Strategies for searching for biosignatures in ancient martian sub-aerial surface environments

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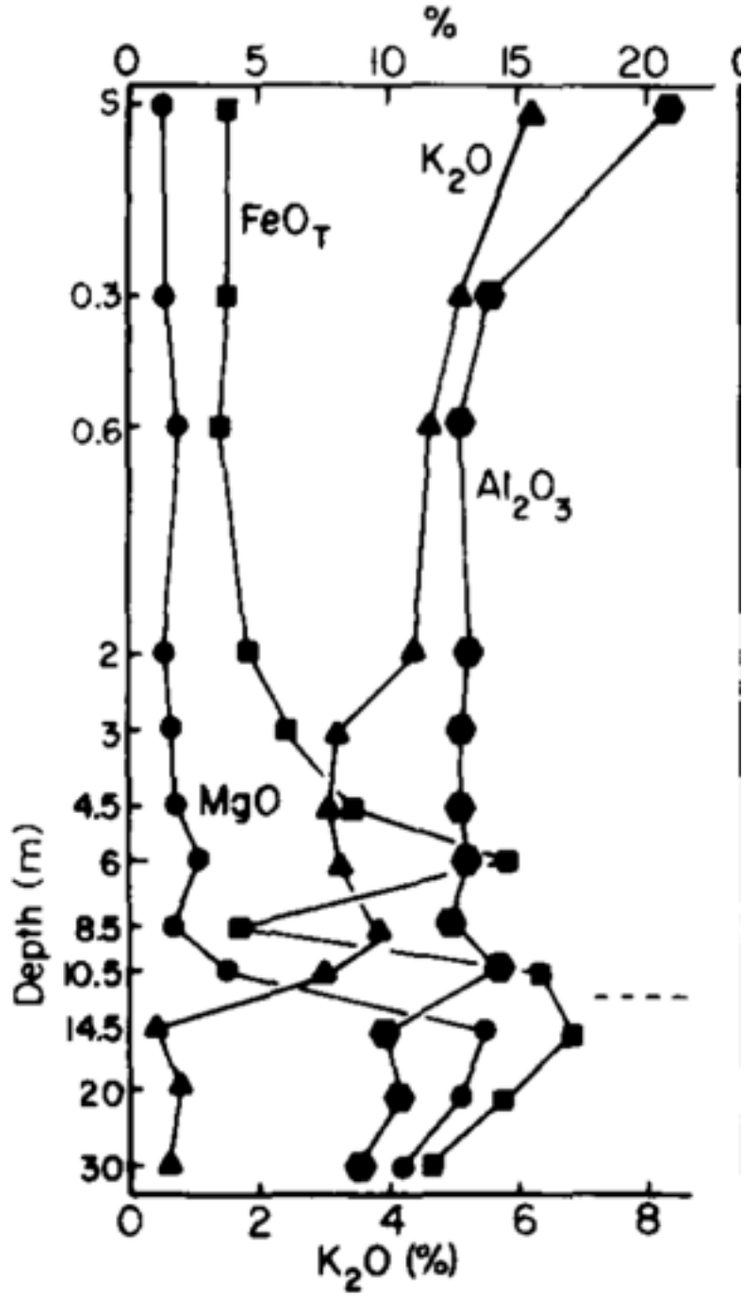
Why study ancient soils (paleosols)?

Soils represent both the most widespread non-marine habitable environment on Earth and some of the most direct records of ancient climates and environments.

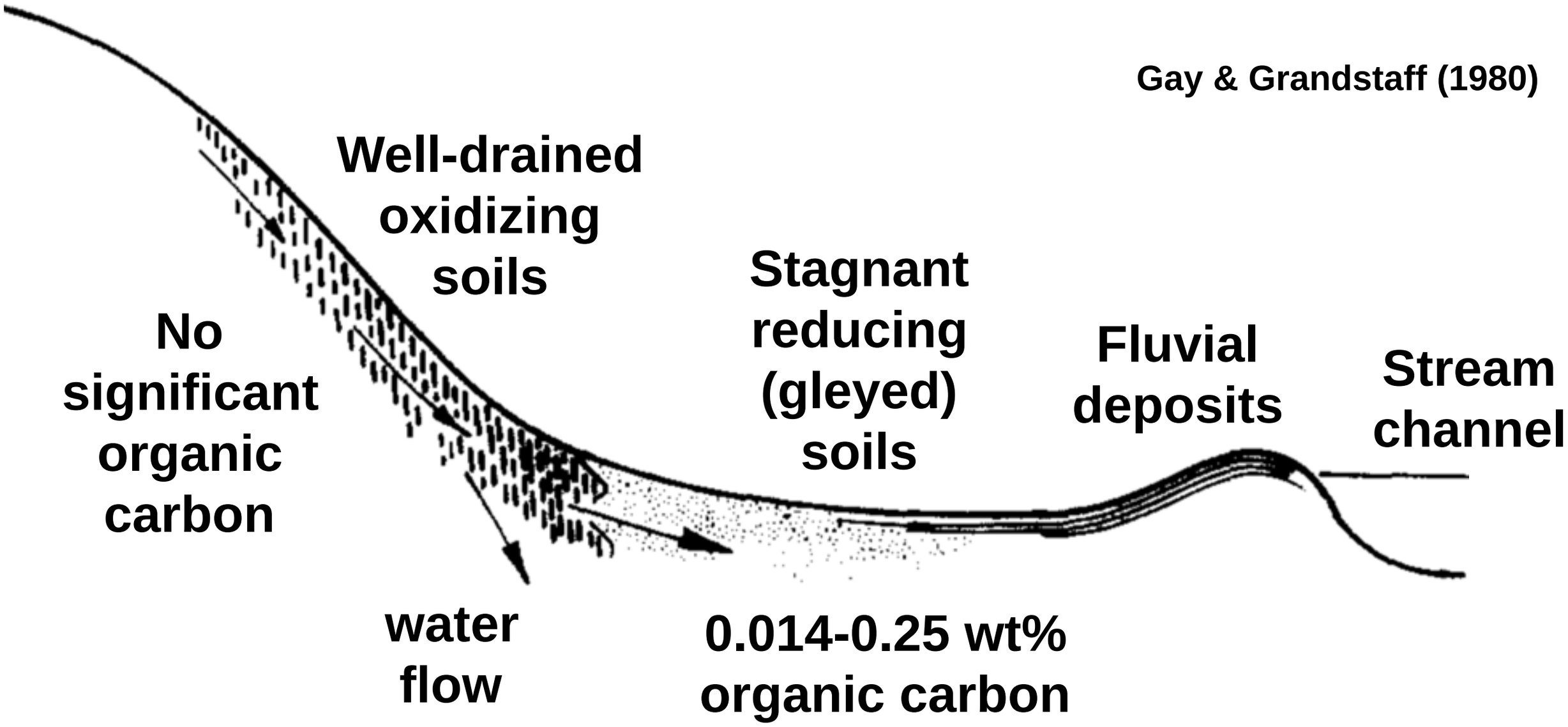


Challenges of identifying paleosols in the ancient geologic record on Earth:

- Metasomatism is common
- Surface horizon is often not present due to erosion
- Most easily identified when present as a thick (meters to tens of meters) profile, but soils are more typically ~meter scale or less

In a pair of 2.3 Gy paleosols on the Superior Craton, reduced soils from the same environment preserve organics but oxidized soils do not

Gay & Grandstaff (1980)



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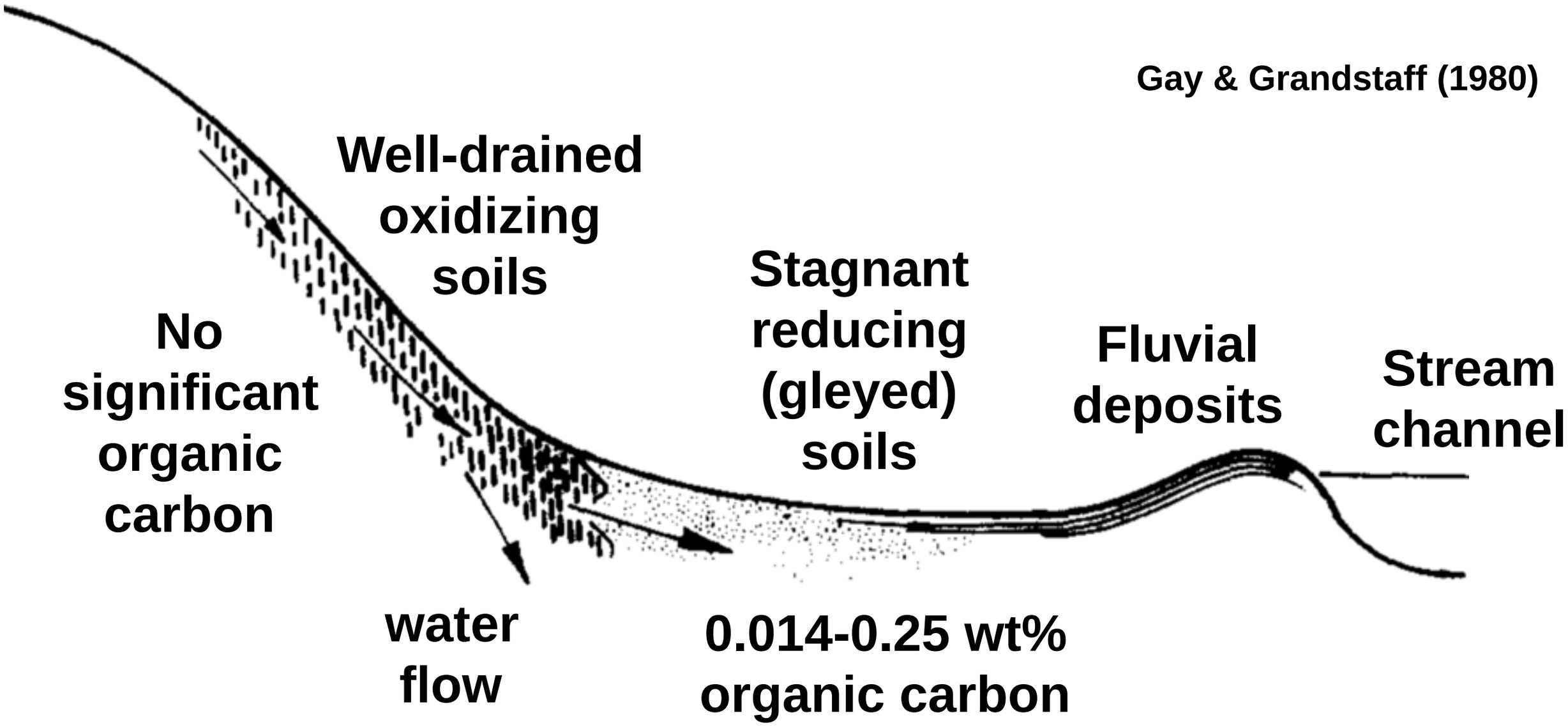
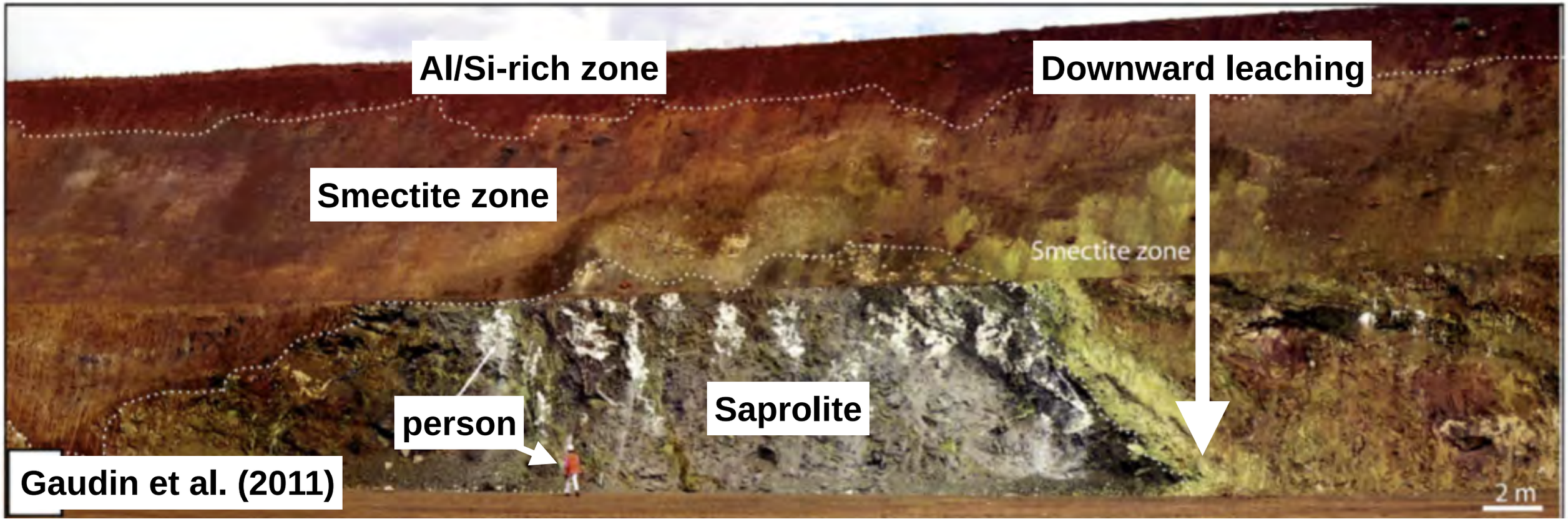


Key point #1: Reducing/waterlogged conditions (seasonally or perennially) in a soil help to prevent oxidation of organics

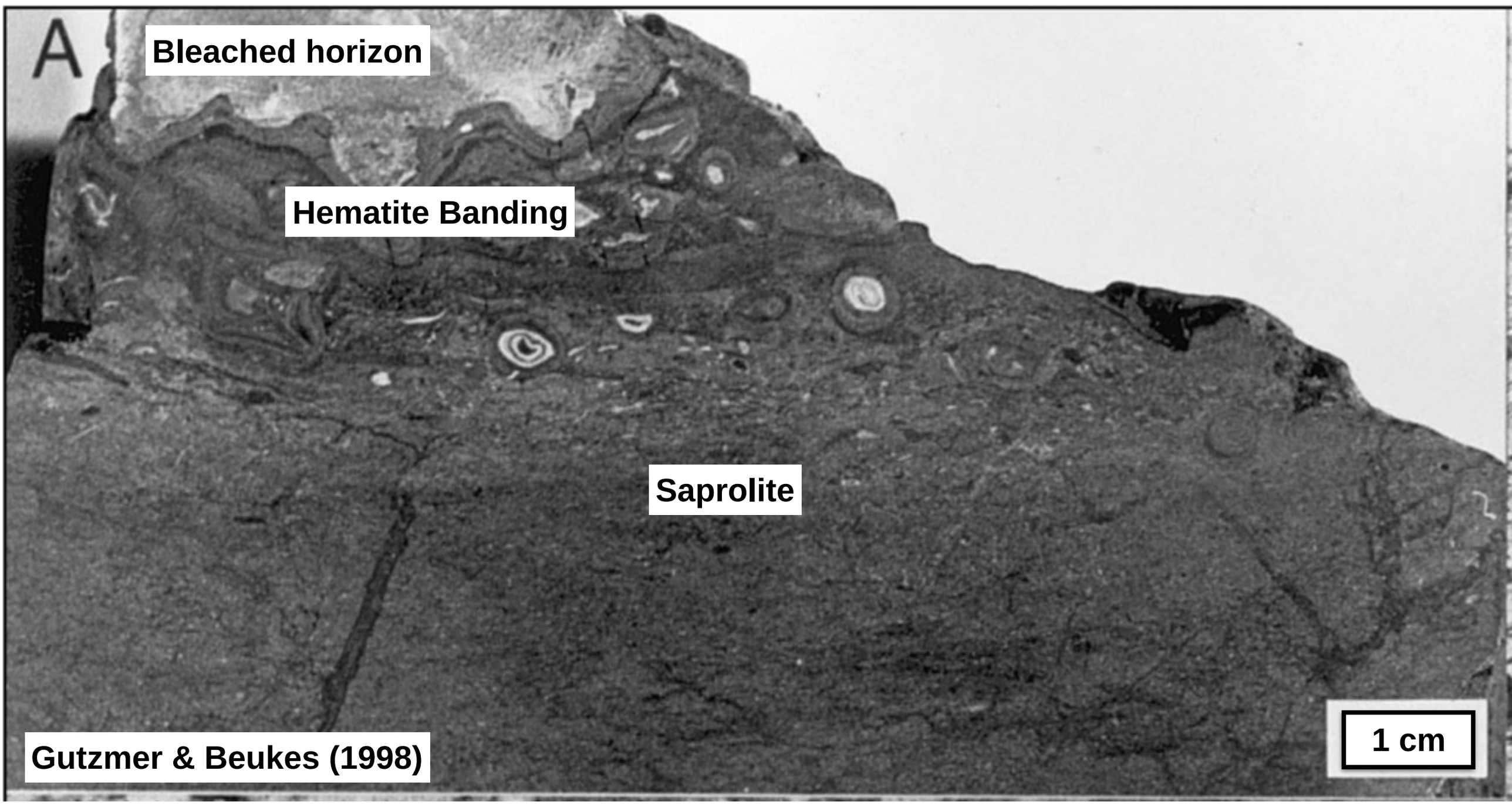
Consequence: Many well-drained soils will not inherently be good sites of organic preservation

Laterite, Western Australia

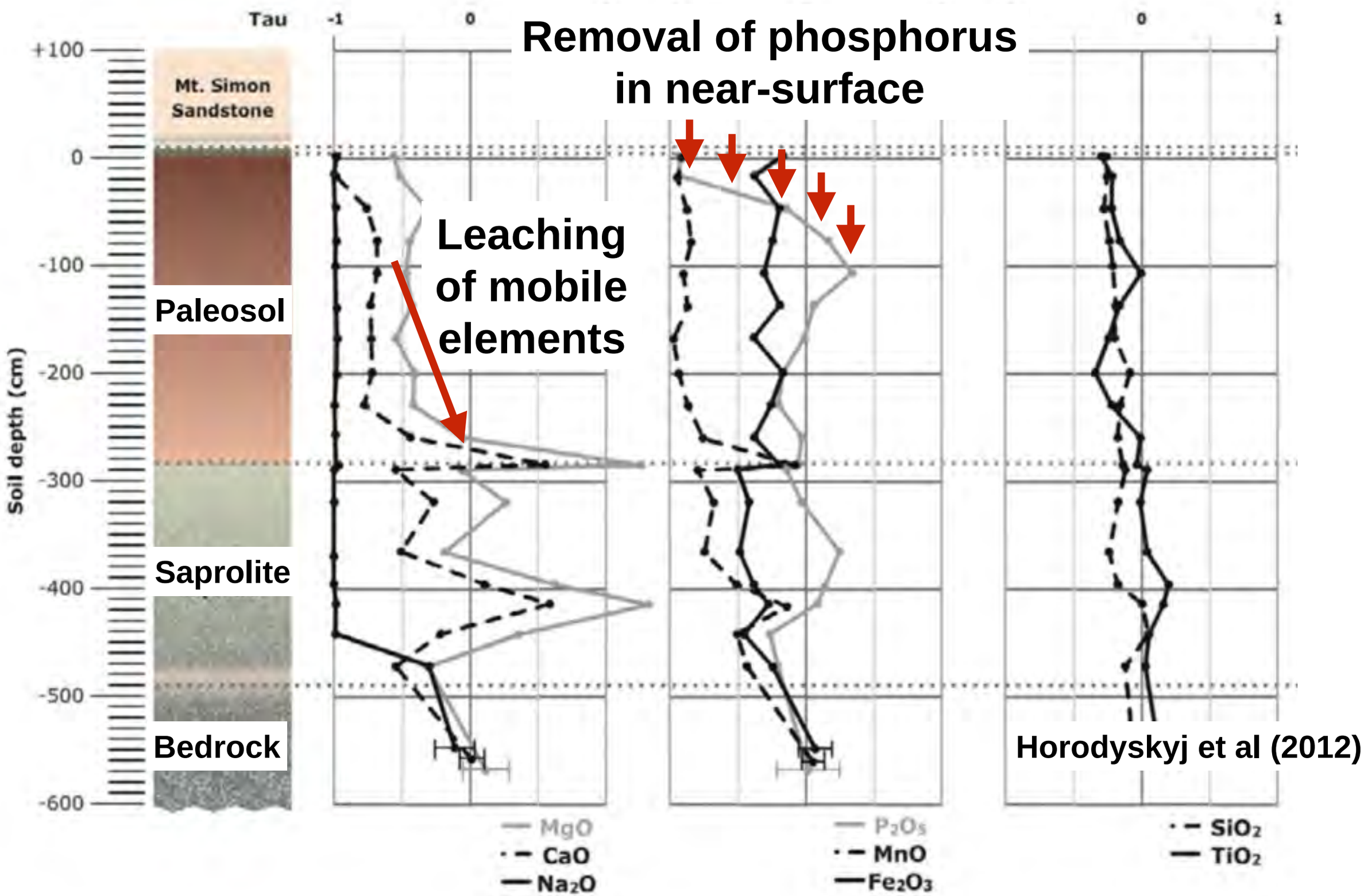


Highly leached and oxidized laterite weathering profiles are especially poor sites for organic preservation

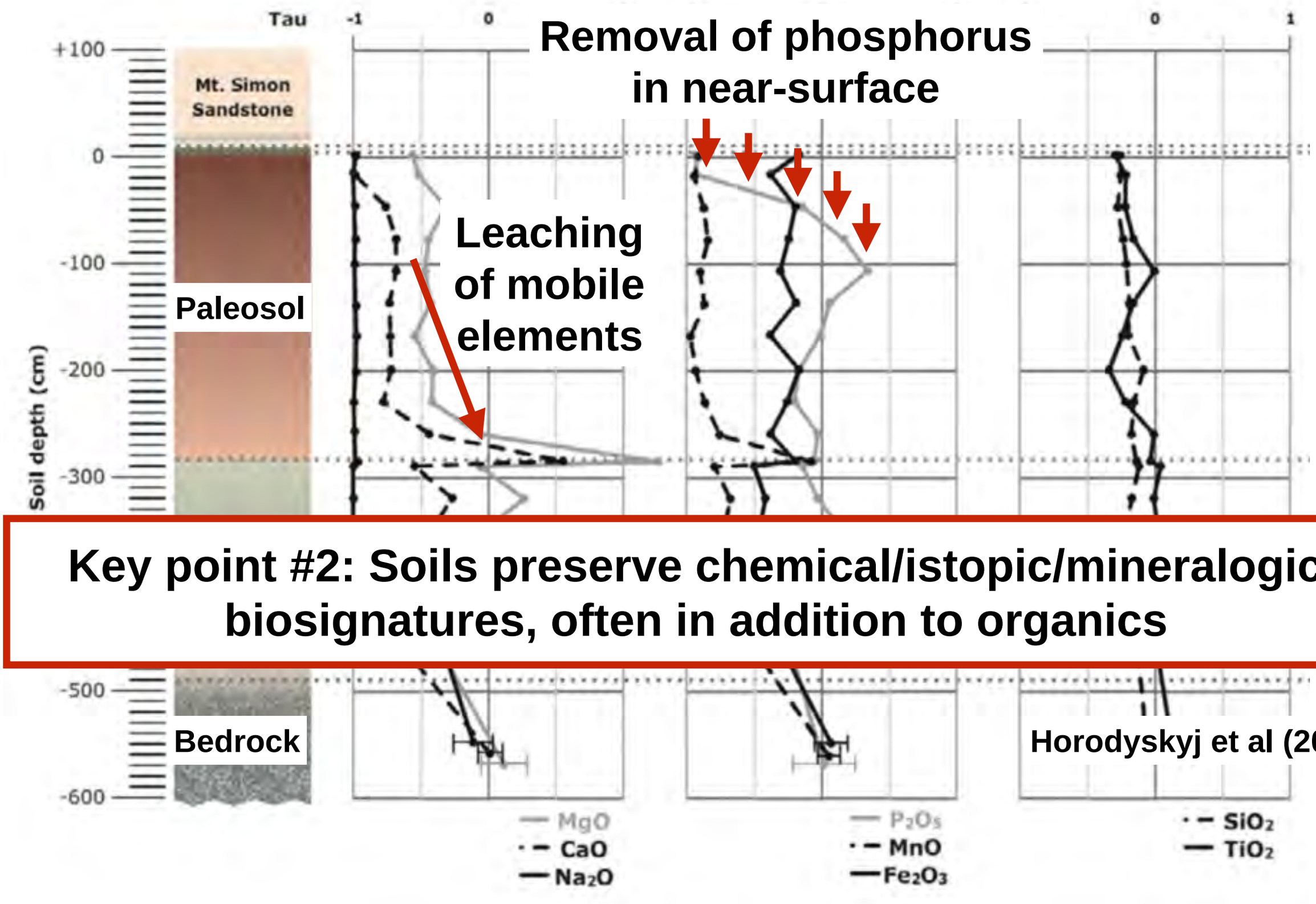
2.0-2.2 Gy Kappvaal Craton laterites do contain “bleached” Fe-poor upper horizons attributed to organic acids from surface microbial communities



Phosphorus depletion could indicate uptake by fungi/etc., as in this 500 My S Dakota paleosol



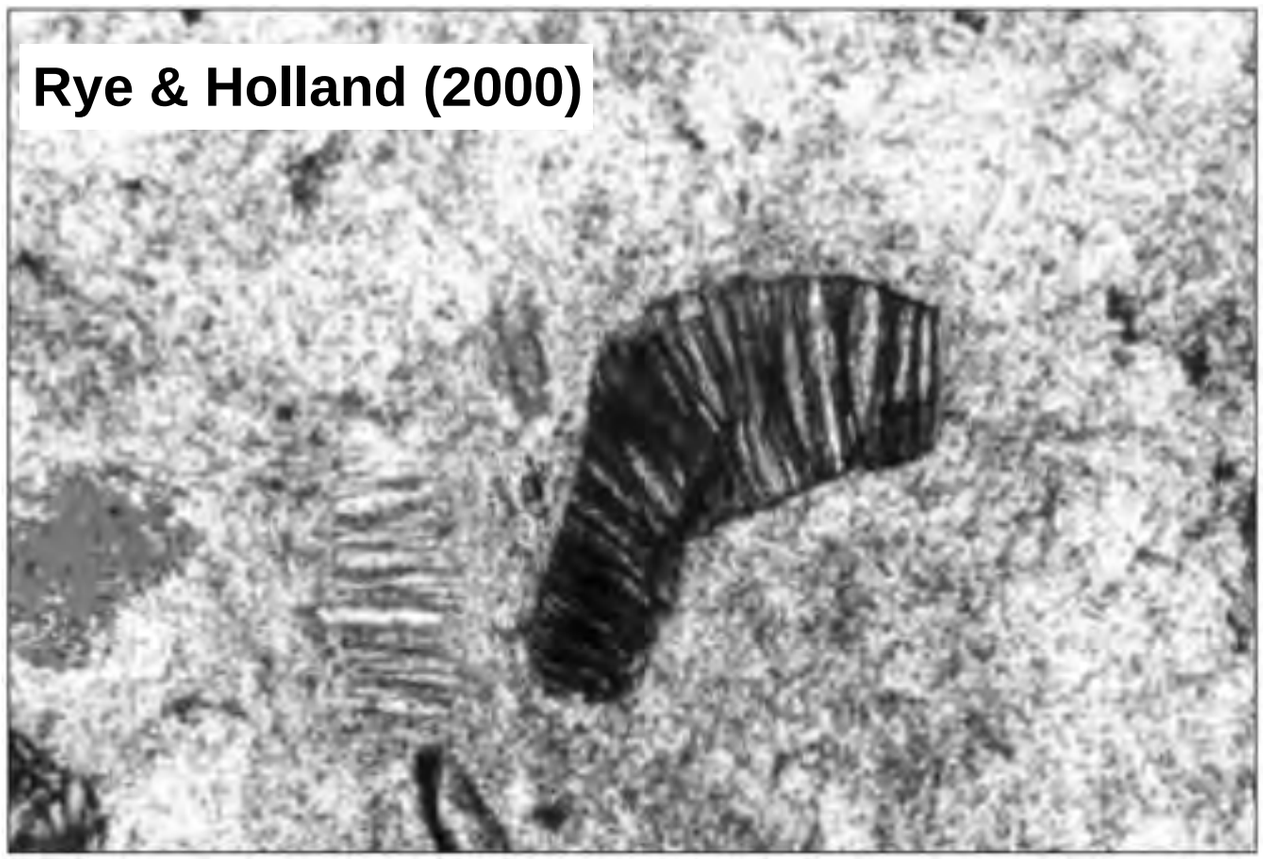
Phosphorus depletion could indicate uptake by life, as in this 500 My S Dakota paleosol

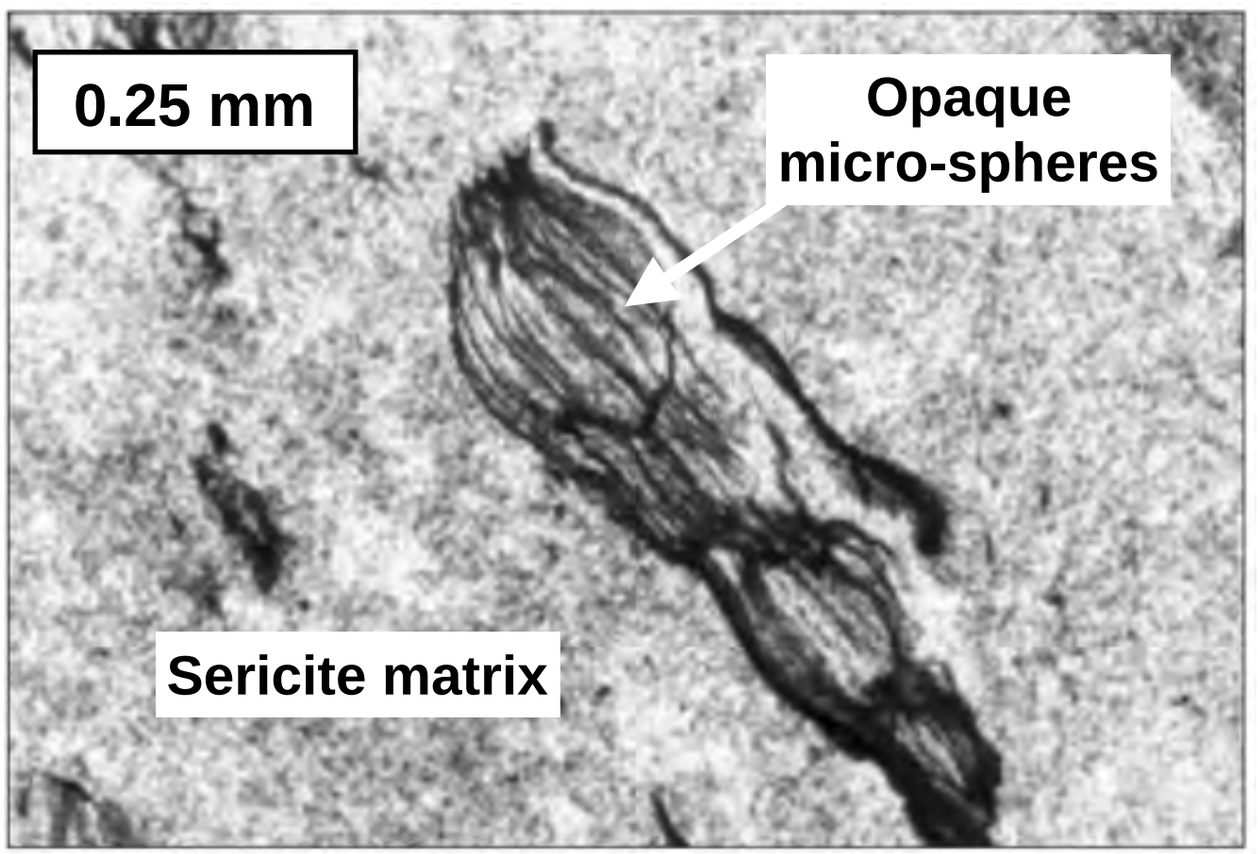


Key point #2: Soils preserve chemical/istopic/mineralogic biosignatures, often in addition to organics

Horodyskyj et al (2012)

A 2.76 Gy paleosol on basalt in the Pilbara Craton preserves organic carbon (0.05-0.1 wt%) and opaque filamentous structures

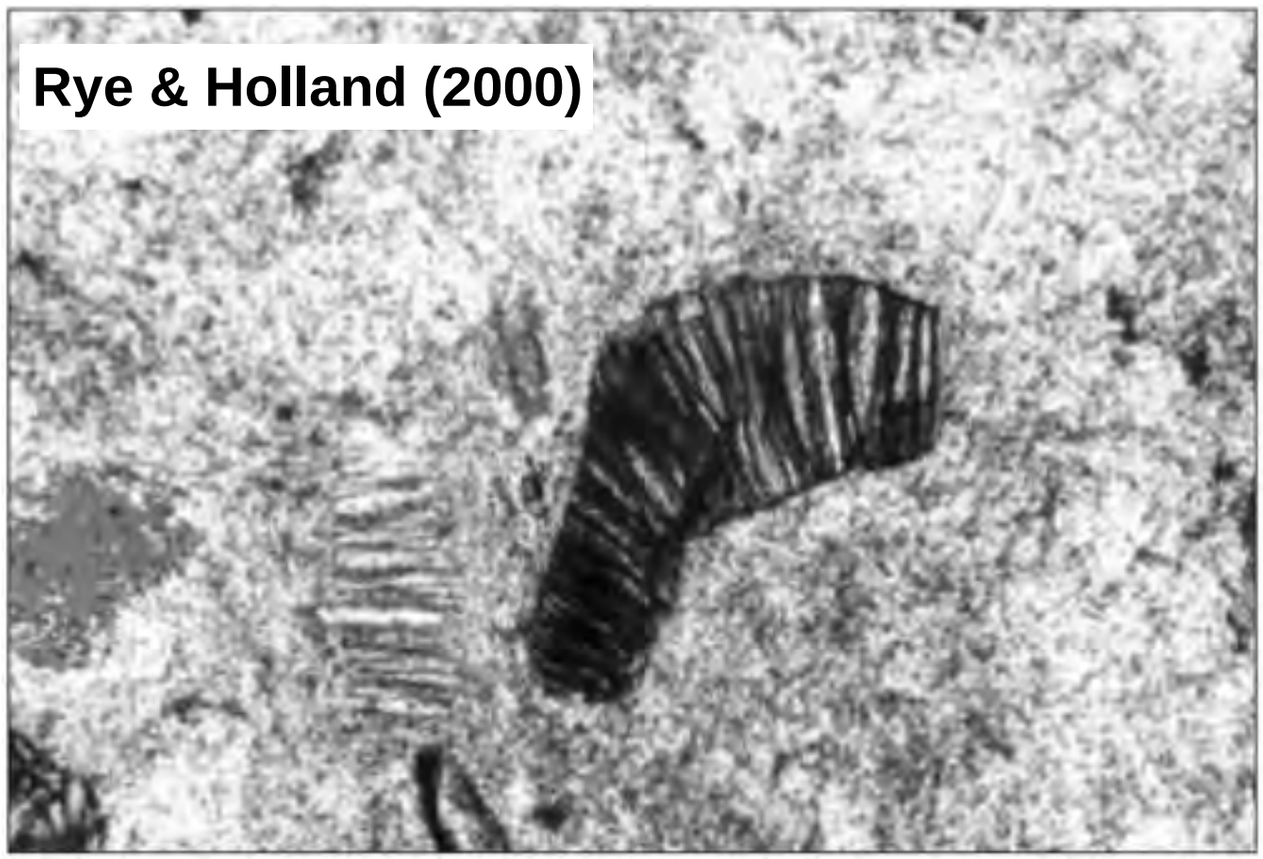


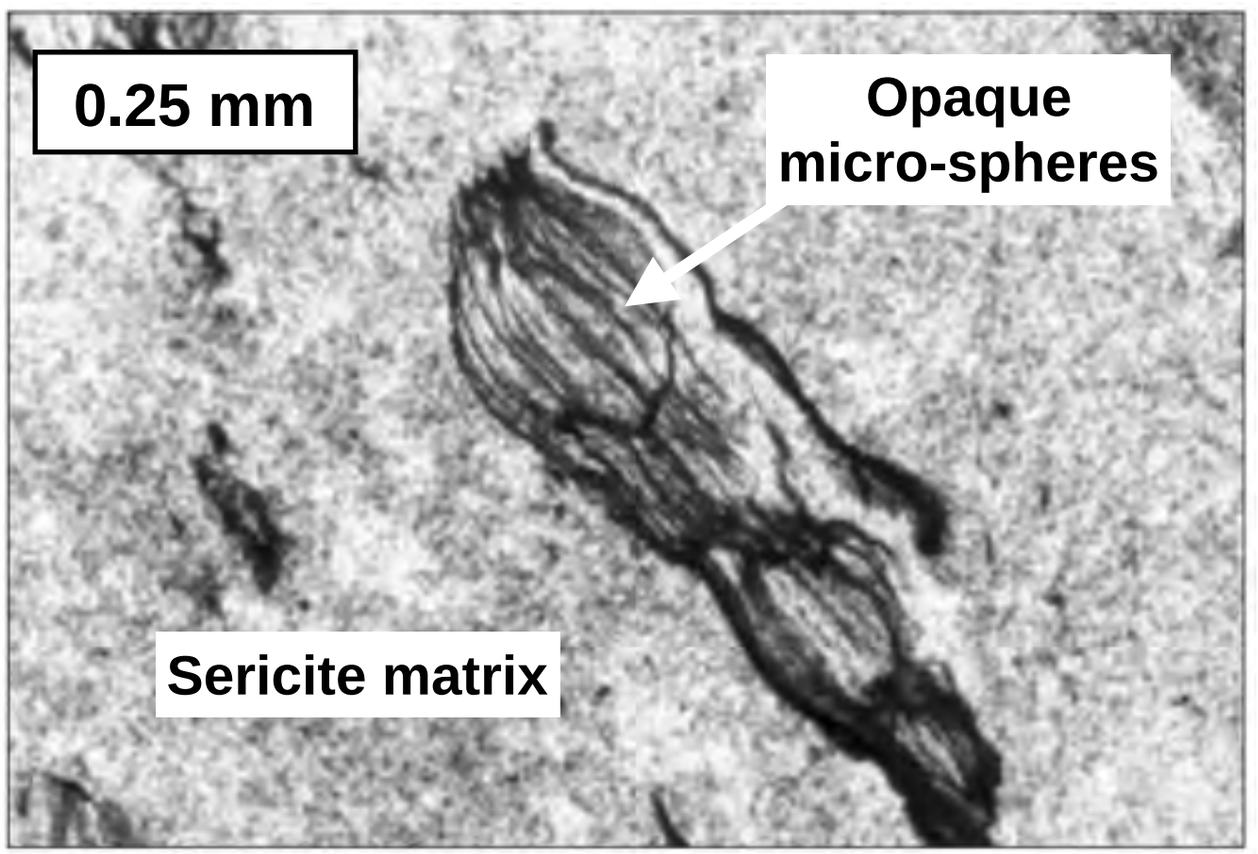


Low $\delta^{13}C$ with large overall range similar to stromatolites of same age; attributed to methanotrophs in a diverse microbial community.

Interpretation: Fragments of microbial mats formed on the edge of ephemeral ponds

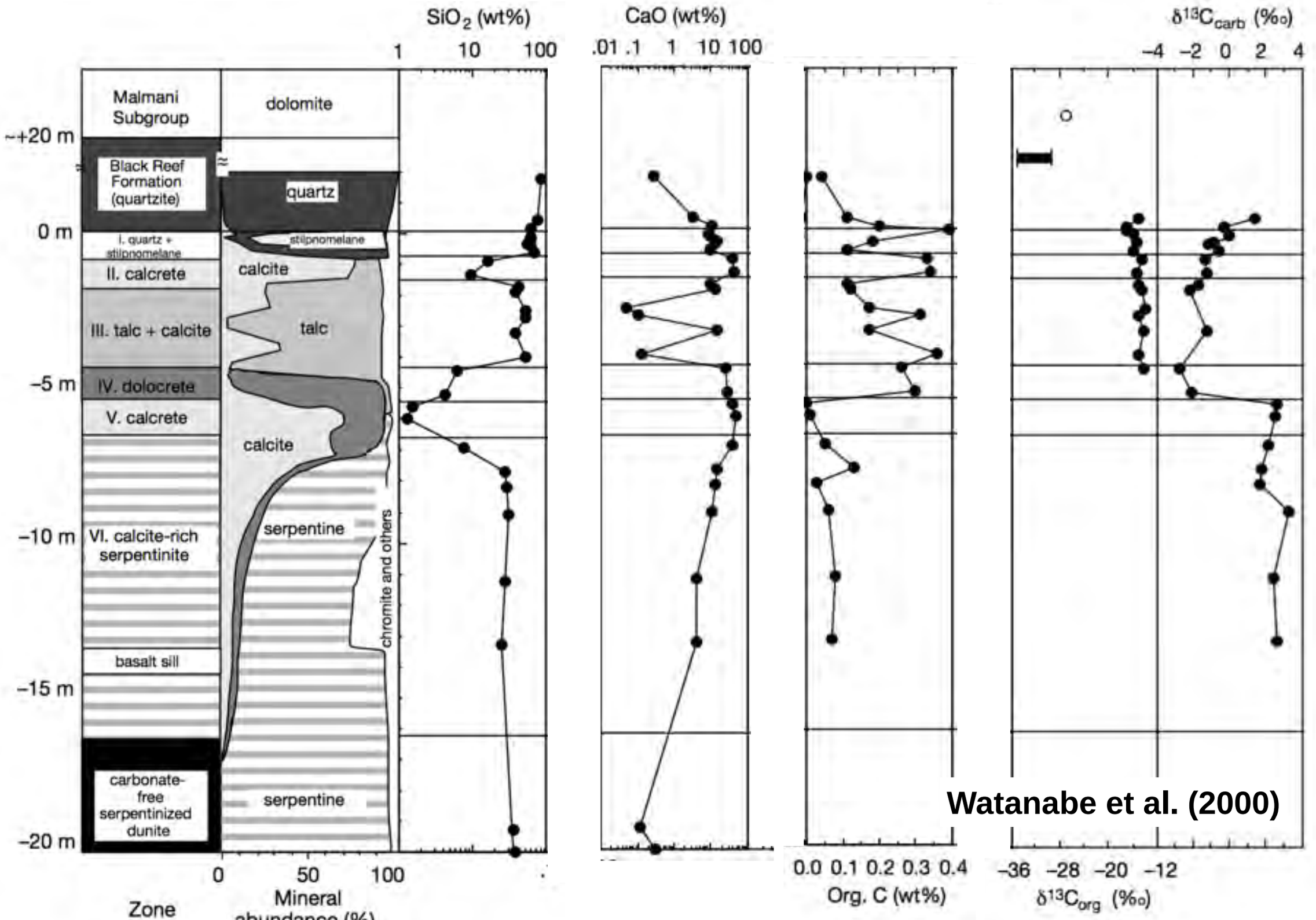
These structures are found in the upper meter of the paleosol, which is preserved due to an overlying basalt flow





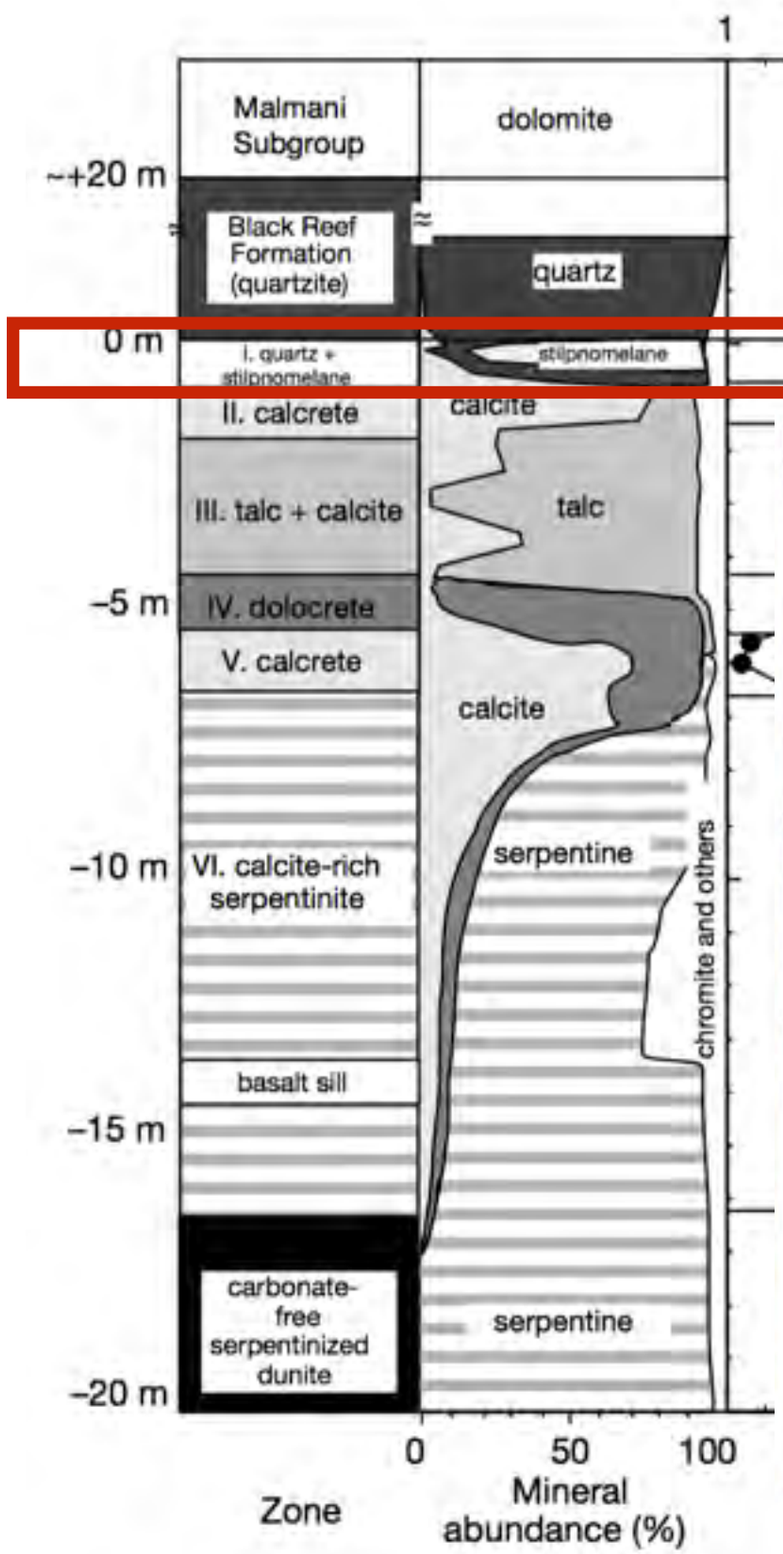
Key point #3: Organics are most commonly found in the near-surface of ancient paleosols, so paleosurface preservation aids in organic preservation

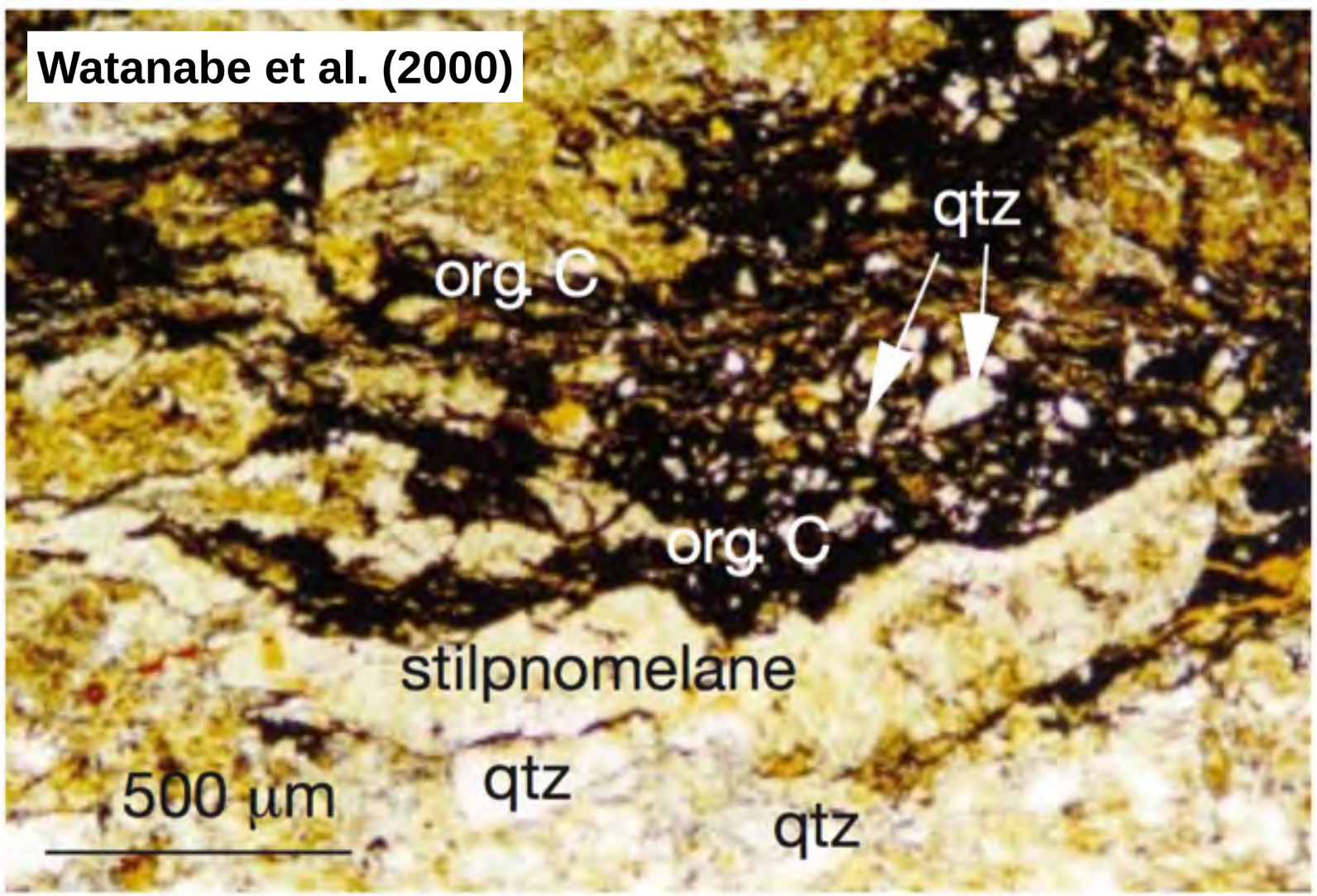
Carbonate-rich 2.6-2.7 Gy Kaapvaal Craton paleosol on serpentinized dunite preserves 0.1-0.36 wt% organic carbon



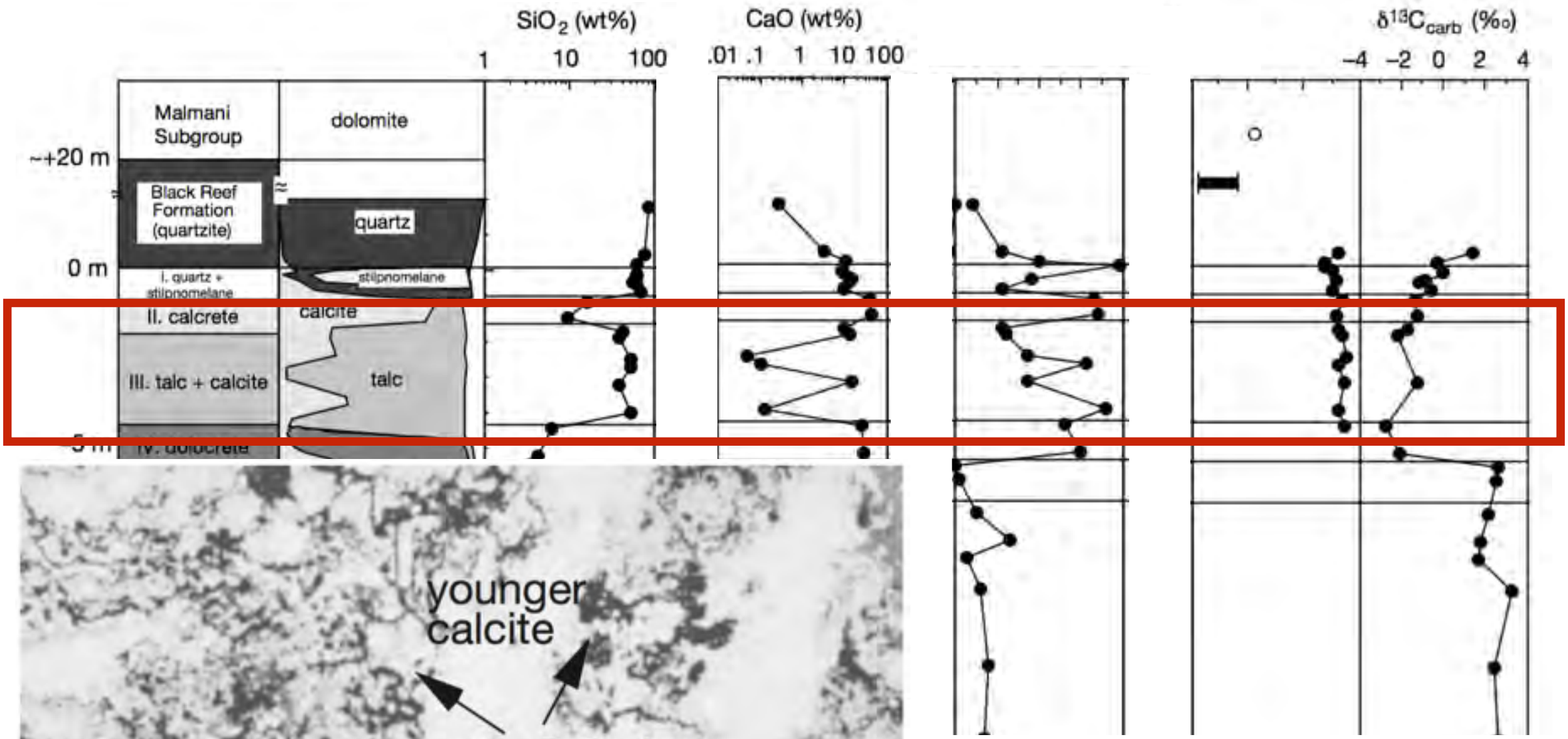
Watanabe et al. (2000)

Organics in the upper meter are interpreted to be remnants of surface microbial mats interlayered with seasonal aeolian deposits





Organics in the underlying calcite are interpreted to have been transported down form the surface in the soil



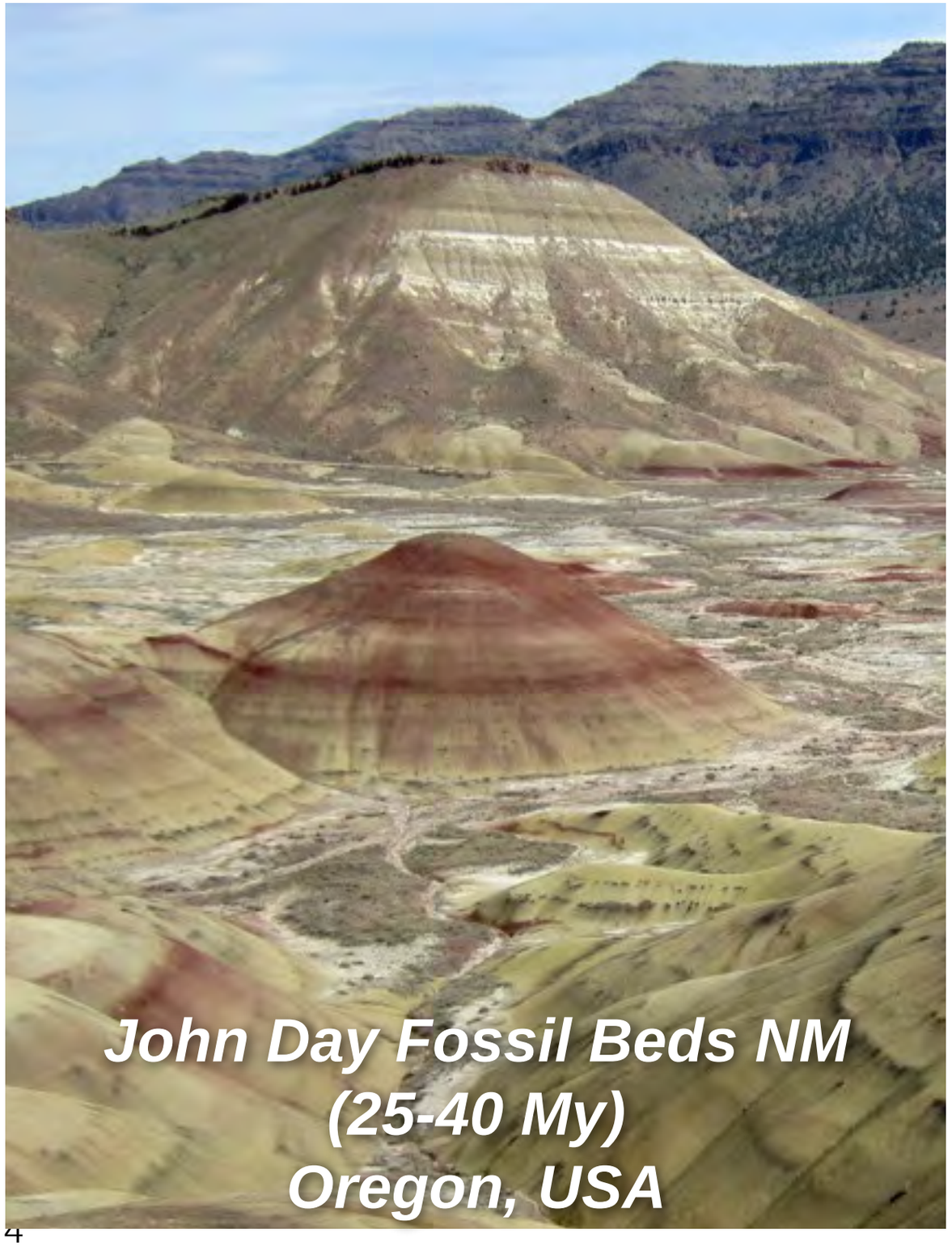
Watanabe et al. (2000)

Organics were partially decomposed by later carbonate dissolution

In the more recent geologic record, recurring sedimentation created thick paleosol sequences

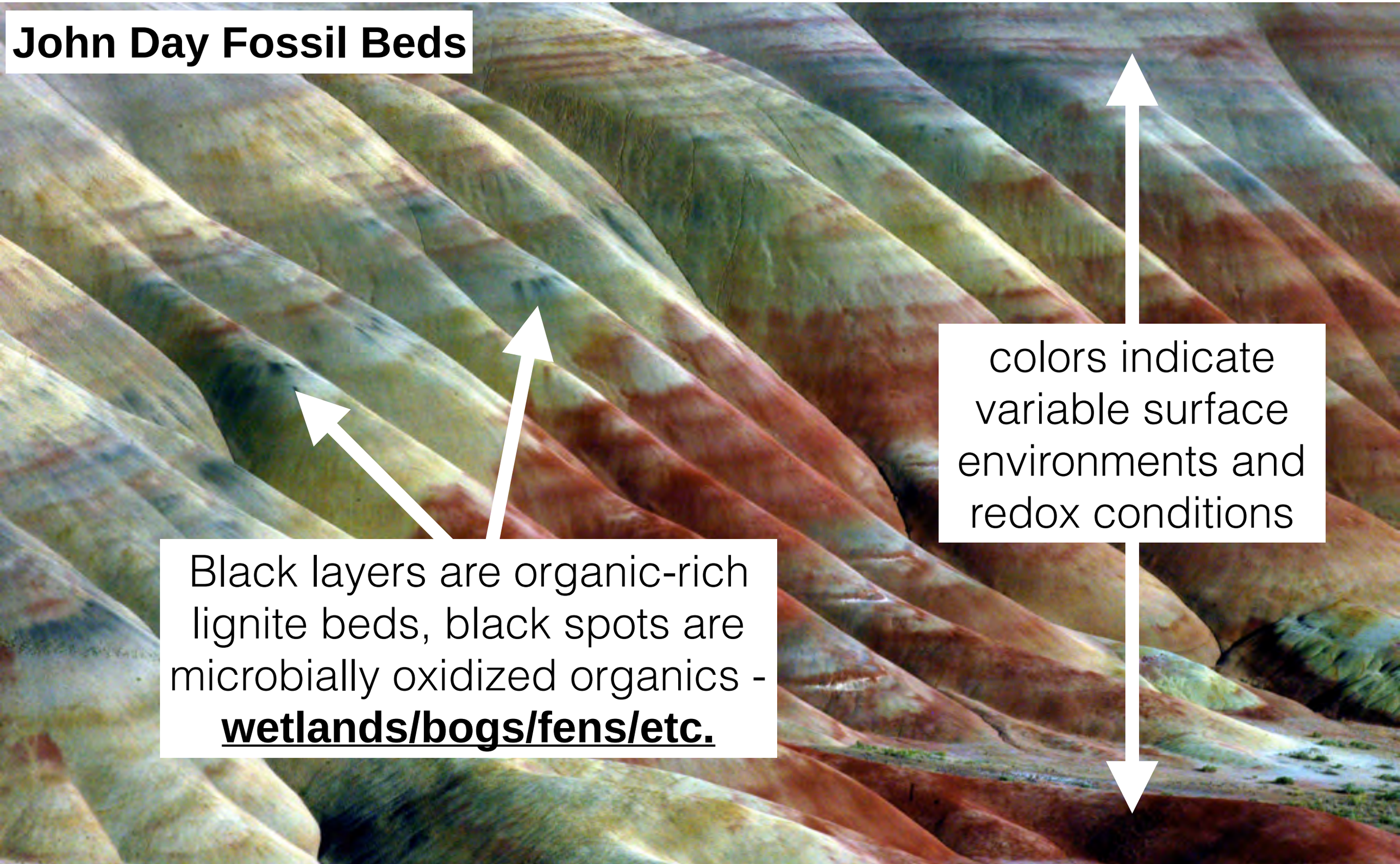
Painted Desert (~200 My)
Arizona, USA

Badlands NP (26-75 My)
South Dakota, USA



John Day Fossil Beds NM
(25-40 My)
Oregon, USA

Paleosol sequences preserve paleosurfaces, diverse geochemistries, and surface aqueous environments



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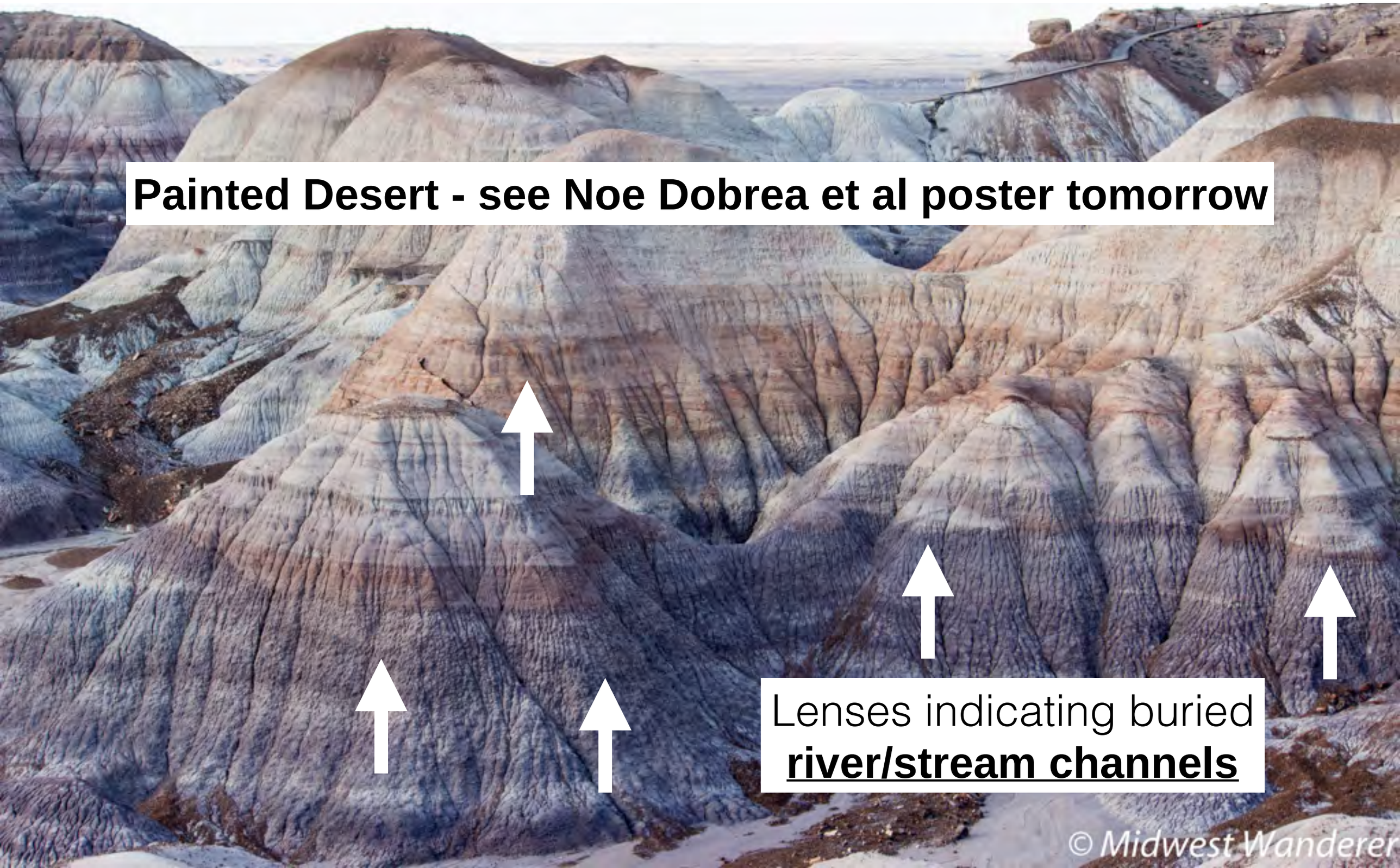


Paleosol sequences preserve paleosurfaces, diverse geochemistries, and surface aqueous environments

Leaf imprints/fossils in carbonate **lake beds** between paleosols, JDFBNM

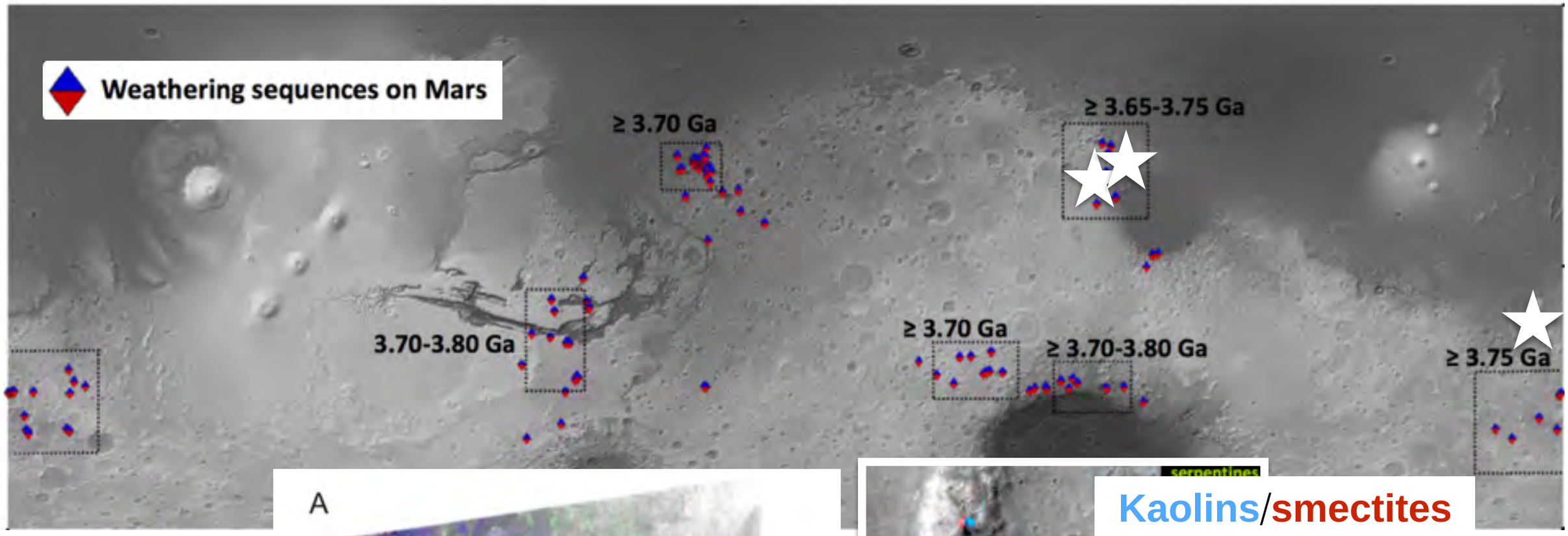
Lenses indicating buried **river/stream channels**

Paleosol sequences preserve paleosurfaces, diverse geochemistries, and surface aqueous environments

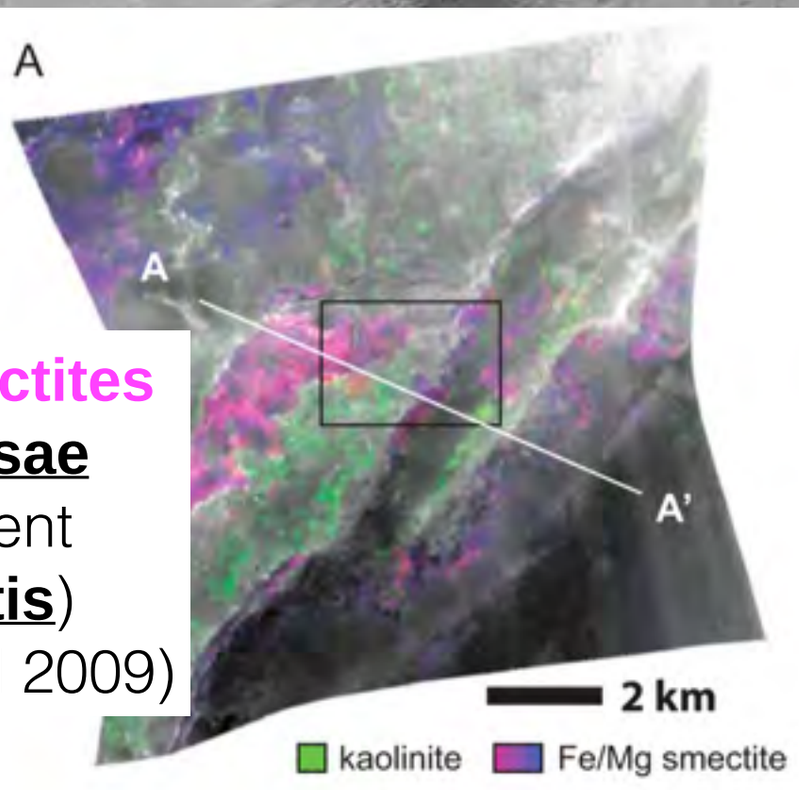
Leaf imprints/fossils in carbonate **lake beds** between paleosols, JDFBNM

Key point #4: Paleosol sequences provide a unique opportunity to investigate not just soils of variable redox states but also multiple ancient surface environments

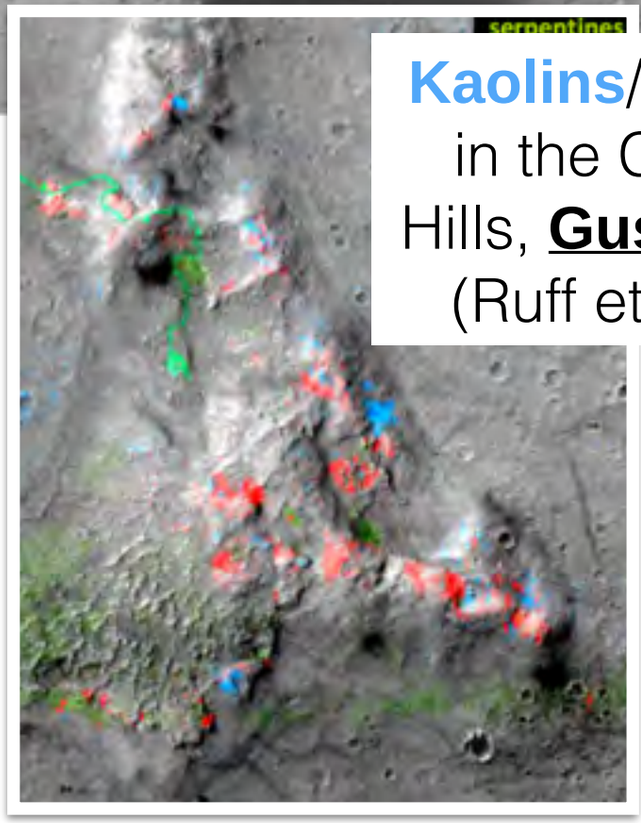
On Mars, globally distributed Noachian laterite-like weathering profiles are probably poor sites for organic preservation, but could preserve other biosignatures



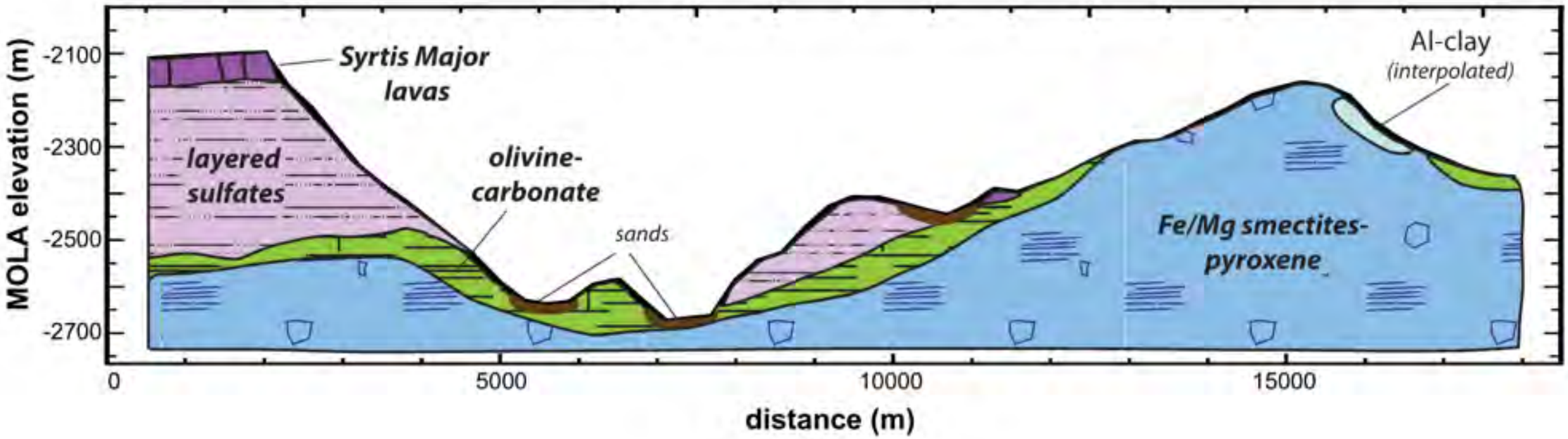
Kaolins/**smectites**
in **Nili Fossae**
(also present
at **NE Syrtis**)
(Ehlmann et al 2009)



Kaolins/**smectites**
in the Columbia
Hills, **Gusev Crater**
(Ruff et al 2015)

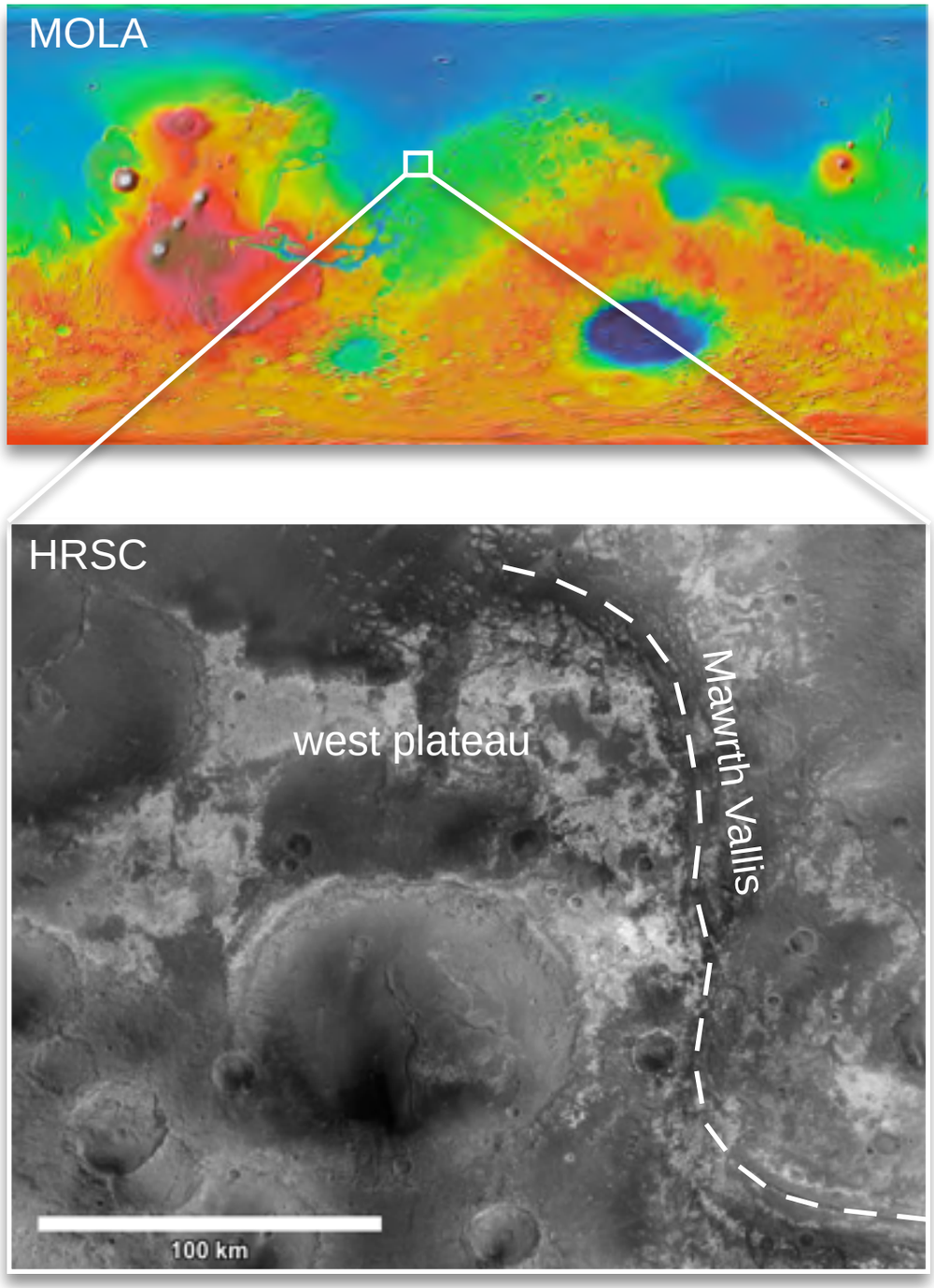


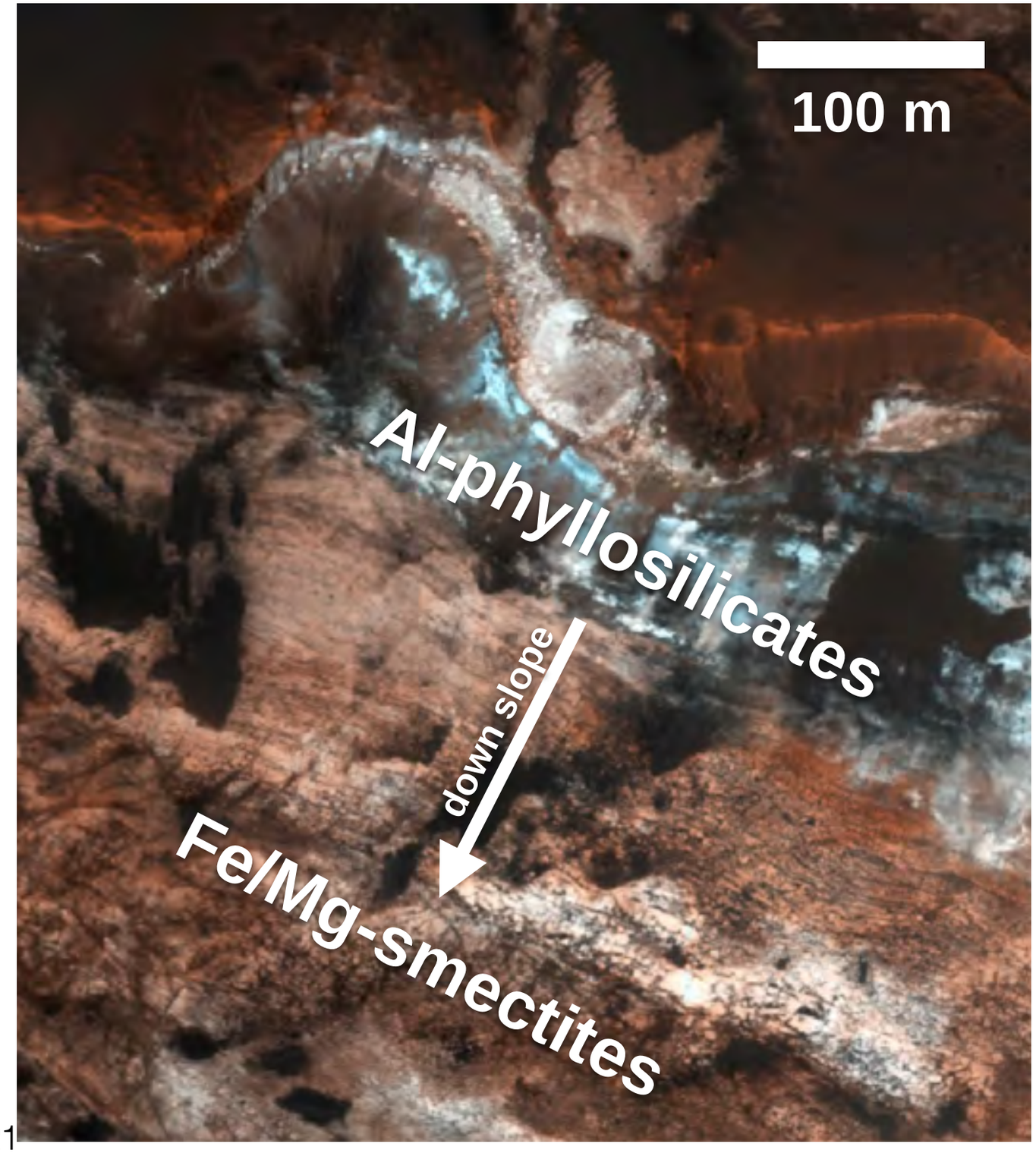
NE Syrtis: Carbonate-bearing olivine unit could be consistent with carbonaceous soil profile



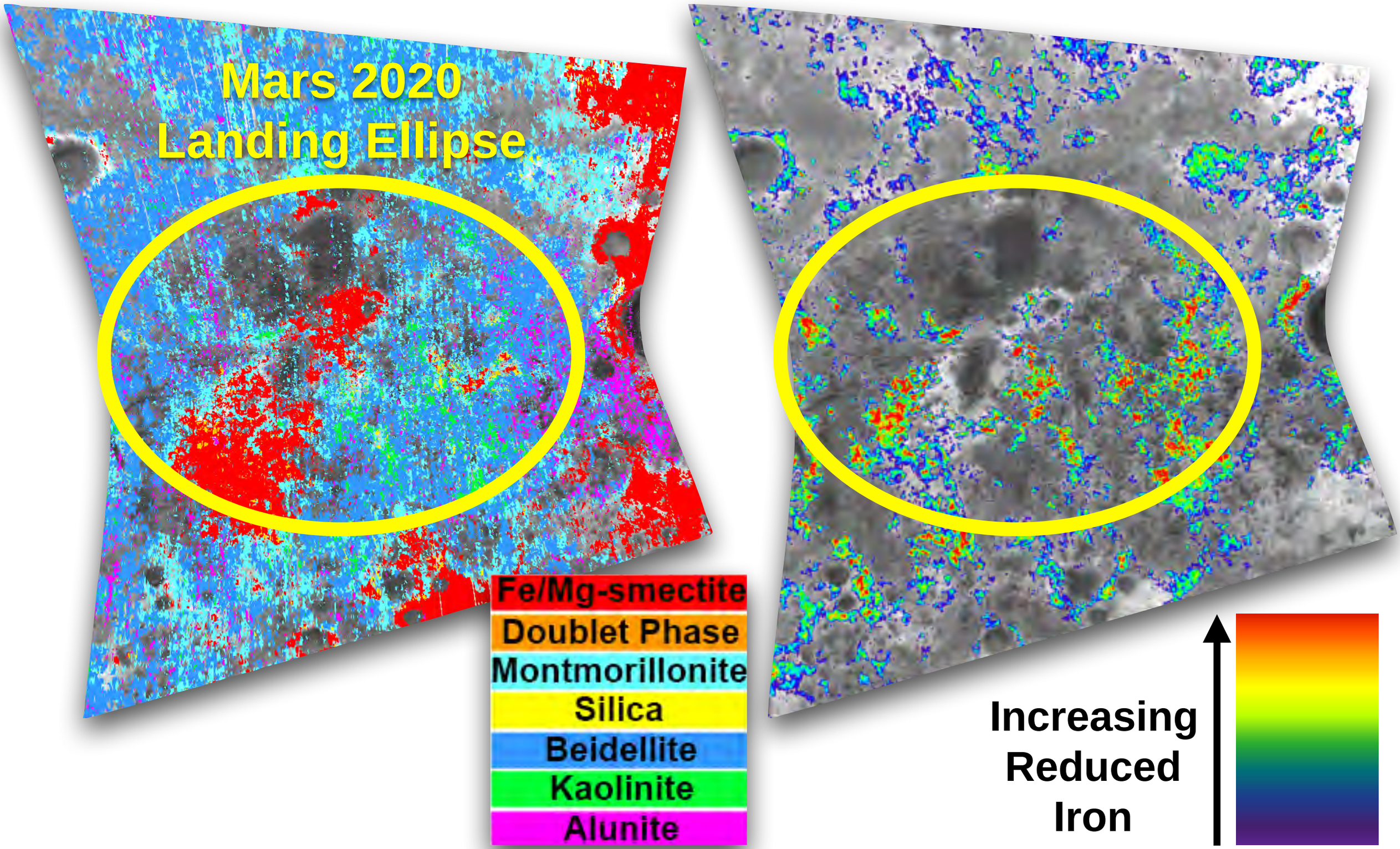
Potential biosignatures could include organics, carbonate isotopes, chemical profiles, etc. Can we access the top of the unit and is the paleosurface preserved?

Mawrth Vallis: Thick regional package of Noachian clay-rich layered sediments are consistent with a paleosol sequence



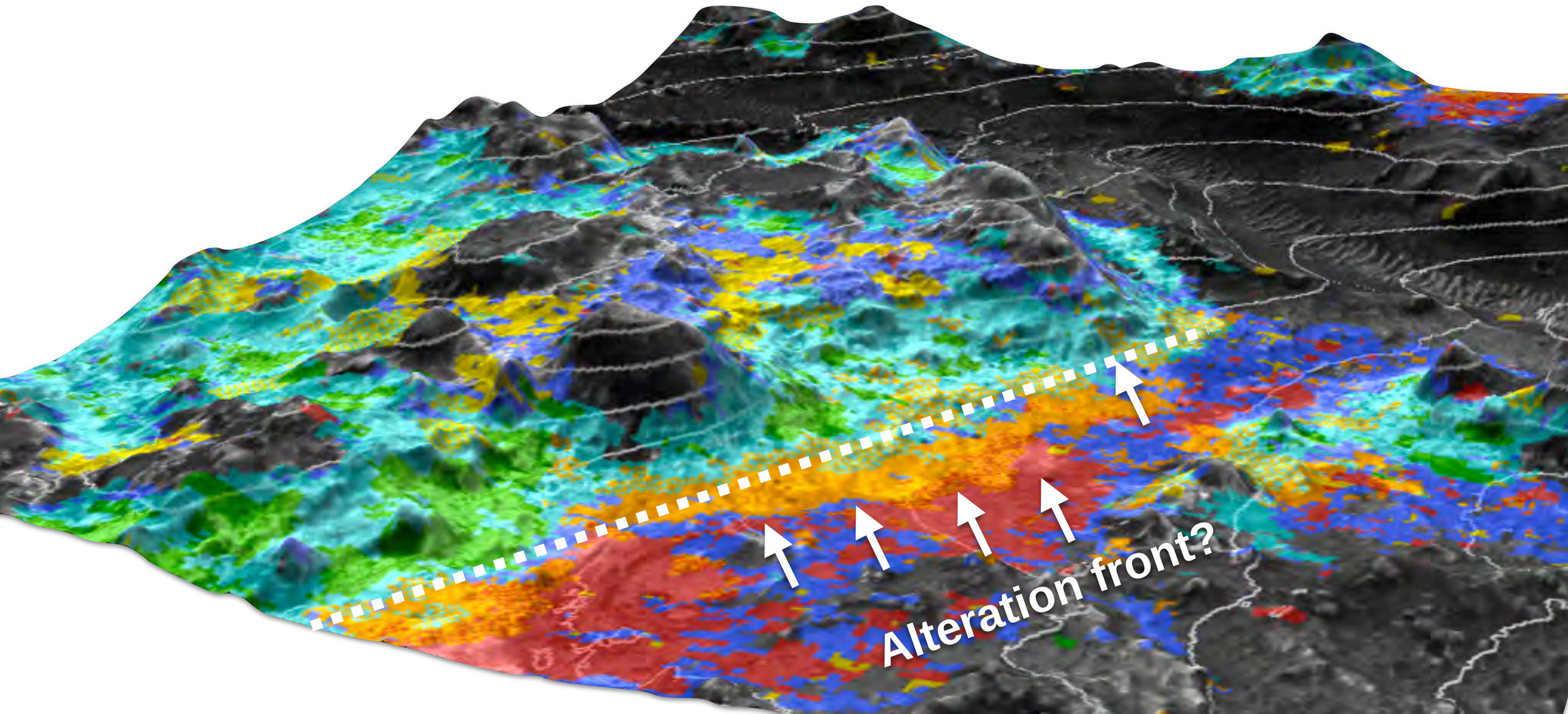


Mawrth Vallis exhibits significant mineral diversity consistent with diverse environmental conditions



Possible biosignatures at Mawrth Vallis:

- preserved organics in reduced units
- preserved organics in sulfates
- sulfur isotopes
- chemical profiles
- biomineralization in silica, carbonates??



Summary of Key Points

(1) **Reducing conditions** in a soil help to prevent oxidation of organics

(2) Soils preserve **chemical/istopic/mineralogic** biosignatures, often in addition to organics

(3) Organics are most commonly **found in the near-surface** of ancient paleosols, so paleosurface preservation aids in organic preservation

(4) **Paleosol sequences** provide a unique opportunity to investigate not just soils of variable redox states but also multiple ancient surface environments

Several possible future landing sites on Mars contain possible paleosols, and Mars2020 is well equipped to investigate them!