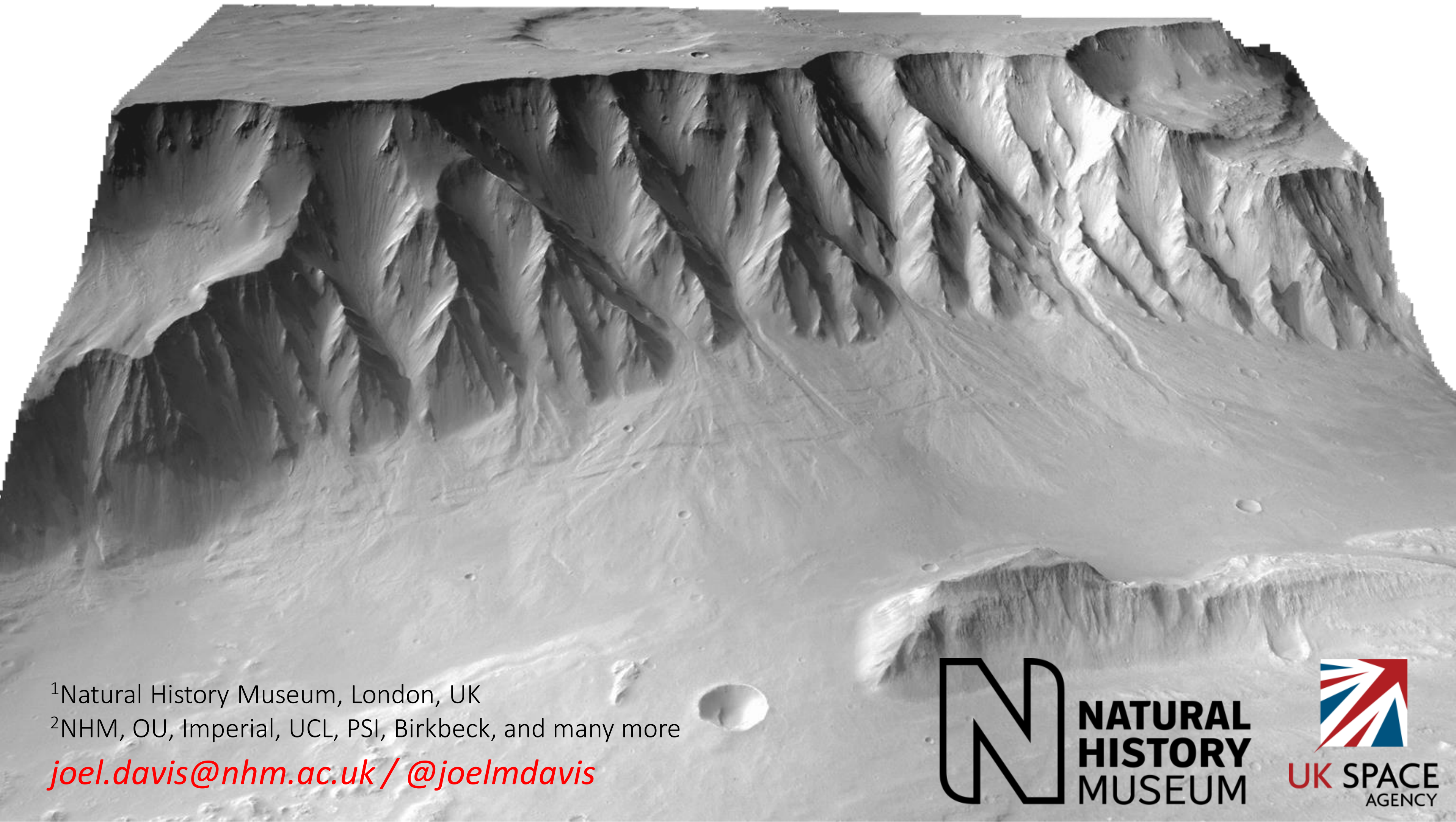
The geology of Mars: Current views and opportunities at Oxia Planum

Joel M. Davis[1]
and countless colleagues[2]



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NATURAL HISTORY MUSEUM

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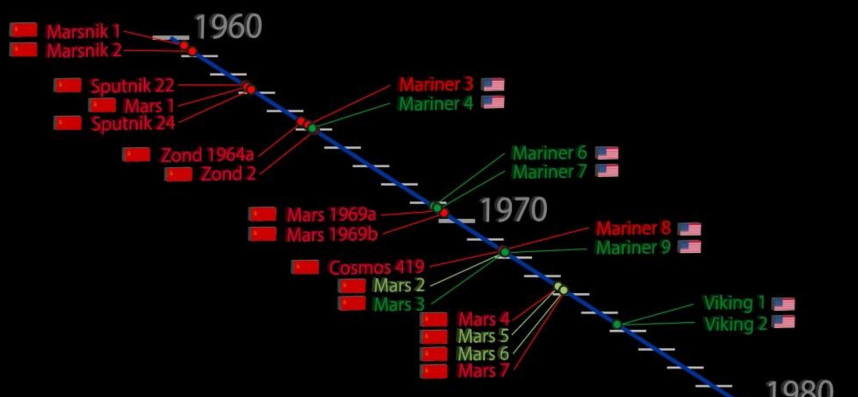
The Exploration of Mars



Why is Mars Special?

- Atmosphere
- Water ice caps
- Sub-surface water ice
- Active volcanism?
- …past conditions for life?

The surface of Mars preserves of one ***best kept, most diverse and most accessible*** geological records of the inner solar system.

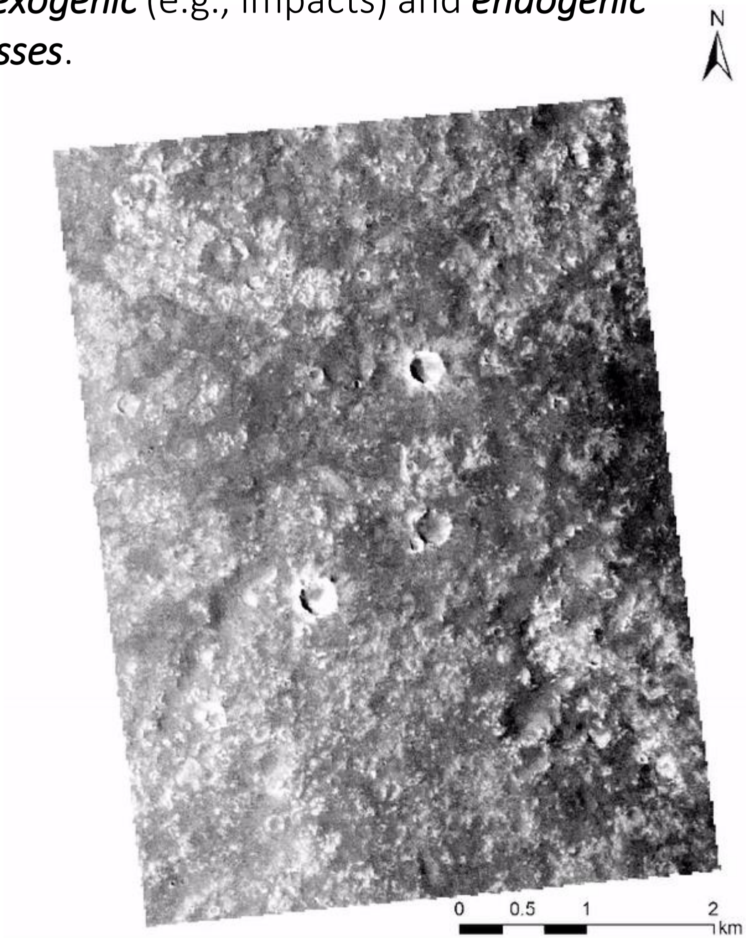
Habitability on ancient and modern Mars

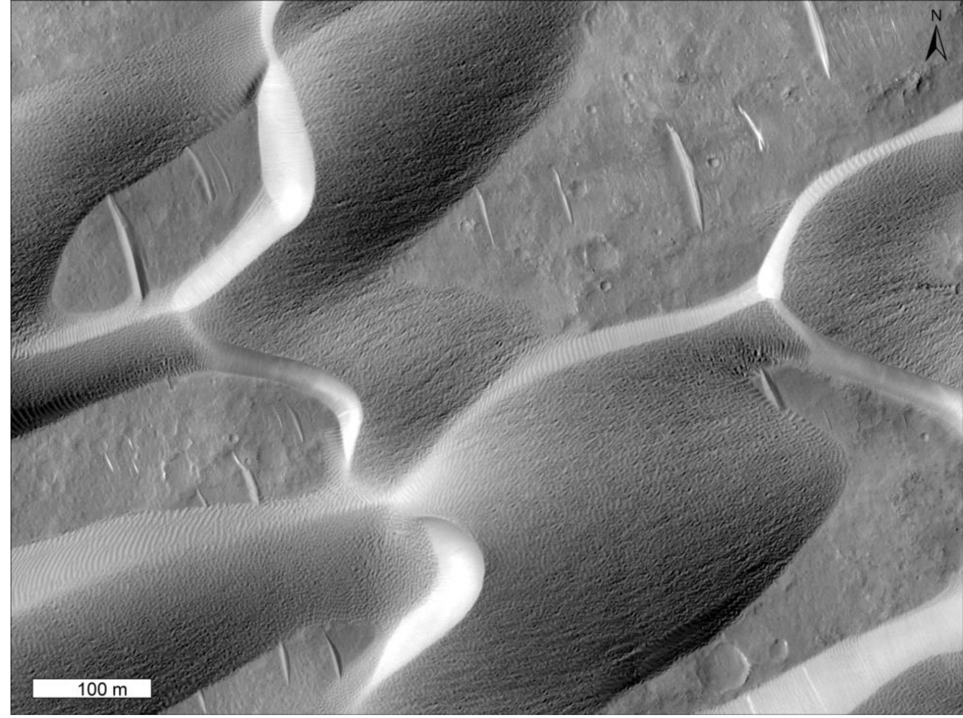
- Today, *the surface of Mars is considered to be inhospitable to life*, but the conditions within the shallow and deep sub-surface of Mars are largely unknown.
- Many of the ancient surfaces on Mars are thought to represent *former habitable environments*, which life could have developed in (e.g, lakes).
- The ancient lake at Gale crater is one such example, where complex organic molecules have been detected in the rock record and *could* be biotic in origin.
- However, *no direct detections of ancient life on Mars have been made* which have stood up to scrutiny.
- Understanding *geological context* is critical for detection of ancient life.

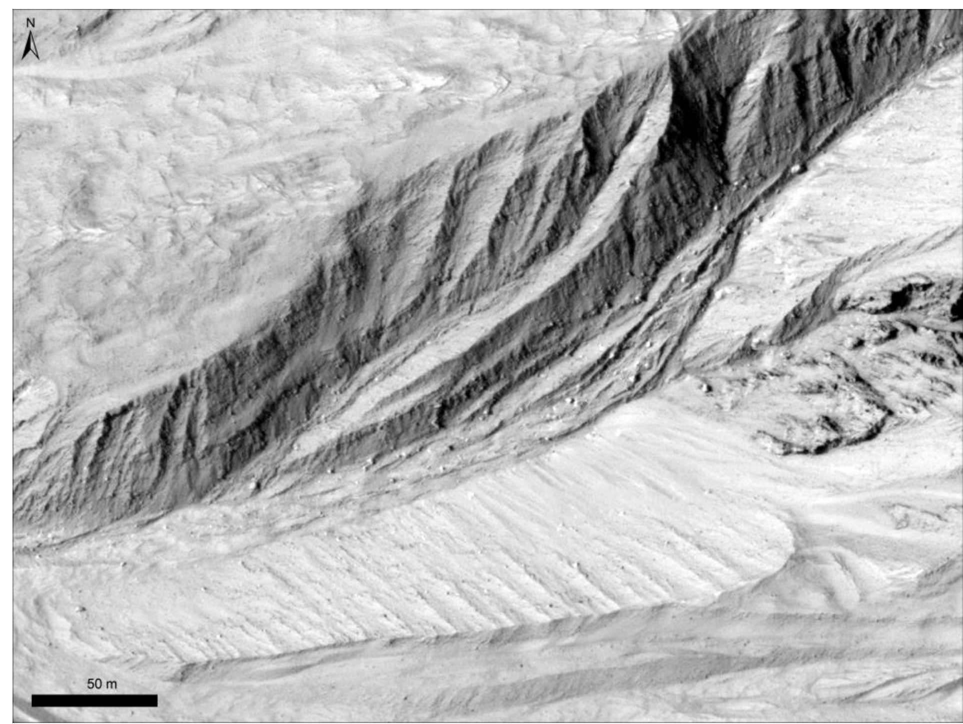
Artist’s impression of ancient Mars. Credit: NASA/MGS/MOLA/Kevin Gill.

Mars today…

Despite being a ***cold and hyperarid environment***, the surface of Mars is not dead and is being shaped by both ***exogenic*** (e.g., impacts) and ***endogenic processes***.



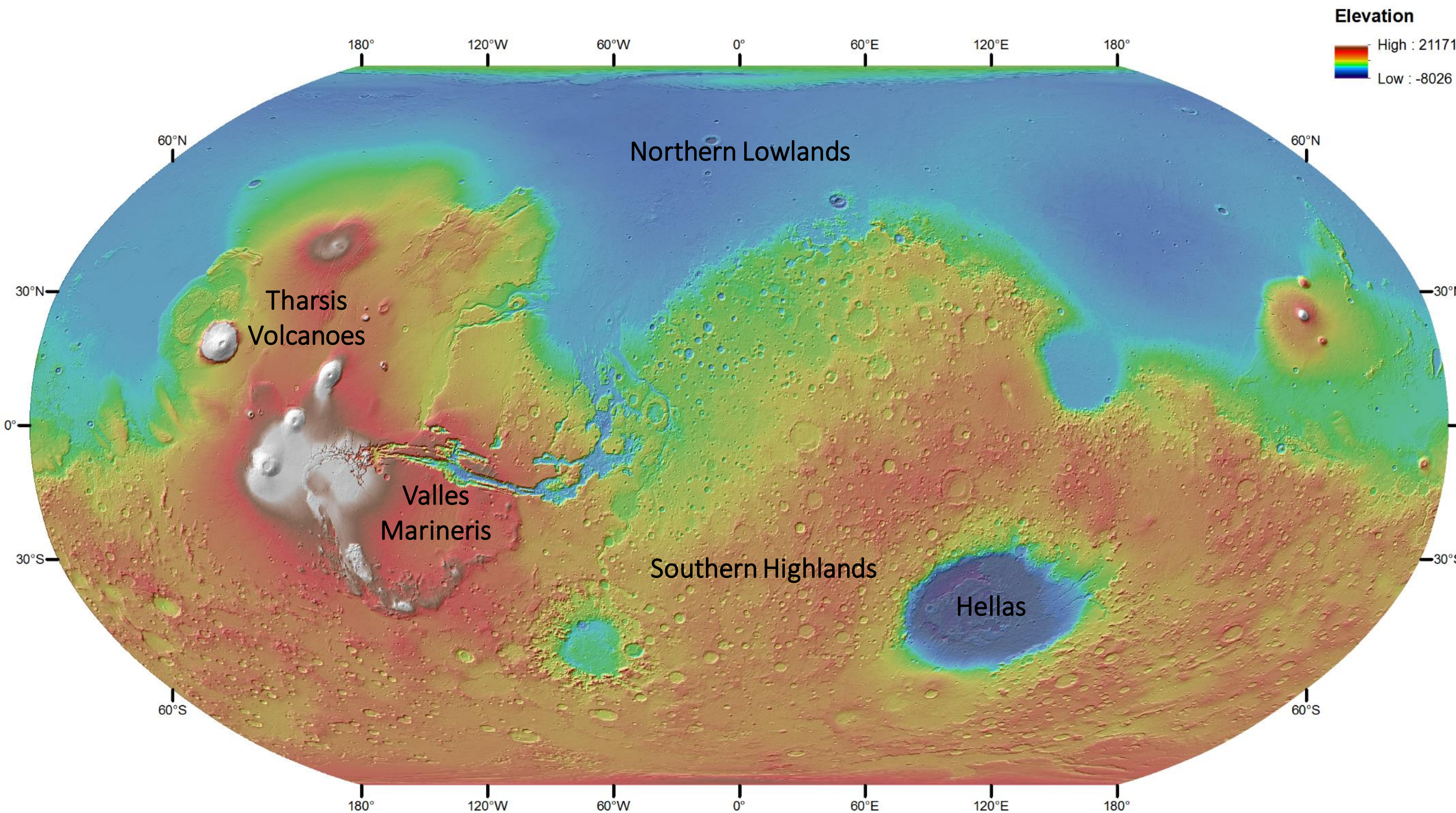




Above: Before and after images of a meteorite forming a new impact crater on Mars. Image credit: NASA/JPL/UoA/Peter Grindrod.
Bottom right: Active flows in gullies in Hale Crater. After De Haas et al., 2019.
Top right: HiRISE gif is barchan dunes at Nili Patera. Image credit: NASA/JPL/UoA.

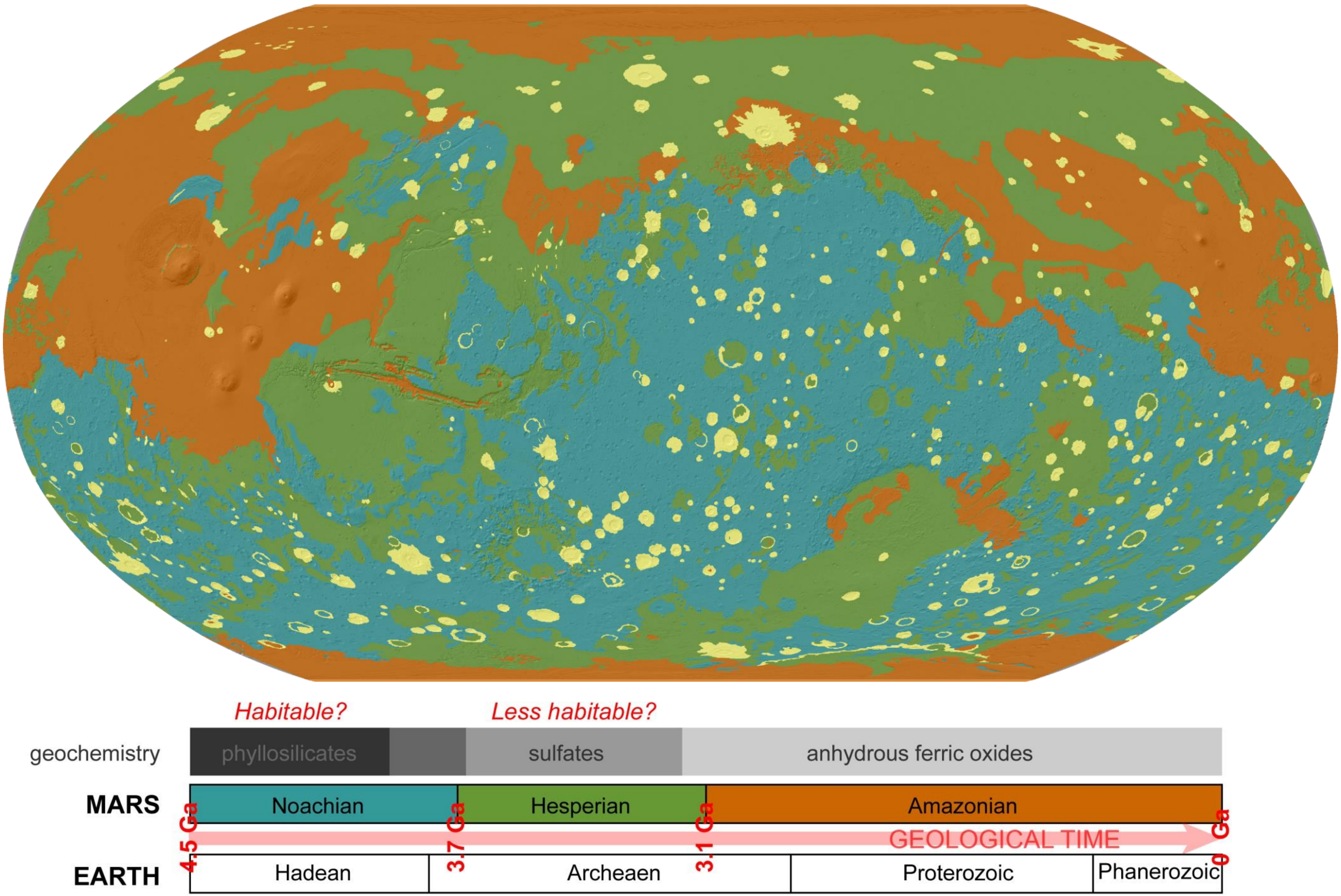
The topography of Mars

- Lack of plate tectonics so topography on Mars is largely modulated by impact cratering;
- Exceptions are volcanic provinces and Valles Marineris canyons;
- Five impact basins >1,000 km: Borealis, Hellas, Argyre, Isidis, Utopia.



Mars Orbital Laser Altimeter data; Smith et al., 2001

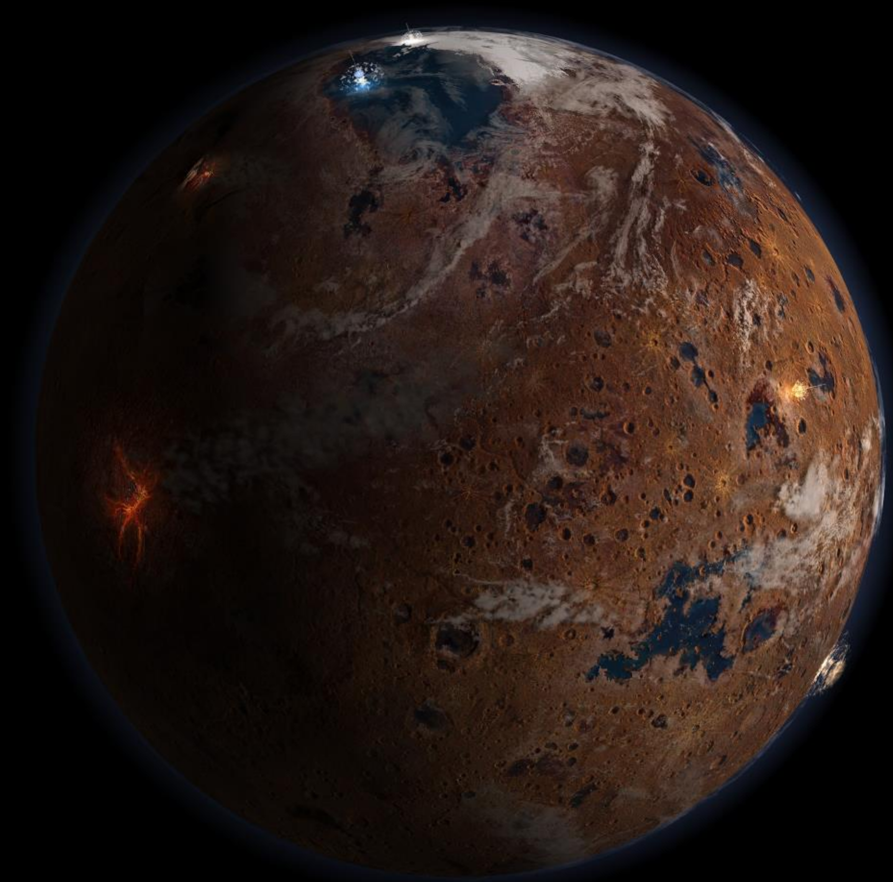
Geological time on Mars



Adapted from Bibring et al. (2006) Science

The Noachian

- Oldest period on Mars is the *Noachian (4.5-3.7 Ga)*.
- The Noachian was a time of intense, but declining impact cratering. The dichotomy and the largest Mars basins formed during the Noachian.
- Erosion rates during the Noachian were 2-5 orders of magnitude higher than subsequent periods, but still lower than Earth.
- It is on Noachian surfaces that Mars shows the strongest evidence for long-lived, liquid water….



Artist's concept of Noachian Mars. NASA/JPL/MOLA/Kees Veenenbos

Valley networks

- Some of the **strongest evidence for widespread erosion** on the martian surface – analogous to river valleys on the Earth?

  e.g. Howard et al., 2005; Hynek et al., 2010

- Up to thousands of kilometres in length - Cumulatively 10^4 km drainage systems, **equivalent to continental drainage basins**. BUT generally poorly integrated with landscape.

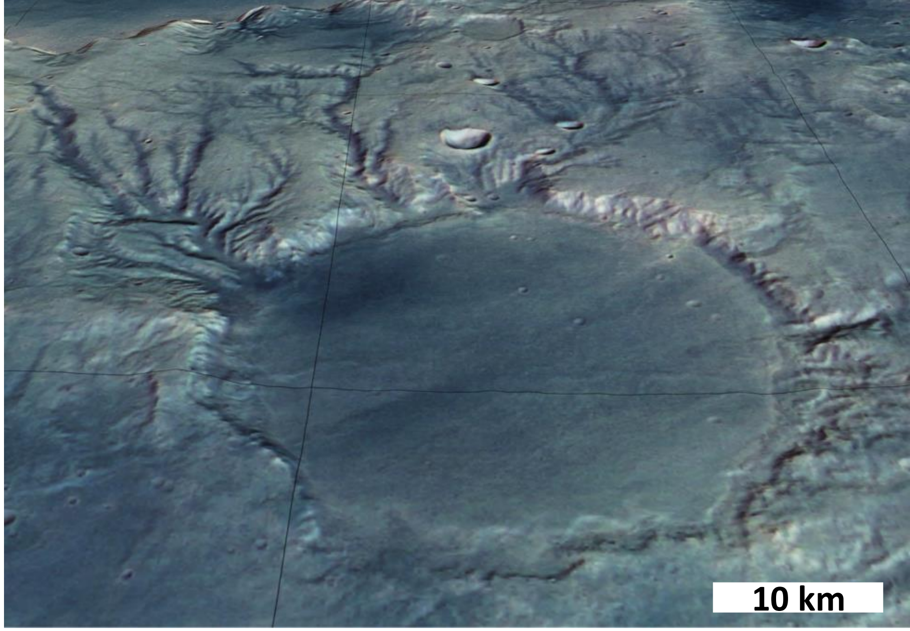
  e.g. Carr, 1995; Hynek et al., 2010

- Most common on **Noachian (> 3.7 Ga)** terrains (~ 90% of known networks);

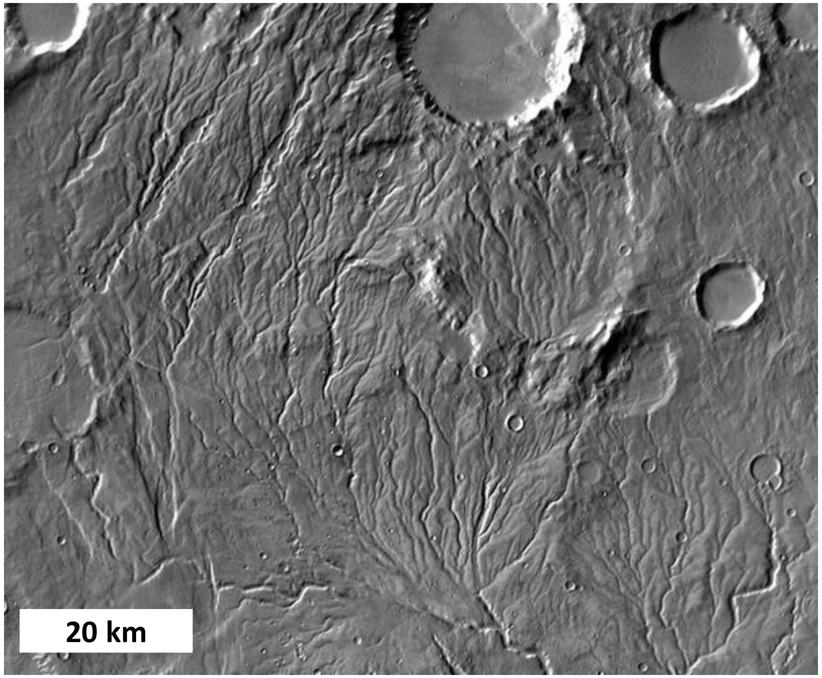
  Hynek et al., 2010

- Formation timescales vague: ~**10^5-10^7 years** ***(potentially much less).***

  e.g., Hoke et al., 2011



Regional fluvial valley network draining into crater basin.



Dense fluvial valley network with multiple tributaries which extend up to watersheds (craters).

Lakes on early Mars

- Craters are the primary source of relief on Mars. They acted both as source regions for sediment and sinks, forming basins. Paleolakes are identified where fluvial valleys intersect basins.

- Around 200 known large palaeolakes on Mars (mostly Noachian and early Hesperian);

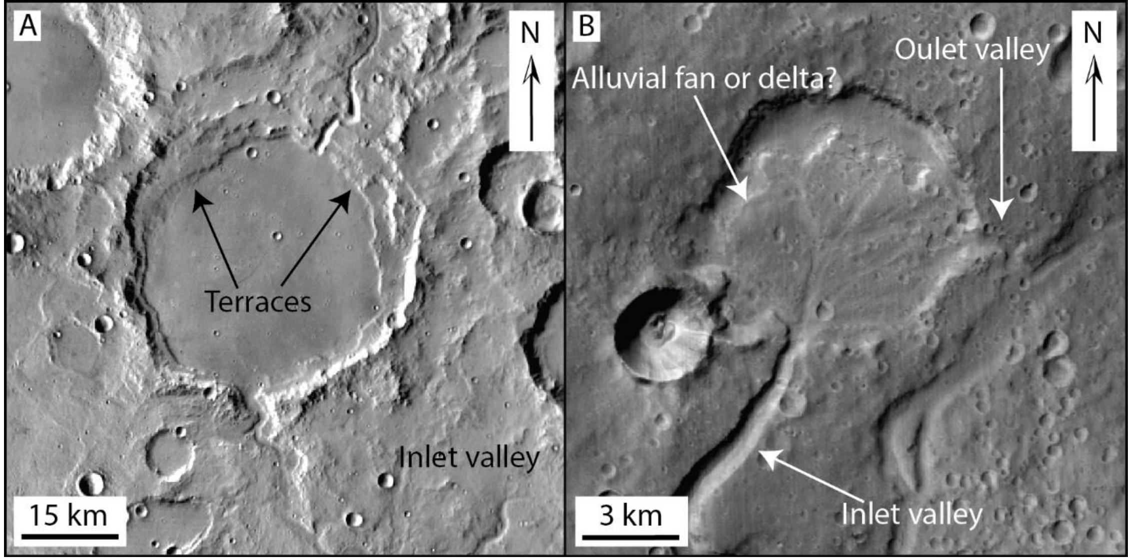
Goudge et al. 2012

- Many basins “outlets” are observed, indicating water filled the basin enough to breach the rim;

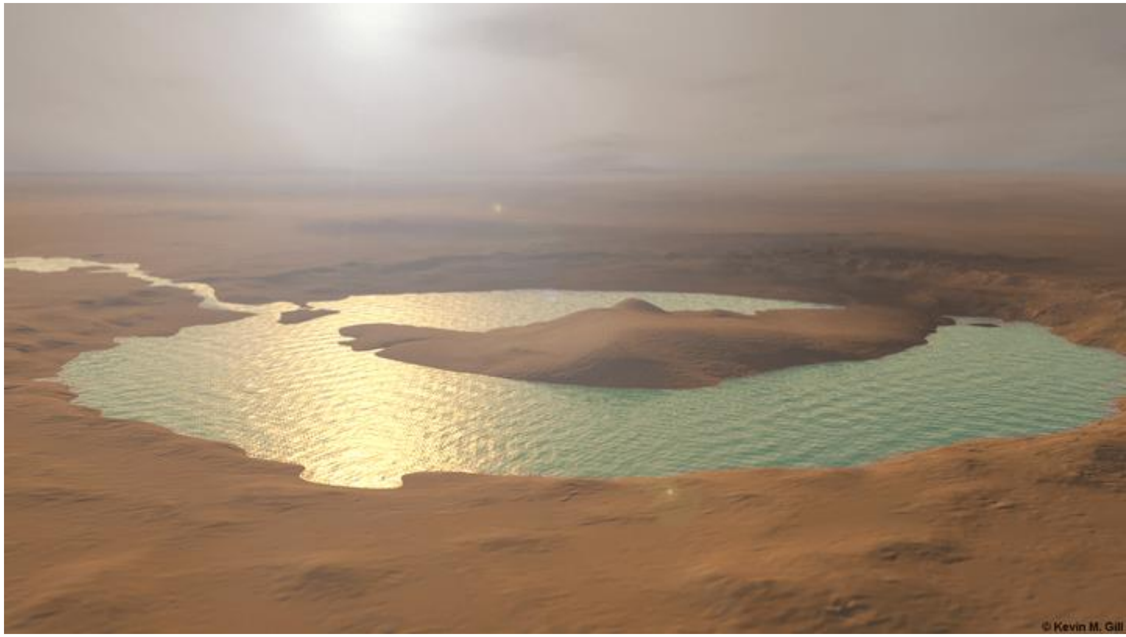
Fassett and Head, 2008; Goudge et al., 2012

- Unclear if large basins such as Hellas or Argyre were lakes;

Carr and Head, 2010



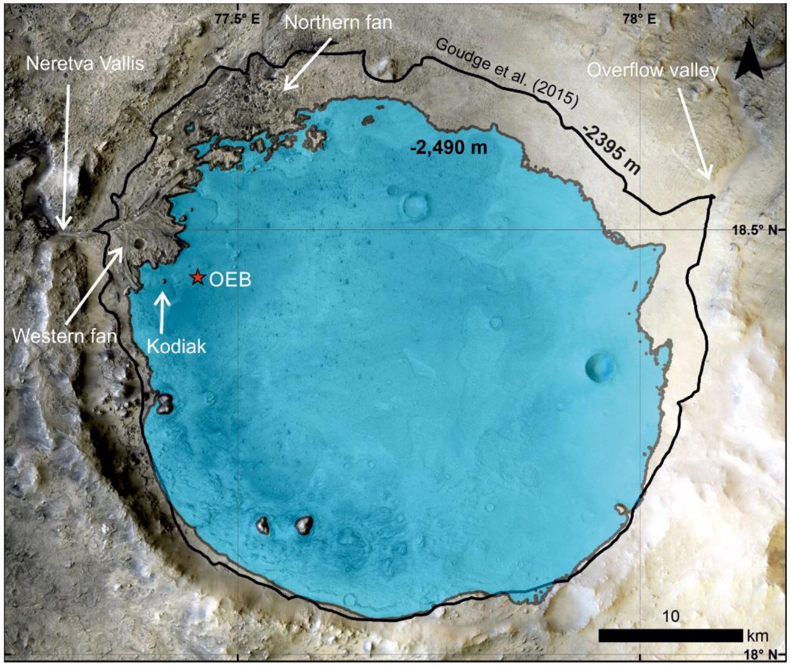
(a) Open basin paleolake with strath terraces. Note the presence of both inlet and outlet valleys. (b) Open basin lake with sediment fan.

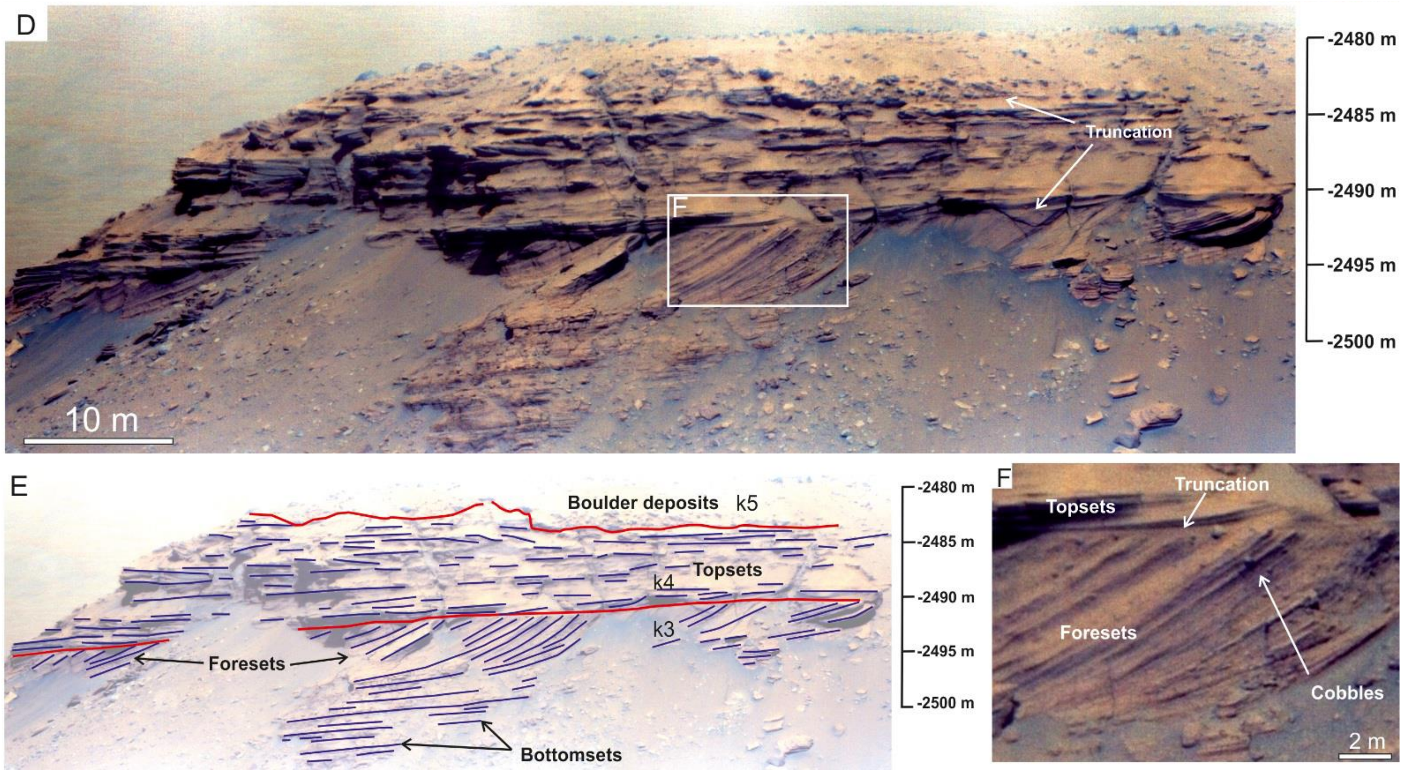


Gale Crater at 4 Ga? Credit: Kevin Gill

Ground truth from Jezero crater

- Observations by the Peseverance rover in Jezero crater *<u>support the presence of an ancient lake (~ 3.6 Ga?)</u>*.
- The deltaic deposits found show the minimum extent of the lake, a closed system.
- Overprinting the deltaic deposits are large boulders, formed from *<u>high-energy flood events – a change in climate?</u>*



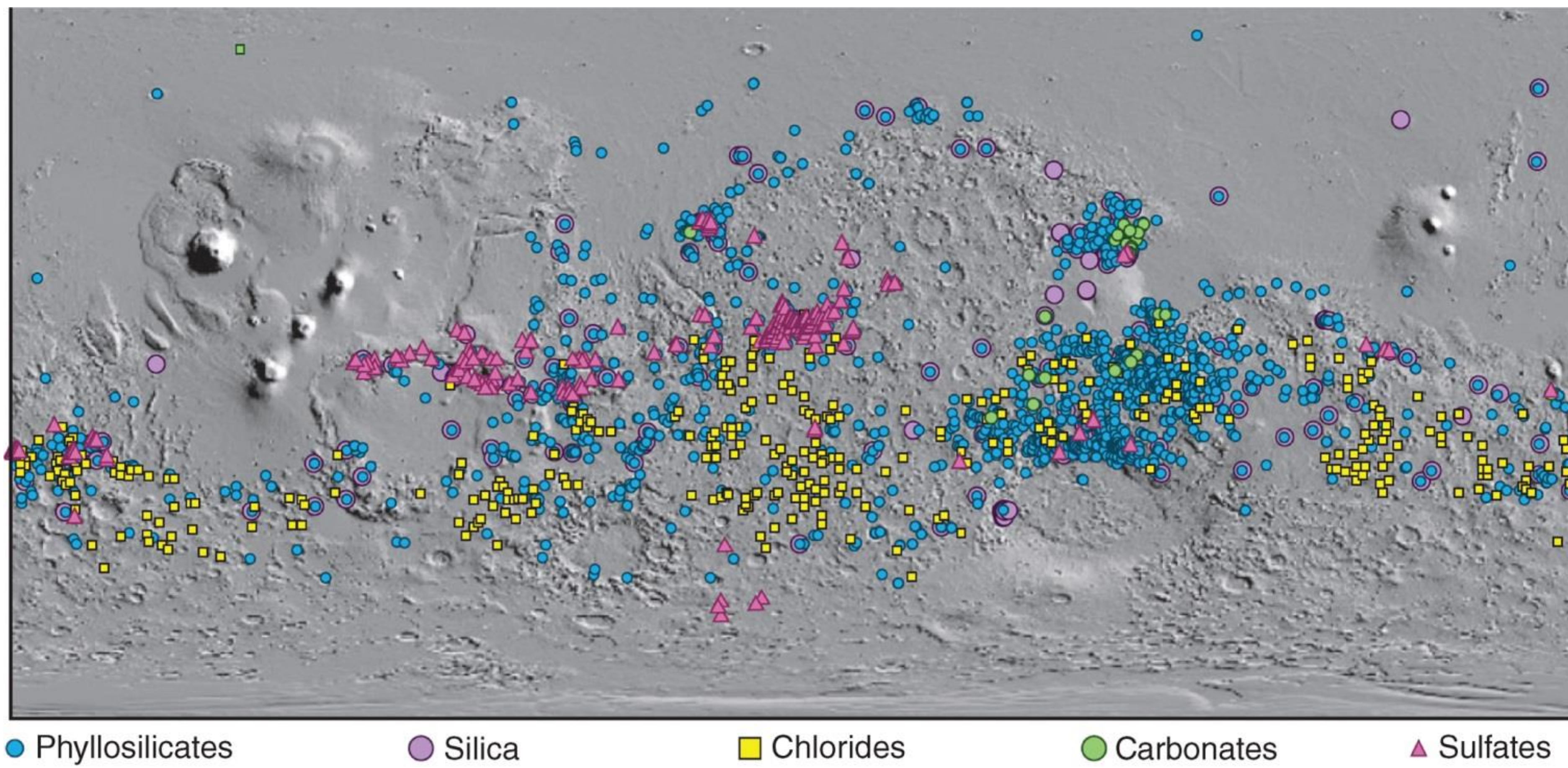


Above: Minimum extent (shaded blue area) of the lake at Jezero crater. After Mangold et al. 2021.

Right: Kodiak butte as seen by Perseverance rover in Jezero crater. Kodiak was likely formed by a river delta at the margins of a closed basin lake. After Mangold et al. 2021.

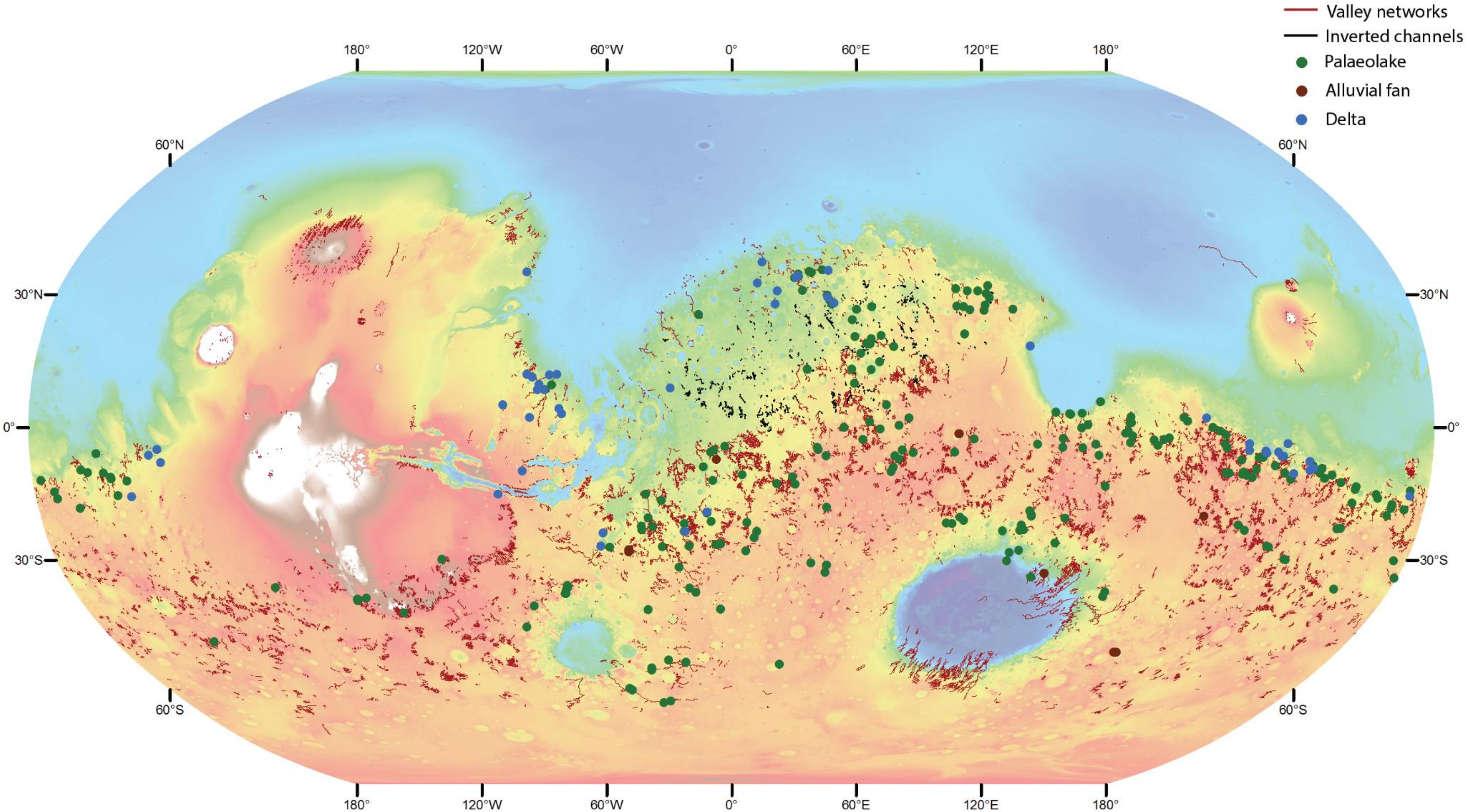
Hydrous minerals

- In addition to geomorphic indicators, hydrous minerals have been detected across ancient surfaces on Mars.
- These minerals are the results of alteration, from water interacting with bedrock.
- Hydrous minerals are likely more widespread, just not detectable from orbit.



Detections of alteration mineral on the surface of Mars. Modified from Ehlmann and Edwards, 2014.

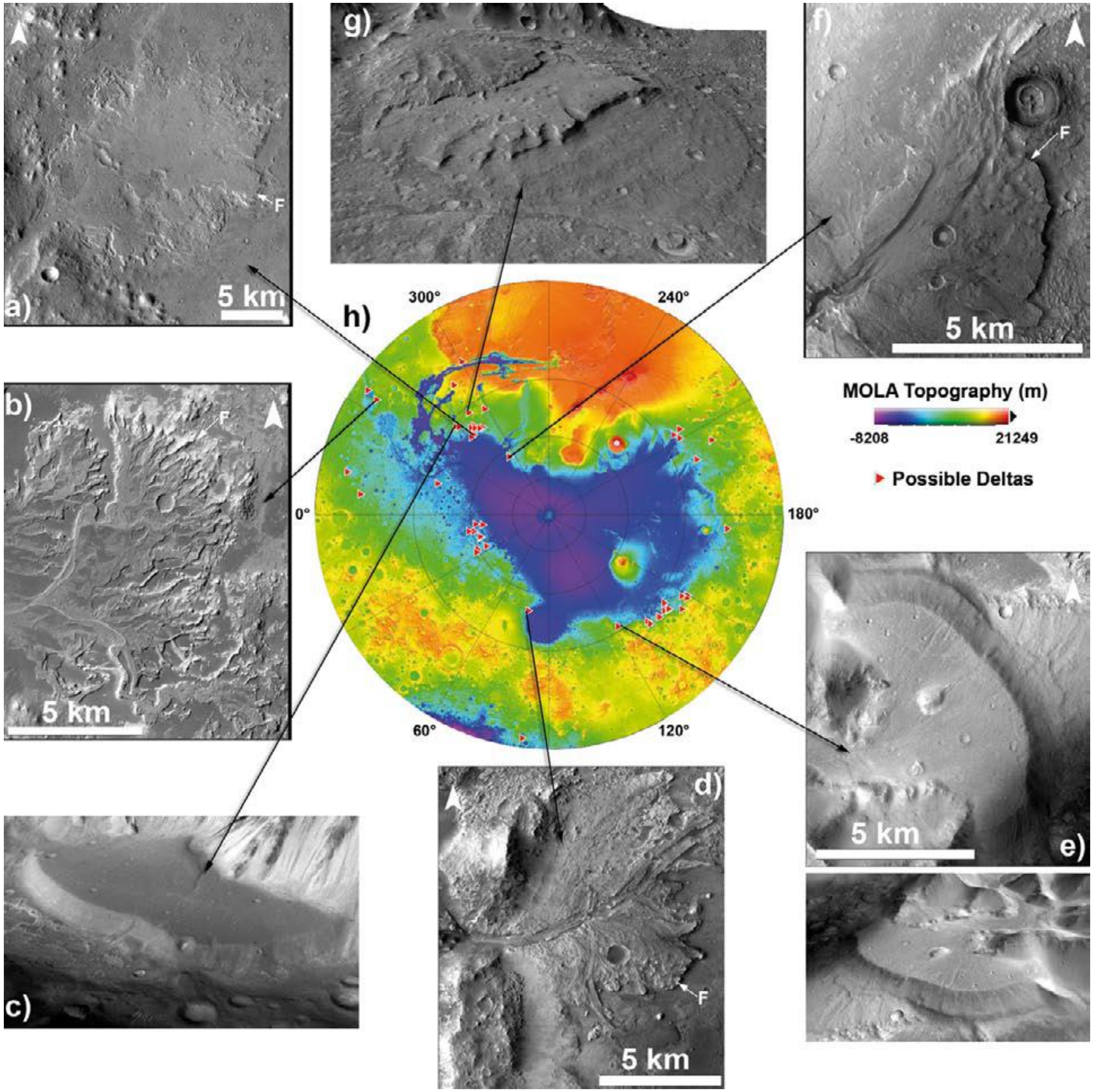
Evidence for Aqueous Processes on Noachian Mars



MOLA topographic map; valley networks adapted from Hynek et al., 2010; palaeolakes from Goudge et al., 2012; alluvial fans from Kraal et al., 2008b; inverted channels from Davis et al., 2016

Deltas on the Dichotomy

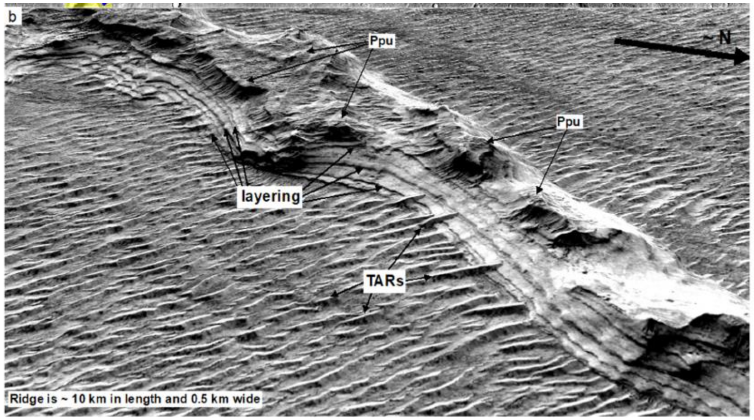
- Multiple deltas are found are the Martian dichotomy at similar elevations.
- This distribution suggests they may have formed an equipotential surface.
- However timing is key. Did all these features form at the same time?

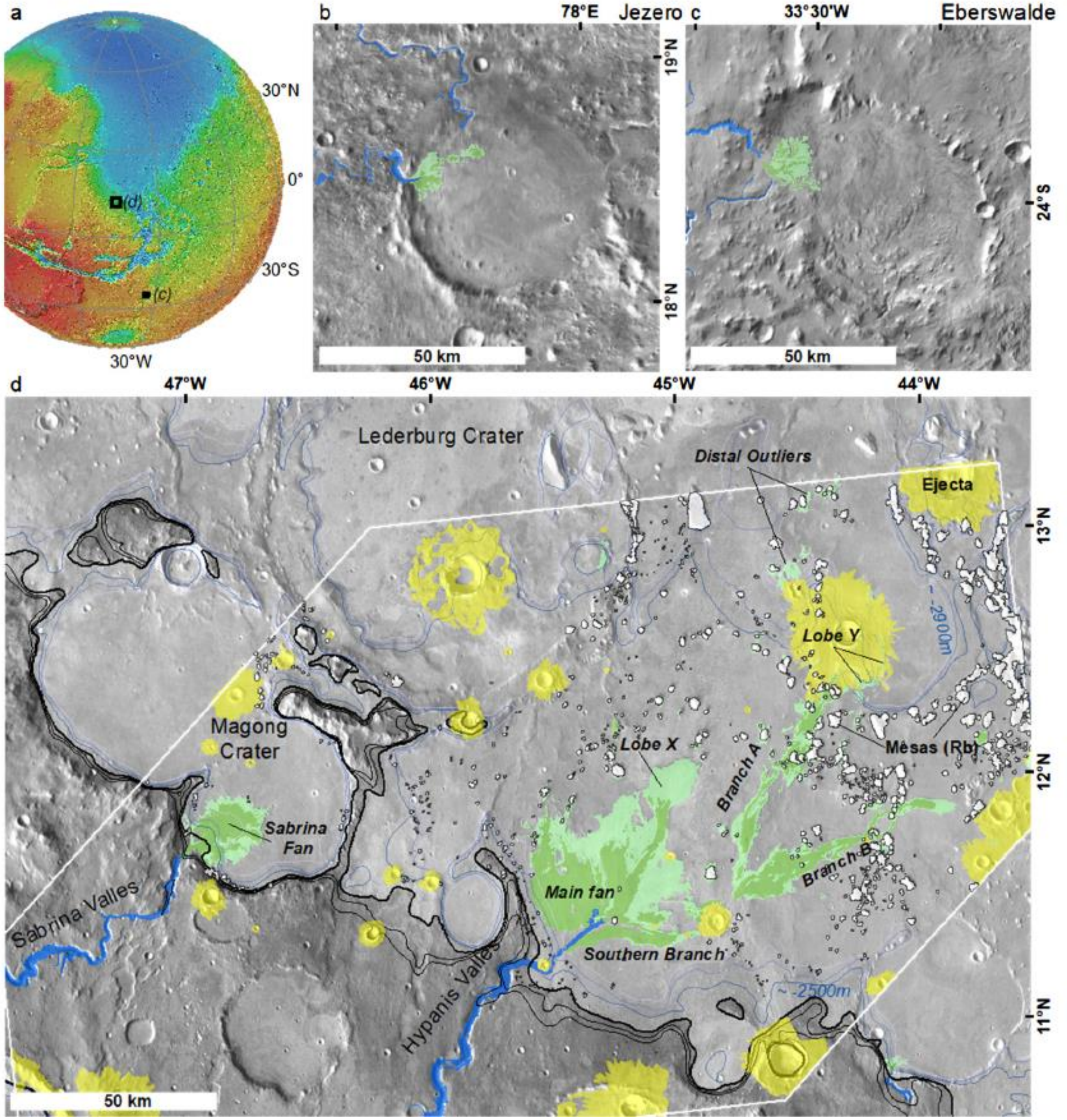


Numerous sediment fans are observed around the northern lowlands, many along an equipotential surface. After Di Achillie and Hynek 2010

The Largest Delta on Mars?

- Hypanis sediment fan, found at the dichotomy (Fawdon et al., 2018; Adler et al., 2019).
- Hypanis is the largest delta on Mars!
- Layering visible in fan margins consistent with sedimentary origin.

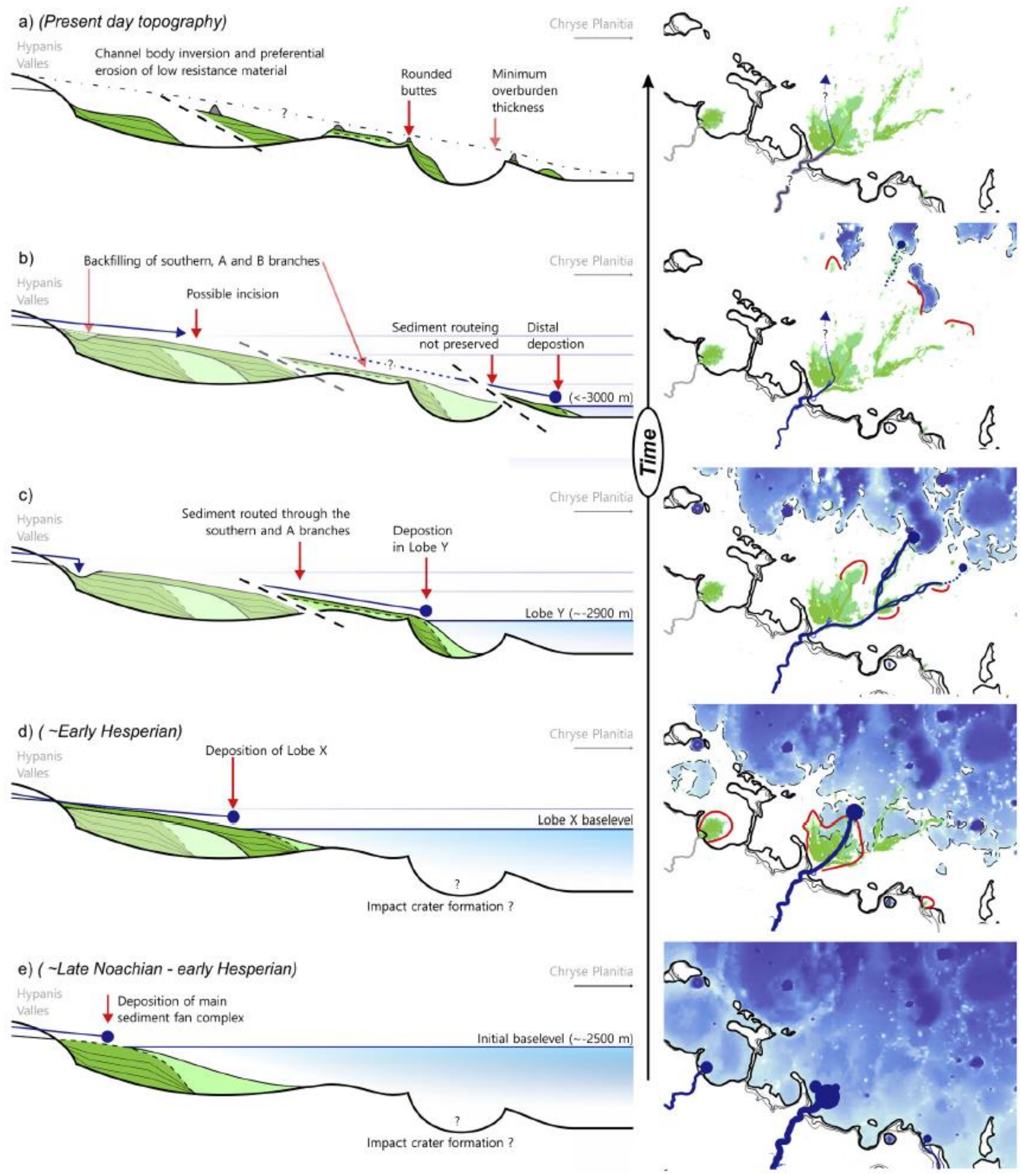




After Fawdon, Gupta, Davis et al., 2018

Hypanis: Evidence for a receding ocean?

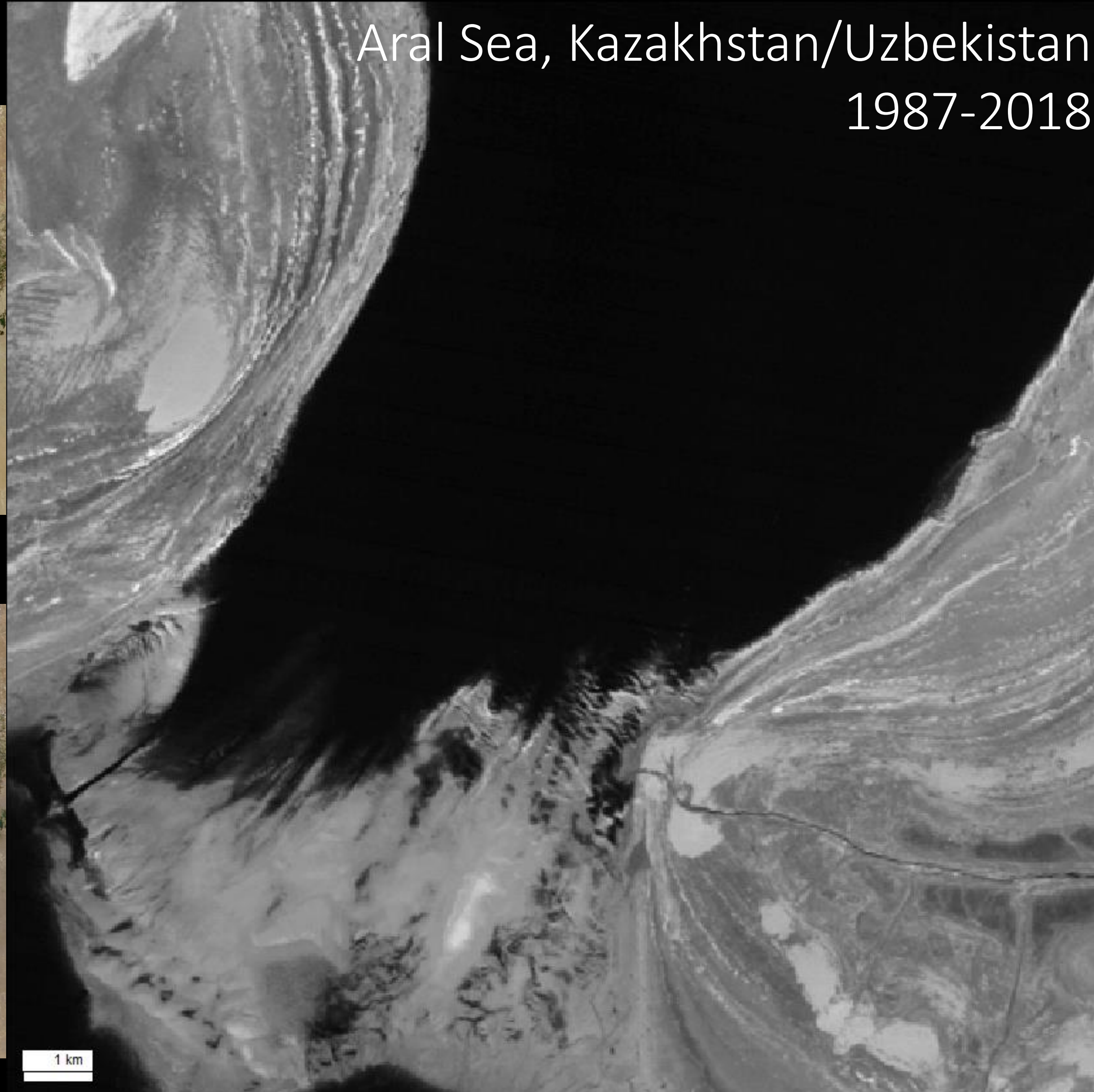
- Geomorphology and stratigraphy of Hypanis fan are difficult to explain without the presence of water body.
- Hypanis expands 200 km into the northern lowlands of Mars – it is not confined by topography (Fawdon et al., 2018; Adler et al., 2019).
- Body of water would have expanded across the northern lowlands, forming an "ocean" around 3.7 Ga.
- As the water level receded, Hypanis grew outward into the basin. (Fawdon et al., 2018; Adler et al., 2019)



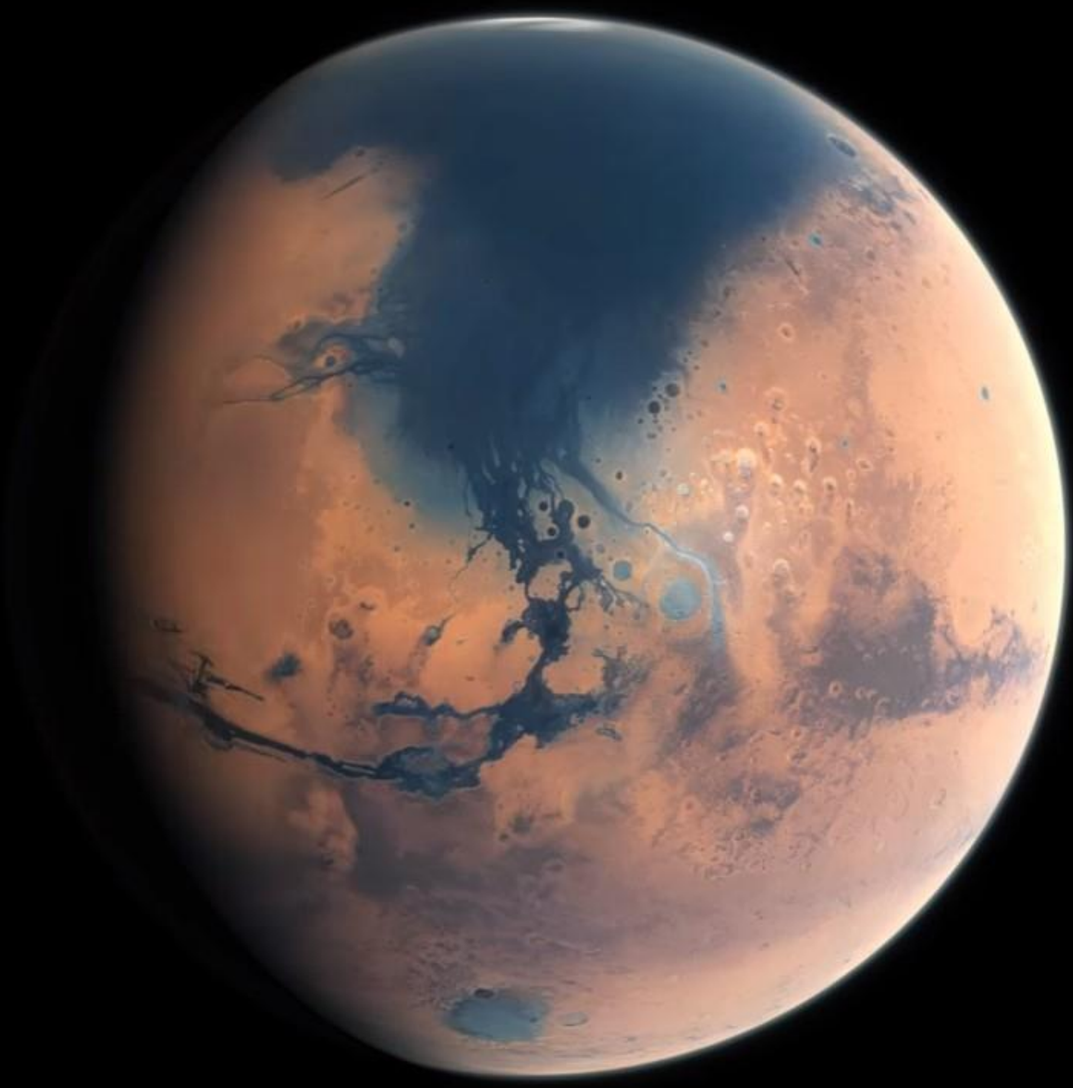
After Fawdon, Gupta, Davis et al., 2018

Aral Sea, 2000

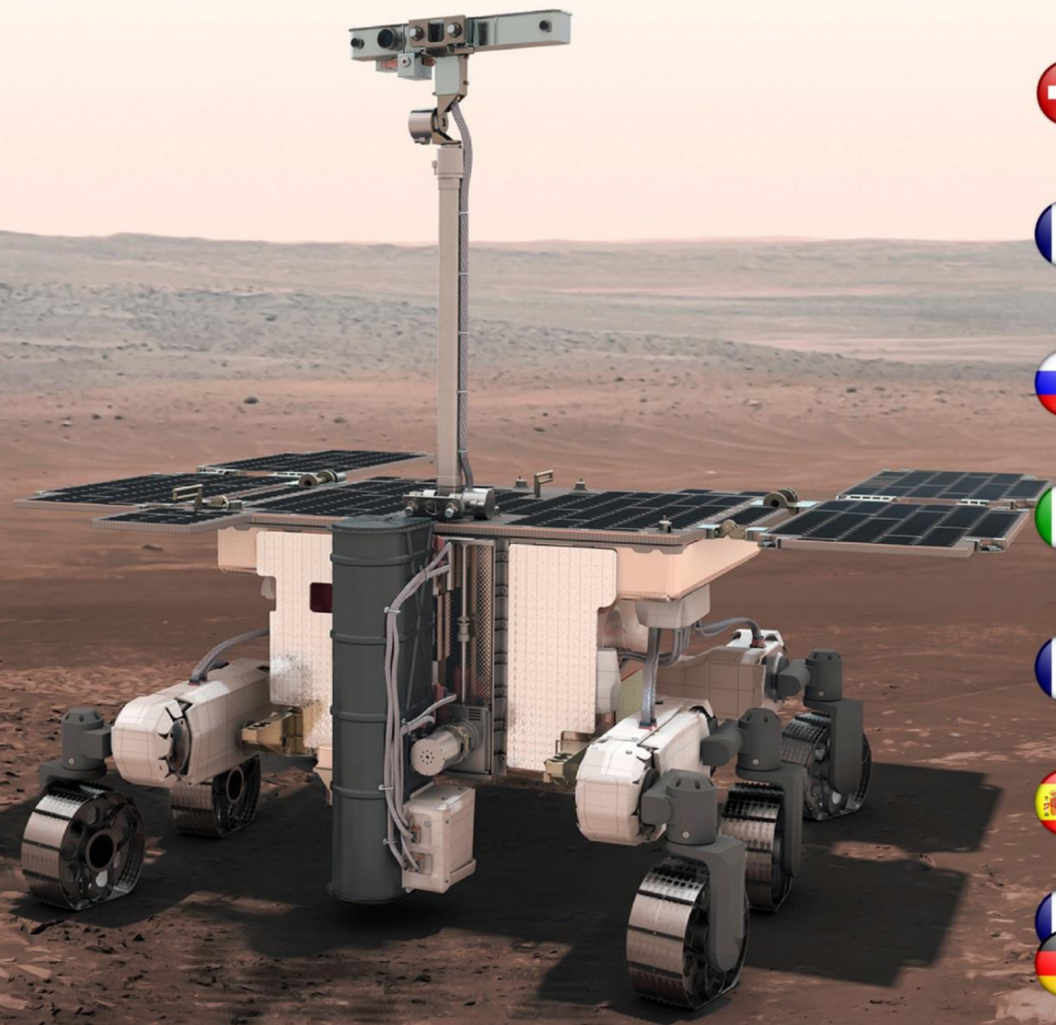
Aral Sea, 2018



A Noachian Northern Ocean?



THE EXOMARS MISSION



Pasteur Payload

PanCam	Wide-angle stereo camera pair High-resolution camera WAC: 35° FoV HRC: 5° FoV	Geological context Rover traverse planning Atmospheric Studies
ISEM	IR spectrometer on mast λ = 1.15 - 3.3 µm 1° FoV	Outctop bulk mineralogy
CLUPI	Close-up imager 20 µm resolution at 50 cm, focus = 20 cm to ∞	Depositional env. Rock microtexture Morph. biomarkers
WISDOM	Ground-penetrating RADAR 3 - 5 m penetration, 2 cm resolution	Subsurface stratigraphy
ADRON	Passive neutron detector	Subsurface H2O
Drill + Ma_MISS	IR borehole spectrometer λ = 0.4 - 2.2 µm	In-situ mineralogy
MicrOMEGA	VIS + IR spectrometer λ = 0.9 - 3.5 µm, 256 x 256 20 µm/pixel, 500 steps,	Sample mineralogy
RLS	Raman spectrometer Spectral shift range 200 - 3800 cm^{-1}, resolution < 6 cm^{-1}	Geochemistry Organic pigments
MOMA	LDMS + Pyr-Dev GCMS	Organic molecules Chirality determination

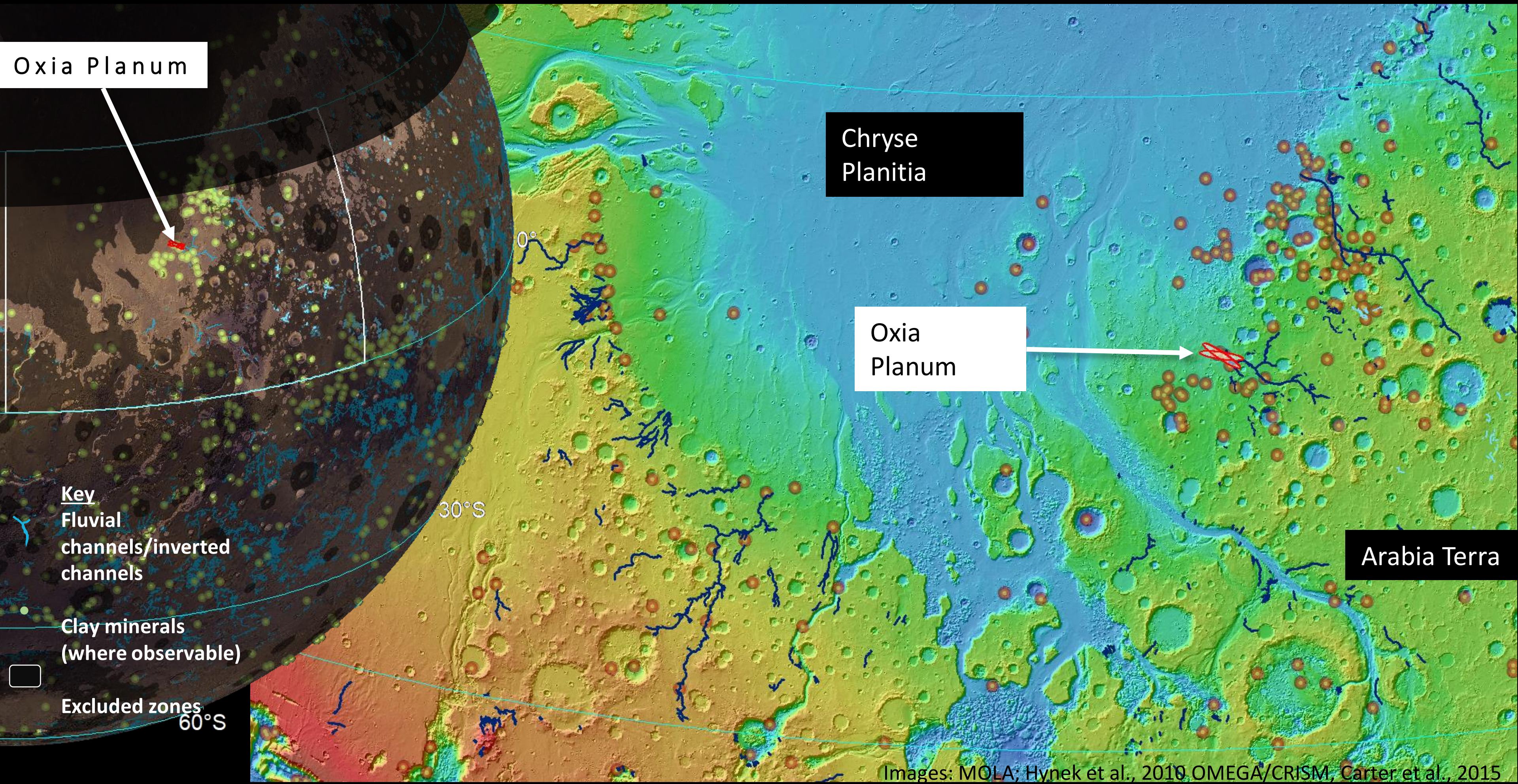
Credit: ESA

Oxia Planum

- ExoMars will at Oxia Planum in 2023, an ancient region bordering the southern highlands and northern lowlands.

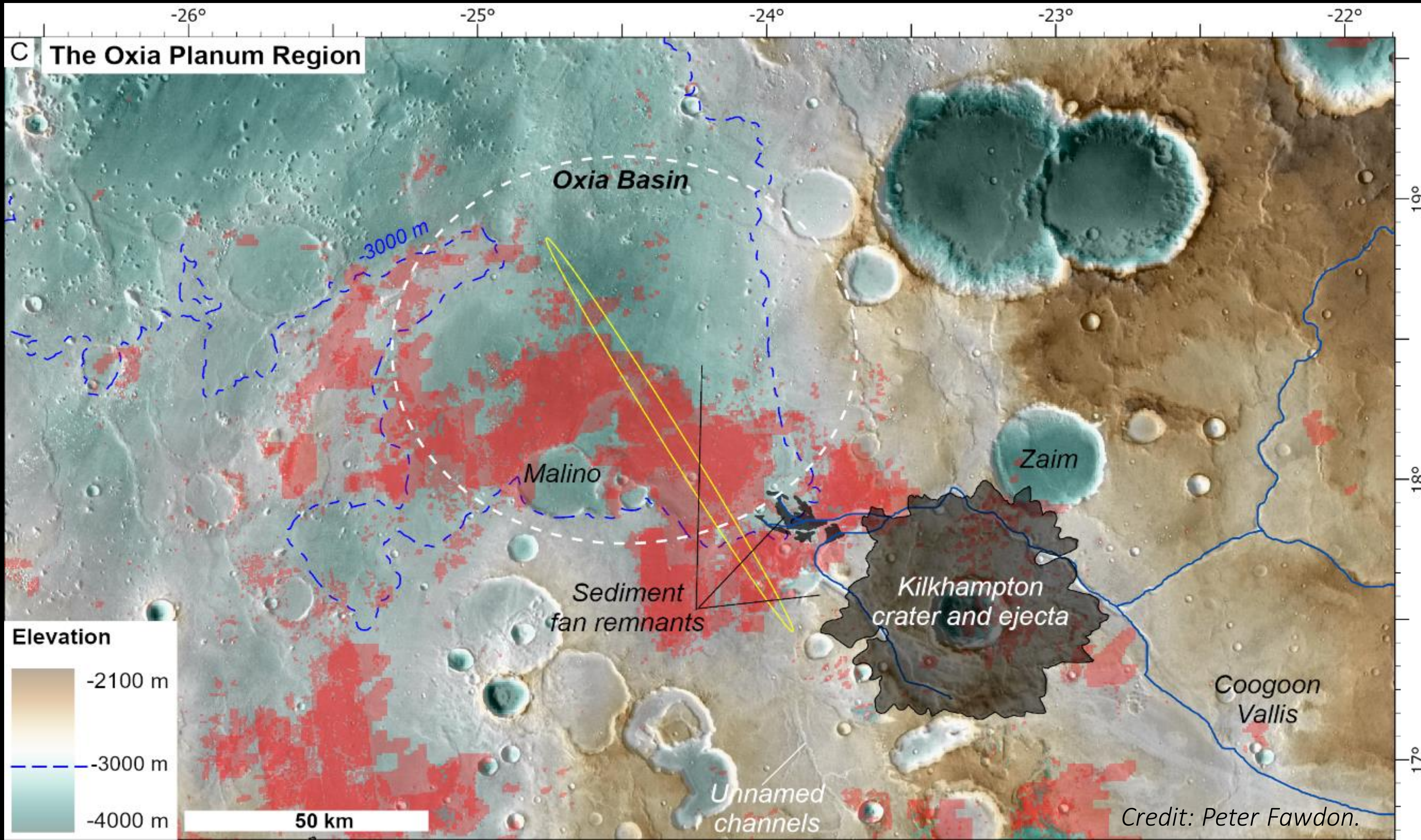
- Oxia Planum will the oldest site we have landed on so far (~3.8-3.9 Ga?)

Global context

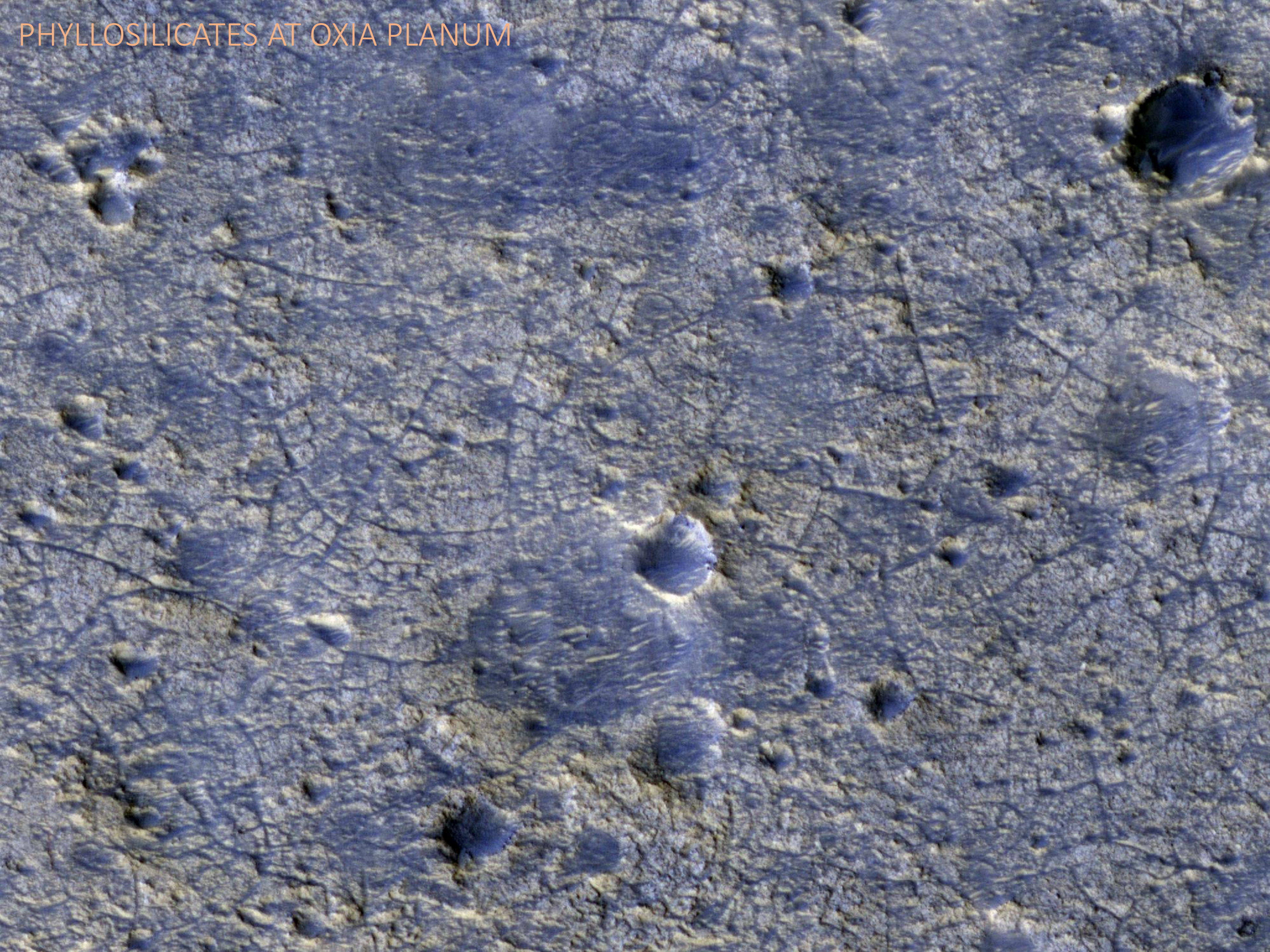


Why Oxia Planum?

- Primary mission targets: widespread phyllosilicate minerals, found within likely sedimentary rocks, but unknown geological origin.
- An insight an ancient Noachian processes?



Credit: Peter Fawdon.

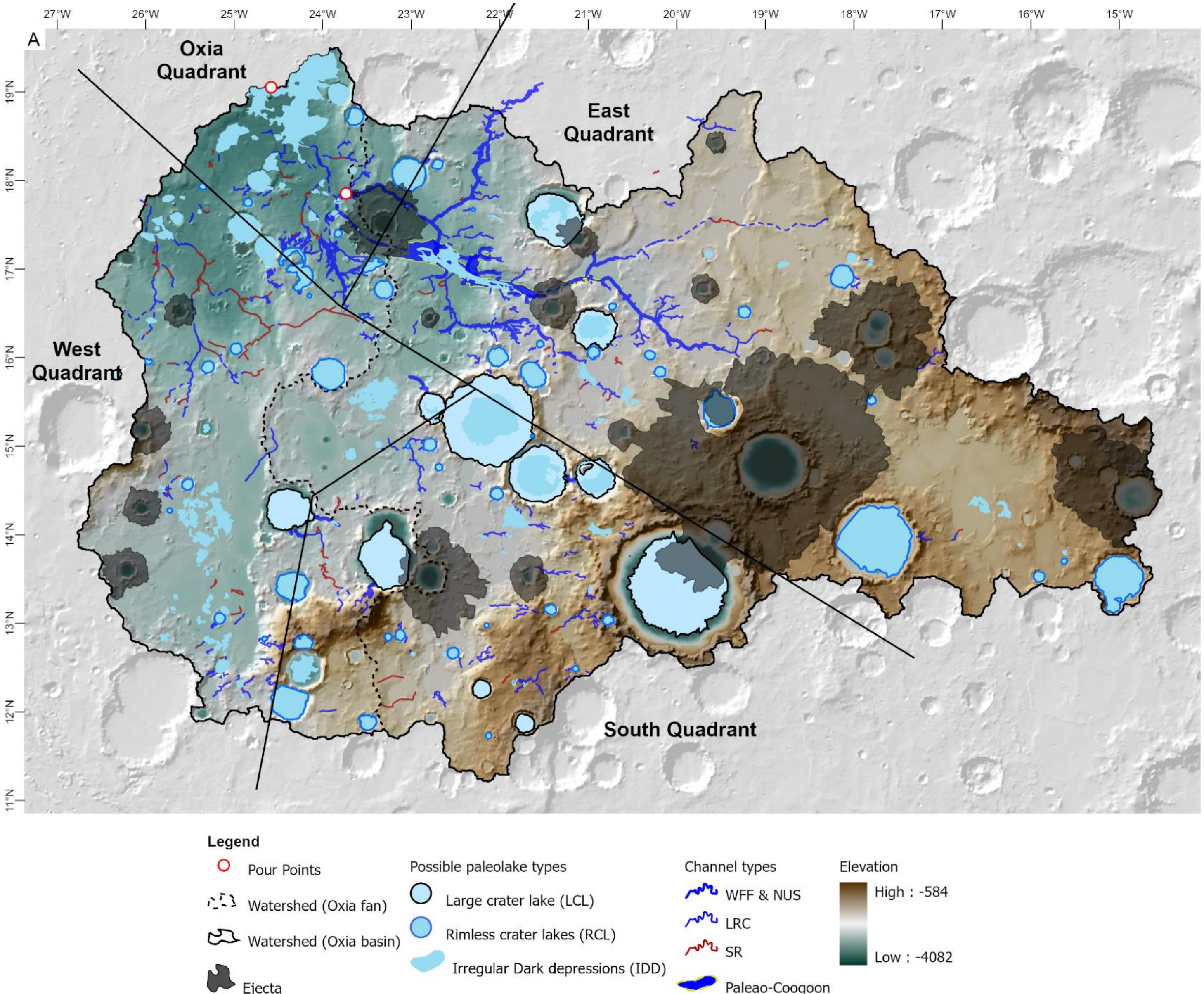

PHYLLOSILICATES AT OXIA PLANUM

Oxia Planum: an extensive fluvial catchment

- An ***extensive fluvial catchment*** (about the area of New Zealand), comprised of valleys and channels, drains into Oxia Planum.

- The catchment is larger than the catchment at Jezero and will ***have transported material into Oxia Planum.***

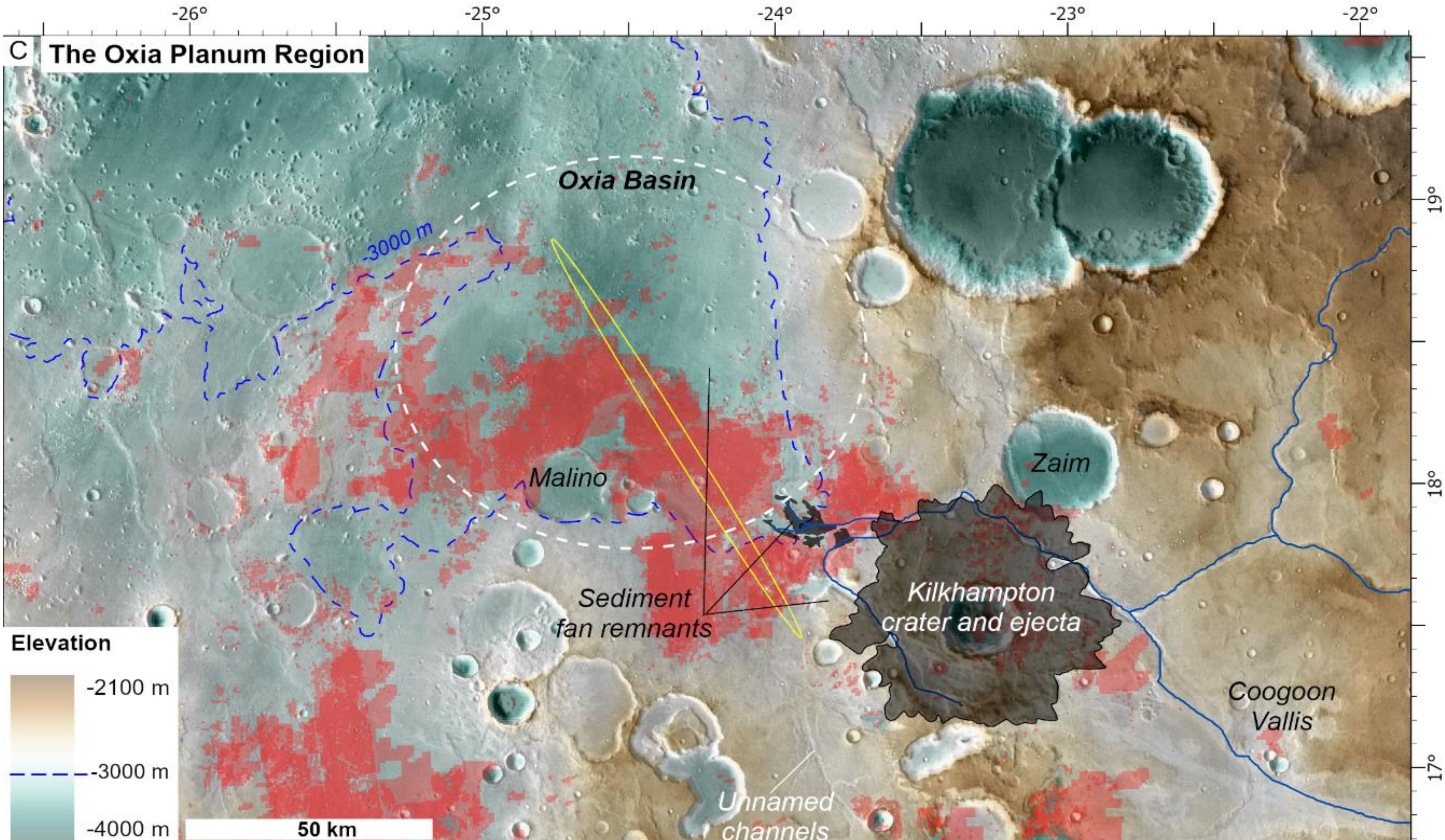
- But what happened to the water once it reached Oxia?



From Fawdon et al. (in review)

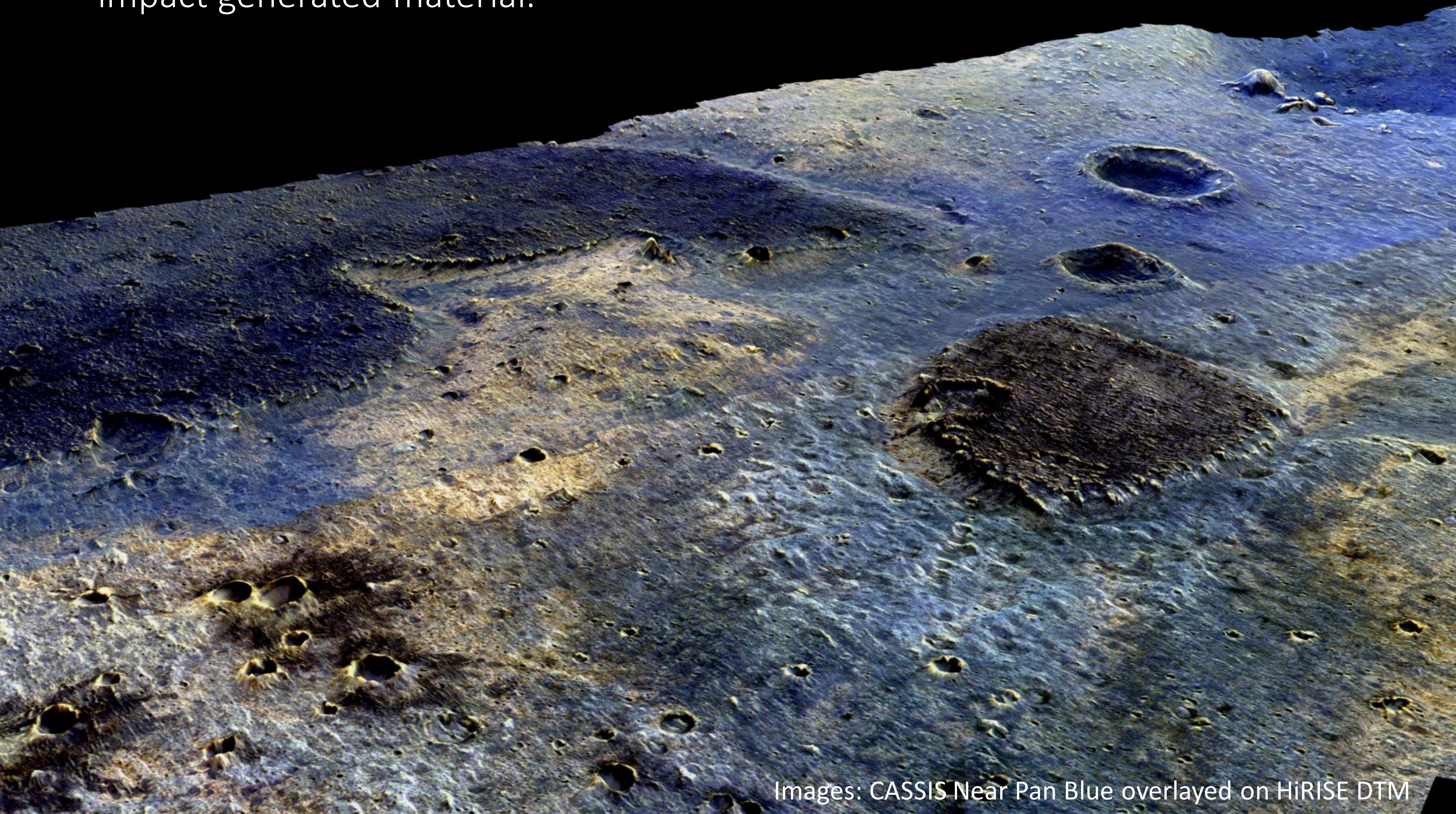
The Oxia Planum basin

- An ancient delta is found at the eastern margin of the Oxia Planum landing site.
- This delta may have formed into an ancient lake, or possible an early ocean!
- Was the lake frozen or not? What was the ancient climate like?

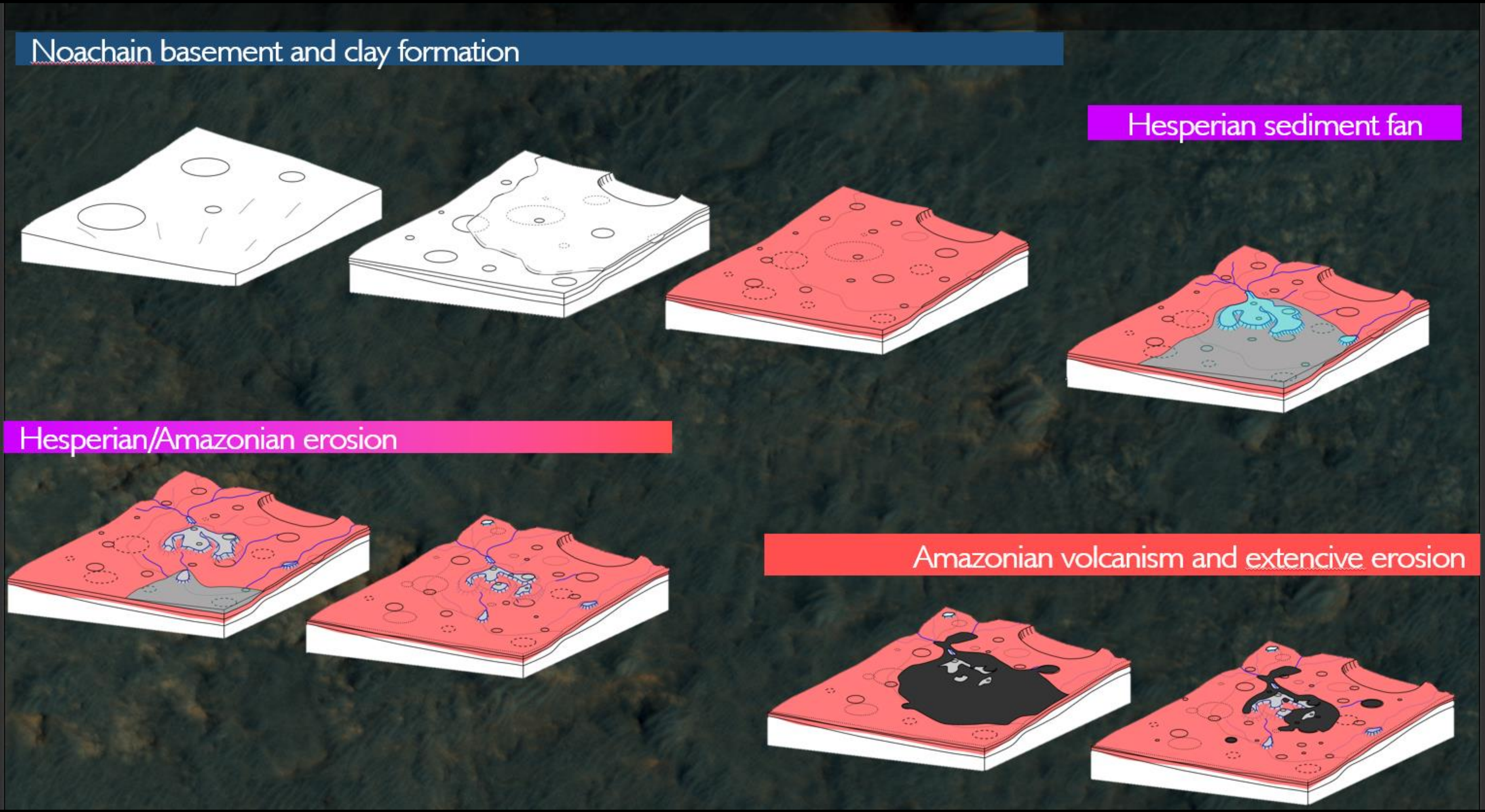


Oxia Planum: late stage volcanism?

- Overlying both the phyllosilicates and fluvially deposited material is spectrally bland dark material.
- Processes that have formed this material include lava, volcaniclastic airfall, or impact generated material.



Evolution of Oxia Planum



From Quantin et al 2021 Astrobiology

Geological questions for ExoMars/Pancam

- How did the phyllosilicates at Oxia Planum form?
- Does the Oxia basin represent a lake, an ocean margin, both, or none?
- What was the ancient Noachian climate like?
- Does the dark material record late stage volcanism?