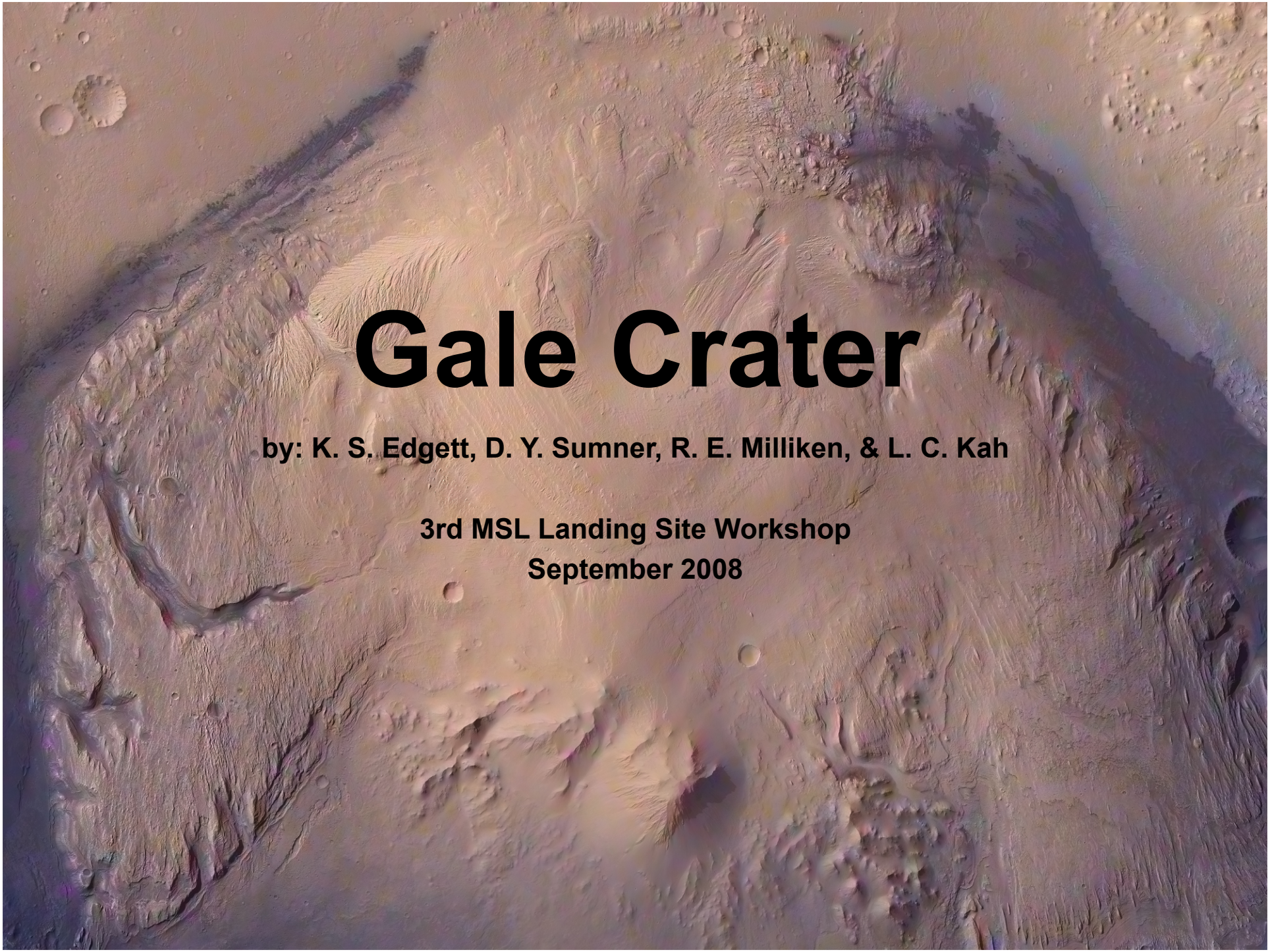


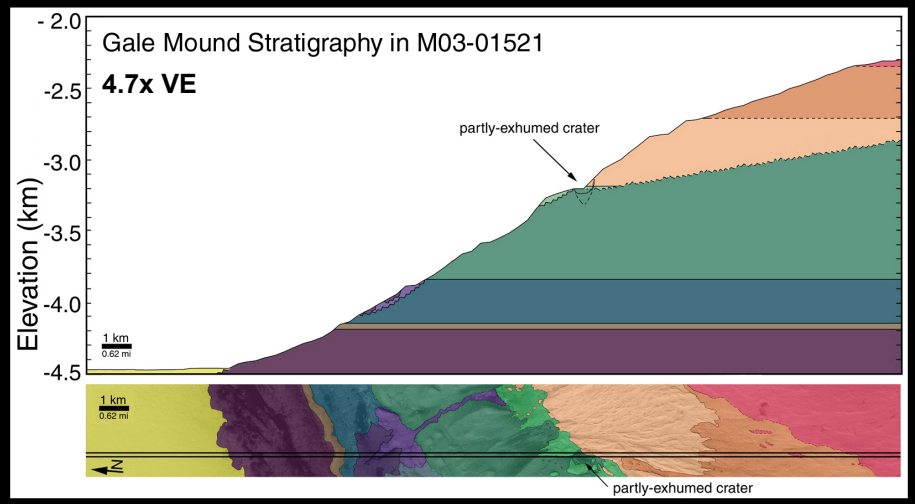
Gale Crater

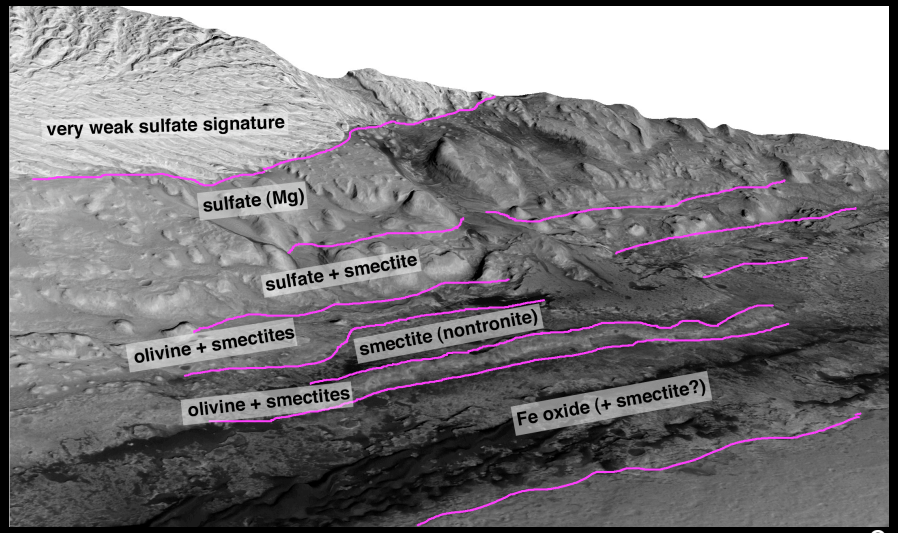
by: K. S. Edgett, D. Y. Sumner, R. E. Milliken, & L. C. Kah

3rd MSL Landing Site Workshop
September 2008

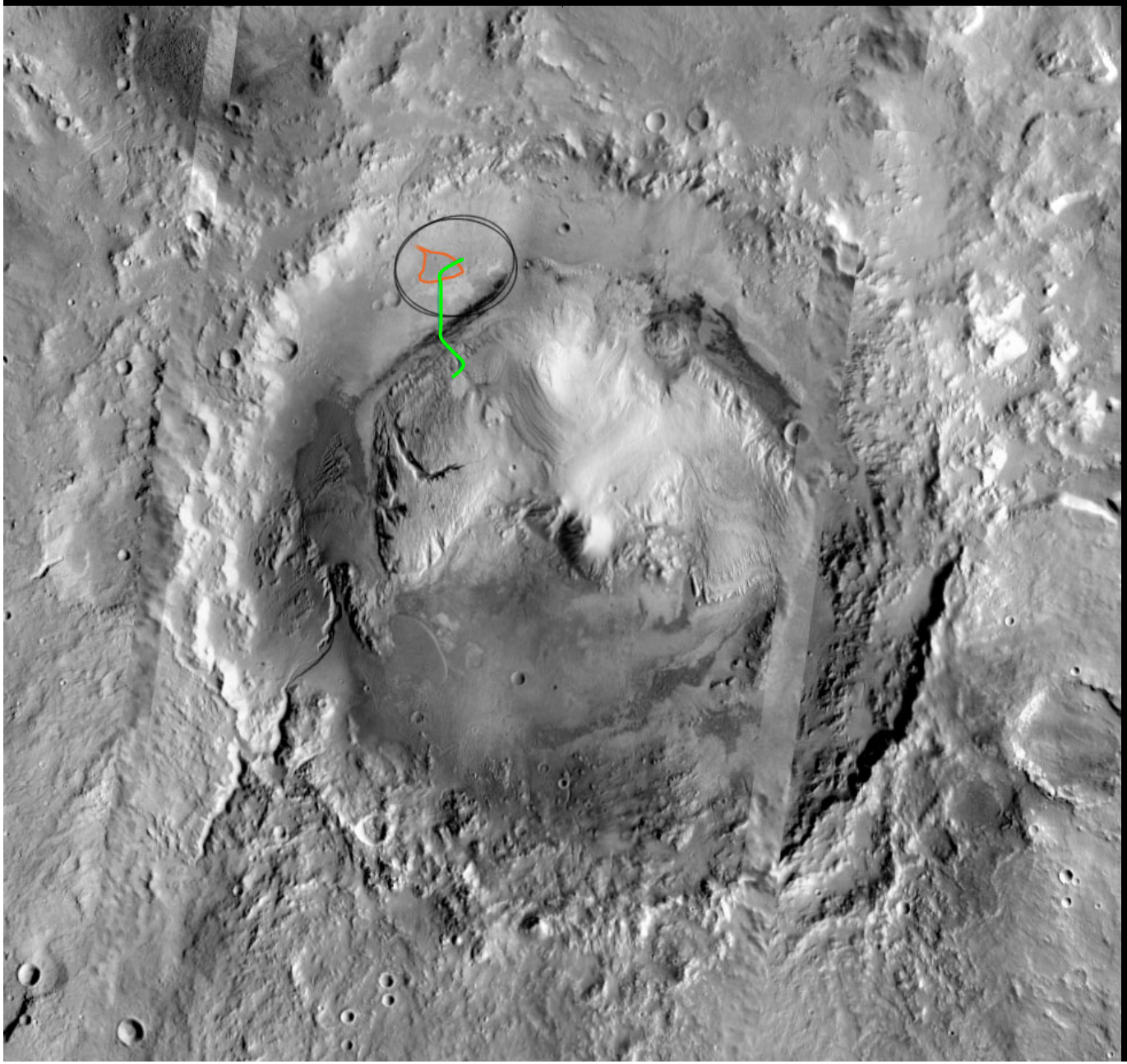
Gale Crater: An Early Mars Type Section

- High diversity of geologic materials with different compositions and depositional conditions
- This diversity is arranged in a stratigraphic context
- Stratigraphy records multiple early Mars environments in sequential order
- Gale is characteristic of a family of craters that were filled, buried, and exhumed, providing insights into an important martian process





Gale Crater Landing Ellipse & Traverse

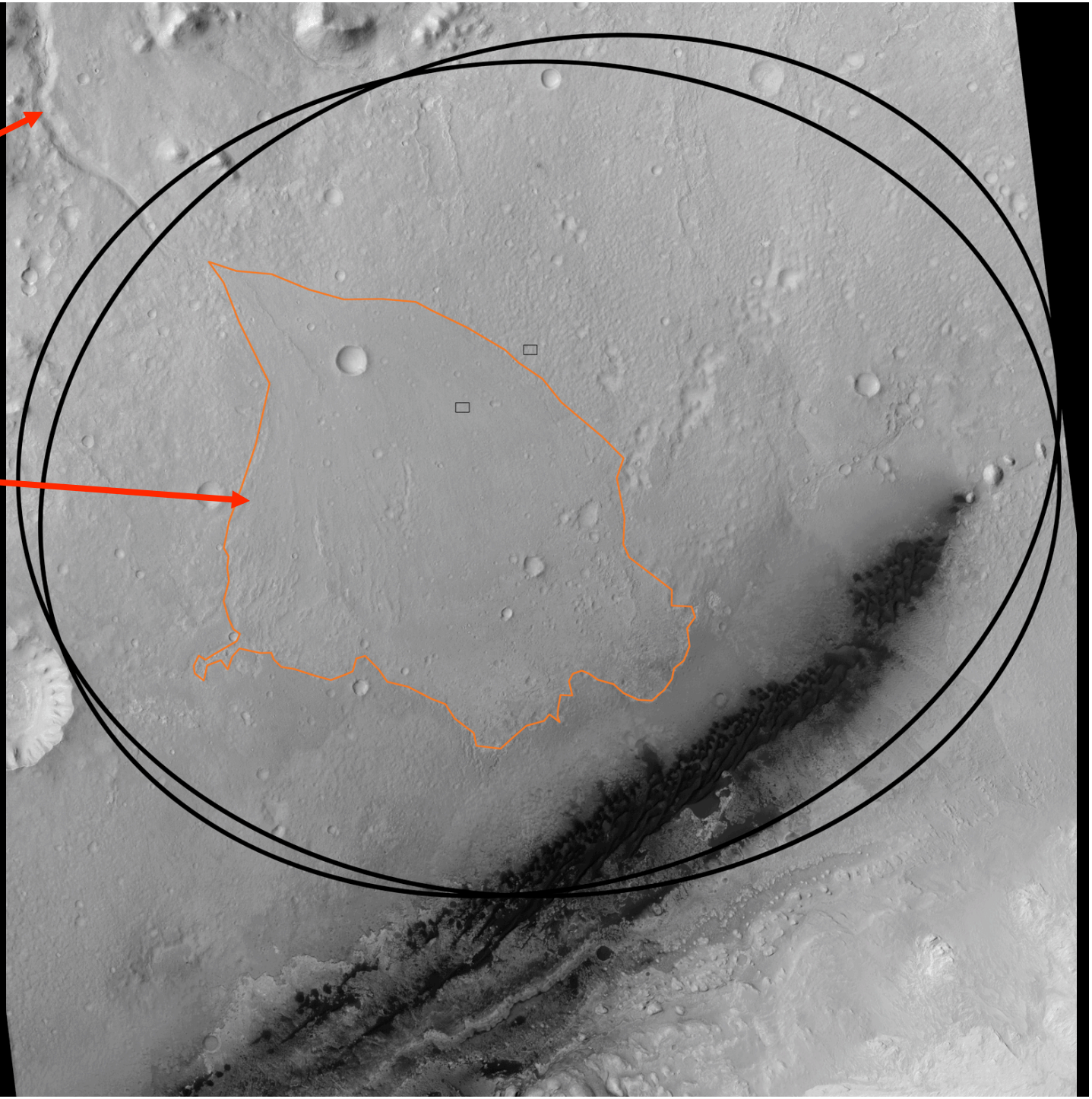


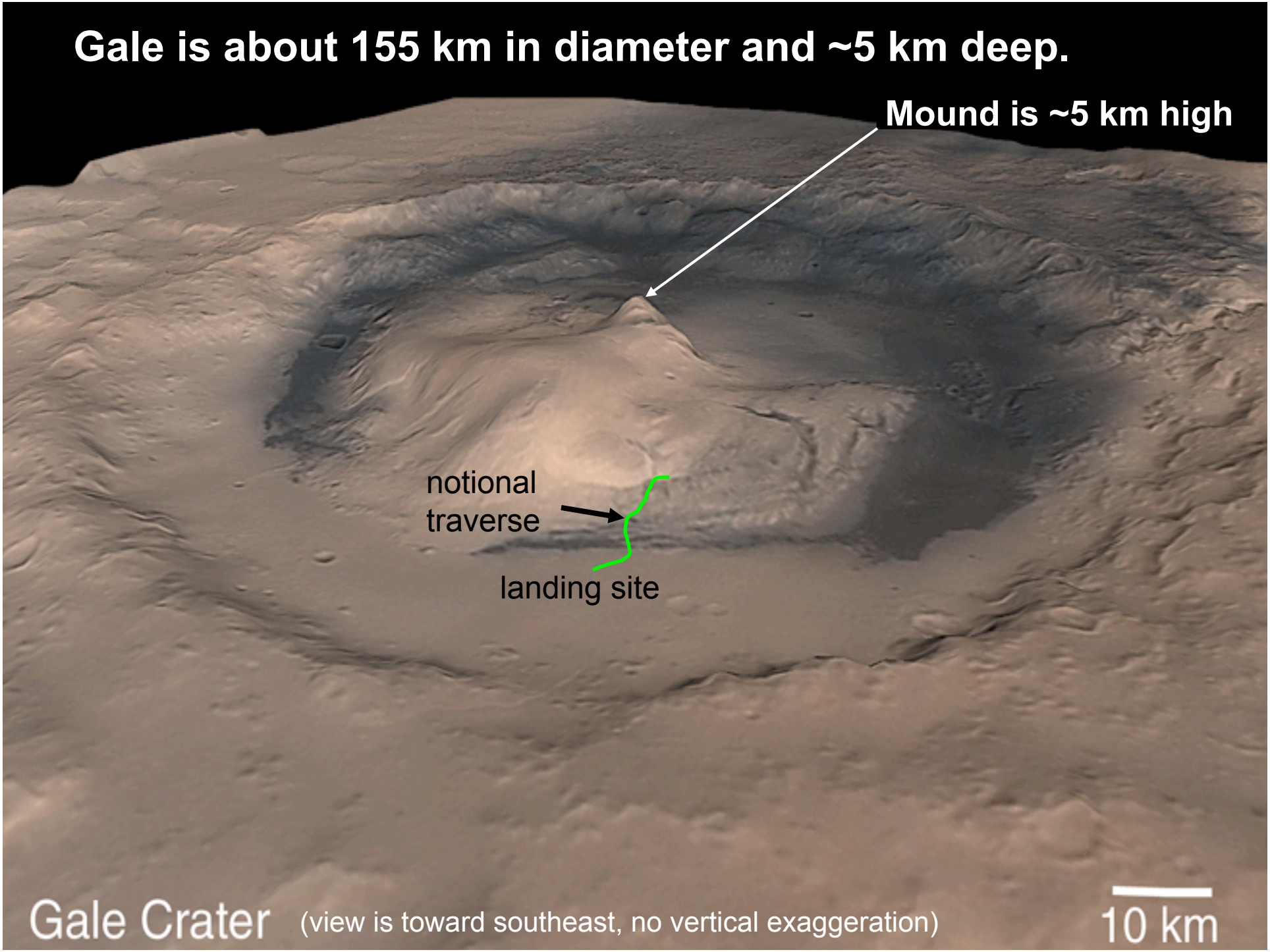
- Gale diameter is ~155 km
- Mound summit is ~5 km high
- 4.5°S, 222.7°W (137.4°E)
- Ellipse elevation is about – 4.5 km
- Orange area is a fan – material deposited from channel off northwest crater wall
- Green line is a notional rover traverse

Material came down crater wall from channel that cuts through wall.

Fan in Ellipse

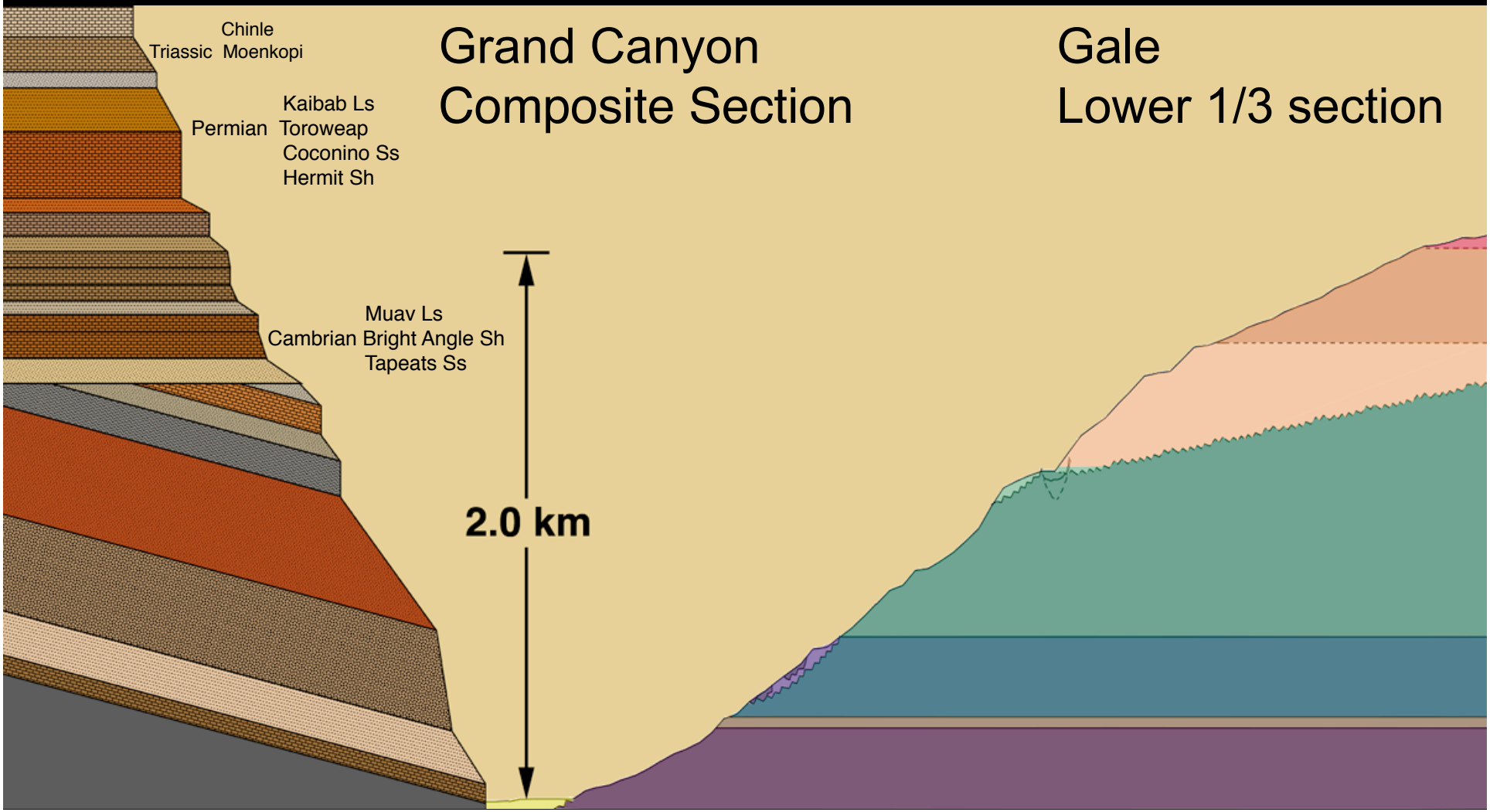
Fan probably includes clasts derived from the Gale wall rock -- i.e., rock that pre-dates the Gale-forming impact.



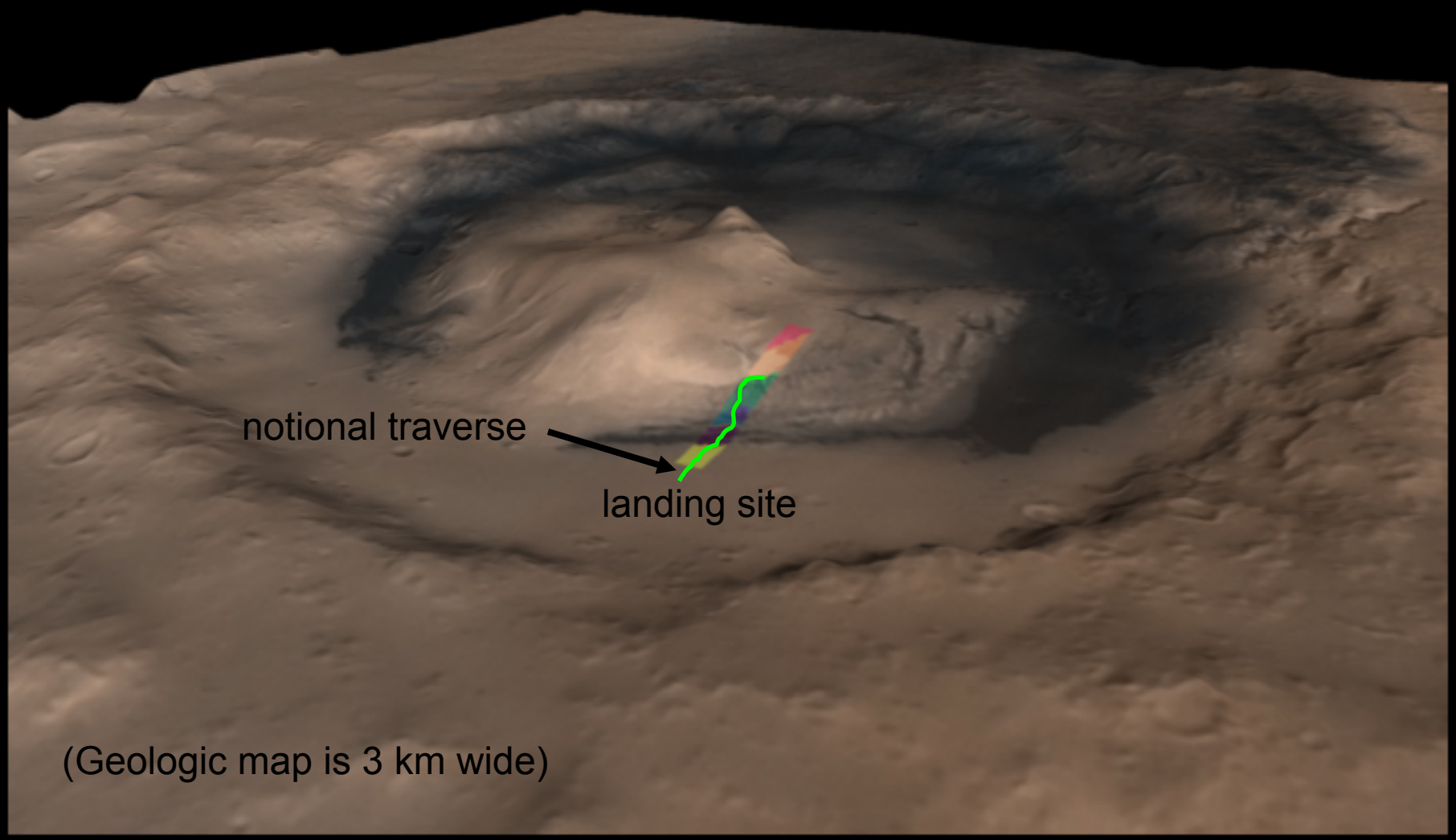

Gale is about 155 km in diameter and ~5 km deep.
Mound is ~5 km high
notional
traverse
landing site
Gale Crater
(view is toward southeast, no vertical exaggeration)
10 km

- Stratigraphy is the history book of the surface of a planet.
- Time is recorded in the layers.
- The Gale mound records a rich history.
- We can read some of this history from orbit, but most of the story is in the details of the layers.

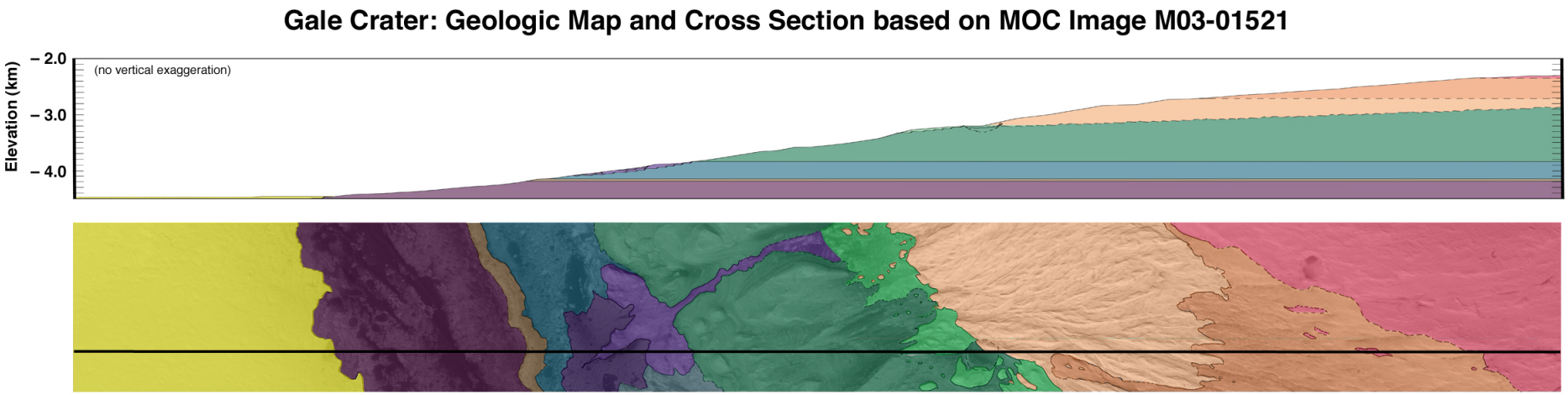
(neither section shows accurate outcrop slopes)



An Early Mars Type Section in Gale Crater



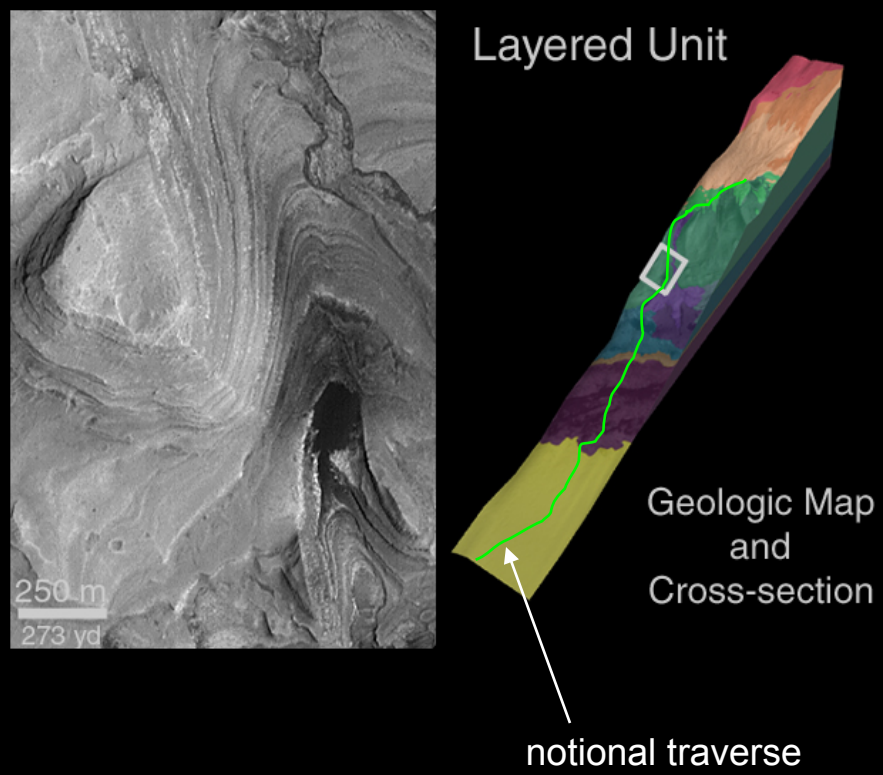
Cross-section with no vertical exaggeration.

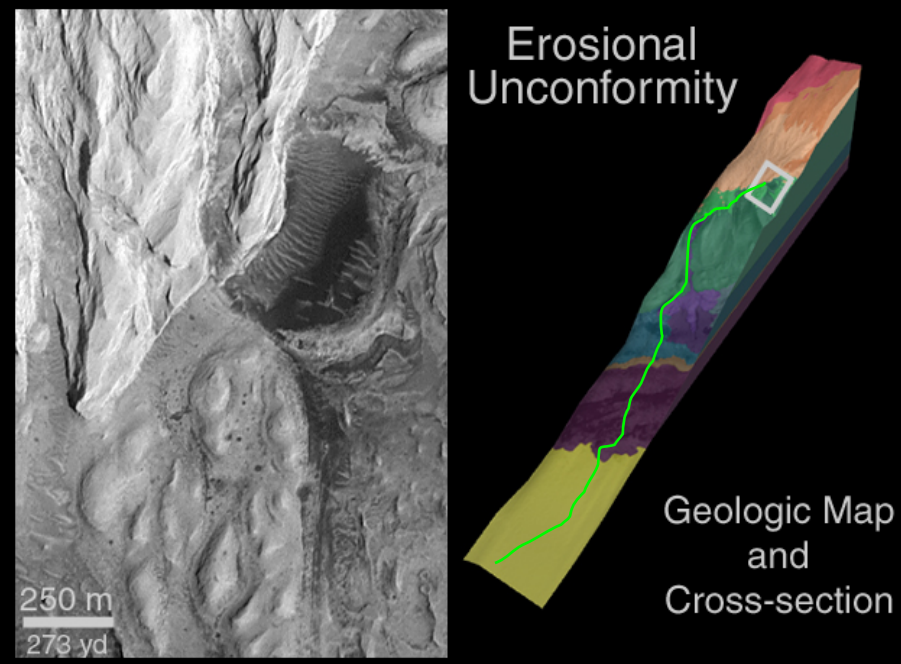


Low slope of ~9.9° provides great stratigraphic exposure!

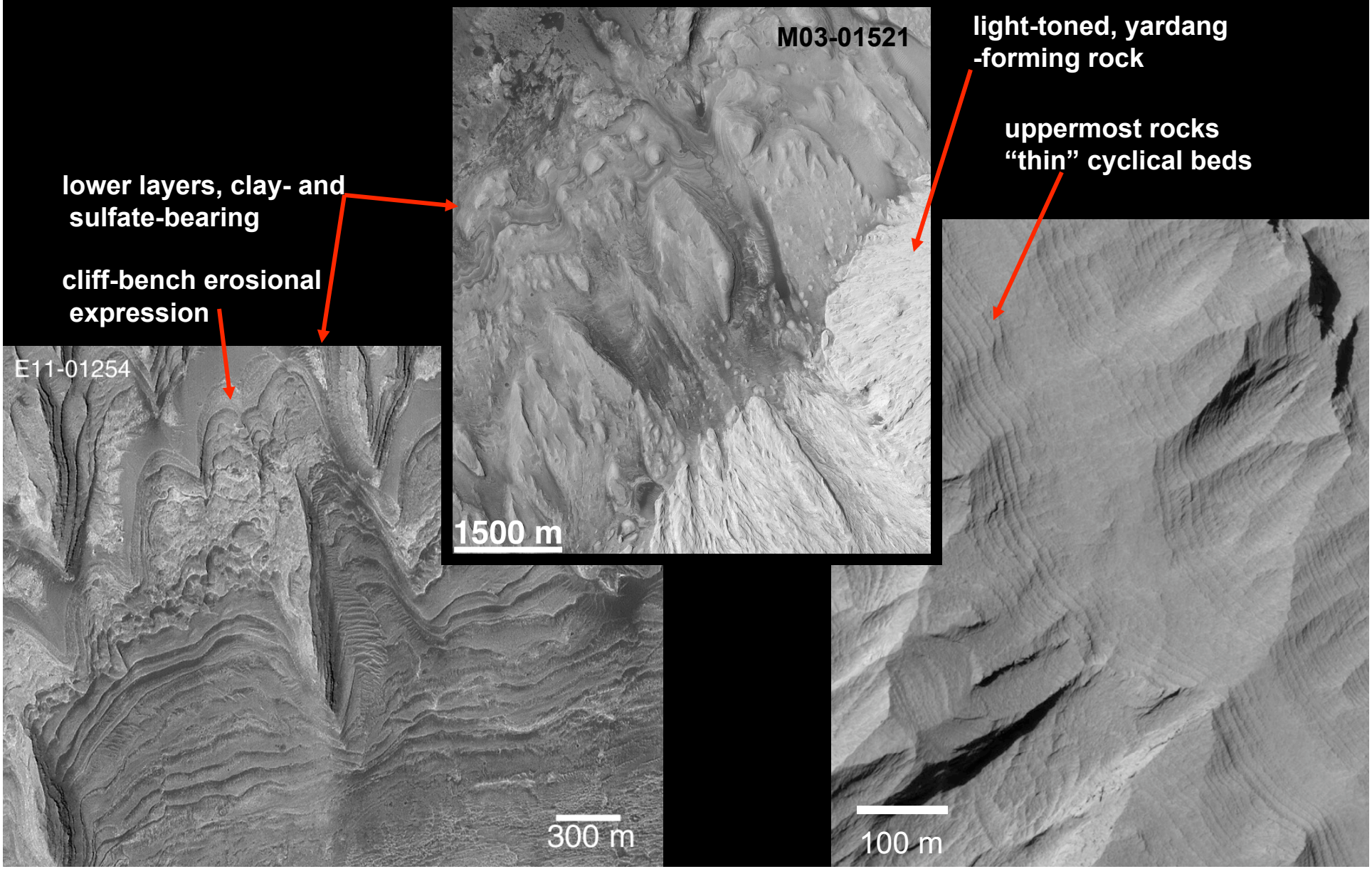
(Geologic map is 3 km wide)

Two Examples of Features Along Notional Traverse

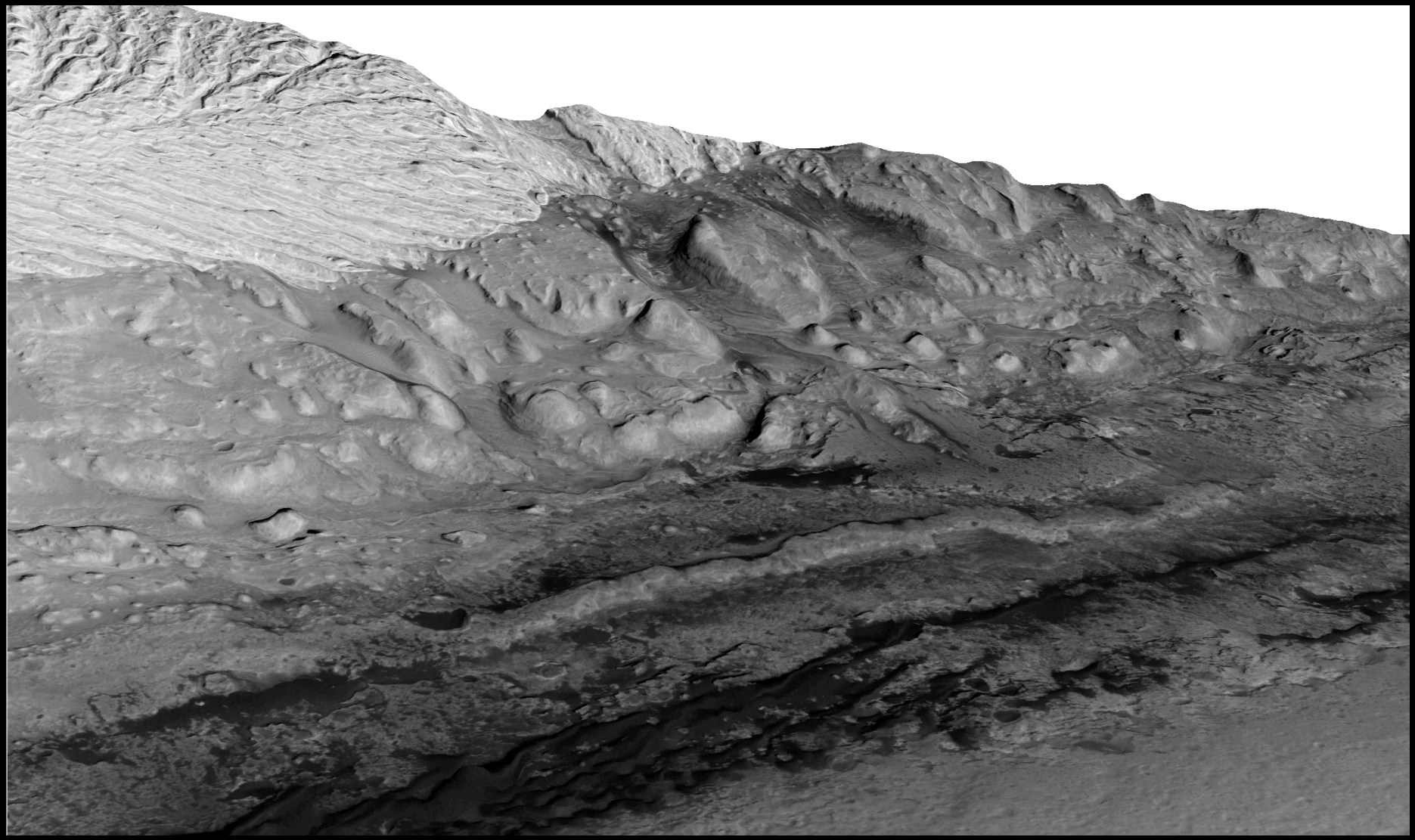




Gale layered rocks show multiple bedding styles and erosional expressions

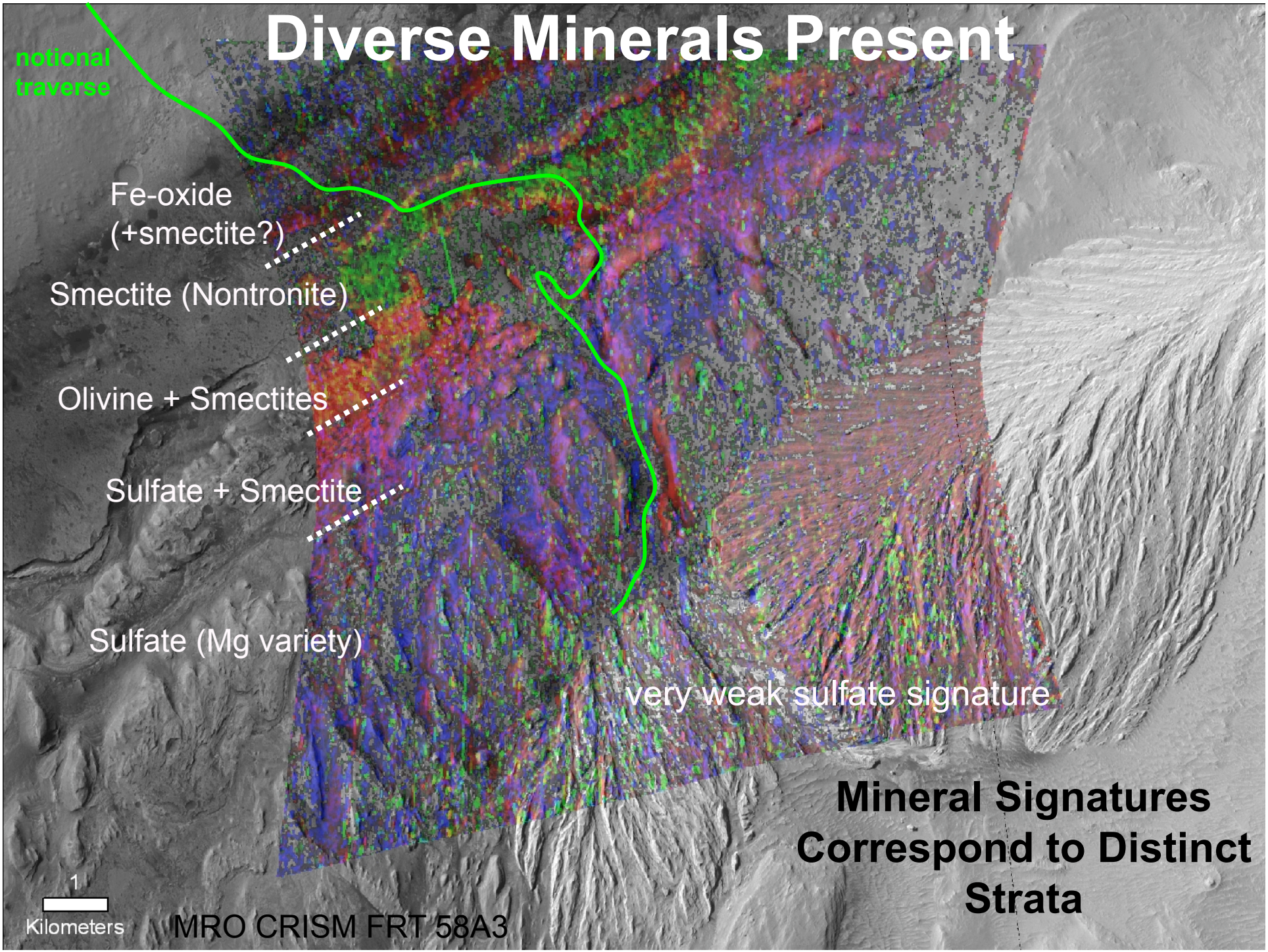


Oblique View of Stratigraphic Diversity Along Notional Traverse



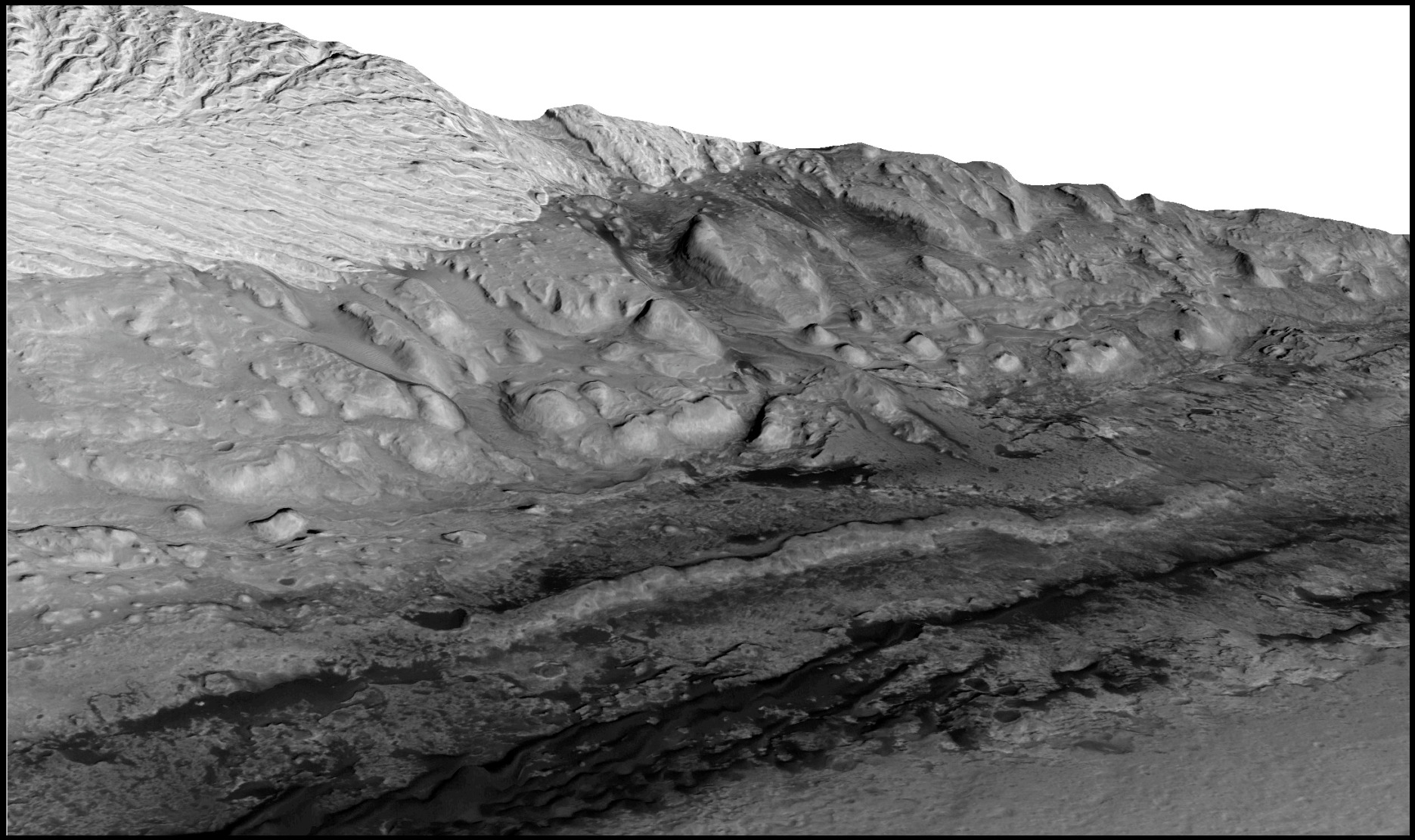
CTX image overlain on DEM by Larry Edwards from CTX stereopairs, looking toward southwest.

Diverse Minerals Present



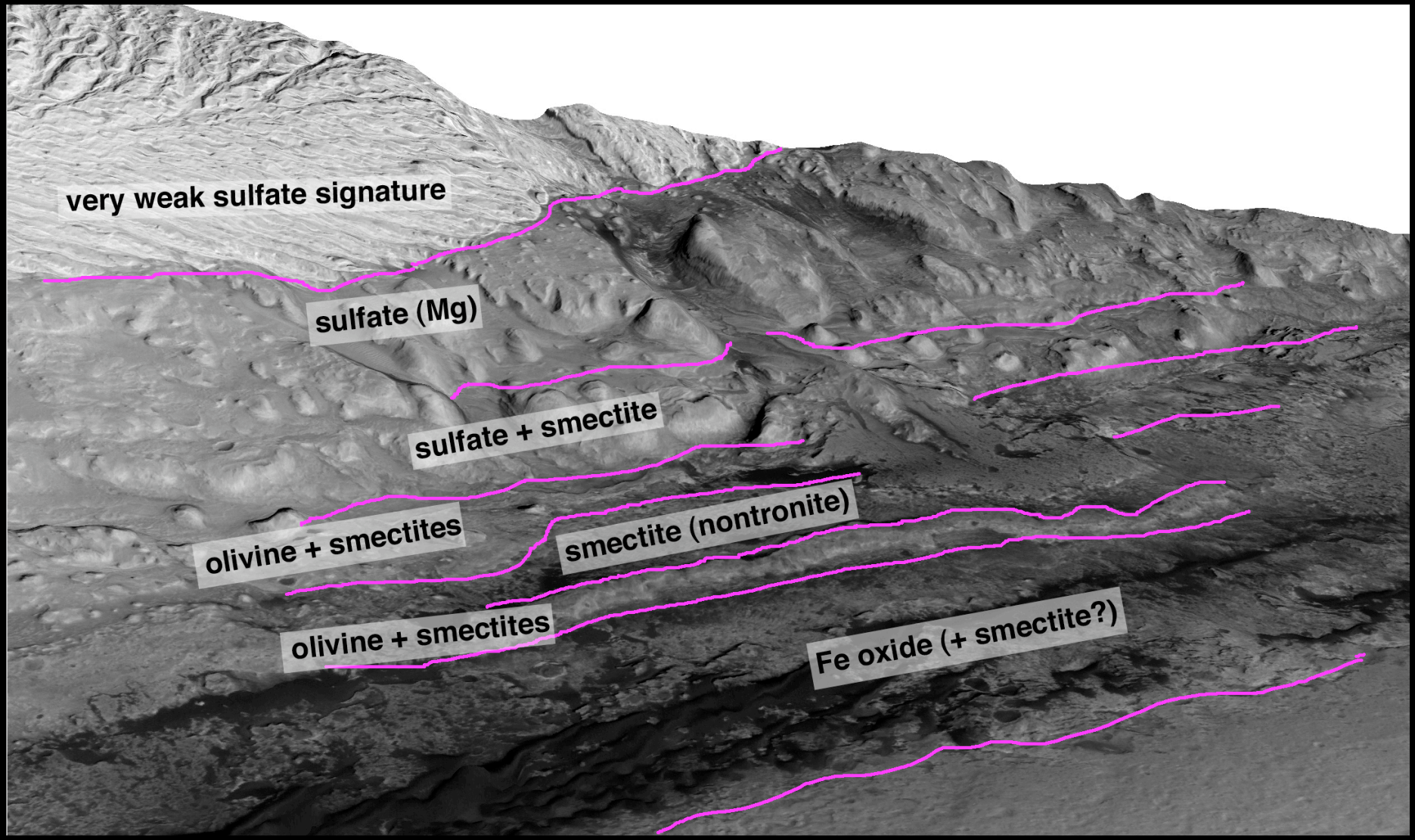
Mineral Signatures Correspond to Distinct Strata

Environmental Transitions in Gale Mound



CTX image overlain on DEM by Larry Edwards from CTX stereopairs, looking toward southwest.

Environmental Transitions in Gale Mound

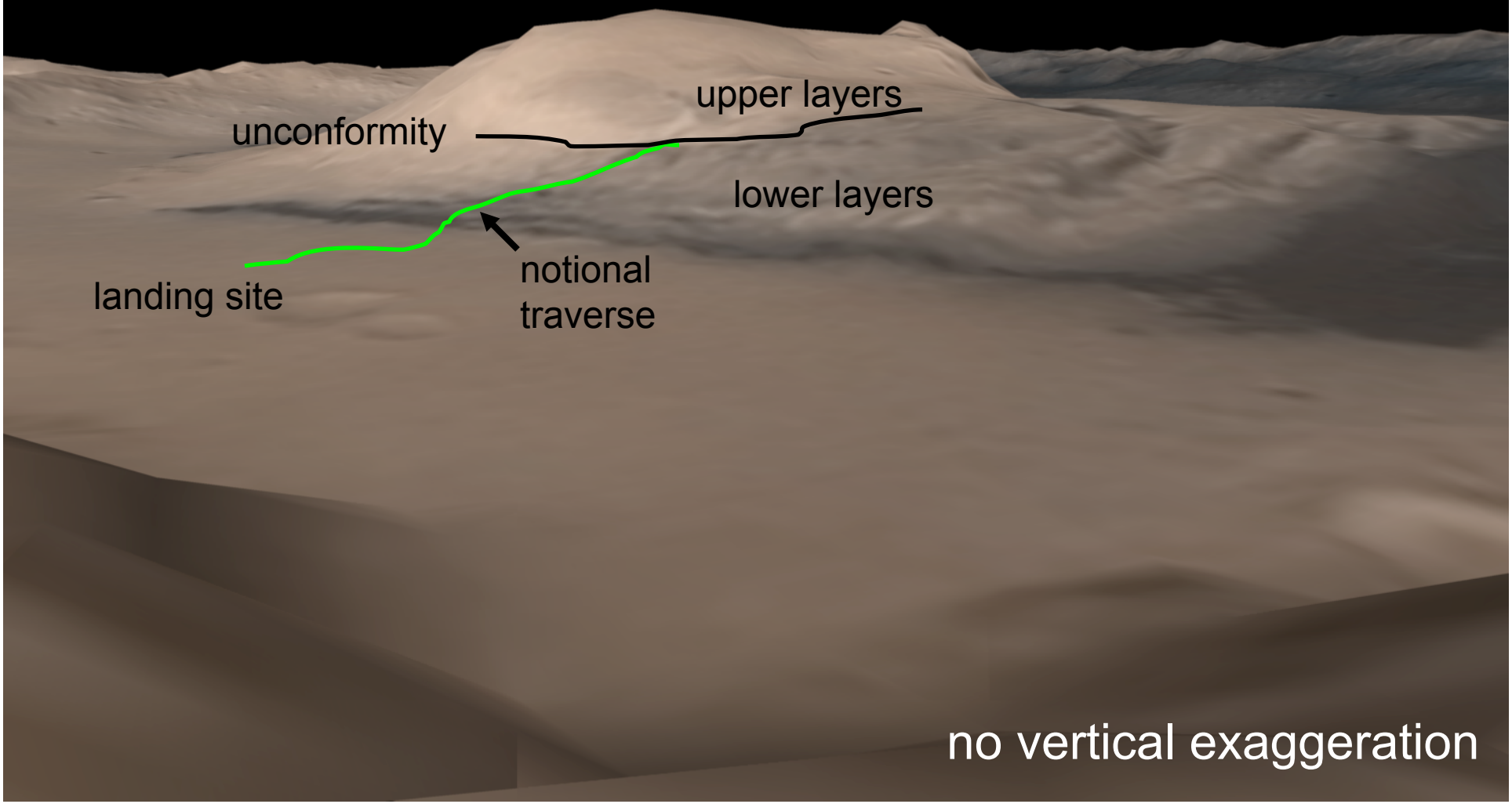


CTX image overlain on DEM by Larry Edwards from CTX stereopairs, looking toward southwest.

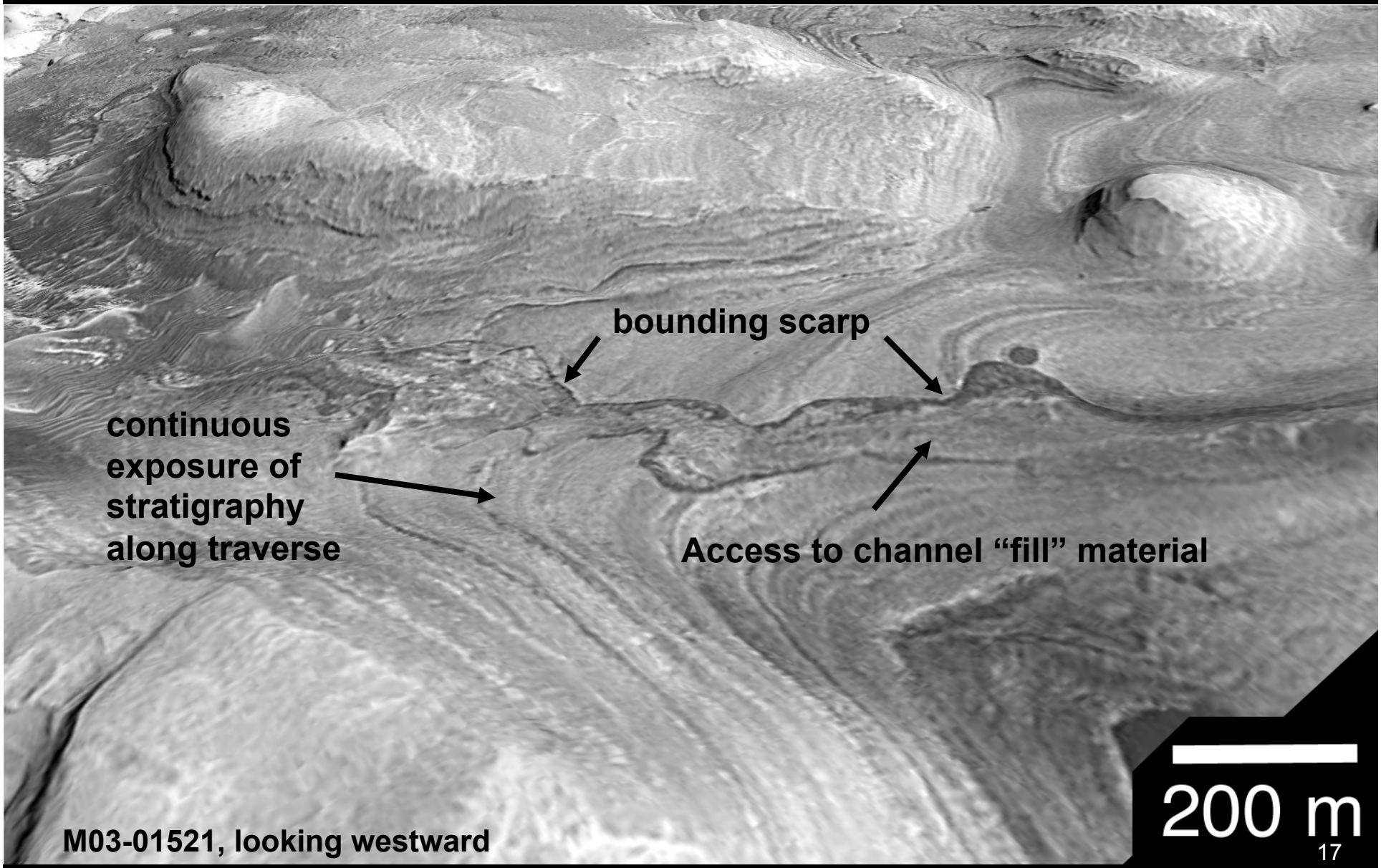
Diverse Minerals Present

- The minerals we identify by orbital remote sensing are not the only minerals present, but we can infer processes from these observations.
- The clays and sulfates imply differences in depositional environment, diagenesis, or subsequent weathering of exposed rock surfaces.
- These differences will tell us about the role of water and how it acted upon the materials that comprise the layers in the Gale mound.
- Gale offers an opportunity to see these materials in a finely layered stratigraphic sequence:
  - transitioning from older, clay-bearing rock
  - to younger sulfate-bearing rock
  - to still younger rocks bearing no specific near-IR spectral signature
- This diversity makes the Gale mound very attractive from geochemical, habitability, and preservational perspectives.

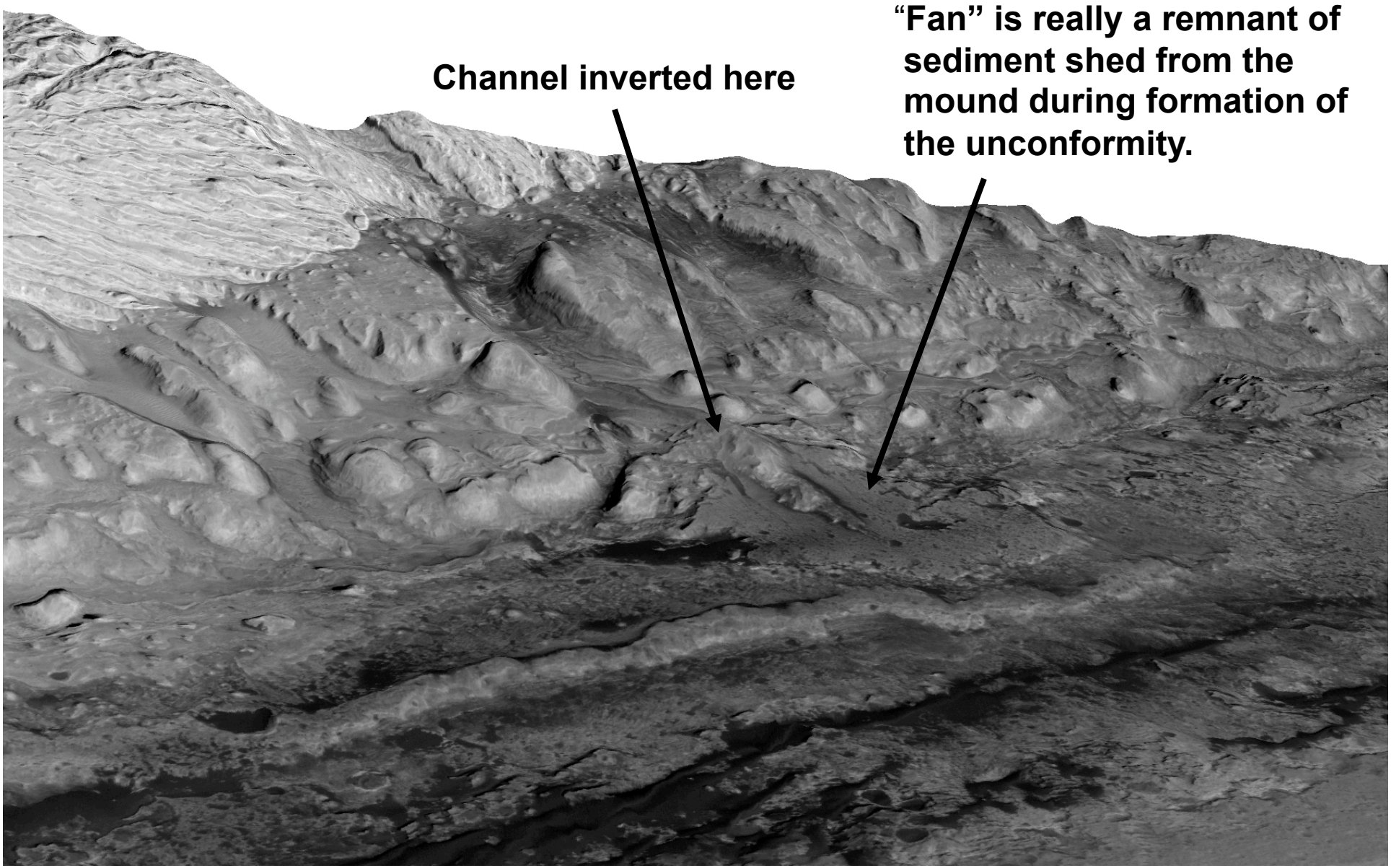
Unconformity in Gale Mound Represents an Important Erosional & Fluvial Episode



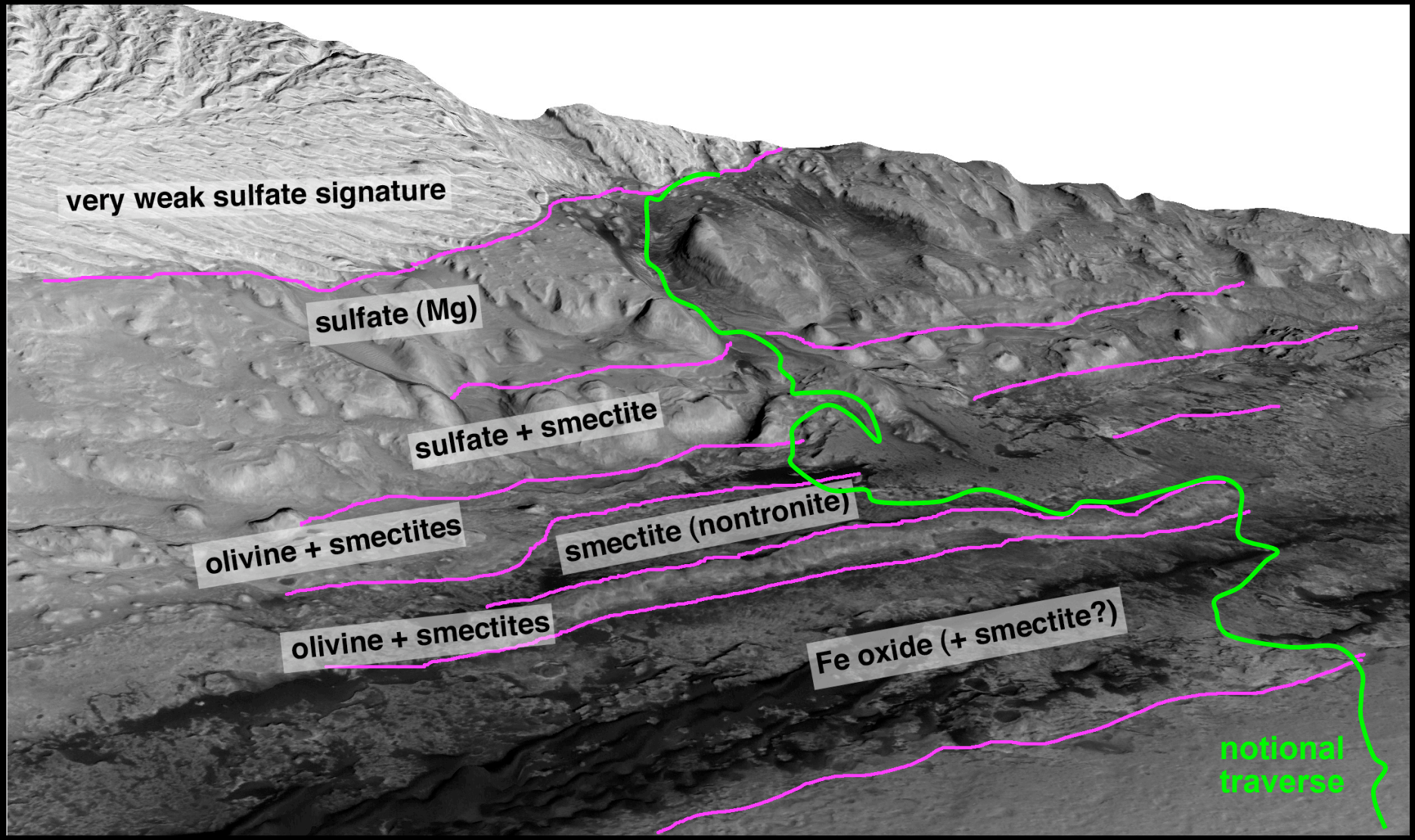
Filled & Re-exhumed Channel Associated with Unconformity



Perspective View of Channel Associated with Unconformity

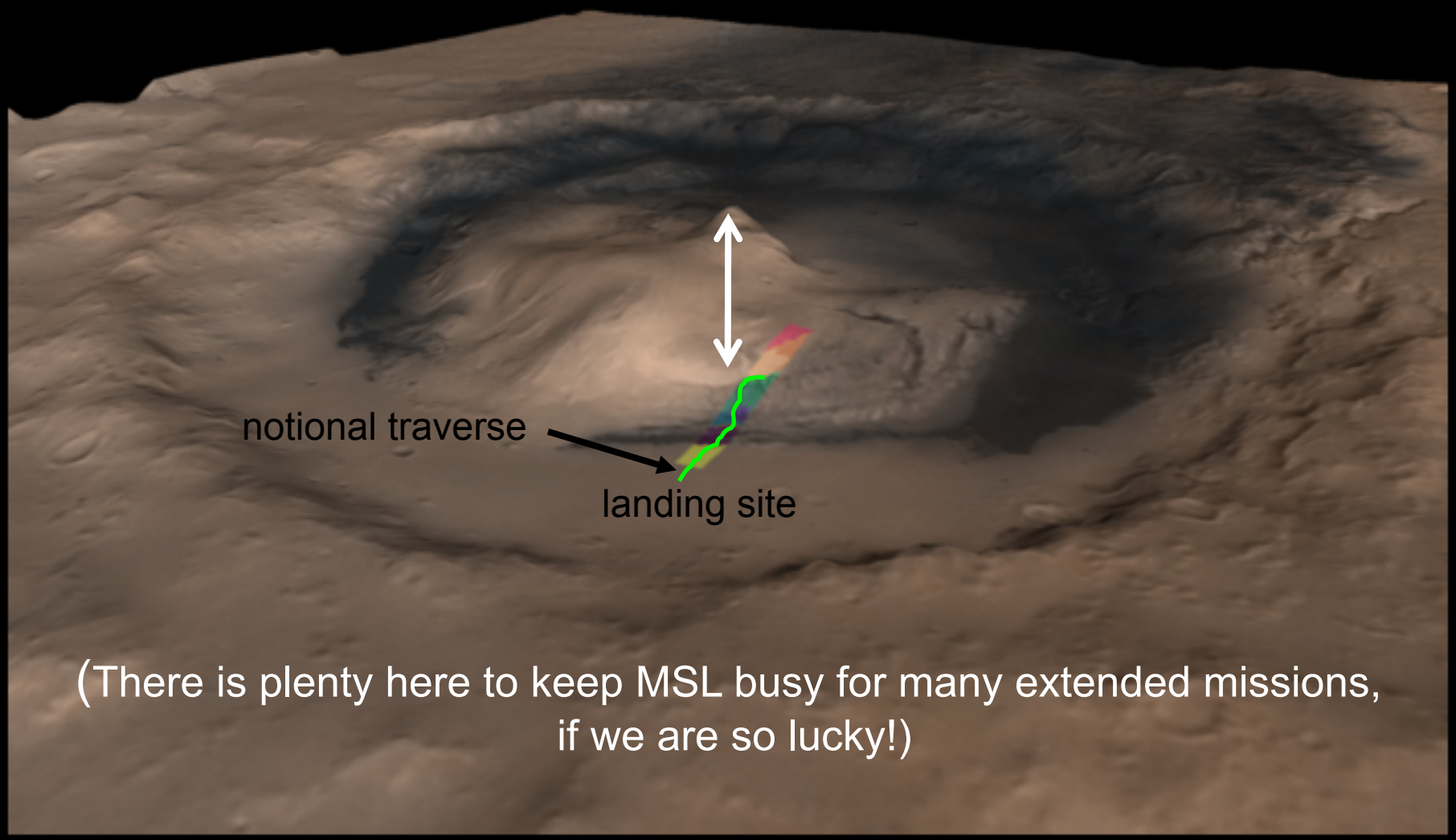


Observing Environments with MSL



CTX image overlain on DEM by Larry Edwards from CTX stereopairs, looking toward southwest.

1+ km Thick Type Section Plus
~3+ km of Strata Above the Notional Traverse



(There is plenty here to keep MSL busy for many extended missions, if we are so lucky!)

Environmental Transitions in Gale Mound:

- Provide a Type Section for Early Mars:
  - Lower rocks are clay-bearing
  - Rocks above that are sulfate-bearing
  - Fluvial erosion occurred during development of an unconformity
  - Some rocks above the unconformity are cyclical

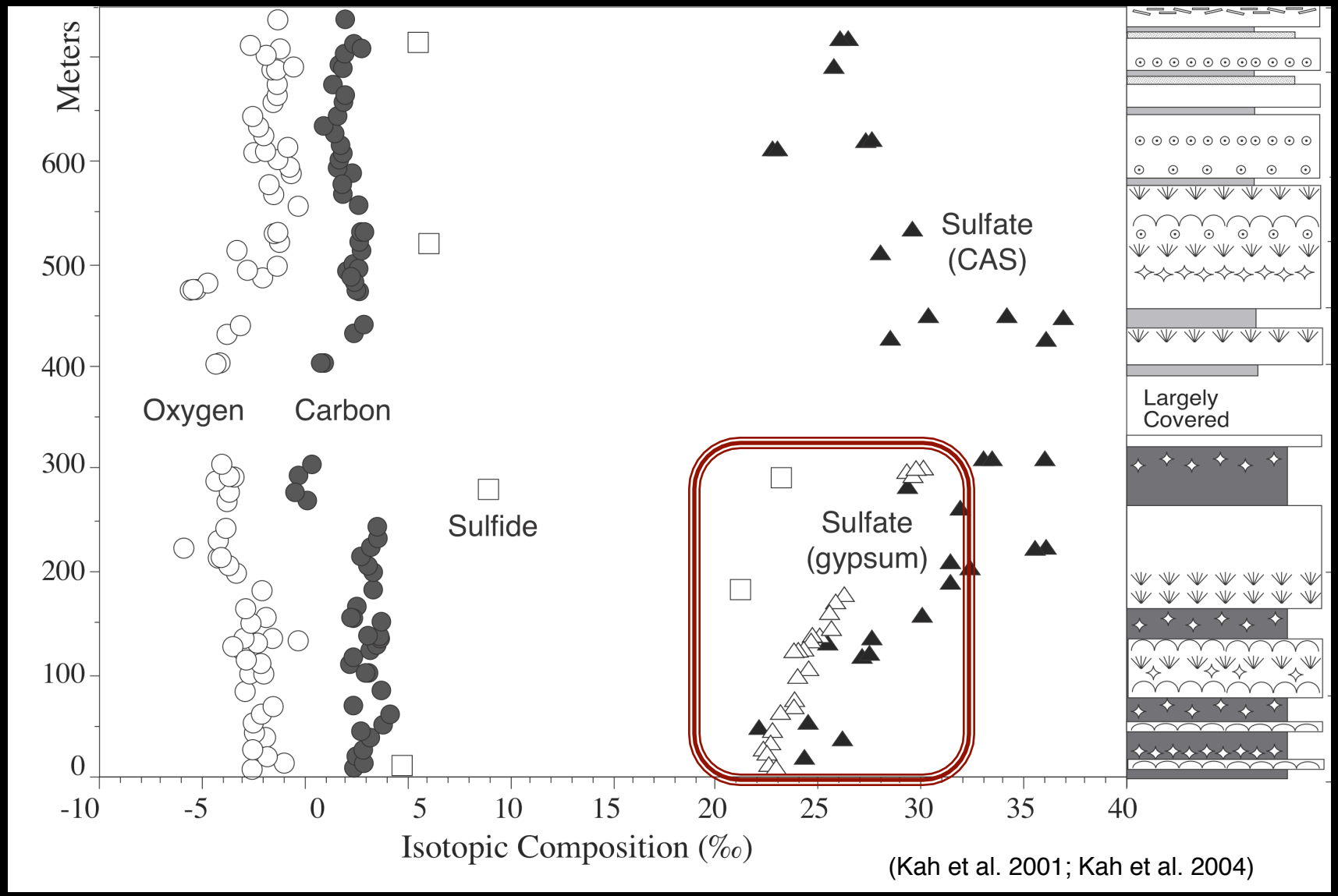
- Provide a Test for the Bibring et al. (2006) hypothesis of geochemical periods with phyllosilicates followed by sulfates

- Allow us to test the hypotheses that mineralogical changes reflect:
  - Changes in sediment source and supply
  - Different depositional environments (known to exist from geomorphology)
  - Different diagenetic conditions
  - Weathering processes

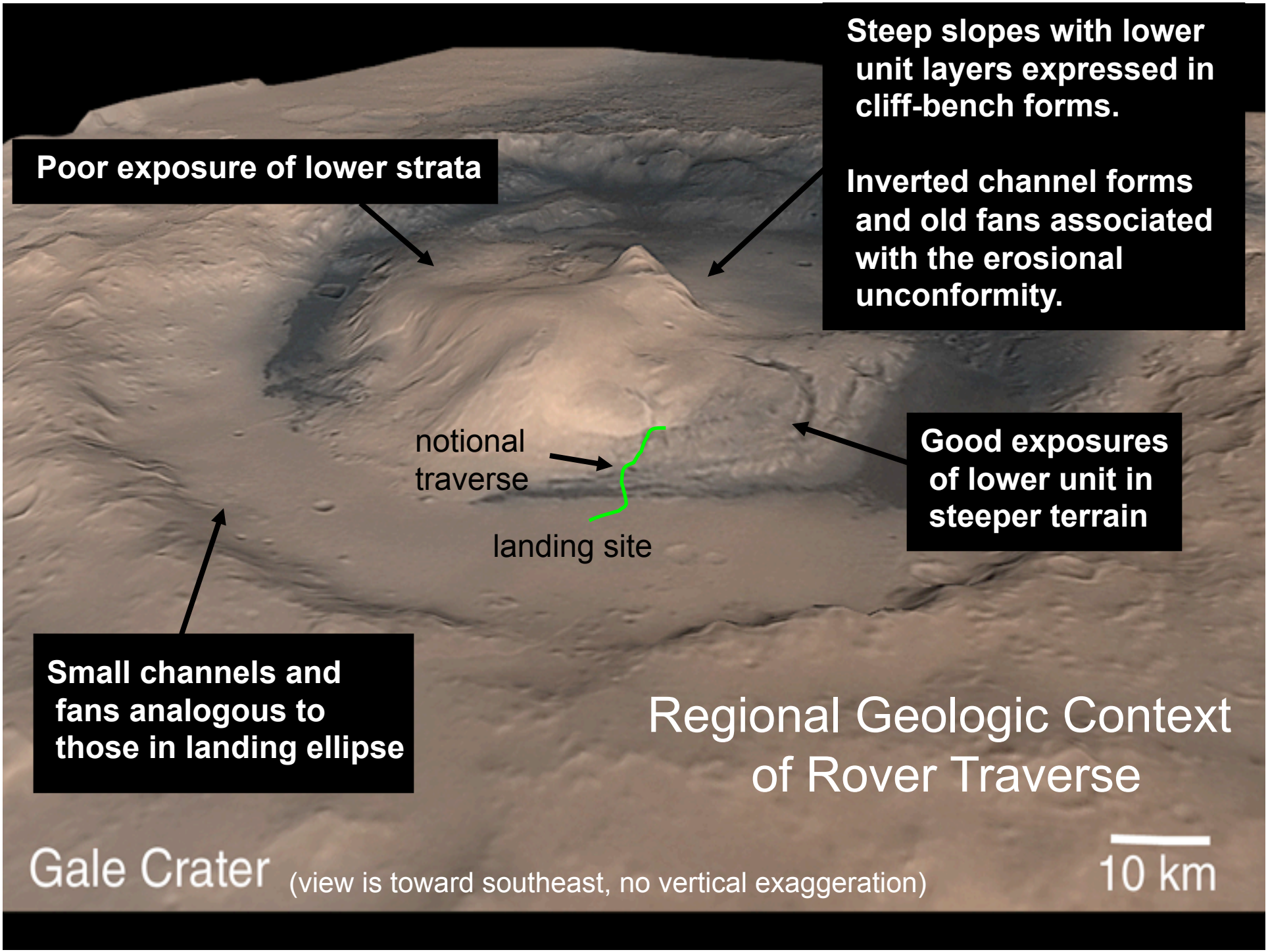
- Key MSL tools:
  - CheMin, ChemCam, APXS for mineralogy and composition
  - SAM for isotopic ratios and carbon detection
  - MAHLI and MastCam for sedimentary structures and textures

1.2 Ga Society Cliffs Formation
Bylot Island, Arctic Canada
(upper 300 meters) Courtesy of L. Kah
Shale
Gypsum
Dolostone

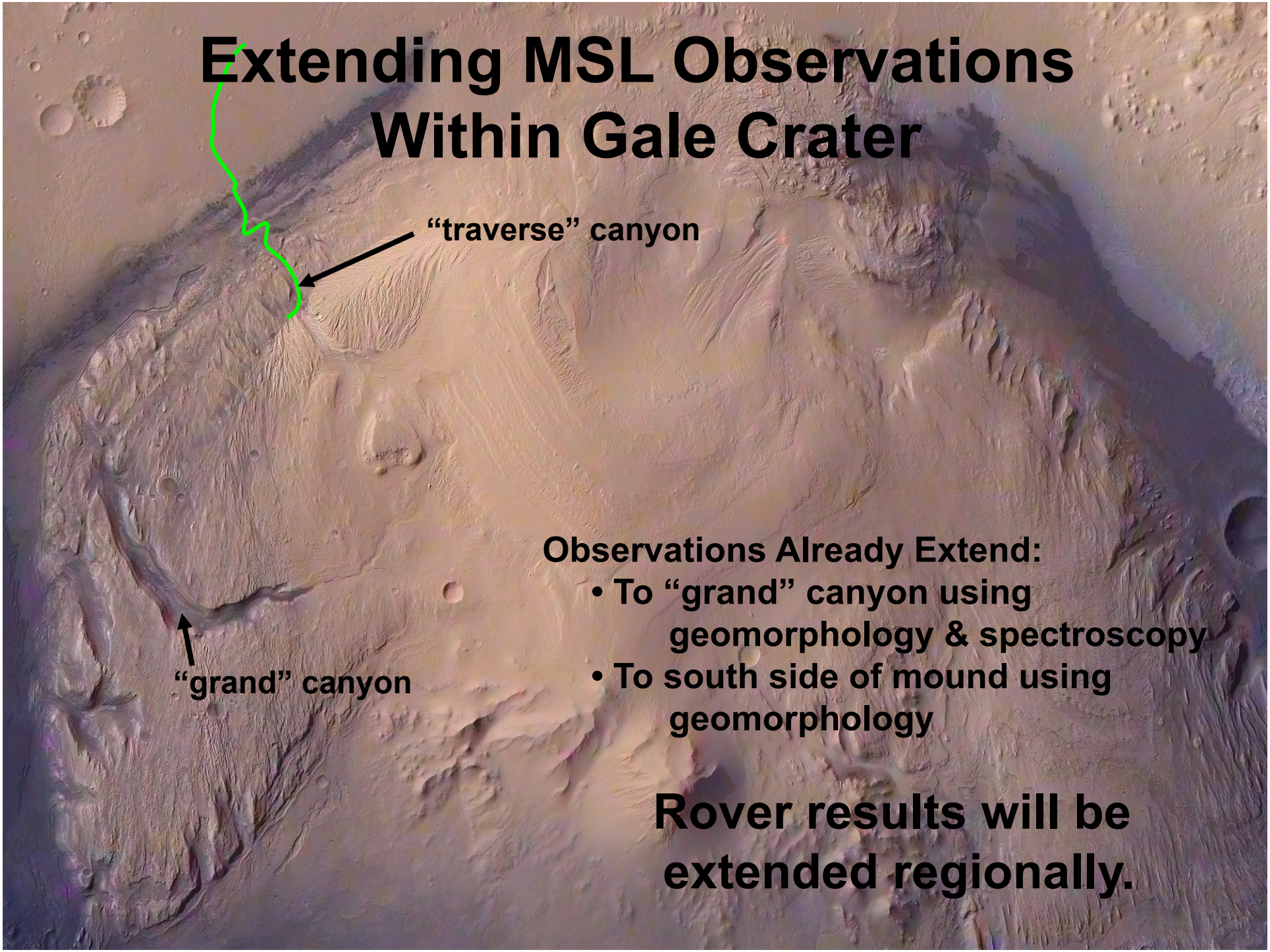
Isotopic Data Within SAM's Analytical Capabilities
(Composition vs. Stratigraphic Position)



(Kah et al. 2001; Kah et al. 2004)


Steep slopes with lower unit layers expressed in cliff-bench forms.
Inverted channel forms and old fans associated with the erosional unconformity.
Poor exposure of lower strata
notional traverse
landing site
Good exposures of lower unit in steeper terrain
Small channels and fans analogous to those in landing ellipse
Regional Geologic Context of Rover Traverse
Gale Crater
(view is toward southeast, no vertical exaggeration)
10 km

Extending MSL Observations Within Gale Crater



Observations Already Extend:

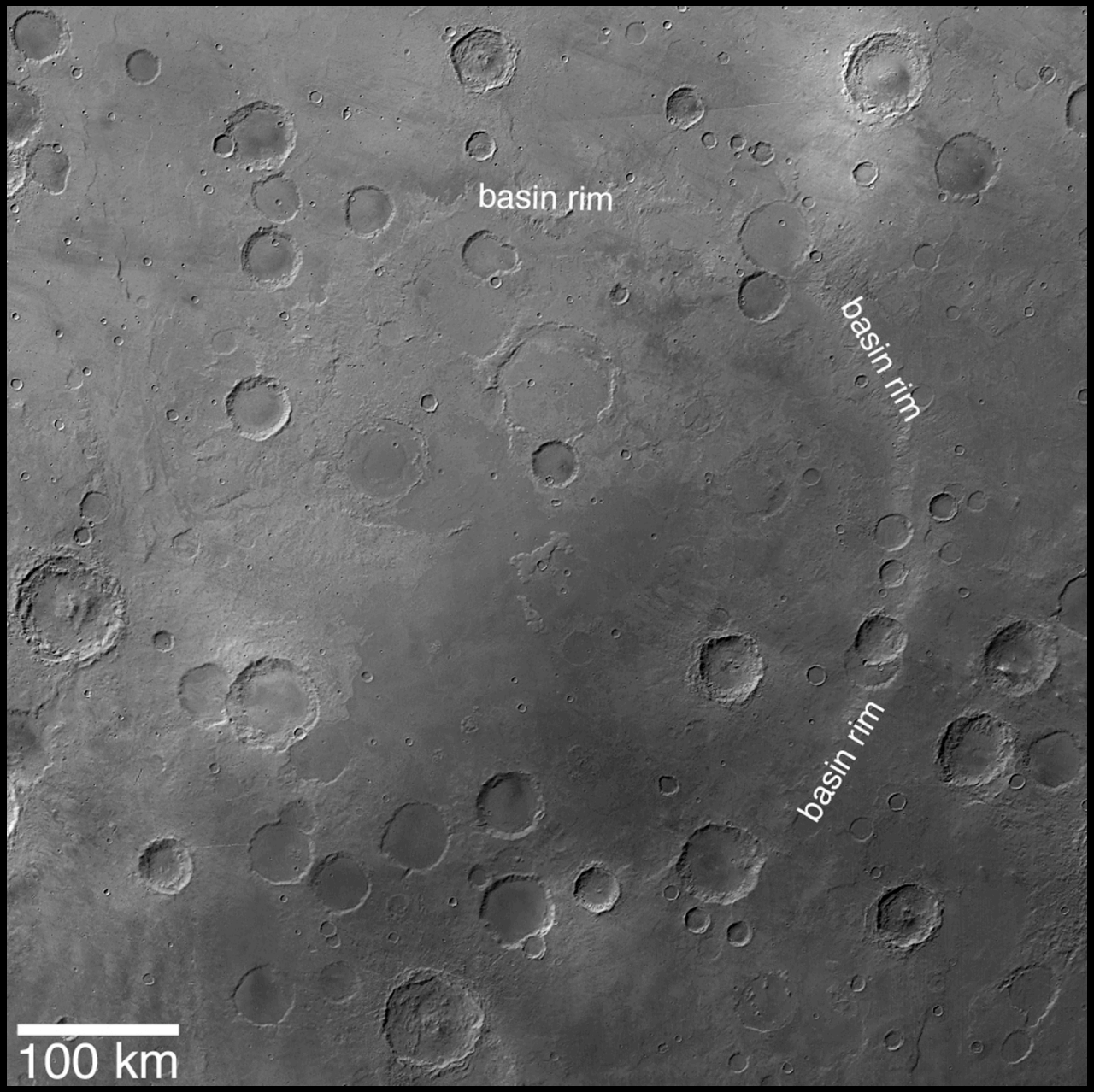
- To "grand" canyon using geomorphology & spectroscopy
- To south side of mound using geomorphology

Rover results will be extended regionally.

Gale Crater is part of the "Big Picture" of Early Mars

- It represents a "family" of Early Mars craters
- Many of Early Mars craters were filled, buried and re-exhumed
- Gale can teach us much about broader Mars processes
- MSL will tell us volumes about similar settings across the planet

Some very large craters were filled or nearly filled.



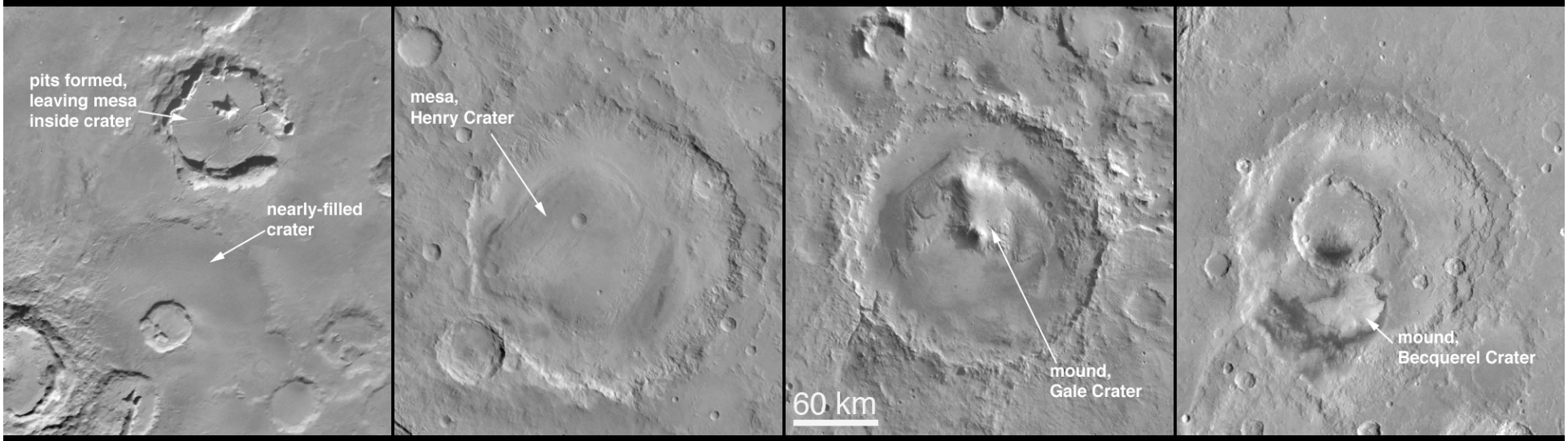
Noachis Terra
37°S, 356°W

Mosaic of MOC red wide angle images: M01-00841, M01-01232, M01-01234, M01-01623, and M01-01625

Burial and Exhumation of Craters and Mounds

Mars has a whole "family" of craters that were filled, buried, and exhumed. Gale Crater is of this family, representing widespread processes on Early Mars.

Noachis craters | **Henry Crater** | **Gale Crater** | **Becquerel Crater**



The scale is the same in these images.

Hypotheses regarding layered rocks in craters:

* Where did the fill materials come from?

*** What were they composed of?

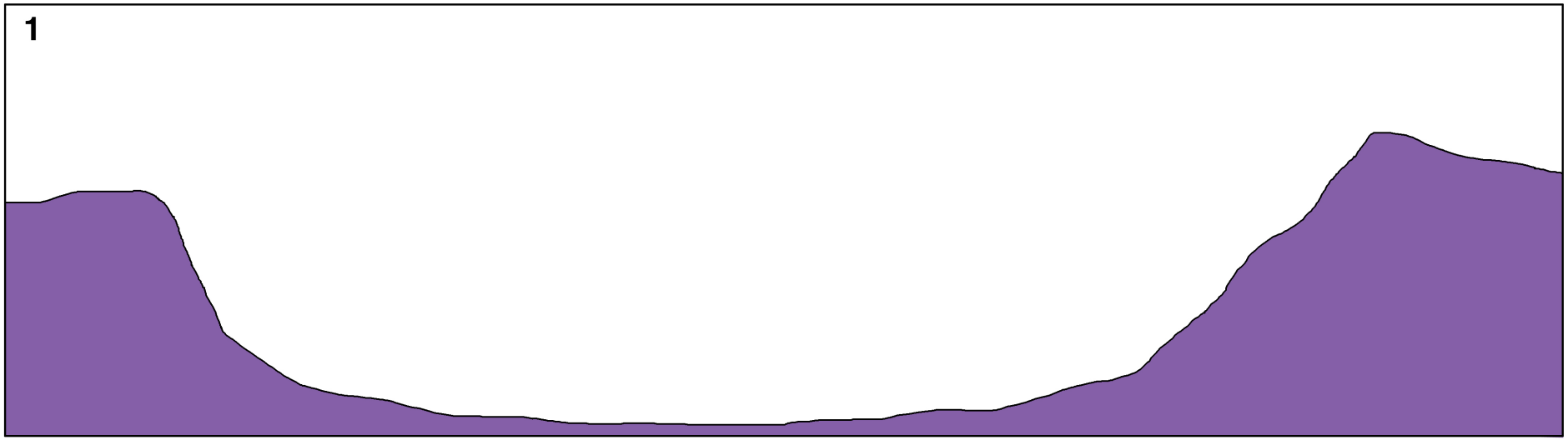
*** How were they deposited?

*** What were the depositional environments?
(Lacustrine proposed due to bedding characteristics and absence of crater wall breaches.)

** Once the materials were lithified, how did they fragment and leave the crater?

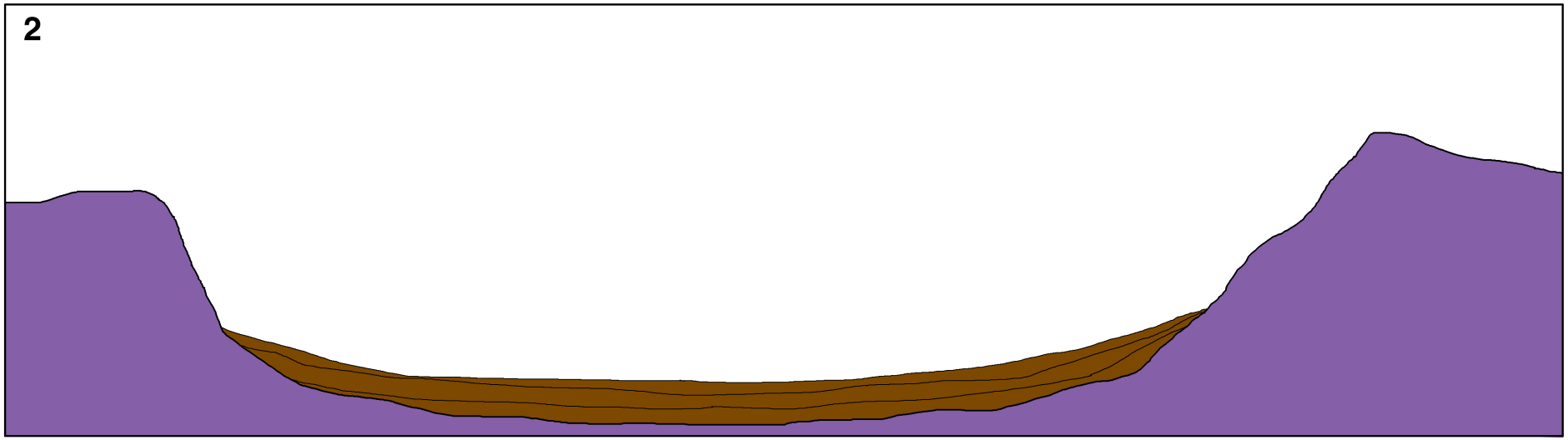
What was the timing of events relative to the rest of Mars?

A Simplified Hypothesis For Gale Crater



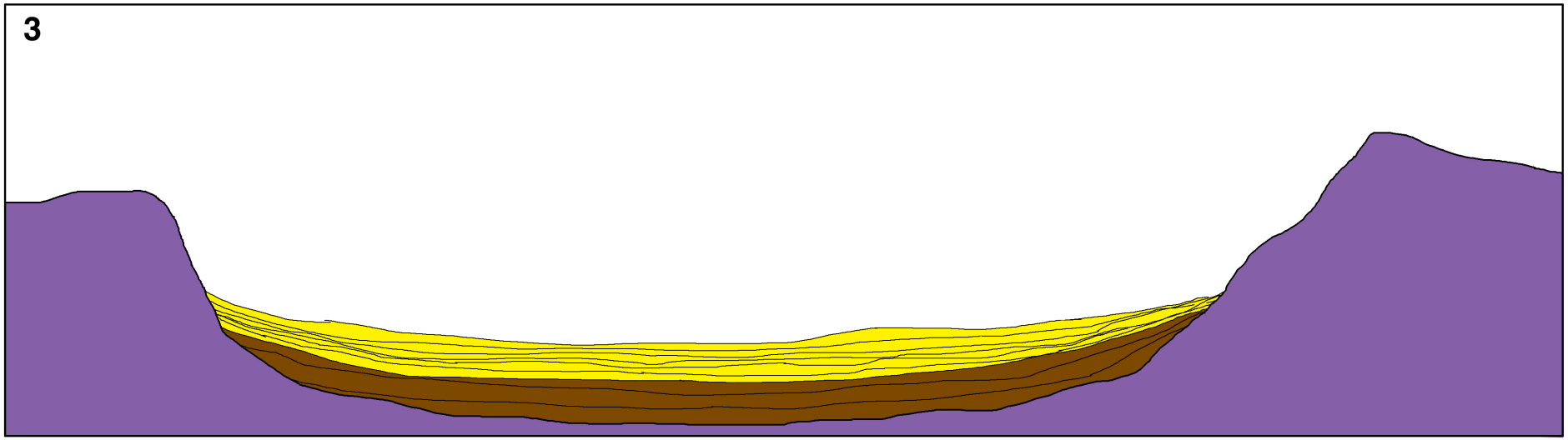
Gale Crater forms

A Simplified Hypothesis For Gale Crater



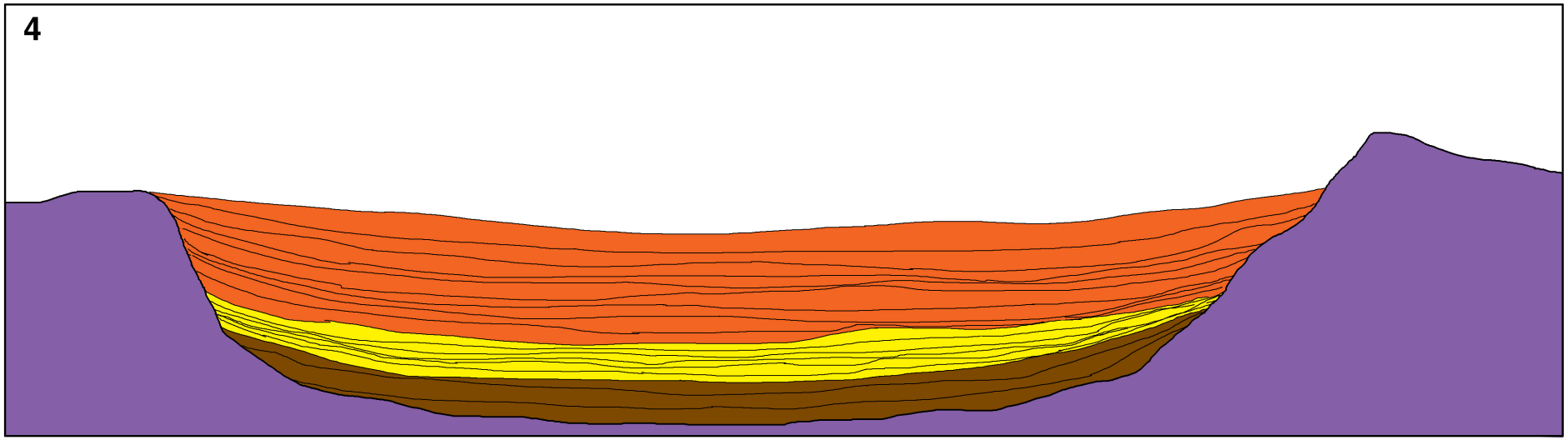
Initial deposition

A Simplified Hypothesis For Gale Crater



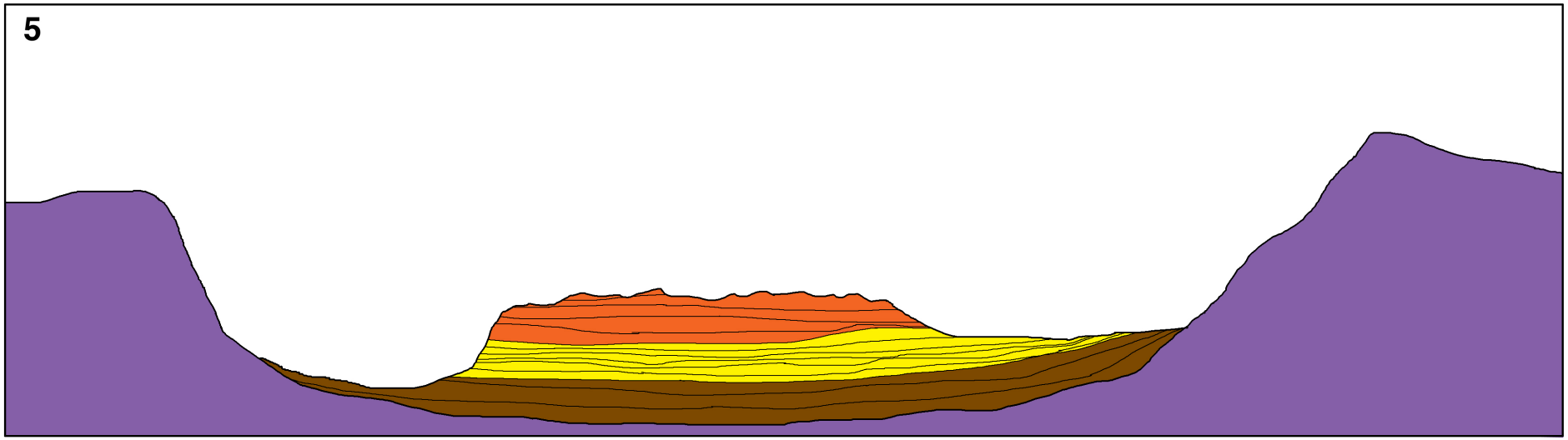
Further deposition includes clay-bearing rocks

A Simplified Hypothesis For Gale Crater



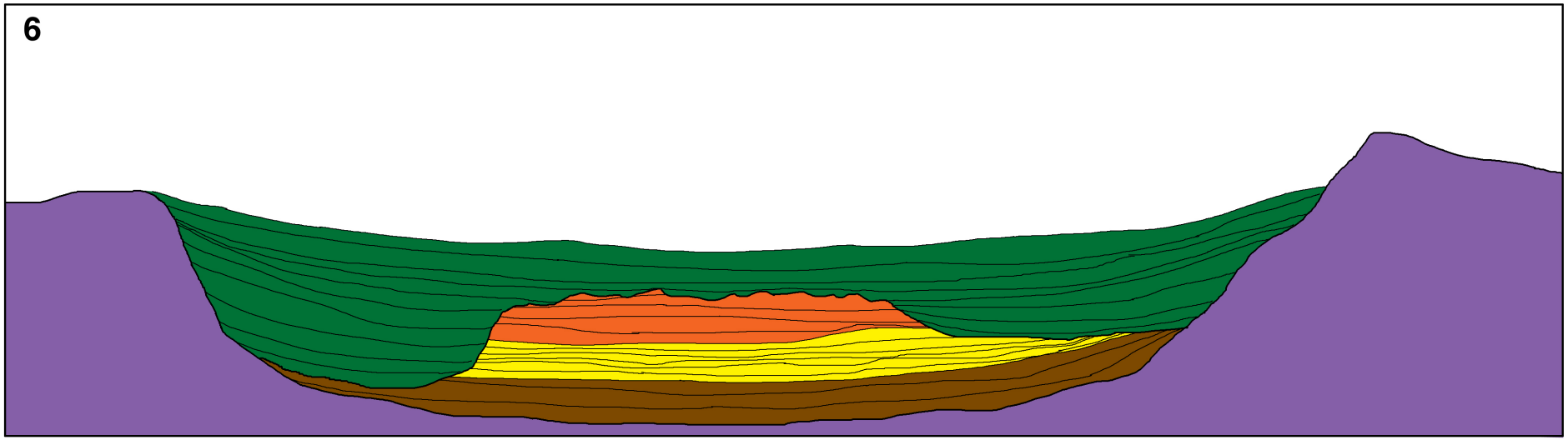
Continued deposition includes sulfate-bearing rocks

A Simplified Hypothesis For Gale Crater



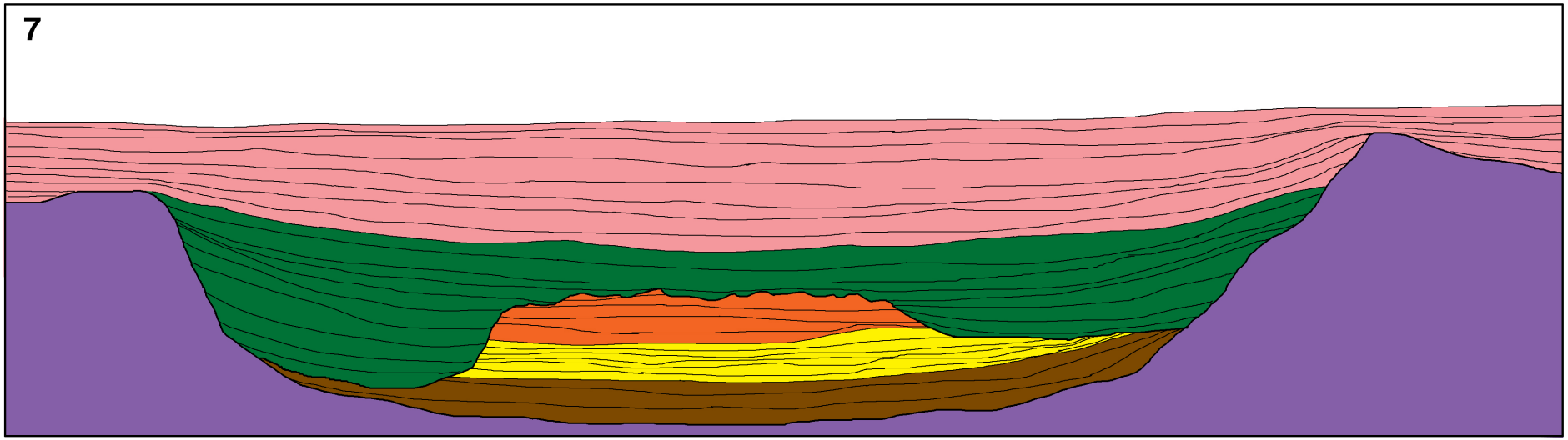
Major erosional period; canyons form

A Simplified Hypothesis For Gale Crater



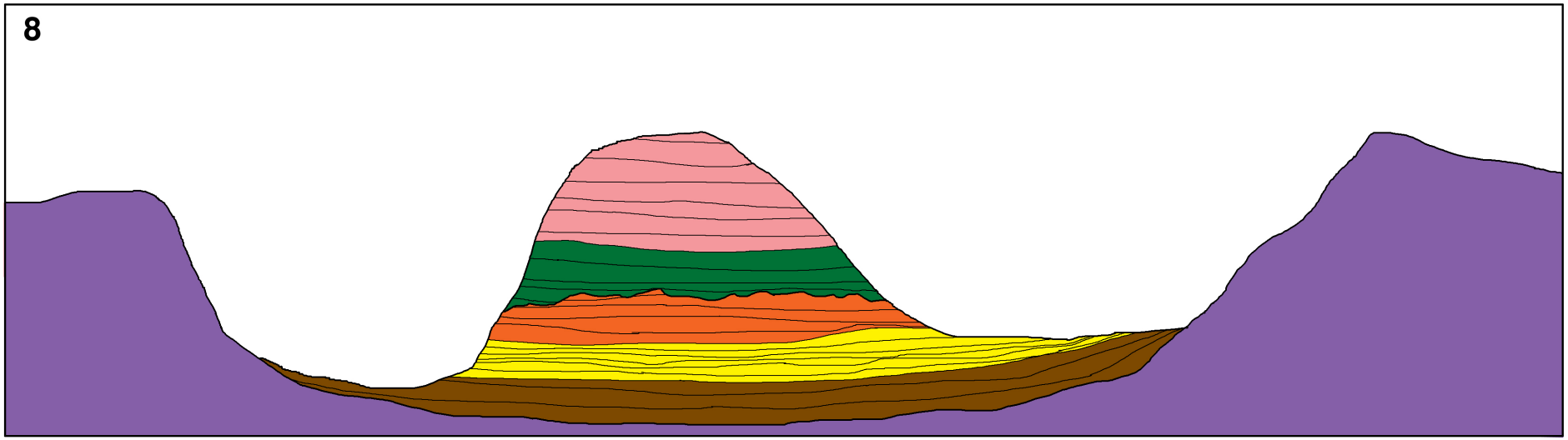
Renewed deposition; no IR spectroscopic signature
Cyclically bedded

A Simplified Hypothesis For Gale Crater



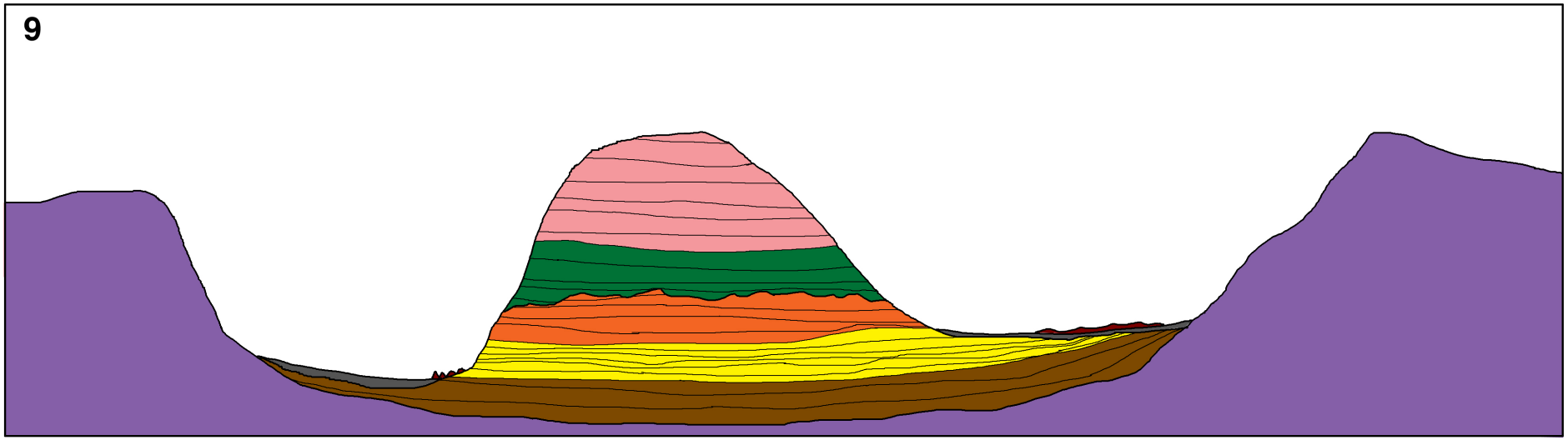
Further deposition; crater might have been filled, buried

A Simplified Hypothesis For Gale Crater



Another period of erosion

A Simplified Hypothesis For Gale Crater



Fluvial fan deposition & recent eolian dunes

Diverse Depositional Settings

- The layered rock erosional expression, bedding thicknesses, etc. differ as one moves up the stratigraphic column, demonstrating changes in depositional conditions.
- The mineralogy also changes as one moves up the stratigraphic column.
- An erosional unconformity indicates a period of vigorous erosion and destruction of part of the stratigraphic record.
- The roles of water and air transport in depositing the lower layered rocks must be tested.
- The time of the erosional unconformity is clearly a subaerial period with fluvial erosion (canyon cutting) and deposition.
- Water MUST have influenced the sequence based on both mineralogic and geomorphologic evidence.

Preservation Potential in Gale Crater Strata

1) A thick stratigraphic section with diverse facies and minerals provides:

• the opportunity to refine facies models to guide the search for and interpretation of habitability indicators

• a variety of potential preservation mechanisms for organics, isotopic signatures (especially sulfur isotopes), and textural biosignatures

Preservation Potential in Gale Crater Strata

2) Stratigraphic control of “systematic” mineralogical compositions allows:

• direct tests of whether mineralogical compositions are depositional, diagenetic, or weathering in nature

• direct tests of whether potential preservation reflects surficial or near-surface ancient “ecosystems”

• exploration of global-scale climate influence on mineralogical composition and its implications for martian habitats

• us to extend our understanding of variable preservation potential of different lithologies and variable mineralogies

> lower (phyllosilicate) to higher (sulfate) water activity environments

> lower (phyllosilicate) to higher (sulfate) potential for morphology preservation

Top 10 Reasons to Send MSL to Gale

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10. Gale presents a 5 km thick record of what early Mars was like.

Top 10 Reasons to Send MSL to Gale

9. If none of the section in this deep crater includes lake sediments, then, by golly, lakes were very rare on early Mars.
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Top 10 Reasons to Send MSL to Gale

8. Diverse materials to explore, including fluvial sediment.
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Top 10 Reasons to Send MSL to Gale

7. Geomorphic evidence for the role of water in landing ellipse and along traverse pathway.
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Top 10 Reasons to Send MSL to Gale

6. Spectroscopic evidence for clays and sulfates.
7. Geomorphic evidence for the role of water in landing ellipse and along traverse pathway.
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Top 10 Reasons to Send MSL to Gale

5. We can test hypotheses about major environmental change, as reflected in mineralogical changes.
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Top 10 Reasons to Send MSL to Gale

4. Gale is one of a family of similar craters with layered rock records in them, all across Mars.
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Top 10 Reasons to Send MSL to Gale

2. Plenty to keep MSL busy for many extended missions!
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Top 10 Reasons to Send MSL to Gale

1. Gale provides the 1st Type Section for Mars!
2. Plenty to keep MSL busy for many extended missions!
3. Its diversity and context provide multiple opportunities for assessing habitability and preserving possible biosignatures.
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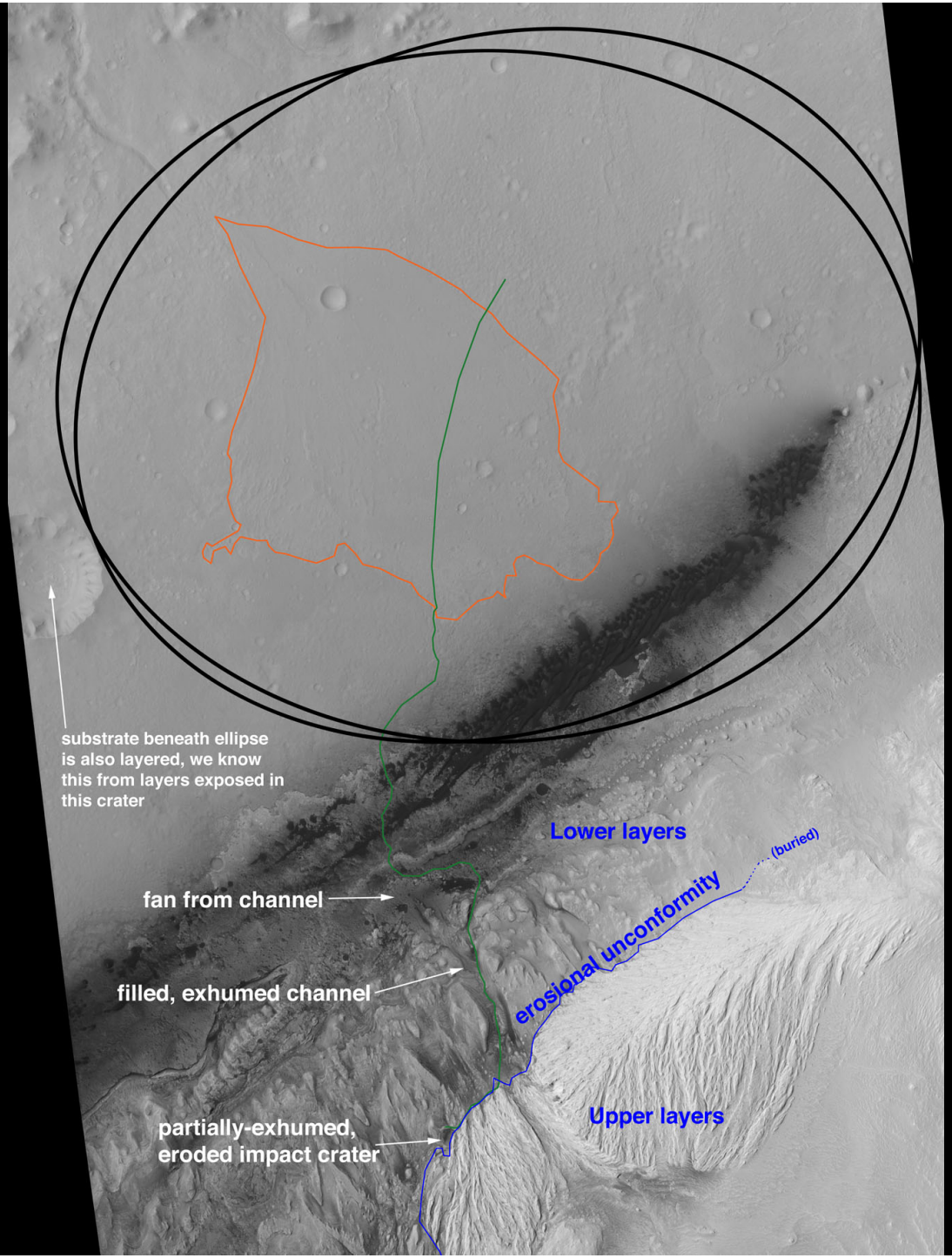
8. Diverse materials to explore, including fluvial sediment.
9. If none of the section in this deep crater includes lake sediments, then, by golly, lakes were very rare on early Mars.
10. Gale presents a 5 km thick record of what early Mars was like.

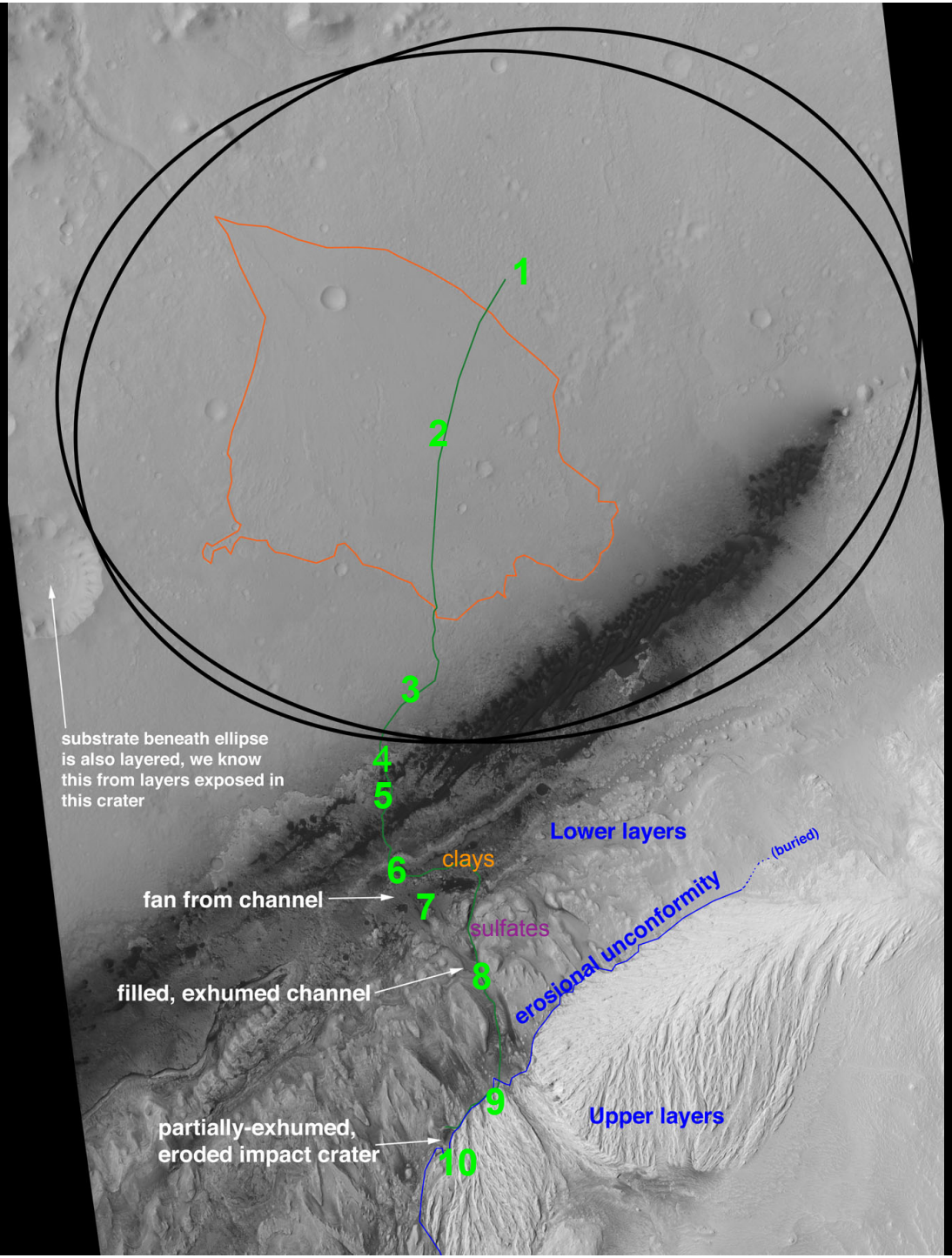
Gale Crater Embodies Landing Site Science Criteria

- **Diversity**
  - Clay-bearing, sulfate-bearing, and "other" arranged in a stratigraphic sequence
  - High diversity of geologic materials with different depositional and diagenetic conditions
- **Context**
  - Stratigraphy records early Mars environments
  - We can examine the strata in sequential order
  - Gale is one of the "family" of craters that were filled or nearly filled, perhaps buried and exhumed
  - At ~5 km deep, if there wasn't a lake in Gale at some time, then lakes were rare; either way, the result is important for surface habitability
- **Habitability**
  - Site has both *Geomorphic* and *Mineralogic* evidence for water
- **Potential Biosignature Preservation**
  - Depositional diversity provides multiple opportunities for preservation
    - Smectite and other clays
    - Sulfates and sulfur isotopes

Supporting Material



- 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



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' associated with 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?

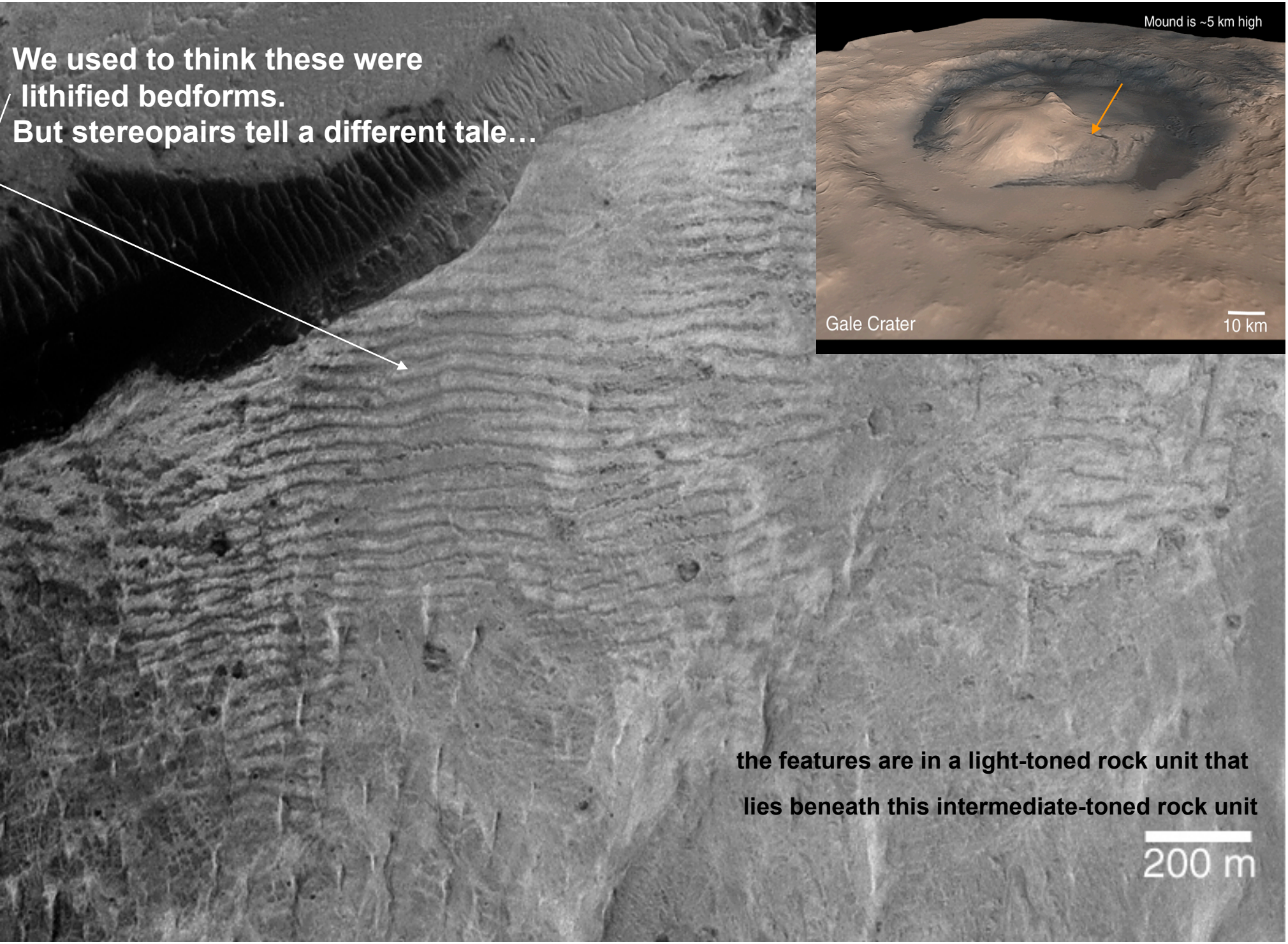
8. investigate layered rock stratigraphy -- sulfate-bearing rock -- and fill material in exhumed channel as rover works its way up slope

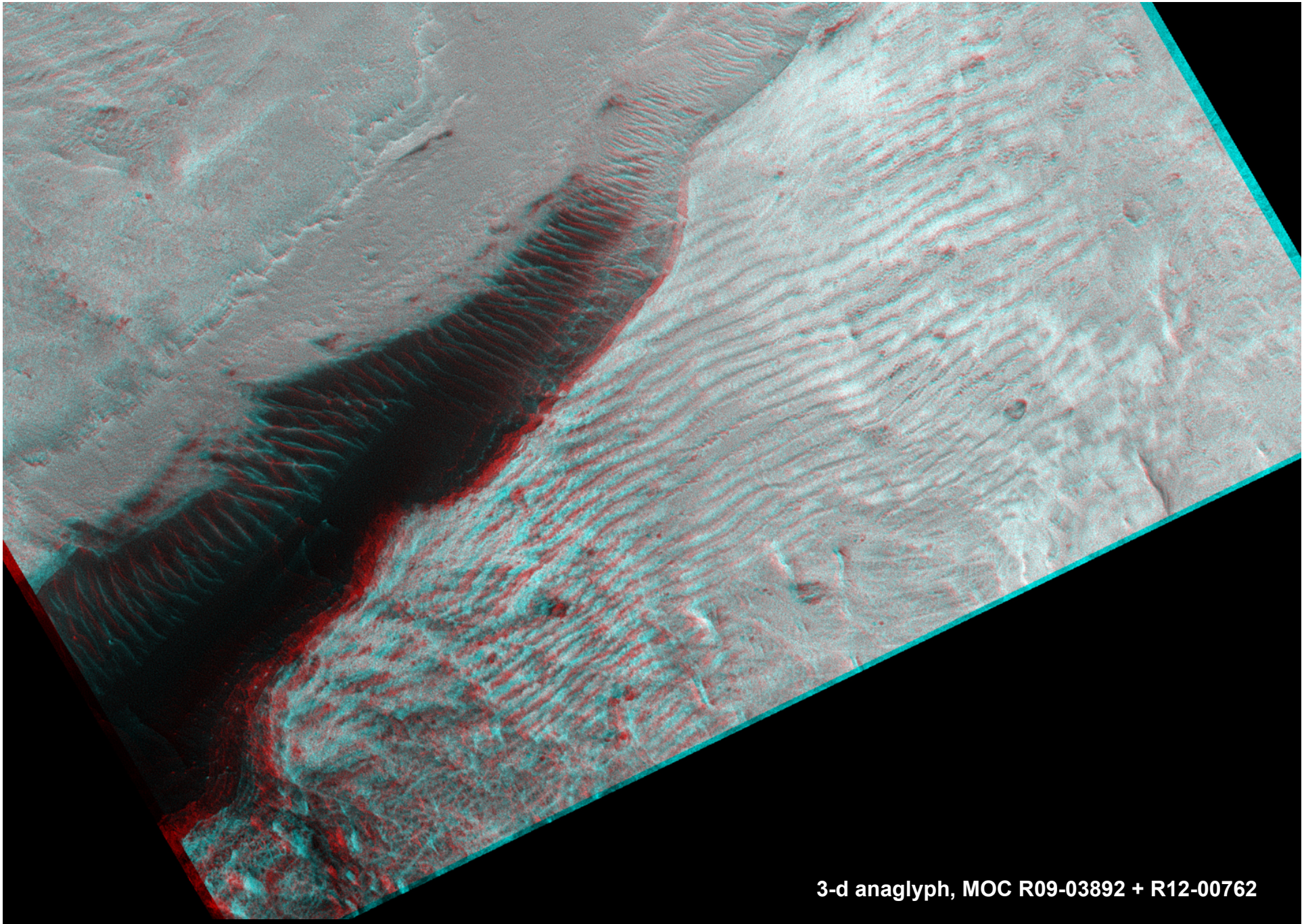
9. reach the erosional unconformity; examine lowermost layers of the upper unit that post-dates the erosional period

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

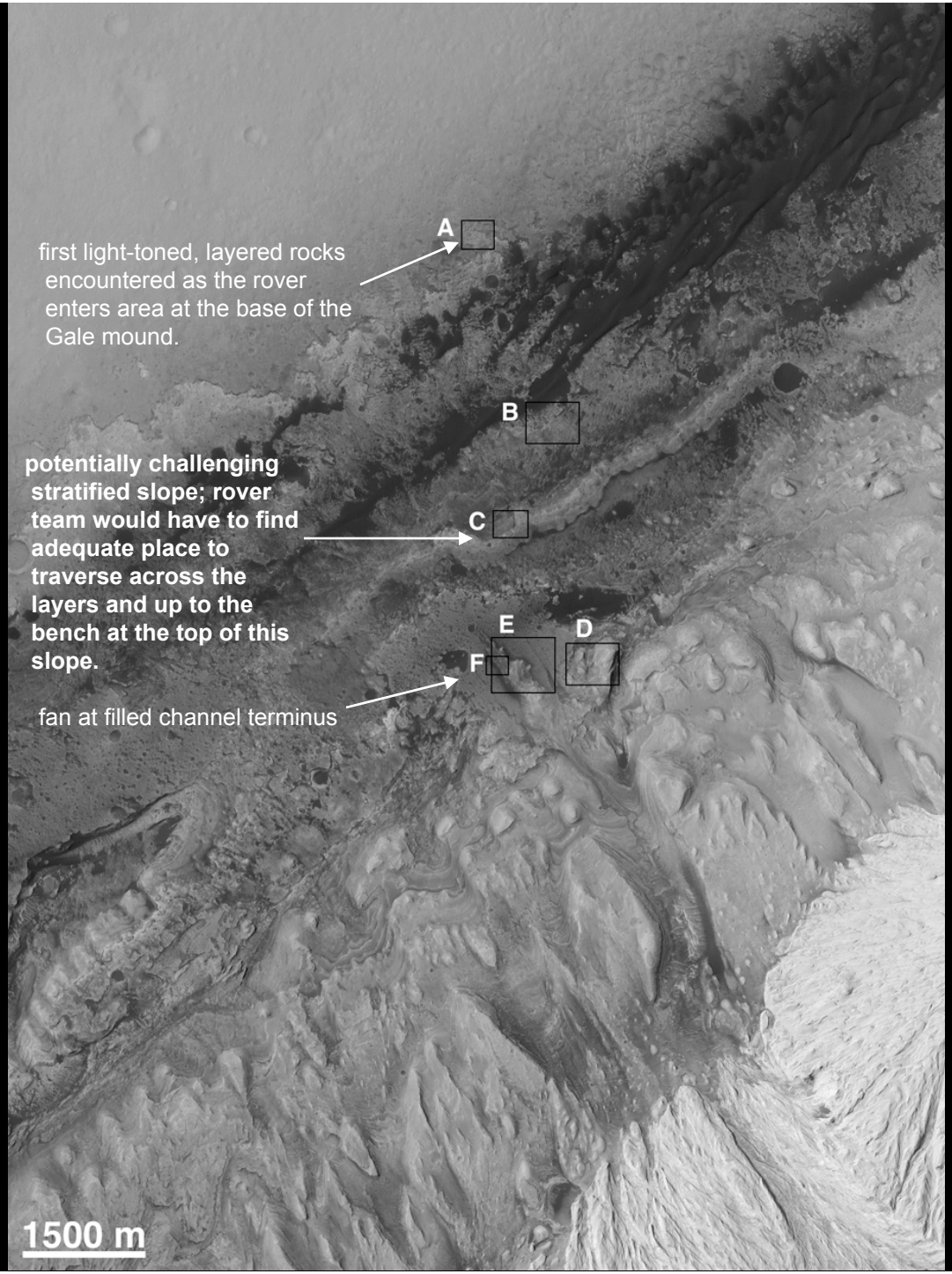
“Bedforms” in Gale’s Mound

- It was reported previously that certain features observed on layers of Gale’s mound appeared to be the lithified remains of large bedforms—subaqueous or subaerial dunes (Edgett and Malin, 2005, GSA annual meeting abstract).
- This was also reported in the July 2008 viewgraphs which describe the case for a MSL landing site in Gale Crater.
- This interpretation might be wrong. They may not be bedforms at all. A stereo anaglyph made from MOC narrow angle images shows that their topographic relations might not warrant a bedform interpretation.
- What these features are — is uncertain at this time.
- The next 2 slides show these features.


We used to think these were
lithified bedforms.
But stereopairs tell a different tale…
Mound is ~5 km high
Gale Crater
10 km
the features are in a light-toned rock unit that
lies beneath this intermediate-toned rock unit
200 m



3-d anaglyph, MOC R09-03892 + R12-00762

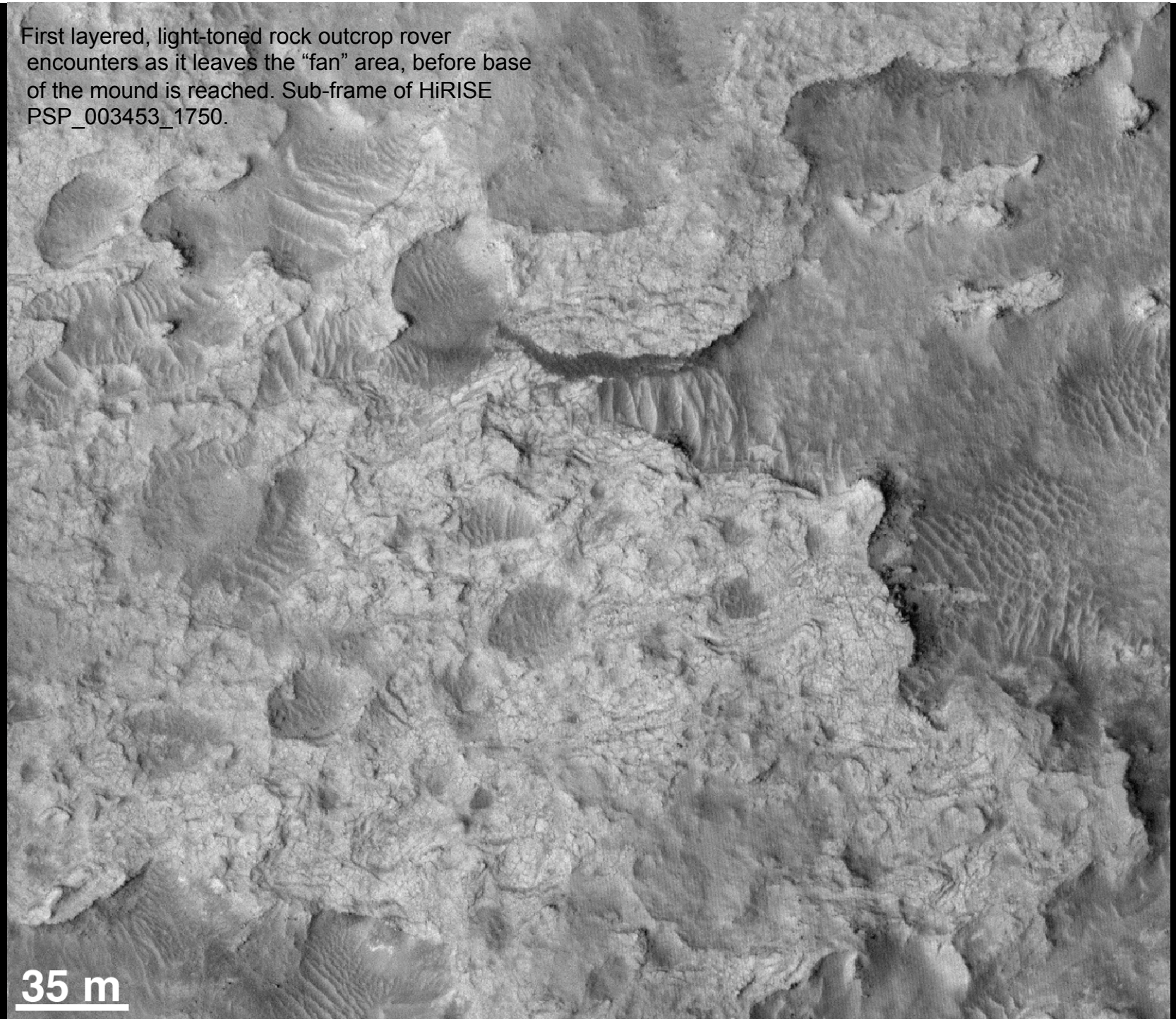


HiRISE PSP_003453_1750 covers a good portion of the landing ellipse and also a portion of the dune field and some of the lowermost layered rocks of the mound. The image does not include the filled channel but it does include much of the "fan" at the channel terminus.

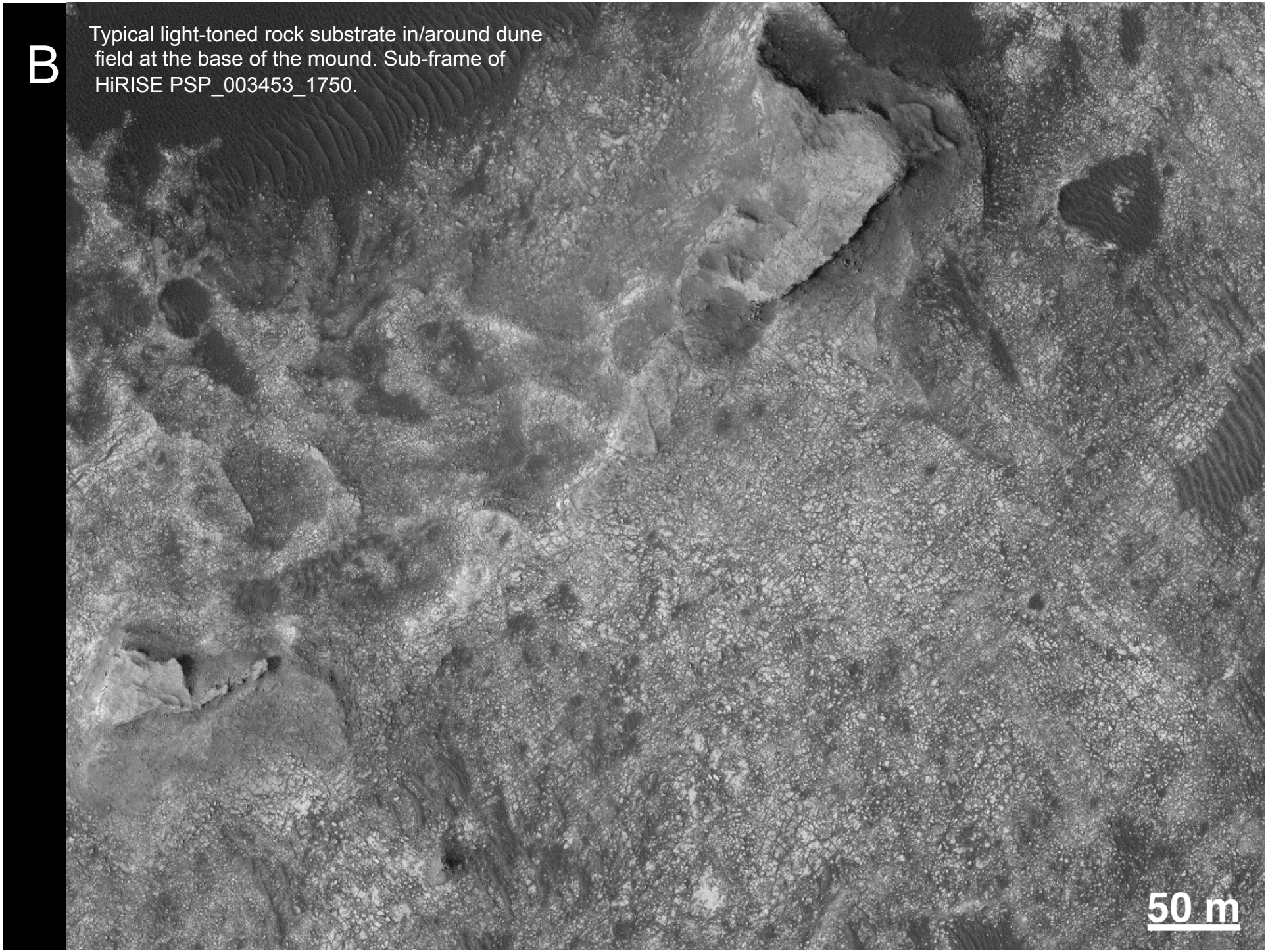
The next 6 pages show details from image PSP_0033453_1750 for the areas labeled A–D in this reference map from CTX.

Images E and F cover a portion of the ancient "fan".

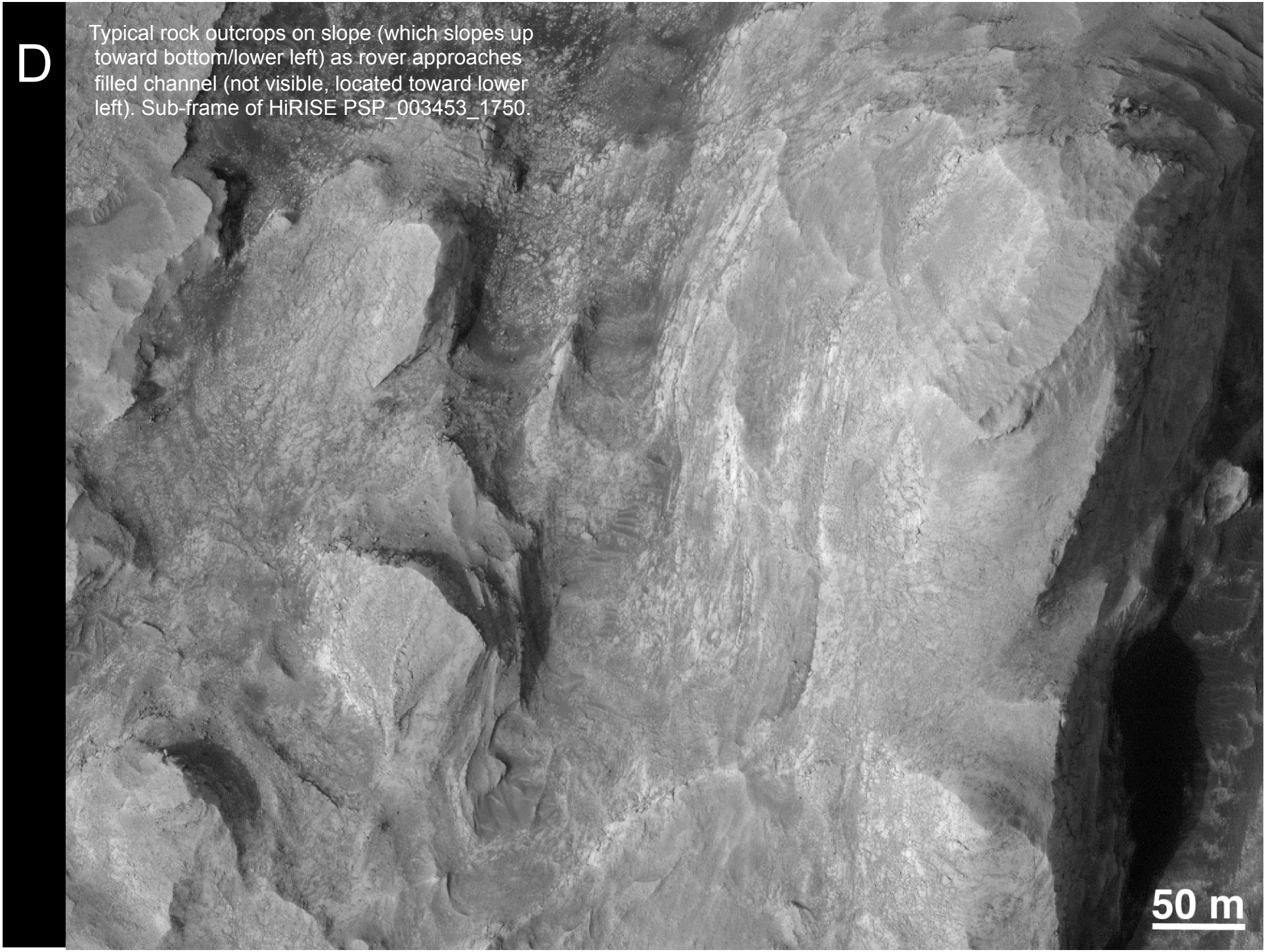
A



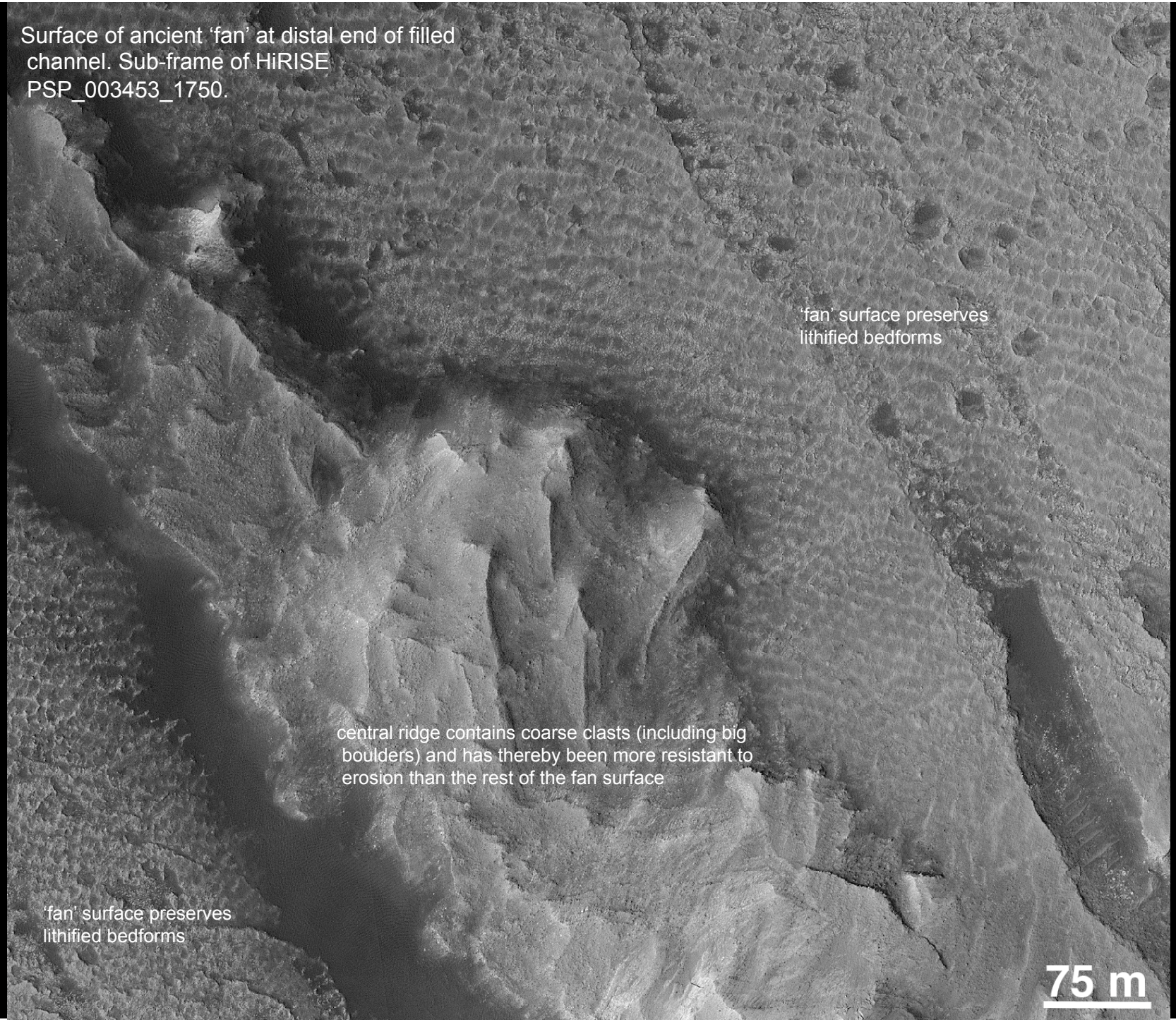
First layered, light-toned rock outcrop rover encounters as it leaves the “fan” area, before base of the mound is reached. Sub-frame of HiRISE PSP_003453_1750.


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

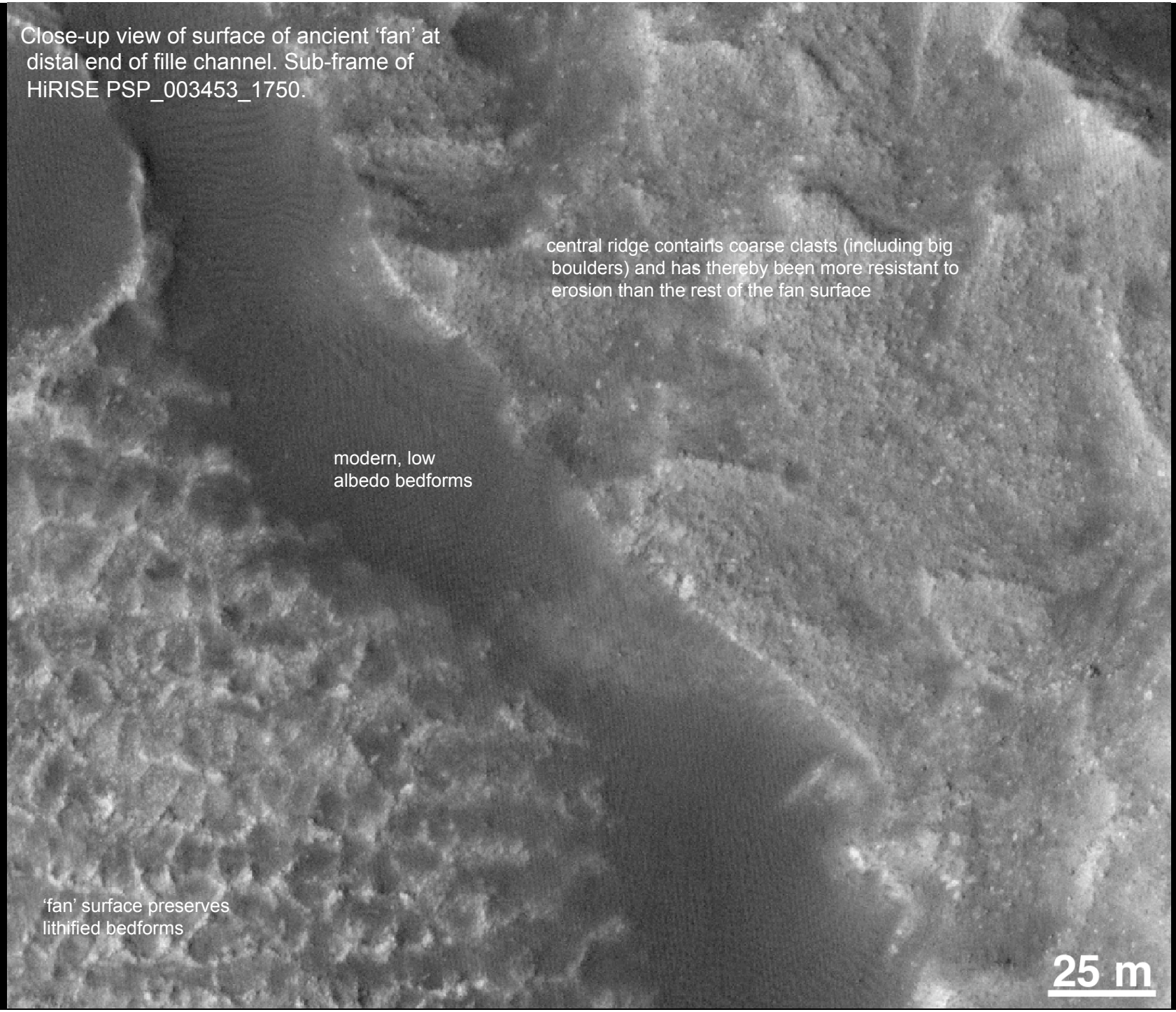
C
Slope (up is toward lower right) with stratified rocks
on lower portion of Gale mound. Sub-frame of
HiRISE PSP_003453_1750.
35 m


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

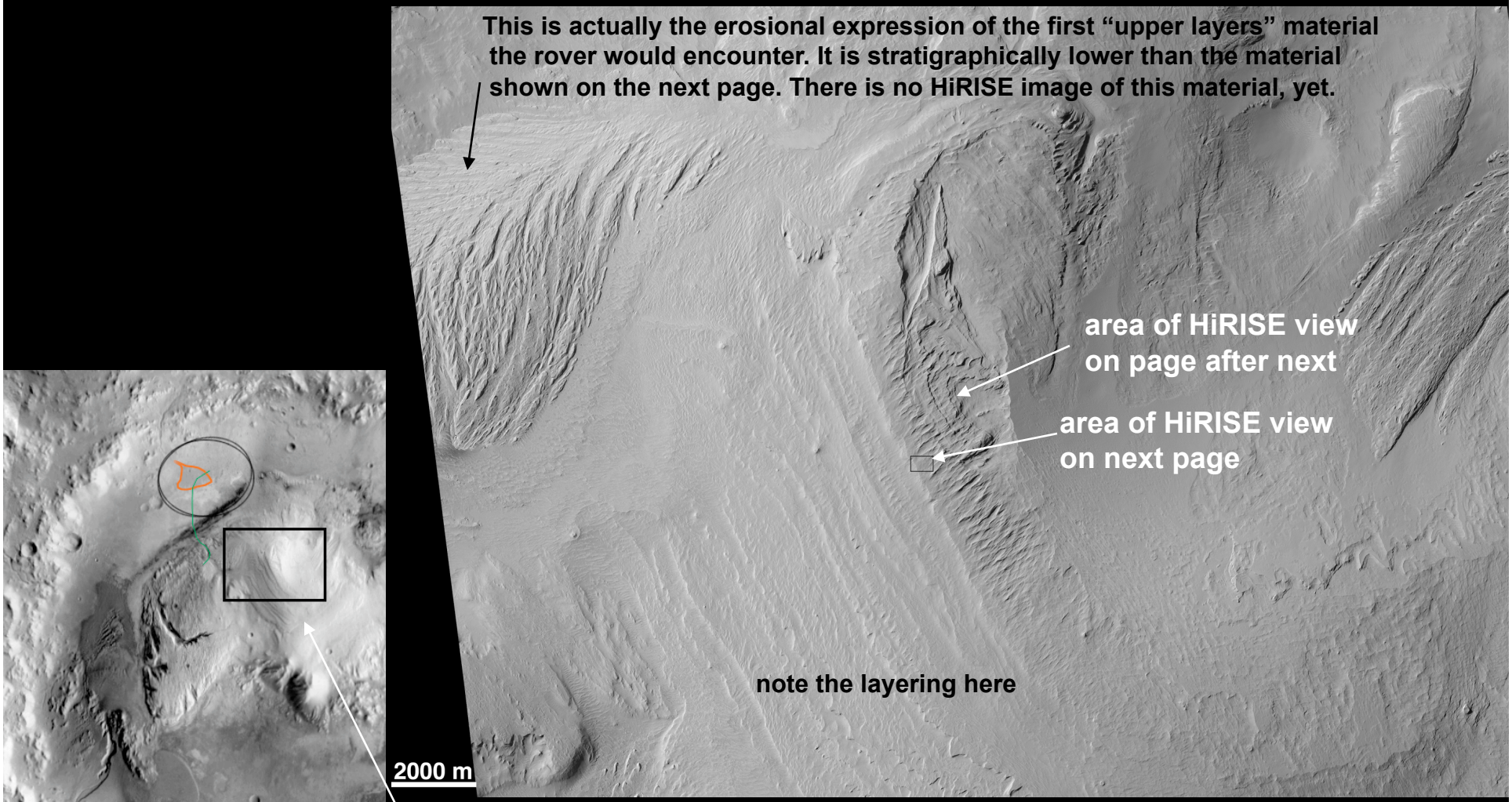
E


Surface of ancient 'fan' at distal end of filled 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

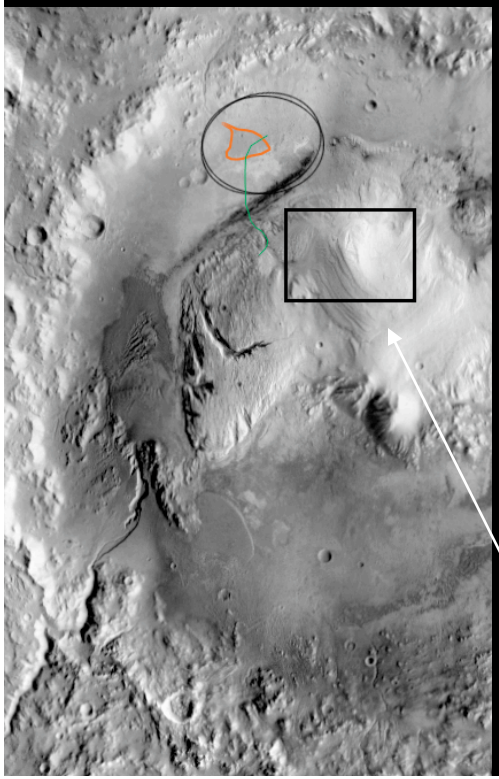
F

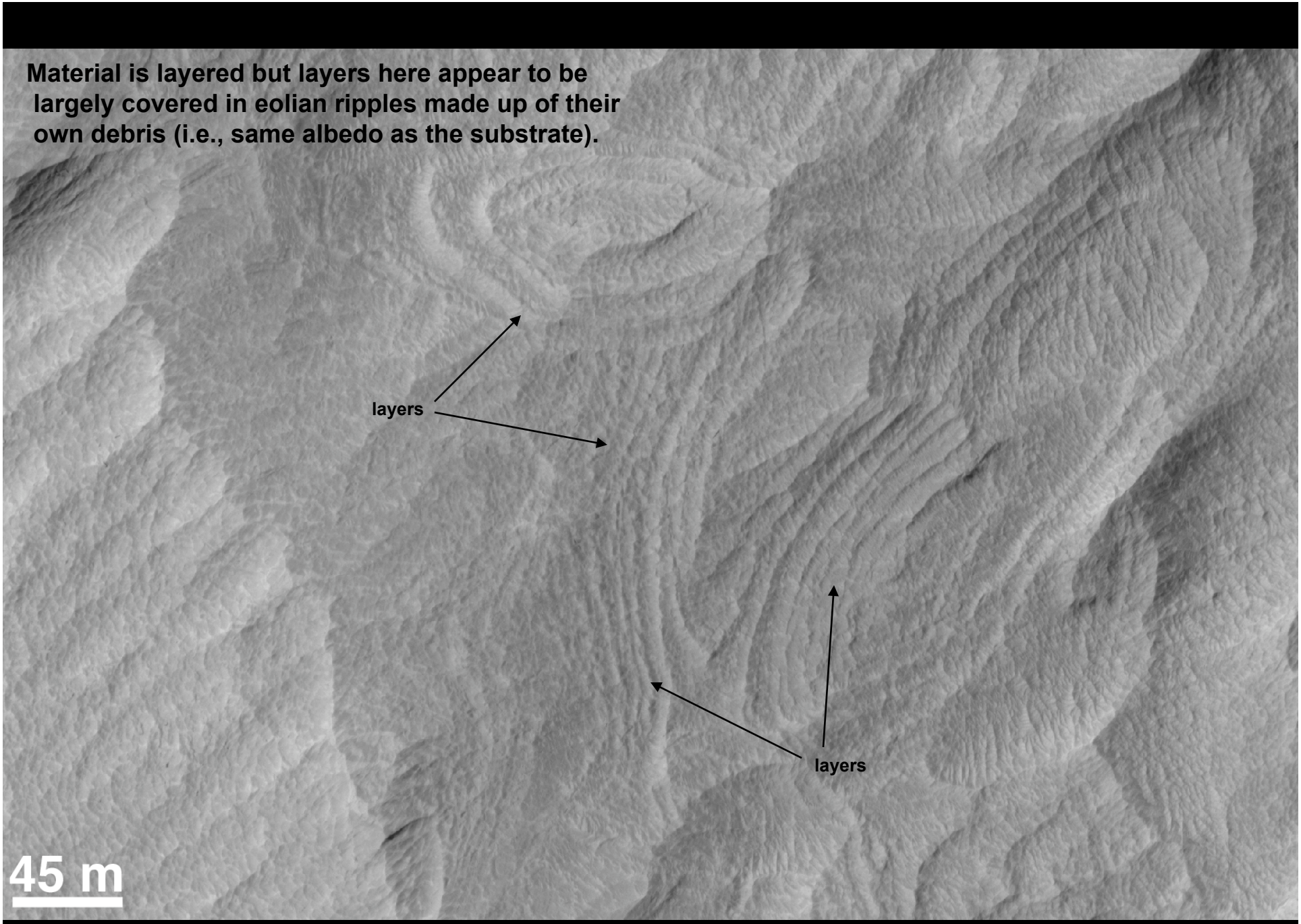

Close-up view of surface of ancient ‘fan’ at distal end of fille channel. Sub-frame of HiRISE PSP_003453_1750.
central ridge contains coarse clasts (including big boulders) and has thereby been more resistant to erosion than the rest of the fan surface
modern, low albedo bedforms
‘fan’ surface preserves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

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





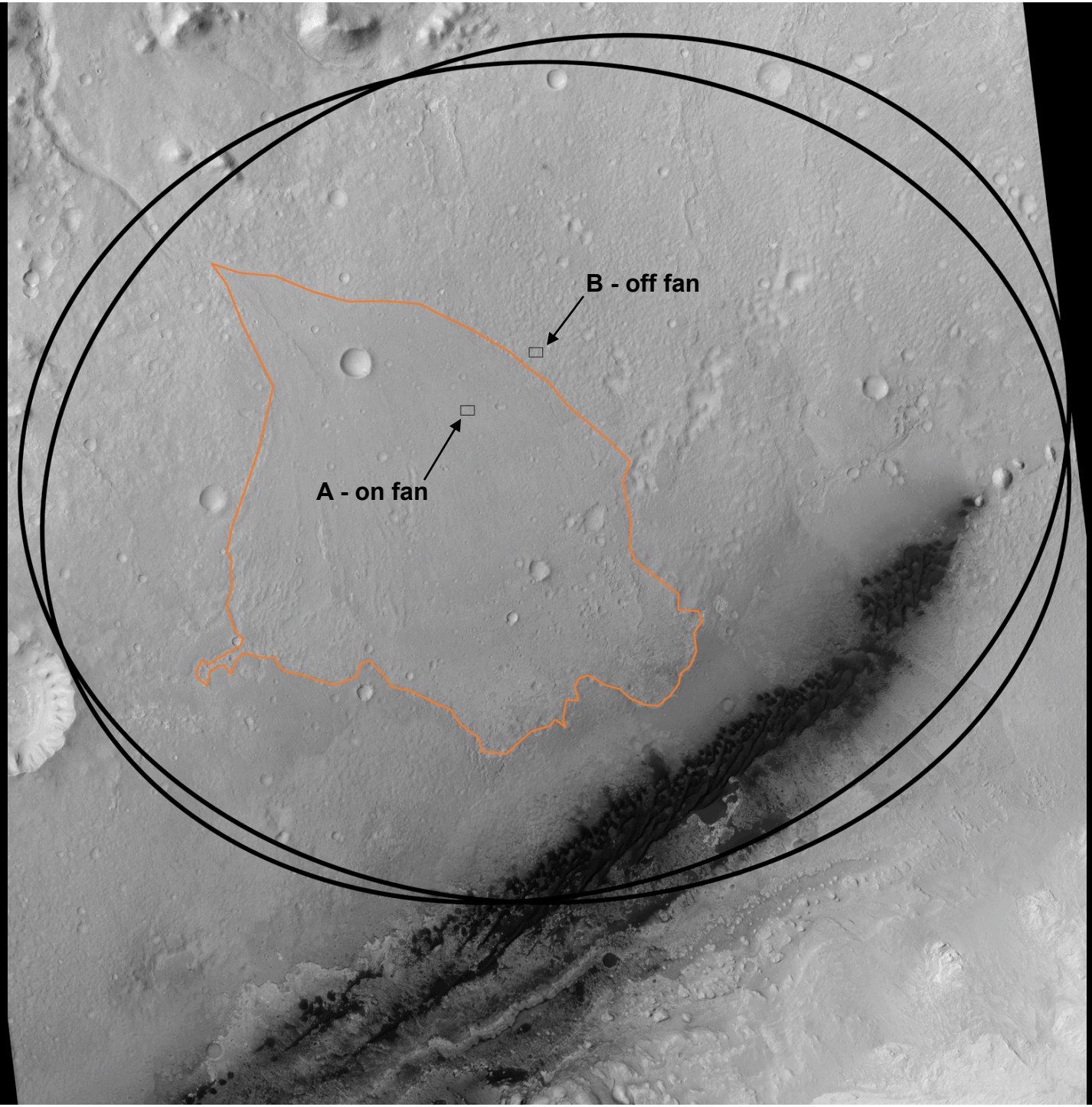
Sub-frame of HiRISE PSP_001422_1750

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