Stratigraphy in Gale Crater

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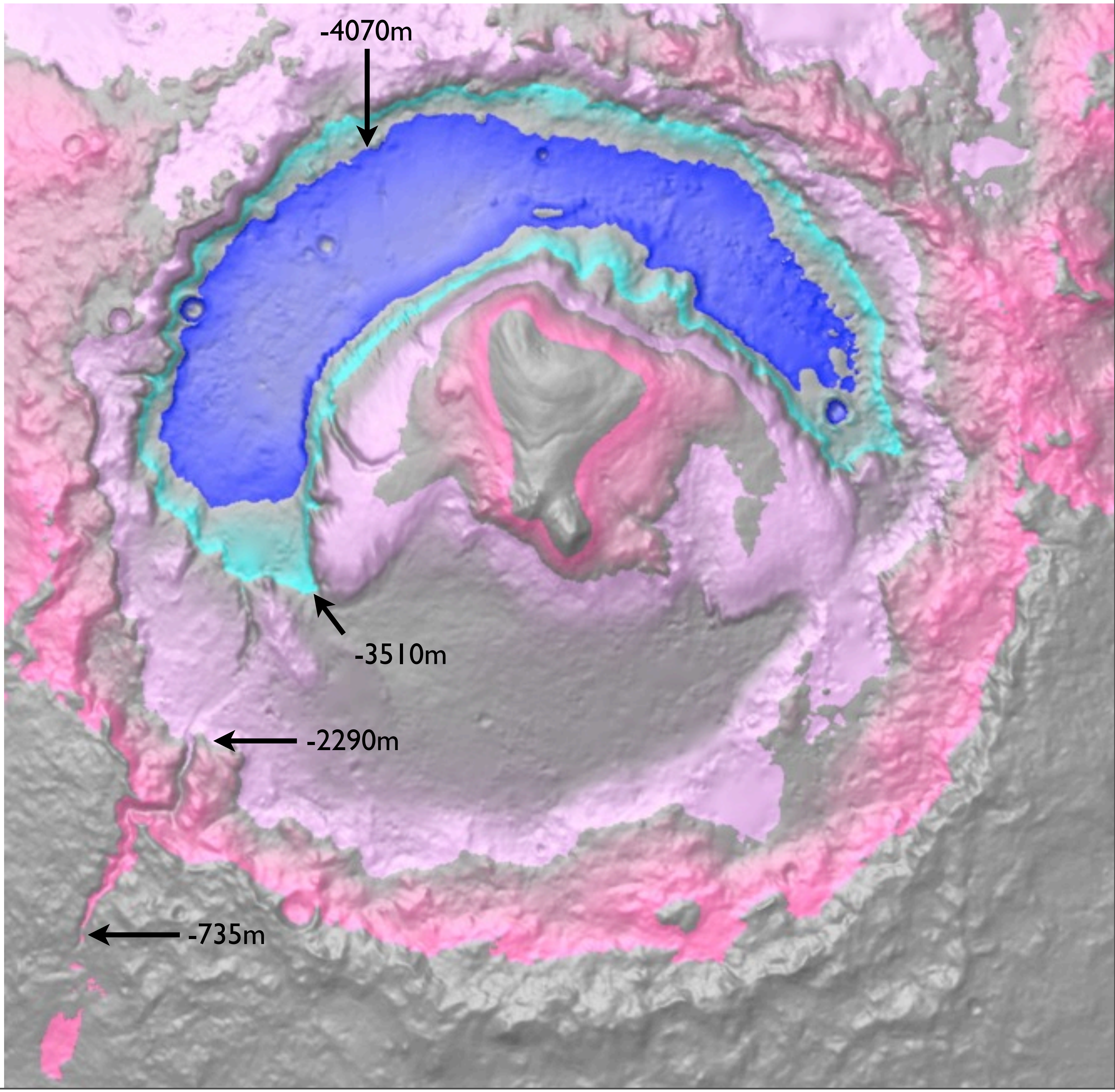
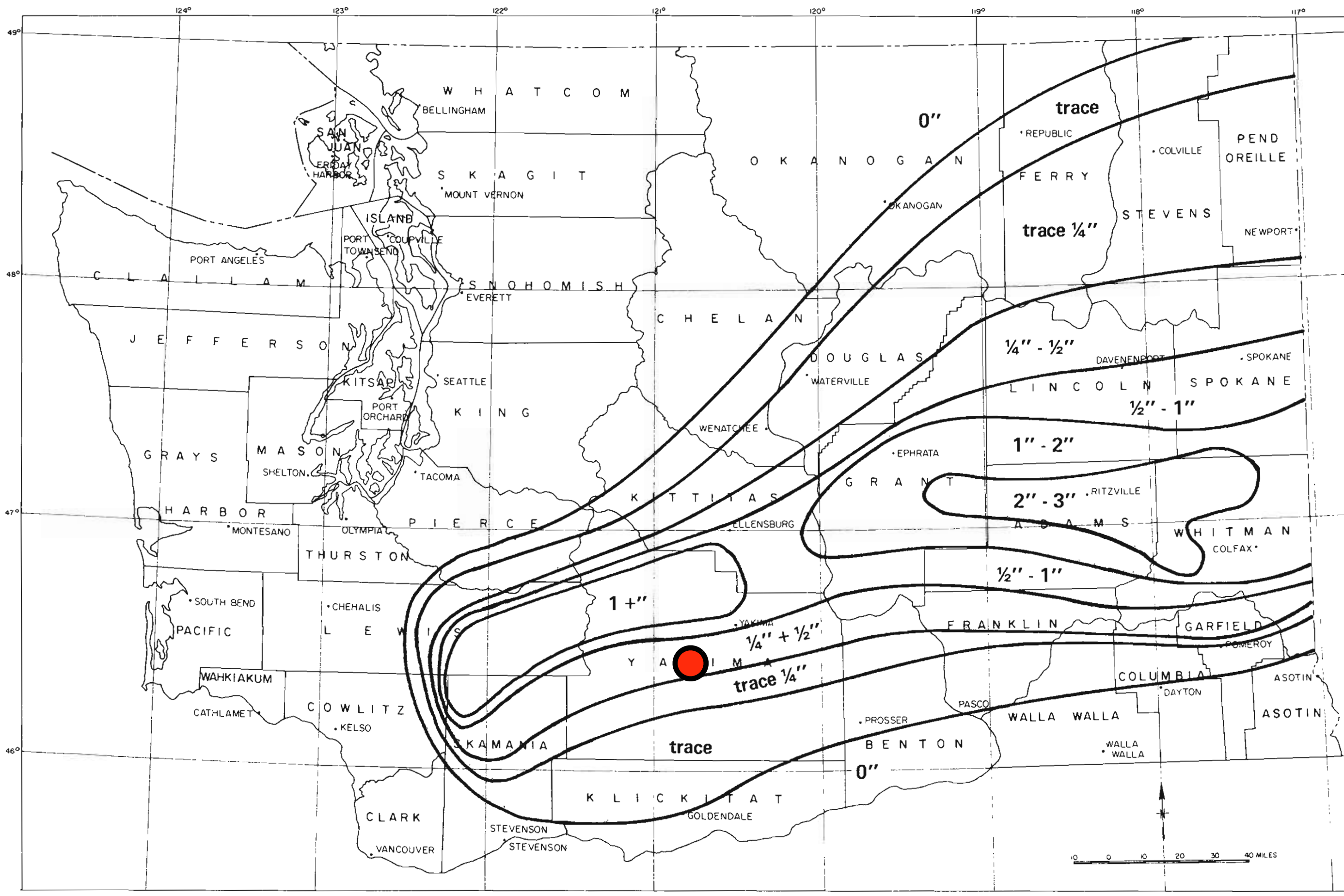
5th MSL Landing Site Workshop, May 17, 2010

- I: Depositional Models & Methods
  - Controls on Airfall, Eolian, Fluvial & Lacustrine Stratal Geometries
  - Criteria for Layering
  - Interactive Software
- II : Observed Stratal Geometries & Interpretations
  - Marker Bed Geometry
  - Downlapping Beds
  - Non-Planar Beds
  - Valleys & Canyons
- III : Why Gale will Change Everyone's View of Mars
  - 4 Scientific Investigations at the Base of the Mound



Depositional Model: Airfall Sediment

- Sediment Characteristics
  - Grain Size: Dust to Sand (e.g. impact spherules)
  - Composition: Dust, Volcanic, Impact
  - Supply: Episodic, Reflecting Regional to Global Events
- Deposited in a Dry Basin
  - Draping Topography, Thickness Reflects Air Dynamics
  - Any Wind Reworks into Bedforms
- Deposited on a Wet Surface
  - Draping Topography, Thickness Reflects Air Dynamics
  - Moisture Can Retain Draping Geometry
  - Ground Moisture Varies with Topography
- Deposited in a Lake
  - Even Layer Draping Topography (Settling through water evens out thickness of grains that can remain suspended)
  - Draping Geometry Retained unless Remobilized by Turbidites, etc.



Preliminary ash thickness distribution map of the May 18, 1980, eruption, Mount St. Helens 17

Ash thickness from Mt. St. Helens, May 18, 1980. (Not the most appropriate illustration, but I was living at the red dot and the time, and tomorrow is Volcano Day.)

(Boyle, 1980, State of Washington Information Circular.)

Depositional Model: Eolian Environments

- Sediment Characteristics
  - Grain Size: Well Sorted, Probably ~100 μm
  - Composition: Depends on Source, Usually Uniform due to Mixing; Evaporites if Ground Water Present
  - Supply: Depends on Source; Nearly Constant if Eolian, Episodic if Airfall

- Accumulation Controlled by Topography
  - Crater = Hole ⇒ Sediment Accumulates
  - Irregular Dune Morphology & Sediment Distribution
  - Poor Large-Scale Layering

- Accumulation Controlled by Ground Water Table
  - Flat, Moderately Continuous Eolian Layers Reflecting Top of Water Table
  - Layer Thicknesses Possibly Variable
  - Interdune Deposits Produce Differently Eroding Layers that are Either Laterally Discontinuous or Time Transgressive

Interdune Deposits in the Navajo Sandstone, UT. Chemical sediments (carbonate) at hammer head, wind-blown quartz sand at end of hammer handle. These beds are laterally discontinuous.

Depositional Model: Fluvial Environments

- Sediment Characteristics
  - Grain Size: Clay-sized to Boulders, but Well Sorted Locally
  - Composition: Depends on Source, Probably Mostly Weathered Bedrock Plus Reworked Airfall & Eolian Sediment
  - Supply: Depends on Water Supply

- Controls on Stratal Geometries
  - Slope
  - Sediment to Water Ratio
  - Proportions of Different Grain Sizes

- Example Stratal Geometries
  - Thick Sand Units With Little Layering
  - Laterally Continuous Sand Layers Separated by Finer-grained Layers
  - Channel-form Sand Bodies in Finer-grained Units

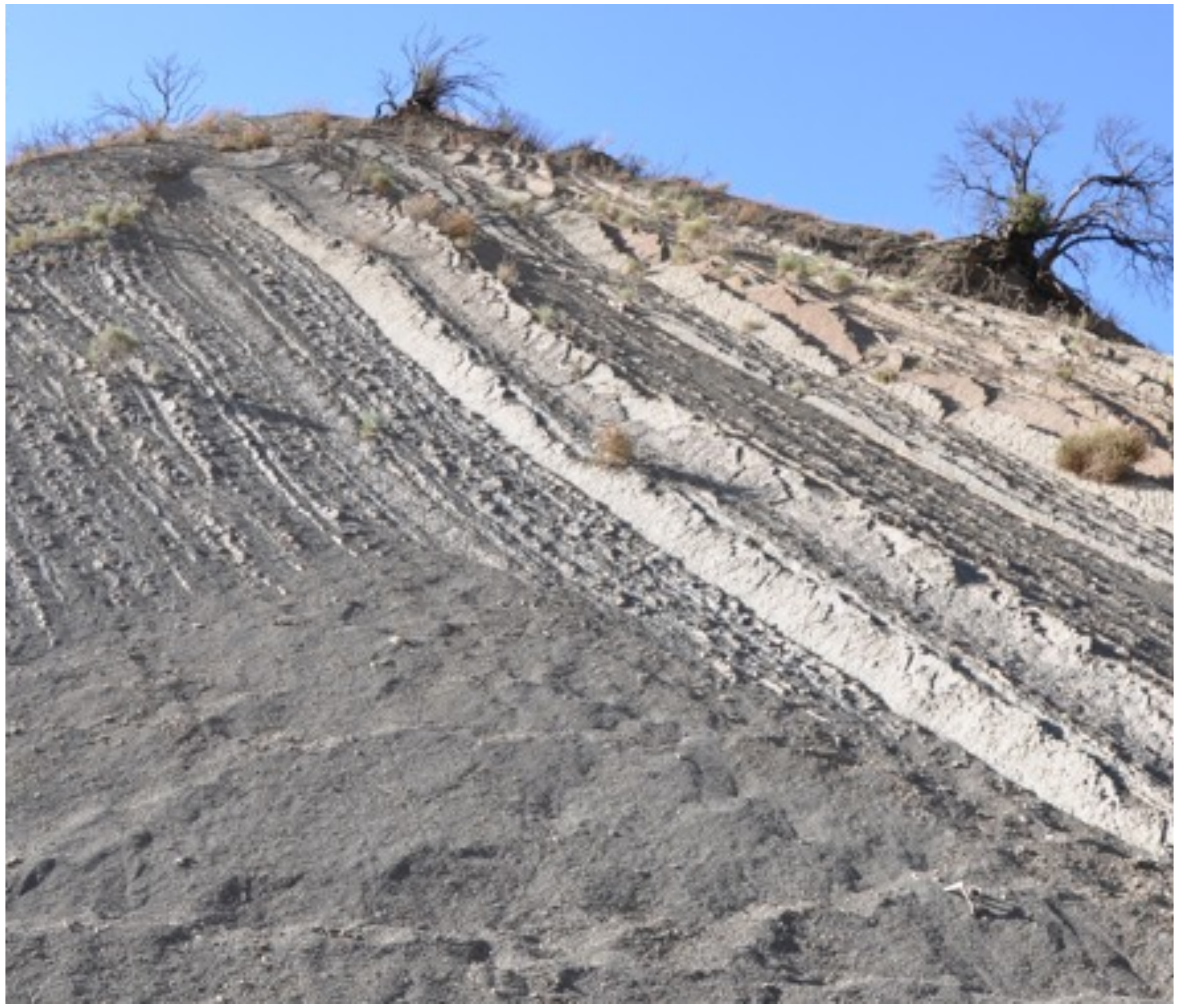
Fluvial sediments of the Morrison Fm., UT. Channel sandstones weather resistantly, whereas floodplain deposits form rounded slopes. Channel sands are both discontinuous and continuous, reflecting migration style.

Depositional Model: Lake Environments

- Sediment Characteristics
  - Grain Size: Fine Grained in Deep Water, Plus Grain Sizes of Airfall Deposits; Coarser Grained Near Shorelines
  - Composition: Depends on Source; Evaporites Possible; Airfall Sediments Expected
  - Supply: Depends on Source; Nearly Constant if Eolian, Episodic if Airfall, Either if Fluvial

- Far From Shore & Depth > Waves
  - Continuous Layers, May Drape Topography or Thicken into Lows
  - Sediment from Airfall and Settling
  - Evaporites Possible, Either as Crystals Growing on Lake Floor or Settling From Suspension
  - Coarser Grains Possible if Frozen Over & Sediment Melted Through Ice; Distributed by Cracks

- Nearshore
  - Deltas if Rivers or Streams Present; downlap geometries
  - Sloping Up to Shorelines & Beaches if Waves Present
  - Evaporites Possible
  - Similar to Deep if Frozen Over, Except More Coarse Grains that can Melt Through Ice (maybe)



Lake shales and sandstones, Ridge Basin, CA. Fine-grained lake deposits settled from suspension, whereas sandstones were deposited via turbidites from two sources - a fault scarp to the west and a delta to the east. Differences in lithology allow one to identify both sources. Airfall sediments (a volcanic ash) have also been identified, but are not shown here.

Methods

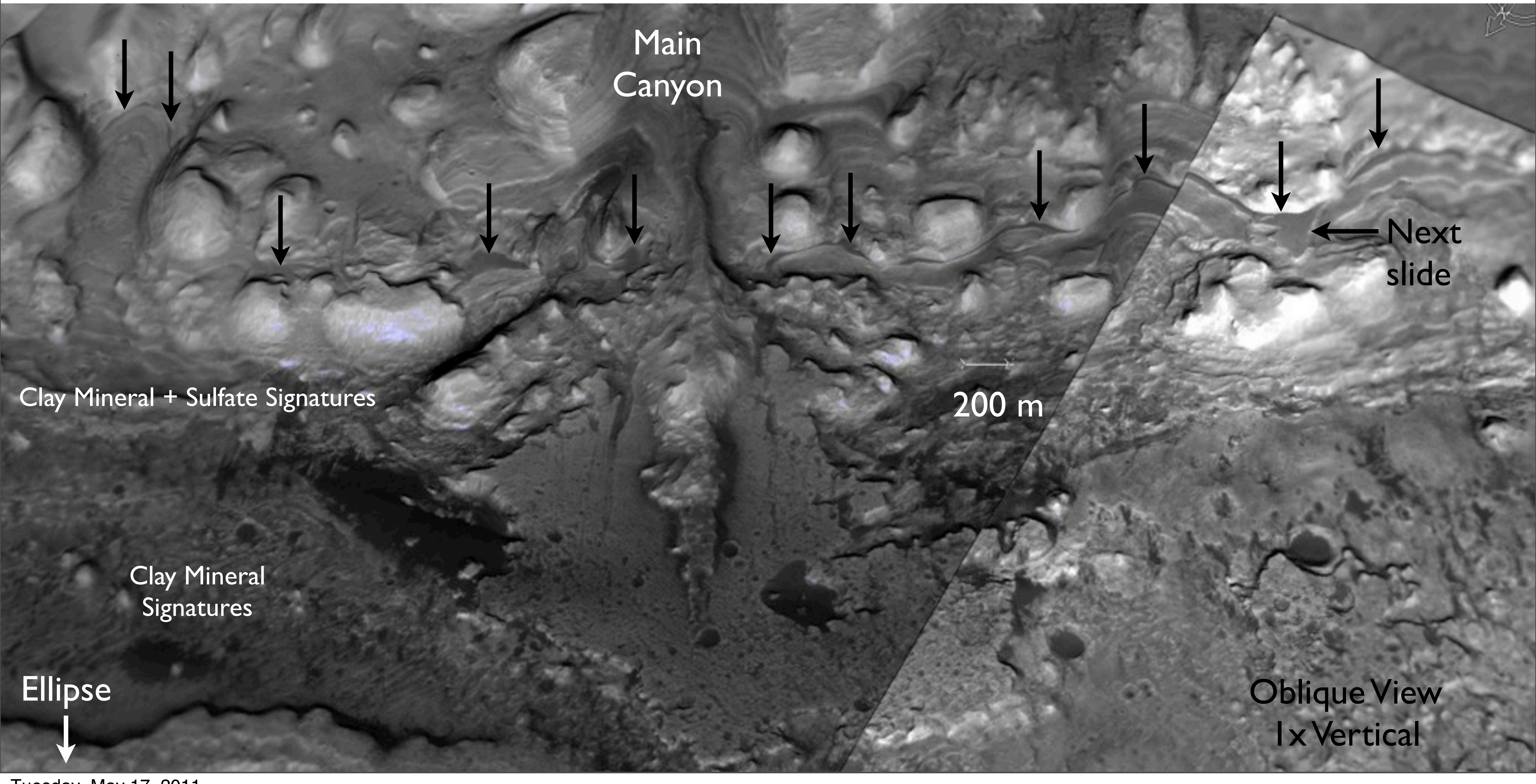
- **Software: Crusta, by Tony Bernardin, UCDavis.**
  - Real-time interactive; anaglyph, 3d TV/monitor; mapping tools
  - Open source, runs on Linux, OS X: http://wiki.cse.ucdavis.edu/keckcaves:crusta
  - Examples: http://youtube.com/crustamars
  - Data: Mola DEM, HRSC Gale DEM, CTX mosaic from Ralph Miliken, HiRISE DEMs, and HiRISE images. They are not all properly georeferenced to each other (yet), leading to image boundaries and variable offset of context data (HRSC & CTX have slightly different projections).

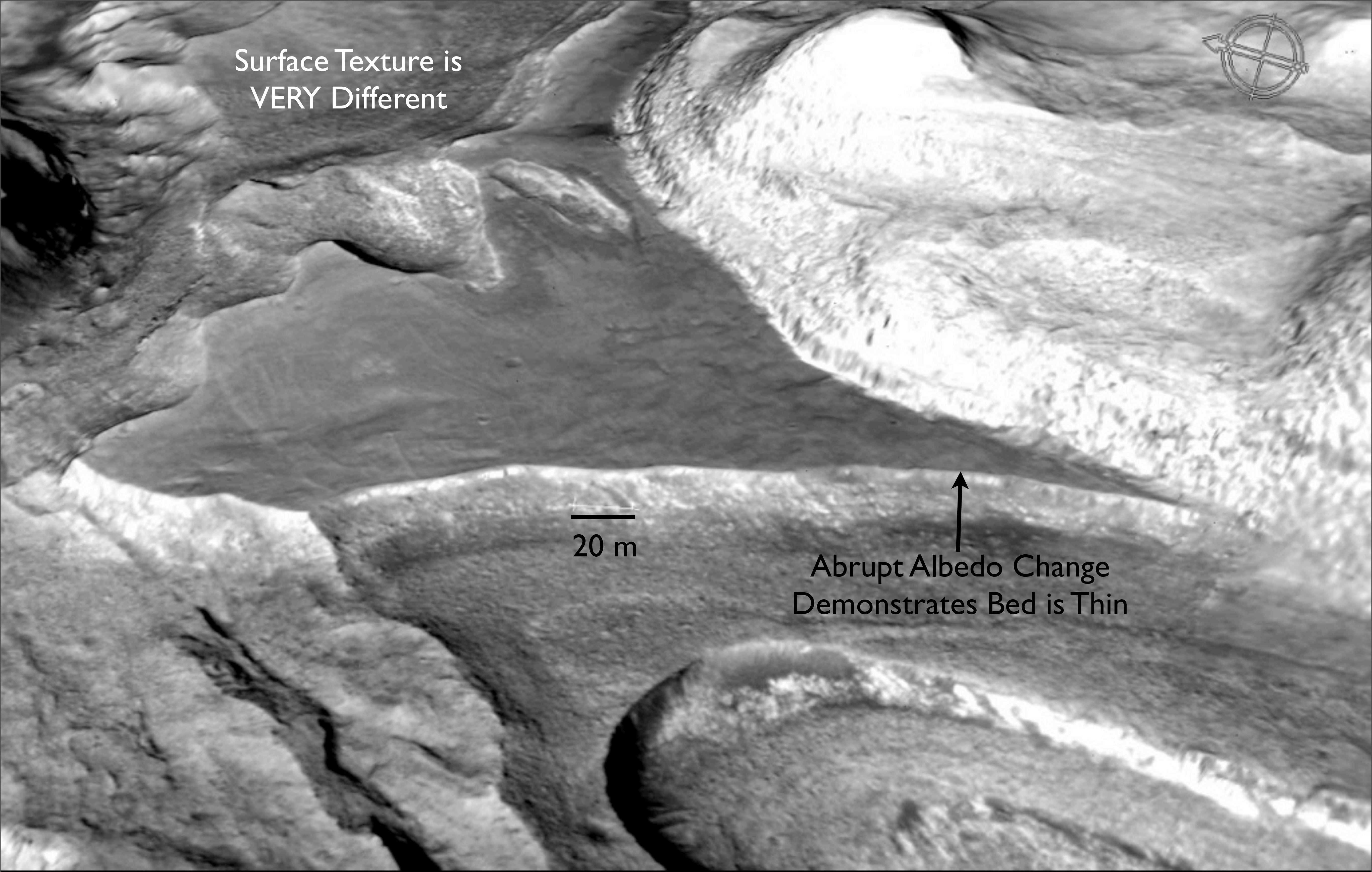
- **Identification of Layering:**
  - Layers are best defined by differences in albedo, which requires multiple sediment types.
  - Differences in weathering style can also define layers, but care is required since factors unrelated to layering also affect weathering style (or scarp development).
  - I have used both albedo differences and scarps to define layers, with higher confidence placed in albedo differences. I have used scarps when I feel that they can be correlated to albedo differences laterally.

Next Slides: Stratal Geometries

1. Evidence for Water: Marker Beds

- Characteristics
  - Laterally Continuous - Not Reworked By Wind
  - Very Thin - Would be Easily Reworked
  - Systematically Variable Dip - Requires Stabilization

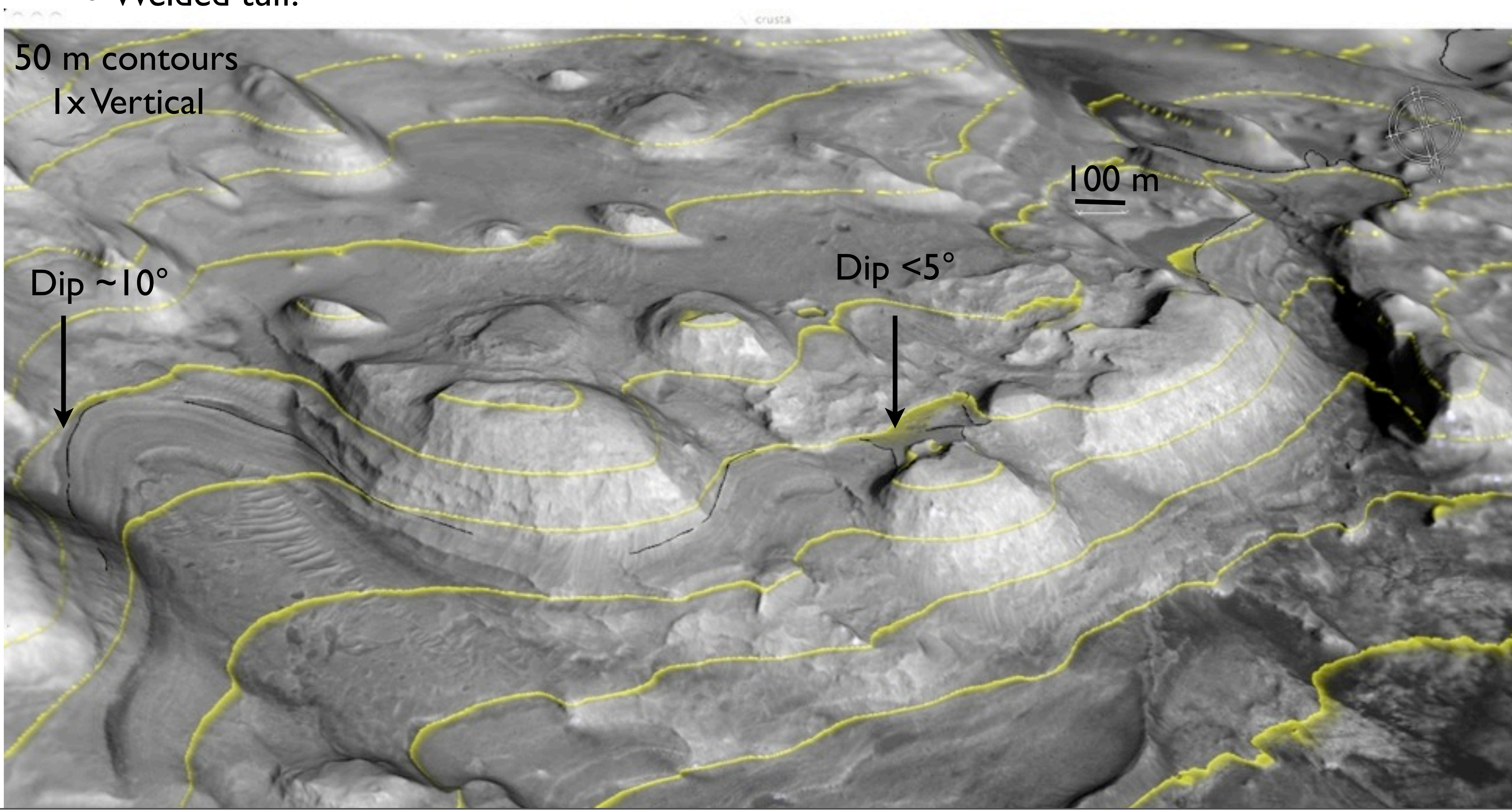



Surface Texture is VERY Different
20 m
Abrupt Albedo Change Demonstrates Bed is Thin

1. Evidence for Water: Marker Beds

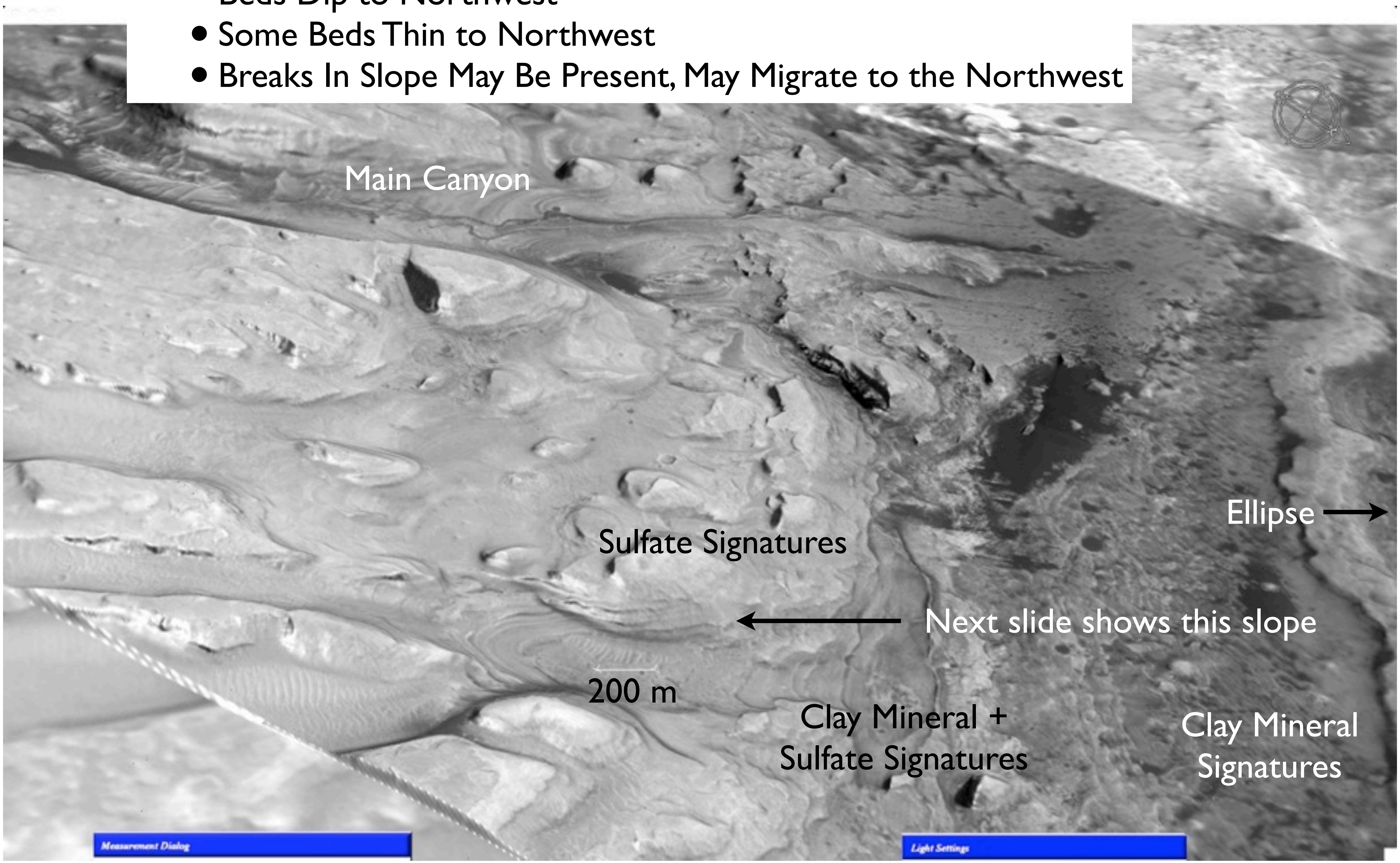
- Interpretation:
  - Either airfall into a lake or cemented immediately by ground moisture.
  - The marker bed is flat, so there were no eolian bedforms prior to deposition.

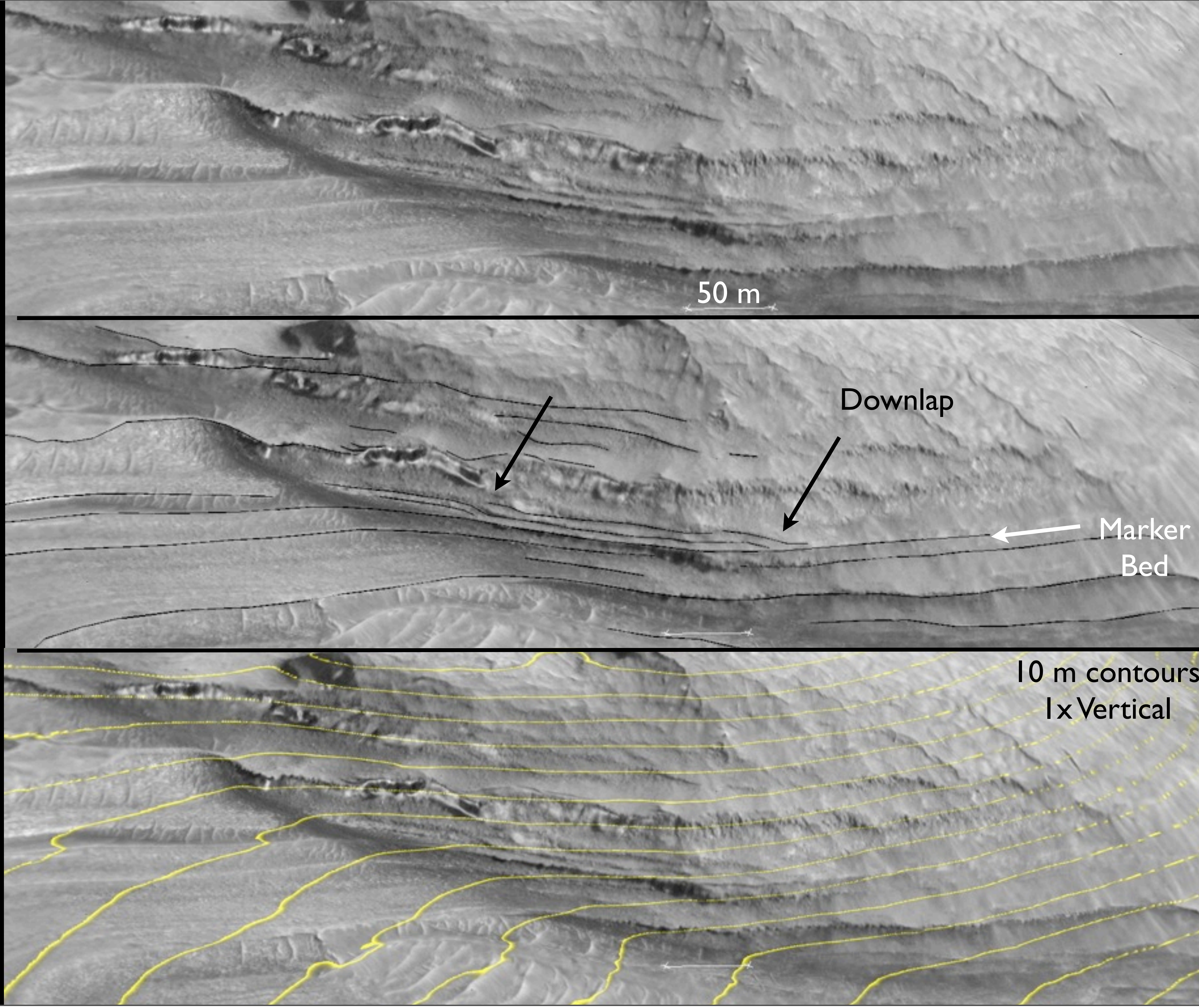
- Alternatives:
  - Welded tuff.



2. Evidence for Standing Body of Water: Downlapping Beds

- Characteristics
  - Beds Dip to Northwest
  - Some Beds Thin to Northwest
  - Breaks In Slope May Be Present, May Migrate to the Northwest

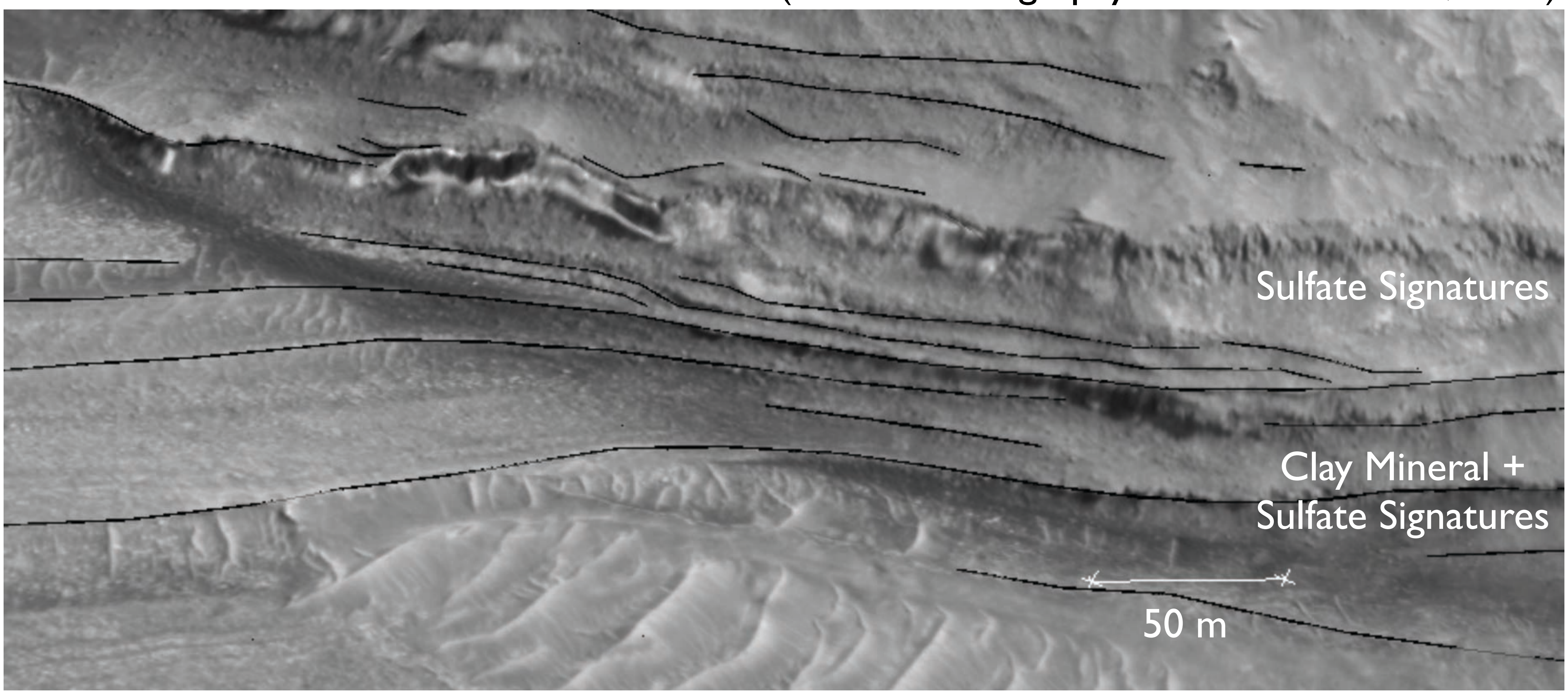



50 m
Downlap
Marker
Bed
10 m contours
1x Vertical

2. Evidence for Standing Body of Water: Downlapping Beds

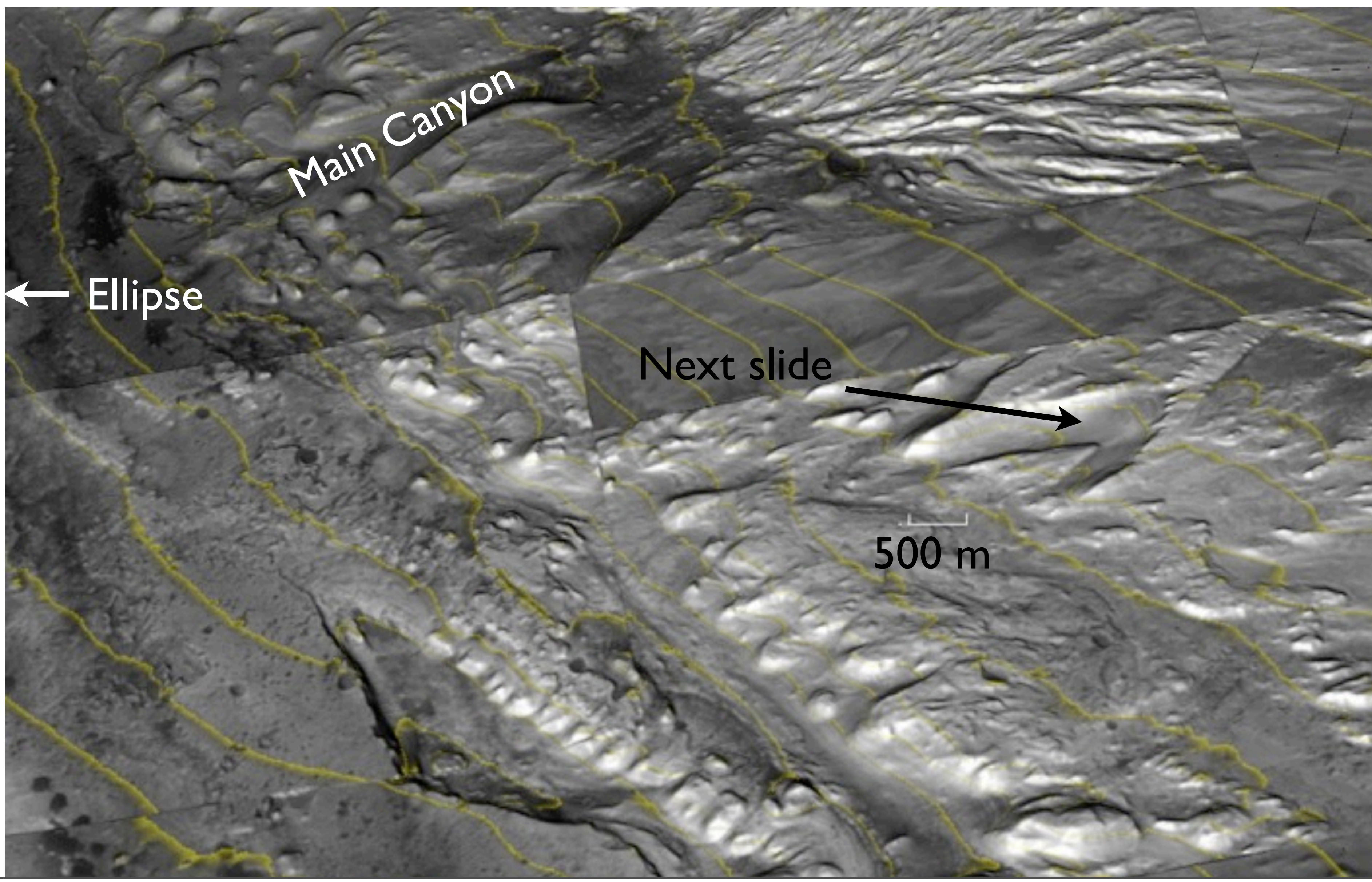
- Interpretation:
  - These bedding geometries are very typical of sediment deposited from the shoreline into a standing body of water.
  - These geometries are not produced by ground water-controlled subareal accumulation of sediment.
- Alternatives:
  - Geometries may be possible in exactly the right fluvial system.
  - Possible that the marker bed represents an unconformity.

(Mineral Stratigraphy from Miliken et al., 2010)

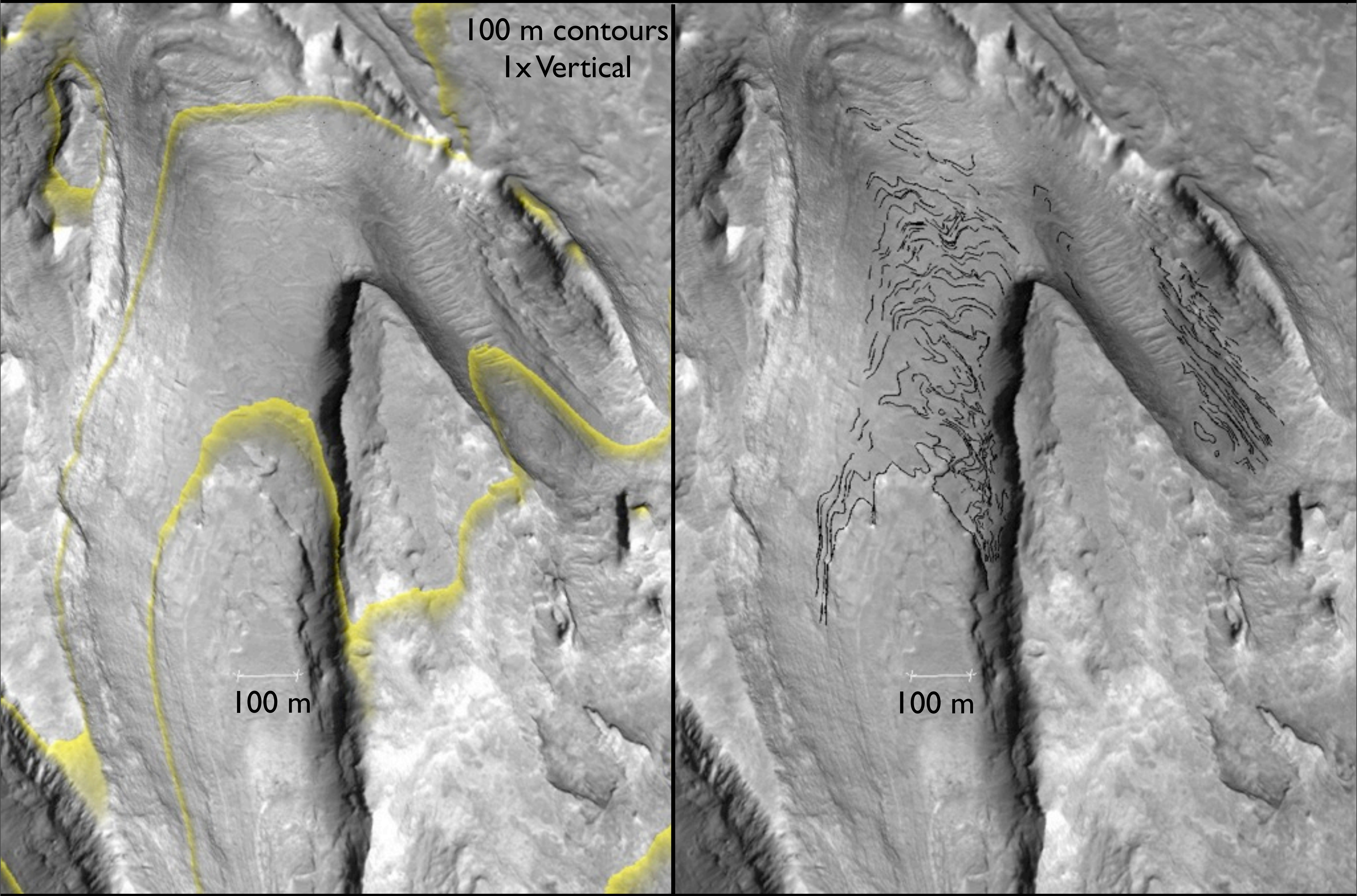


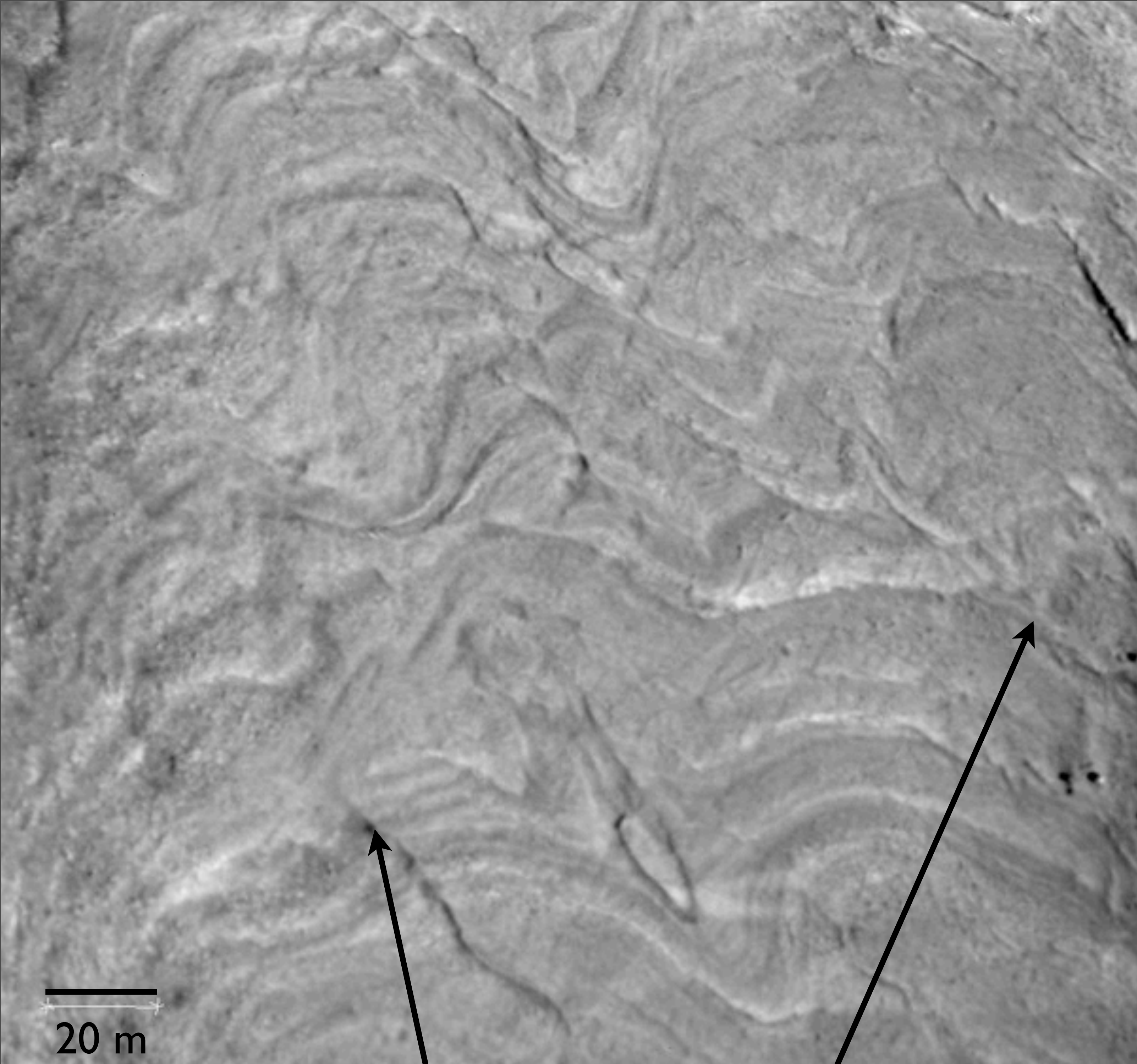
3. Evidence for Flowing Water: Non-Planar Beds

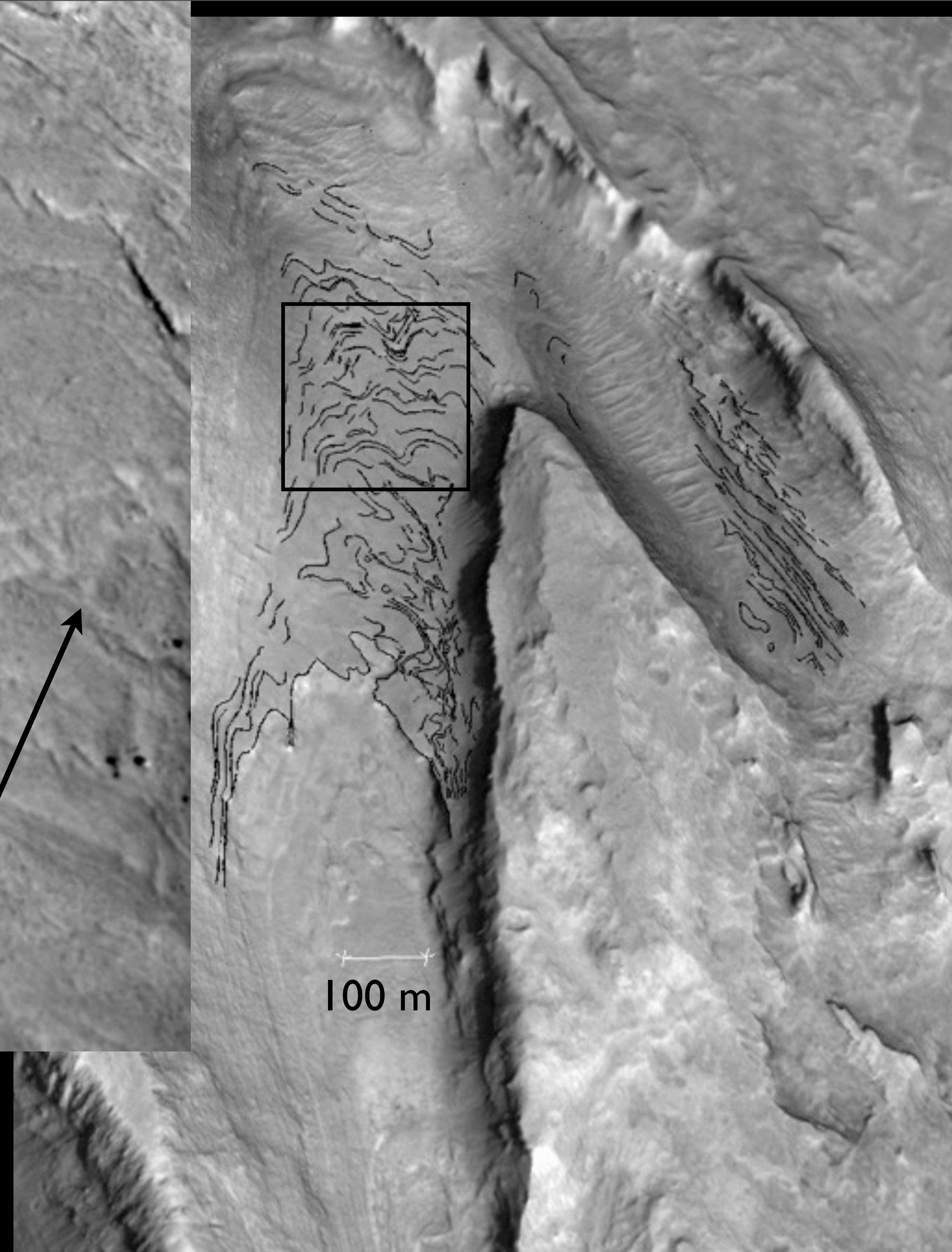
- Characteristics
  - Beds Defined by Albedo Variations - 2+ Compositions; Not Mixed by Eolian Processes
  - Arcuate Beds - Depositional Surface Had Meter-Scale Topography
  - Truncated Beds - Synsedimentary Erosion or Non-Uniform Deposition
  - Concave-up Geometry in Cross Section - Trough-like or Bowl-like Depressions in Depositional Surface
  - Rare Linear Features - Unknown Timing and Origin

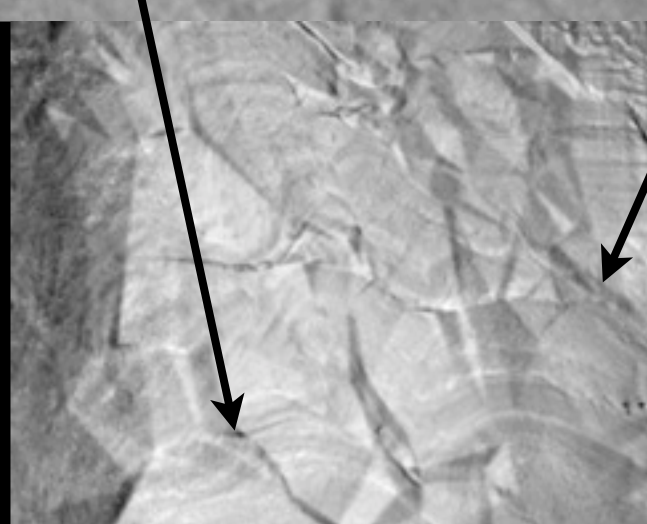


100 m
contours
1x Vertical

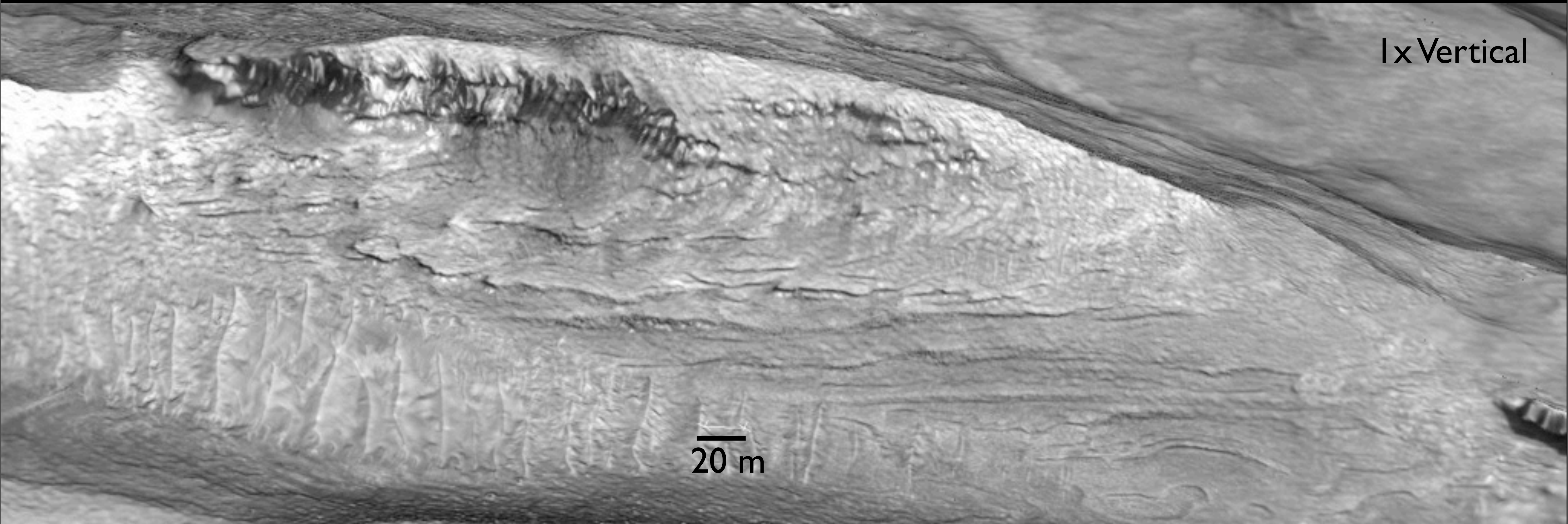

100 m contours
1x Vertical
100 m
100 m

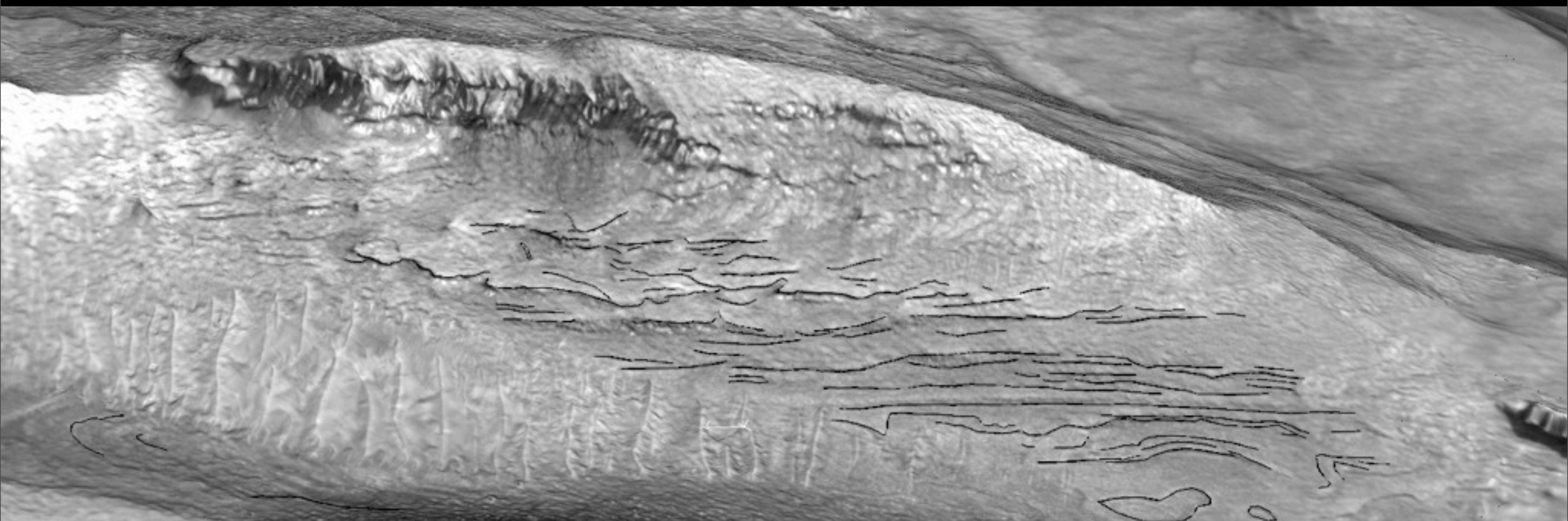






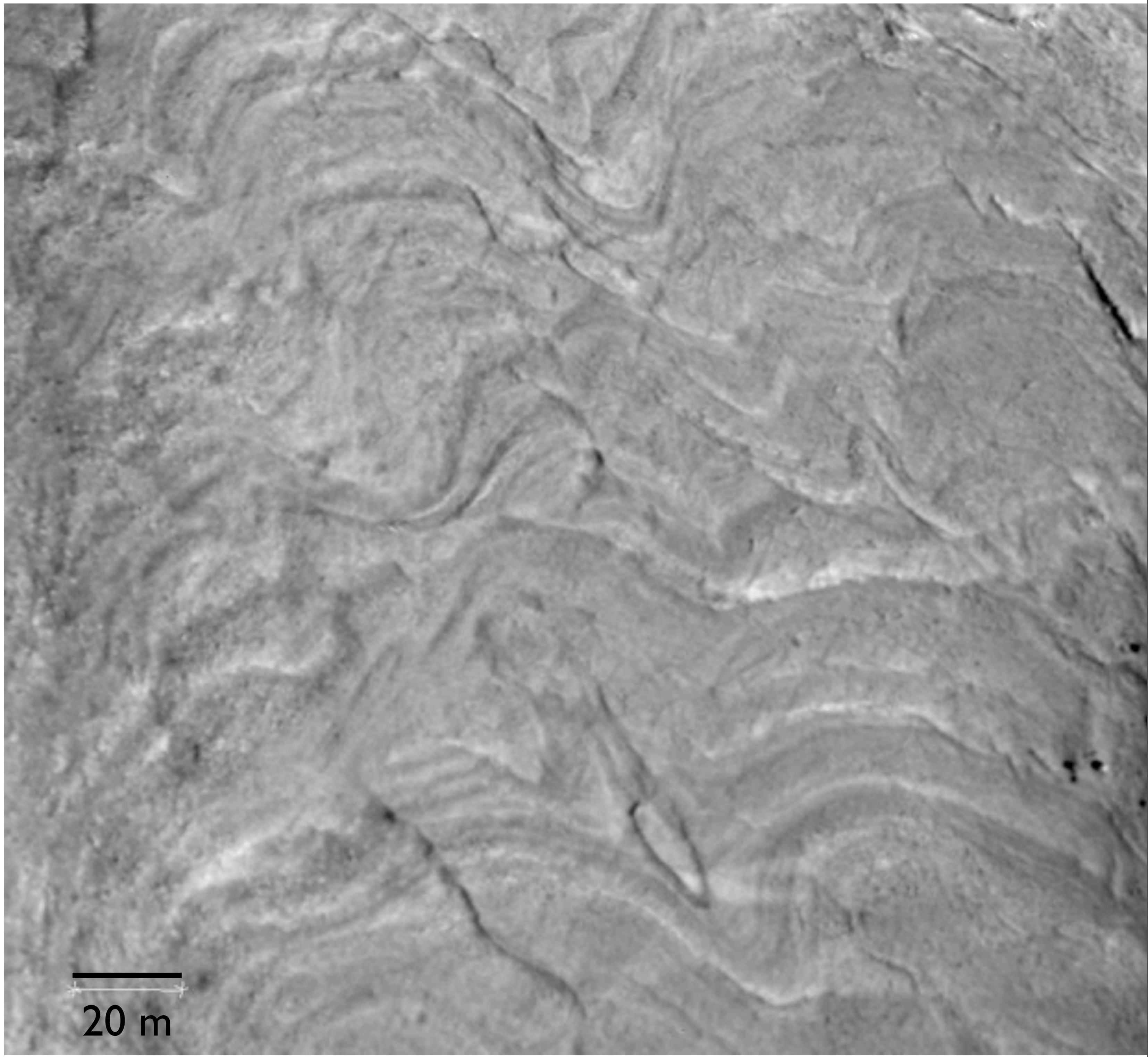
Left, lighting set to highlight the bad topographic control in this area. This produces artifacts in the above image but they can be excluded by manipulating lighting angles to distinguish albedo from “topographic” features.


1x Vertical
20 m

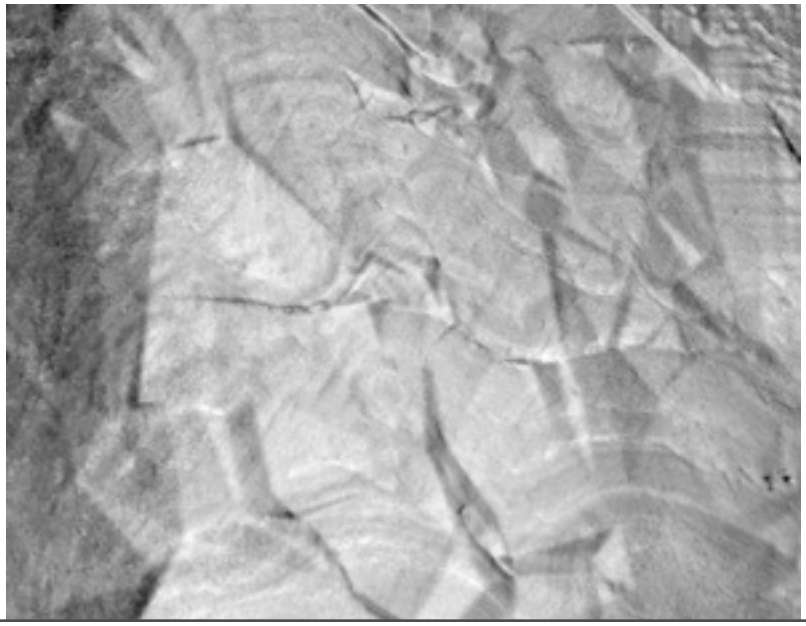


3. Evidence for Flowing Water: Non-Planar Beds

- Interpretation:
  - Bedding geometry is consistent with a braided fluvial system with channels that form and fill. No specific evidence for channel migration observed, but data are sufficiently vague that migration can not be excluded.
- Alternative:
  - Another form of alternating erosion and deposition that creates specific lows, continuous beds, and little decameter-scale cross stratification.



1x Vertical



Left, lighting set to highlight the bad topographic control in this area. This produces artifacts in the above image due to lighting in Crusta.

4. Evidence for Water Flowing into a Standing Body of Water: Valleys & Canyons

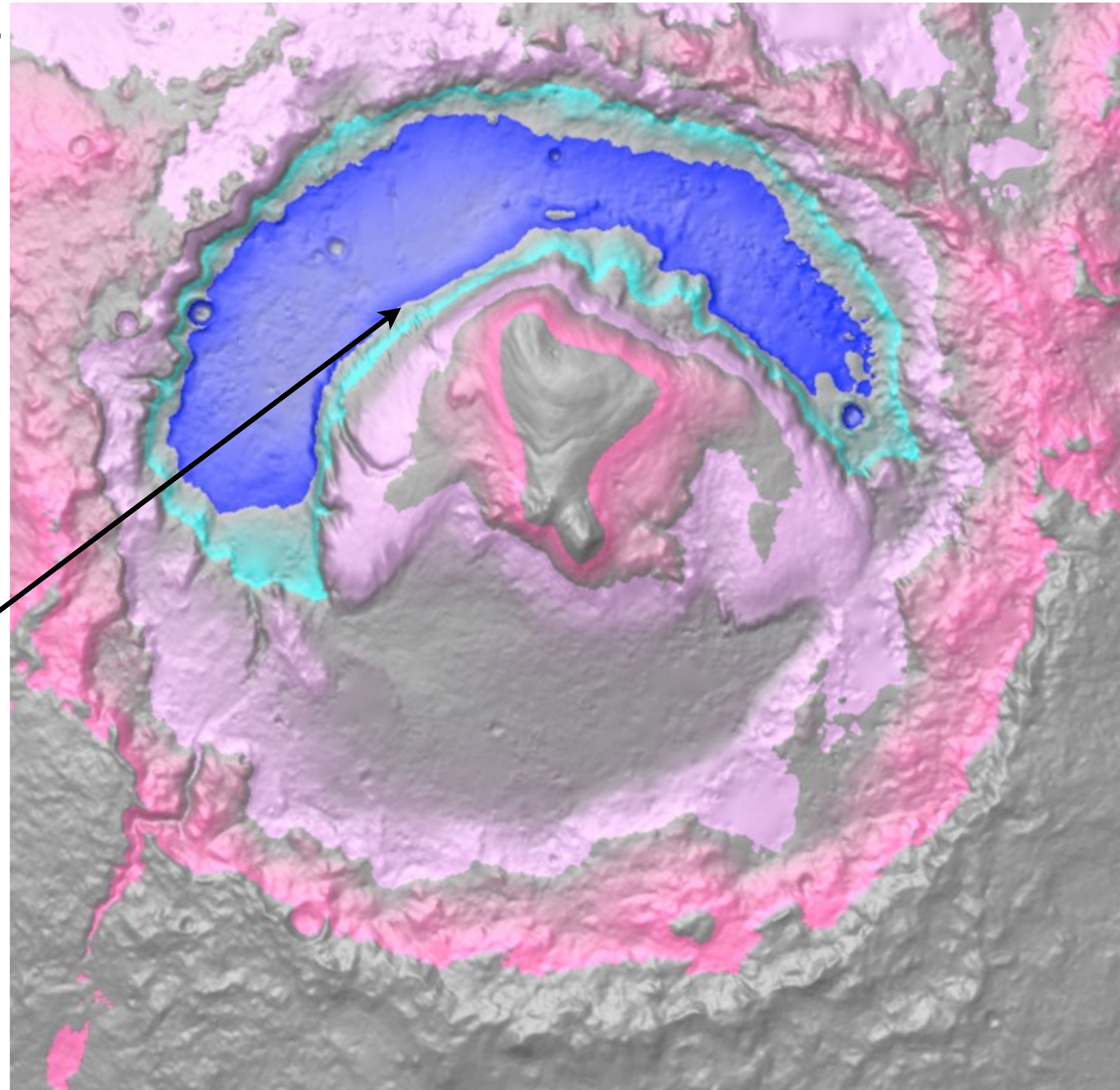
"Base Level" ~ elevation of a river mouth.

- Usually controlled by a standing body of water or a larger river.

Three Major Systems

- Canyon Near Ellipse
- "Grand Canyon" in Mound
- Major River Valley from SSW with upper and lower canyons

Base Level for Canyon Near Ellipse (-4070m)
(Could be slightly lower - geomorphology not well preserved)



HRSC Topography

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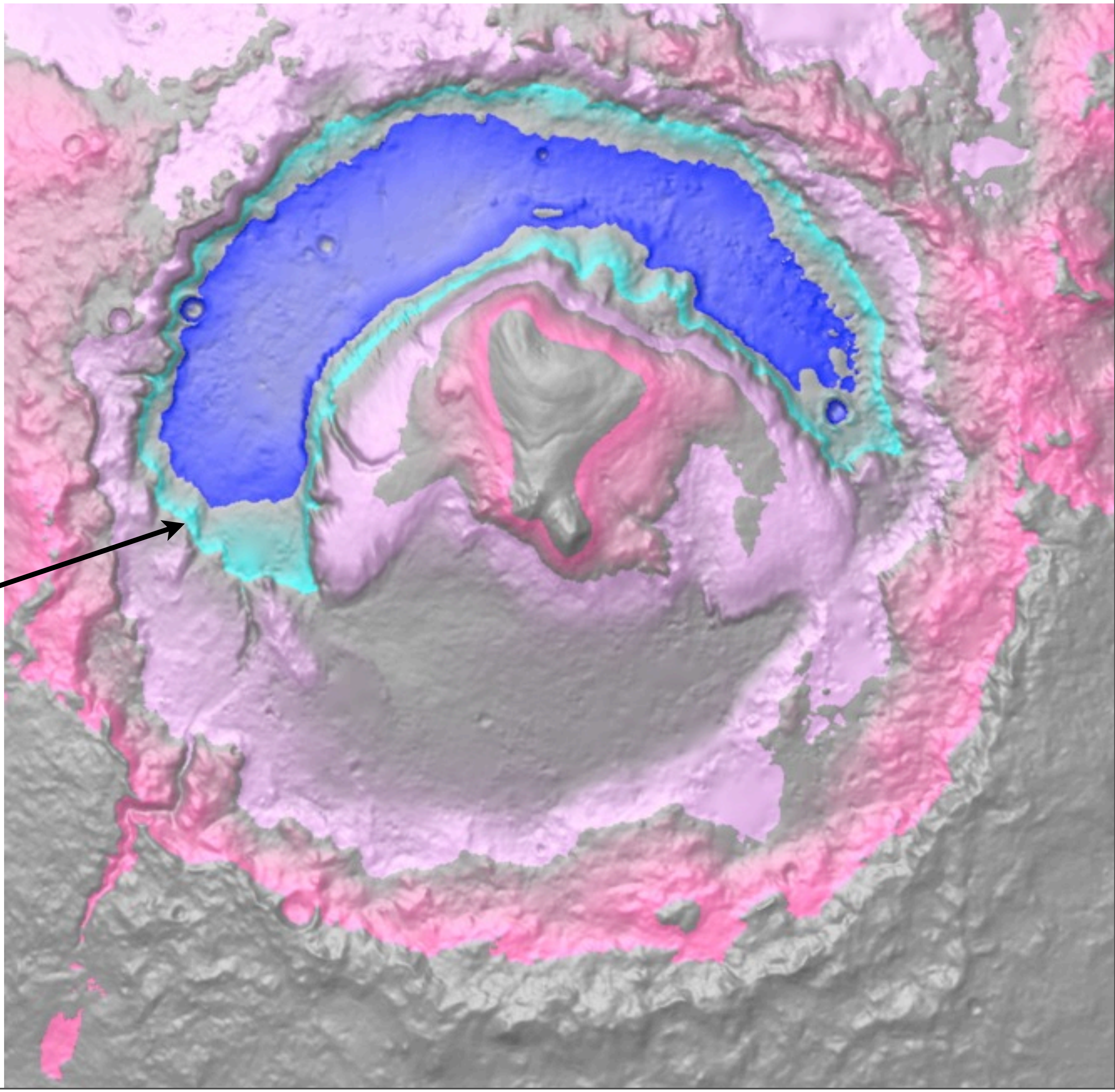
Base Level for "Grand Canyon" & Lower River Canyon (-3510m)
Also, Elevation of Fractures
Shown by Anderson



HRSC Topography

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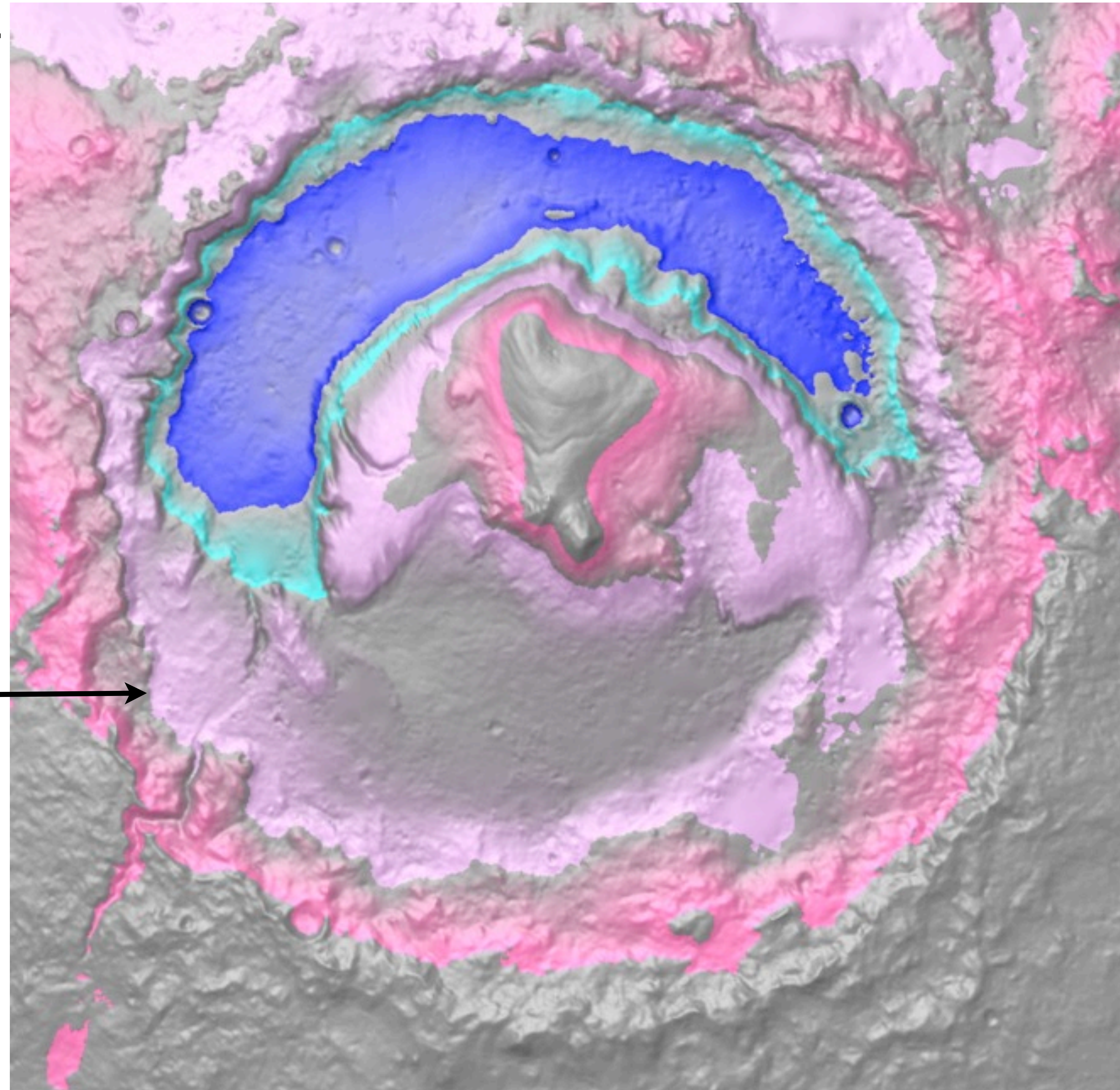
Base Level for Upper River Canyon & Head of "Grand Canyon" (-2290m)



HRSC Topography

4. Evidence for Water Flowing into a Standing Body of Water: Valleys & Canyons

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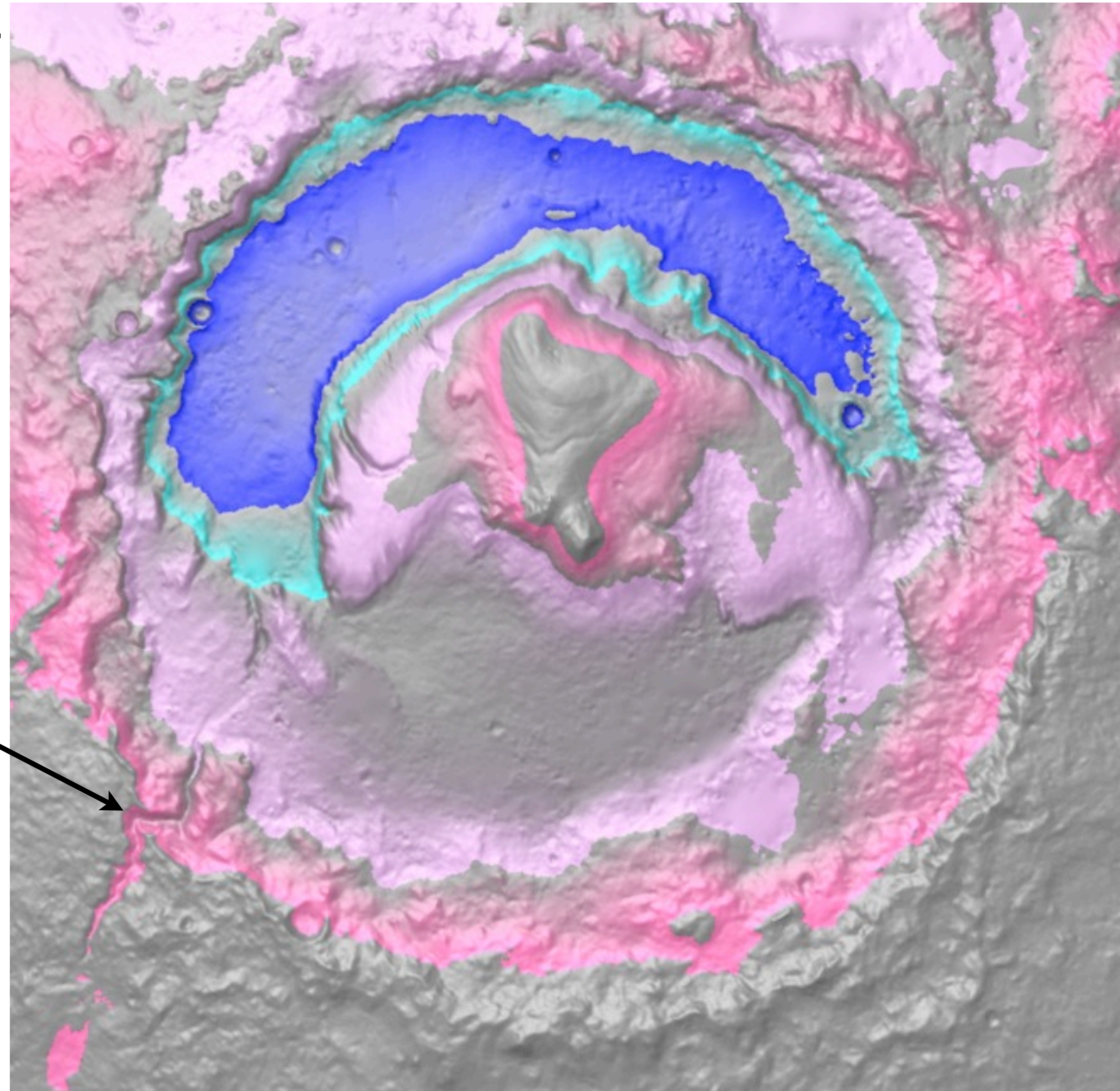
Top of Upper River Canyon
(-735m)



HRSC Topography

4. Evidence for Water Flowing into a Standing Body of Water: Valleys & Canyons

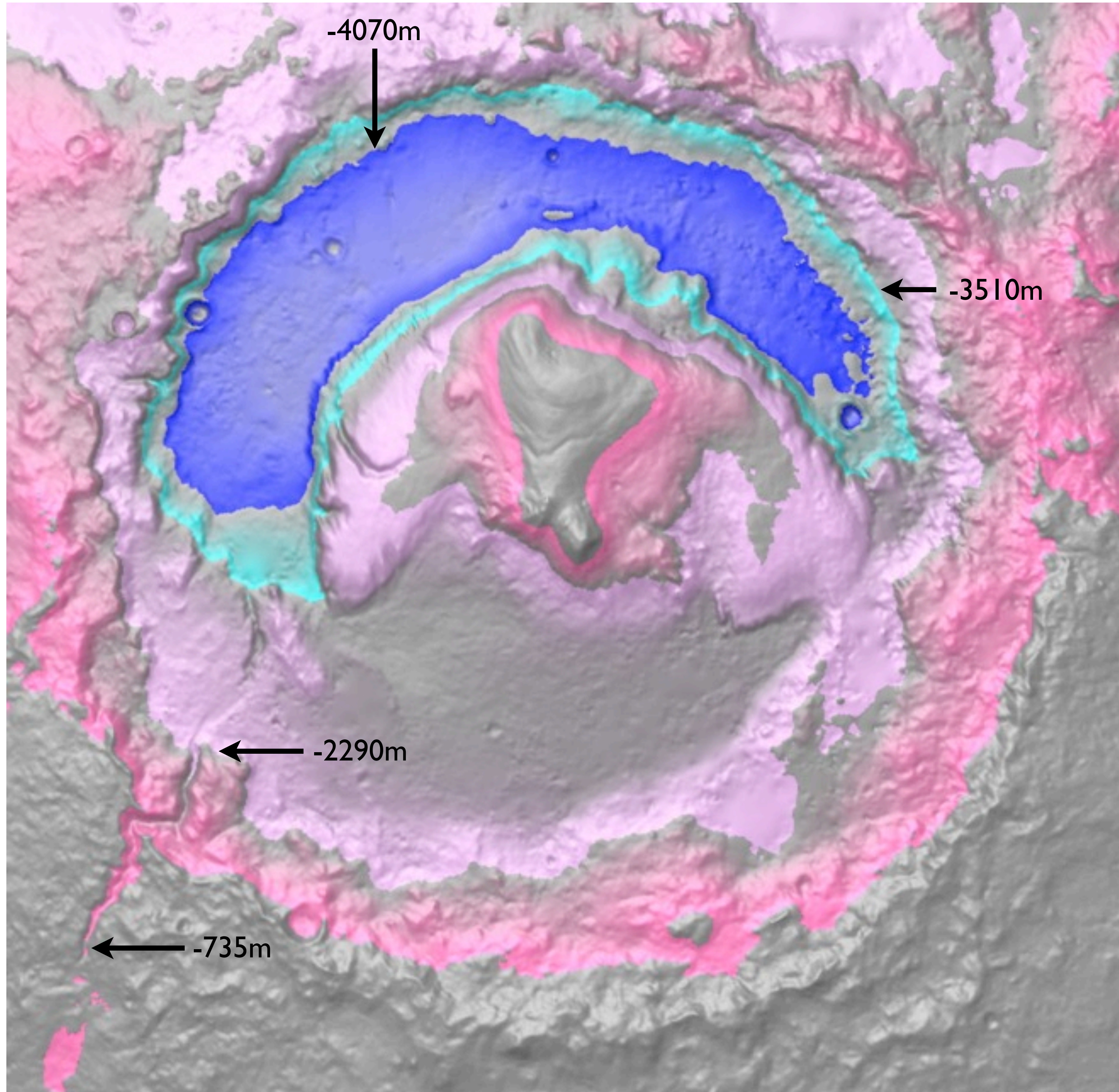
Summary Observations:

- More than one fluvial feature is controlled by the two intermediate "base levels".
- Benches commonly very close to "base level" heights.

- **Top of Turquoise:**
  - Base Level for "Grand Canyon"
  - Base Level for River from SSW
  - Fractures very abundant -3500 to -3600 m. (See Anderson's talk, traverse target in mound)
  - Basin South of Mound is Just above this Level

Interpretations:

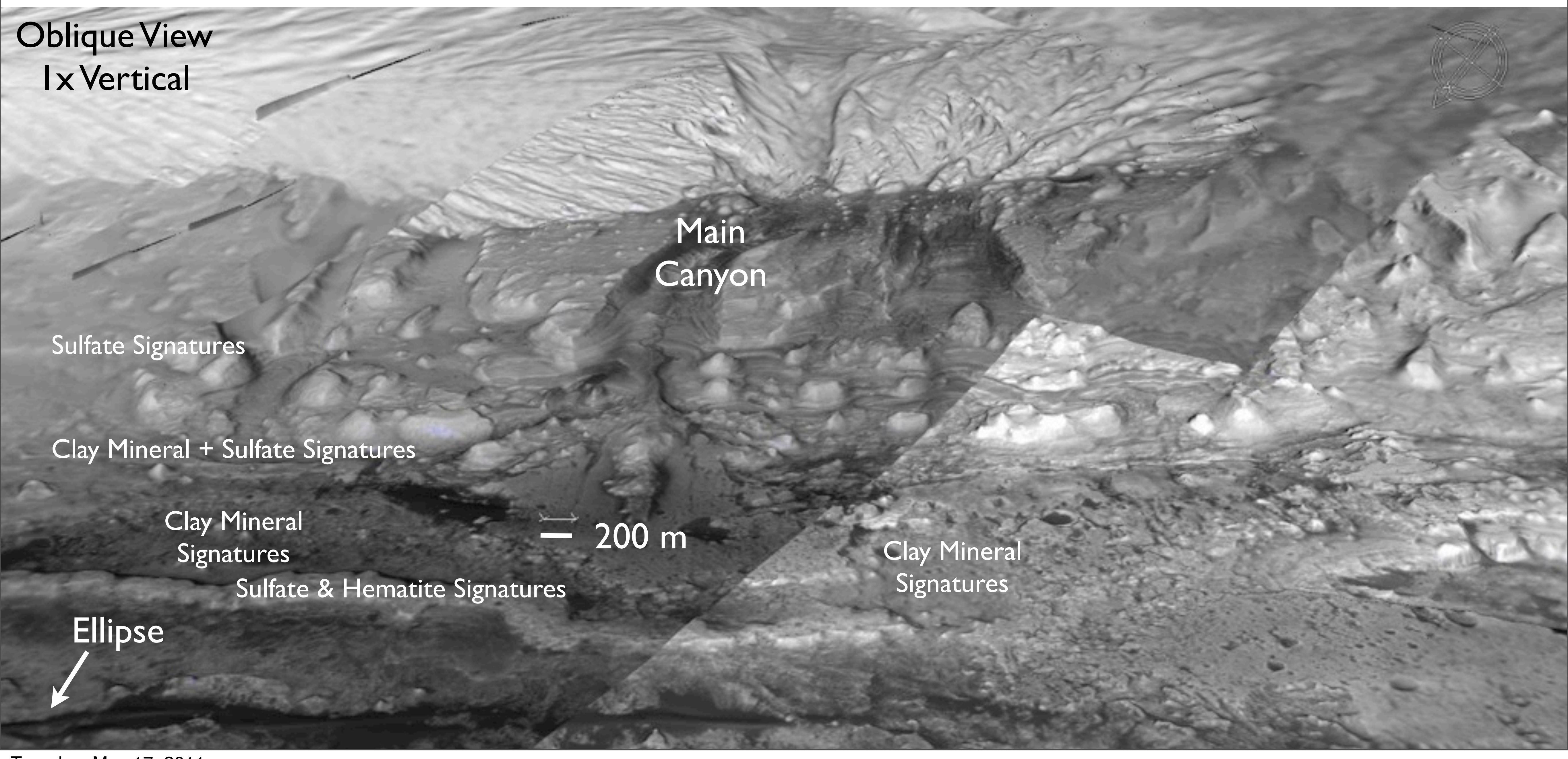
- Three different significant lake levels showing progressively less water (light pink, turquoise, and blue).
- All after deposition of the strata in the lower mound.



HRSC Topography

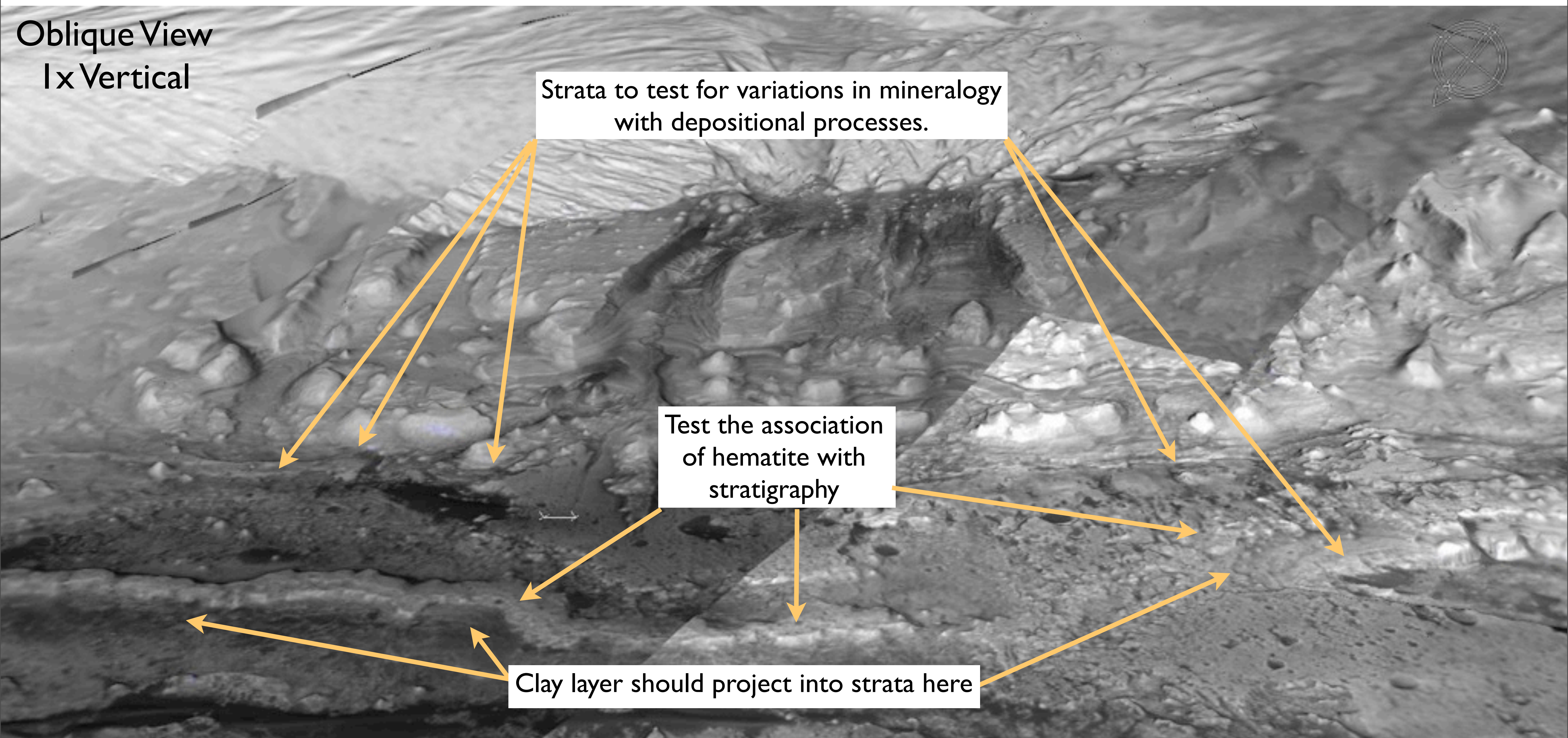
Why Gale Will Change Everyones' View of Mars

- Minerals and cross cutting relationships at the base of the mound will transform our understanding of environmental processes occurring on Mars from ~Late Noachian to Recent times.



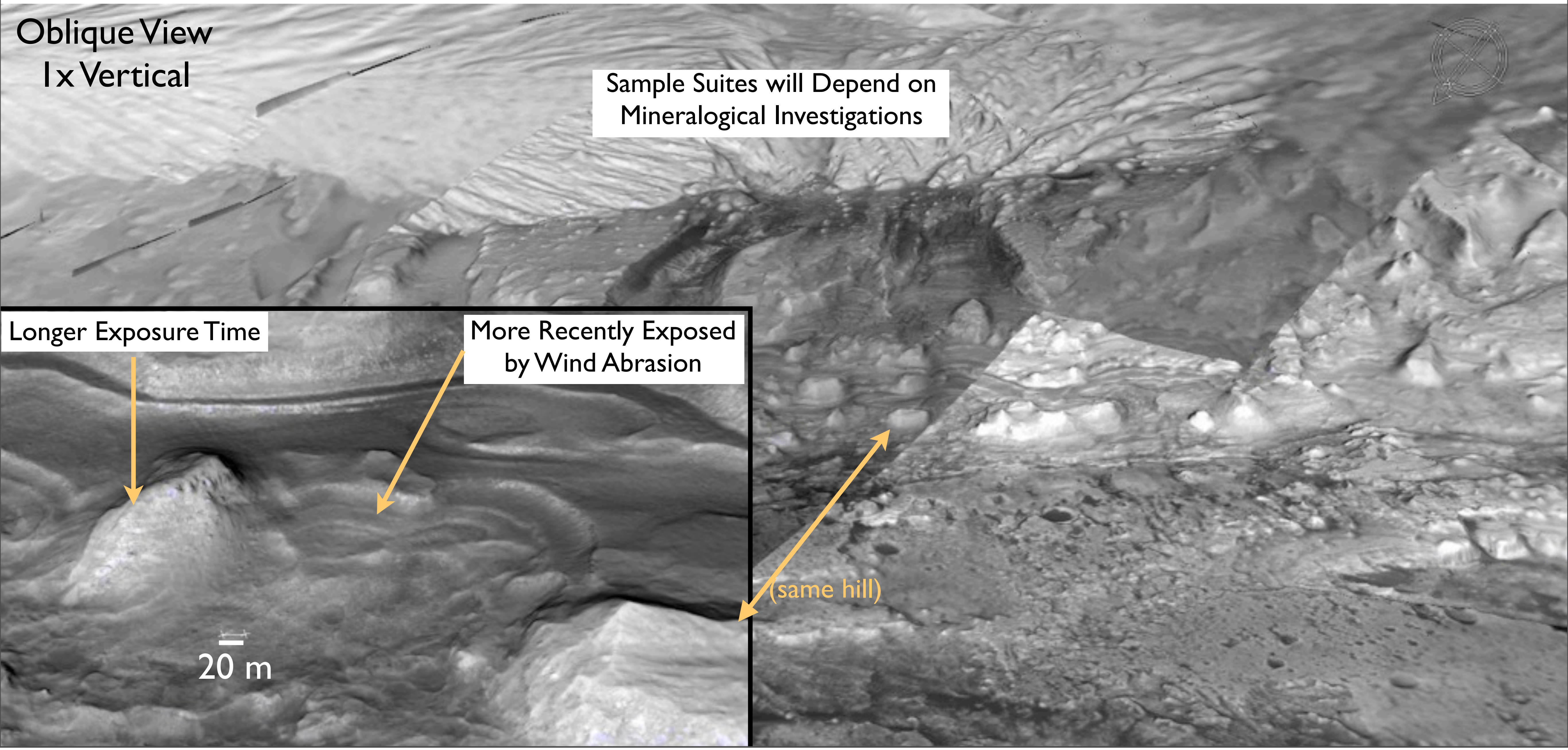
Relationships Among Hematite, Sulfates, and Clay Minerals

- **Hypothesis:** A clay mineral bed is present within the lower mound strata, and some clay minerals are intermixed with sulfates in overlying strata (Miliken et al., 2010).
- **Test:** Characterize bedding by texture, elemental composition, and mineralogy to see if a clay mineral-rich layer is present and to characterize the spatial relationships among all hydrous minerals present.
- **Importance:**
  - 1. Constrain whether clay mineral accumulation represents a depositional event or a long-term process.
  - 2. Characterize sulfate mineral variability with variations in albedo and depositional processes.
  - 3. Determine if hematite is part of the stratigraphic package or a surface patina to understand history of oxidation state.
  - 4. Identify targets for best preservation of organic carbon based on composition, permeability, and depositional processes.



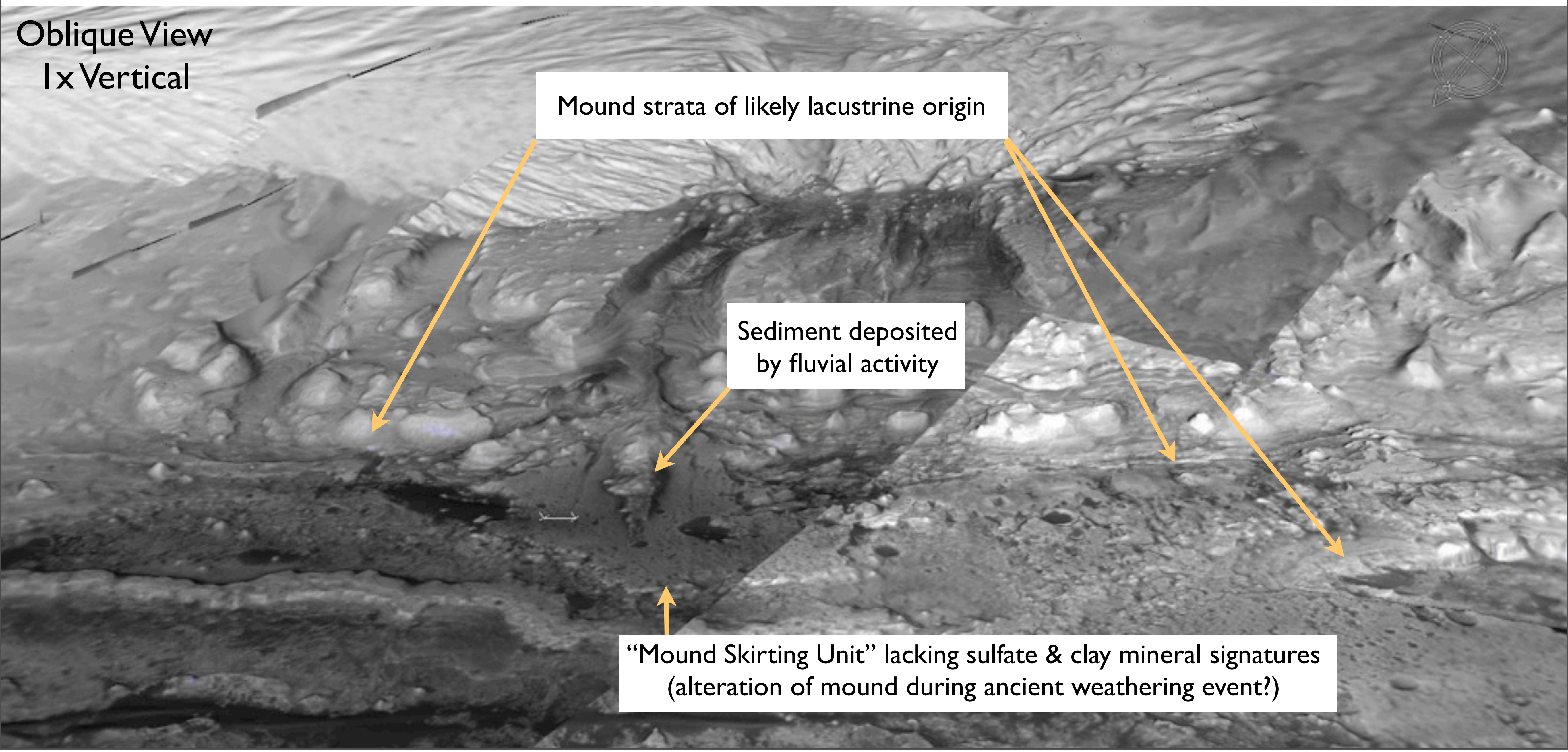
Search for Organic Compounds & Understanding Their Preservation

- **Hypothesis**: Diversity of mineralogic compositions and exposure times provides multiple targets for the search for organic compounds and for characterizing preservation potential whether or not they are present.
- **Test**: Evaluate sample suites with variable mineralogy and different exposure times within a constrained sedimentary context.
- **Importance**: (of the relationships available here, not of organic carbon detection)
    - 1. Suites of samples provide different preservation styles, providing multiple opportunities for organic carbon detection.
    - 2. Context allows one to characterize processes, whether or not organic compounds are detected.
    - 3. If organic compounds are detected, context allows detailed hypothesis testing about their origin and preservation.



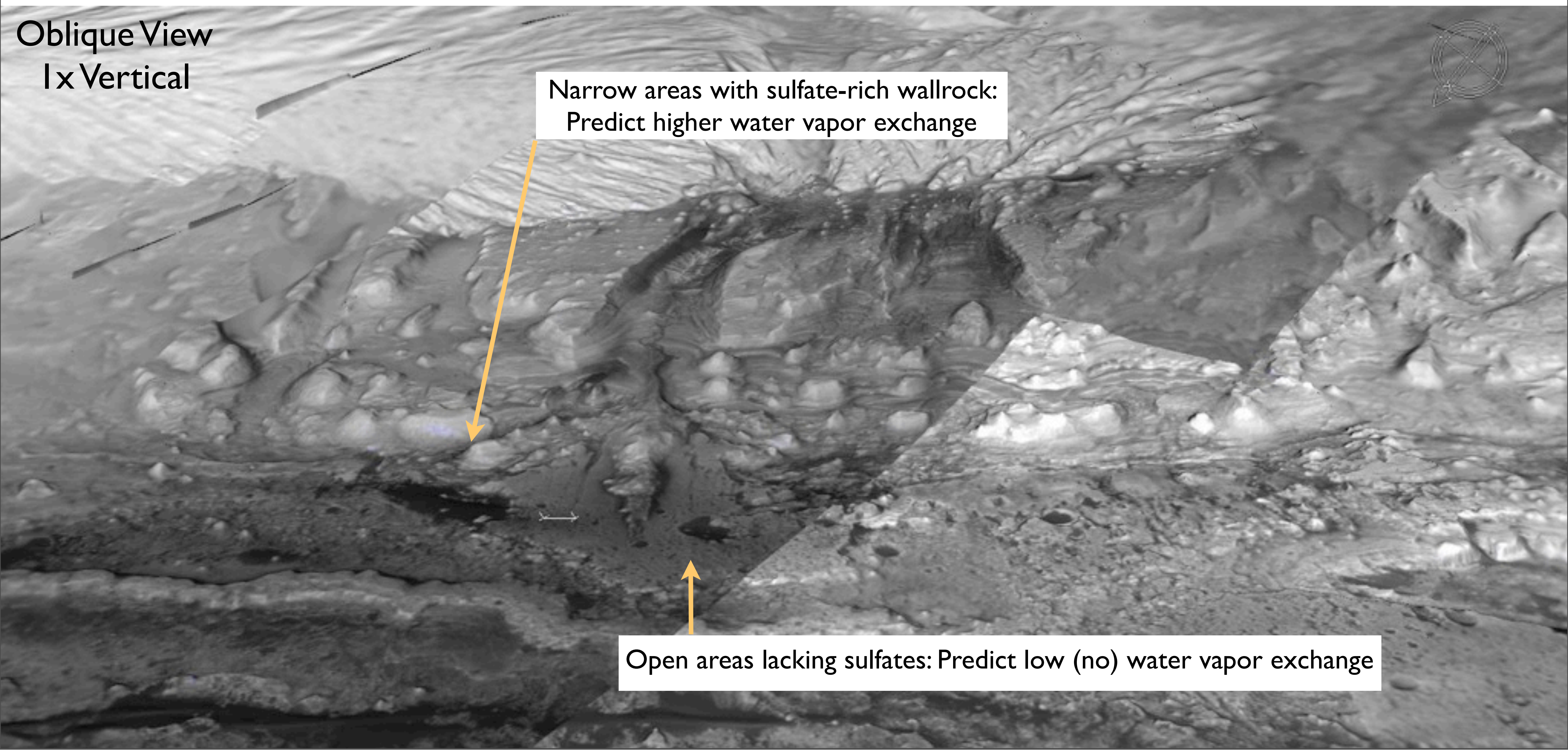
Changes in Sedimentary Environment & Habitability Through Time

- **Hypothesis:** Multiple processes affected deposition, erosion, and alteration of sediments, and the habitability of multiple environments can be assessed without climbing the mound.
- **Test:** Characterize sedimentary structures, texture, elemental composition, and mineralogy of (from oldest to youngest): 1) Layered mound sediments (focus only on those at base initially); 2) Fluvial sediments deposited at the mouth of the canyon; 3) "Mound Skirting Unit" of Anderson and Bell (2010). Compare to fan deposits and high thermal inertia unit in ellipse.
- **Importance:**
  - 1. Multiple environments can be characterized across an extended period of time.
  - 2. Water chemistry varied (hydrous mineral variations), providing diversity in chemical environment.
  - 3. Provides tests for specific hypotheses related to larger scale predictions for mound sedimentation.



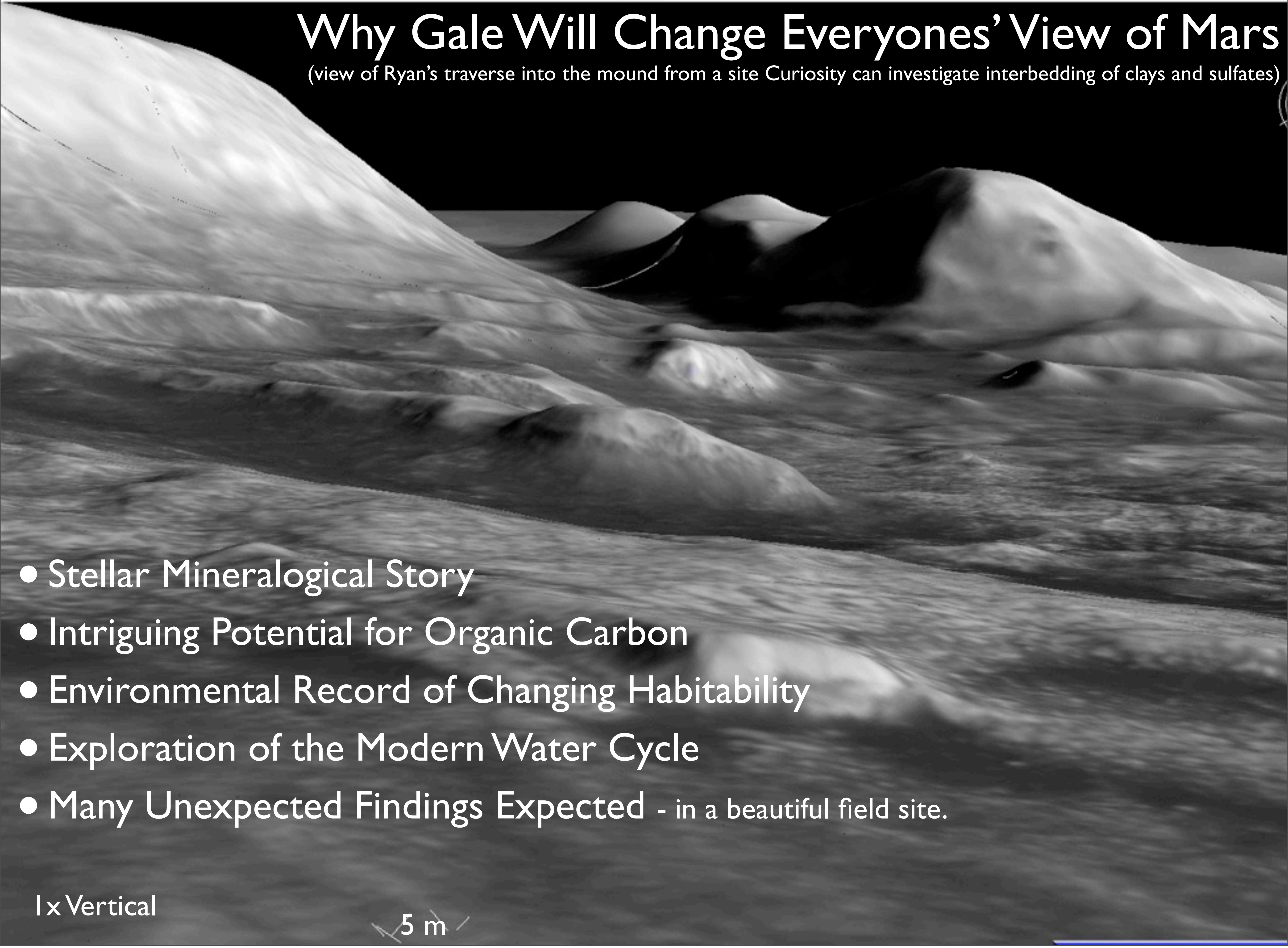
Water Cycling Between Hydrous Minerals & Atmosphere

- **Hypothesis:** Small amounts of water vapor are exchanged between hydrous Mg sulfates (and possibly other hydrous minerals) and the atmosphere due to diurnal and seasonal temperature changes. (Frost on Opportunity...)
- **Test:** Cataloging variations in relative humidity & surface temperature in time and with local topography; comparing surface hydration with estimates of H concentration in the upper meter of bedrock; and correlating data to variations in sulfate mineralogy and abundance in surface outcrops.
- **Importance:**
  - 1. Understand the current water cycle (locally) on Mars.
  - 2. Refine the conceptual framework for conditions required to raise the activity of water sufficiently to produce a modern habitable environment.
  - 3. Understand processes of mineral diagenesis to constrain weathering and organic carbon preservation potential.



Why Gale Will Change Everyones' View of Mars

(view of Ryan's traverse into the mound from a site Curiosity can investigate interbedding of clays and sulfates)



- Stellar Mineralogical Story
- Intriguing Potential for Organic Carbon
- Environmental Record of Changing Habitability
- Exploration of the Modern Water Cycle
- Many Unexpected Findings Expected - in a beautiful field site.