

Mawrth VallisLocation
(lat,lon):

24°N, 341°E

Summary of observations and interpreted history, including unknowns:

The Mawrth Vallis region contains extended outcrops of phyllosilicate-rich rocks. OMEGA and CRISM have detected Fe/Mg-smectites, Al-smectites, kaolinite, hydrated silica, and sulfates in association with light-toned exposures of Noachian bedrock. The Mawrth Vallis site would enable investigation of some of the most ancient outcrops of sedimentary and clay-bearing rocks on Mars.

The clay-bearing units correspond to exposures of thick (>300 m), finely layered (layer thickness <<10 m) sedimentary rocks extending across a 300*300 km wide region. The origin of the layering is unknown: interpretations include subaqueous, fluvial and volcanoclastic deposits; the orbital facies does not allow a definitive interpretation. This unit is dominated by Fe/Mg smectites with local interbeds of sulfates. OMEGA and CRISM unmixing models suggest clay mineral abundances as high as 50 wt.%. It is unclear if the Fe/Mg-smectites are related to the global population of crustal Noachian Fe/Mg-smectites.

Some portions of the Fe/Mg-unit exhibit large resistant filled fractures and halo-bounded veins that are interpreted to have formed due to fluid circulation. The close proximity of the large Oyama crater, which impacted into the Fe/Mg-unit, suggests that these may be impact hydrothermal deposits; however, low-T groundwater diagenesis cannot be ruled out based on orbital data.

Al-rich clays, grading from Al-smectite and silica into kaolinite and possibly allophane, dominate the top 10-30m of the section. The Al-clays are interpreted to have formed during sub-aerial weathering (pedogenic leaching). However, significant mineralogical variability as well as features interpreted as inverted channels suggest that the surface supported aqueous environments. The kaolinite is concentrated near the top of the section, and may either have been formed due to (a) localized acid leaching in a “wetland” environment, (b) regional or global acid surface leaching, (c) long term, more neutral leaching (a laterite). Possible alunite detections at the top of the section support either scenario (a) or (b). Strong spectral signatures consistent with Fe(II)-bearing phyllosilicates associated with the kaolinite may support reducing, poorly drained conditions, but the spectral signature is non-unique.

Two scenarios have been proposed for the origin of the Al-unit: (1) The Al-unit postdates the underlying Fe/Mg clays and the contact is an unconformity; (2) The Al-unit is the result of intense leaching of the pre-existing Fe/Mg-clays. The contact between the units is often also characterized by a spectral signature that is consistent with Fe(II)-bearing phyllosilicates, possibly indicating alteration by Fe-rich reducing groundwater. In some locations, close proximity to jarosite and copiapite may imply a strong Fe/S redox gradient, possibly due to oxidation at sub-aerial seeps (Farrand et al, 2014).

The clays are capped by a regionally-extensive dark mesa-forming unit that exhibits pyroxene spectral signatures. This unit may either be a pyroclastic deposit or a mafic sandstone. From crater counts, the cap rock is 3.7 Gy old (Early Hesperian). The Al-unit predates this episode and is interpreted as being Late Noachian whereas the thicker layered deposits were deposited before (Middle Noachian or earlier).

Summary of key investigations

- Establish the composition, nature and origin of the clay-bearing deposits inside the ellipse.
- Determine the nature of the terminal aqueous environment; search for biosignatures in association with sulfates and reduced iron alteration phases
- Determine whether or not mineral diversity corresponds to Noachian climate variations and constrain nature of Noachian climate
- Search for organics in these clay-bearing deposits, at paleosurfaces, minerals precipitated at seeps, and in surface aqueous environments
- Determine the origin of filled fractures; search for biosignatures in precipitated minerals
- Determine nature and composition of the dark cap rock; if volcanic, sample for age dating

Cognizant Individuals/Advocates:

Damien Loizeau, Briony Horgan, François Poulet, Nicolas Mangold, Janice Bishop

Link to Workshop 2 rubric summary

<https://docs.google.com/spreadsheets/d/16Rmn2qHFQc6BKJtiyleDLcyBxJqq8Oq4VO3etqrZ8lo/edit?invite=CNm8lqYF&pref=2&pli=1#gid=868597987>

Key Publications list (grouped by topic):

Mineralogy:

Bishop, J. L. et al (2008) Phyllosilicate Diversity and Past Aqueous Activity Revealed at Mawrth Vallis, Mars. *Science* 321, 830. DOI: 10.1126/science.1159699.

Bishop, J. L. et al (2013), What the ancient phyllosilicates at Mawrth Vallis can tell us about possible habitability on early Mars, *Planetary and Space Science*, 86, 130–149, doi:10.1016/j.pss.2013.05.006.

Bishop, J. L., and E. B. Rampe (2016), Evidence for a changing Martian climate from the mineralogy at Mawrth Vallis, *Earth and Planetary Science Letters*, 448, 42–48, doi:10.1016/j.epsl.2016.04.031.

Farrand, William H.; Glotch, Timothy D.; Rice, James W.; Hurowitz, Joel A.; Swayze, Gregg A. (2009) Discovery of jarosite within the Mawrth Vallis region of Mars: Implications for the geologic history of the region Icarus, Volume 204, Issue 2, p. 478-488. DOI: [10.1016/j.icarus.2009.07.014](https://doi.org/10.1016/j.icarus.2009.07.014).

Farrand, W. H., T. D. Glotch, and B. Horgan (2014), Detection of copiapite in the northern Mawrth Vallis region of Mars: Evidence of acid sulfate alteration, *Icarus*, 241(C), 346–357, doi:10.1016/j.icarus.2014.07.003.

Loizeau, D. et al (2007). Phyllosilicates in the Mawrth Vallis region of Mars. *Journal of Geophysical Research*, Volume 112, Issue E8, CiteID E08S08. DOI: 10.1029/2006JE002877.

McKeown, N. et al. (2009) Characterization of phyllosilicates observed in the central Mawrth Vallis region, Mars,

their potential formational processes, and implications for past climate. *Journal of Geophysical Research*, Volume 114, Issue 52, CiteID E00D10. DOI: [10.1029/2008JE003301](https://doi.org/10.1029/2008JE003301).

Poulet, F. et al (2008). New evidence of significant abundance of clay minerals on Mars. *A&A* 487, L41–L44. DOI: [10.1051/0004-6361:200810150](https://doi.org/10.1051/0004-6361:200810150).

Wray, James J. et al (2010) Identification of the Ca-sulfate bassanite in Mawrth Vallis, Mars. *Icarus*, Volume 209, Issue 2, p. 416-421. DOI: [10.1016/j.icarus.2010.06.001](https://doi.org/10.1016/j.icarus.2010.06.001).

Stratigraphy and Physical Properties:

Howard, A. D.; Moore, J. M. (2007) The Light-toned Sediments in and near Lower Mawrth Vallis May be a Drape Deposit. 38th LPSC, p.1339.

Loizeau, D. et al. (2010) Stratigraphy in the Mawrth Vallis region through OMEGA, HRSC color imagery and DTM. *Icarus*, Volume 205, Issue 2, p. 396-418. DOI: [10.1016/j.icarus.2009.04.018](https://doi.org/10.1016/j.icarus.2009.04.018).

Michalski, J. R.; and E.Z. Noe Dobrea. 2007. Evidence for a sedimentary origin of clay minerals in the Mawrth Vallis region, Mars. *Geology*, October 2007; v. 35; no. 10; p. 951–954; doi: [10.1130/G23854A.1](https://doi.org/10.1130/G23854A.1)

Michalski, Joseph R.; Fergason, Robin L. (2009) Composition and thermal inertia of the Mawrth Vallis region of Mars from TES and THEMIS data. *Icarus*, Volume 199, Issue 1, p. 25-48. DOI: [10.1016/j.icarus.2008.08.016](https://doi.org/10.1016/j.icarus.2008.08.016).

Wray, J. J. et al (2008) Compositional stratigraphy of clay-bearing layered deposits at Mawrth Vallis, Mars. *Geophysical Research Letters*, Volume 35, Issue 12, CiteID L12202. DOI: [10.1029/2008GL034385](https://doi.org/10.1029/2008GL034385).

Astrobiology:

Bishop, J. L. et al (2013), What the ancient phyllosilicates at Mawrth Vallis can tell us about possible habitability on early Mars, *Planetary and Space Science*, 86, 130–149, doi:10.1016/j.pss.2013.05.006.

Horgan, B. H., et al (2015), Possible Microbial Energy Pathways From Iron and Sulfur Redox Gradients at Mawrth Vallis and Gale Crater, Mars, *Astrobiology Science Conference*, #7463, doi:10.1126/science.12.

Horgan B. (2016) Strategies for searching for biosignatures in ancient martian sub-aerial surface environments, *Biosignature Preservation and Detection in Mars Analog Environments*, #XXXX.

Regional/Global Context:

Carter, J. Loizeau, D, Mangold, N., Poulet, F., Bibring, J.-P., 2015, Widespread surface weathering on early Mars: a case for a warmer and wetter climate, *Icarus*, 248, 373-382, doi:10.1016/j.icarus.2014.11.011

Loizeau, D. et al (2012) Characterization of hydrated silicate-bearing outcrops in Tyrrhena Terra, Mars: Implications to the alteration history of Mars. Submitted to *Icarus*.

Noe Dobrea, E. Z. et al. (2010) Mineralogy and stratigraphy of phyllosilicate-bearing and dark mantling units in the greater Mawrth Vallis/west Arabia Terra area: Constraints on geological origin. *Journal of Geophysical Research*, Volume 115, Issue E11, CiteID, E00D19. DOI: [10.1029/2009JE003351](https://doi.org/10.1029/2009JE003351).

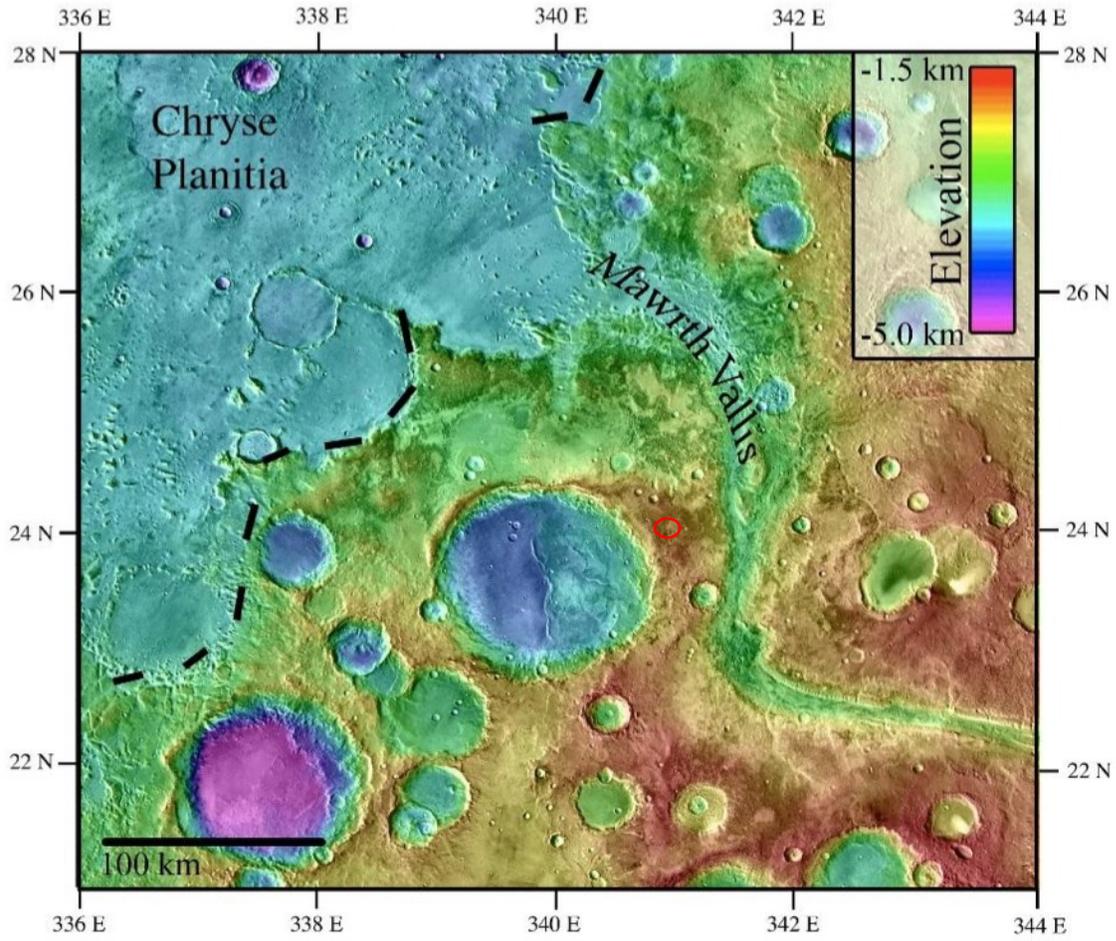
Poulet, F (2005). Phyllosilicates on Mars and implications for early martian climate. *Nature*, Volume 438, Issue 7068, pp. 623-627. DOI: [10.1038/nature04274](https://doi.org/10.1038/nature04274).

Landing site studies:

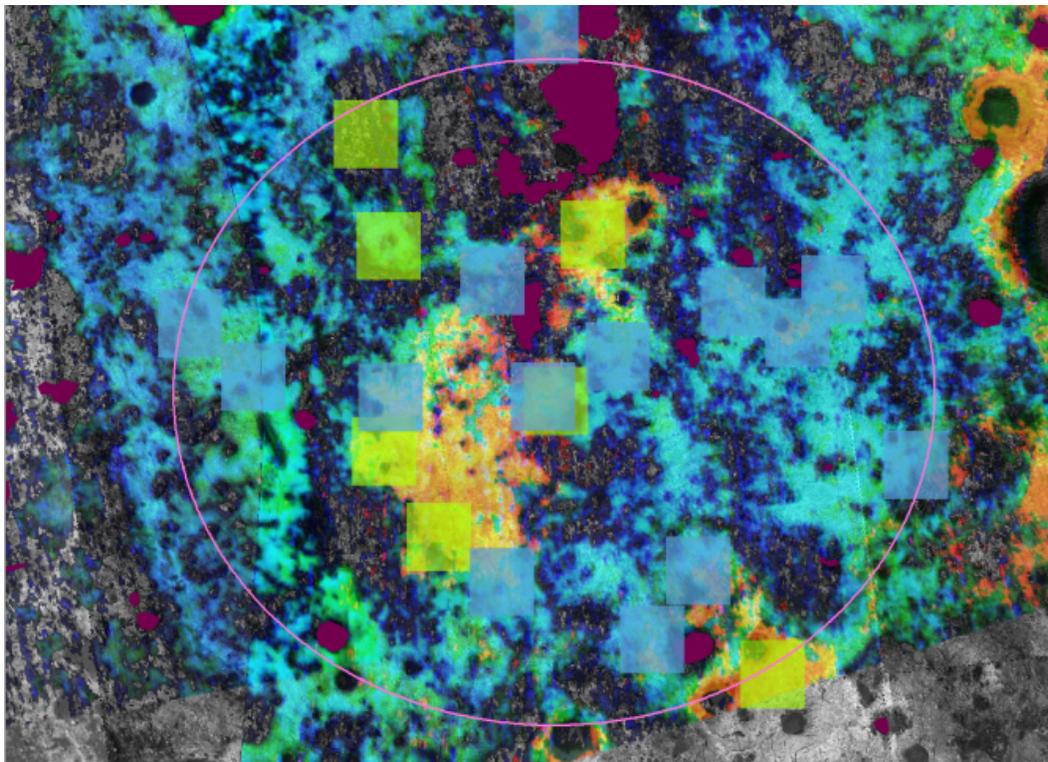
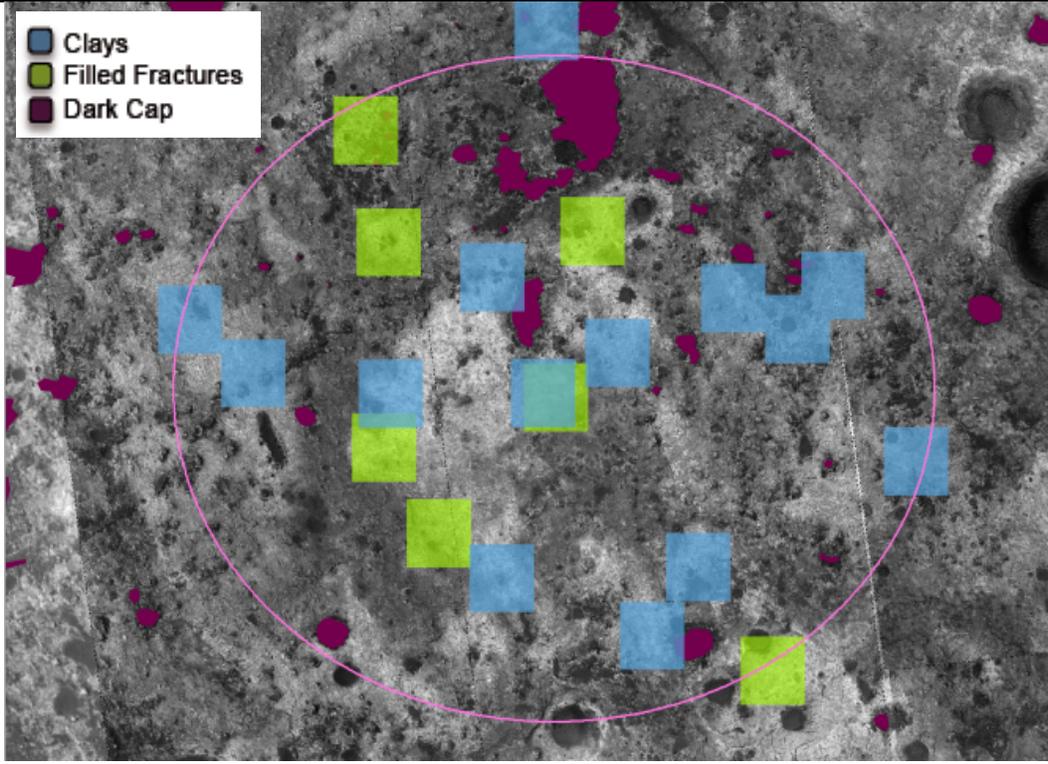
Loizeau, D. et al (2015). History of the clay-rich unit at Mawrth Vallis, Mars: High-resolution mapping of a candidate landing site, *JGR-Planets*, [10.1002/2015JE004894](https://doi.org/10.1002/2015JE004894).

Michalski, J. (2010) The Mawrth Vallis Region of Mars: A Potential Landing Site for the Mars Science Laboratory (MSL) Mission. *Astrobiology*, Volume 10, Issue 7, pp. 687-703. DOI: [10.1089/ast.2010.0491](https://doi.org/10.1089/ast.2010.0491).

Regional Context Figure (ref: Loizeau)



Ellipse ROI Map or Geologic Map Figure (ref: Loizeau, MCKeown)

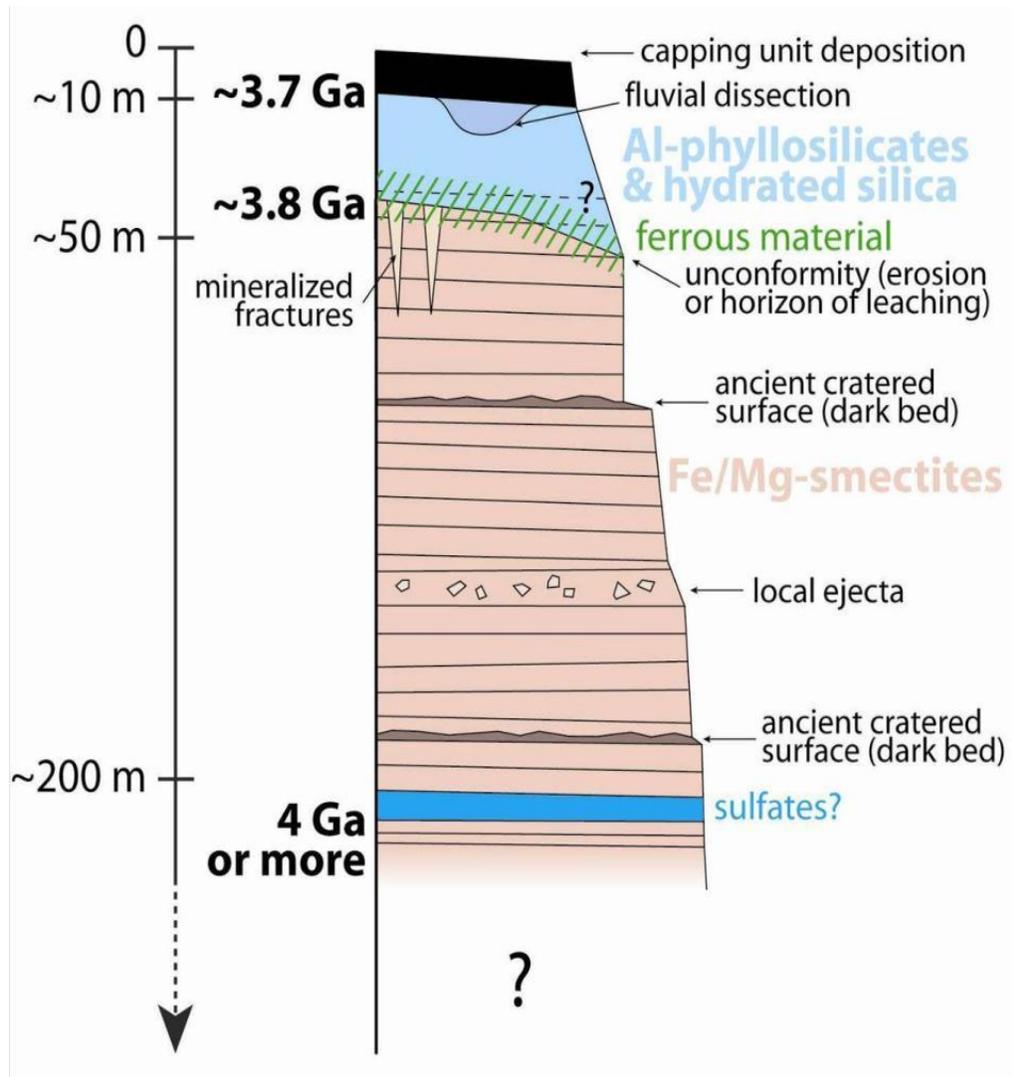


Red: Fe/Mg-smectites

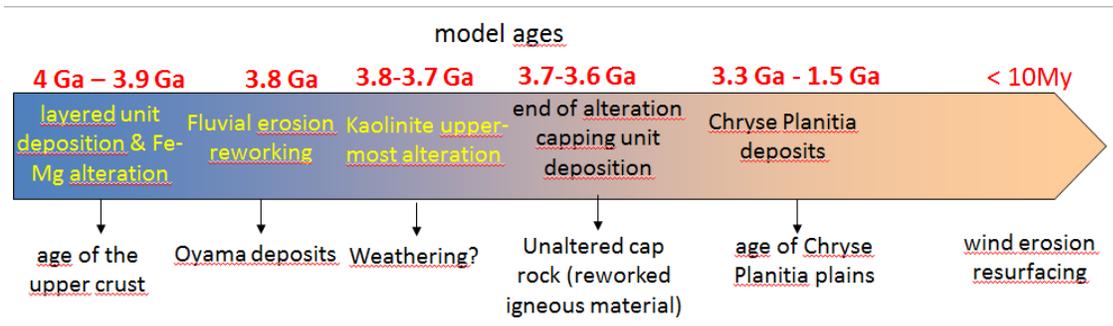
Blue: Al-clays

Green: ferrous
alteration phases

Regional (~3x ellipse) Stratigraphic Column Figure



Inferred Timeline Figure



- beginning of deposition and alteration is unknown
- part of the layered unit could have been deposited as early as 4 Ga ago
- the layered unit was probably entirely deposited 3.8 Ga
- Kaolinite upper section formed by weathering linked to a global episode 3.8-3.7 Gy ago
- alteration was finished 3.7 Ga ago
- Recent erosion and crater-free surfaces suggest good preservation

Summary of Top 3-5 Units/ROIs

ROI	Aqueous or Igneous?	Environmental settings for biosignature preservation	Aqueous geochemical environments indicated by mineral assemblages
1. Clay stratigraphy	Aqueous	Pedogenic, fluvial, possible wetlands; Pedogenic/diagenetic/subaqueous clays; subsurface aquifers and seeps	Al-clays/alunite/ferrous clays/silica; Fe/Mg-smectites; ferrous clays/jarosite
2. Halo-bounded fractures/veins	Aqueous	Impact hydrothermal system or subsurface low-T fluid flow	--
3. Dark capping unit	Igneous	May preserve underlying paleosurface & surface communities	Pyroxene-bearing dark deposits
4. Elongated mesas	Aqueous	Fluvial	--

Top 3-5 Units/ROIs Detailed Descriptions

Unit/ROI Name: 1. Clay stratigraphy
Aqueous
<p>Description:</p> <ul style="list-style-type: none"> ● Predominant thick (up to 300 m) clay-bearing unit composed of Fe-Mg smectites, changes to Al-clays (Al-smectites, kaolinite), and silica in top 10-30m. ● Ferrous phases and oxidized sulfates in close proximity. ● Main target of interest is the top of the sequence and the terminal aqueous environment. <p>Interpretation(s):</p> <ul style="list-style-type: none"> ● Origin of deposition of sediments is unclear: lacustrine, fine-grained eolian, ash can explain the deposition style. Fluvial and eolian cross bedding not observed. Local ejecta from craters are interbedded with layers, suggesting long term deposition. ● Fe/Mg-smectites: Origin of the alteration into clays includes diagenetic alteration (authigenic clays on any previously deposited sediments) or detrital clays if subaqueous deposition was predominant. ● Al-unit: Pedogenic weathering sequence formed under a temperate climate, formed either as a deep leaching profile of a single depositional unit or as a paleosol sequence (weathering concurrent with long-term deposition). Kaolinite at top of sequence either indicates long-lived leached paleosurface (laterite) or weathering in acidic wetlands. ● Ferrous alteration phases proximal to localized sulfates (jarosite and alunite) suggests an Fe/S redox gradient in surface wetlands (Al-unit, terminal aqueous environment) and in subsurface aquifers and springs (contact between Fe/Mg- and Al-units). <p>In Situ Investigations:</p> <ul style="list-style-type: none"> ● Evaluate the habitability of Early Noachian to Early Hesperian surface and subsurface environments ● Establish the nature and origin of the regional clay rich basement — crustal low-T hydrothermal alteration, magmatic/impact alteration, pedogenic weathering, etc. ● Interrogate the origin of Al phyllosilicates — weathering zones indicating clement temperatures; zones of acid-leaching.

- Determine whether or not redox gradients existed and their origin — groundwater fluctuations, chemical reactions between units, oxidizing atmosphere, etc.
- Determine origin of apparent layering, search for preserved paleosurfaces and paleoenvironments
- Determine whether or not mineral diversity corresponds to Noachian climate variations and constrain nature of Noachian climate
- In situ facies at meter to mm-scale to determine facies, grain sizes and texture.
- Chemo-stratigraphy to constrain the alteration origin in both units.
- Search for organics in terminal aqueous environment - concentrated in reducing (e.g., ponded) surface environments as indicated by ferrous phases or in fluvial deposits (overbanks, floodplains, etc.)
- Search for paleosurfaces where organics could have accumulated
- Search for organics and morphological biosignatures associated with sulfates and silica
- RIMFAX to map the internal structure of layered deposits; search for discontinuities (e.g. stronger/weaker reflections) and lateral changes in layering. If possible determine density, internal rock abundance of the layers to help determine origin. Examine structure of contact with underlying basement units
- RIMFAX to search for internal layering; examine contact with lower units.

Returned Sample Analyses:

- Precipitated minerals, if present, would record atmospheric composition within paleo-weathering sequences, enabling evaluation of stable isotopes of authigenic minerals for temperature, changing atm/water chemistry
- Organics extracted from clay minerals could be examined as a function of time to search for biosignatures and understand the paleo-influx of exogenous organic matter
- Sample sulfates for stable isotope studies that constrain fluid/atmospheric chemistry
- Retention/depletion of redox sensitive minor and trace metals would constrain atmospheric/aquifer redox and changes with time
- Mineral assemblages, detailed petrology, and stable isotopes would constrain the origin of the clays by weathering or hydrothermal activity
- If layers are igneous in origin and retain primary materials, evaluate evolution of igneous processes over time

Unit/ROI Name: 2. Halo-bounded fracture-fills
Aqueous
<p>Description:</p> <ul style="list-style-type: none"> • 10 m wide fracture fills that are more resistant to erosion than the clay-bearing rocks. • Fractures transition to eroded veins in some locations. • A halo with distinct color is present around the fractures and veins. <p>Interpretation(s):</p> <ul style="list-style-type: none"> • Impact hydrothermal system due to Oyama crater impact during period between deposition of Fe/Mg-unit and Al-unit – impact may have caused both fracturing and fluid flow. • Alternatively, precipitation in fractures due to low-T subsurface diagenesis. <p>In Situ Investigations:</p> <ul style="list-style-type: none"> • Use morphology, mineralogy, geochemistry to determine origin of fracture fills • Evaluate host-rock for signs of impact disturbance • Search for organic and morphological biosignatures in precipitated minerals • RIMFAX to seek reflections from fracture fills; if detectable, examine subsurface geometry. Map subsurface layering on either side of the fracture fills. <p>Returned Sample Analyses:</p> <ul style="list-style-type: none"> • Precipitated minerals in fractures - search for isotopic and other biosignatures, evaluate fluid chemistry from trapped fluids

Unit/ROI Name: 3. Dark cap rock
Igneous (rock waypoint)
<p>Description: Dark cap rock, pyroxene bearing, locally thinly layered or massive. Never exceed 20-30 m in thickness. Typically fills troughs and craters. Often as inverted topography (so more resistant than clay-bearing deposits)</p> <p>Interpretation(s):</p>

<ul style="list-style-type: none"> ● Either eolian or igneous (pyroclastic) deposits; regional extent regardless of topography is more consistent with pyroclastic origin. ● Exhibits strong pyroxene spectral signatures, no signs of alteration ● Non-altered material deposited after end of alteration in this region ● Crater counts suggest 3.7-3.6 Ga (Early Hesperian) <p>In Situ Investigations:</p> <ul style="list-style-type: none"> ● Analyze facies/texture/mineralogy to determine igneous vs. aeolian origin ● RIMFAX to seek reflections from base of cap rock deposits; if detectable, examine subsurface geometry and contact with surrounding layers. If possible, determine density of deposits, search for internal large blocks that could help determine origin. <p>Returned Sample Analyses:</p> <ul style="list-style-type: none"> ● Unaltered material for geochronology; constrain critical Early Hesperian timing ● Igneous petrology
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<p>Unit/ROI Name: 4. Mesa chains</p>
<p>Aqueous</p>
<p>Description: Lines of elongated mesas oriented along regional slope in Oyama crater</p> <p>Interpretation(s):</p> <ul style="list-style-type: none"> ● Inverted valleys preserving terminal aqueous environment <p>In Situ Investigations:</p> <ul style="list-style-type: none"> ● Search for organics in any preserved overbank deposits, floodplains, etc. ● Sedimentology to constrain seasonality, duration of terminal aqueous environment <p>Returned Sample Analyses:</p> <ul style="list-style-type: none"> ●

Biosignatures (M2020 Objective B and Objective C + e2e-iSAG Type 1A, 1B samples)

Biosignature Category	Inferred Location at Site	Biosig. Formation & Preservation Potential
Organic materials	In association with paleosurfaces, within clay-bearing units, in association with reduced phases and precipitated minerals, within filled fractures	Rapidly buried paleosurfaces can preserve organics from surface communities; Clay minerals are able to preserve organics; reducing environments preserve organics; precipitated minerals preserve organics
Chemical	Clay-bearing unit, Fe-Mg and Al unit, Halo bounded fracture fills	Zonation in chemistry in the transition from Fe-Mg to Al clays unit. Role of the reduced (ferrous) horizon.
Isotopic	Clay bearing unit, dark cap unit, fracture fills	Light isotopes in clays
Mineralogical	All	Mineralization in halos, zonations with specific minerals
Micro-morphological	Fe-Mg clay layered unit, precipitated minerals	Any structure preserved in clay deposits or precipitated minerals
Macro-morphological	Al-rich clay unit	Mats preserved in paleosurfaces

Dateable Unit(s) for Cratering Chronology Establishment

Unit Name	Total Area (km ²)	Time Period	Geologic Interpretation and uncertainties	What constraints would the unit provide on crater chronology?
Dark cap rock	Regional in extent	Early Hesperian	Could be eolian deposits from reworked igneous rock or pyroclastic deposits; regional extent may be more consistent with pyroclastics	Well constrained stratigraphic unit with regional extent. However, if this is primary volcanic is unclear.

Key Uncertainties/Unknowns about the Site

List the most important uncertainties, unknowns or potential drawbacks about the site

- Poorly constrained origin of the Fe-Mg rich layered deposits
- No obvious geomorphic evidence of standing body of water
- Oyama crater may have disturbed the deposits (although it could also have provided a heat source for a habitable impact-generated hydrothermal system)