

A more vast and accessible Martian sedimentary rock record

Ken Edgett – February 2017





Malin
Space
Science
Systems

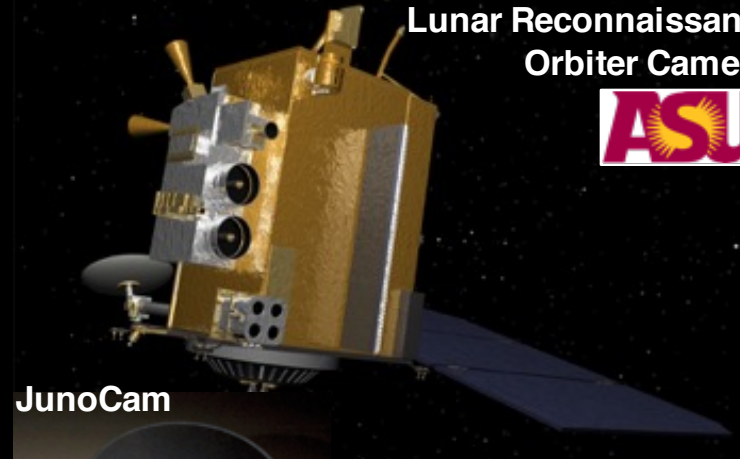
www.msss.com

We Build & Operate Space Cameras in San Diego

Mast Camera, Mars Hand Lens Imager,
Mars Descent Imager

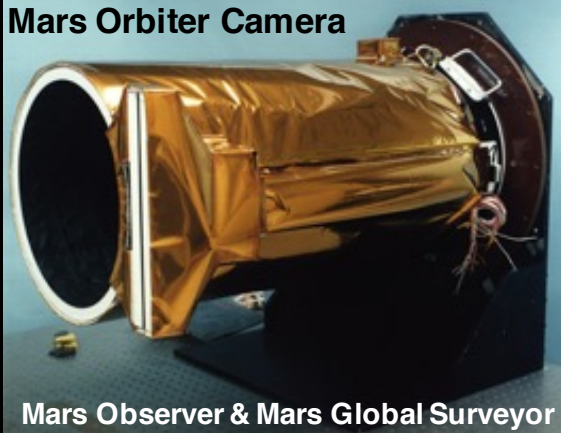


Lunar Reconnaissance
Orbiter Cameras

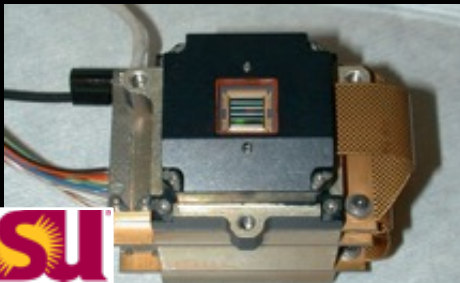


JunoCam

Mars Orbiter Camera



Mars Observer & Mars Global Surveyor



THEMIS VIS Mars Odyssey

Engineering
Cameras



OSIRIS-REx TAGCAMS



Mars Context Imager



Mars Reconnaissance Orbiter

Mars Color Imager



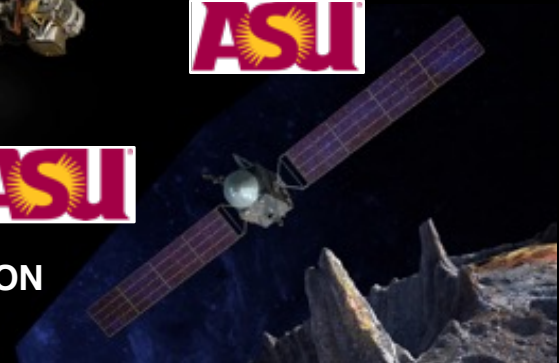
Mars Climate Orbiter &
Mars Reconnaissance Orbiter

Psyche cameras



Mars 2020 rover

- Mastcam-Z
- SHERLOC/WATSON
- descent cameras



sediment – example – windblown sand

8 February 2017

a week ago

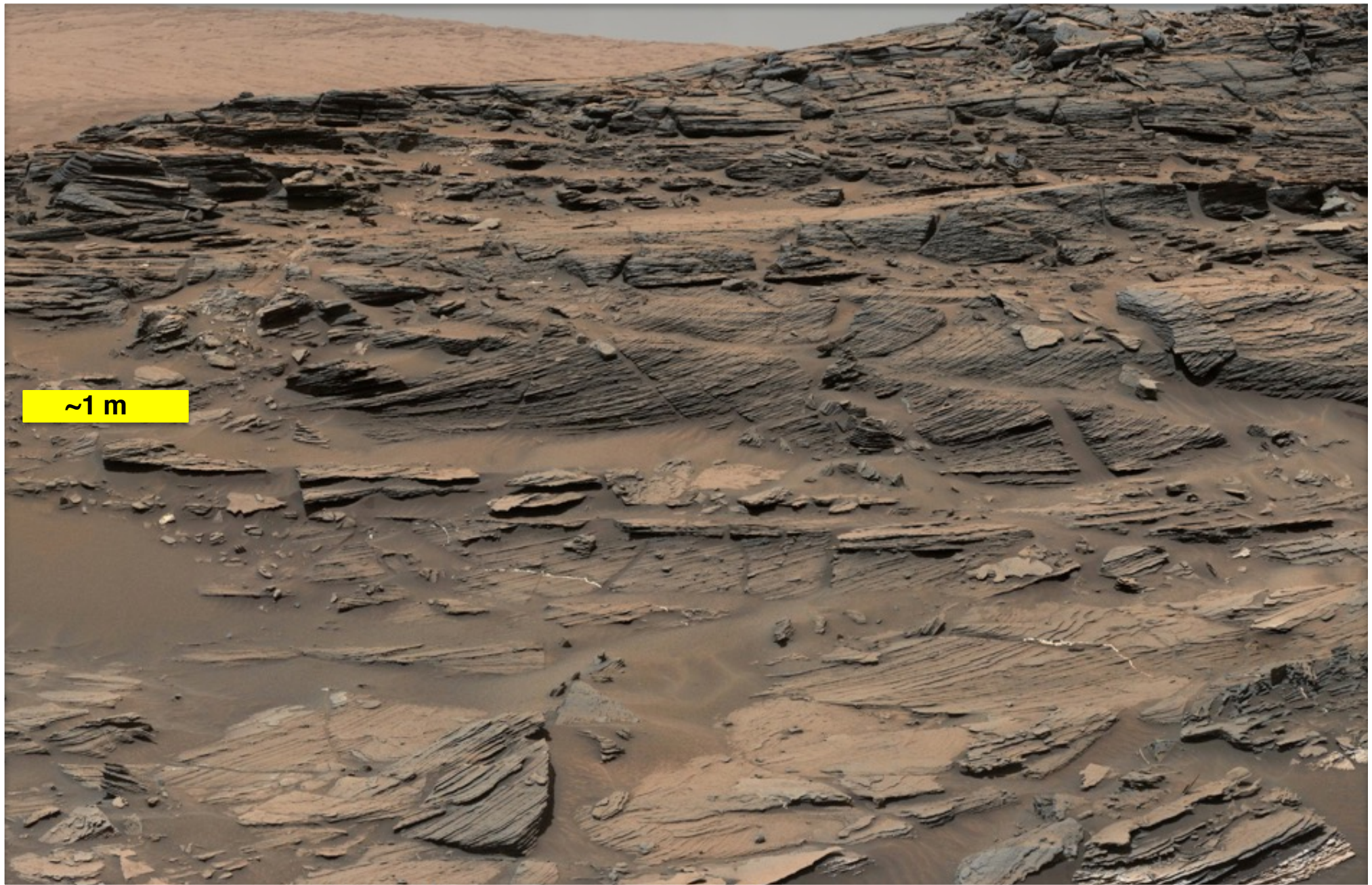


2 mm

sedimentary rock – example – sandstone



sedimentary rock – records of past environment



Mars sedimentary rock record importance

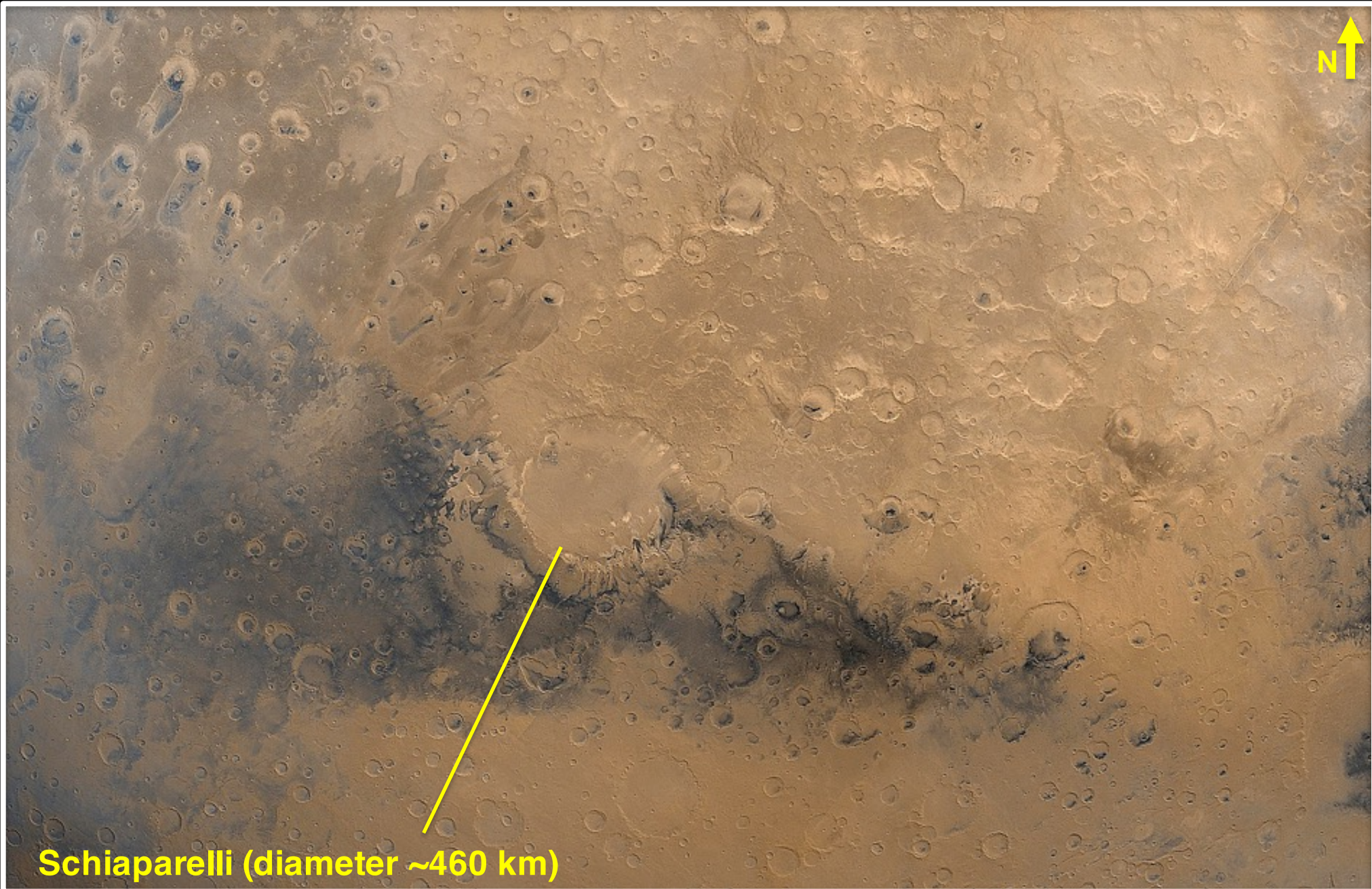
Mars – sedimentary rock record (environment record) older than the oldest preserved on Earth (or Venus).



Physics the same but the “experiment” ran differently.

- **no plate tectonics, more mafic, different fluids, less(?) organics.**

Mars heavily cratered terrain – very ancient



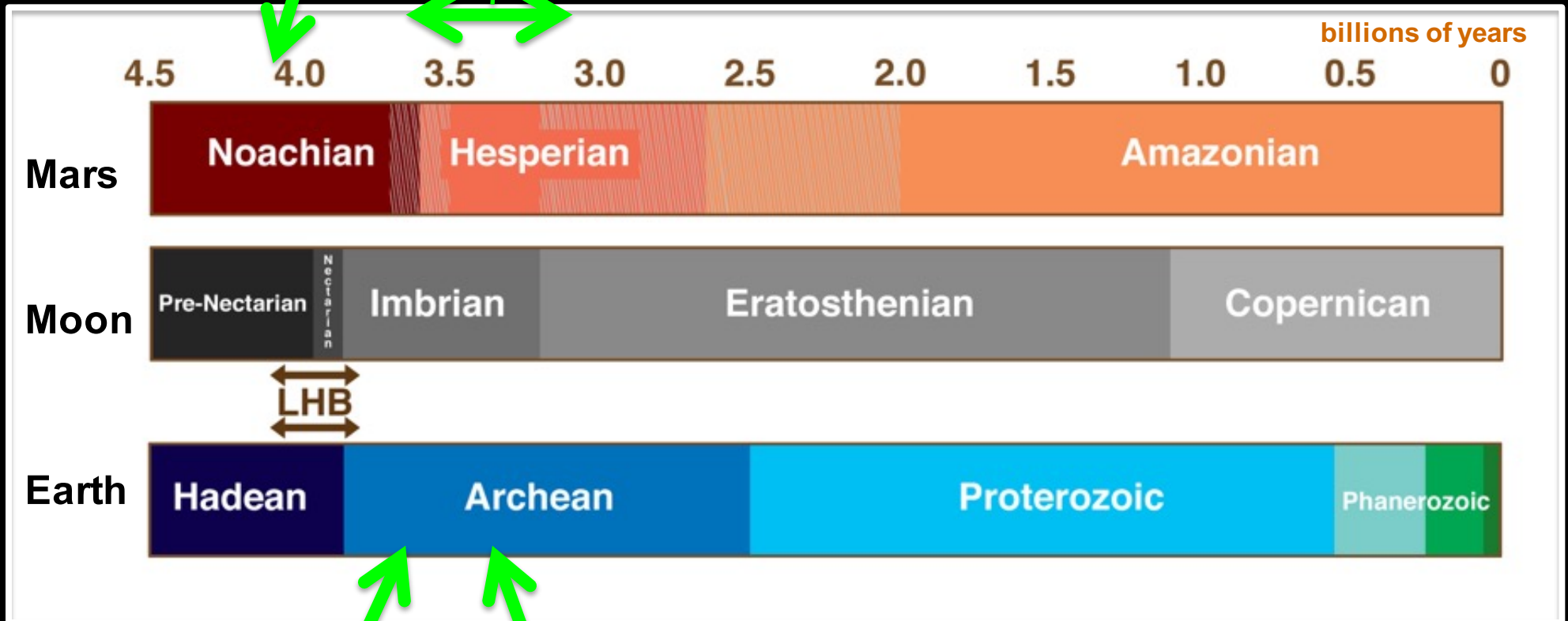
Schiaparelli (diameter ~460 km)

Mars sedimentary rock record importance

MARS

Sedimentary rocks older than Earth's oldest

Sedimentary rocks in Gale (Curiosity)



EARTH

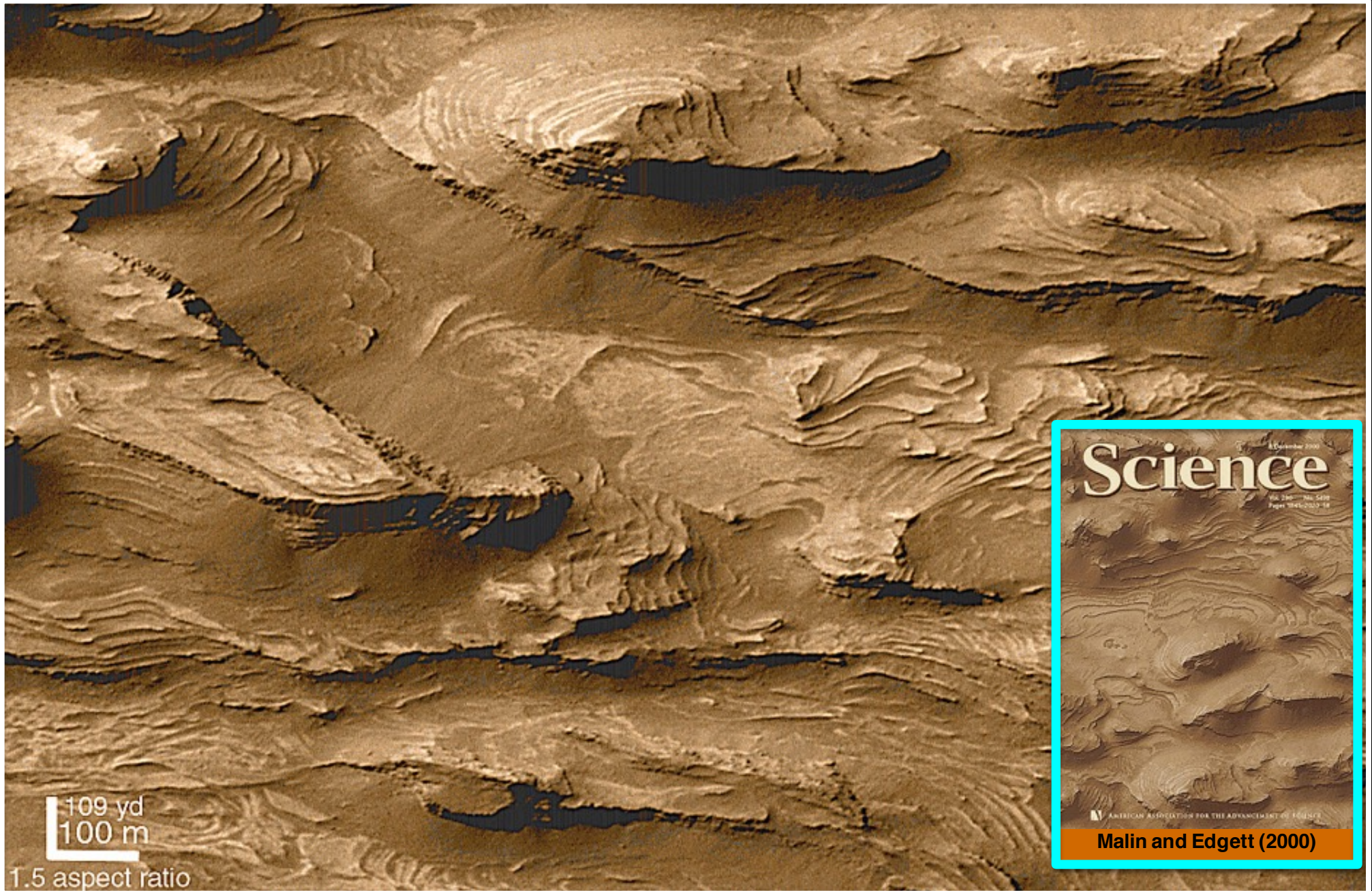
~3.8 Ga

~3.4 Ga

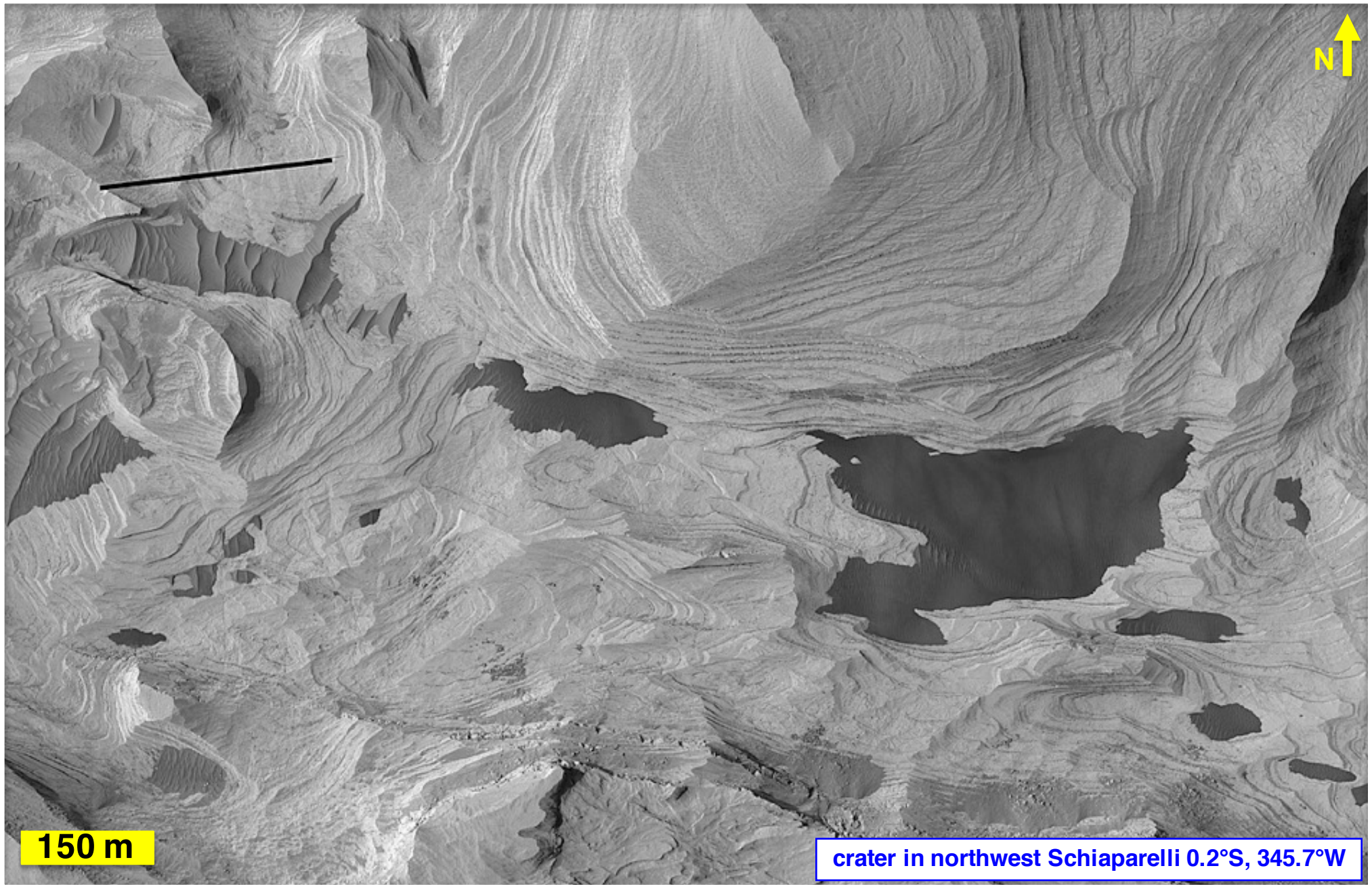
Isua Greenstone Belt, Greenland

**Warawoona Group, Western Australia
Barberton Greenstone Belt, South Africa**

sedimentary rock – published December 2000



typical – light-tone, layered, few impact craters

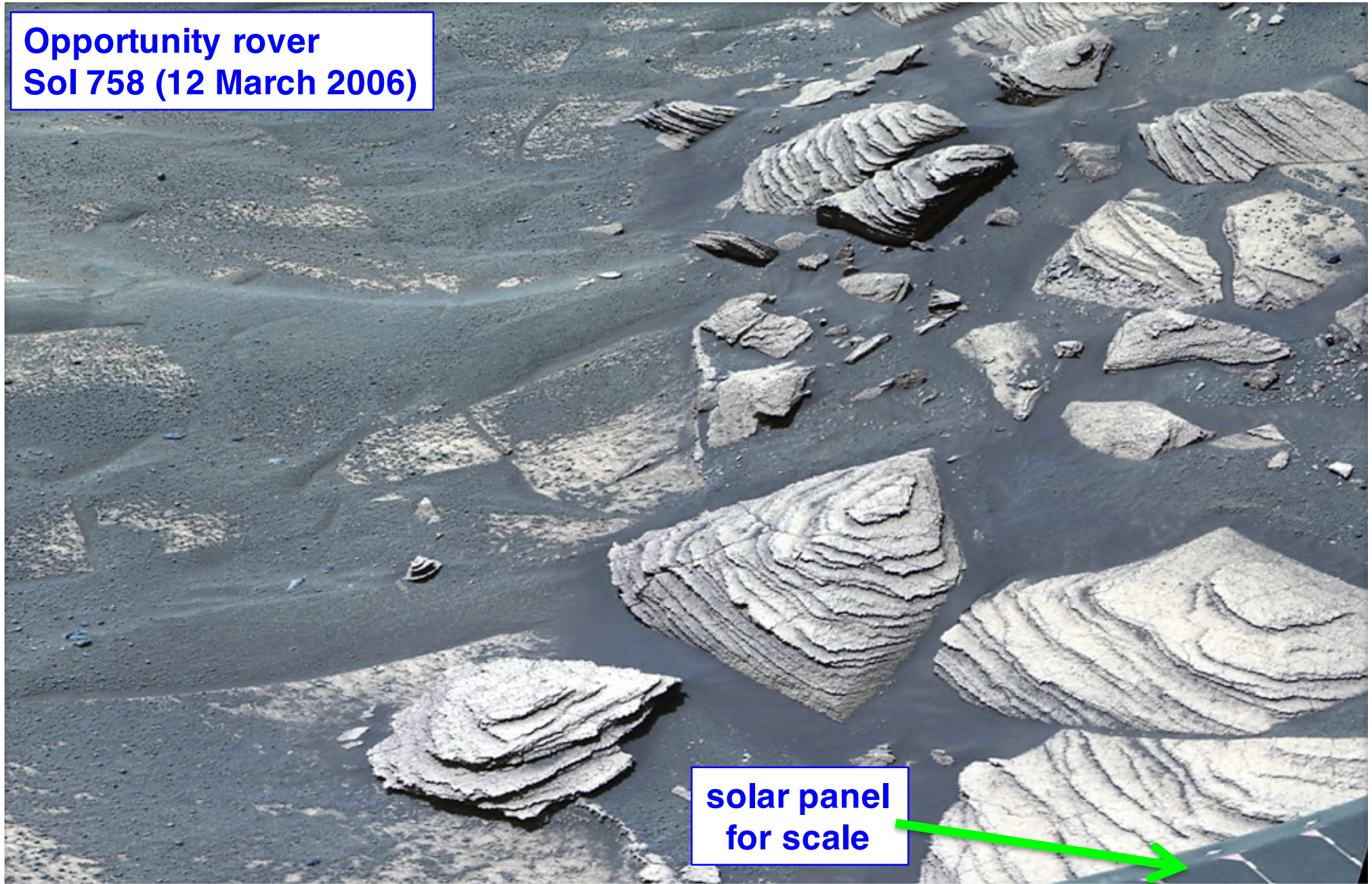


150 m

crater in northwest Schiaparelli 0.2°S, 345.7°W

typical – light-tone, layered, few impact craters

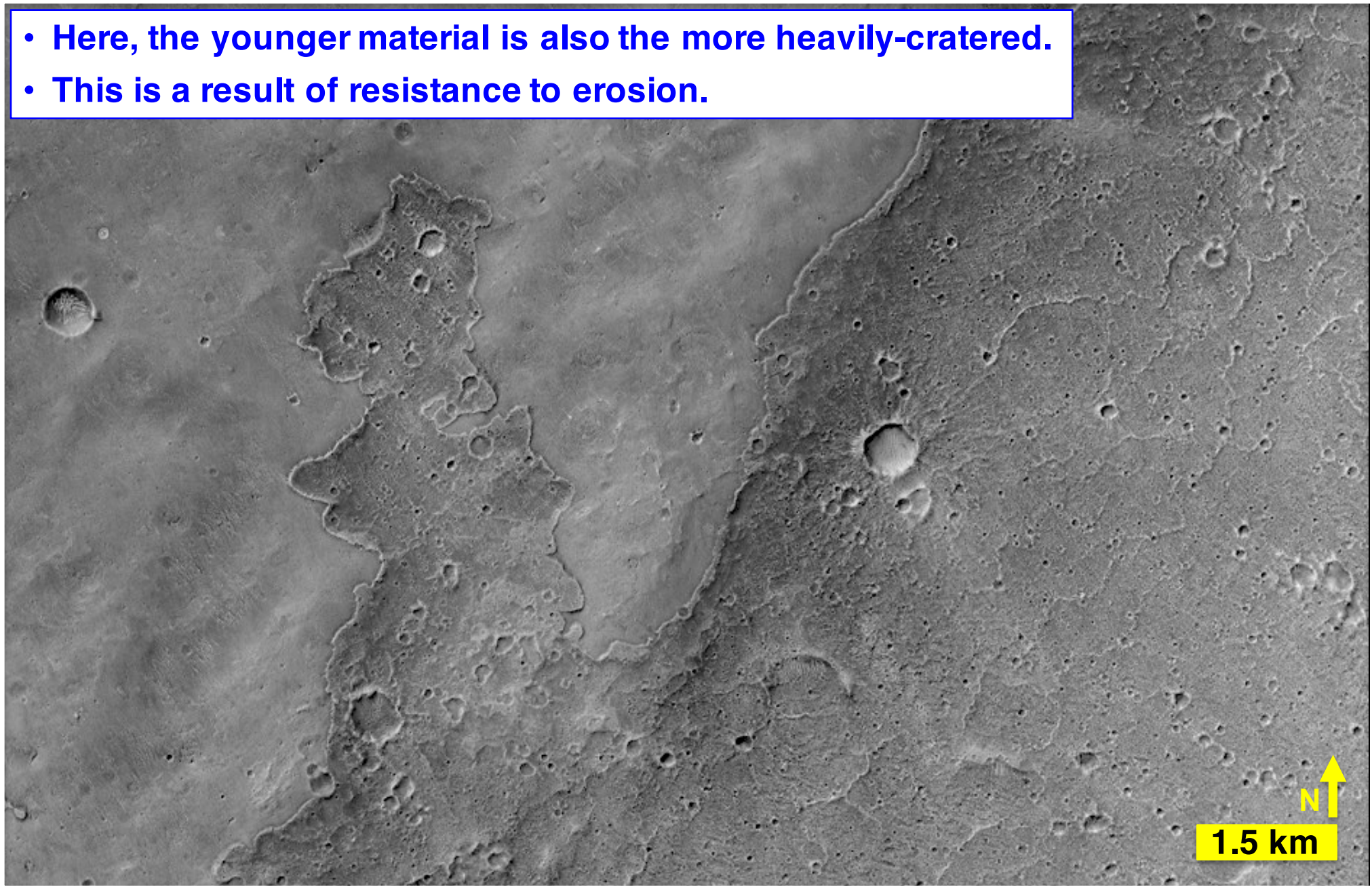
Opportunity rover
Sol 758 (12 March 2006)



solar panel
for scale

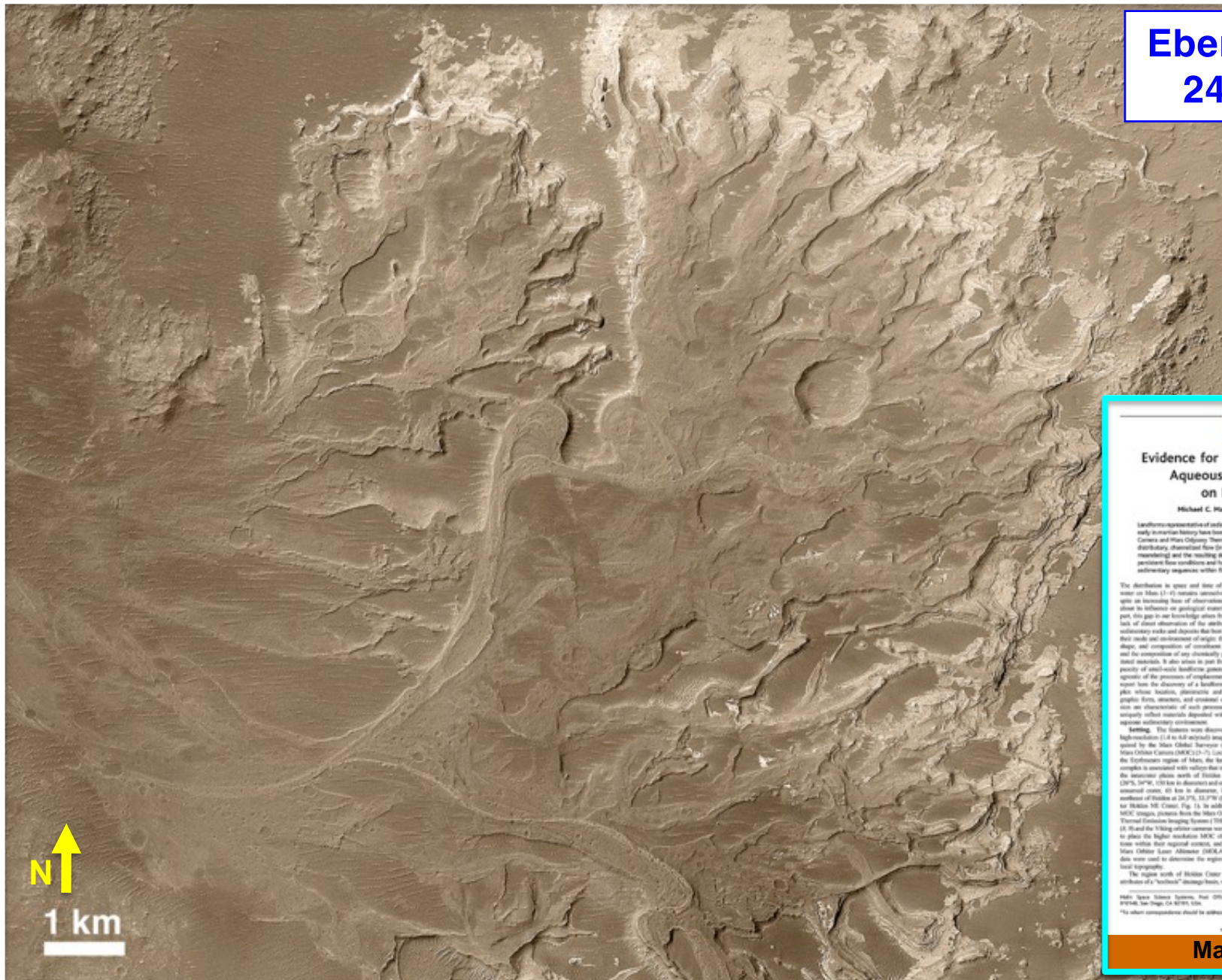
typical – lavas are more resistant to erosion

- Here, the younger material is also the more heavily-cratered.
- This is a result of resistance to erosion.



fluvial transport and deposition of sediment

Eberswalde Crater
24.1°S, 33.7°W



RESEARCH ARTICLES

Evidence for Persistent Flow and Aqueous Sedimentation on Early Mars

Michael C. Malin* and Kenneth S. Edgett

Landscape representative of sedimentary processes and environments that occurred early in Martian history have been recognized in Mars Global Surveyor Mars Orbiter Camera and Mars Odyssey Thermal Emission Imaging System images. Evidence of distributary, channelized flow (in particular, flow that lasted long enough to later meander) and the resulting deposition of a fan-shaped apron of silt indicate persistent flow conditions and formation of at least some large interrelated layered sedimentary sequences within floras, and potentially lacustrine environments.

The distribution in space and time of liquid water on Mars (1–4) remains controversial, despite an increasing flow of observational data about its influence on geological materials. In part, this gap in our knowledge arises from the lack of direct observation of the distribution of sedimentary rocks and deposits that best record their mode and environment of origin: the size, shape, and composition of sedimentary channels, and the composition of any chemically precipitated materials. It also arises in part from the paucity of small-scale landforms generally diagnostic of the processes of emplacement. We report here the discovery of a landform complex whose location, planimetric and topographic form, structure, and erosional expression are characteristic of such processes and uniquely reflect materials deposited within an aqueous sedimentary environment.

Setting. The features were discovered in high-resolution (1.4 to 4.0 m/pixel) images acquired by the Mars Orbiter Camera (MOC) Mars Orbiter Camera (MOC) (13–17). Located in the northern region of Mars, the landform complex is associated with ridges that record the distributary apron north of Eberswalde Crater (24.1°S, 33.7°W). Our data in this report and other environmental context, 60 km in diameter, located southwest of Eberswalde at 24.2°S, 33.7°W (hereafter Eberswalde SE Crater; Fig. 1). In addition to MOC images, pictures from the Mars Odyssey Thermal Emission Imaging System (THEMIS) (18) and the Viking orbiter cameras were used to place the higher resolution MOC observations within their regional context, and Mars Orbiter Laser Altimeter (MOLA) (19) data were used to determine the regional and local topography.

The region north of Eberswalde Crater shows evidence of a "bedrock" drainage basin, with 10

Distributary fan. At the distal end of the drainage system, within the eastern portion of Eberswalde SE Crater, is a complex of layered sedimentary rock and a fan-like landform (13) consisting of a wide of numerous ridges (Fig. 2). The fan-shaped landform, which is 11 km by 65 km and covers 110 km², consists of at least three lobes, defined planimetrically by cross-cutting ridges raised above surrounding silt-like apron, together standing above the surrounding sedimentary plain. The ridge complex has a low longitudinal gradient (2.03, 0.27 (12.5) of the maximum section, and a relatively steep distal front. Three variations within these lobes are especially noteworthy: (i) the sinuous, meandering nature of the ridge forms, in particular the appearance of ridges resembling meandering and oxbow meanders (Fig. 2A); (ii) the expression of three-dimensional anastomosing relations, as seen in the cross-cutting of ridges and their interdigitation position with respect to light-colored, flat-lying apron (Fig. 2B); and (iii) a horizontal view of planimetric topographic relations with sinuous, gently sinuous, distal ridge forms (see Fig. 2) the meandering and largest, most broadly sinuous proximal ridge forms higher in the sequence.

We assigned the landform in Eberswalde Crater to be the eroded and/or eroded remnant of a fluvial distributary fan. The sinuous ridge forms are interpreted to result from initial incision of channels (15), and the

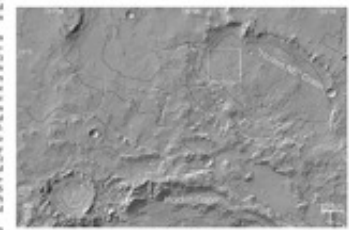


Fig. 1. Regional context of Eberswalde SE Crater. Distribution region. This image is a mosaic of THEMIS B images, GDTM002, GDTM003, GDTM004, GDTM005, GDTM006, GDTM007, GDTM008, GDTM009, GDTM010, and GDTM011, in simple cylindrical projection of 48 m/pixel, topography derived from MOLA data and relative to the martian datum, is shown in 20-m contours, with alternate contours (200 m) derived with thicker lines. The white line indicates the location of Fig. 2.

www.sciencemag.org SCIENCE VOL 302 12 DECEMBER 2003 1891

Malin and Edgett (2003)

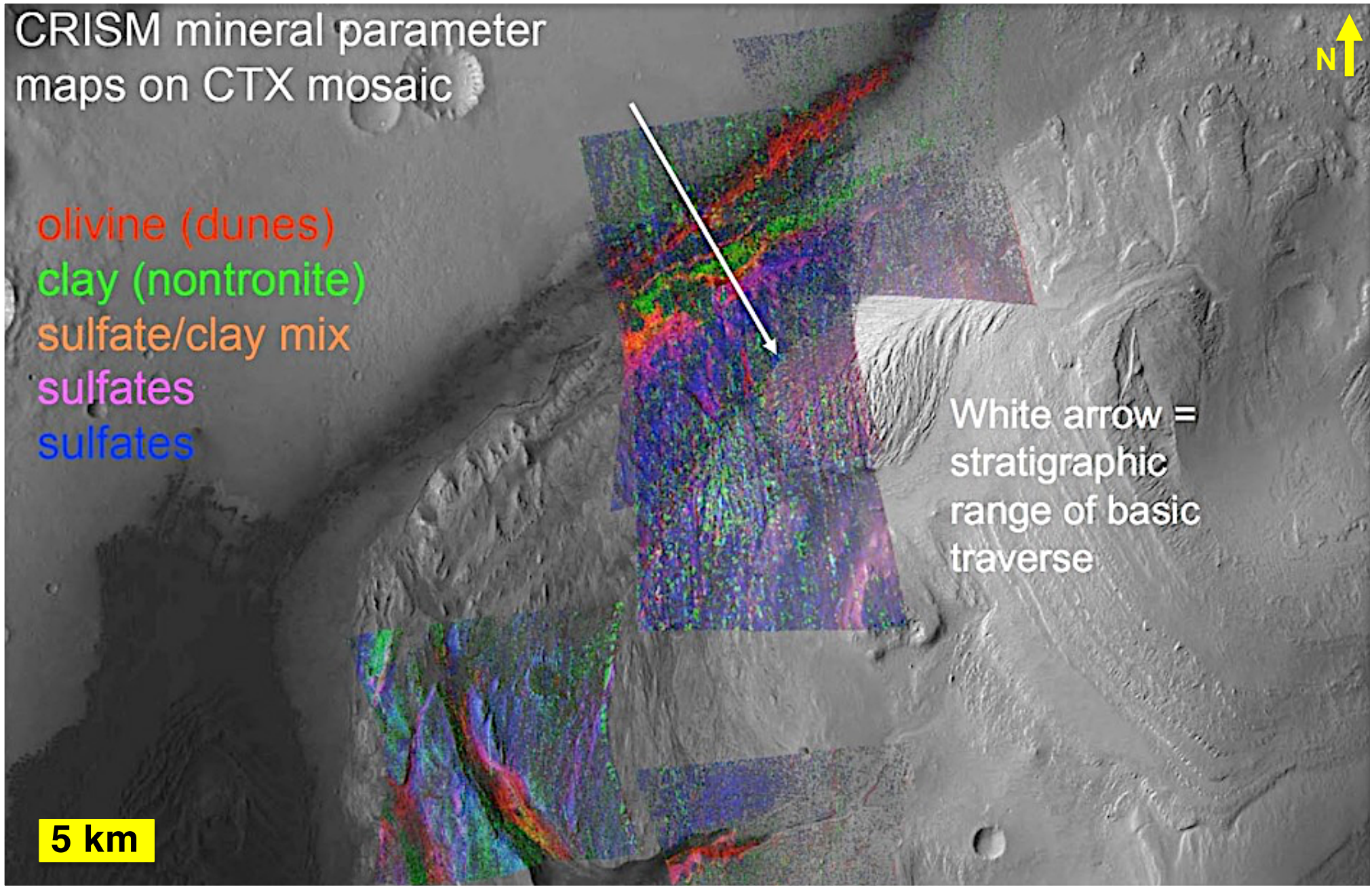
where not obscured by dust – some mineral info

CRISM mineral parameter maps on CTX mosaic

olivine (dunes)
clay (nontronite)
sulfate/clay mix
sulfates
sulfates

White arrow =
stratigraphic
range of basic
traverse

5 km



but... there was this weird problem...

igneous extrusive rock



sedimentary rock



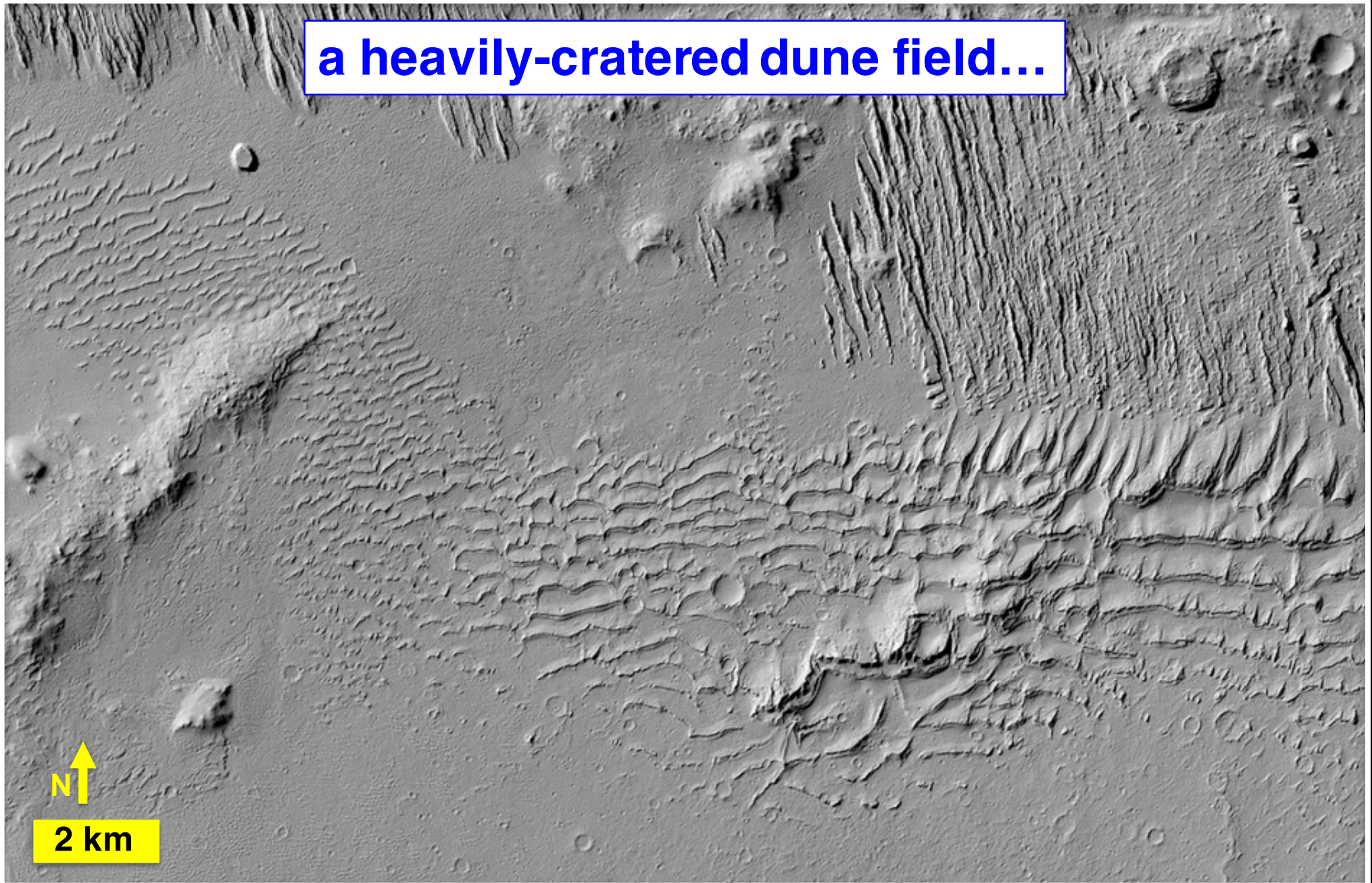
shield volcano in Arsia Mons caldera – 9.8°S, 120.9°W

800 m

west Candor Chasma – 6.3°S, 75.6°W

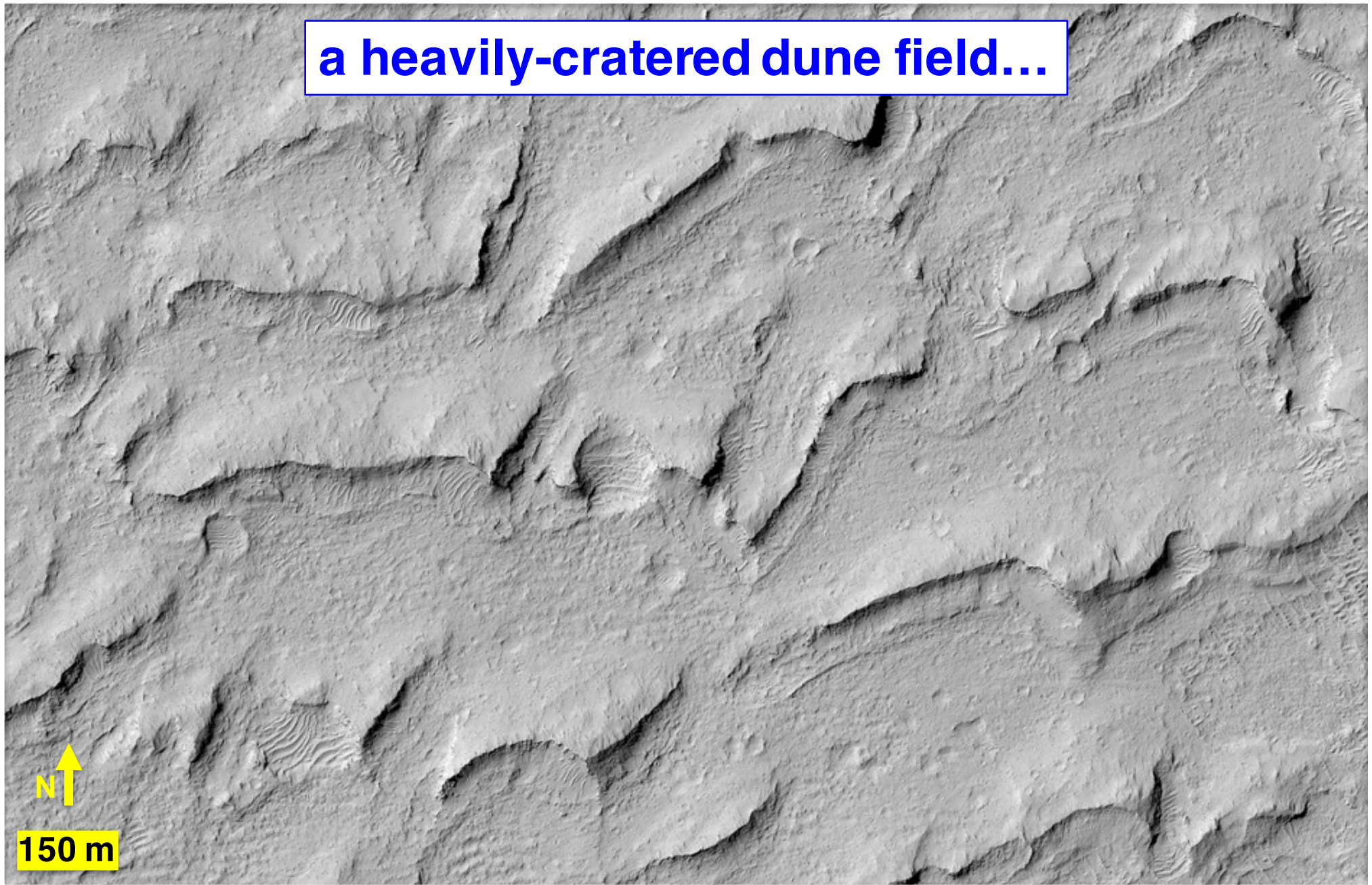
but... there was this weird problem...

a heavily-cratered dune field...



but... there was this weird problem...

a heavily-cratered dune field...



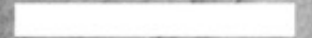
sedimentary rock that resists erosion like lava?

a heavily-cratered dune field...

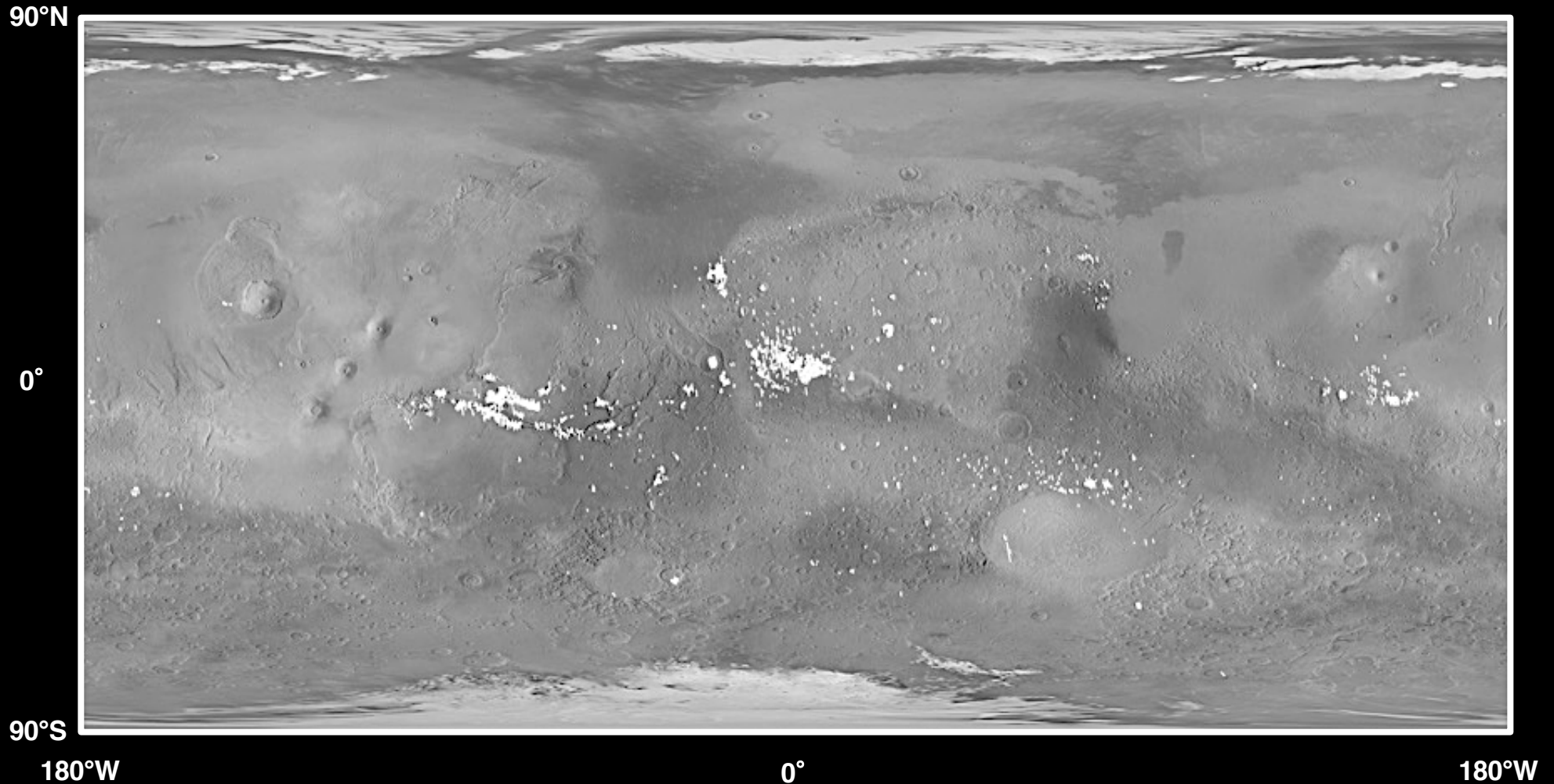


cliff-forming & boulder-producing... it is rock

400 m



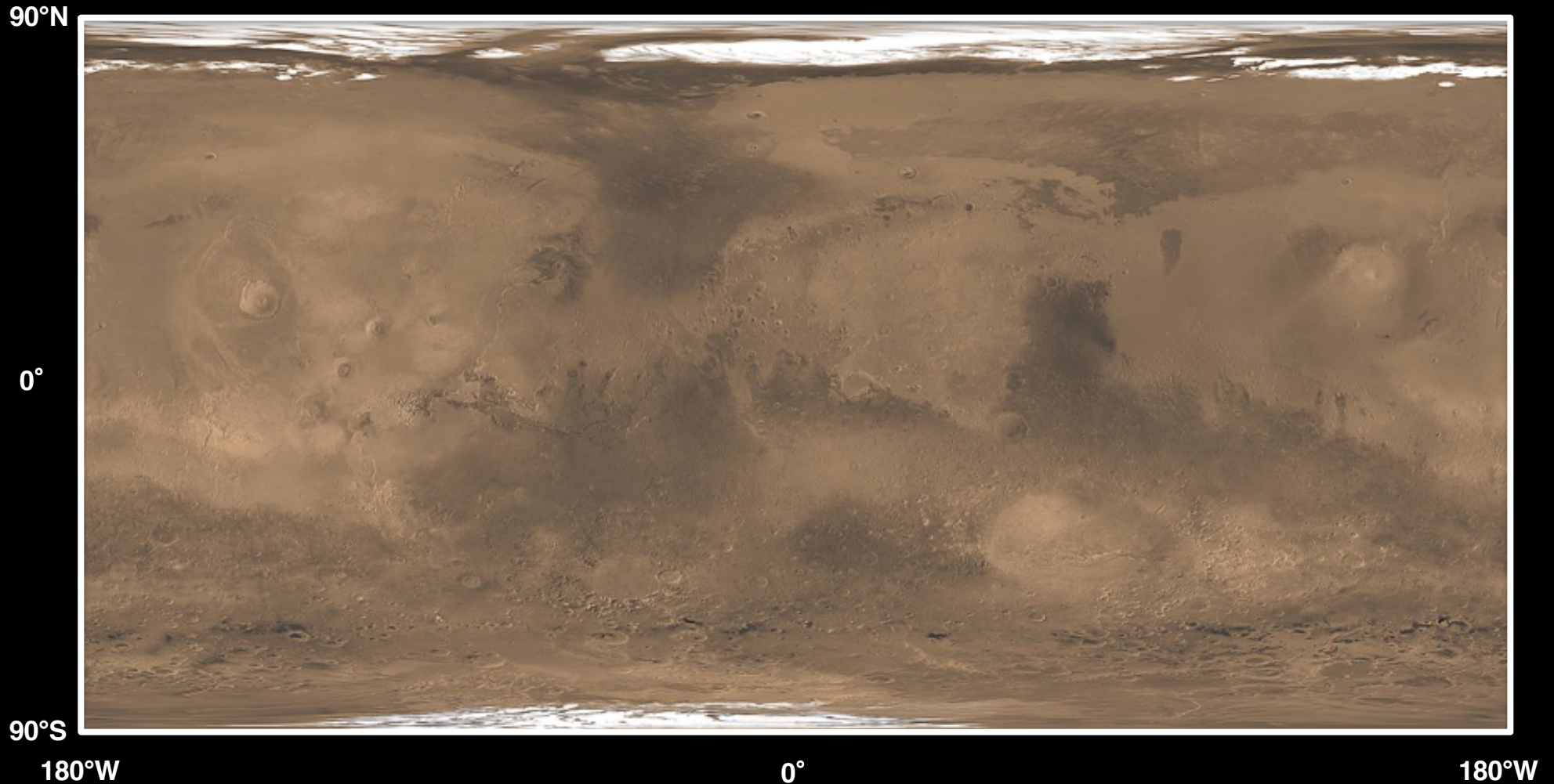
sed. rock occurrences – what we used to think



Identified from MGS MOC Images

Malin, Edgett, *et al.* (2010) doi:10.1555/mars.2010.0001

sedimentary rock occurrences – NOW



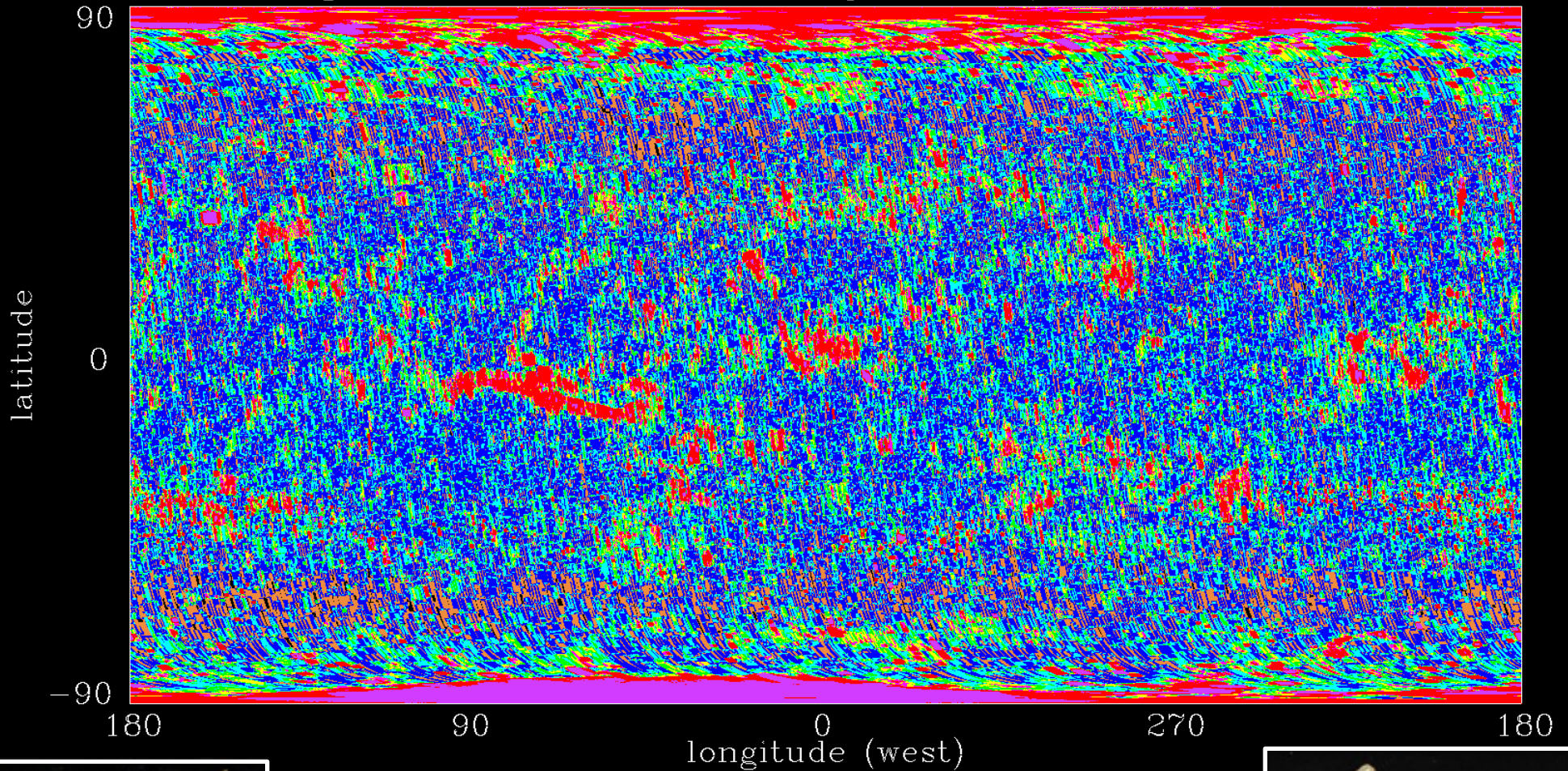
Can't.... Map....

One could spend the rest of one's career putting dots on the map!

Mars >99% mapped, 6 m per pixel and higher

MRO CTX Coverage through January 2017

CTX coverage T01-J11 (total 99.1%, repeat 60.2%)



MGS

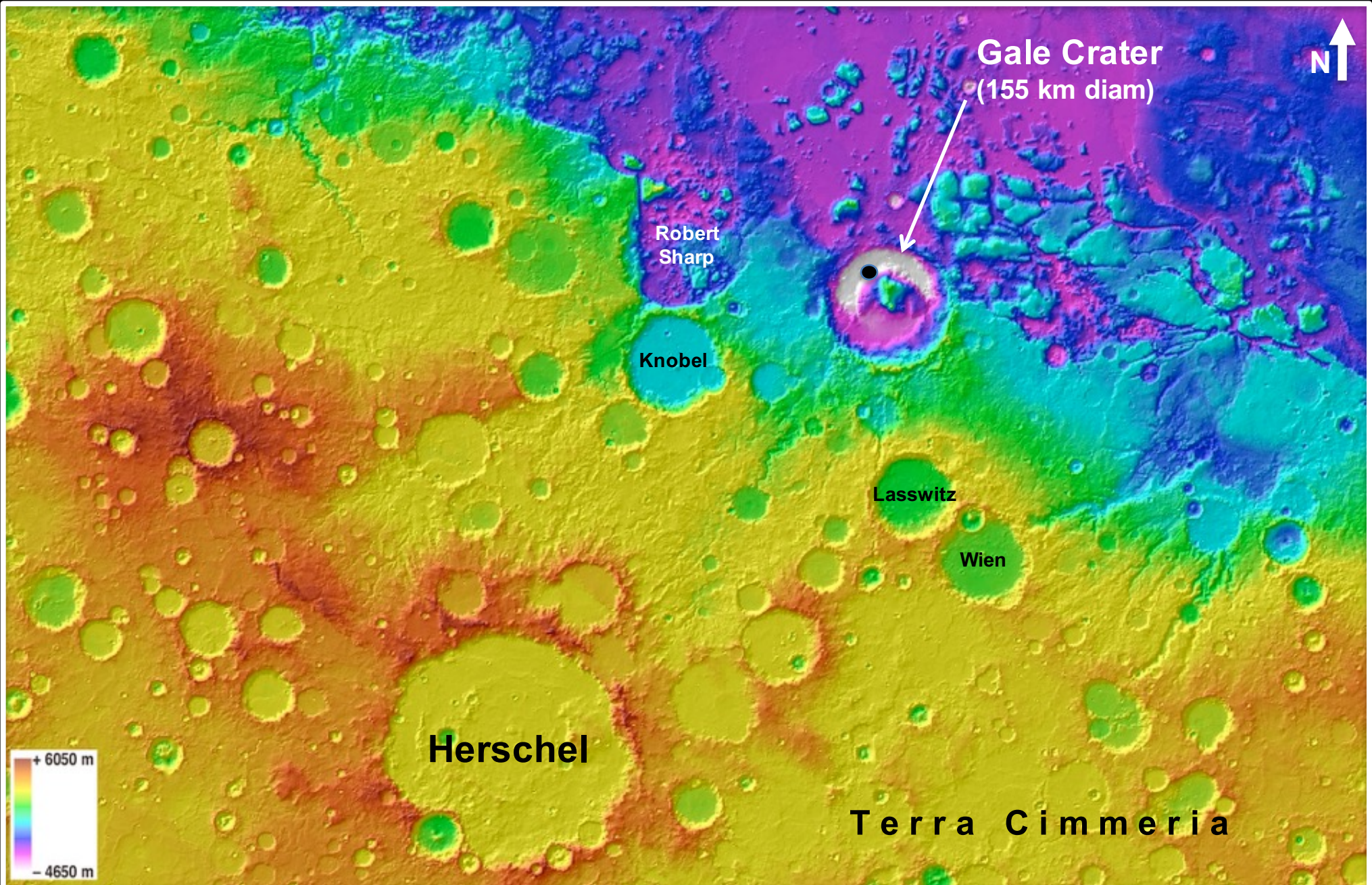


MGS MOC + MRO HiRISE + MRO CTX

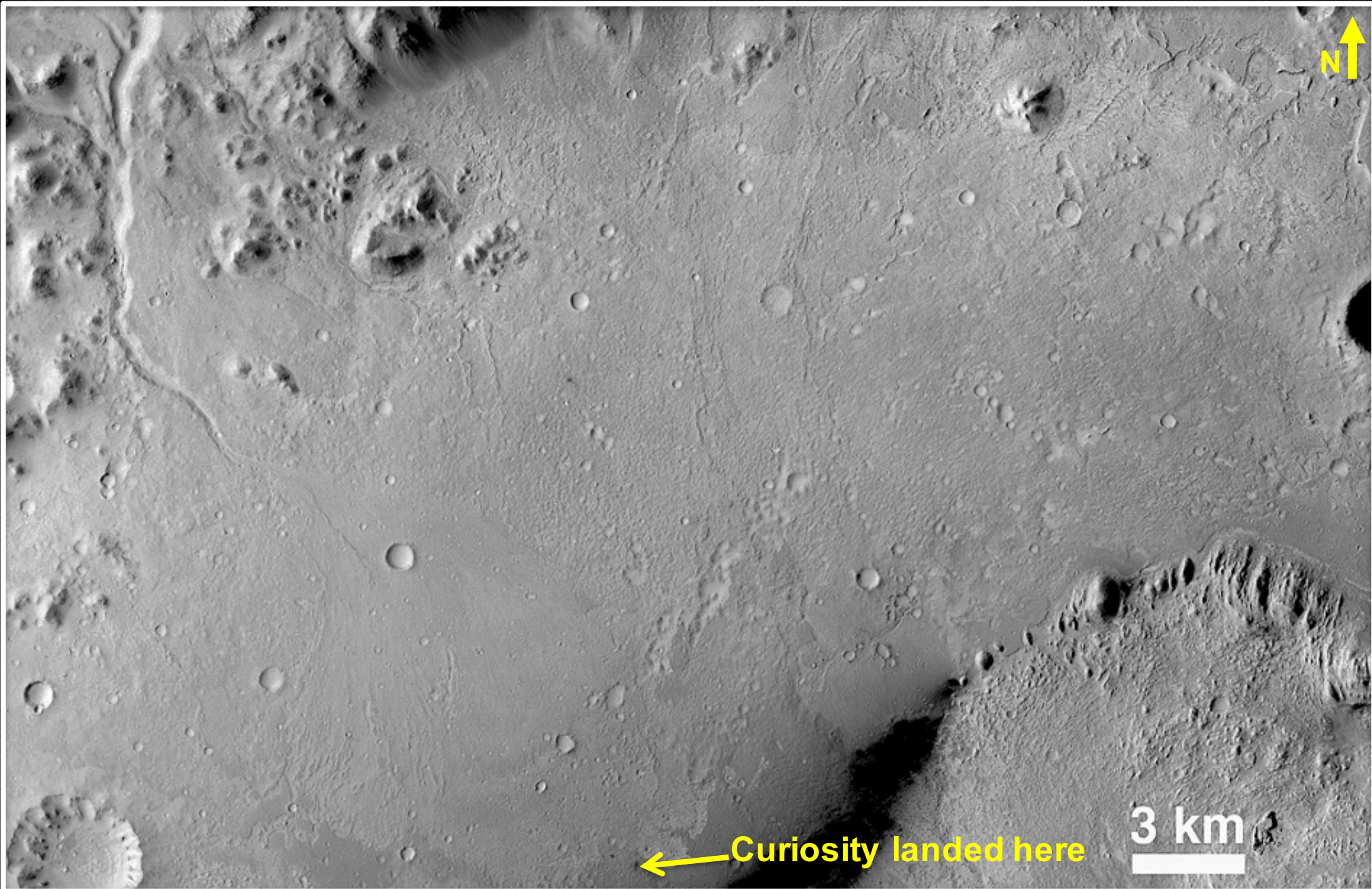


MRO

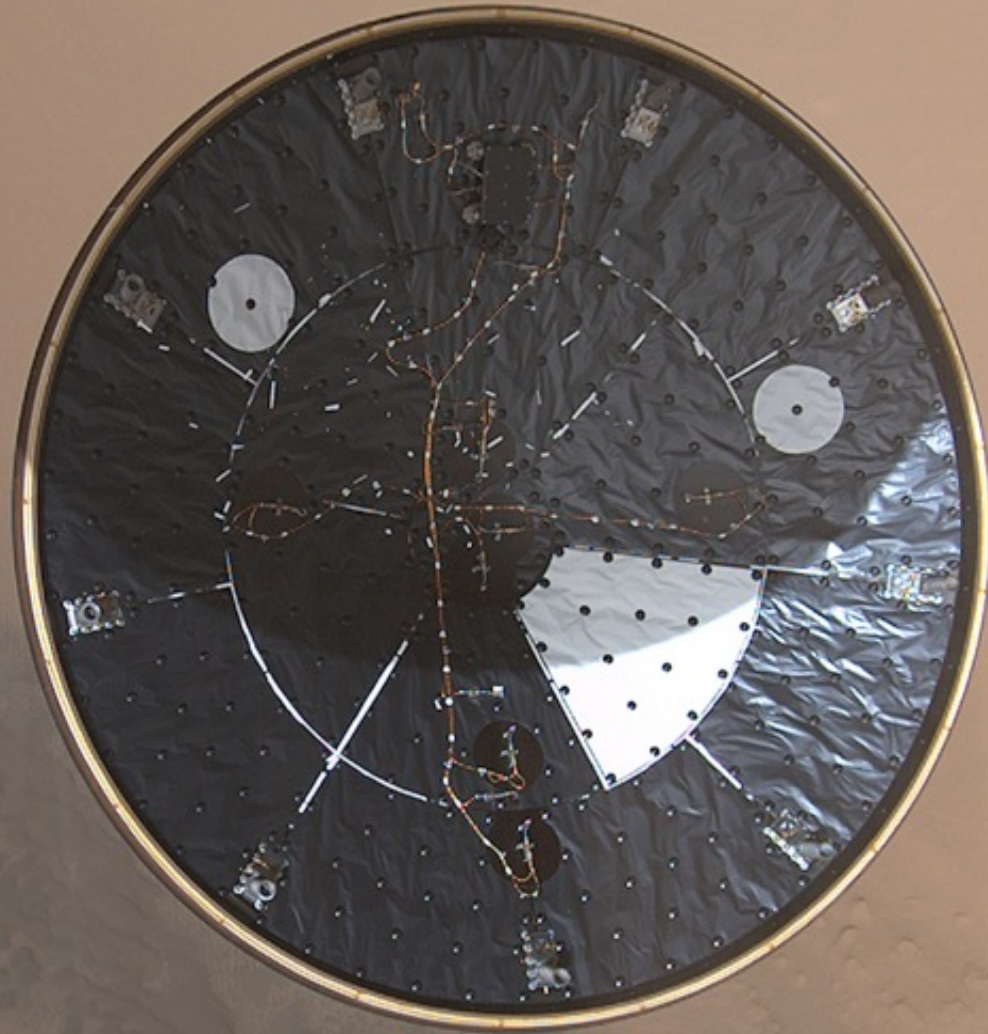
+ Curiosity rover in Gale crater



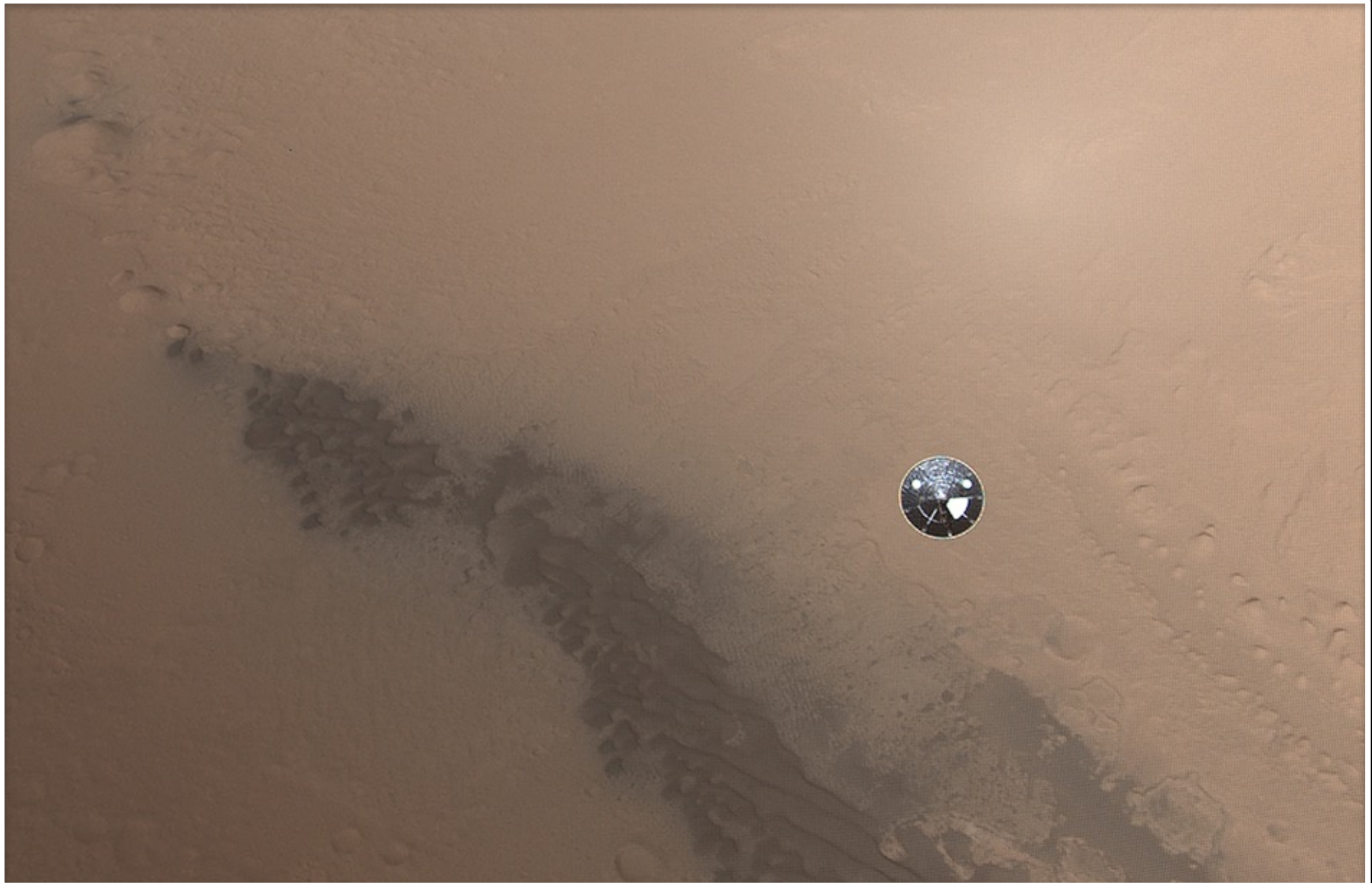
+ Curiosity rover in Gale crater



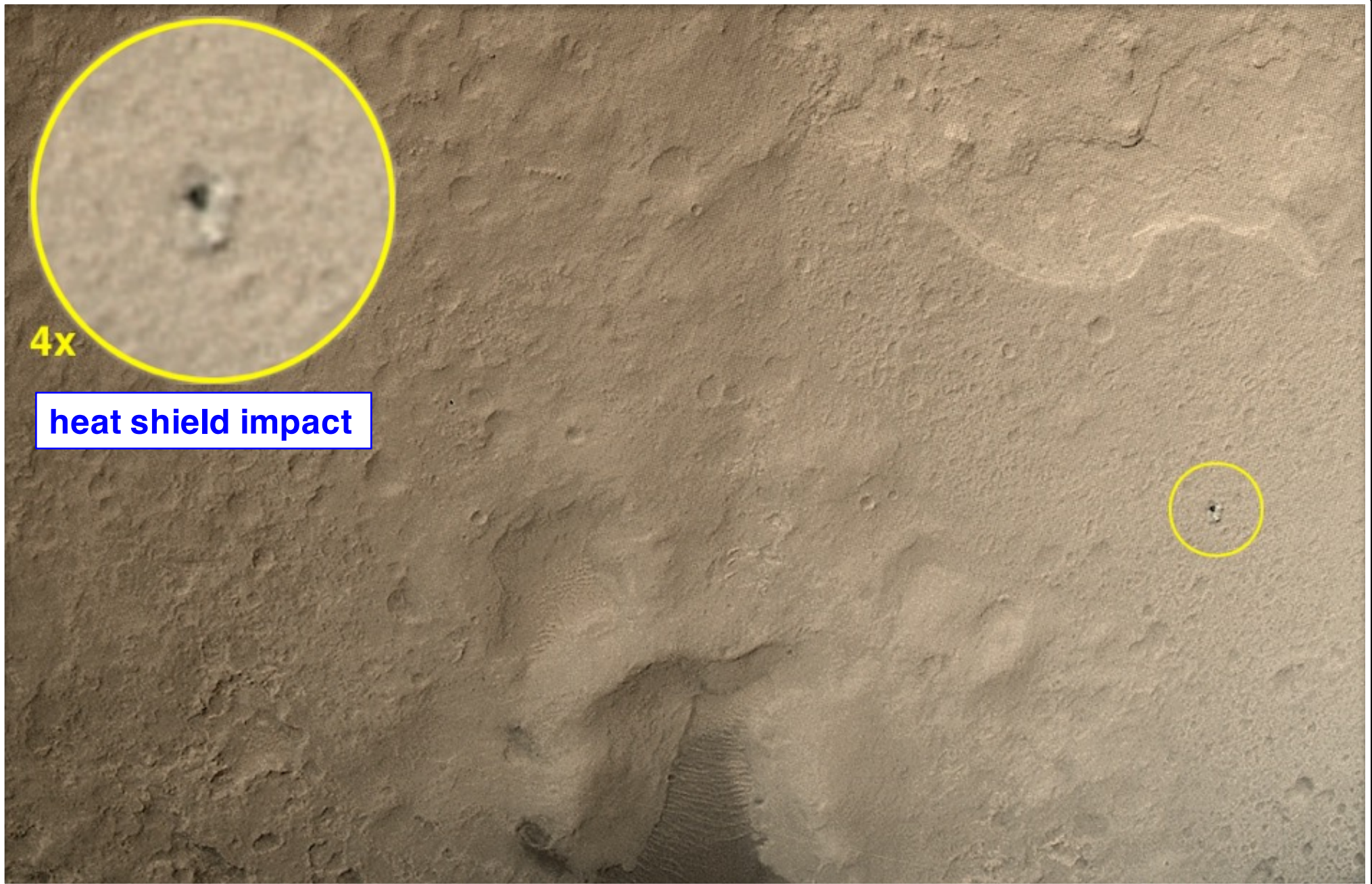
+ Curiosity rover in Gale crater



+ Curiosity rover in Gale crater



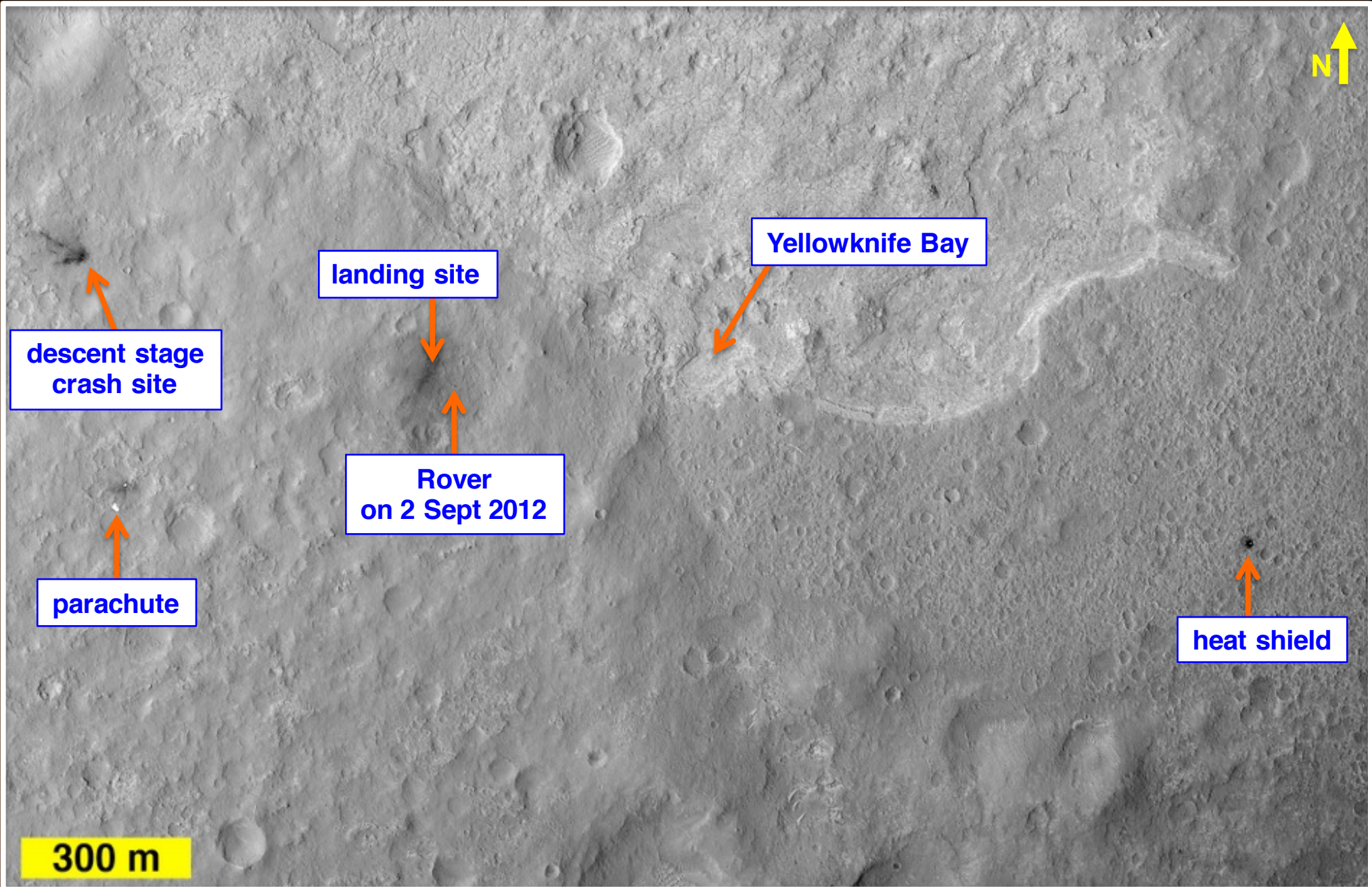
heat shield impact site on cratered surface



4x

heat shield impact

heat shield impact site on cratered surface



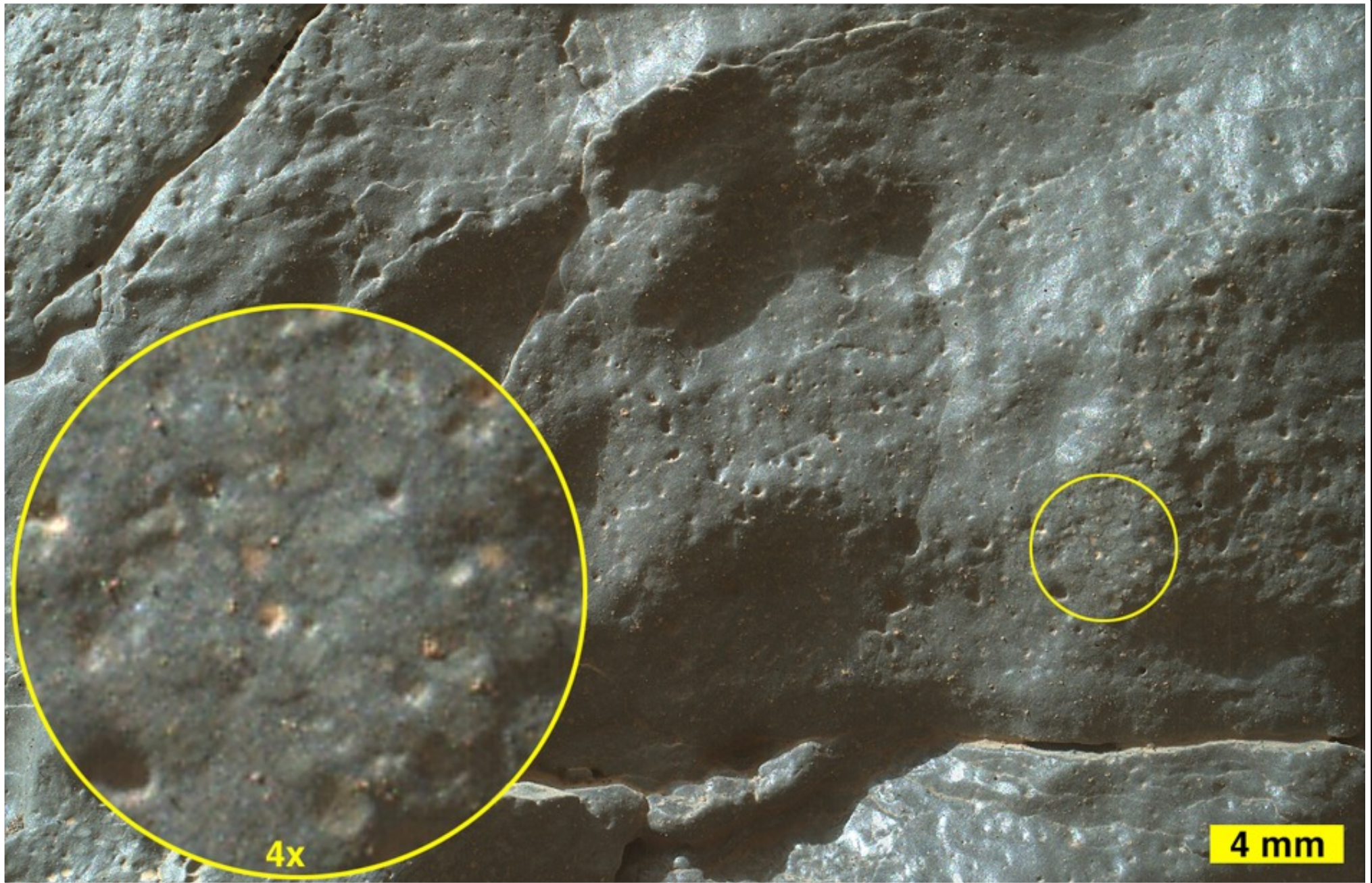
that cratered surface – the rock is sandstone!



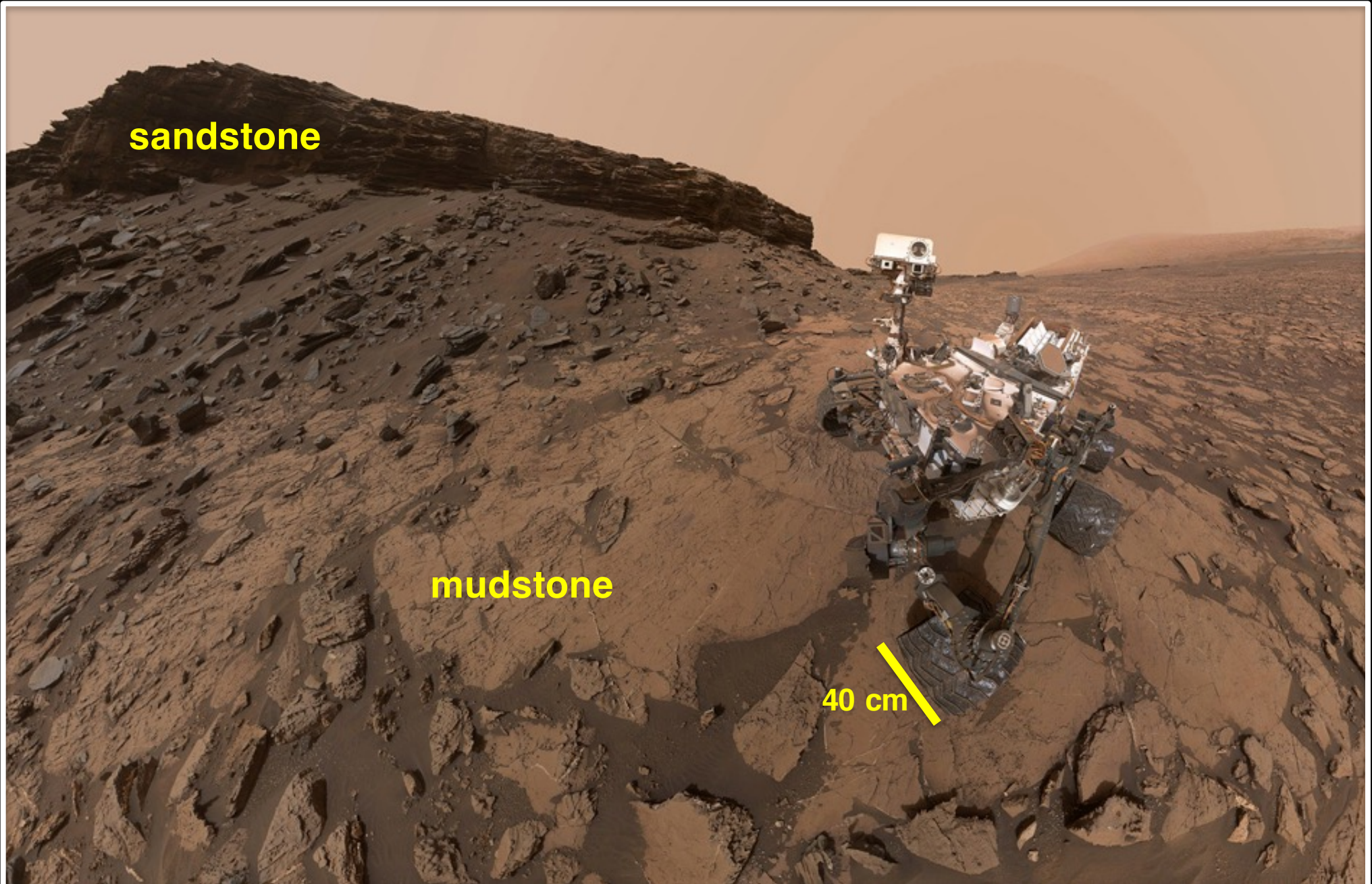
Sol 309 – 19 June 2013

~20 cm

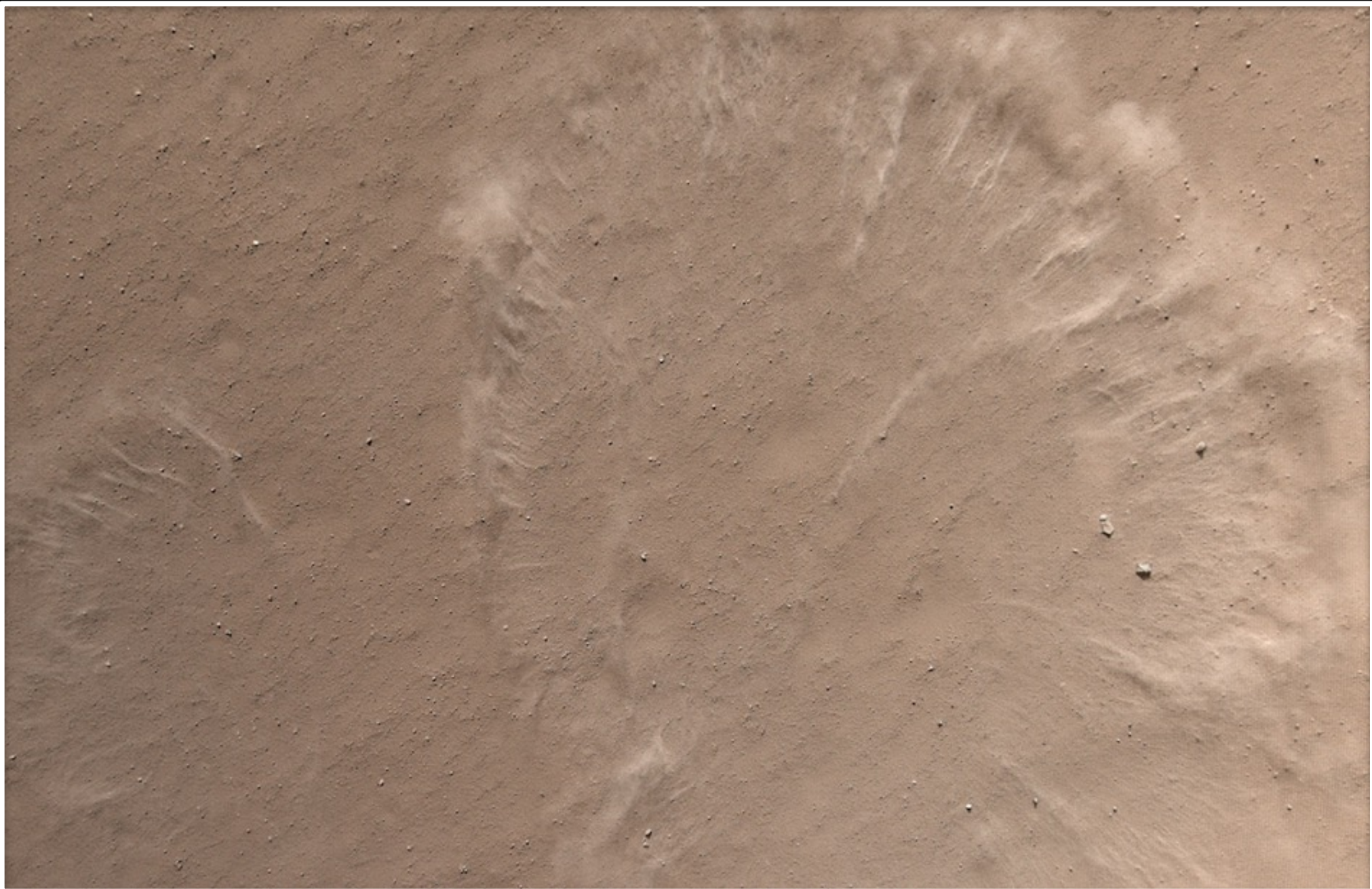
dark gray well-cemented sandstones common



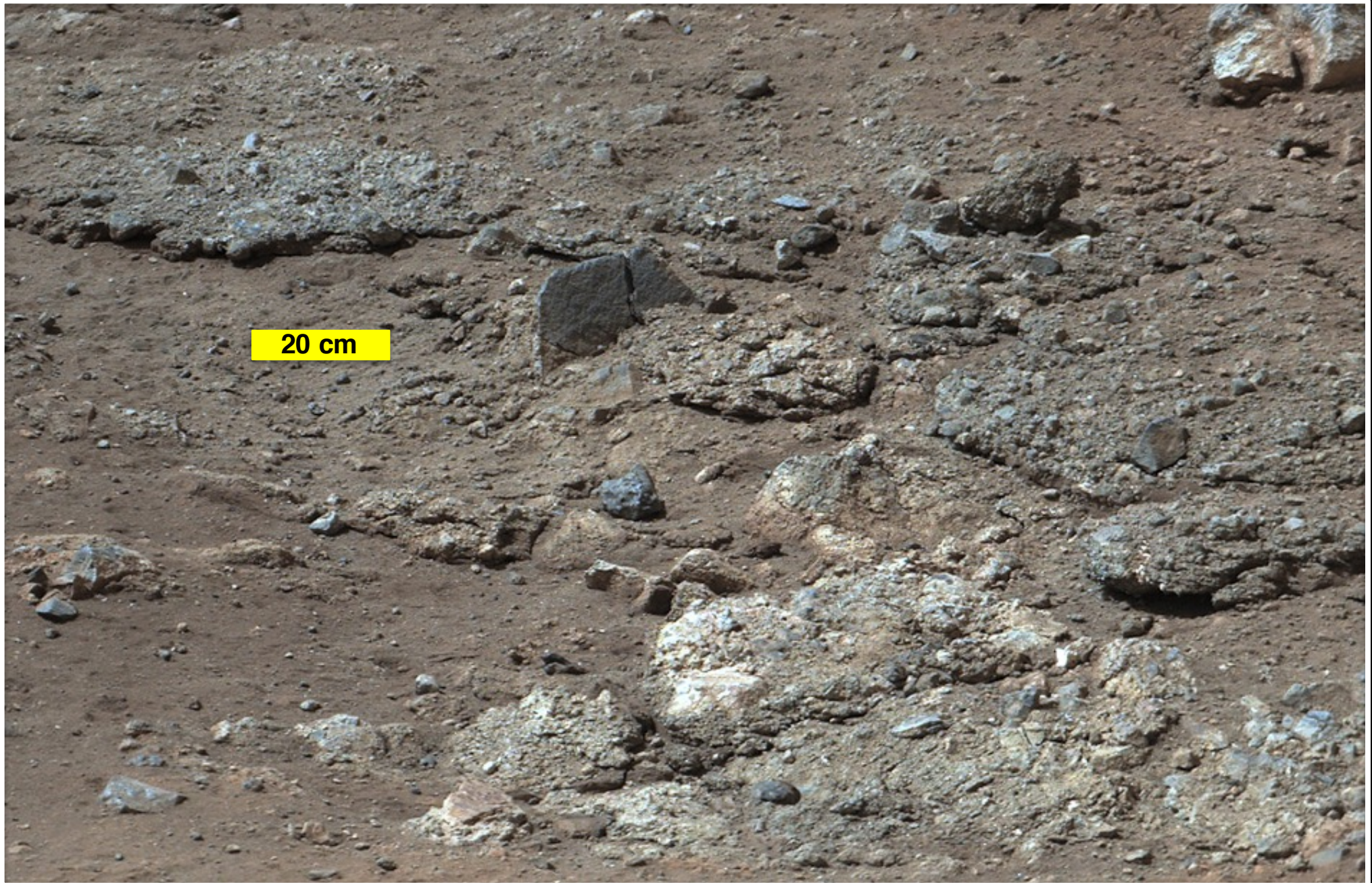
... and erosion-resistant



back to... Curiosity's terminal descent...



descent engines exposed conglomerates

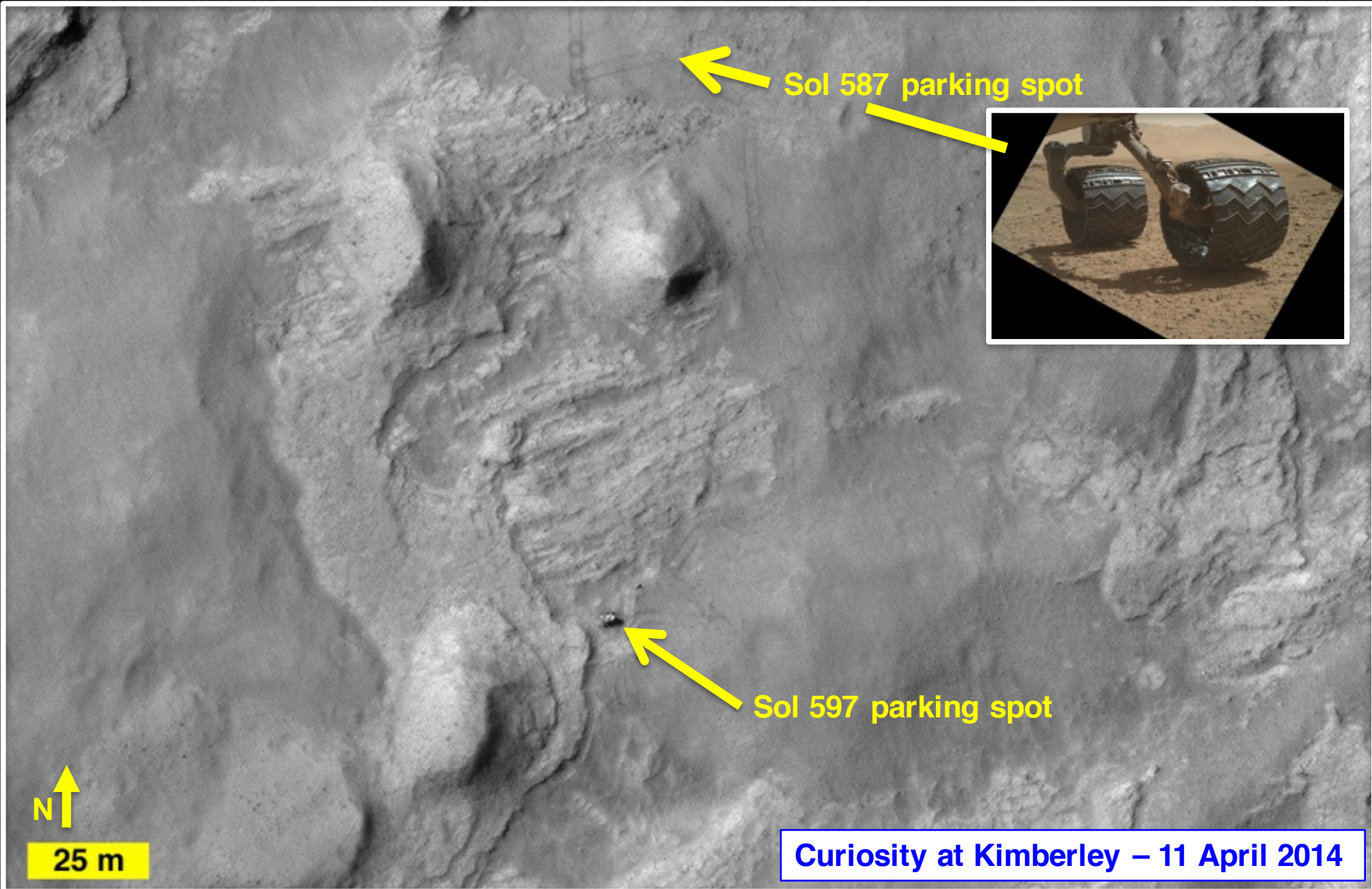


conglomerate – erosional expression



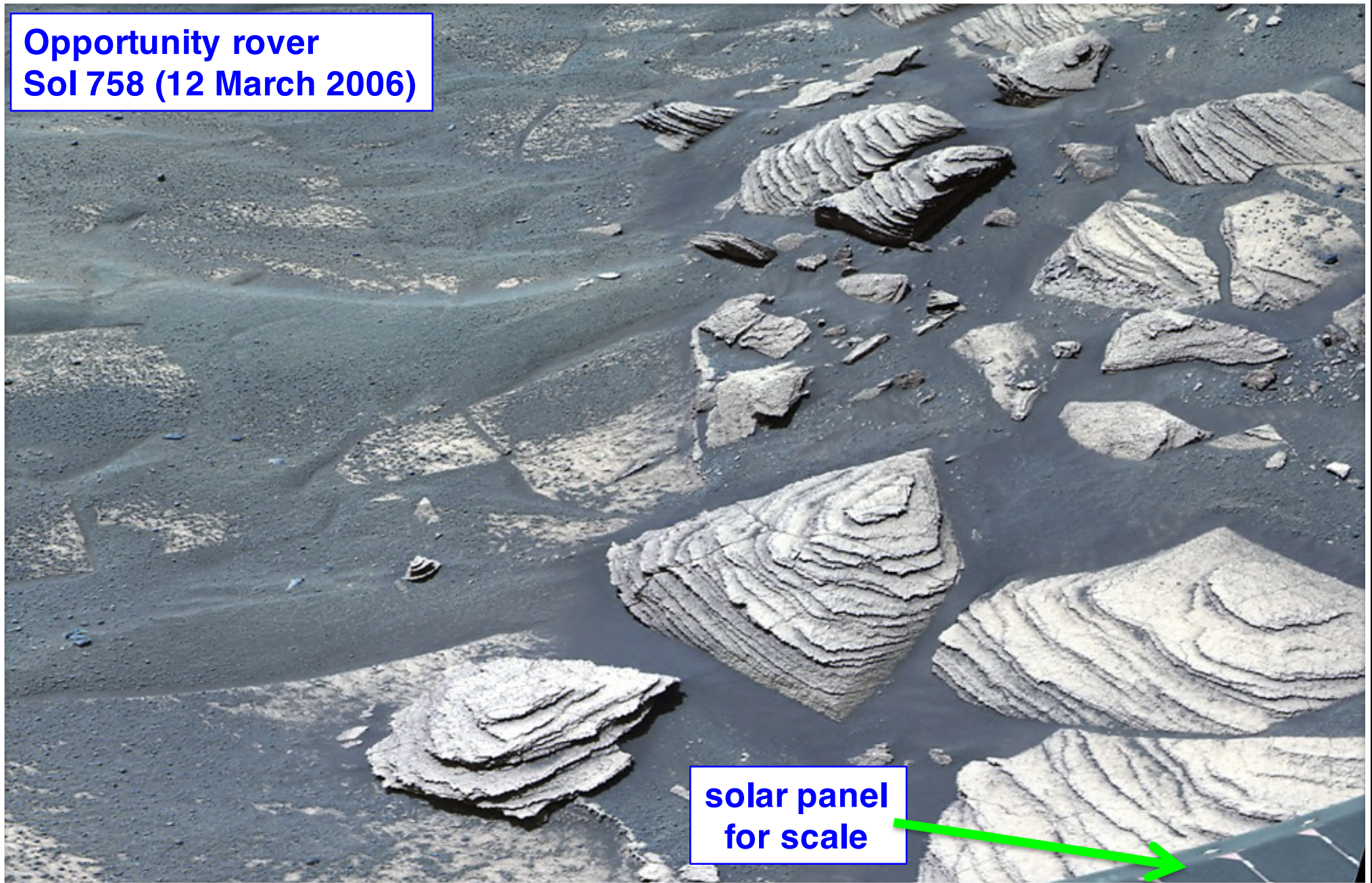
Imaged at Sol 587 parking spot

conglomerate erosional expression from above



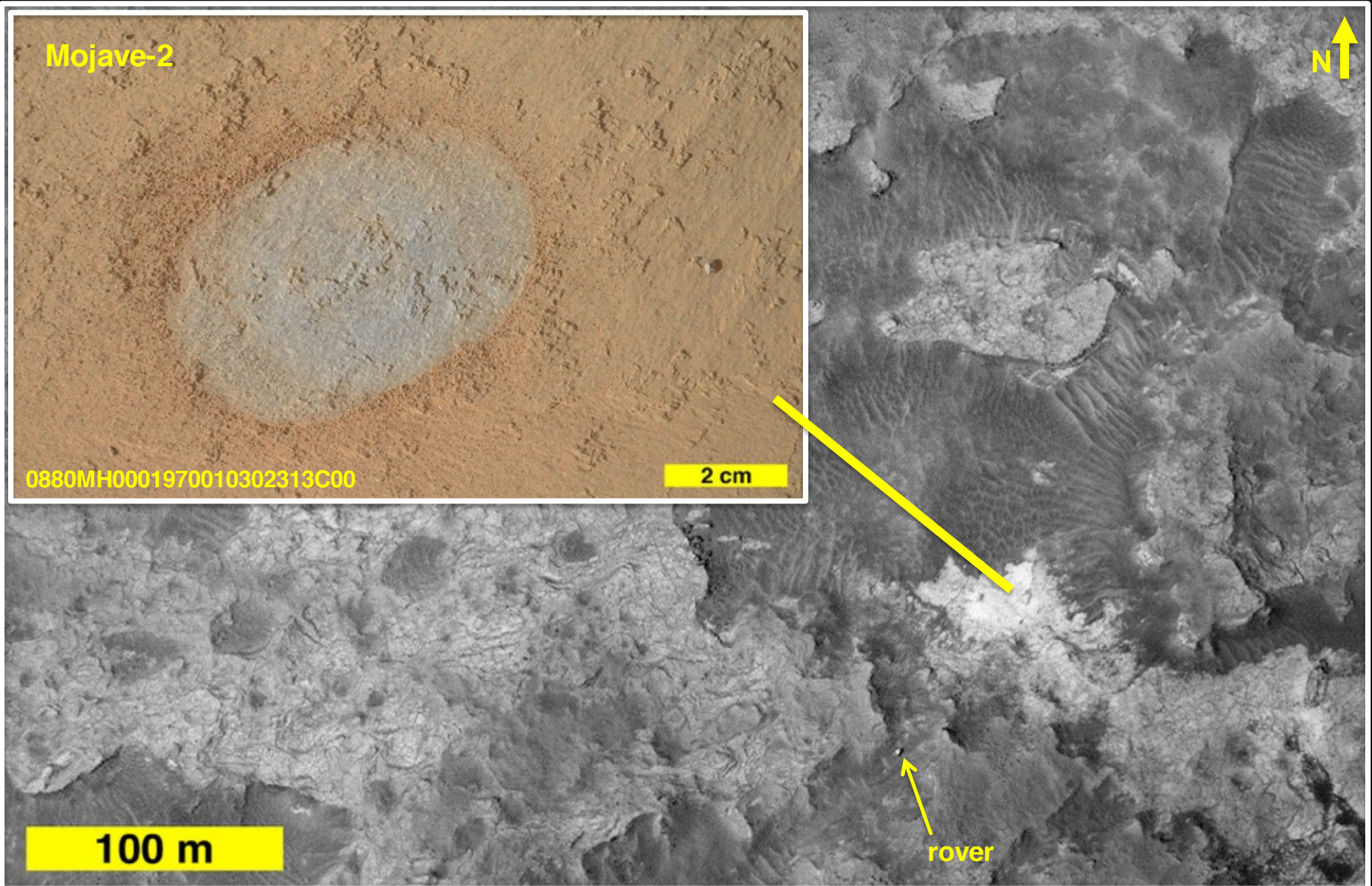
the meaning of light tone

Opportunity rover
Sol 758 (12 March 2006)



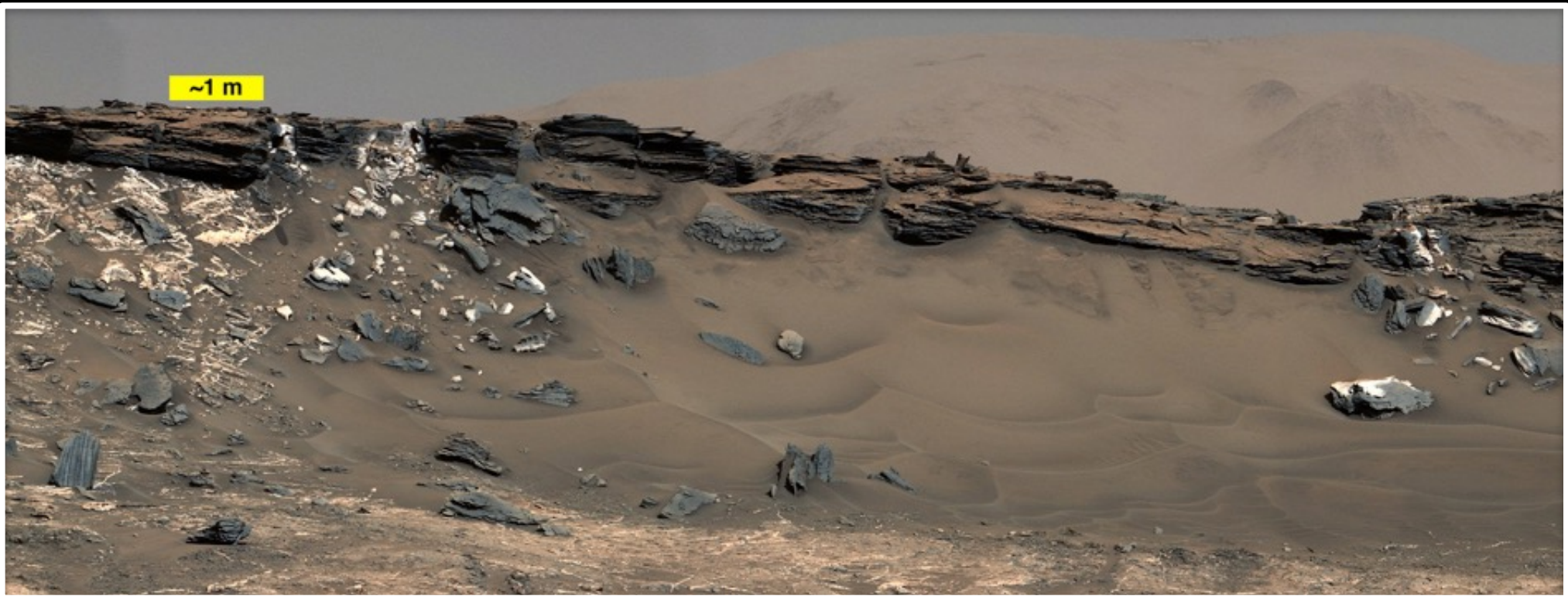
solar panel
for scale

the meaning of light tone



even more stuff learned from Curiosity...

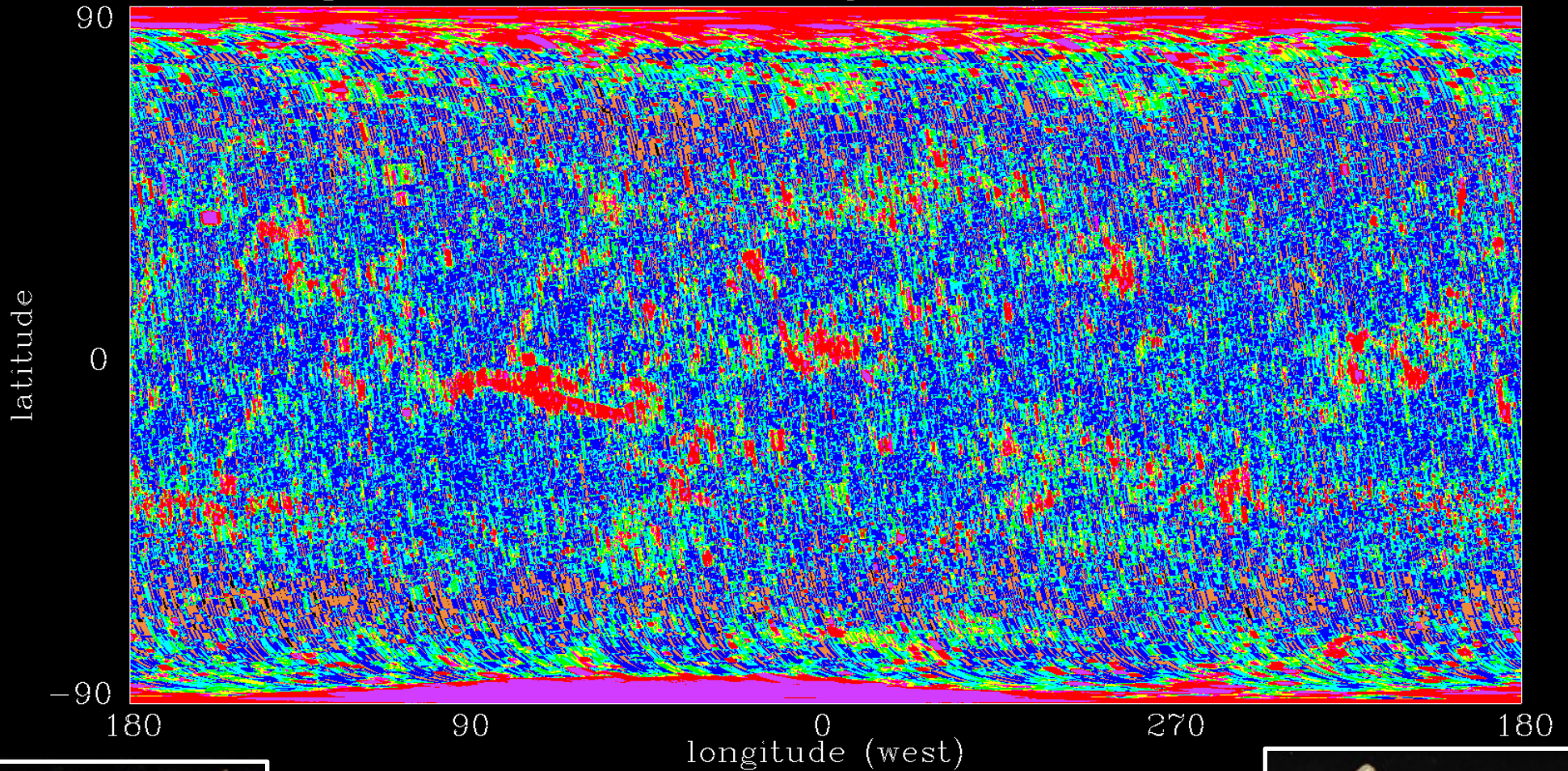
- Bedrock always at or near the surface.
- Importance of wind erosion.
- Rock type and erosion resistance influence on landscape geomorphology.
- Fracture patterns, veins, halos in sedimentary rock.



the rest of Mars...

MRO CTX Coverage through January 2017

CTX coverage T01-J11 (total 99.1%, repeat 60.2%)

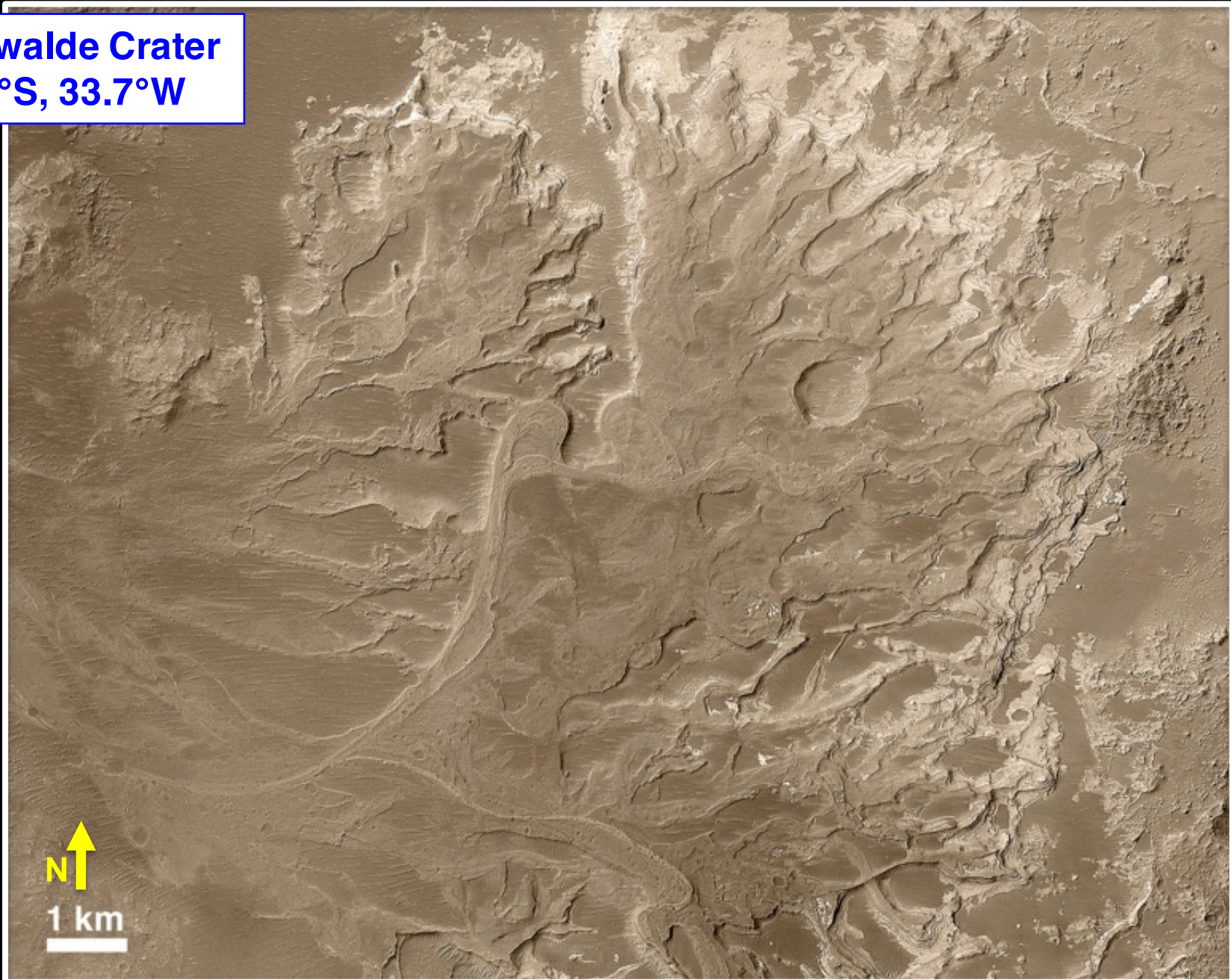


MGS MOC + MRO HiRISE + MRO CTX

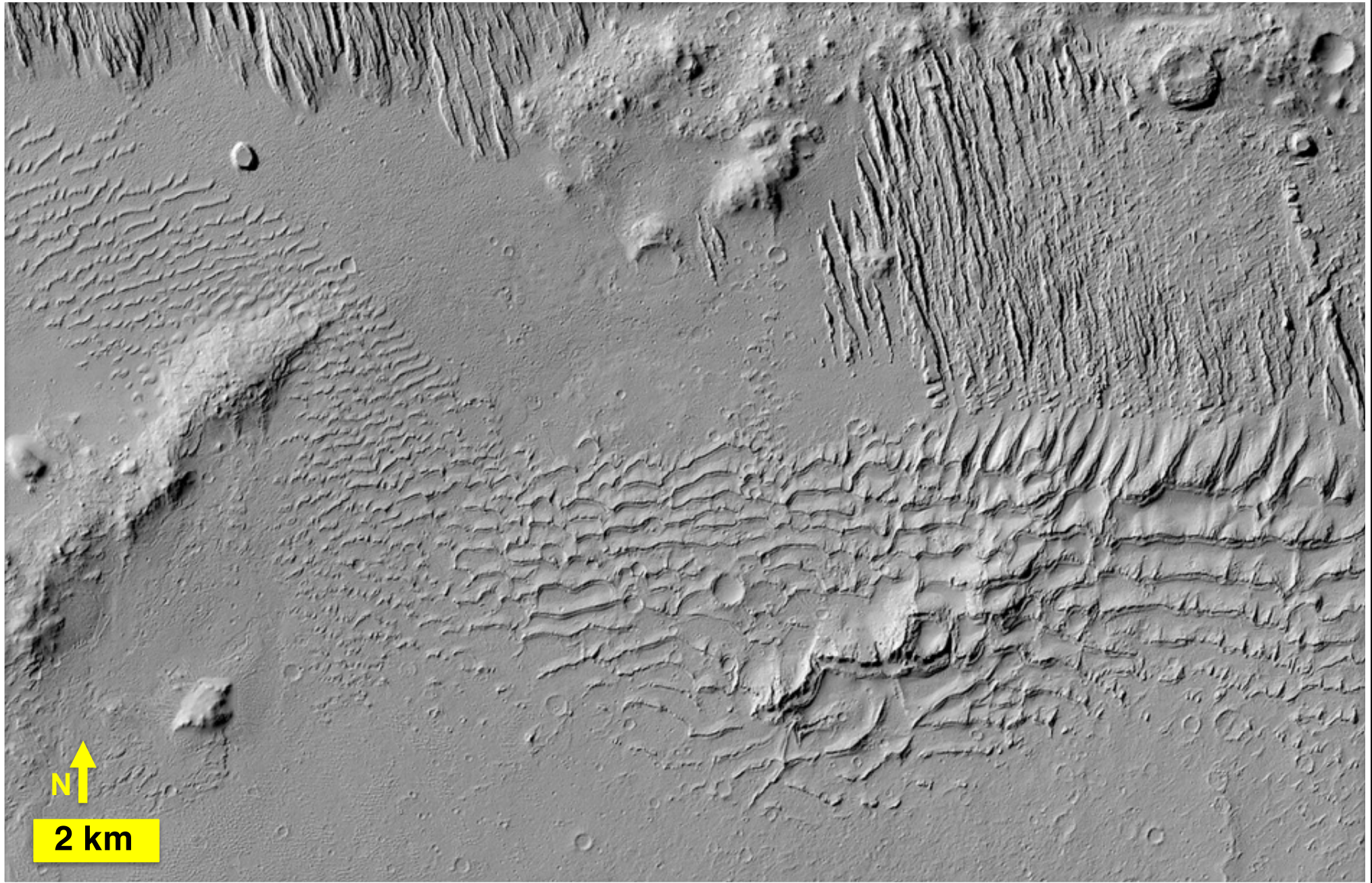


depositional setting mimicry – fluvial delta

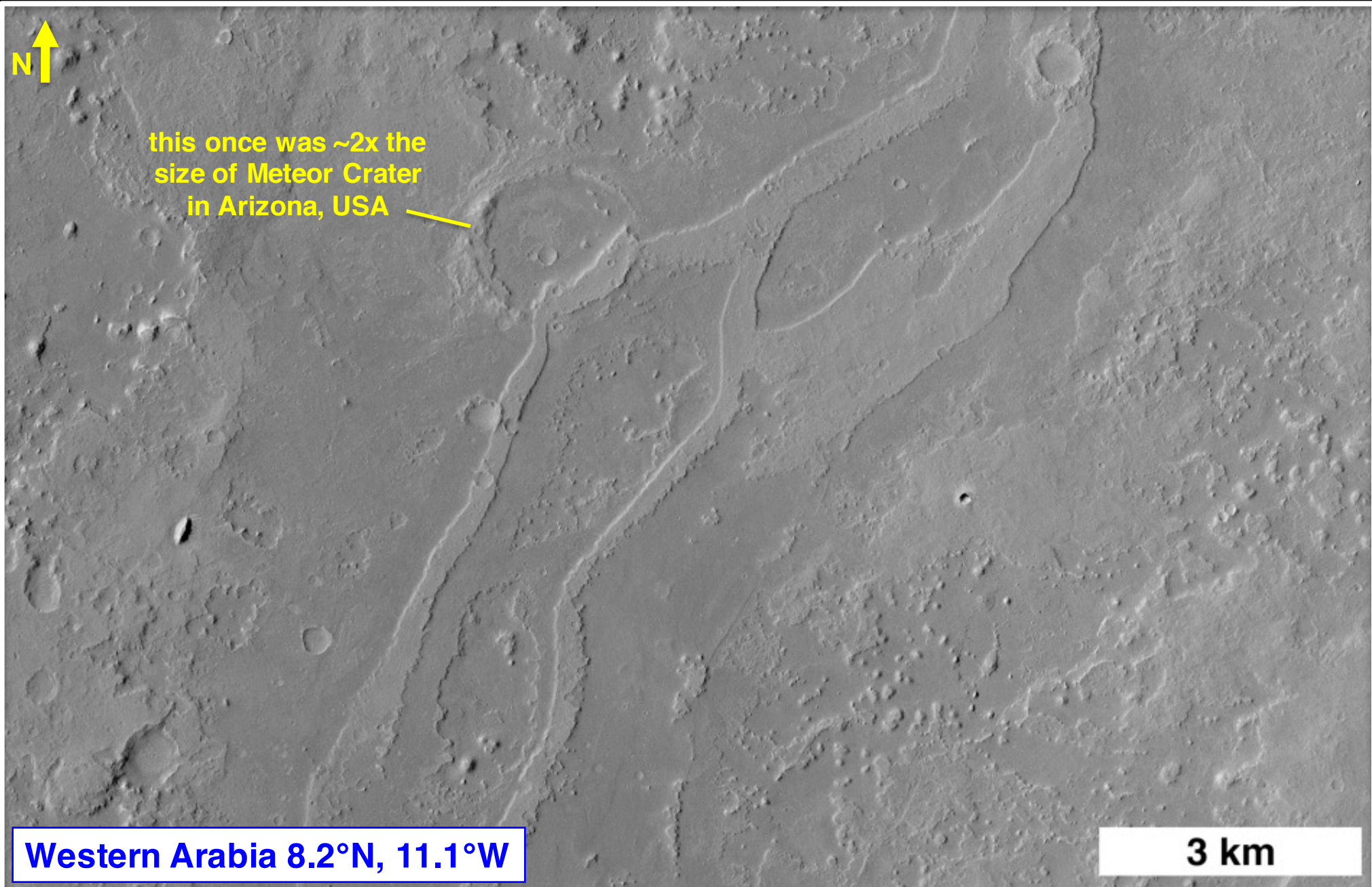
Eberswalde Crater
24.1°S, 33.7°W



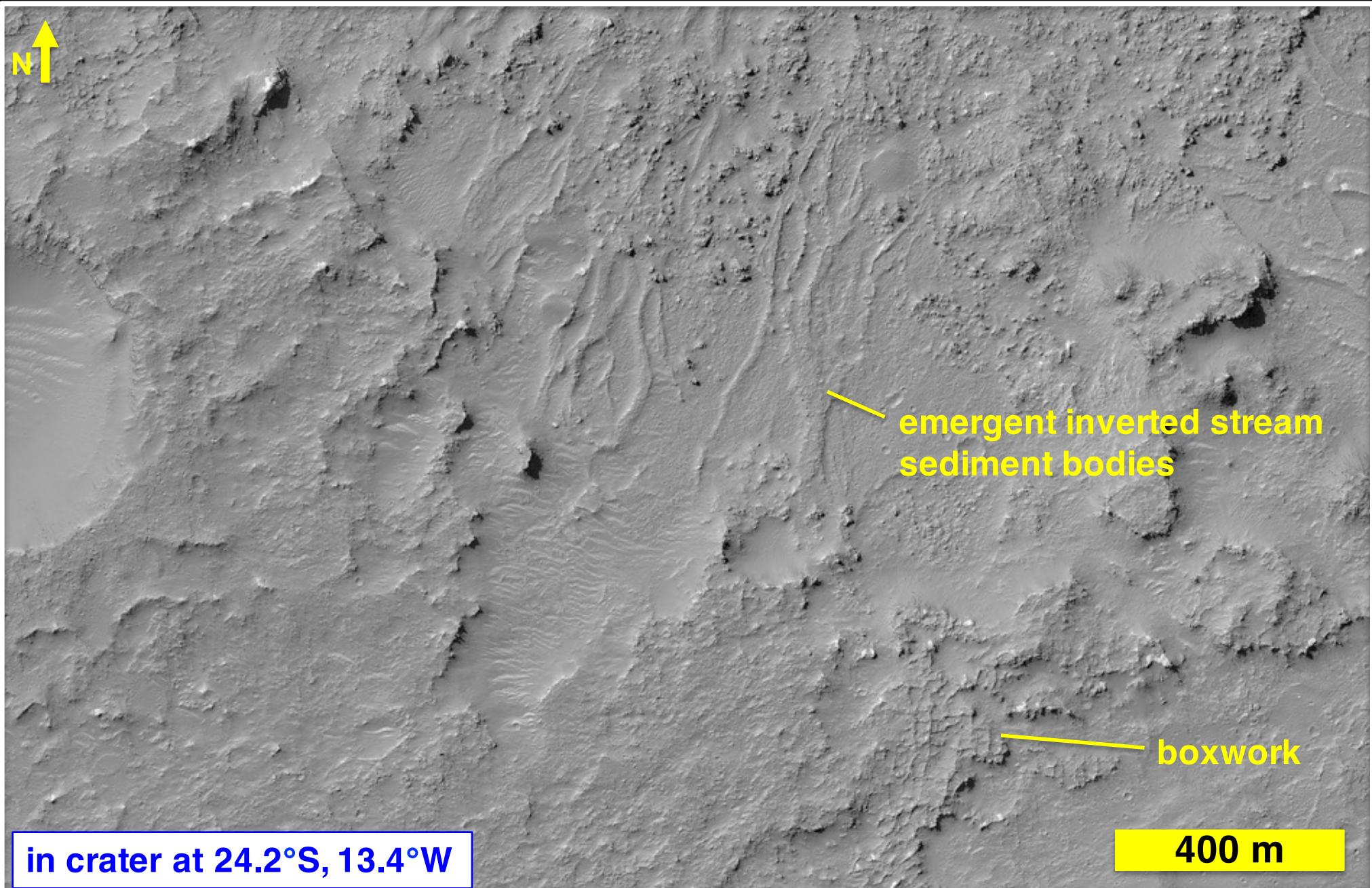
depositional setting mimicry – eolian dune field



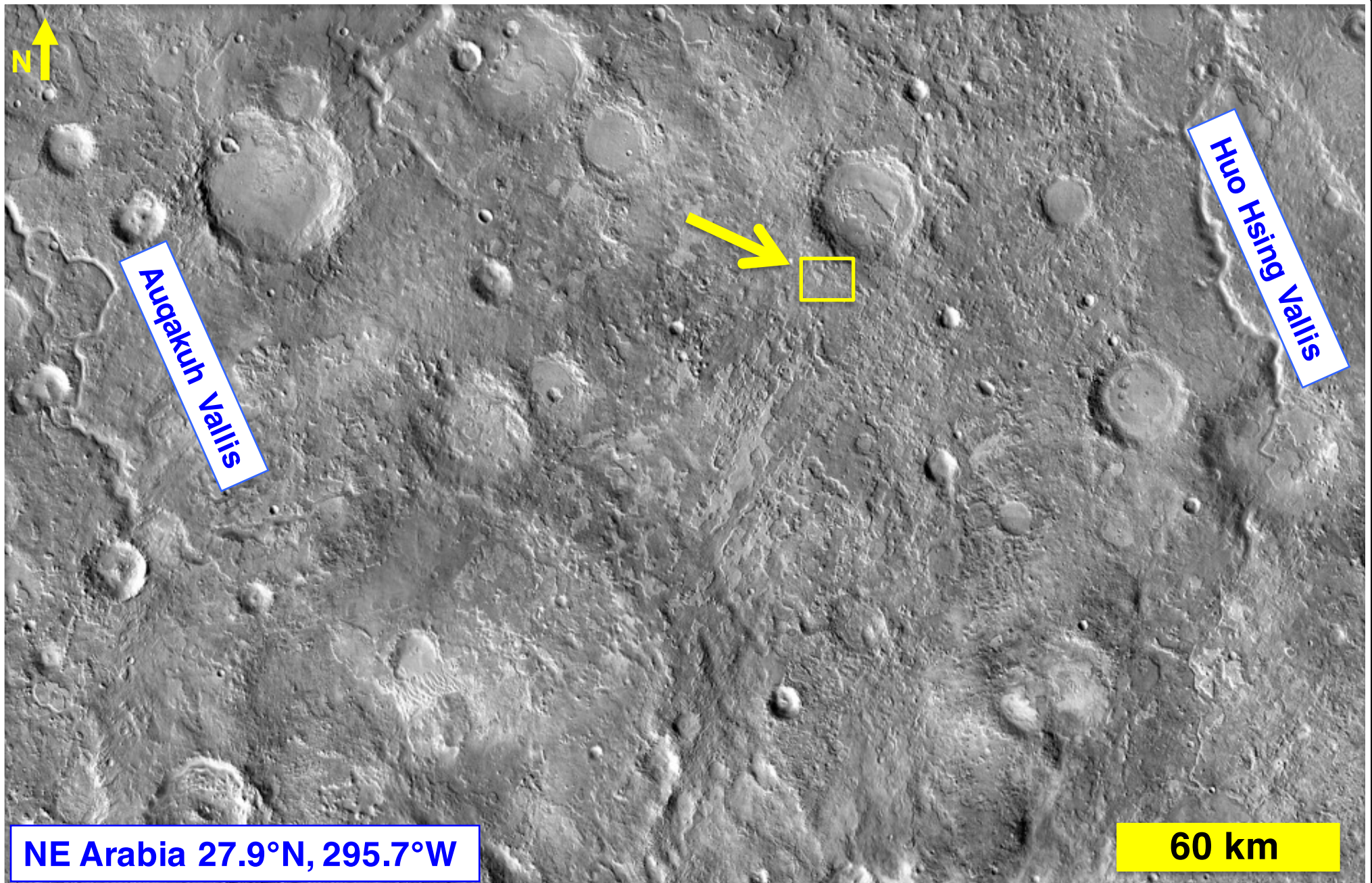
depositional setting mimicry – stream channel



depositional setting mimicry – stream channel



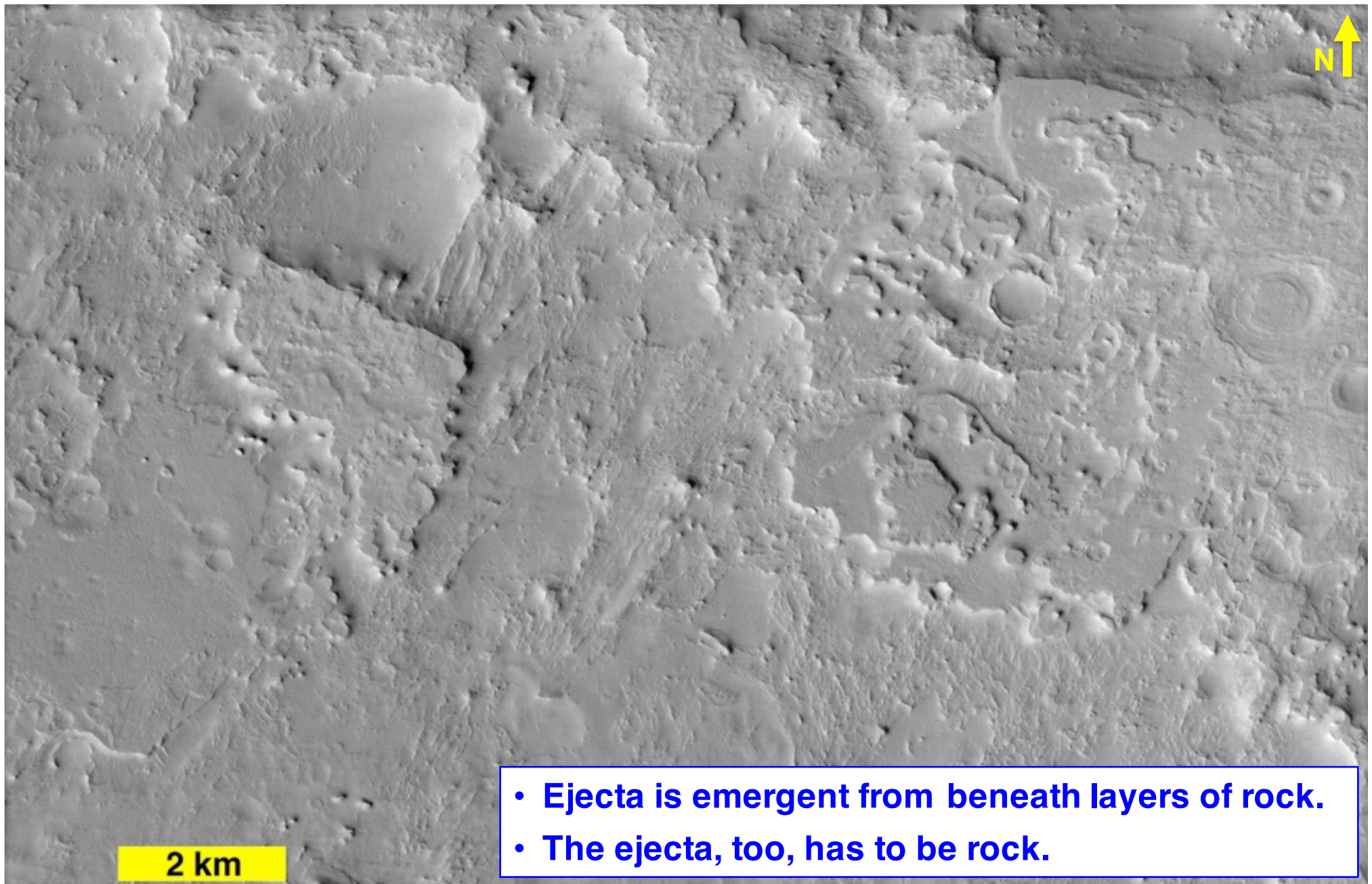
depositional setting mimicry – impact ejecta



NE Arabia 27.9°N, 295.7°W

60 km

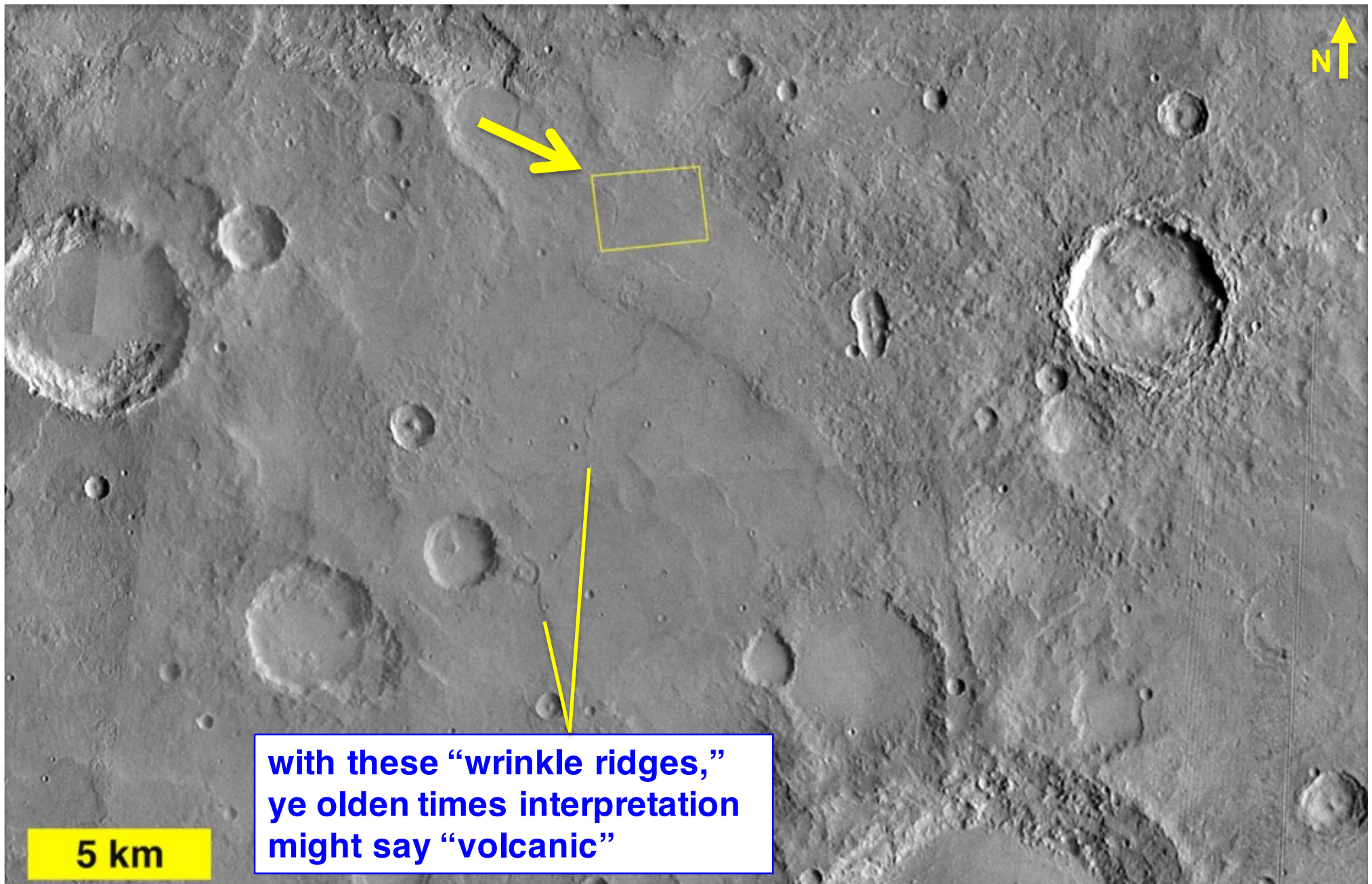
depositional setting mimicry – impact ejecta



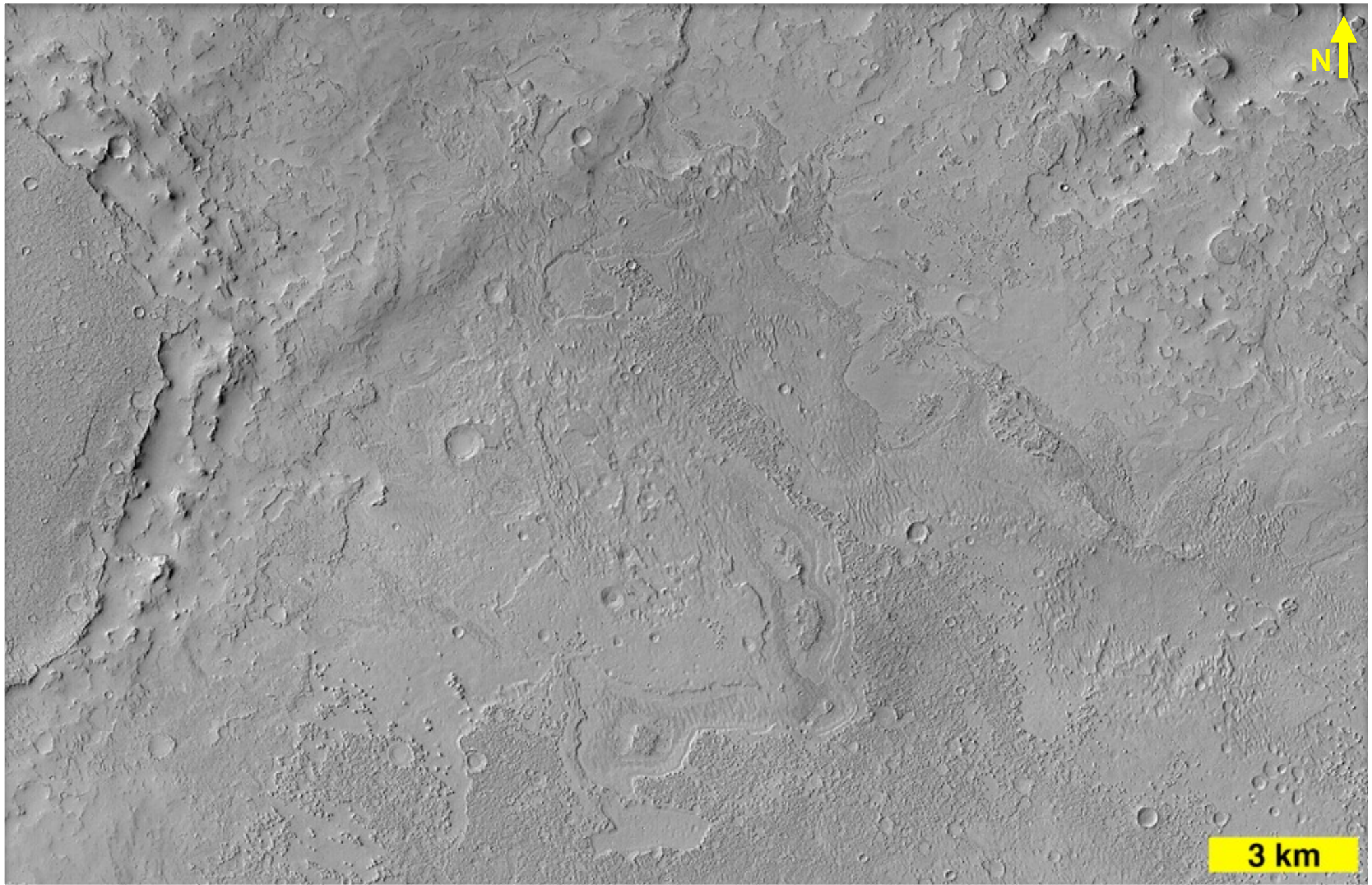
2 km

- Ejecta is emergent from beneath layers of rock.
- The ejecta, too, has to be rock.

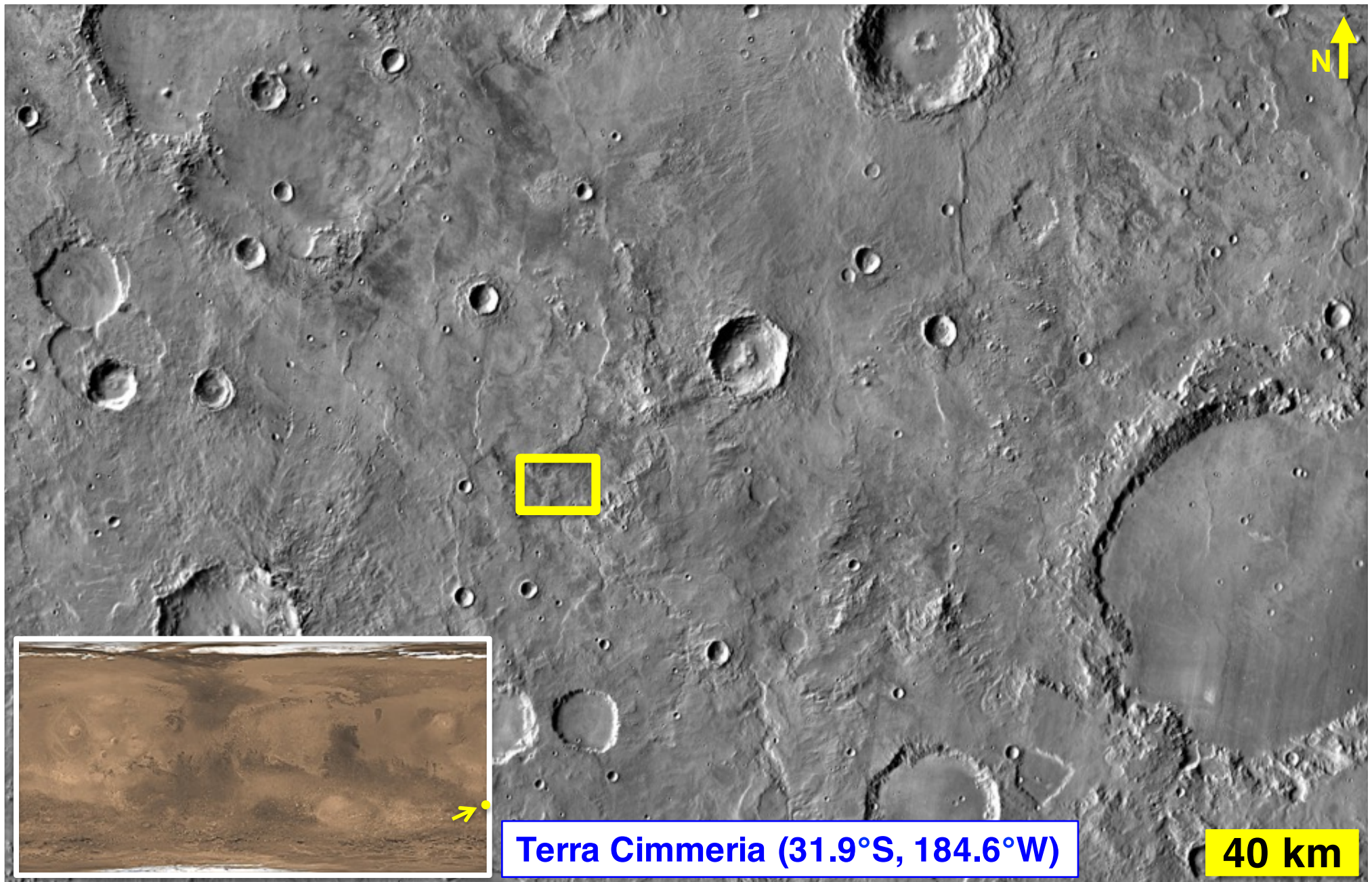
intercrater plains in heavily cratered terrain...



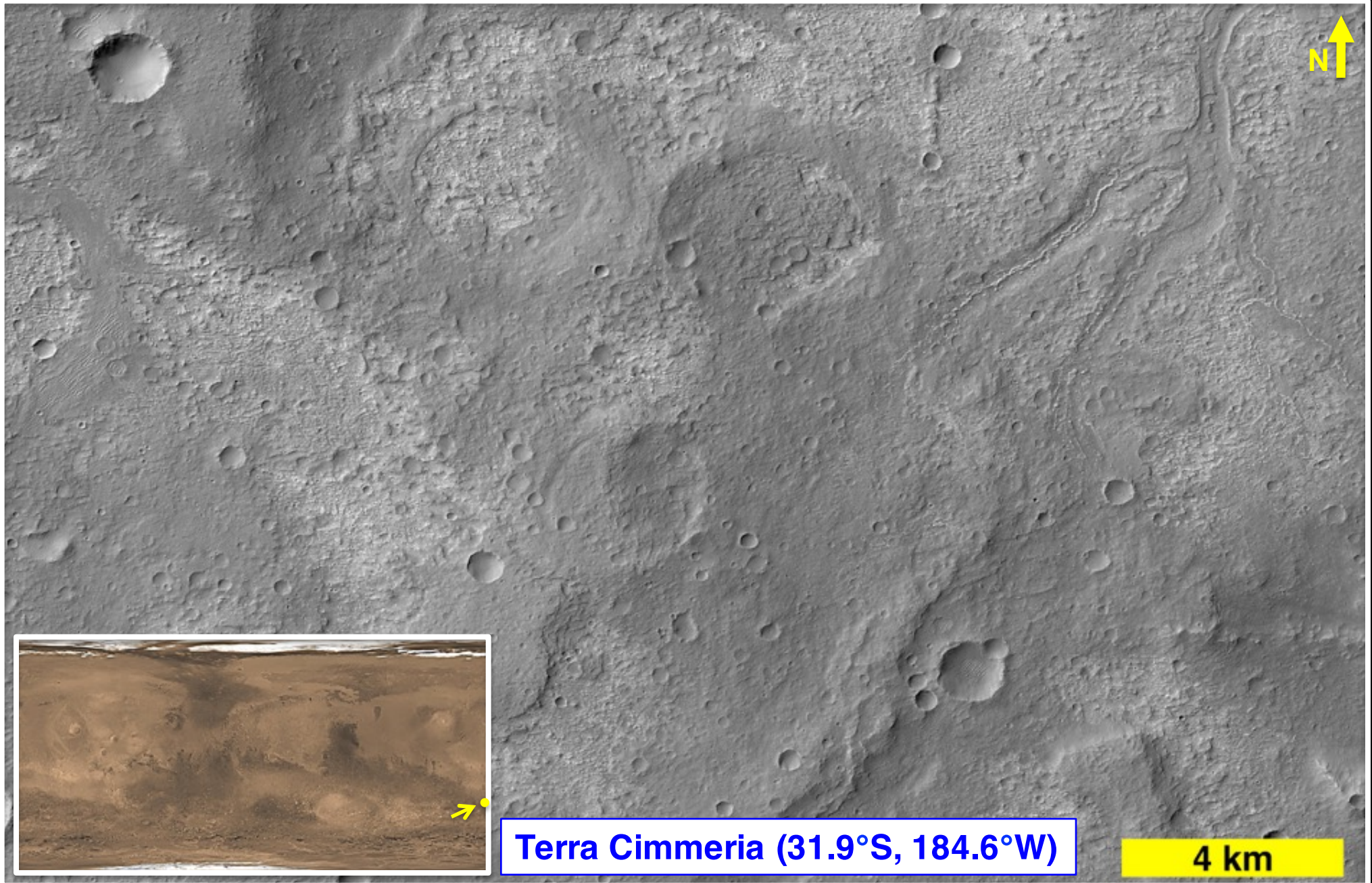
intercrater plains in heavily cratered terrain...



examples abound in heavily-cratered terrain...



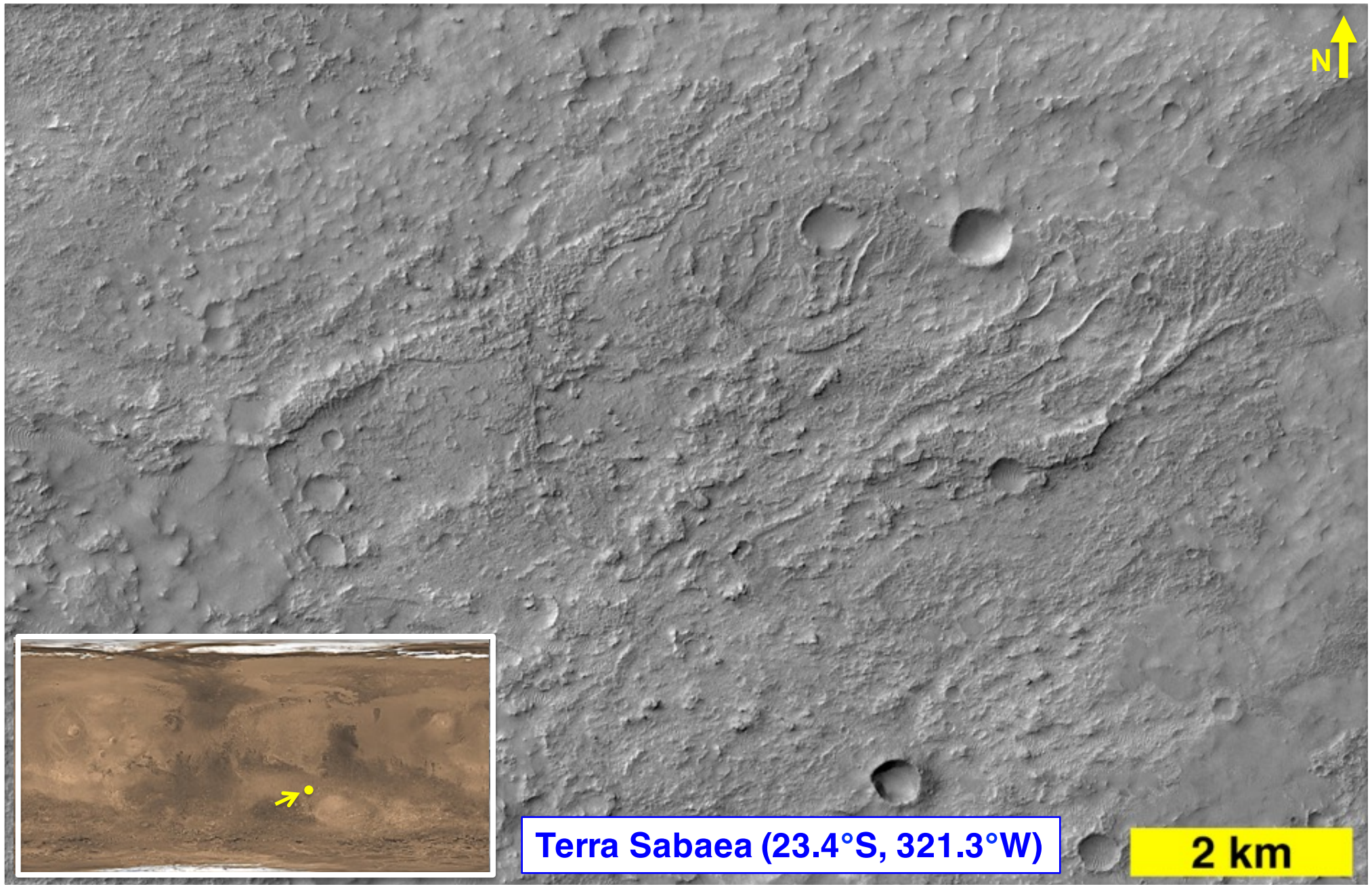
examples abound in heavily-cratered terrain...



Terra Cimmeria (31.9°S, 184.6°W)

4 km

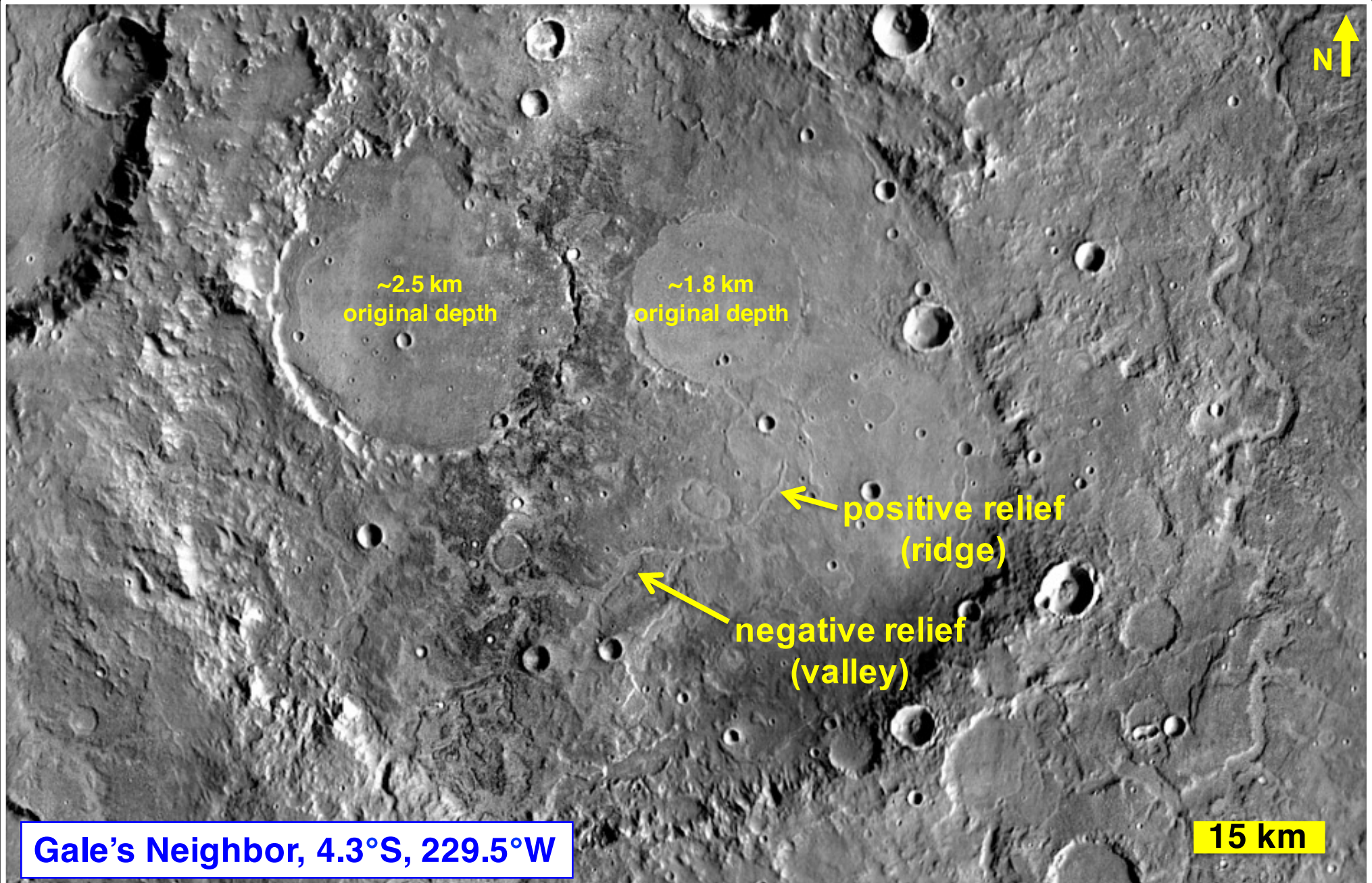
examples abound in heavily-cratered terrain...



Terra Sabaea (23.4°S, 321.3°W)

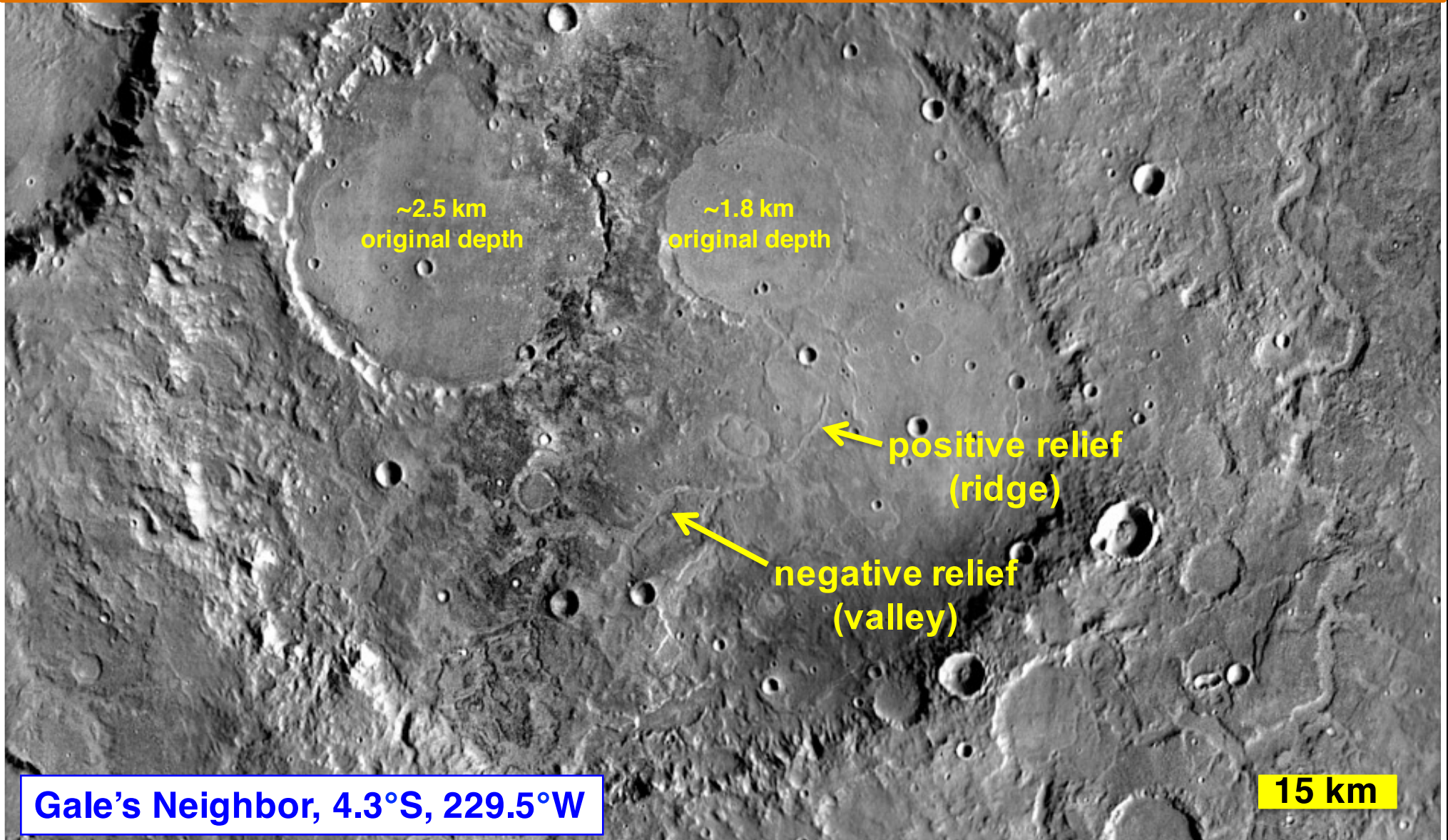
2 km

finally... always have to ask “what is missing?”



“what is missing?”

and “how did it go missing?”



take-home messages

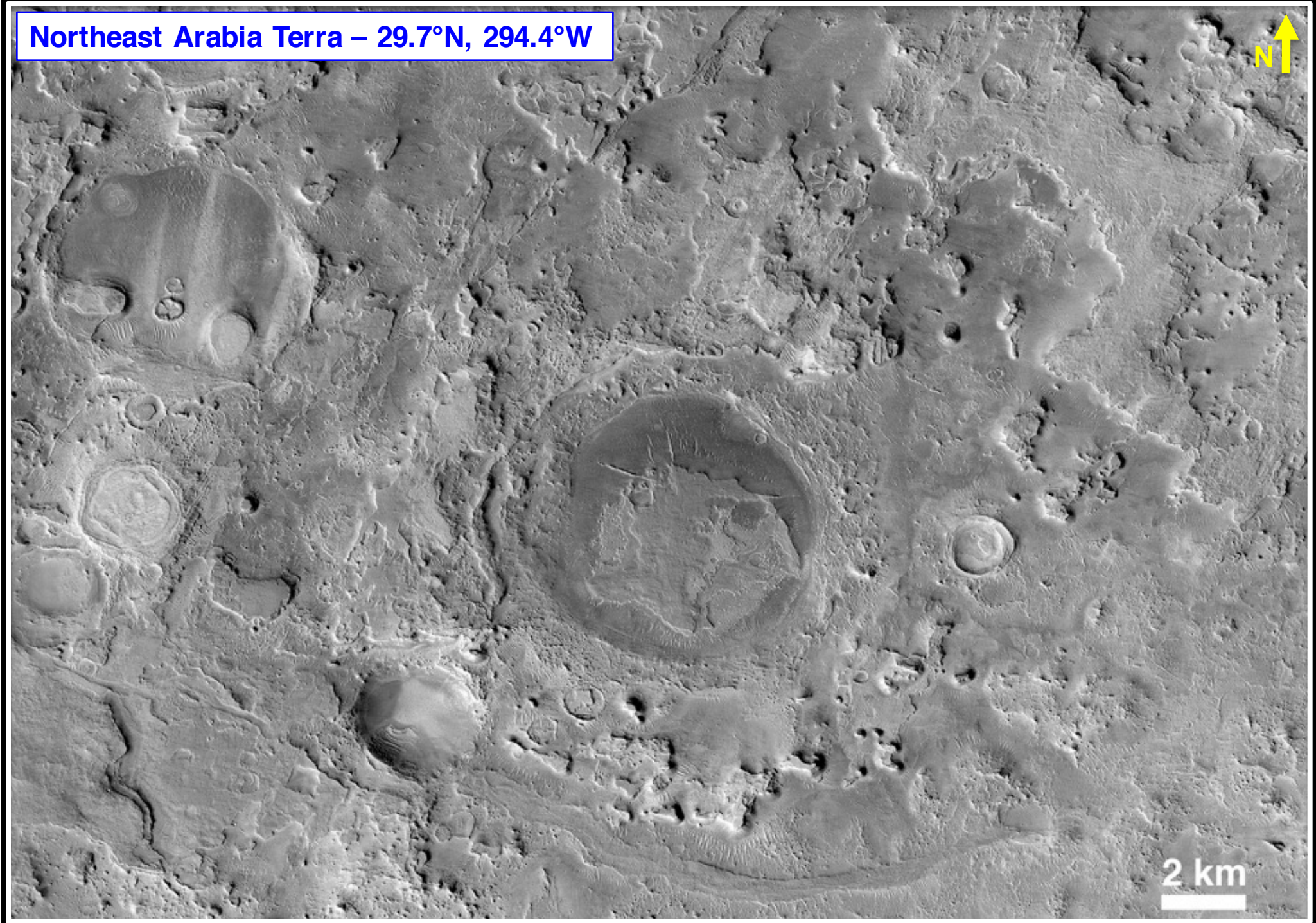
Mars sedimentary rock record –

- the last 16 years focused on most obvious sub-set
- new observations → new interpretation capabilities
- still building the foundation
 - how to recognize examples missed for 16+ years
 - role in landscape evolution
 - always ask, “what is missing?” – and how did stuff go missing?
 - Curiosity & Opportunity landscape observations suggest rocks are at and near the surface
- burden of proof may have shifted – what you see might be sedimentary until demonstrated otherwise



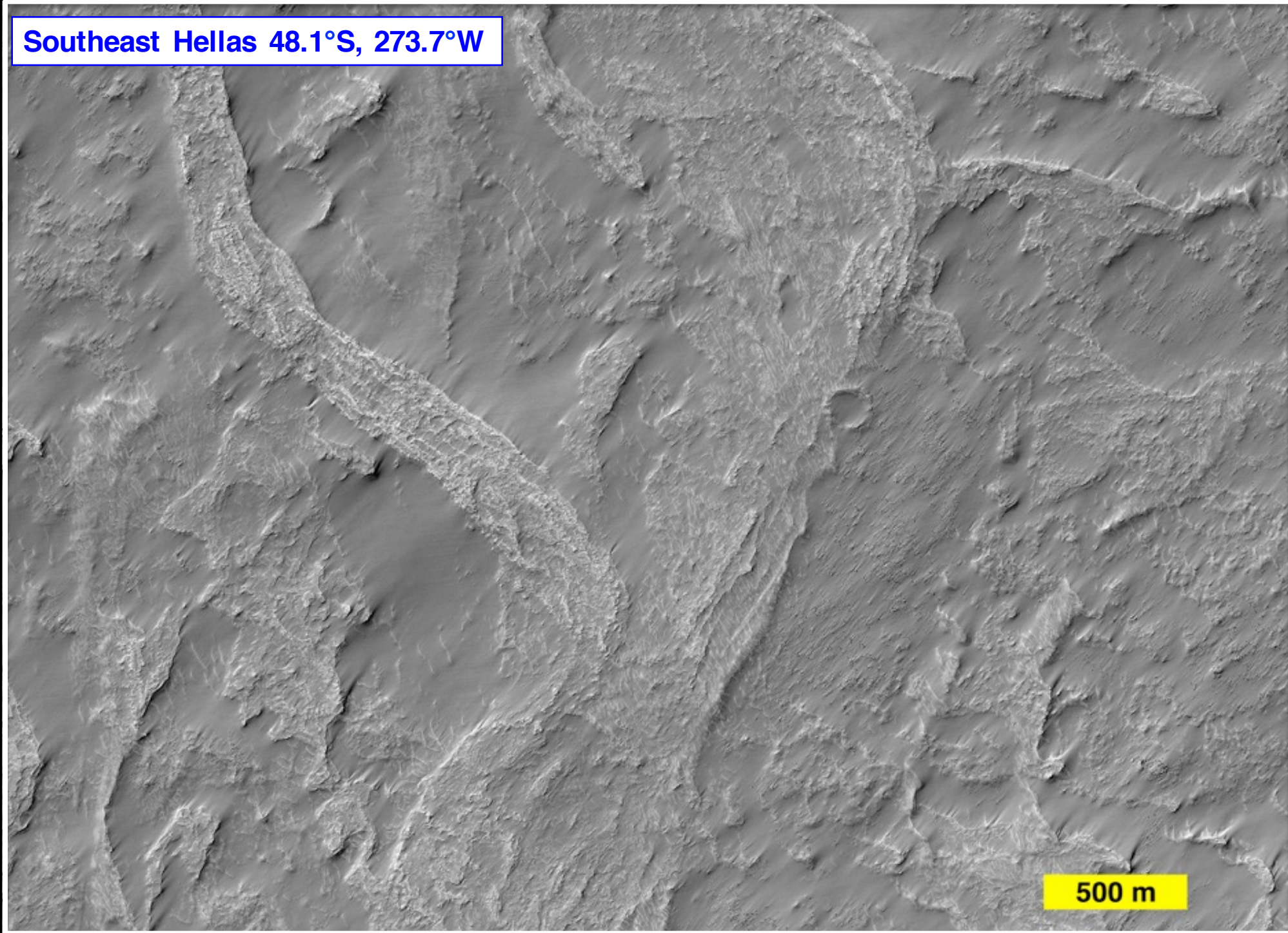
→ ADDITIONAL FIGURES / BACKUP

Northeast Arabia Terra – 29.7°N, 294.4°W

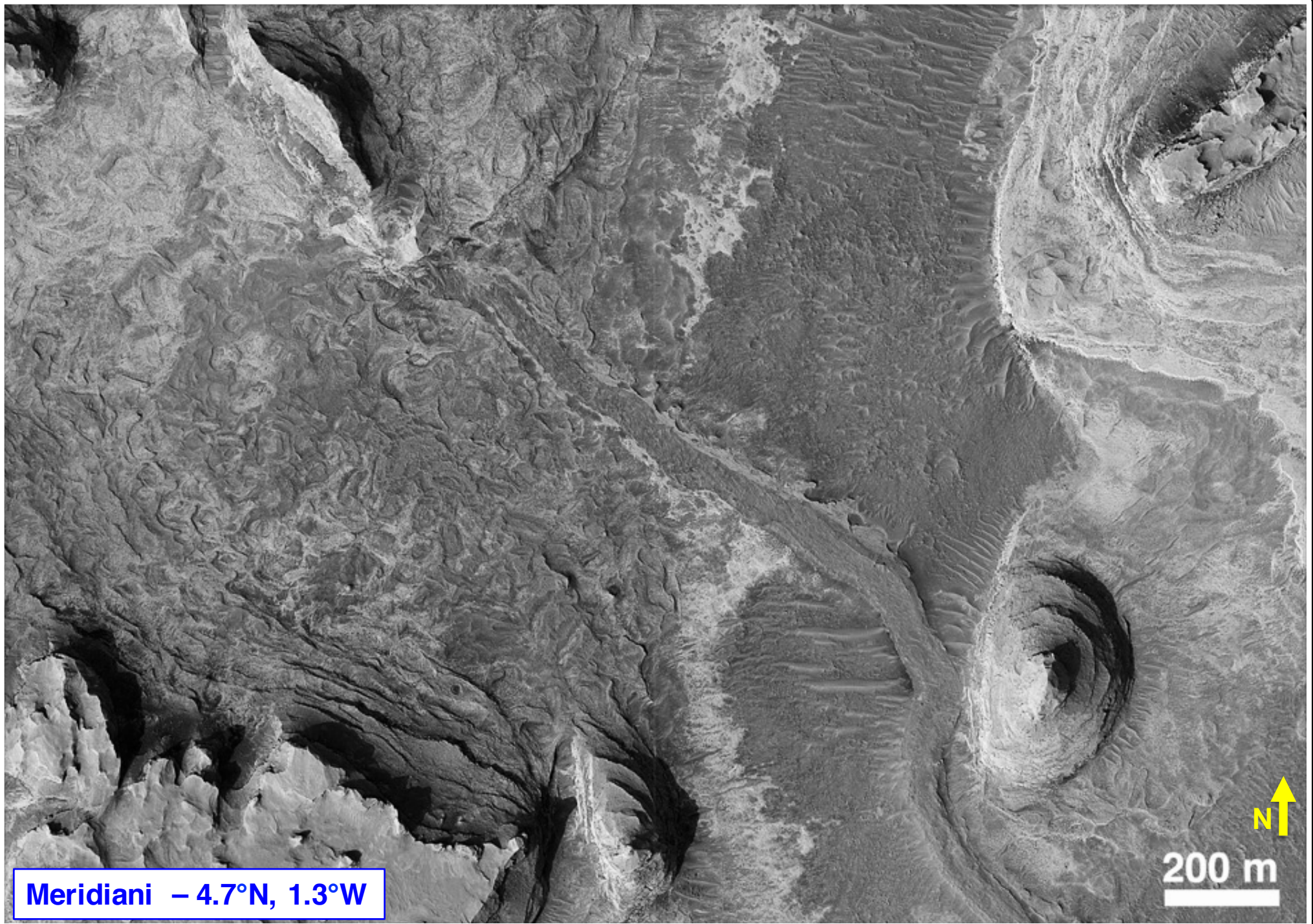


2 km

Southeast Hellas 48.1°S, 273.7°W



500 m

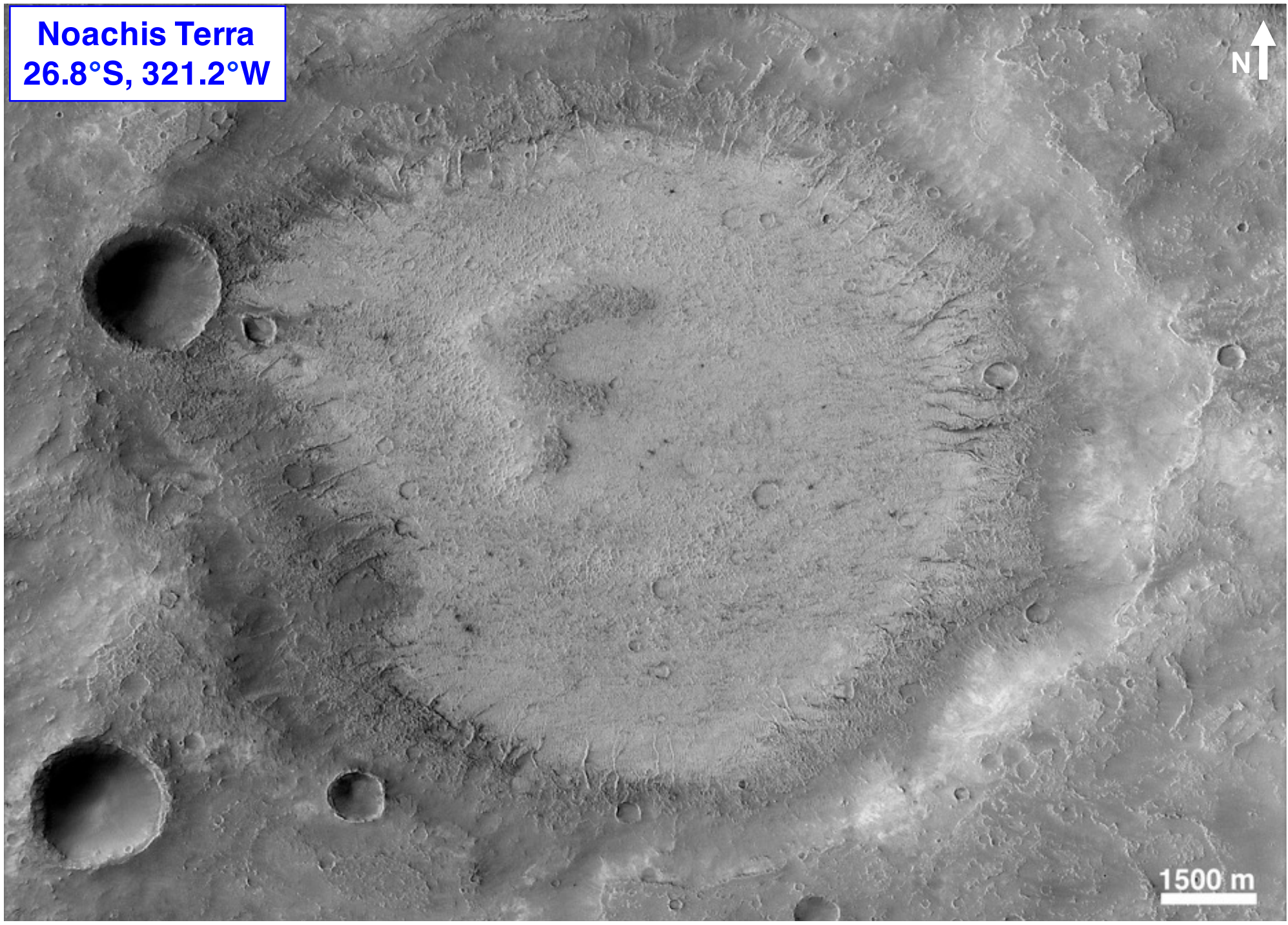


Meridiani - 4.7°N, 1.3°W

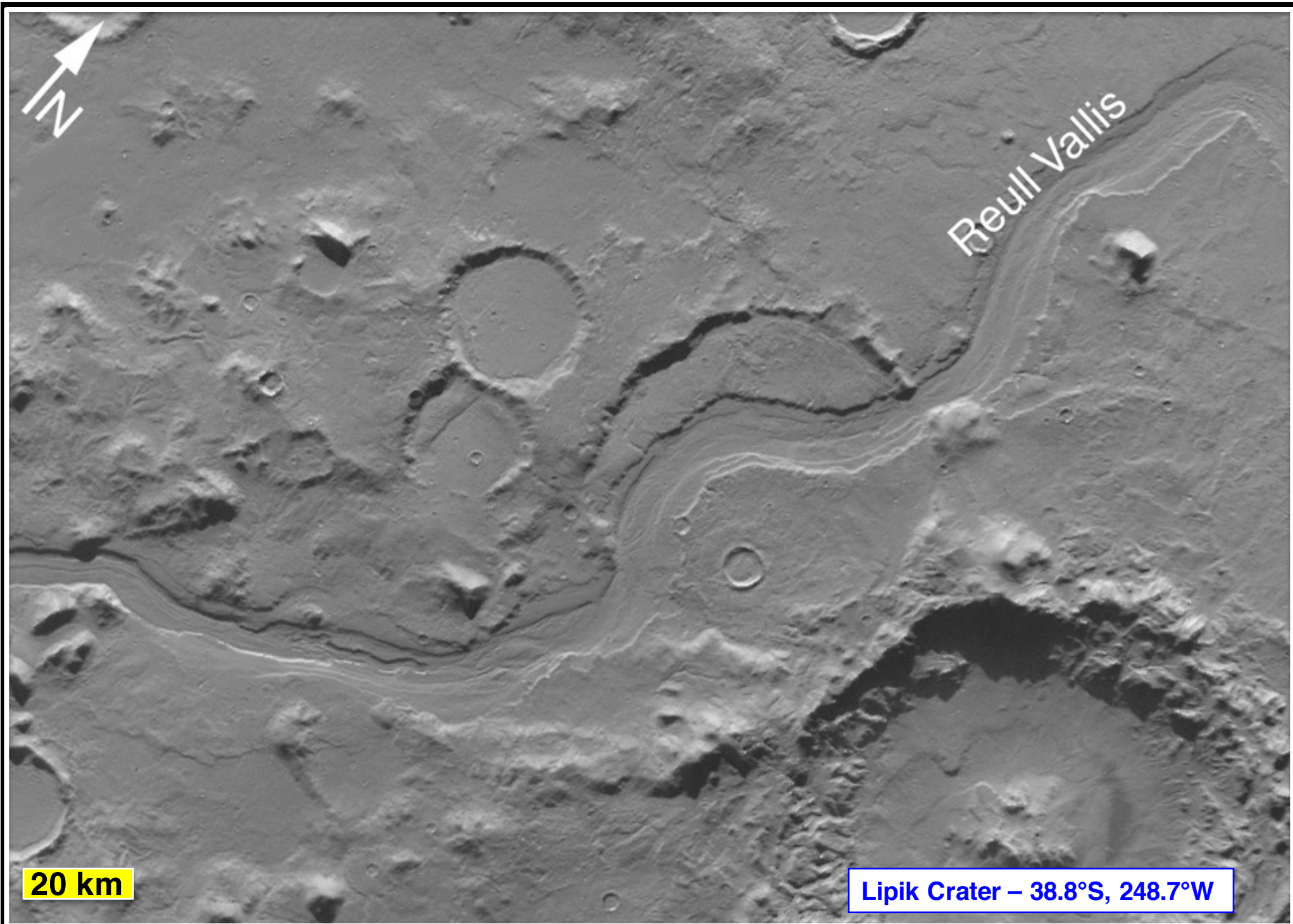
200 m



Noachis Terra
26.8°S, 321.2°W



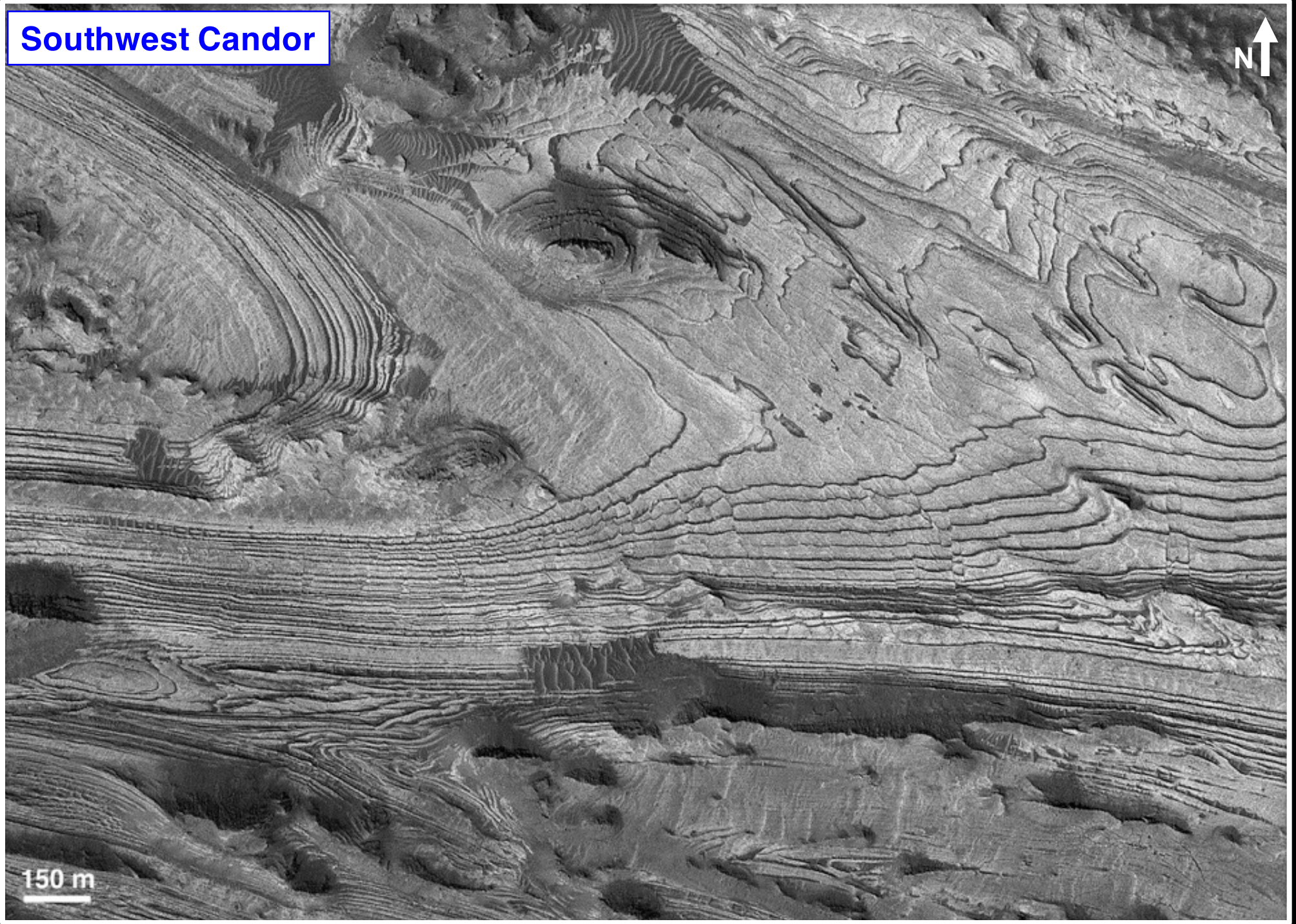
1500 m



20 km

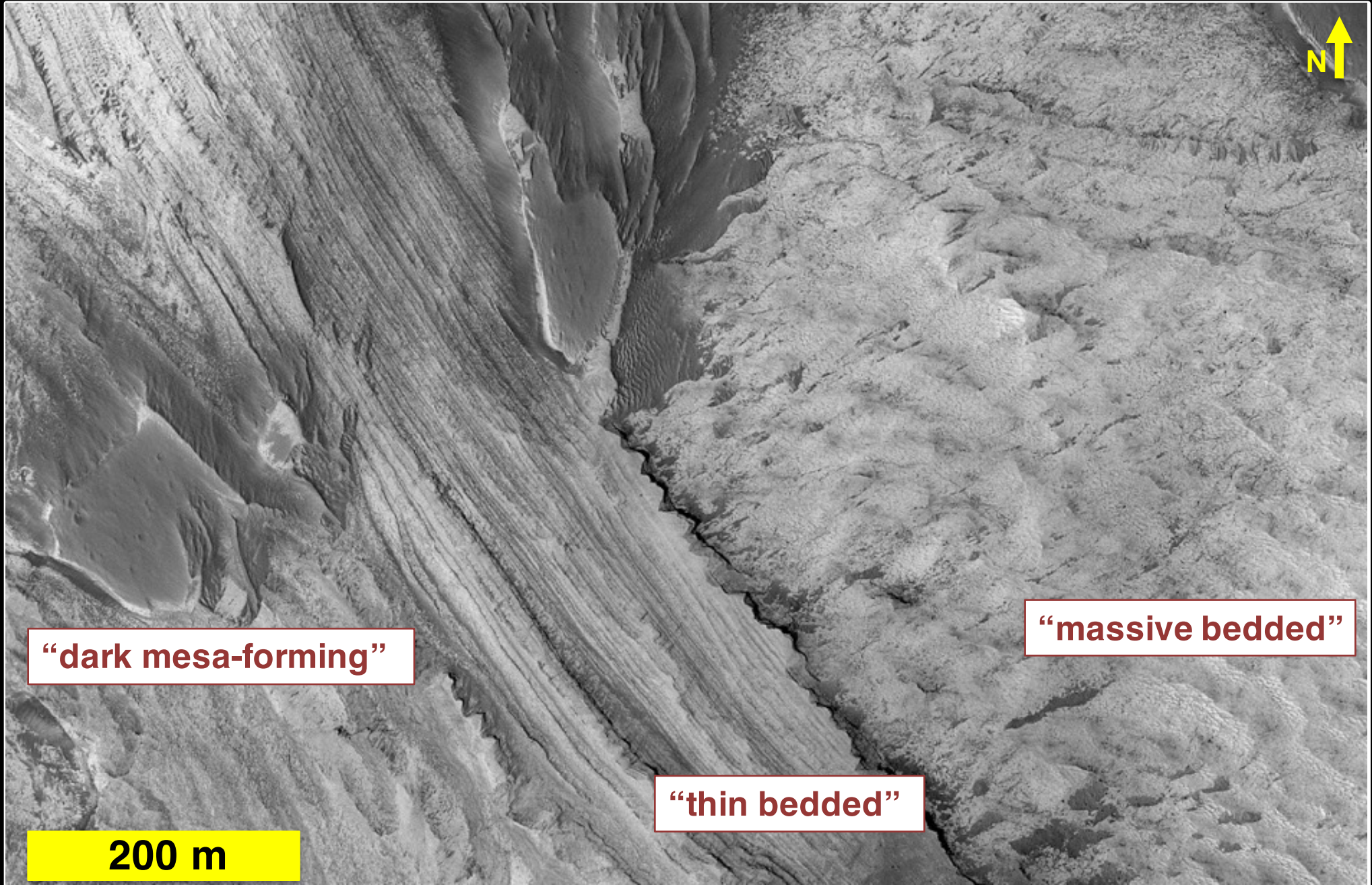
Lipik Crater - 38.8°S, 248.7°W

Southwest Candor



150 m

typical – light-tone, layered, few impact craters



“dark mesa-forming”

“massive bedded”

“thin bedded”

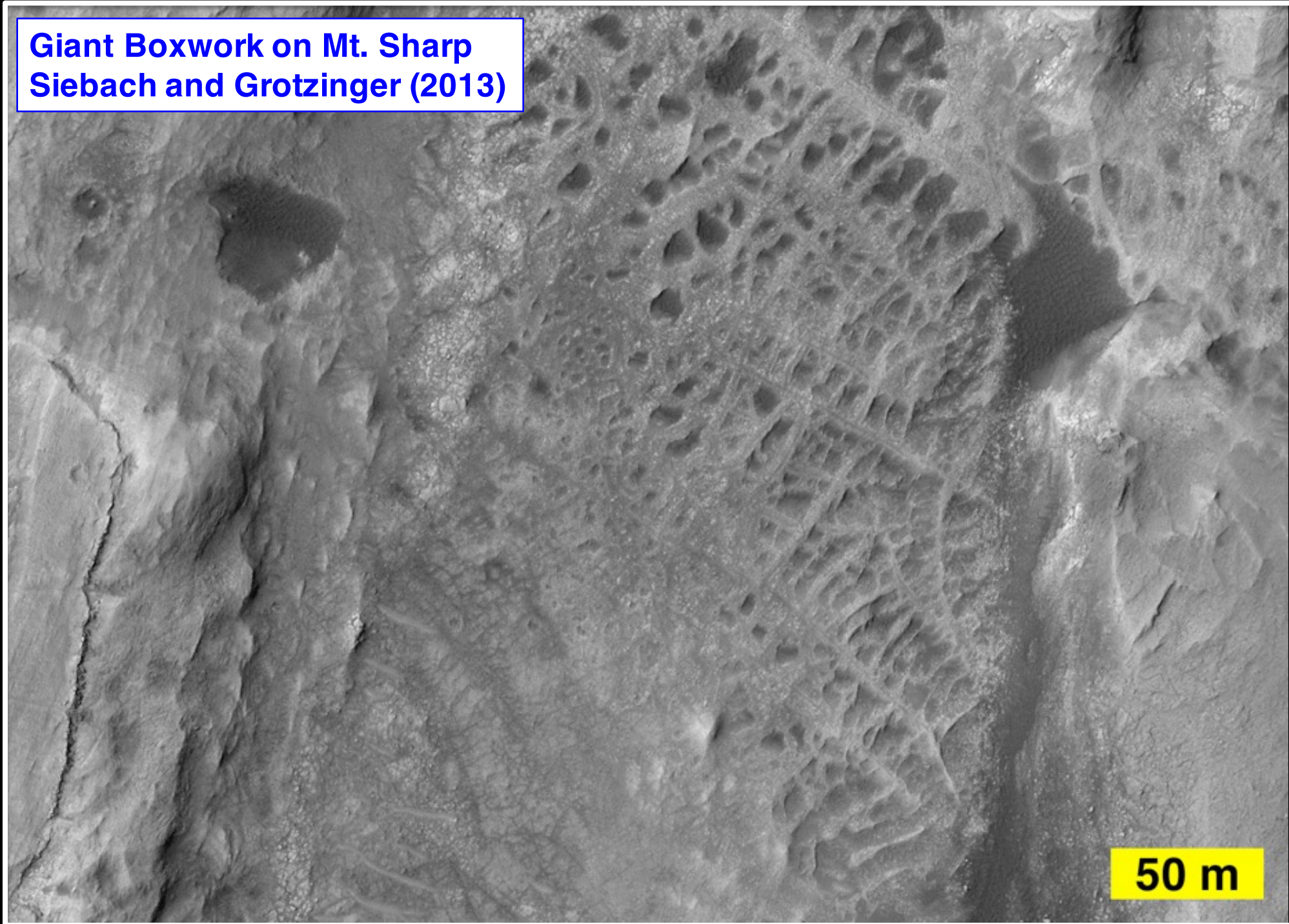
200 m

sedimentary rock – example – pebbly sandstone



19 mm diameter

**Giant Boxwork on Mt. Sharp
Siebach and Grotzinger (2013)**



50 m

Erosion-Resistant Vein Material - boxwork

