Stony Brook University

INTERPRETING THE ROCK RECORD OF EARLY MARS, FROM ORBIT

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Powered by: JMARS

Funding sources: NASA MDAP; Mars Odyssey Project

MARS TODAY – A COLD, DRY DESERT

Mars is cold.

Daily mean. at equator -60C

Typically-120C at the poles

(Annual avg at Earth's south pole: -48C)

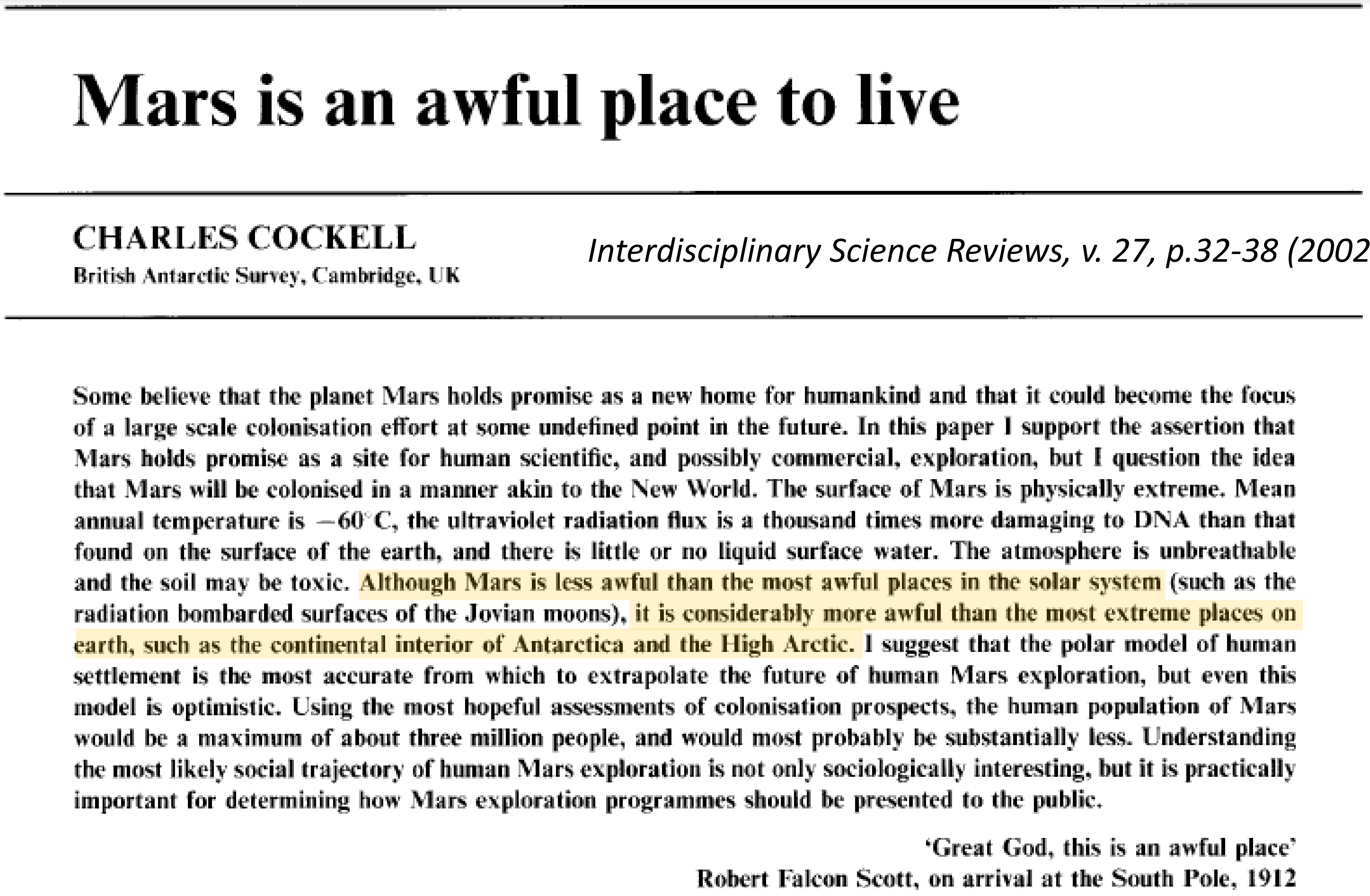
The atmosphere is thin.

The pressure is less than 1/100th of the Earth's atmosphere and it is nearly all carbon dioxide – almost no oxygen, nitrogen.

Mars is dry. The atmosphere is too thin and too cold for liquid water to be stable at the surface.

Or, to put it another way…

Introduction



Mars is an awful place to live

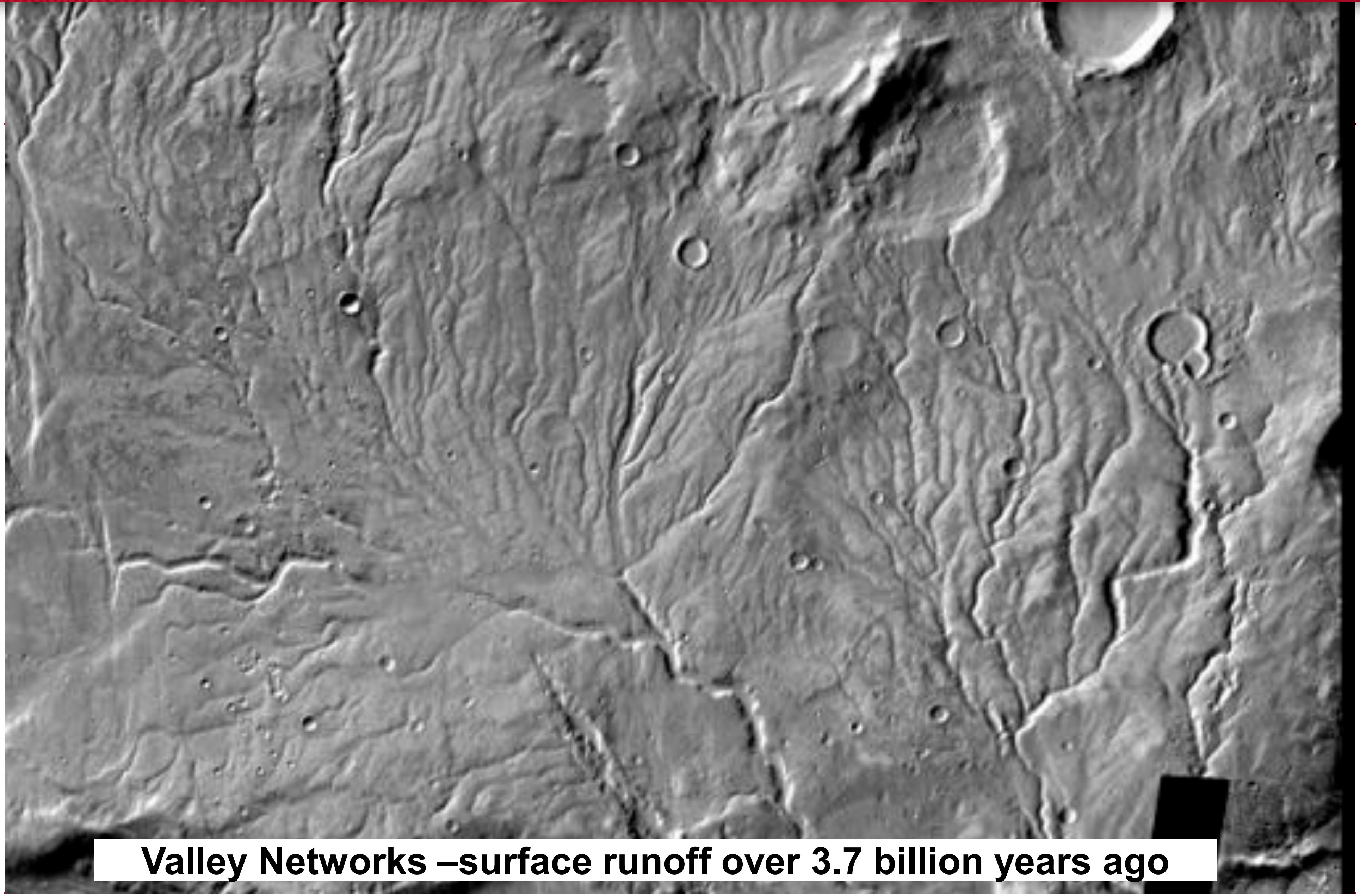
CHARLES COCKELL
British Antarctic Survey, Cambridge, UK

Interdisciplinary Science Reviews, v. 27, p.32-38 (2002)

Some believe that the planet Mars holds promise as a new home for humankind and that it could become the focus of a large scale colonisation effort at some undefined point in the future. In this paper I support the assertion that Mars holds promise as a site for human scientific, and possibly commercial, exploration, but I question the idea that Mars will be colonised in a manner akin to the New World. The surface of Mars is physically extreme. Mean annual temperature is −60°C, the ultraviolet radiation flux is a thousand times more damaging to DNA than that found on the surface of the earth, and there is little or no liquid surface water. The atmosphere is unbreathable and the soil may be toxic. Although Mars is less awful than the most awful places in the solar system (such as the radiation bombarded surfaces of the Jovian moons), it is considerably more awful than the most extreme places on earth, such as the continental interior of Antarctica and the High Arctic. I suggest that the polar model of human settlement is the most accurate from which to extrapolate the future of human Mars exploration, but even this model is optimistic. Using the most hopeful assessments of colonisation prospects, the human population of Mars would be a maximum of about three million people, and would most probably be substantially less. Understanding the most likely social trajectory of human Mars exploration is not only sociologically interesting, but it is practically important for determining how Mars exploration programmes should be presented to the public.

> 'Great God, this is an awful place'
> Robert Falcon Scott, on arrival at the South Pole, 1912

Was Mars always ~~an awful place to live~~ a cold, dry desert? What was the climate like on Early Mars?

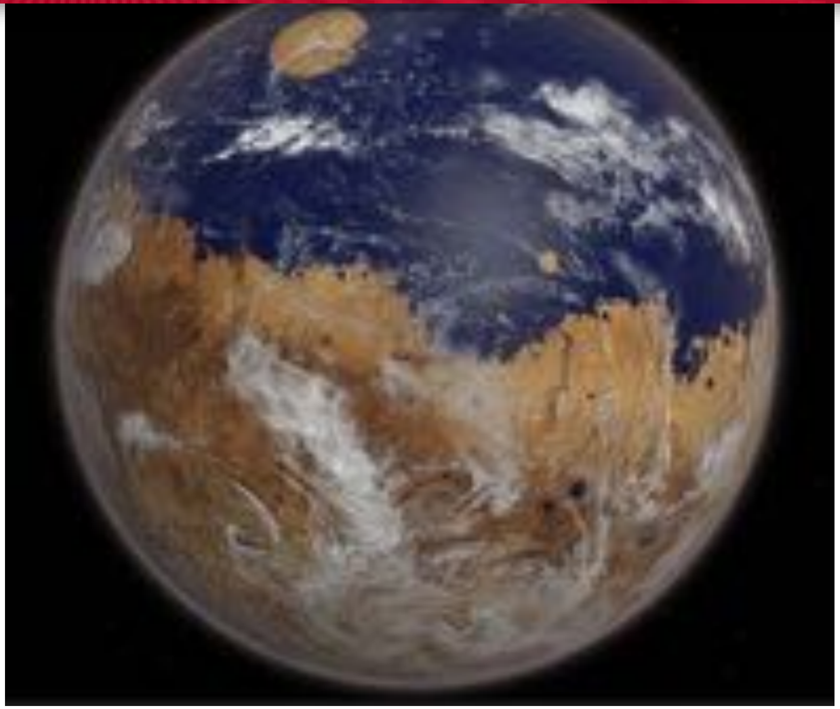


Valley Networks –surface runoff over 3.7 billion years ago

Uncertainties about the conditions and duration that produced these features.

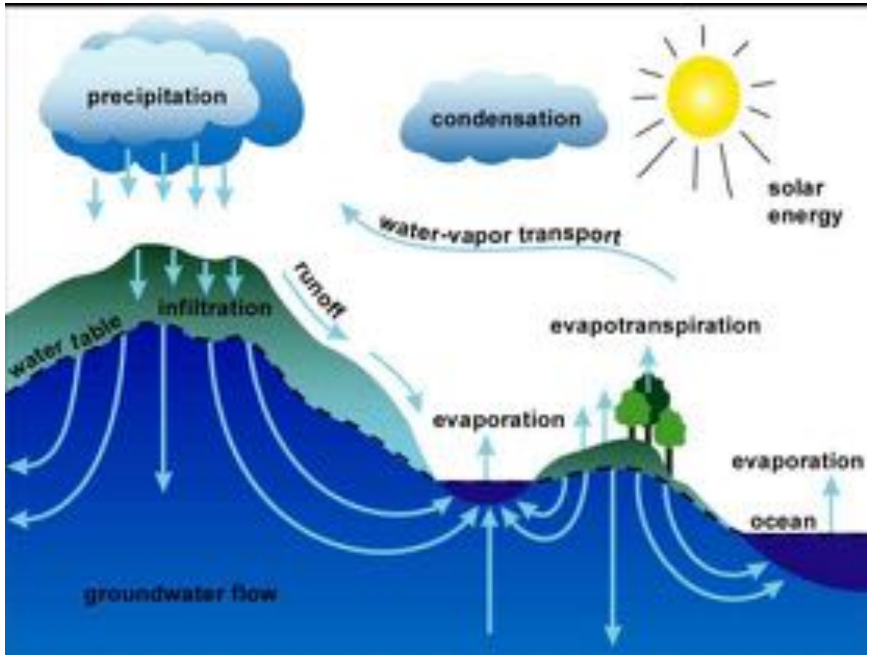
Introduction

Warm, wet with fully integrated hydrologic cycle?

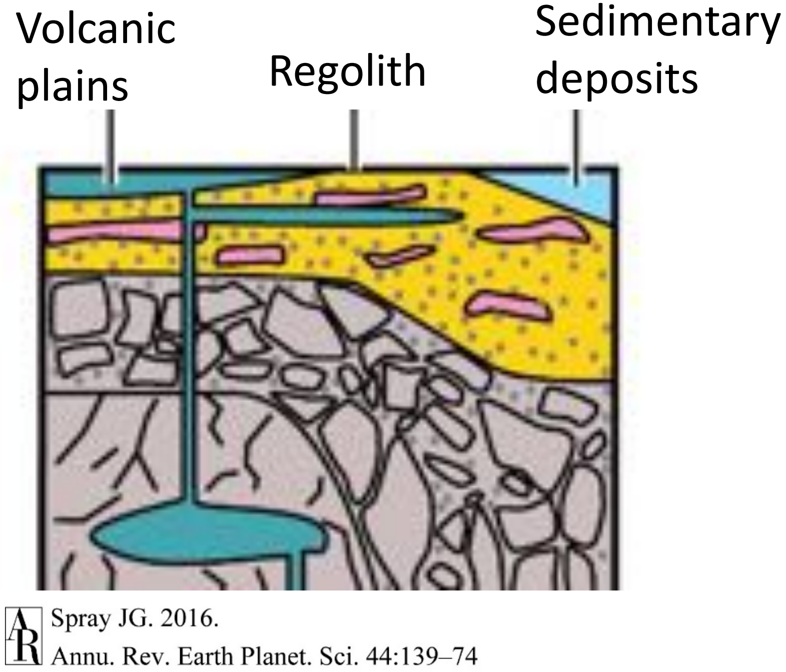


⇦ ? ⇨

Cold and icy, with periodic snowmelt?



What surface processes were dominant on Early Mars?



Spray JG. 2016.
Annu. Rev. Earth Planet. Sci. 44:139–74

Volcanism—*what style(s)? Timing, transitions?*


Explosive volcanism

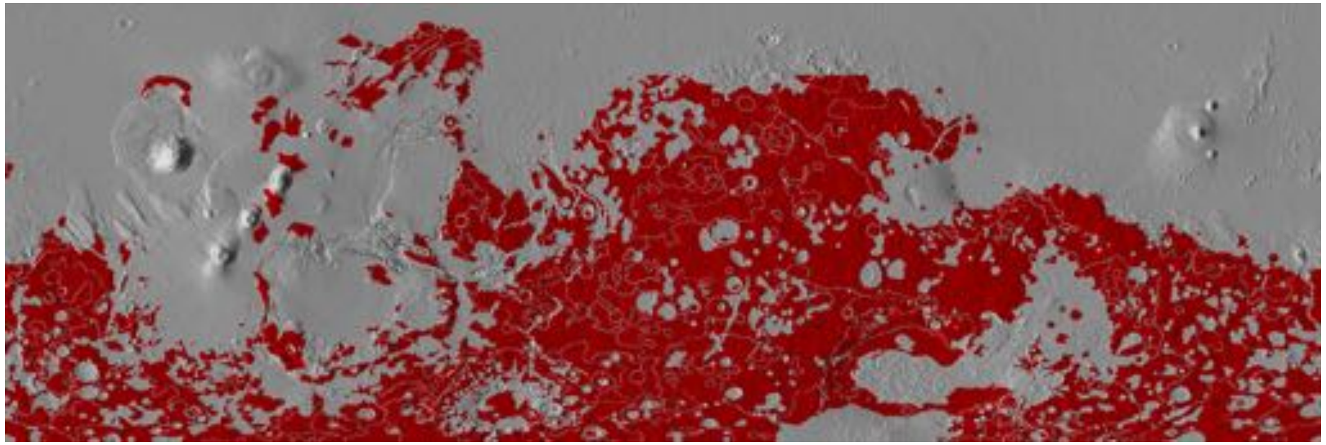

Effusive volcanism

Global transition from explosive to effusive with time? [e.g. Greeley et al. 2000; Robbins et al. 2011; Bandfield et al. 2013]

Sedimentary deposition *– Lakes common? Fluvial transport? Aeolian? Glacial deposits?*

What surface processes were dominant on Early Mars?

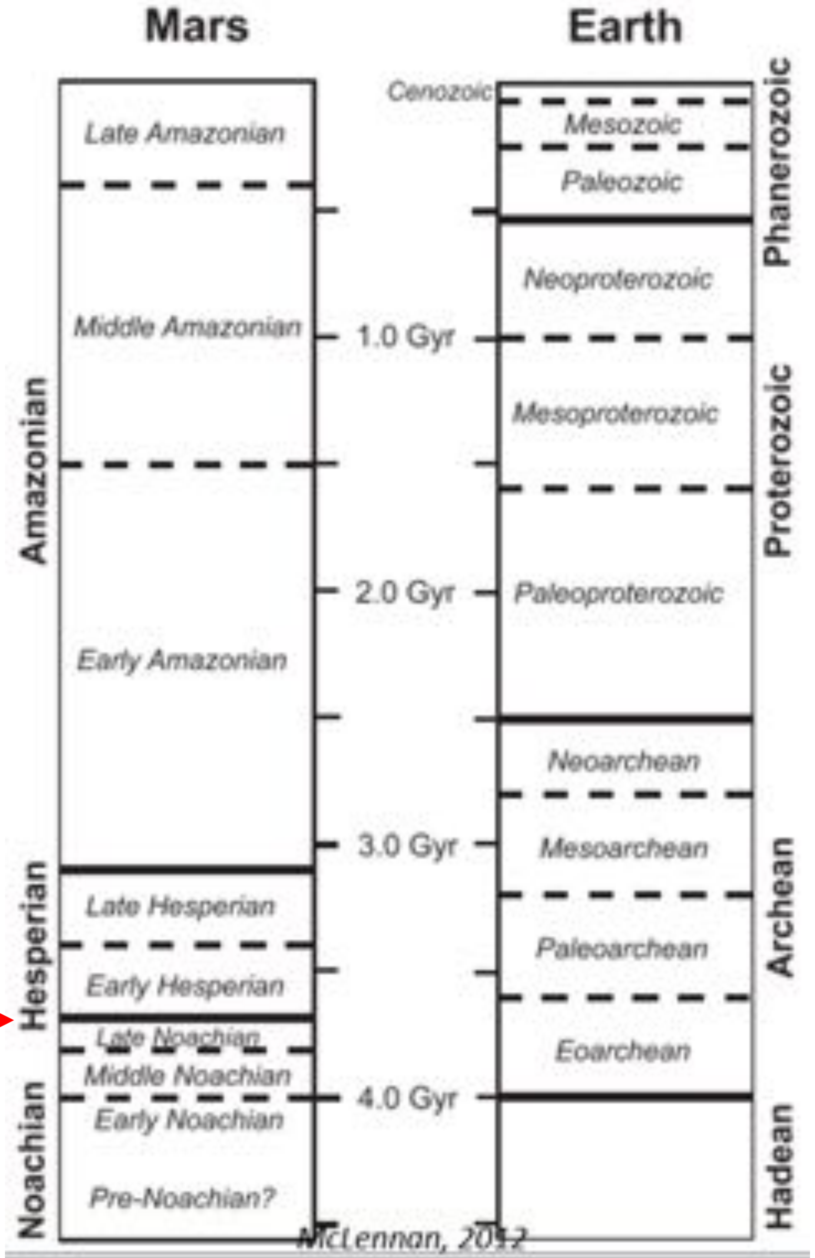
→ Study the exposed rock record for potential clues to ancient surface processes and climate.



Distribution of "Noachian" crust

Much of the crust-forming material and rock exposed at the surface is >3.7 billion yrs old! ☺

But…this means 3.7 billion years of history have happened to these surfaces… ☹



valley networks

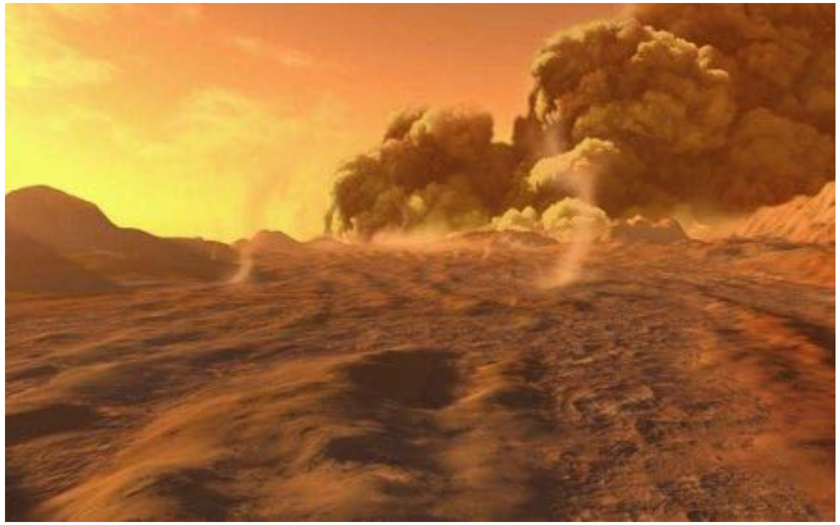
McLennan, 2012


W. Hartmann

Impacts


Utopia Planitia, VL2

Frost / ice


Wind, saltation, abrasion

Motivating questions:

What was the climate like on Early Mars?

What surface processes were dominant on Early Mars?

How have near-surface, ongoing processes shaped the surfaces we interpret today?

OVERVIEW

1. There is a vast rock record exposed in ancient terrains of Mars

   It's not all sand and dust and cobbles…

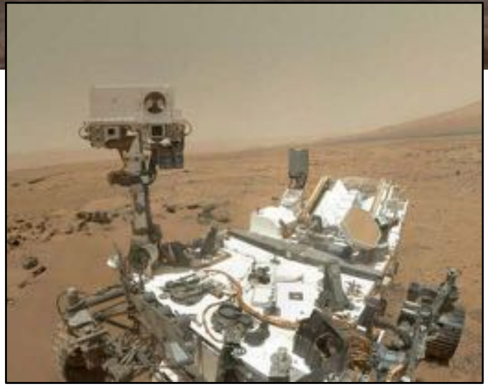
2. Most of the exposed rock is weak, easily eroded clastic rock

   Evidence for deposition through both volcanic and sedimentary processes

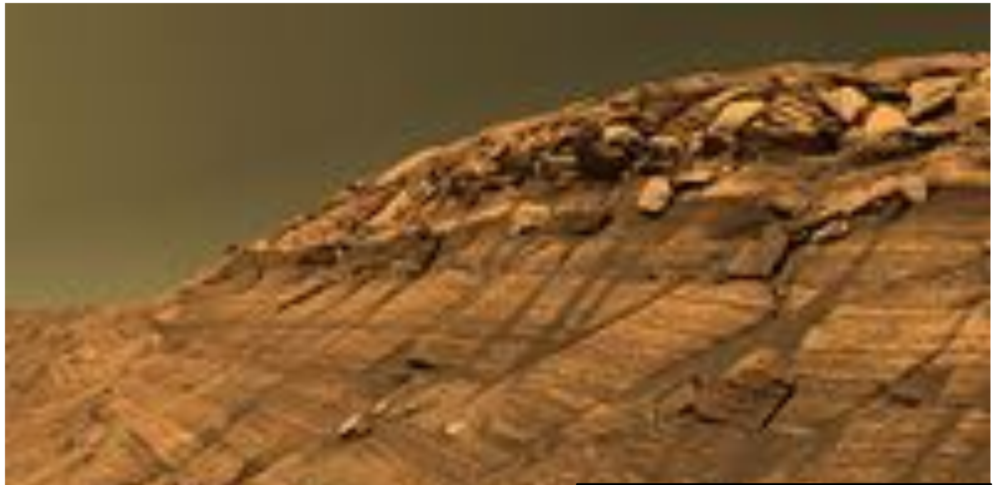
3. Complex interplay of processes have shaped what we see today

   Affects how we interpret the surface from orbit.

Rock records at multiple scales



Mount Sharp rocks investigated with the Mars Science Laboratory



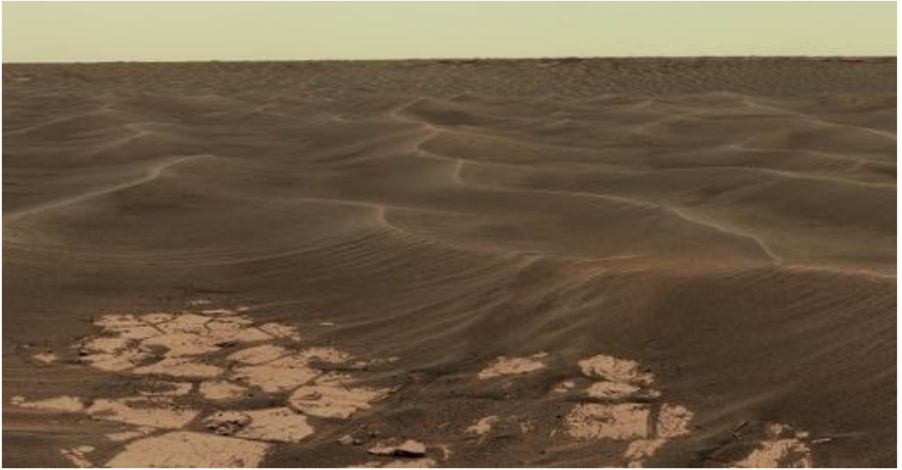
Burns formation investigated with MER Opportunity

Rovers allow access to rock records with a suite of high precision instruments, at cm scales

Orbiting spacecraft provide complementary global information at ~100 m scales.

Much of the Martian surface is covered with unconsolidated sediment

Dust, sand, regolith, loose rocks



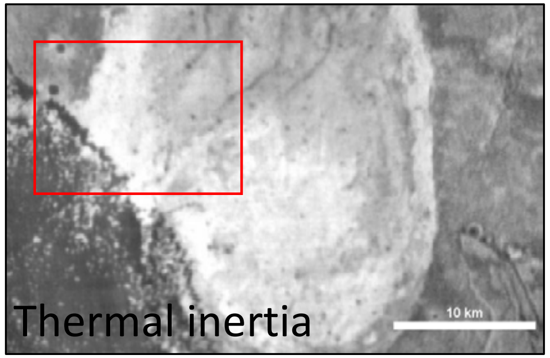
We can use high-resolution imaging (thermal, visible, short-wave infrared) to locate exposed, intact bedrock.

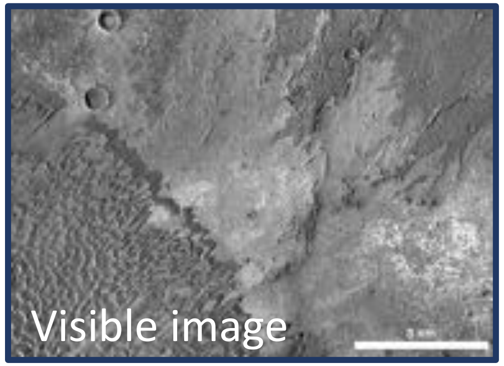
What we want to find:

USING THERMAL INERTIA (TI) TO LOCATE AND MAP BEDROCK

Thermal inertia describes a material's resistance to change in temperature.

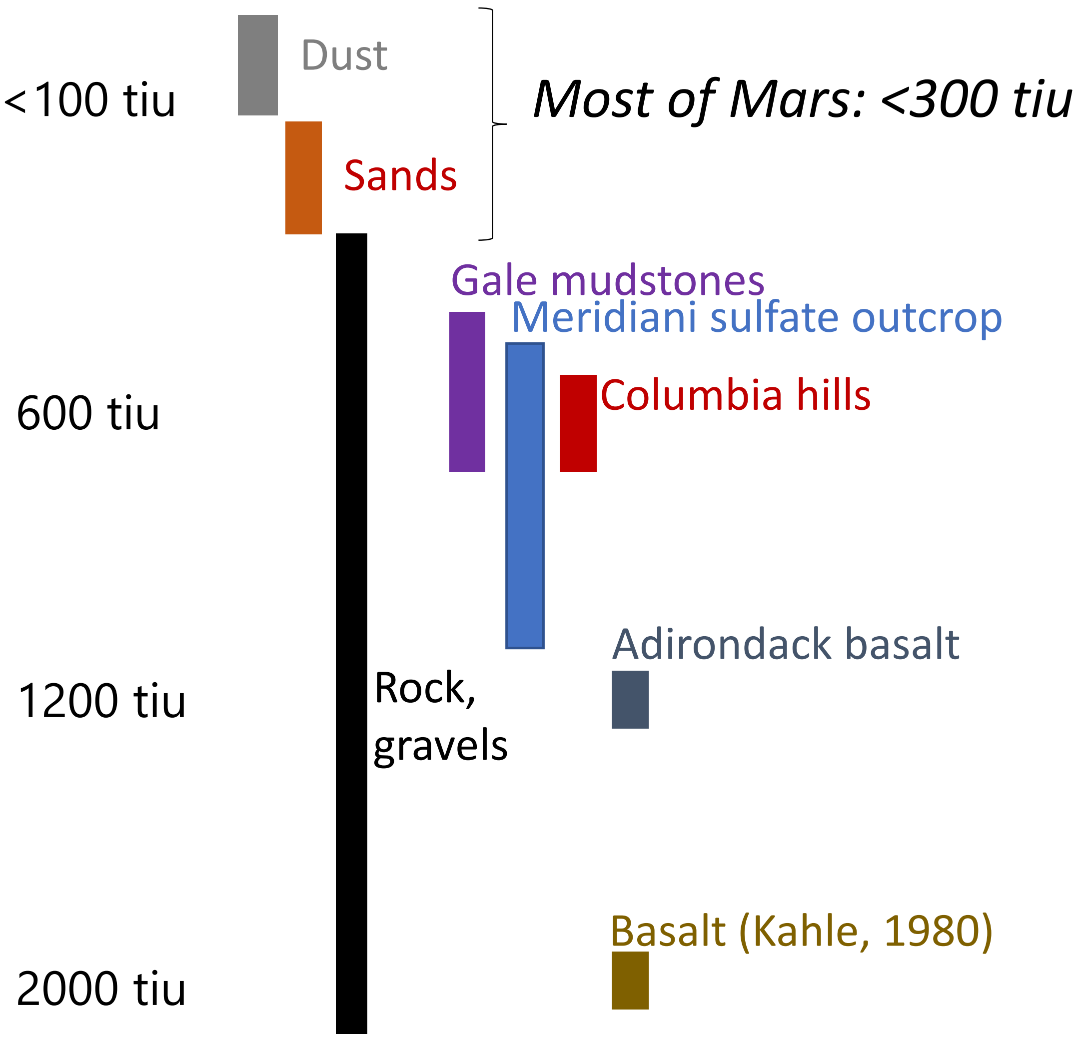
It is primarily controlled by the bulk thermal conductivity of the surface
→grain size
→porosity
→degree of induration, etc.





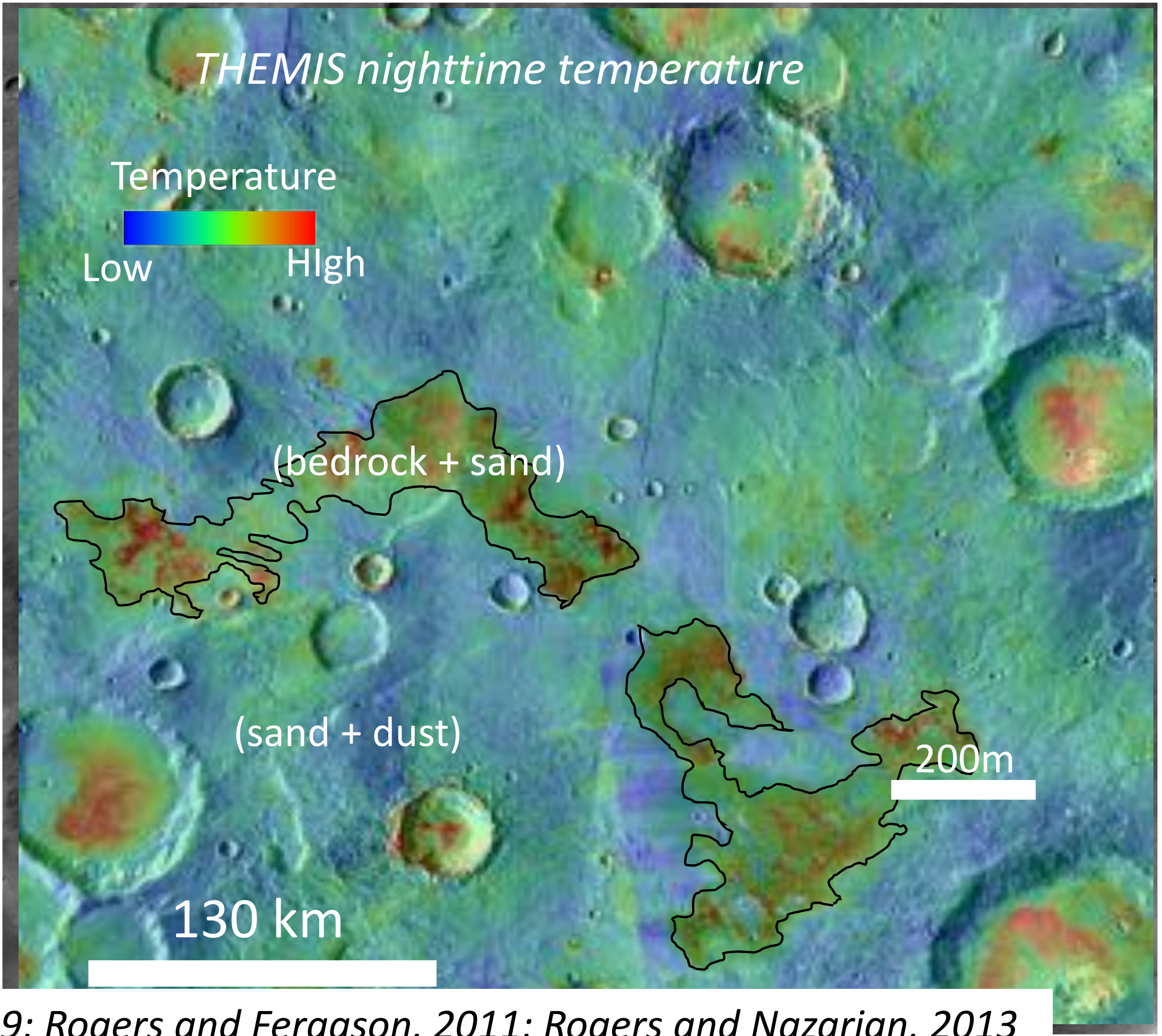
Materials of varying thermal inertia can be distinguished using temperature images.

Thermal inertia



Units are J m^{-2} K^{-1} $s^{-1/2}$ → "tiu"

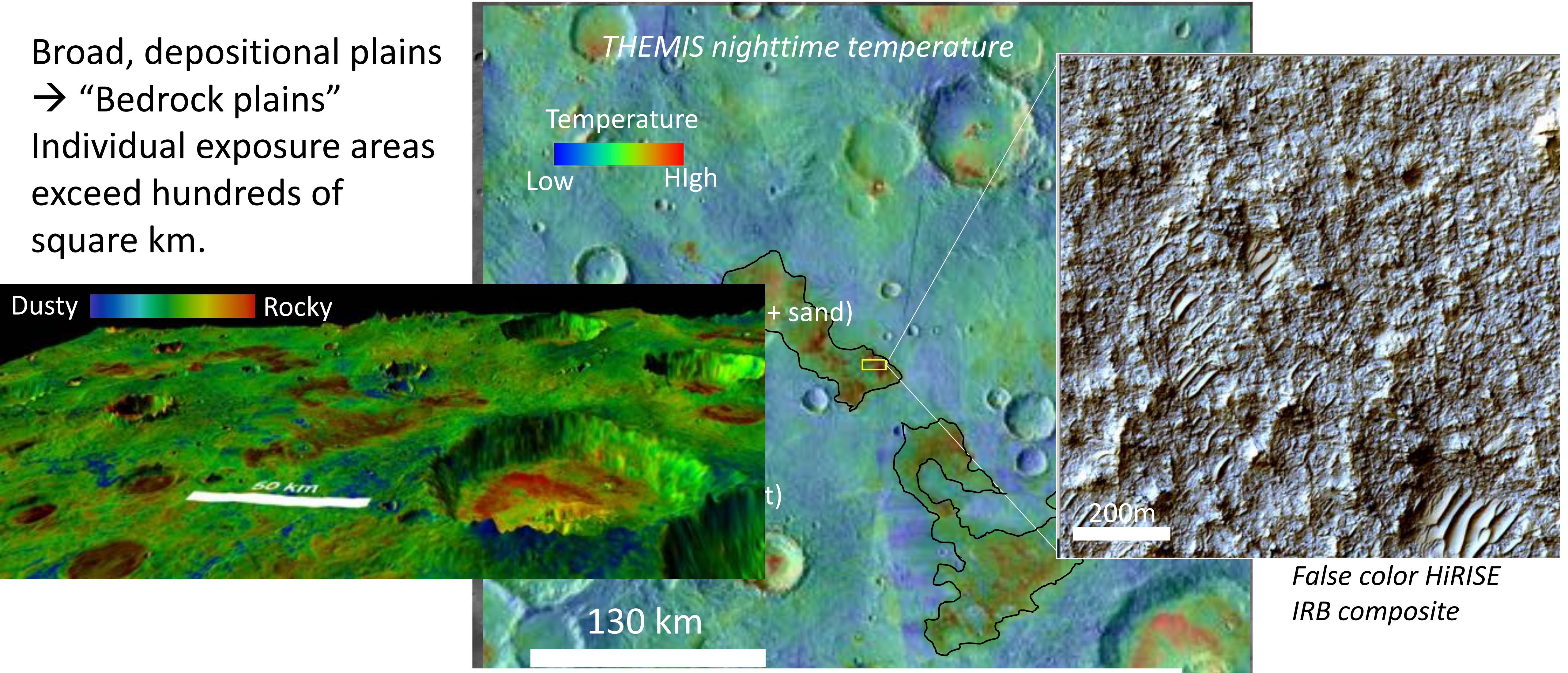
DISCOVERY OF ANCIENT BEDROCK PLAINS WITH MARS ODYSSEY THEMIS



Rogers et al. 2009; Edwards et al. 2009; Rogers and Fergason, 2011; Rogers and Nazarian, 2013

DISCOVERY OF ANCIENT BEDROCK PLAINS WITH MARS ODYSSEY THEMIS

Broad, depositional plains
→ "Bedrock plains"
Individual exposure areas exceed hundreds of square km.



False color HiRISE IRB composite

Rogers et al. 2009; Edwards et al. 2009; Rogers and Fergason, 2011; Rogers and Nazarian, 2013

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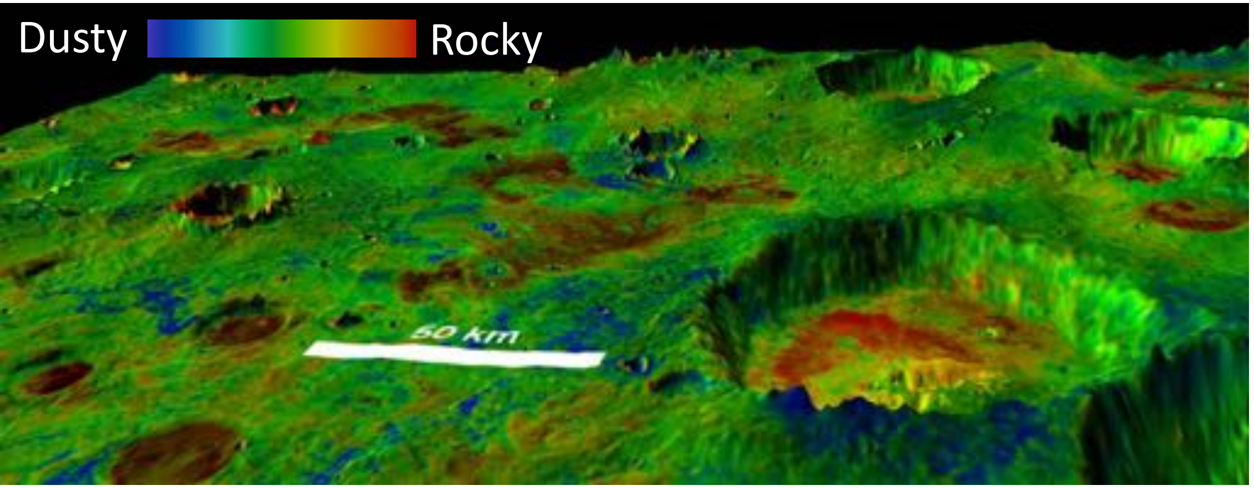
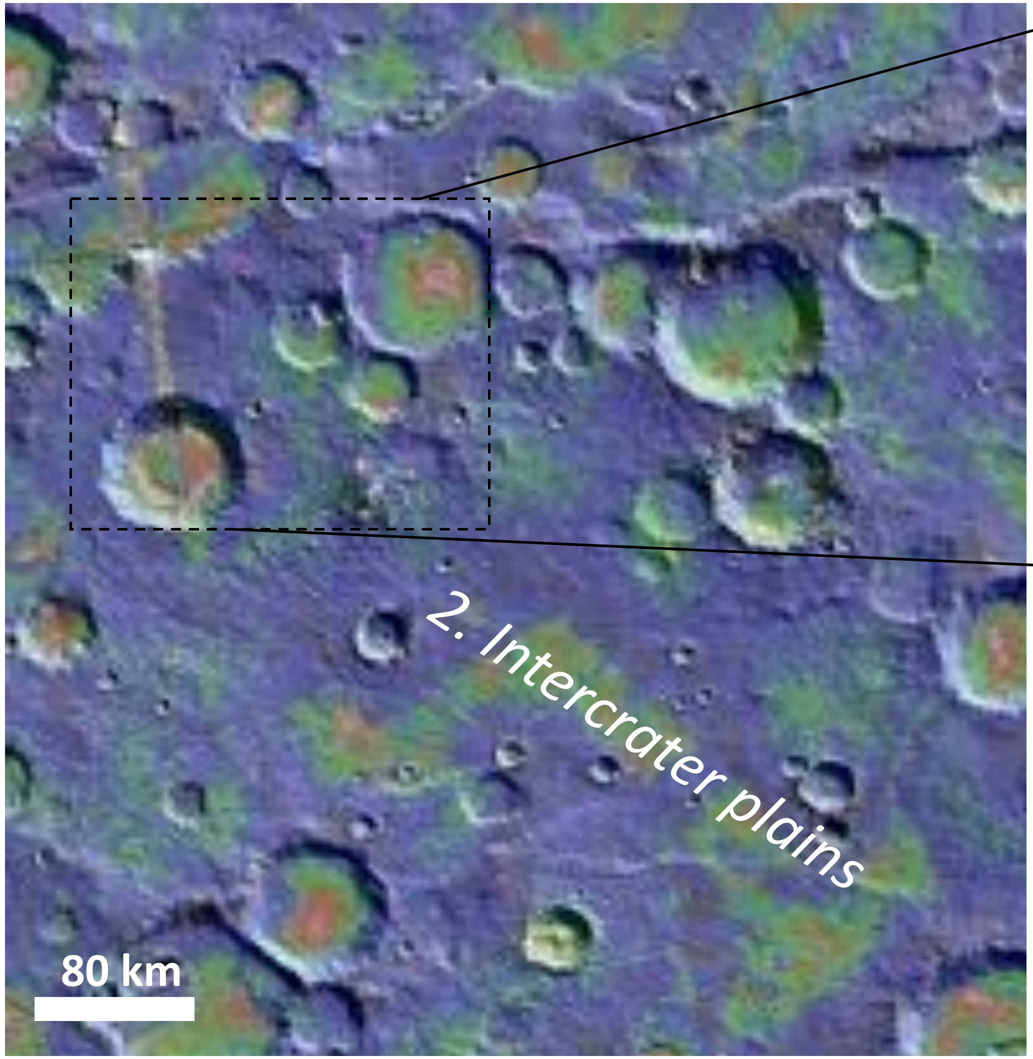


Coming up:

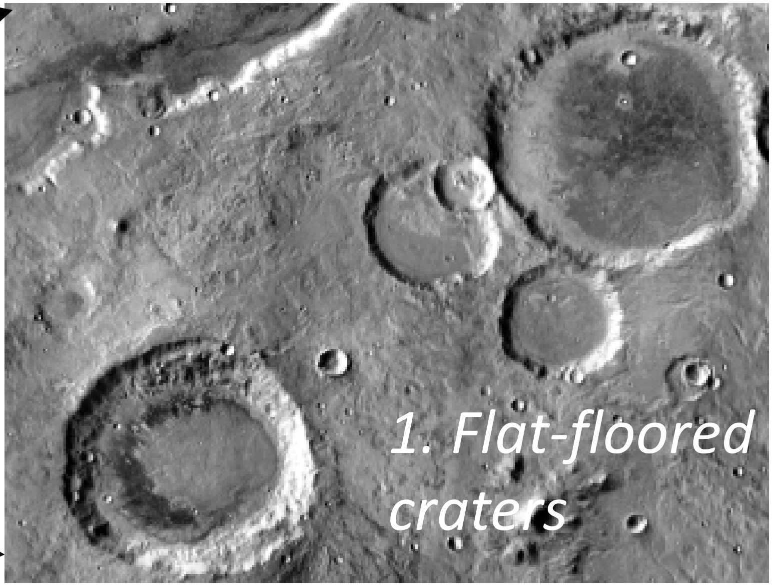
1. Geologic settings of bedrock plains
2. Global distribution of bedrock plains
3. Bedrock characteristics
4. Interpreted petrogenetic origin(s)

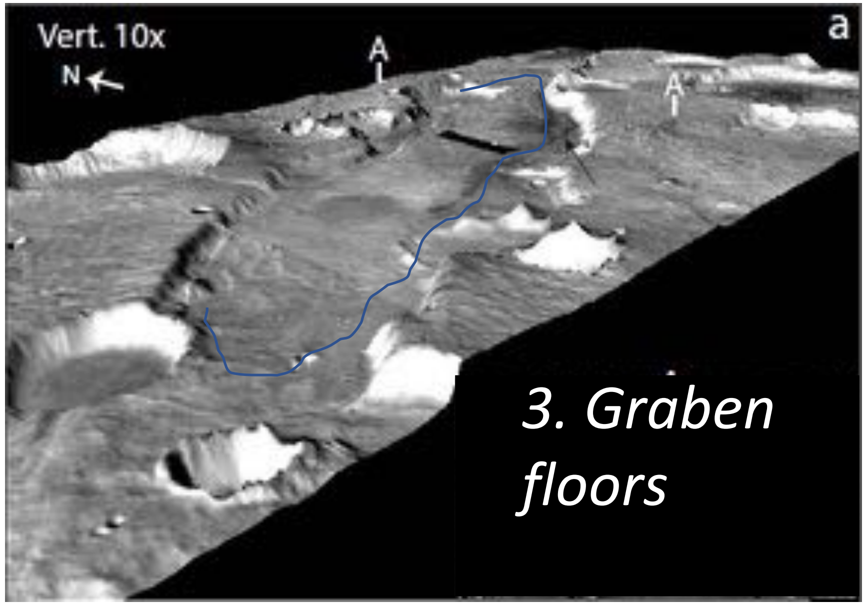
Rogers et al. 2009; Edwards et al. 2009; Rogers and Fergason, 2011; Rogers and Nazarian, 2013; Edwards et al., 2014; Ody et al., 2012; Loizeau et al., 2012; Rogers et al., 2018; Cowart and Rogers, 2018

DIFFERENT GEOLOGIC SETTINGS OF BEDROCK PLAINS

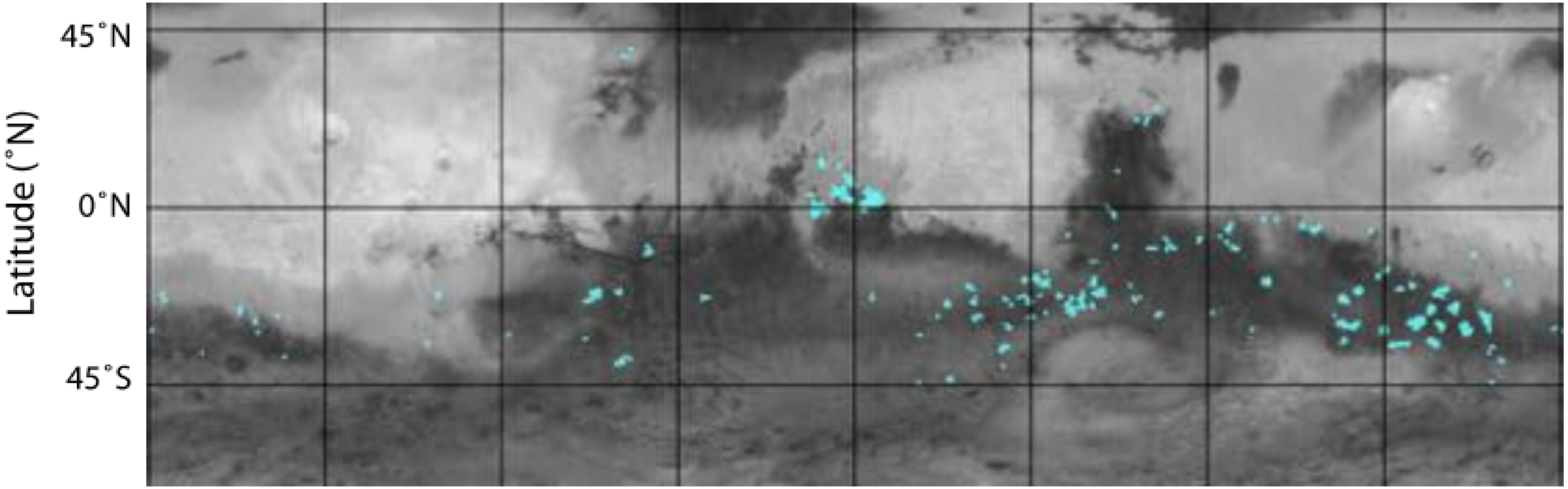


THEMIS nighttime temperature





GLOBAL DISTRIBUTION OF BEDROCK PLAINS

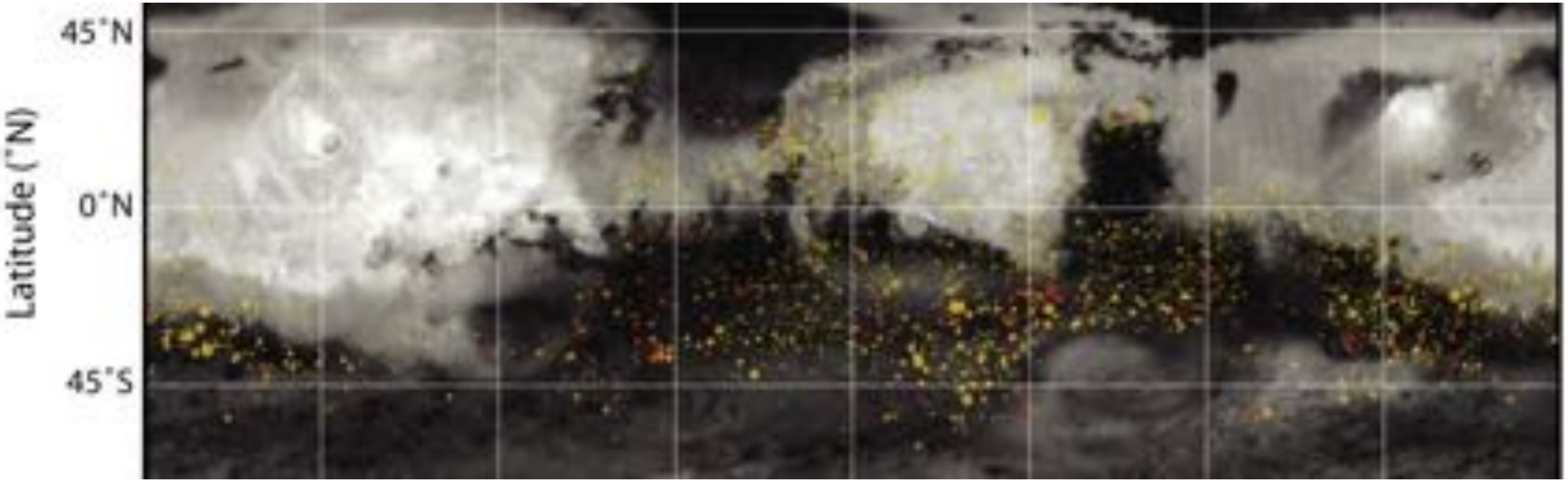


Cowart and Rogers, LPSC 2017

Intercrater bedrock plains (>250 sq km)

Using TES thermal inertia threshold > 350tiu

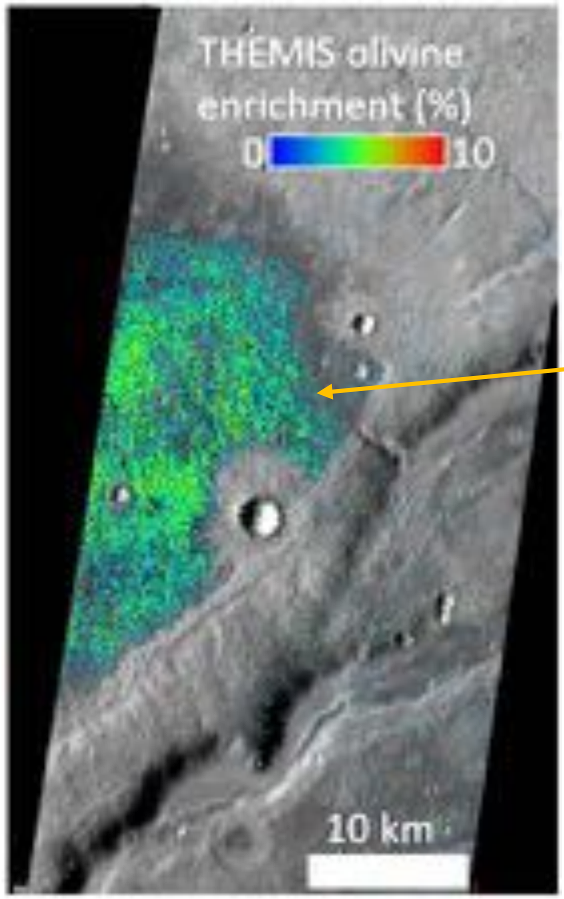
Intracrater bedrock plains

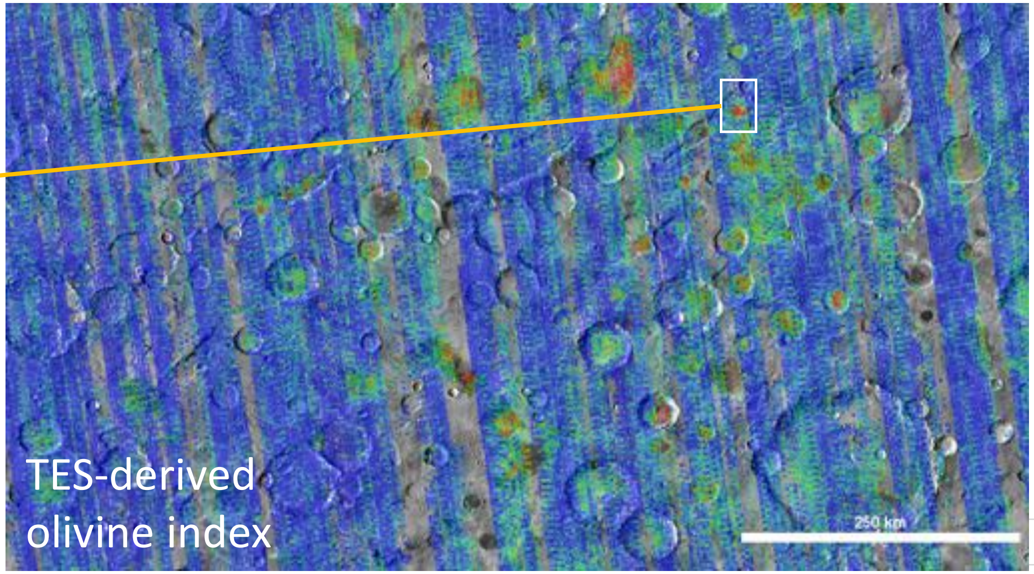


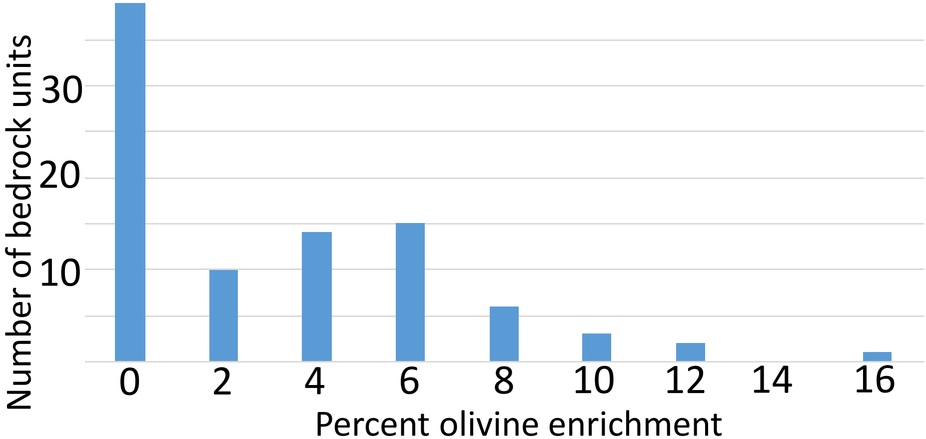
Edwards et al. (2014), Icarus

BEDROCK PLAINS CHARACTERISTICS: COMPOSITION

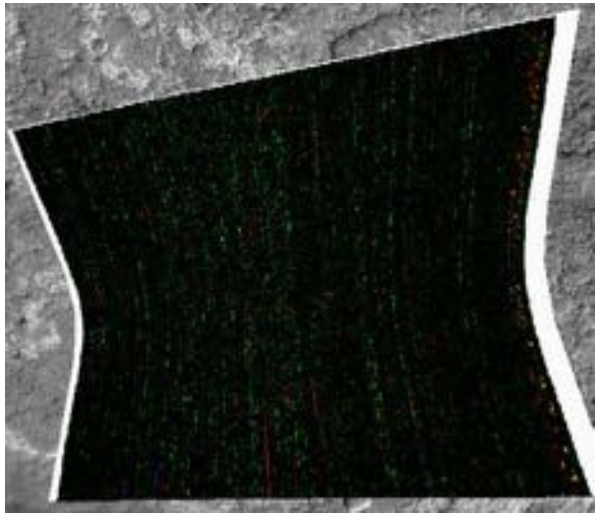
Bedrock plains commonly exhibit **olivine enrichments** of ~1-15% above surrounding materials







Hydrous minerals, carbonates *not* detected



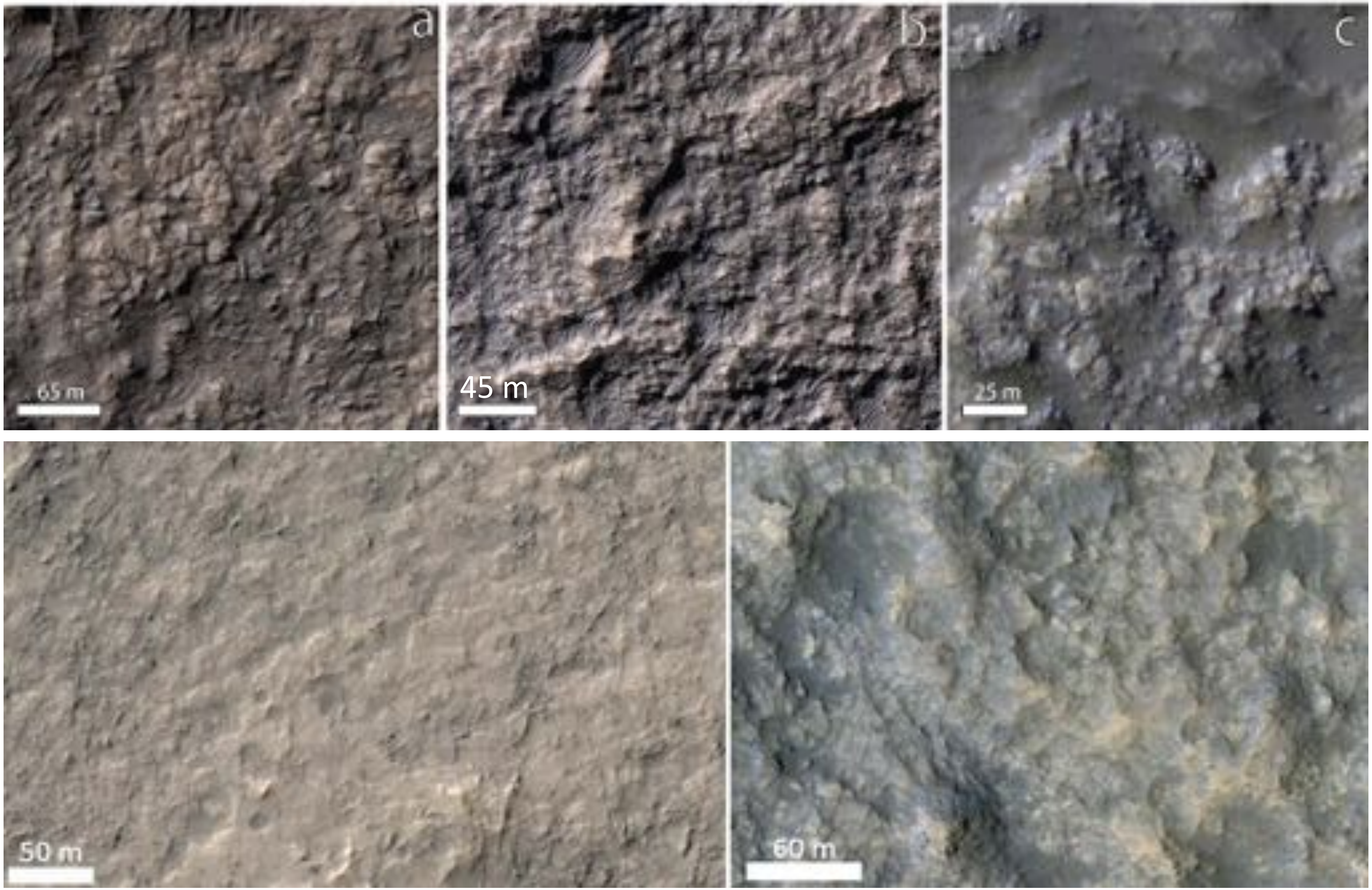
CRISM hydroxylated silicates browse image

Rogers et al. 2009; Edwards et al. 2009; Rogers and Fergason, 2011; Ody et al., 2012; Loizeau et al., 2012; Rogers and Nazarian, 2013; Cowart and Rogers, 2017

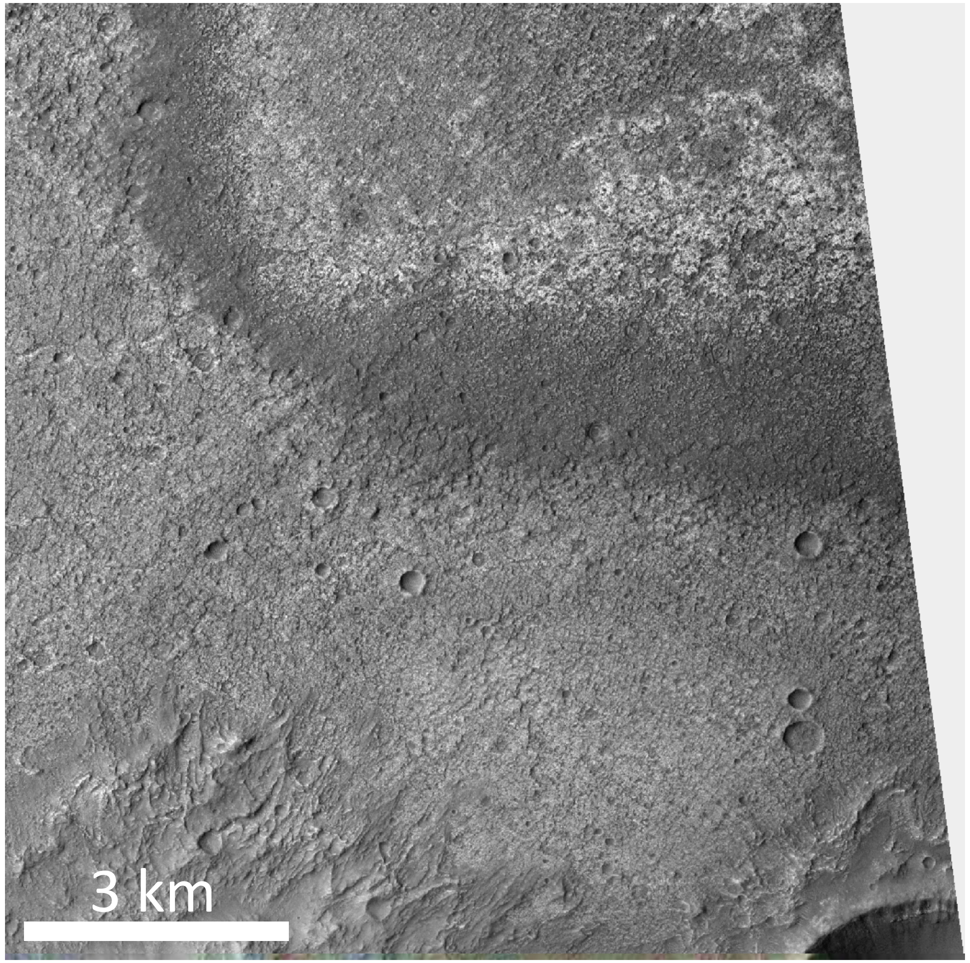
BEDROCK PLAINS CHARACTERISTICS: TEXTURES AND MORPHOLOGIES

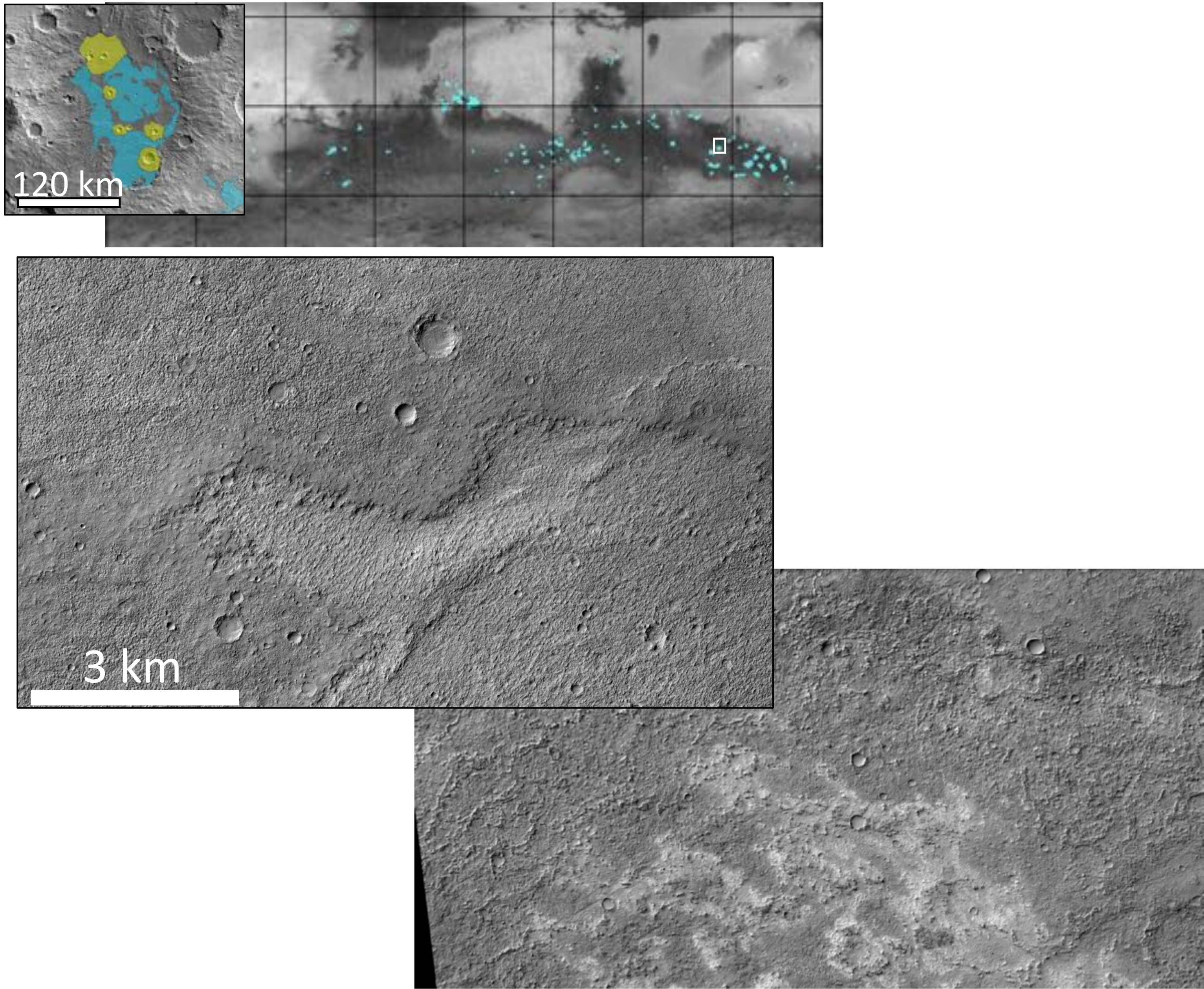
Views from HiRISE (30 cm/pix)

- Variable textures
- Fine-scale layering absent
- Boulders sometimes observed



BEDROCK CHARACTERISTICS: MULTIPLE UNITS IN A SINGLE EXPOSURE

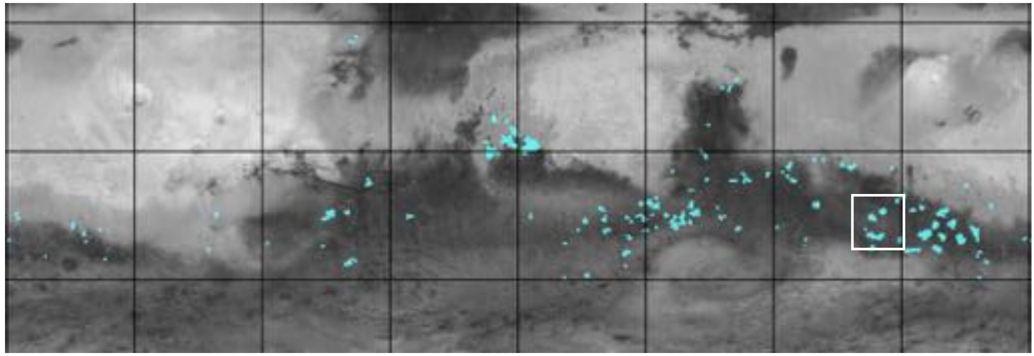




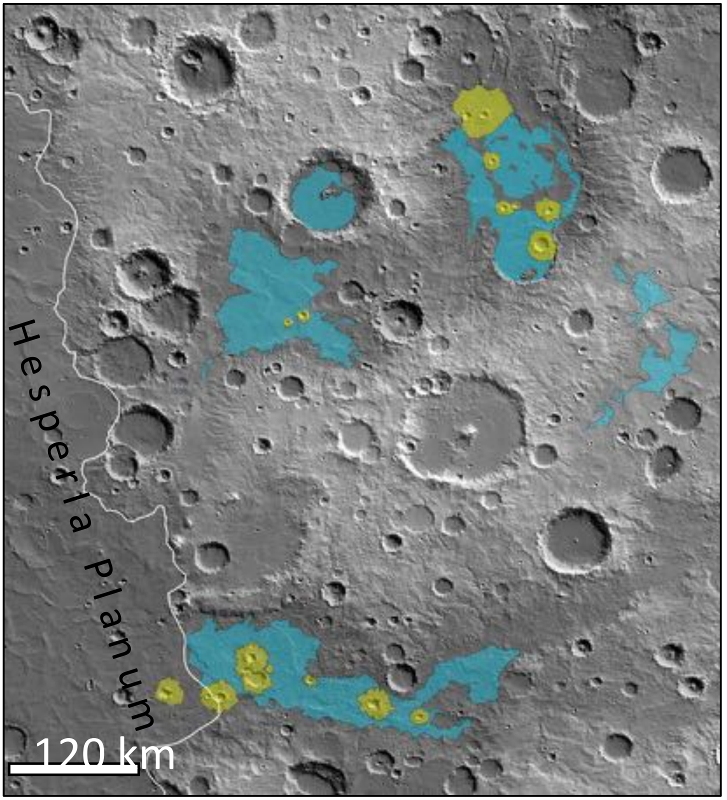
MRO CTX images

Multiple depositional episodes

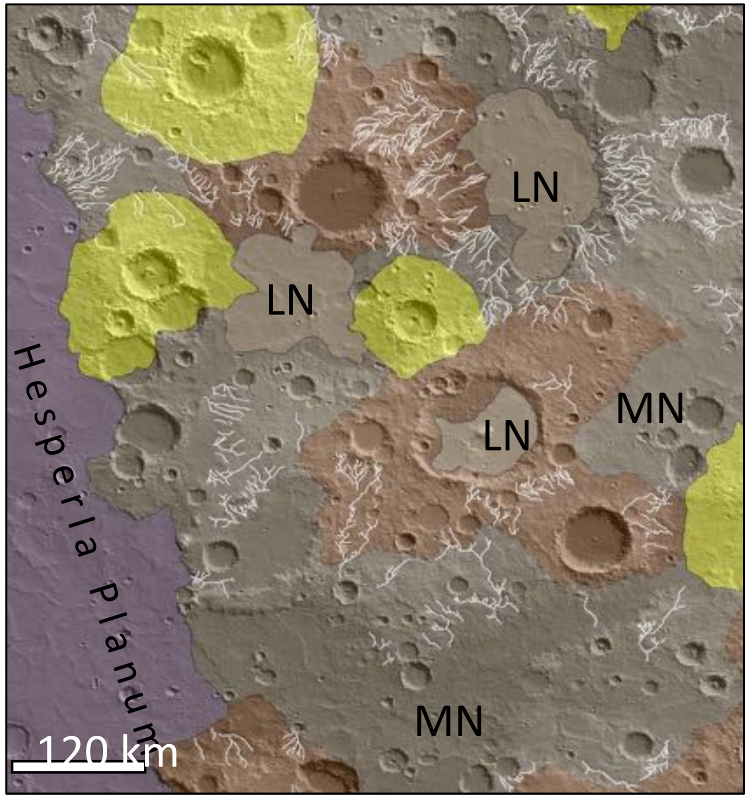
BEDROCK PLAINS CHARACTERISTICS: AGE



Many are likely Noachian to early Hesperian in age (>~3.6 billion years)



Map of bedrock exposure



Geologic map of
Tanaka et al., 2014; Irwin et al., 2013

Summary of bedrock characteristics:

- Hundreds of plains exposures
- Olivine enrichments; no “aqueous” minerals
- Variable textures

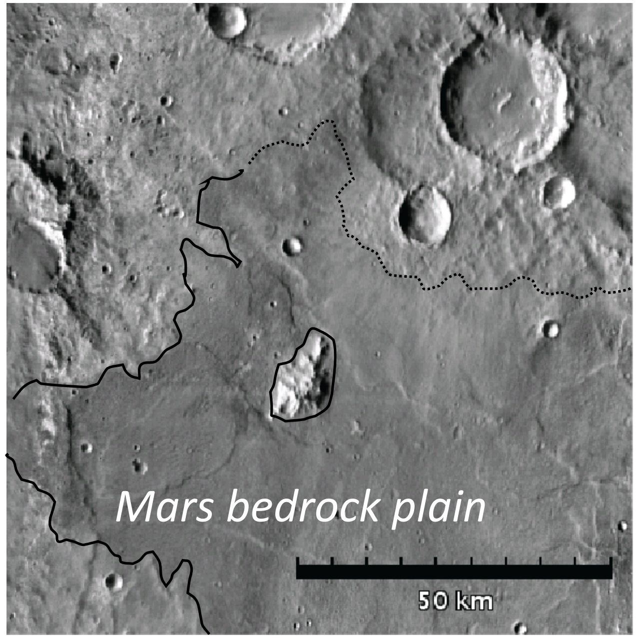
WHAT ARE THESE WIDESPREAD AND DISTINCTIVE UNITS?

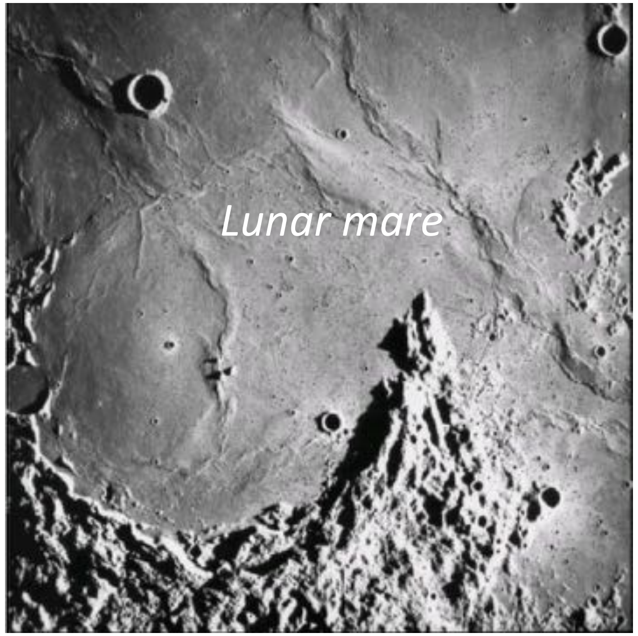
EVOLVING VIEWS ON THEIR PETROGENETIC ORIGIN(S):

Previously interpreted as <u>lava plains</u>; e.g. "plateau plains" volcanism described by Greeley and Spudis (1981)

Rogers et al. 2009; Edwards et al. 2009; Rogers and Fergason, 2011; Ody et al., 2012; Loizeau et al., 2012; Rogers and Nazarian, 2013; Edwards et al., 2014

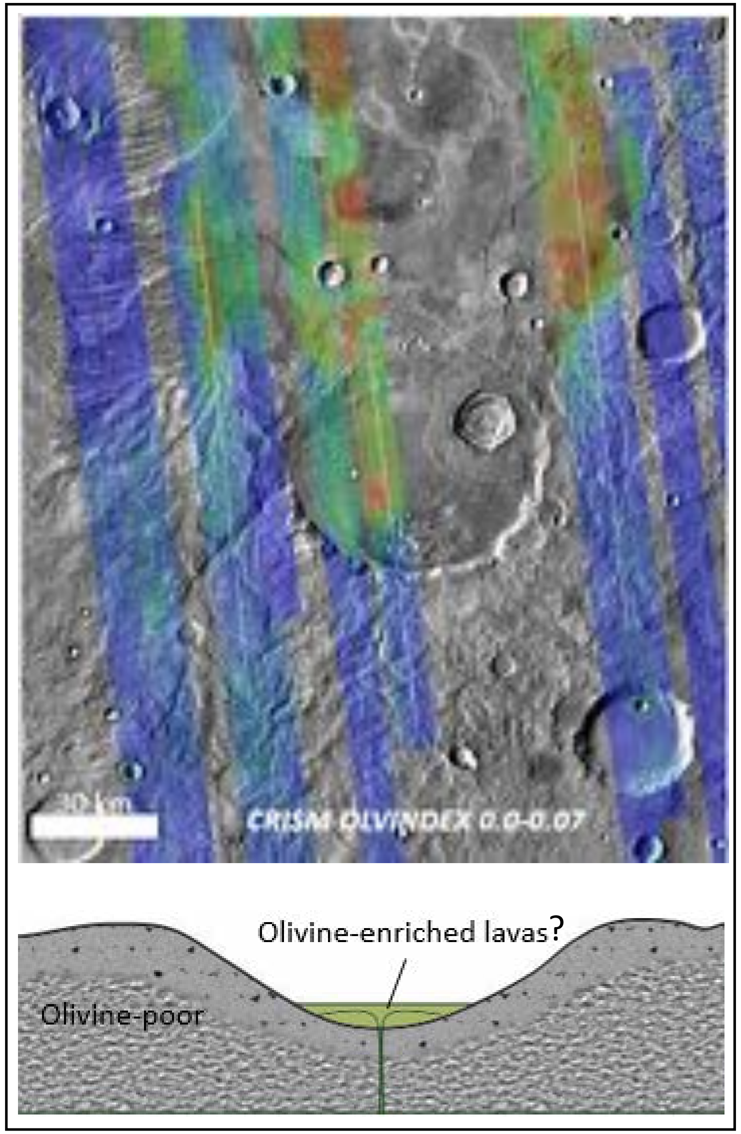
⇩ 1. Mare-like outcrop patterns





2. Relatively high thermal inertia

3. Abrupt change in composition (e.g. olivine abundance) on/off rock ⇨

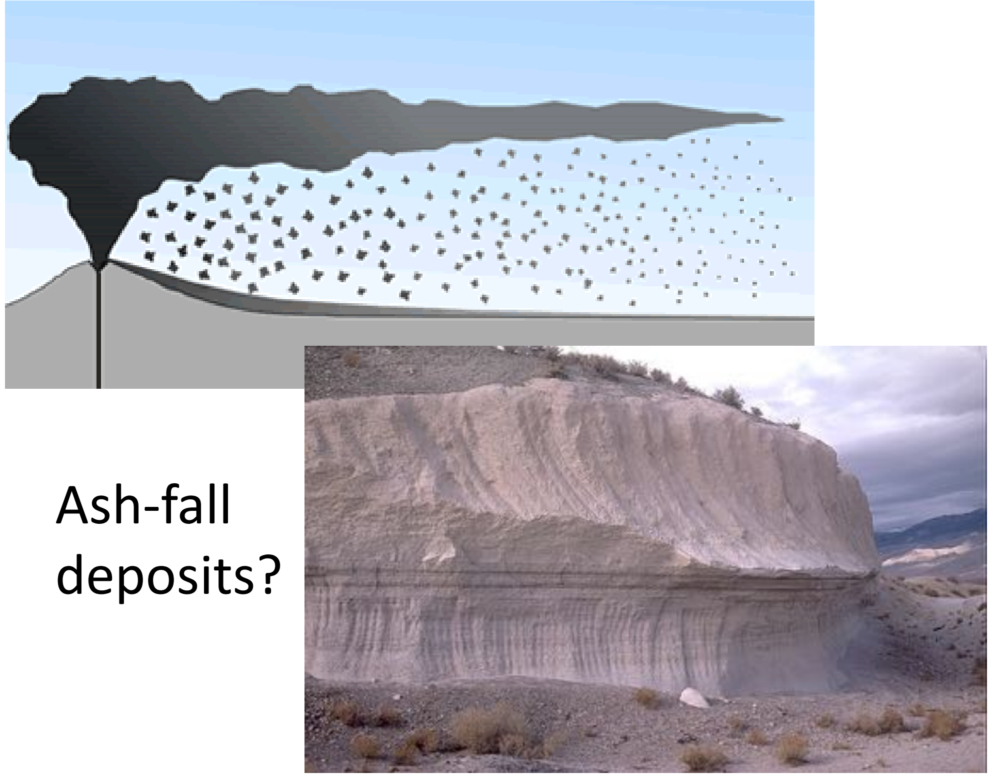


WHAT ARE THESE WIDESPREAD AND DISTINCTIVE UNITS?

EVOLVING VIEWS ON THEIR PETROGENETIC ORIGIN(S):

More recently, a subset were re-interpreted as fine-grained clastic rocks (pyroclastic, sedimentary, or impact related)

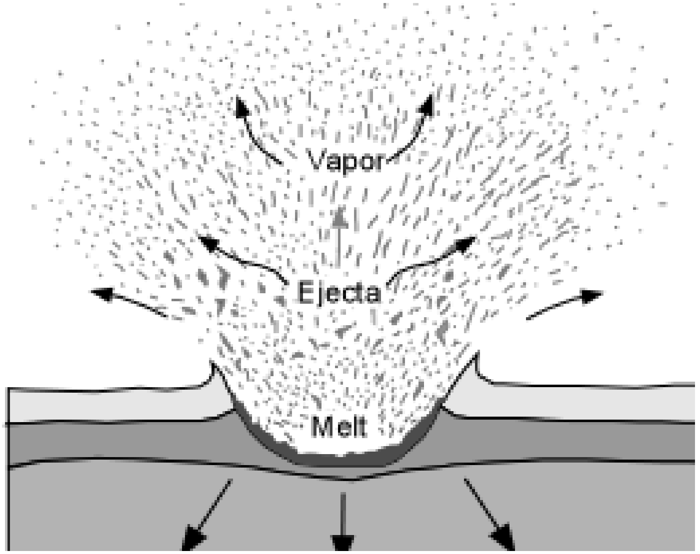
Rogers et al. 2018, GRL; Cowart and Rogers, 2018; Kremer et al., 2018



Ash-fall deposits?

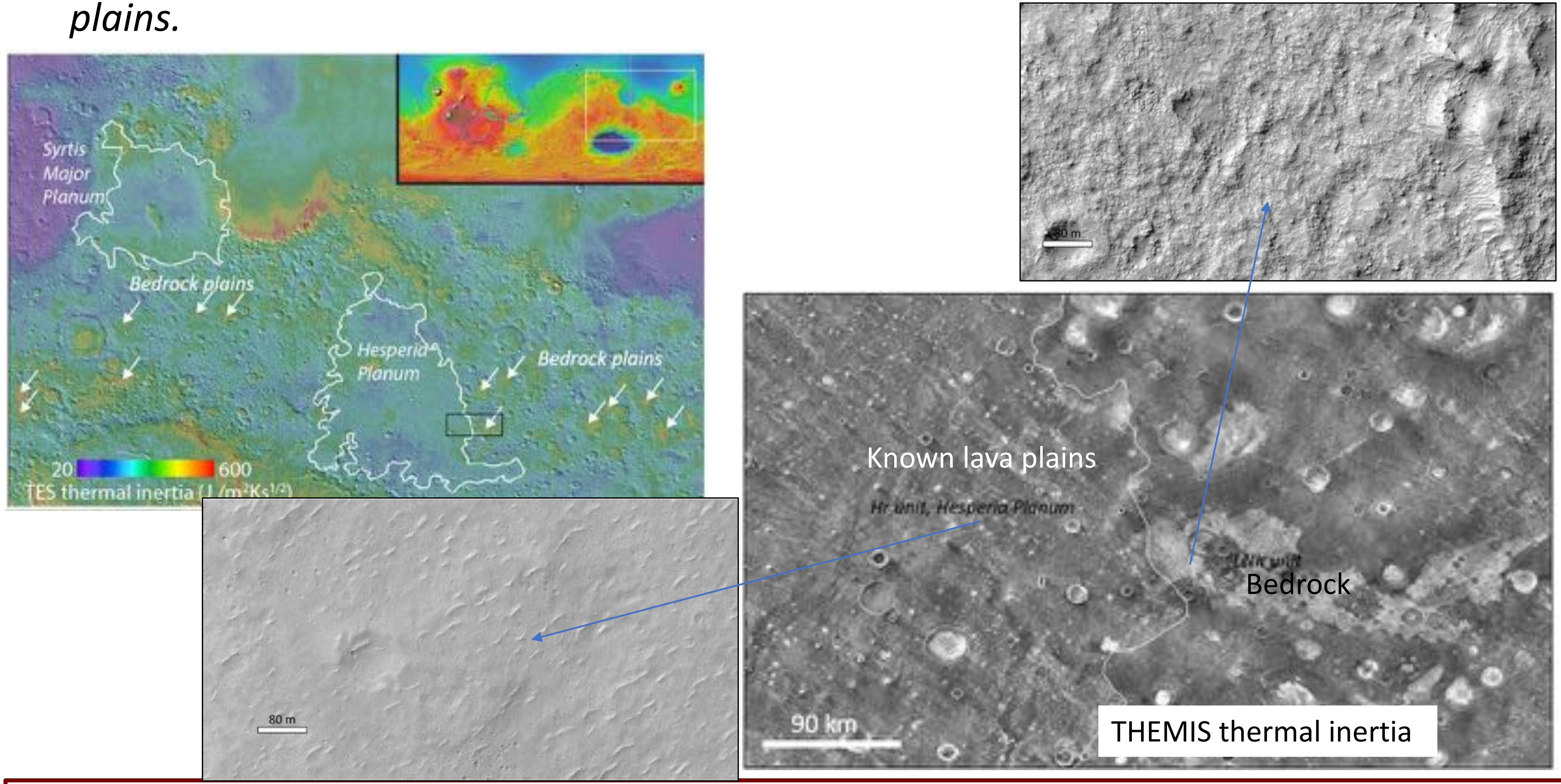
Fluvially transported sediments?
Wind-transported?

Fallout of vaporized crust during giant impacts?



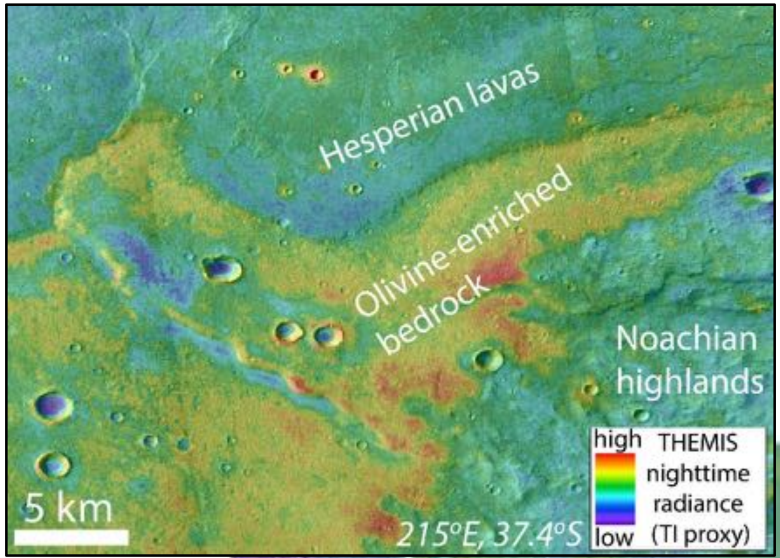
Bedrock Petrogenetic Origins: Evidence for clastic rocks

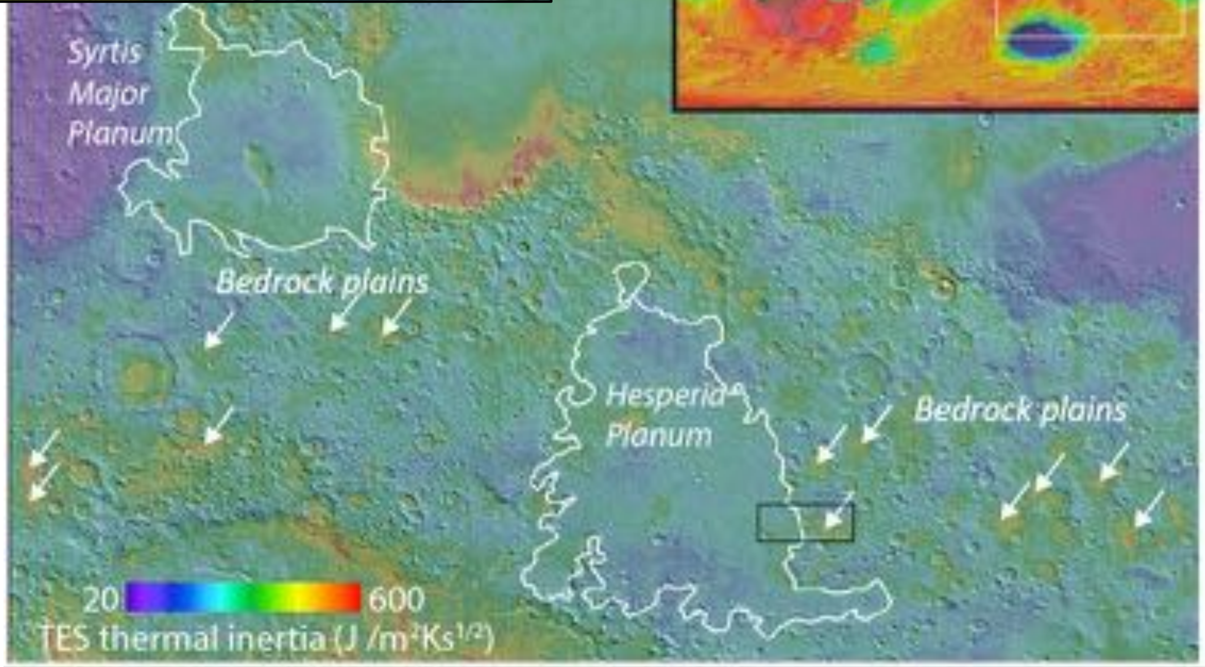
1. Bedrock plains have not followed the same regolith development path as known lava plains.



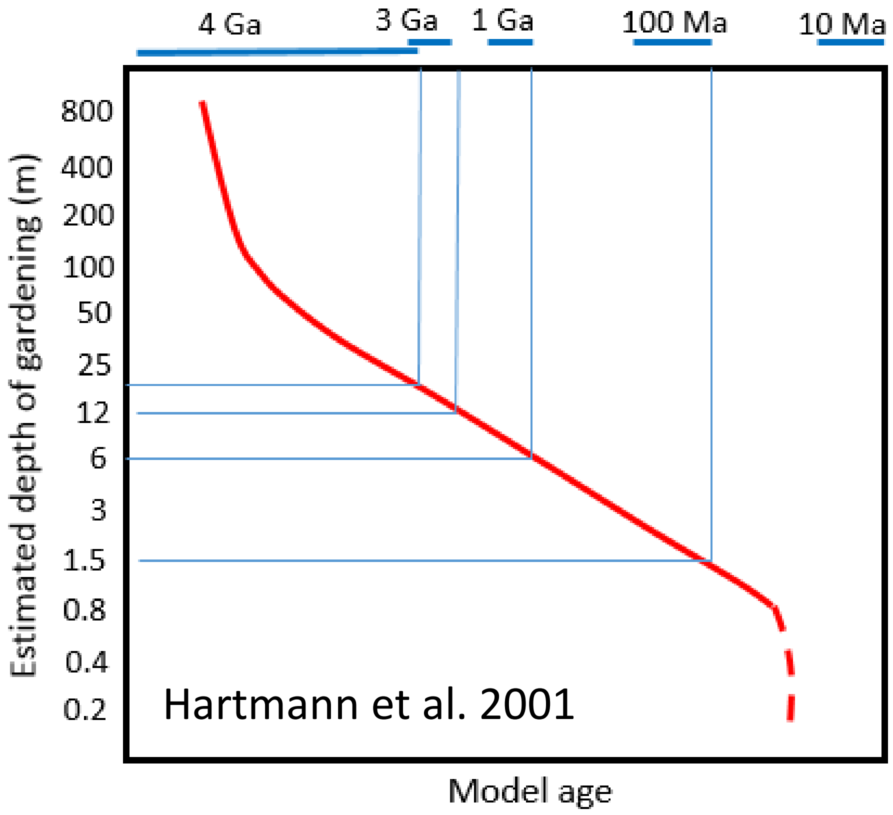
Younger lava plains have developed a thick regolith and have a notable lack of bedrock exposure.

1. Bedrock plains have not followed the same regolith development path as known lava plains.



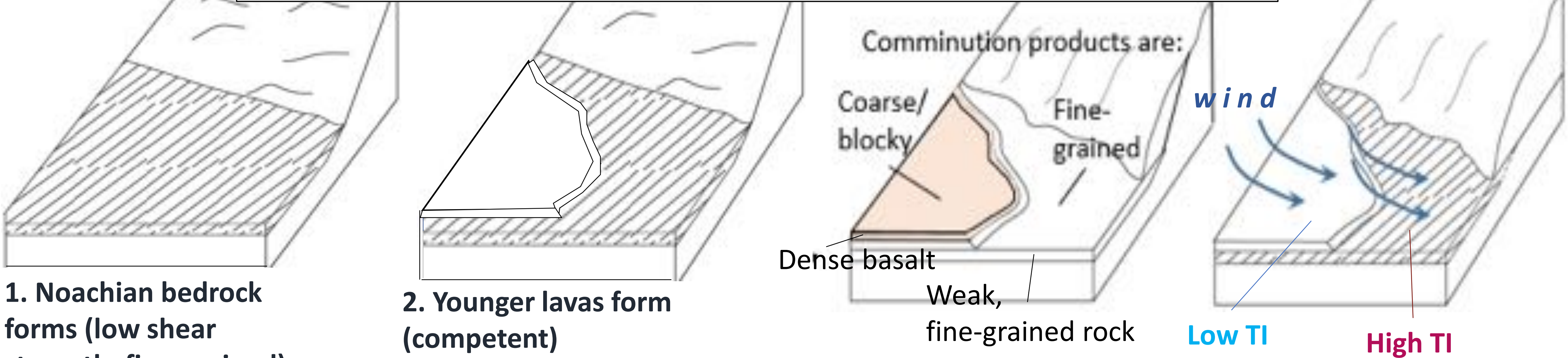


High cratering rates on Early Mars should have generated regolith exceeding tens of meters thick. ⇨



Younger lava plains have developed a thick regolith and have a notable lack of bedrock exposure.

HYPOTHESIS: BEDROCK PLAINS CONSIST OF MECHANICALLY-WEAK MATERIALS



1. Noachian bedrock forms (low shear strength; fine-grained)

2. Younger lavas form (competent)

3. Both surfaces exposed to impacts

4. Fine-grained comminution products more easily moved by wind

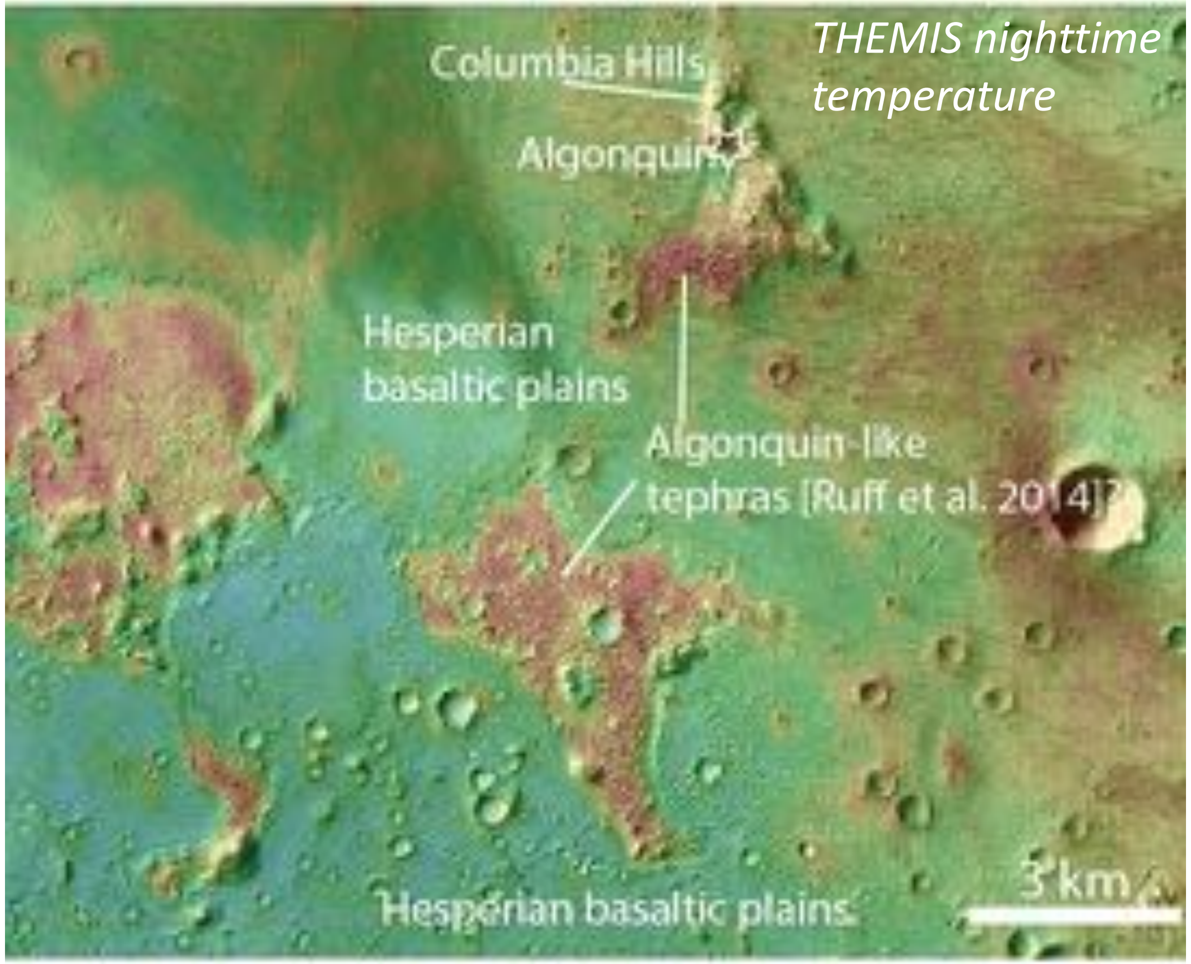
Fine-grained comminution products are more easily moved by wind. → Lithified surface is continually **exposed** → **High thermal inertia**

Blocky/coarse comminution products form regolith; trap dust. → Rock **buried** by/converted to unconsolidated materials → **Low thermal inertia**

Supporting evidence found in Gusev crater

High thermal inertia surfaces are exposed in windows through Hesperian lavas

- High-thermal inertia material: Possible olivine-bearing basaltic tephras? *(Ruff et al. 2014)*

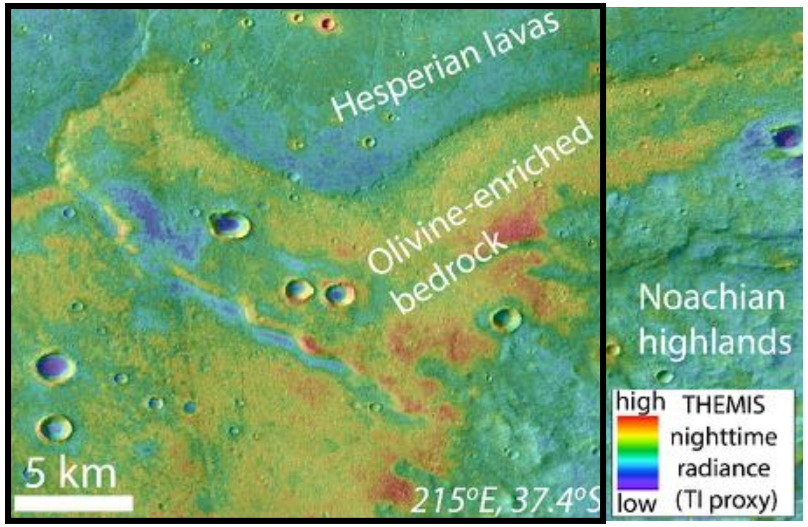


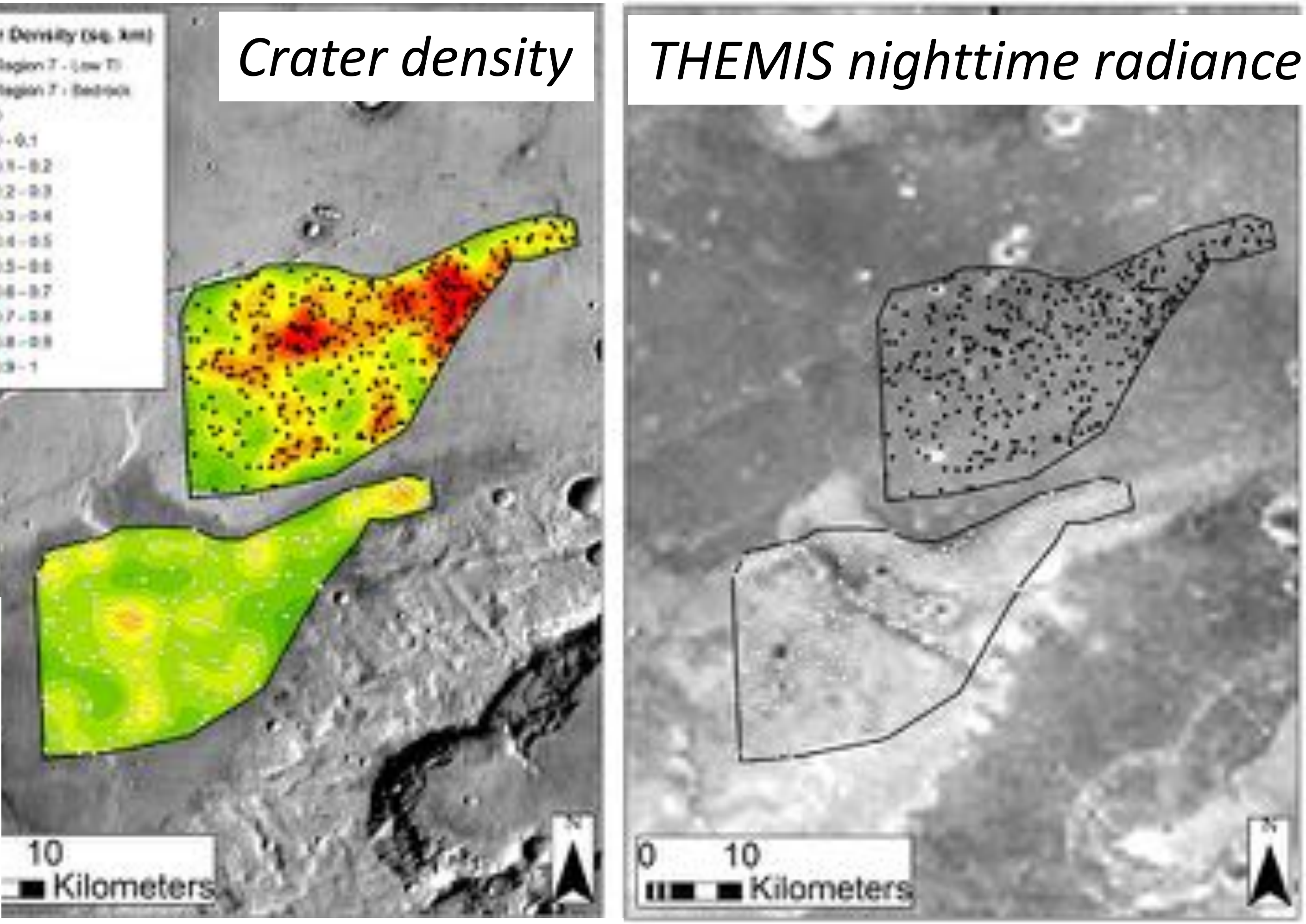
Mini-TES derived thermal inertia values of individual rocks (*Fergason et al. 2006*):

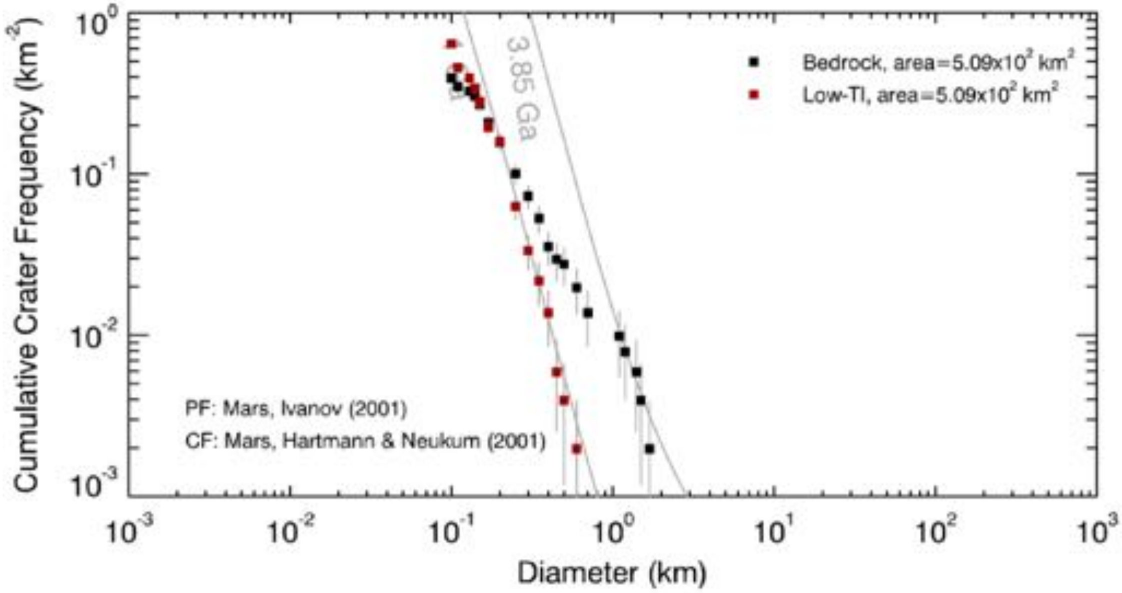
Columbia Hills (clastics): ~600 J $m^{-2}K^{-1}s^{-1/2}$

Hesperian plains (lavas): ~1200 J $m^{-2}K^{-1}s^{-1/2}$

2. The rock exposures exhibit poor crater retention compared to adjacent surfaces.



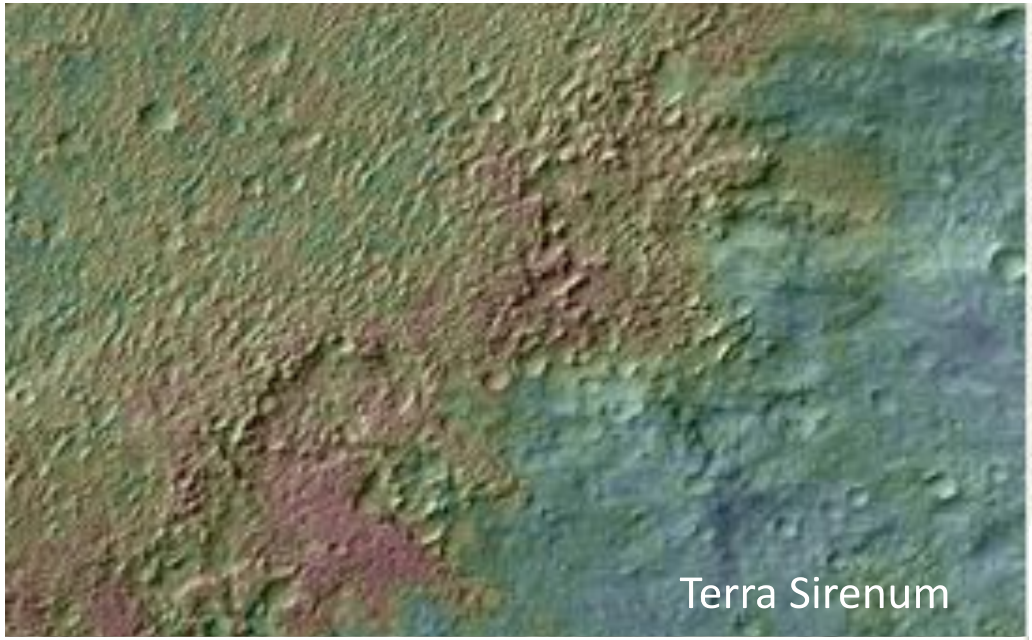


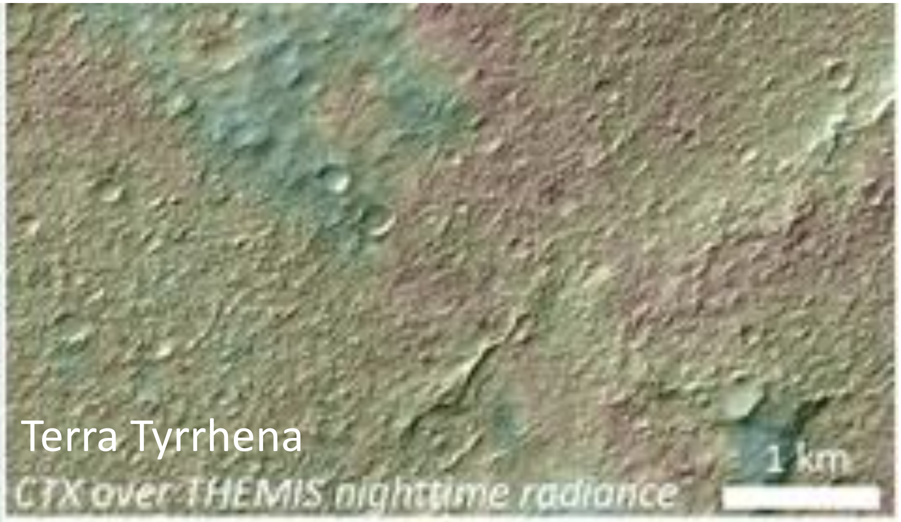


Rogers et al., 2018

- 10 bedrock exposures examined
- 18-78% lower crater density relative to adjacent low-TI surfaces

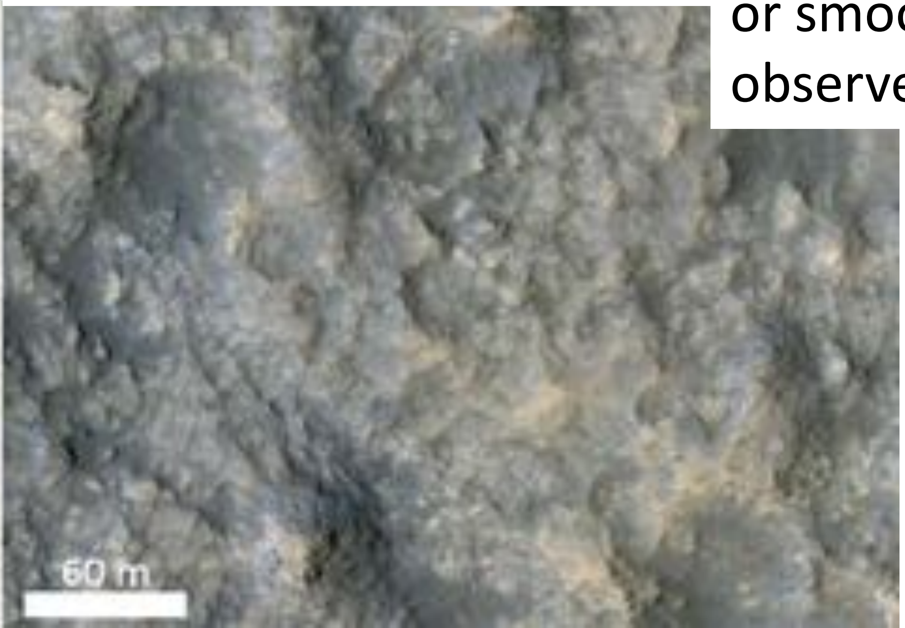
3. Morphologies are consistent with easily eroded, soft rocks.





CTX over THEMIS nighttime radiance

Yardangs, scalloped or smooth surfaces observed



Bedrock Petrogenetic Origins

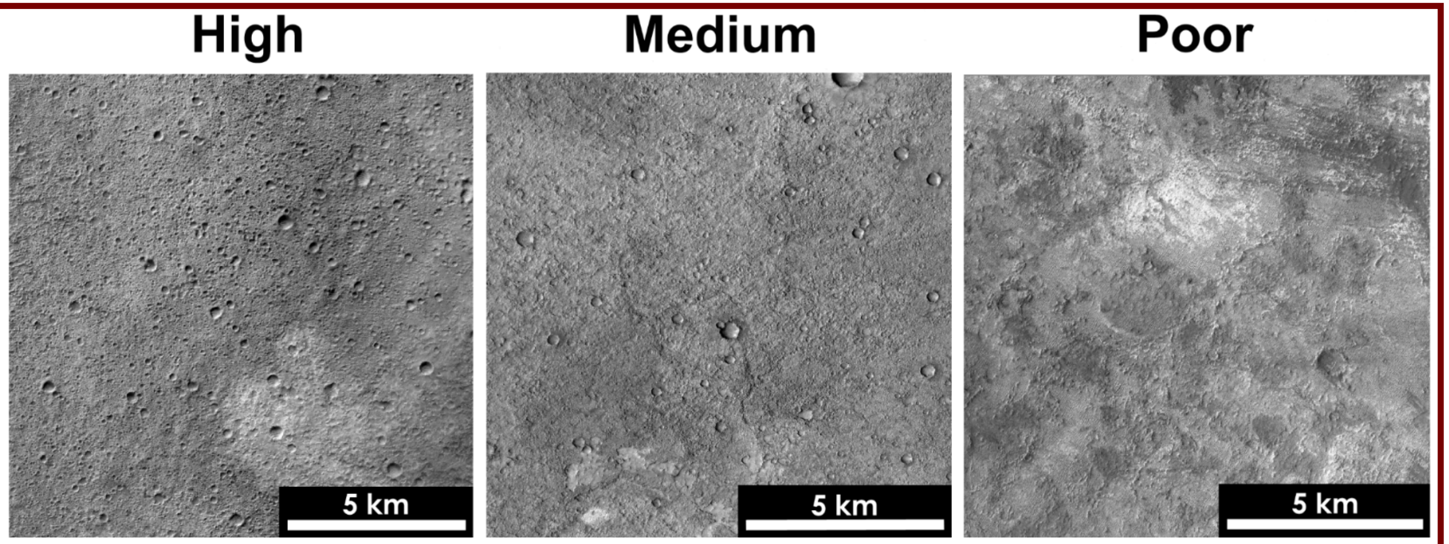
Hypothesis: Many bedrock units are mechanically weak, clastic rocks. They are exposed because they are in a state of relatively recent deflation.

How common are mechanically weak materials? → A global, qualitative assessment was carried out:

Crater retention

High crater retention:
Many craters of all sizes; preserved rims.

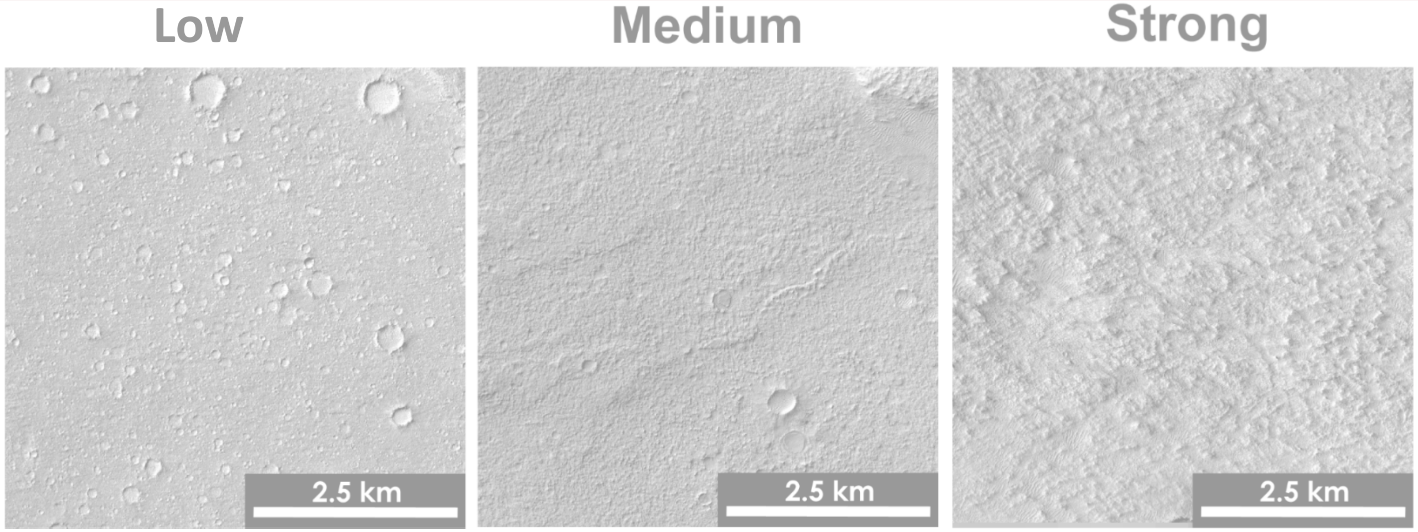
Low crater retention:
Few/no craters < 1km; rims absent; craters shallow.



Erosional degradation

Strong erosional degradation:
Prominent, deep yardangs or buttes

Low degradation:
Absence of erosional features



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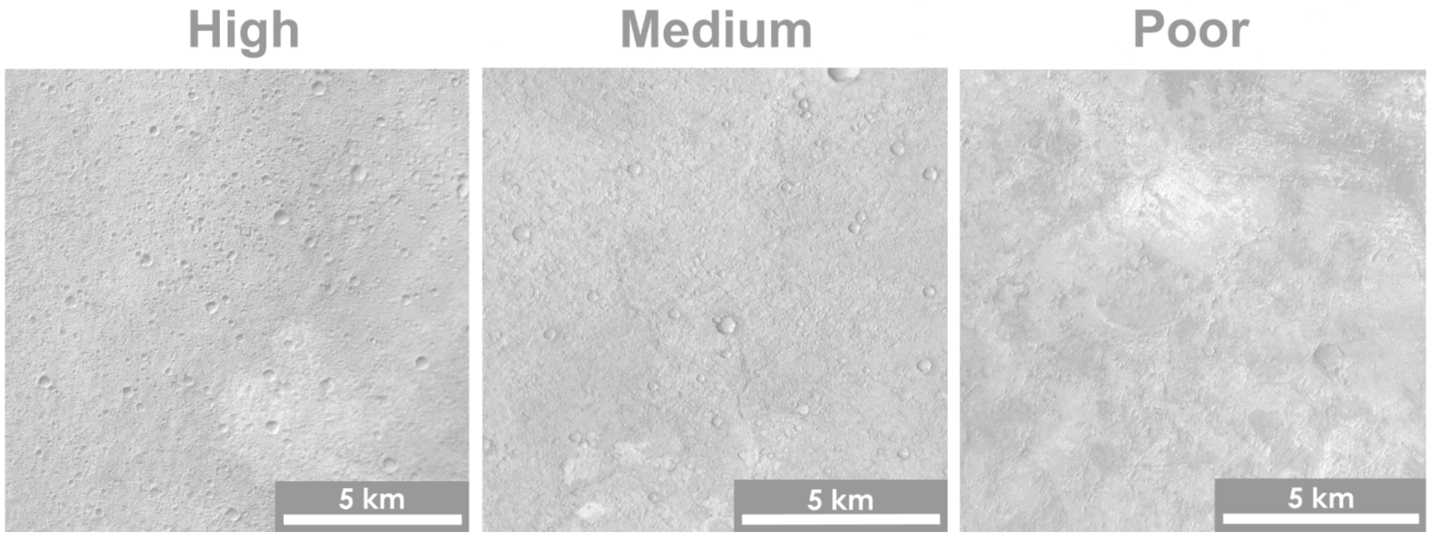

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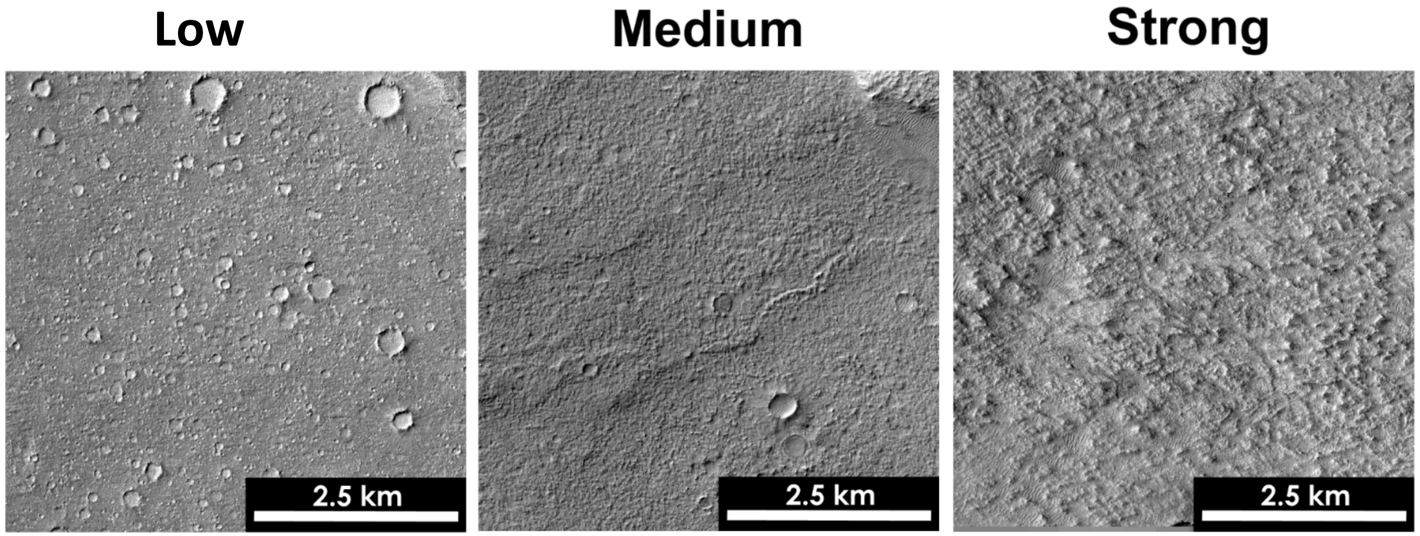
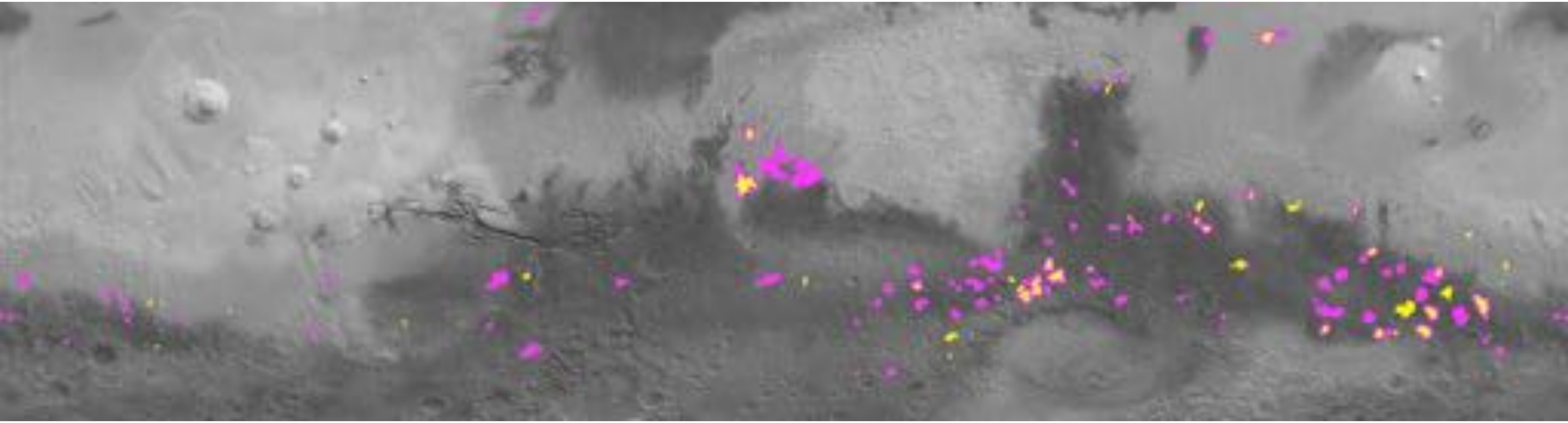


Weak, easily-eroded rocks are common; some exceptions.

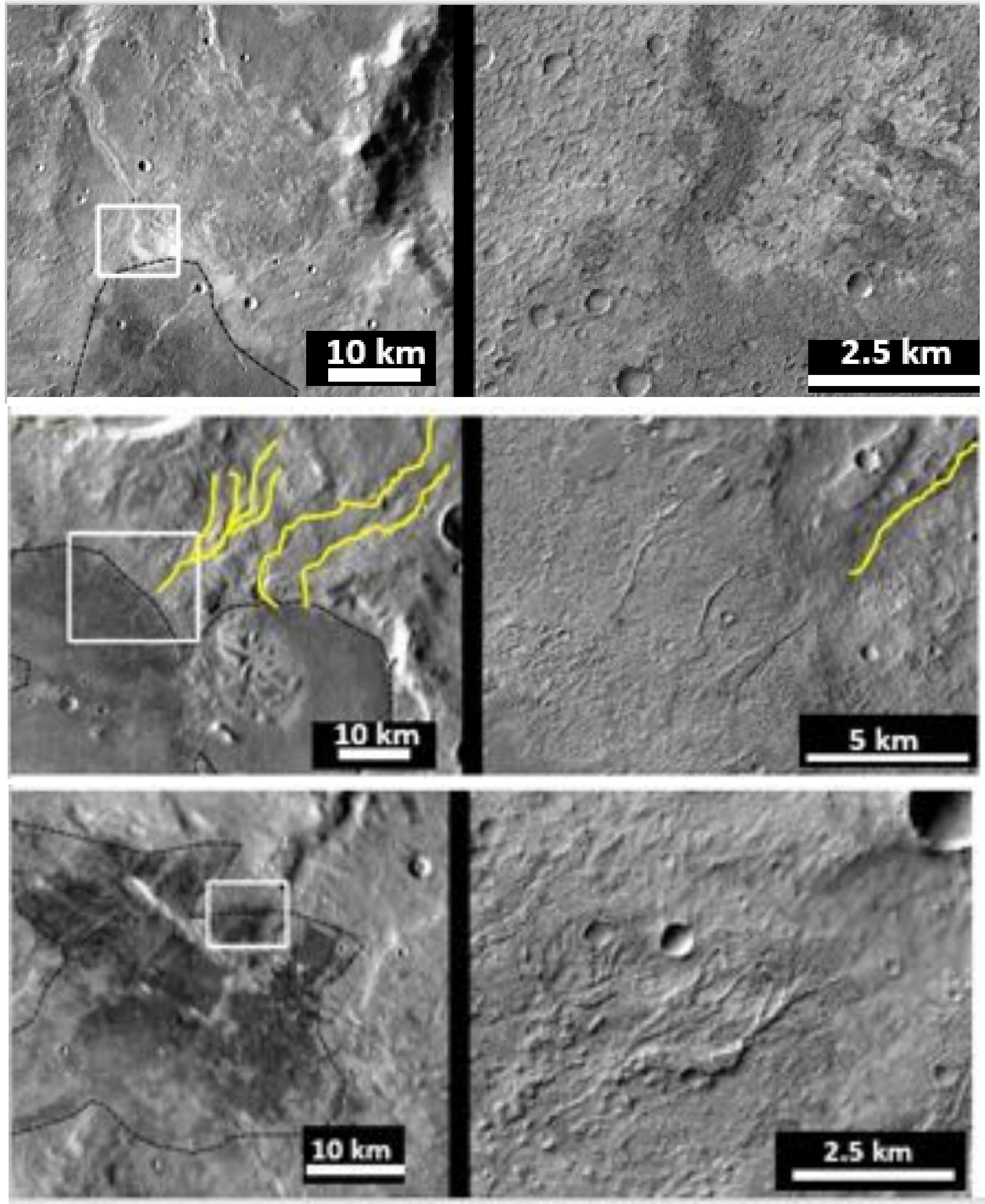
Roughly 3/4 of bedrock plains show medium- to poor-crater retention and medium- to strong-erosional degradation.

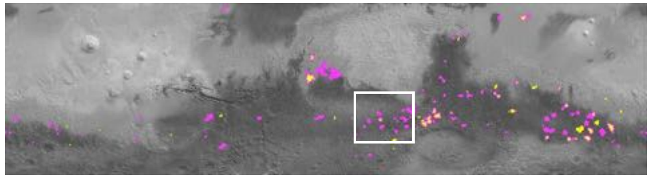
		Erosional state		
		Weak	Medium	Strong
Crater Retention	High	17	9	0
	Medium	14	45	25
	Poor	4	23	59

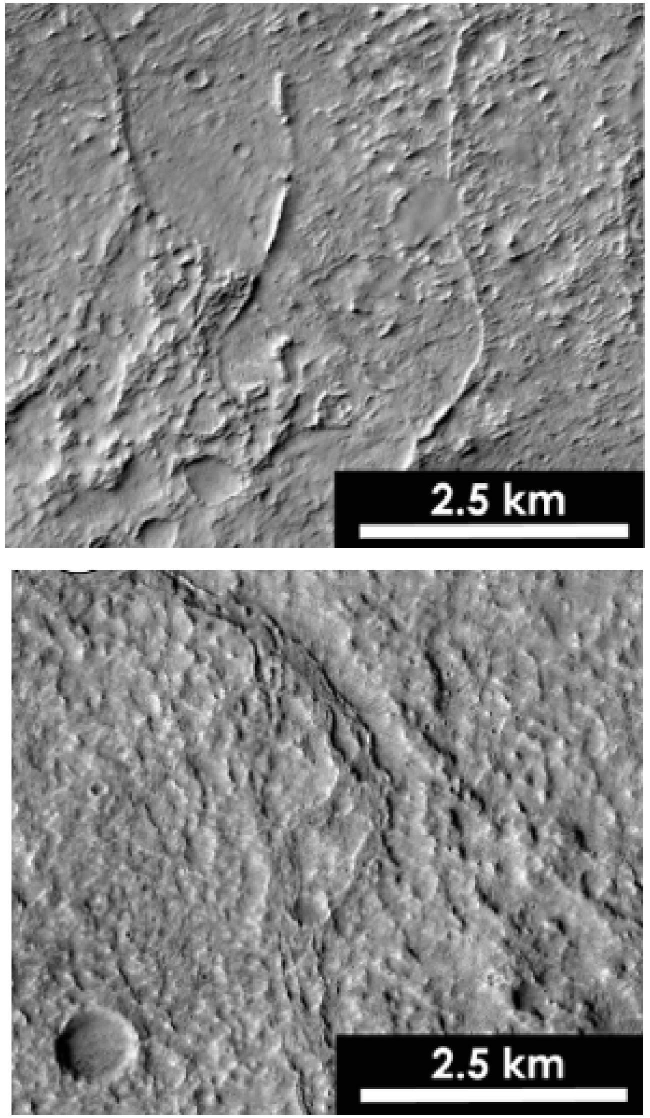


Bedrock Petrogenetic Origins: Discriminating between clastic origins

Potential inverted channels?







Sinuous ridges are sometimes observed in association with bedrock; in some cases, can be traced to valleys

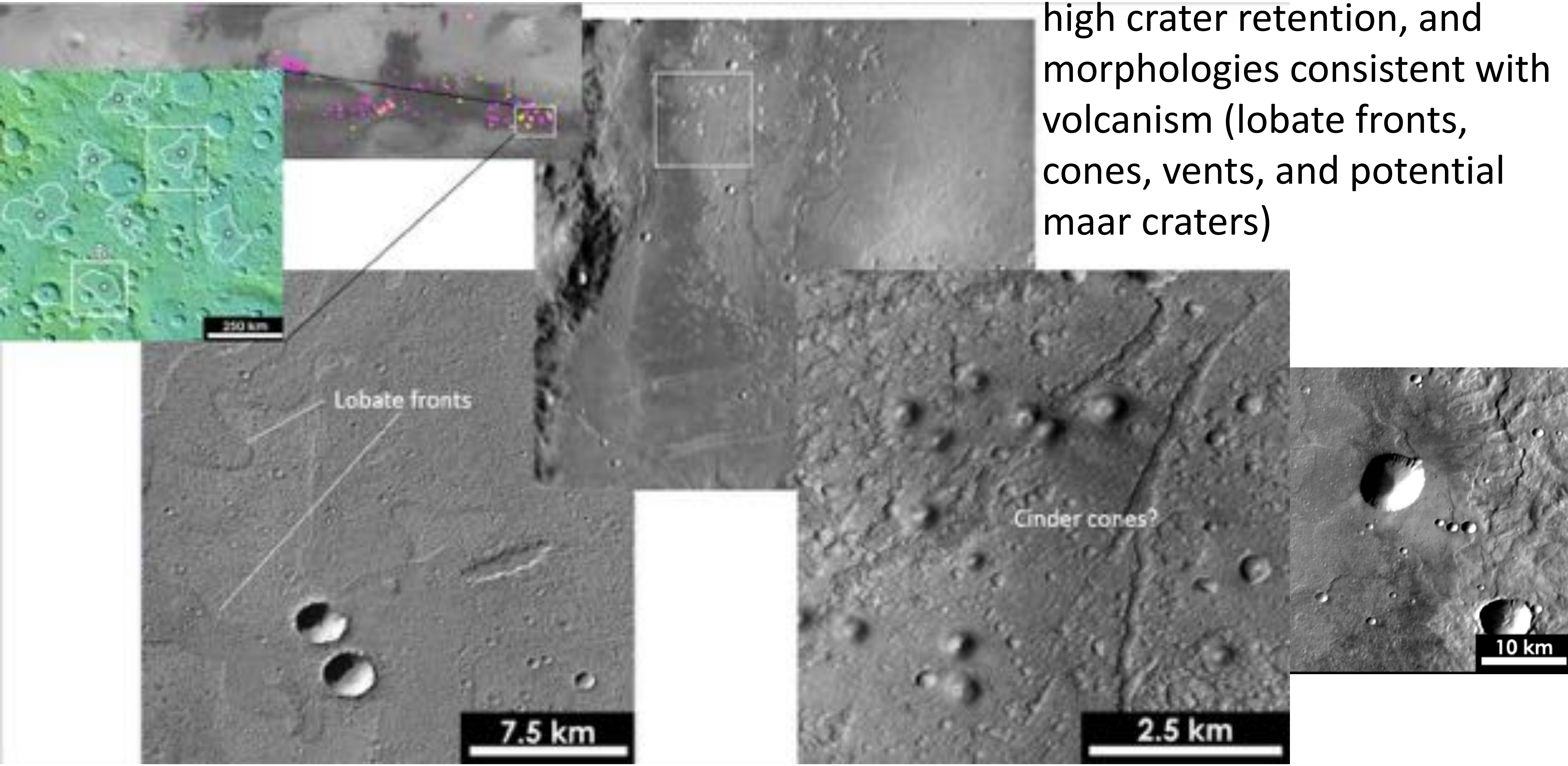
→Suggests role of fluvial transport in the formation of some bedrock units

Lack of fine layering and no hydrous mineral detections – short and episodic deposition.

(See also Irwin et al. 2018 JGR for more examples)

Volcanic flows?

Cluster of bedrock units with high crater retention, and morphologies consistent with volcanism (lobate fronts, cones, vents, and potential maar craters)



SUMMARY

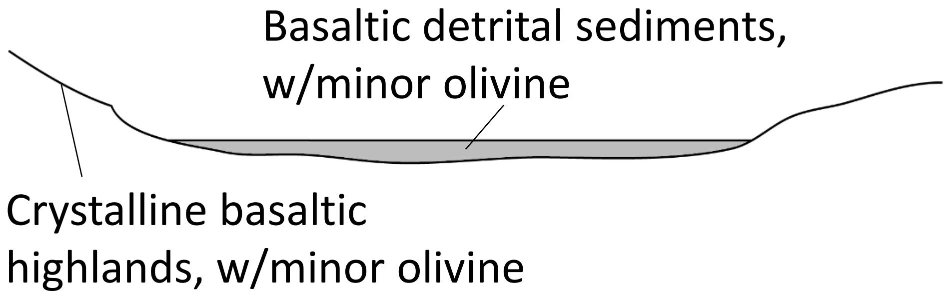
1. There is a vast rock record exposed in ancient terrains on Mars
2. Most exposed bedrock likely consists of easily-eroded fine-grained material
3. Evidence for deposition through both volcanic and sedimentary processes
    - For fluvial deposits, lack of fine layering and no hydrous mineral detections – short and episodic deposition.
    - Explosive volcanism potentially more widespread.

See also Kremer et al., 2018; Ruff et al., 2018 Mars 2020 workshop presentations

If sedimentary, what about the olivine enrichments?

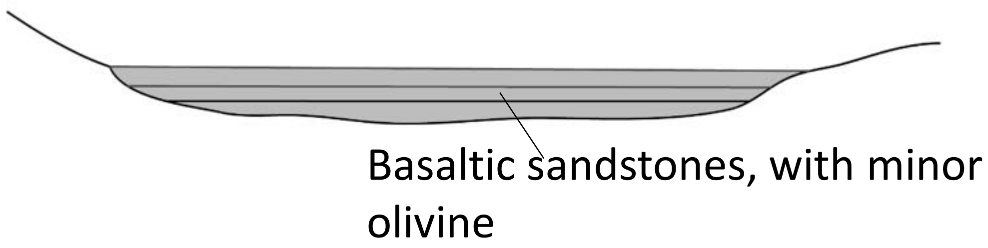
A mechanism for getting olivine-enriched, high-thermal inertia surfaces from olivine-poor, low-thermal inertia surfaces

1.



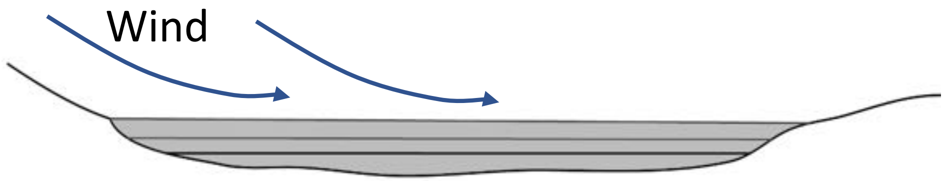
1. Sediments transported through fluvial, eolian, glacial (?) and/or diffusive processes

2.



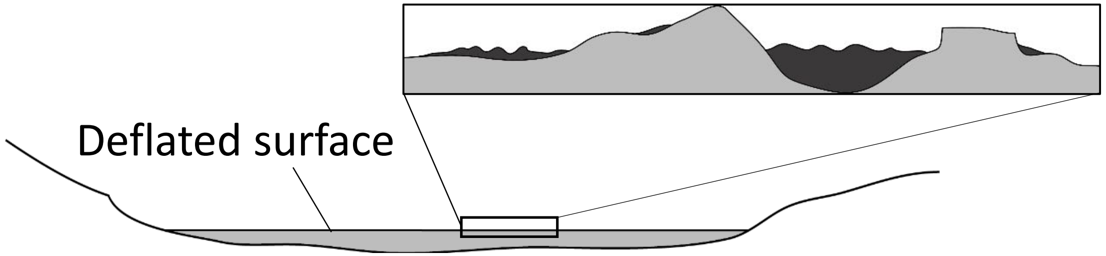
2. Burial and lithification

3.



3. Rock exposed to wind for ~3 Ga → slowly deflated. Olivine-bearing grains preferentially lag behind.

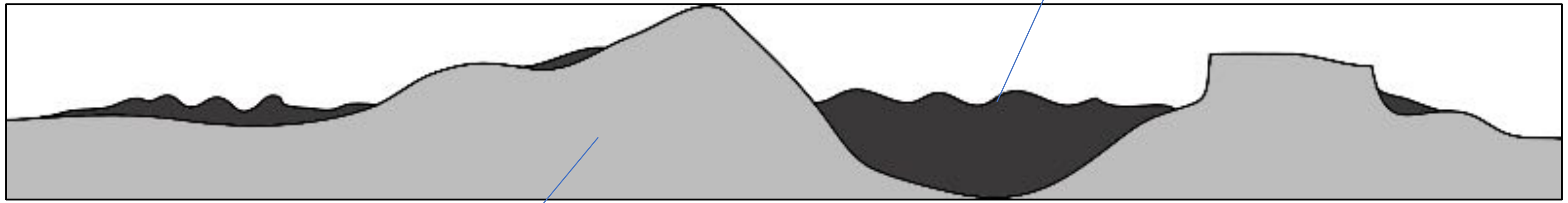
4.



4. Lag sediments collect in lows and isolated patches of bedforms.

Explaining olivine enrichment in sedimentary bedrock

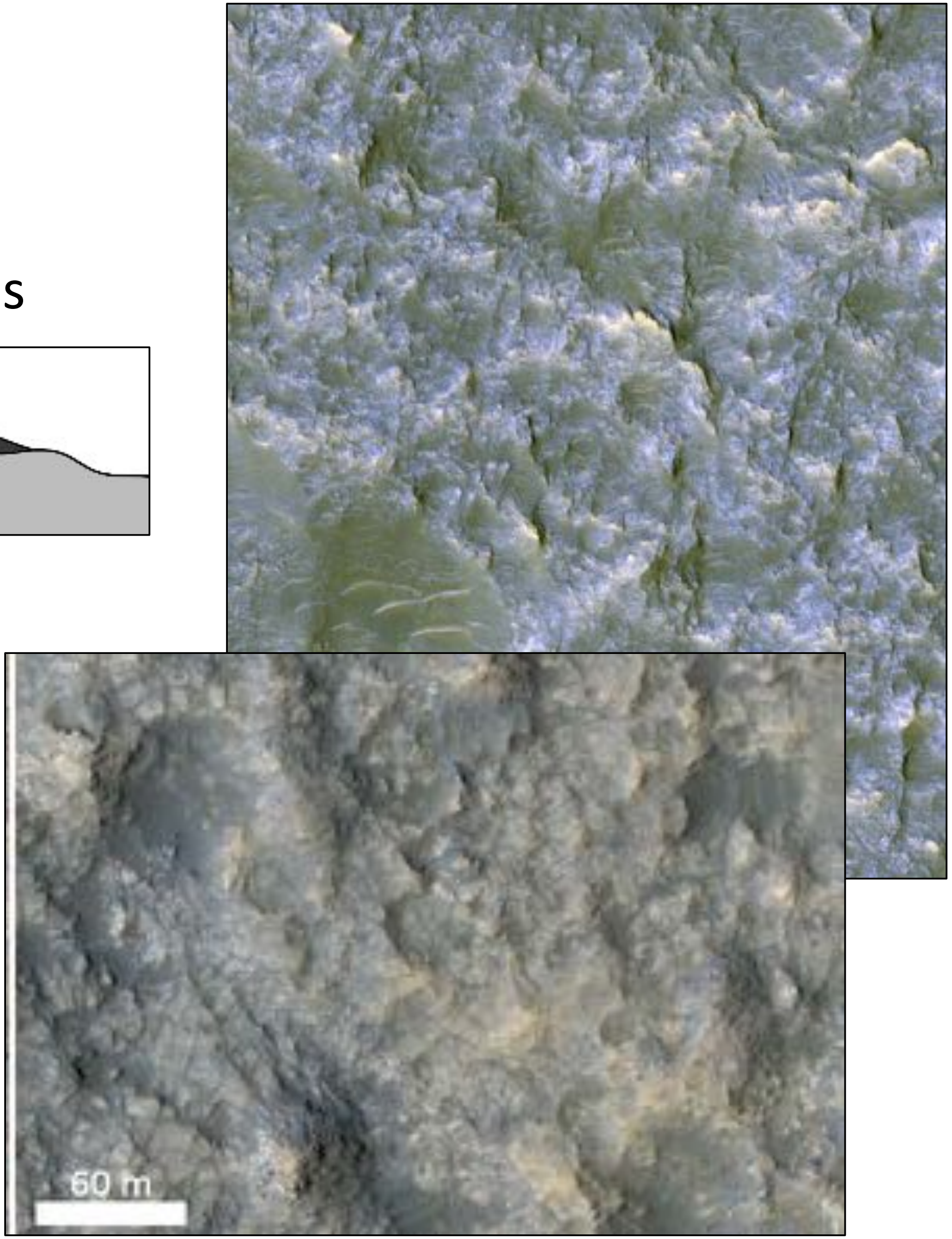
Warm/fine grained materials dominate spectral measurements over the exposed rock component.



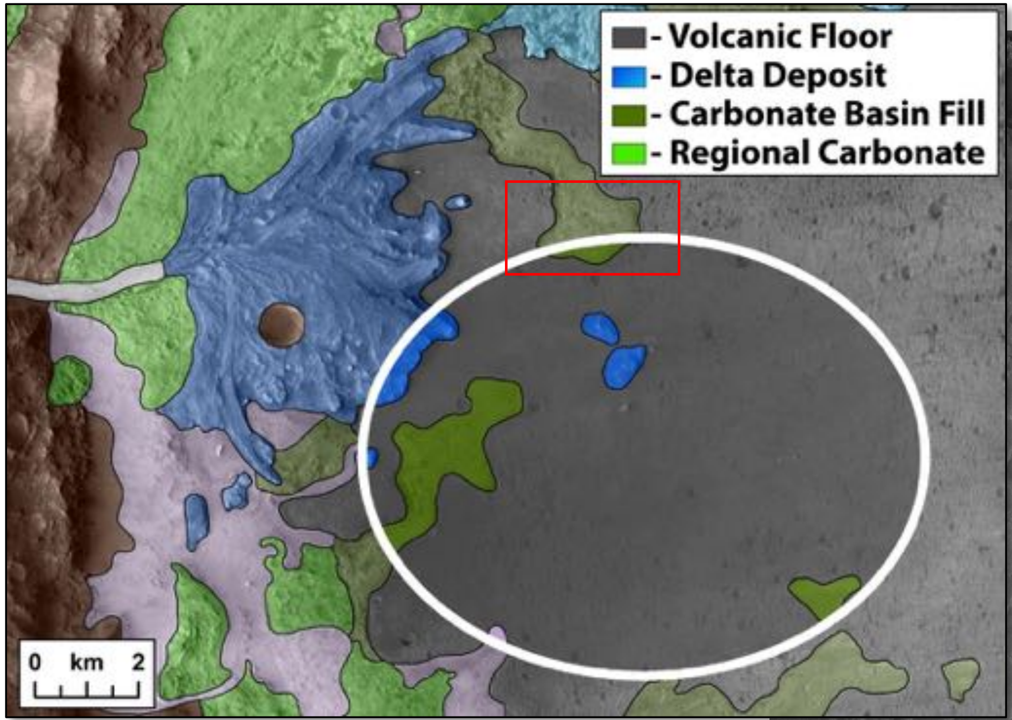
Olivine-enriched sands

Basaltic clastic rock with minor olivine.

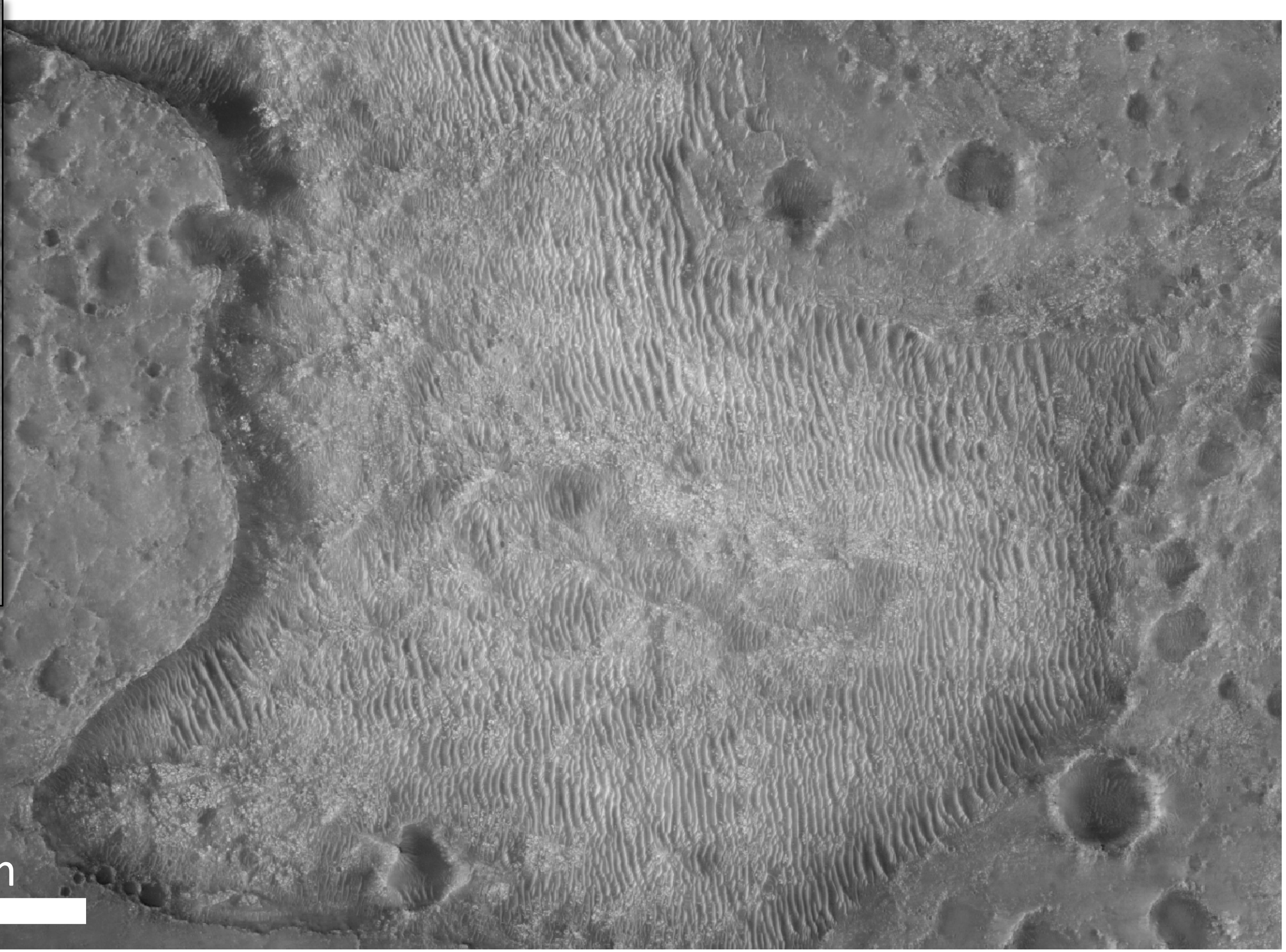
Implication would be that the rock itself is not olivine-enriched.



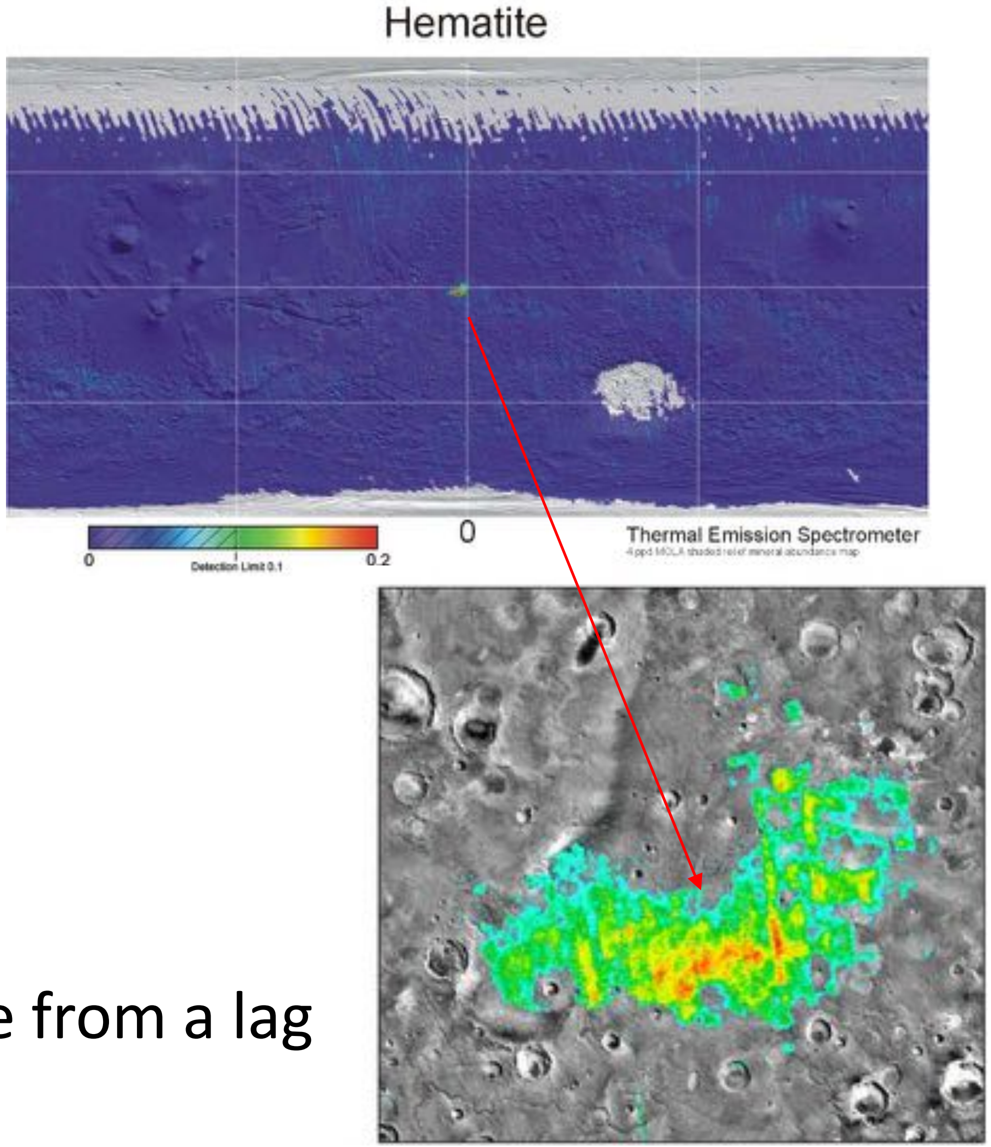
Jezero crater, Olivine and carbonate-bearing unit. Are one or both of these minerals concentrated in the dunes?



Map from Goudge et al., 2015, JGR



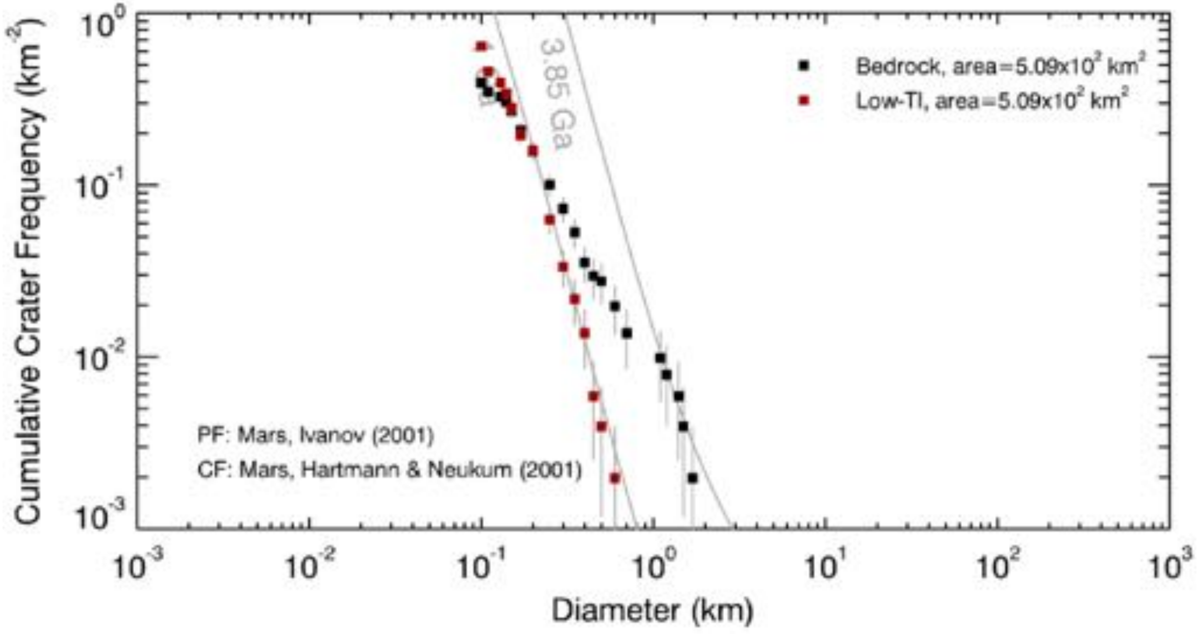
1. To what extent are <u>deflation</u> and <u>development of lag deposits</u> influencing our interpretations of spectral detections?

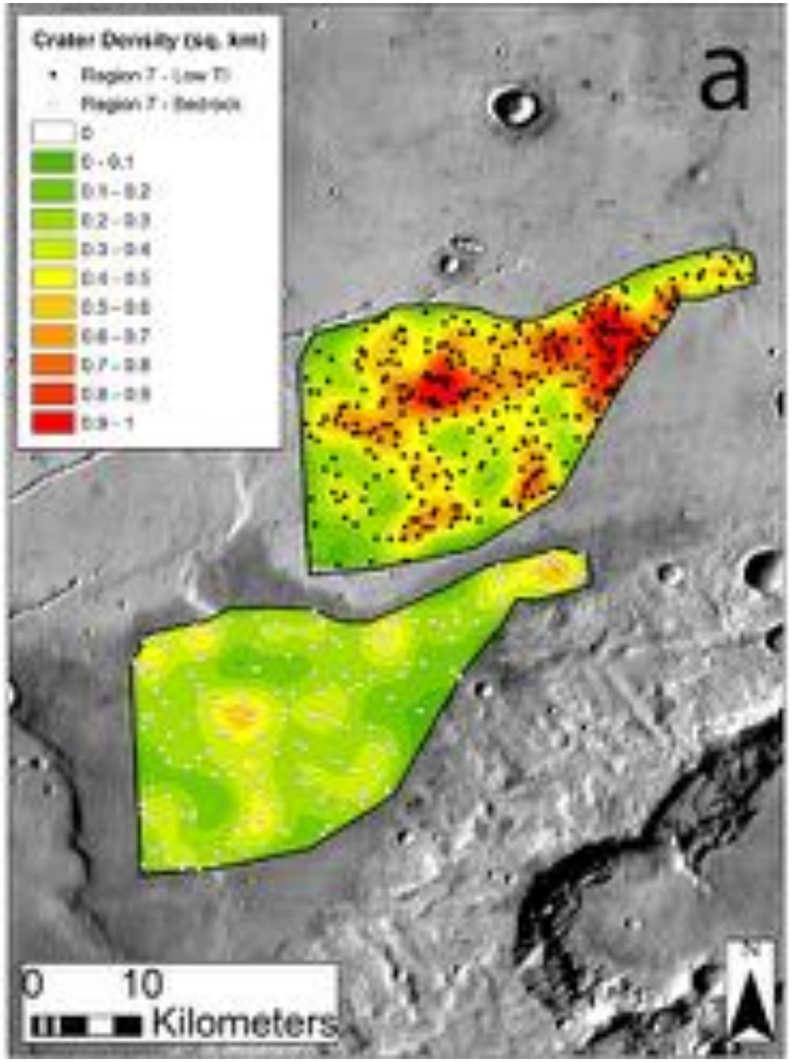


Hematite signature measured by TES came from a lag deposit.

2. Estimates of crater retention age, even relative ages, could be affected by varying rock strength.

e.g. Hartmann 1971; Chapman and Jones, 1971; Dundas et al., 2010; Fassett 2016





Crater counters beware…

Conclusions and Implications

1. Most exposed bedrock likely consists of easily-eroded fine-grained material
    - A larger volume of clastic rock in the highlands, in agreement with others [e.g., Edgett, Irwin et al.]
    - <u>High thermal inertia from orbit = weak fine-grained rocks</u> (unless young)

2. Evidence for deposition through both volcanic and sedimentary processes
    - For fluvial deposits, lack of fine layering and no hydrous mineral detections – short and episodic deposition – prolonged wet period not required.

Speculation

Deflation and preferential winnowing could be a cause of mineral enrichments, in some places.