Intact Stratigraphy Traversing the Phyllosilicate to Sulfate Eras at the Syrtis-Isidis Contact, Mars

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Stratigraphy of Nili Fossae/NE Syrtis record multiple aqueous environments from the Middle Noachian to Early Hesperian.
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Isidis Basin
Early/Mid Noachian
(~3.96 Ga, Werner, 2005)

Syrtis Major
Early Hesperian

Nilli Fossae graben

Jezero Crater

NE Syrtis Landing Ellipse

Isidis Basin
Early/Mid Noachian
(~3.96 Ga, Werner, 2005)
Chronology of Geological Processes Defined in a Mineralogic/Morphologic Stratigraphy Across 1000s km²

Isidis Basin and Syrtis Major lavas are major time-stratigraphic markers

Significant gradation (mass wasting? aeolian? alluvial? all?) between Isidis basin formation and Syrtis lava emplacement

Defined wet periods, marked by mineralogy & morphology

Mustard et al., JGR 2009

Mustard et al., JGR 2009
The Noachian basement

- altered (to Fe/Mg smectite)
- breccia blocks (altered/unaltered) are common throughout
  - raised ridges upon erosion: conduits of fluid flow?
- mafic (low-Ca pyroxene) materials cap
- Q: clays created or distributed by impact

*Mustard et al., 2009, JGR*
Widespread olivine-bearing unit is a distinctive stratigraphic marker
Shows the same texture, thickness, and composition across 1000s km²

- Volcanic flows [Tornabene et al. 2007] vs impact melt [Mustard et al., 2007]
- Drapes topography and is cut by fossae
- Associated with carbonate and serpentine in the region near and north of Jezero Crater

Draping basement topography, banded olivine-rich unit beneath a mafic cap
Ridged, brecciated, altered phyllosilicate-bearing basement

1 km
Morphology and Orientation of Ridges
Widespread ridges in the Noachian crustal unit, 10s m wide, 100s m long
Mapping of over 2200 ridges shows a NE-SW orientation that parallels Nili Fossae
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Active from Noachian into Hesperian

Both well-developed drainage networks (e.g. Jezero) and short, amphitheatre headed valleys
Kaolinite-smectite alteration
occurs where precursor rock is not olivine-rich (pyx, Fe/Mg smectite)

Carbonate-smectite alteration
occurs where precursor rock is olivine-rich

Ehlmann et al., Science 2008; Ehlmann et al., JGR, 2009
Kaolinite, carbonate, and serpentine mineralization

• Chemistry controlled by precursor mineralogy

(MAFIC) basalt $\xrightarrow{\text{partial alteration}}$ Fe/Mg smectite $\xrightarrow{\text{enhanced leaching}}$ Kaolin group mineral
\[
\text{Al}_2\text{Si}_2\text{O}_5(\text{OH})_4
\]

(Analog: soil formation under intermittently wet conditions, Hawaii, Italy)

---or---

(ULTRMAFIC) olivine $(\text{Fe,Mg})_2\text{SiO}_4$ $\xrightarrow{\text{partial HT alteration}}$ serpentine $\xrightarrow{\text{partial low-T alteration}}$ carbonate
\[
(\text{Fe,Mg})_3\text{Si}_2\text{O}_5(\text{OH})_2 \quad \text{Mg, Fe)}\text{CO}_3
\]

(Analog: weathering serpentinites in Oman, N. California)

• Carbonate: Surface alteration related to near-surface hydrology? Hydrothermal serpentinizing system?
  • $\text{H}_2$ an energy source for organisms, potential for methane production
• Kaolinite: Leaching from an active hydrologic system
**NE SYRTIS: Ellipse and Go-To Science**

Cross the Noachian-Hesperian boundary and the transition from phyllosilicate/carbonate (alkaline) to sulfate (acidic).

Investigate hydrothermal, fluvial, and volcano-ice interactions which present a number of diverse habitable environments on early Mars.

Thick sedimentary sequence is accessible at the go-to site.

In-ellipse science includes immediate investigation of Noachian alteration in breccias and of kaolinite and carbonate alteration with reactants and products in direct association.

Extended region includes four distinct aqueous environments with clear local stratigraphic relationships that fit within a regional stratigraphic and geologic framework.

Fe/Mg smectite basement, kaolinite alteration, olivine-rich unit with serpentine and carbonate alteration, Hesperian volcanic flows emplaced on sediments and interacting with volatile-rich deposits with hydrothermal alteration and sulfate mineral deposition.
1. NE Syrtis inflow
Beneath the capping lava is a 500 m stack of layered rock that appears sedimentary.
3. Beneath the capping lava is a 500 m stack of layered rock: Sedimentary?
Regional Stratigraphy provides the context for in-ellipse and go-to science.
In Ellipse Science and Notional Traverses
NE Syrtis Acid-Alkaline Transition

Cross the Noachian-Hesperian boundary and the transition from phyllosilicate/carbonate (alkaline) to sulfate (acidic)

Emplacement of lava into a volatile-rich environment and onto the olivine-bearing units and Fe/Mg phyllosilicate-bearing basement with serpentine formation

Sulfate deposits include jarosite and polyhydrated sulfate, largely with volcanic units

Evidence for circulation of fluids by heat of lava source

In direct stratigraphic section and in situ are units that encompass many elements of the transition from the early phyllosilicate-forming era to the later sulphate-forming era

Long record of aqueous processes with alteration minerals
Conclusions

- Target-rich in ellipse science; go-to science traverses Noachian to Hesperian
- Bedrock strata in-situ representing four distinct environments of aqueous alteration where reactants and products are together
  - early crustal: creation or distribution by impact
  - carbonate/serpentine: surface alteration or hydrothermal?
  - layered phyllosilicates (Al- over Fe/Mg): from leaching with surface hydrology?
  - (sedimentary?) acid sulfate formation
- A record of aqueous geochemistry preserved in-situ, in mineral-bearing strata, distinct in age, primary mineralogy, and geologic setting well-suited for the MSL instrument suite
- Key stratigraphies from Bibring’s Phyllosian and Theiikian eras: do the changes recorded here represent Mars global environmental change?