Physical Outcrop Characteristics of the Mawrth Candidate Landing Site &
The potential role of impacts in shaping stratigraphy

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with special thanks to Ken Edgett, Ralph Milliken, James Wray, and Joe Michalski for science discussions.

Paper submitted to Mars Journal:

http://mygeologypage.ucdavis.edu/sumner/Sumner_Mawrth.pdf

∞ Thanks to Chris Haley for data wrangling and Tony Bernadin for Crusta (my favorite virtual globe).

Outline:

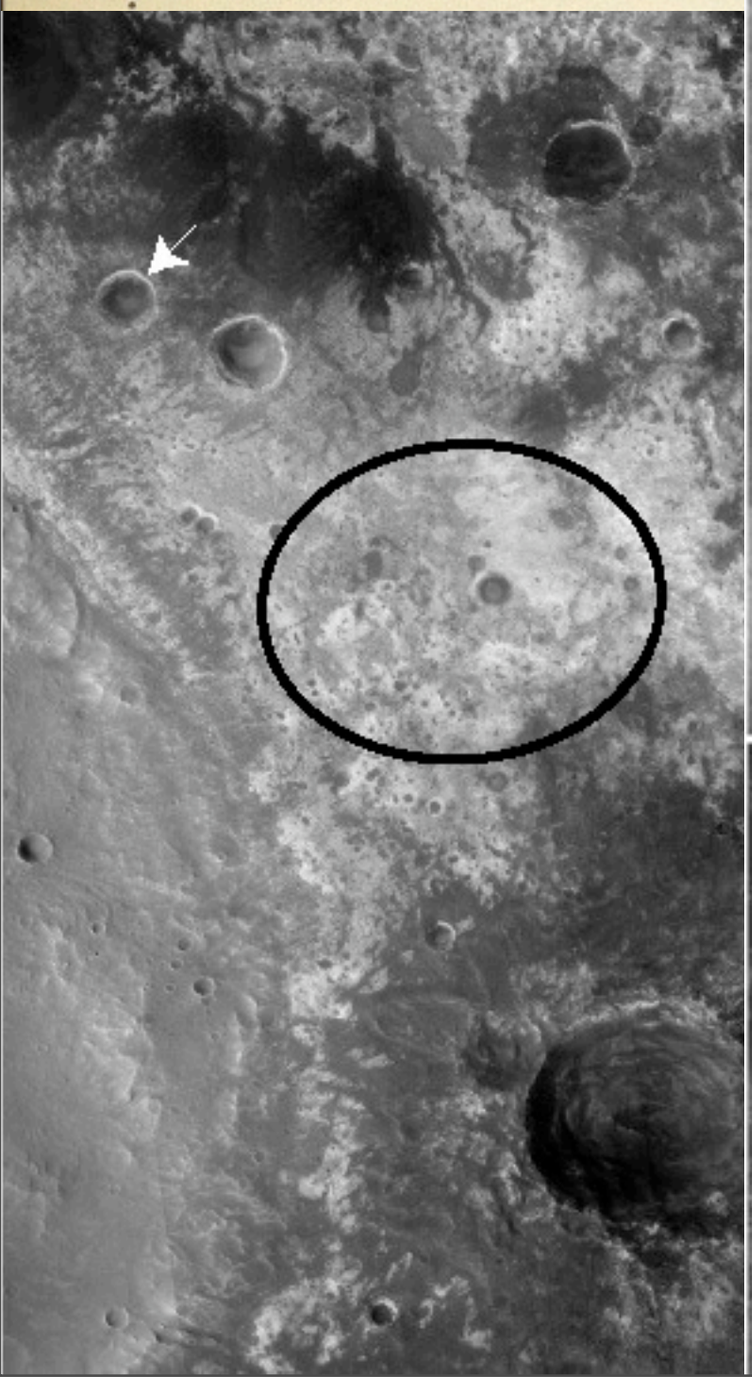
(I am ONLY addressing the light-toned outcrops below the dark capping unit.)

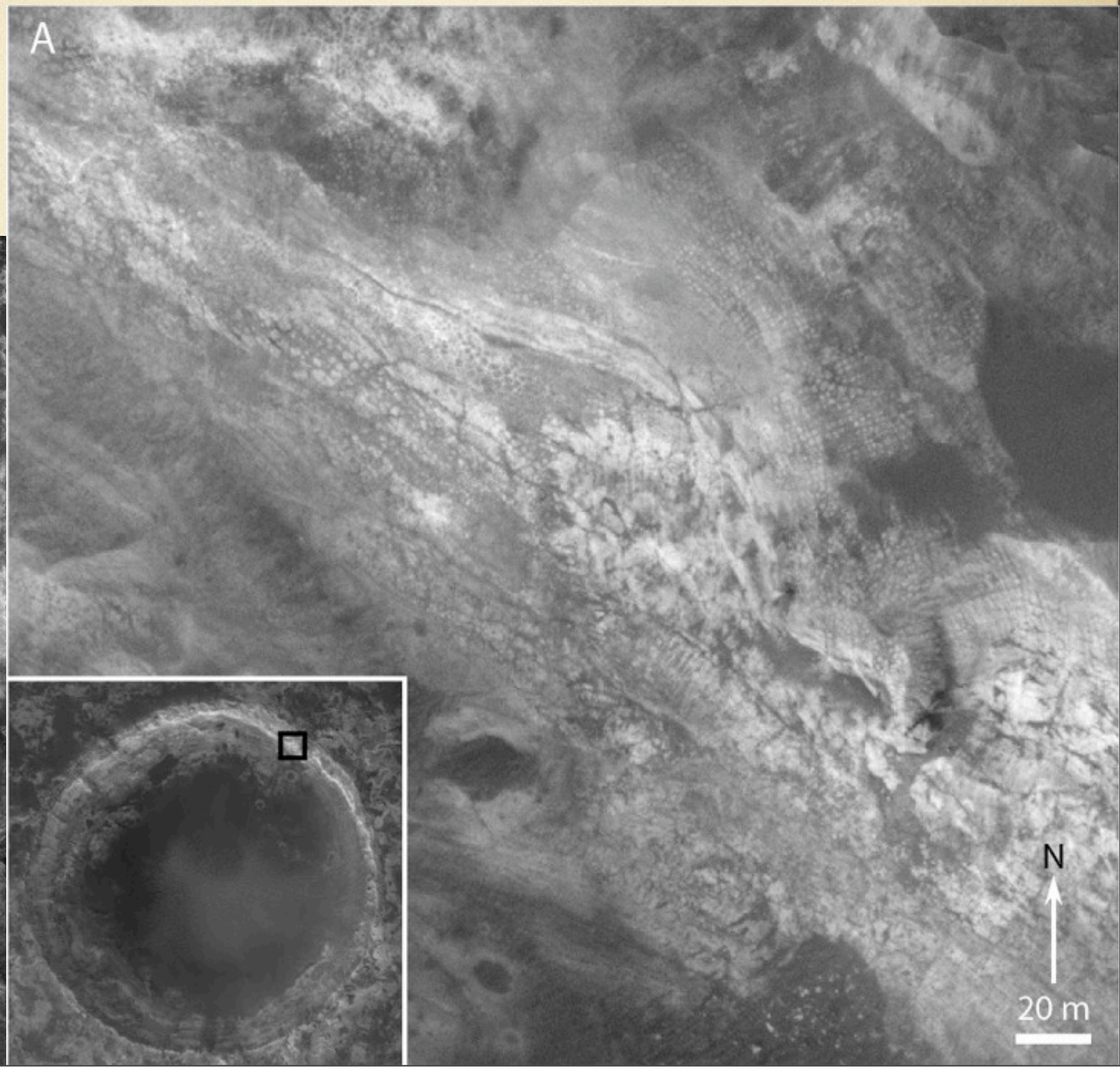
- Abundant Brecciation of Outcrop
  - Polygonal (contraction) fracture patterns
  - Conjugate (regional stress) fracture patterns
  - Breccia pods of uncertain origin
  - Other irregular breccia very abundant

- Layered Sequences
  - Paucity of layering within the landing ellipse
  - Layering in the west bank of Mawrth Vallis near ellipse
  - Layering in the ~17 km diameter crater south of landing ellipse

- Working Model for Impact-Dominated Deposition
- Implications for Mawrth

Polygonal Breccia:

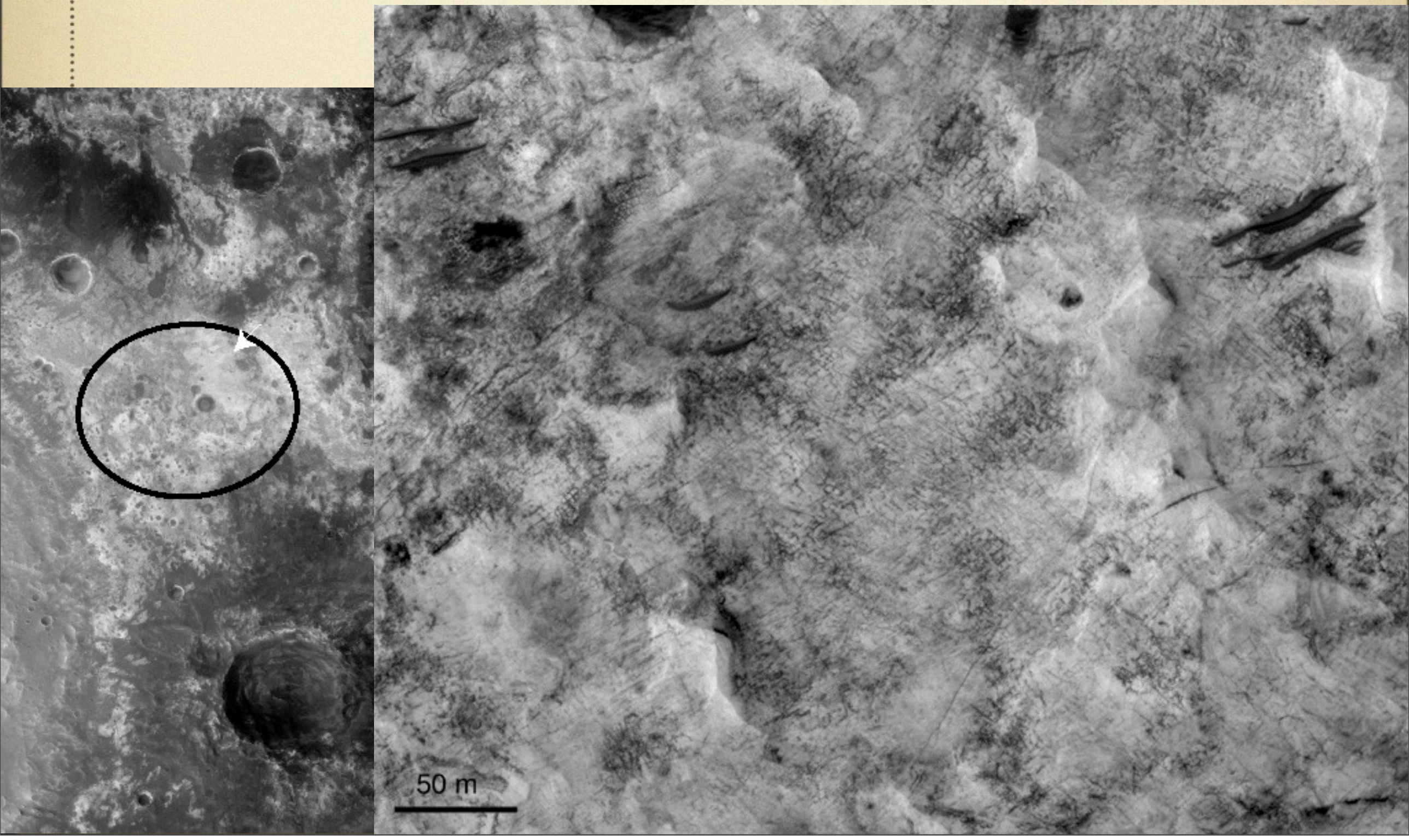




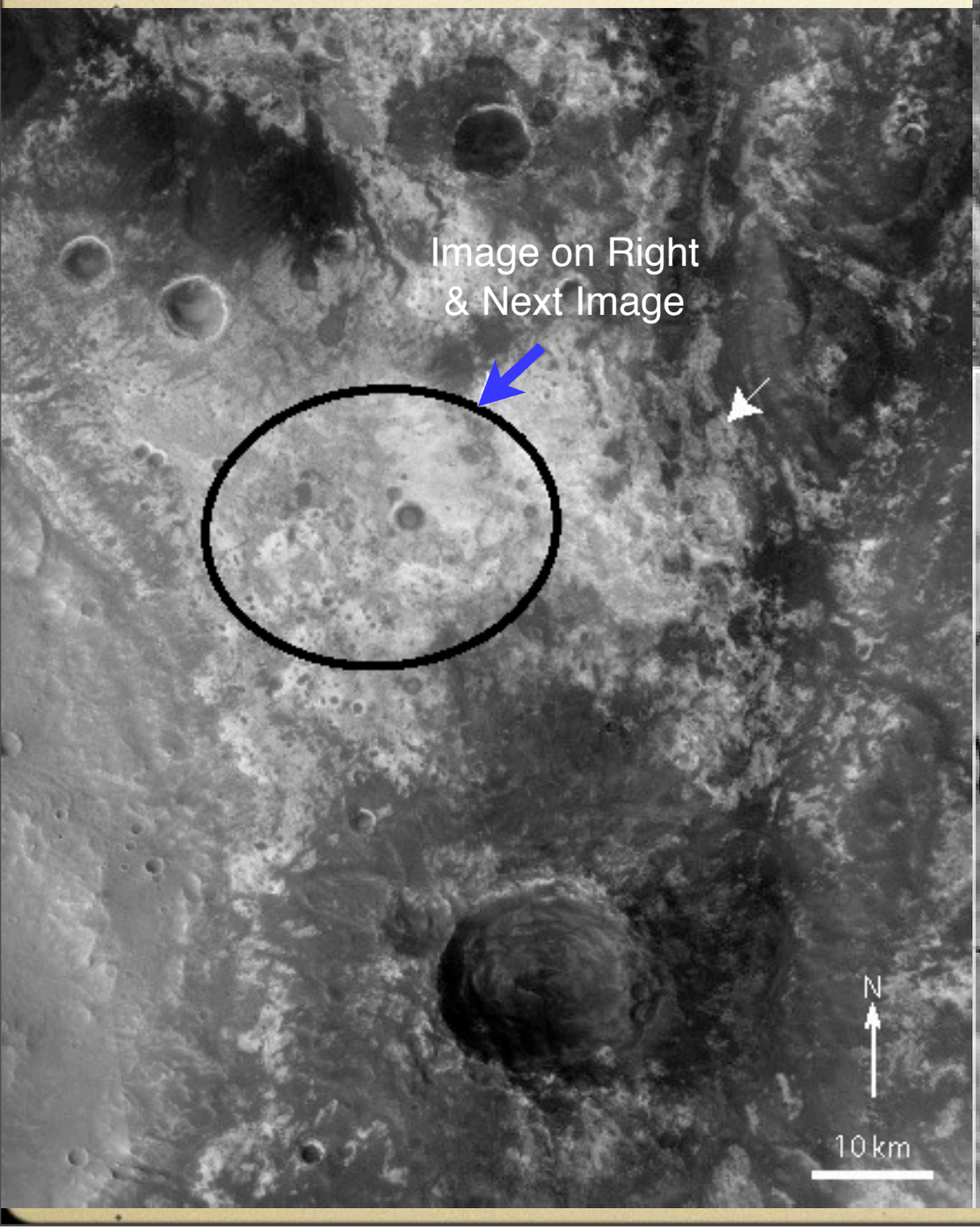
Polygonal Breccia Origins

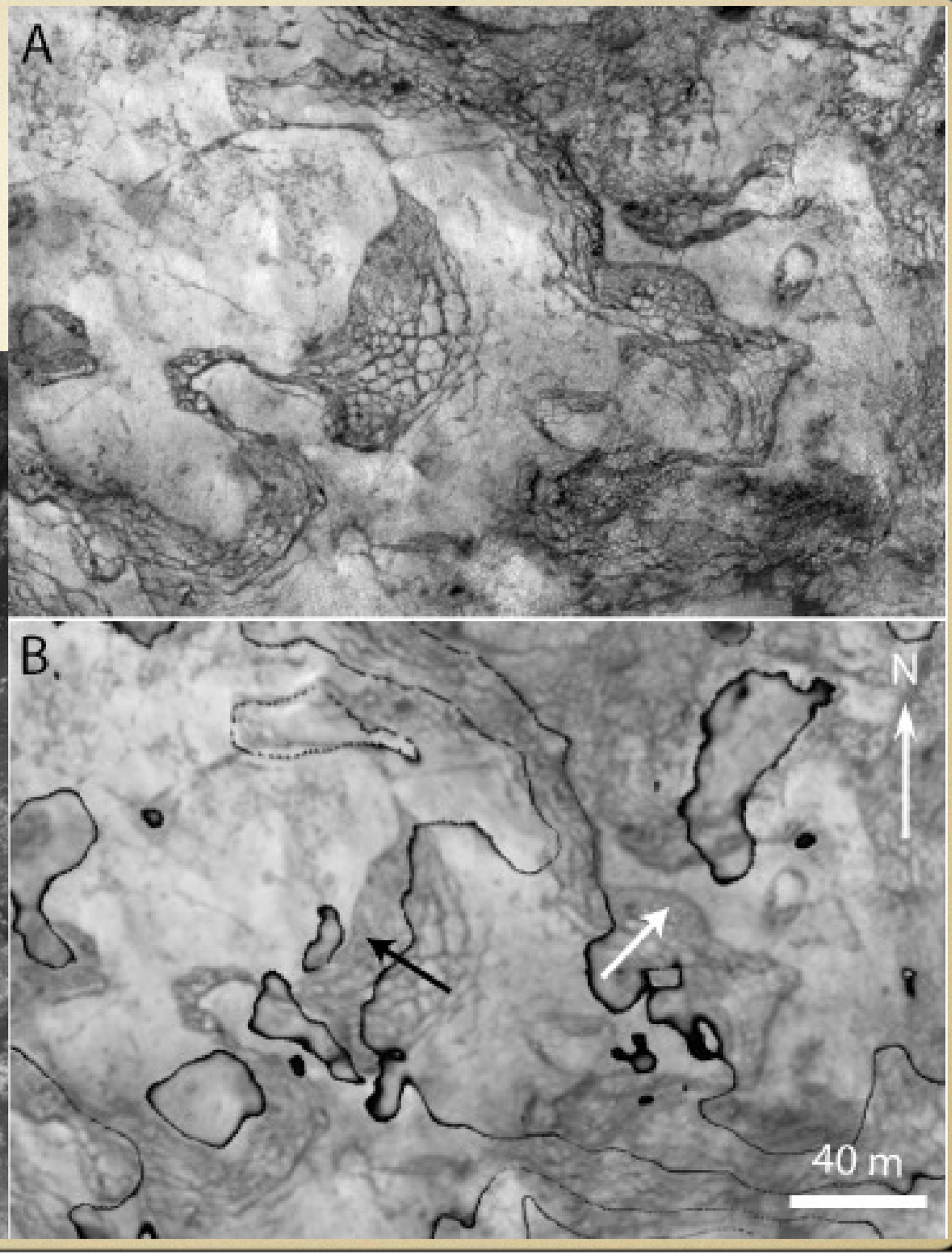
- Observations:
  - Hydrous mineralogy
  - Patterns crosscut topography, including on a “young” crater
  - Abundant triple junctions
  - Crack widths often >30 cm
- Interpretations:
  - Contraction of hydrous materials due to water loss at present surface
  - Dark cracks between light polygons may have opened substantially and collected dust/sand
  - Light cracks require a different interpretation.
    - Earlier opening of cracks, followed by cementation, then erosion
    - Contraction of a light layer overlain by a dark layer, little dust accumulation in cracks

Conjugate Fractures: Two Orientations Interpreted as regional stress

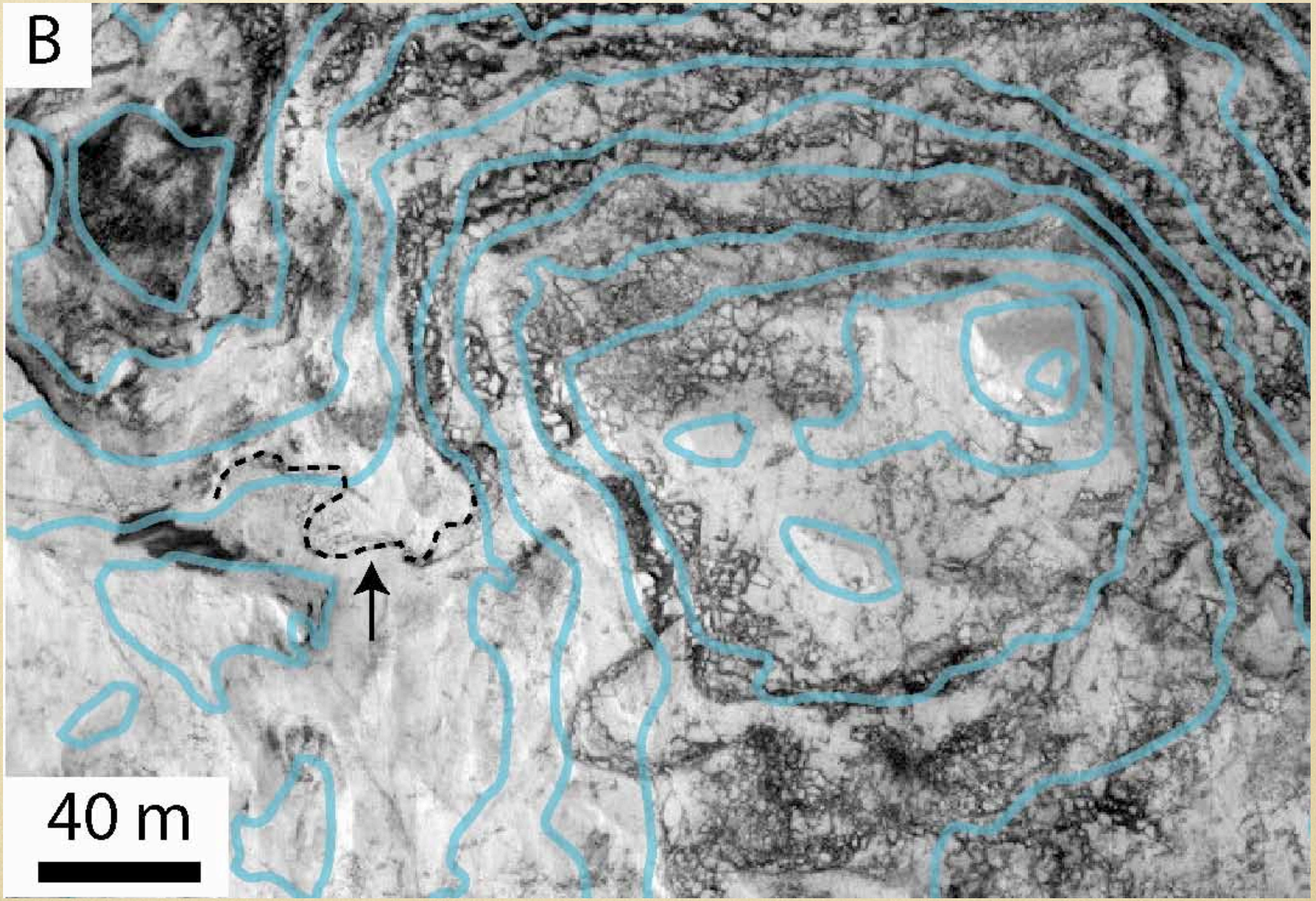


Pods of Breccia: (2m contours)



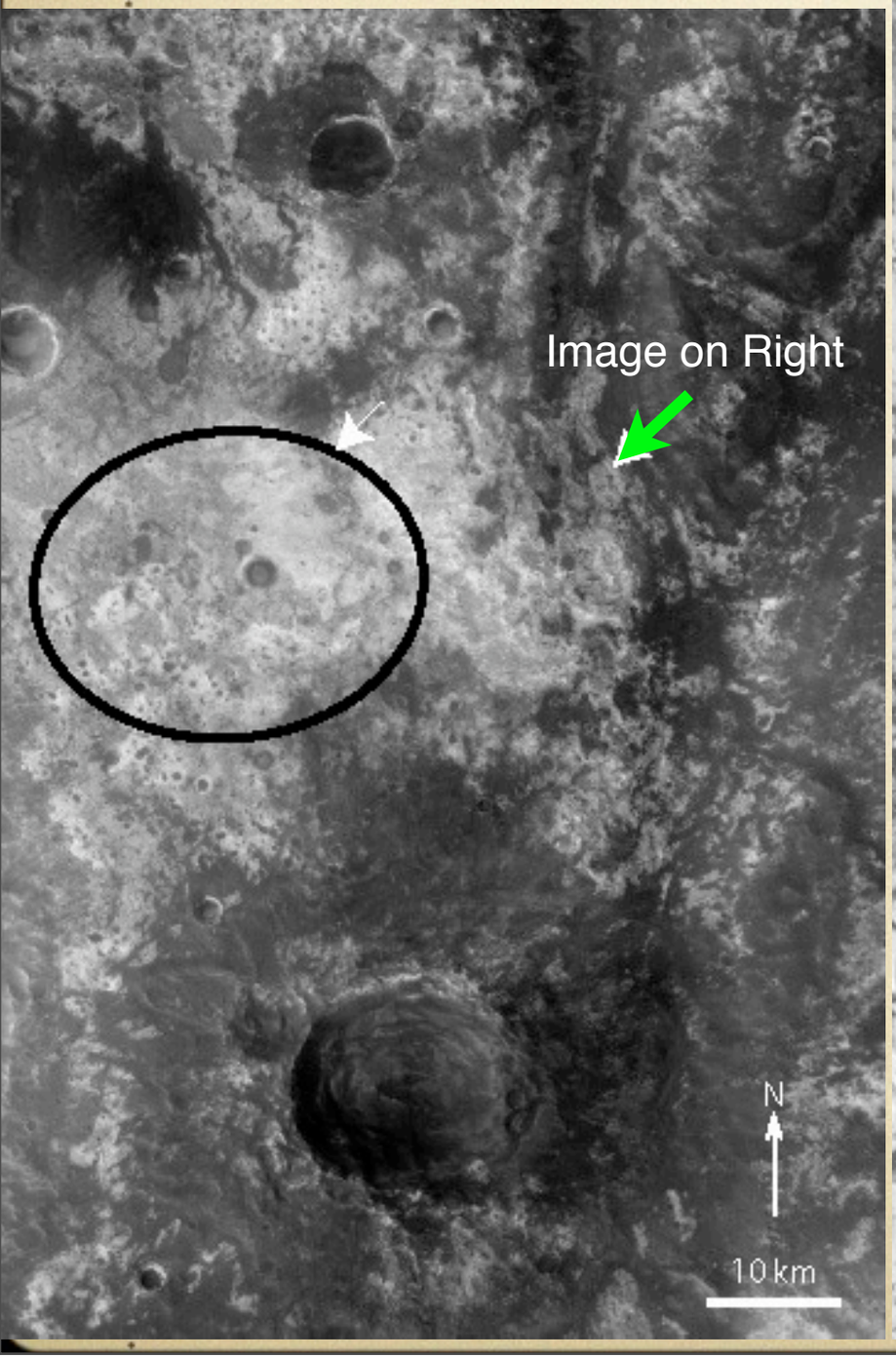


Pods: Not Planar



(2m contours)

Pods: Following Layering

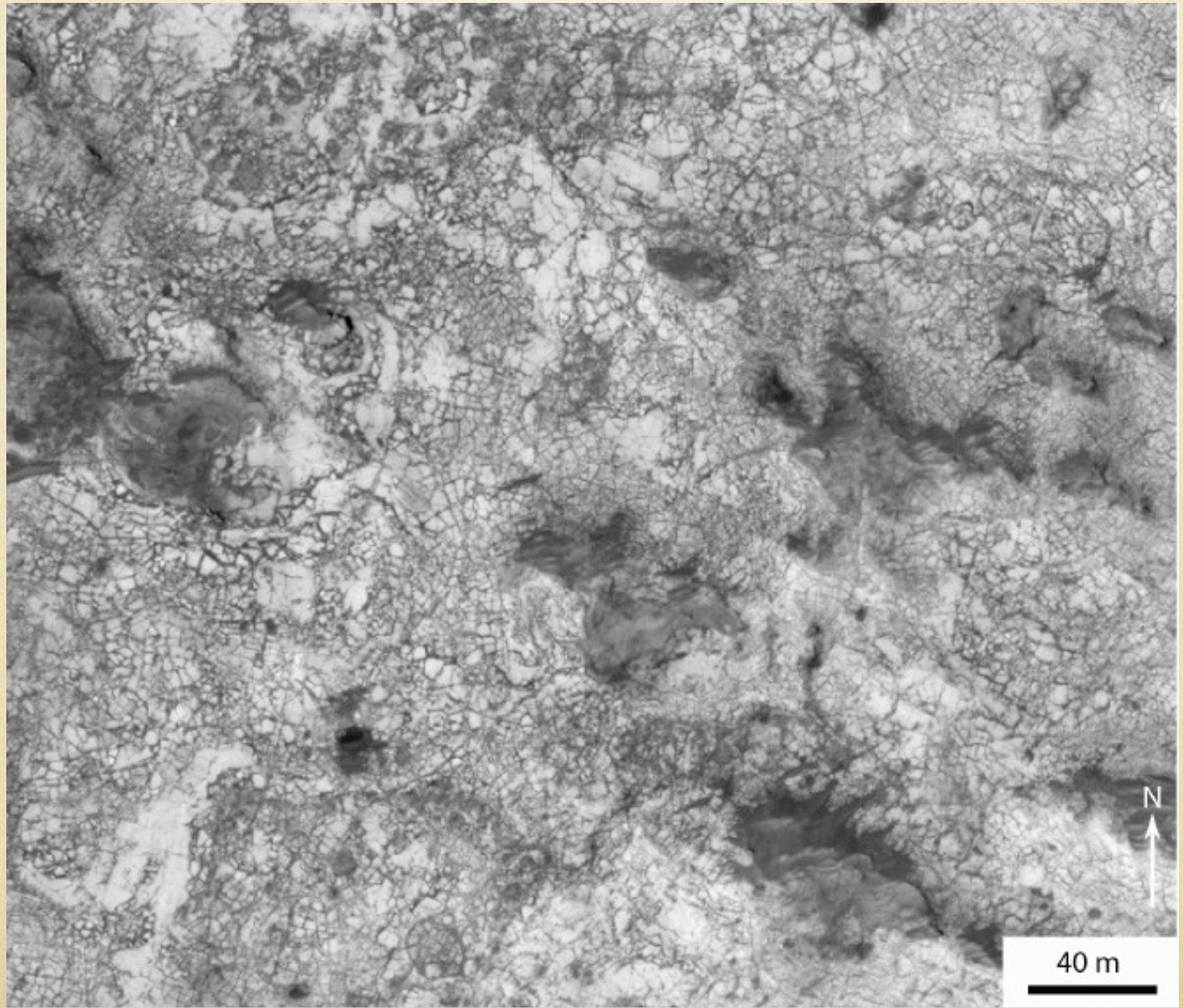


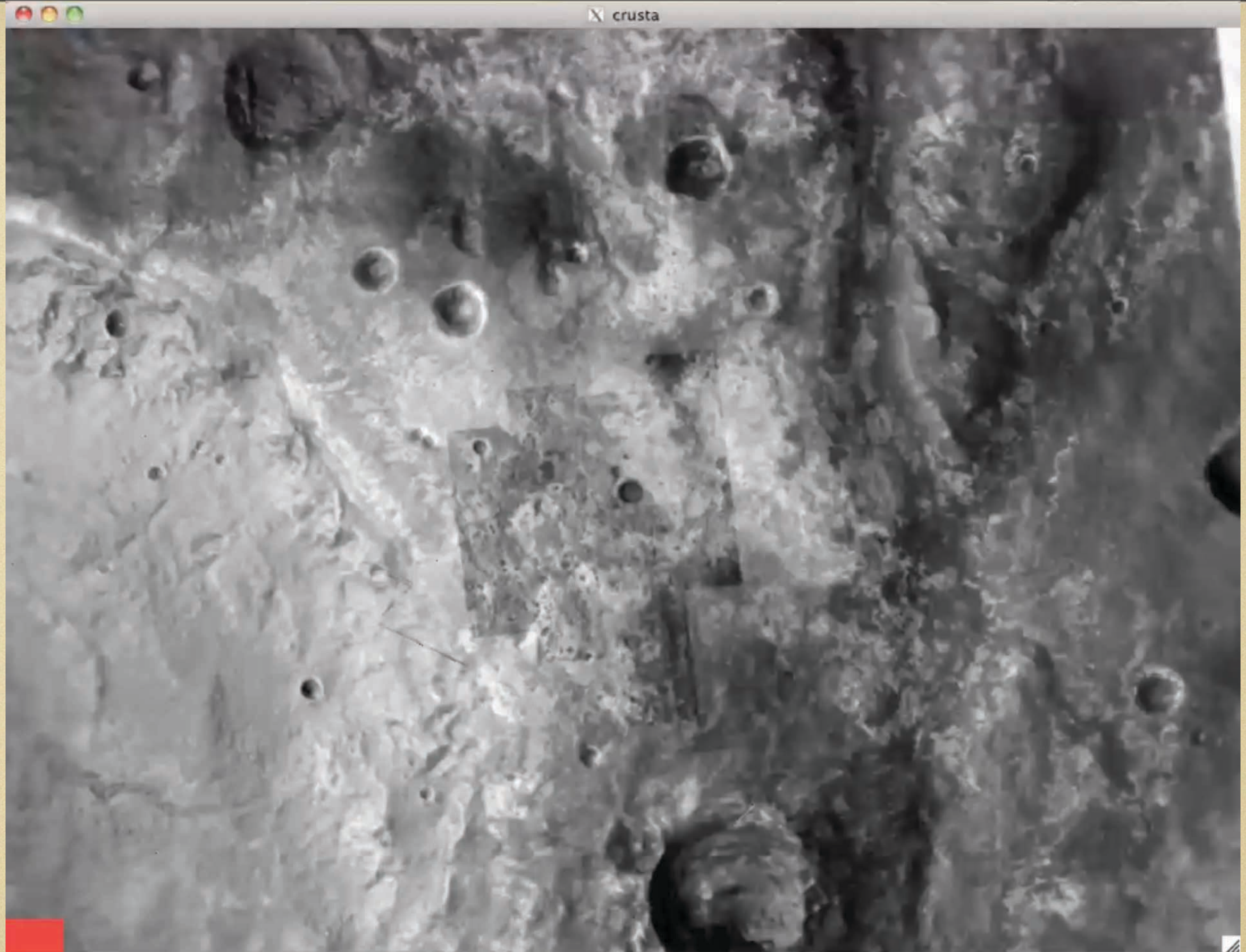
Breccia Pod Origins

- Observations:
  - Sometimes follow layering (E & NE of landing ellipse is where I've observed this)
  - Often not planar surfaces inside landing ellipse
  - Width can be 40 m with 2 m of topography
  - Usually observed in fairly flat areas

- Some Interpretation Options:
  - Follow layering, but layering is not planar in the landing ellipse
  - Fracture zones that follow layering when convenient, but not always (but lacking a model for non-planar fractures with these characteristics)
  - Expansion of specific rock compositions that are sometimes layered and sometimes not (cause(s) of expansion needed)

Misc. Breccia in Ellipse

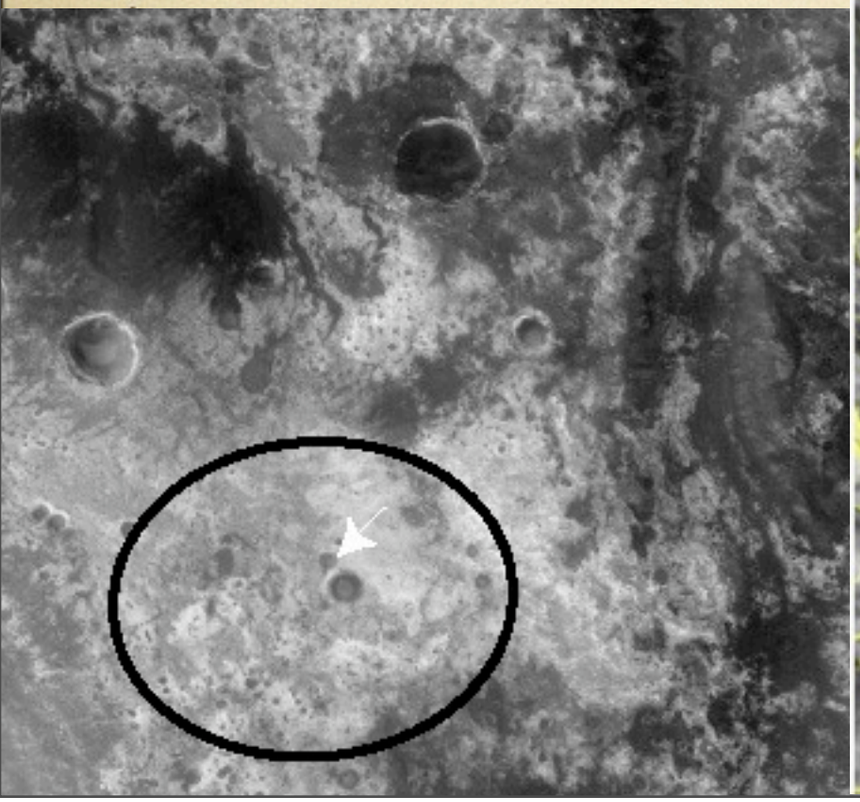


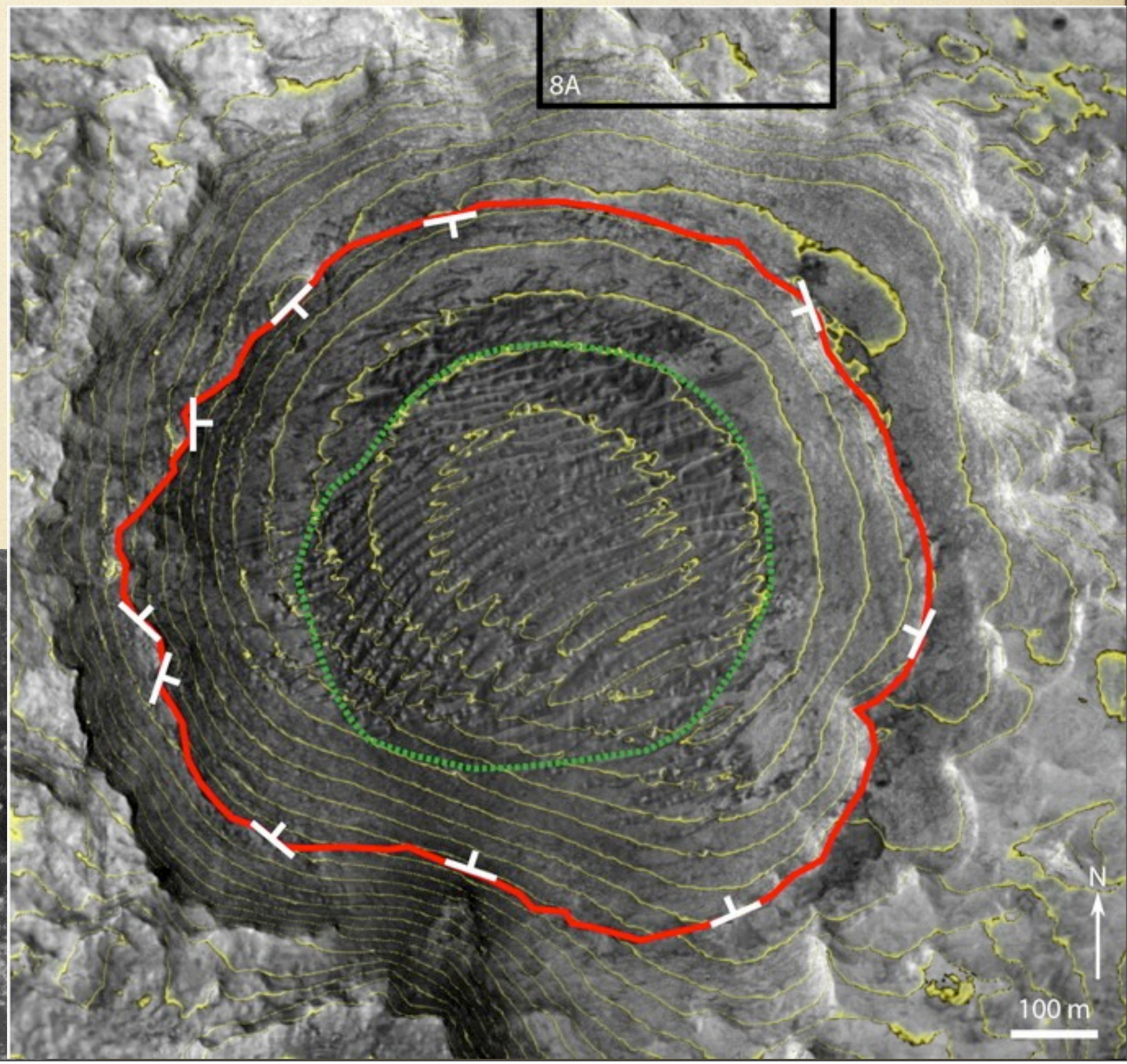


- Movie: http://www.youtube.com/crustamars

Topographic Bench in Crater

- Contour interval = 5m
- Red line = bench
- Green line = floor
- Apparent dip symbols



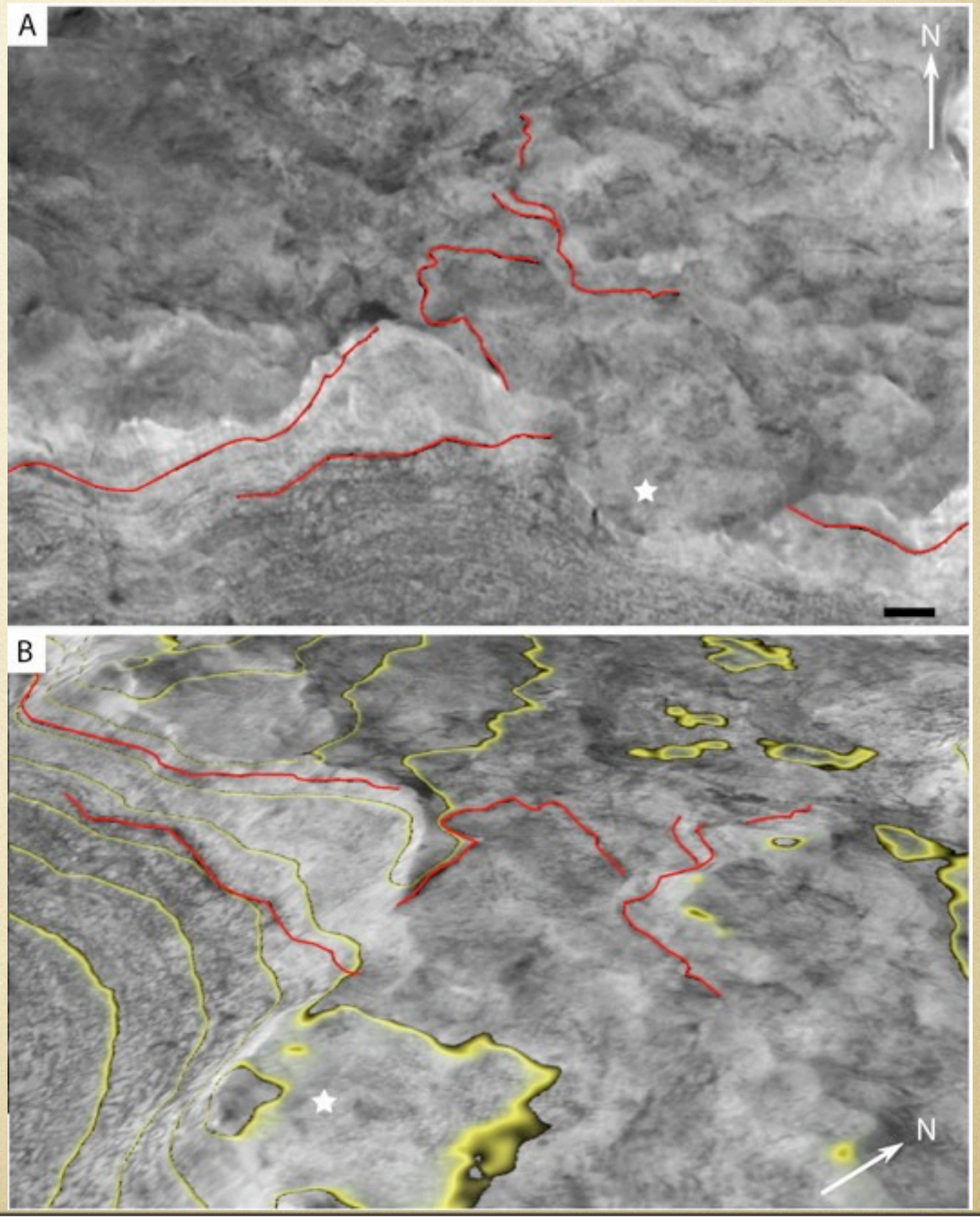


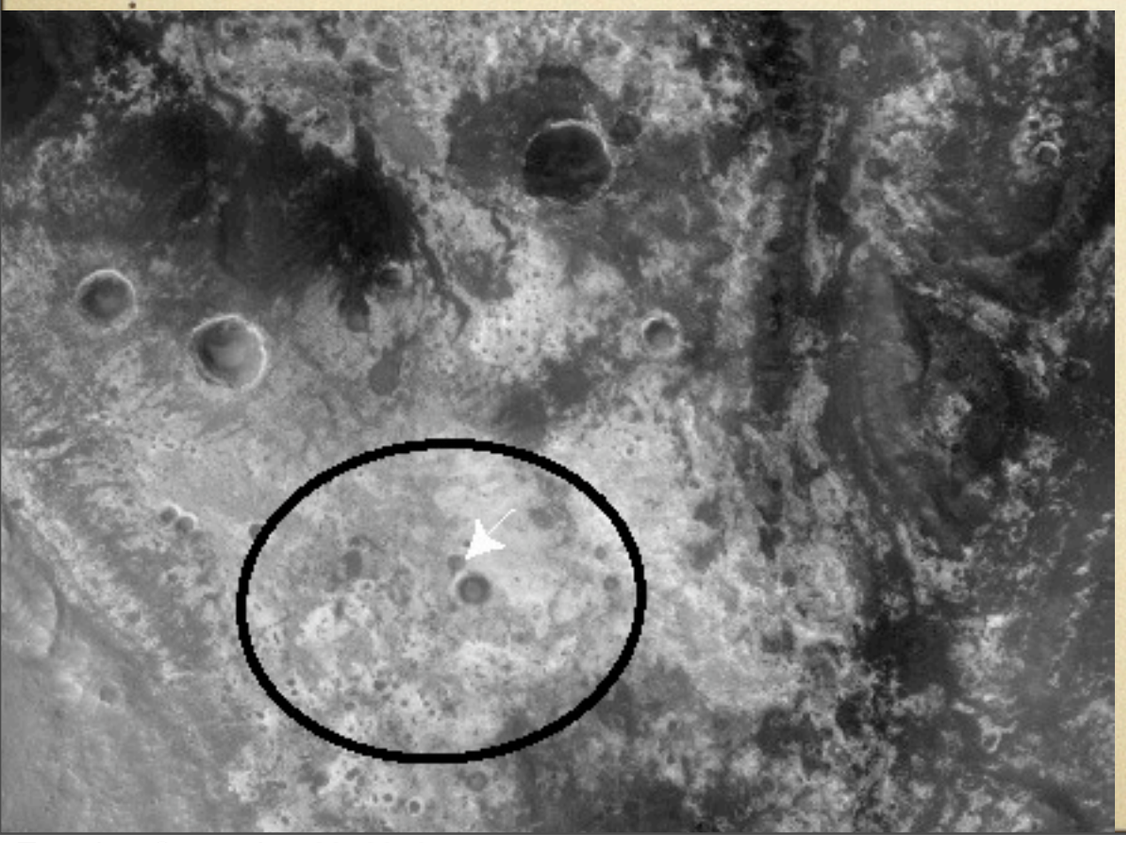
Bench Origin

- Observations:
  - Bench cuts across topography
  - Local apparent dip is always inward and varies rapidly
  - Crater widens above the bench
  - Bench shows similar shape to modern crater floor fill
- Interpretations:
  - Bench can not be the erosional expression of a planar layer
  - Bench likely represents a paleo fill level for the crater
  - Widening of crater above bench may reflect wind erosion

Layering in Crater Wall

- Red line = mapped layers
- White star in the same place
- Oblique view in B
- Contour interval = 5m



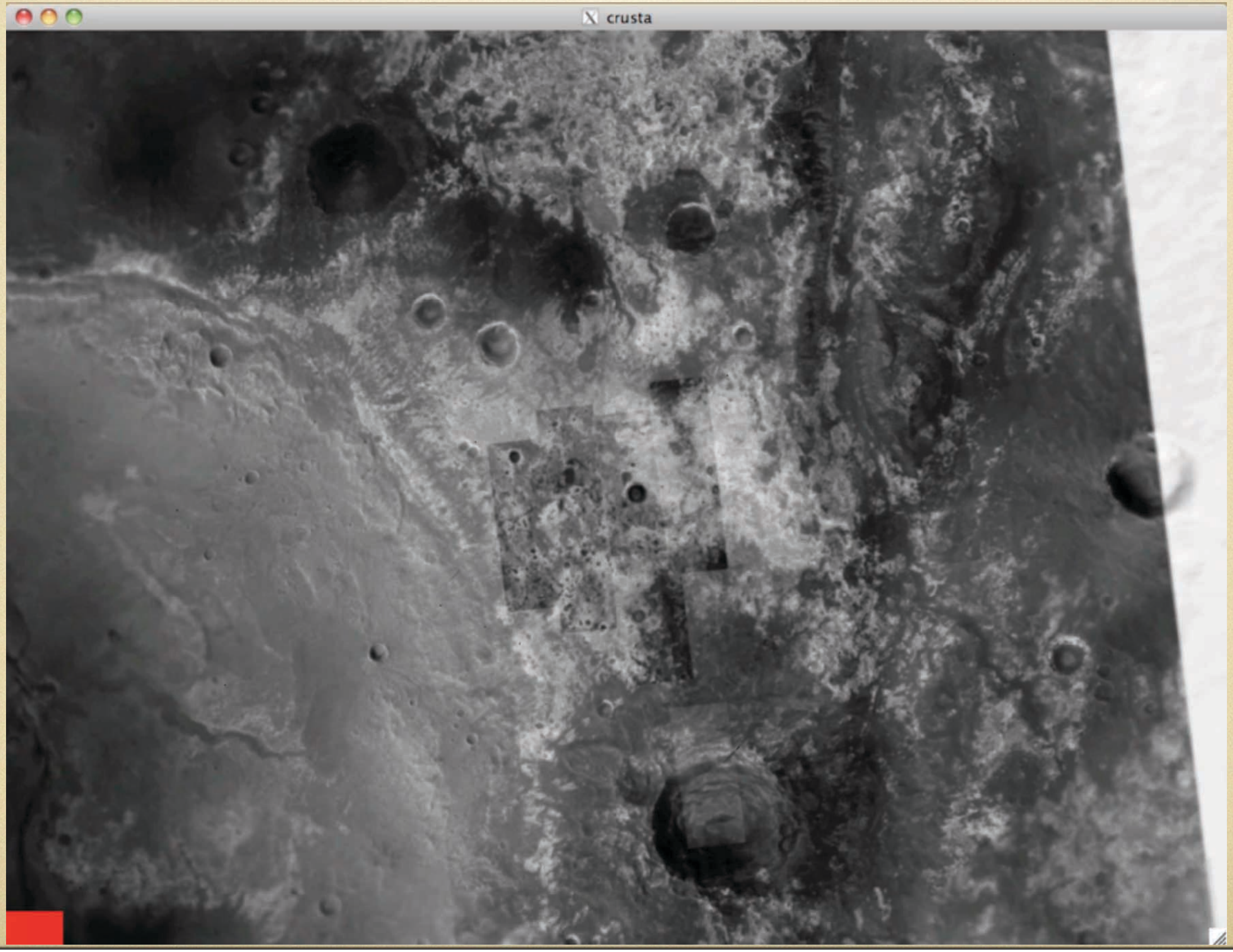


Layering Characteristics

(in landing ellipse; more continuous layering present E & NE of ellipse)

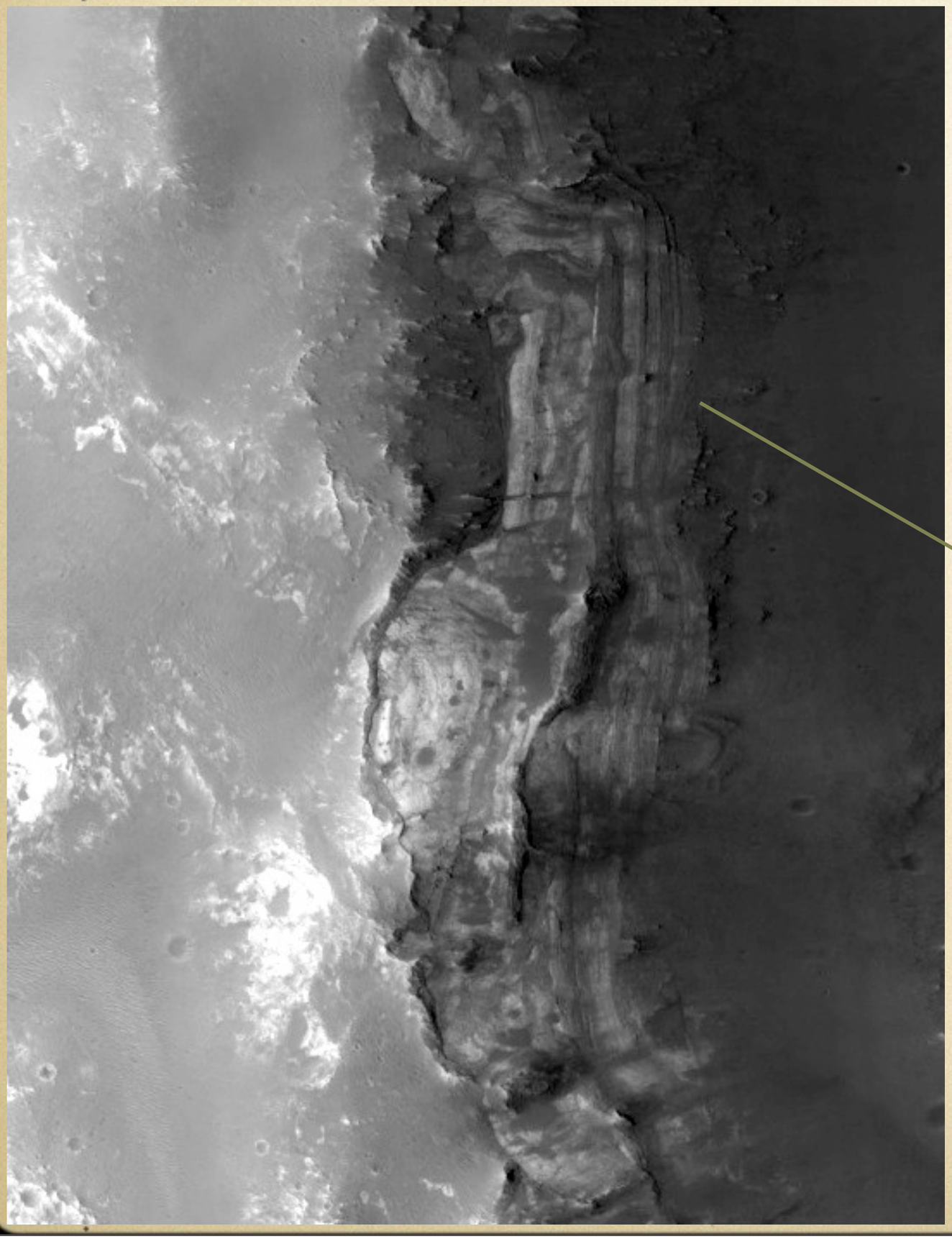
- Observations:
  - Dark "layers" can be mapped for 10's to (rarely) 100's meters.
  - They do not connect to other "layers" that appear similar.
  - There is rarely more than one continuous "layer" in any given sequence.
  - "Layers" are rarely found on the other side of a topographic high.
- Interpretation Options:
  - Layering is not present or persistent in these outcrops.
  - Layering is present, but not expressed in the ellipse.
    - Because layering is seen E & NE of ellipse in similarly flat outcrops, I don't think this is likely.
  - "Layers" could be fractures that collected dark dust.

Layering in Mawrth Vallis

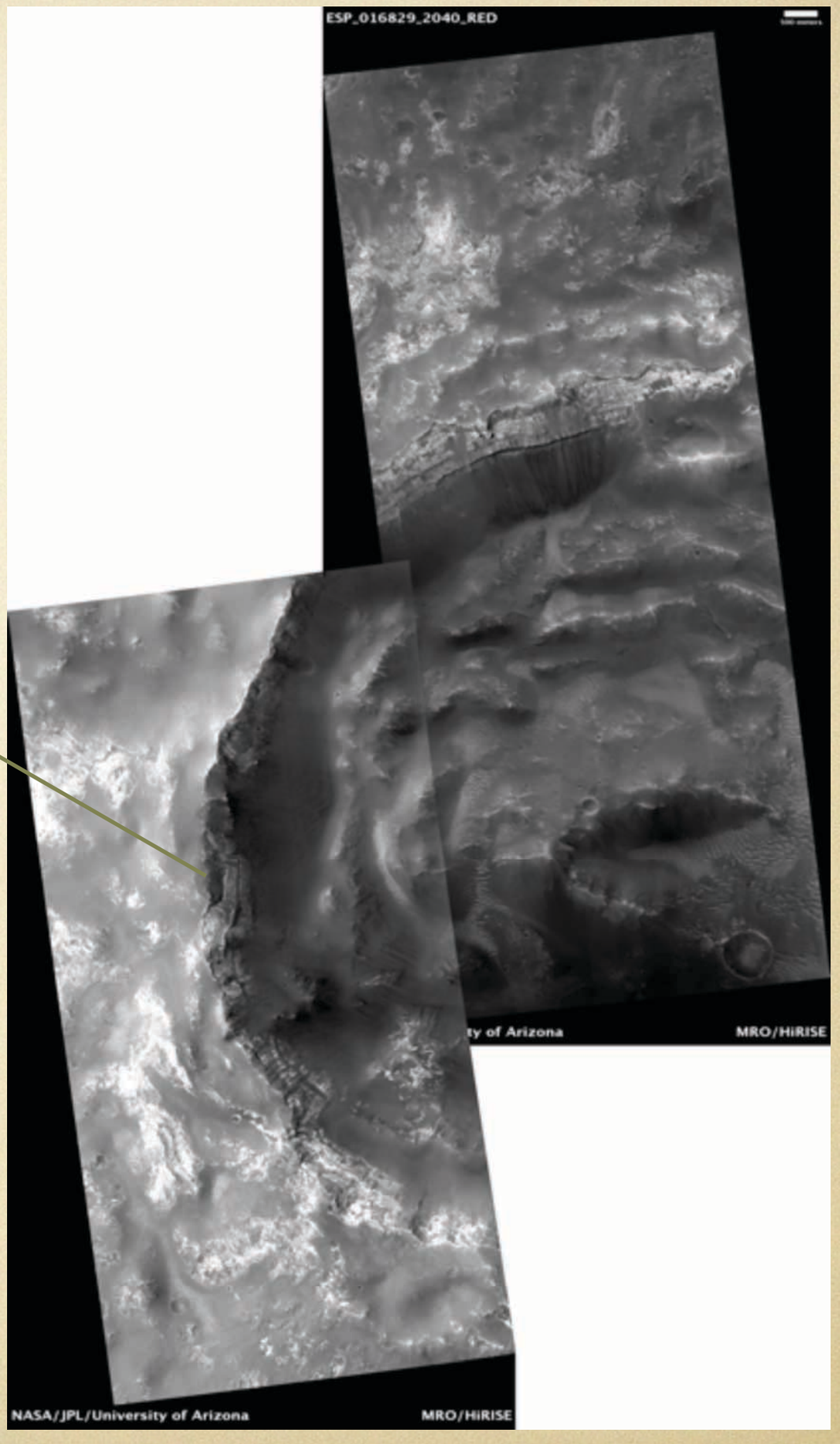


Layering in ~17 km Crater

~ 17 km Crater

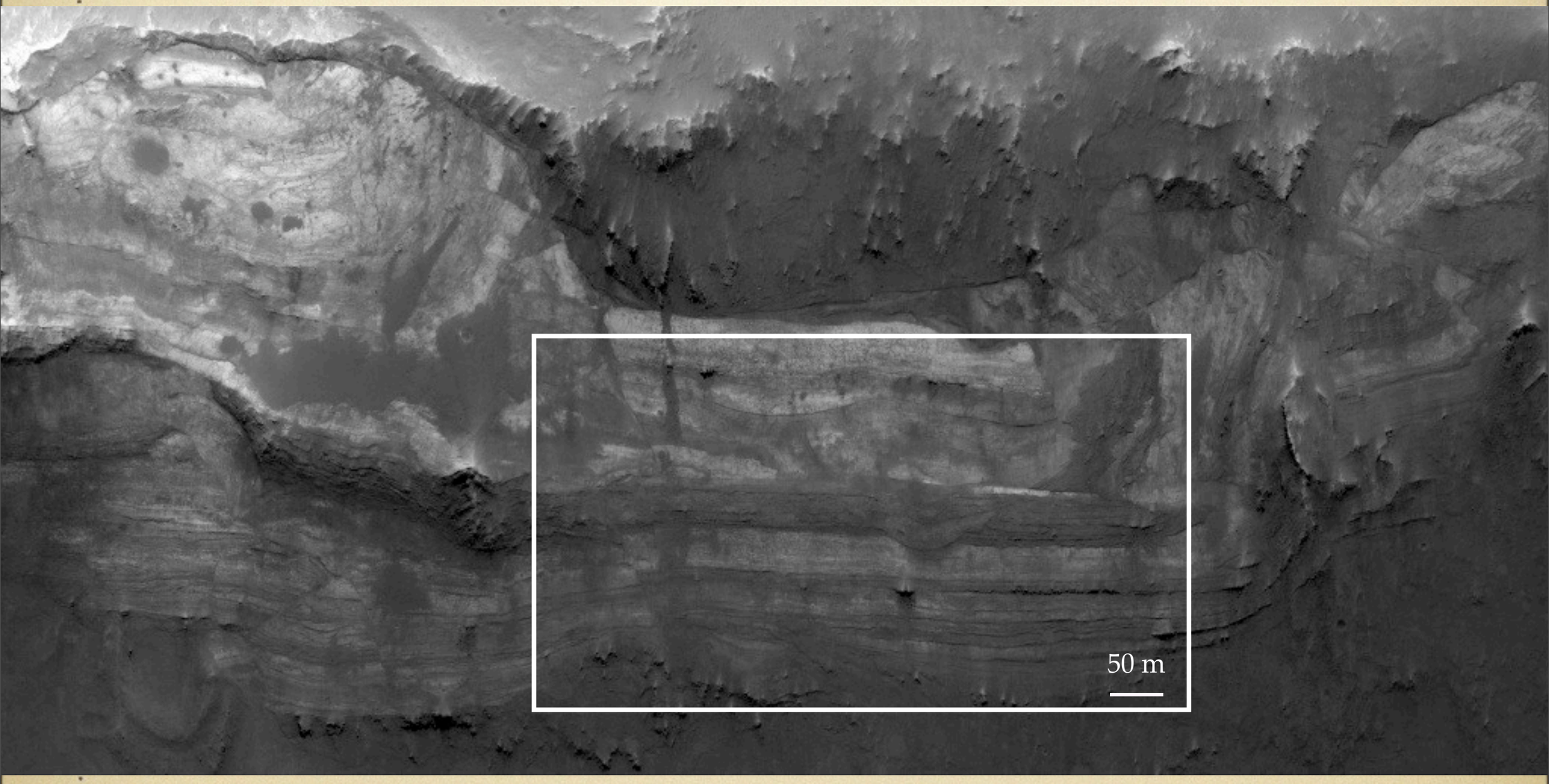


500 m



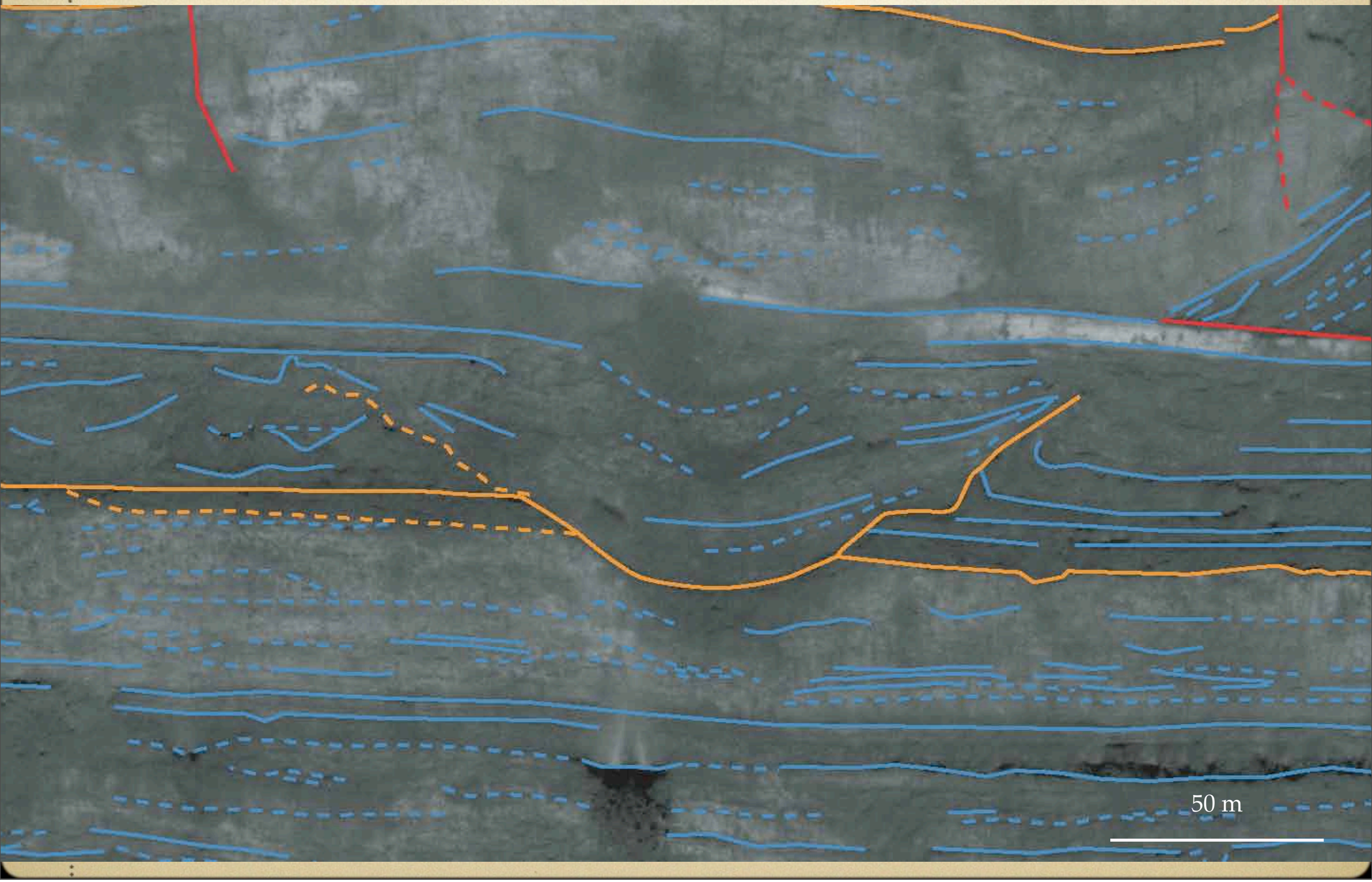
“Homework”: Map the boxed area

(Me, John Grotzinger, Linda Kah, Gilles Dromart, Ralph Milliken, Ken Edgett, Dave Vaniman)



Red = fault, Orange = major contact, Blue = layering
Solid = more confident, Dashed = less confident

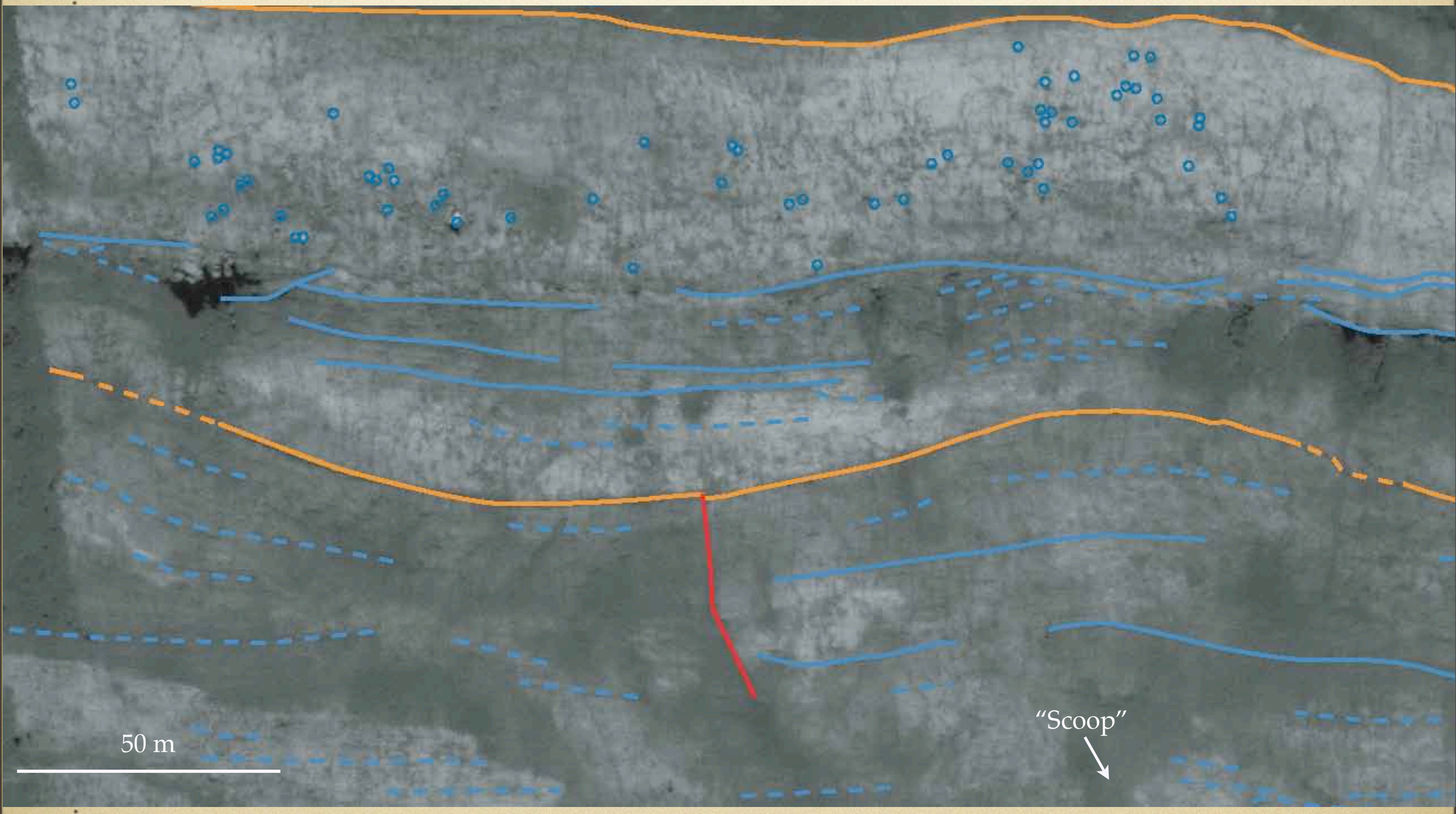
Everyone Identified Upturned Layers at Edge of “Scoop”, No Fault in Lower or Higher Strata



Scoop-shaped Feature Origin

- Observations:
  - Strata on one margin upturned by meters
  - No fault along this contact because lower and higher layers are continuous
  - Strata infill topographic low
- Interpretations:
  - Strata were upturned by the process creating the “scoop”
    - Channel erosion does not deform strata like this.
  - Formation and fill of the “scoop” occurred prior to deposition of the overlying lighter layers.
  - The generally preferred interpretation (and my interpretation) is that the “scoop” is a small impact crater embedded in the stratigraphy.

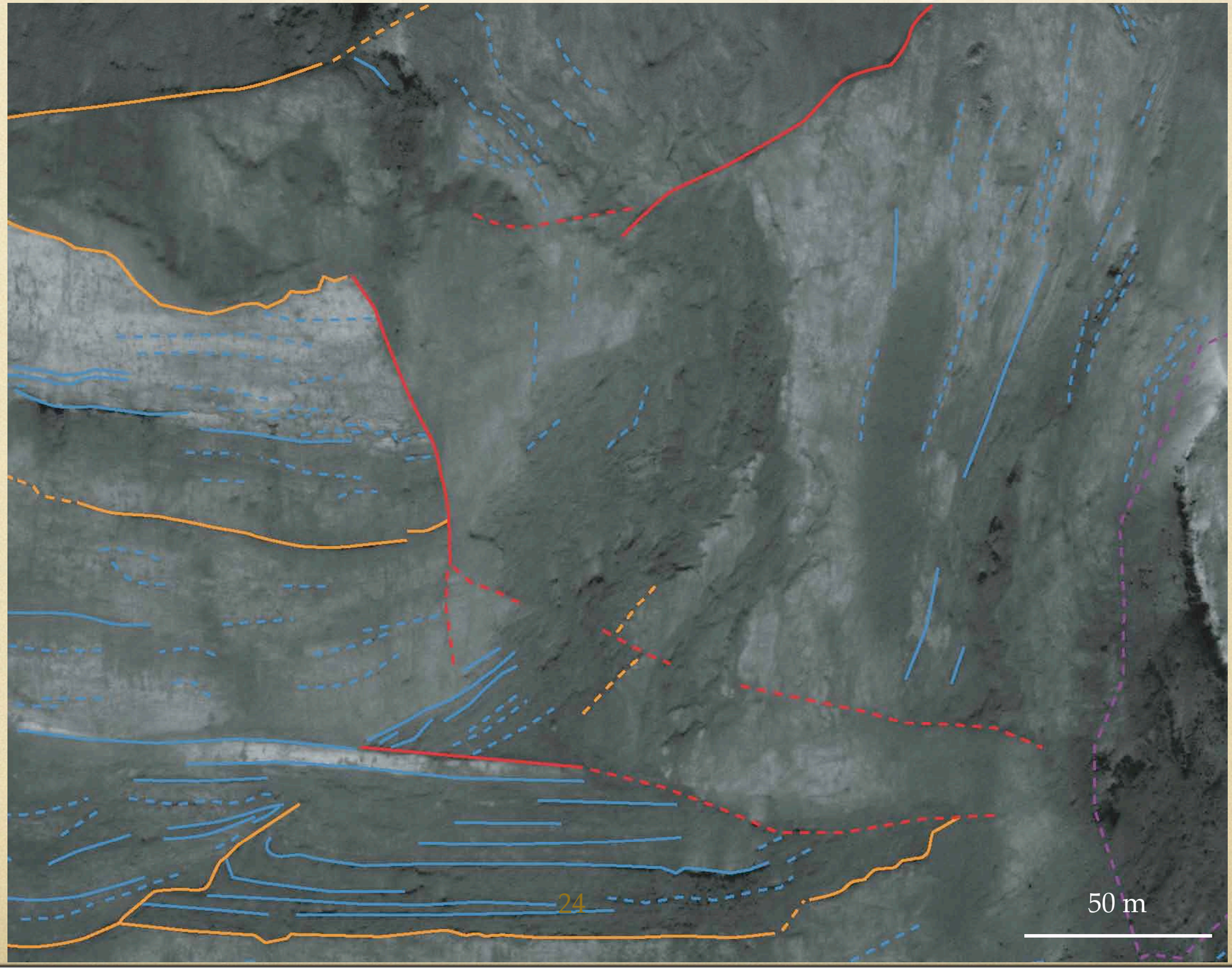
6/7 Identified accretionary topography filled with sediment; Dawn mapped higher and identified breccia.



Accretionary Topography Origin

- Observations:
  - Faint layering suggests domed topography increased gradually upward
  - Topographic low at upper surface of domed unit does not truncate underlying layers
  - Strata infill topographic low
- Interpretation:
  - A depositional process created the mound
    - Long-wavelength, low-amplitude folding possible, but no basal surface identified.
- Discussed Options:
  - A mega base surge deposit was posited, but the scale is outside the realm of anything we have knowledge of.
  - No other possible sedimentary process was identified.

Everyone mapped a fault at the base of the steeply dipping layers; how that fault connected to other structures varied greatly.



Cause of Deformation

- Observations:
  - Upturned layering
  - Faults are not continuous
  - Relationship with laterally equivalent flat-lying rocks unclear
- Interpretations:
  - Geometry is not consistent with tectonic faulting
  - Impact-related deformation is likely
    - Two impacts that may have caused this deformation: a small, older crater to the north (right) or the impact that formed the 17 km diameter crater
  - Dave Vaniman raised the critically important issue of possible vaporization of hydrous minerals during impacts, and some of the observed relationships might be influenced by phase changes.
- There are many other similar deformational relationships in many craters...

Summary of Physical Outcrop Characteristics

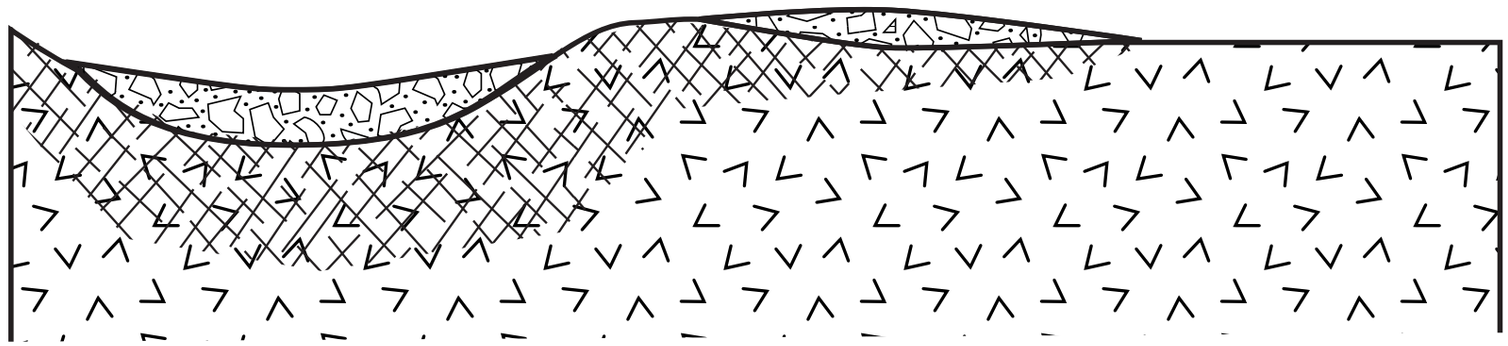
(back to Dawn's work)

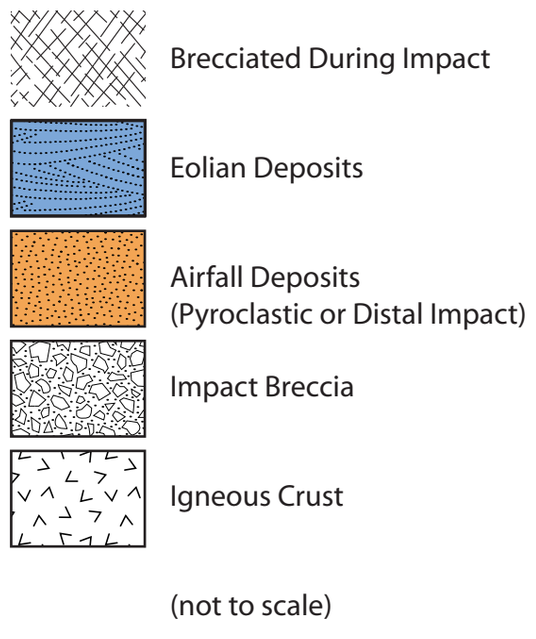
- Deformation is present in the form of:
  - Deformed layering in crater walls.
  - Variably dipping beds in west bank of Mawrth Vallis
  - Non-contractional brecciation of rocks in the landing ellipse
- Layering is sparse in the vicinity of the landing ellipse.
  - I did not find anything within the ellipse that I would consider sedimentary layering, although it may be present.
  - Layering is present in deeper small craters outside the ellipse, but it is deformed.
  - Layering is present in Mawrth Vallis and elsewhere ~10 km E and NE of ellipse, possibly closer.
- Craters are abundant, both on the surface and embedded in the stratigraphy.
  - See Michalski and Noe Dobrea 2007; Wray et al. 2008; Loizeau et al. 2010.

An End-Member Model for Impact-Dominated Rock Accumulation

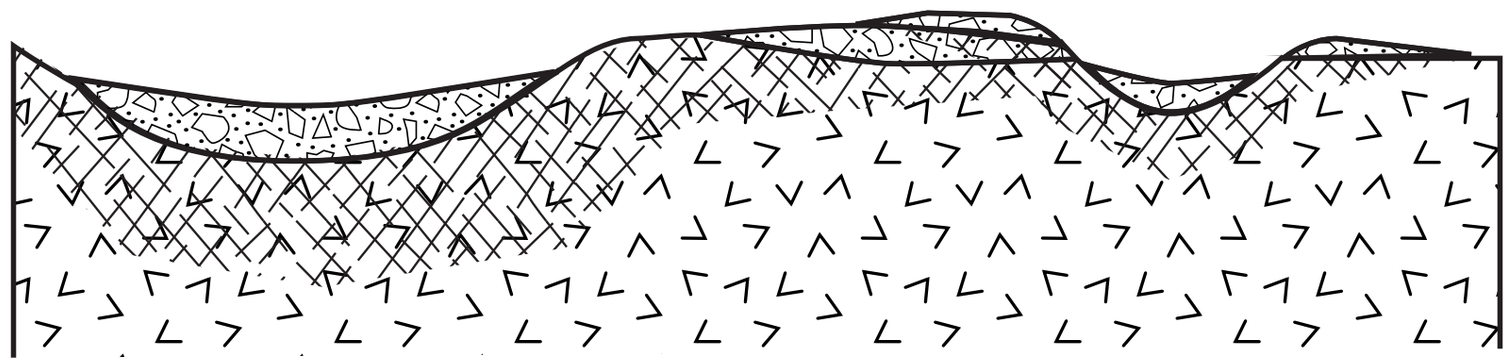
- The following slides represent my first-order model for how rock might accumulate in an environment that is dominated by impacts (maybe more so than Mawrth).
- Assumptions (mostly based on reasonable extrapolation of literature; see Sumner, in review, link at beginning and end of presentation)
  - Impacts fracture bedrock for ~1 crater radius from the crater wall at depth & more at the surface because it is a free boundary.
  - Ejecta are distributed ~1 crater diameter from the crater
  - Airfall processes add material (from eruptions or distant impacts)
  - Eolian processes redistribute materials
  - Other sedimentary processes are ignored for simplicity, but likely would be present.

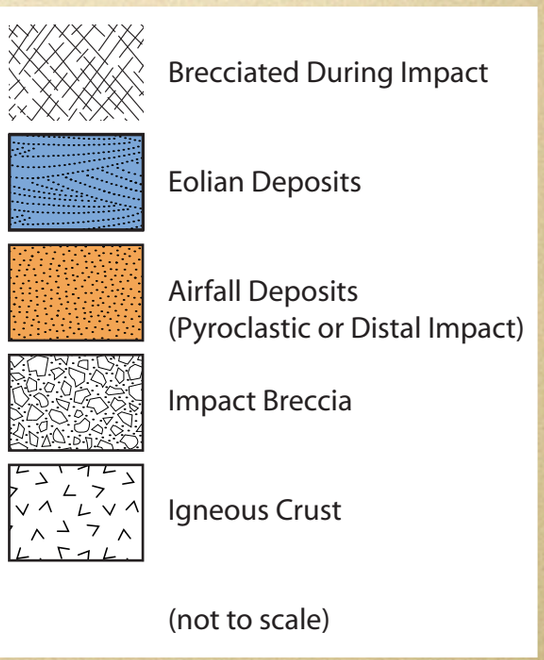
Time 1




Brecciated During Impact
Eolian Deposits
Airfall Deposits
(Pyroclastic or Distal Impact)
Impact Breccia
Igneous Crust
(not to scale)

Time 2

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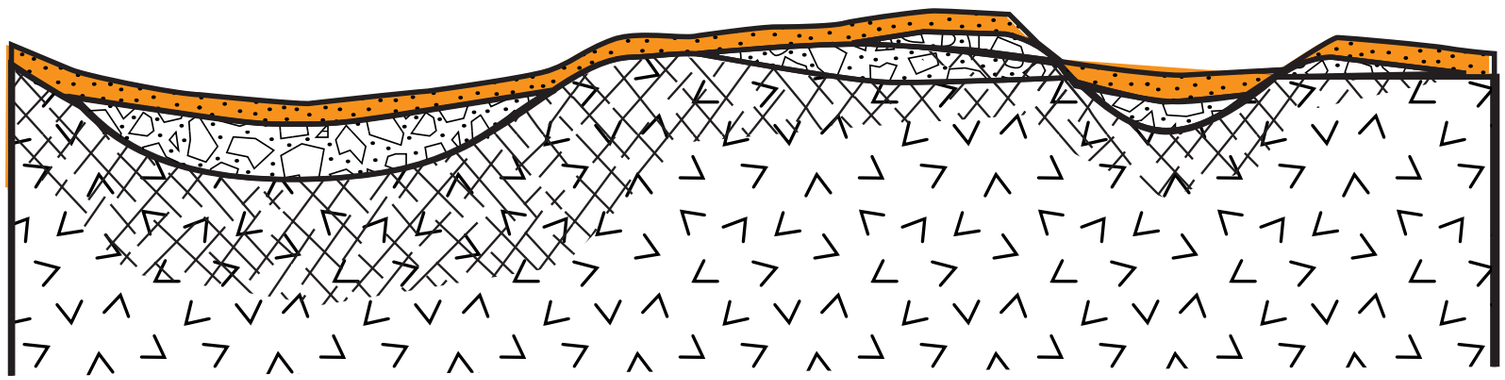
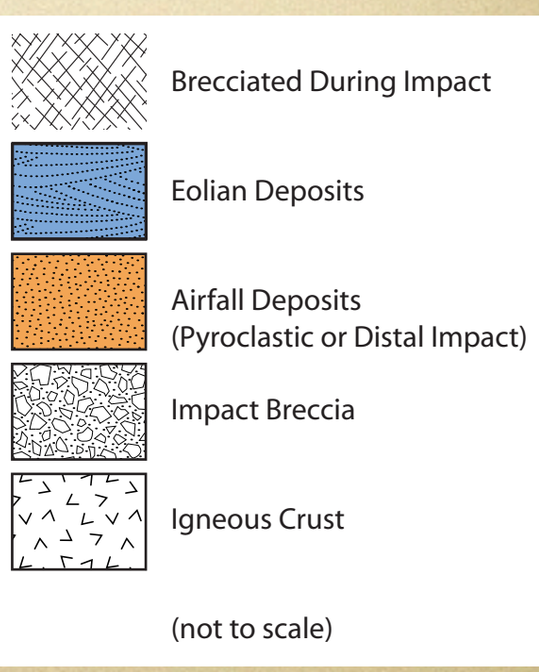
Time 3

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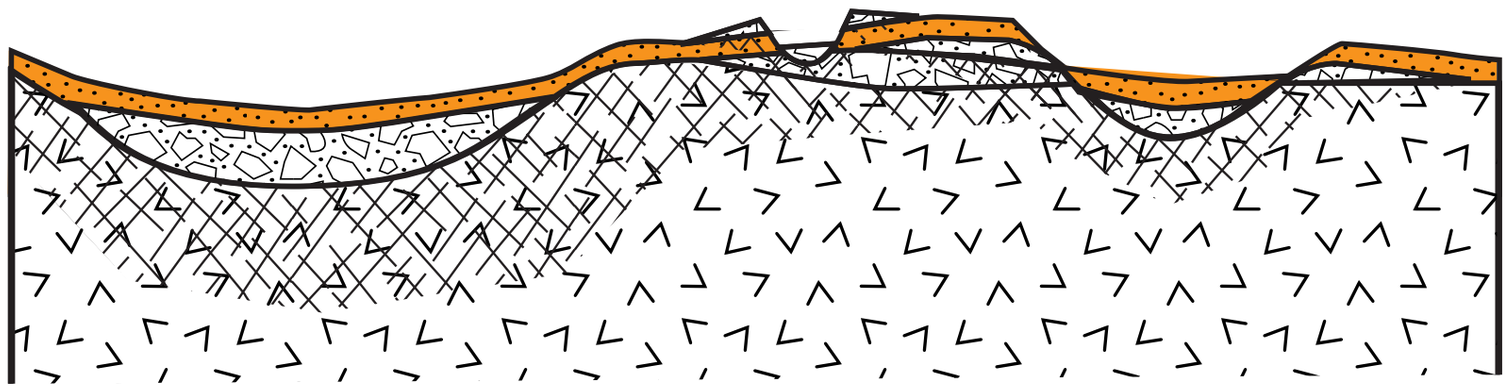
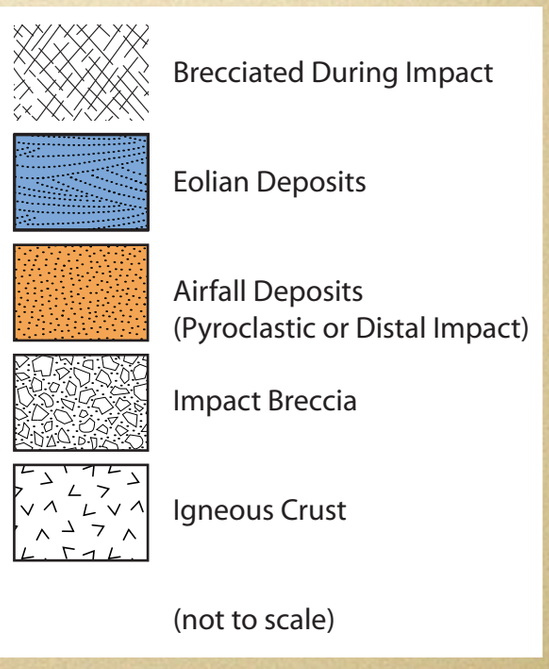
Time 4

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Igneous Crust
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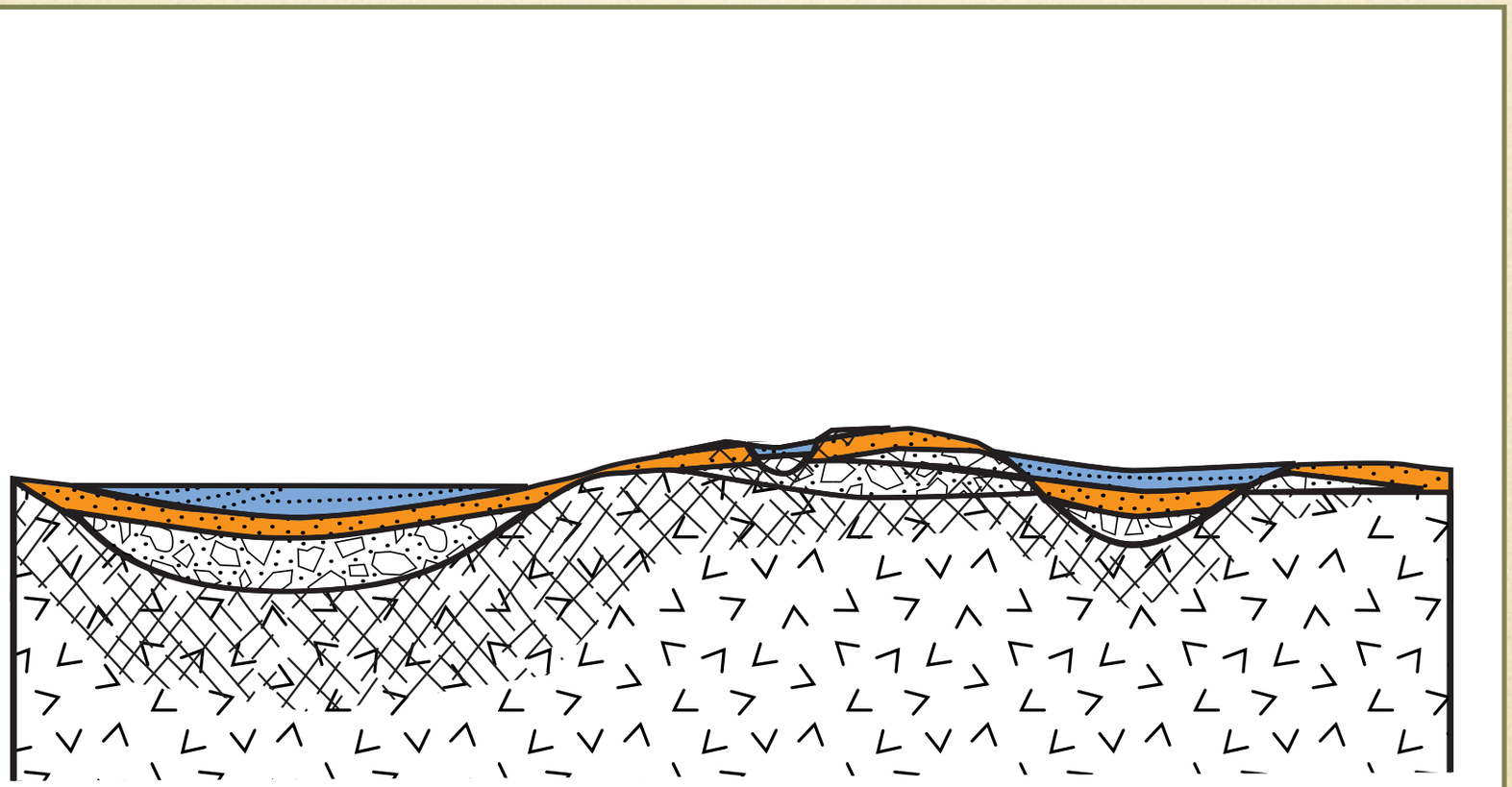
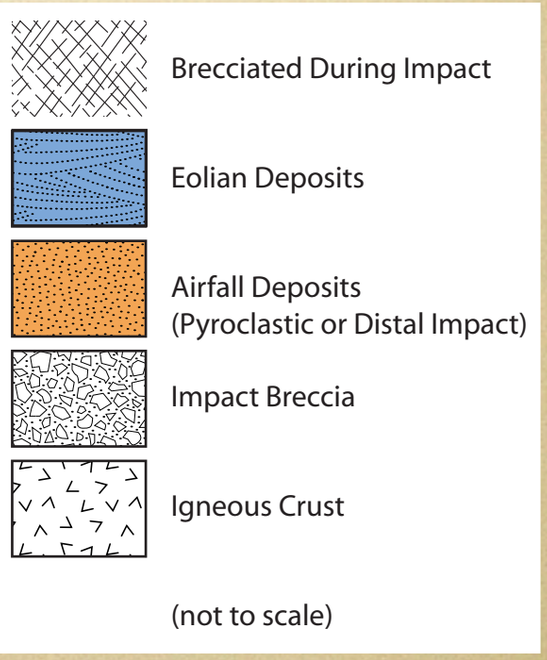
Time 5

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Igneous Crust
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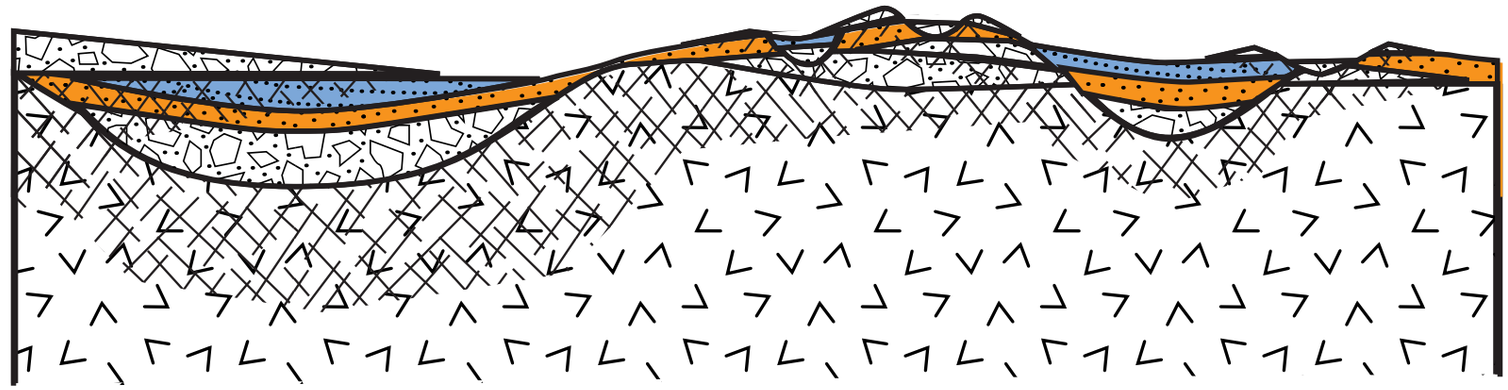
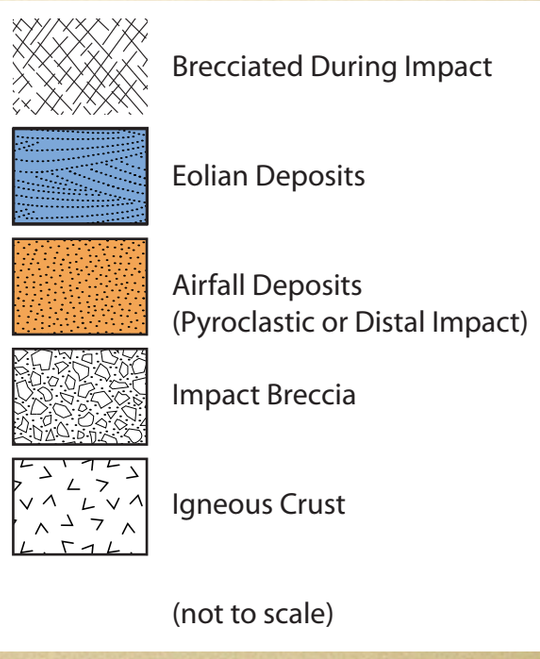
Time 6

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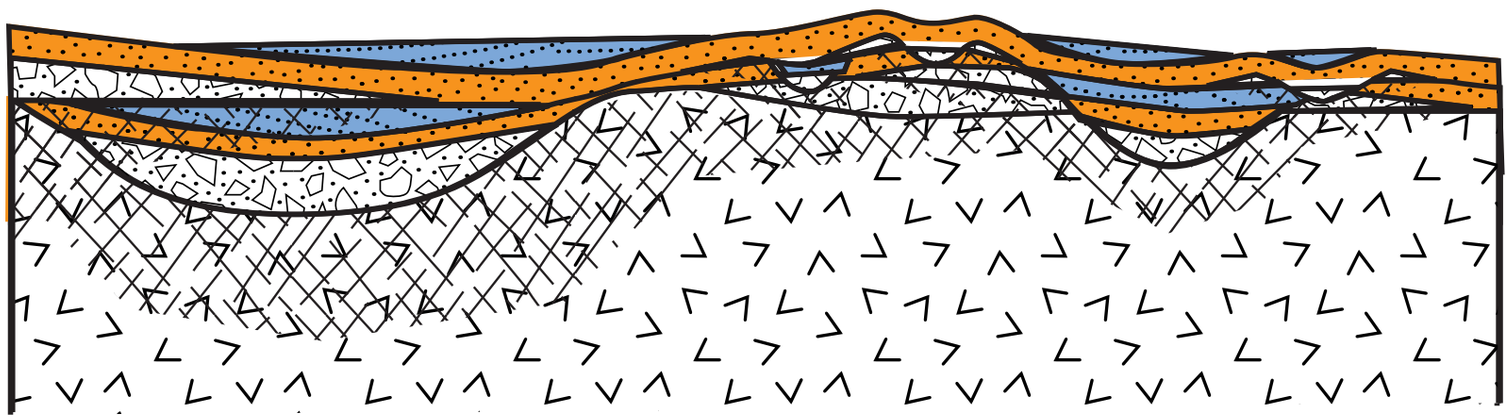
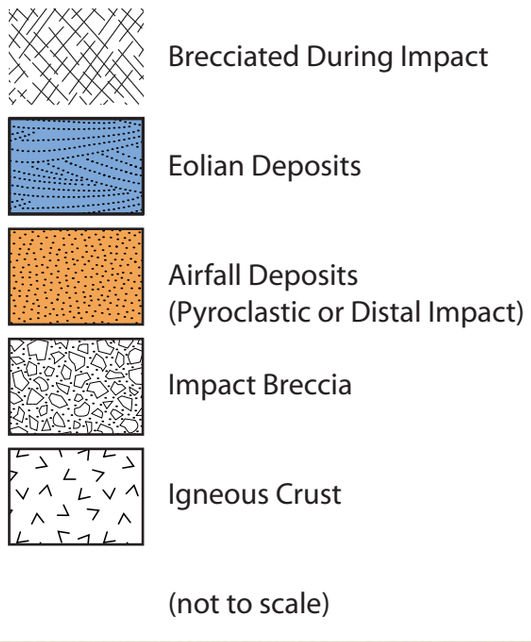
Igneous Crust
(not to scale)

Time 7

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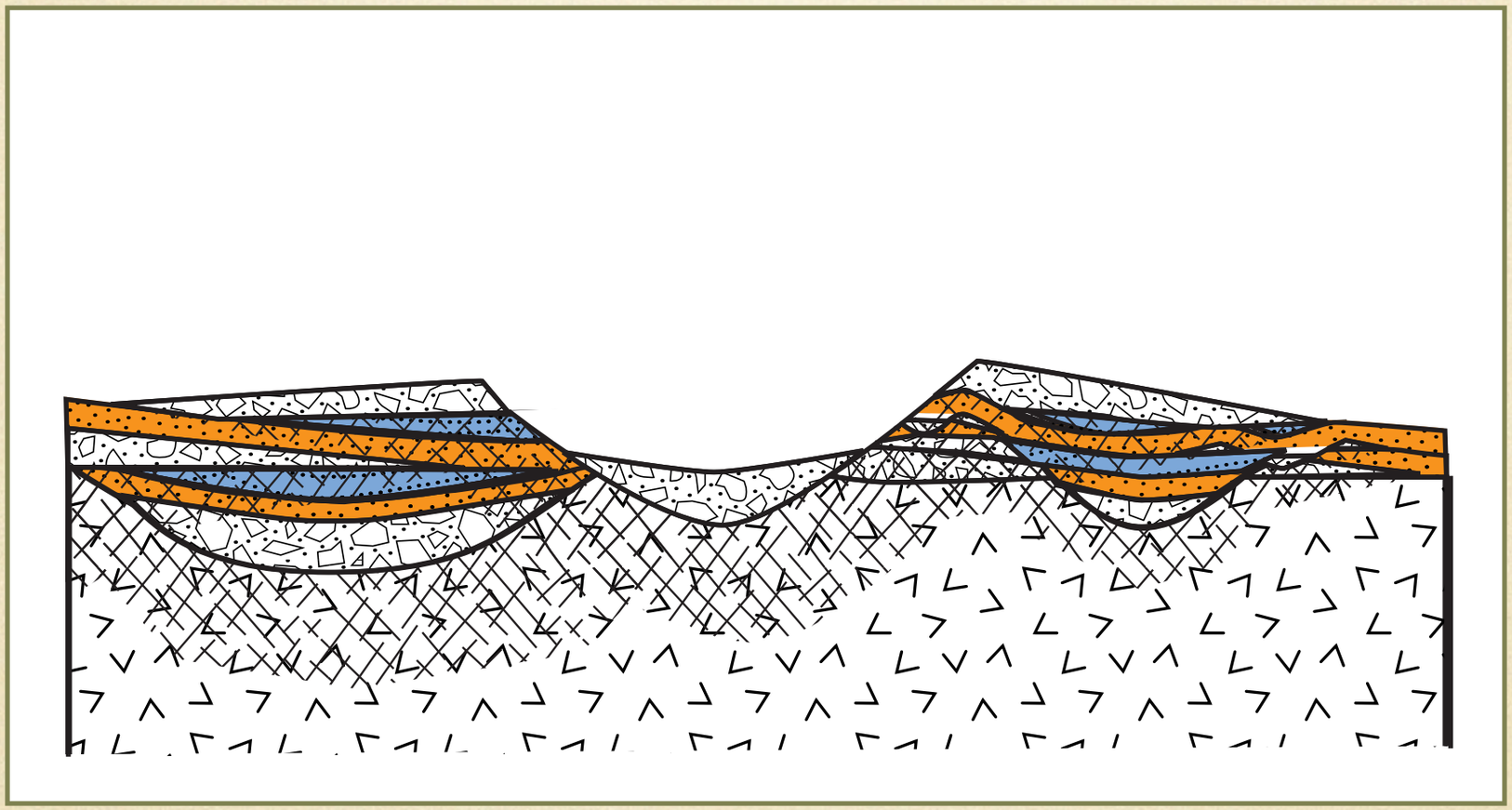
Time 8



- Results of Deposition Dominated by Impacts:
  - Laterally discontinuous strata
  - Abundant brecciation of bedrock and strata
  - Layers with very diverse grain sizes (breccia to eolian sand, plus dust as always)

How Much Might the Impact Rock-Accumulation Model Apply to Mawrth?

- My observations are consistent with the impact rock-accumulation model, but they do not require this model.
- My observations are inconsistent with "normal" sedimentary models unless deformation process(es) overprinted them. (There are not laterally continuous strata exposed across the region.)
- One can "relax" the impact model and allow additional processes such as impact melts, hydrothermal activity (including regional low temperature groundwater circulation), crater lakes, local fluvial systems, etc. These will increase the heterogeneity of accumulated rock.
- The Mawrth Landing Ellipse is next to the ~100 km diameter Oyama Crater, which should have influenced bedrock in the landing ellipse.

How Consistent is the Impact Rock-Accumulation Model with Observed Mineralogy?

Very!

- The **only** previously proposed origins of the hydrous minerals that the impact model is **inconsistent** with are those for sedimentary accumulation in a regional sea or through-going fluvial system.
- Impacts might enhance hydrous-mineral formation by increasing permeability and providing heat for groundwater circulation.

Conclusions

Some of these results can be found in
http://mygeologypage.ucdavis.edu/sumner/Sumner_Mawrth.pdf (submitted to Mars 9/2010)

- Impacts may have played a significant role in shaping the light-toned bedrock at the Mawrth candidate landing site.
- Minimally, the impact rock-accumulation model provides a rough framework for additional studies of the Mawrth candidate field site. For example:
  - Careful mapping of breccia types/fracture orientations with special attention to proximity to Oyama Crater and smaller craters will provide insights into whether Oyama or smaller impacts played a larger role in shaping Mawrth outcrops (or neither).
  - The effects of impact processes on bedrock weathering could be considered in models of hydrous mineral formation, especially the effects of regional groundwater flow increasing water-rock ratios.
- Habitability and preservation issues related to impacts were addressed by Jen Eigenbrode on day 1; please see her presentation.