Mawrth Vallis clay unit: probing the early Mars Habitability, Climate and Origin of Life

D. Loizeau, F. Poulet, B. Horgan, N. Mangold, J. Michalski, J. Bishop

Mars 2020 Landing Site Workshop

NOTE ADDED BY JPL WEBMASTER: This content has not been approved or adopted by NASA, JPL, or the California Institute of Technology. This document is being made available for information purposes only, and any views and opinions expressed herein do not necessarily state or reflect those of NASA, JPL, or the California Institute of Technology.
- Extended unit with a large variety of hydrated minerals associated with layers (several ellipses were studied)
- Largest clay content identified on Mars
- Numerous studies (40+ peer-reviewed papers including science and nature papers)
Attractive points

1. Mineralogically very diverse site
2. Lithologically diverse site that captures multiple environments
3. Both ancient altered Noachian deposits and remobilized sediments
4. Extremely ancient section of rocks probing an enigmatic epoch in Solar System history
5. Several types of science (astrobiological) targets
6. Opportunity to sample rocks from the deep Noachian up through the global transition into the Hesperian
Early Noachian to the Hesperian
Complex aqueous diversity on Mars

Gale Crater
- Fe/Mg-phyllosilicate
- Al-phylllosilicate
- Hydrated silica
- Acid-treated clays
- Sulfates (polyhydrated)

Mawrth Vallis
- Fe/Mg-phyllosilicate
- Al-phylllosilicate
- Hydrated silica
- Kaolinite
- Acid-treated clays
- Sulfates (bassanite jarosite)
- Alunite
Complex aqueous history on Mars

Phase 1

Progressive deposition and alteration of sediments or pyroclastic deposits => smectites

Early to middle Noachian

Moderate water rock ratio

Local precipitation of sulfates
Complex aqueous history on Mars

Phase 2

Continued surface weathering, greater or acidic leaching of the surface layers

Surface assemblage: Kaolins, alunite, ferrous clays

Local precipitation of sulfates (jarosite)

Extreme Fe/S redox gradient: excellent source of energy for likely Martian microbes.

Fluid circulation in fractures => halo-bounded fractures
Phase 3

**Pyroxene-bearing dark cap deposition**

- Early Hesperian
- Probable volcanic/pyroclastic deposits
- No more aqueous alteration
- Preservation of clays and morphologic features (inverted valleys)
Phase 4

Wind erosion

the whole section is progressively and continuously exhumed

Hesperian and Amazonian
Best Terrestrial Analogs

Painted Desert, AZ: Floodplain soils formed in fluvial/lacustrine/deltaic/aeolian sediments (~200 My)

Some fluvial landforms at HiRISE scales, but many other aqueous environments as well

John Day Fossil Beds, OR: Soils formed in pyroclastic sediments, modified by local fluvial/lacustrine activity (~30 My)

Very few obvious fluvial landforms at HiRISE scales, but many preserved lake beds, wetlands, overbank deposits, etc.

Black spots are biosignatures

Horgan (2014, 2015)
Habitability and Preservation of Organics

- Soils are **highly habitable** environments - energy, water, nutrients, etc.
- High clay content and rapid burial leads to **organic preservation** in paleosols
- Concentration of organics is overall low-mod, but can be **locally high**
- Reducing soils cause immediate **preservation** and can lead to concentrated organics in wetlands
- Reduced paleosols at Mawrth shall be excellent targets for **in situ** search for organics and biosignatures

Archean paleosols preserve the oldest non-marine organics on Earth (1-3 Gy)

Dorset, UK tonstein. Mineralogical analog for Mawrth Vallis. Organic-rich!
Probing for past climatic conditions

Al-clays over Fe/Mg-smectites sequence is common on Mars during this time period:

Consistent with long-term (~million years) leaching profiles in a wetter climate

MV and its weathering profile allow to characterize Mars’ ancient climate and underlying processes

Mawrth sequence is several time thicker than others and mineralogy much more complex

Carter et al. (2015)
Two ellipses: Plateau ellipse and Oyama crater.
ROI 1

Al/Si unit

jarosite/acid treated smectites

kaolinite/alunite

Al-smectites/hydrated silica

Fe/Mg unit

MARS 2020 at MAWRTH VALLIS

1 km
ROI 1

- Al/Si unit
- Fe/Mg unit
- Jarosite/acid treated smectites
- Kaolinite/alunite
- Al-smectites/hydrated silica
- Transition between units
- Fe-clay layers

1 km
ROI: ancient inverted valleys

series of elongated buttes
ROI: Halo-bounded fractures and veins
ROI: Pitted layers

Pitted surface
ROI: Paleo-features

200 m

Red member (lower layers)

Dark paleo-surface

Red member (upper layers)

200 m

inverted valley
<table>
<thead>
<tr>
<th>Unit</th>
<th>Morphology</th>
<th>Mineralogy</th>
<th>Objectives</th>
<th>Ranking</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dunes</td>
<td>in local lows, generally ancient craters and valleys, direction: W-E in eastern part, SW-NE in western part</td>
<td>no hydrated signature, maybe basaltic sand if erosion product from the dark cap</td>
<td>...</td>
<td>5</td>
</tr>
<tr>
<td>Dark cap</td>
<td>flat-top mesas or crater filling, surrounded by dark talus: probably a “duricrust” protecting more easily erodible material</td>
<td>no hydrated signature, weak pyroxene signature (Loizeau et al., 2007)</td>
<td>Sample caching</td>
<td>4</td>
</tr>
<tr>
<td>Upper blue member</td>
<td>gentle slope forming unit, generally regular polygons 0.5-1.5 m across*</td>
<td>Al-phylosilicates (montmorillonite, kaolinite), hydrated silica, ferrous component at the contact with the red unit</td>
<td>Habitability, biosignatures, sample caching</td>
<td>1</td>
</tr>
<tr>
<td>Red member (above paleo-sand-sheet)</td>
<td>generally irregular polygons 2-5 m across, with variation in fracture styles, few exposed layers*</td>
<td>Fe-smectite, ferrous component at the contact with the upper blue unit</td>
<td>Habitability, biosignatures, sample caching</td>
<td>1</td>
</tr>
<tr>
<td>Bright circular features</td>
<td>similar to red unit, but with many quasi-circular features 15-50m across</td>
<td>Fe-smectite</td>
<td>Habitability, biosignatures, sample caching</td>
<td>3</td>
</tr>
<tr>
<td>Paleo-sand sheet</td>
<td>rough, linear features trending NW-SE (different direction than surface dunes)*</td>
<td>no hydrated signature</td>
<td>Sample caching</td>
<td>3</td>
</tr>
<tr>
<td>Red member (on the plateau, below the paleo-dunes)</td>
<td>generally irregular polygons 2-5 m across, with variation in fracture styles, few exposed layers*, very eroded areas</td>
<td>Fe-smectite</td>
<td>Habitability, biosignatures, sample caching</td>
<td>2</td>
</tr>
<tr>
<td>Red member (on Mawrth Vallis flank and floor)</td>
<td>generally irregular polygons 2-5 m across, with variation in fracture styles*, with many exposed layers</td>
<td>Fe-smectite</td>
<td>Habitability, biosignatures, sample caching</td>
<td>2</td>
</tr>
<tr>
<td>Lower blue member</td>
<td>partly fractured in blocks up to 1.5 m across, exposed layers</td>
<td>possibly bassanite, or zeolite (spectrally close minerals when weak signal)</td>
<td>Habitability, biosignatures, sample caching</td>
<td>2</td>
</tr>
<tr>
<td>Dark paleo-surface</td>
<td>hummocky terrain with many quasi-circular features 10 to 100 m across, interpreted as exhumed filled craters</td>
<td>Fe-smectites</td>
<td>Habitability, biosignatures, sample caching</td>
<td>2</td>
</tr>
<tr>
<td>Putative Ancient Valleys</td>
<td>Part of ancient valleys, or inverted valleys, or a series of buttes that could be an ancient inverted valley</td>
<td>Eroded inside the clays, often filled by dark cap</td>
<td>Habitability, biosignatures, sample caching</td>
<td>2</td>
</tr>
</tbody>
</table>
- very few small craters
- widespread aeolian activity and erosion due to dark sands
- easily erodible, very fine grained deposits
**Ellipse Plateau: To Summarize**

- Very diverse aqueous alteration (from low to strong) inside the ellipse
- Long and continuous stratigraphic altered section
- Diverse lithologies that capture multiple environments (deposition, alteration & erosion)
- Reducing conditions, silica and very high clay content - high preservation potential
- Fresh surfaces (continuous erosion of clays) and no diagenetic overprinting
- Sample biosignatures in the habitable environment in which they were formed
Ellipse Plateau: To Summarize

- Consistent with a paleosol sequence ending in a wetlands-like environment
- Reducing terrains (soils) cause immediate preservation and can lead to concentrated organics if a biological cycle is active
- Unique window into climate of early Mars (EN to H)
- Dateable ~EH surface (mafic capping unit) present at numerous locations inside the landing ellipse
Perfect site to address in detail the questions of habitability & the potential origin and evolution of life on Mars

Minimizes the quantity of driving to maximize the quantity of field characterization and coring
Transition from the Upper-blue to Red member

Highest priority

The alteration is also revealed by difference in color and texture
ALTERED UNIT, priority 1
Special strata in the Red member
- rounded deposits
- paleo-sand sheet (parallel dunes)
- pits differential erosion
- veins differential erosion
- halo-bounded fractures
- veins
- dense networks of fractures

=> alteration in the subsurface through fluid circulation
- Fluvial features are present throughout units but are only obvious below capping unit due to inverted relief in resistant unit
- Relief inversion shows the softness of the clays wrt the dark cap
CAPPING UNIT, priority 3

- dateable igneous surface, regionally extensive
- eroded and redeposited (tallus, layered filling, dunes)
- rests of ejecta (15 km fresh crater south of the site)