
MSL Landing Sites:
Gale, Reconsidered
Edgett, Milliken, Grotzinger, Malin

What does a MSL Landing Site Need?

- Context
  - What can be learned that gives us greater insight into Martian geology and history in general?
  - Where does what we will learn at a site fit into that history?
- Diversity
  - of rock types/varieties, as best as can be understood based on our limited information about
    - erosional expression
    - bedding style
    - mineralogy/composition
- Hypothesis
  - wherever we land, there should be some overarching hypothesis (or hypotheses) we are trying to test, for which the MSL payload is suited to conduct the test(s)
- Note the Unknowns and Assumptions
  - There's a lot we don't know about Mars and about each site, but this does not always come across when someone is advocating a landing site, especially if a lot of work has been done and a lot of pretty viewgraphs have been presented.
  - we all tend to make assumptions and not remember to state what those assumptions are
  - often, we make assumptions we don't even know we are making
- Habitability
  - do we have information that would suggest the site could have been habitable?
- Biosignature Preservation Potential
  - do we have information that would suggest the site could have had conditions favorable to preservation?
- Safety
  - for EDL, rover mobility, and operational thermal constraints

Why reconsider Gale? (1 of 2)

– Current list of 6 lacks a site with a very low elevation, something good for adding margin to the EDL timeline
  - Gale landing ellipse is near –4.5 km

– Gale's story is much more rich than presented at the 2nd MSL Landing Site Workshop in October 2007.

– CRISM shows phyllosilicates <u>and</u> sulfates in layered rock that MSL would investigate
  - Fe-rich smectite clays in lower strata (reducing environment?)
  - sulfates in overlying strata (mono- and polyhydrated; the former are mixed with possible Mg sulfates)
  - some areas have mixtures of clays and sulfates at same location
  - having both phyllosilicates and sulfates = diversity = reduced risk that we'll find nothing considered 'habitable'

– Images from MGS & MRO show terrific diversity of geologic materials that we can expect to encounter on MSL traverse
  - good for "pushing every button to see which one lights up as 'habitable'"

continued on next page…

Why reconsider Gale? (2 of 2)

- Gale has both mineral and geomorphic clues that liquid water was present in the past
  - 2 channels and their sediments (1 channel & sediments from both are accessible to rover)
  - clay-bearing strata
  - sulfate-bearing strata
  - bedforms preserved in rock — the largest examples have wavelength, apparent amplitude, and morphology suggestive of having formed in a subaqueous setting, but this is uncertain

- Thick, diverse, detailed stratigraphic section covering ‘a long time’
  - more than 2x thicker than Grand Canyon, AZ stratigraphy

- Gale presents examples of very important themes seen all over Mars (Gale is a “microcosm” of the geologic story of Mars)
  - craters with layered materials in them — study one, gain insight into many
  - burial, exhumation, and erosional unconformity
  - phyllosilicates and sulfates are observed
  - fan of sediment transported to crater floor through channel that cuts crater wall
  - mafic eolian dunes

- Plenty to do if MSL has an extended mission
  - Nearly 5 km of stratigraphic section to be explored -- we can’t do it all during the primary mission -- we’ll never run out of new things to study

- Visually spectacular/pretty views for the public

Gale – Context

- What we can learn in Gale is broadly applicable to craters across Mars
  - Many craters & Valles Marineris have layered sedimentary rock in them.
  - Were these at some point during their history the site of bodies of standing water?
    - Most do not have ‘deltas’ or ‘fans’
      - Eberswalde and Jezero are exceptions, and Jezero doesn’t have the layered material
    - Many have ‘rhythmic’ layering (beds of repeated thickness, bedding style, and erosional expression) -- suggests low energy depositional setting (e.g., settling from suspension, whether in ‘air’ or ‘water’).
      - Henry, Becquerel, Candor Chasma, Crommelin, crater at 8°N, 7°W, and so forth

- Layers in Gale present a stratigraphy representing an unknown but apparently long period of time
  - up to 5 km thick stratigraphic section (2x thicker than Grand Canyon record!)
  - Stratigraphy is the tape recorder of the history of the Earth, and this must also apply for Mars
    - This record serves as a "carrier signal" for other embedded proxy records of global or regional climate variability, tectonic events, and the evolution of life.
  - The longer the record the more likely it becomes to detect these changes.
    - Because we know this record contains a major erosional unconformity, we also know that
      - (a) some of the record is missing,
      - (b) at least three major environmental changes occurred (from deposition to erosion, then back to deposition again, the back to erosion),
      - (c) the presence of the major unconformity could signal a significant change in depositional style across the boundary; this helps mitigate the risk that, while thick, the Gale stratigraphic section could consist of the same materials deposited by the same processes.

Gale – Diversity

- Mineralogy and Layered Rock Stratigraphy story
  - includes major erosional unconformity and likely changes in depositional setting with time.

- Apparent wide variety of materials to examine with MSL
  - both sulfates and phyllosilicates are present in distinct layered rock units, plus lots of material has mineralogy that is yet to be determined.
  - differing layer properties, bedding styles, and erosional expressions of the several major layered rock units indicate diversity of materials, events, and settings.
  - surfaces with differing abundance of sub-kilometer-diameter impact craters, and boulders produced by the impacts, attest to differing substrate hardness and resistance to erosion.
  - liquid water likely cut the channels and deep canyons that formed during the period marked by an erosional unconformity; these deposited sediment, too.
  - fan in the landing ellipse likely composed of sediment (transported by water) derived from the ancient rocks of Gale's north wall (rocks that pre-date the Gale impact, and thus pre-date everything else MSL would examine).
  - mafic eolian dune sand is also present (not clear where this material came from… there are no mafic dark-toned rock outcrops)

Gale – Hypothesis

- Some of the strata in the 5 km-high mound were deposited in a subaqueous setting -- in other words, for some periods during its history, Gale Crater hosted a lake.
  - the strata most likely to have been deposited in a lake are the lowermost layers in the mound -- the ones MSL would encounter first
  - fluvial deposition also occurred, in the form of a fan within the landing ellipse and in the form of lithified channel fill and channel deposits that were created during a period of erosion (the erosional unconformity)
  - some layered materials are likely to have been deposited in a subaerial setting
    - difficult or impossible to distinguish without field study

Gale – Unknowns and Assumptions

- There is a lot we don’t know, especially:
  - Subaqueous deposition of layered material? -- As is the case for nearly every place on Mars where we see light-toned, layered rock outcrops from orbit, we don’t know if any of these represent sediment deposited in a subaqueous setting -- evidence from orbiter images for depositional setting is extremely rare on Mars (and Earth).
  - Sediment vs. airfall tephra? -- Sediment vs primary tephra ambiguity for most of the material in the mound -- a problem nearly everywhere on Mars except where 2 rovers have investigated + Eberswalde + where bedforms are preserved in rock (and Gale has some examples of those).
  - Bulk mineralogy and composition? -- We don’t know what most of the minerals that comprise the mound actuall are. In addition, where we see sulfates or phyllosilicates are present, we don’t know their abundance.
  - When did Detected Minerals Form? Cannot distinguish whether the minerals detected were deposited in that form, were altered to that form after deposition; nor do we know that they are in the bulk rock or in a weathering rind/coating.
  - Age of the materials? Cannot even determine absolute or relative age of materials because crater counting is unreliable on soft-rocks some have been exhumed. All materials are younger than the day Gale Crater formed, but so old that many billions of cubic meters of layered rock were broken down and transported out of Gale Crater (by processes and pathways indiscernable today) to leave behind the 5 km high mound.

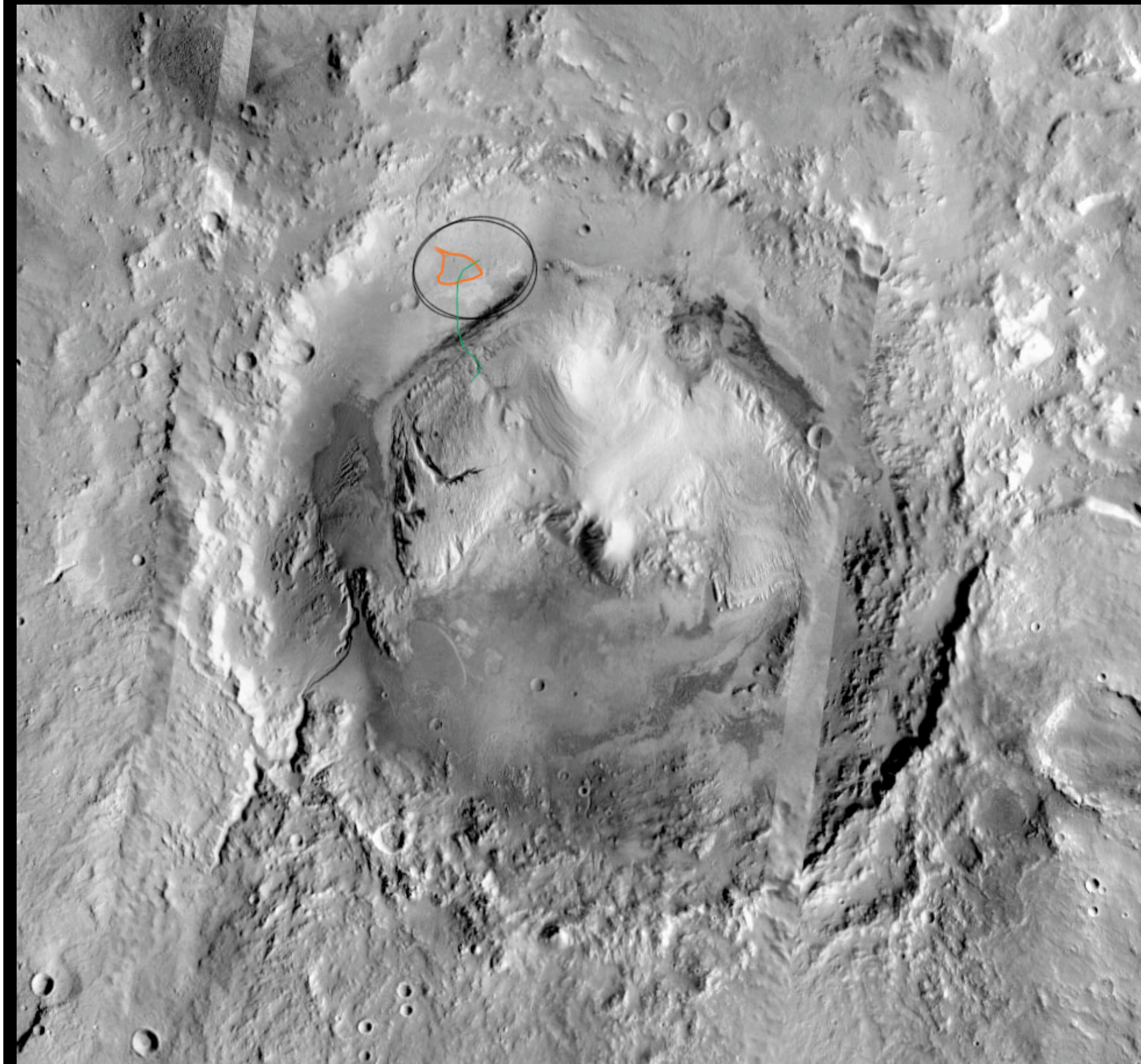
Gale – Habitability + Biomarker Preservation

- Habitability
  - water evidence
    - minerals
      - CRISM shows site has phyllosilicates (Fe-rich smectites)
      - CRISM shows site has sulfates (mono- and poly- hydrated)
    - fluvial landforms and deposits
      - fan in landing ellipse
      - lithified fan and channel floor materials cutting layered rock of mound
    - layered rock
      - bedforms preserved in some rock -- unknown whether subaqueous or subaerial
      - it is generally unknowable whether these rocks represent subaqueous settings, but the observations do not negate the possiblity
  - diversity
    - site offers considerable diversity in geologic materials and deposits
    - site offers a clear stratigraphy and clear approach to examining that stratigraphy
      - stratigraphic section --> assessment of environments over the period of time represented by this rock record
  - bedforms preserved in rock
    - Don't provide a fix on subaerial vs. subaqueous, but do rule-out a host of other processes (at least for the strata in which they occur)
      - material can't be dust settled from suspension
      - material can't be primary volcanics: lava, airfall tephra, pyroclastic flows
- Biomarker Preservation Potential
  - Unknowable, but that would be true almost anywhere on Mars.

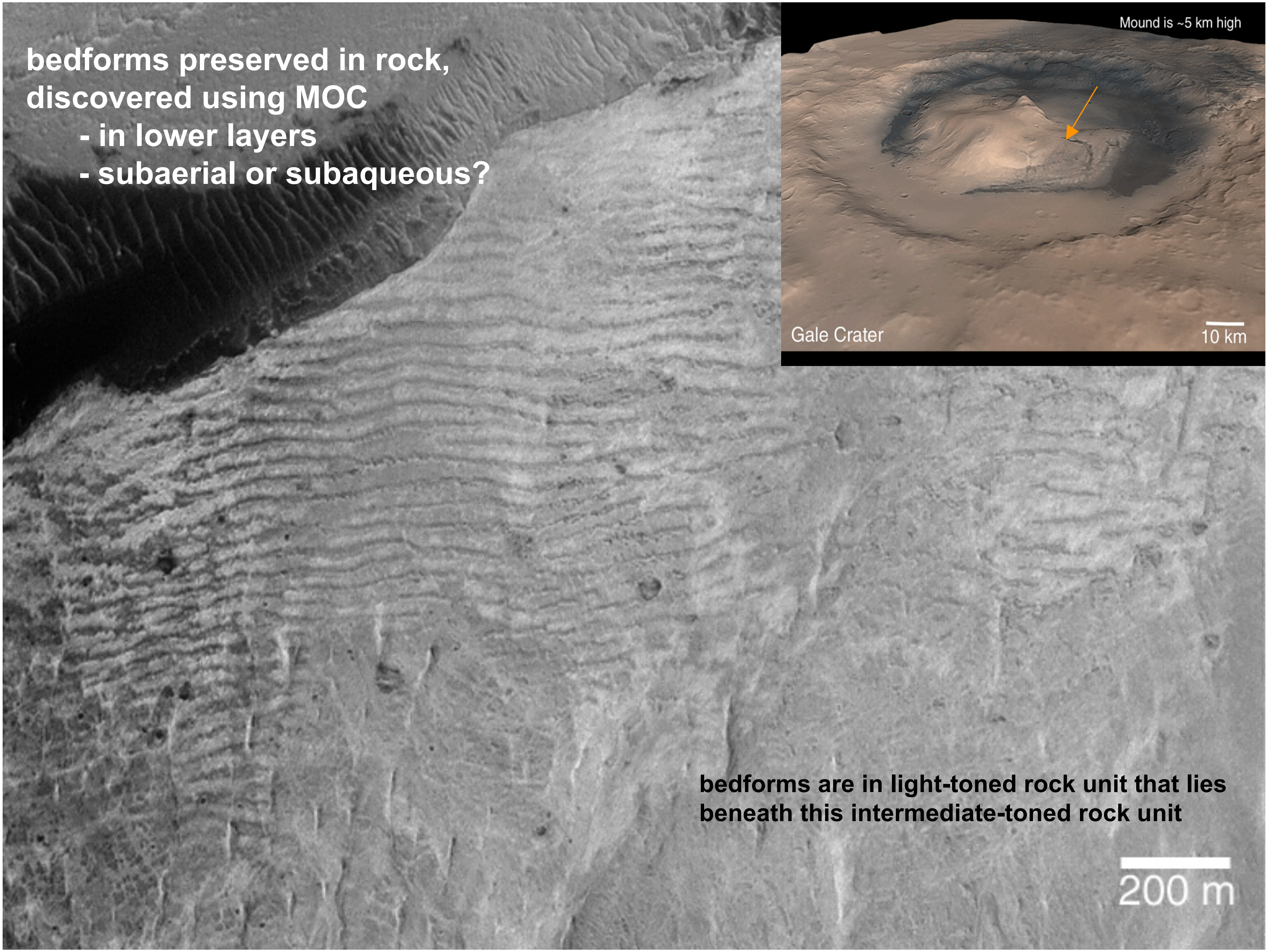
Gale – Safety

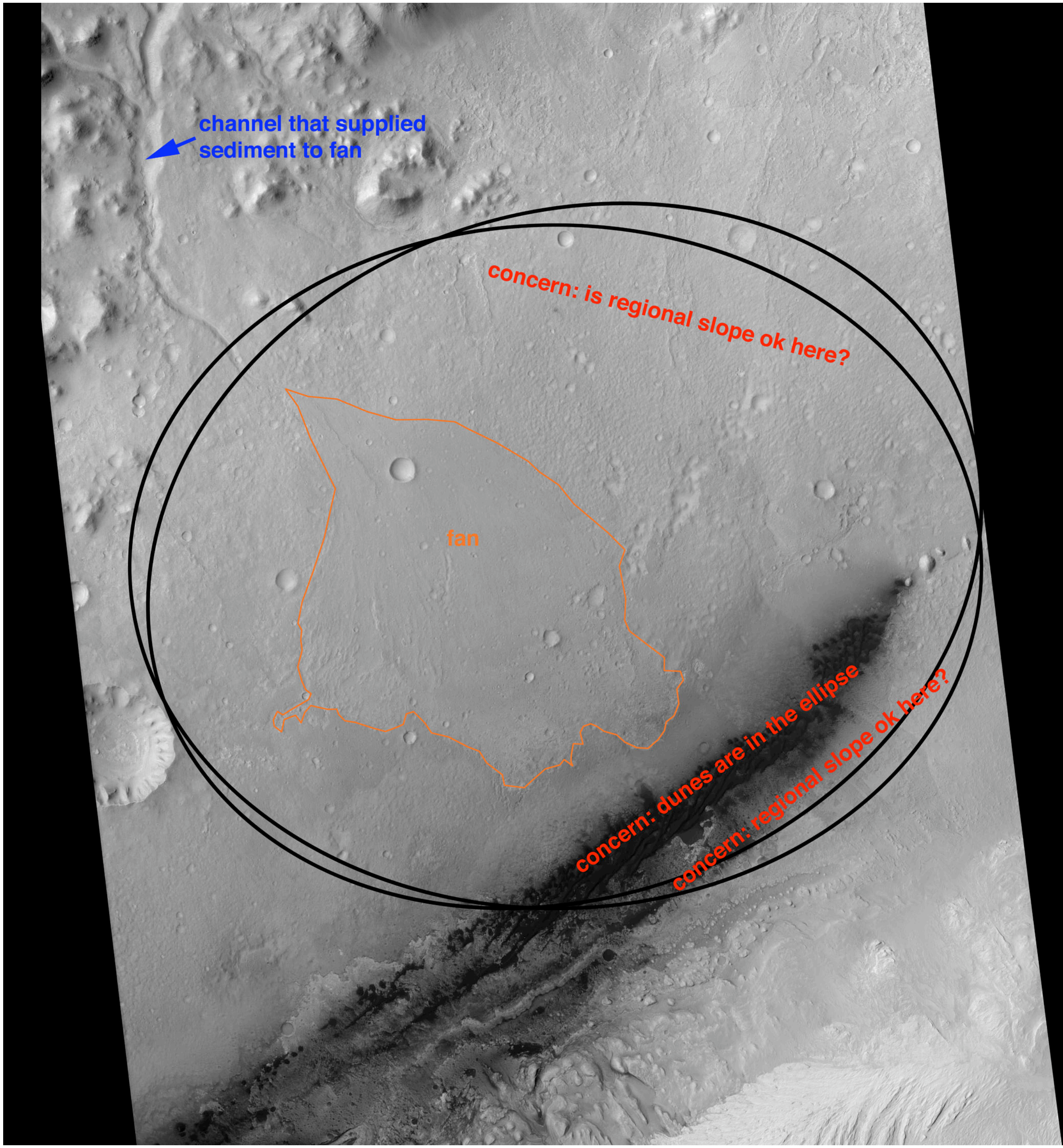
- These issues will need further assessment by Golombek et al.
- EDL
  - very low elevation (–4.5 km) -- great for EDL timeline margin
  - present 25 x 20 km ellipse size means, however, there are some real hazards at the south/southeast end of the ellipse (dunes, mesas, buttes, scarps, etc.)
  - regional slopes across the ellipse need to be evaluated
  - atmospheric conditions (winds) need to be evaluated
  - HiRISE image of ellipse shows few boulders; most that do occur are associated with impact craters -- craters and boulders present the usual hazard (like was present at the MER-A site)
- Operational Constraints
  - Thermal / Heat-to-Use
    - equatorial site (4.5°S), so won't get to cold
    - traverse up the mound would have rover deck pointed northward
  - Trafficability
    - surface should be as trafficable as MER-A site inside landing ellipse (not much dust, sand)
    - can identify in HiRISE images pathways around sand dunes and cliffs as rover approaches mound
    - surface of mound is mostly bare rock or rock with very thin regolith
    - driving up mound will have elements similar to MER-A drive up Columbia Hills, and MER-B drives into/out of Endurance and Victoria

Landing Ellipse Location



- 4.5°S, 222.7°W
- orange area is a fan -- material deposited from channel off northwest crater wall.
- green line is notional rover traverse

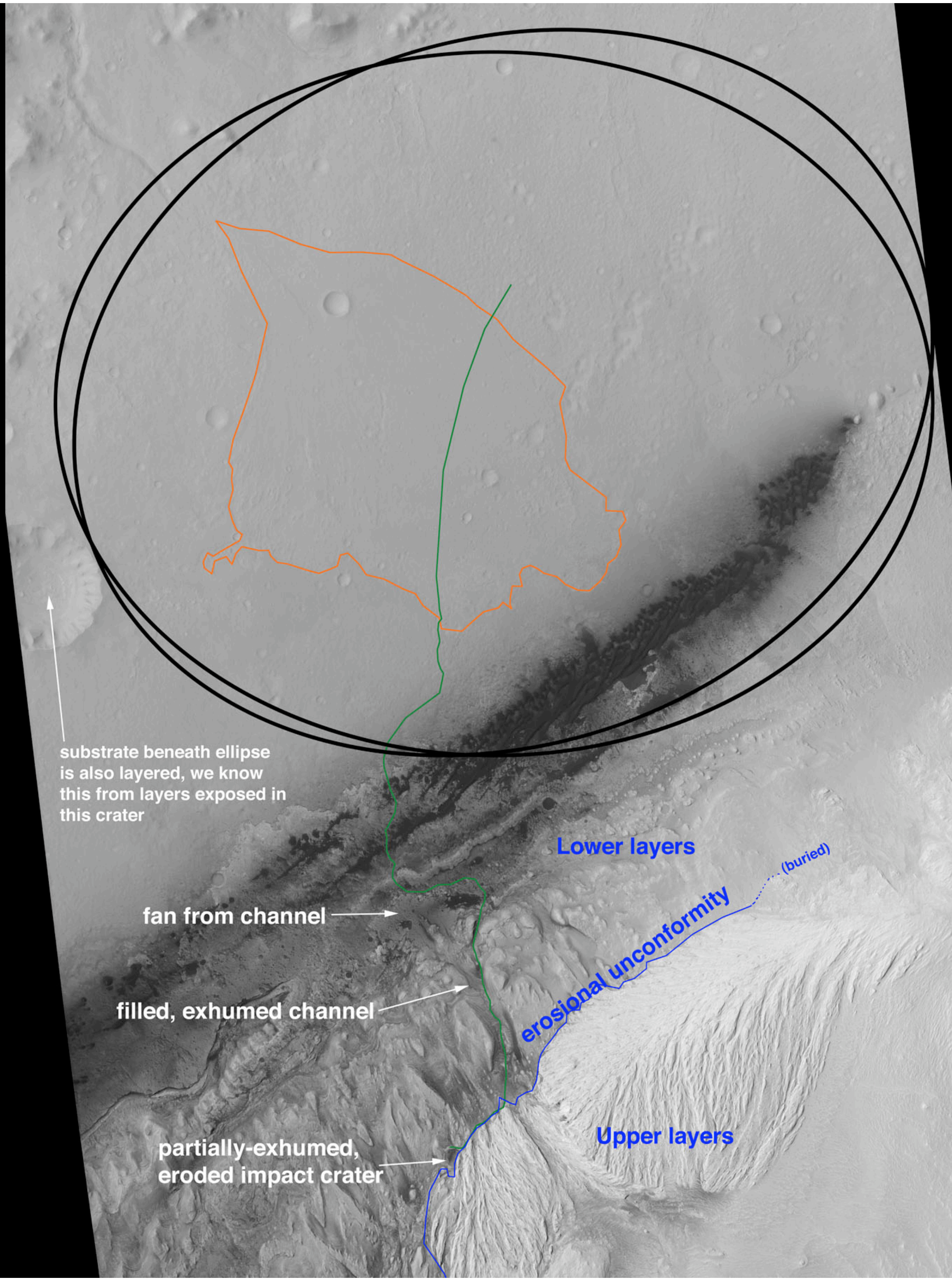

bedforms preserved in rock,
discovered using MOC
- in lower layers
- subaerial or subaqueous?
Mound is ~5 km high
Gale Crater
10 km
bedforms are in light-toned rock unit that lies
beneath this intermediate-toned rock unit
200 m



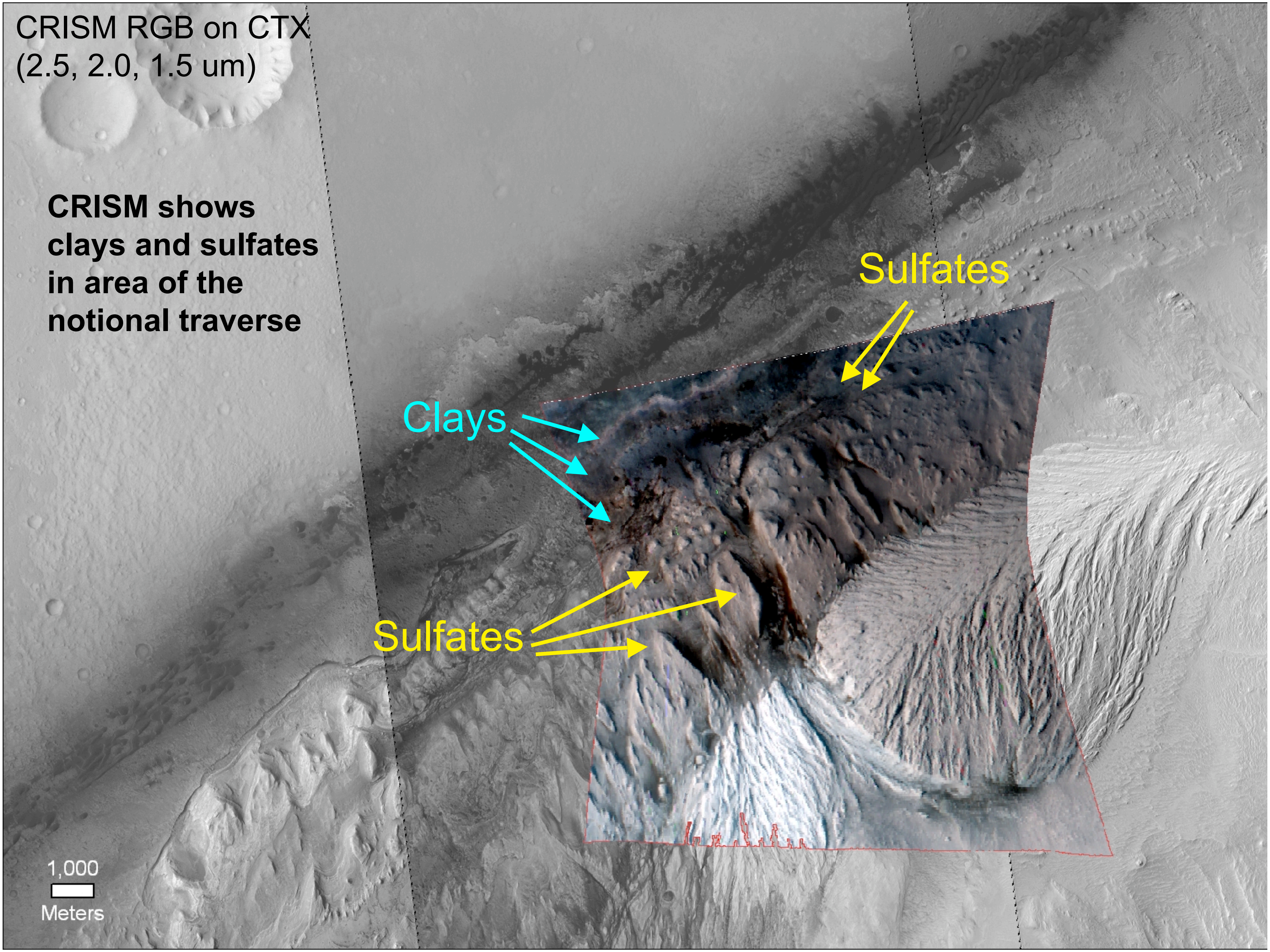
- landing ellipse -- there are some regional slope concerns and dunes in that someone (Golombek's group) would have to examine and determine whether these are safety issues.

- This is a go-to site. The objective is the mound to the south of the ellipse.

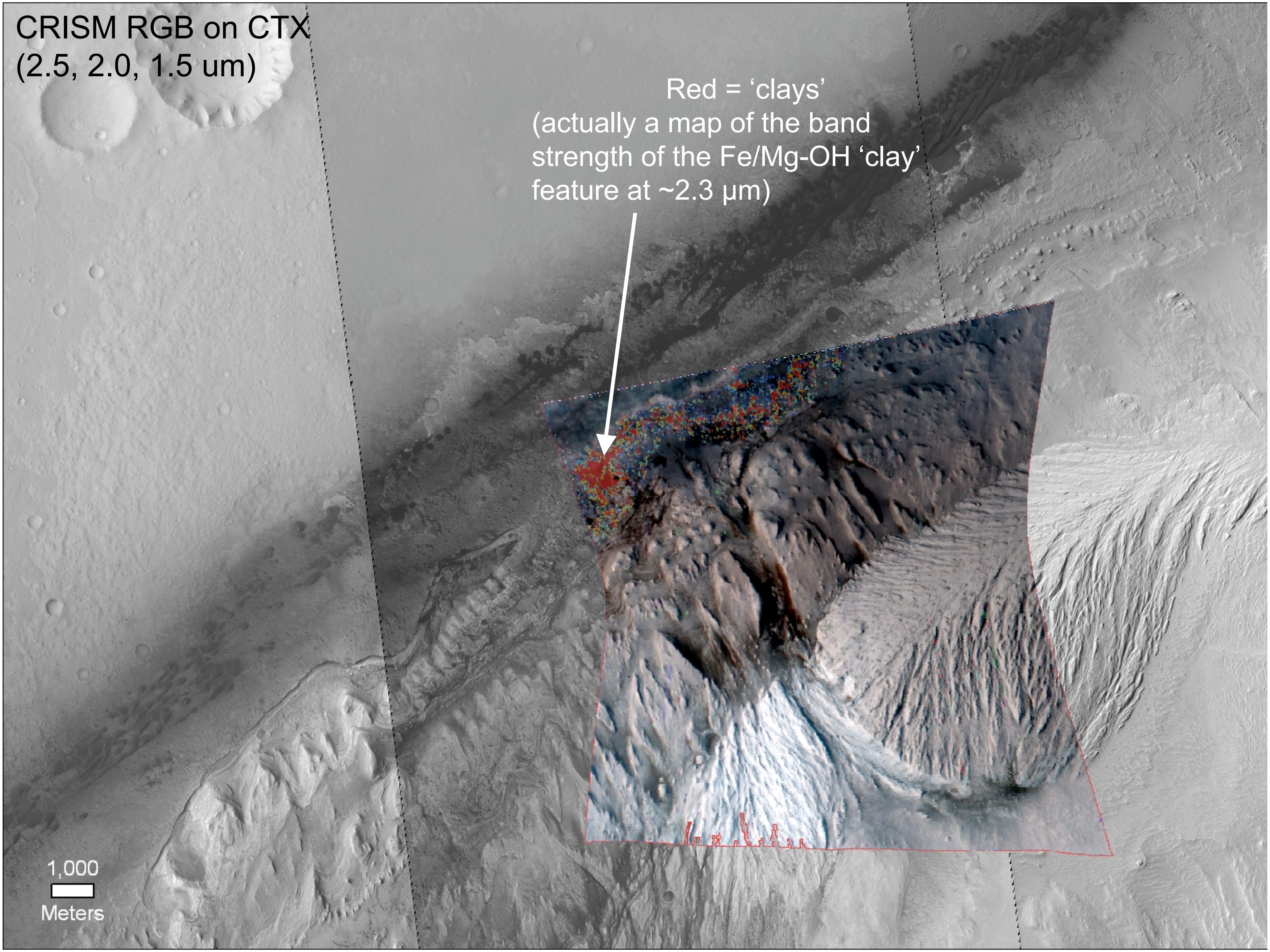
- Basemap is a portion of CTX image P14_006644_1747_XI_05S222W_071227

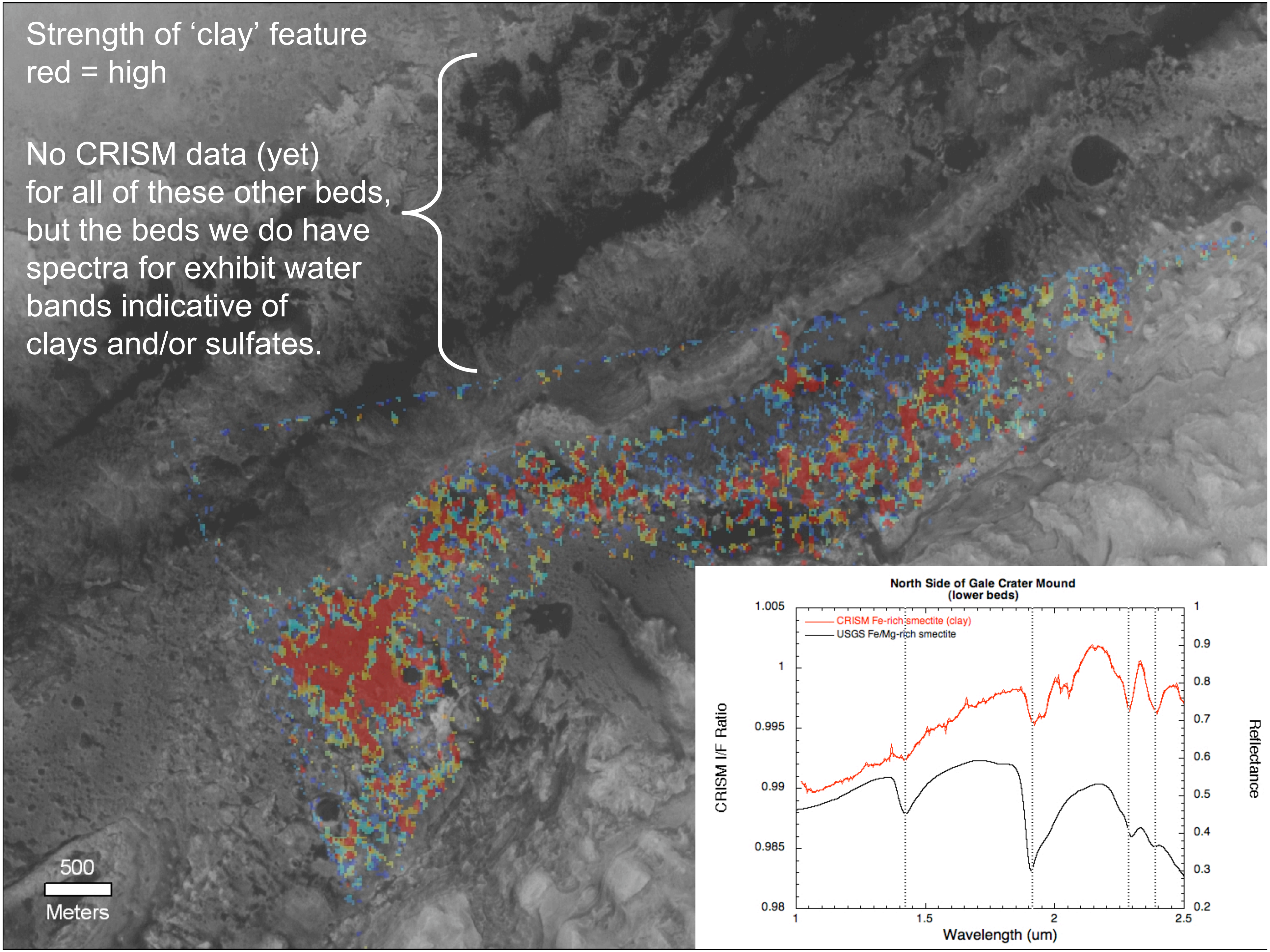


- green line is a potential rover traverse from an arbitrary touchdown location, across a portion of the fan (orange outline), to the mound, and up the mound in a trough with filled/exhumed inner channel to the erosional unconformity and a partially-exhumed impact crater.
- the notional traverse isn't the only route possible, just a conversation-starter. Depending on what is learned, it may be impossible to complete this traverse in 1 Mars year
- there may be some locally steep areas to be avoided a long the traverse, just before the dunes are reached, and as the rover goes up the slope, onto the mound. In general, the MER-A experience on the Columbia Hills and MER-B experience in/out of Endurance and Victoria provide proof-of-concept for the traverse we'd do in Gale with MSL.
- Basemap is a portion of CTX image P14_006644_1747_XI_05S222W_071227



CRISM RGB on CTX
(2.5, 2.0, 1.5 um)
CRISM shows clays and sulfates in area of the notional traverse
Sulfates
Clays
Sulfates
1,000
Meters


CRISM RGB on CTX
(2.5, 2.0, 1.5 um)
Red = ‘clays’
(actually a map of the band strength of the Fe/Mg-OH ‘clay’ feature at ~2.3 μm)
1,000
Meters

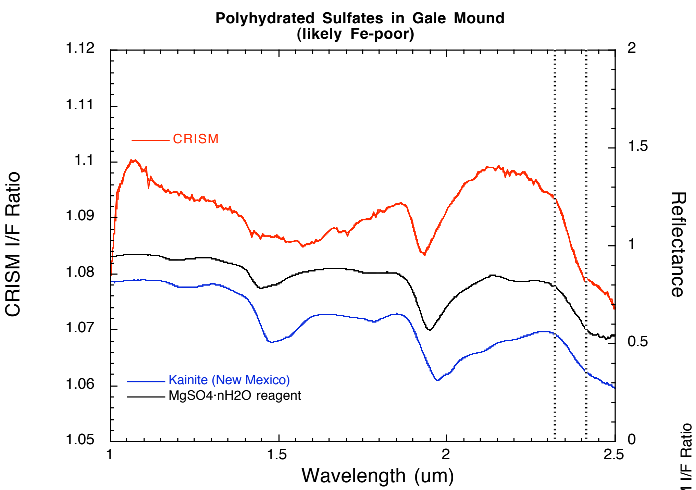

Strength of ‘clay’ feature
red = high
No CRISM data (yet)
for all of these other beds,
but the beds we do have
spectra for exhibit water
bands indicative of
clays and/or sulfates.
500
Meters
North Side of Gale Crater Mound
(lower beds)
CRISM Fe-rich smectite (clay)
USGS Fe/Mg-rich smectite
CRISM I/F Ratio
Reflectance
Wavelength (um)
1.005
1
0.995
0.99
0.985
0.98
1
1.5
2
2.5
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2

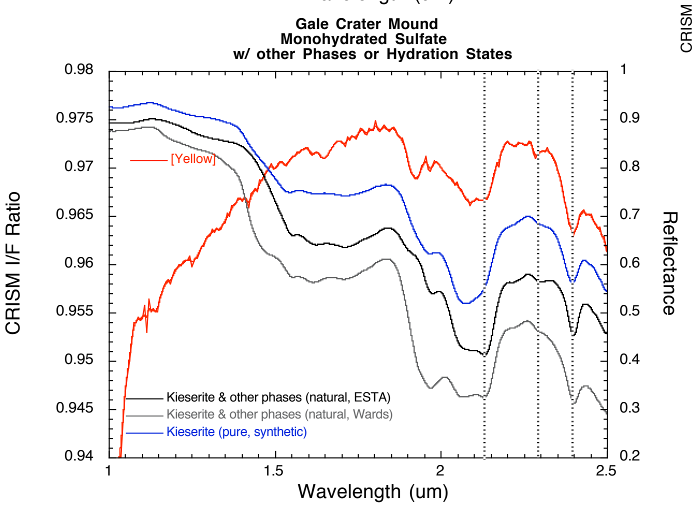
Sulfates

- in strata overlying clays
- evidence for mono- and poly- hydrated sulfates
- no strong evidence for FeSO4, so conditions could have been non-acidic
- monohydrated spectra are most consistent with a mixture of phases or hydration states, not a pure kieserite

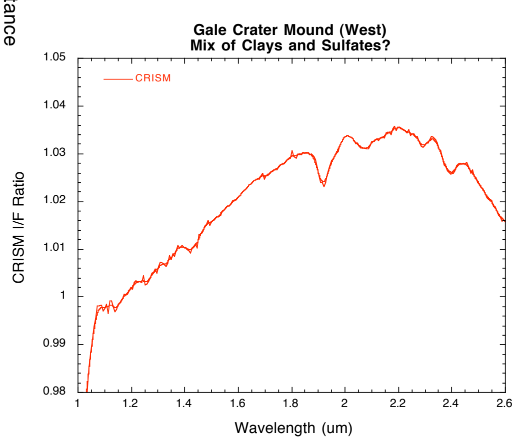
Clays

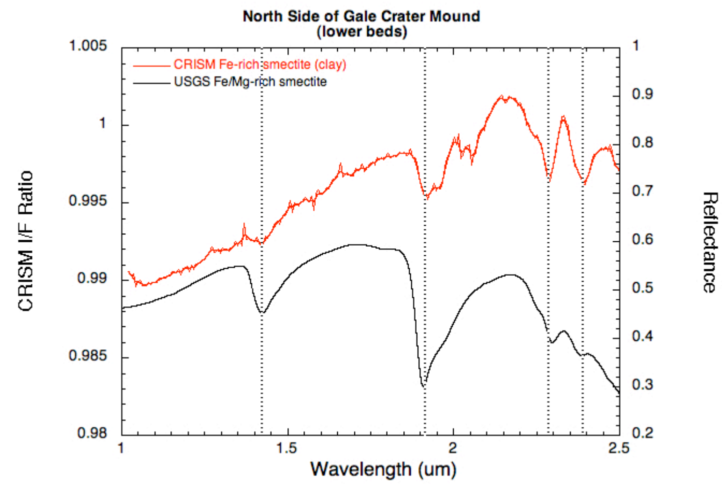
- in lower strata, under sulfates
- consistent with Fe-rich clays with minor Al
- some spectra exhibit a strong slope from 1-2 um, possibly due to an Fe^{2+} phase
- these clays suggest 'high' pH (>7) and reducing conditions (if formed *in situ*)

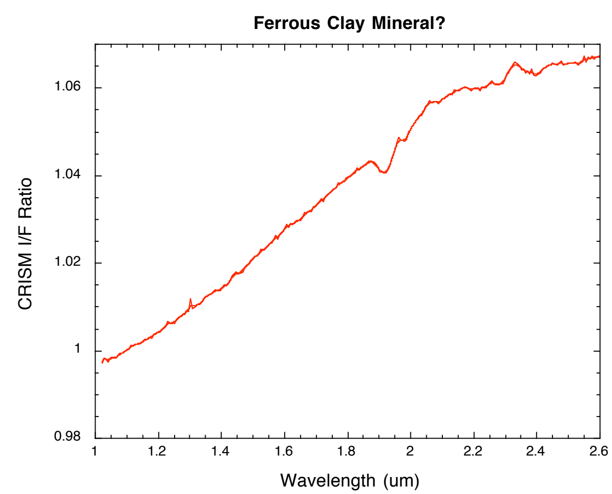


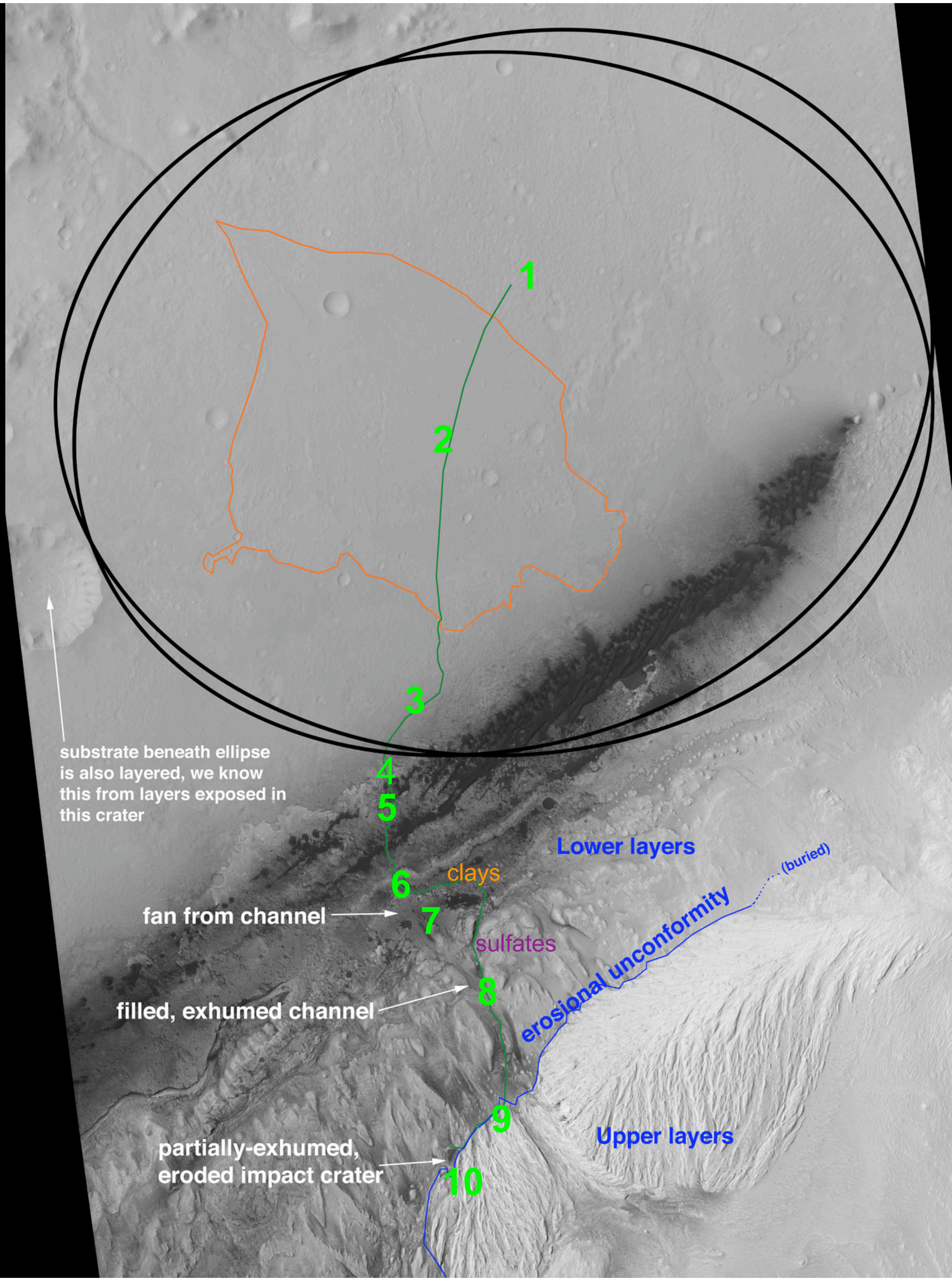


Some spectra appear to represent a mixture of clays and sulfates…









Notional Traverse:

1. arbitrary touchdown site -- examine the substrate material

2. examine fan material

3. examine hard substrate (lava flow? more fan material?)

4. enter area of light-toned rock outcrops (many mesas and buttes in this area; rocks have polygonal cracking patterns similar to other light-toned rocks elsewhere on Mars)

5. navigate around the eolian dunes, but be sure to examine some of the sand because of broader application to dunes everywhere on Mars

6. more light-toned layered rock -- with clays -- to investigate, moving up the mound slope, now

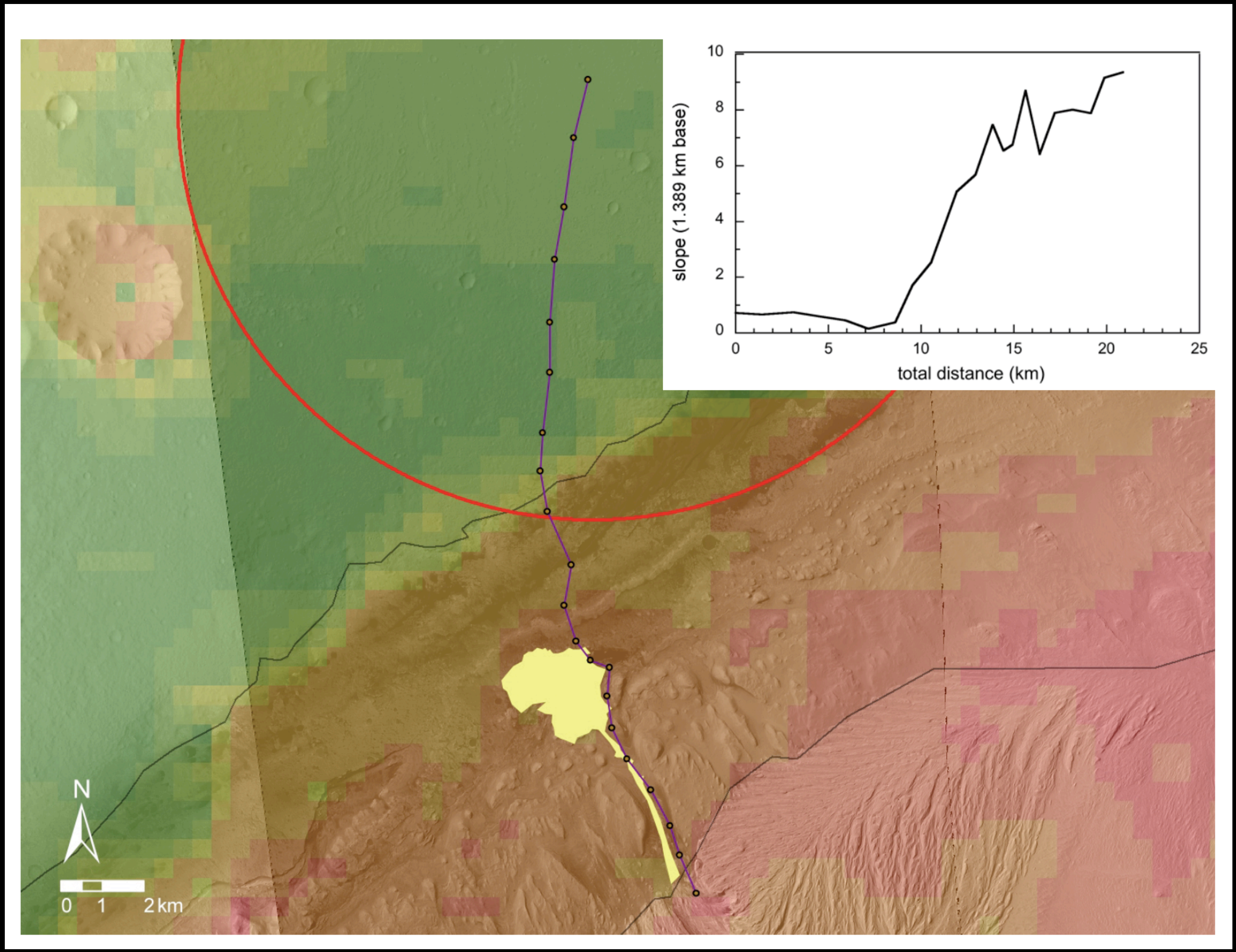
7. 'fan' from exhumed channel -- bounded by a low scarp, but there may be pathways for MSL to get to this material and examine it; surface has something resembling miniature star dunes--perhaps lithified wind-reworked fan sediment?

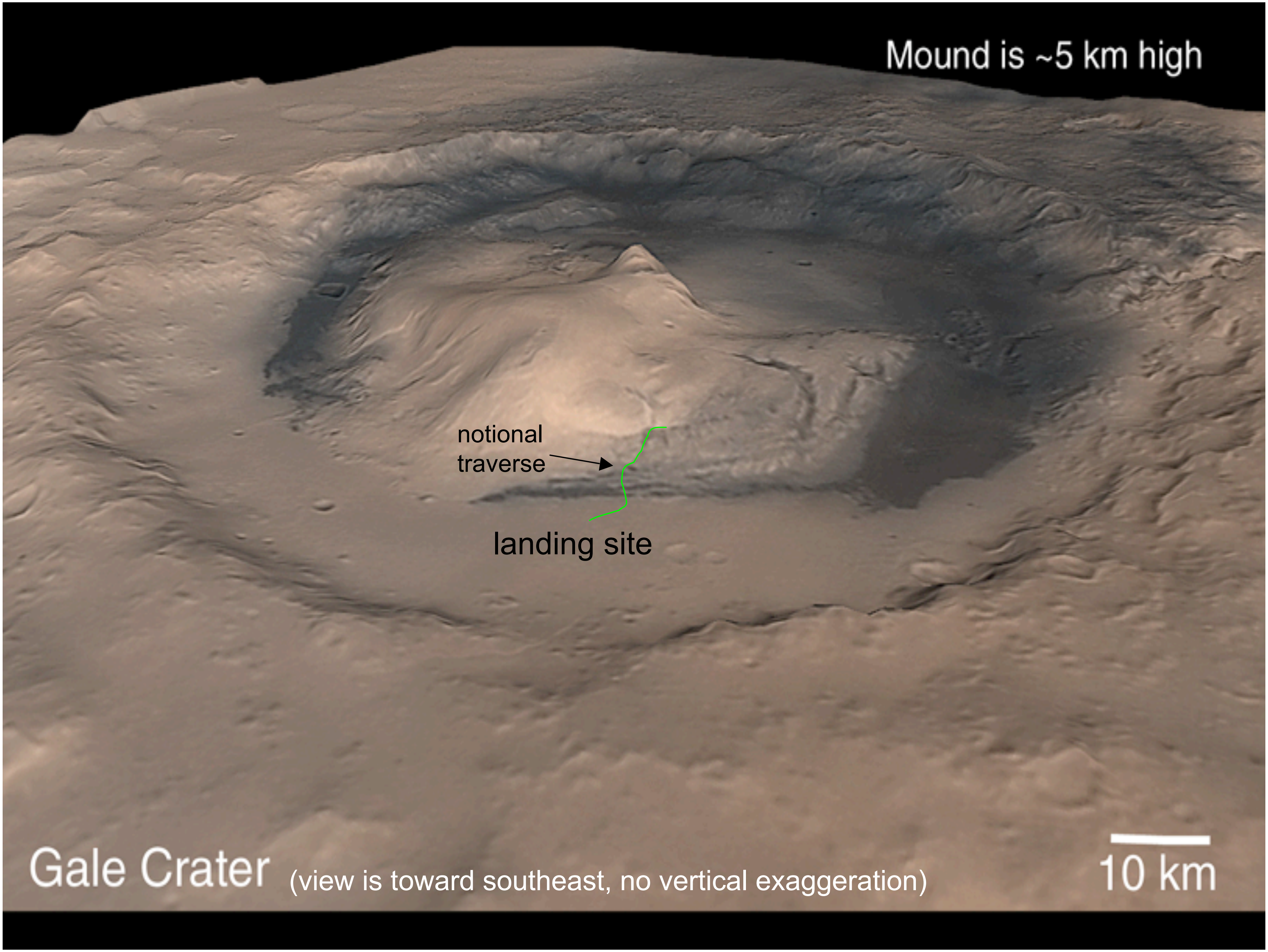
8. investigate layered rock stratigraphy -- sulfate-bearing rock -- and fill material in exhumed channel as rover works its way up slope

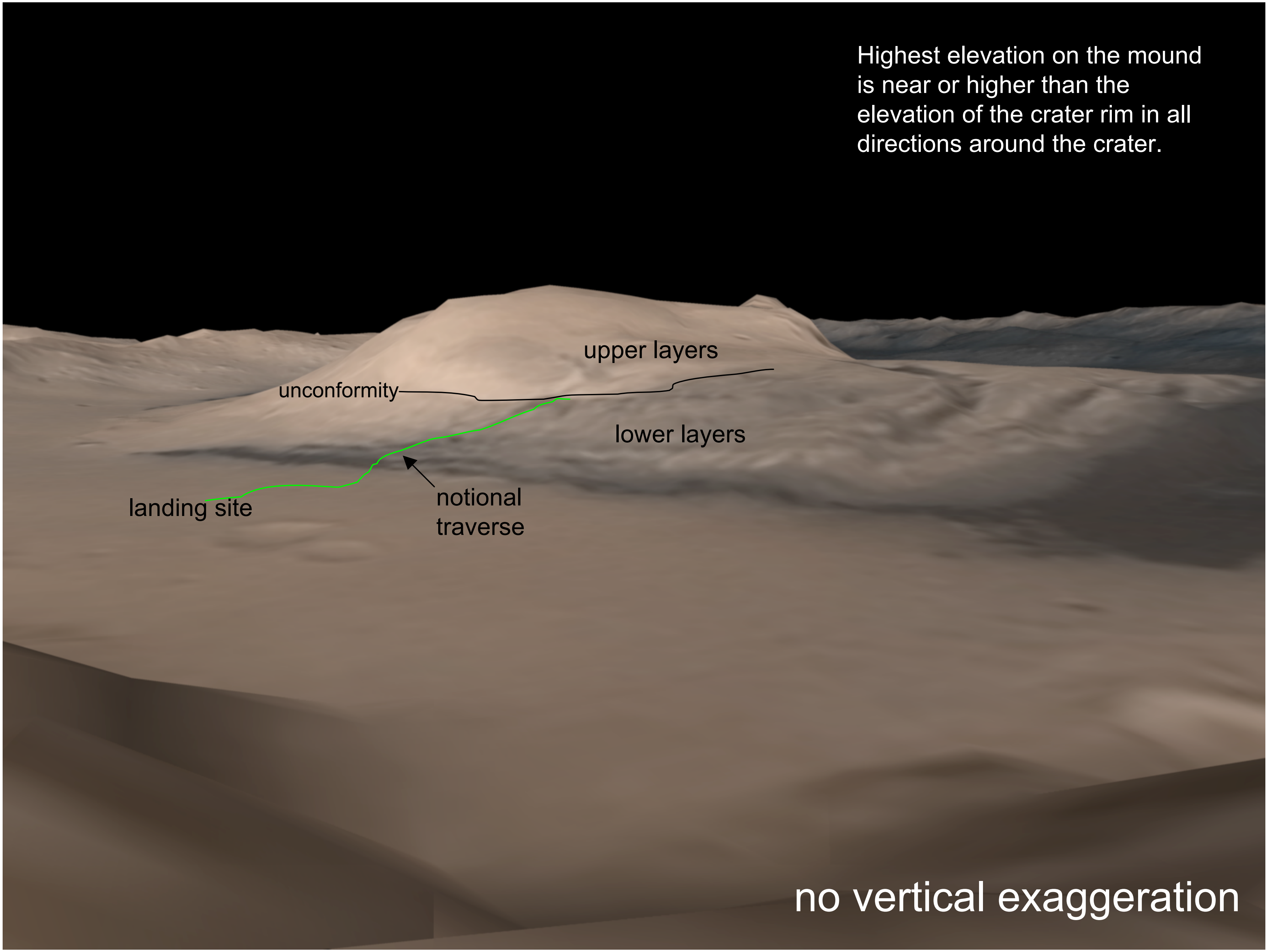
9. reach the erosional unconformity; examine lowermost layers of the upper unit that post-dates the erosional period

10. (optional) examine partly-exhumed crater (alternative, continue up the slope in the trough, southeast of #9)

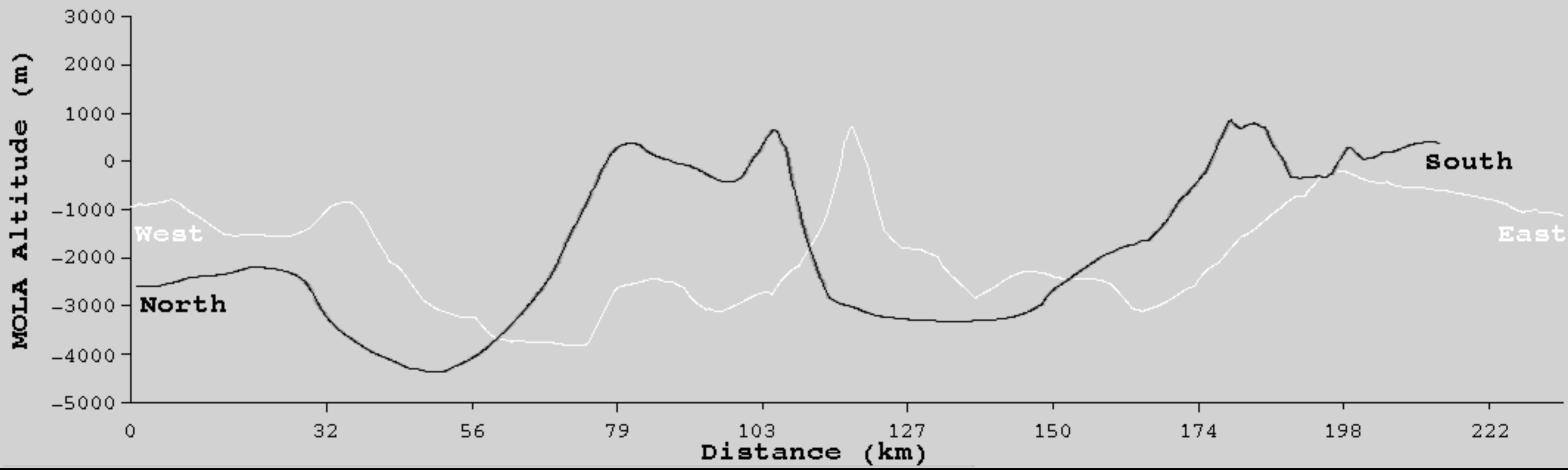
The notional traverse presented in this package is essentially the same as presented at the 2nd Landing Site workshop by Brad Thomson et al. (below).




Mound is ~5 km high
notional
traverse
landing site
Gale Crater
(view is toward southeast, no vertical exaggeration)
10 km


Highest elevation on the mound is near or higher than the elevation of the crater rim in all directions around the crater.
upper layers
unconformity
lower layers
landing site
notional traverse
no vertical exaggeration

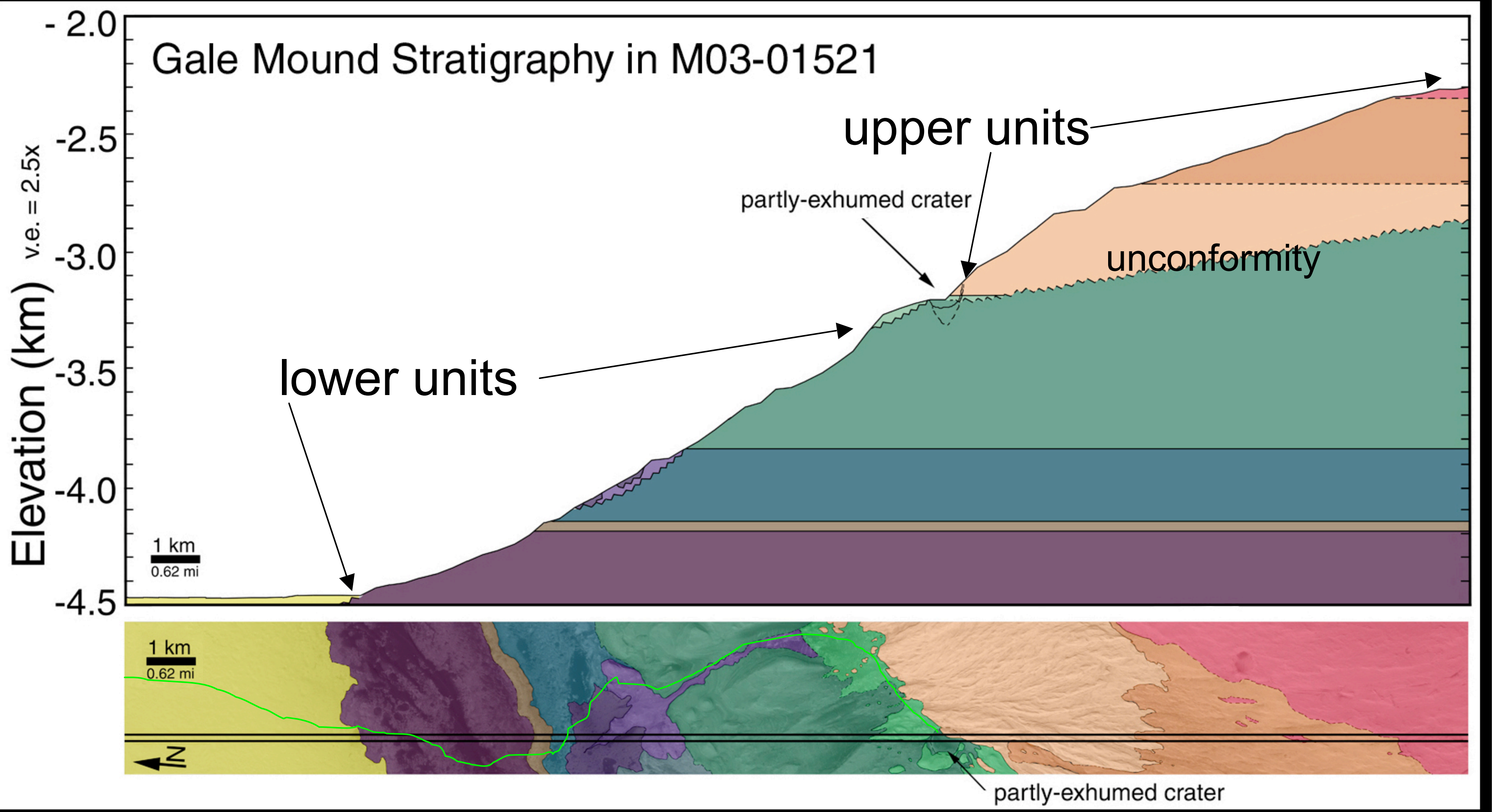
The highest elevation on the mound is near or higher than the rim in all directions around the crater.



Topographic profiles through the highest point in the Gale Crater mound. One profile runs East-West, the other North-South.

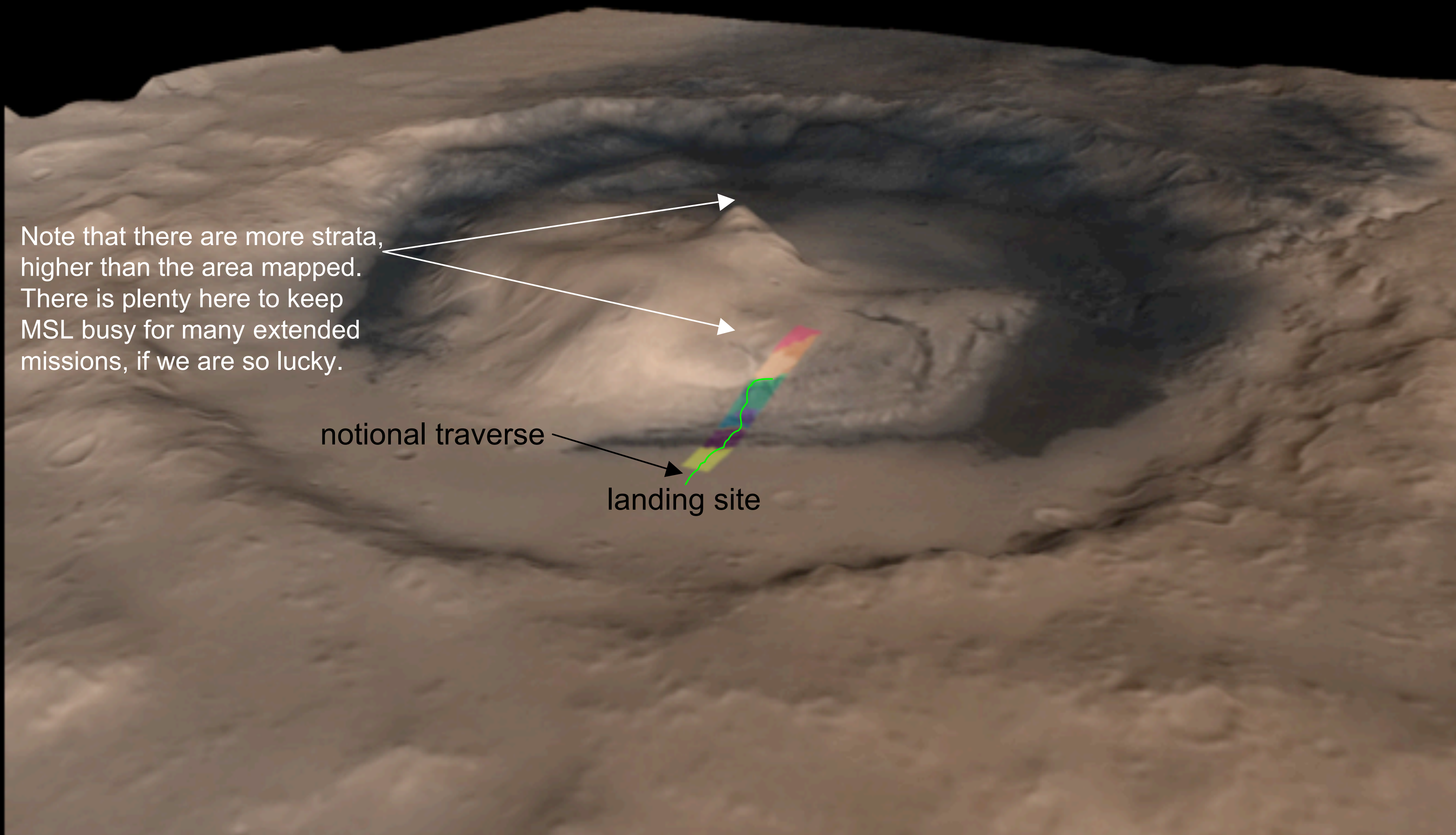
Both are derived from MGS MOLA observations, referenced to the geoid, thus accounting for planetary curvature.

Stratigraphic Section (Malin and Edgett 2000)

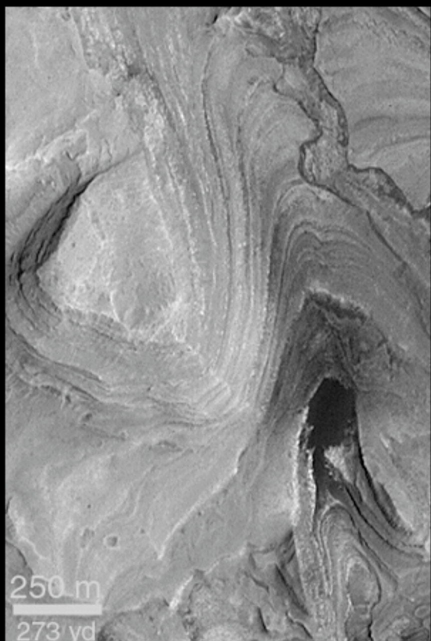


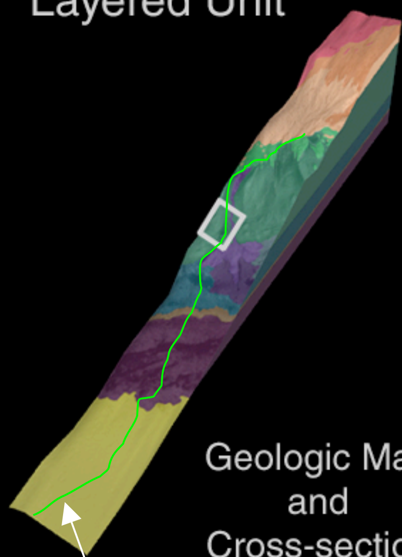
This shows stratigraphy as could be determined for just a small portion of the mound using a single MOC image and singe MOLA ground track (shot points between the 2 parallel black lines in the map, bottom). Green line (bottom) shows notional MSL traverse from landing ellipse to unconformity.

Context of the small geologic map based on MOC M03-01521



Layered Unit

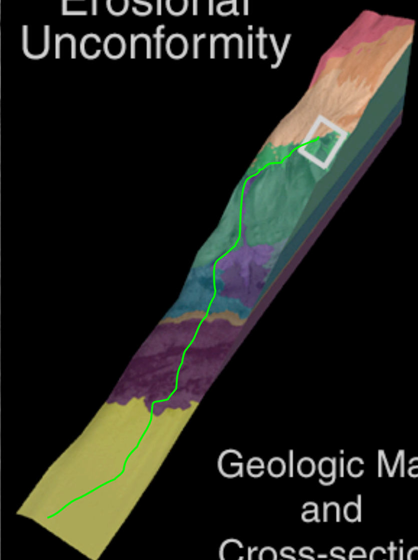




Geologic Map
and
Cross-section

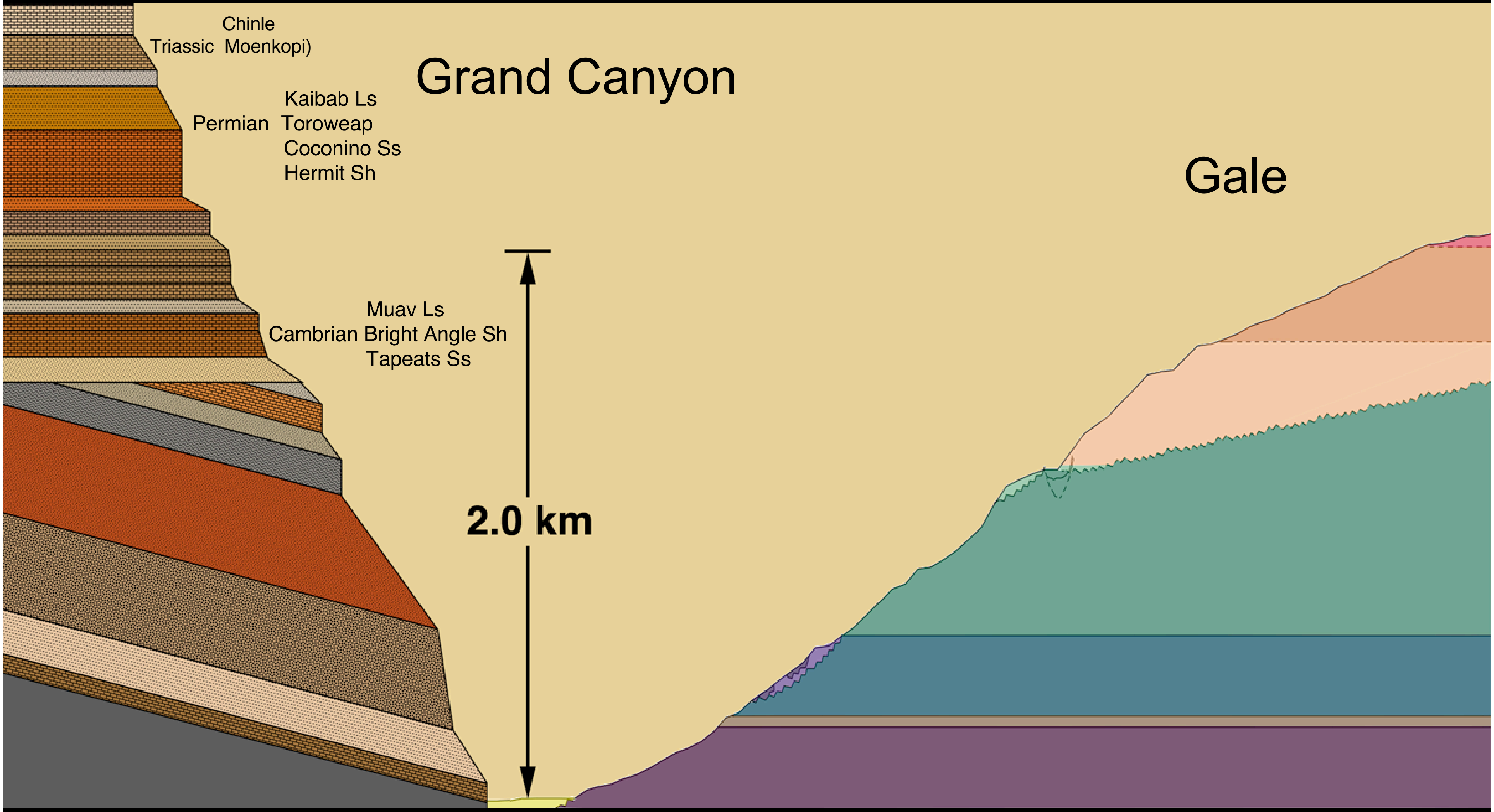
notional traverse

Erosional Unconformity



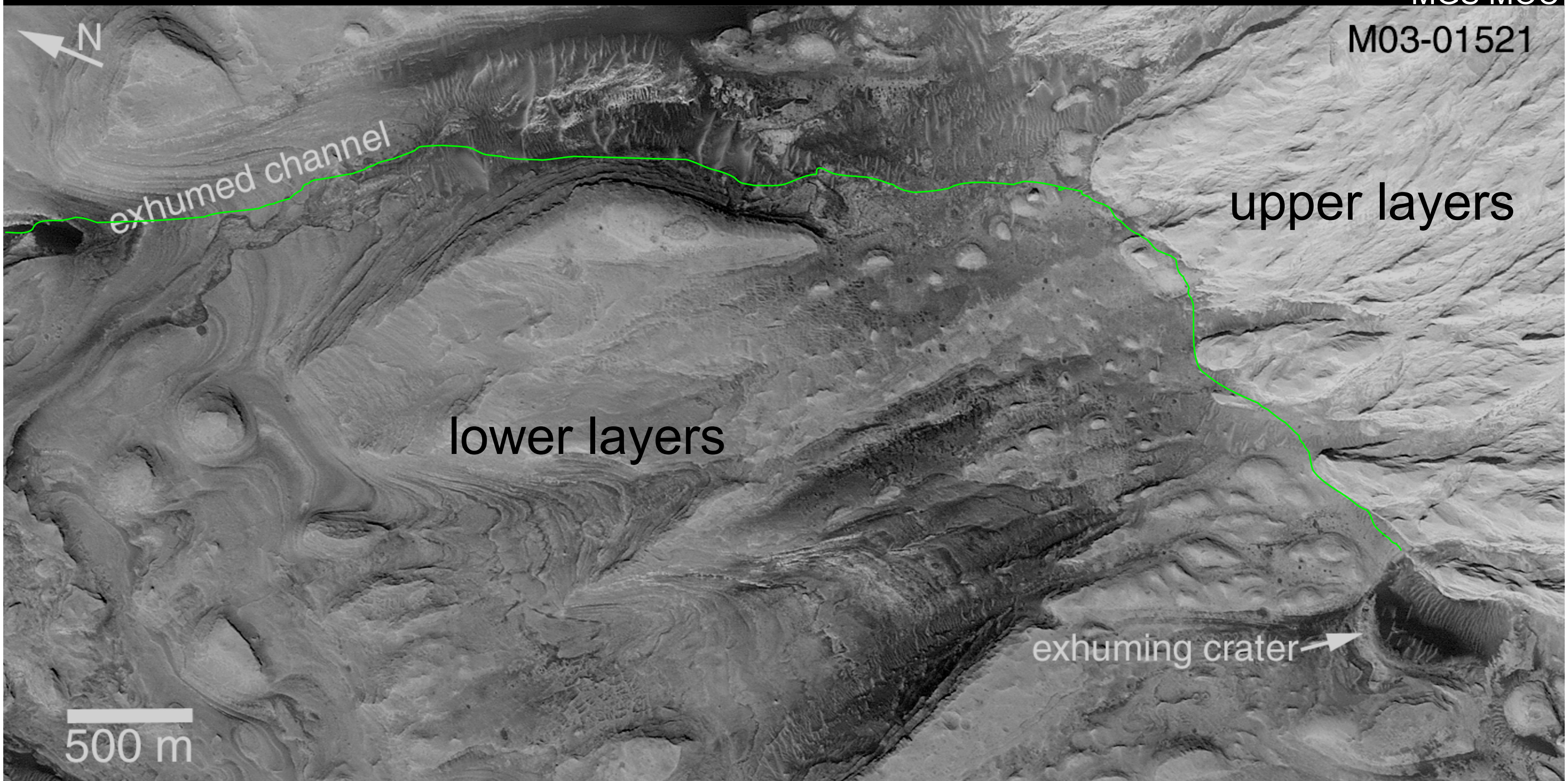
Geologic Map
and
Cross-section

- The Gale mound is in places up to 5 km high.
- The stratigraphy in the previous slide only covers the lower few kilometers.
- This figure is a comparison with the thickness of the Grand Canyon strat column.
- Remember the complex story recorded in the rocks at the Grand Canyon.
  - recognize how little you'd know about the Grand Canyon story if all you had to work with was data like that from MOC, MOLA, TES, THEMIS, HRSC, HiRISE, CTX, and CRISM.



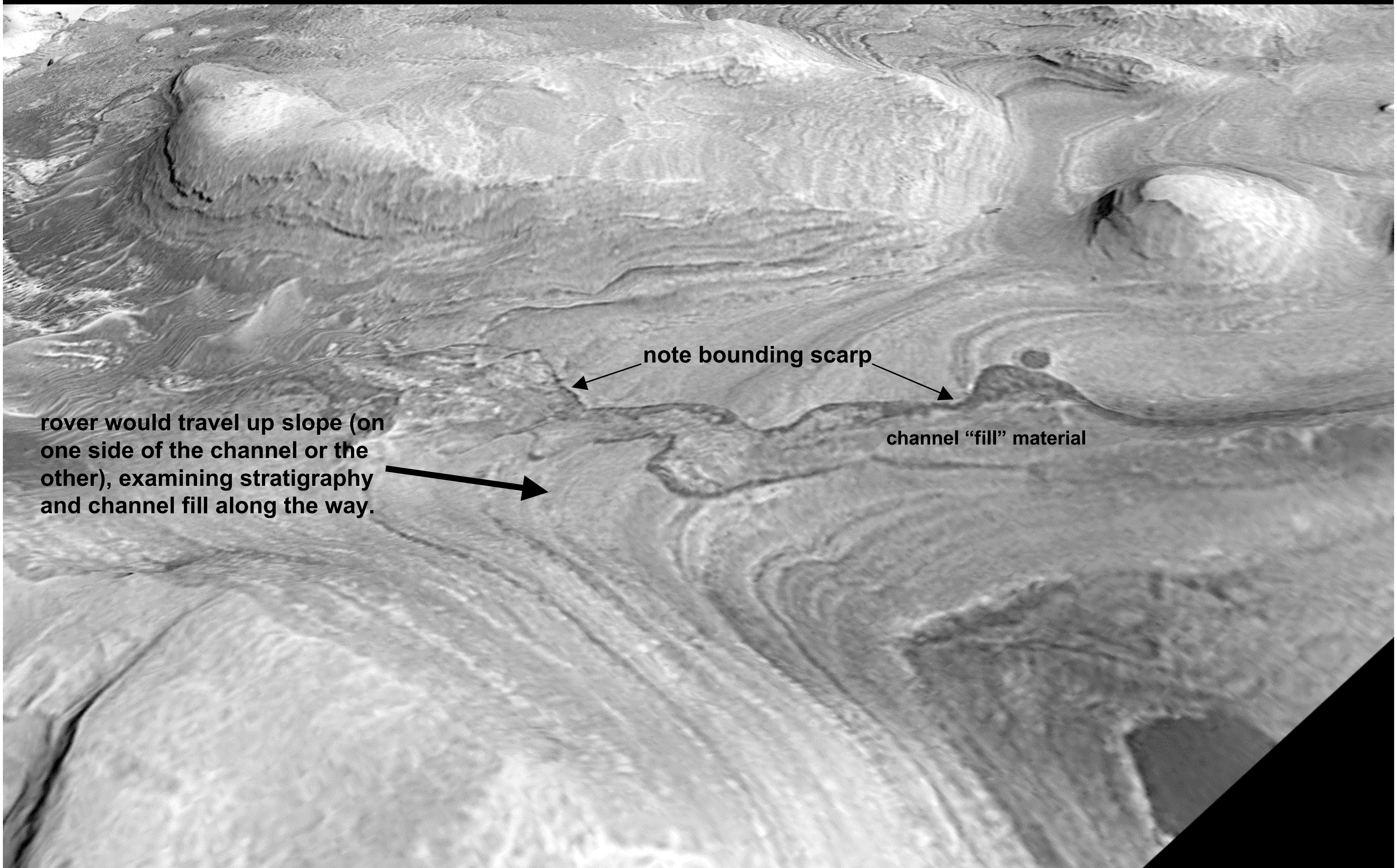
Unconformity; buried erosional surface in Gale Crater
-- channel formed during the erosion period --

MGS MOC



green line is notional traverse path for MSL

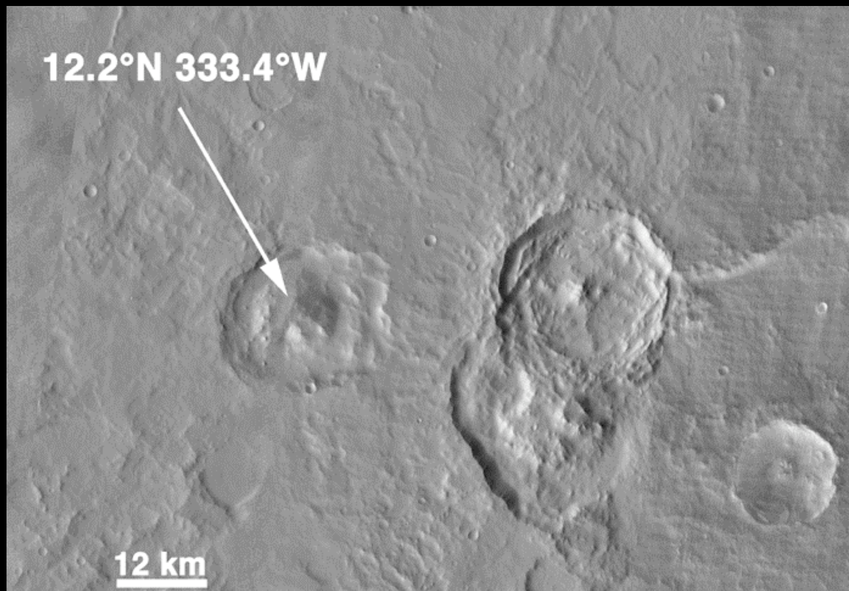
Perspective view of the filled/exhumed channel.

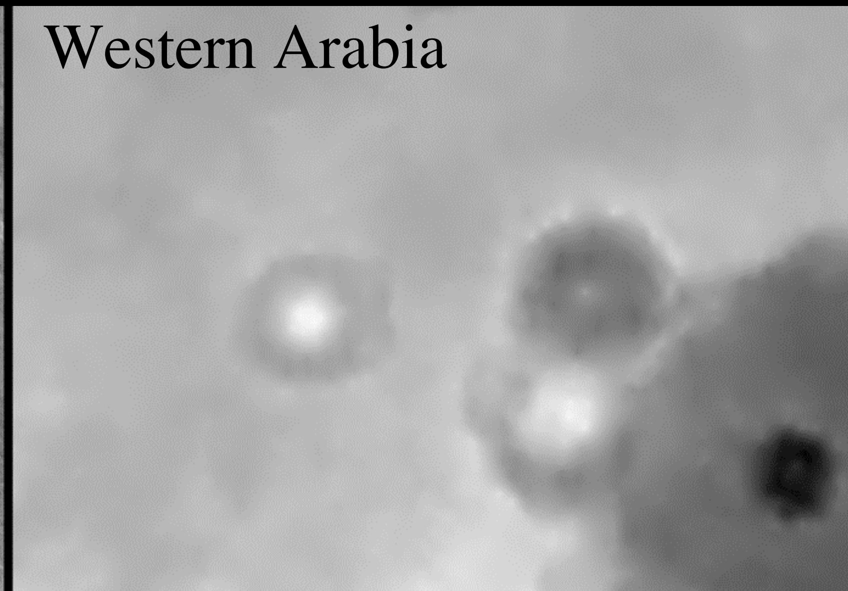


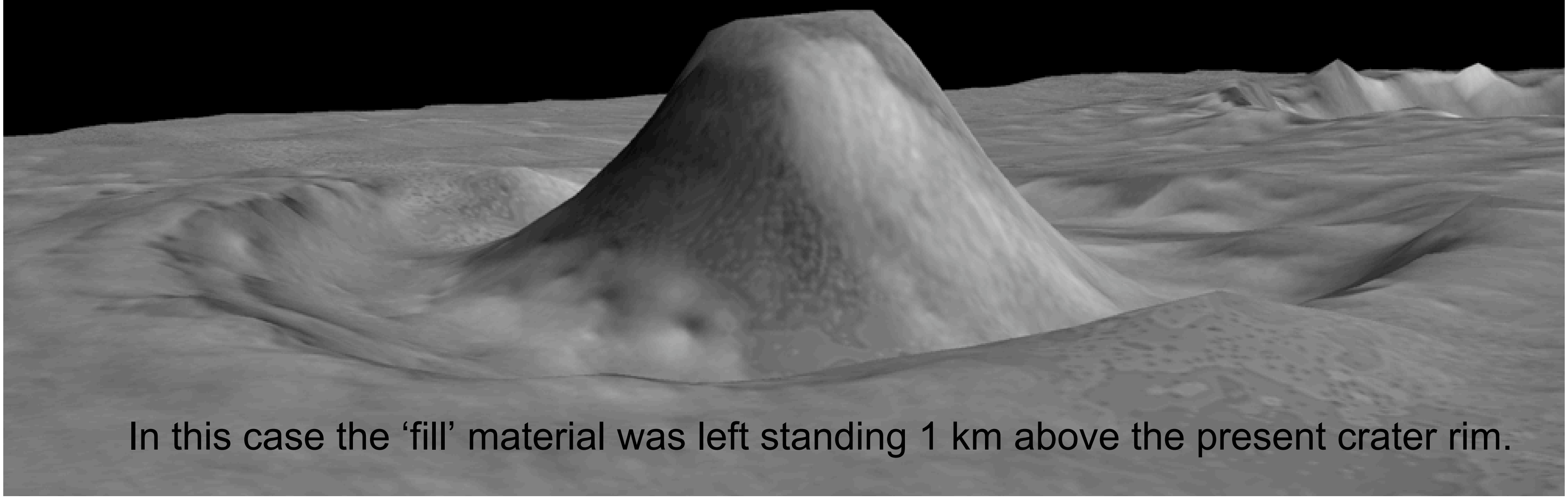
Gale is a member of the broad family of craters that have been filled or partially filled with layered rock. Like Gale, many of these have the odd relationship of being found today in a 'mound' somewhere inside the crater. Why this has occurred is not really known.

Note that the scale is the same in each figure.

We know that some craters on Mars have been completely filled, buried, and exhumed. here is a small example:

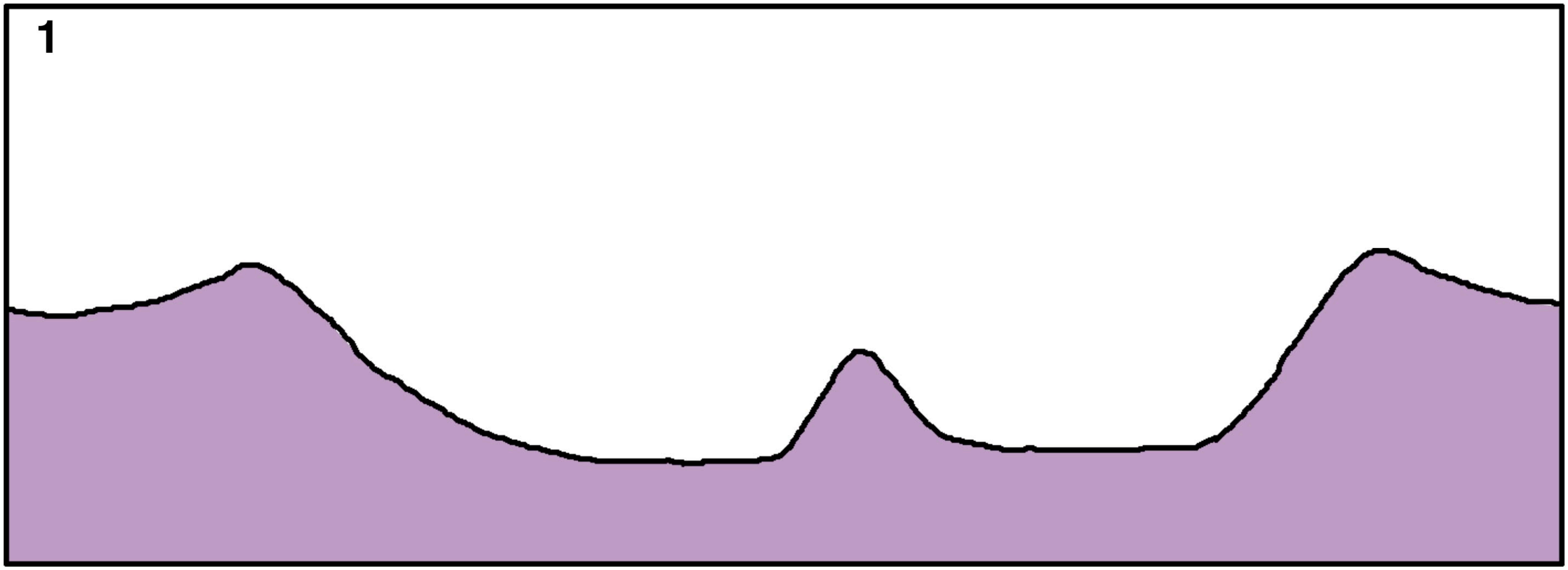






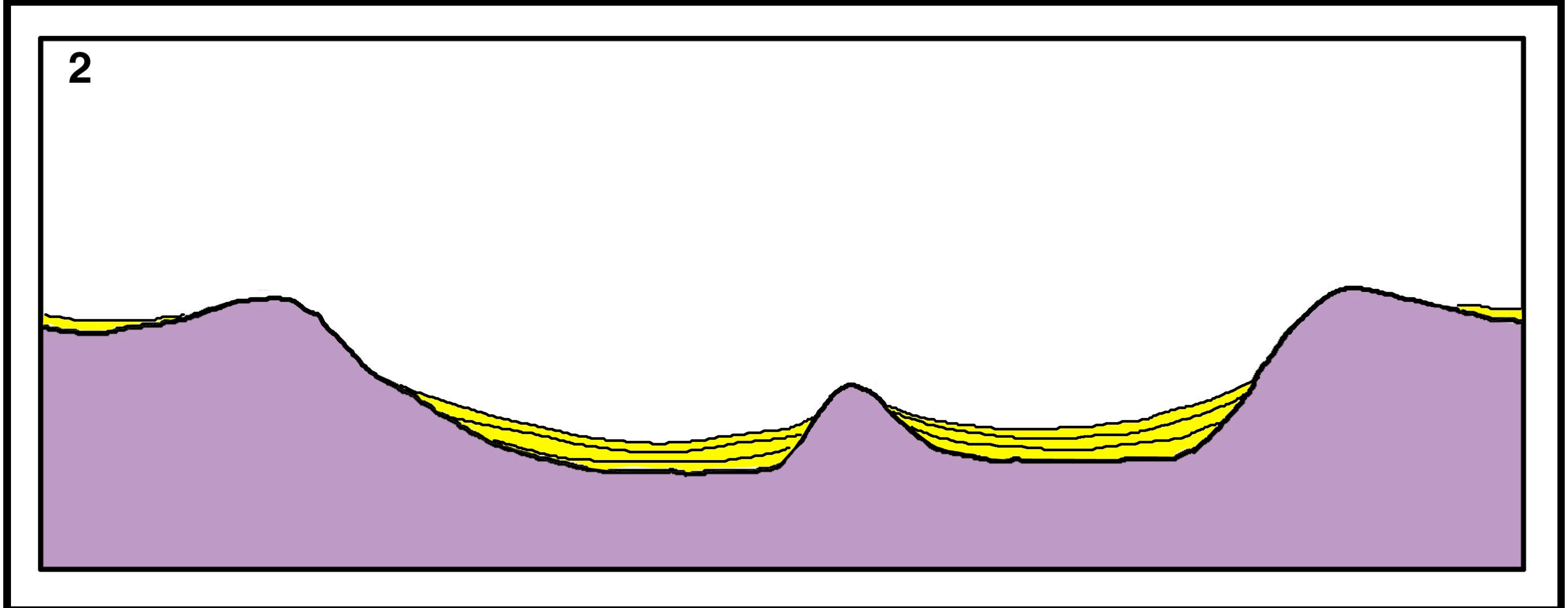
In this case the 'fill' material was left standing 1 km above the present crater rim.

The next 7 slides show a cartoon, from 2002, of an interpretation for Gale Crater in which the crater was filled with sediment, which was then eroded to form the mound, then later buried under additional material which might have filled the crater completely.

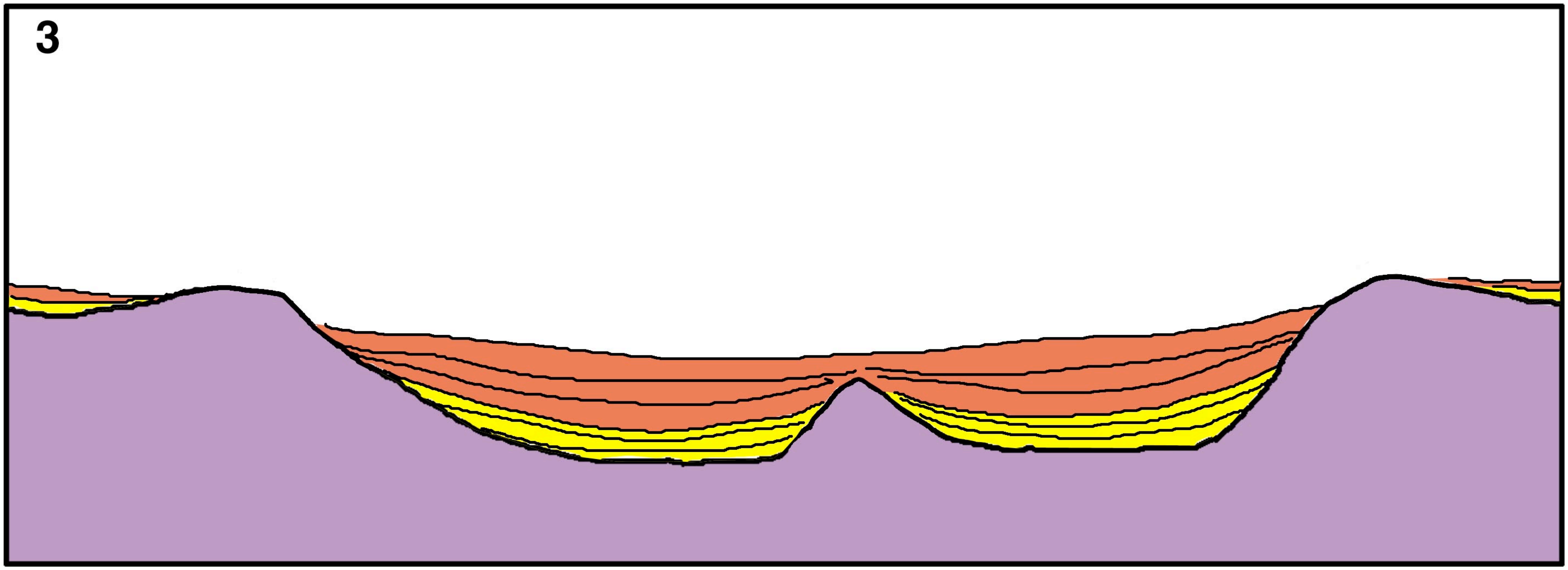


Gale Crater, shortly after it formed.

(This cartoon series is ~5 years old; we now think Gale did not have a central peak.)

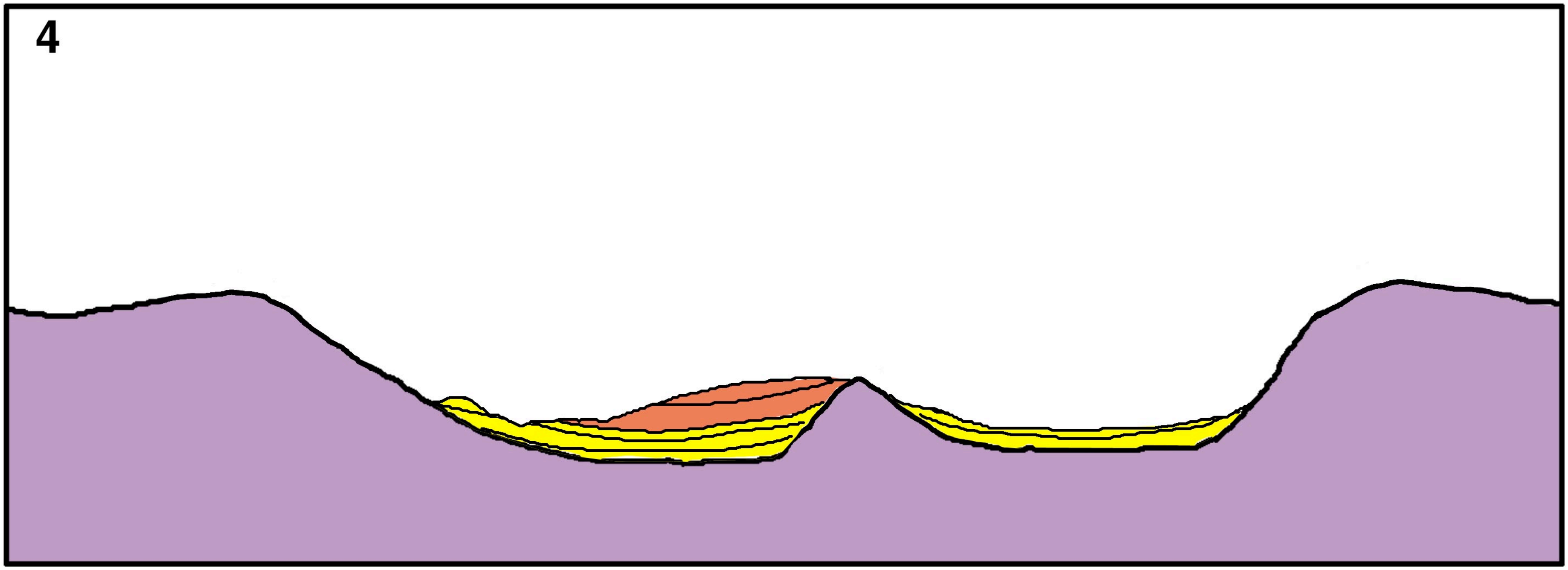


First pulse of layered material is deposited.
(Whether similar material was deposited outside the crater, as speculated here, is unknown.)

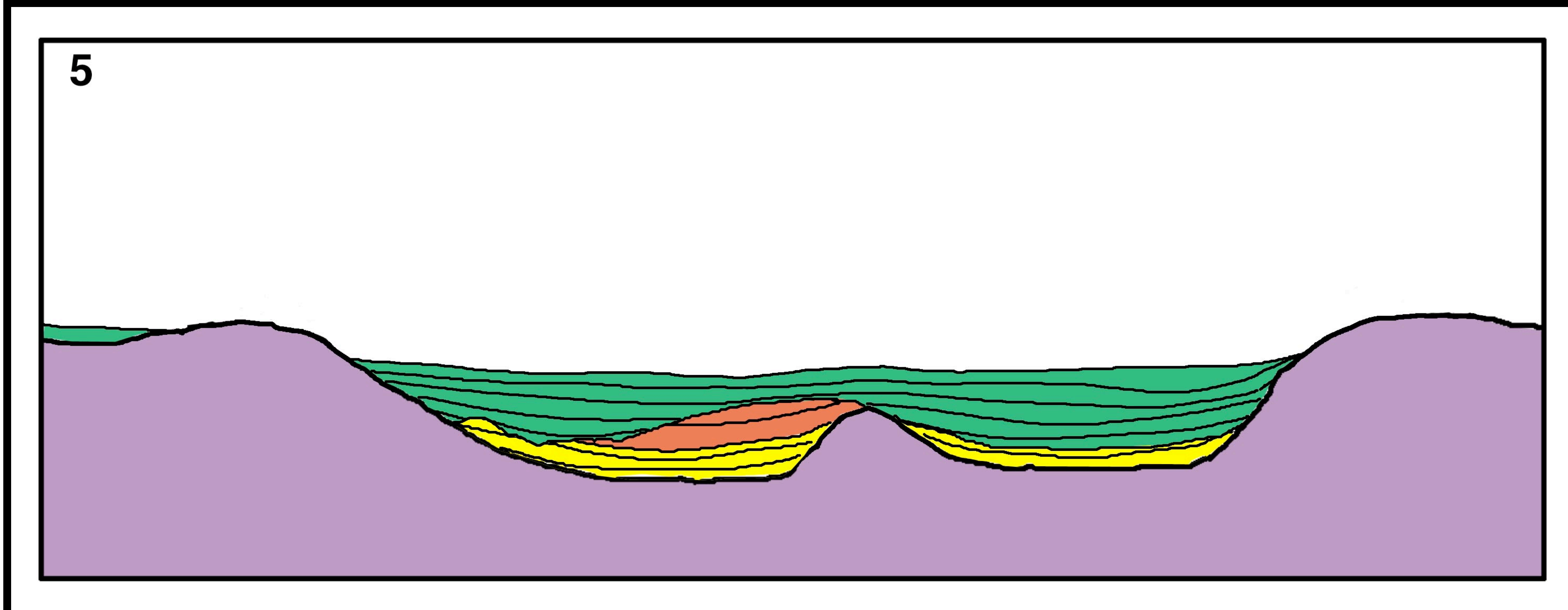


More layered sediments are deposited.

(Whether similar material was deposited outside the crater, as speculated here, is unknown.)

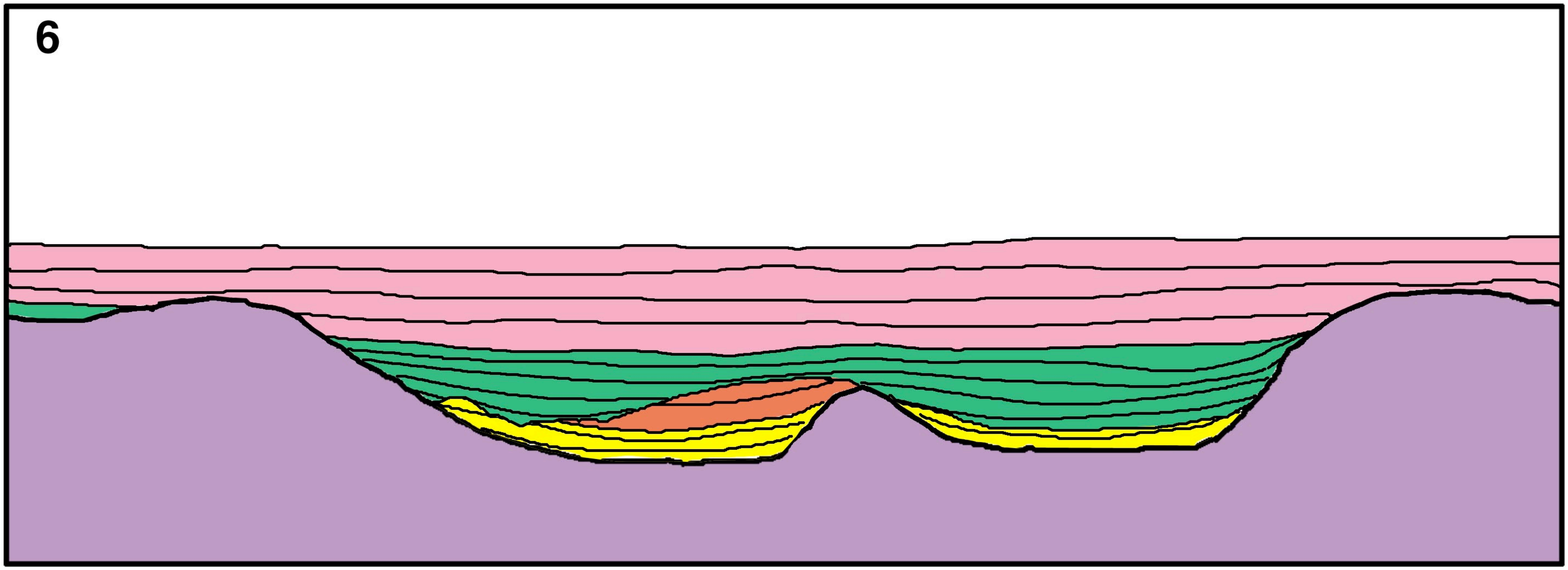


The earlier layers are lithified, then become eroded.
This forms the erosional unconformity observed in the Gale mound and these are the “lower layers”. This erosional period is when the several observed canyons and channels cut the mound.

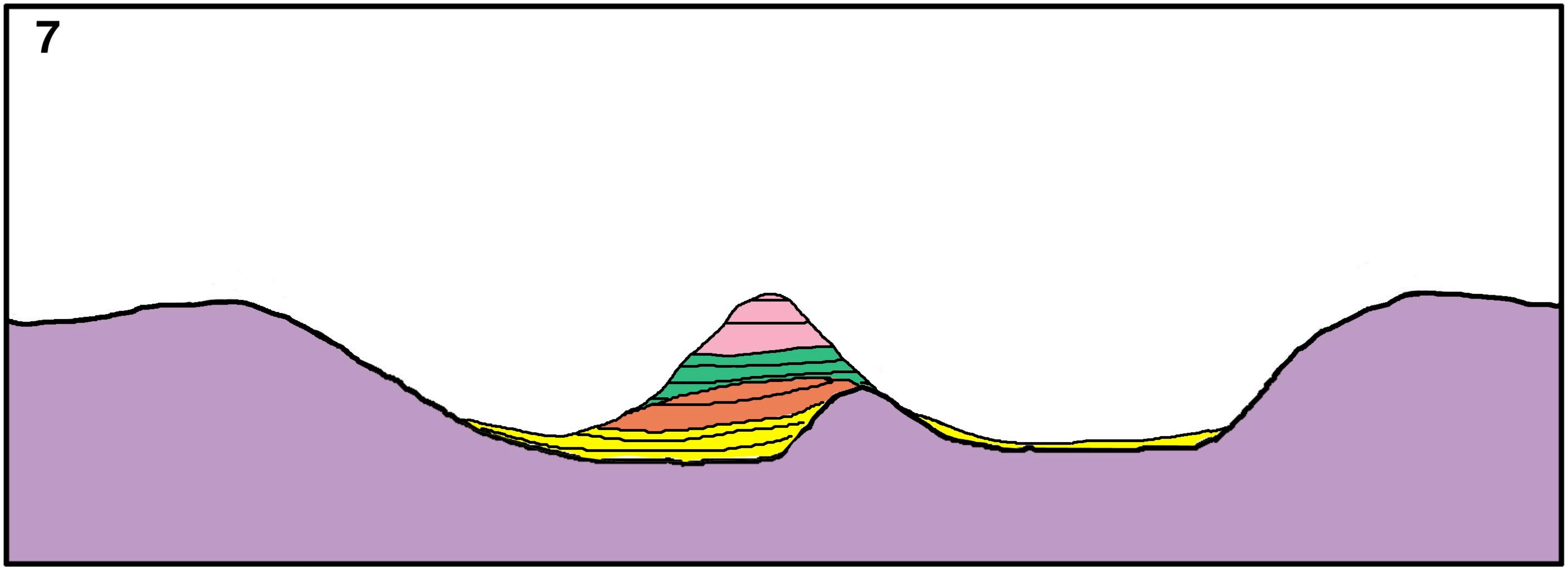


New material is deposited.

(Whether similar material was deposited outside the crater, as speculated here, is unknown.)



Still more material is deposited. This time, the crater is filled and perhaps buried to an unknown depth. This is interpreted based on the height of the mound relative to the crater rim elevations.

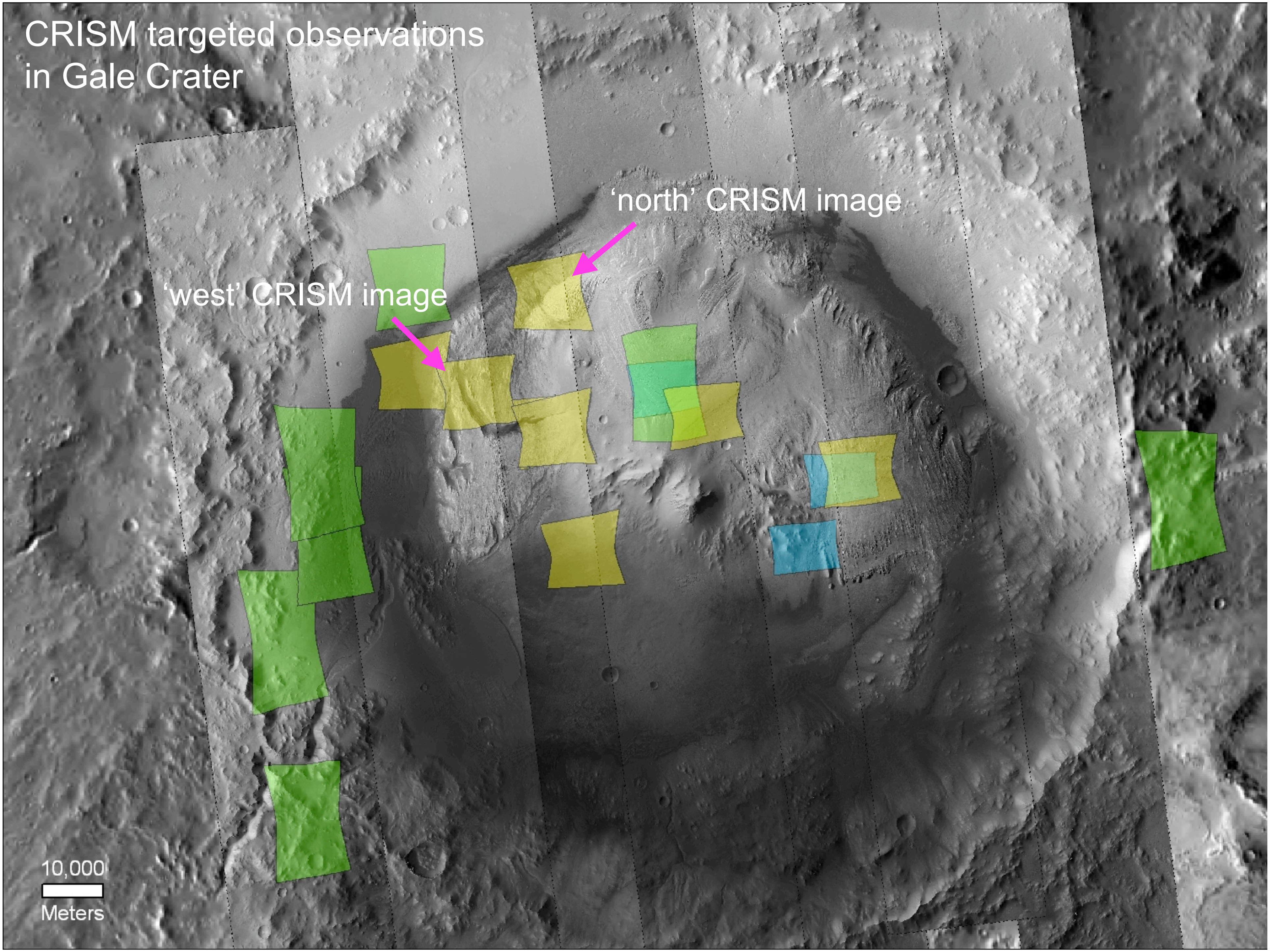


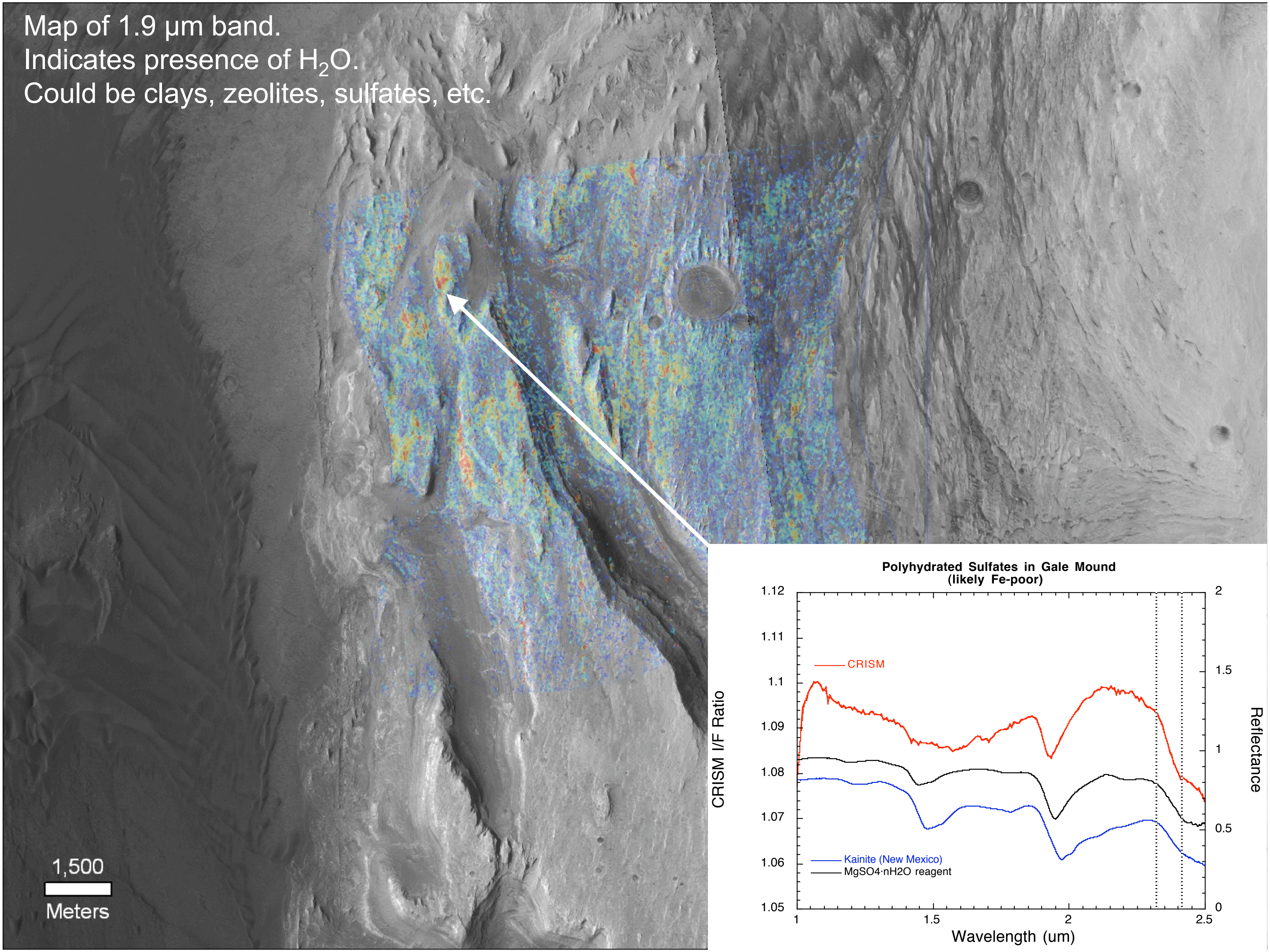
The later sediments are lithified and then the material is eroded to its present form.

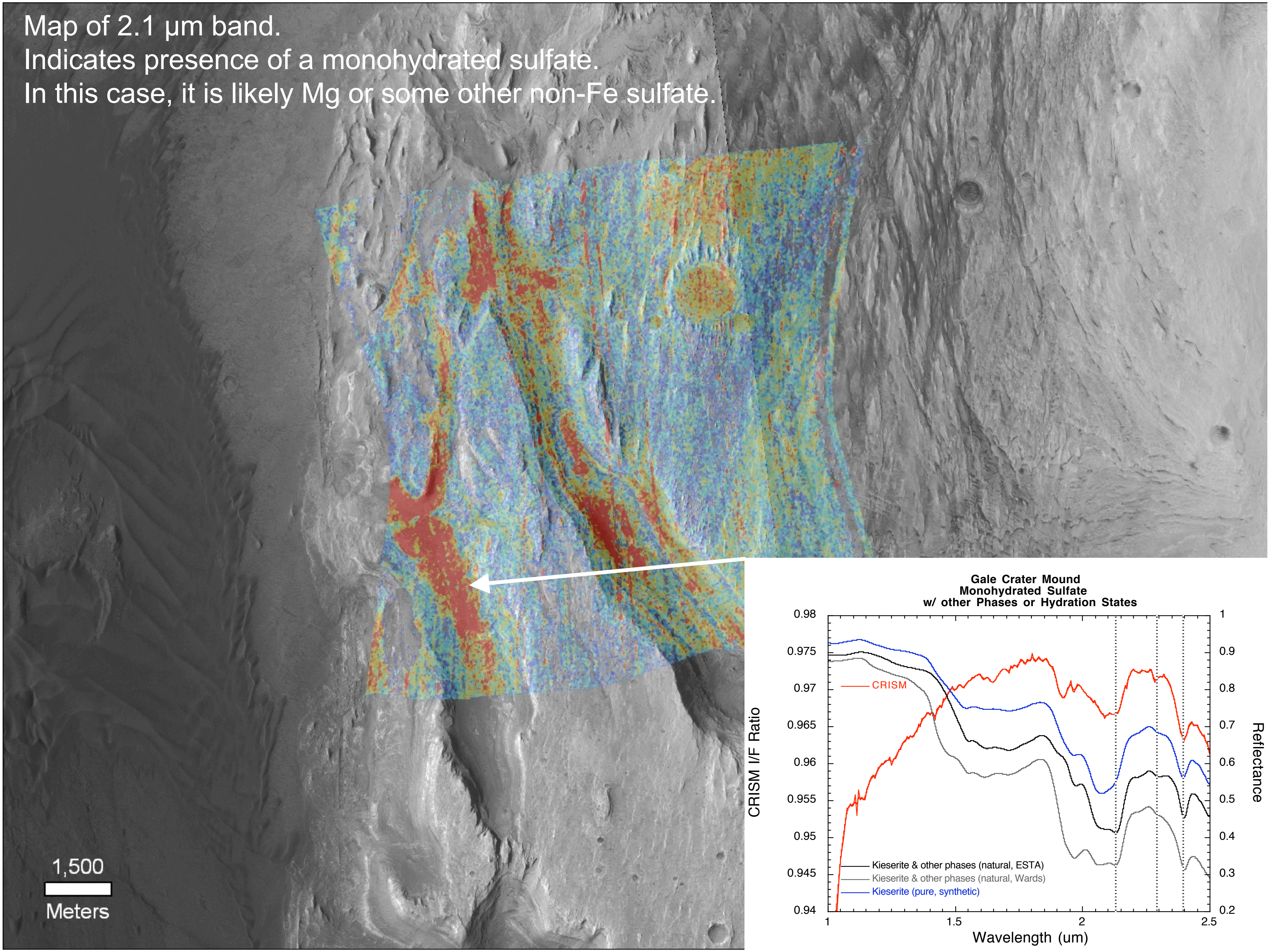
More CRISM Mineralogical Details

Earlier pages in this package showed interpretations regarding mineralogies observable by CRISM along the proposed MSL traverse up the mound. In the pages that follow, we note:

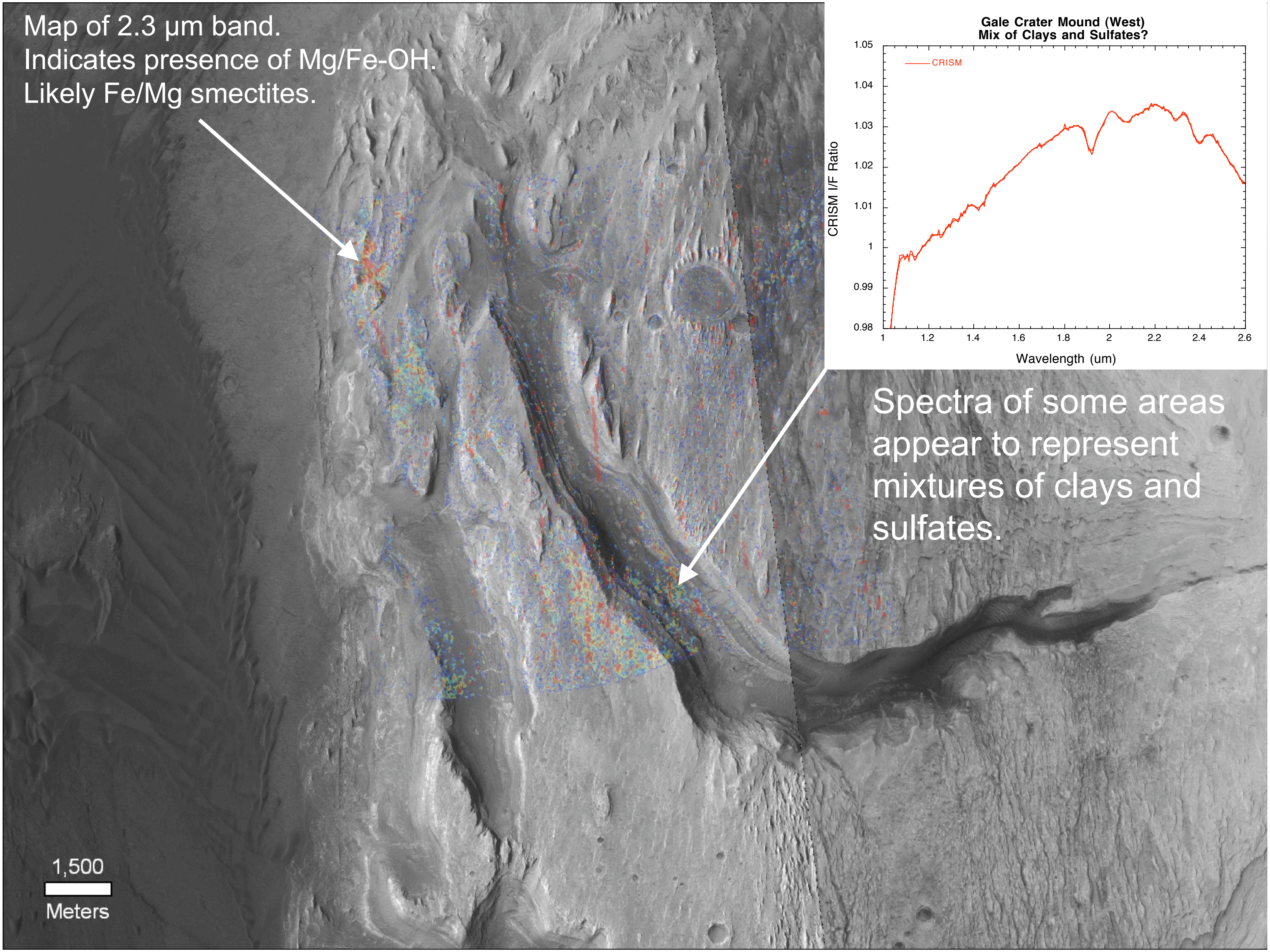
1. targeted CRISM coverage of Gale Crater.
2. mineral observations associated with the large canyon on the west side of the mound.
3. Summary of clays and sulfates story, thus far.

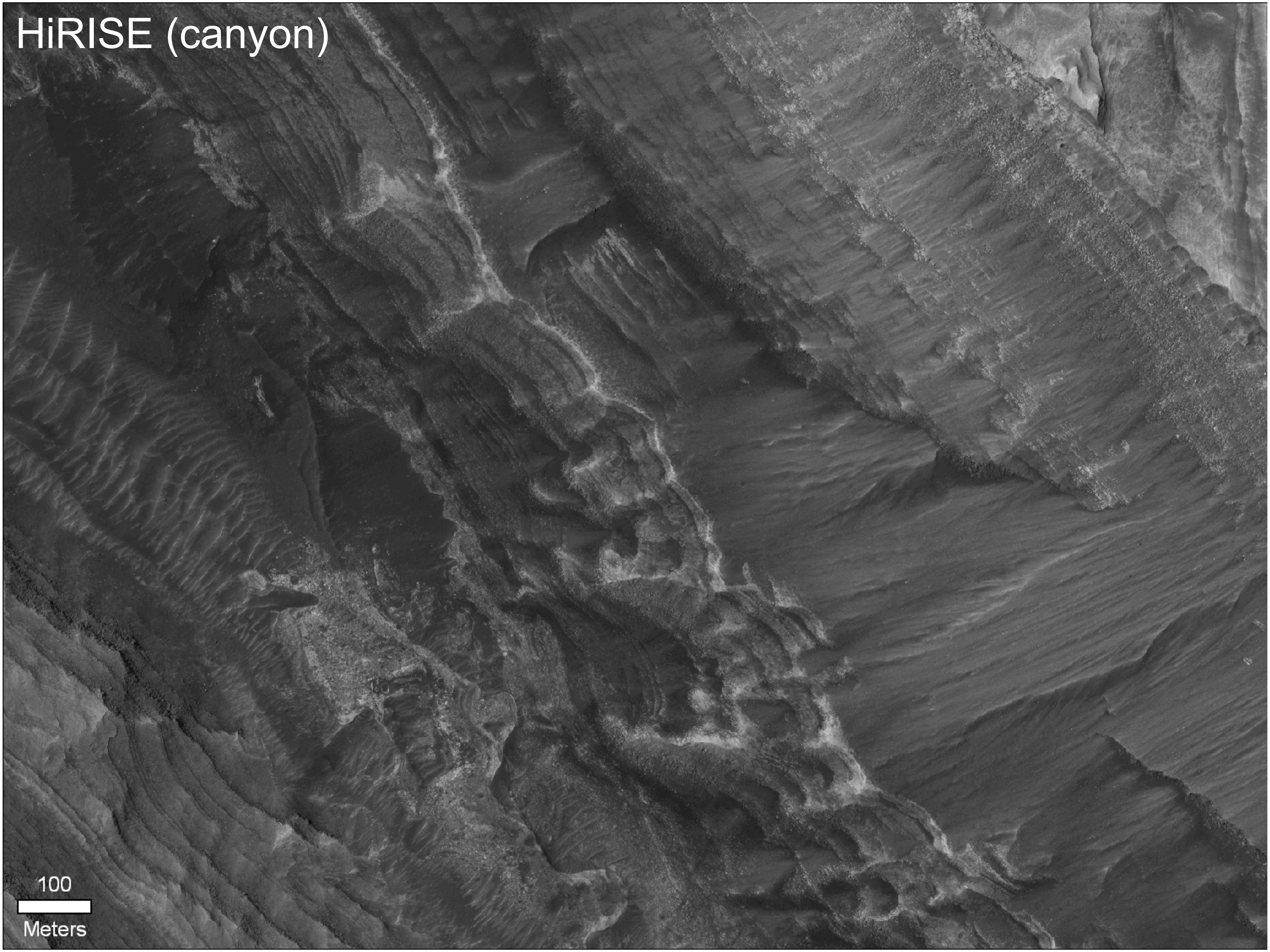

CRISM targeted observations
in Gale Crater
'north' CRISM image
'west' CRISM image
10,000
Meters

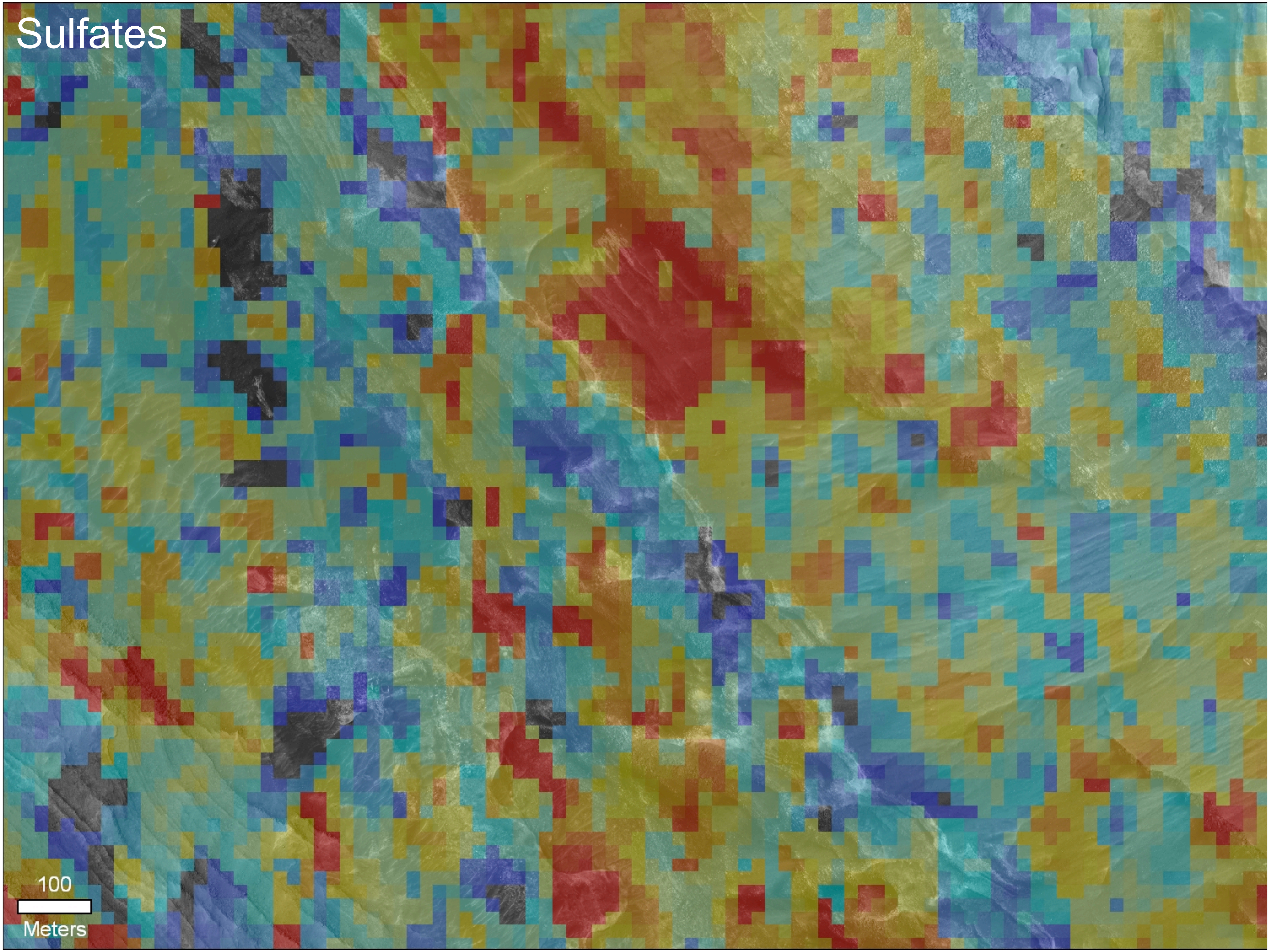

Map of 1.9 μm band.
Indicates presence of H_2O.
Could be clays, zeolites, sulfates, etc.
1,500
Meters
Polyhydrated Sulfates in Gale Mound
(likely Fe-poor)
CRISM
Kainite (New Mexico)
MgSO4·nH2O reagent
CRISM I/F Ratio
Reflectance
Wavelength (um)
1.12
1.11
1.1
1.09
1.08
1.07
1.06
1.05
1
1.5
2
2.5
0.5
0

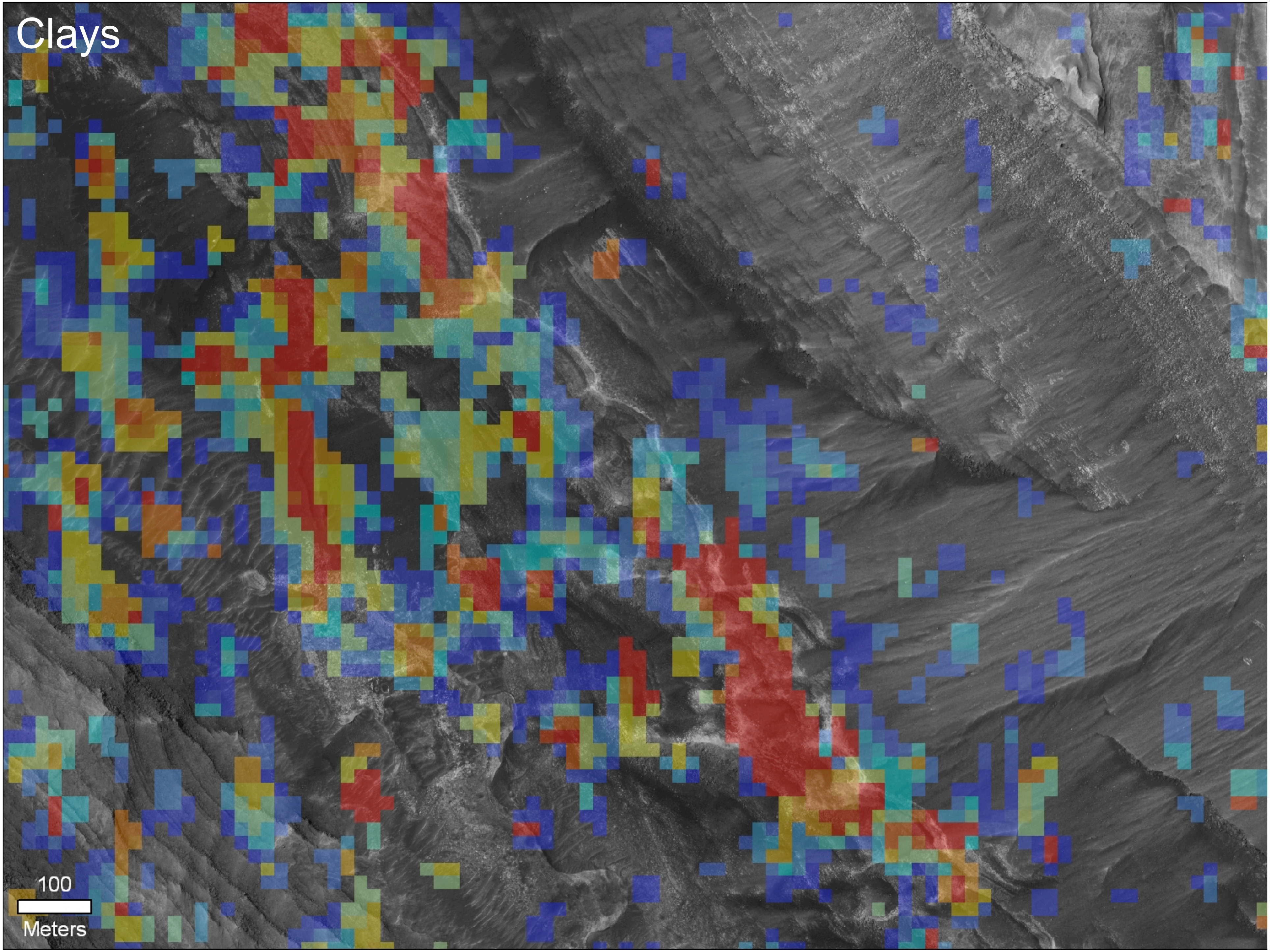


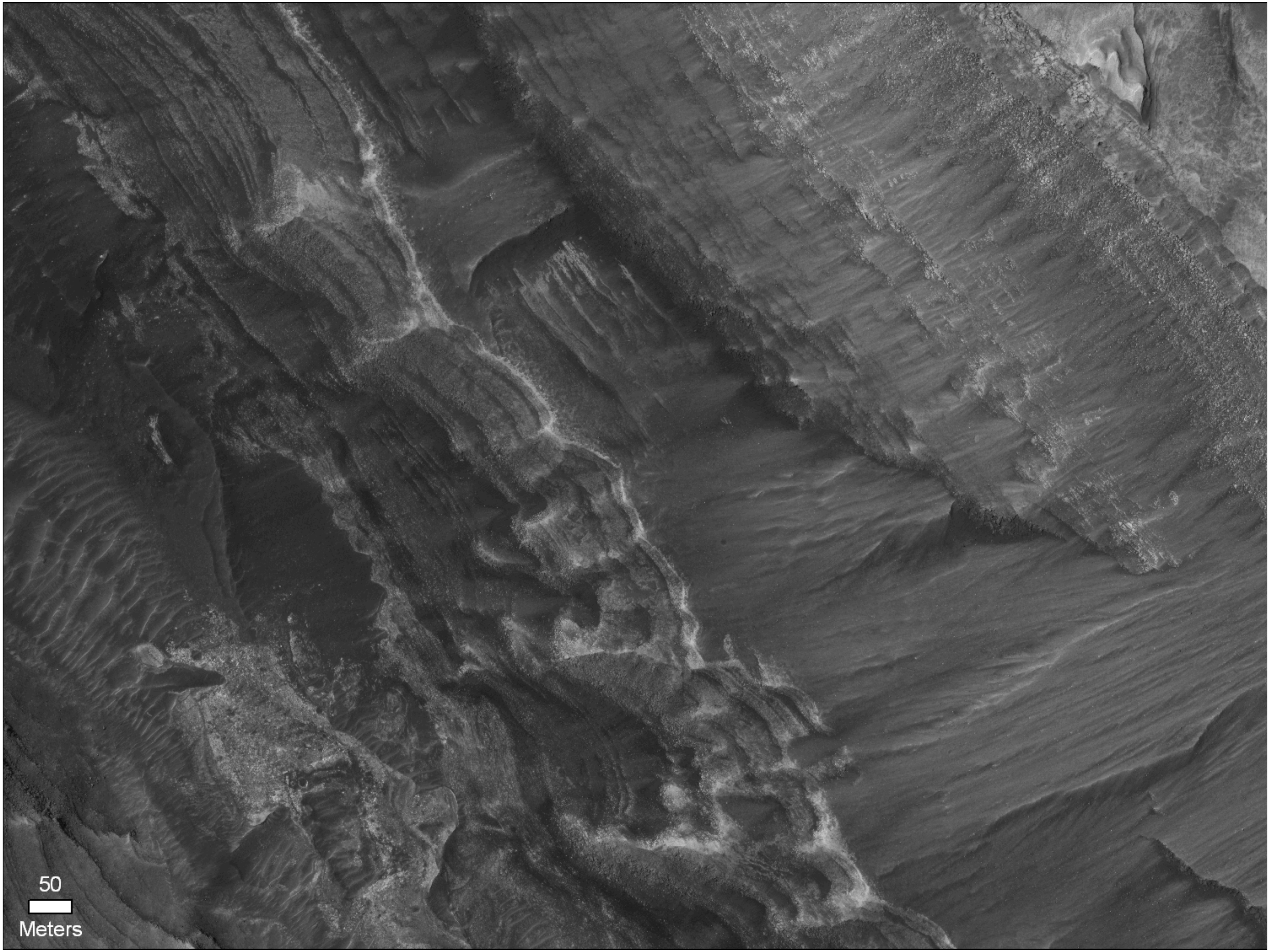
Map of 2.1 µm band.
Indicates presence of a monohydrated sulfate.
In this case, it is likely Mg or some other non-Fe sulfate.
1,500
Meters
Gale Crater Mound
Monohydrated Sulfate
w/ other Phases or Hydration States
CRISM
Kieserite & other phases (natural, ESTA)
Kieserite & other phases (natural, Wards)
Kieserite (pure, synthetic)
CRISM I/F Ratio
Reflectance
Wavelength (um)
0.98
0.975
0.97
0.965
0.96
0.955
0.95
0.945
0.94
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
1
1.5
2
2.5

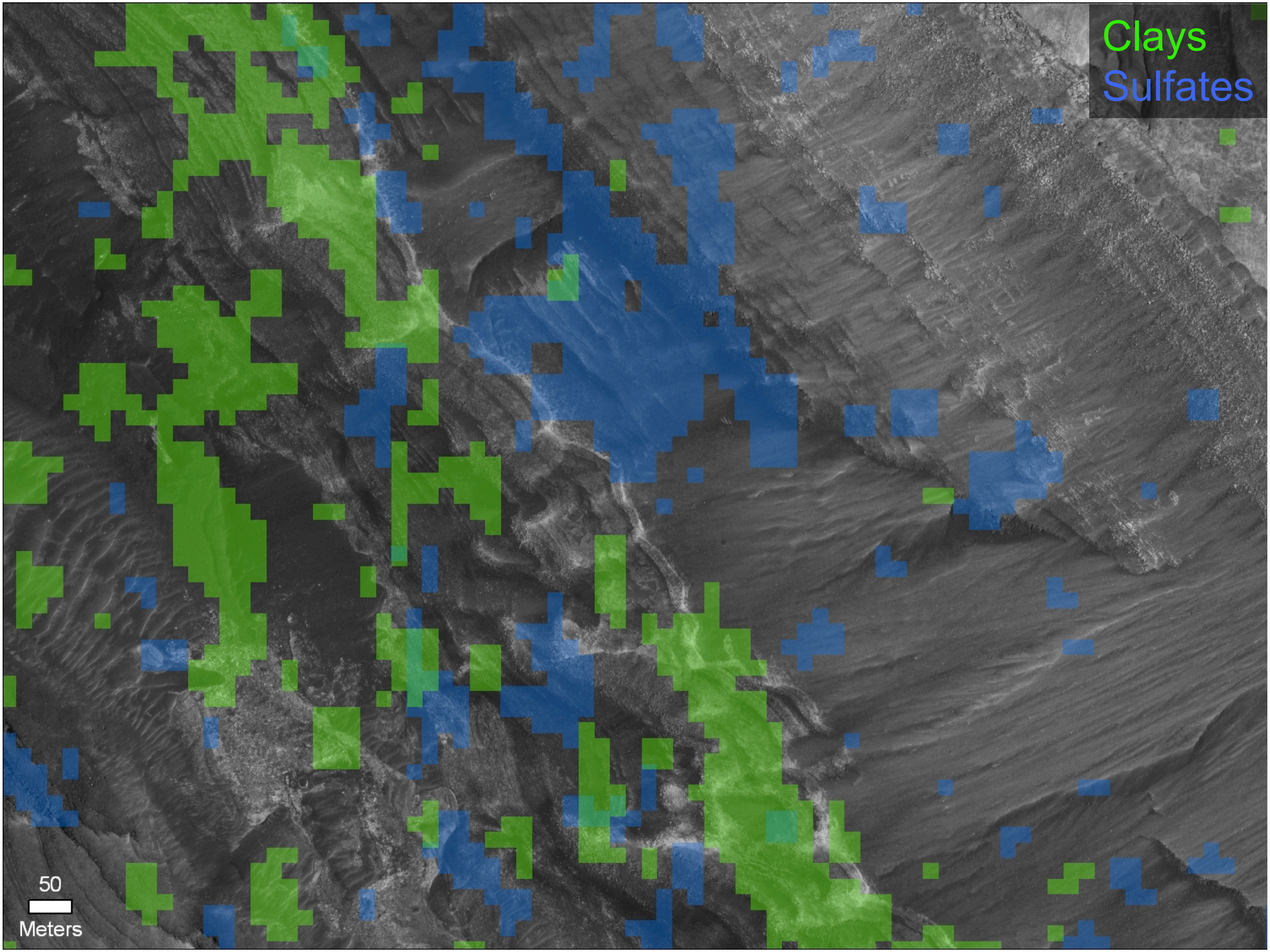

Map of 2.3 μm band.
Indicates presence of Mg/Fe-OH.
Likely Fe/Mg smectites.
Gale Crater Mound (West)
Mix of Clays and Sulfates?
CRISM
CRISM I/F Ratio
1.05
1.04
1.03
1.02
1.01
1
0.99
0.98
1
1.2
1.4
1.6
1.8
2
2.2
2.4
2.6
Wavelength (um)
Spectra of some areas appear to represent mixtures of clays and sulfates.
1,500
Meters


HiRISE (canyon)
100
Meters


Sulfates
100
Meters

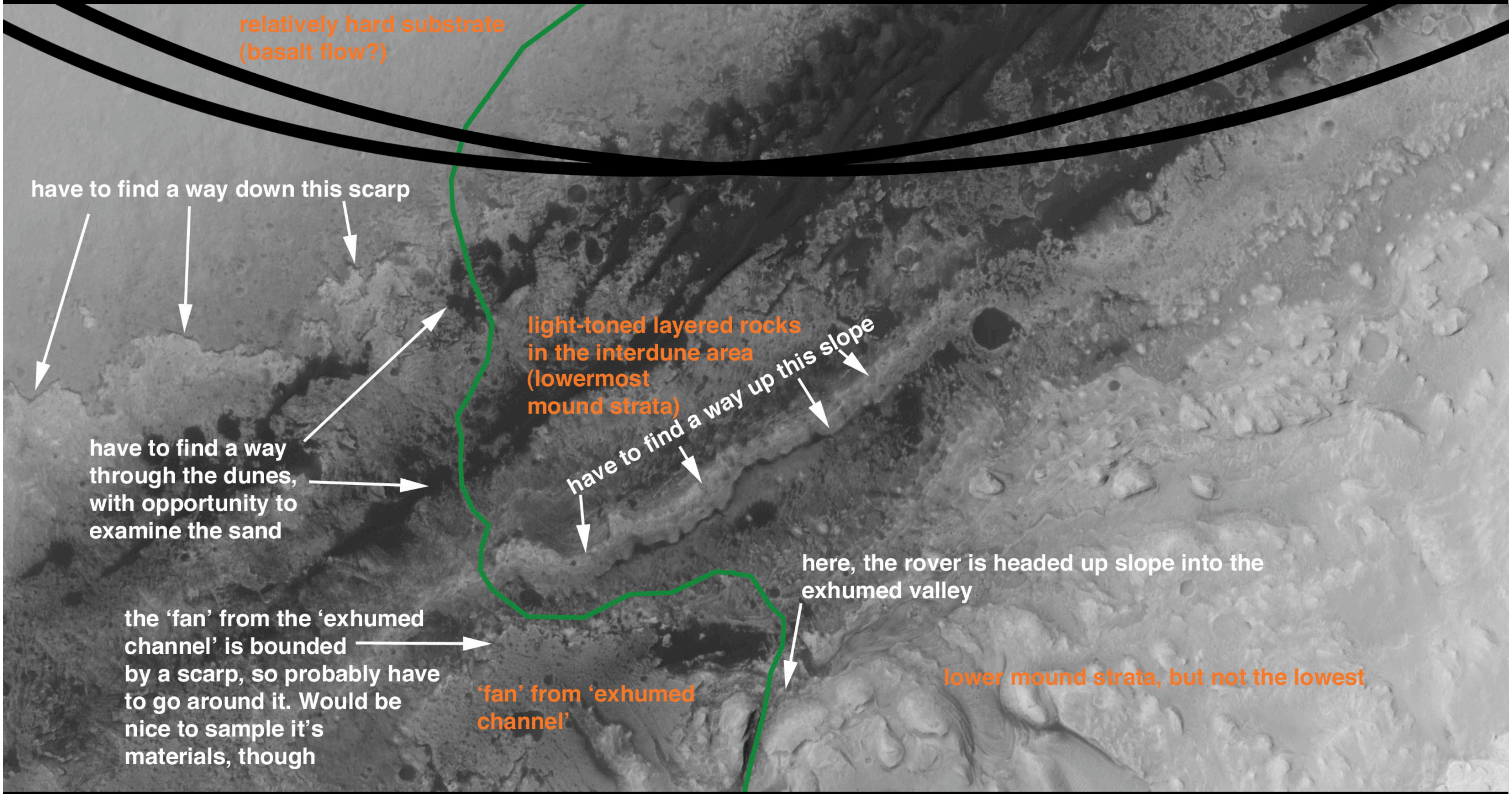

Clays
100
Meters


50
Meters


Clays
Sulfates
50
Meters

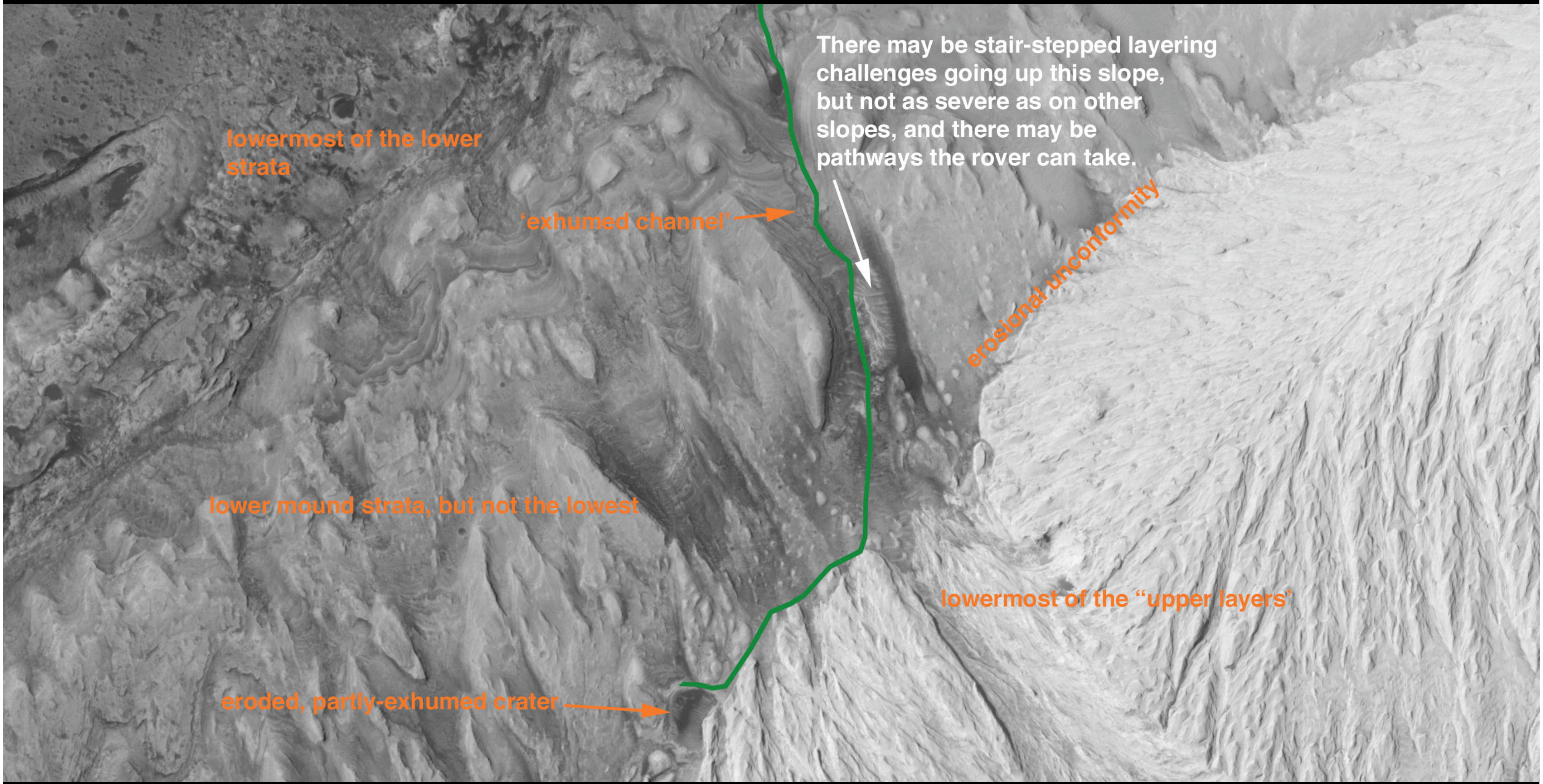
Some Geology/Geomorphology Details

Notional traverse, as rover travels out of ellipse, toward mound.

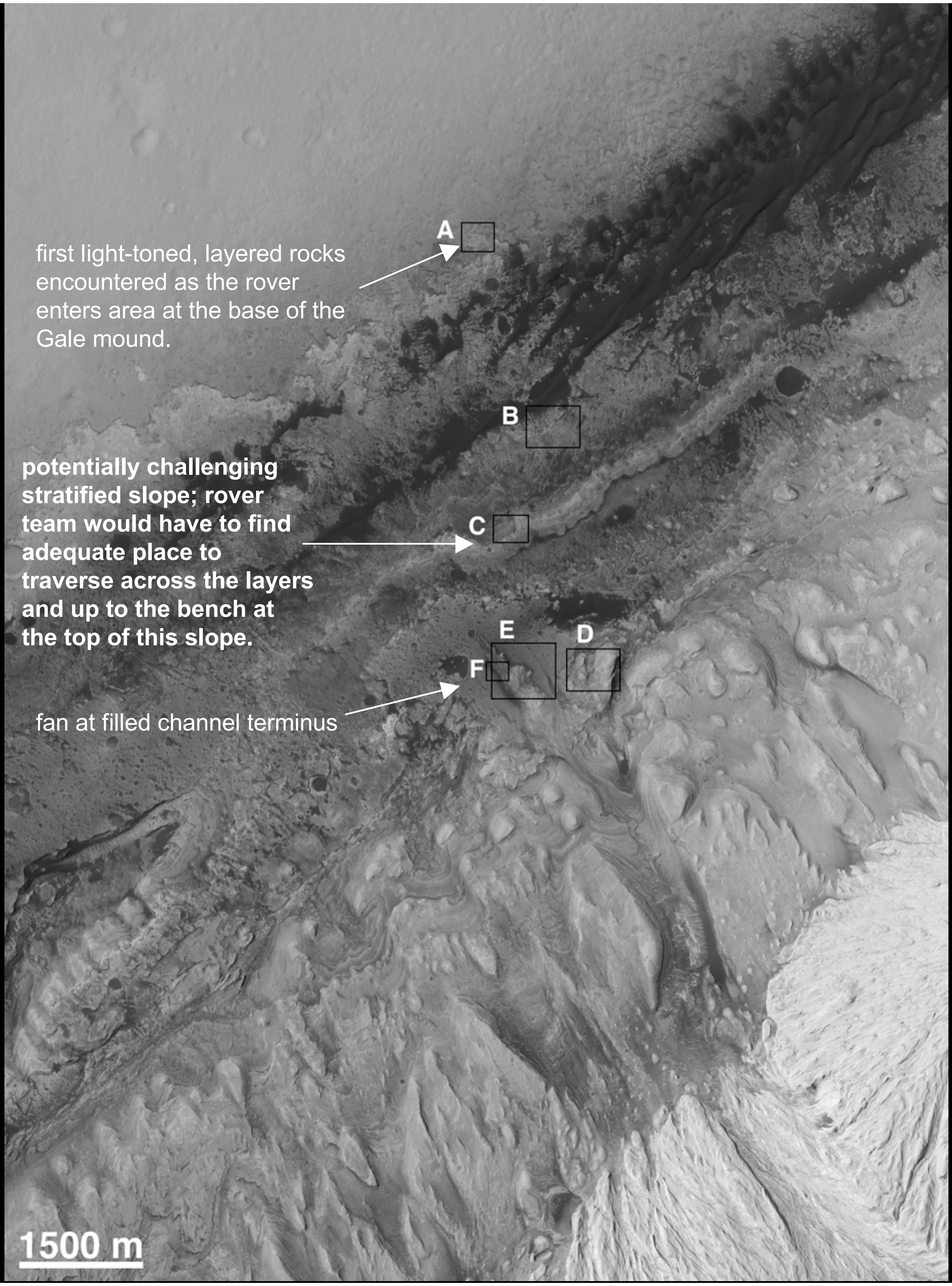


There is potentially a wide range of things the rover would encounter, based on what is seen in HiRISE and MOC images at this location. There is a variety of 'rock type,' if you assume rock type relates to erosional expression and bedding style. Nearly all of the traverse in this area is on hard rock substrate with minimal regolith.

Notional traverse, as rover travels out of dune area, up mound.



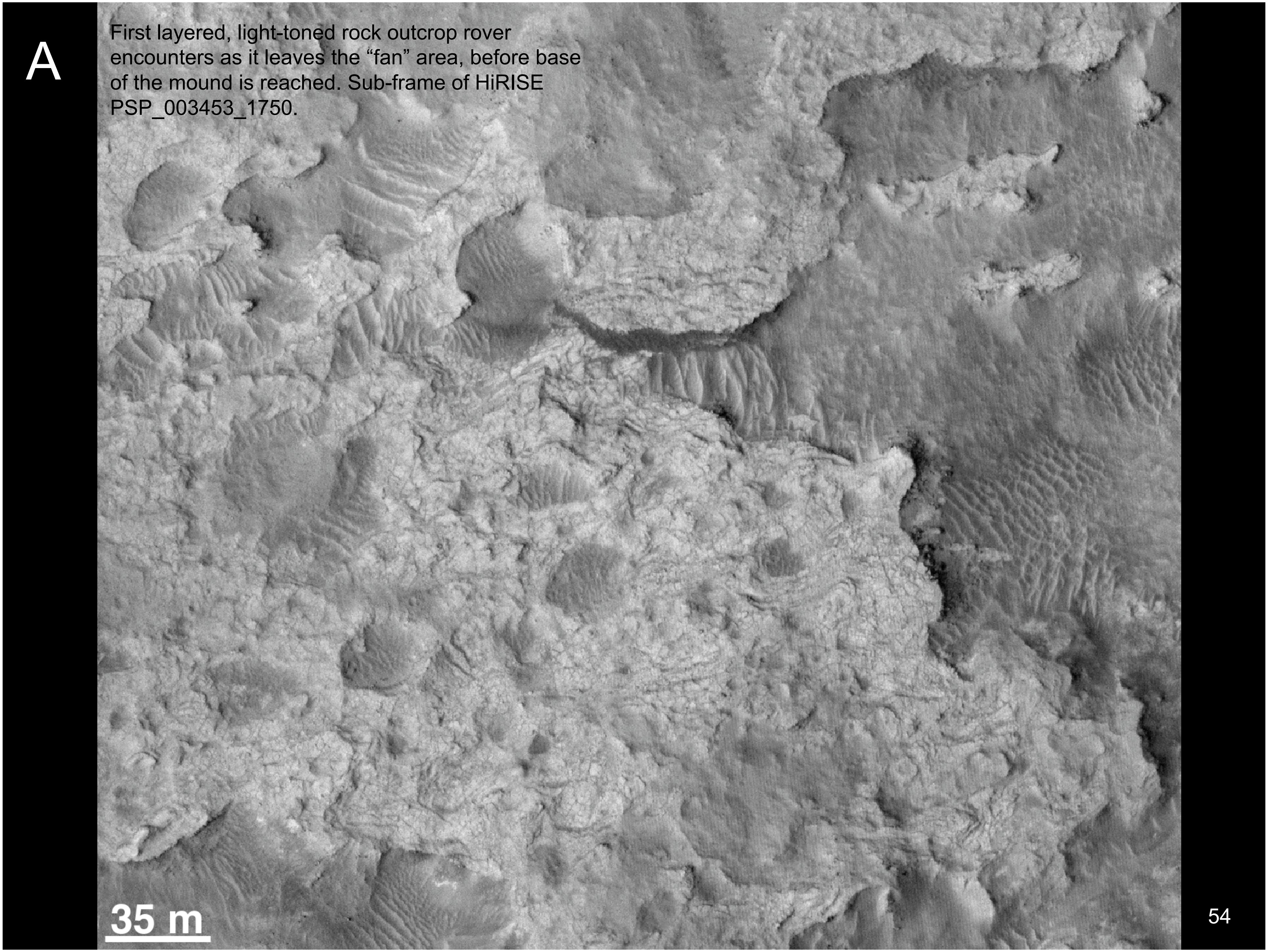
Nearly all of the traverse in this area is on hard rock substrate with minimal regolith. Rover examine stratigraphy as it goes up through the paleovalley and exhumed/filled channel (looking at the filling material, too). Rover goal is to get to the erosional unconformity and look at the lowermost rocks of the upper layers unit.

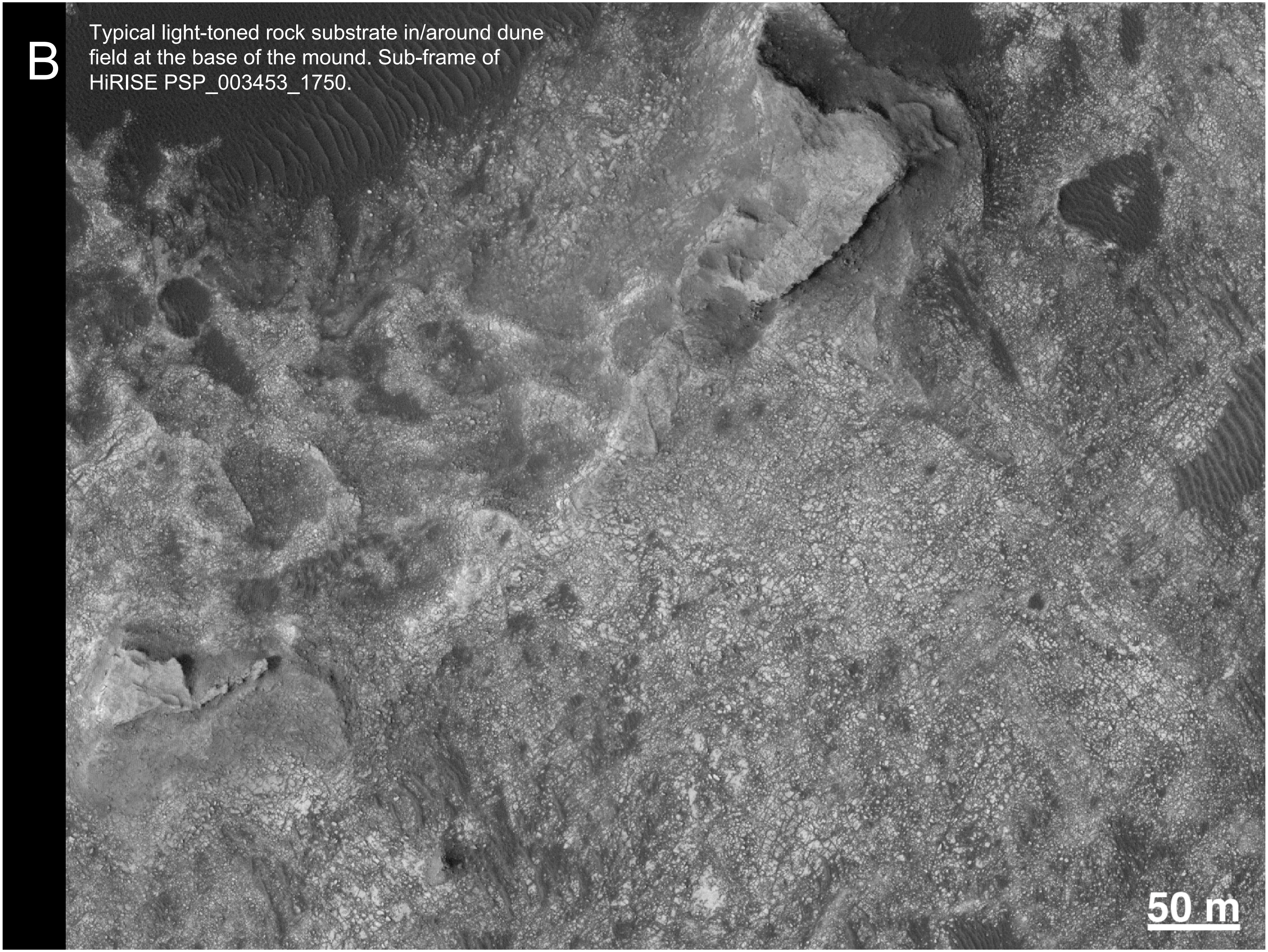


HiRISE PSP_003453_1750 covers a good portion of the landing ellipse and also a portion of the dune field and some of the lowermost layered rocks of the mound. The image does not include the filled channel but it does include much of the “fan” at the channel terminus.

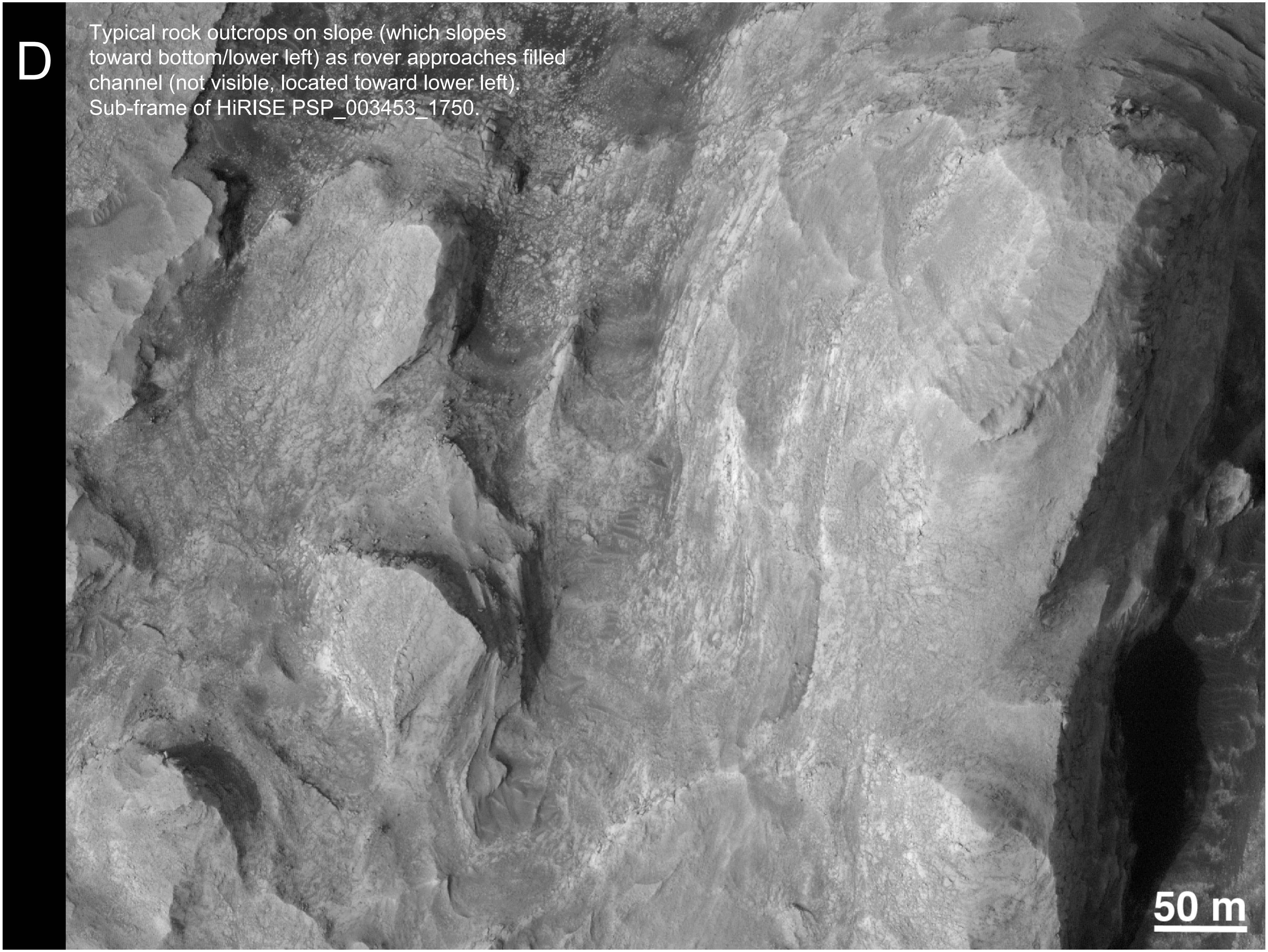
The next 6 pages show details from image PSP_0033453_1750 for the areas labeled A–D in this reference map from CTX.

Images E and F cover a portion of the “fan”.


A
First layered, light-toned rock outcrop rover encounters as it leaves the “fan” area, before base of the mound is reached. Sub-frame of HiRISE PSP_003453_1750.
35 m

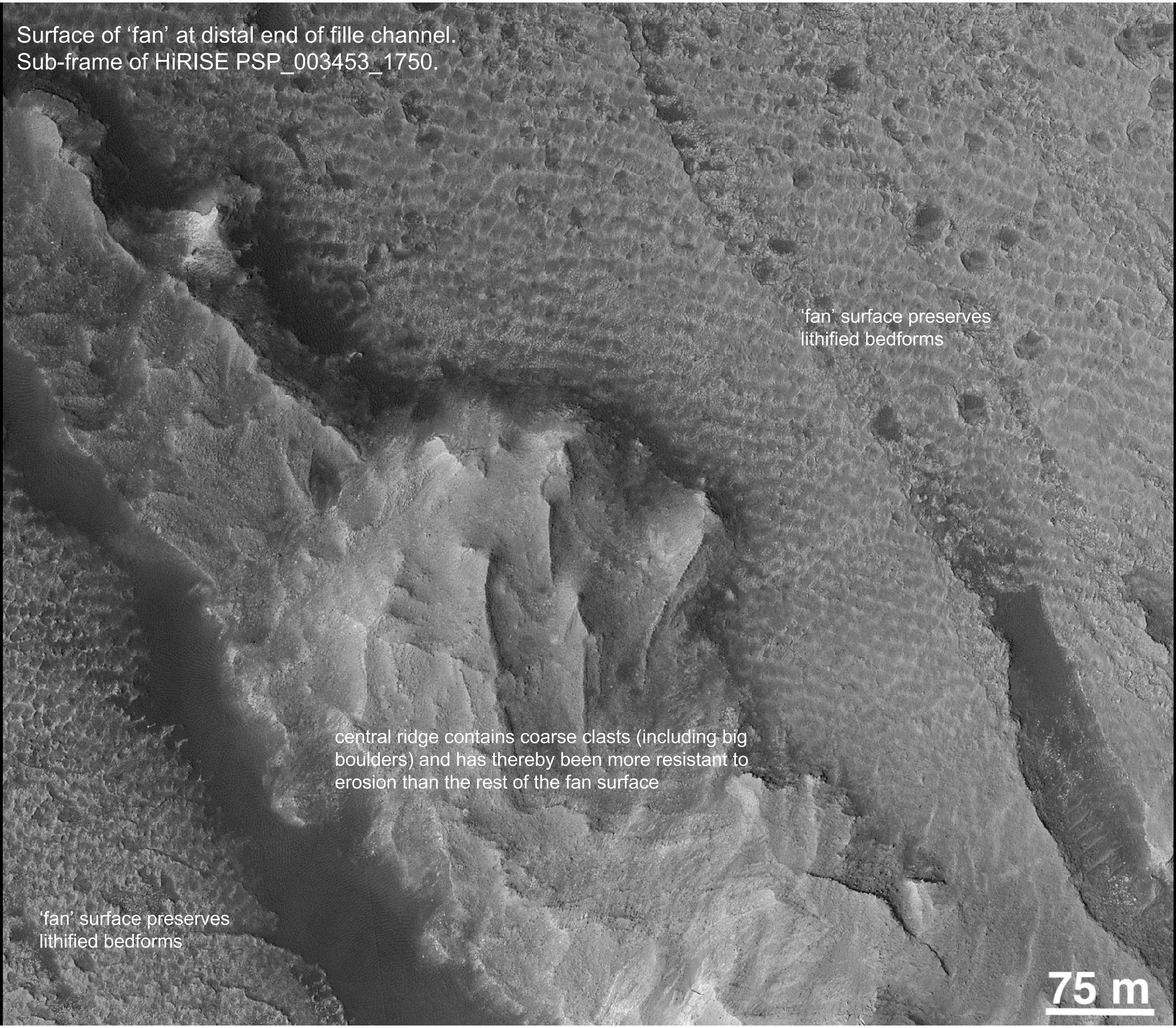

B
Typical light-toned rock substrate in/around dune field at the base of the mound. Sub-frame of HiRISE PSP_003453_1750.
50 m

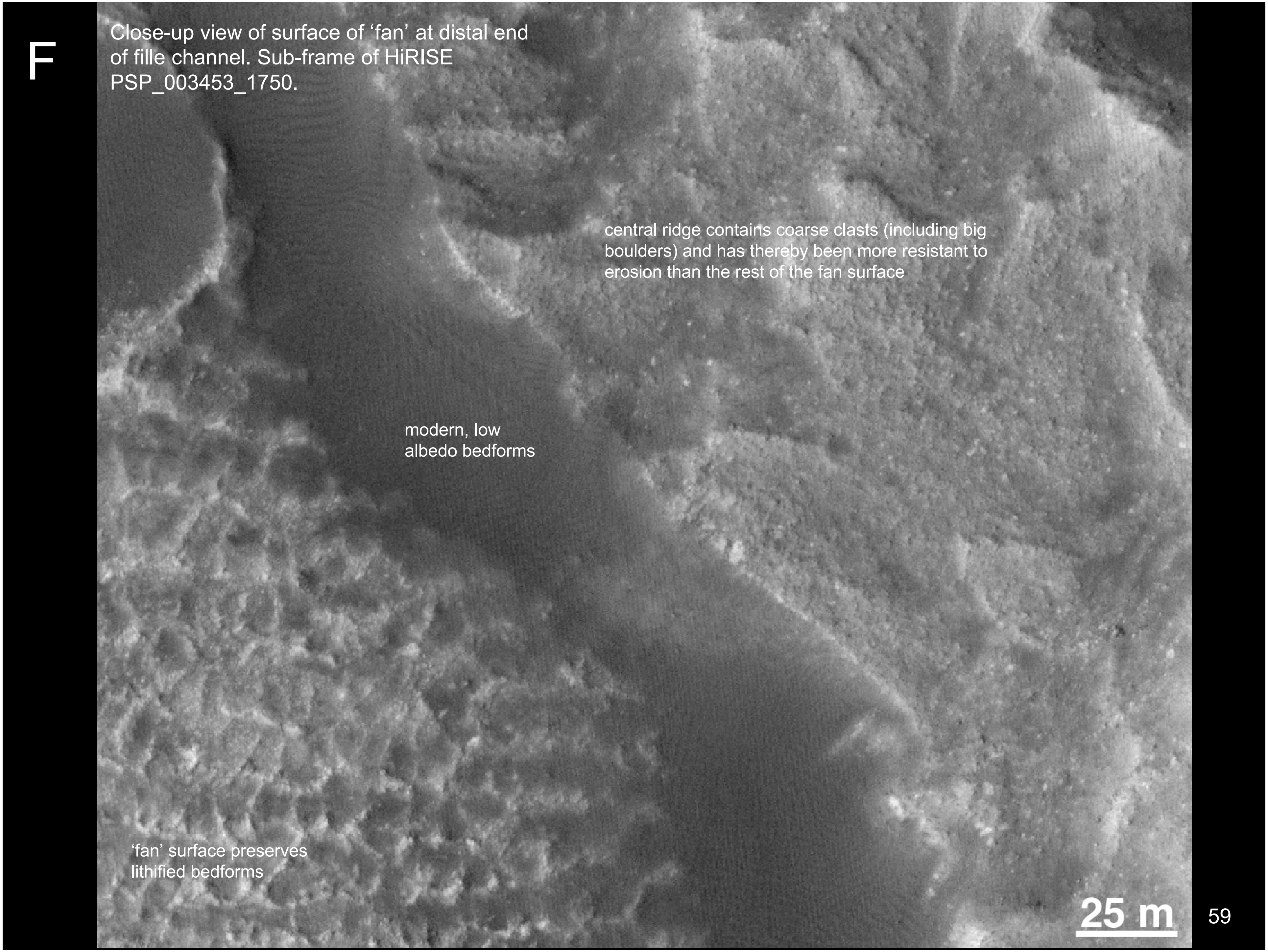

C
Slope (up is toward lower right) with stratified rocks on lower portion of Gale mound. Sub-frame of HiRISE PSP_003453_1750.
35 m

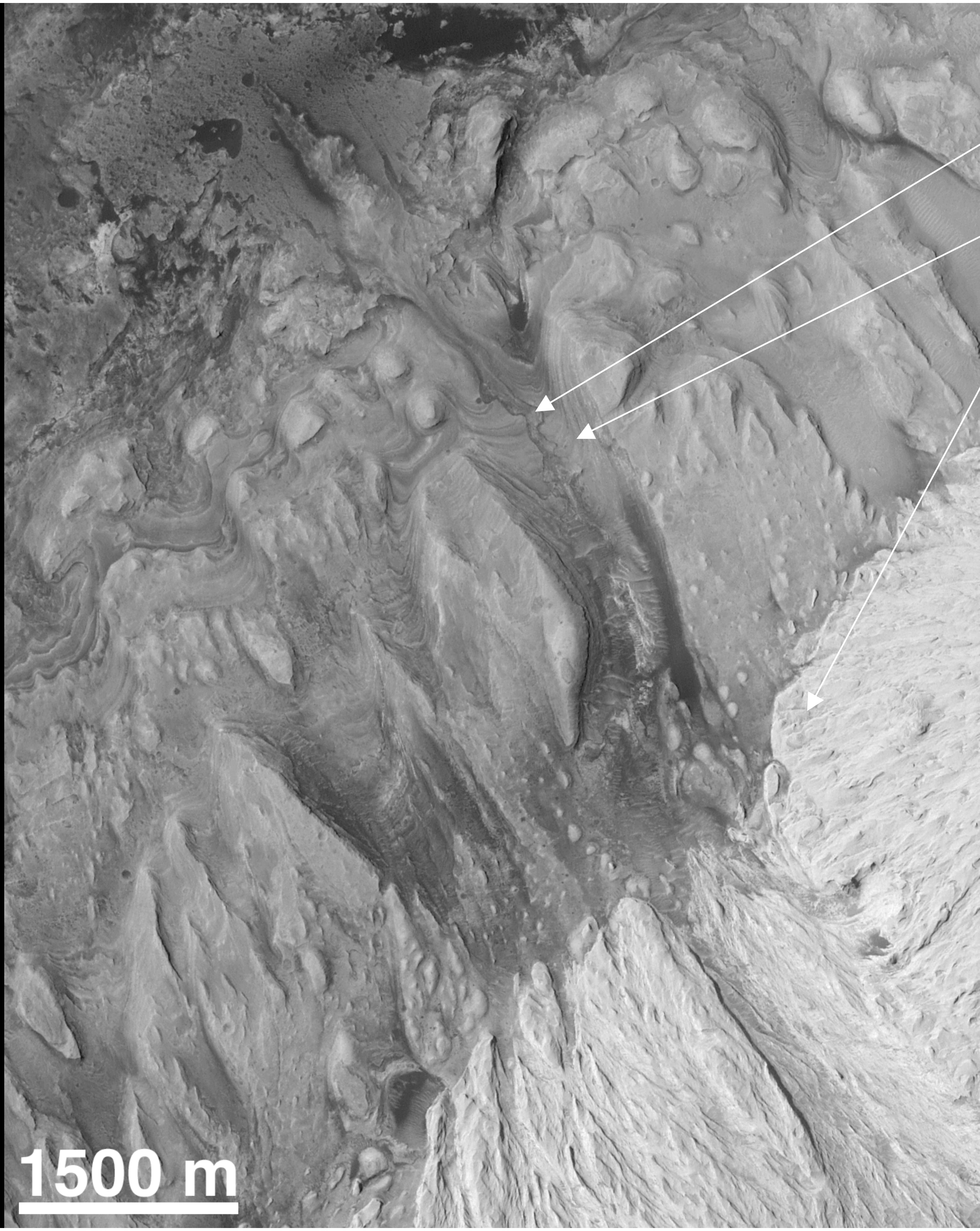


Typical rock outcrops on slope (which slopes toward bottom/lower left) as rover approaches filled channel (not visible, located toward lower left). Sub-frame of HiRISE PSP_003453_1750.

E


Surface of 'fan' at distal end of fille channel.
Sub-frame of HiRISE PSP_003453_1750.
'fan' surface preserves lithified bedforms
central ridge contains coarse clasts (including big boulders) and has thereby been more resistant to erosion than the rest of the fan surface
'fan' surface preserves lithified bedforms
75 m


F
Close-up view of surface of ‘fan’ at distal end
of fille channel. Sub-frame of HiRISE
PSP_003453_1750.
central ridge contains coarse clasts (including big
boulders) and has thereby been more resistant to
erosion than the rest of the fan surface
modern, low
albedo bedforms
‘fan’ surface preserves
lithified bedforms
25 m



- What is the channel fill like?
- What are these layers like?
- What is this material like?

There is CTX coverage at 6 m/pxl and MOC at 3 m/pxl but no higher resolution images of these areas yet (no higher res MOC, no HiRISE).

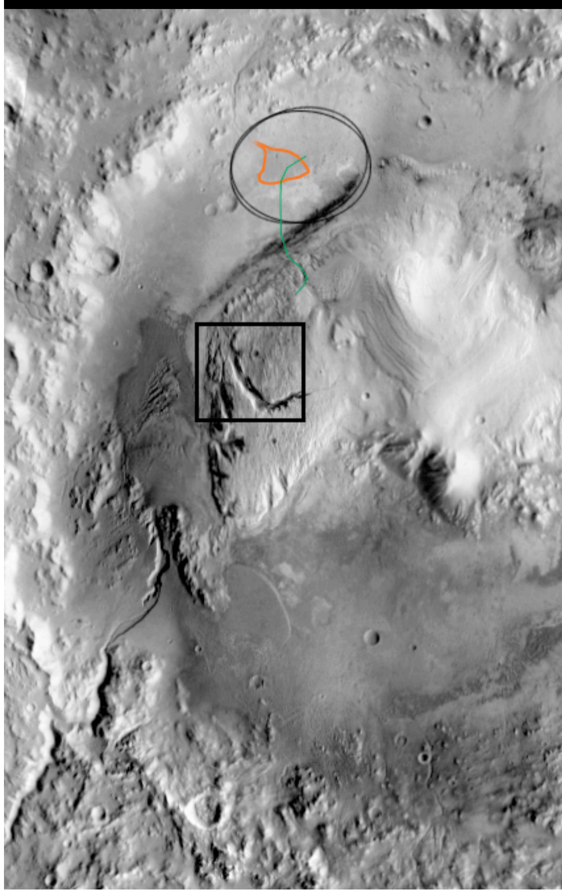
BUT we can gain insight to the nature of these 3 areas by looking at similar strata and landforms in other HiRISE images on the western part of the Gale Crater mound.

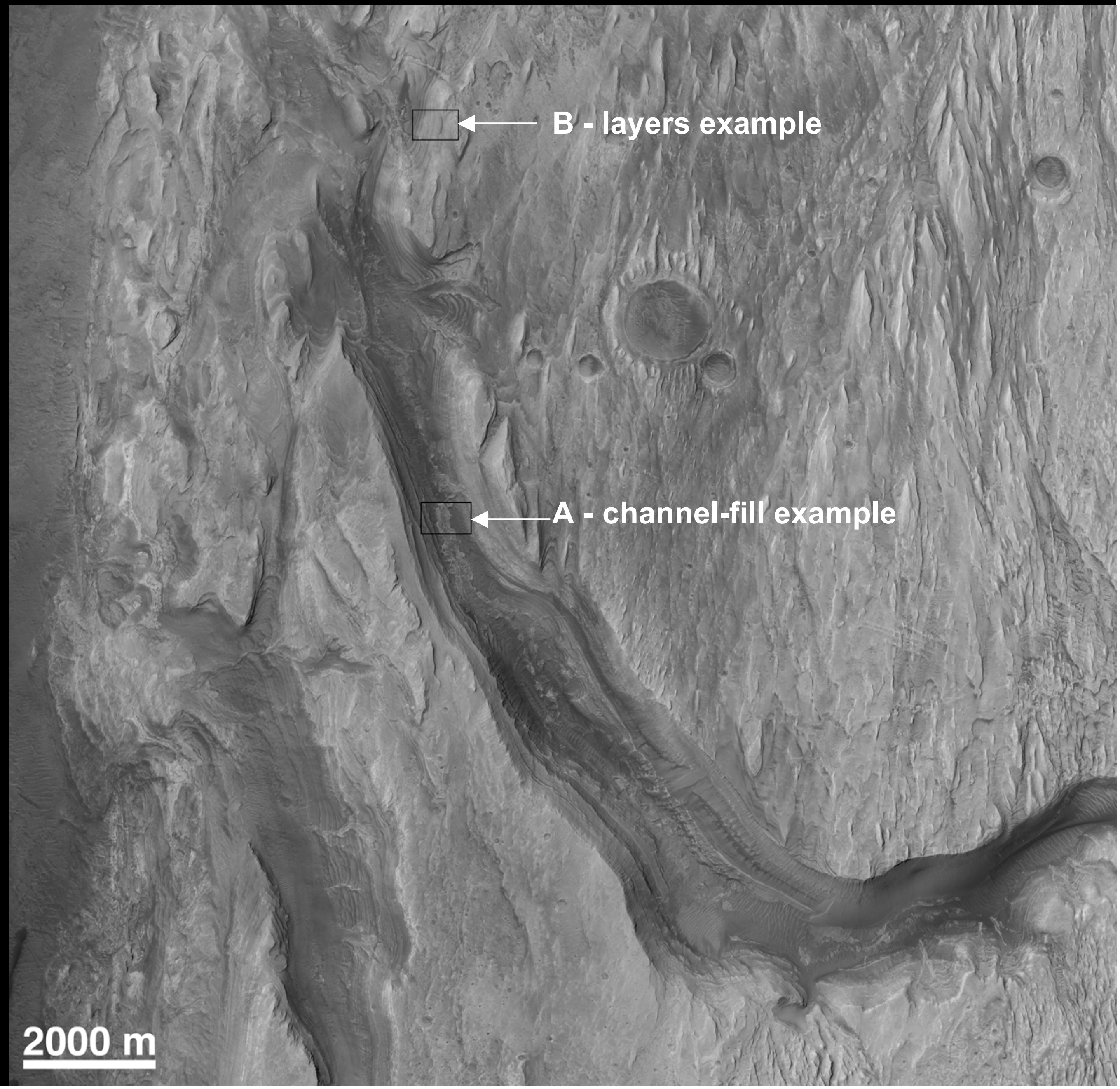
The next 6 pages present those observations.

Examples of what channel fill and layers near the channel likely look like, based on a HiRISE image elsewhere on the mound.

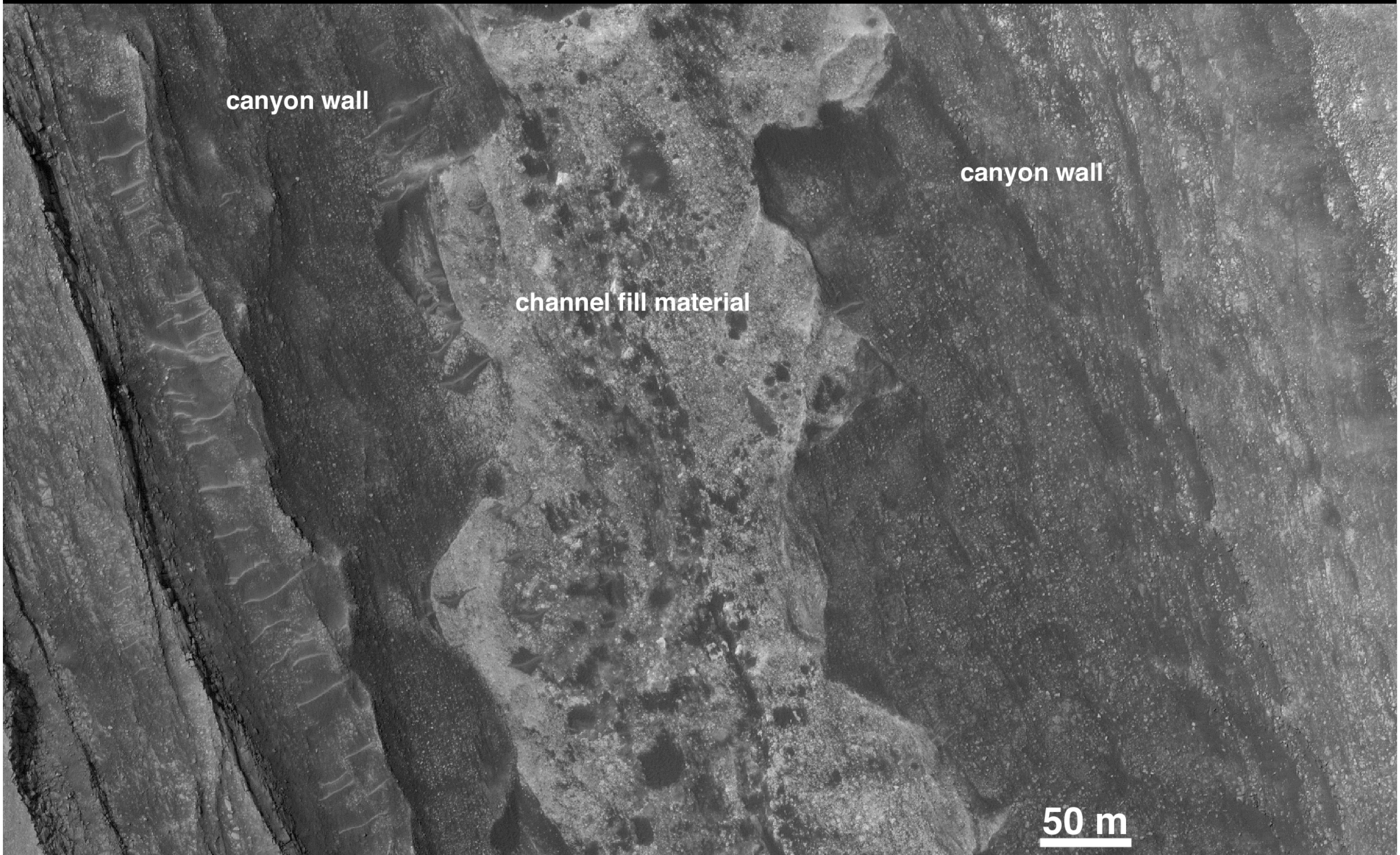
These figures show the context of sub-frames (A, B) of HiRISE image PSP_006855_1750, which are shown on the 2 pages which follow this one.

Figure to the right is sub-frame of CTX image P15_006855_1746_XN_05S222W_080112, which was taken at the same time as the HiRISE image which is sub-framed on the next two pages.





A - channel fill example



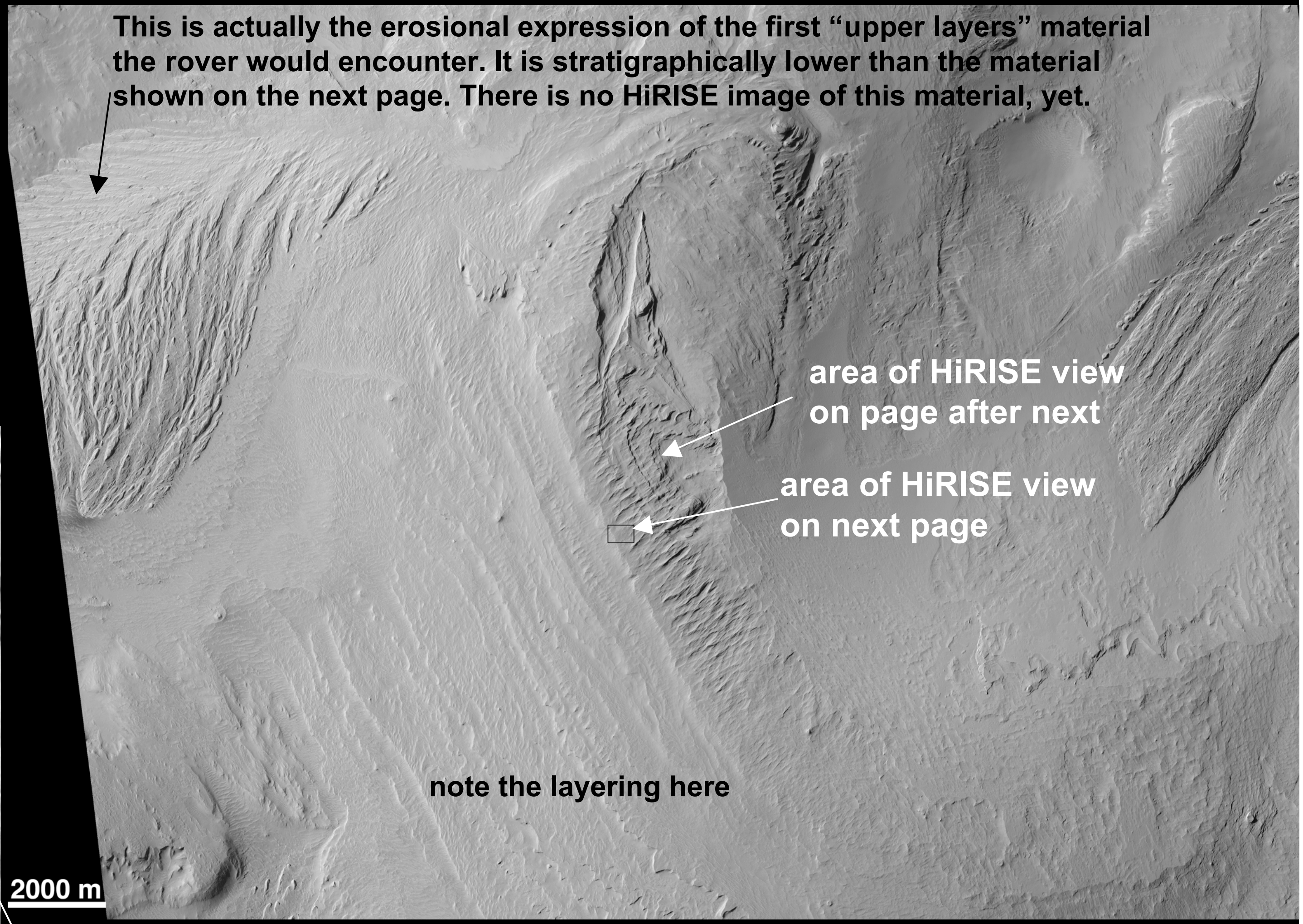
sub-frame of HiRISE PSP_006855_1750

B - layers of the lower geologic unit; example

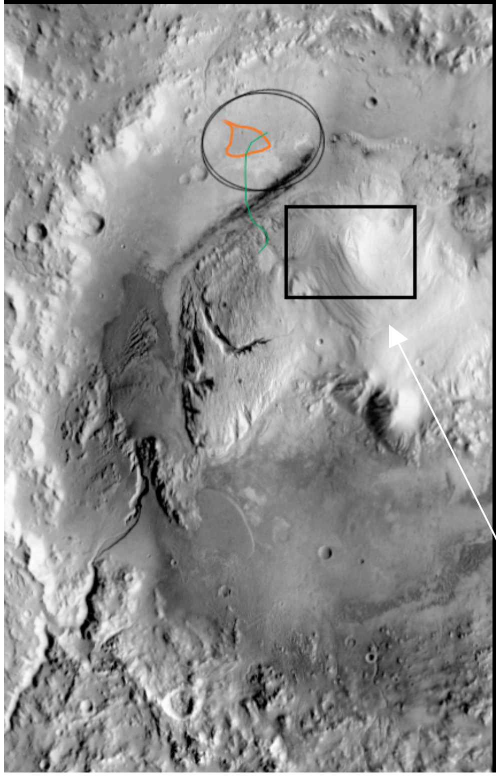
up-slope is to the right

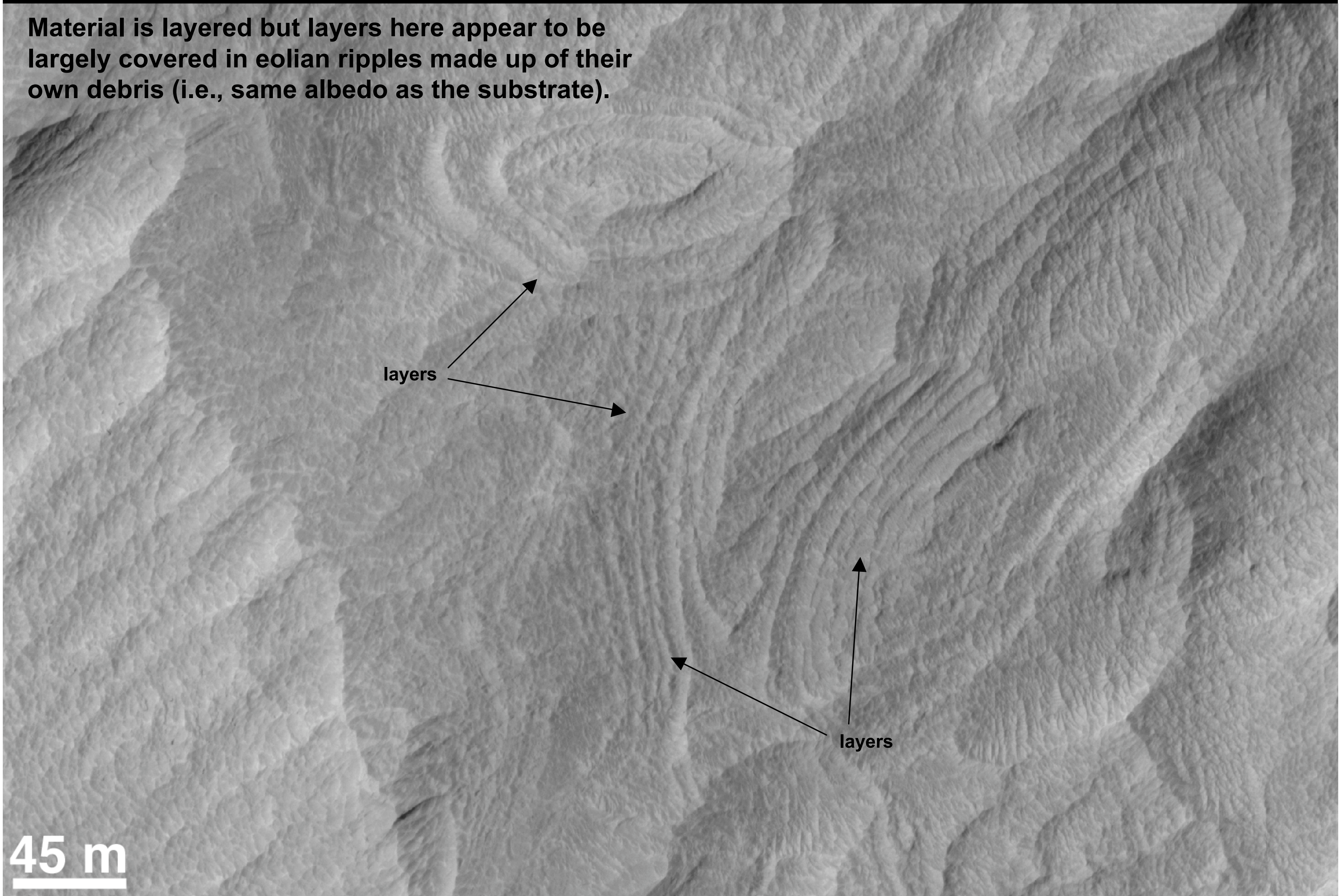
sub-frame of HiRISE PSP_006855_1750

Example of what some of the "upper layers" material might look like, based on a HiRISE image elsewhere on the mound.



Sub-frame of CTX image P01_001422_1747_XN_05S222W_061115





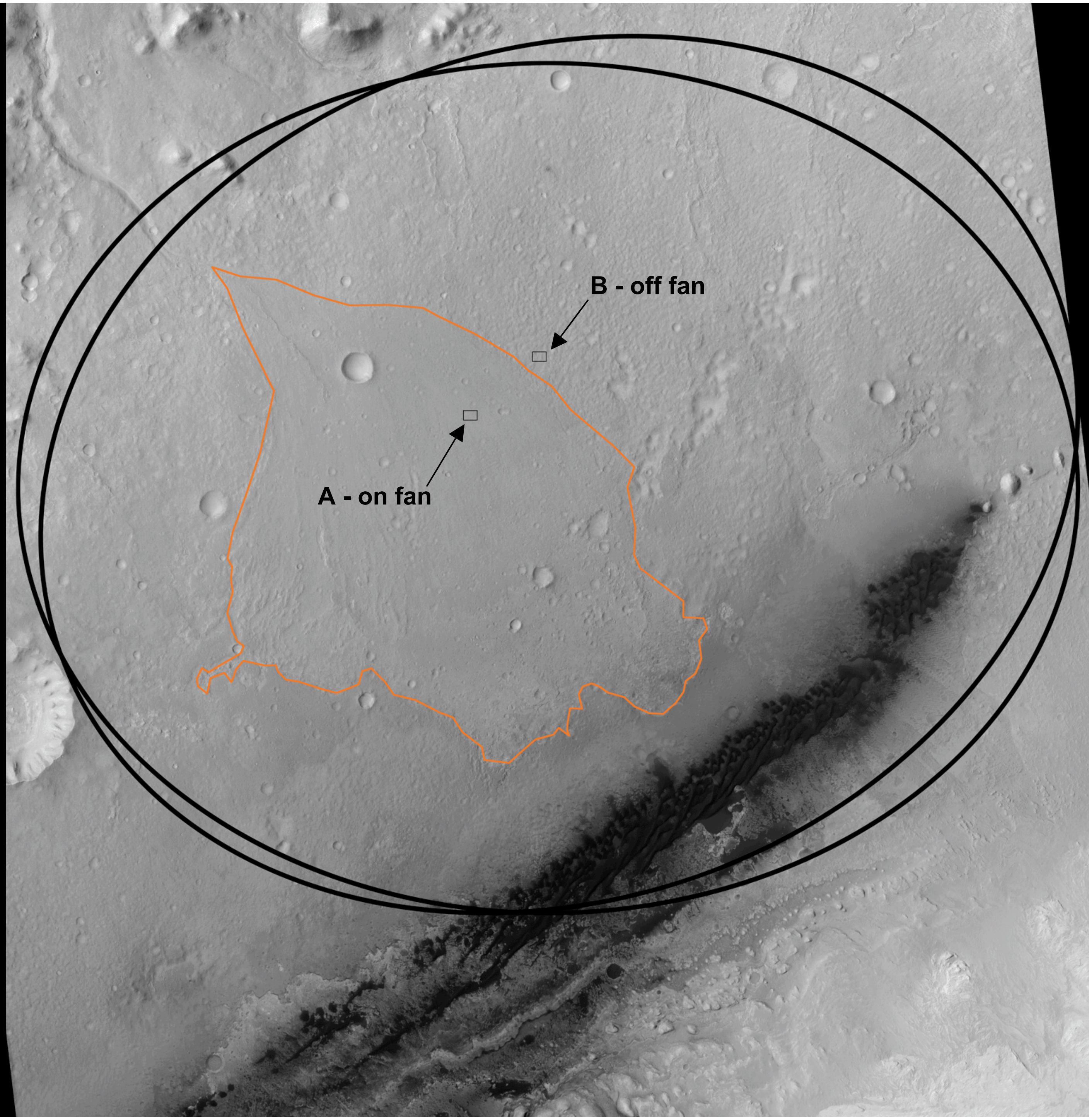
Sub-frame of HiRISE PSP_001422_1750

Additional view of beds near the top of the stratigraphic column in Gale Crater shows very rhythmic bedding. This pattern, similar to bedding seen in dozens of other craters on Mars (e.g., Becquerel) might represent a climate signal in the rock record; materials may have been deposited from suspension, either subaerially or subaqueously.

Landing ellipse at HiRISE scale

The next 2 pages show examples from HiRISE image PSP_003453_1750 of surfaces in the landing ellipse both on and off the fan. The fan is outlined in orange.

Hazards for EDL include the dunes, layers, and scarps associated with layering in the south and southeast portions of the landing ellipse and the various impact craters and depressions elsewhere in the ellipse.



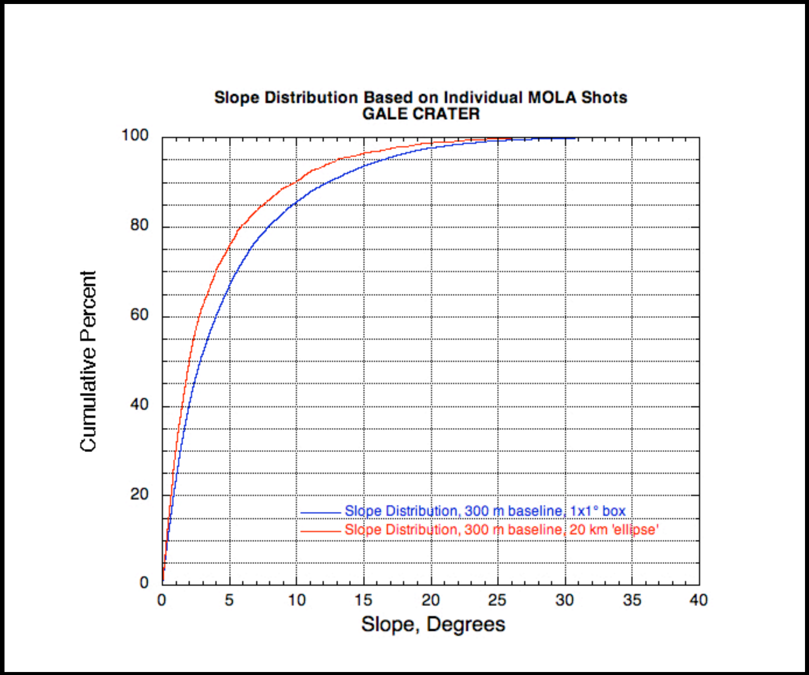
A - Example HiRISE View of Fan Surface

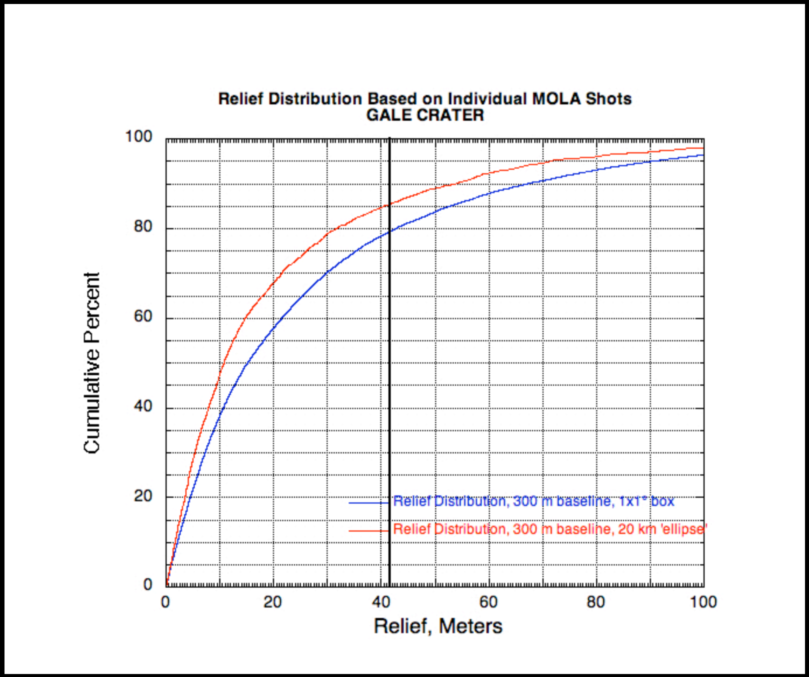
Sub-frame of HiRISE image PSP_003453_1750

B - Example HiRISE View not on Fan Surface

Sub-frame of
HiRISE image PSP_003453_1750

Slopes and Relief in landing ellipse (derived from MGS MOLA observations)





(a) These are MOLA along-track bidirectional slopes on a 300 m baseline; statistics are for a 1x1 degree box around the landing ellipse center for a 20 km ellipse).

(b) Via analysis, about 3% of ellipse has slopes >15°.

(c) Obviously, one would have to do a more detailed analysis using DEMs derived from HiRISE and/or CTX stereopairs, and one can hope that the landing ellipse size can be tightened to move it off the dune field and layers at the south/southeast end of the ellipse.

Further Study Needed

- New MRO data needed
  - HiRISE stereopairs covering the landing ellipse and the notional traverse area -- to create DTMs to assess EDL hazards and traverse slopes/trafficability.

- Examine additional CRISM targeted coverage of the mound

- Refine the Stratigraphy
  - true geologic mapping (as opposed to what usually passes for ‘geologic’ mapping in planetary science) can actually be done on the mound. The Malin and Edgett (2000) map demonstrated this.
  - the geologic map based on MOC results from Malin and Edgett (2000) has held up very well, but needs to be refined and extended beyond the area mapped in 2000.
  - the entire mound and crater interior should be mapped
  - integrate the CRISM results to the mapping
  - need geologic unit descriptions

- EDL hazard assessment, including slopes, winds, rocks
  - “rocks” generally looks good in HiRISE coverage

- Further explore rover traverse options to find pathways through the dune field and avoid cliffs/scarps near the base of the mound
  - both of these things are do-able with additional HiRISE coverage

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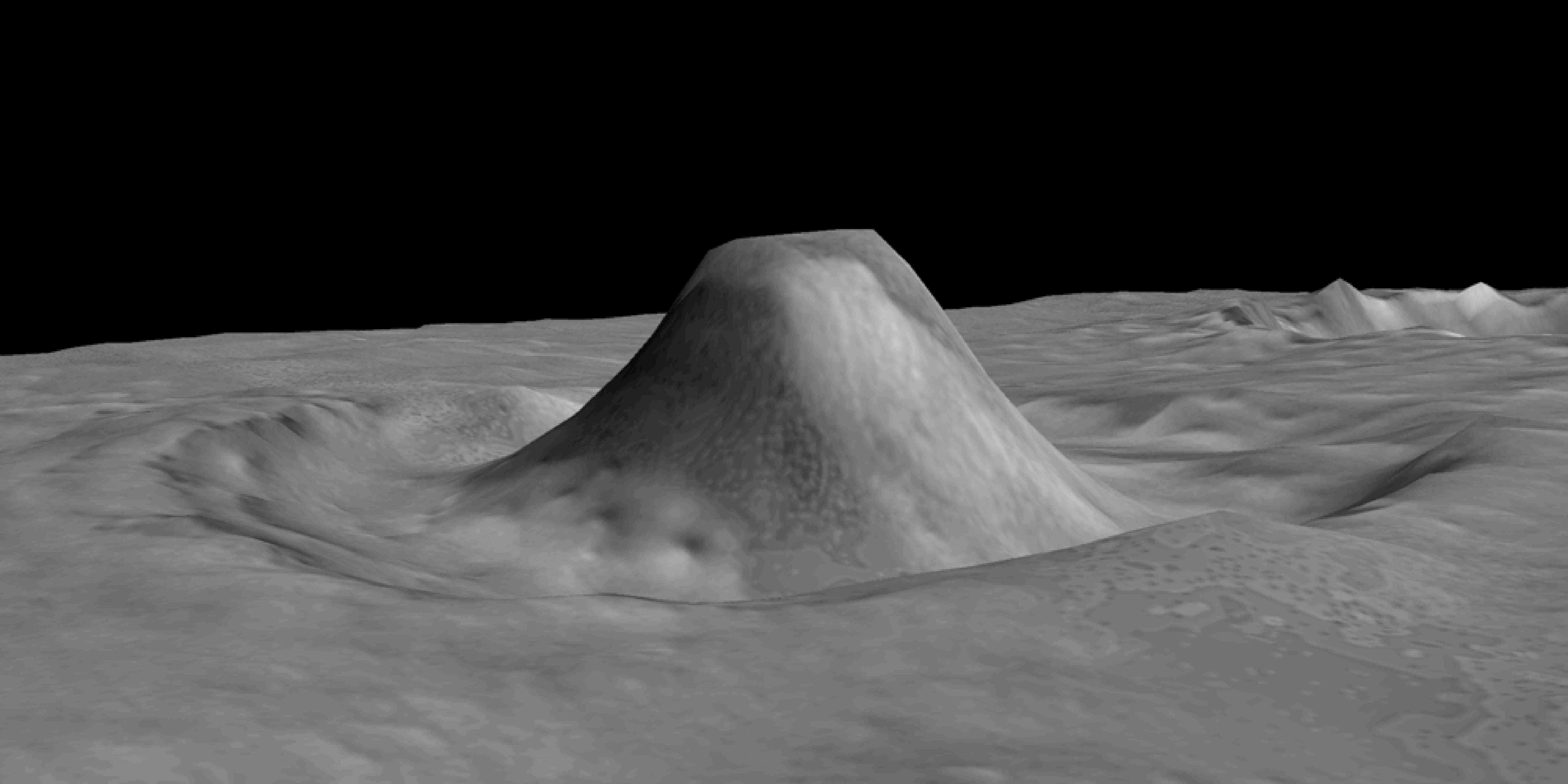

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