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Physical Sedimentology in Gale Crater, Mars*

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Abstract

Gale Crater was selected as the Mars Science Laboratory landing site largely because remote images suggested the crater contains a thick sequence of sedimentary rocks interpreted to be eolian, fluvial, and lacustrine deposits (previous work summarized by Anderson and Bell, 2010). In the year since landing, the rover, Curiosity, identified and examined deposits of all three of these depositional environments. Eolian deposits examined by Curiosity include the Rocknest sand shadow (unconsolidated sand in the lee of rocks on the surface described by Blake et al. in press) and thin sandstones beds with pinstripe laminae deposited by migrating wind ripples. On its route to Mt. Sharp, it is likely that the rover will pass near active eolian dunes and "washboard" deposits that have previously been interpreted as preserved eolian dunes. Fluvial deposits examined by Curiosity include both conglomerates and sandstones. The conglomerates have textures of fluvial conglomerates and contain rounded pebbles indicating substantial abrasion (Williams et al., 2013). The fluvial sandstones are cross-bedded (including compound cross-bedding), with dip directions indicating transport generally toward the southeast (toward Mt. Sharp rather than away from it). Fractures interpreted to be desiccation cracks and interbedded eolian (pinstriped) sandstones suggest that fluvial activity alternated with dry, windy, periods. Curiosity also examined deposits interpreted as distal fluvial or lacustrine mudstones (Sheepbed mudstone) at a location that is topographically lower than the fluvial sandstones and conglomerates. That unit is discussed in other abstracts in this session.

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Physical Sedimentology in Gale Crater, Mars

David M. Rubin[1], Lauren A. Edgar[2], Kevin W. Lewis[3], and the MSL Science Team
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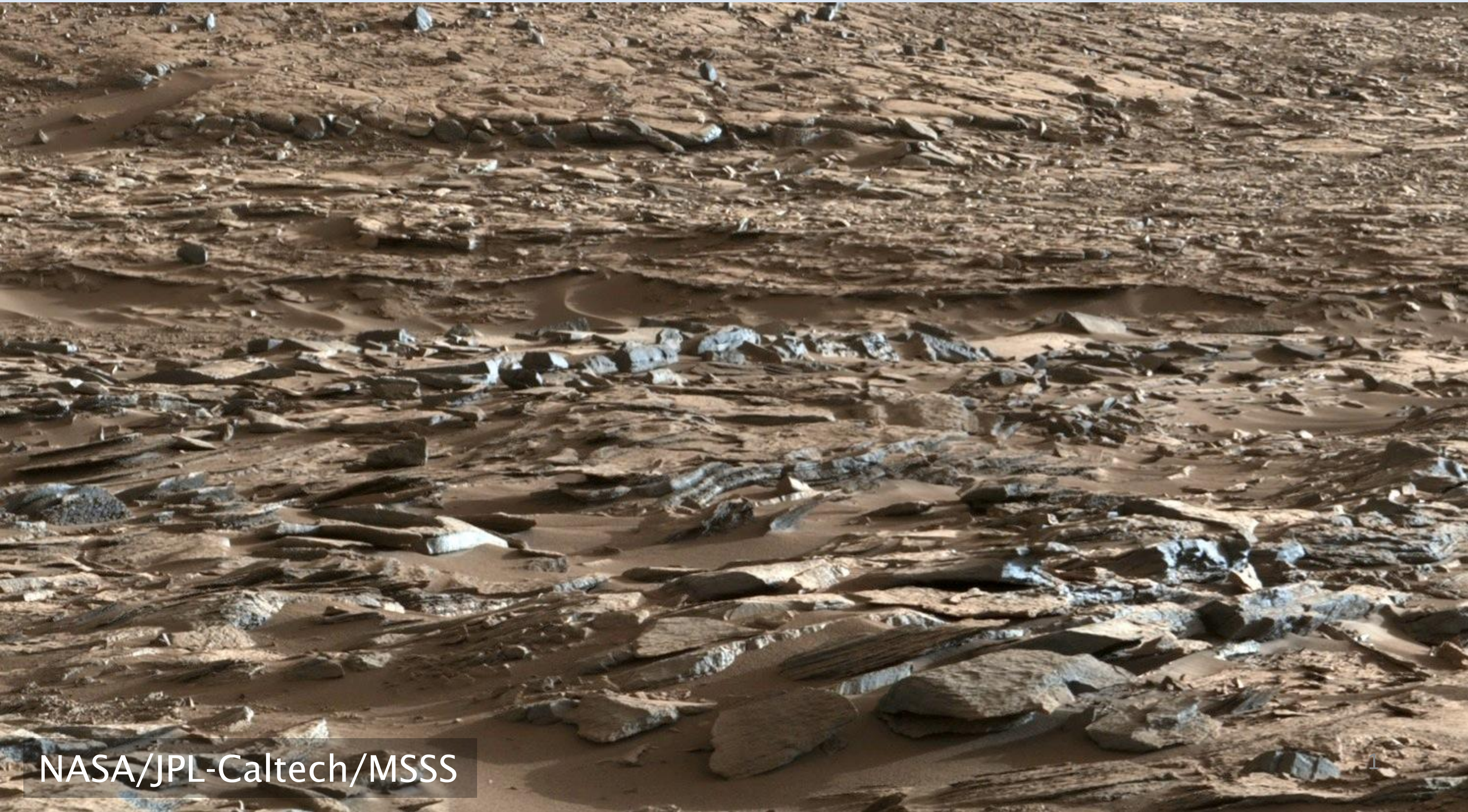


Lacustrine deposits

Fluvial deposits

- Conglomerates
- Sandstones
- Mudstones

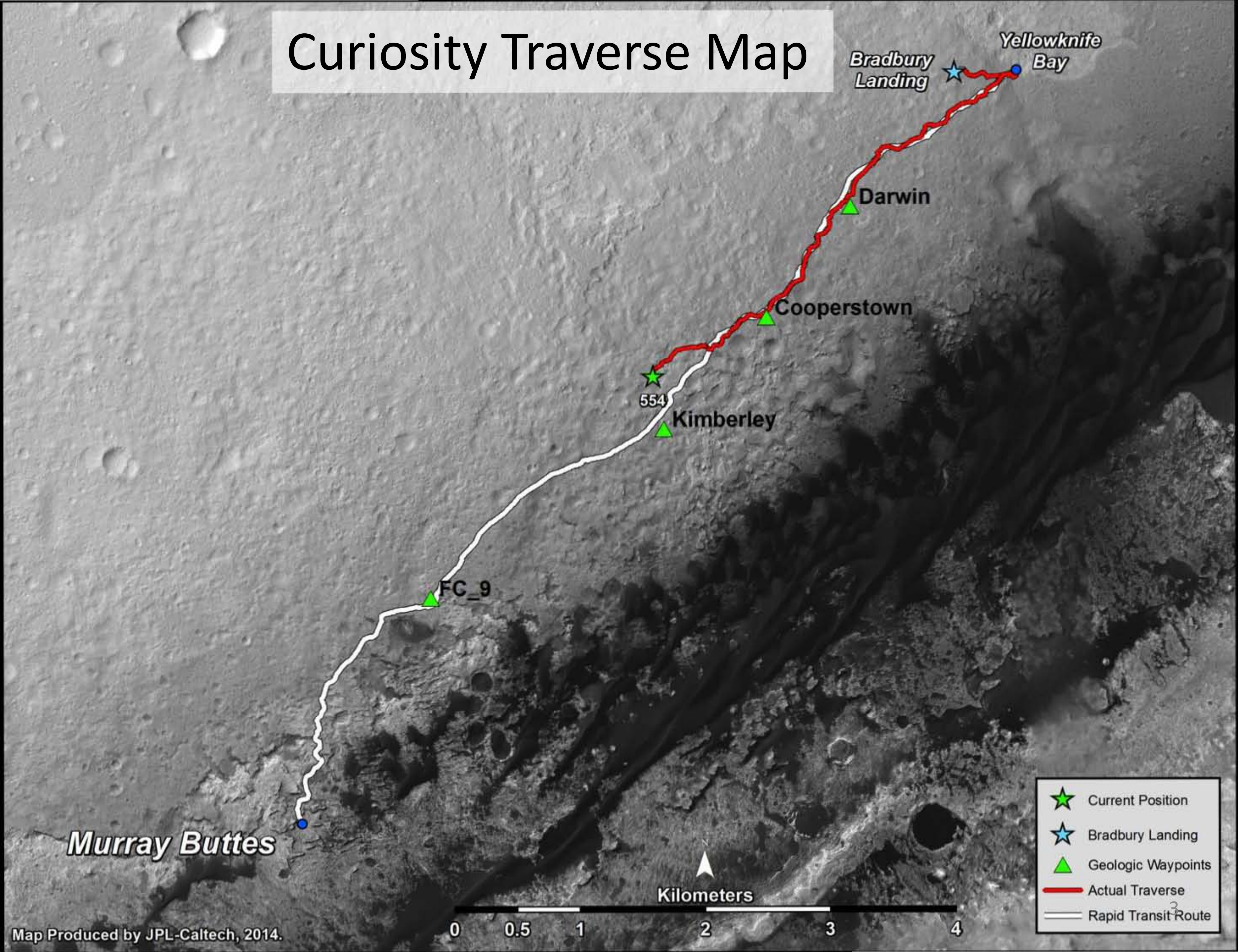
Aeolian deposits

- Sandstones
- Dunes
  - Sand-shadow dunes
  - Polygonal dunes
  - Bagnold dunes

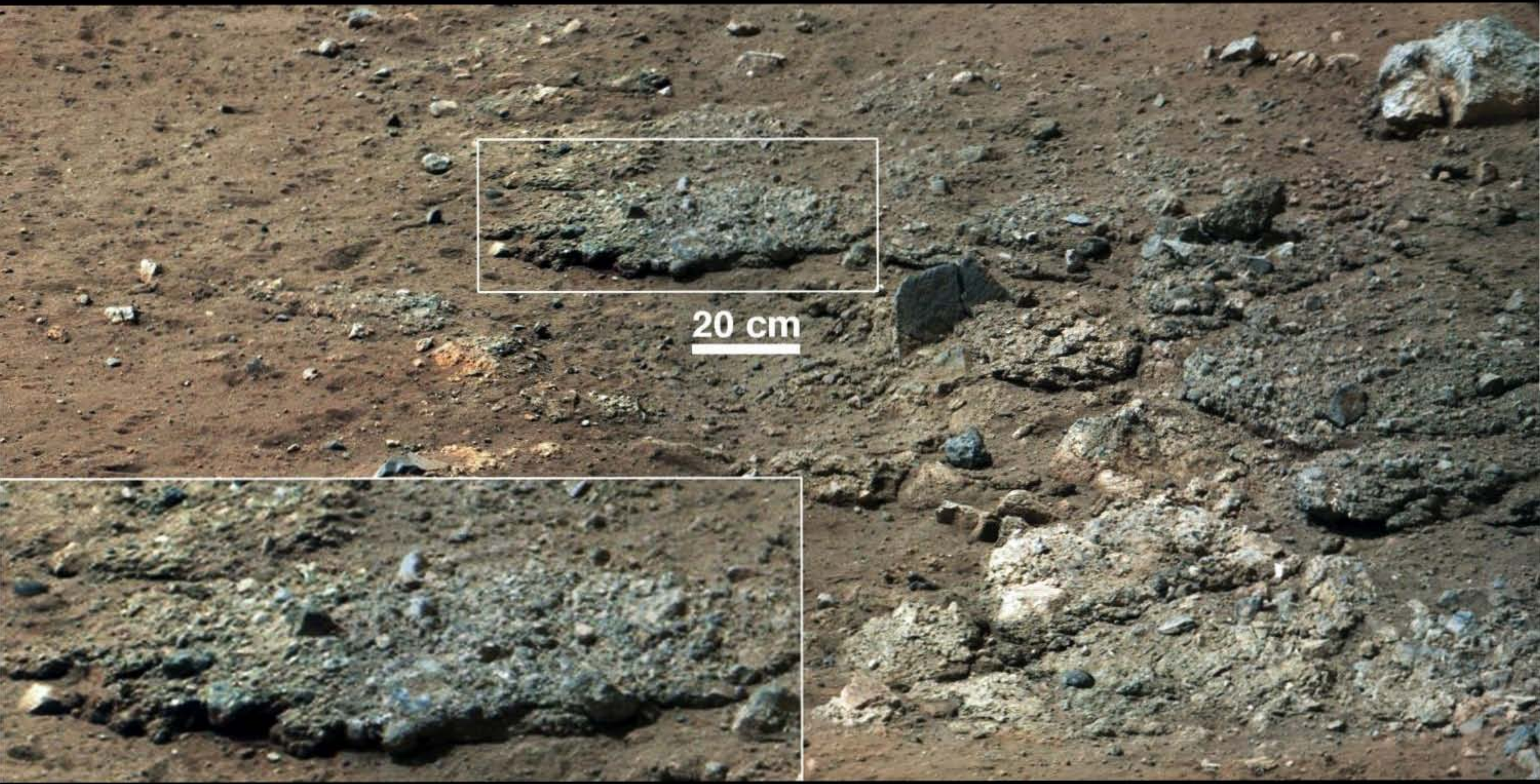
Upcoming highlights

NASA/JPL-Caltech/MSSS

Curiosity Traverse Map



Fluvial conglomerates



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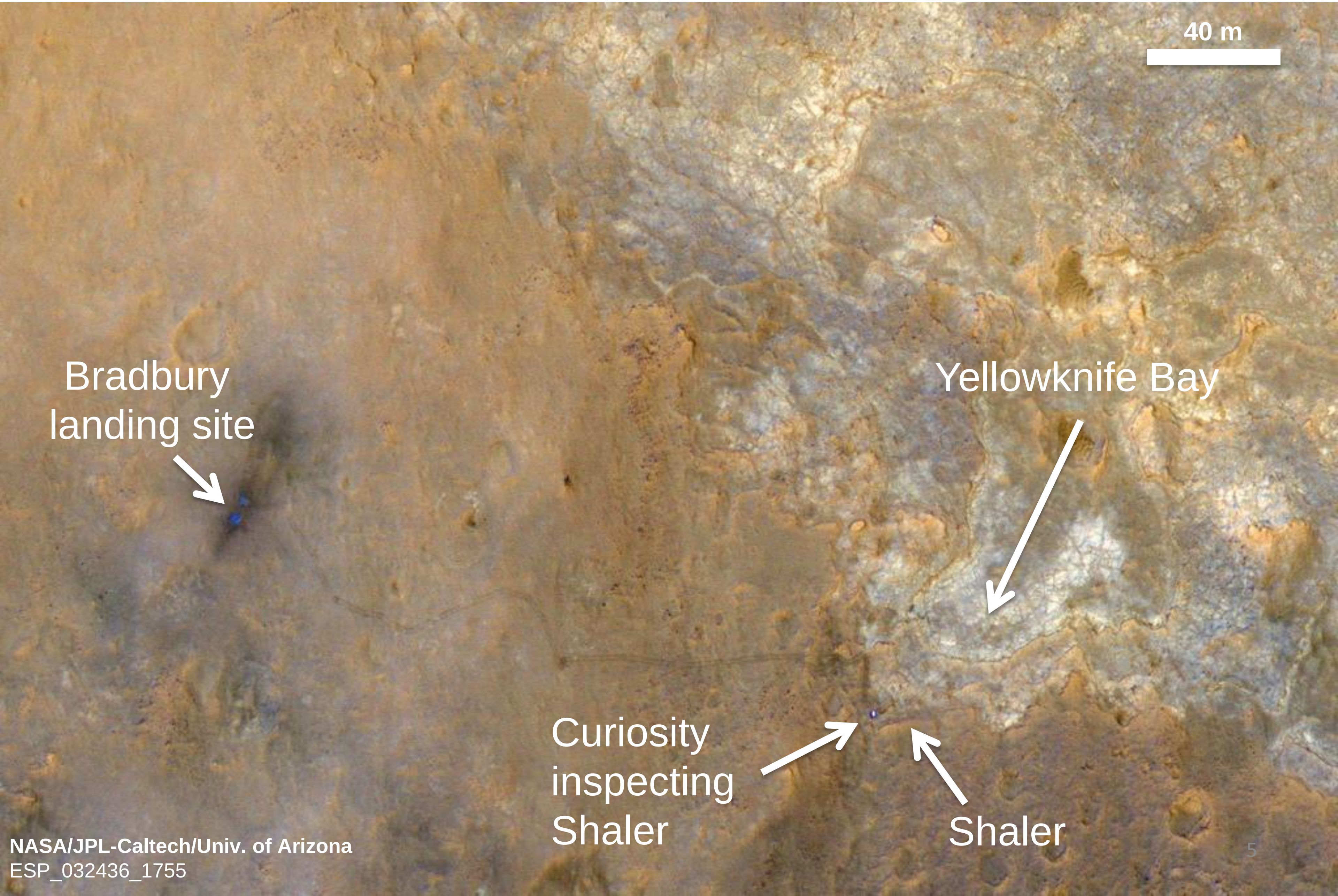
Goulburn, scoured by Curiosity's descent rockets, first revealed bedrock.

Curiosity at Shaler, as seen by HiRISE

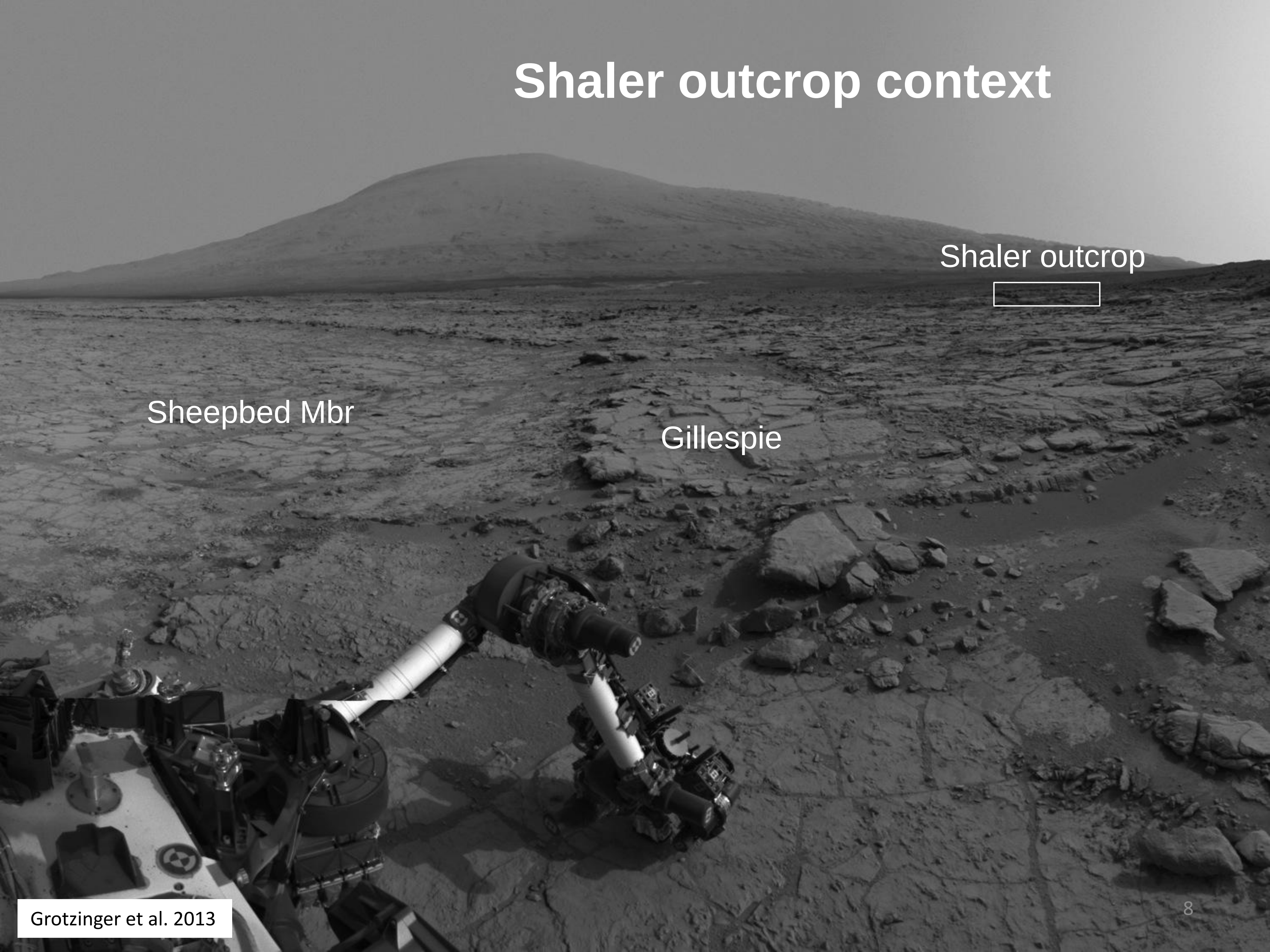


Lacustrine Sheepbed mudstone.
Many veins, but few (if any) primary physical structures documented.

NASA/JPL-Caltech/MSSS

NASA/JPL-Caltech/MSSS

Shaler outcrop context



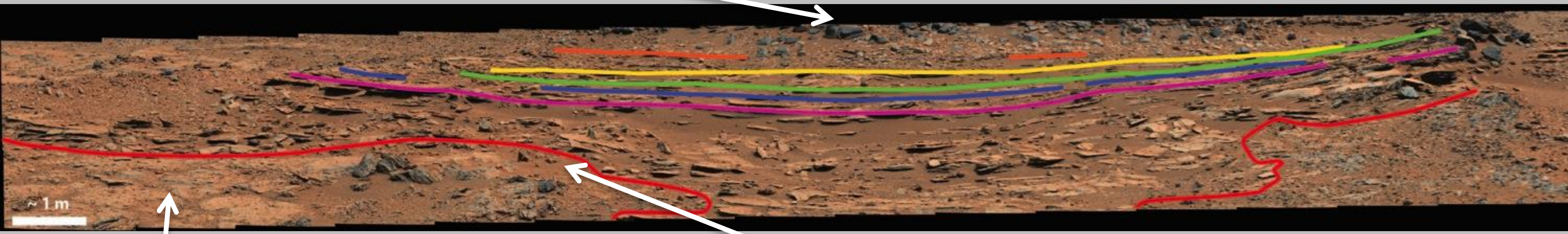
Grotzinger et al. 2013

Stratigraphic architecture

NE

SW

Shaler ‘Upper’ Unit

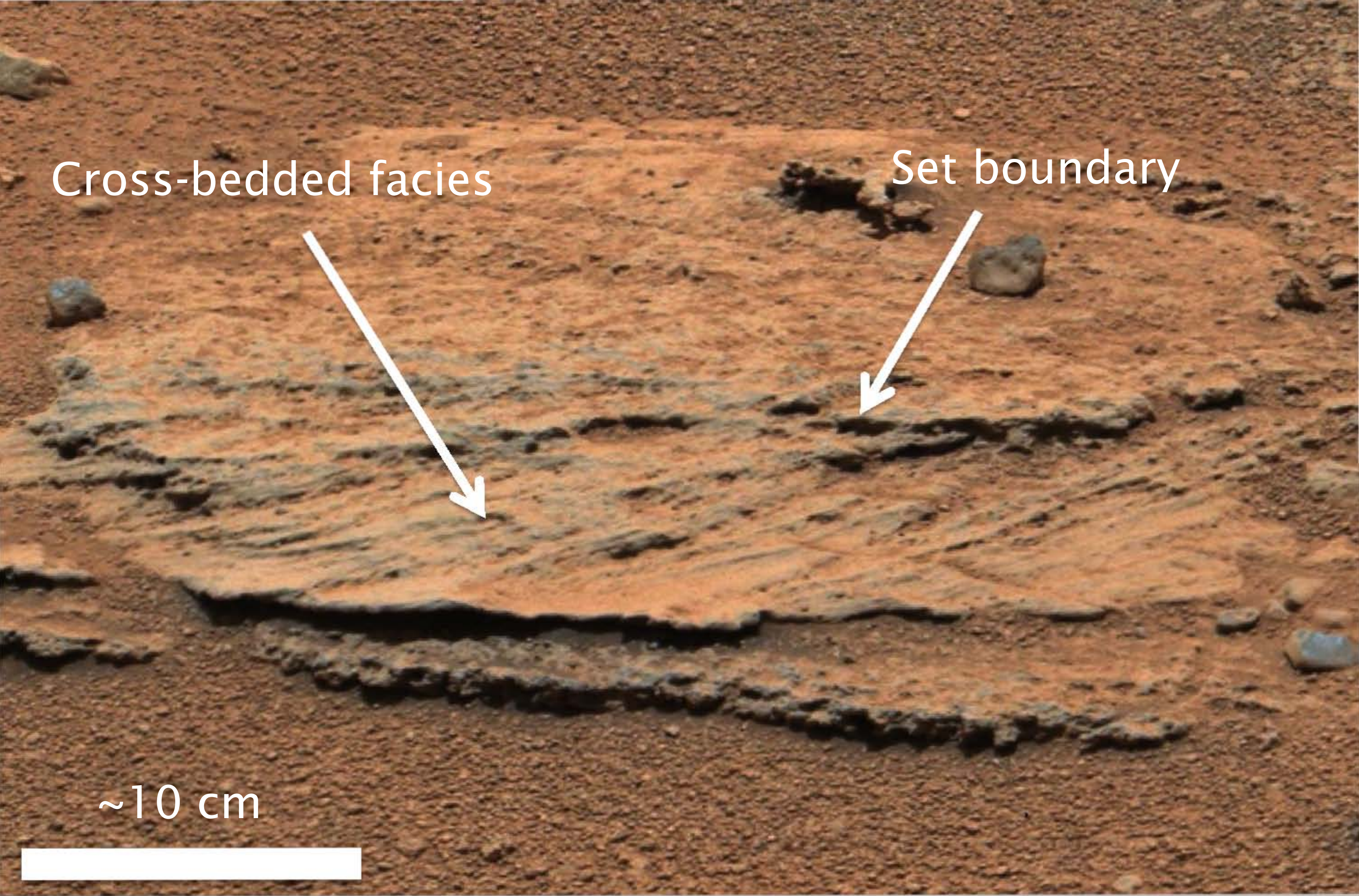


Gillespie Mb

Shaler basal surface (erosional relief exaggerated due to outcrop geometry)

NASA/JPL-Caltech/MSSS

Sol120_mcam00752



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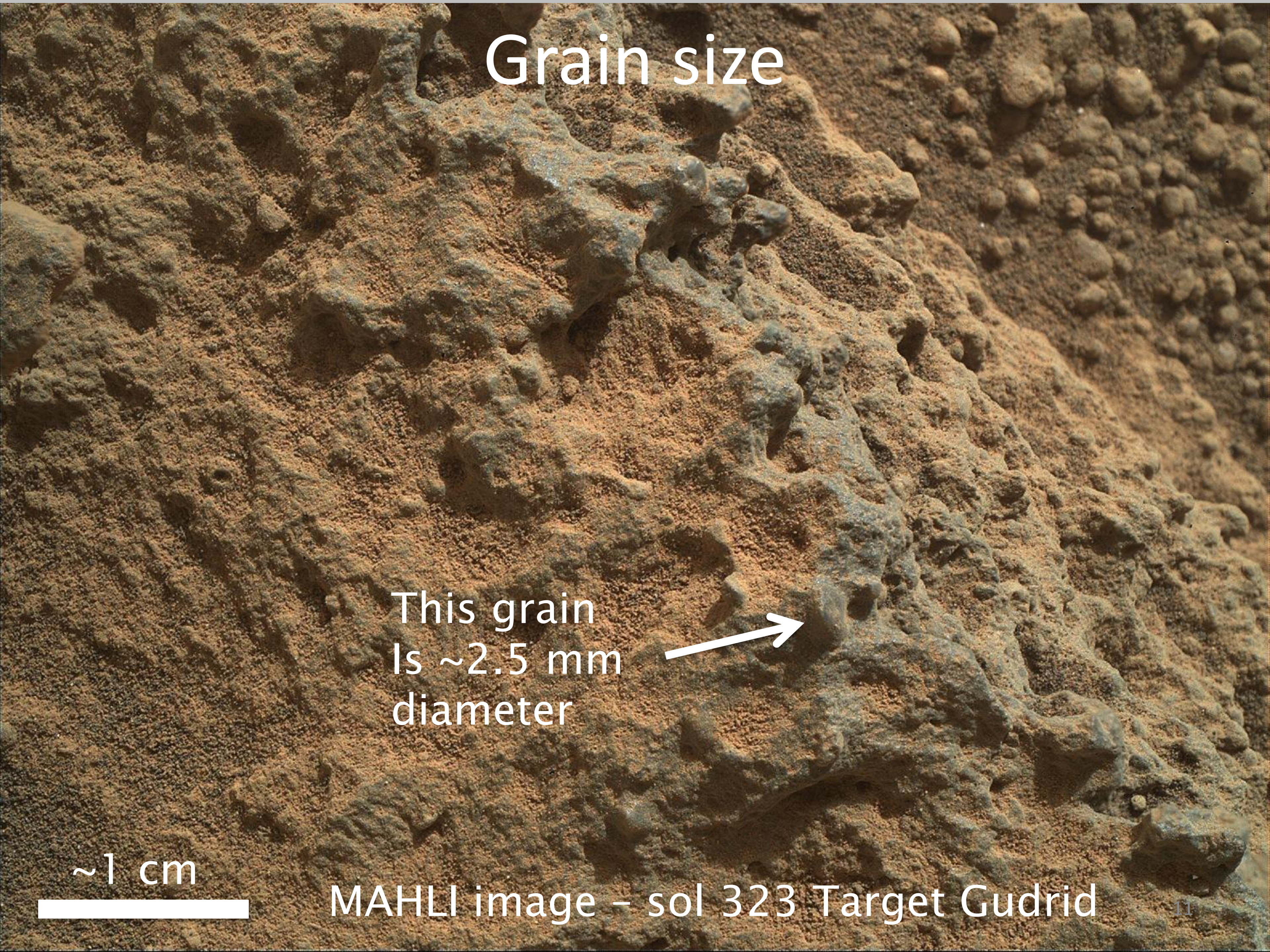
Sol318_mcam01302

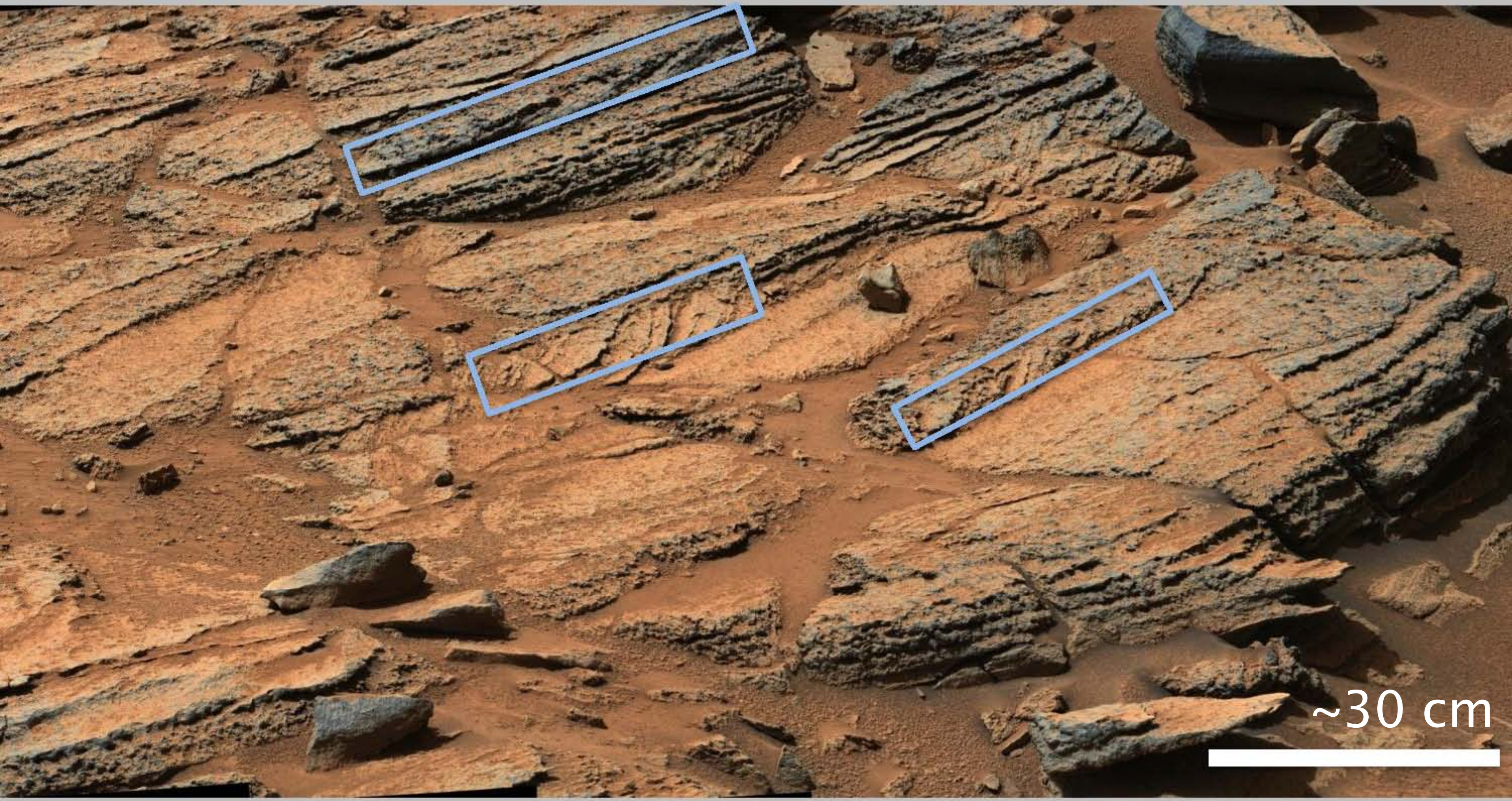

Grain size
This grain
Is ~2.5 mm
diameter
~1 cm
MAHLI image - sol 323 Target Gudrid

Cross-stratification

NASA/JPL-Caltech/MSSS

Sol319_mcam01306

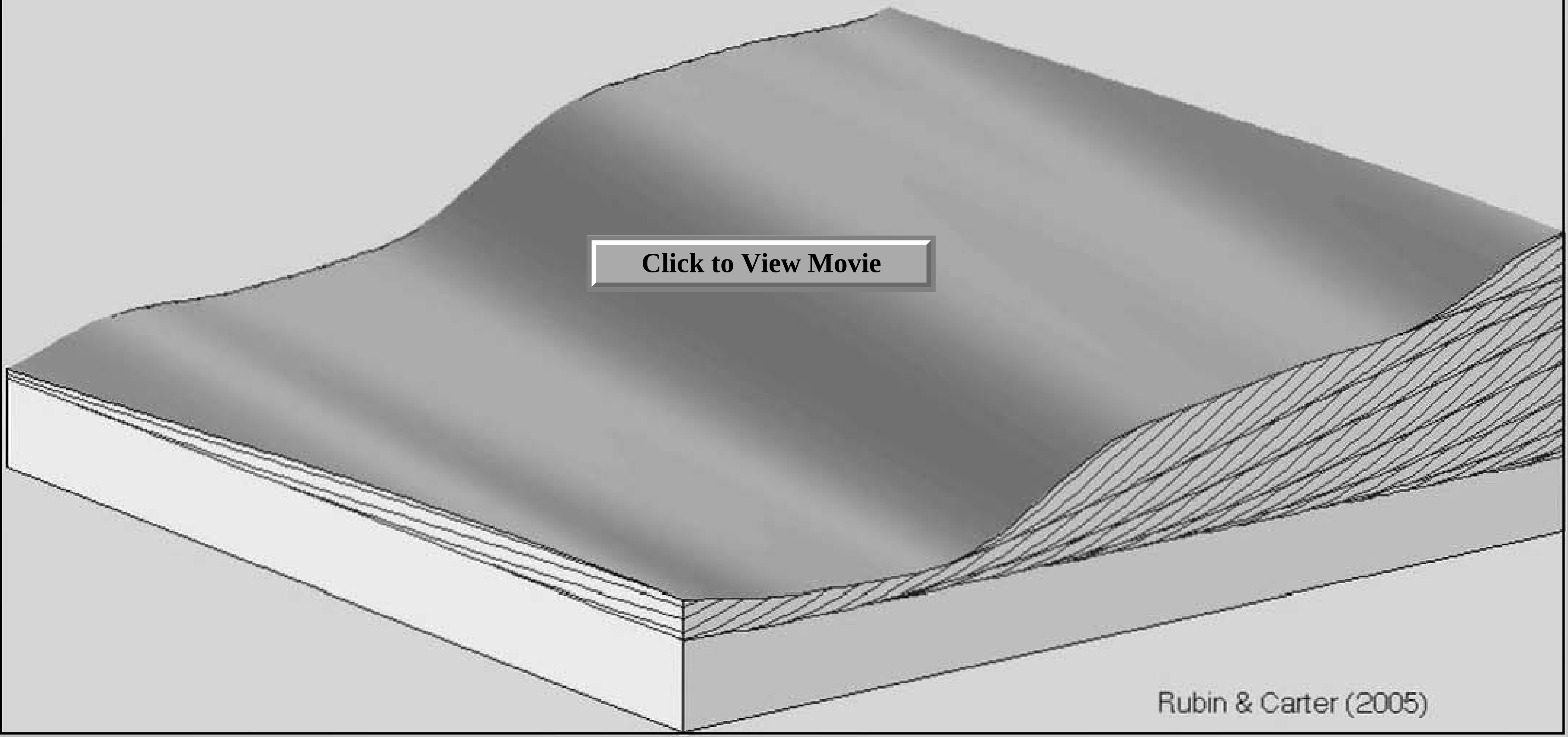
Compound cross-stratification



NASA/JPL-Caltech/MSSS

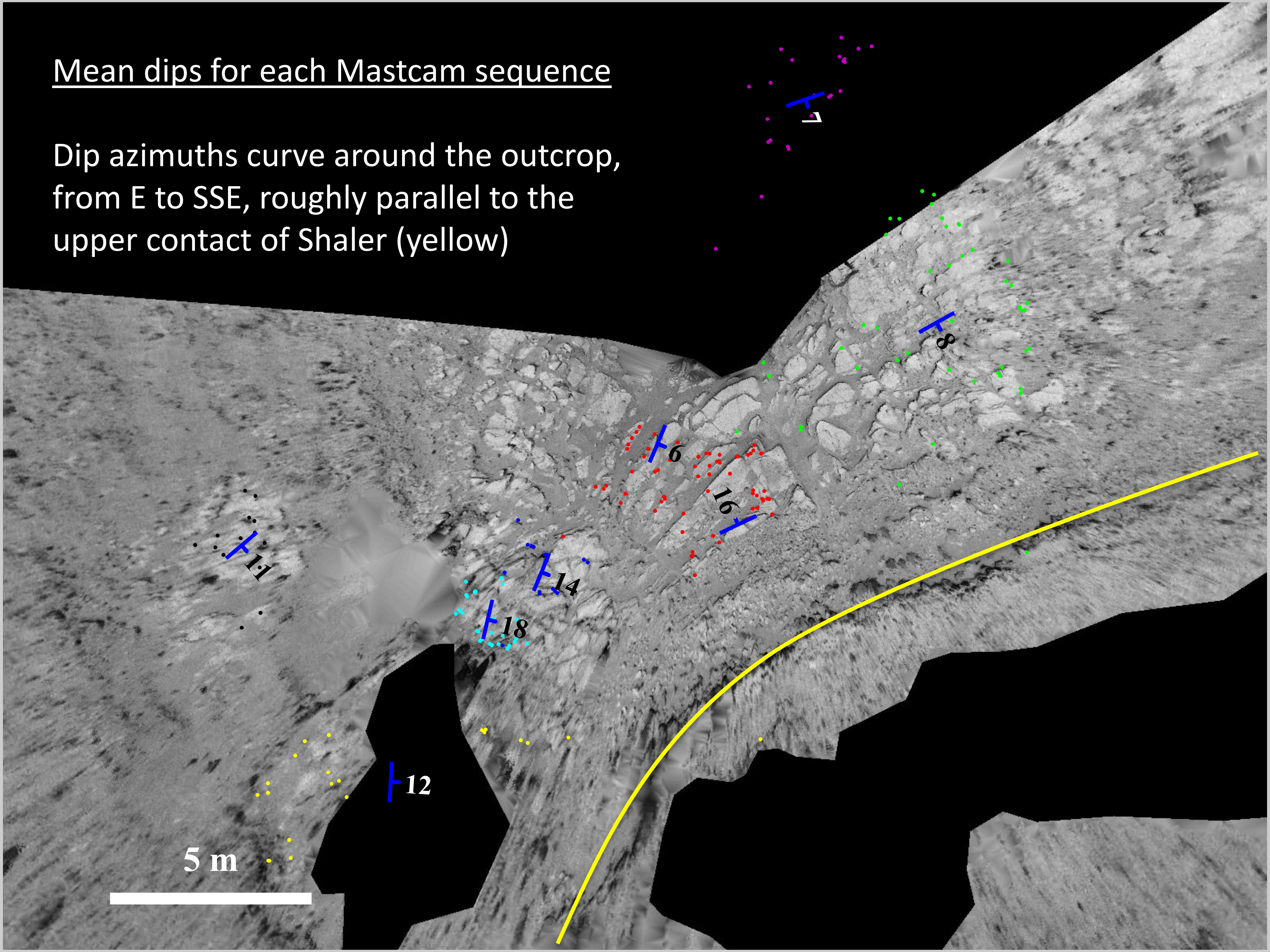
Sol319_mcam01306

Compound cross-stratification

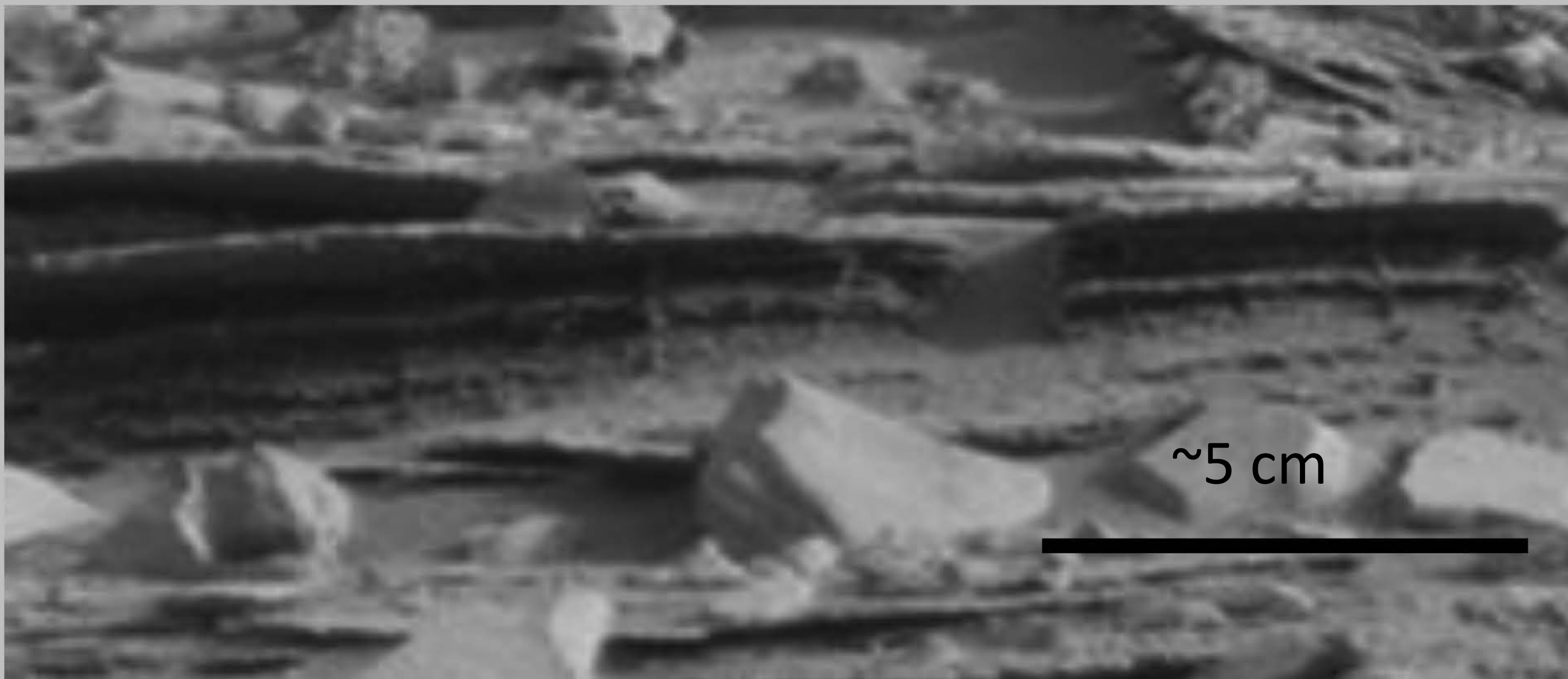


Mean dips for each Mastcam sequence

Dip azimuths curve around the outcrop, from E to SSE, roughly parallel to the upper contact of Shaler (yellow)



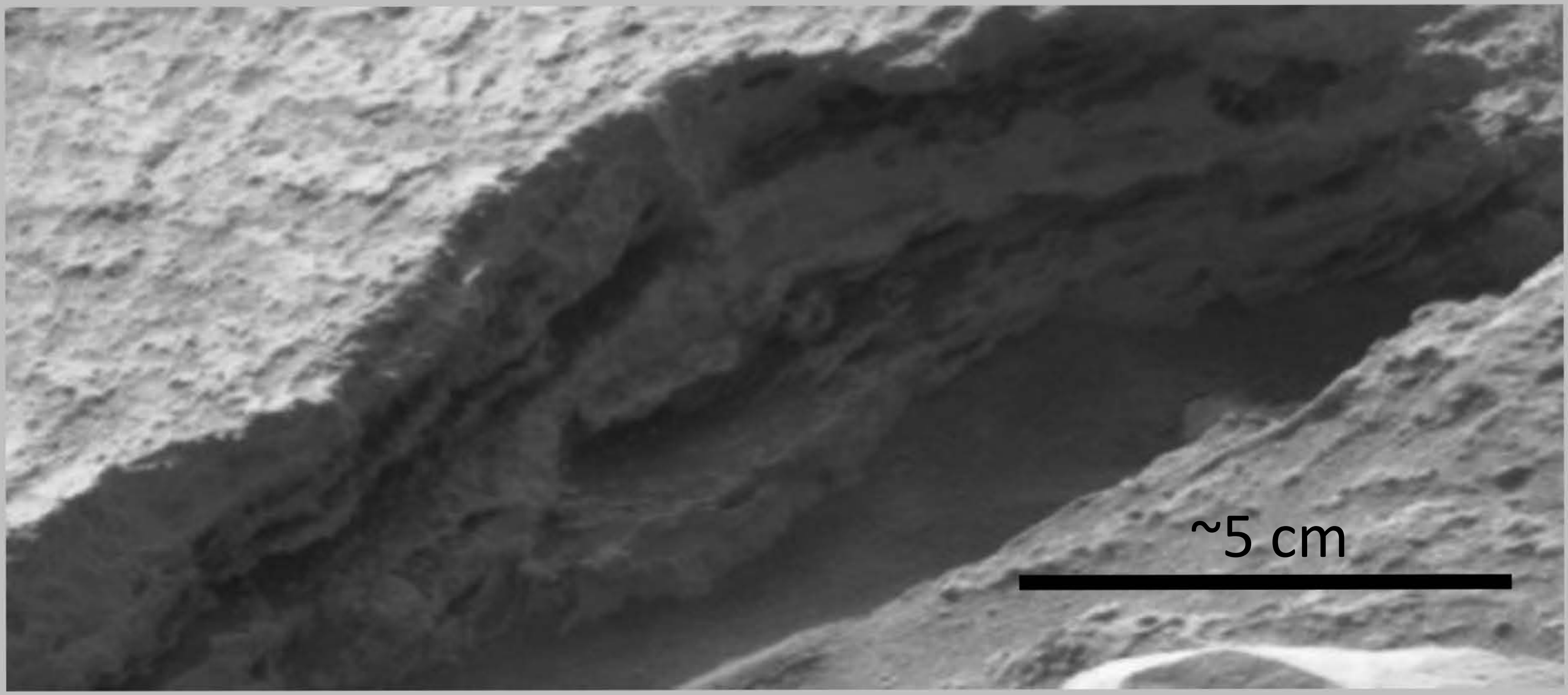
Recessive facies with desiccation cracks



Sol311_mcam01279

NASA/JPL-Caltech/MSSS

Convoluted facies



Sol311_mcam01279

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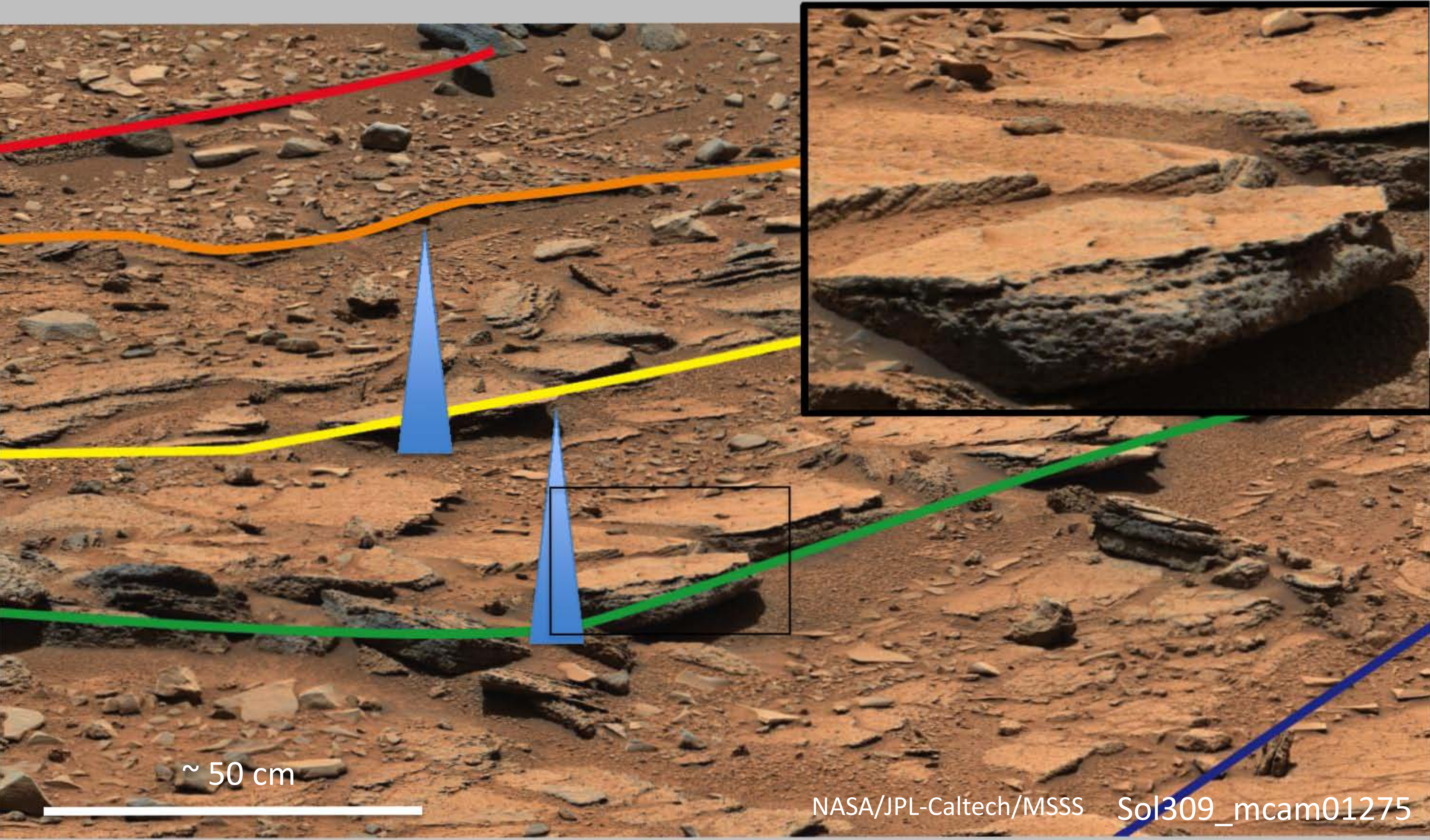
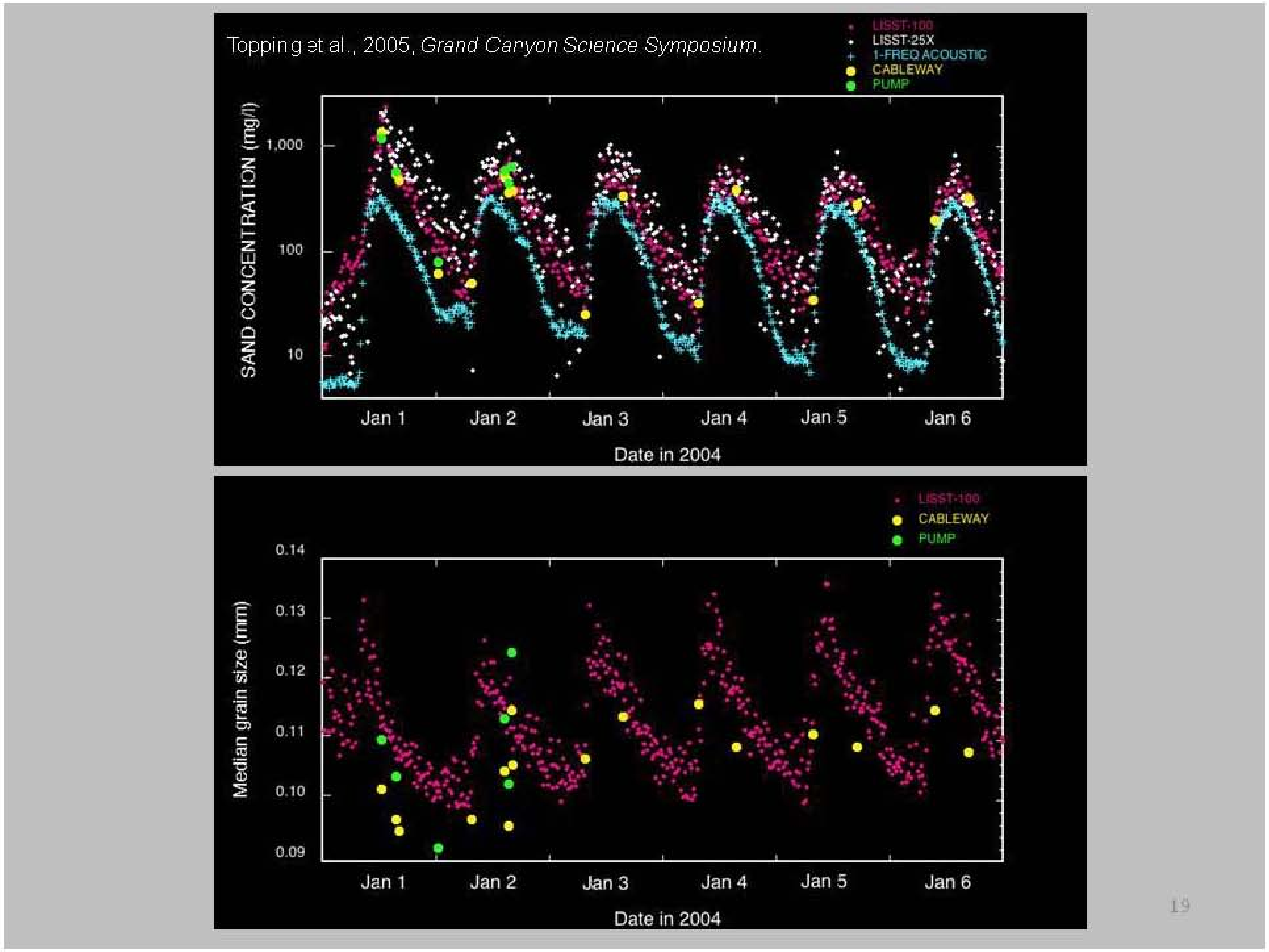
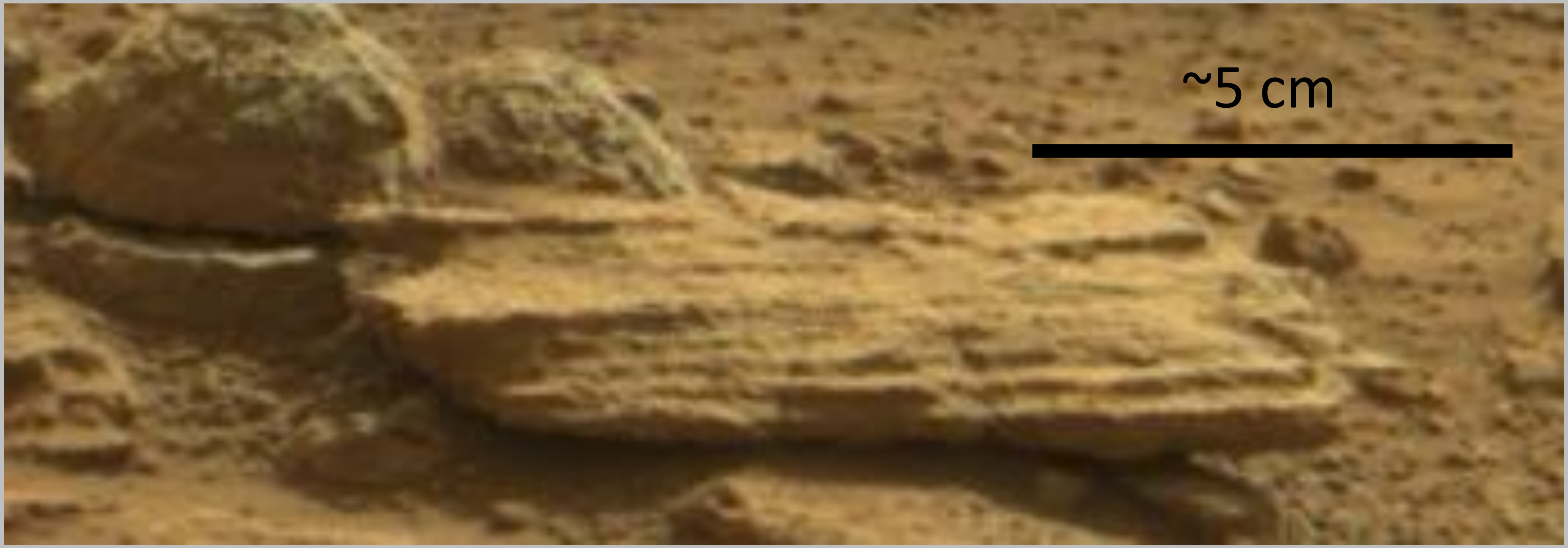
Vertical variability in grain size (fining upward)





Presenter's notes: Daily cycles in river discharge. Peak discharge can suspend more sand (top) and coarser sand (lower plot). Positively correlated trends indicate flow-regulated transport.

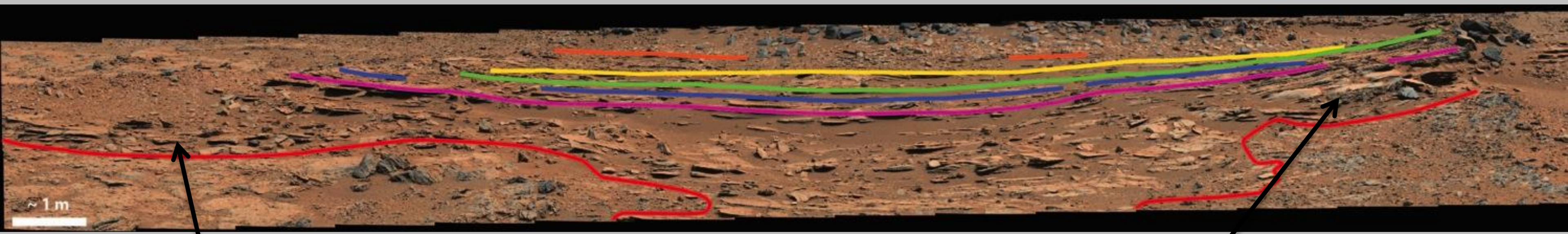
Aeolian sandstone at Shaler



Sol311_mcam01279
NASA/JPL-Caltech/MSSS

Aeolian wind-ripple pin-stripe laminae (Hunter, 1977), in Entrada Sandstone.

Spatial variability in grain size and sedimentary structures



Sol120_mcam00752 NASA/JPL-Caltech/MSSS

<u>NE Shaler</u>

- More recessive
- Soft sediment deformation
- Desiccation cracks
- Aeolian reworking

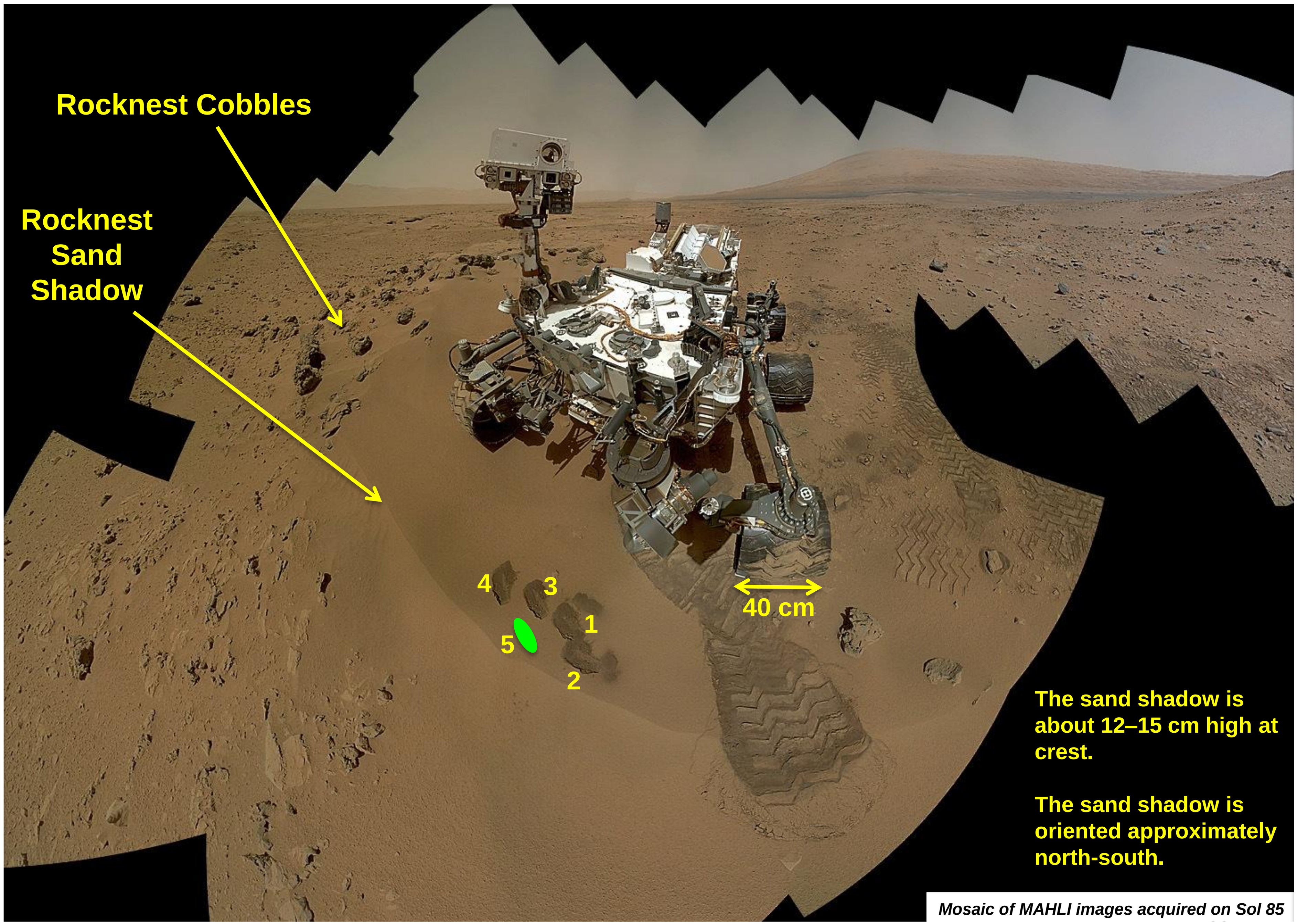
<u>SW Shaler</u>

- More resistant
- Compound cross-bedding
- Higher abundance of gravel

Stratification (lenses) or veins?

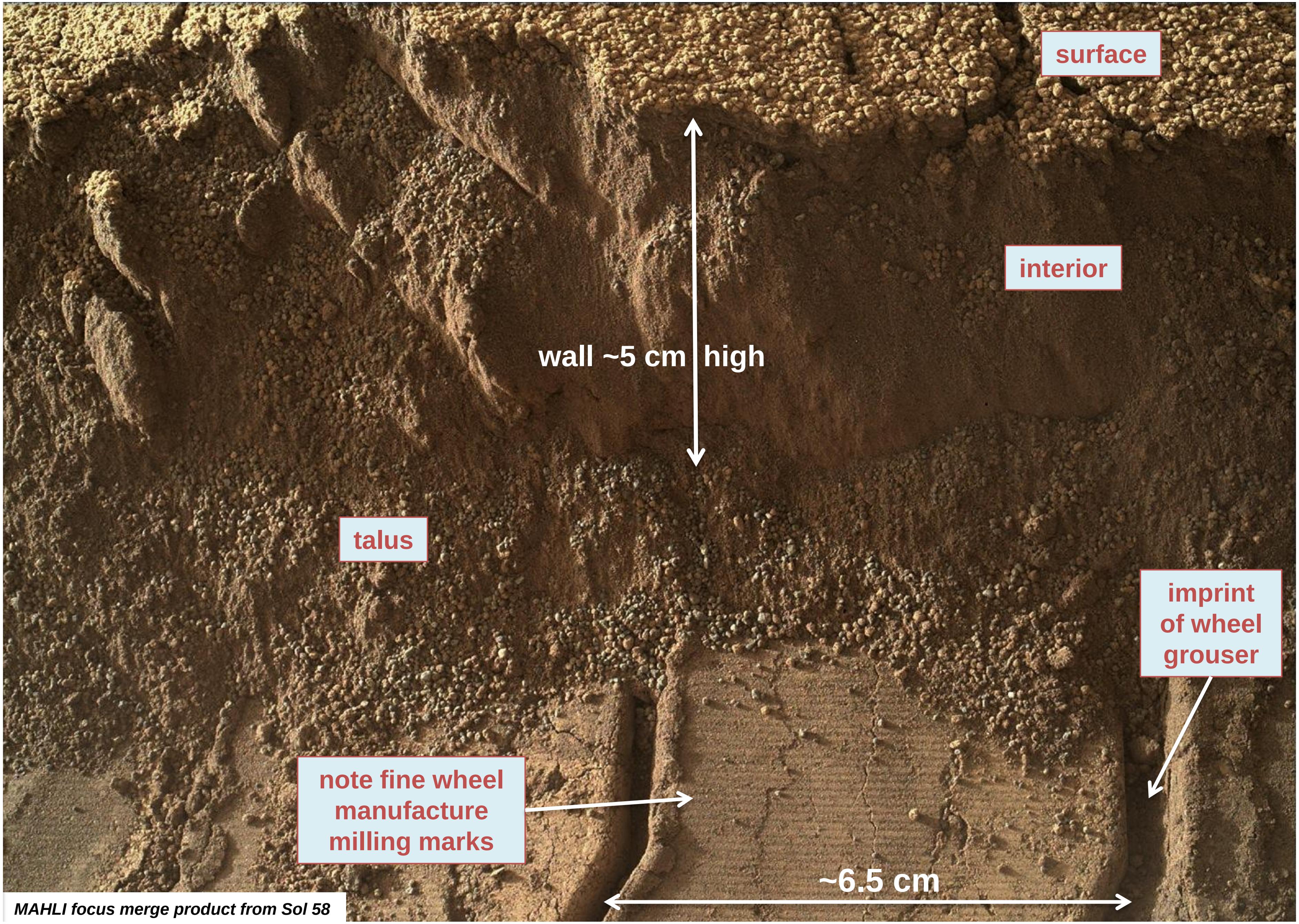
NASA/JPL-Caltech/MSSS

Sol 392

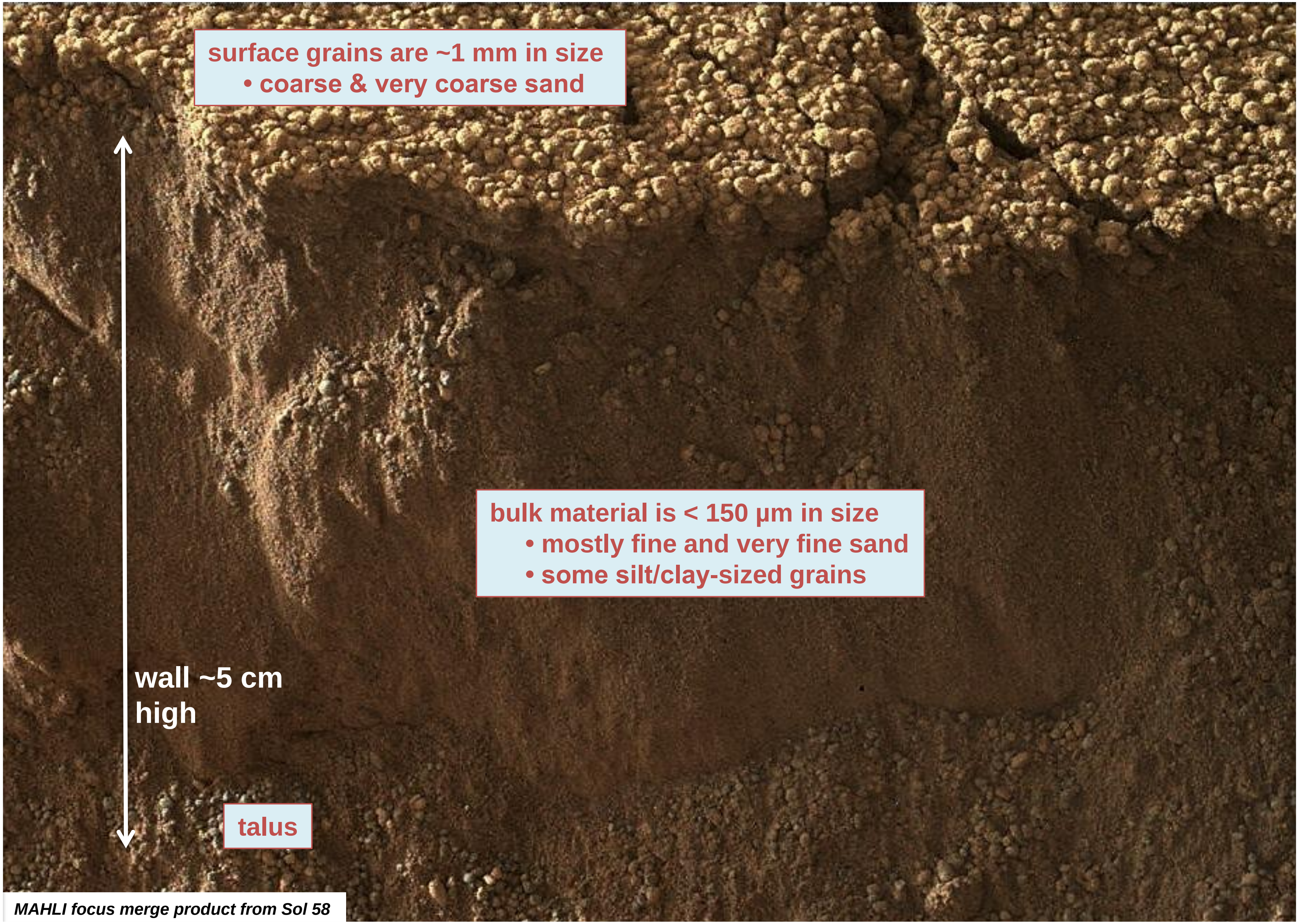


Rocknest Cobbles
Rocknest Sand Shadow
4
3
1
5
2
40 cm
The sand shadow is about 12–15 cm high at crest.
The sand shadow is oriented approximately north-south.
Mosaic of MAHLI images acquired on Sol 85

Sand-shadow dunes in Qaidam Basin, China
Sand accumulates in weak flow in lee of obstacles (Bagnold).

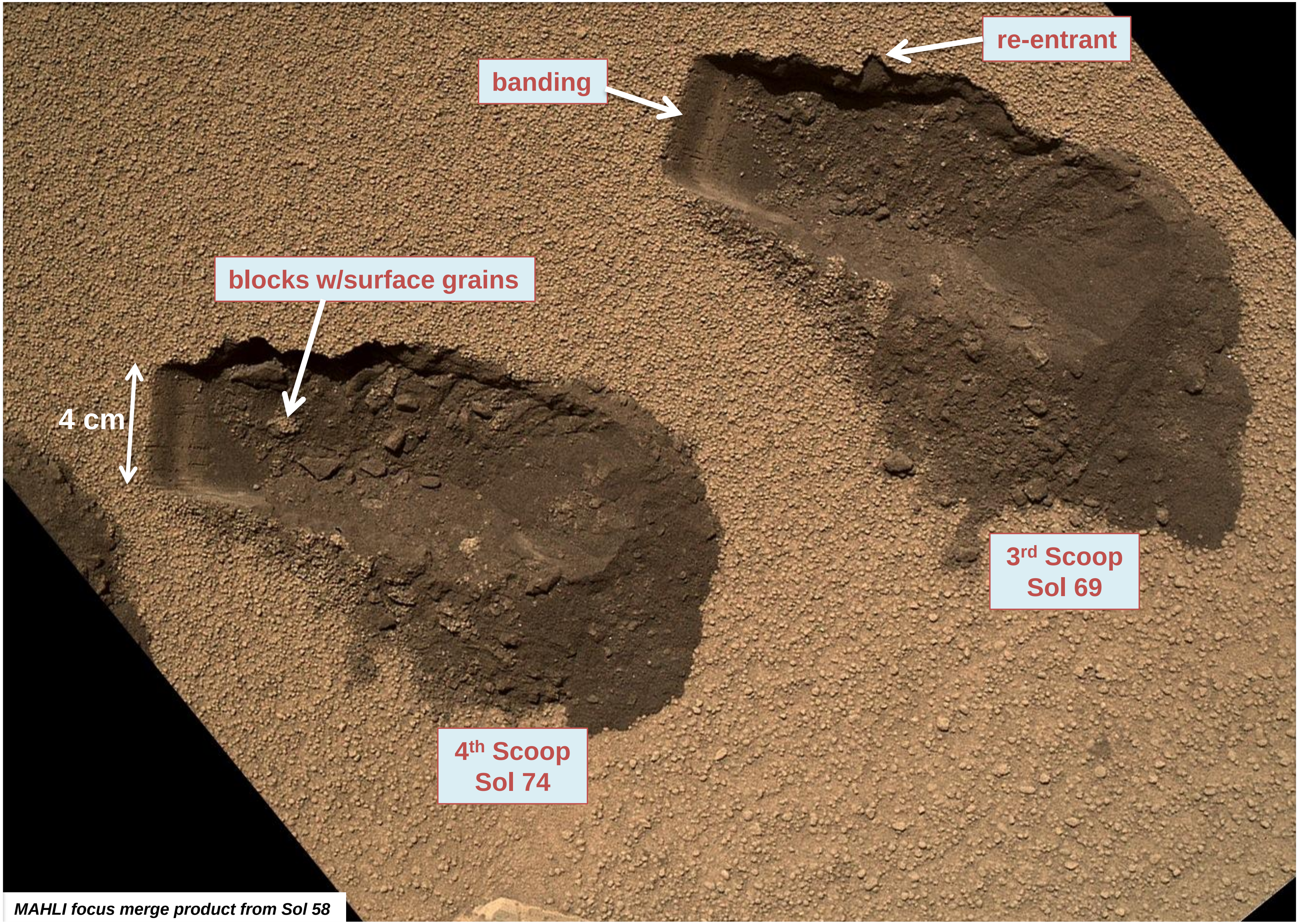


MAHLI focus merge product from Sol 58

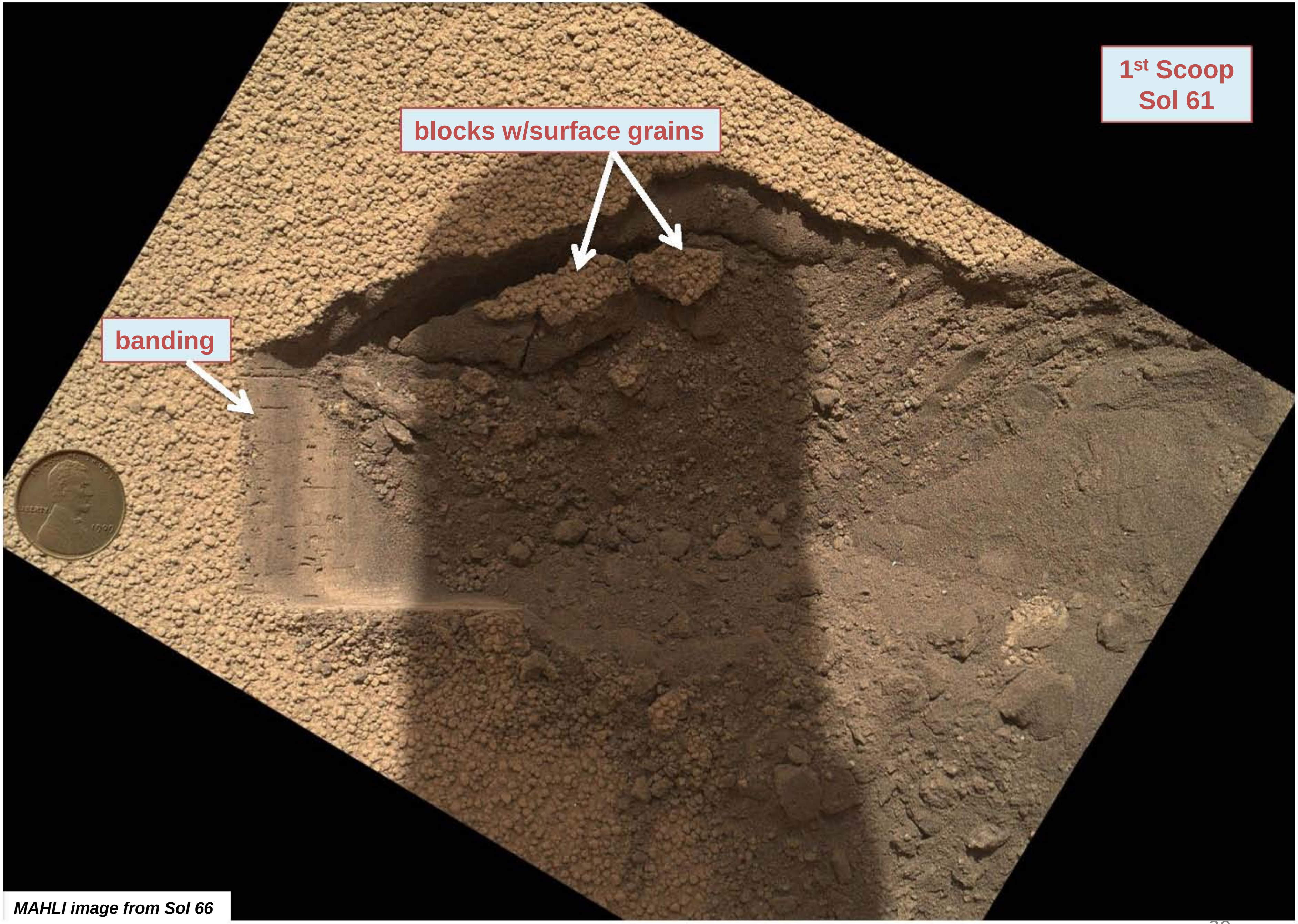


MAHLI focus merge product from Sol 58

MAHLI image from Sol 67



MAHLI focus merge product from Sol 58


1st Scoop
Sol 61
blocks w/surface grains
banding
MAHLI image from Sol 66

Assume Application of Law-of-the-Wall

$$u_z = \frac{u_*}{k} \ln\left(\frac{z}{z_o}\right)$$

u_z = wind speed at height z

$k = 0.407$

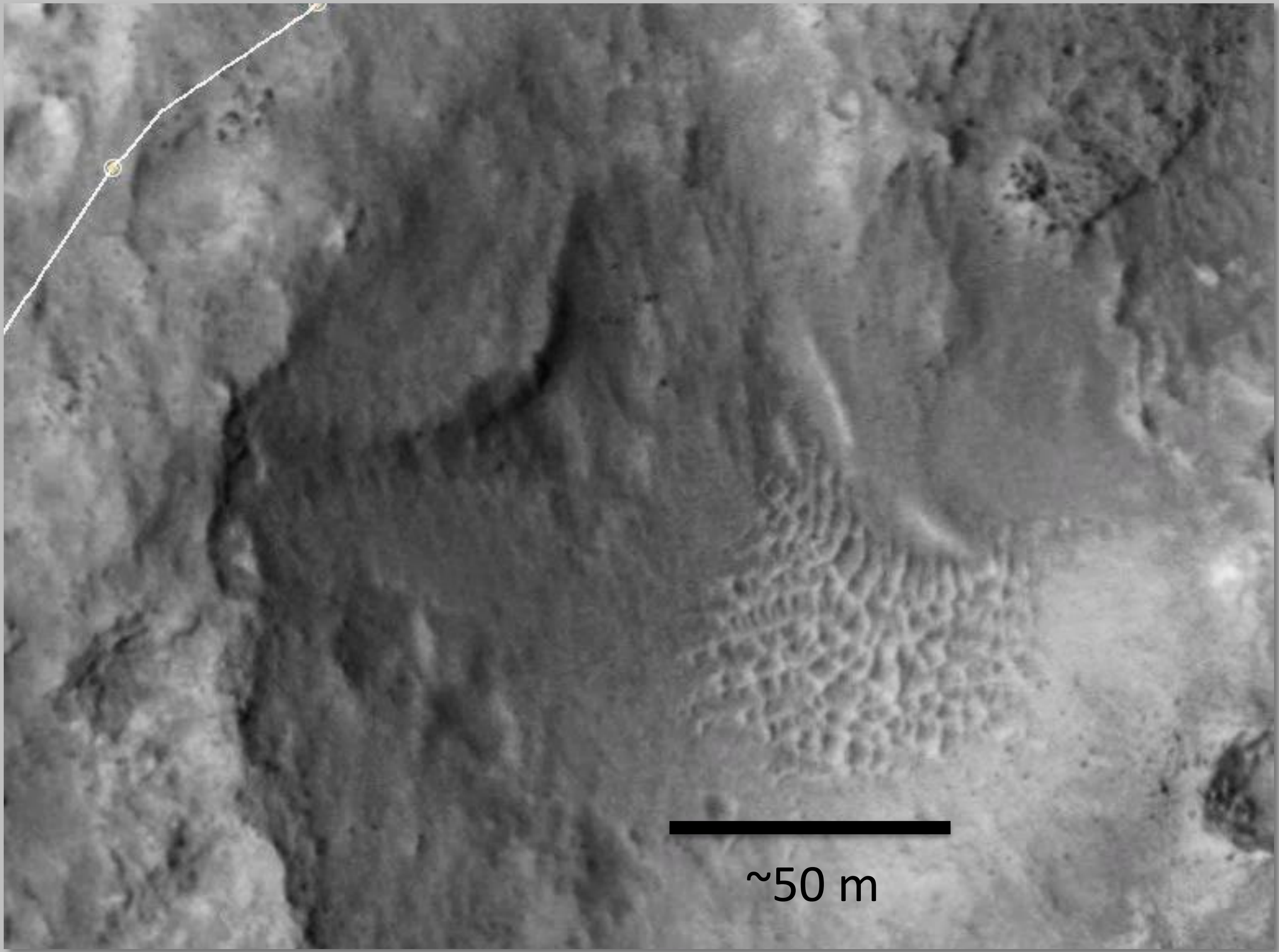
z_0 varies with grain size and height of surface features such as wind ripples (Bagnold 1941), but also the height and intensity of the saltation cloud (Owen 1964).

Assume z_0 = 0.3 mm where z_o = k/30 and k is 10 mm ripple height.

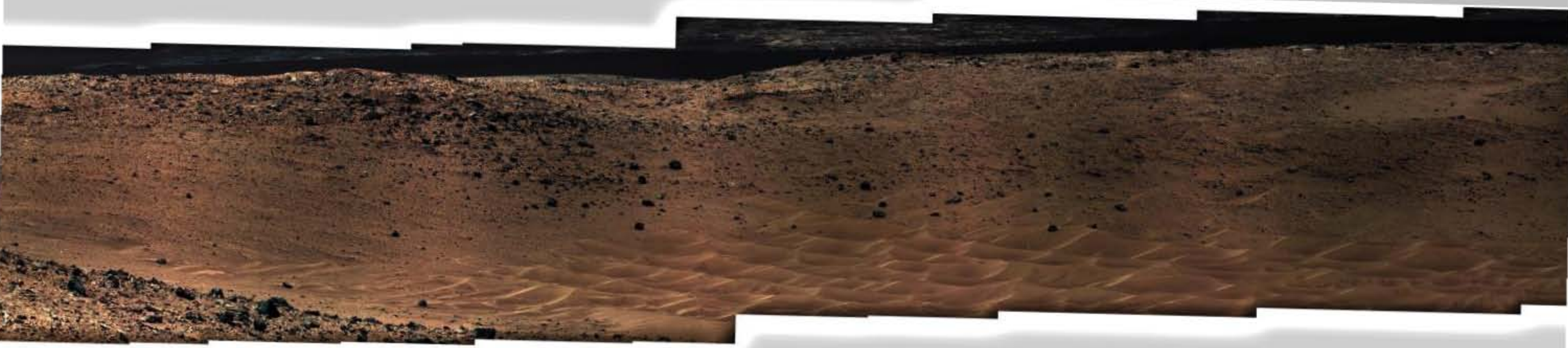
$u_{1\,m}$ = 51 m/s (114 mph) = Fluid threshold speed

$u_{1\,m}$ = 37 m/s (84 mph) = Impact threshold speed

Kocurek and others, 2013.



Dunes in crater, sol 426.
NASA/JPL-Caltech/Univ. of Arizona

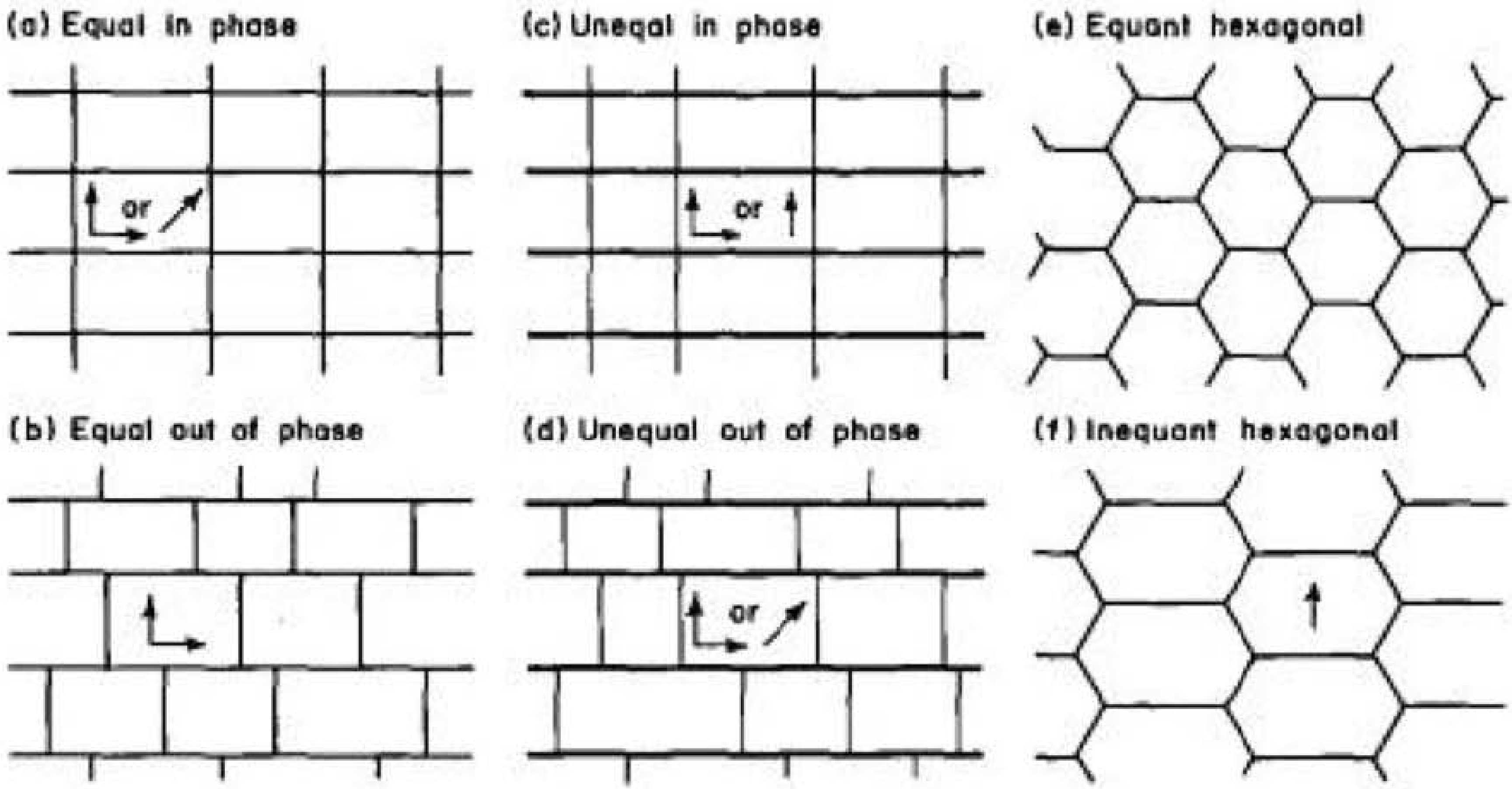


NASA/JPL-Caltech/MSSS. Dunes in crater, sol 426.

NASA/JPL-Caltech/MSSS. Dunes in crater, sol 426.

Polygonal dunes, Victoria Crater, Mars

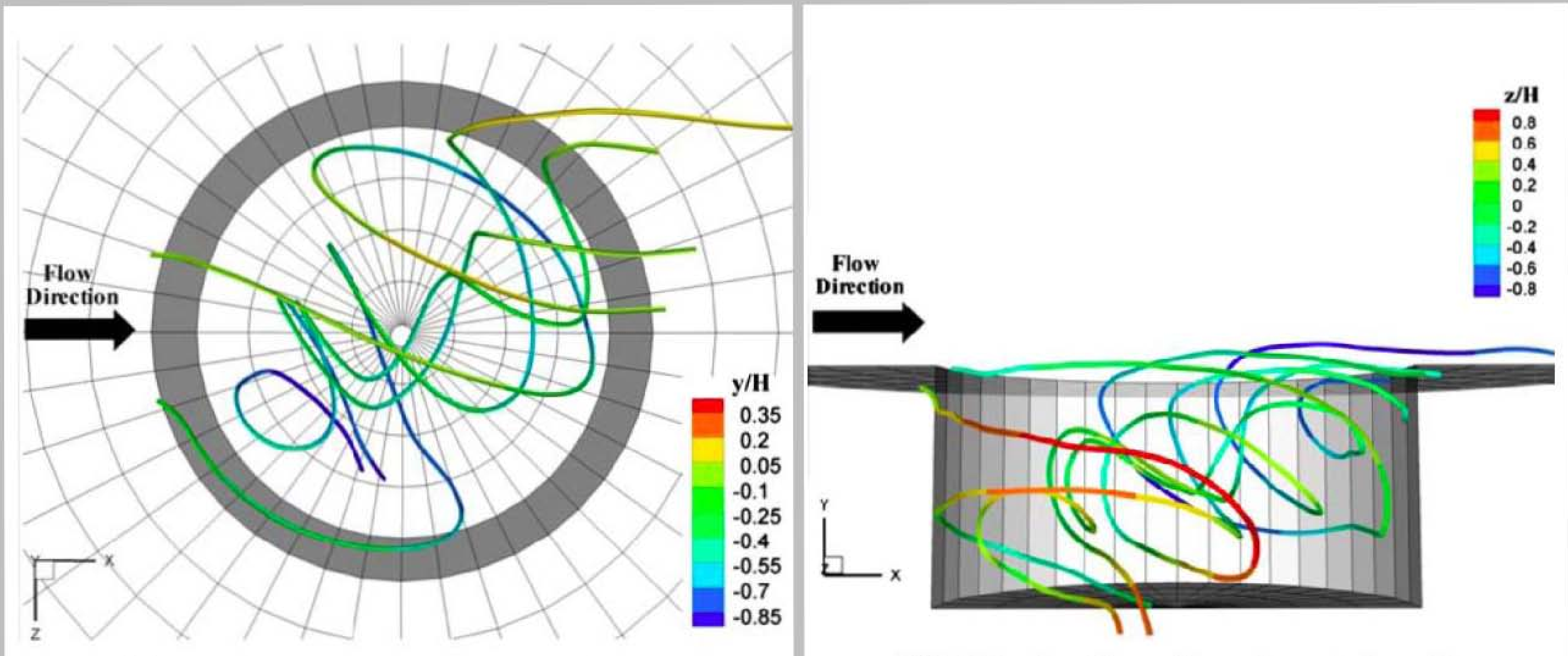
CREDIT: NASA/JPL/Univ. of Arizona



J.R.L. Allen, 1982, *Sedimentary Structures, Their Character and Physical Basis, Volume 1*

Lab

Observed streamlines in recirculating flow in cylinder with open top.

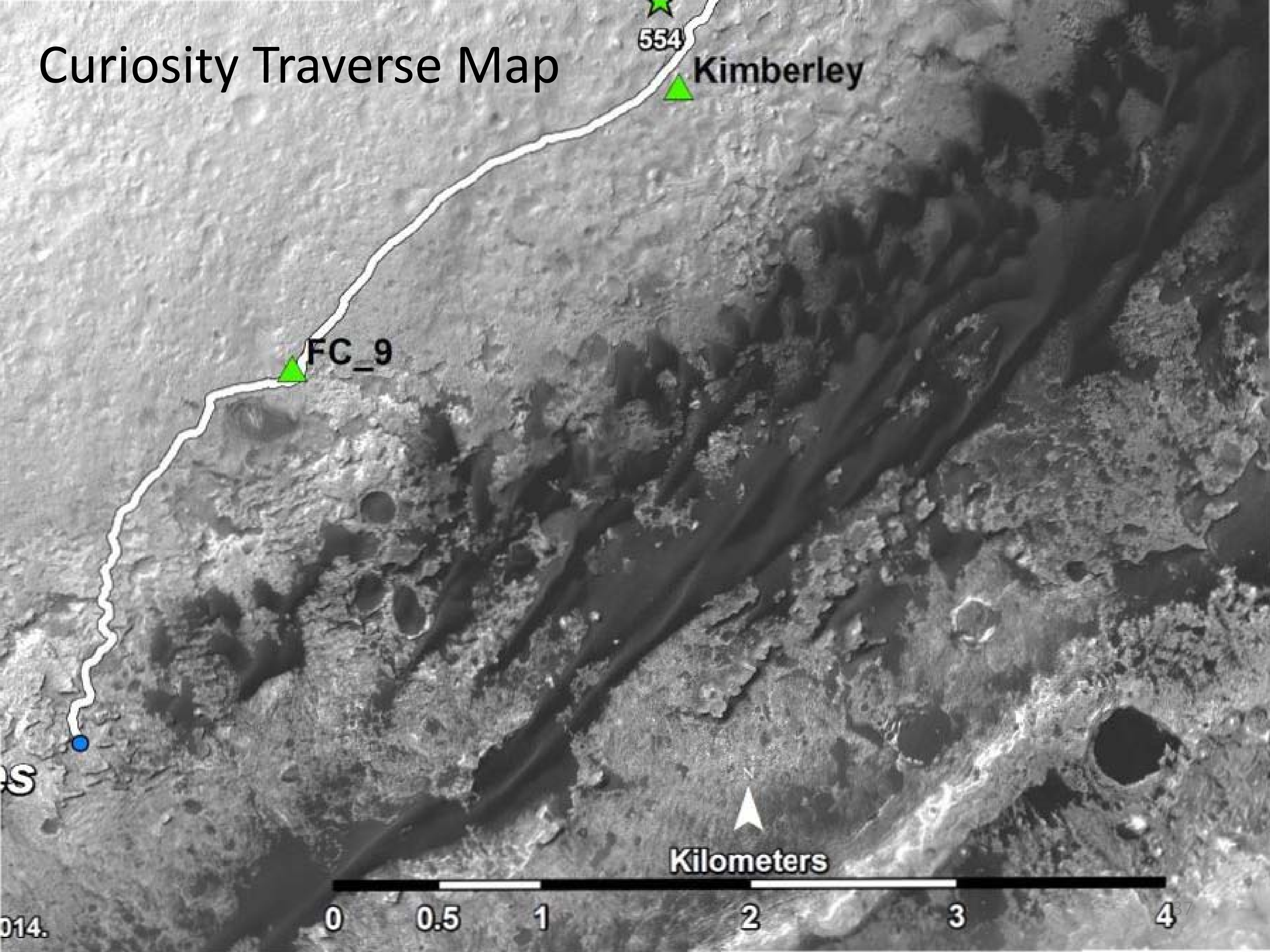


(a) Top view. Streamline color coded by y/H.

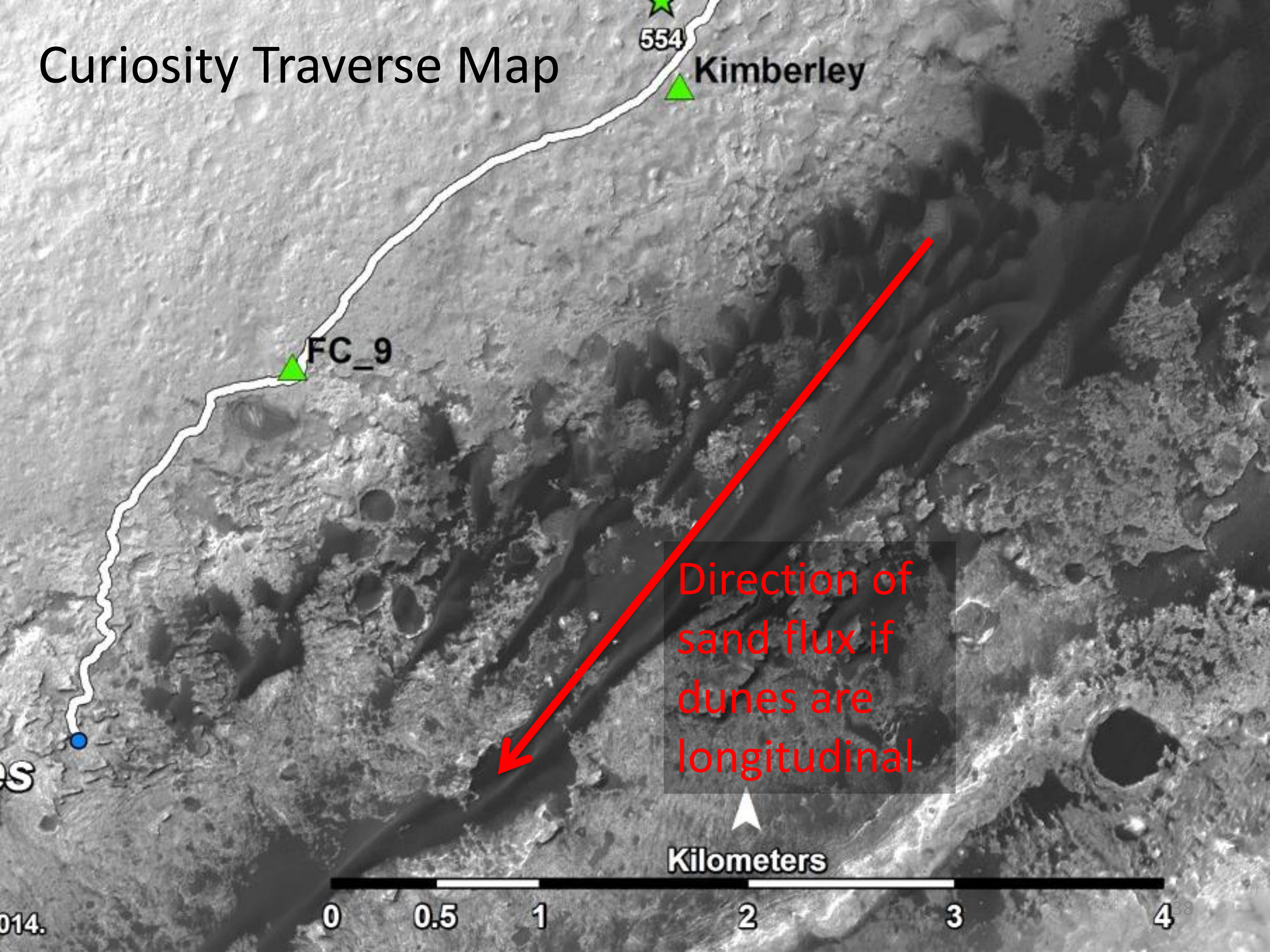
(b) Side view. Streamline color coded by z/H.

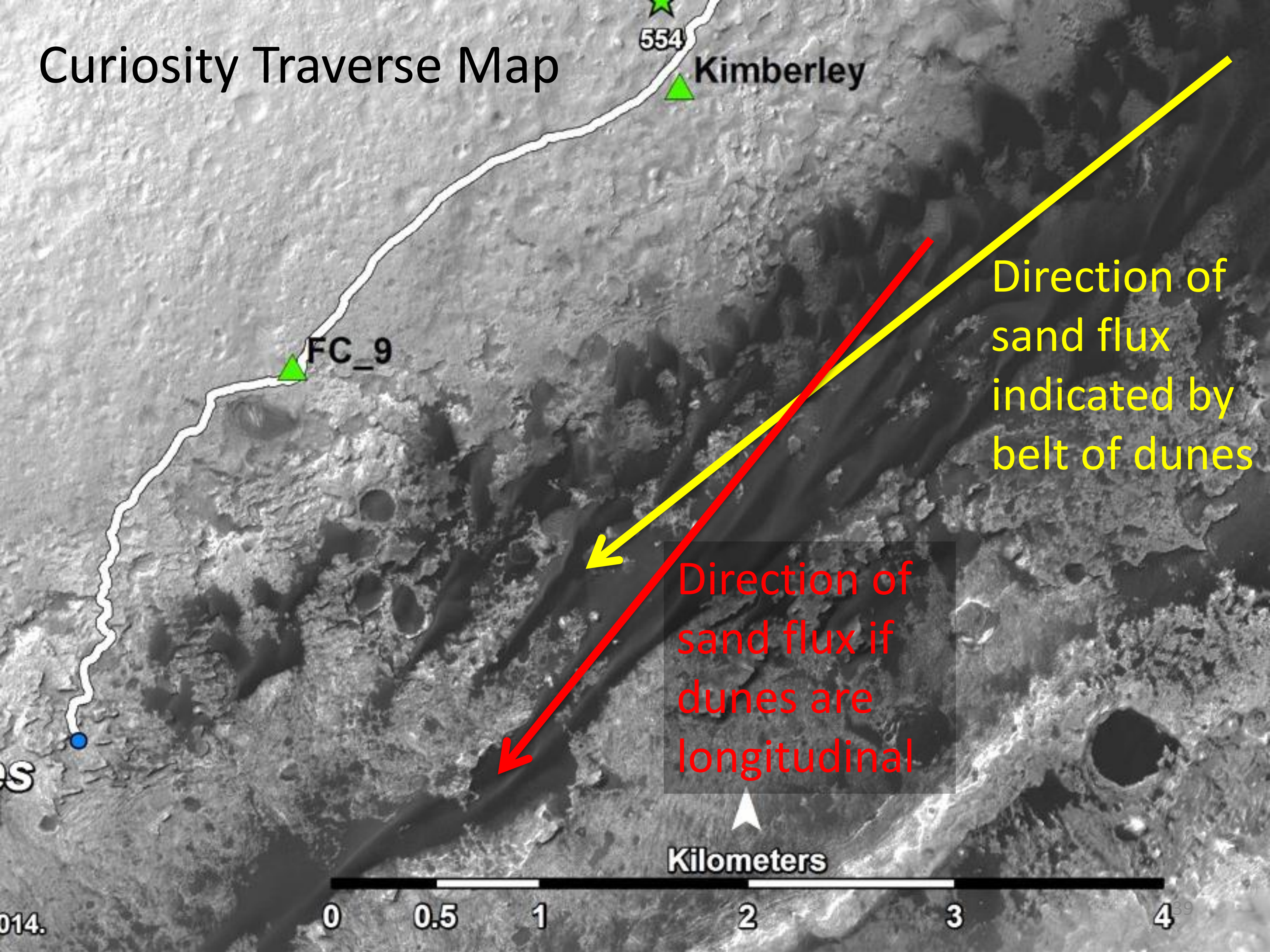
From Haigermoser, Scarano, Onorato, 2009, *Experimental Fluids*

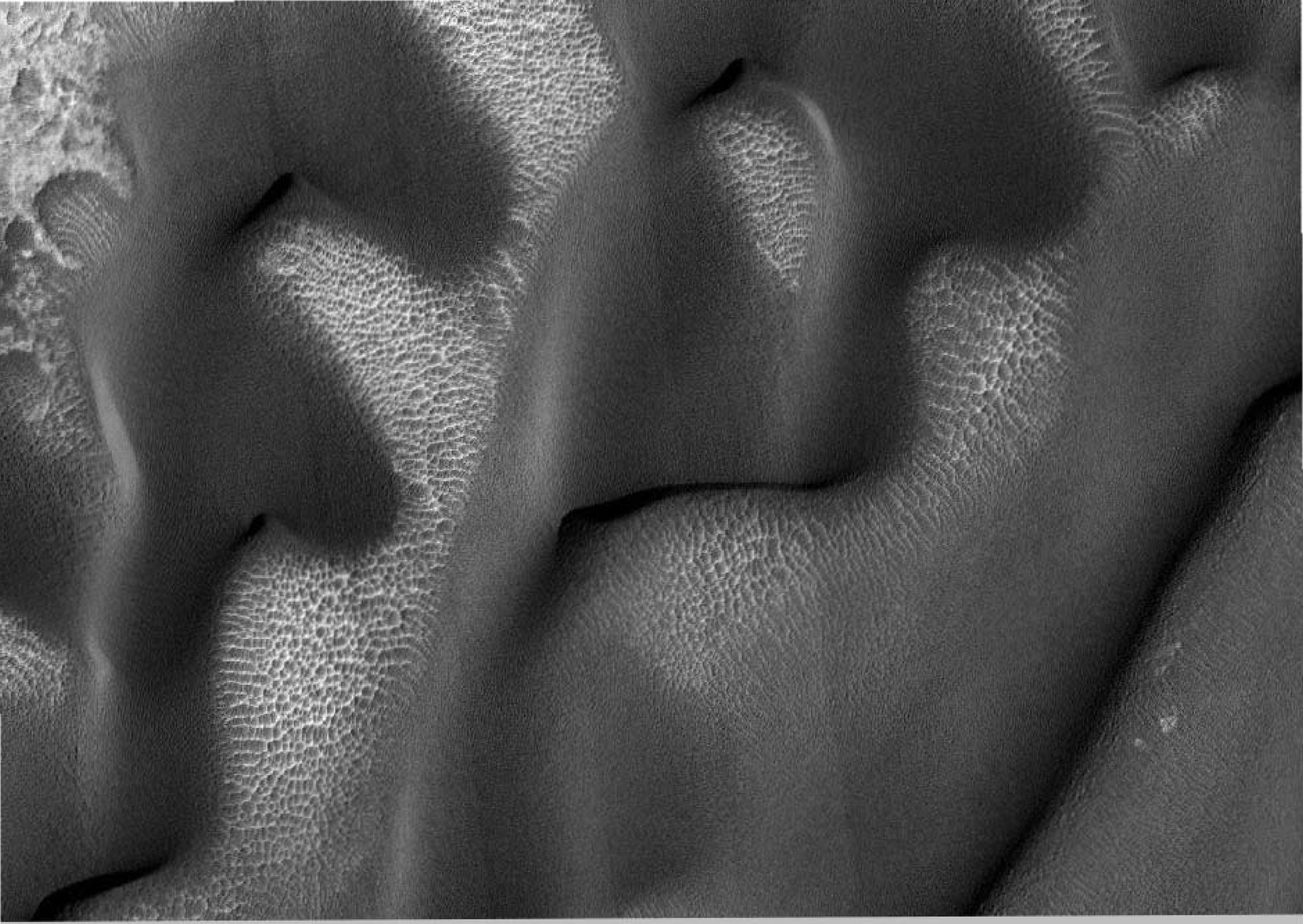
Curiosity Traverse Map



Curiosity Traverse Map

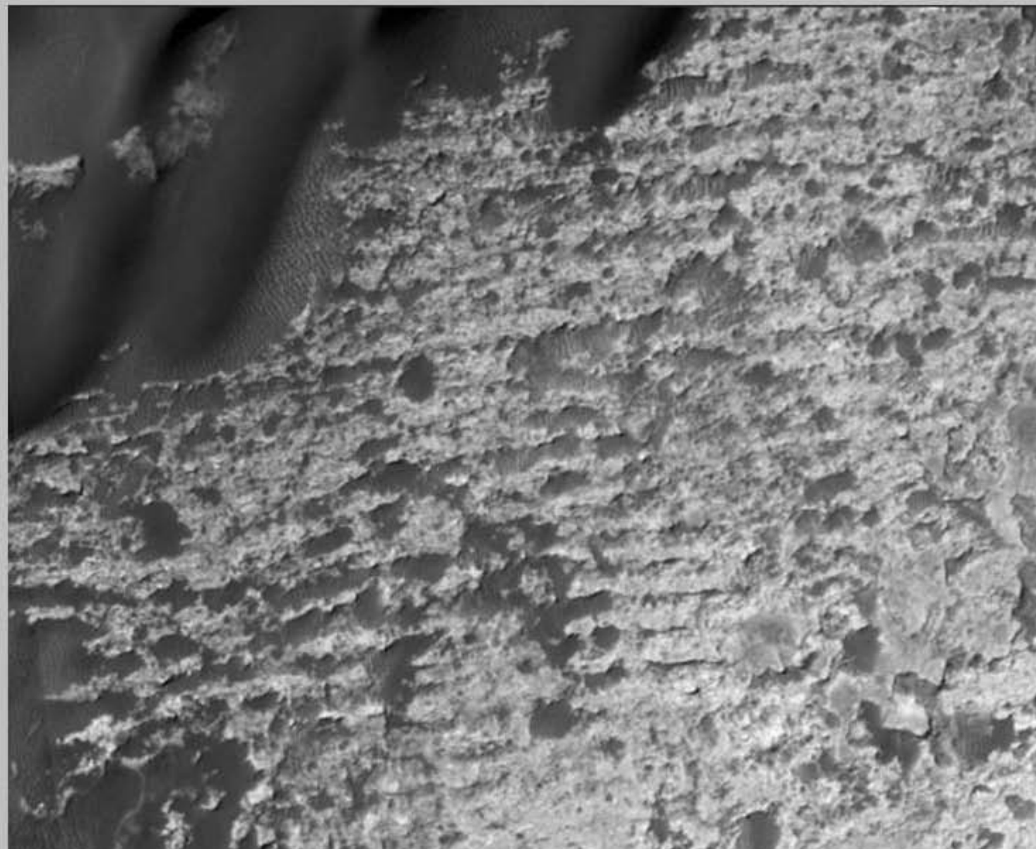



Curiosity Traverse Map
554
Kimberley
FC_9
Direction of sand flux indicated by belt of dunes
Direction of sand flux if dunes are longitudinal
Kilometers
0
0.5
1
2
3
4



NASA/JPL-Caltech/Univ. of Arizona

Washboard unit (wavelength ~40m)

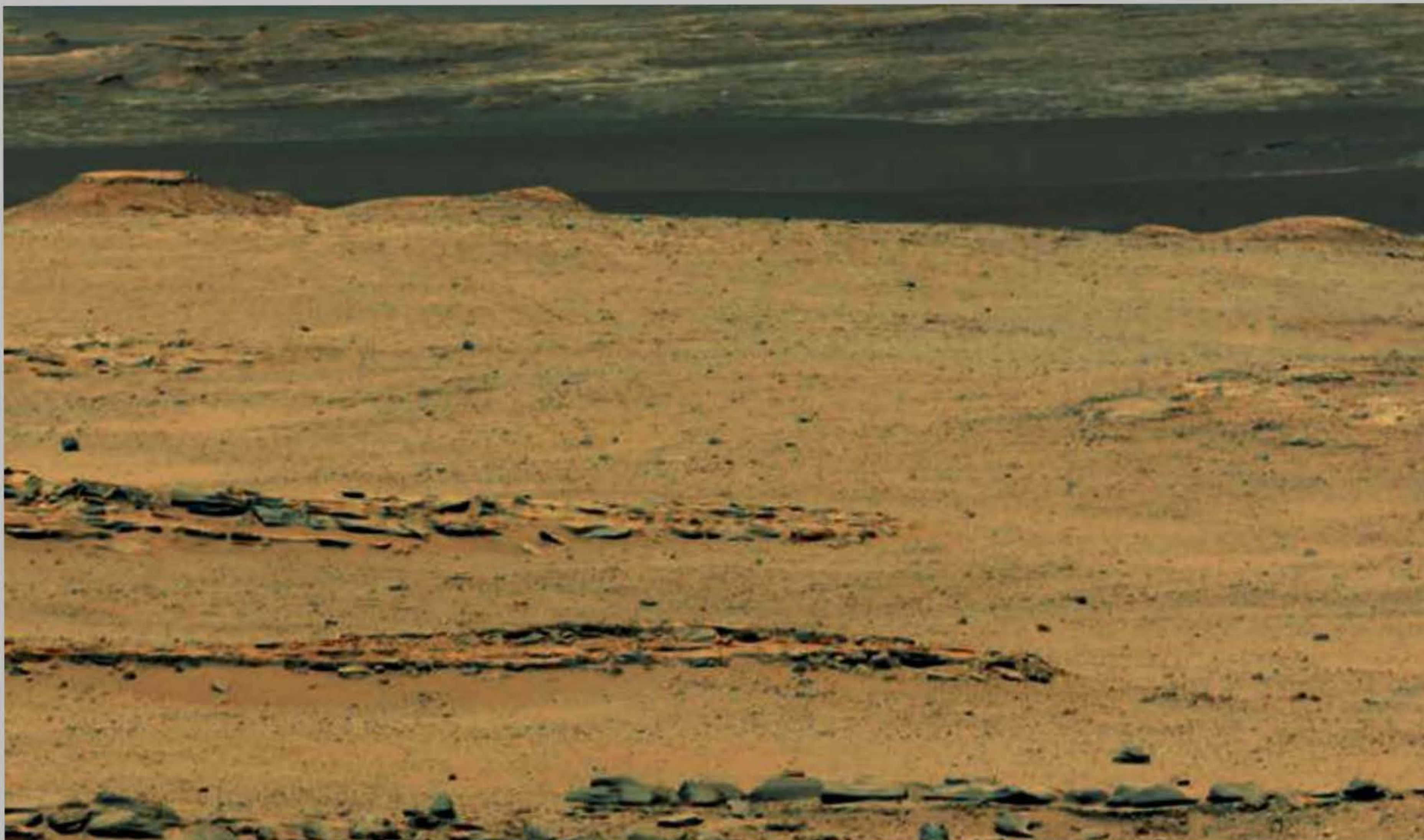


NASA/JPL-Caltech/Univ. of Arizona

Presenter’s notes: So what is the potential origin of the washboard unit. It has been previously suggested that they might represent either preserved sedimentary bedforms, or the exposure and differential erosion of preferentially lithified strata. We suggest that both of these suggestions are, in part correct. Easily see how these could be interpreted as preserved bedforms.

Fire ring

NASA/JPL-Caltech/MSSS; Sol 528



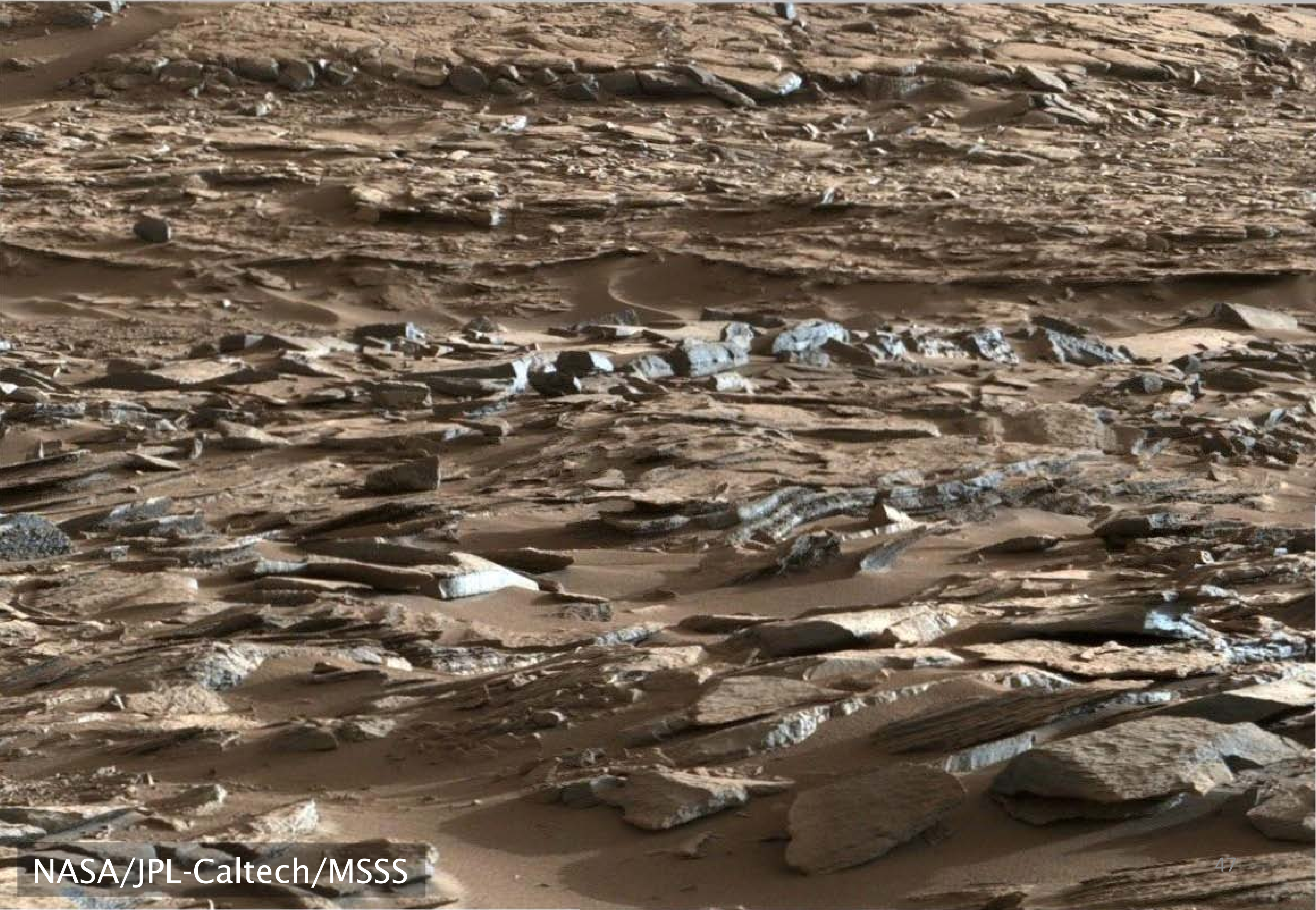
NASA/JPL-Caltech/MSSS
Sol 567

NASA/JPL-Caltech/MSSS
Sol 569


N
Meters
0 10 20 40 60 80 100

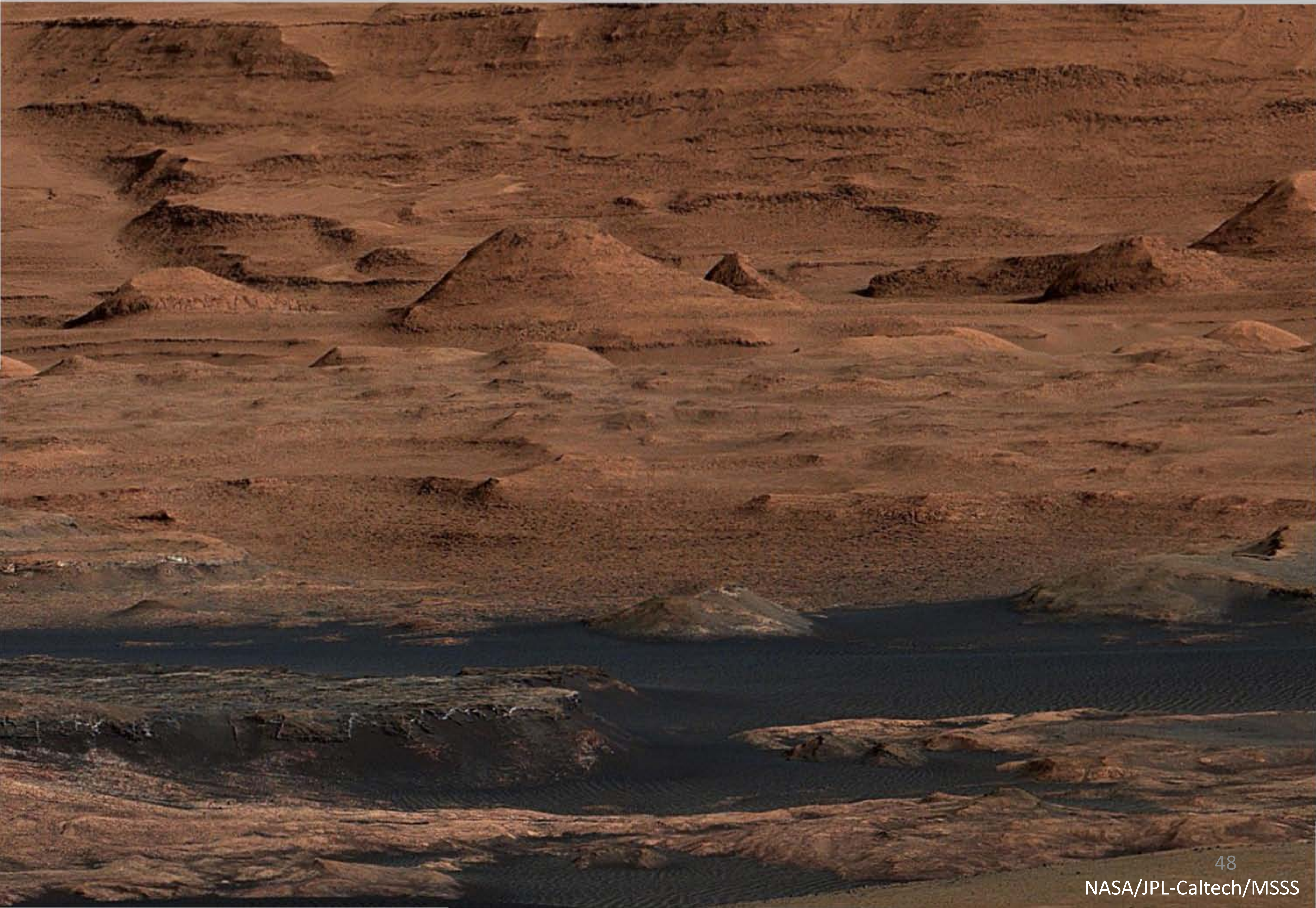
Daily cycles in flow cause daily cycles in grain size of sediment.
In this case (Colorado River), daily flow cycles are dam releases for hydropower.

Kimberley (where *Curiosity* is now)



NASA/JPL-Caltech/MSSS

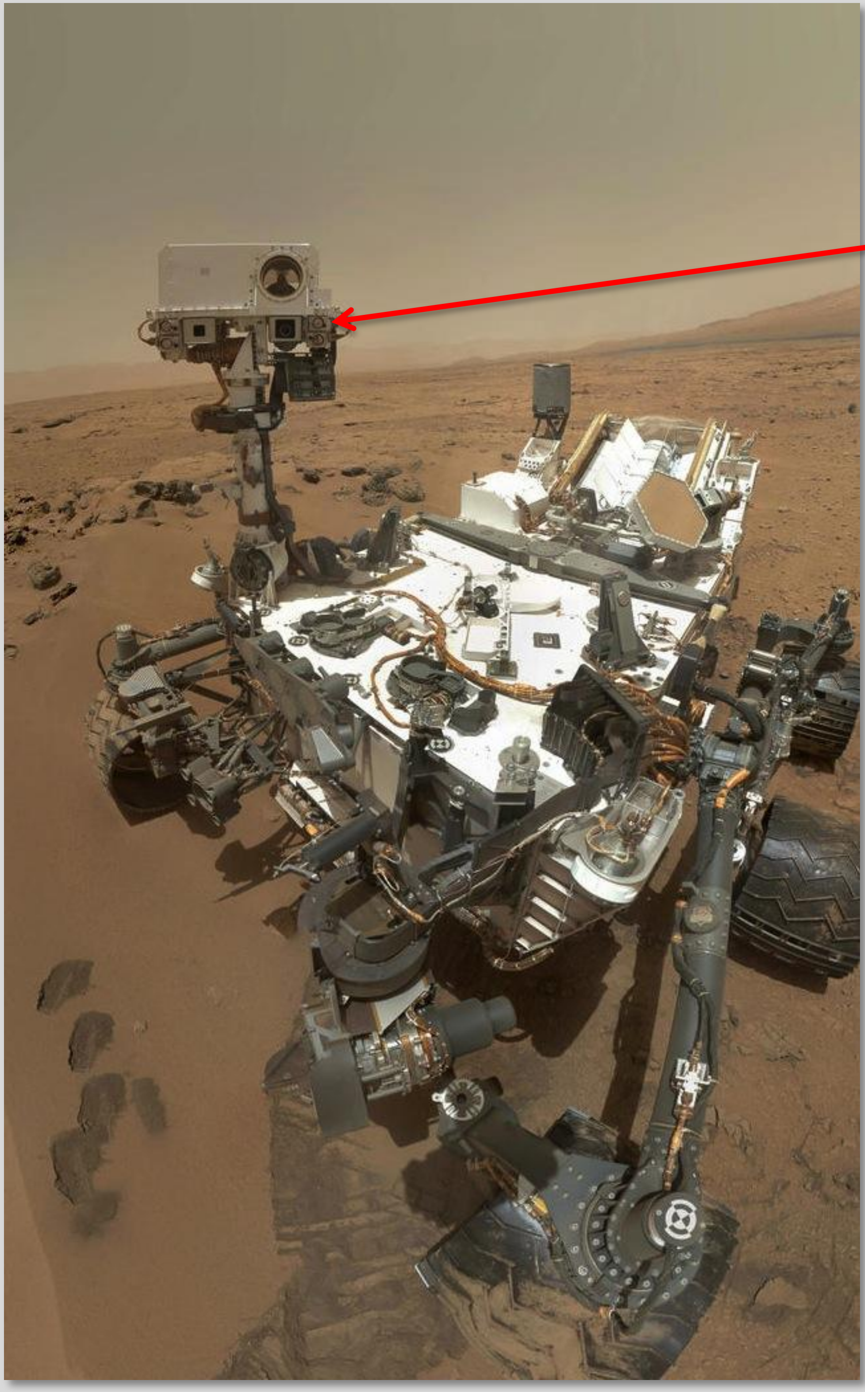
Mt. Sharp foothills



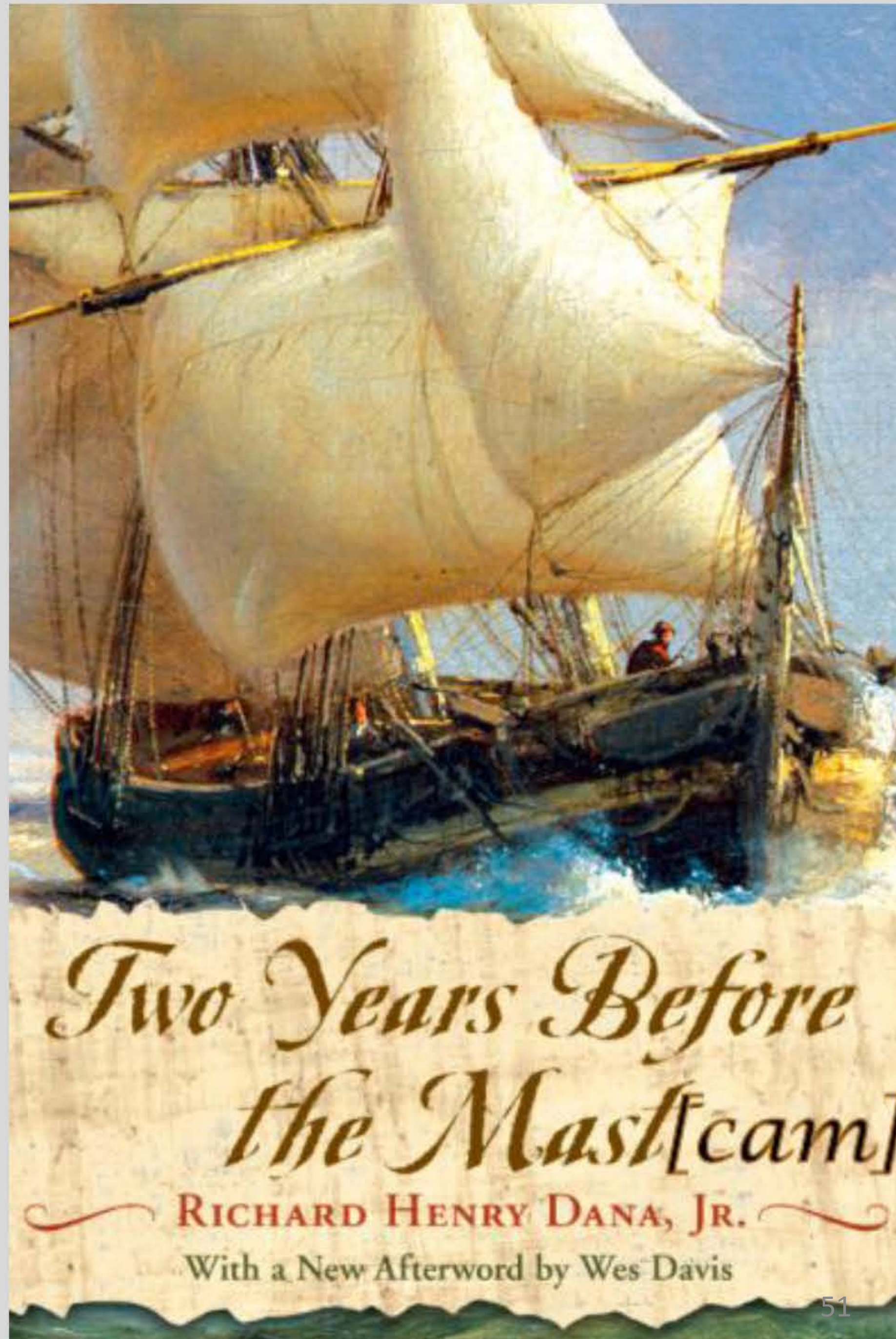
NASA/JPL-Caltech/MSSS

CURIOSITY

Layers, Canyons, and Buttes of Mount Sharp



Most of these images from our 20-month journey were taken using *Curiosity's* Mastcam.


Two Years Before the Mast[cam]
RICHARD HENRY DANA, JR.
With a New Afterword by Wes Davis