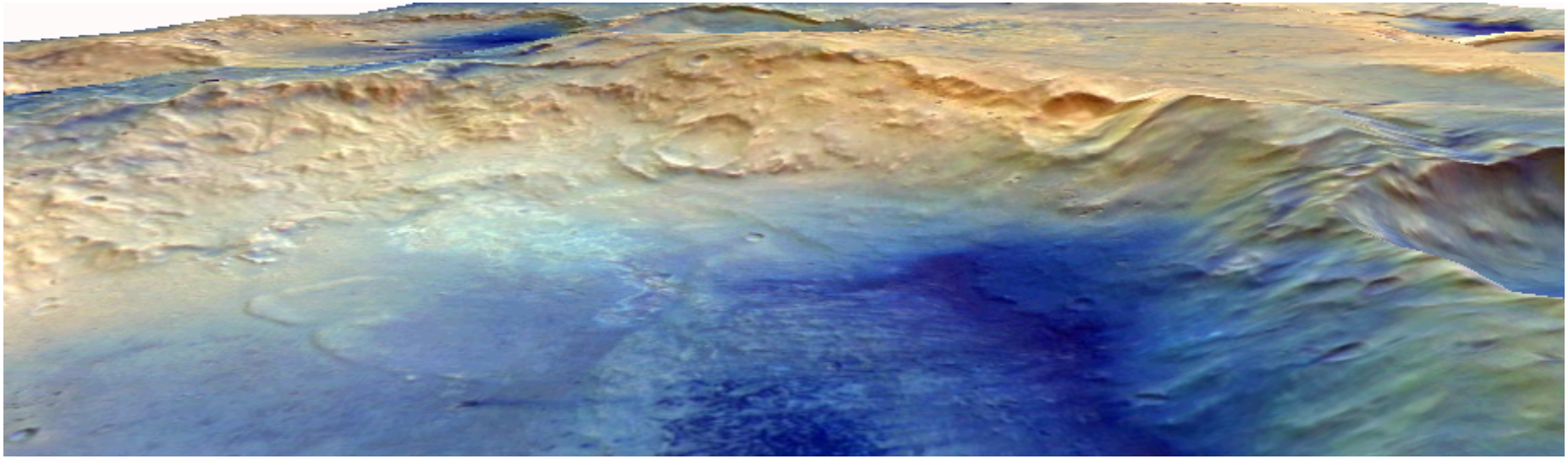
McLaughlin Crater

Three ancient terrain types

A candidate landing site for a long-term presence on Mars

Abstract #1025

Joe Michalski, Paul Niles,
Brad Sutter & Mary Sue Bell



COMMUNICATION

Education

We have 20-30 years to raise a generation of science literate people who will support this endeavor IF they really understand why we are doing it

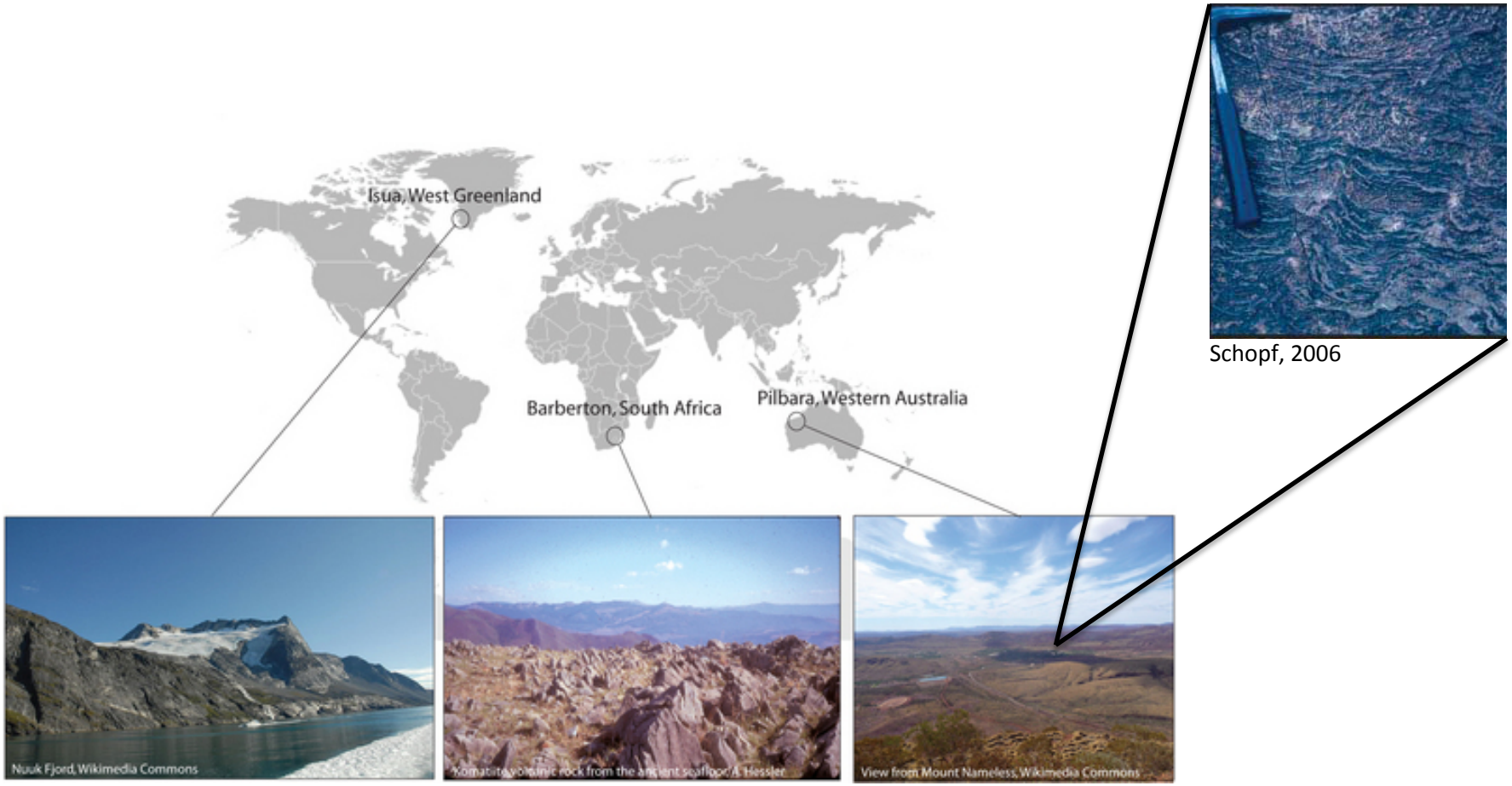
Collaboration

We can get Earth scientists on board by explaining why Mars is essential to understanding life and early geology on Earth.

Priorities

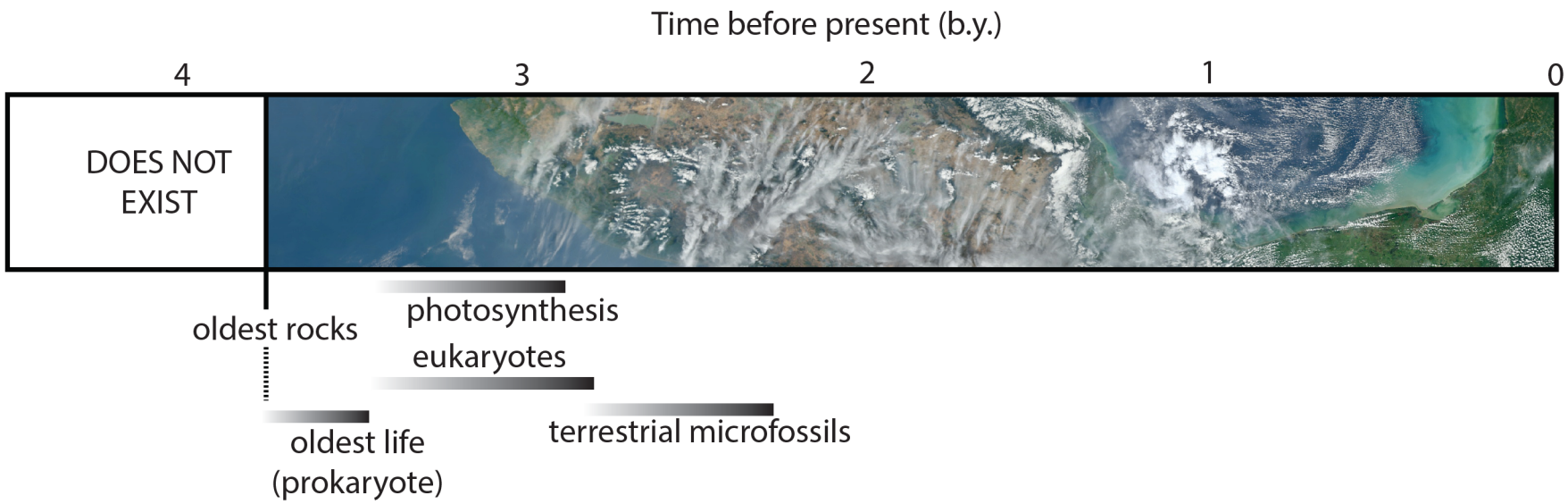
What do we really hope to accomplish scientifically? (prebiotic chemistry is super interesting in its own right; origin of life is clearly awesome)

The Terrestrial Record of Ancient Life

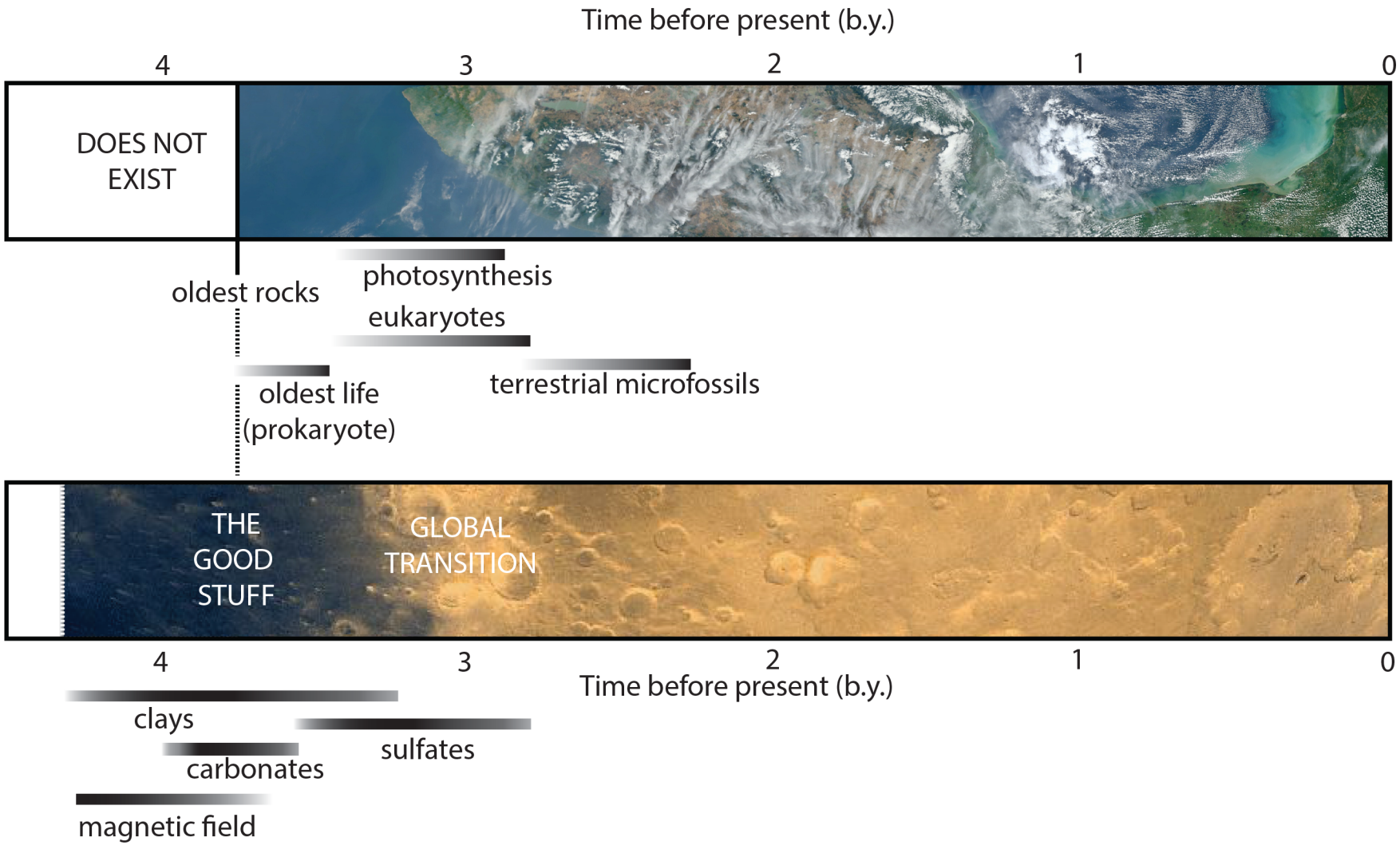


Schopf, 2006

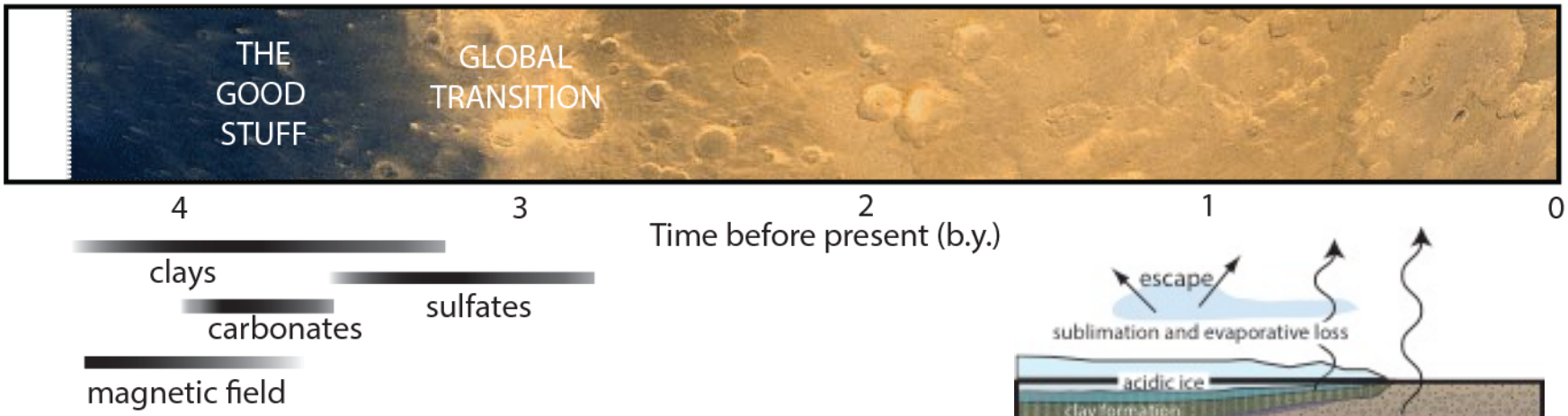
We will never understand the origin of life by exploring Earth

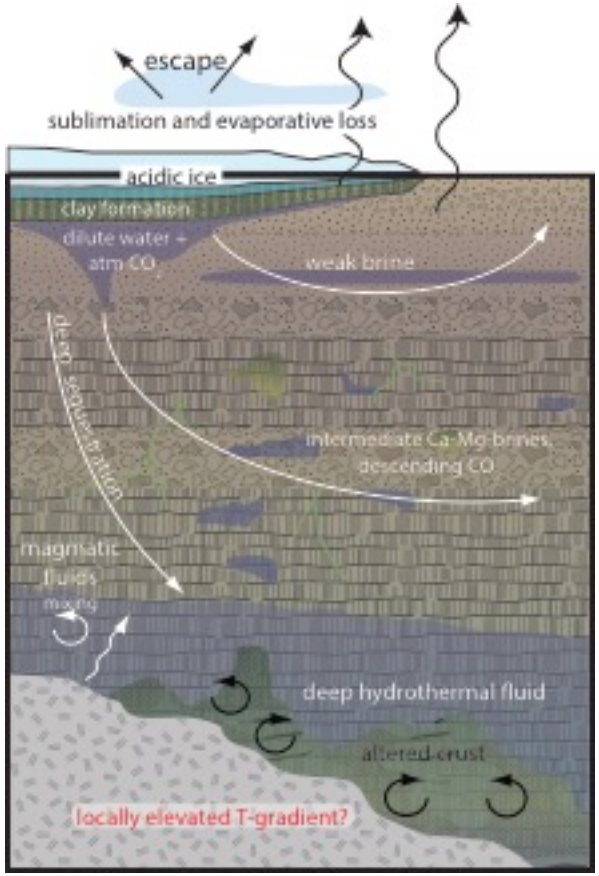


Comparing the Earth and Mars



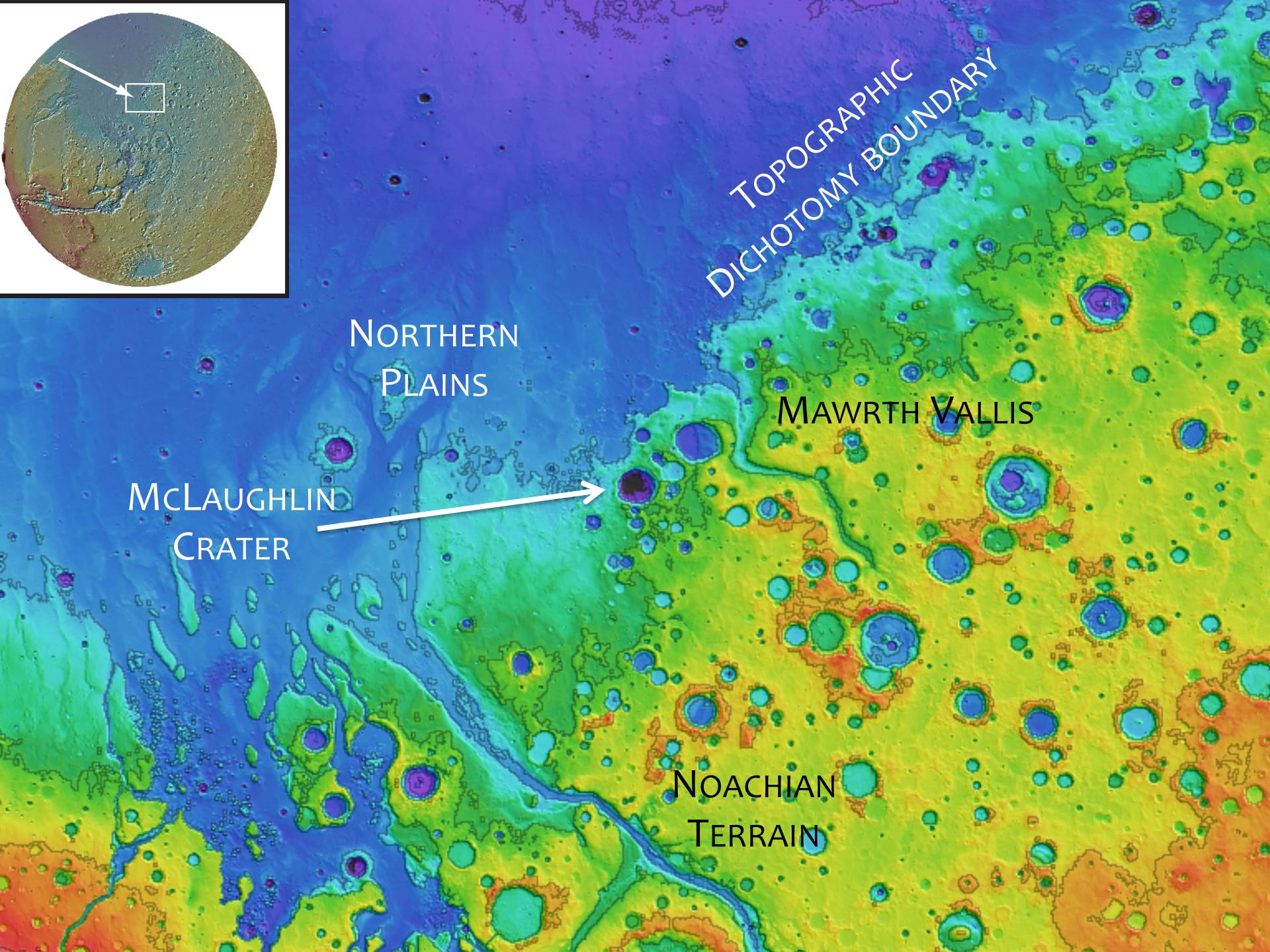
EARLY LIFE ON MARS?

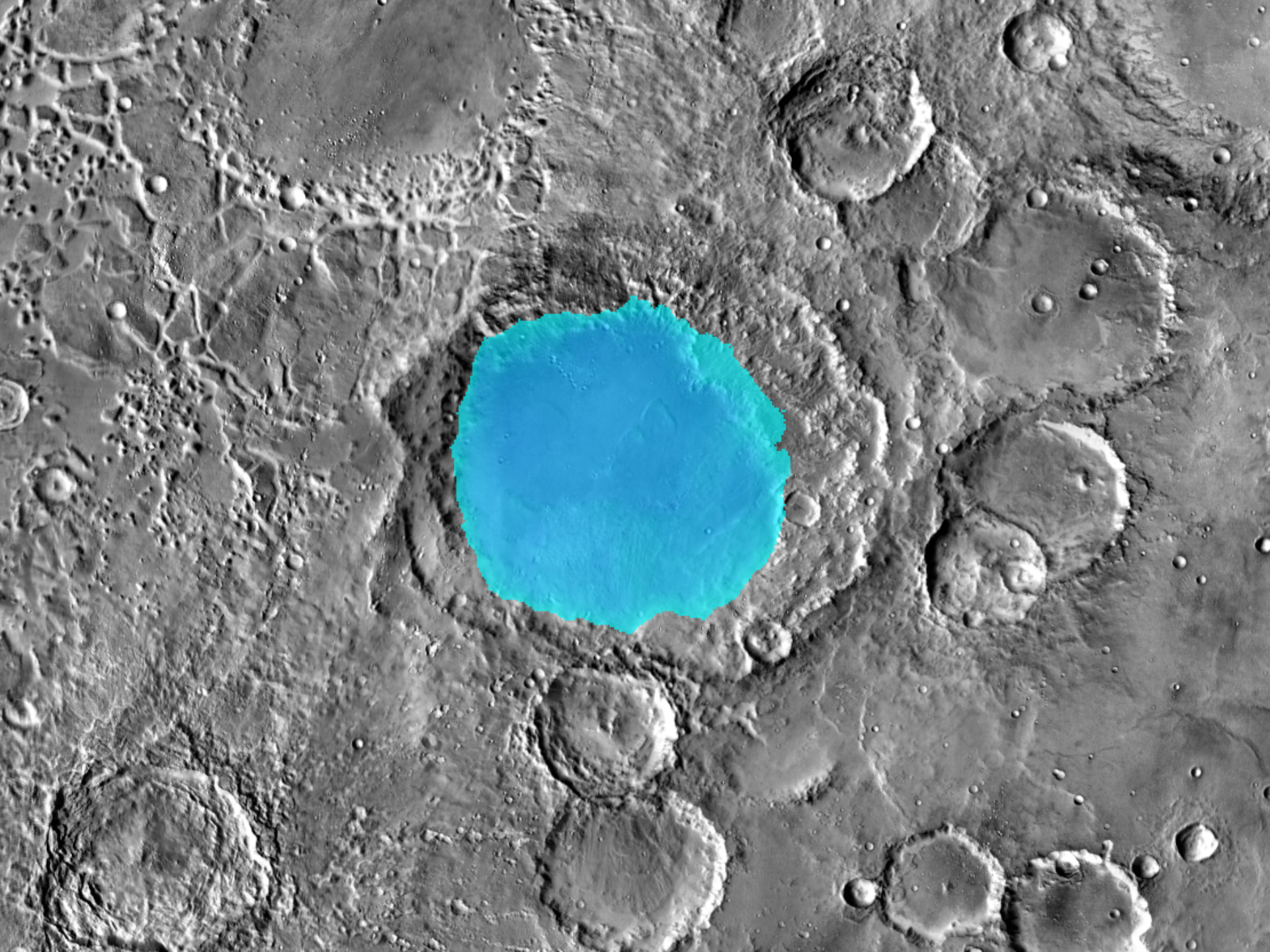




+ consider that solar energy is much less at Mars (44%)
+ consider faint young sun (~70% present)
+ no magnetic field
→ THE SURFACE IS AND WAS A BUMMER
→ WHY PHOTOSYNTHESIS?

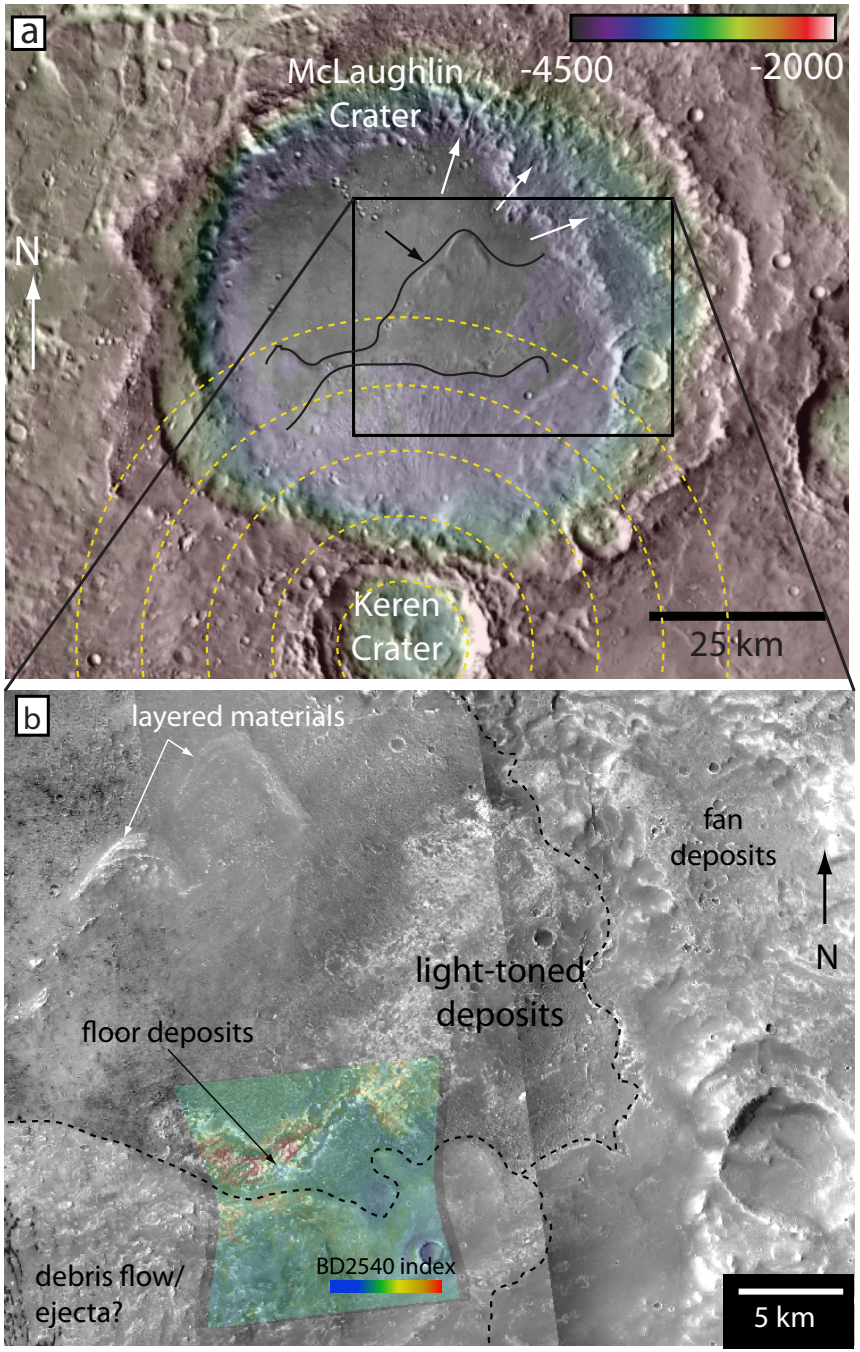
We might want to tap subsurface, hydrothermal, and groundwater-fed environments


Topographic Dichotomy Boundary
Northern Plains
Mawrth Vallis
McLaughlin Crater
Noachian Terrain



McLaughlin Crater

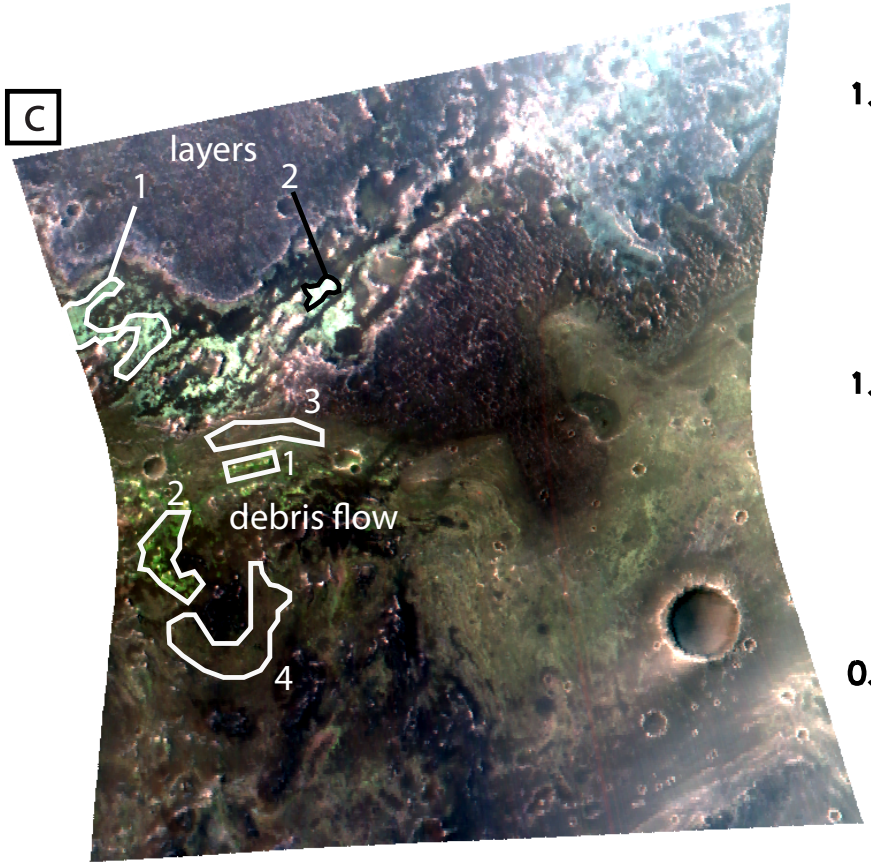
- Channels in wall, terminate ~500 m above the floor
- Ejecta from Keren on floor
- Lobate materials
- Layered sed rx

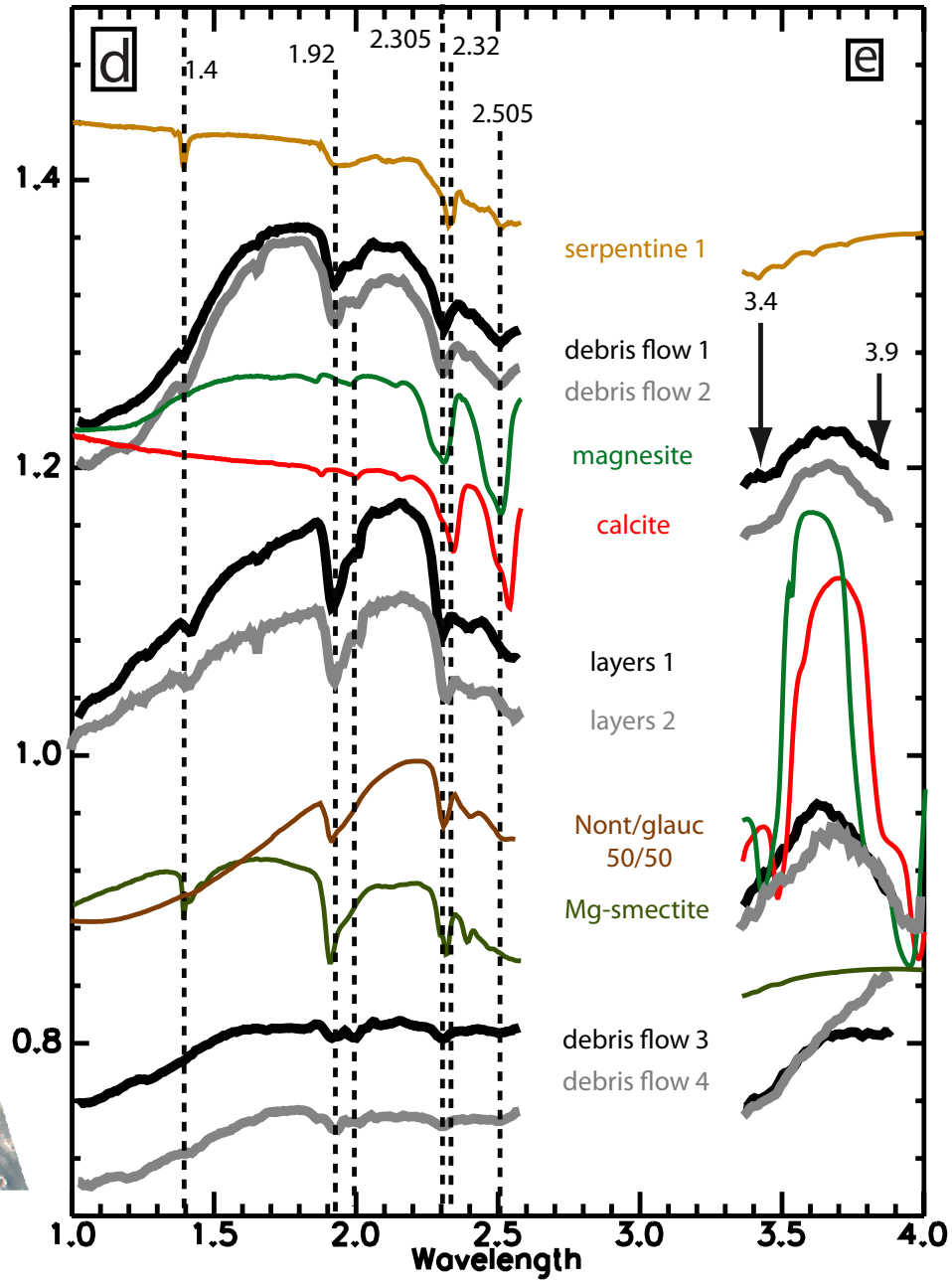


Michalski et al., Nature Geoscience, 2013

CRISM RESULTS

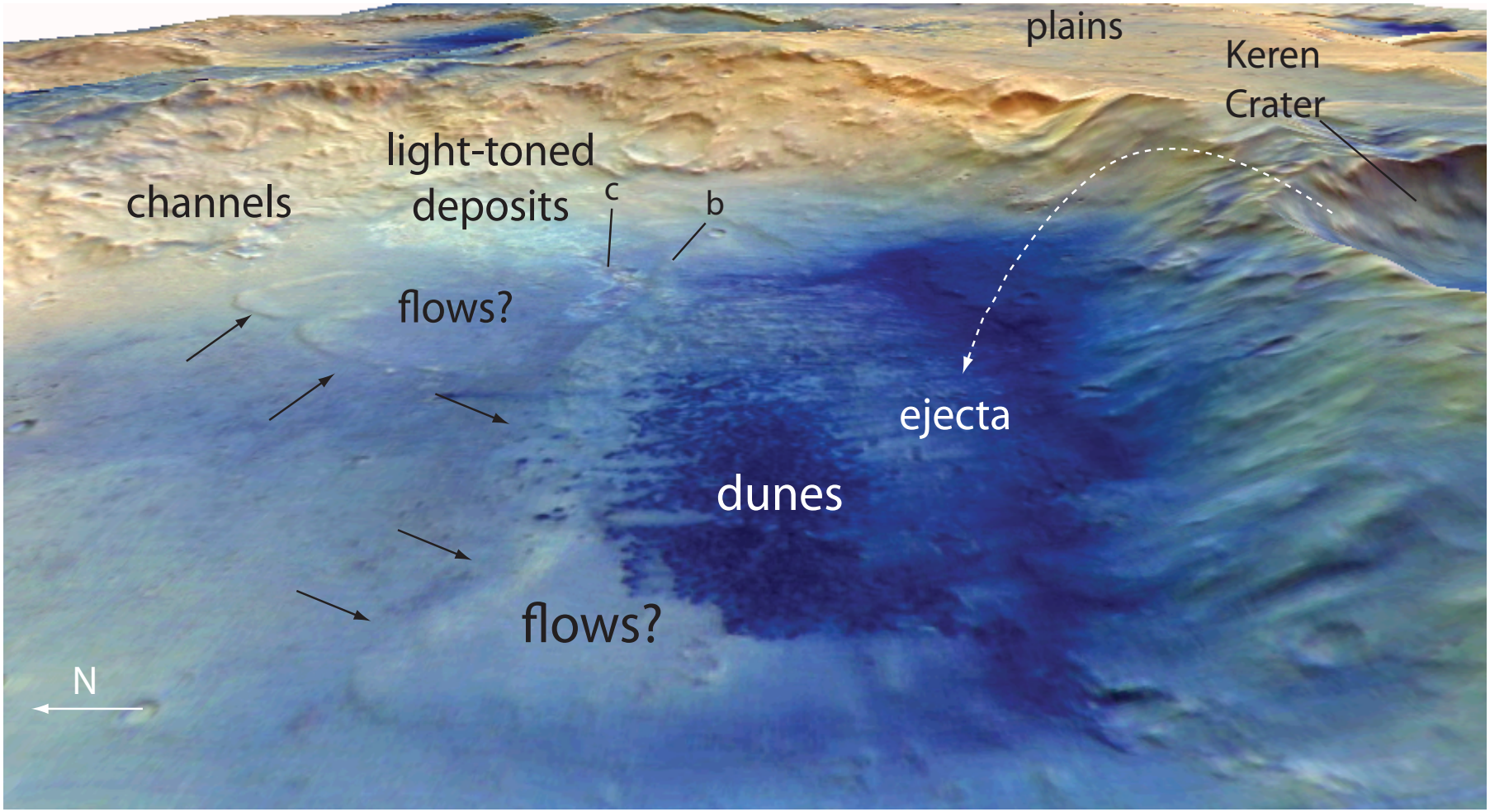
CLAYS AND CARBONATES



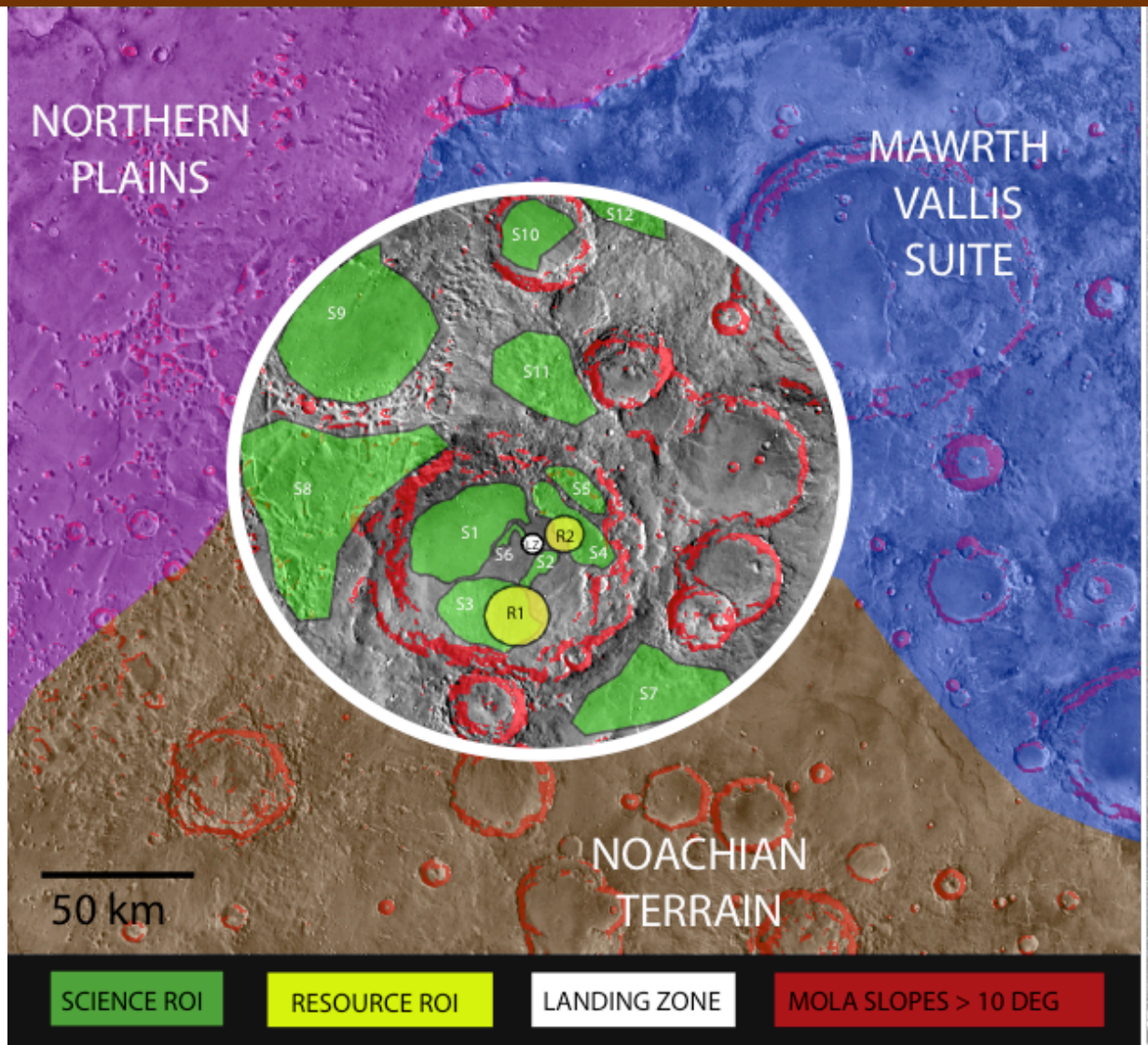


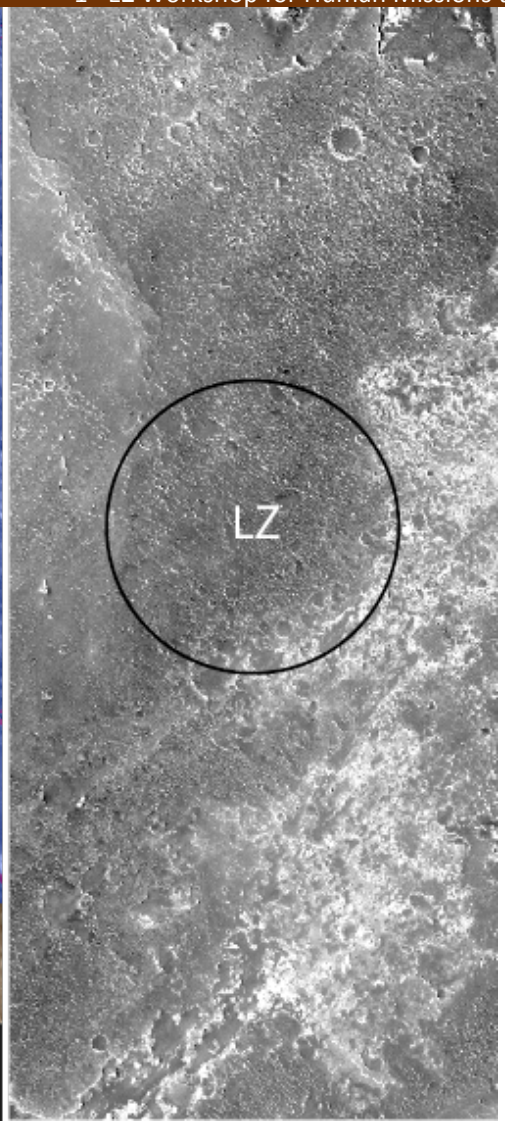
Michalski et al., Nature Geoscience, 2013

LAYERED SEDIMENTS AND LOBATE MATERIALS



Exploration Zone Map





Exploration Zone Summary

SUMMARY

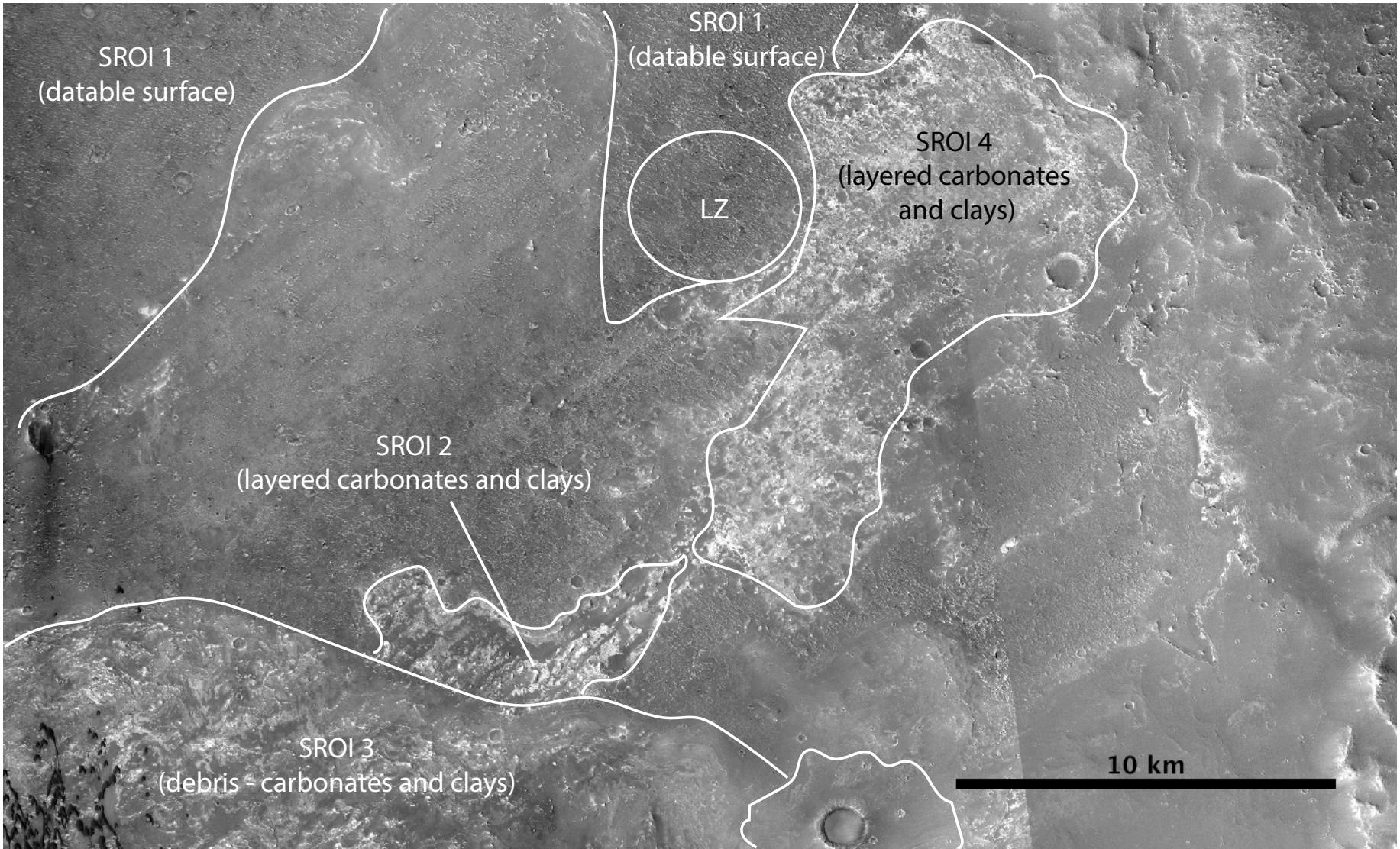
Resources	Science
no known ice	layered, ancient, hydrothermal/ground water-fed lacustrine sediments
no known sulfates	datable regional igneous surface
significant amounts of clay minerals (not all clays are equal!)	layered Fe-rich clays and carbonates
significant amounts of hydrated Mg-carbonates	blocks of subsurface carbonates and clays
accessible, disagreggated materials	Mawrth-type clays, Acidalia deposits, ancient Noachian crust

Table 1: ROI characteristics for McLaughlin Crater site.

EXPLORATION ZONE: McLAUGHLIN CRATER AND SURROUNDING TERRAIN

ROI	
R1	Blocks of hydrated carbonates (already fragmented)
R2	Smectitic clay minerals (both dioctahedral and trioctahedral clays)
S1	Datable airfall igneous unit with regional extent; same as in Mawrth
S2	Thick section of layered Noachian lacustrine carbonates and clays
S3	Ejecta and debris flow with large sampling of deep crustal igneous and hydrothermal materials. Key for both igneous petrology and deep biosphere. Igneous materials are likely datable.
S4	Delta deposits in ~500 m-deep Noachian lake
S5	Channels in crater wall
S6	Likely subaqueous debris flow deposits
S7	Datable igneous surface: ridged plains
S8	Pyroclastic deposits
S9	Northern plains deposits
S10	Datable surface, likely igneous
S11	Altered ejecta; deep crustal materials
S12	Mawrth Vallis clays

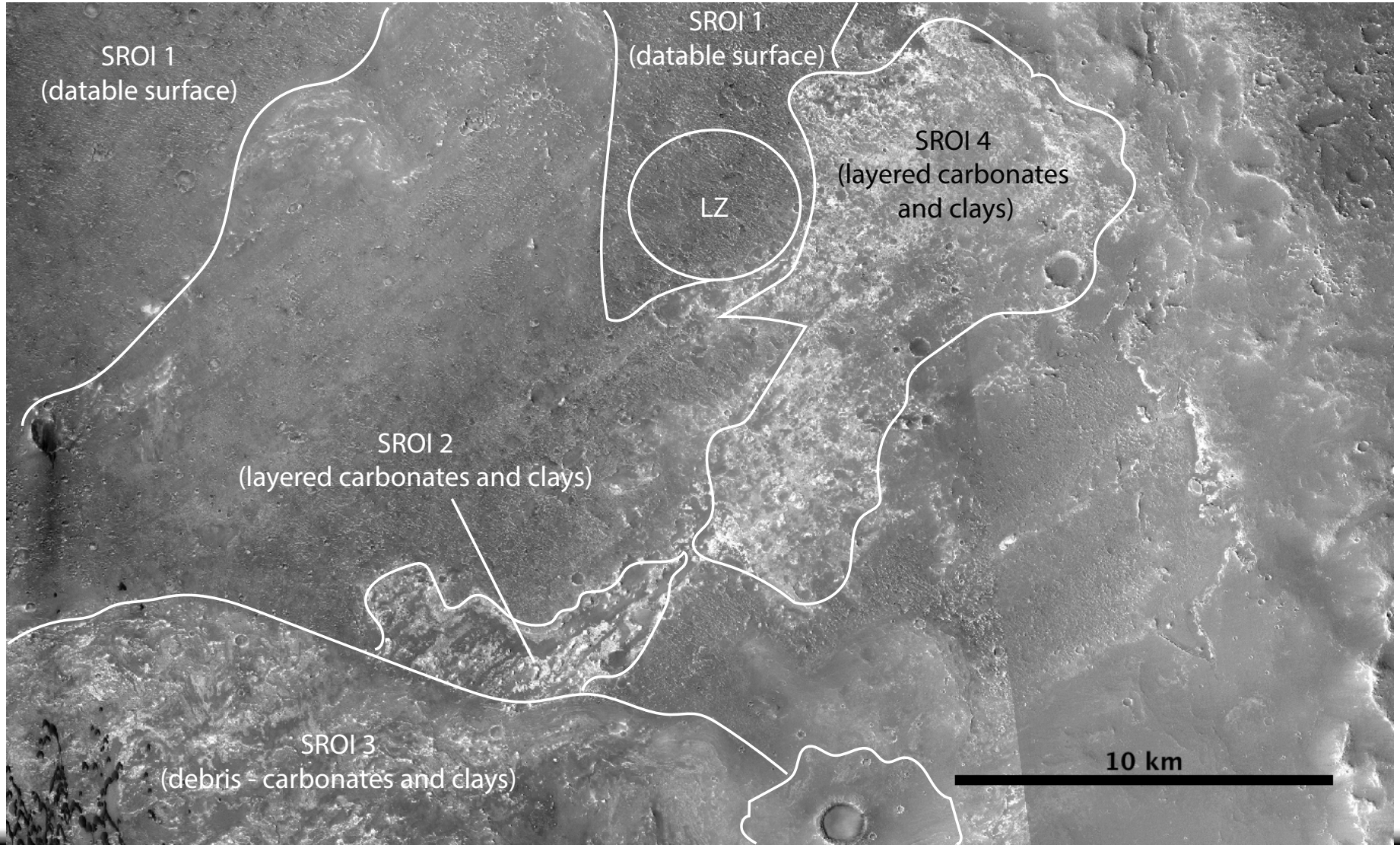
Primary Science ROIs



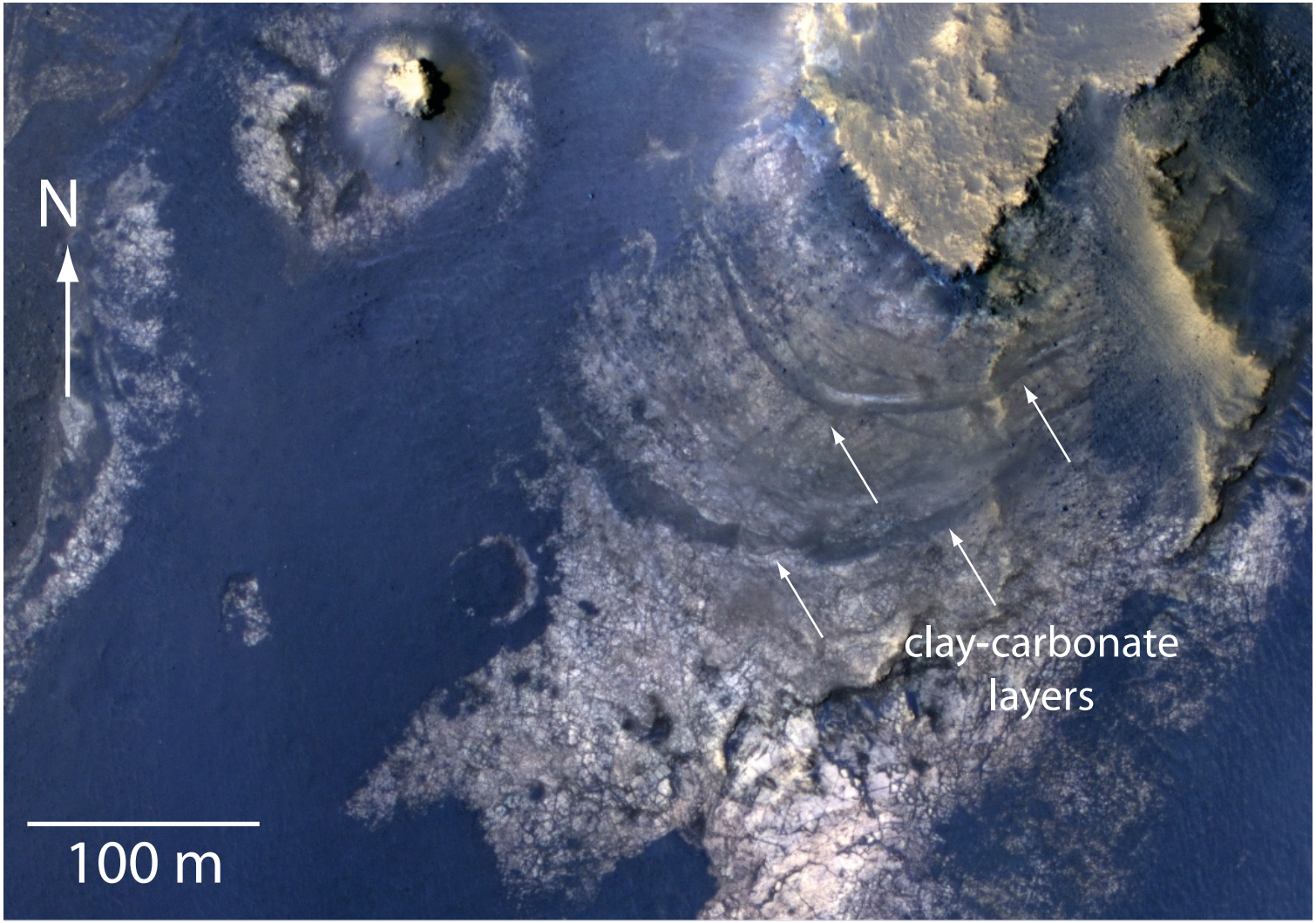
We need to talk… about dating

SROI1: regional dark unit – probably ash, probably 3.7-3.8 Ga)

Primary Science ROIs

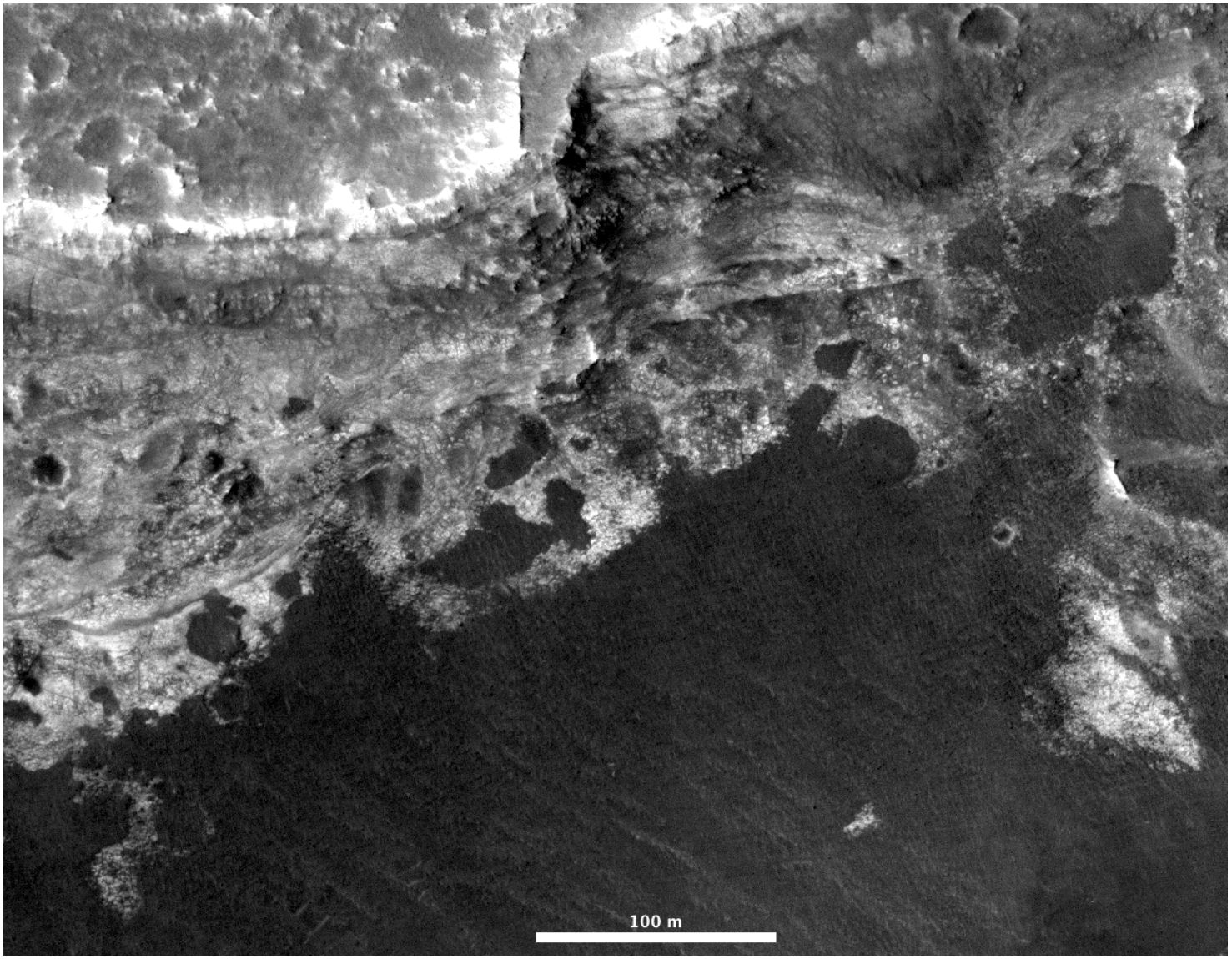


SROI2: Layered units on the crater floor

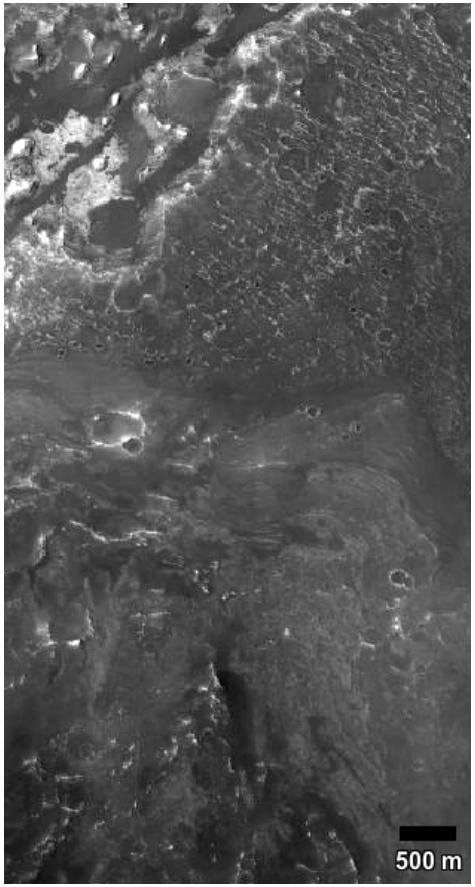


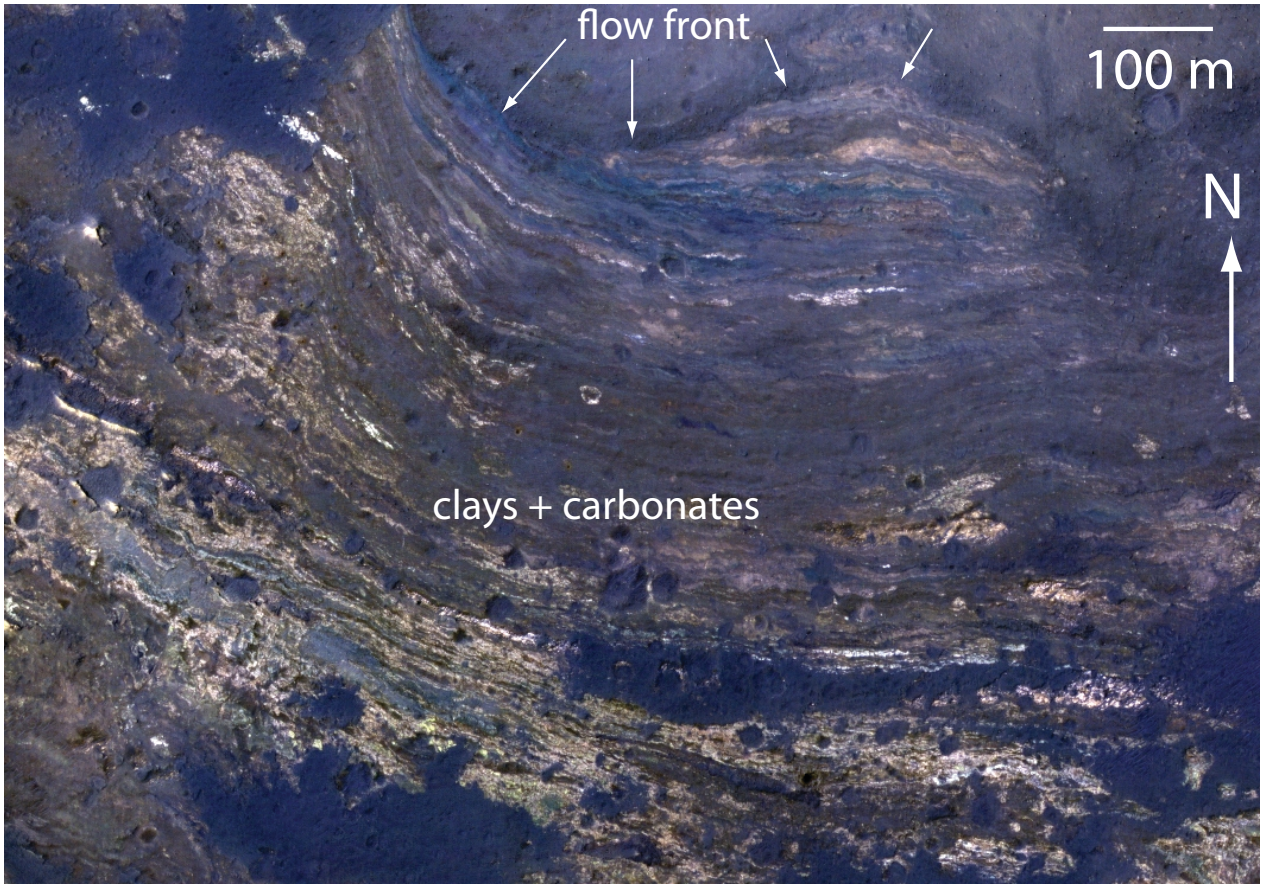
SROI2: Layered units on the crater floor

SROI2: Interesting bedding in the floor unit

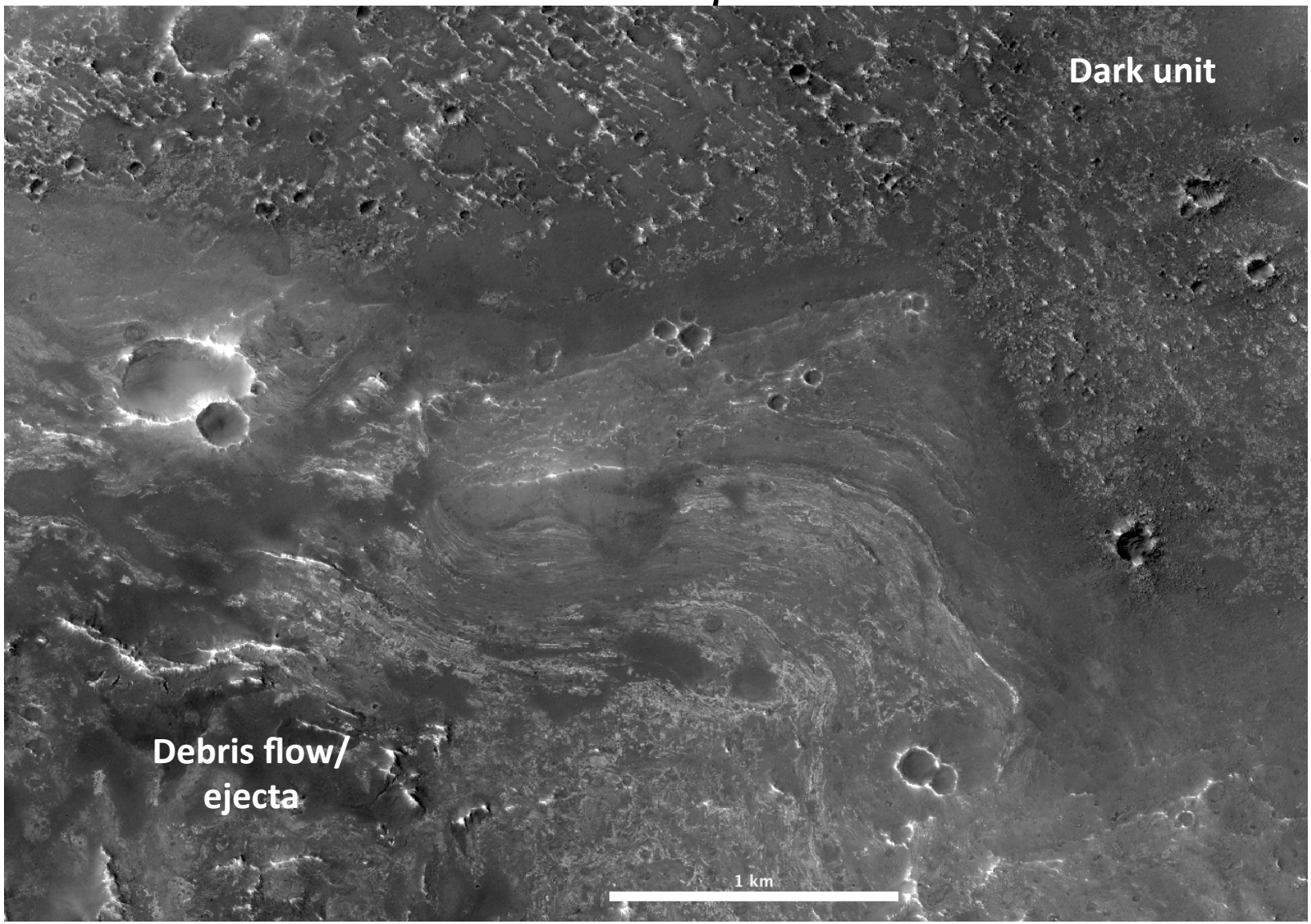


SROI3: DEBRIS FLOW

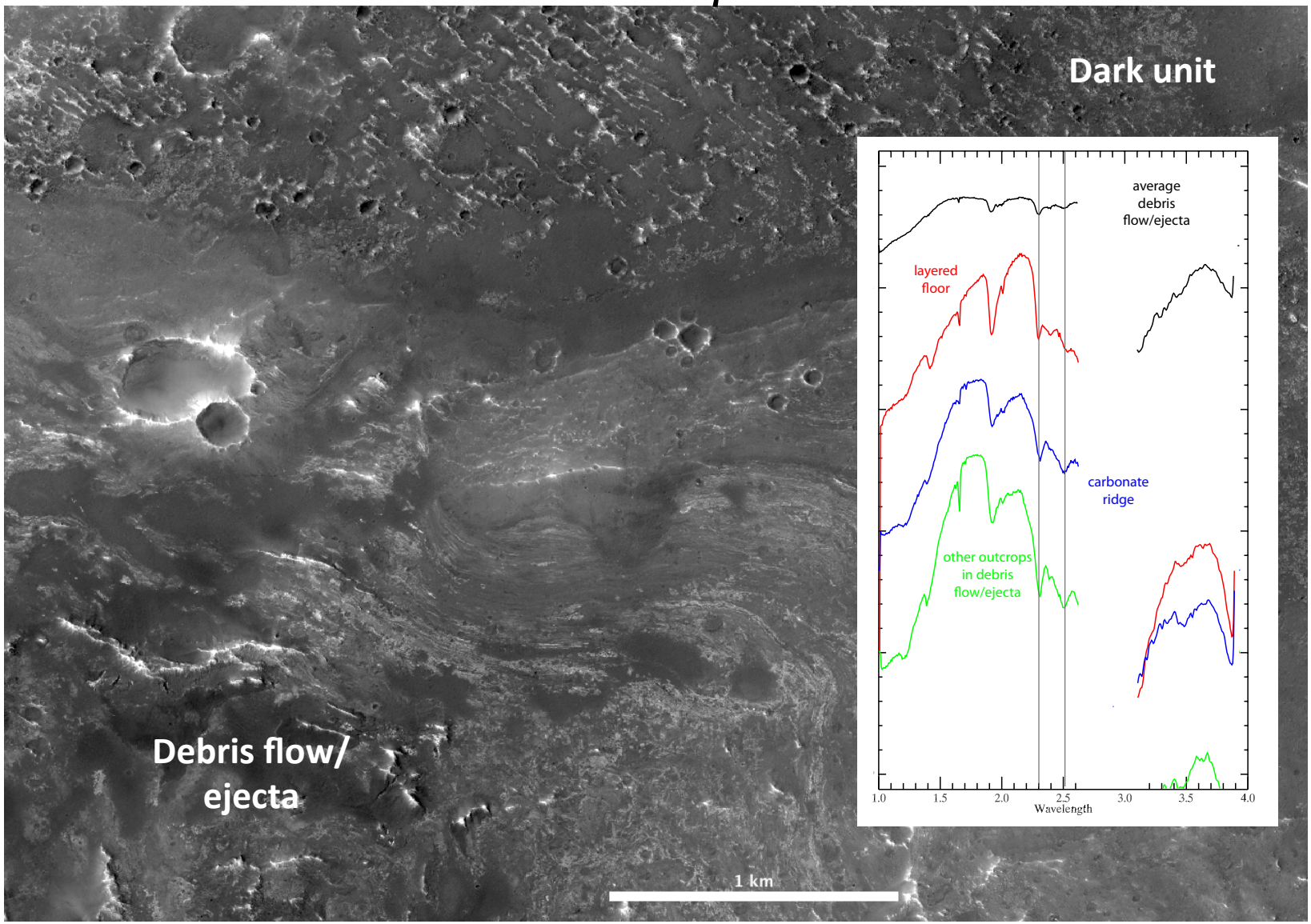




RROI 1: FRAGMENTED CARBONATE AND CLAYS IN DEBRIS FLOW/EJECTA



RROI 1: FRAGMENTED CARBONATE AND CLAYS IN DEBRIS FLOW/EJECTA



Science ROI(s) Rubric

Site Factors					SROI1	SROI2	SROI3	SROI(n)	RROI1	RROI2	RROI3	RROI(n)	EZ SUM
Science Site Criteria	Astrobio	Threshold	AND/OR	**Potential for past habitability**	●	●	●						
				Potential for present habitability/refugia	●	●	●						
		Qualifying		Potential for organic matter, w/ surface exposure	●	●	●						
	Atmospheric Science	Threshold		**Noachian/Hesperian rocks w/ trapped atmospheric gases**	●	●	●						
		Qualifying		Meteorological diversity in space and time	?	?	?						
				High likelihood of surface-atmosphere exchange	●	●	●						
				Amazonian subsurface or high-latitude ice or sediment									
				High likelihood of active trace gas sources	○	○	○						
	Geoscience	Threshold		**Range of martian geologic time; datable surfaces**	●	●	●						
				Evidence of aqueous processes	●	●	●						
				Potential for interpreting relative ages	●	●	●						
		Qualifying		Igneous Rocks tied to 1+ provinces or different times	●	●	●						
				Near-surface ice, glacial or permafrost									
				Noachian or pre-Noachian bedrock units	●	●	●						
				Outcrops with remnant magnetization									
				Primary, secondary, and basin-forming impact deposits	●	●	●						
				Structural features with regional or global context	●	●	●						
				Diversity of aeolian sediments and/or landforms	○	○	○						

Key	
●	**Yes**
○	**Partial Support or Debated**
	No
?	**Indeterminate**

Resource ROI(s) Rubric

			Site Factors	RROI1	RROI2	RROI3	RROI(n)	EZ SUM
ISRU and Civil Engineering Criteria	Engineering		Meets First Order Criteria (Latitude, Elevation, Thermal Inertia)					
	Water Resource	Threshold	AND/OR: **Potential for ice or ice/regolith mix**					
			Potential for hydrated minerals	●				
			Quantity for substantial production	●				
			Potential to be minable by highly automated systems	●				
			Located less than 3 km from processing equipment site	?				
			Located no more than 3 meters below the surface	●				
			Accessible by automated systems	?				
		Qualifying	Potential for multiple sources of ice, ice/regolith mix **and** hydrated minerals					
			Distance to resource location can be >5 km	●				
			Route to resource location must be (plausibly) traversable	●				
	Civil Engineering	Threshold	**~50 sq km region of flat and stable terrain with sparse rock distribution**					
			1–10 km length scale: <10°	●				
			Located within 5 km of landing site location	●				
		Qualifying	Located in the northern hemisphere	●				
			Evidence of abundant cobble sized or smaller rocks and bulk, loose regolith	●				
			Utilitarian terrain features	●				
	Food Production	Qualifying	Low latitude	●				
			No local terrain feature(s) that could shadow light collection facilities	●				
			Access to water	●				
			Access to dark, minimally altered basaltic sands	●				
	Resource	Threshold	**Potential for metal/silicon**					
			Potential to be minable by highly automated systems					
			Located less than 3 km from processing equipment site					
			Located no more than 3 meters below the surface					

Key	
●	Yes
○	Partial Support or Debated
	No
?	Indeterminate

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ARTICLES

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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 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.

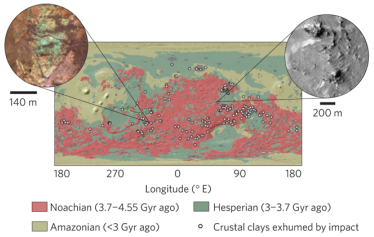

Figure 1 | Distribution of exhumed deep crustal rocks on Mars. Detections of deep crustal clays reported previously[2] are overlaid on global surface geology. Exhumed clays in Noachian terrains represent subsurface hydrothermal processes early in Mars's history. Insets show textures of two examples of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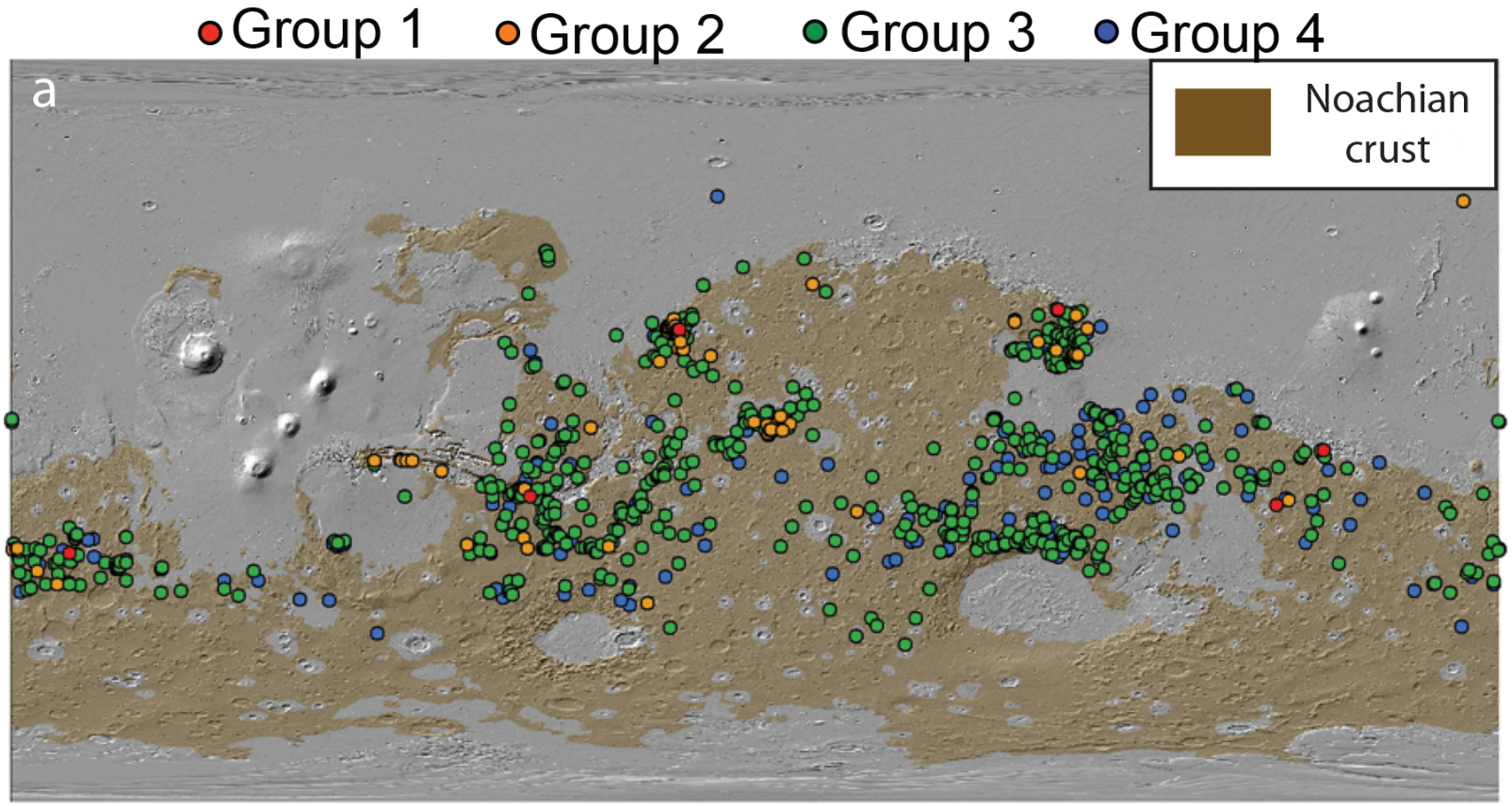
Exploration Zone Summary