Targeting habitable subsurface environments with Mars 2020

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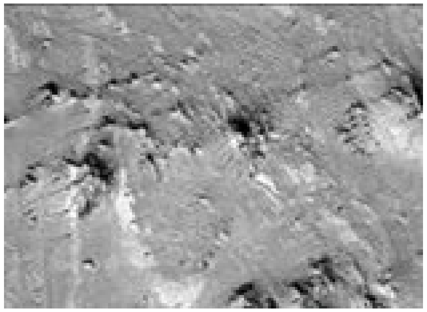
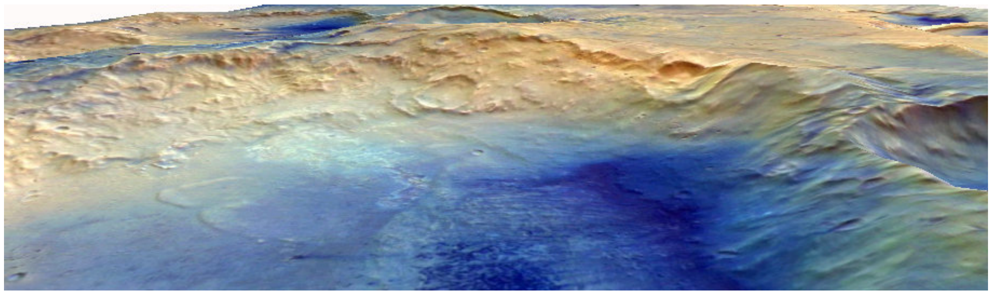
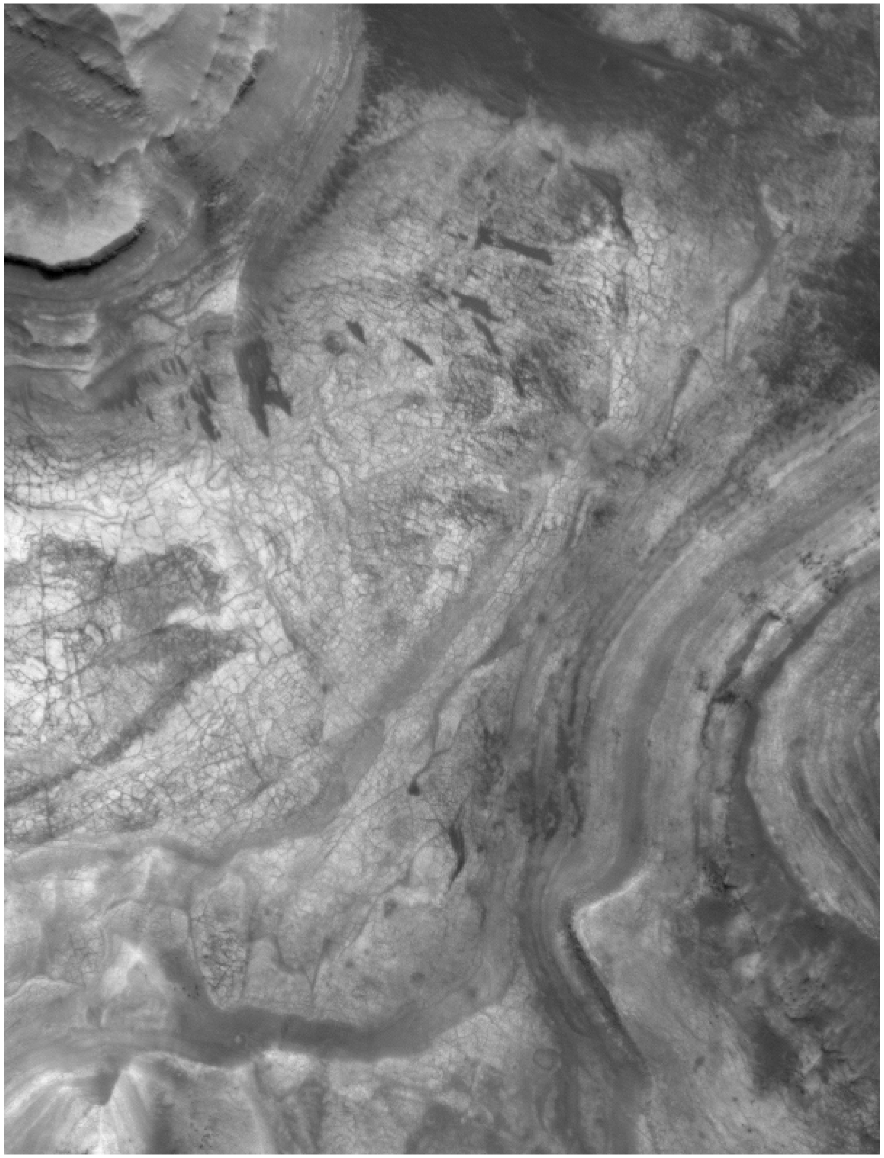
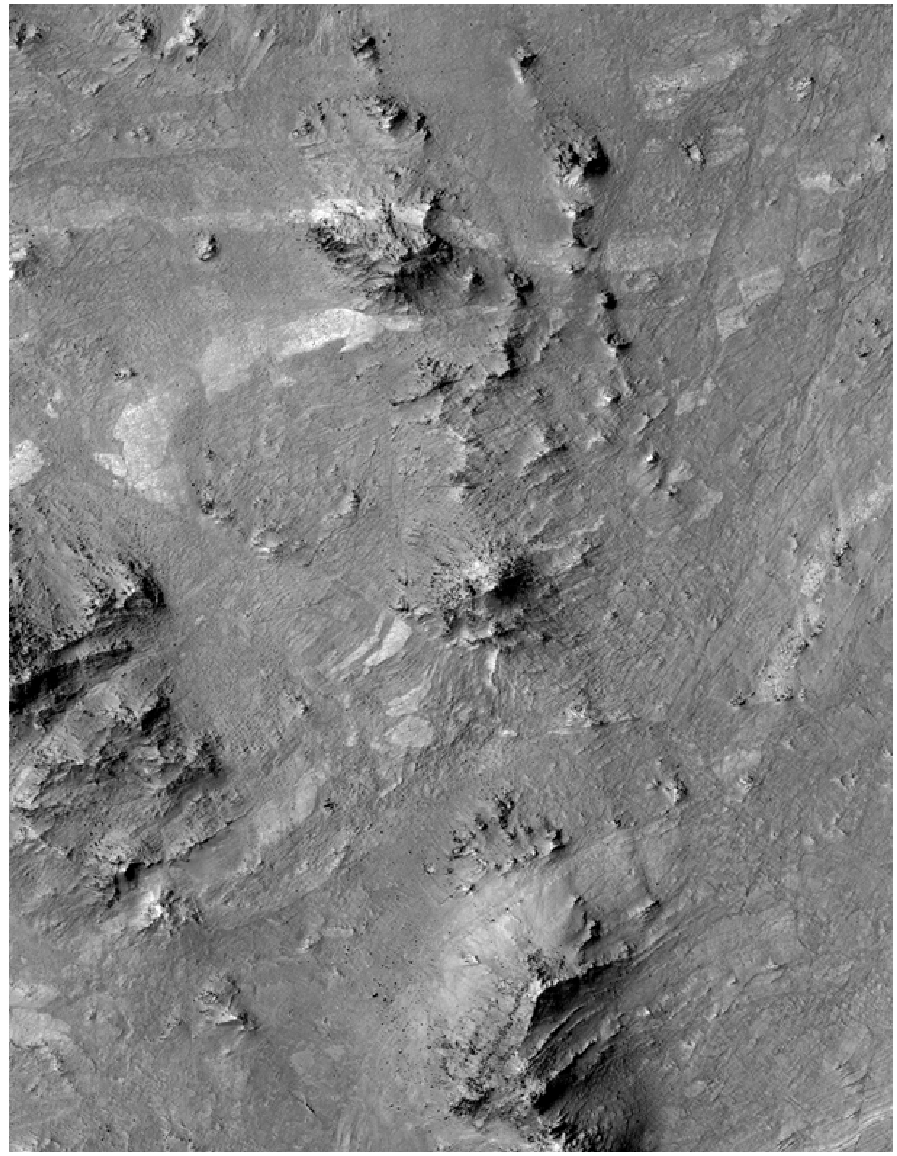




SEDIMENTARY
-OR-
"SURFACE"

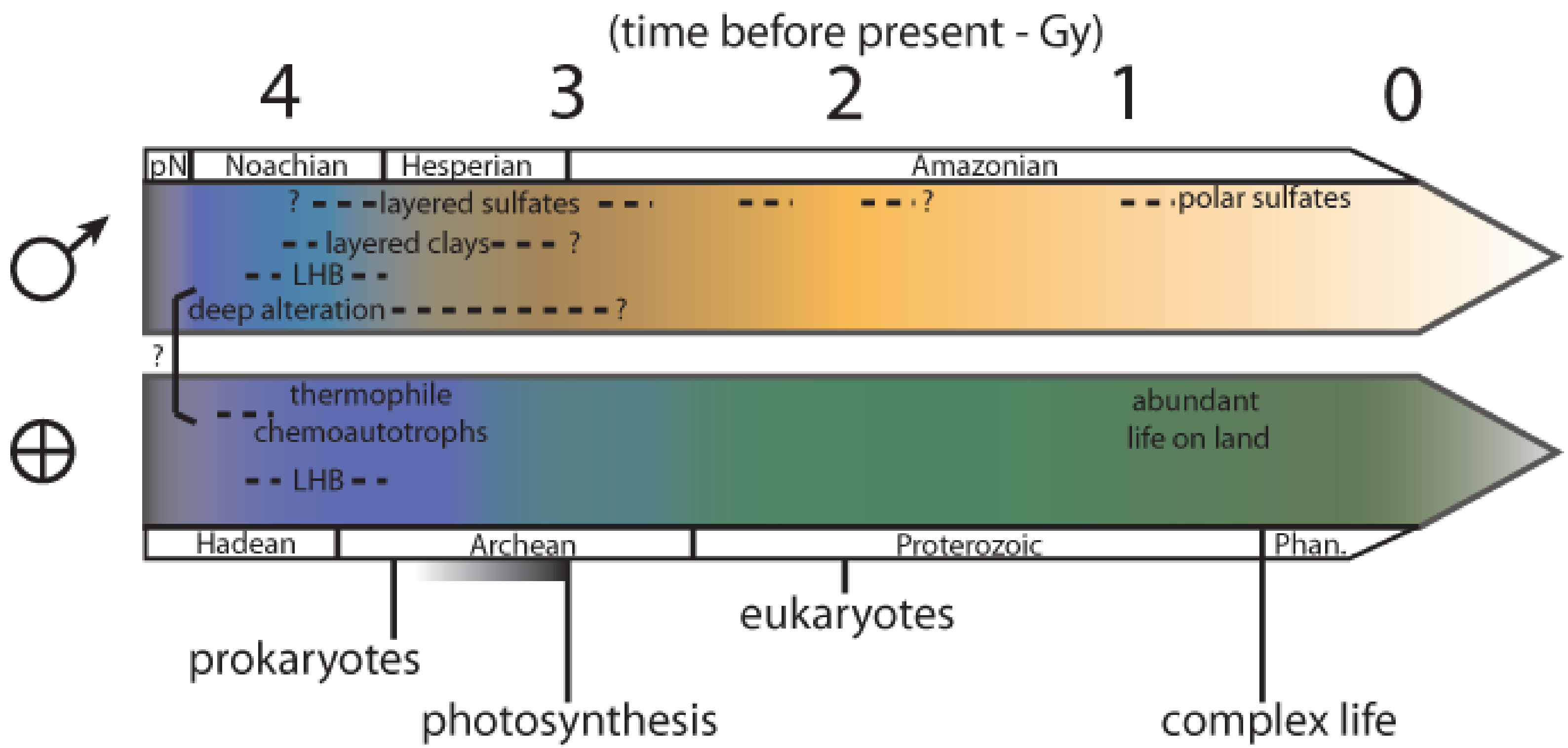


HYDROTHERMAL
-OR-
"SUBURFACE"



THE BIG PICTURE

BY 3.5 GA, MARS WAS PROBABLY MOSTLY HYPERARID, COLD, ACIDIC, BATHED IN UV AND GENERALLY A BUMMER

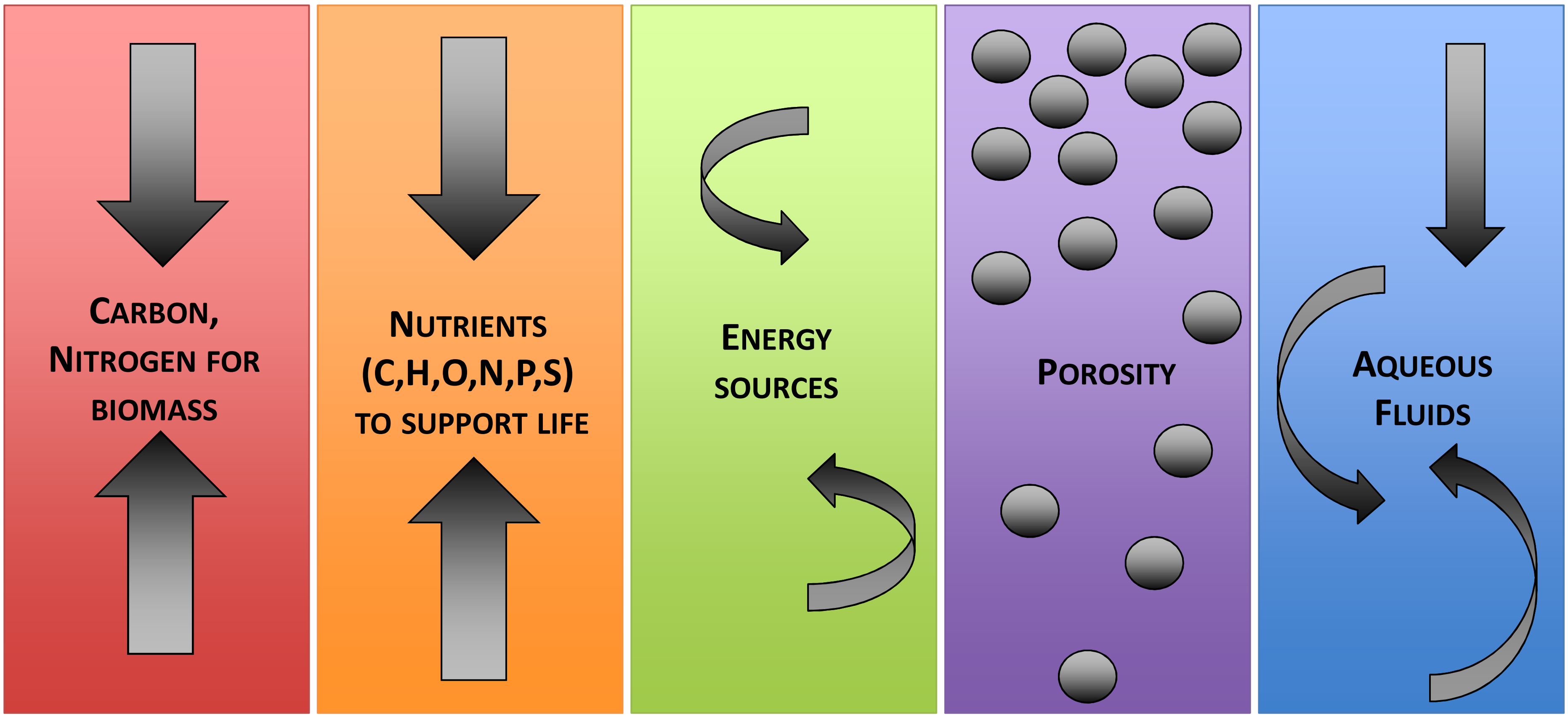


Michalski et al., Nature Geoscience, 2013

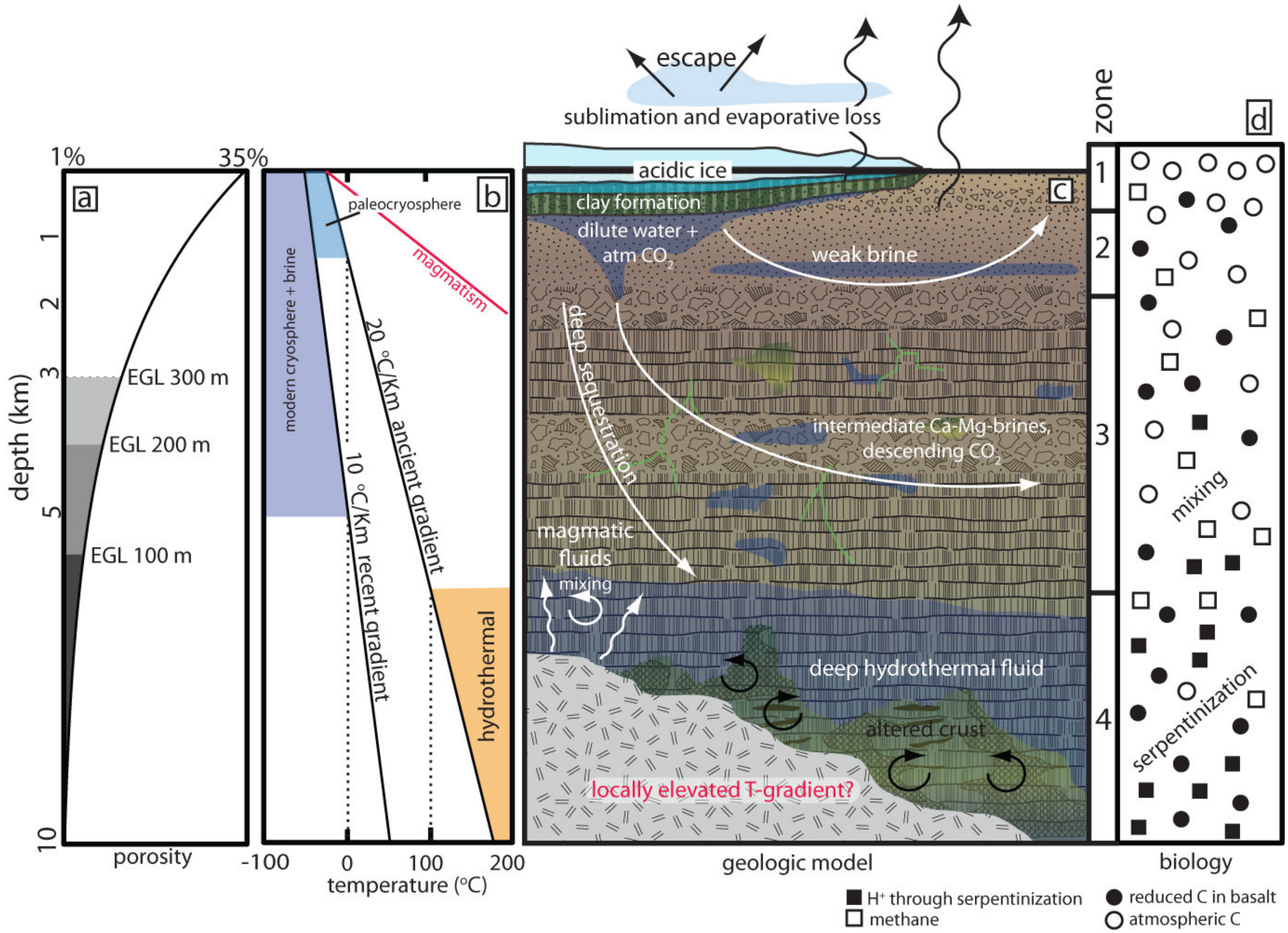
Deep Biosphere

Factors to consider

How do these factors relate to the Martian environment?

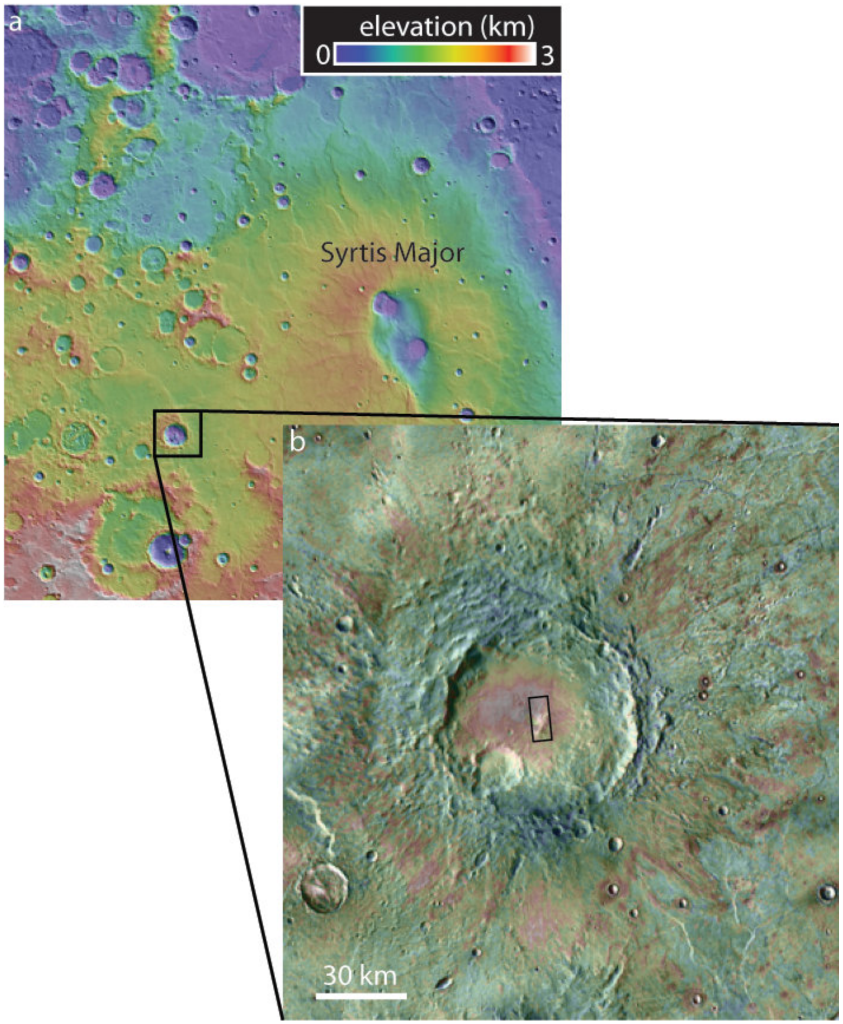


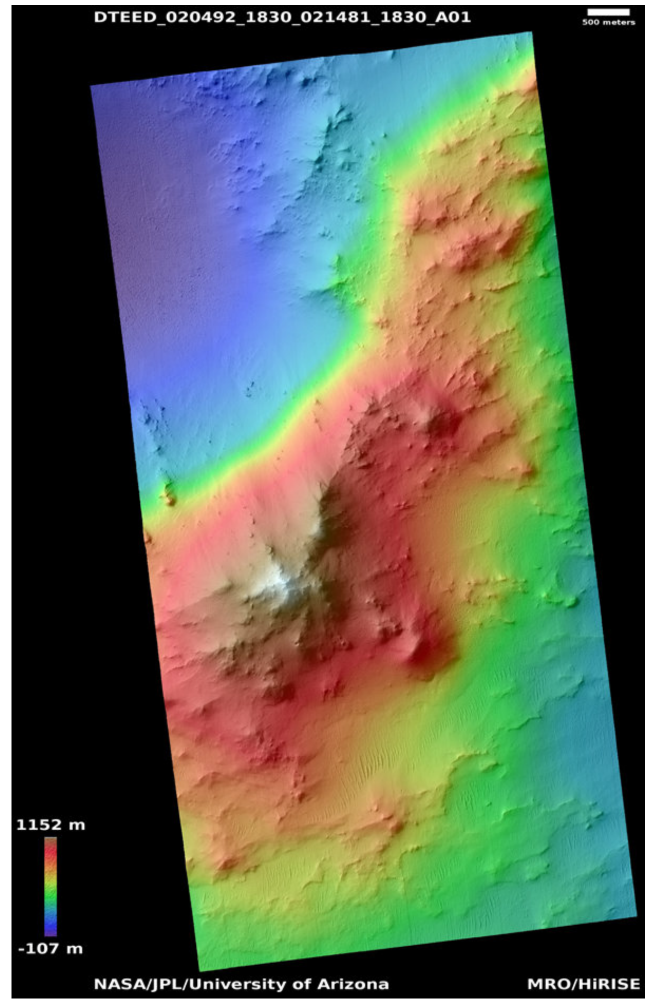
THE MARTIAN SUBSURFACE



Michalski et al., Nature Geoscience, 2013

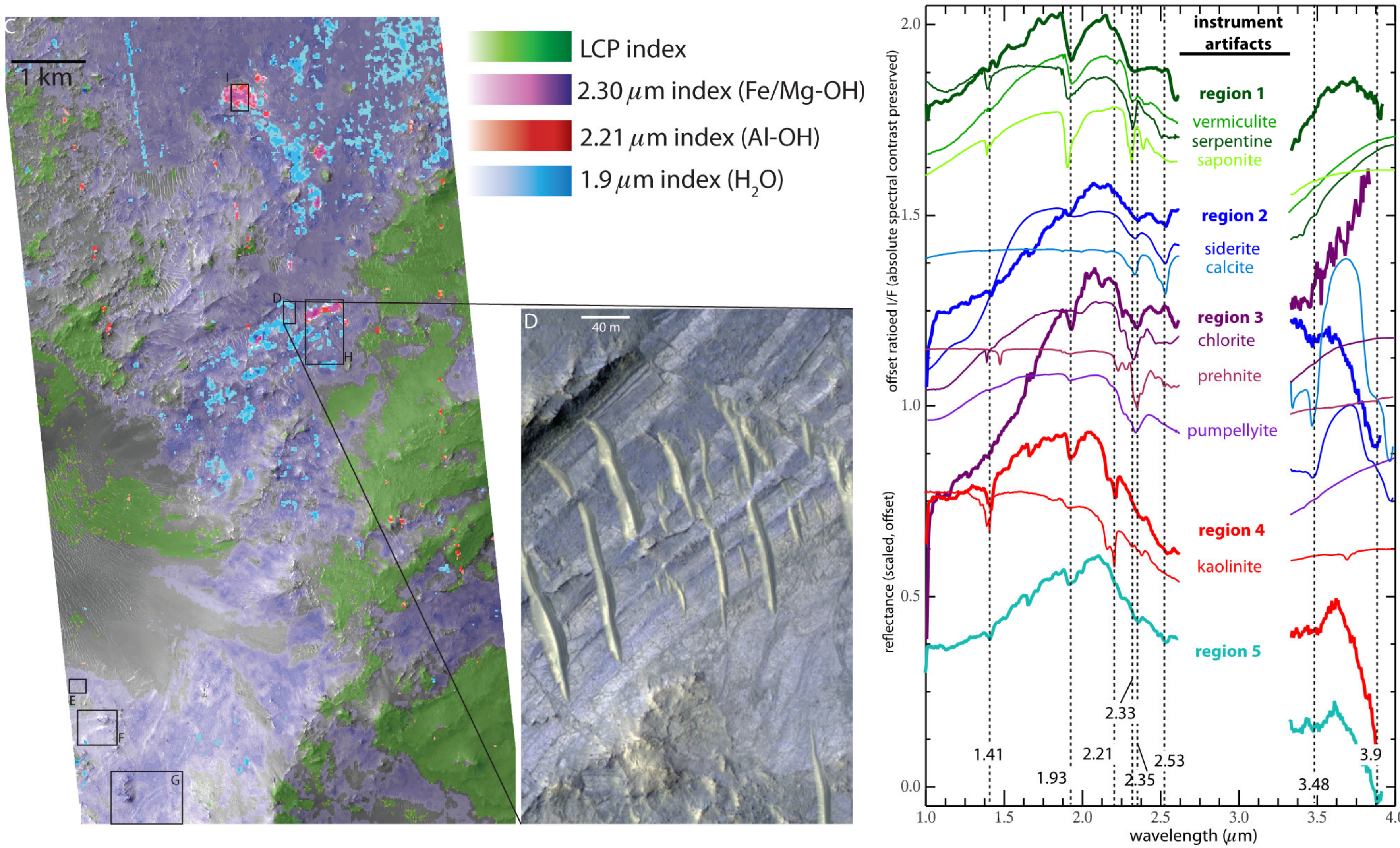
EXAMPLE OF EXHUMED MATERIALS IN LEIGHTON CRATER, MARS





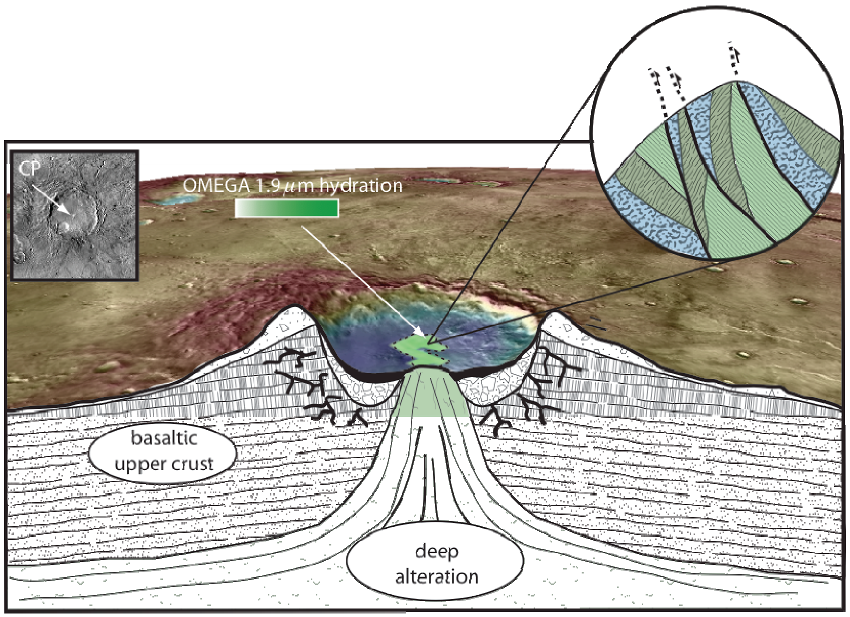
Michalski and Niles., Nature Geoscience, 2010

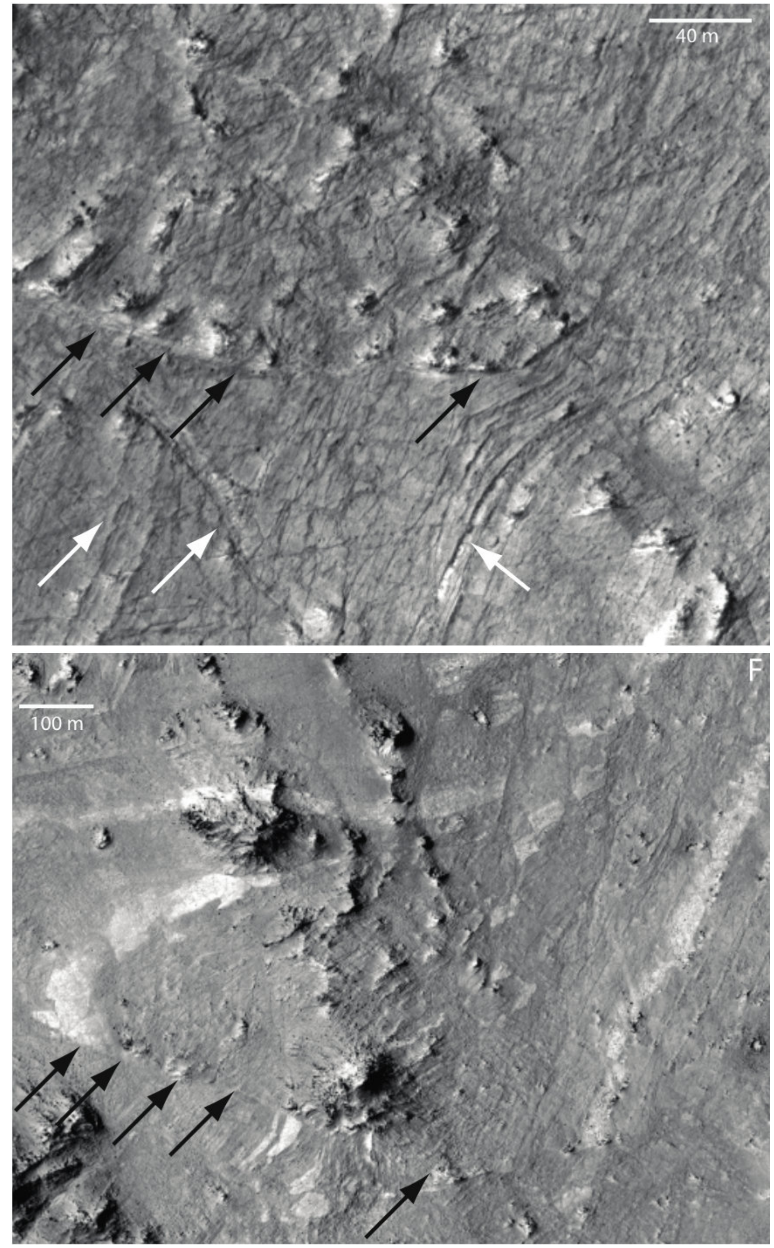
Deep Crustal Clays and Carbonates Observed Through Remote sensing



Michalski and Niles., Nature Geoscience, 2010

FAULTED, FOLDED, FRACTURED AND FOLIATED

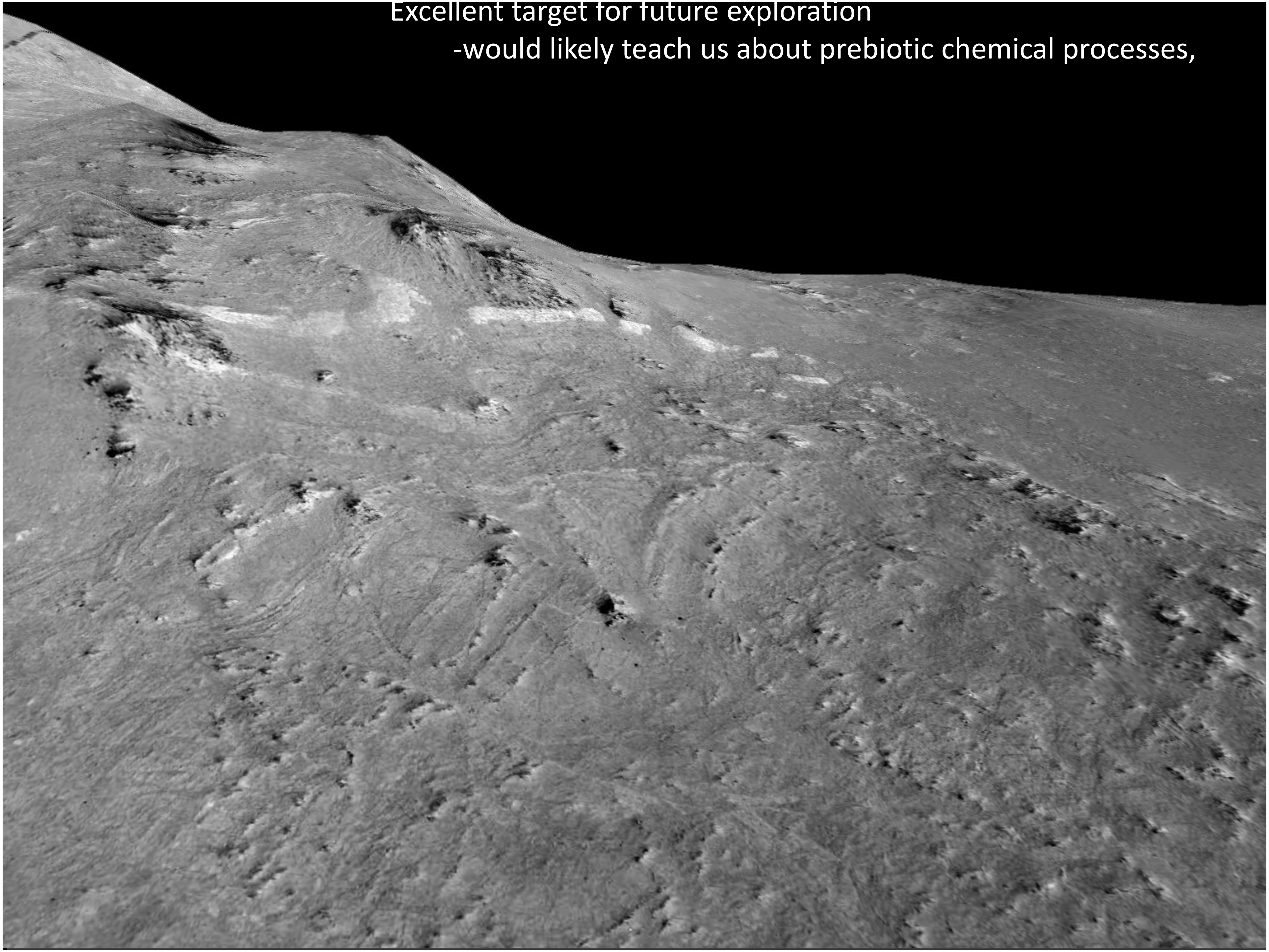




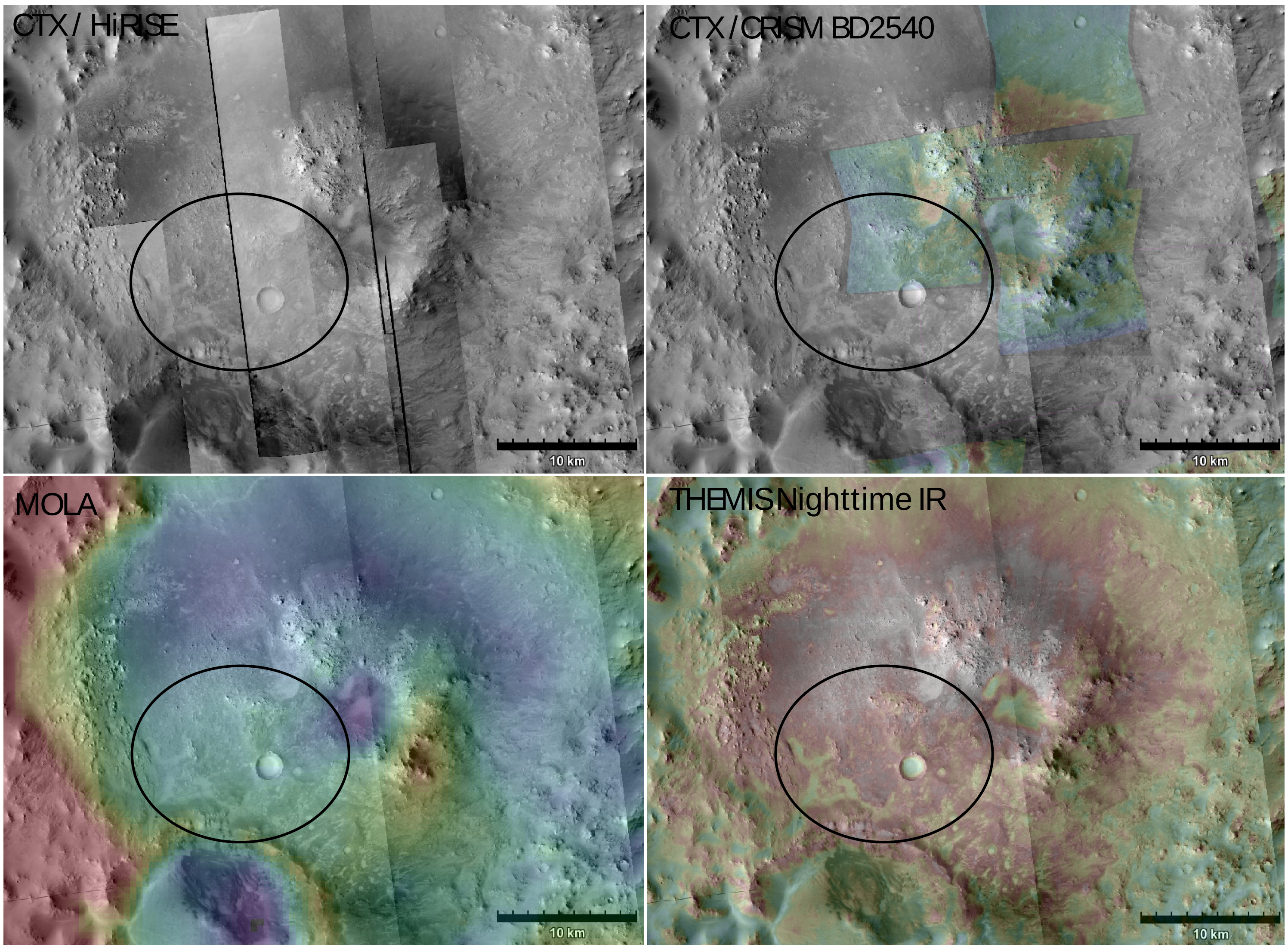
Michalski and Niles., Nature Geoscience, 2010

Excellent target for future exploration

-would likely teach us about prebiotic chemical processes,



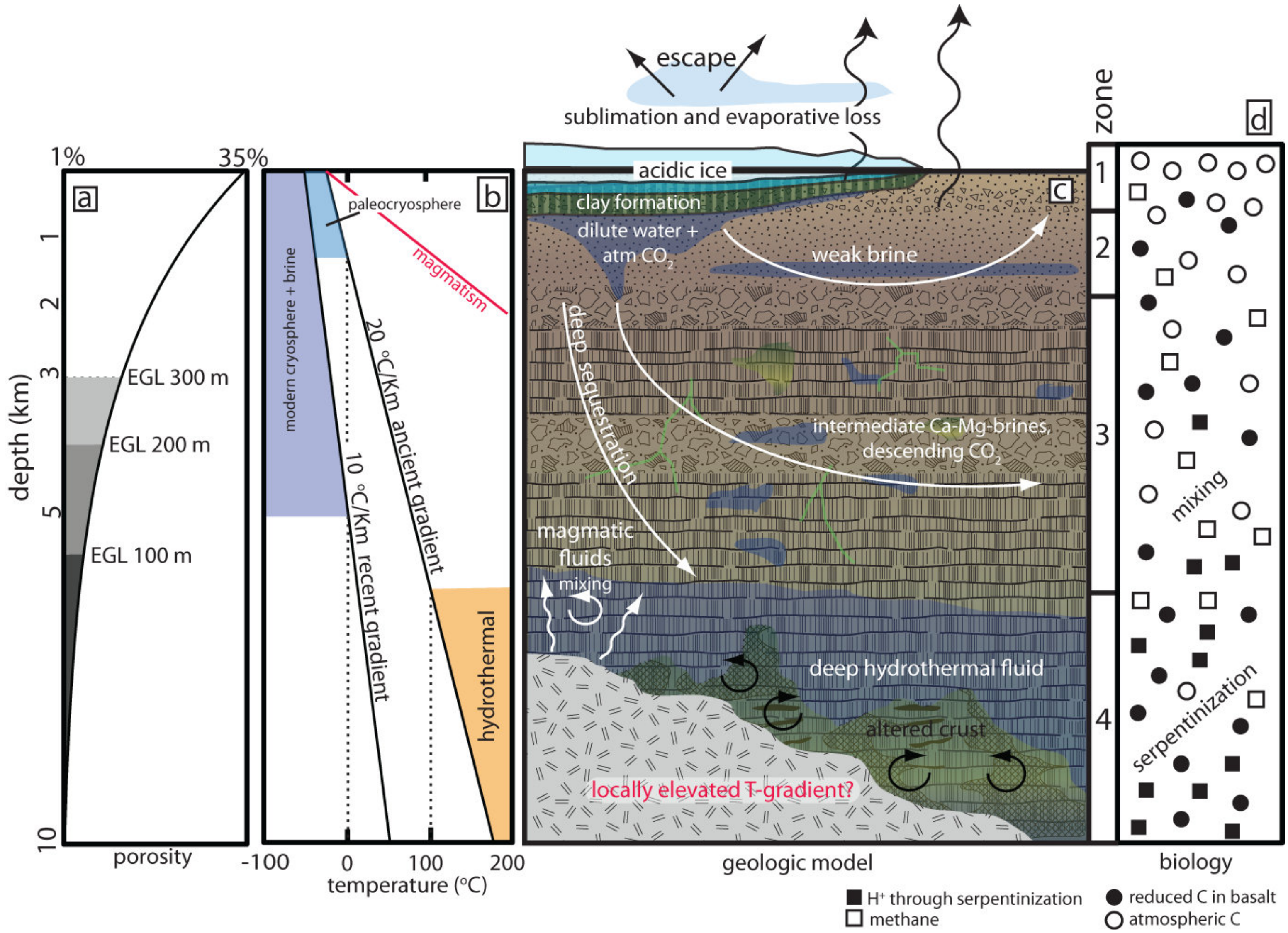
Candidate landing site



Issues with category 1 sites (Exhumed Crust)

- Would these environments have high cell densities in the deep crust? — Testable!
- Shock pressures and temperatures could "impact" preservation potential — Testable!
- Are the biosignatures detectable with a Mars rover-type payload? — Testable!

A DEEP MARTIAN BIOSPHERE?



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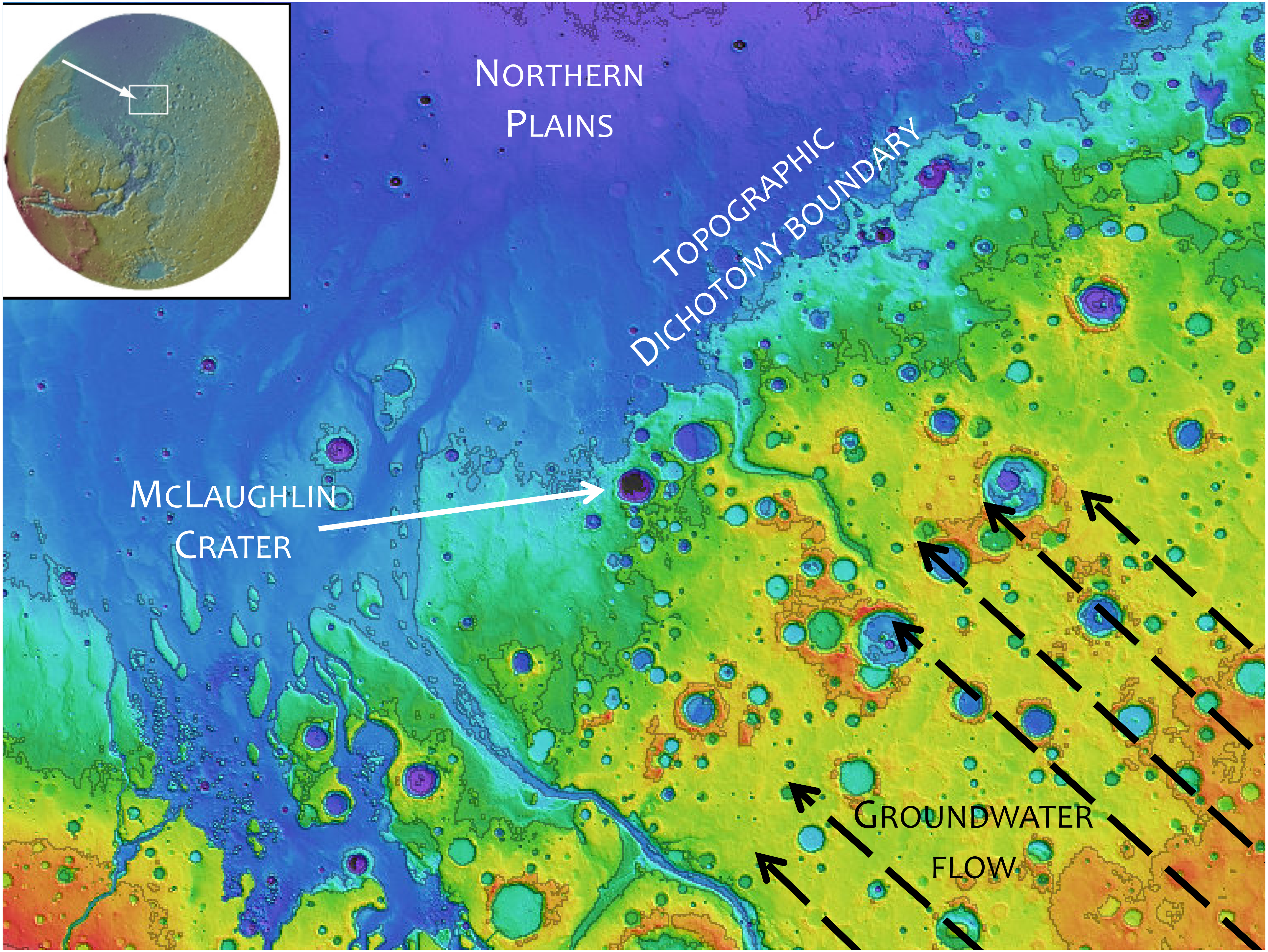
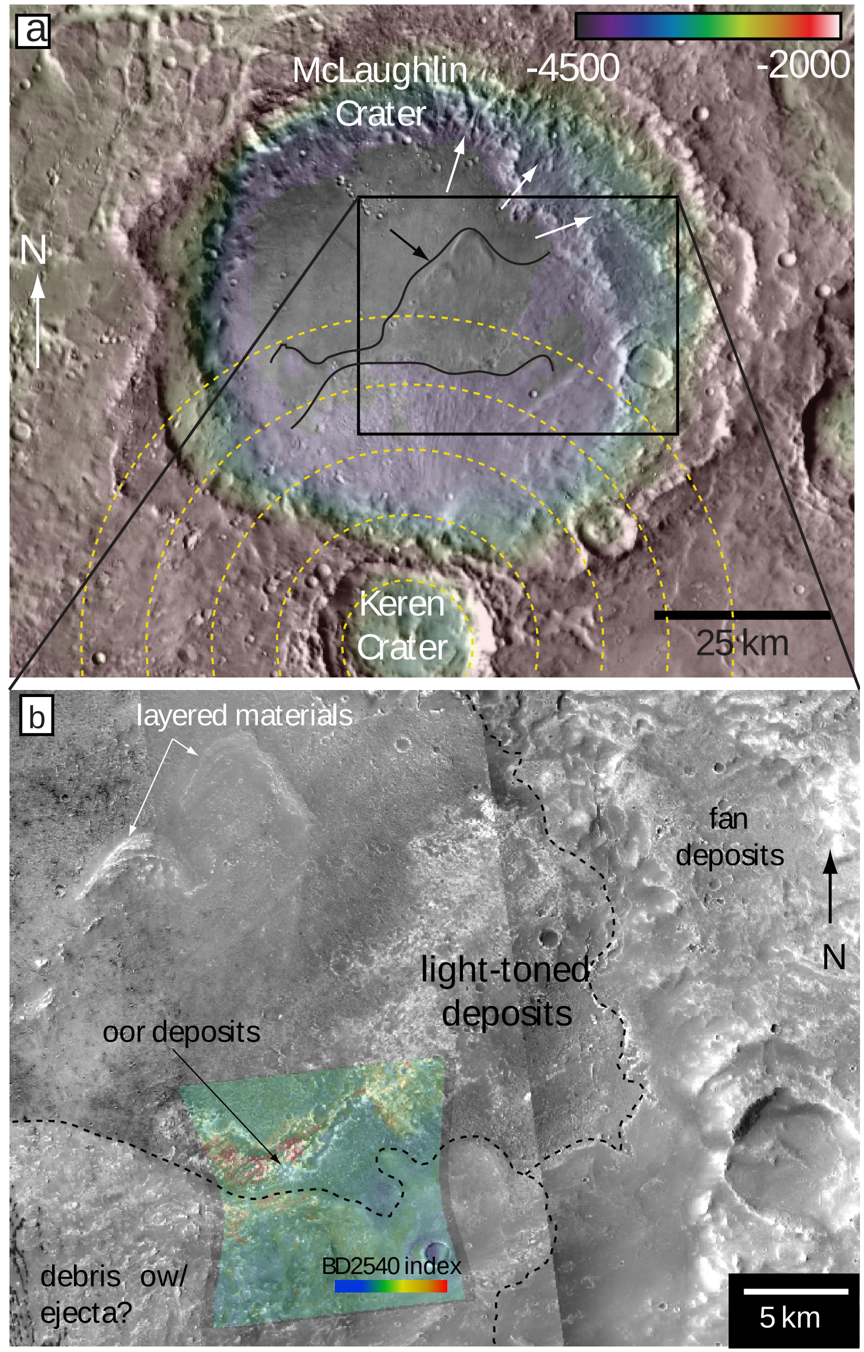

Northern
Plains
Topographic
Dichotomy boundary
McLaughlin
Crater
Groundwater
flow

McLaughlin Crater

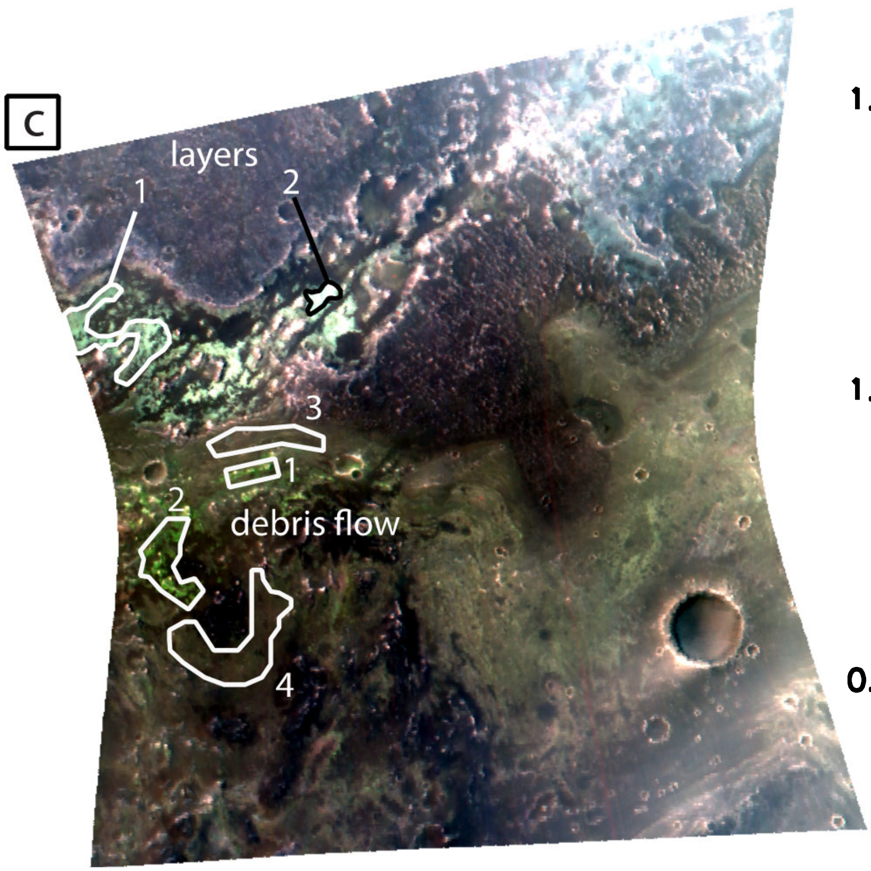
- Channels in wall, terminate ~500 m above the floor
- Ejecta from Keren on floor
- Lobate materials
- Layered sed rx

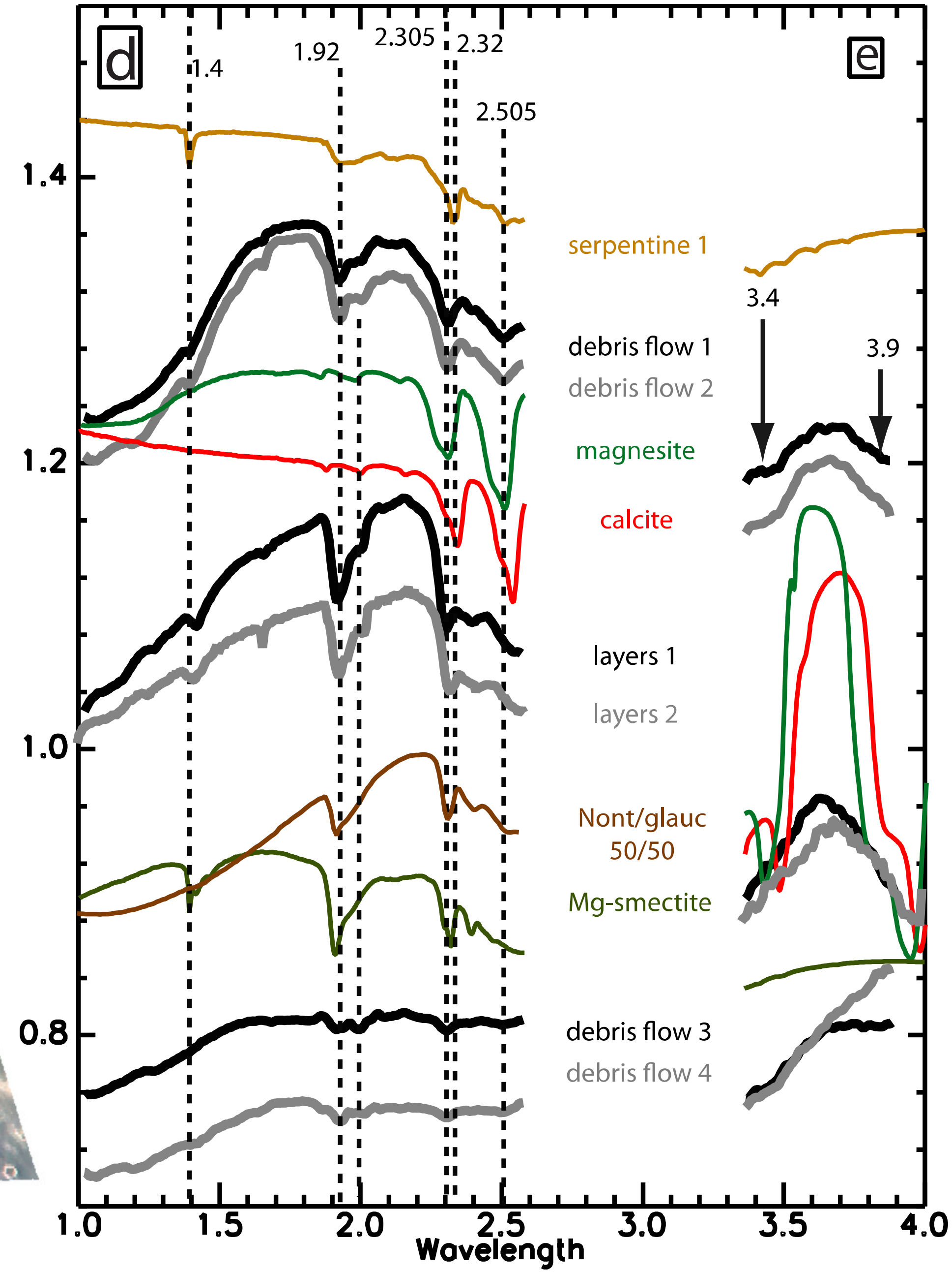


Michalski et al., Nature Geoscience, 2013

CRISM RESULTS

CLAYS AND CARBONATES

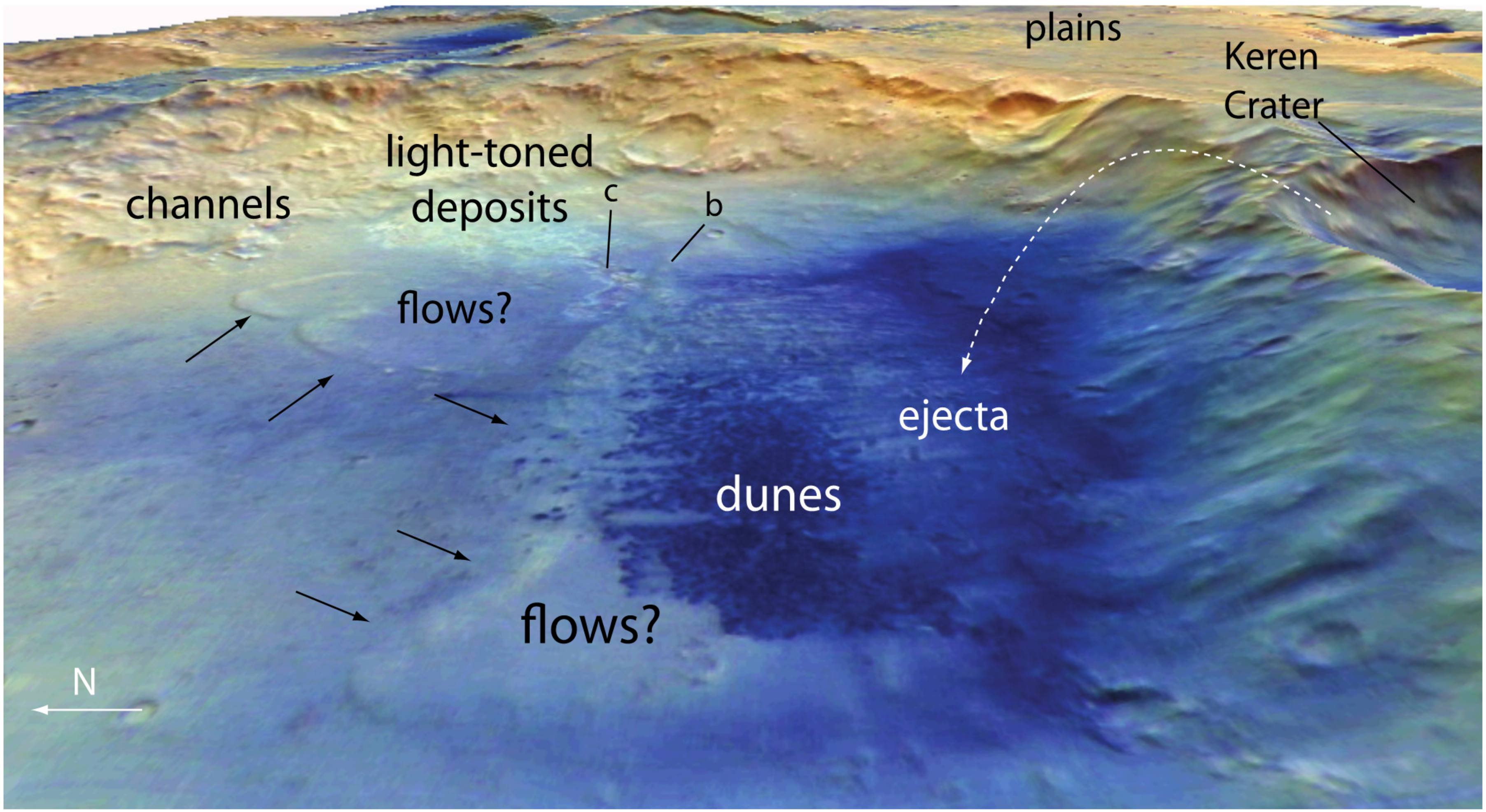




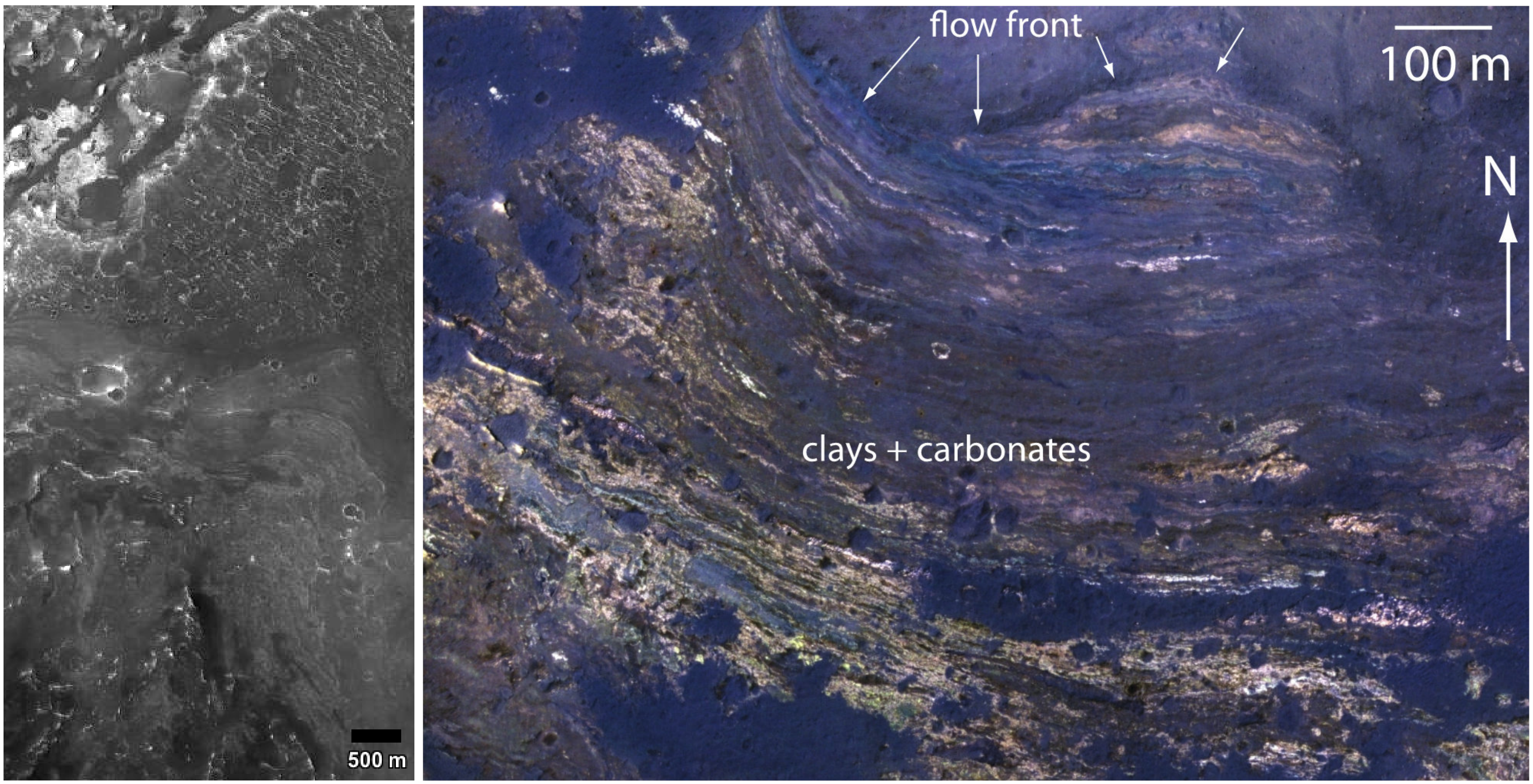
Michalski et al., Nature Geoscience, 2013

HiRISE Imaging

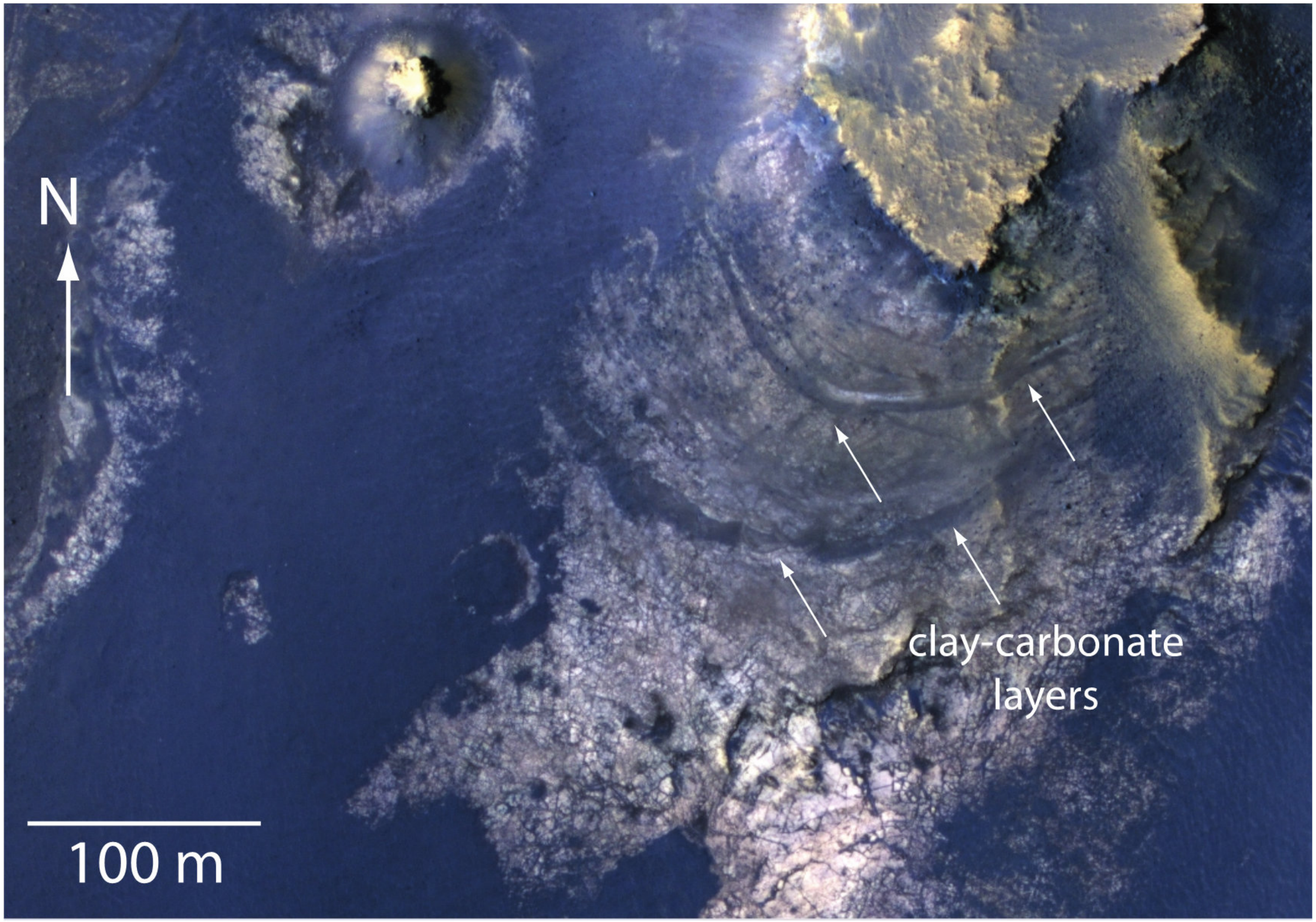
LAYERED SEDIMENTS AND LOBATE MATERIALS



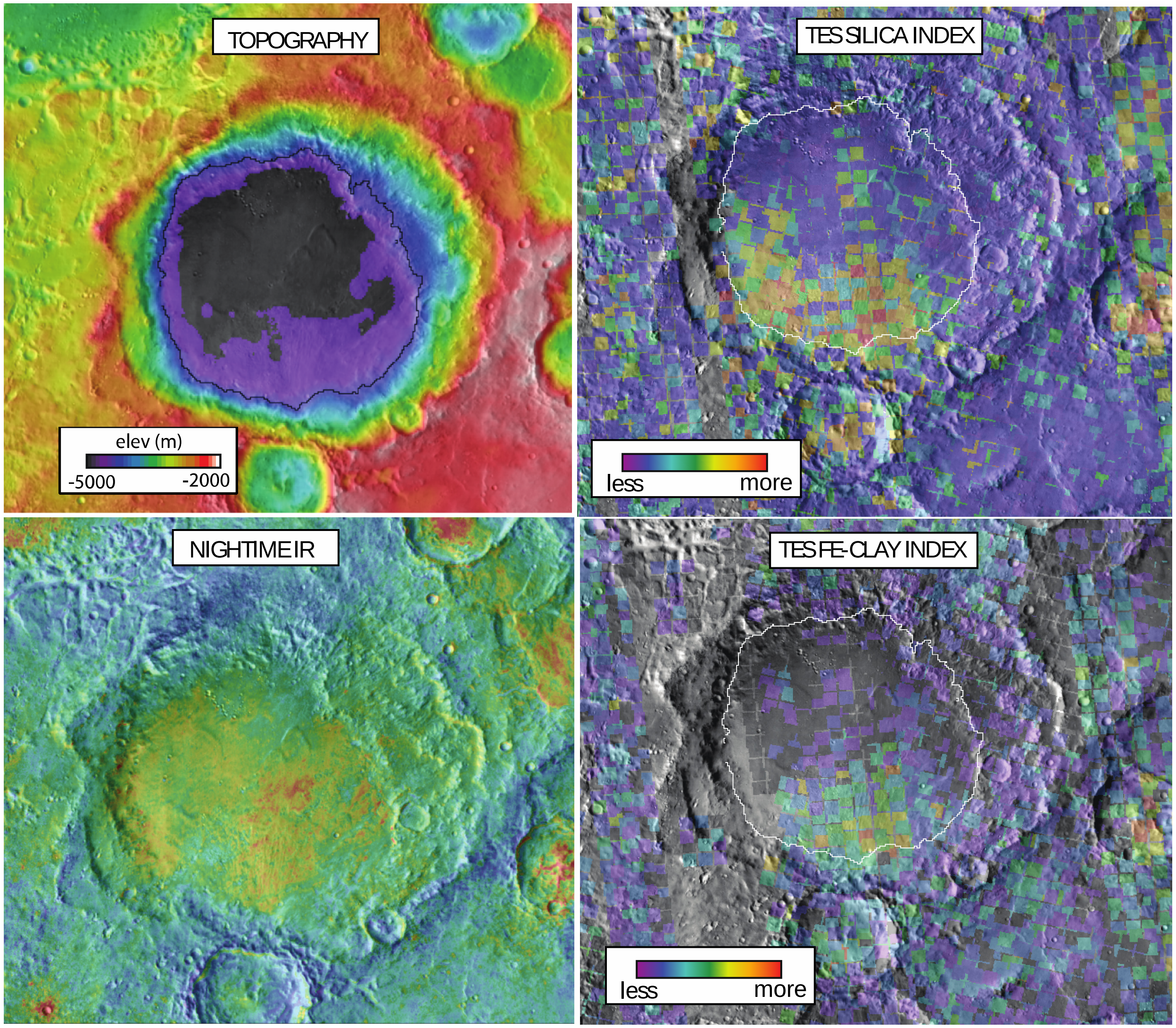
Morphology of debris flow



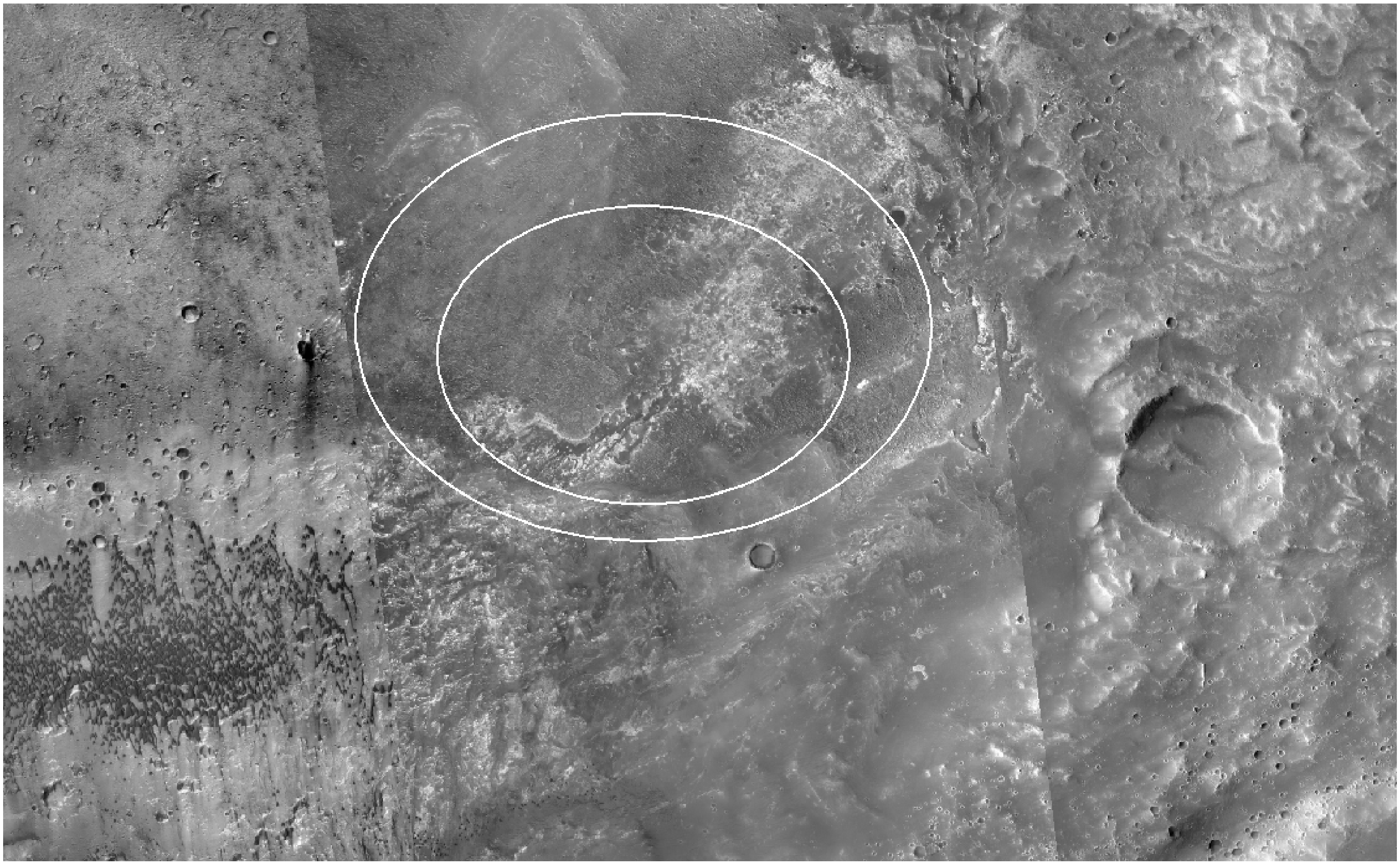
LAYERED UNITS ON THE CRATER FLOOR



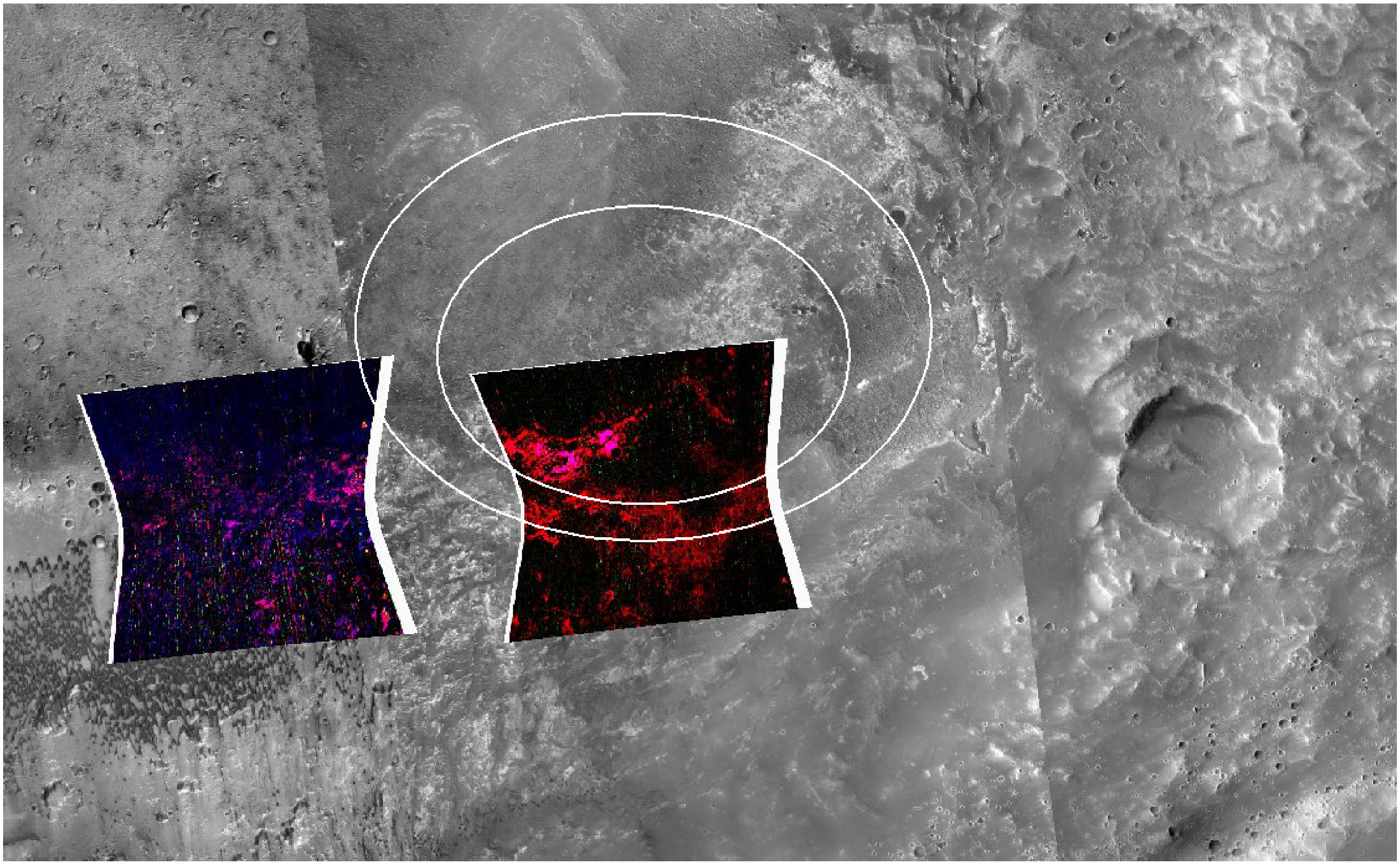
Evidence for alteration below a base level?



CANDIDATE LANDING ELLIPSE

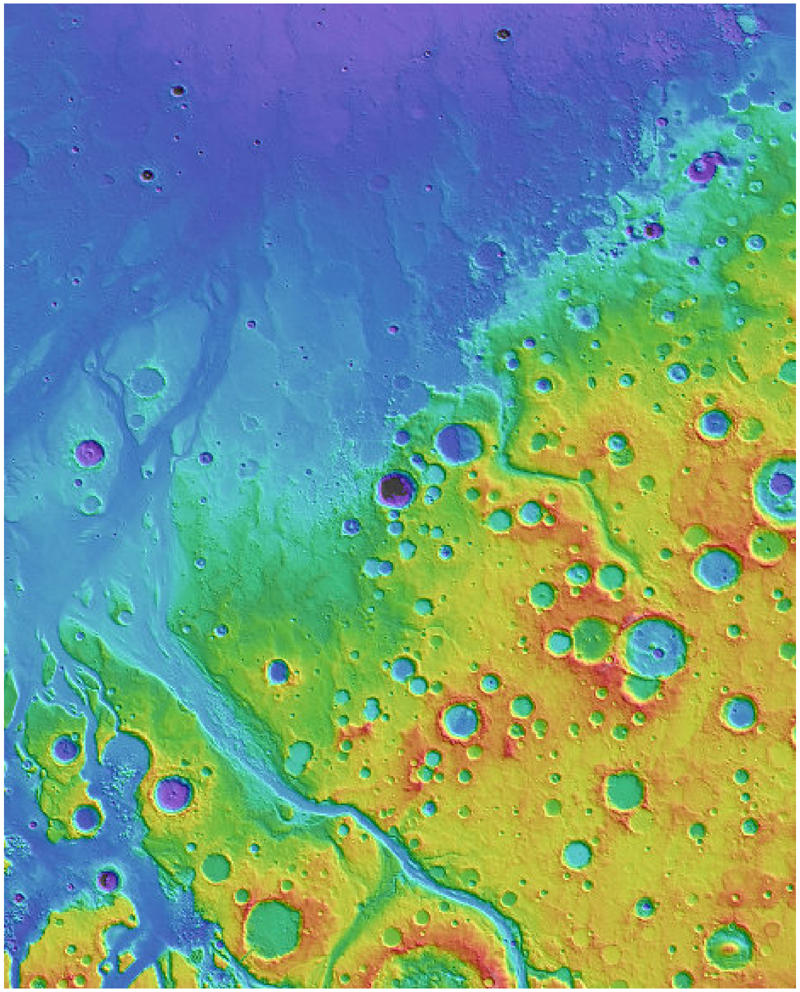


Candidate landing ellipse



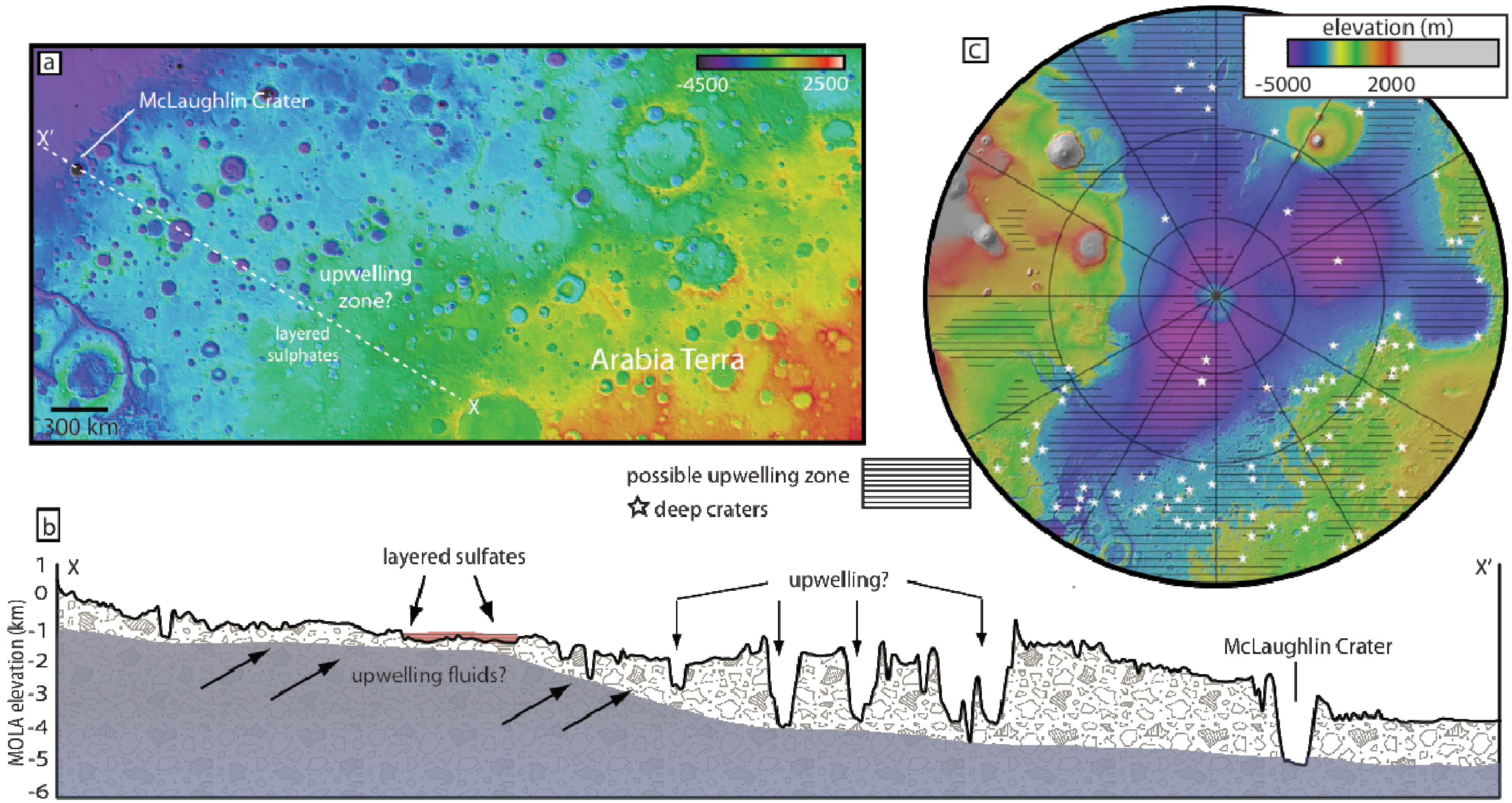
McLaughlin Crater Summary

- Evidence for lacustrine setting
- Alkaline, saline, Mg-Ca-Fe-rich fluids
- Sedimentary rocks/hydrothermally driven activity?



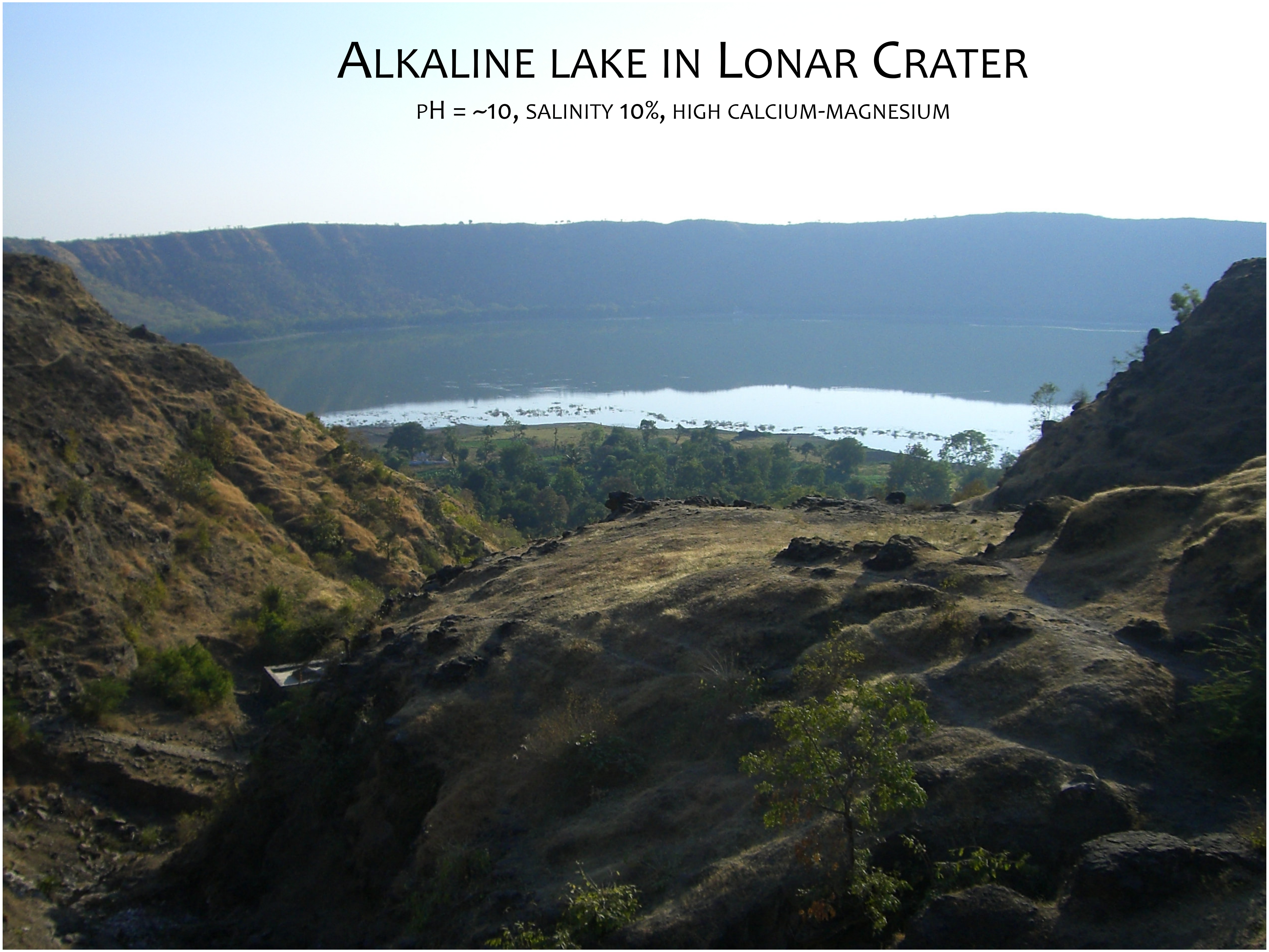
UPWELLING SHOULD OCCUR FIRST IN DEEP BASINS

MCLAUGHLIN MIGHT BE THE BEST CANDIDATE FOR UPWELLING ON MARS



Alkaline lake in Lonar Crater

pH = ~10, salinity 10%, high calcium-magnesium



McLaughlin Crater: Conclusions

- Mineralogy and geomorphology suggestive of lacustrine setting
- Possibly hydrothermal/driven by groundwater
- Land-on science
- Low elevation (-5000 m)
- Connection to a regional cap unit

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Groundwater activity on Mars and implications for a deep biosphere

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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 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.

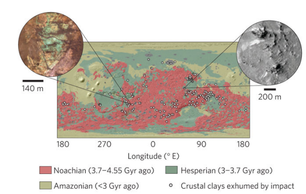

Figure 1 | Distribution of exhumed deep crustal rocks on Mars. Detections of deep crustal clays reported previously[2] are overlaid on global surface geology. Exhumed clays in Noachian terrains represent subsurface hydrothermal processes early in Mars's history. Insets show textures of two examples of 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).

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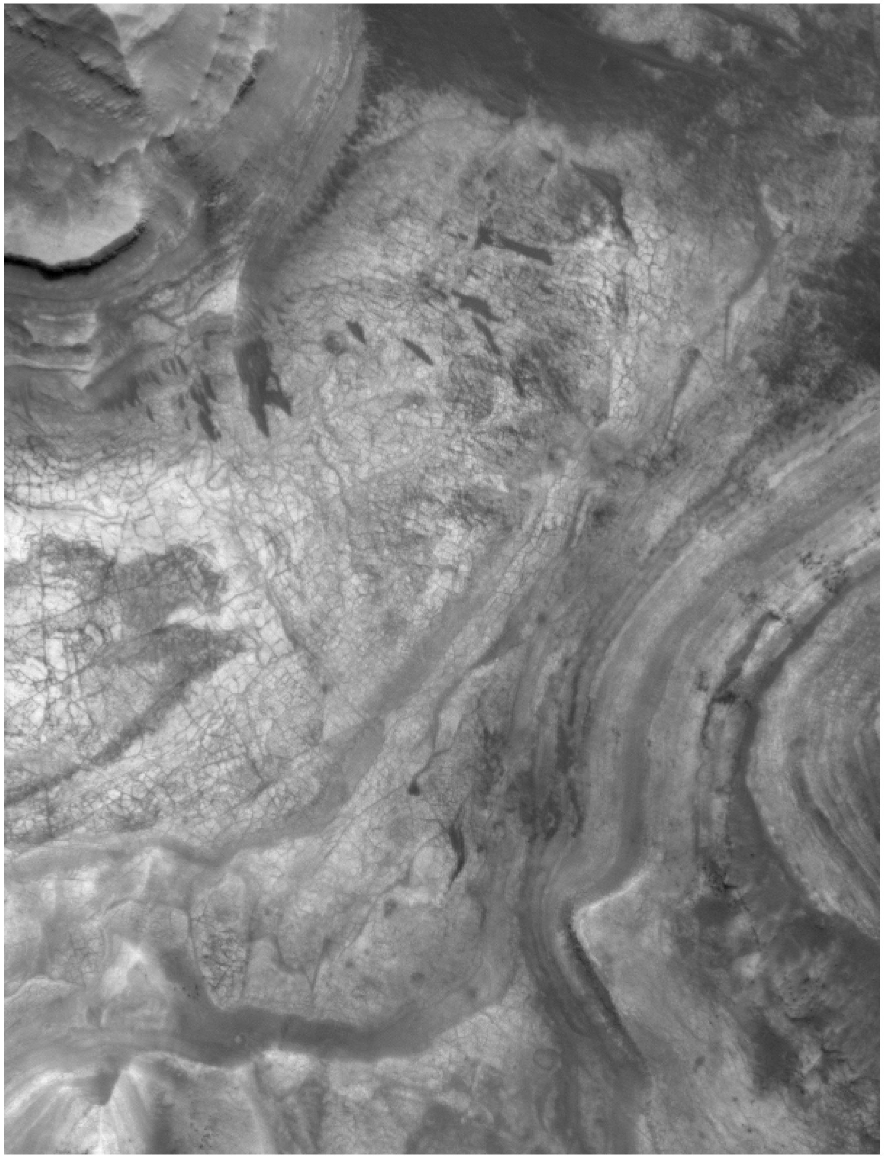
Sedimentary
-or-
“Surface”



Hydrothermal
-or-
“Suburface”