures of aqueous alteration
- Known early Hesperian age (crater counting)
NE SYRTIS UPPER STRATIGRAPHY: NEW FRAMEWORK

Methods
- 3D structural analysis
- Geologic mapping

Results
- Three sets of units postdating the Noachian basement stratigraphy
- Multiple episodes of surface- and groundwater activity postdating Noachian basement alteration

NE SYRTIS UPPER STRATIGRAPHY: NEW FRAMEWORK

Layered sulfates

Diagenesis

Erosion (1)

Smooth cap surface

Syrts Major lavas

Erosion (2)

Fluvial-deltaic deposits

SULFATES
Late Noachian-Early Hesperian
- Layered
- Mantled
- Altered
- Uncertain

Boxwork fractures

SYRTIS MAJOR
Early Hesperian
- Lava plains
- Uncertain

CAP SURFACE
Early Hesperian (?)
- Smooth
- Hummocky

SEDIMENTARY FILL
Hesperian-Amazonian
- Undivided
- Channel deposit
- Basin floor
- Valley fill

Syrts Major lavas infilling fluvial channels

Groundwater-altered sulfate-bearing sediments

Post-Syrtis fluvial-deltaic deposits

Noachian stratigraphy (basement, megabreccia)

Preprint manuscript: https://eartharxiv.org/fzhk7
GEOLOGIC MAP of NE Syrtis focusing on the upper sedimentary stratigraphy

- Define and characterize units
- Evaluate potential depositional processes

All units accessible from NE Syrtis ellipse in extended mission traverse:
1. Late sedimentary deposits
2. Layered sulfates
3. Syrtis Major lavas

Preprint manuscript: The Deposition and Alteration History of the NE Syrtis Layered sulfates (https://eartharxiv.org/fzhk7)
**LAYERED SULFATES**

**Thick stratigraphy**
~400 m relief in this scene (NF6)

**Layered at meter-scale**
\[ \mu = 1.4 \text{ m}, s = 0.4 \text{ m} \]
(NF1, NF6, and NF7)

**Easily eroded**
Preserved where capped or buttressed by resistant ridges

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Preprint manuscript:
https://eartharxiv.org/fzhk7
SULFATES

- Basaltic composition detrital sedimentary rock
- Deposited above Noachian basement units
- Polyhydrated sulfate mineral signatures
- Jarosite-bearing boxwork ridges

Sulfates represent an environmental transition to:
- Clearly sedimentary deposition
- More acidic style of aqueous alteration
STUDY METHODS

Build elevation models providing detailed topographic data

CTX and HiRISE elevation models, 1-10 m per pixel

Detailed geologic mapping
Structural characteristics to distinguish depositional mechanisms

Preprint manuscript: https://eartharxiv.org/fzhk7
LAYERED SULFATES: DEPOSITIONAL MECHANISMS

Structural characteristics can help distinguish depositional mechanism between possible options.

Preprint manuscript: https://eartharxiv.org/fzhk7
REGIONAL ORIENTATIONS

DIP MAGNITUDE

- < 0.5°
- 0.5-1.5°
- 1.5-4°
- 4-7°
- > 7°

Orientation errors

LAYERED DEPOSITS

Layered sulfates

Sedimentary fill

CAPPING SURFACES

Smooth capping surface

Syrtis Major lavas

Preprint manuscript: https://eartharxiv.org/fzhk7
LAYERVERD SULFATES: CROSS SECTIONS

- Thick (up to 600 m) layered deposits
- Layers drape and onlap basement topography

![Diagram of layered sulfate deposits with cross sections A, B, C, and D, showing proposed point of rover access and model constraints based on observed contact.]

Preprint manuscript: https://eartharxiv.org/fzhk7
Thick (up to 600 m) layered deposits

Deposition by settling from suspension

- Consistent, meter-scale bedding
- Low-angle (<10°) but nonzero dips
- Layers drape and onlap basement topography
Boxwork fractures

• ~500 m scale

• polygonal geometry

• penetrate entire thickness of unit (>200 m)

• filled with jarosite-bearing material to form resistant ridges

Scene ~3 km wide with 400 m of relief

Preprint manuscript: https://eartharxiv.org/fzhk7
LAYERED SULFATES: BOXWORK FRACTURES

Filled-fracture morphology

*Isopachous fill*
Progressive mineralization by continuous fluid flow

*Fractures were mineralized after formation.*

*Jarosite (Fe-sulfate) mineral signature in fracture fills*

Aqueous alteration with an acidic character

Preprint manuscript: https://eartharxiv.org/fzhk7
LAYERED SULFATES: BOXWORK FRACTURES

No favored orientation → Not tectonically controlled
Mechanism: internal volume loss

Segment azimuth

Comparison

Ridges in Noachian basement
Tectonically controlled by Isidis Basin formation

Preprint manuscript: https://eartharxiv.org/fzhk7
LAYERED SULFATES: BOXWORK FRACTURES

Polygonal faulting – an Earth analog

Key characteristics

• polygonal fracture geometry
• hundred-meter to kilometer scale

Mechanism

Compaction of clay-rich sediments forms layer-bound faults during diagenesis and shallow burial

On Earth, typically associated with thick, subaqueous basin sediments.

Cartwright and Lonergan, Basin Research, 1996

Preprint manuscript: https://eartharxiv.org/fzhk7
**LAYERED SULFATES:**
**DEPOSITIONAL MECHANISMS**

Thick (up to 600 m) layered deposits

**Deposition by settling from suspension**
- Consistent, meter-scale bedding
- Low-angle (<10º) but nonzero dips
- Layers drape and onlap basement topography

**Single-stage diagenetic volume loss**
Boxwork polygonal fractures
- Penetrate entire thickness of unit
- No external tectonic control

Preprint manuscript: [https://eartharxiv.org/fzhk7](https://eartharxiv.org/fzhk7)
POST-SULFATE HISTORY

- Capping surfaces
- Several erosional phases
- Late fluvial/lacustrine deposits

Preprint manuscript:
https://eartharxiv.org/fzhk7
SMOOTH CAPPING SURFACE: NEWLY DEFINED UNIT

Distinct from and formed prior to Syrtis Major lavas
Also caps layered sulfates

- ~10-20 m thick
- Low thermal inertia
- Low crater density

Preprint manuscript:
https://eartharxiv.org/fzhk7
• Partially eroded sulfate stratigraphy
• Syrtis Major lavas cap remaining sulfates, forming inverted topography

PALEOVALLEYS CHANNELIZING SYRTIS MAJOR LAVAS

Preprint manuscript: https://eartharxiv.org/fzhk7
PALEOVALLEYS CHANNELIZING SYRTIS MAJOR LAVAS

- Partially eroded sulfate stratigraphy
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Preprint manuscript: https://eartharxiv.org/fzhk7
Paleovalleys bypassed or re-incised by flow postdating Syrtis Major lavas
Fluvial and deltaic systems postdating Syrtis Major lavas

Preprint manuscript: https://eartharxiv.org/fzhk7
 Basin-filling and fan deposits: likely lacustrine origin

- The rover will traverse these deposits to access the sulfates
- 1.29 Ga (Amazonian) crater-counting age (Skok and Mustard, 2014)

Preprint manuscript: https://eartharxiv.org/fzhk7
MULTIPLE EPISODES OF AQUEOUS ACTIVITY FROM NOACHIAN—EARLY AMAZONIAN

1. Deposition of sediments gently draping basement

2. Diagenesis and volume-loss fracturing

3. Erosion to unconformity and paleovalley formation

4. Fracture mineralization and formation of smooth capping surface

5. Erosion to mesas and embayment and capping by Syrtis Major lavas

6. Differential erosion and deposition of fluvial sediments

AQUEOUS EPISODE
regionally extensive subaqueous sedimentation

single-stage dewatering

fluvial erosion

subsurface fluid flow
*relative timing uncertain

fluvial erosion

fluvial and lacustrine sedimentation

Wind erosion to present

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IMPLICATIONS FOR NE SYRTIS/JEZERO REGIONAL SEDIMENTARY SYSTEM

- Aggradation of a thick stratigraphy adjacent to the NE Syrtis Plains
- Multiple episodes of fluvial incision and erosion
- Deltas and lacustrine deposits at nearly the same elevation (~2300 m) as the Jezero crater delta

Preprint manuscript: https://eartharxiv.org/fzhk7
Key rover deliverables
at N margin of sulfates

1. **Layering style** of sulfate units can determine depositional environment

2. **Chemistry of fracture-filling cements** can illuminate alteration history

3. **Dateable volcanic surface** of the Syrtis Major lava plains

4. **Composition of smooth capping surface** will suggest formation mechanism

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