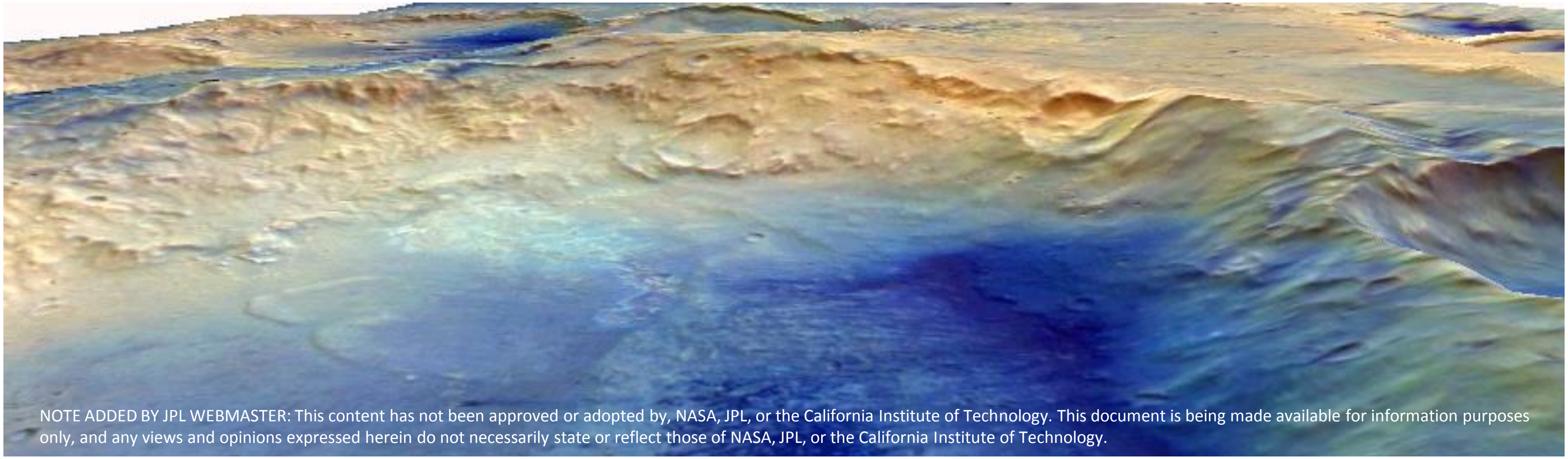
McLaughlin Crater

Groundwater fed, lacustrine clays and carbonates

A candidate landing site for Mars 2020

Joe Michalski, Paul Niles &
Sarah Stewart Johnson



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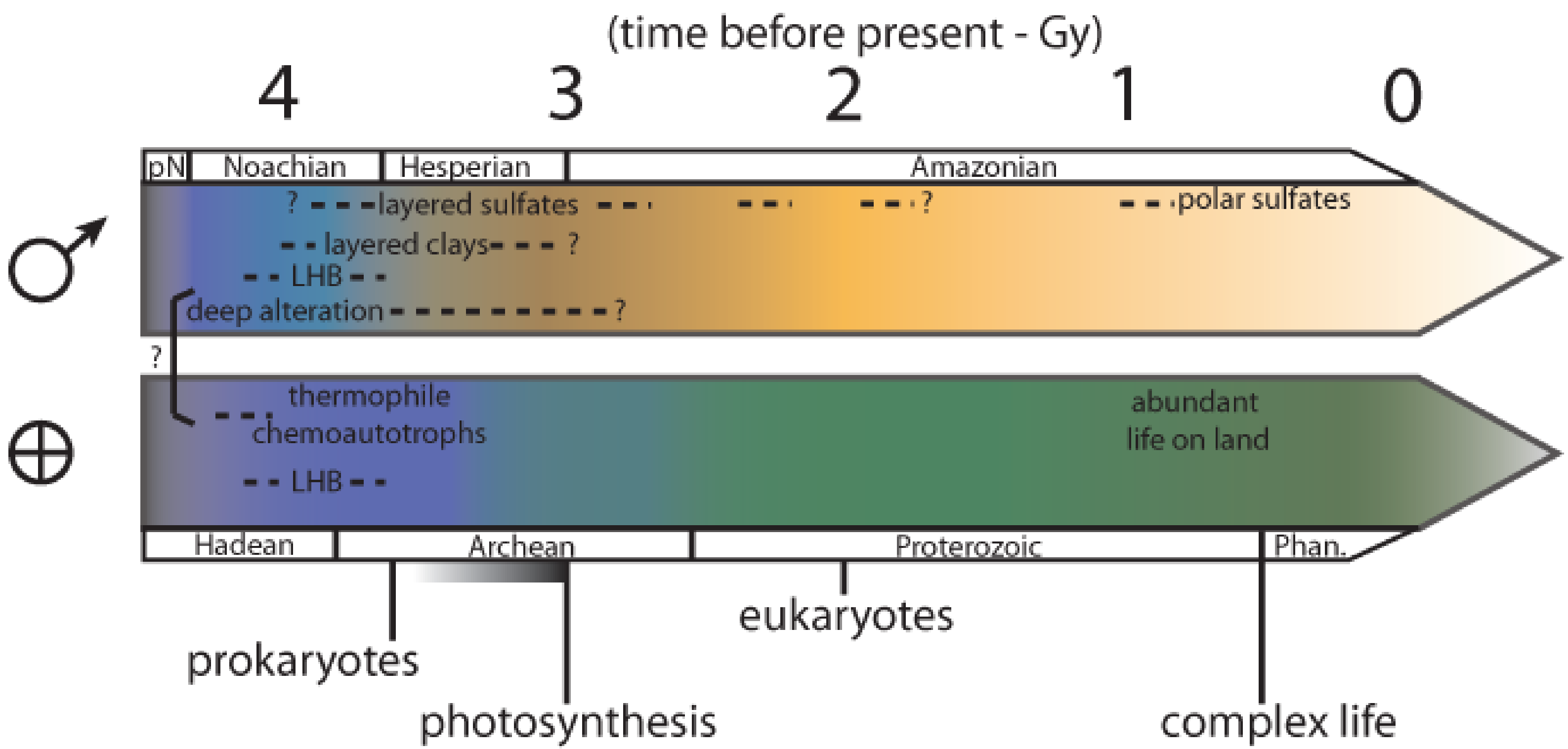
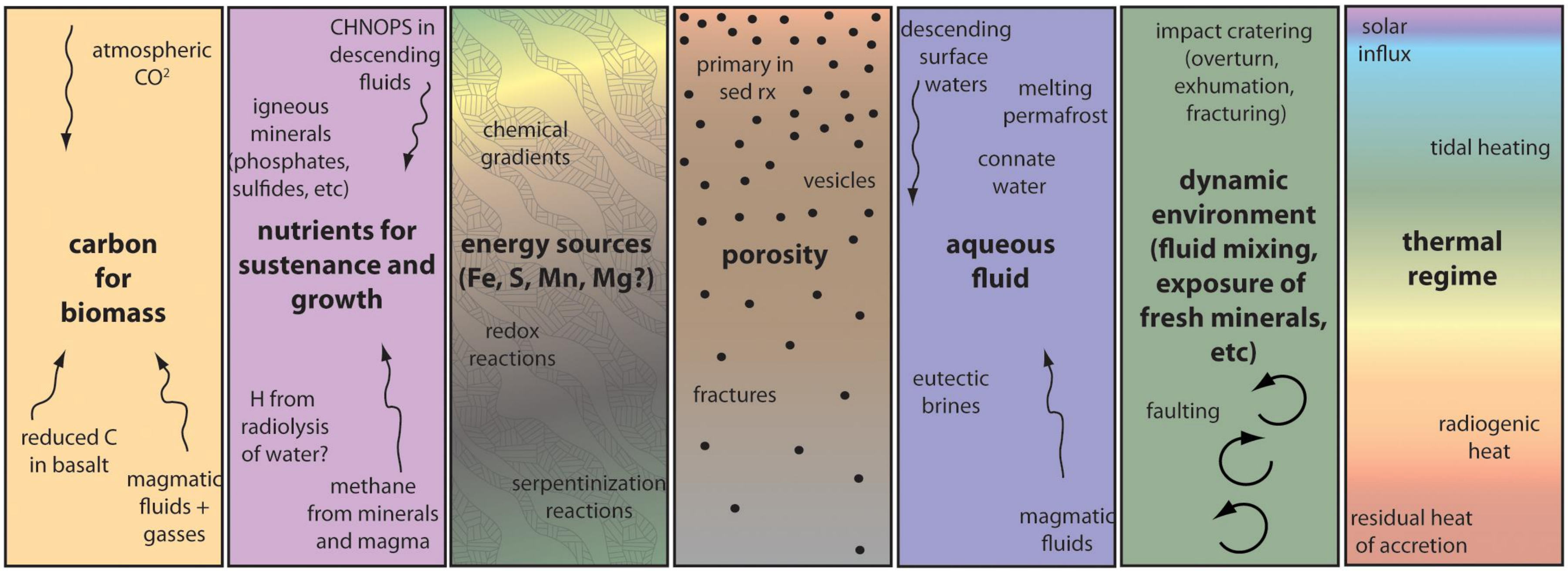
The big picture

By 3.5 Ga, Mars was probably mostly hyperarid, cold, acidic, bathed in UV and generally a bummer



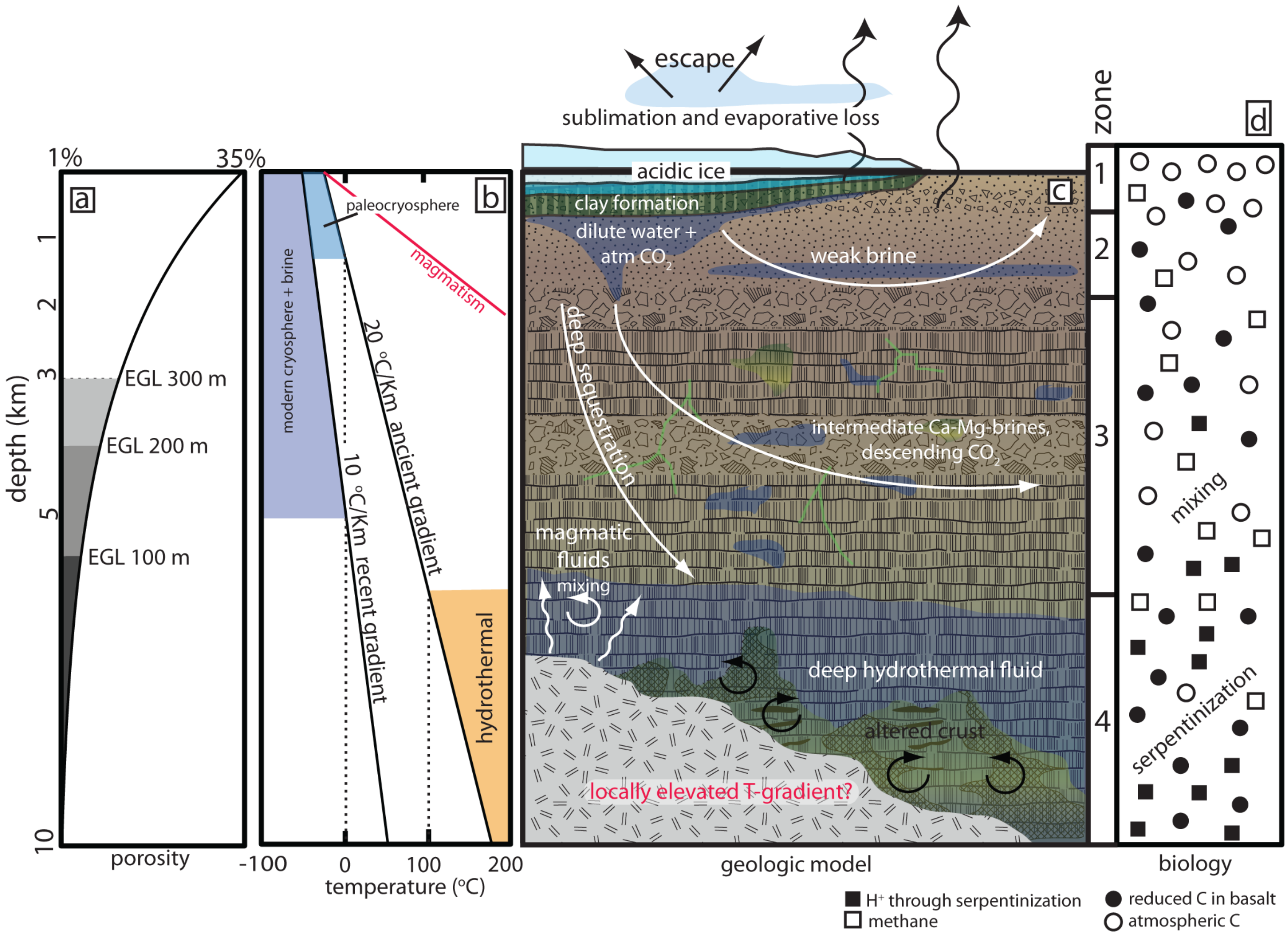
Michalski et al., Nature Geoscience, 2013

Considerations for Deep Biospheres



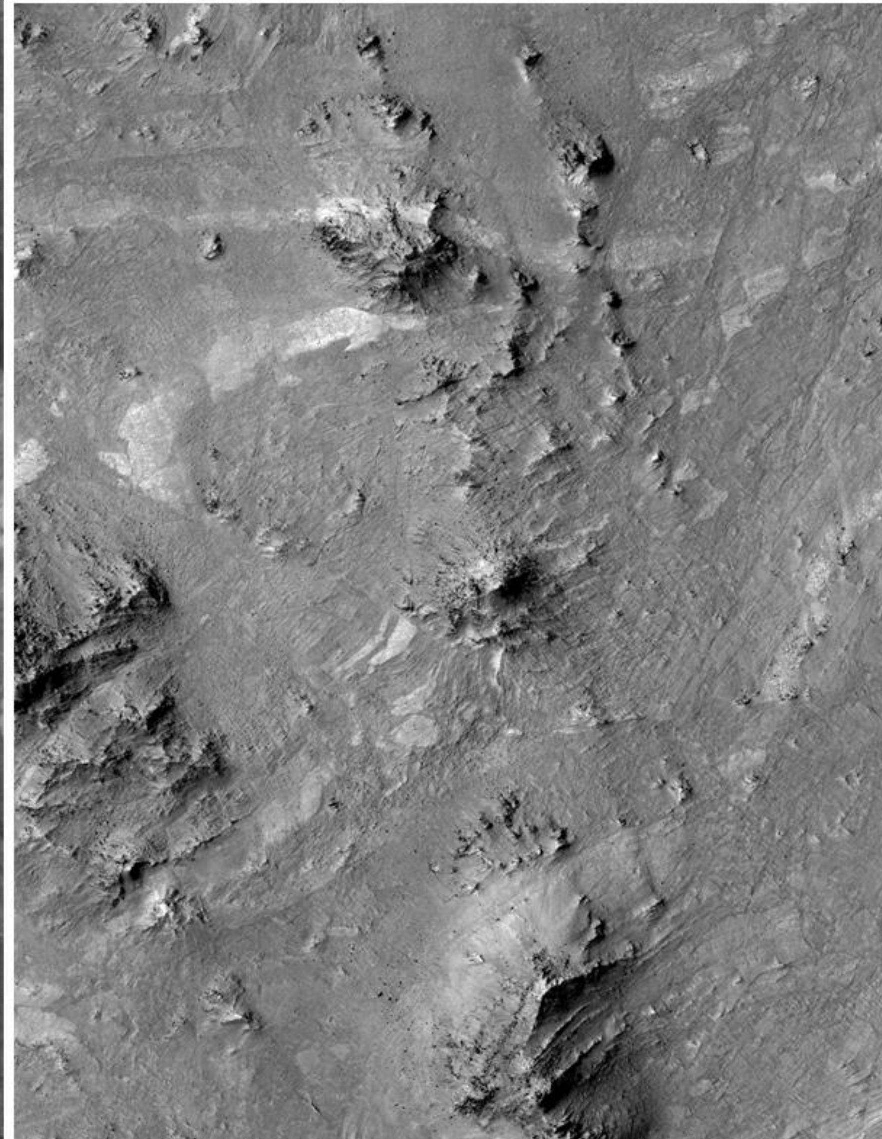
The Martian Subsurface

ALL THE INGREDIENTS FOR LIFE WERE/ARE PRESENT

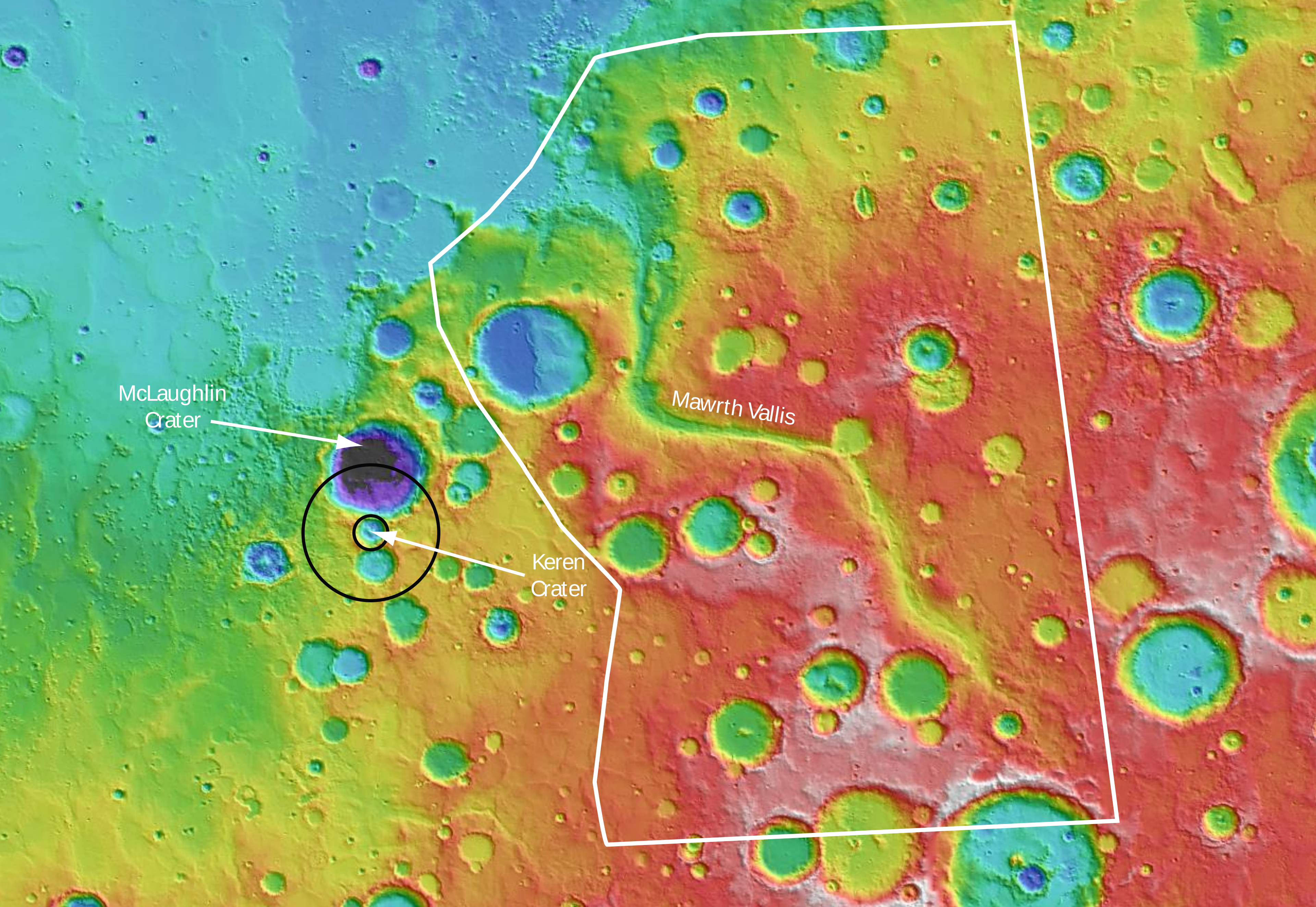


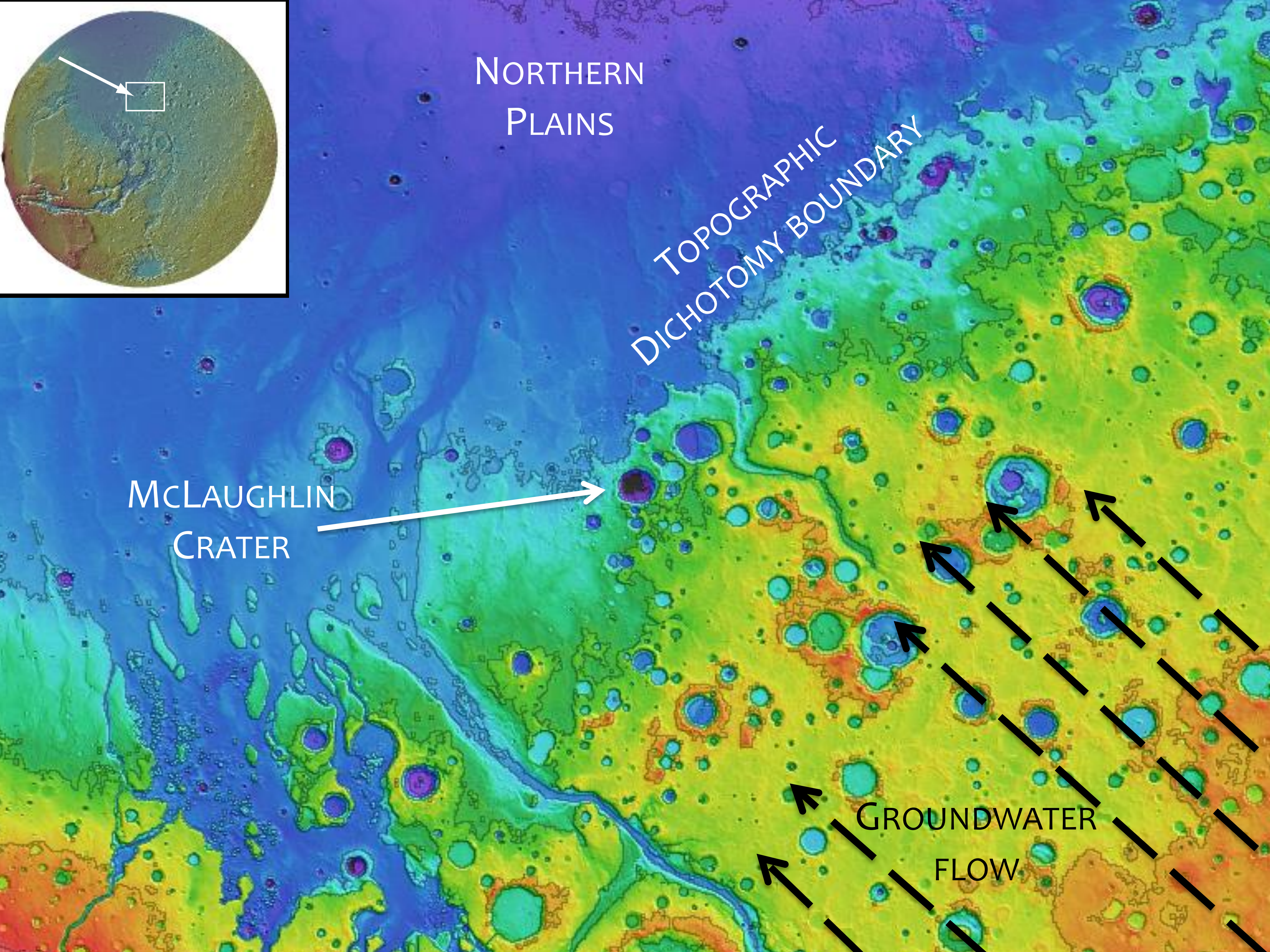
SEDIMENTARY
-OR-
"SURFACE"

HYDROTHERMAL
-OR-
"SUBURFACE"



McLaughlin: what you need to know

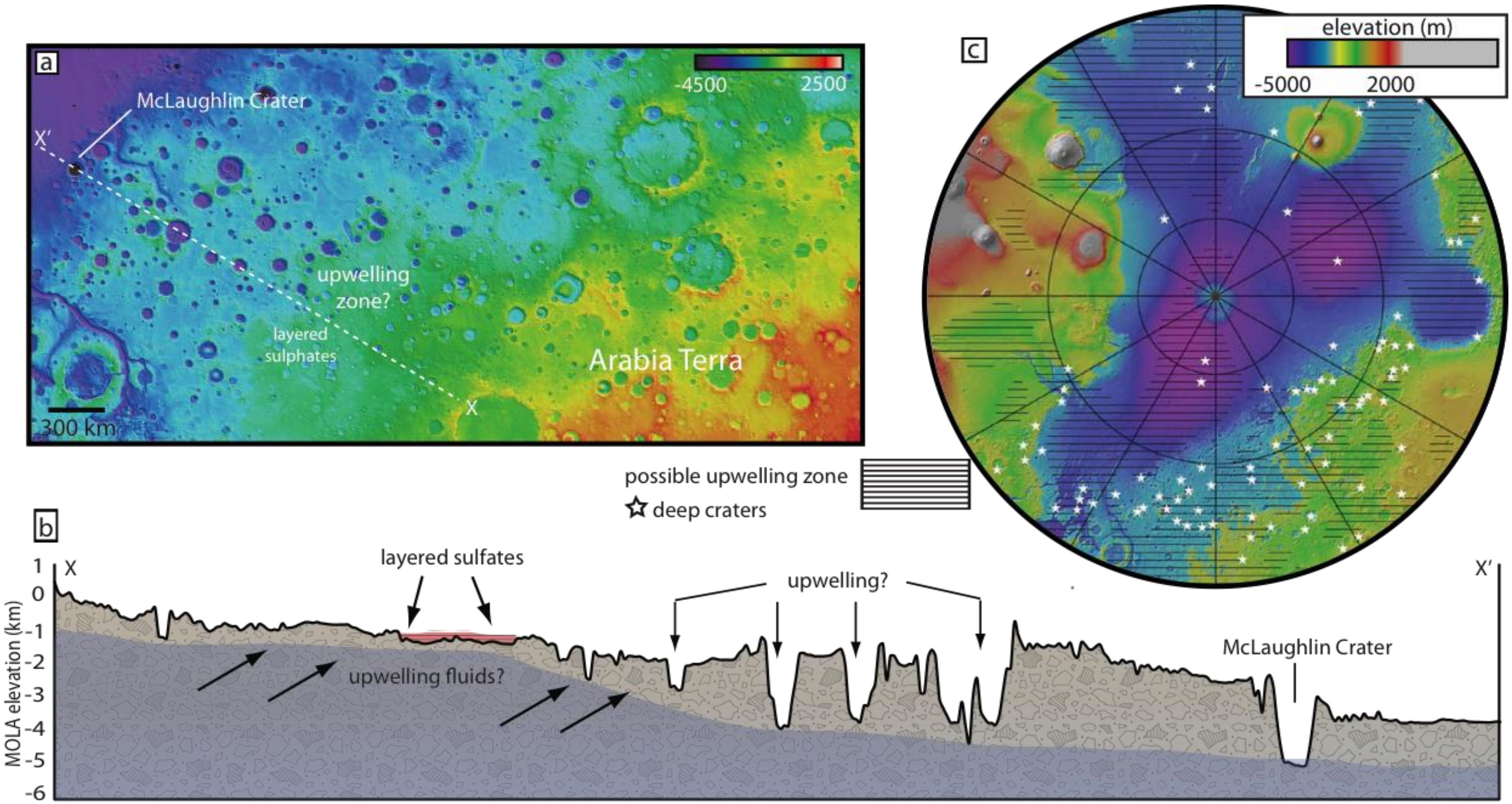


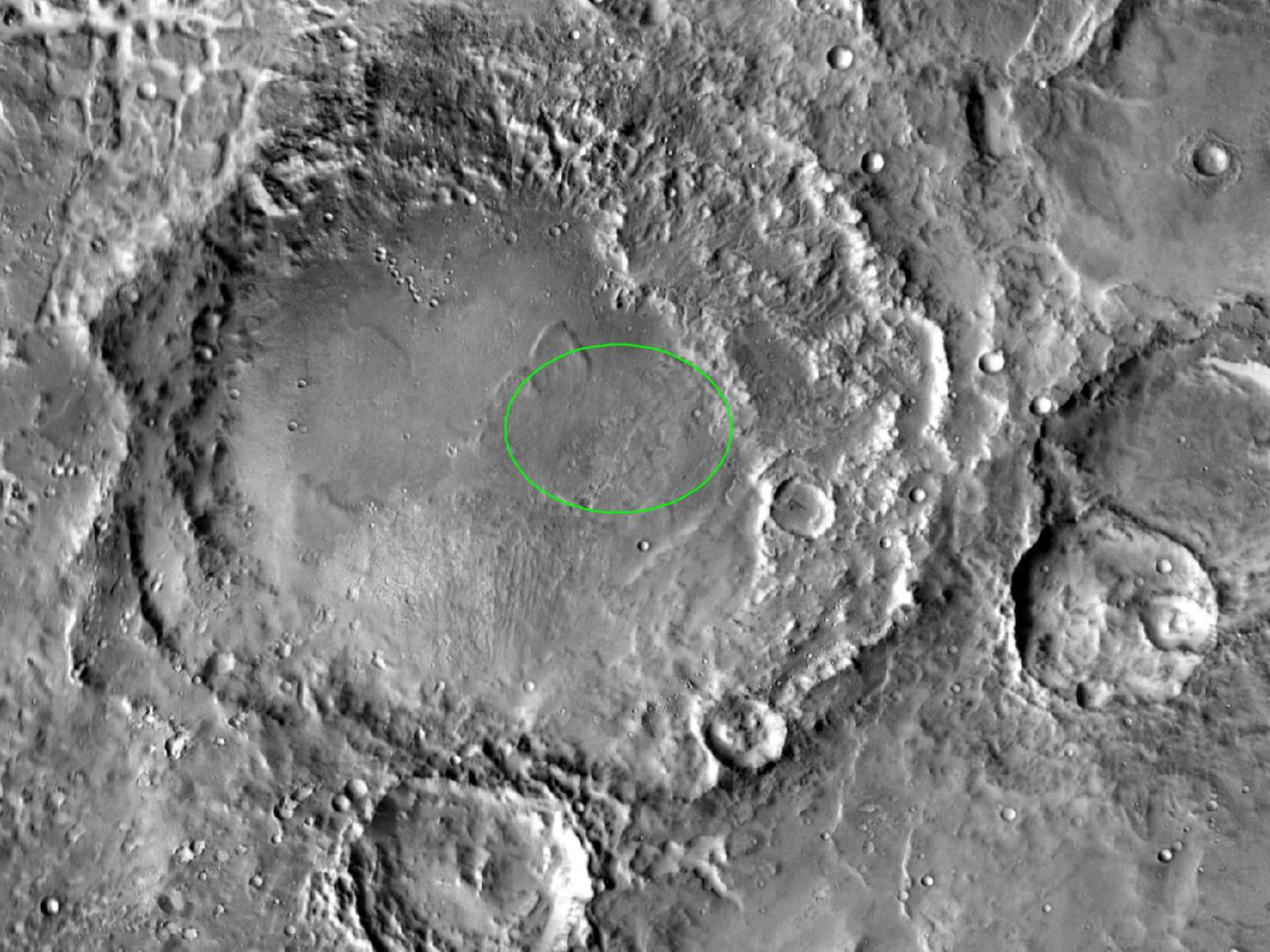


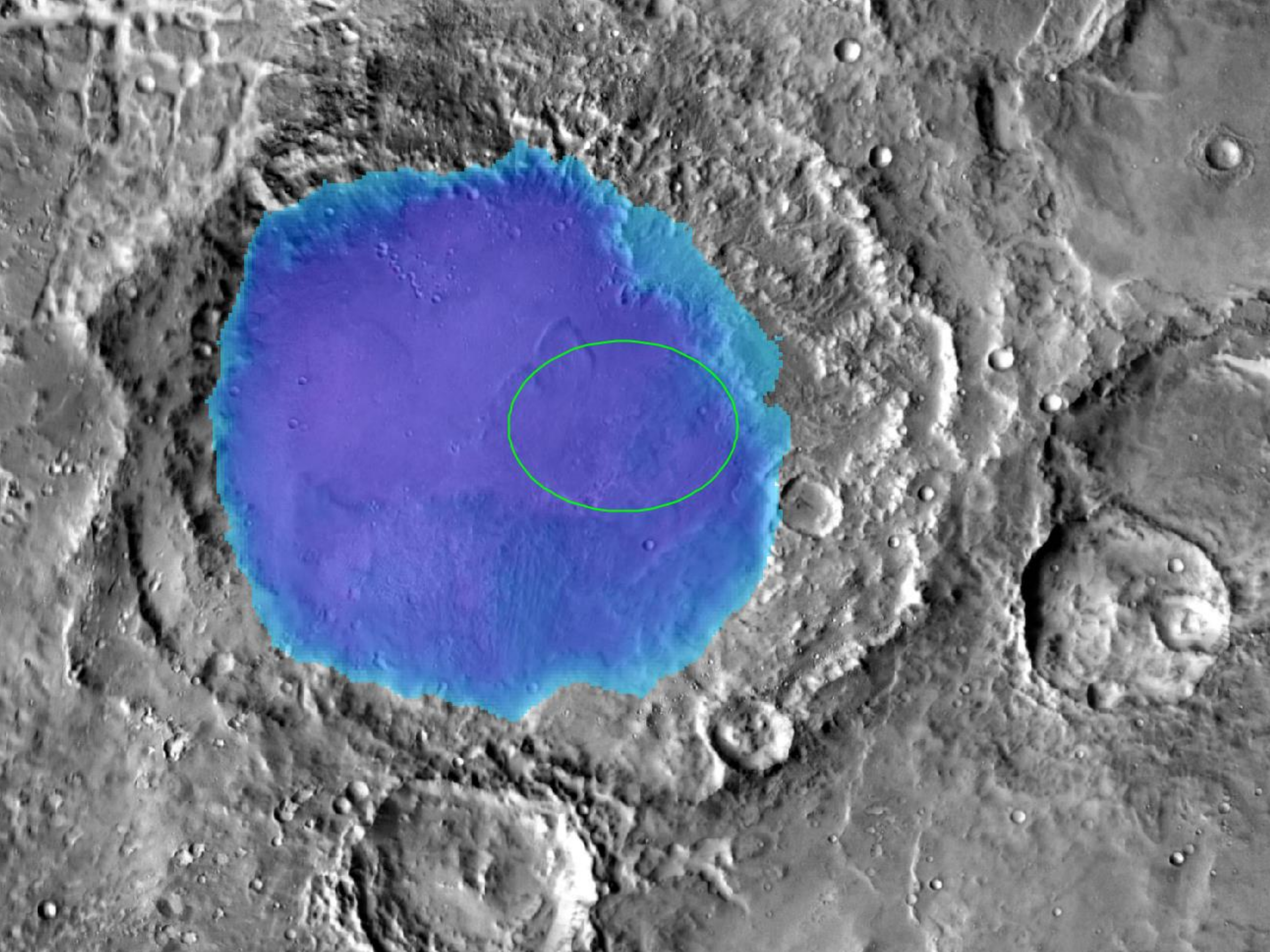
Northern Plains
Topographic Dichotomy Boundary
McLaughlin Crater
Groundwater flow

UPWELLING SHOULD OCCUR FIRST IN DEEP BASINS

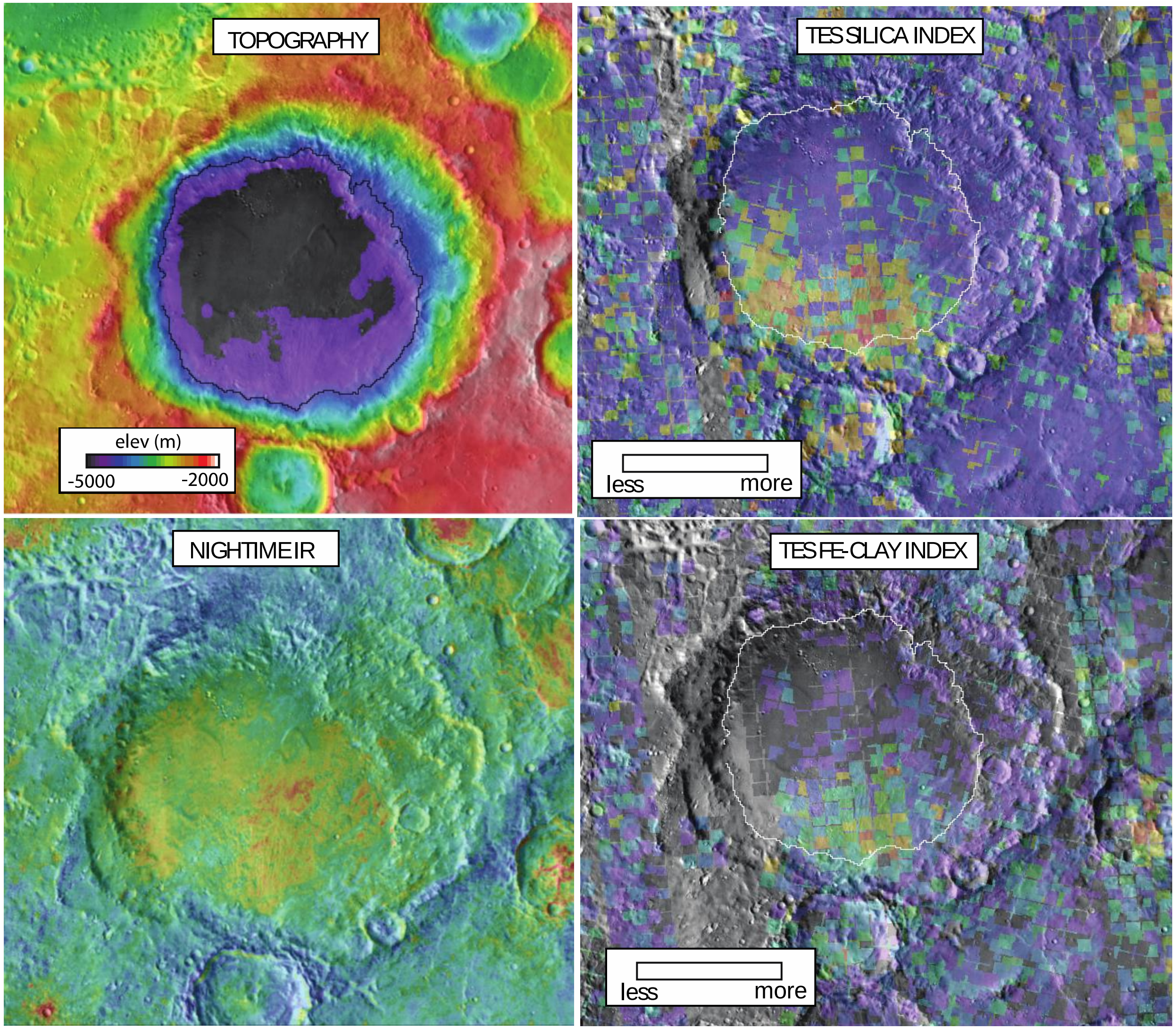
MCLAUGHLIN MIGHT BE THE BEST CANDIDATE FOR UPWELLING ON MARS





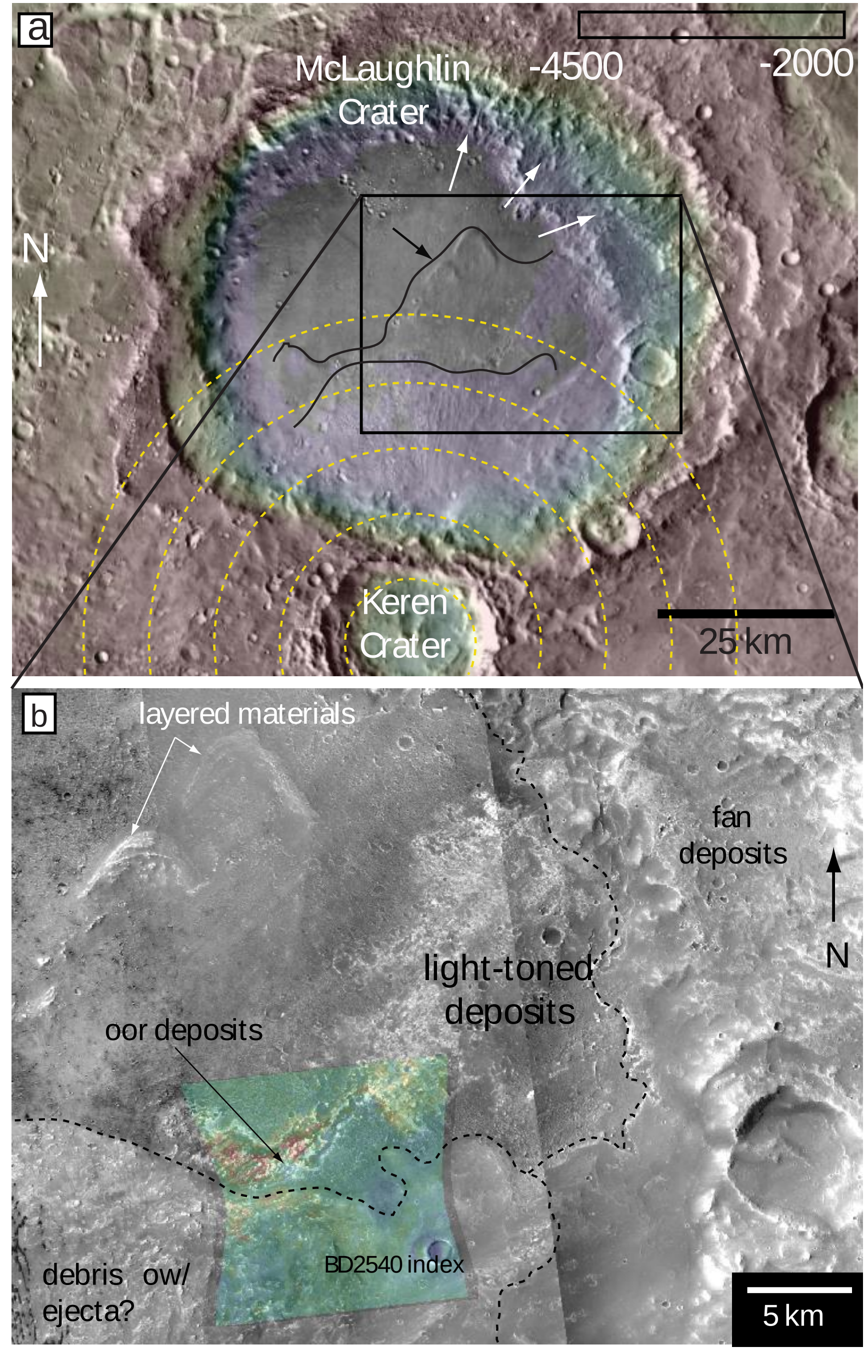


EVIDENCE FOR ALTERATION BELOW A BASE LEVEL



McLaughlin Crater

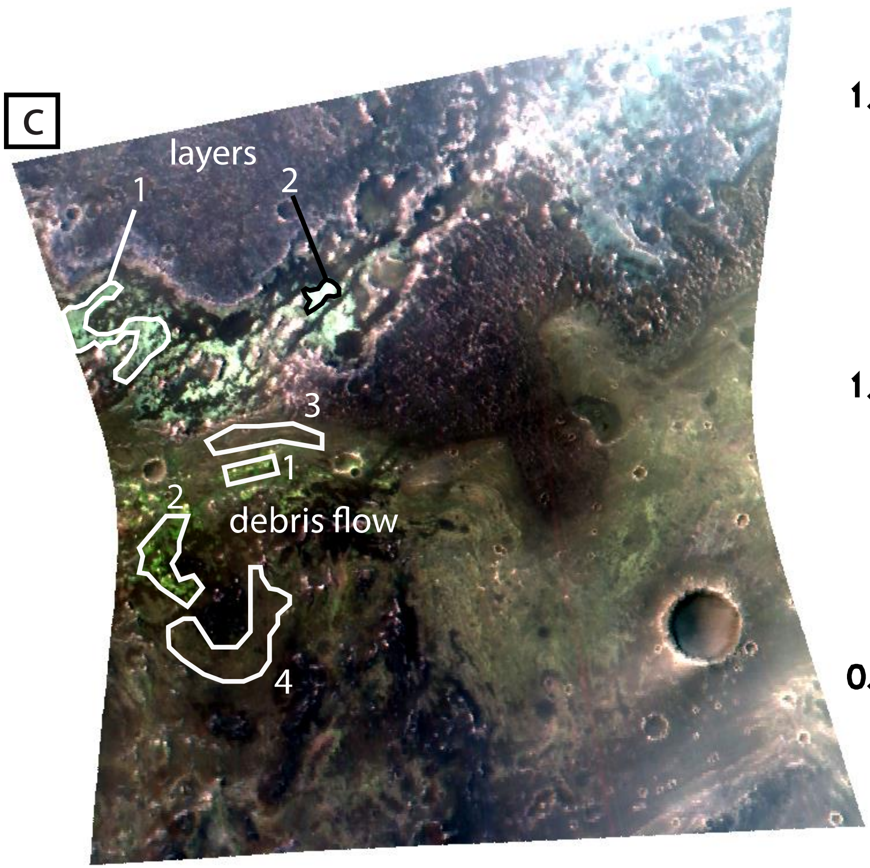
- Channels in wall, terminate ~500 m above the floor
- Ejecta from Keren on floor
- Lobate materials
- Layered sed rx

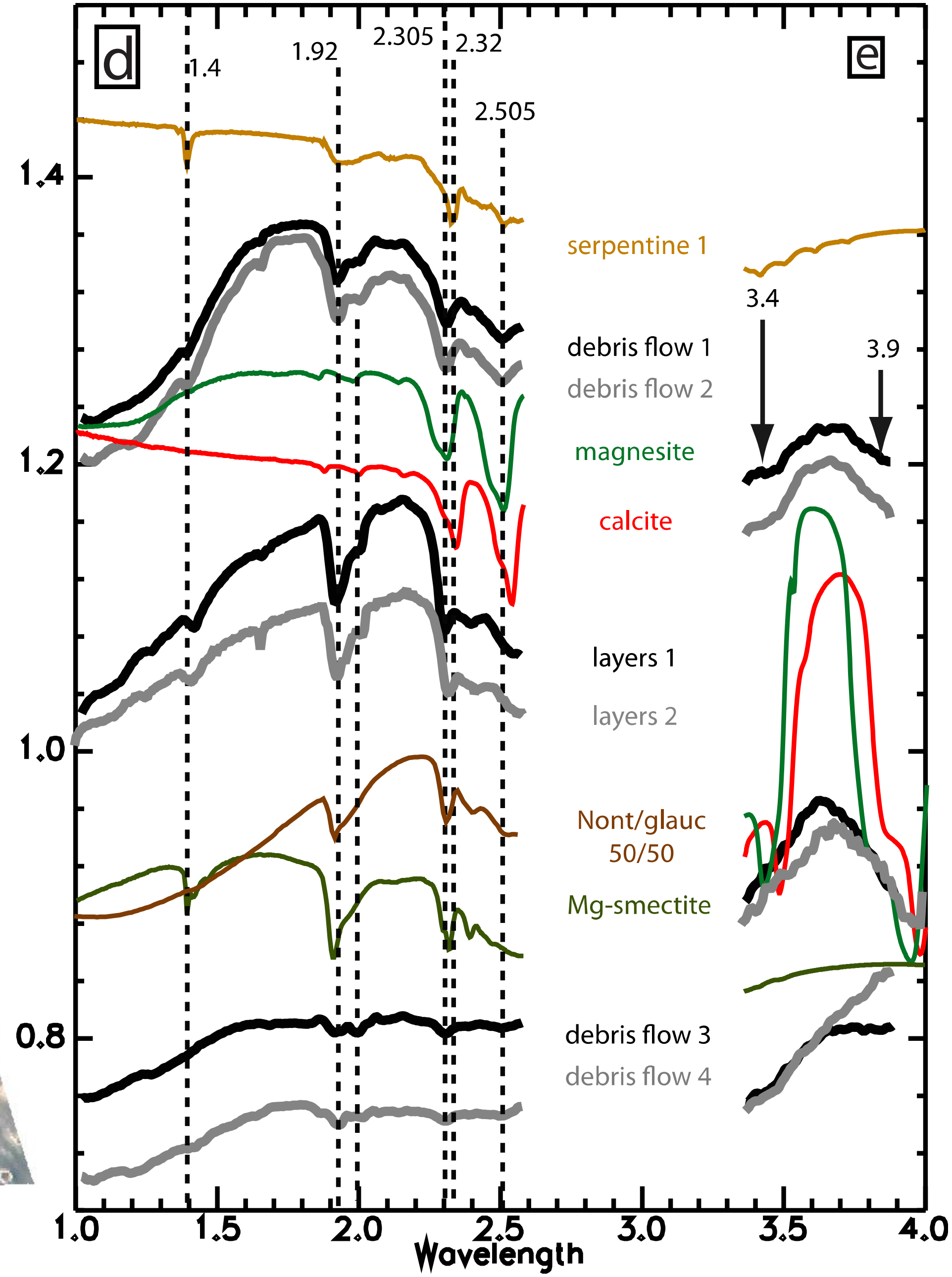


Michalski et al., Nature Geoscience, 2013

CRISM RESULTS

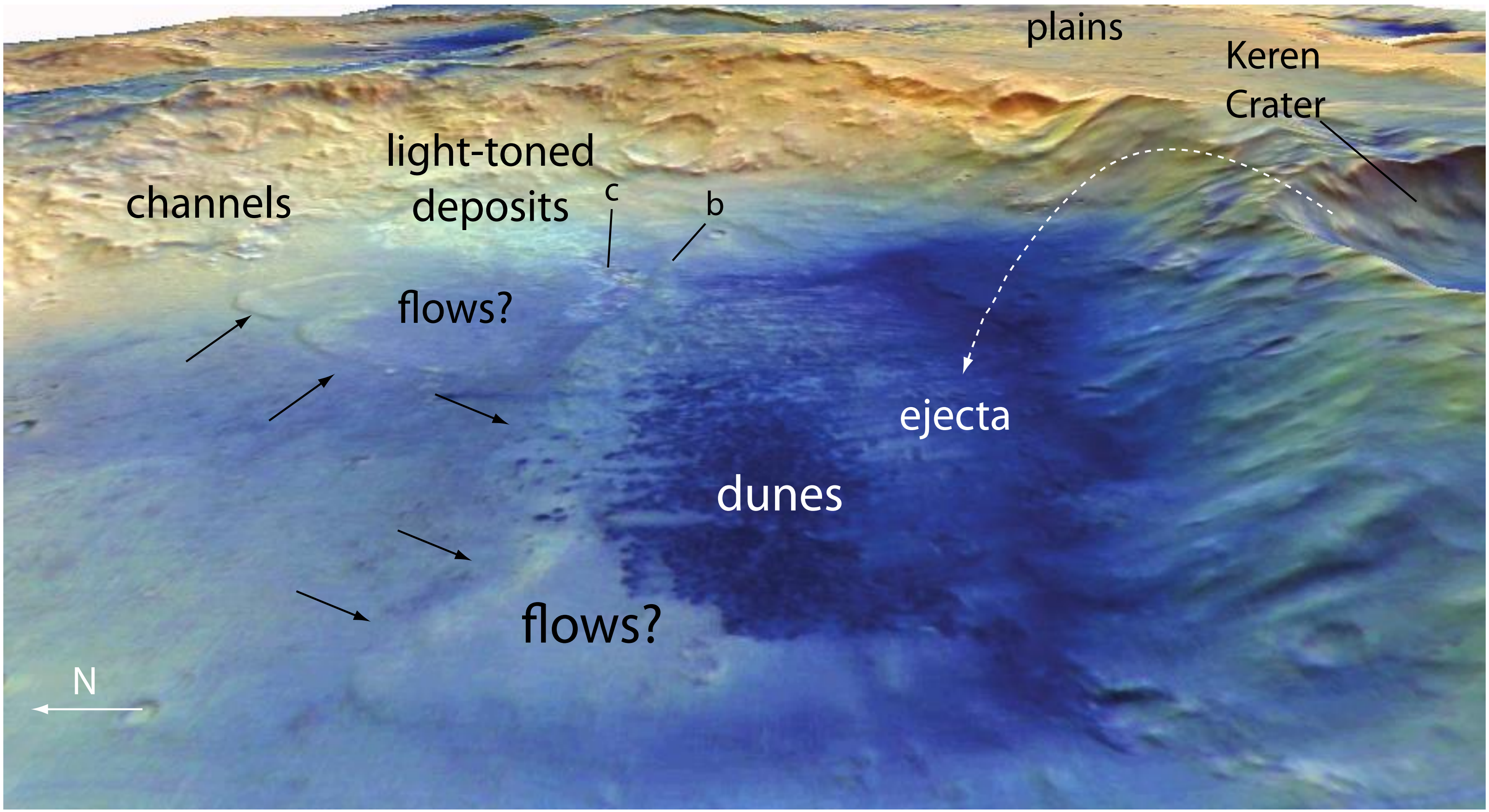
CLAYS AND CARBONATES

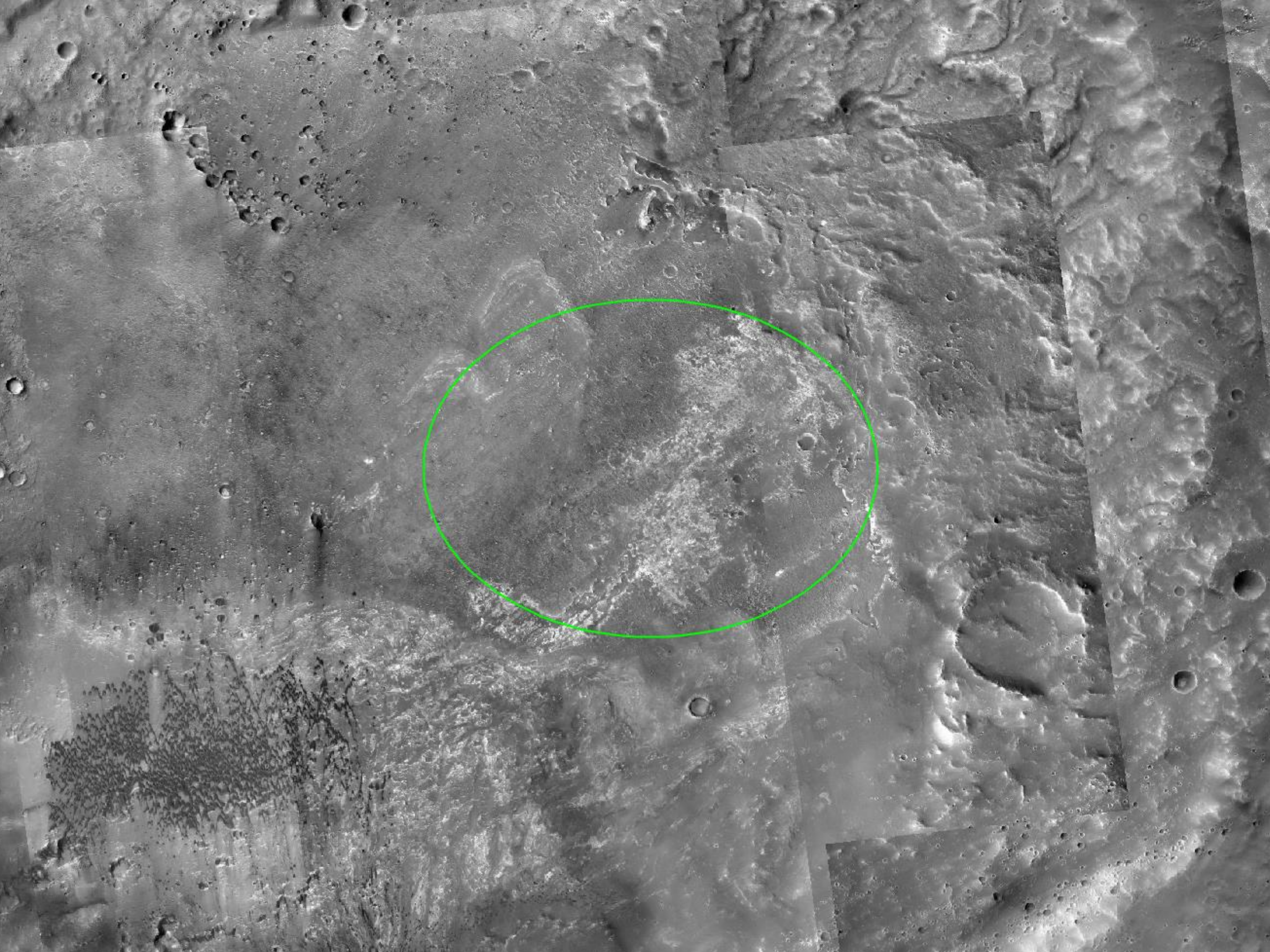




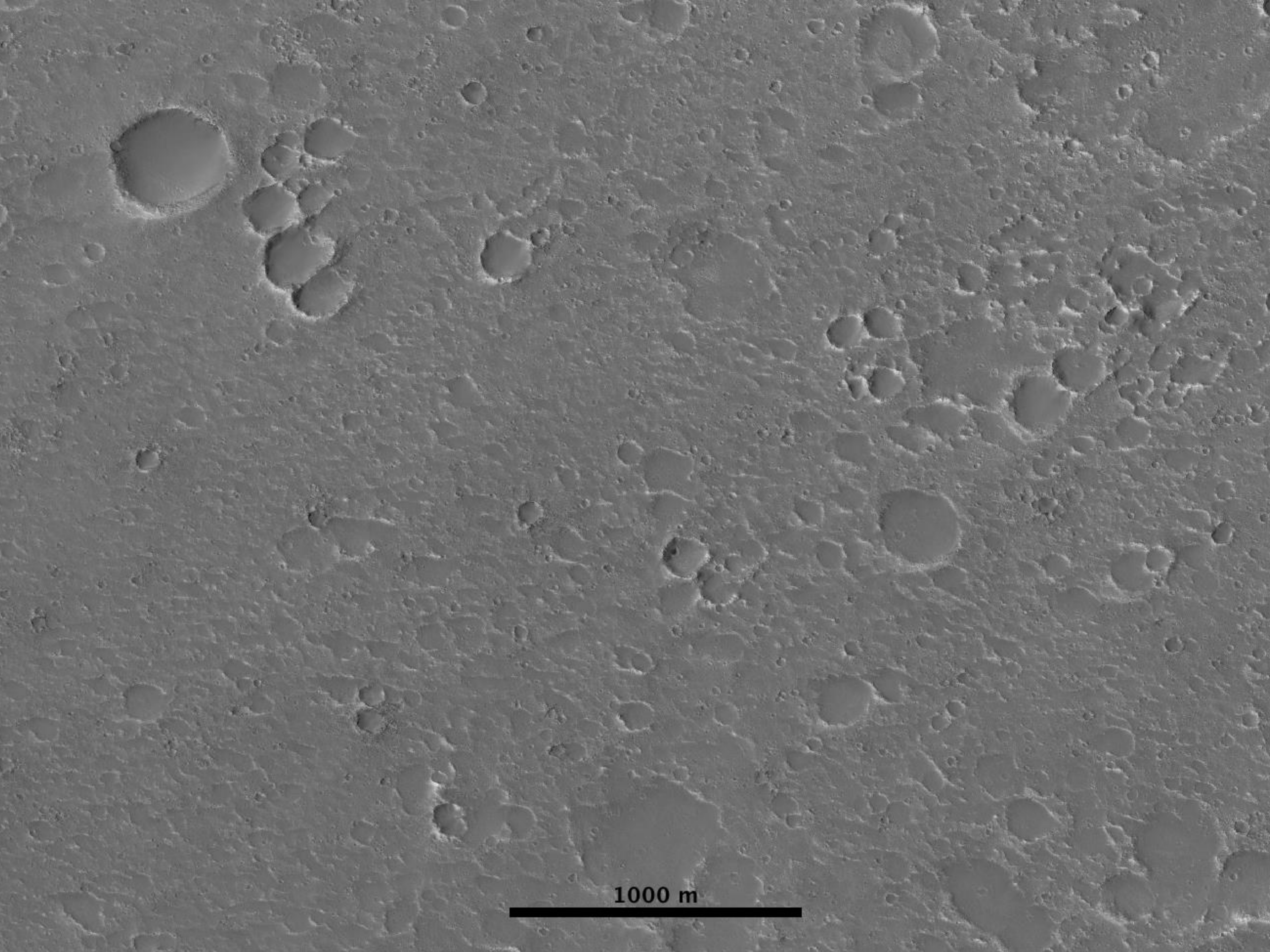
Michalski et al., Nature Geoscience, 2013

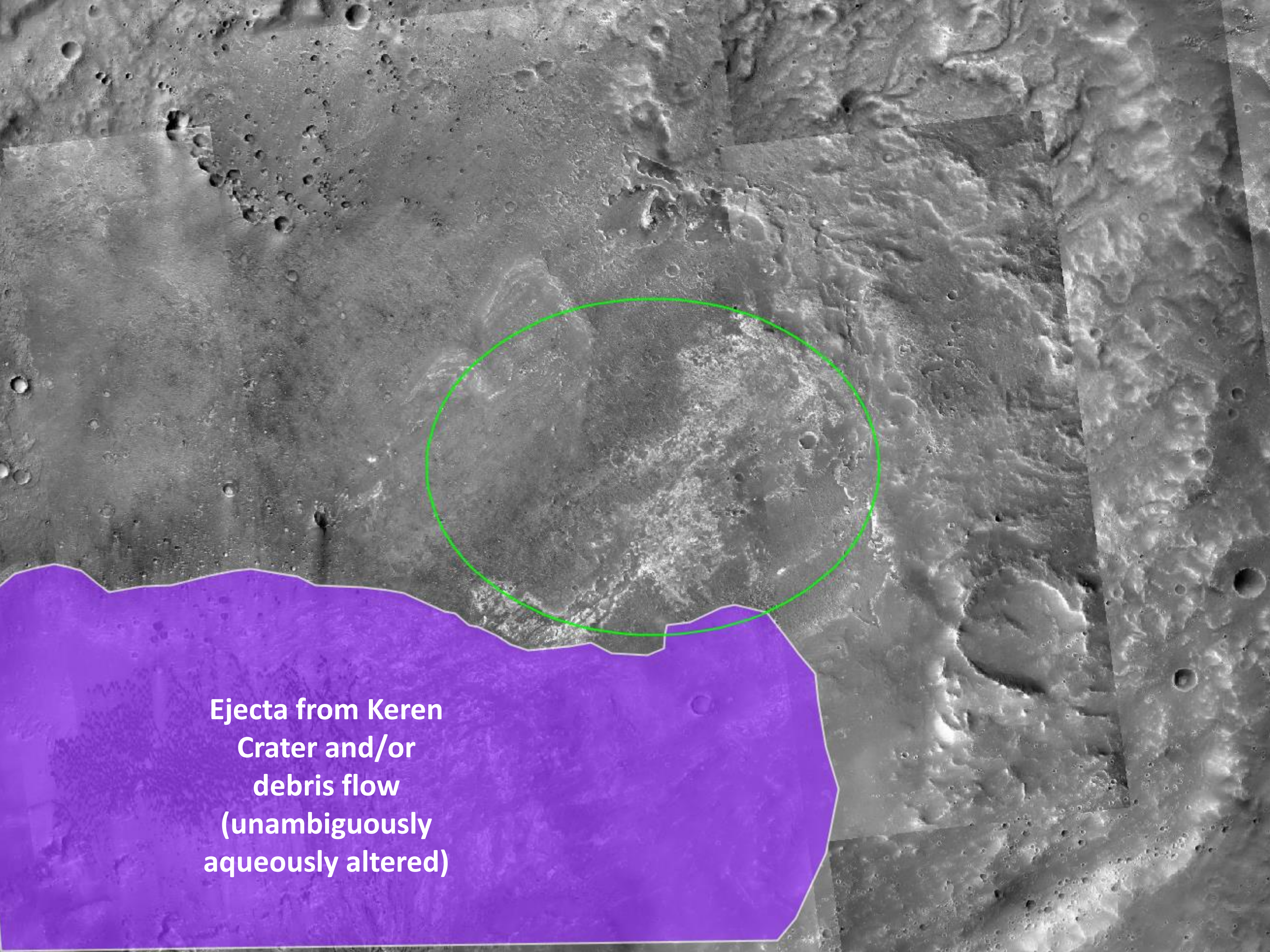
LAYERED SEDIMENTS AND LOBATE MATERIALS



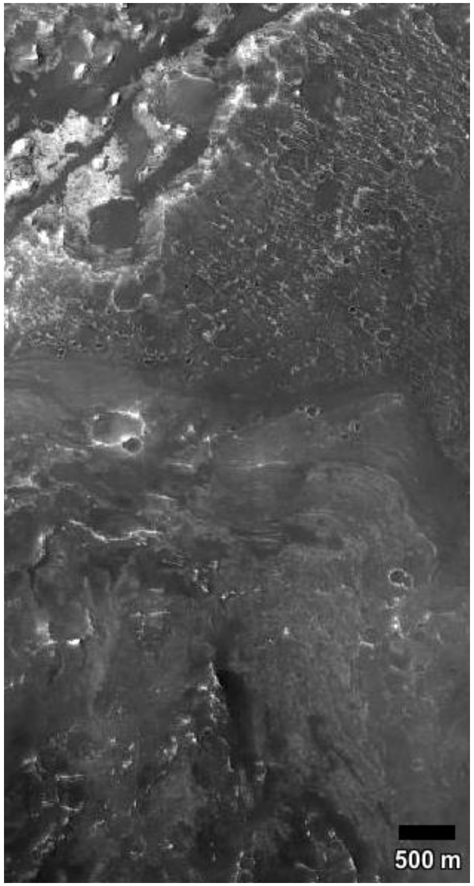


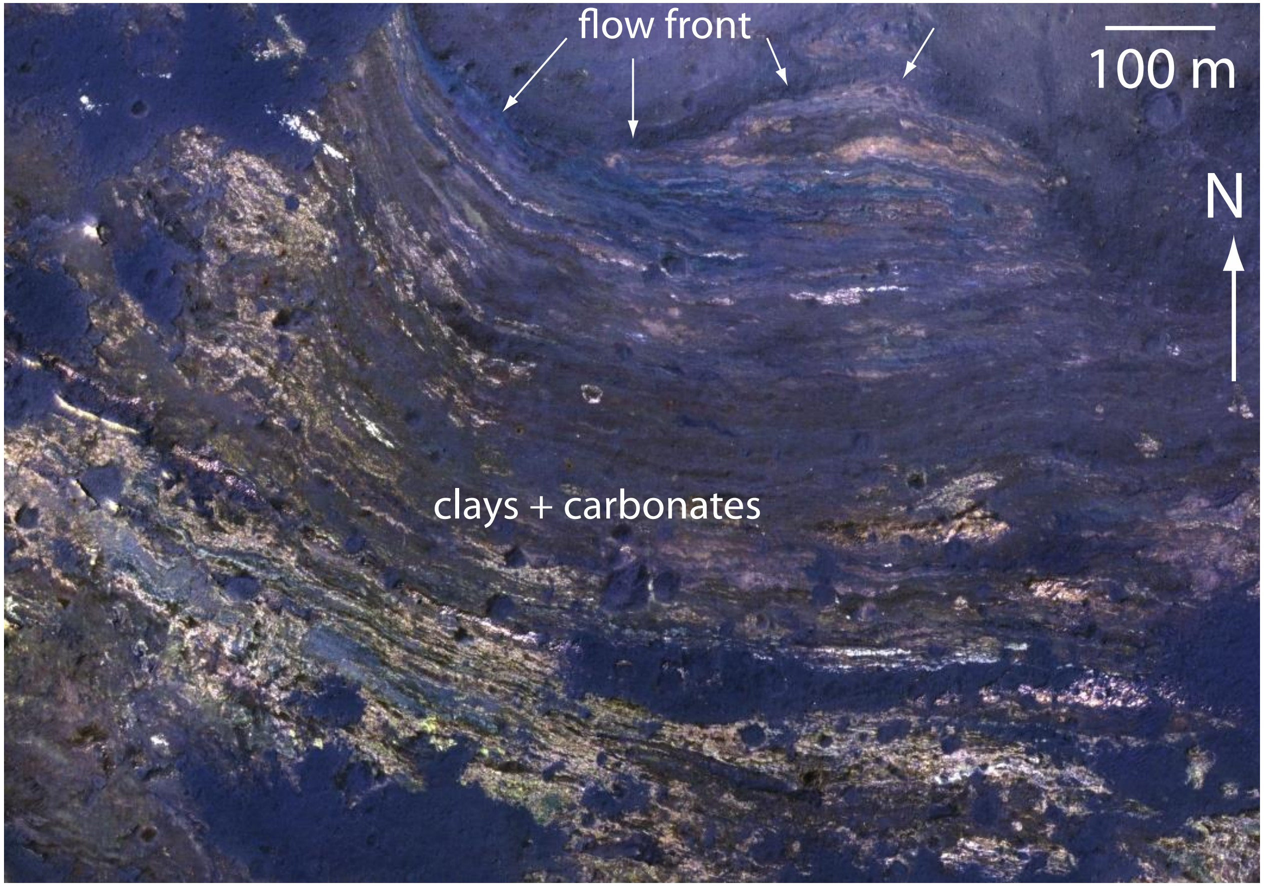

Dark unit
(igneous,
stratigraphic
marker)


1000 m

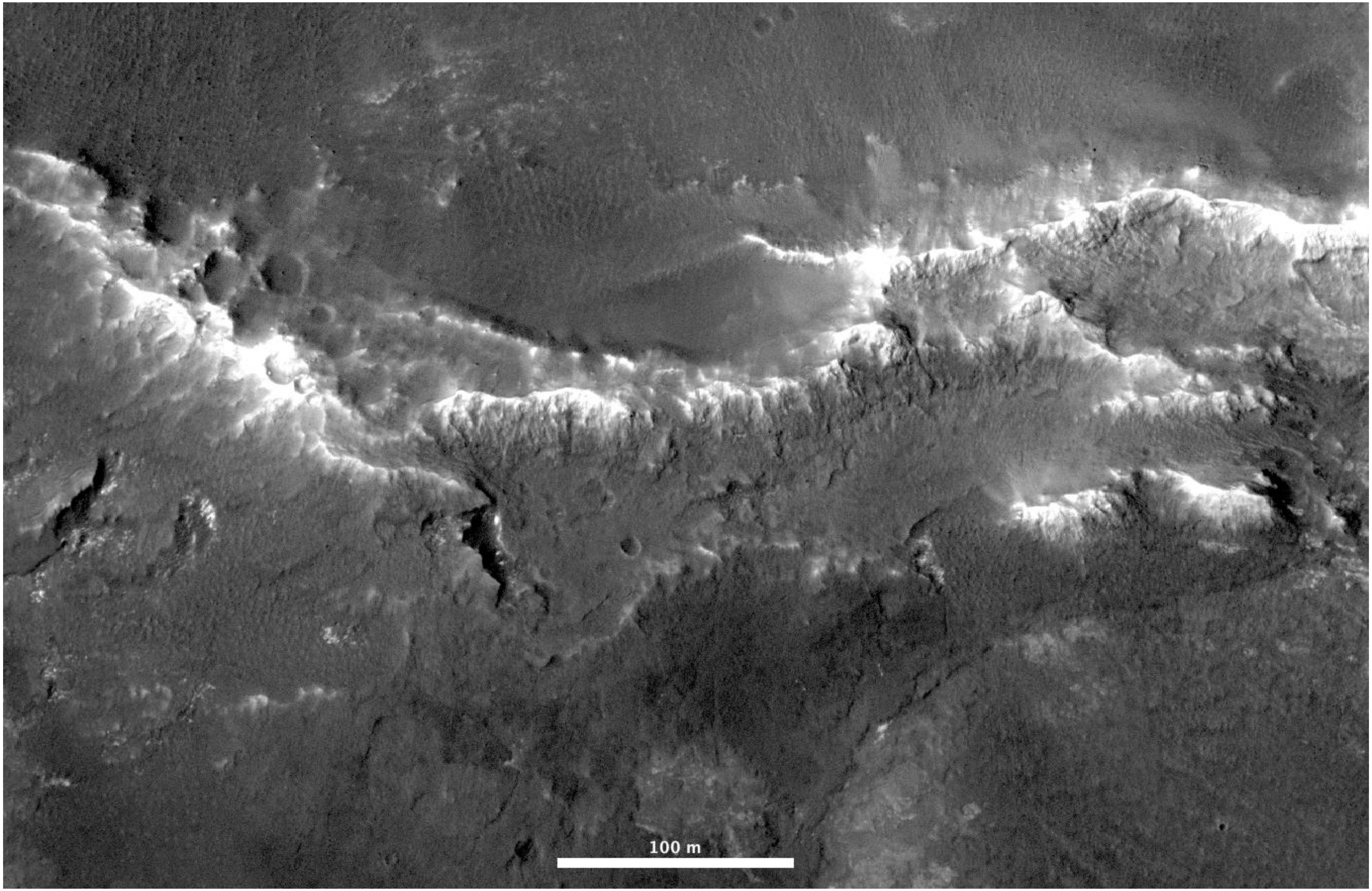

Ejecta from Keren Crater and/or debris flow (unambiguously aqueously altered)

Morphology of debris flow

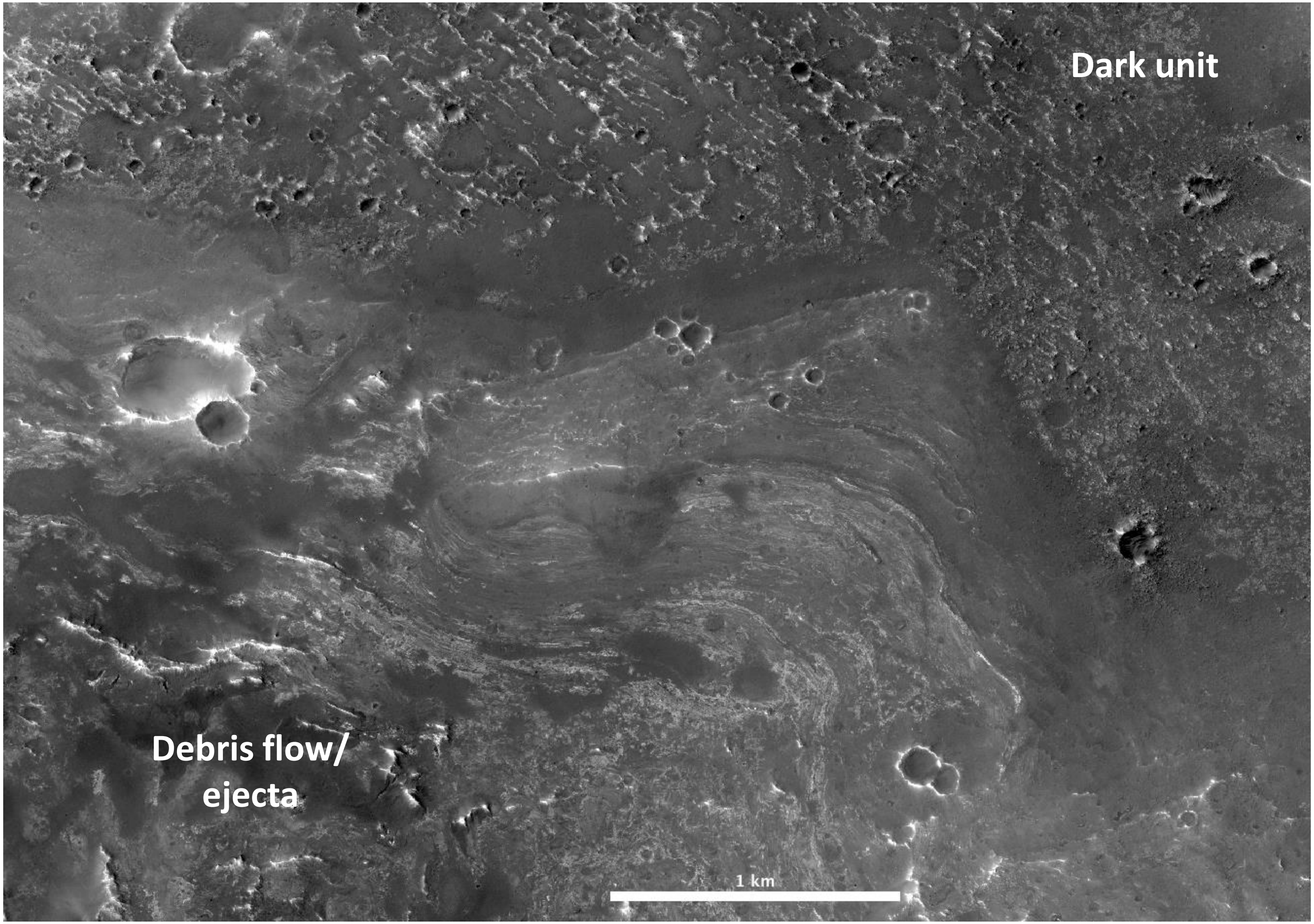




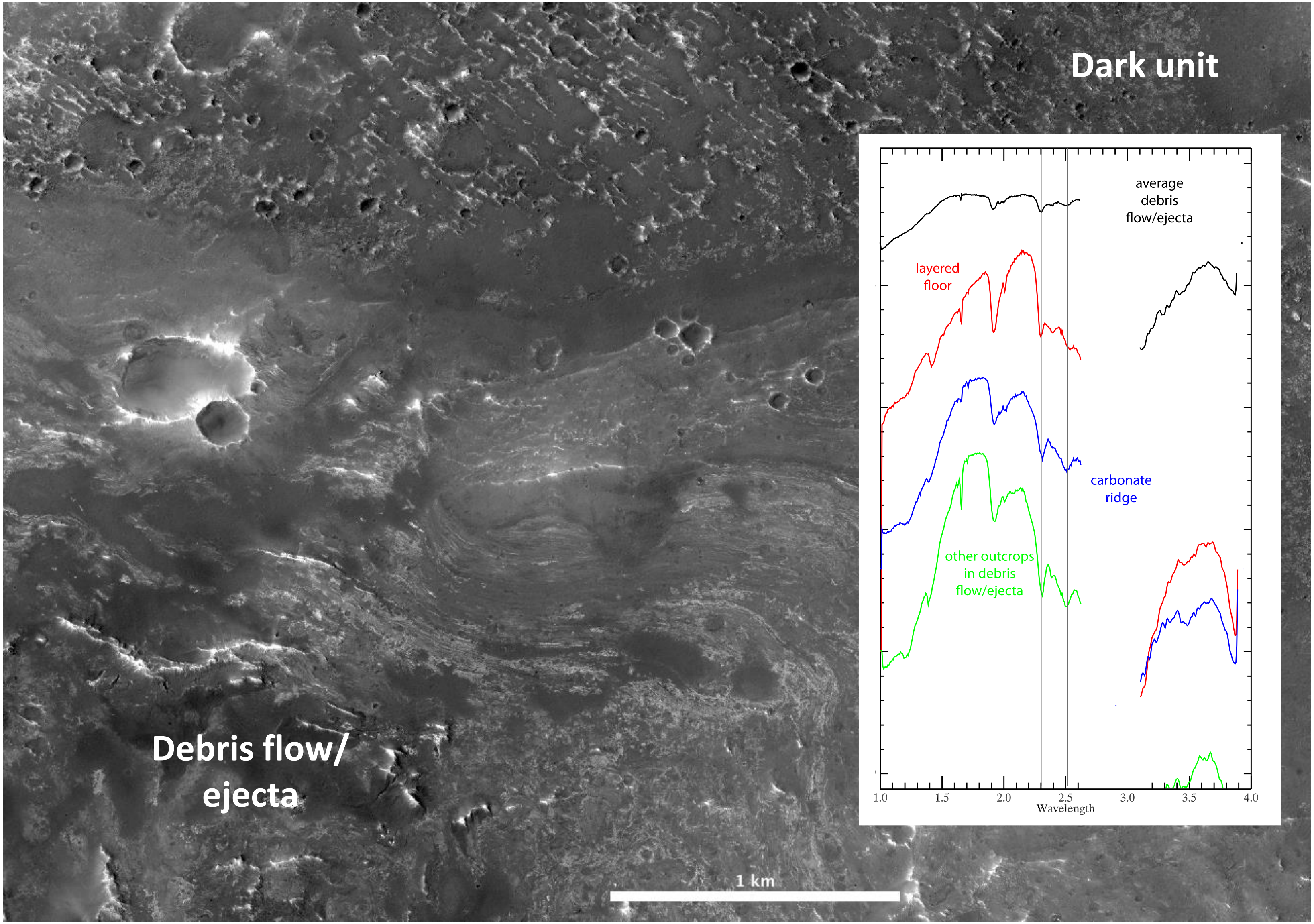
Ridges in the debris flow/ejecta



Debris flow/ejecta: was it wet?

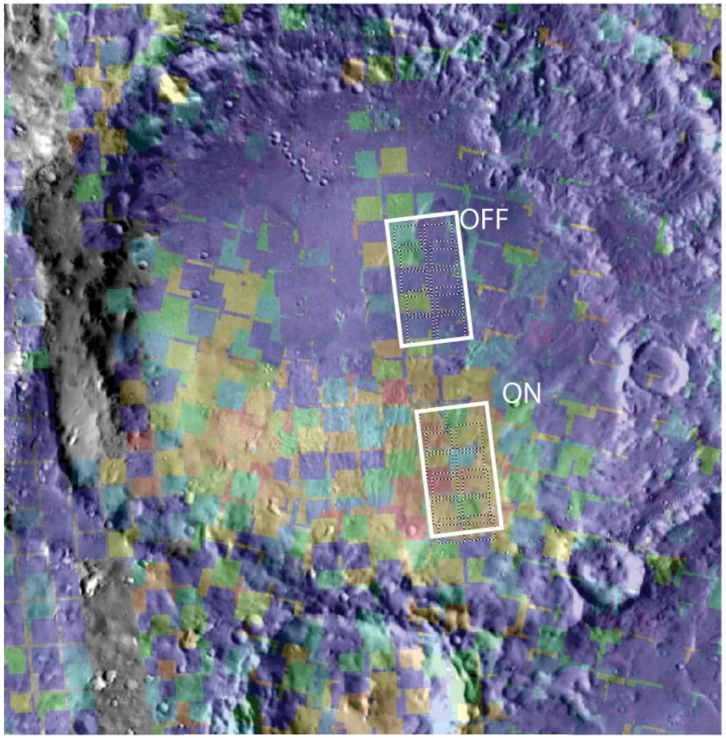


Debris flow/ejecta: was it wet?



Evidence for igneous phases?

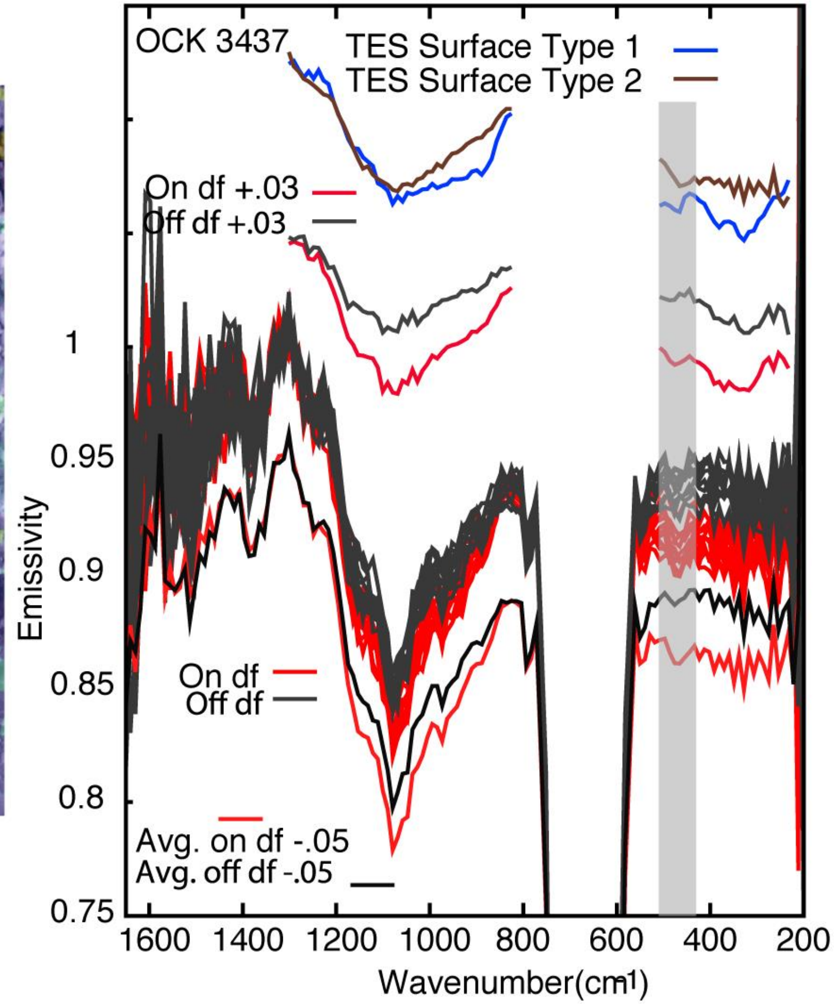
McLaughlin Crater



Derived mineral abundances OCK 3437

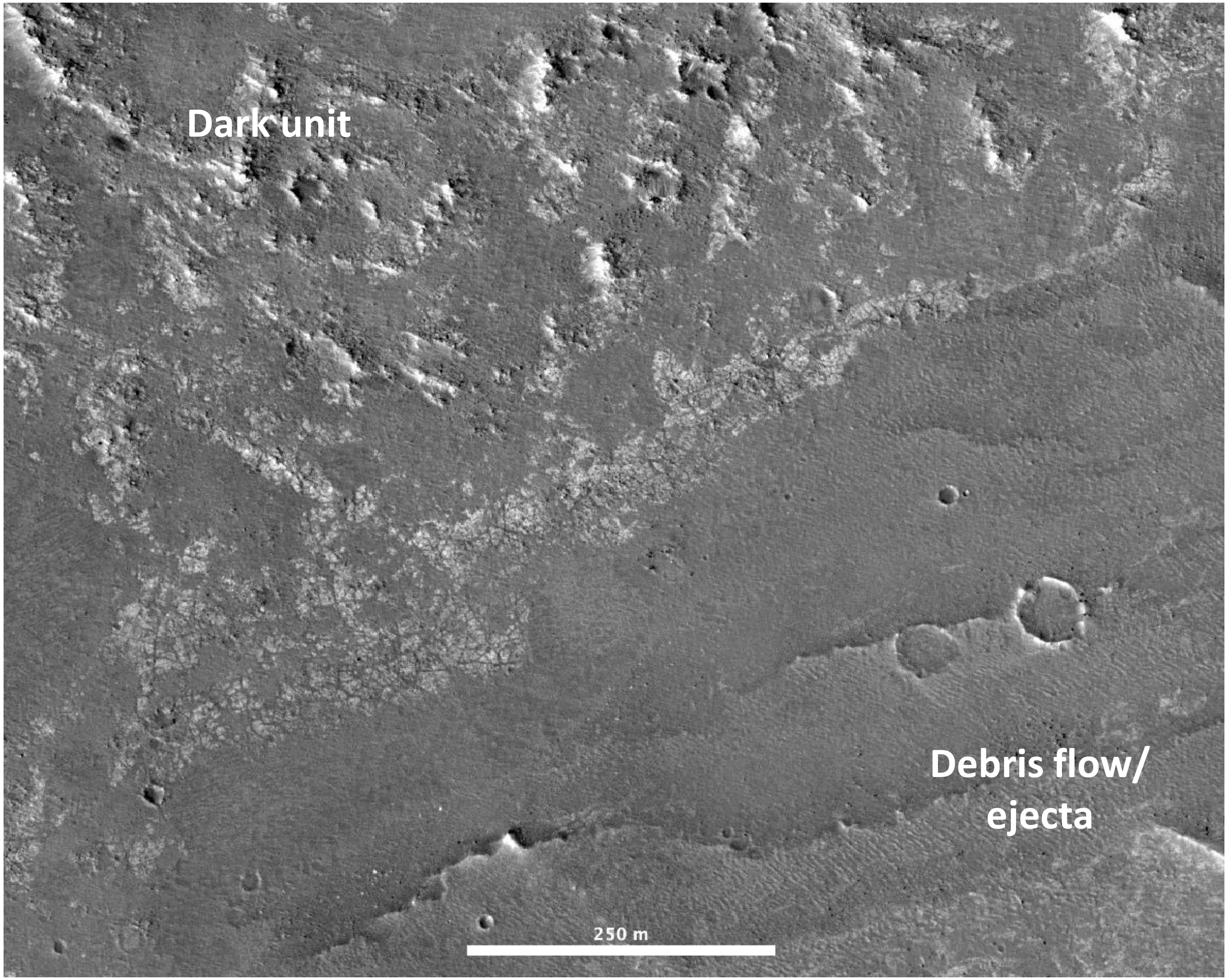
	On DF
Feldspar	30(4)
High-silica	25(4)
Pyroxene	27(3)
Sulfate	8(2)
Carbonate	6(1)
Olivine	4(2)
Other	2

TES

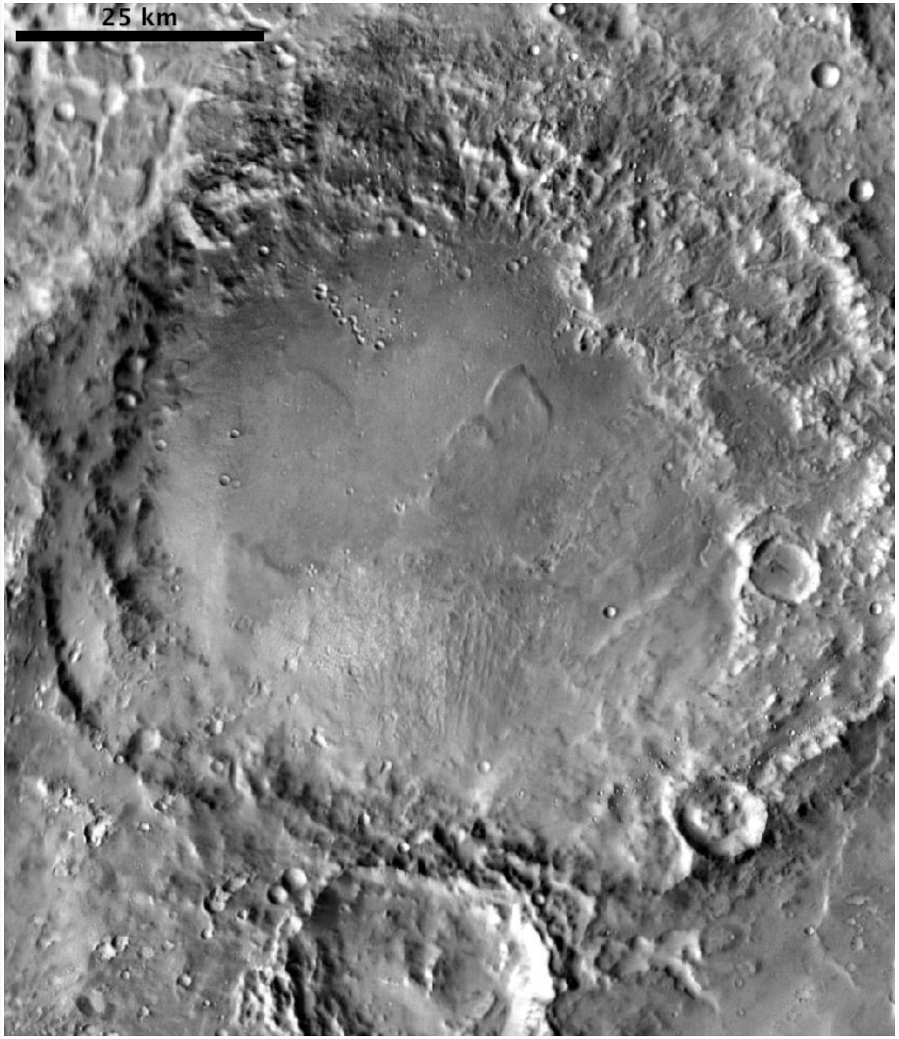


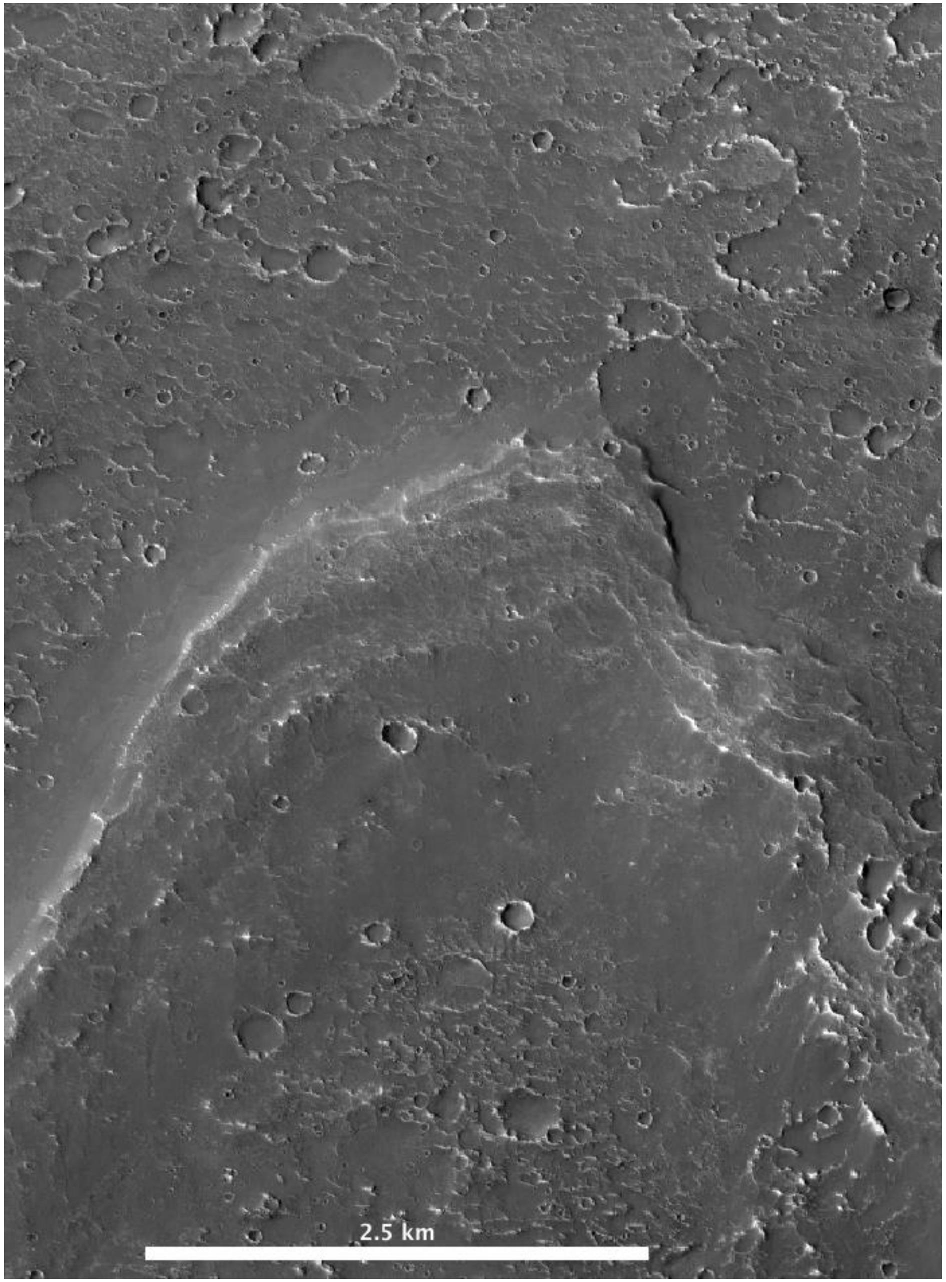
Michalski et al., Nature Geoscience, 2013

Mystery #3: Why isn't the dark unit altered?



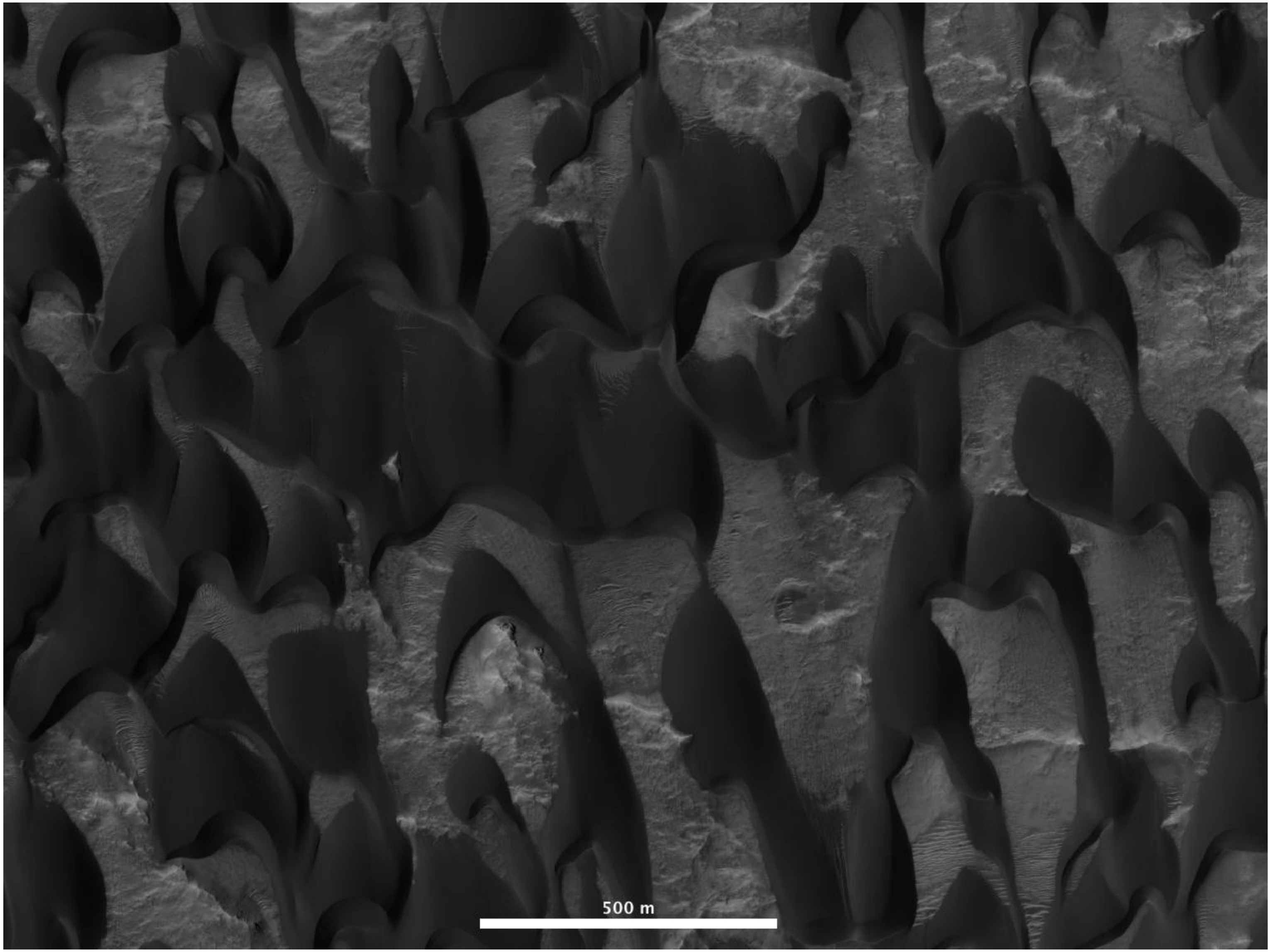
MYSTERY FEATURE

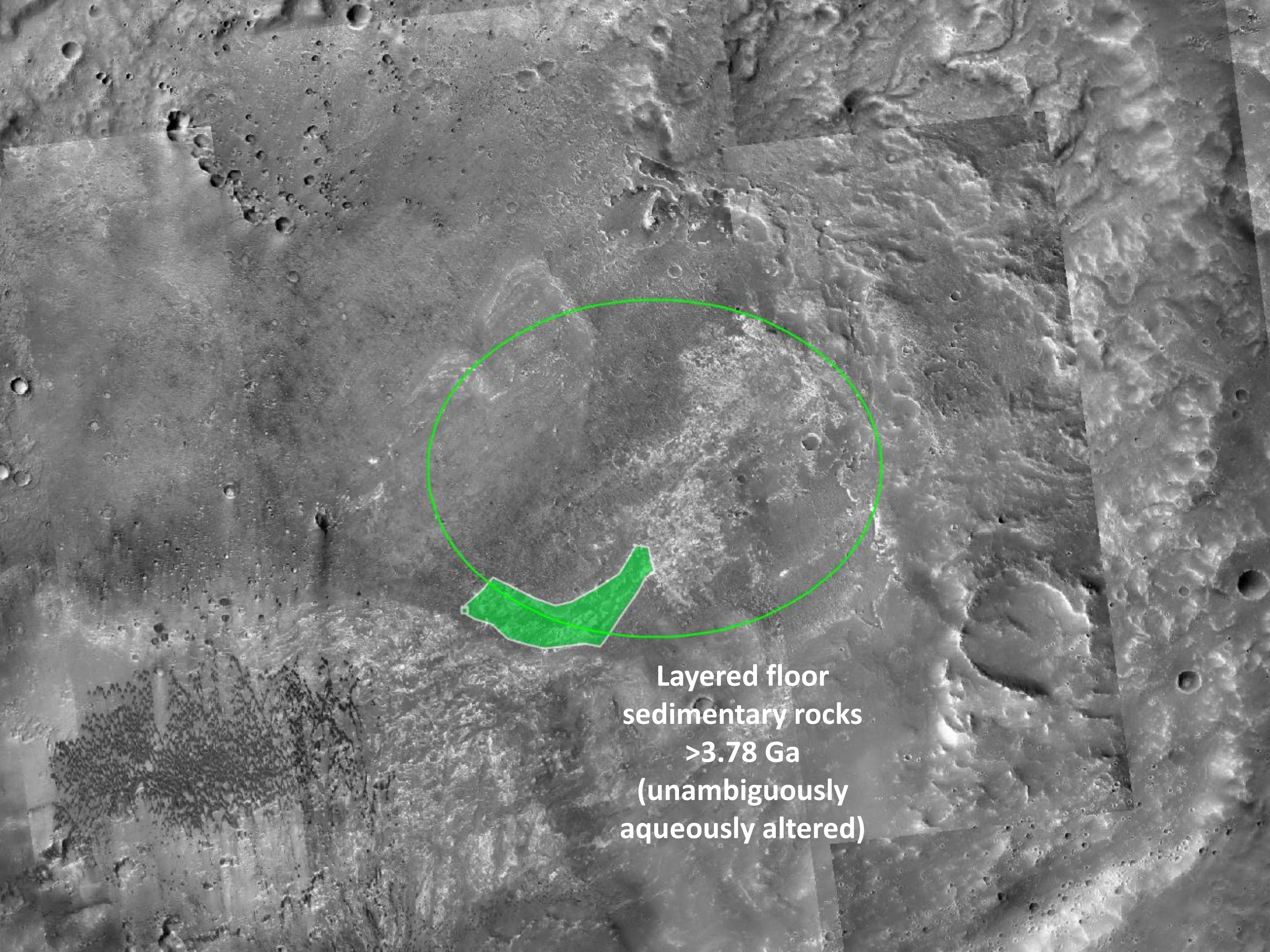




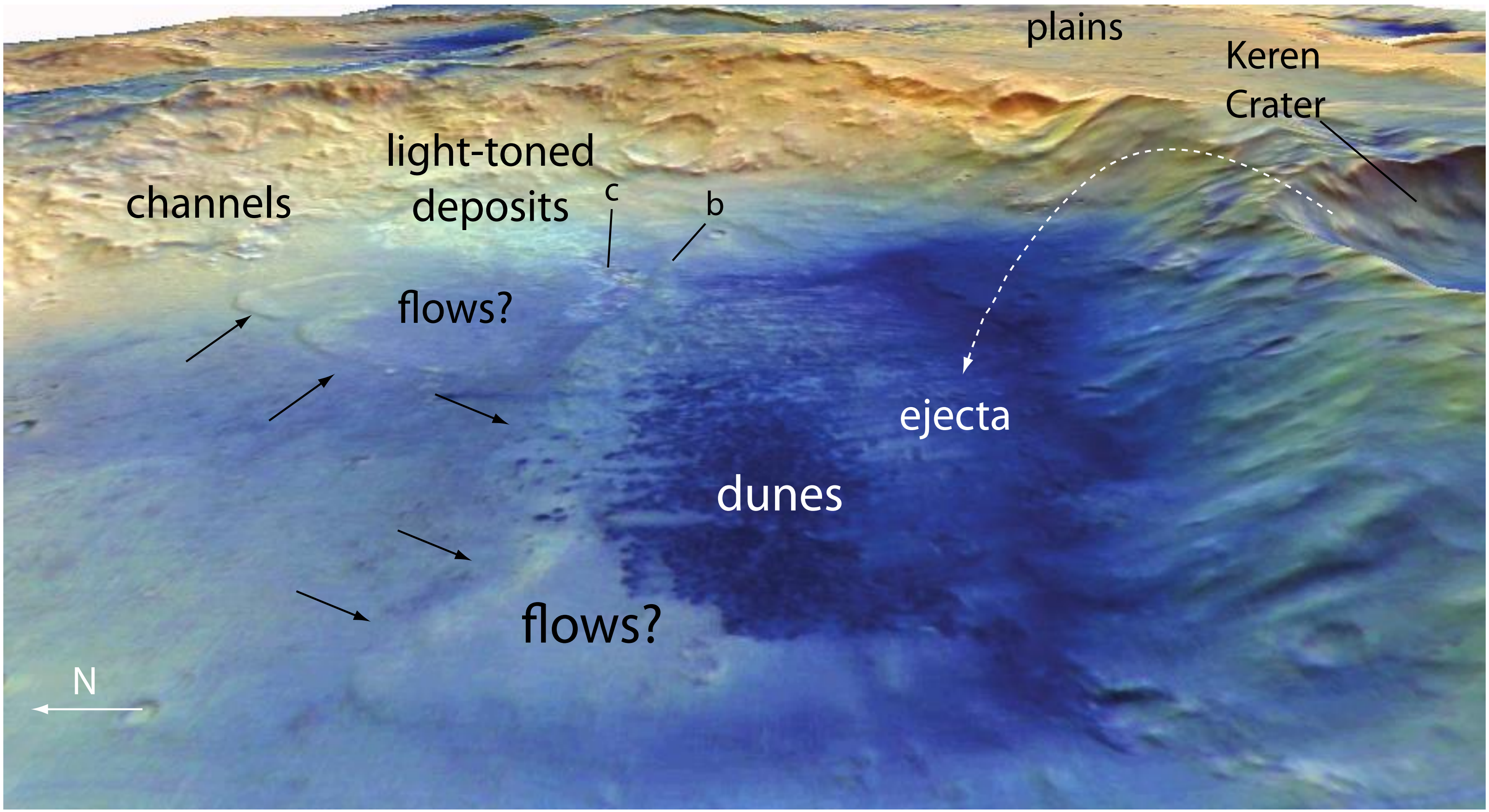
Clues to youthful surfaces?

Few craters, reworking by sand



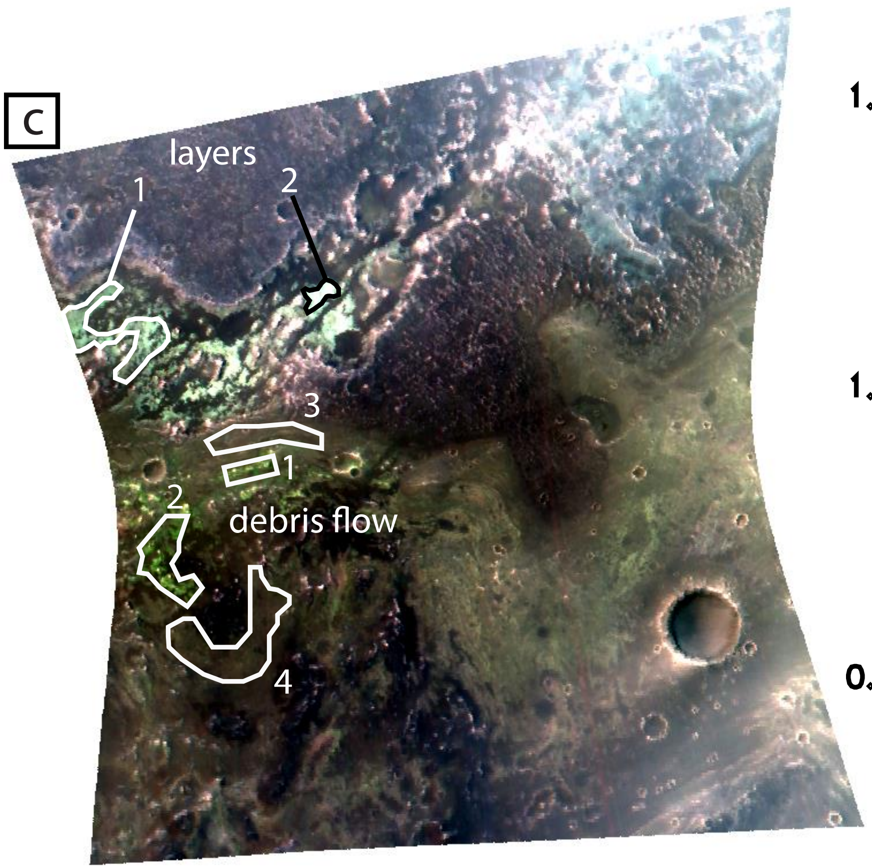

Layered floor
sedimentary rocks
>3.78 Ga
(unambiguously
aqueously altered)

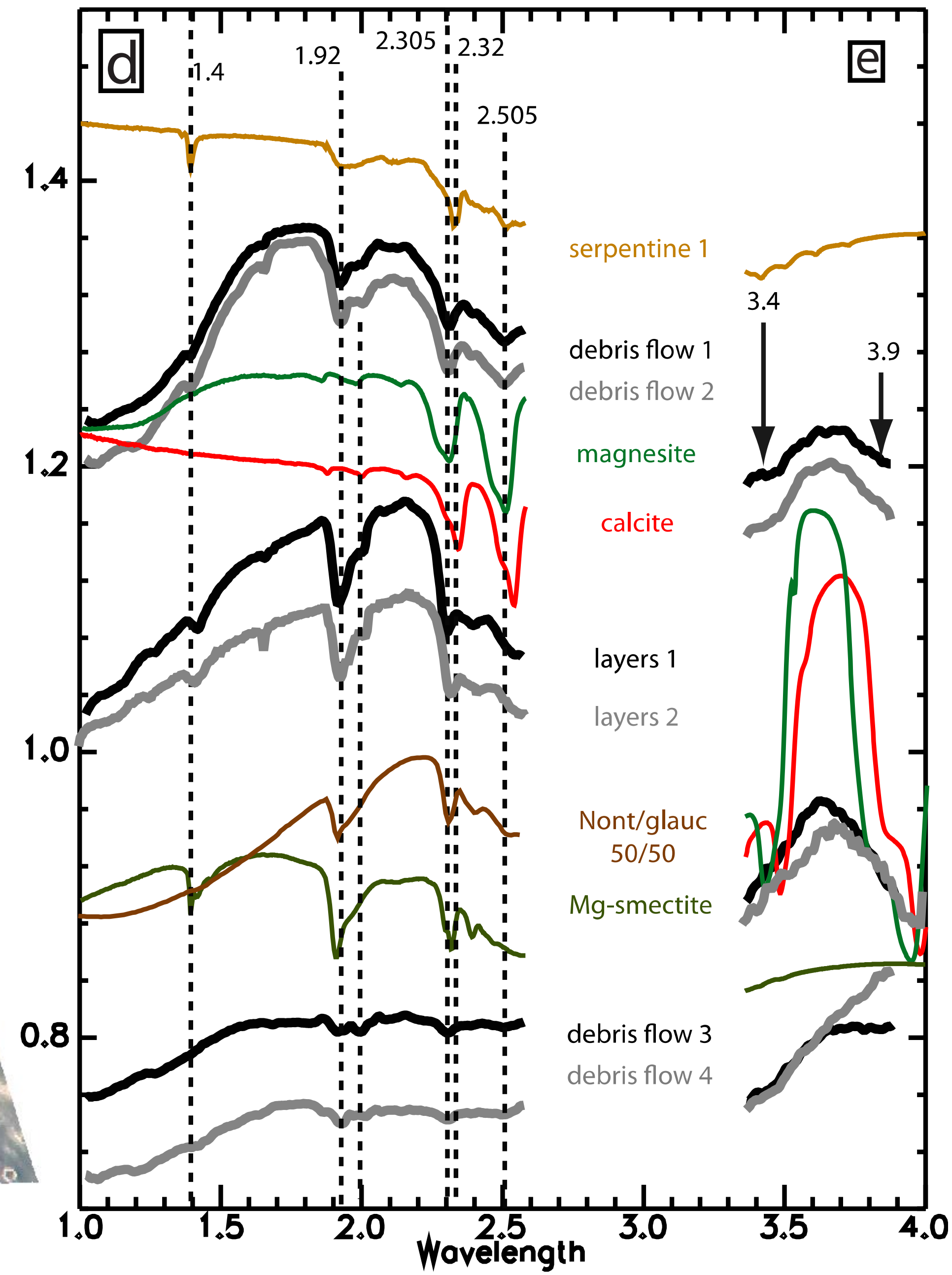
LAYERED SEDIMENTS AND LOBATE MATERIALS



CRISM RESULTS

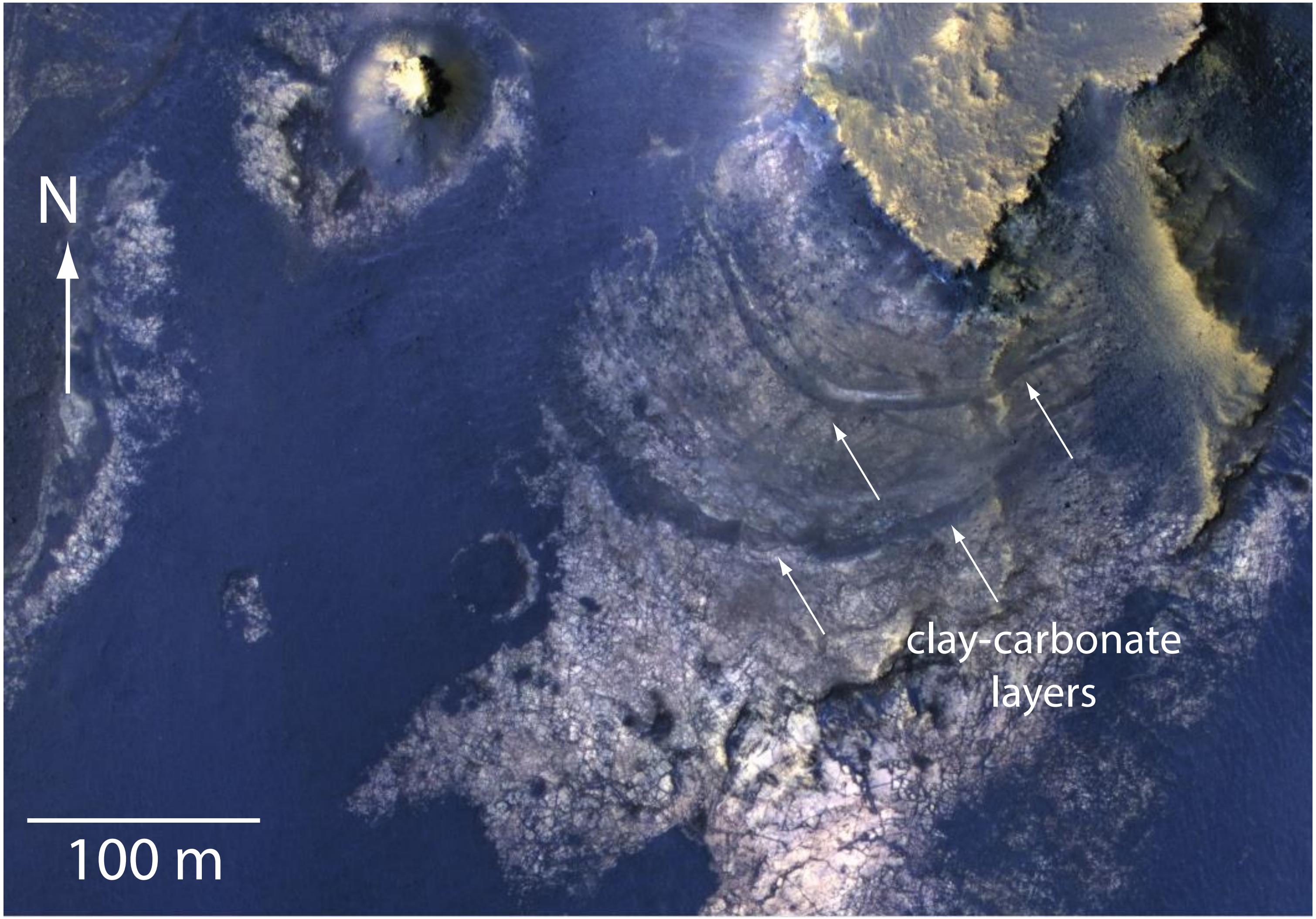
CLAYS AND CARBONATES





Michalski et al., Nature Geoscience, 2013

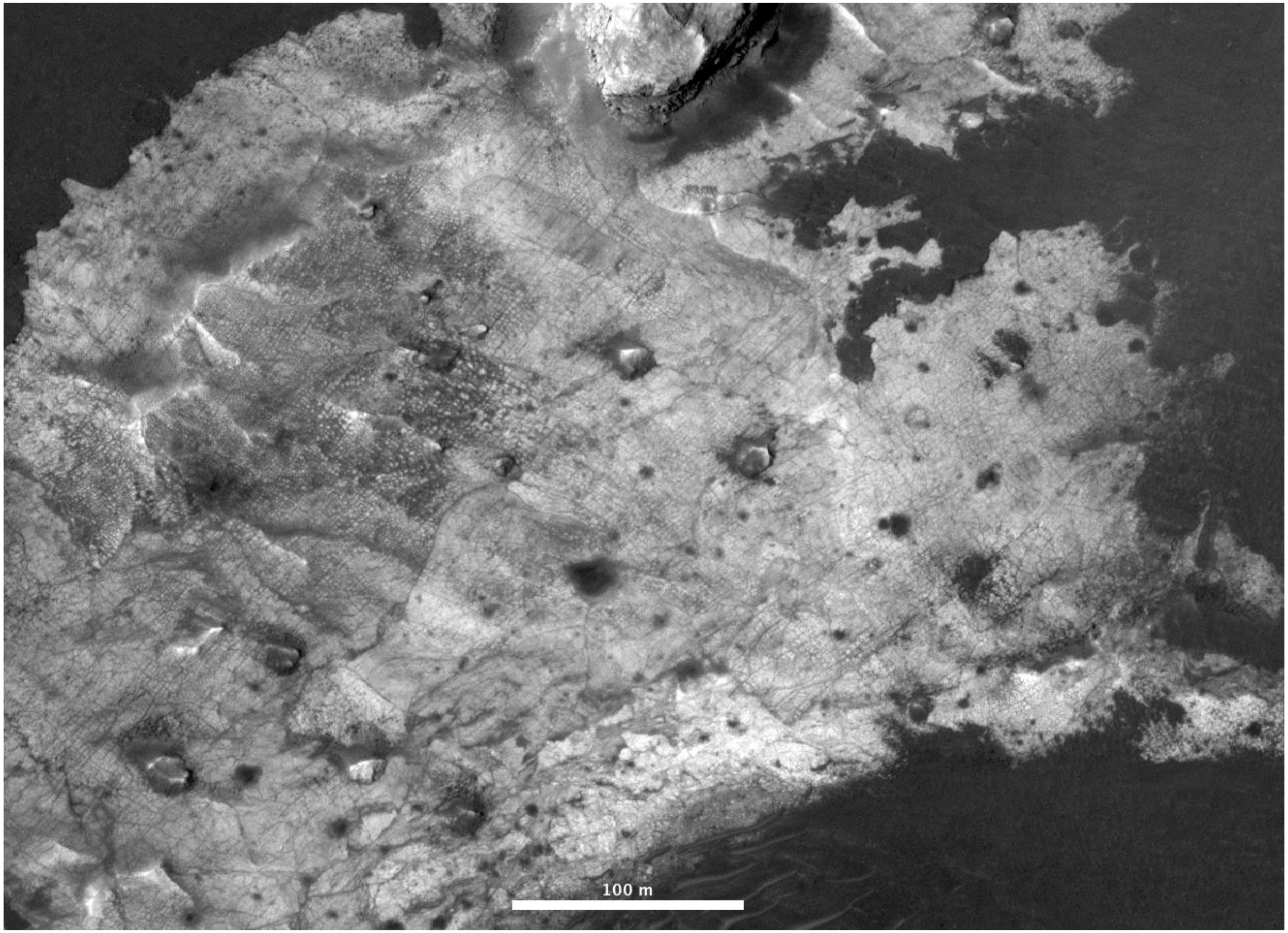
LAYERED UNITS ON THE CRATER FLOOR



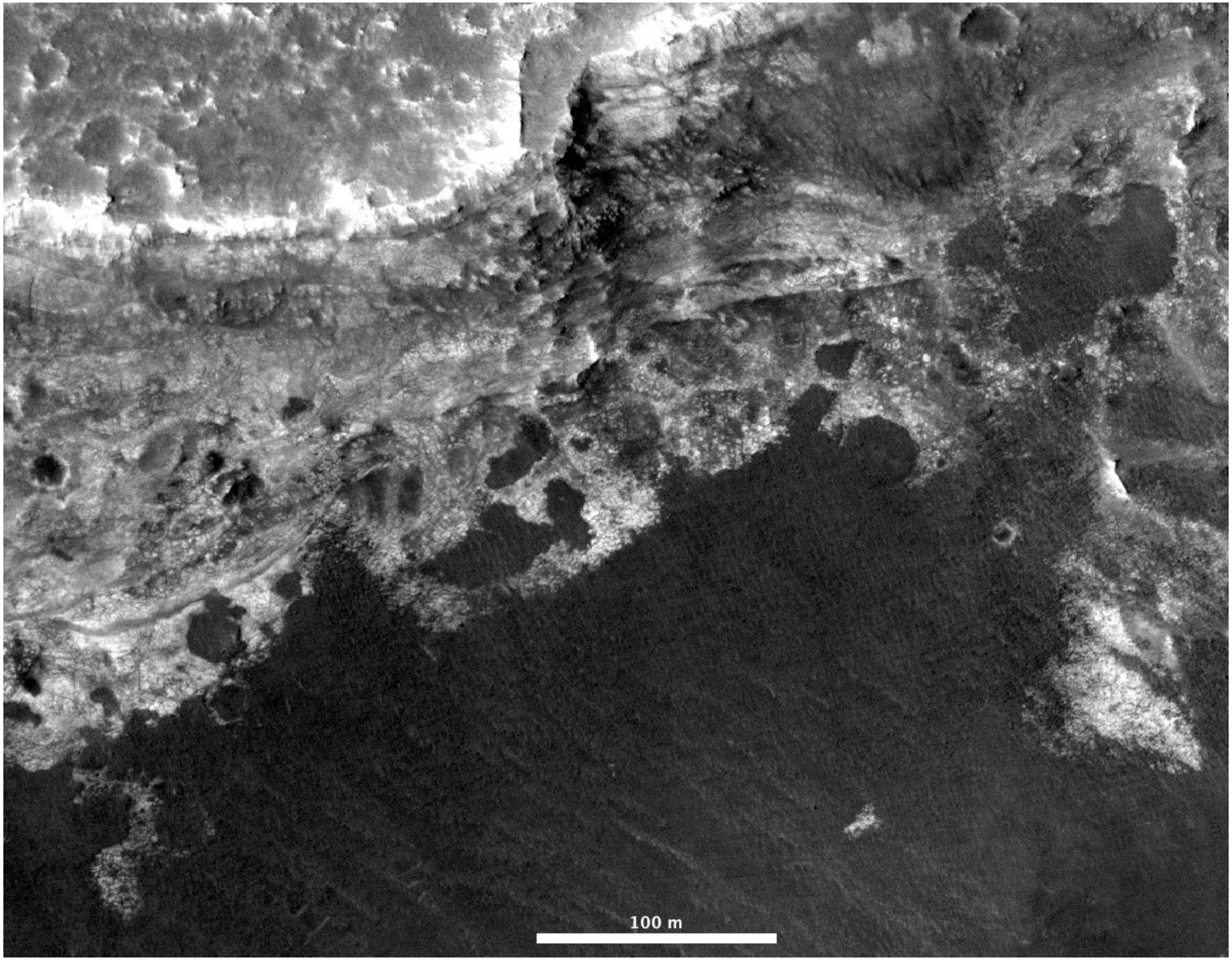
HiRISE Imaging

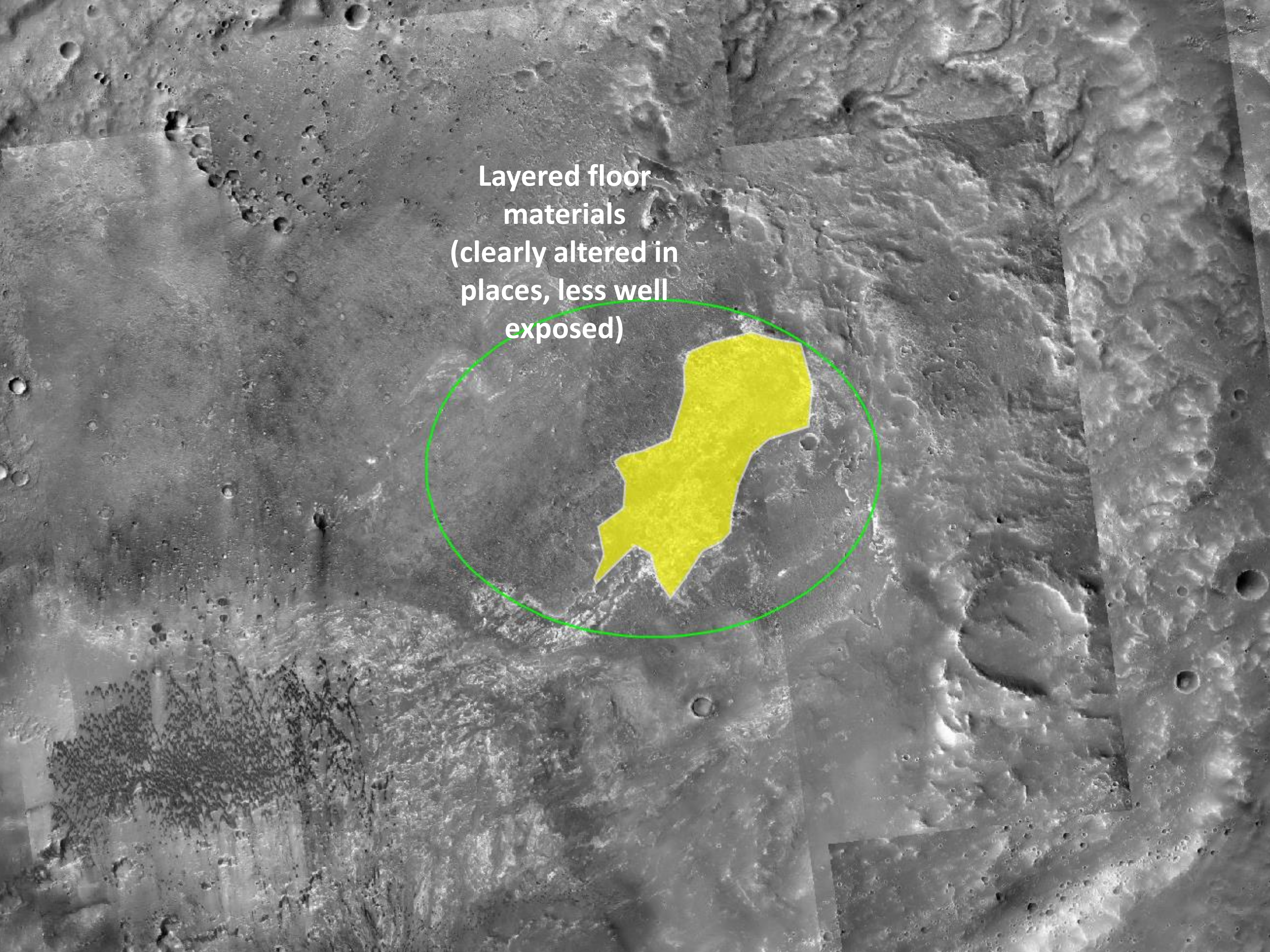
Clues to youthful surfaces?

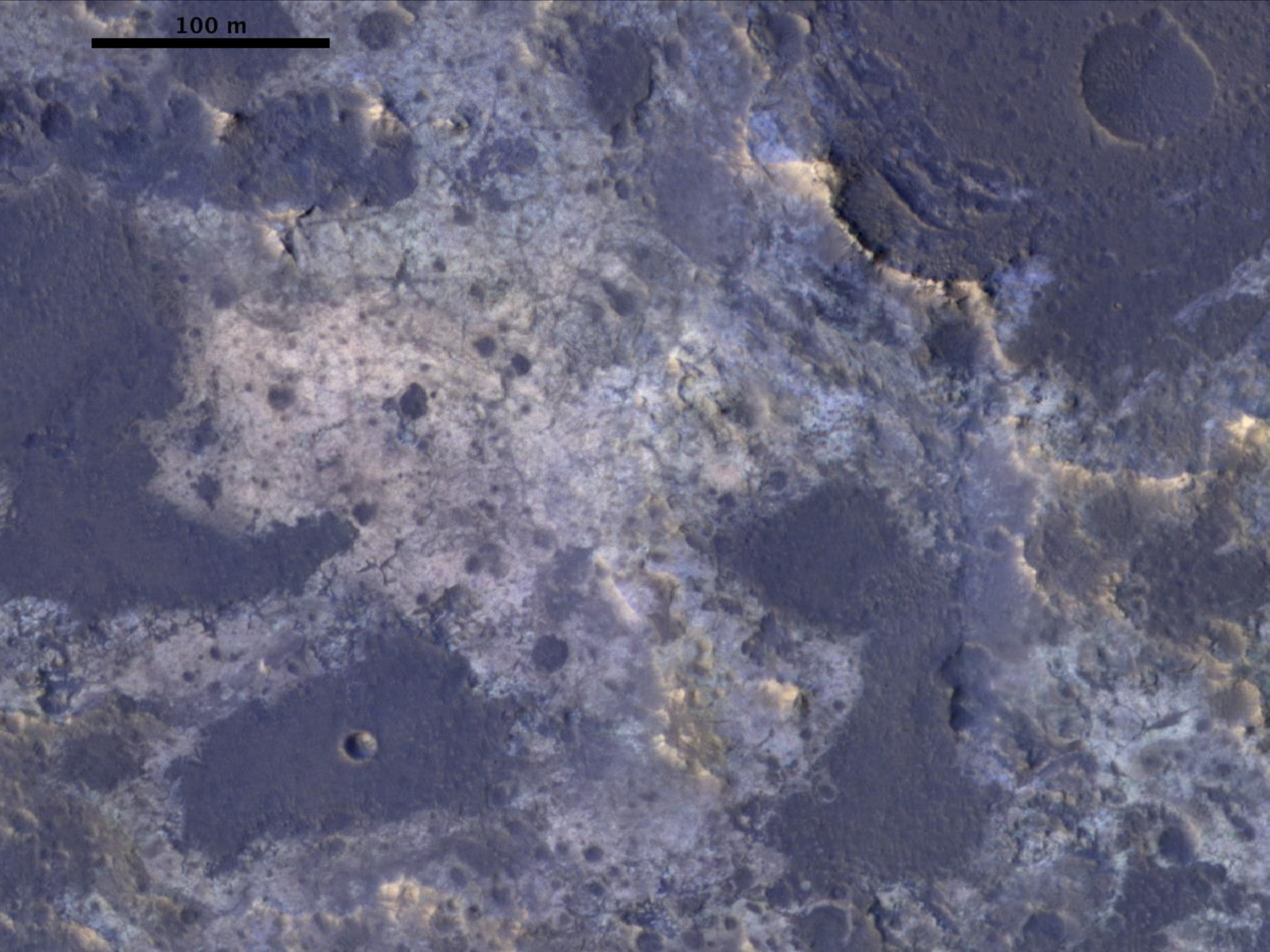
Few craters, eroded buttes, reworking by sand

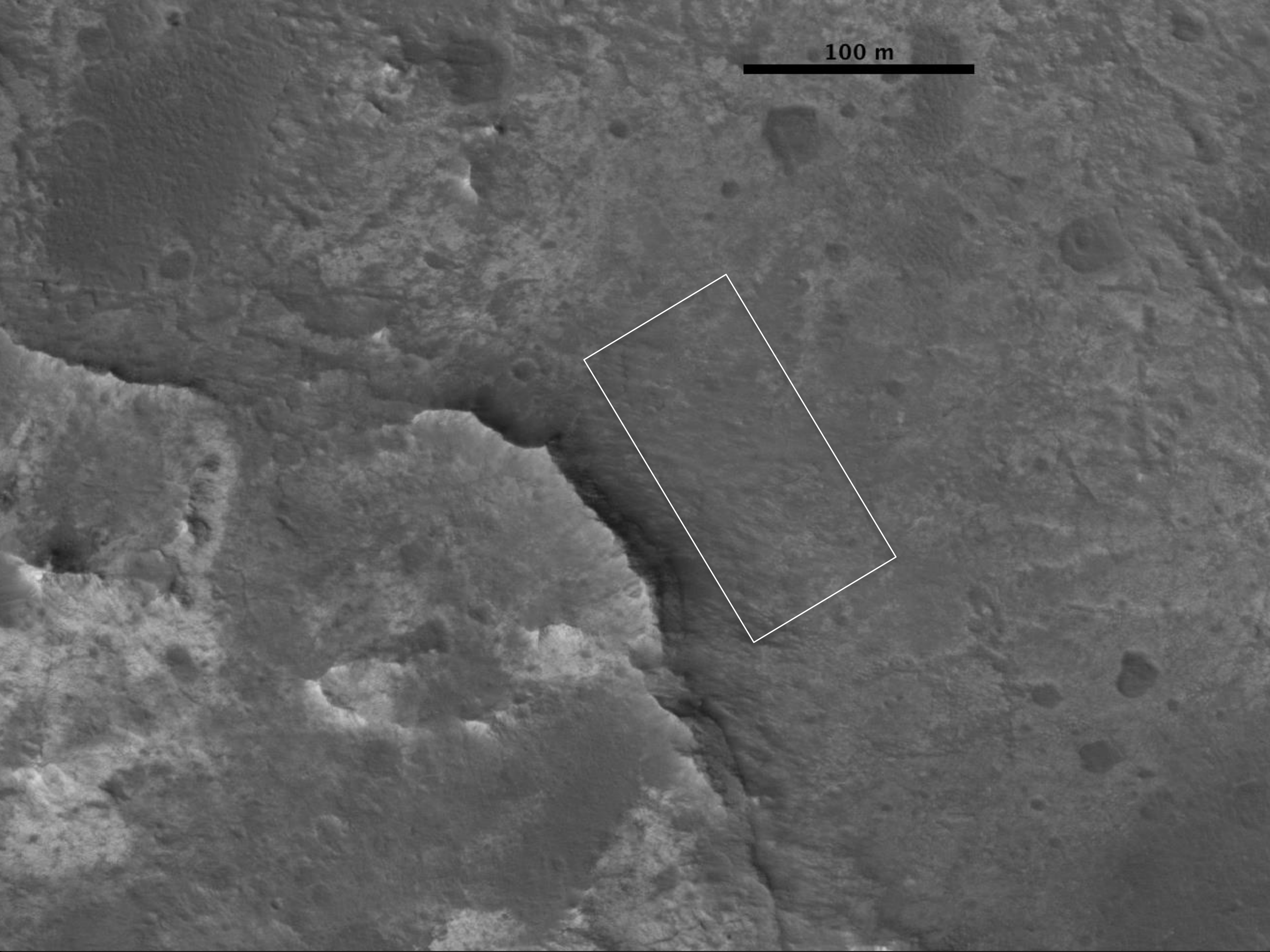


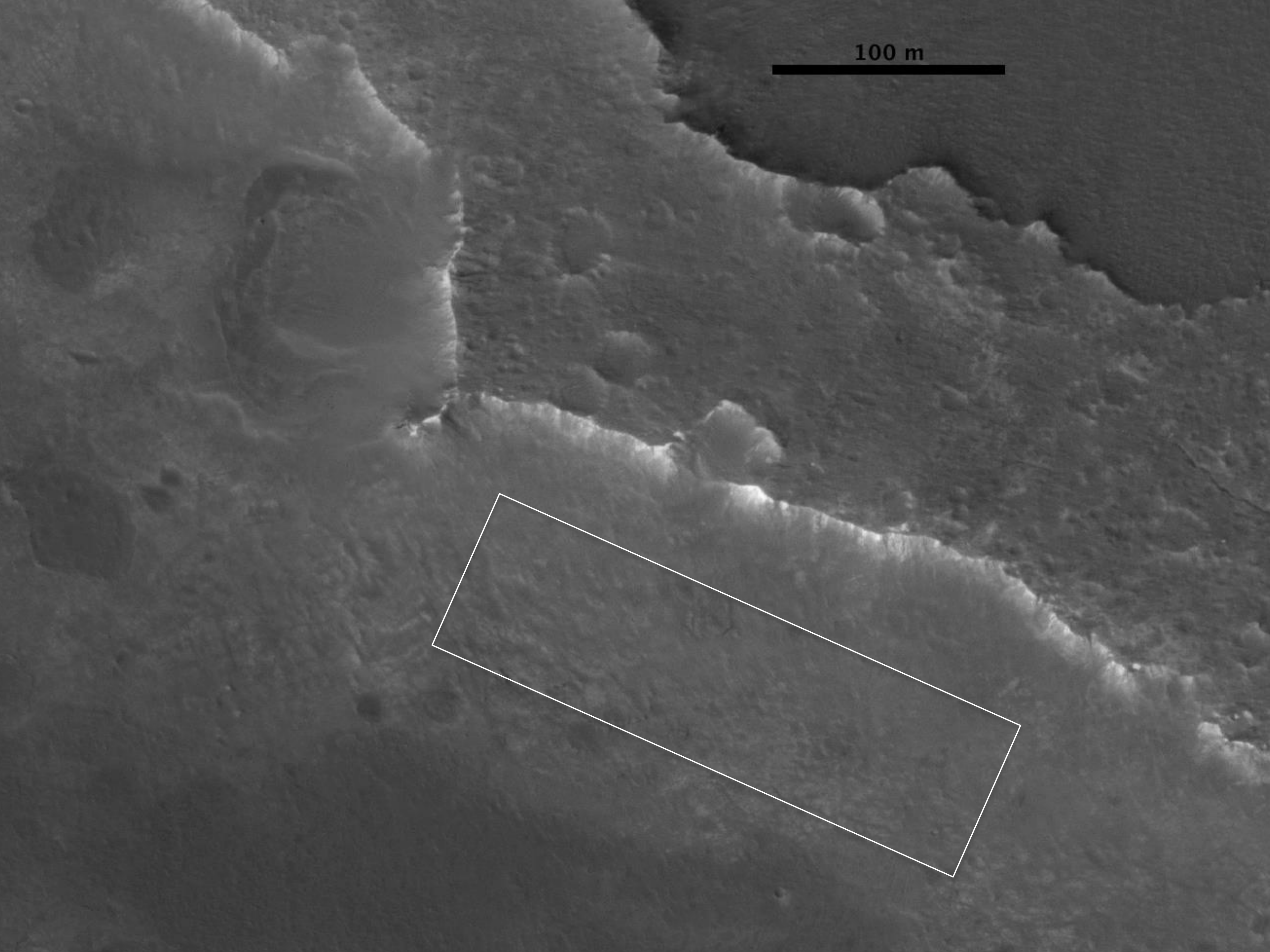
Interesting bedding in the floor unit

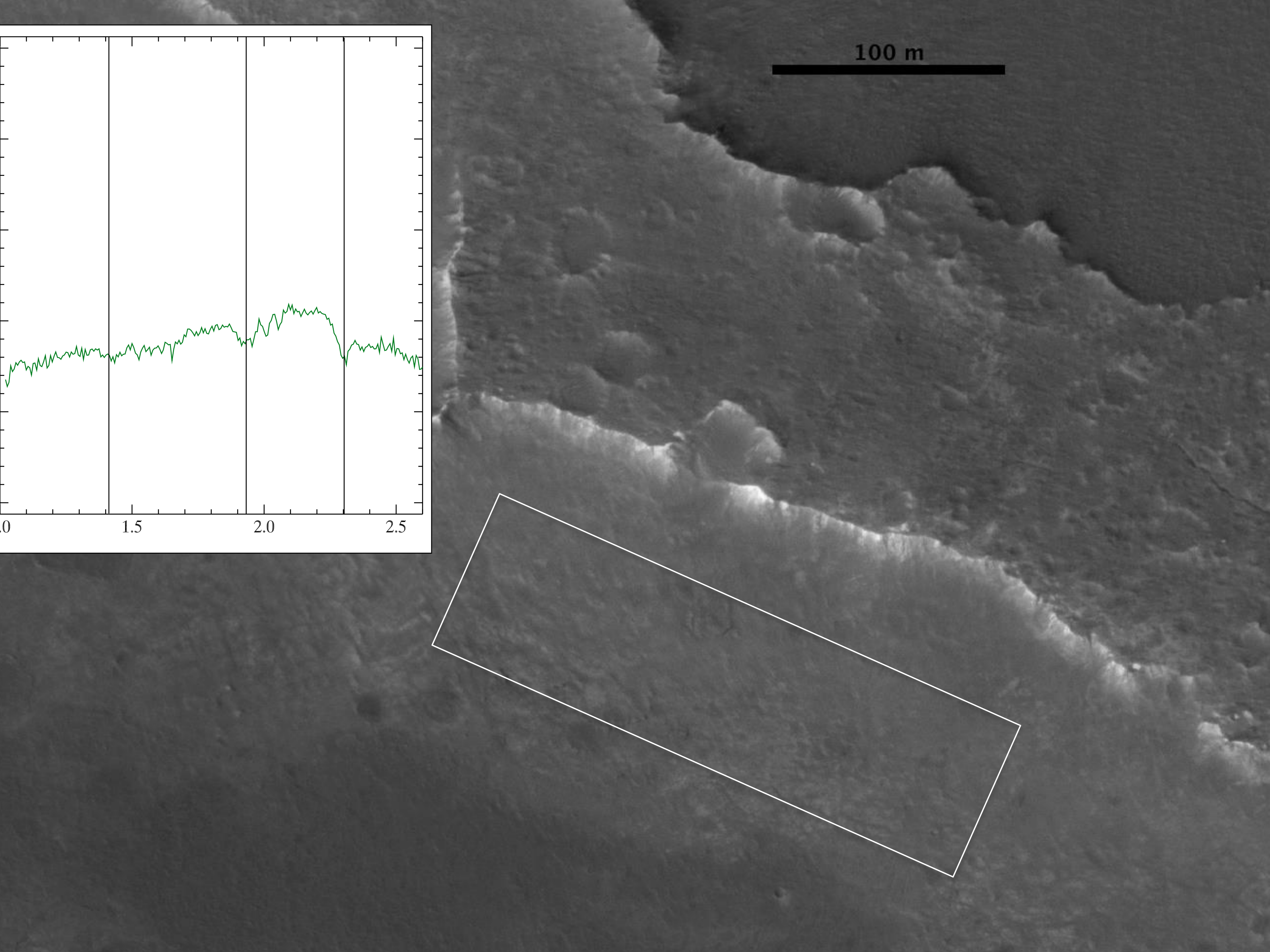



Layered floor
materials
(clearly altered in
places, less well
exposed)

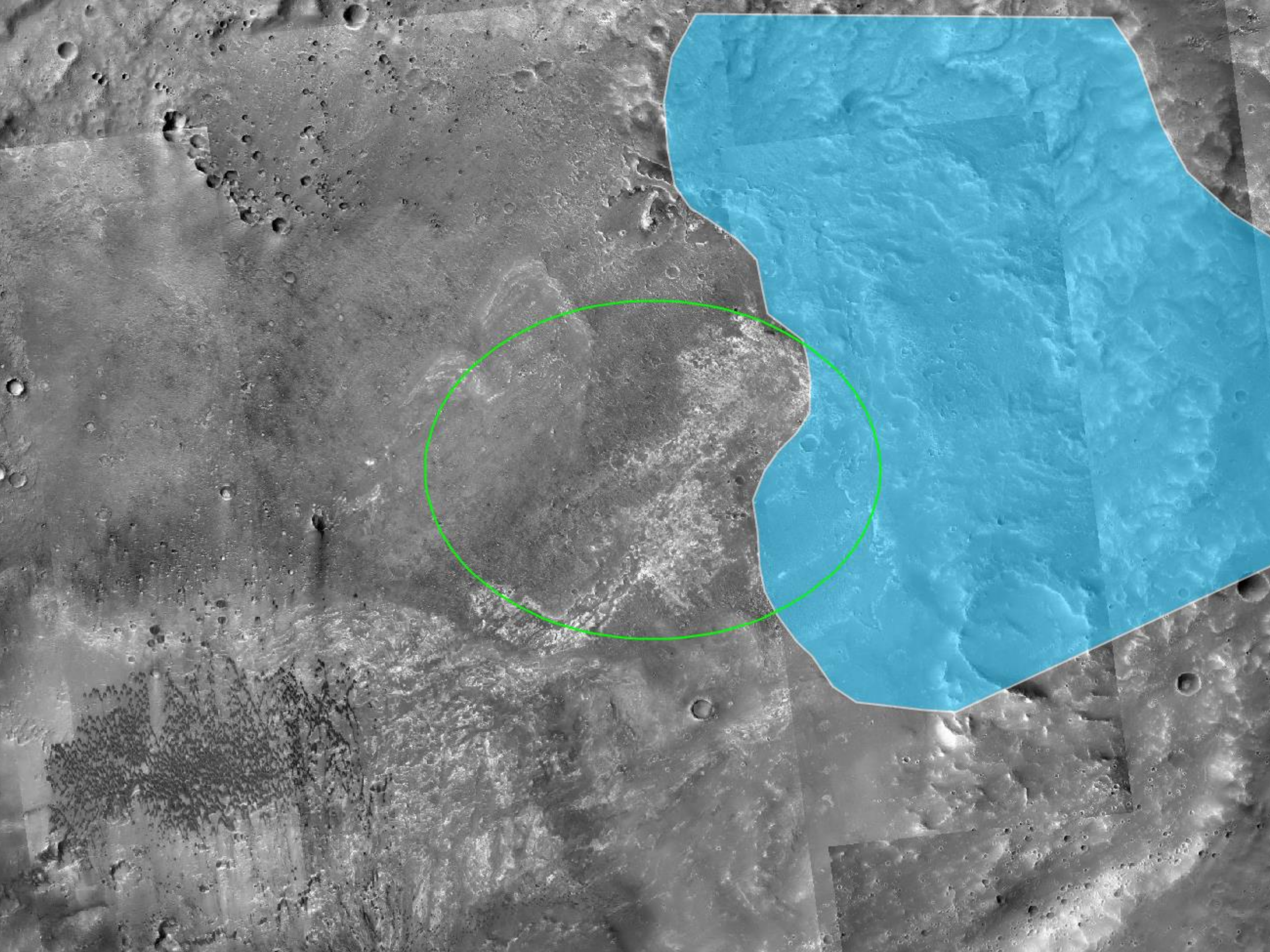

100 m


100 m

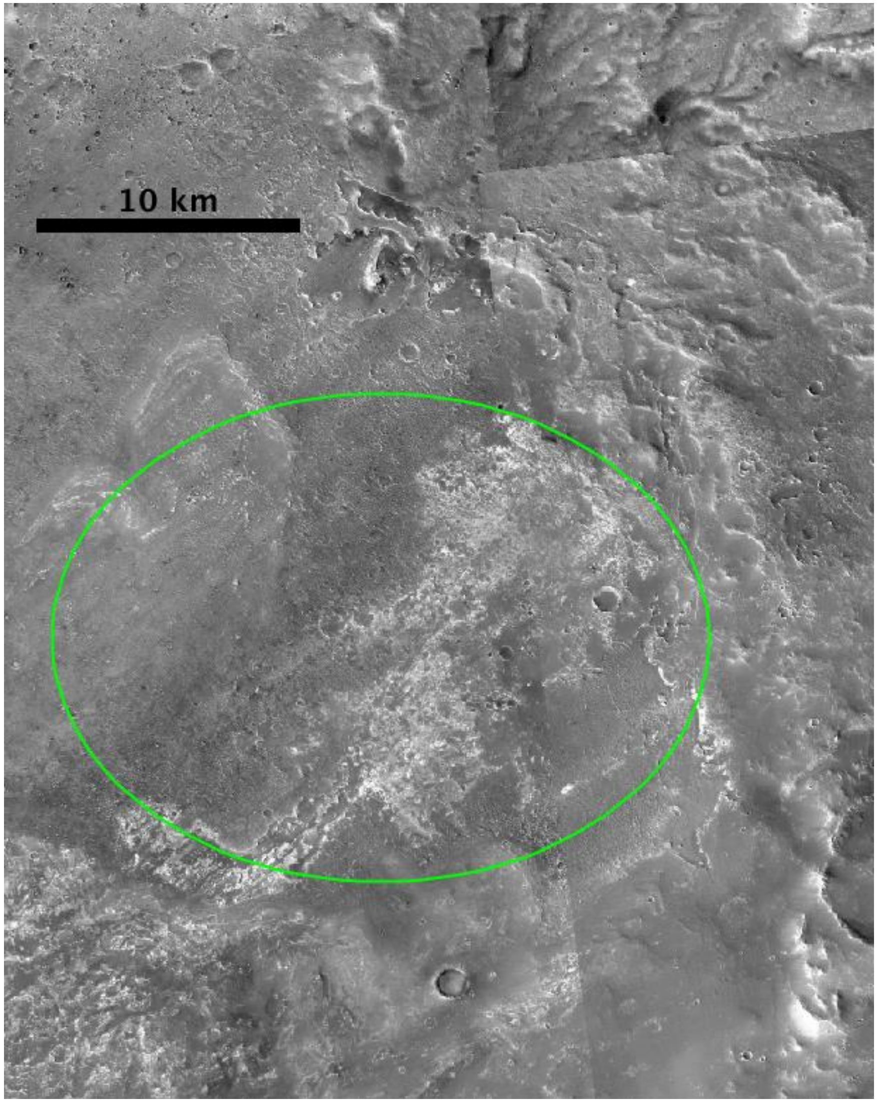

100 m

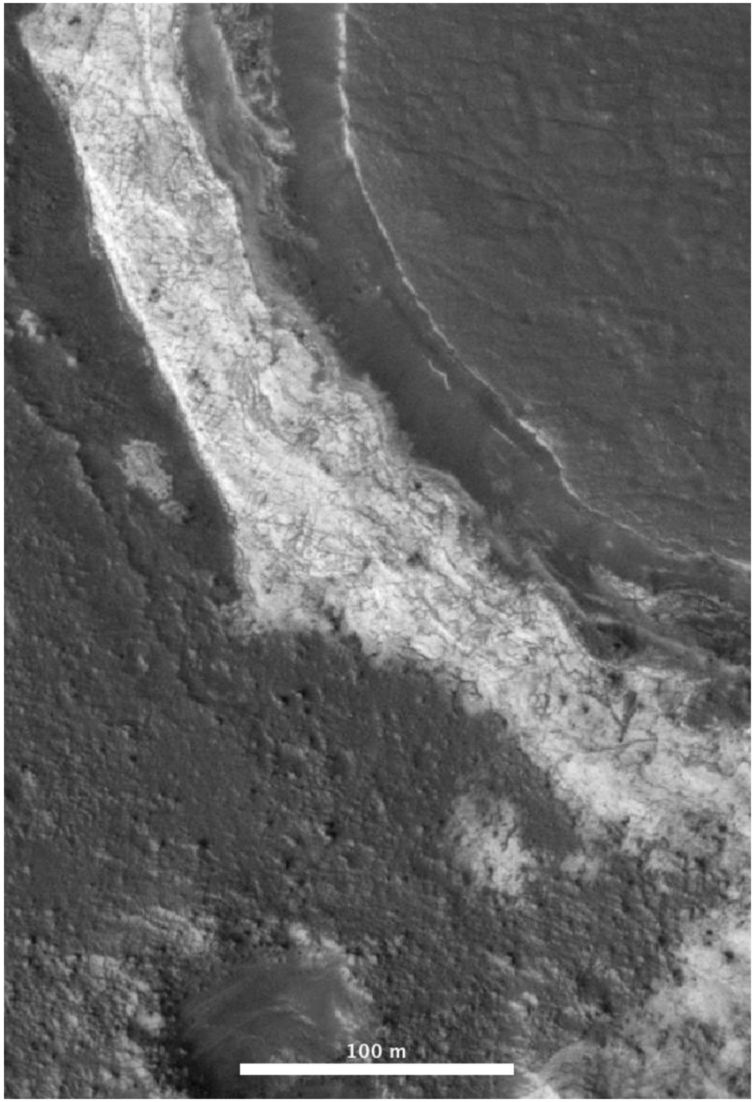


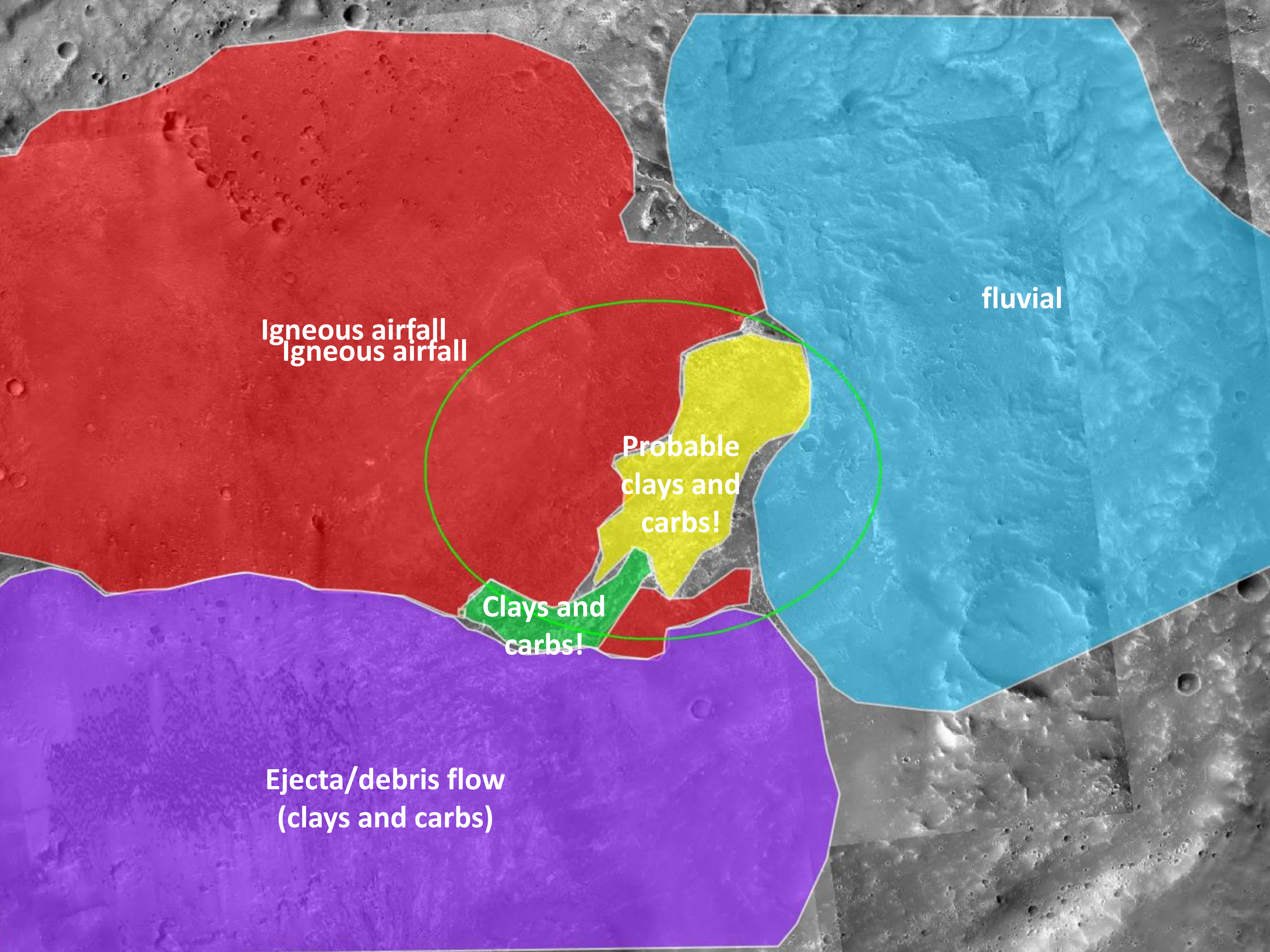
100 m
.0
1.5
2.0
2.5



Floor materials are widespread!






Igneous airfall
Igneous airfall
fluvial
Probable clays and carbs!
Clays and carbs!
Ejecta/debris flow (clays and carbs)

Appeal of Alkaline Systems

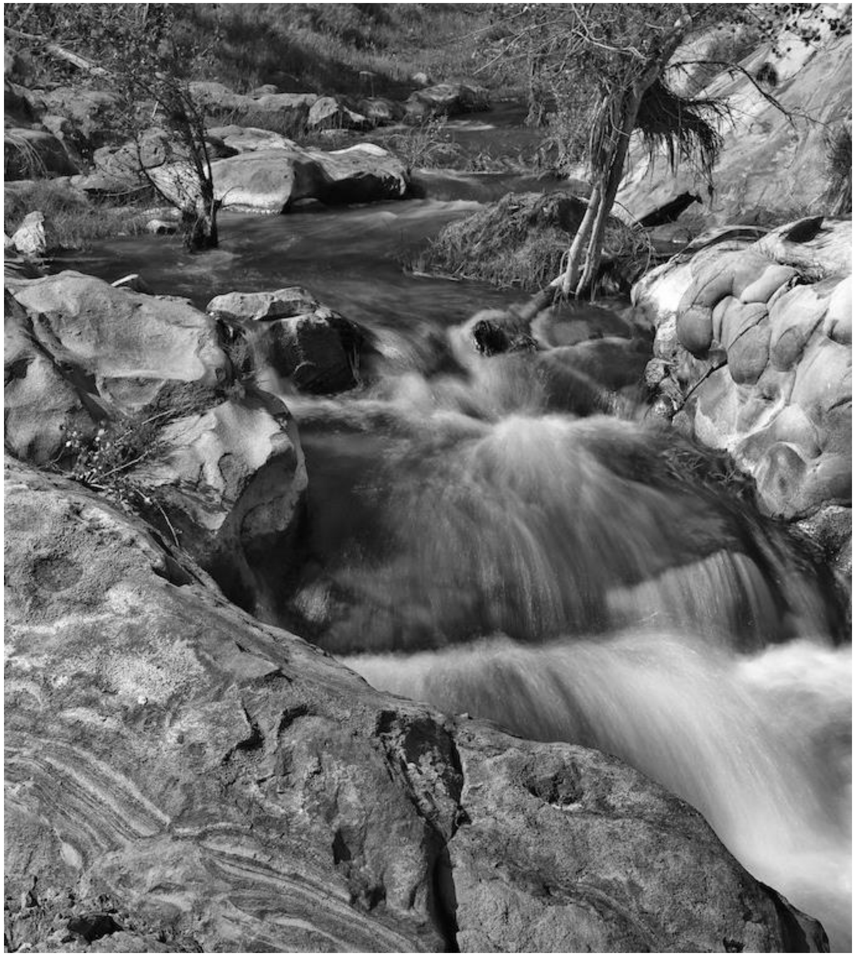
- Soda lakes are often characterized by high productivity (>10gcm^{-2} per day)
- Home to diverse functional groups of microbes (methanogens, methanotrophs, phototrophs, denitrifiers, sulfur oxidizers, sulfate reducers, syntrophs…)
- Abundant in terrestrial deserts and steppes, believed to have existed throughout Earth's geological history

LONAR CRATER LAKE

- Only impact crater in the Deccan Traps
- Ca/Mg-Rich
- High Microbial Diversity, High Cell Counts (Wani et al., 2006; Antony et al., 2012)
- Spatial Heterogeneity of Lipid Biomarkers (Sarkar et al., 2014)

Ophiolite-hosted Alkaline Springs

- Del Puerto Ophiolite has been studied as a Mars Analog (Blank et al., 2011)
- Methane and hydrogen from the process of serpentinization serve as sources of energy for chemosynthetic organisms



Landing Site Factor	Mars 2020 Mission and Decadal Priority Science Factors																						
	Environmental Setting for Biosignature Preservation and Taphonomy of Organics								Type 1A & 1B Samples: Aqueous Geochemical Environments indicated by Mineral Assemblages									Type 2 Samples: Igneous		Context: Martian History Sampled, Timing Constraints				
	Deltaic or Lacustrine (perennial)	Lacustrine (evaporitic)	Hydrothermal (<100°C) surface	Hydrothermal (<100°C) subsurface	Pedogenic	Fluvial/Alluvial	No diagenetic overprinting	Recent exposure	Crustal phyllosilicates	Sedimentary clays	Al clays in stratigraphy	Carbonate units	Chloride sediments	Sulfate sediments	Acid sulfate units	Silica deposits	Ferric Ox./Ferrous clays	Igneous unit (e.g, lava flow, pyroclastic, intrusive)	2nd Igneous unit	Pre- or Early-Noachian Megabreccia	Oldest stratigraphic constraint	Youngest stratigraphic constraint	Stratigrapy of units well-defined	Dateable surface, volcanic (unmodified crater SFD)
McLaughlin	●	~	~	~		○		~	~	●		●				~	~	●	~		LN	?	●	●
	layer, nearly flat-lying floor materials, carbonates, Fe-Mg-clays, termination of channels in wall	same as above, but also unconformities in wall stratigraphy could mean the lake dried up	likely involved authigenic formation of clays and carbonates in deep water environments, at least during some periods	lake almost certainly fed by subsurface fluids, clear alteration minerals, but lacks obvious high-T phases; ejecta/debris flow certainly contains subsurface materials	No	Channels in wall, fan deposits (colluvium or weakly developed delta?)	difficult to know	evidence for sand erosion, few small craters, eroding buttes, fresh surfaces	almost certainly exhumed by Keren Crater, but not clearly proven	Very strong evidence for high Fe clays in layered floor and in ejecta/debris flow	no	very strong features of Mg-carbonates	no	no	no	TES spectral index data and some THEMIS analyses Michalski et al., 2013)	clays likely contain some Fe^{2+}	Cratered dark airfall unit; great time-stratigraphic marker in the MV area	model-based evidence; no direct observation; geologically highly reasonable, however	no	IF this is the same marker bed as in Mawrth (3.78 b.y.)	there are active eolian processes today/recently	yes, floor stratigraphy is clear	yes, probably airfall

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Groundwater activity on Mars and implications for a deep biosphere

Joseph R. Michalski[1,2]*, Javier Cuadros[1], Paul B. Niles[3], John Parnell[4], A. Deanne Rogers[5] and Shawn P. Wright[6]

By the time eukaryotic life or photosynthesis evolved on Earth, the martian surface had become extremely inhospitable, but the subsurface of Mars could potentially have contained a vast microbial biosphere. Crustal fluids may have welled up from the subsurface to alter and cement surface sediments, potentially preserving clues to subsurface habitability. Here we present a conceptual model of subsurface habitability of Mars and evaluate evidence for groundwater upwelling in deep basins. Many ancient, deep basins lack evidence for groundwater activity. However, McLaughlin Crater, one of the deepest craters on Mars, contains evidence for Mg-Fe-bearing clays and carbonates that probably formed in an alkaline, groundwater-fed lacustrine setting. This environment strongly contrasts with the acidic, water-limited environments implied by the presence of sulphate deposits that have previously been suggested to form owing to groundwater upwelling. Deposits formed as a result of groundwater upwelling on Mars, such as those in McLaughlin Crater, could preserve critical evidence of a deep biosphere on Mars. We suggest that groundwater upwelling on Mars may have occurred sporadically on local scales, rather than at regional or global scales.

One of the most important discoveries in the exploration of Mars has been the detection of putative hydrothermal phases, including serpentine[1] and phyllosilicates[2], within materials exhumed from the subsurface by large impact craters[2–5] (Fig. 1). Deep (kilometre-scale) subsurface alteration probably peaked in the Noachian (>4.1 Gyr ago) and into the Early Hesperian (~3.7–4.1 Gyr ago) periods[2], when heat flow was significantly higher[6]. This time period roughly coincides with the earliest record of life on Earth, which consists of prokaryote thermophiles[7] (Fig. 2).

Today, prokaryotic life in the deep subsurface comprises up to 50% of the total biomass on Earth[8]. A significant amount of diversity exists throughout the huge volume of subsurface habitable environments that may reach >5 km depth[9]. As chemoautotrophs and thermophiles are some of the oldest phyla, it stands to reason that life may have originated in the subsurface by taking advantage of existing chemical gradients associated with serpentinization reactions[10], or that thermophiles uniquely survived the Late Heavy Bombardment by taking refuge in the subsurface[11]. The subsurface could have been the most viable habitat for ancient, simple life forms on Mars as well.

Exploration of the habitability of the martian subsurface would provide critical information about geochemical processes in the early history of the Solar System and an essential piece of Earth's geologic puzzle. The investigation of life's origins on Earth will always be limited by the poor state of preservation of the earliest geologic record (>3.5 Gyr old). Therefore, the search for early chemical steps that led to life's origins may ultimately require exploration beyond Earth, specifically characterization of ancient crustal environments on Mars.

Subsurface processes on Mars could be studied indirectly, either by the analysis of deep crustal rocks that have been exhumed

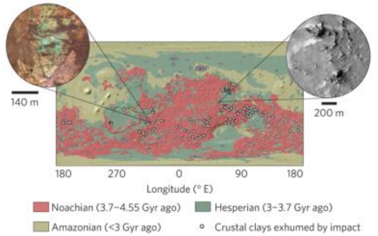

Figure 1 | Distribution of exhumed deep crustal rocks on Mars. Detections of deep crustal clays reported previously[2] are overlaid on global surface geology. Exhumed clays in Noachian terrains represent subsurface hydrothermal processes early in Mars's history. Insets show textures of two examples of exhumed crust: hydrated minerals along with mafic mineralogy exhumed from a ~2.5-km-deep unnamed crater at 306.4° E, 20.5° S (left) and Fe-Mg clays and Fe/Ca carbonates exhumed from ~6 km deep in Leighton Crater (right).

by impact or through investigation of materials formed from subsurface fluids[12], where they have reached the surface. Here, we produce a synthesis model of the subsurface geology of Mars, with predictions for the nature and fate of fluids in the crust and testable hypotheses for the habitability of various zones at depth. We also present evidence that crustal fluids have emerged at the surface, resulting in an alkaline lacustrine system within McLaughlin Crater.

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Constraints on the crystal-chemistry of Fe/Mg-rich smectitic clays on Mars and links to global alteration trends

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ABSTRACT

Near-infrared remote sensing data of Mars have revealed thousands of ancient deposits of Fe/Mg-rich smectitic clay minerals within the crust with relevance to past habitability. Diagnostic metal–OH infrared spectroscopic absorptions used to interpret the mineralogy of these phyllosilicates occur at wavelengths of 2.27–2.32 μm, indicating variable Fe/Mg ratios in the clay structures. The objective of this work is to use these near infrared absorptions to constrain the mineralogy of smectites on Mars. Using Fe/Mg-rich seafloor clay minerals as mineralogical and spectroscopic analogs for Martian clay minerals, we show how crystal-chemical substitution and mixed layering affect the position of the diagnostic metal–OH spectral feature in smectitic clay minerals. Crystal-chemistry of smectites detected on Mars were quantitatively constrained with infrared data and categorized into four mineralogical groups. Possible alteration processes are constrained by comparisons of clay chemistry detected by remote sensing techniques to the chemistry of candidate protoliths. Of the four groups identified, three of them indicate significant segregation of Fe from Mg, suggestive of alteration under water-rich and/or oxidizing conditions on Mars. The fourth group (with low Fe/Mg ratios) may result from alteration in reducing or water-limited conditions, potentially in subsurface environments. Some samples are interstratified di-trioctahedral clay minerals that have characteristics of dioctahedral clay minerals but clear chemical evidence for trioctahedral sheets. Approximately 70% of smectite deposits previously detected on Mars are classified as Fe-rich (FeO/MgO > 10). Only 22% of detections are trioctahedral and relatively Mg-rich. An additional ~8% are difficult to characterize, but might be very Fe-rich. The segregation of Fe from Mg in Martian clay minerals suggests that Mg should be enriched in other contemporaneous deposits such as chlorides and carbonates.

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1. Introduction

Near-infrared remote sensing data of Mars collected by two instruments, OMEGA (*Observatoire pour la Minéralogie, l'Eau, les Glaces et l'Activité*) and CRISM (Compact Reconnaissance Imaging Spectrometer for Mars), have revealed thousands of detections of ancient Fe/Mg-rich smectite clay minerals (in addition to other clay minerals) within the Martian crust (Poulet et al., 2005; Murchie et al., 2009; Ehlmann et al., 2011; Carter et al., 2013). These materials likely formed through aqueous chemical alteration of pyroxene, olivine, and mafic glass within volcanic and impact-fragmented materials (Christensen et al., 2001; Poulet et al., 2007). Because these clay minerals are key indicators of aqueous activity, they are of astrobiological interest and important for understanding the climate history of Mars (Bibring et al., 2006). Despite the fact that remotely detected Martian smectites are unlikely to be pure clay deposits, the spectra of the clay mineral components contain key information about their crystal chemistry and structure. However, the precise mineralogy of the Fe/Mg-rich smectites is not well understood, limiting the ability to connect these deposits to their protoliths through their geochemistry, or to understand the nature of aqueous processes from whence they formed on ancient Mars.

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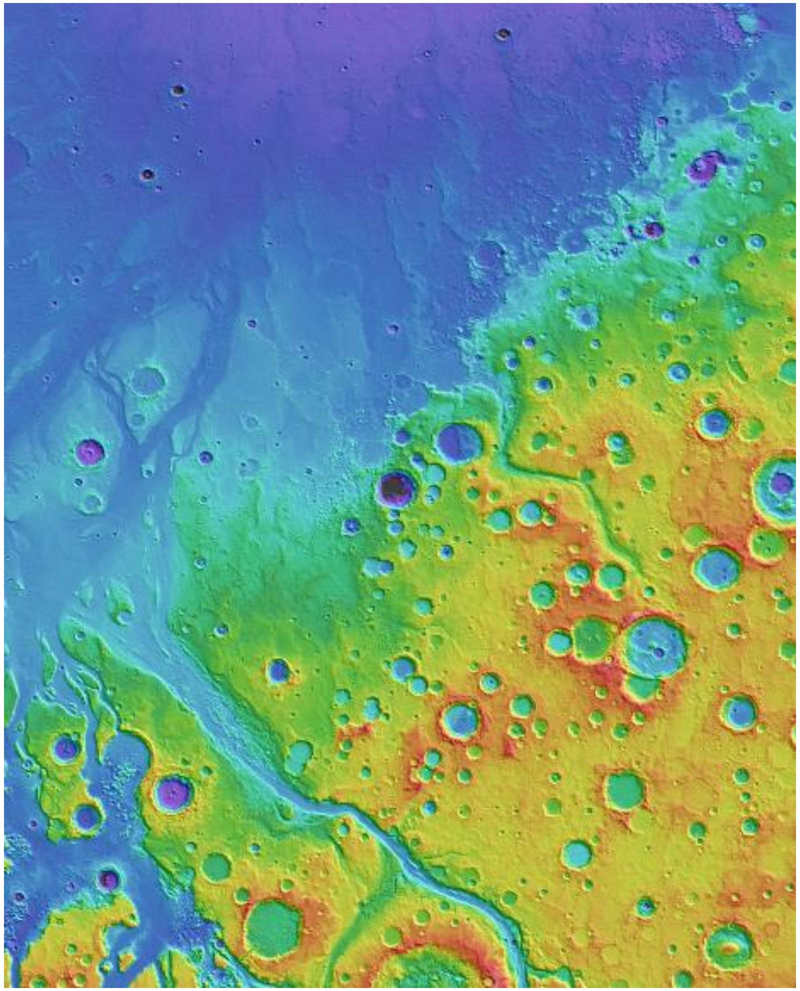
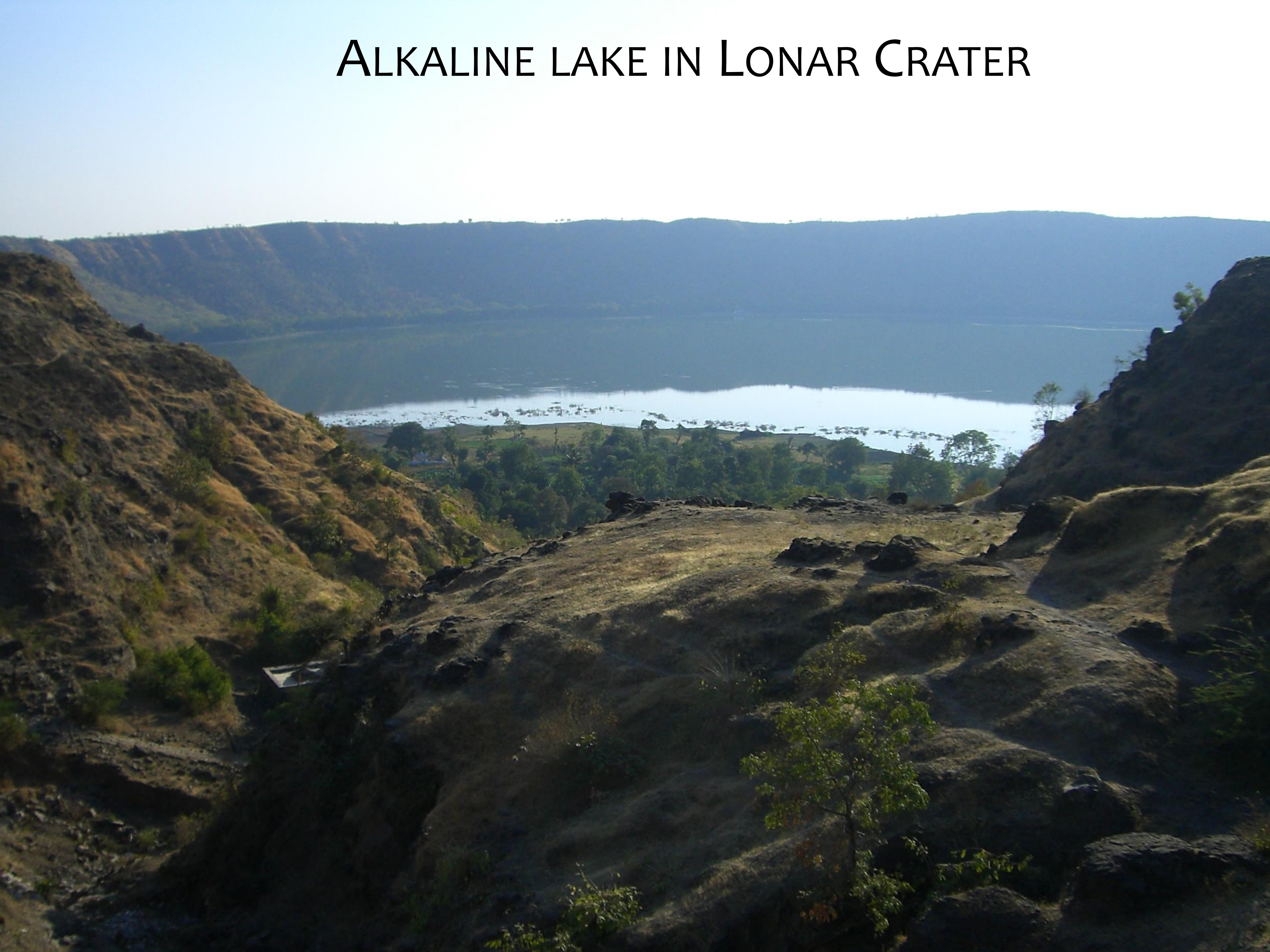
McLaughlin Crater Summary

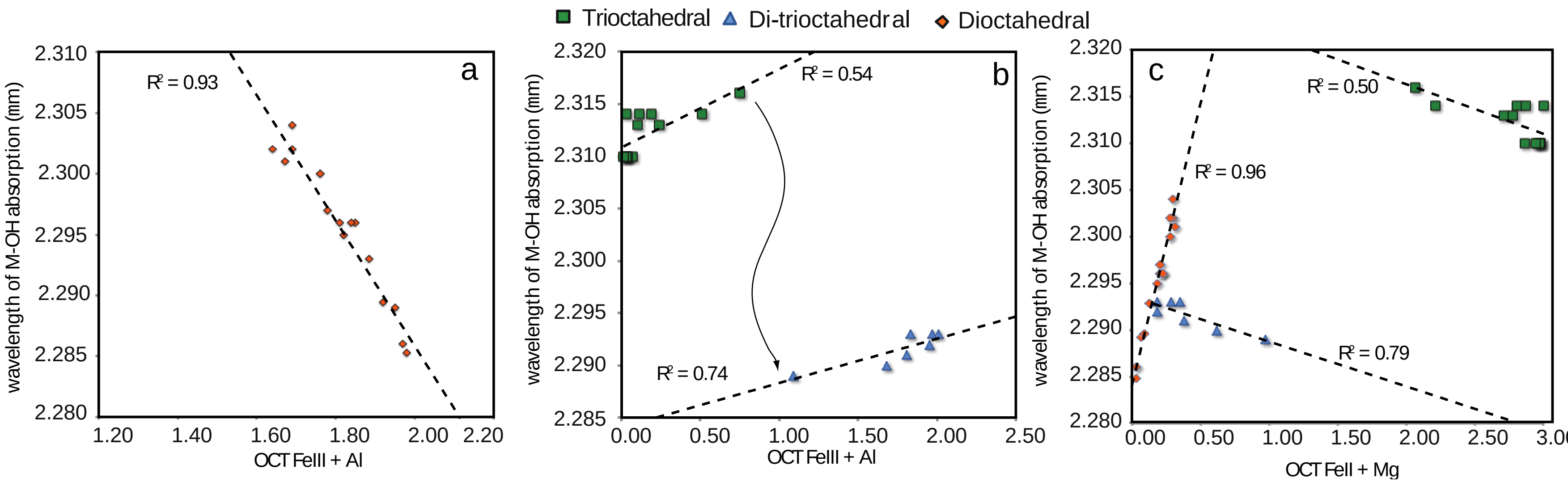
- Evidence for lacustrine setting
- Alkaline, saline, Mg-Ca-Fe-rich fluids
- Origin of fluids?
  - Precipitation?
  - Groundwater Upwelling?



ALKALINE LAKE IN LONAR CRATER



Position of metal-OH feature versus crystal chemistry



Dioctahedral clays are relatively straightforward

Di-trioctahedral clays are complicated, but too important to ignore!

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