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

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Known: Hydrothermal, diagenetic and pedogenic phyllosilicates across Mars

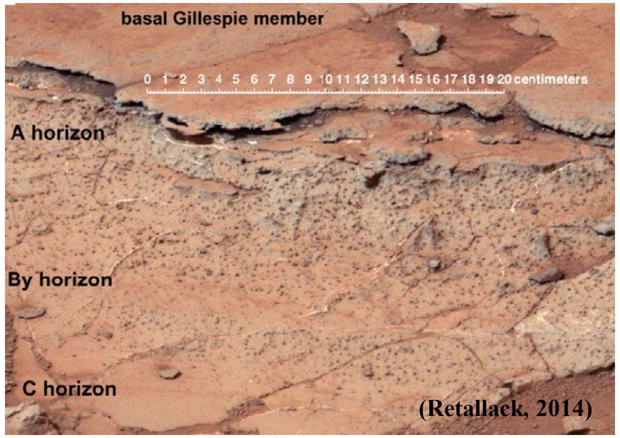
Poorly understood: How does clay mineralogy influence organic matter preservation through geological time?

Mawrth Vallis clay stratigraphy (HiRISE/NASA/JPL/University of Arizona)

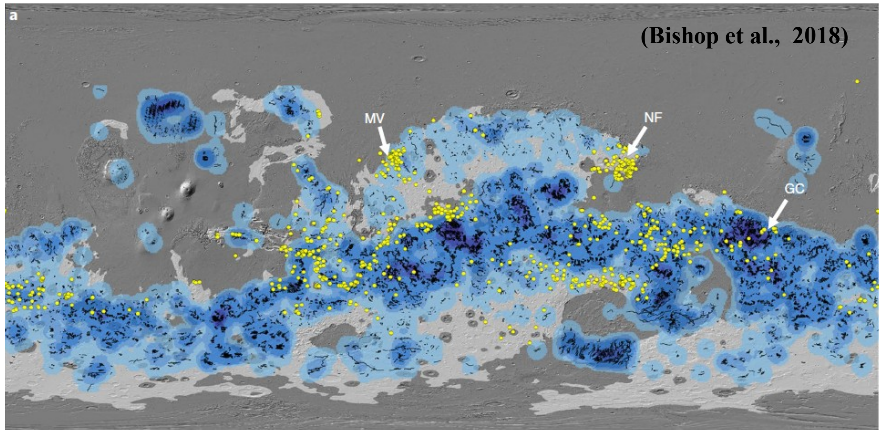
Paleosols on Mars?

Paleosol: A buried, lithified soil

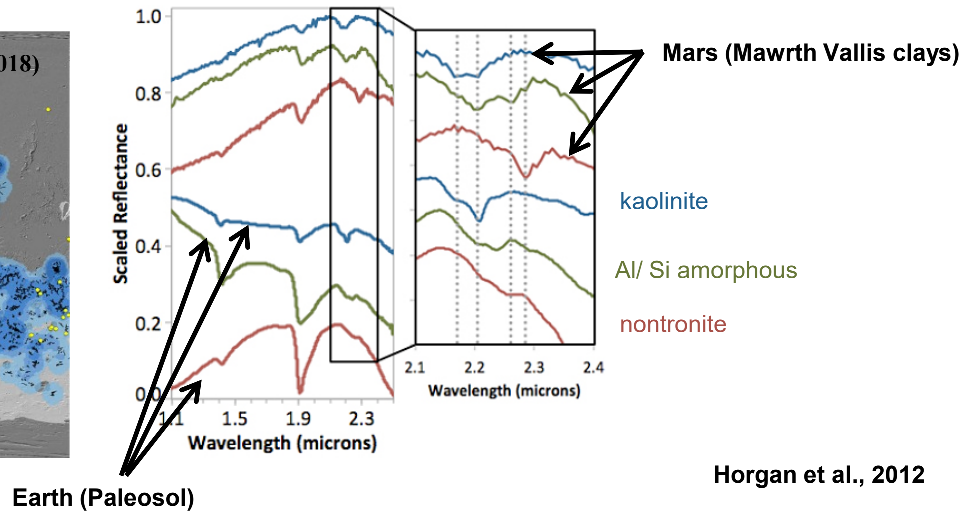
1. Potential paleosols at Gale Crater



2. Dioctahedral clays (yellow) across the surface of Mars



3. Striking spectral similarities to Earth paleosols



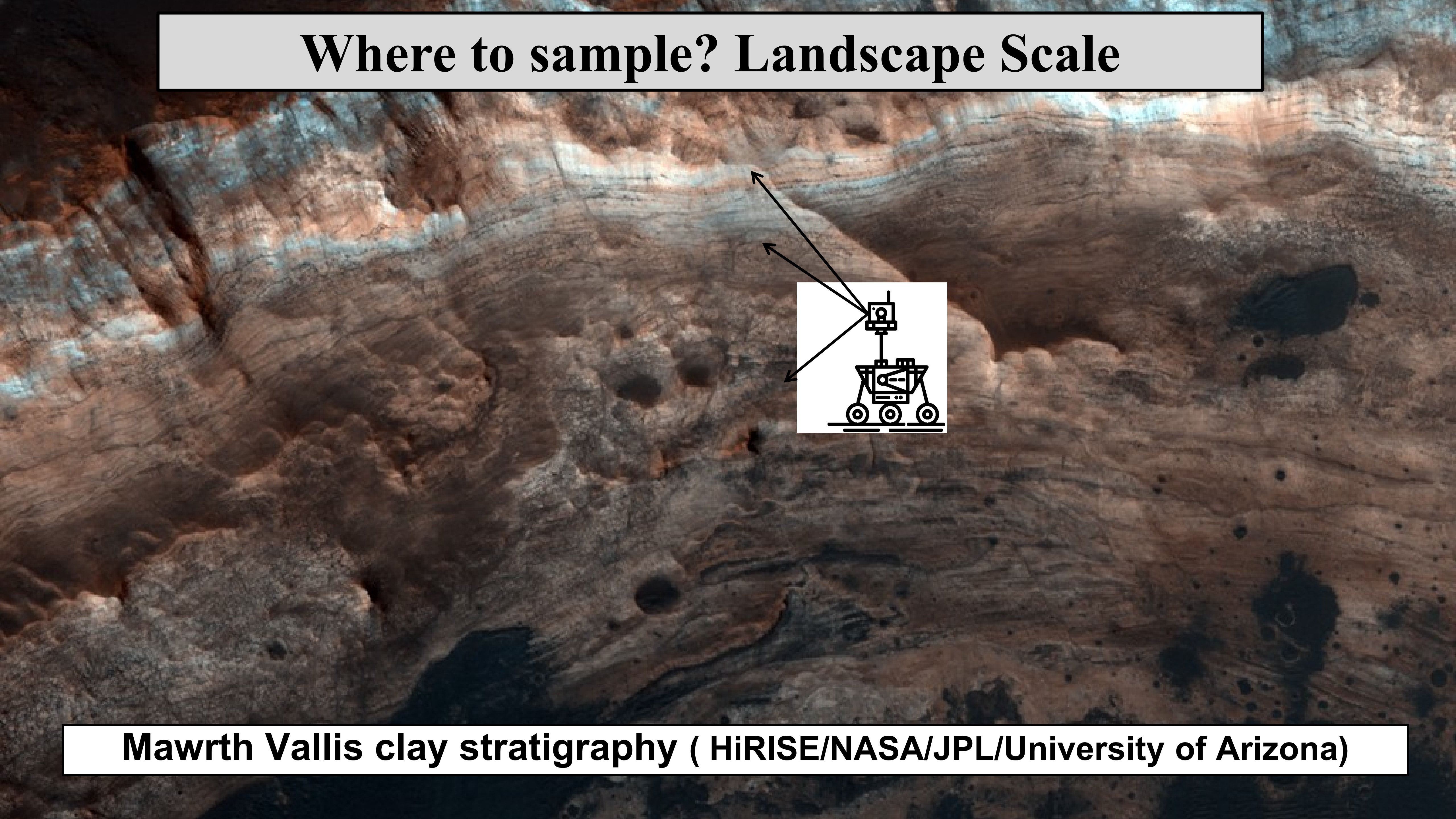
4. Possible Noachean (4.1-3.7 Ga) paleosols at Mawrth Vallis

(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

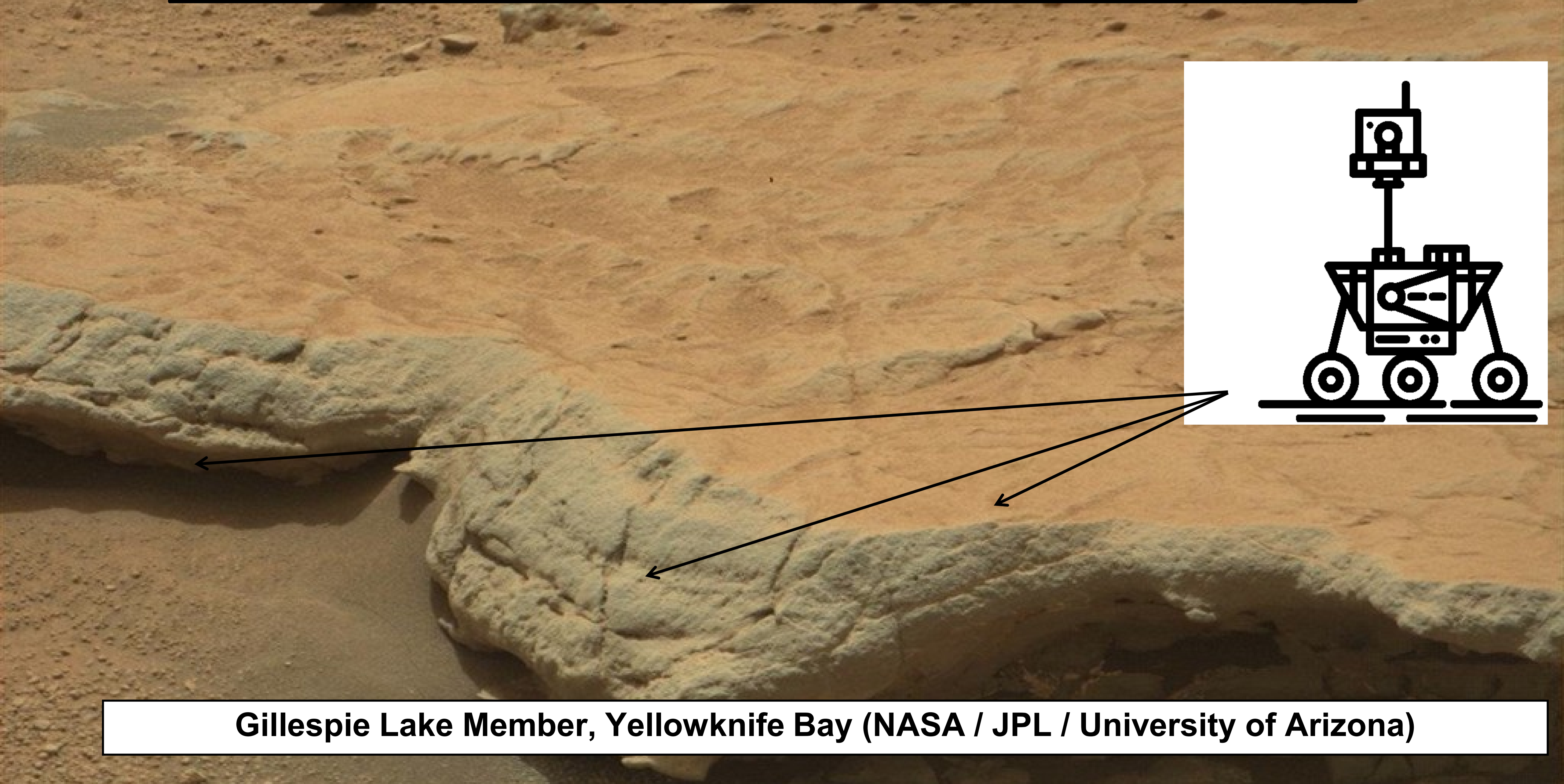
In-situ biosignature detection (Hays et al., 2016) and Mars Sample Return (Bishop et al., 2018)

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)

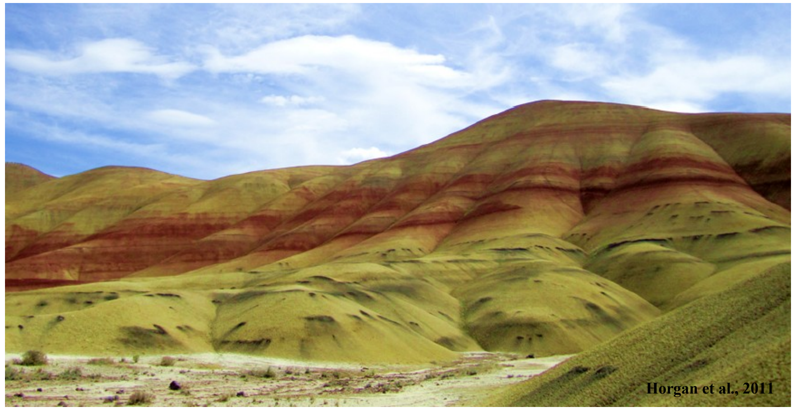
Eocene – Oligocene (42-28 Ma) volcaniclastic paleosols, Painted Hills Unit, John Day Fossil Beds National Monument, eastern Oregon. Photo – Tamer Ghonheim

What factors influence organic matter preservation in pedogenic clay sequences on Earth?

Eocene – Oligocene (42-28 Ma) volcaniclastic paleosols, Painted Hills Unit, John Day Fossil Beds National Monument, eastern Oregon. Photo – Tamer Ghonheim

John Day Paleosols: Eastern Oregon

Brown Grotto – Painted Hills Unit



Painted Hills inner basin, Painted Hills Unit

Blue Basin – Sheep Rock Unit

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

Time

Eocene (41 Ma)

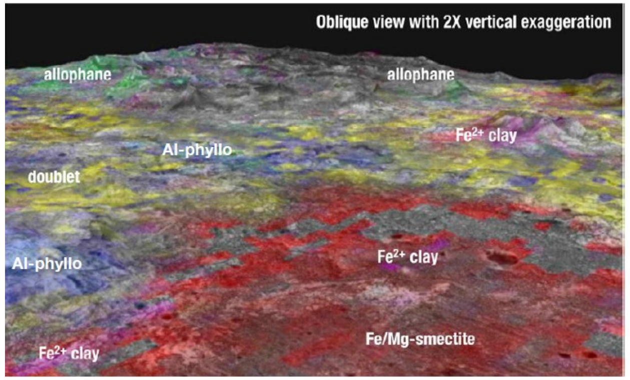
Early Oligocene (32 Ma)

Oligocene (~29 Ma)

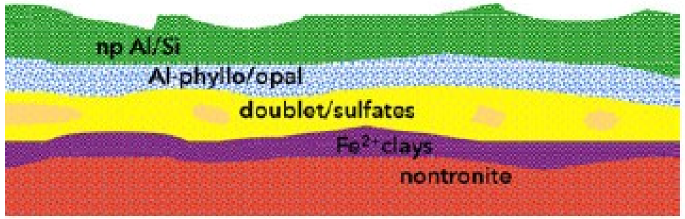
Retallack et al., 2000

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**



CRISM parameters draped over HiRISE DTM;
Image width ~2 km.



Bishop et al., 2016 LPSC

Cool and dry

Drying out

Warm and wet

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)

Eocene – Oligocene (42-28 Ma) paleosols, Painted Hills Unit, John Day Fossil Beds National Monument, eastern Oregon. Photo – Tamer Ghonheim

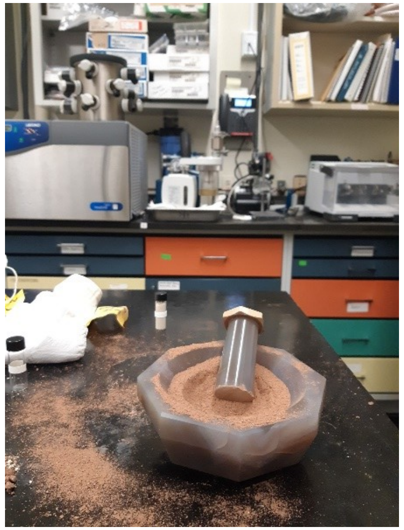
First evolved gas analysis of Mars-analog paleosols

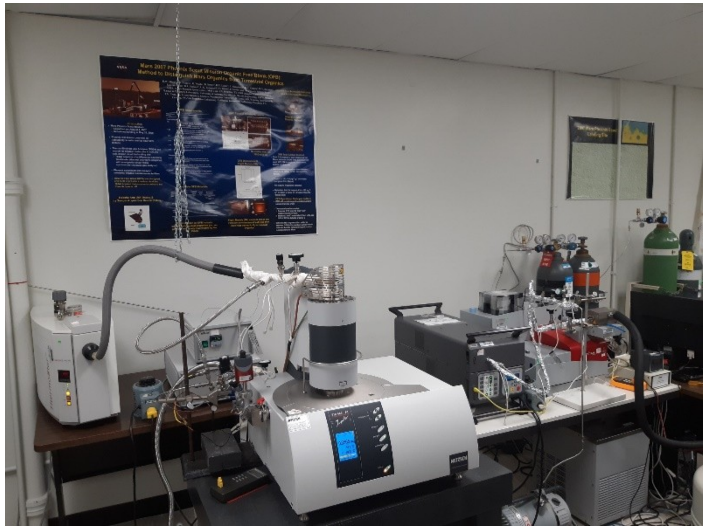
ME^{3}GA Lab

JACOBS

- Ambient (O_2, 1000 mbar) and SAM-like conditions (He, 30 mbar)

- **<u>Goals</u>**
- 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 mbar)

SAM-like (He, 30 mbar)

Results

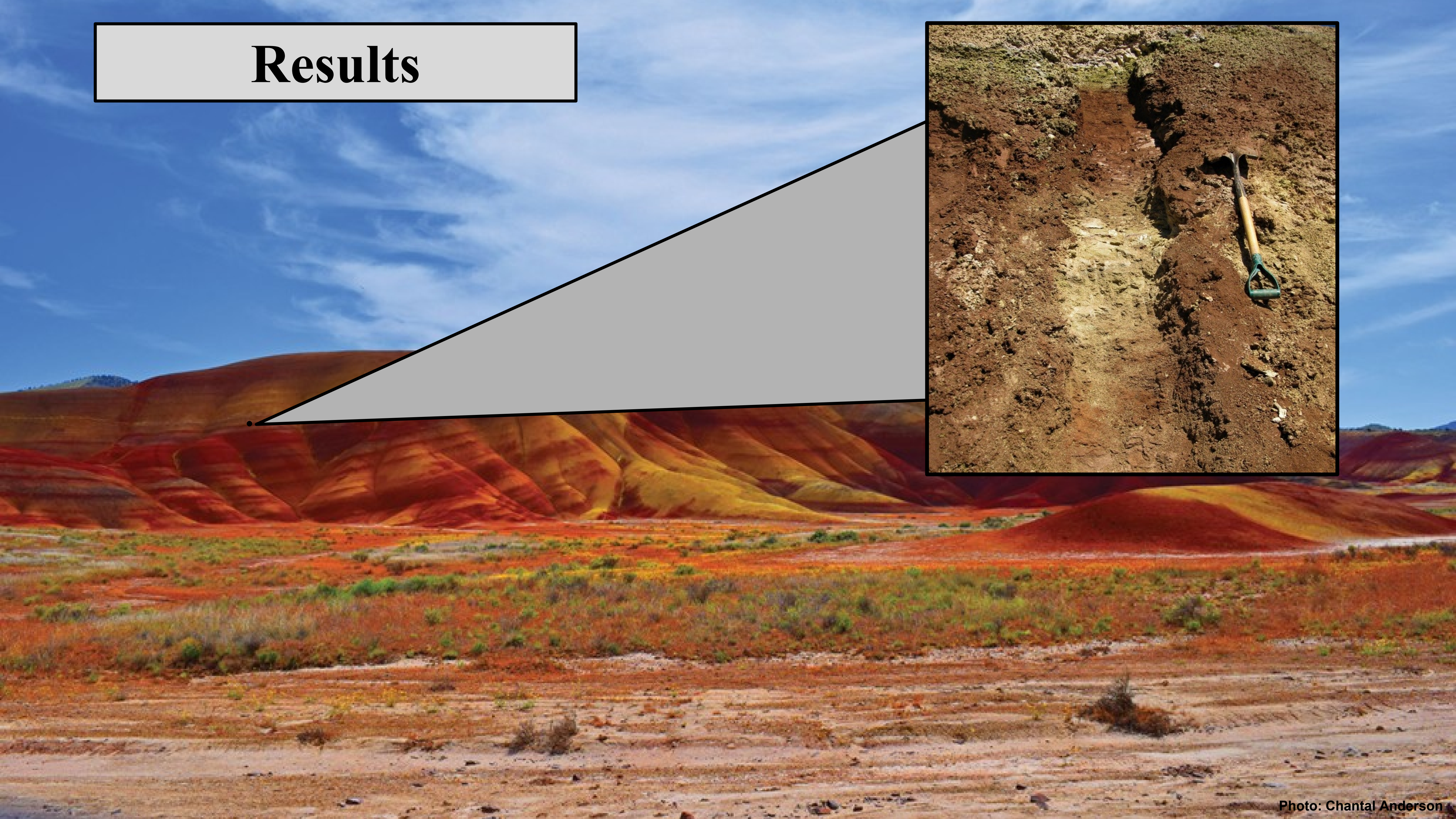
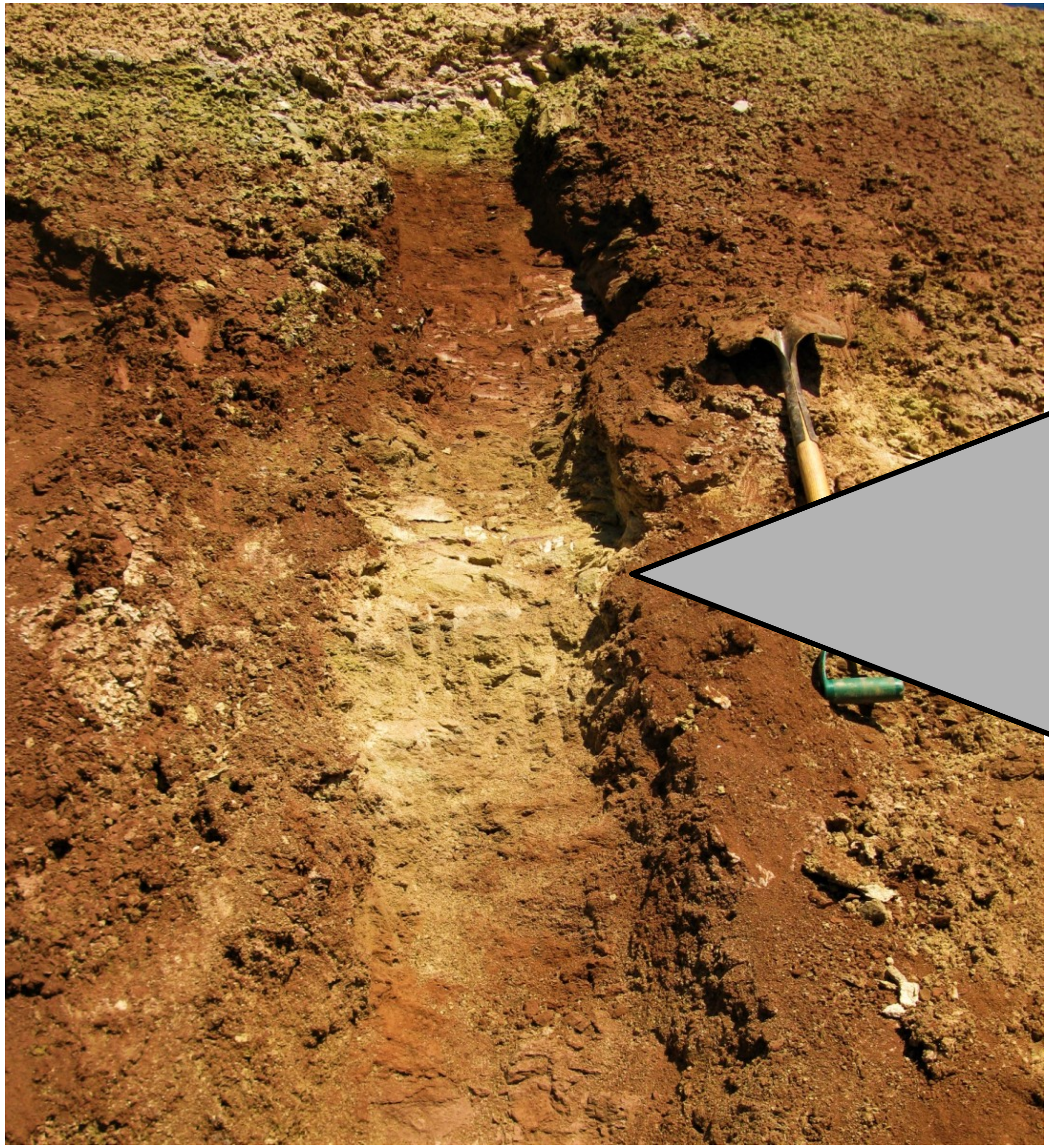
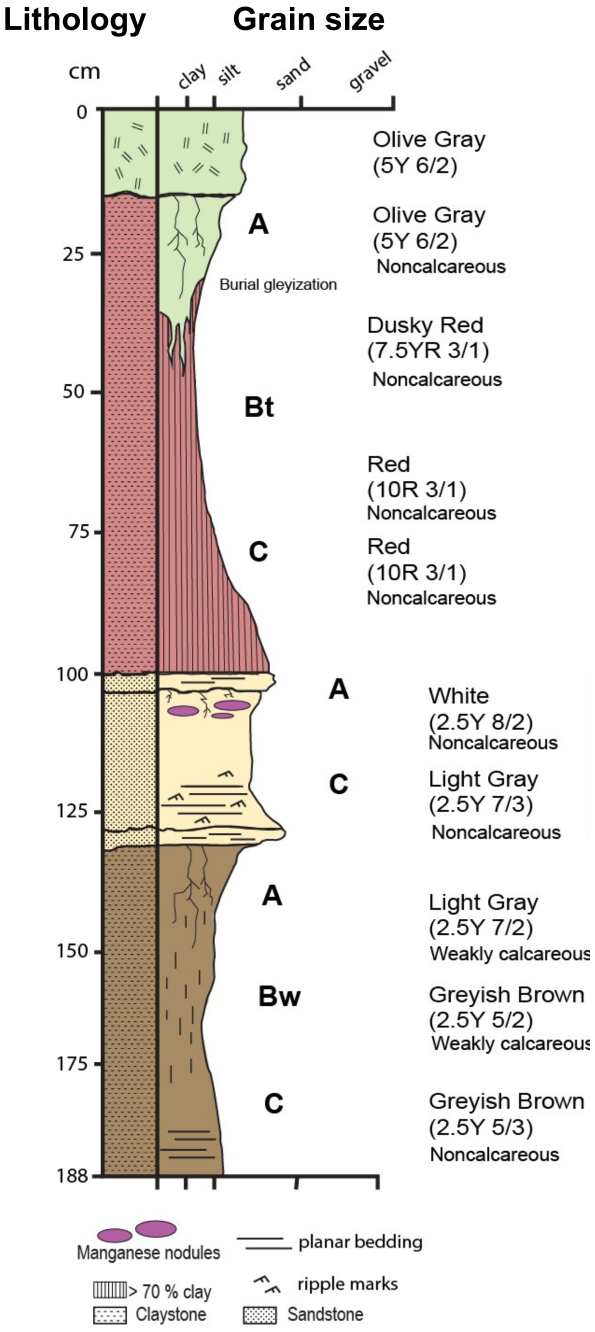


Photo: Chantal Anderson





~ 83 wt % clay

Alfisol

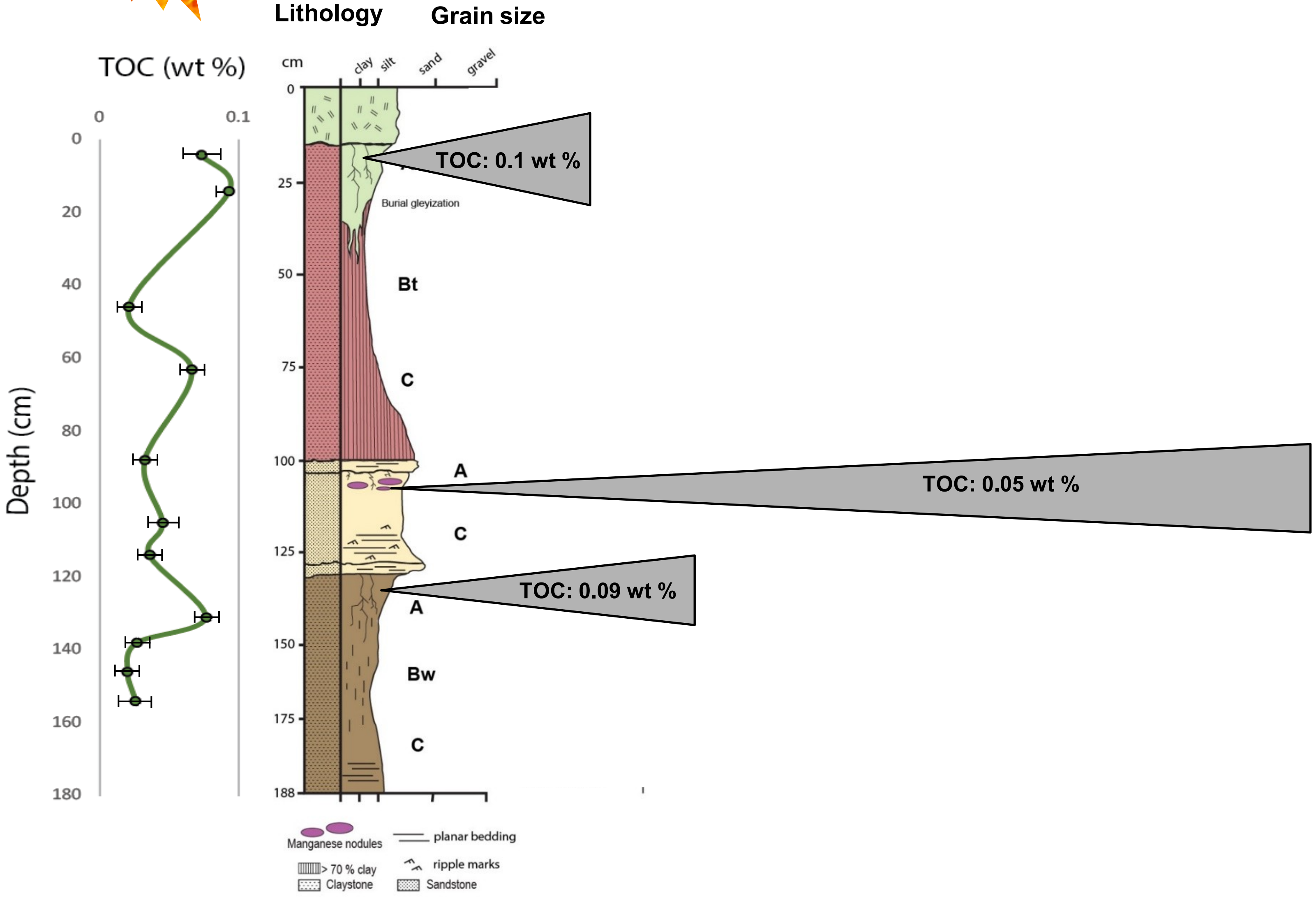
~ 75 wt % clay

Entisol

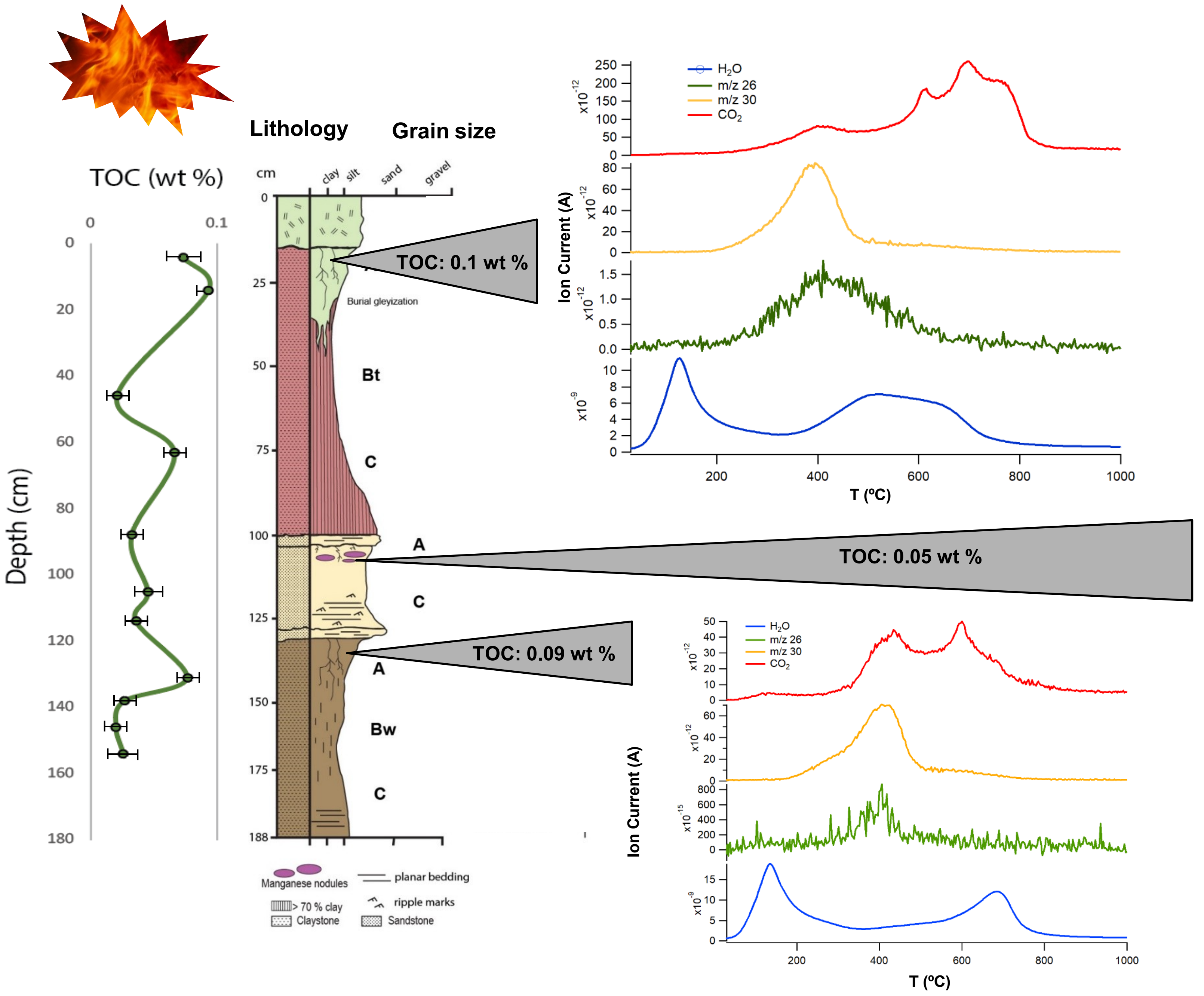
~ 78 wt % clay

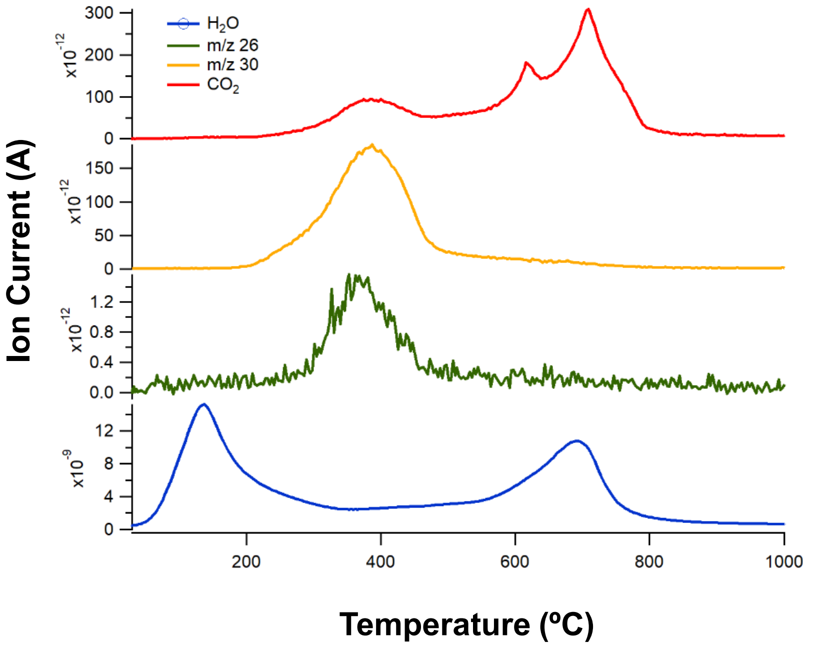
Inceptisol

Results: Evolved Gas Analysis

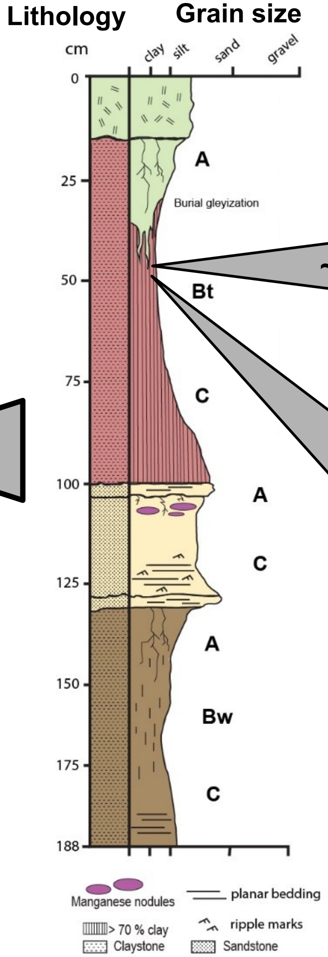


Results: Evolved Gas Analysis





Results: VNIR and TIR spectra



~ 83 wt % clay red alfisol

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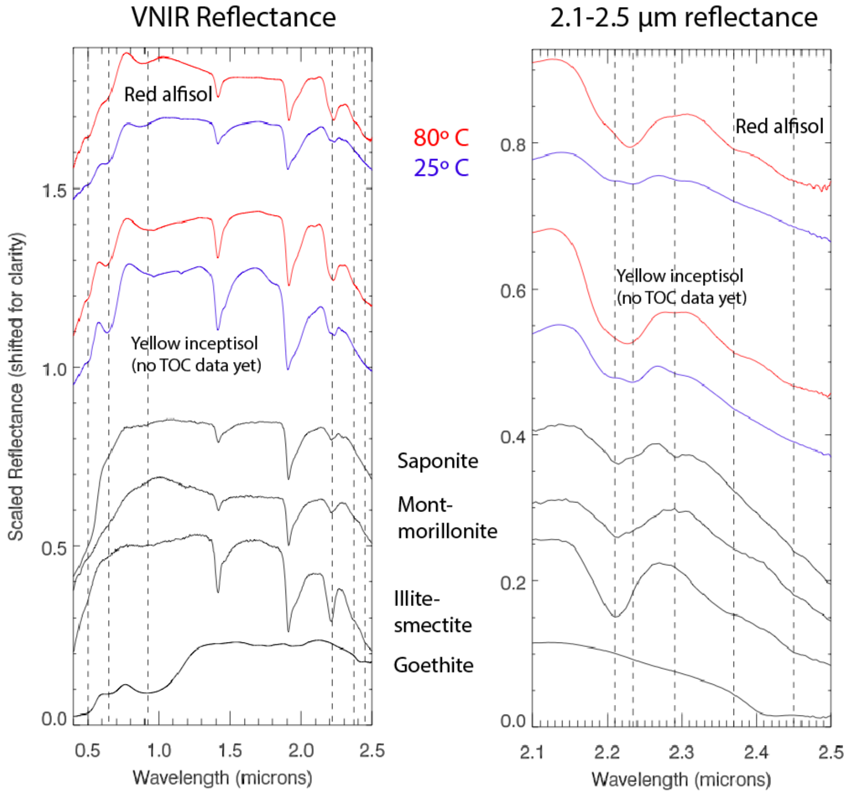
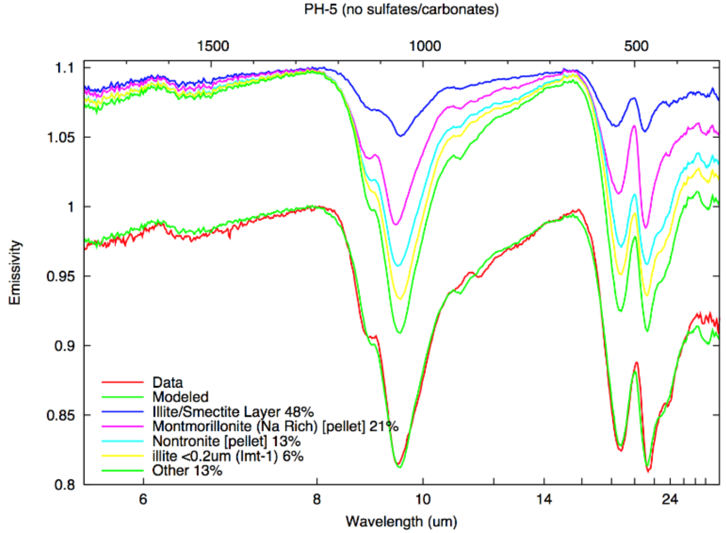


VNIR



TIR

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

(HiRISE/NASA/JPL/University of Arizona)

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Barry Hughes

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Thanks!