Stuck in the clay: Organic matter preservation in Paleosols of Earth and Mars

Adrian Broz\textsuperscript{1,2}, Greg Retallack\textsuperscript{1}, Briony \v{H}organ\textsuperscript{3}, Lucas Silva\textsuperscript{4}, and Matt Polizzotto

\textsuperscript{1}Department of Earth Sciences, University of Oregon
\textsuperscript{2}Jacobs JETS contract, NASA Johnson Space Center
\textsuperscript{3}Department of Earth, Atmospheric, and Planetary Sciences, Purdue University
\textsuperscript{4}Department of Geography, University of Oregon
Known: Hydrothermal, diagenetic and pedogenic phyllosilicates across Mars
Poorly understood: How does clay mineralogy influence organic matter preservation through geological time?

Mawrth Vallis clay stratigraphy (HiRISE/NASA/JPL/University of Arizona)
Paleosols on Mars?

Paleosol: A buried, lithified soil

1. Potential paleosols at Gale Crater
2. Dioctahedral clays (yellow) across the surface of Mars
3. Striking spectral similarities to Earth paleosols

![Paleosol image](image1)

4. Possible Noachean (4.1-3.7 Ga) paleosols at Mawrth Vallis
(Bishop et al., 2013, 2018; Horgan et al., 2012; Le Diet et al., 2012; Loizeau et al., 2015)

5. Martian paleosols named potential high-priority sampling location
In-situ biosignature detection (Hays et al., 2016) and Mars Sample Return (Bishop et al., 2018)
Where to sample? Landscape Scale

Mawrth Vallis clay stratigraphy (HiRISE/NASA/JPL/University of Arizona)
Where to sample? Outcrop Scale

Gillespie Lake Member, Yellowknife Bay (NASA / JPL / University of Arizona)
Eocene – Oligocene (42-28 Ma) volcaniclastic paleosols, Painted Hills Unit, John Day Fossil Beds National Monument, eastern Oregon. Photo – Tamer Ghonheim
What factors influence organic matter preservation in pedogenic clay sequences on Earth?
Highly weathered paleosols:
- Kaolinite and oxide-rich
- Humid climate
- No amorphous materials

Moderately weathered paleosols:
- Fe/Mg smectites – montmorillonite,
- Low amounts of amorphous materials

Minimally-weathered paleosols
- Low clay content
- Lots of amorphous materials
- Celadonite and clinoptolite

Brown Grotto – Painted Hills Unit
Painted Hills inner basin, Painted Hills Unit
Blue Basin – Sheep Rock Unit

Time

Eocene (41 Ma)
Early Oligocene (32 Ma)
Oligocene (~29 Ma)

Retallack et al., 2000
Horgan et al., 2011
Horgan et al., 2011
John Day Paleosols: Mars analog

1. Similar dioctahedral clay mineralogy
   - Kaolins, Al-smectites, Al/Fe oxyhydroxides, and Fe/Mg smectites
2. Similar amorphous phase mineralogy
   - Nanophase aluminosilicates, opal, allophane
3. Stratigraphic mineral distribution – Suggests cooling and drying

Bishop et al., 2016 LPSC
Knowledge Gaps and Hypothesis

**Known:**
Paleosols at John Day are a good analog for Noachean (4.1-3.7 Ga) clay sequences on Mars

**Not known:**
Organic matter (OM) content of John Day paleosols
Role of clay mineralogy / content on preservation of organics
Role of amorphous phase content on preservation of organics

**Hypothesis:** Surface layers of reduced paleosols with abundant Fe / Mg smectite clays have greatest levels of OM
Methods

Task 1: Analyze total organic carbon (TOC) in paleosol samples
Task 2: Perform EGA on samples under SAM-like conditions
Task 3: Acquire VNIR + XRD spectra / traces of all 26 pedotypes; correlate dominant clay mineralogy with TOC (November 2019)
First evolved gas analysis of Mars-analog paleosols

- Ambient \((O_2, 1000 \text{ mbar})\) and SAM-like conditions \((He, 30 \text{ mbar})\)

**Goals**
- Quantify total organic carbon (TOC) in three paleosols
- Determine which paleosols have the highest amounts of TOC;
- Correlate TOC with depth, clay mineralogy, amorphous phase abundance

![Ambient \((O_2, 1000 \text{ mbar})\)](image1)

![SAM-like \((He, 30 \text{ mbar})\)](image2)
Lithology

Grain size

~ 83 wt % clay
Alfisol

~ 75 wt % clay
Entisol

~ 78 wt % clay
Inceptisol

- Olive Gray (5Y 6/2) Noncalcareous
- Dusky Red (7.5YR 3/1) Noncalcareous
- Red (10R 3/1) Noncalcareous
- White (2.5Y 8/2) Noncalcareous
- Light Gray (2.5Y 7/3) Noncalcareous
- Light Gray (2.5Y 7/2) Weakly calcareous
- Greyish Brown (2.5Y 5/2) Weakly calcareous
- Greyish Brown (2.5Y 5/3) Noncalcareous
Results: Evolved Gas Analysis

Lithology
Grain size

TOC (wt %)

Depth (cm)

0
0.1
0.05
0.09

TOC: 0.1 wt %
TOC: 0.05 wt %
TOC: 0.09 wt %
Results: Evolved Gas Analysis
Results: VNIR and TIR spectra

Lithology

Grain size

~ 83 wt % clay red alfisol

~ 83 wt % clay red alfisol

VNIR Reflectance

2.1-2.5 μm reflectance

Horgan et al., 2011 AGU
Conclusions

- Oxidized Fe/Mg smectite-bearing paleosols have low but detectable amounts of TOC (0.02 – 0.14 wt %)
- Highest TOC values (> 0.1 wt %) in surface or shallow subsurface layers
- EGA: Sensitivity to distinguish between organic and inorganic carbonate; organic fragments present
- VNIR: Spectral similarities to phyllosilicate clay sequences on Mars
Acknowledgements

**NASA JSC:** Joanna Hogancamp, Paul Niles, Liz Rampe, Doug Archer, Doug Ming, Brad Sutter, and Valerie Tu

Barry Hughes