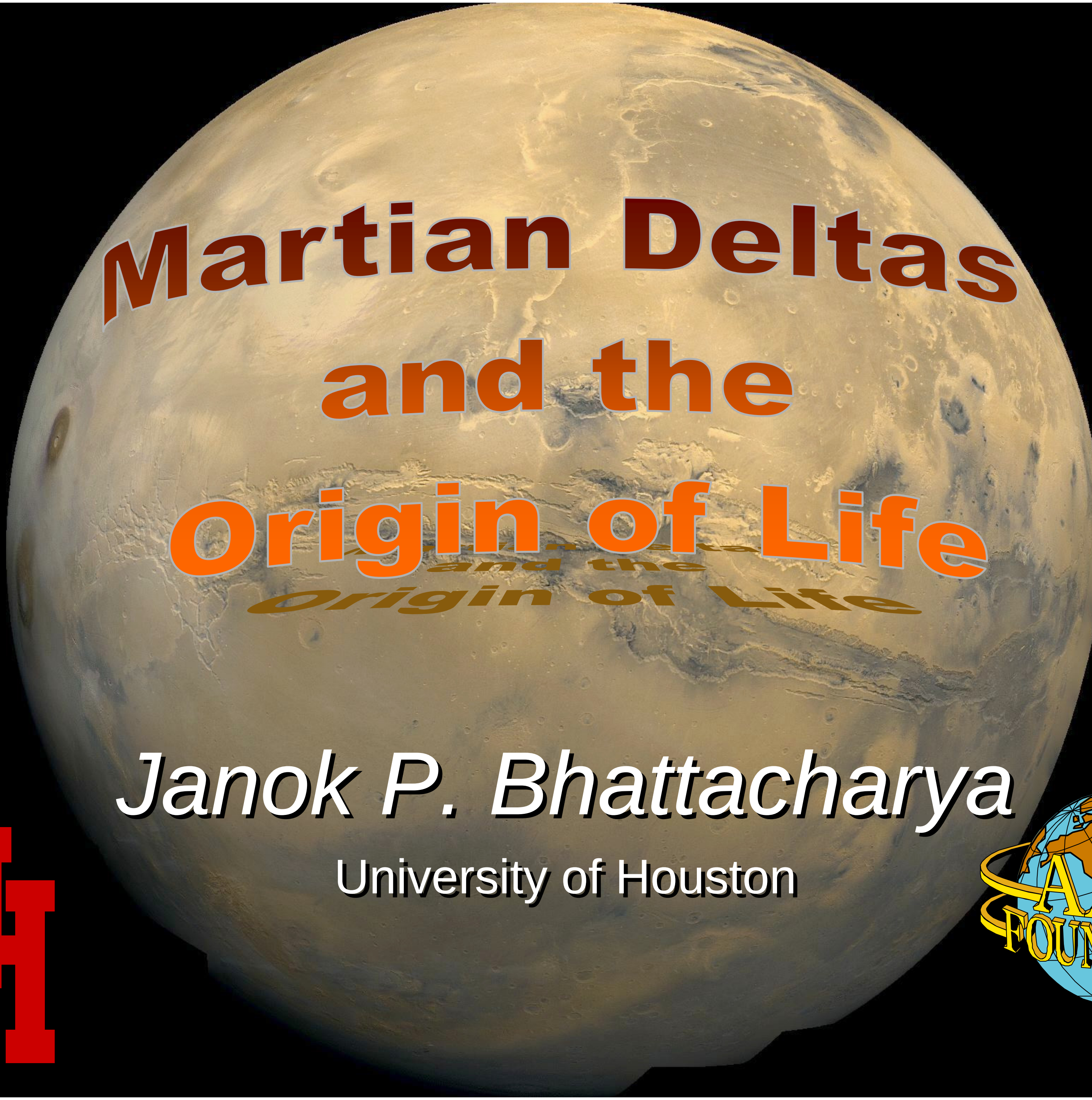

Martian Deltas and the Origin of Life

Janok P. Bhattacharya

University of Houston

Outline

- Introduction
- History of Life on Earth
- Martian Deltas
  - Possible ancient habitat
- Conclusion

Key Questions

- When did life appear on earth?
- Could life have appeared anywhere else in the solar system or universe?
- Where and how to look for evidence of life in the "universe"?
  - Need to find habitable environments.

Outline

- Introduction
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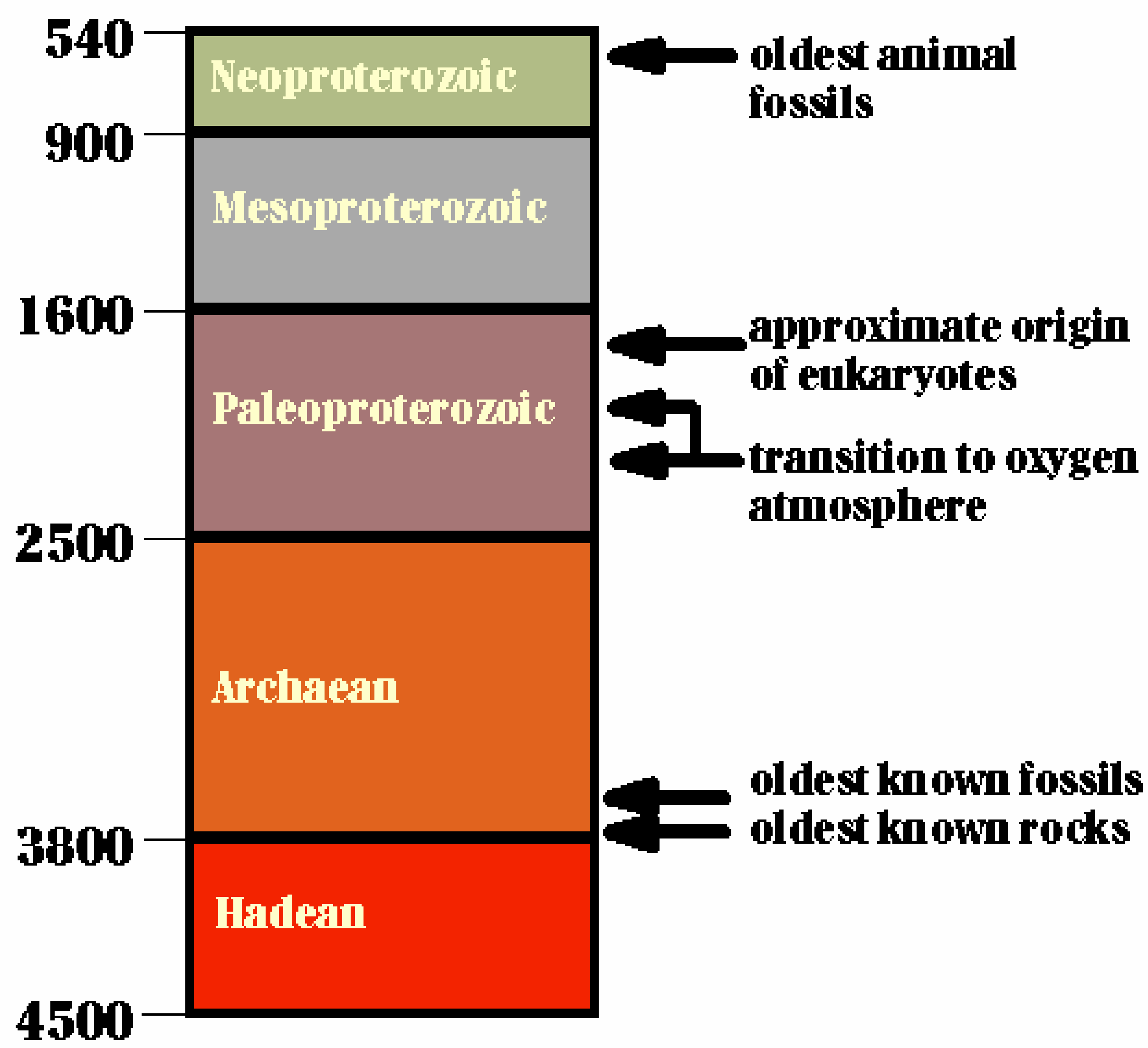
Precambrian - Early Earth Time Line

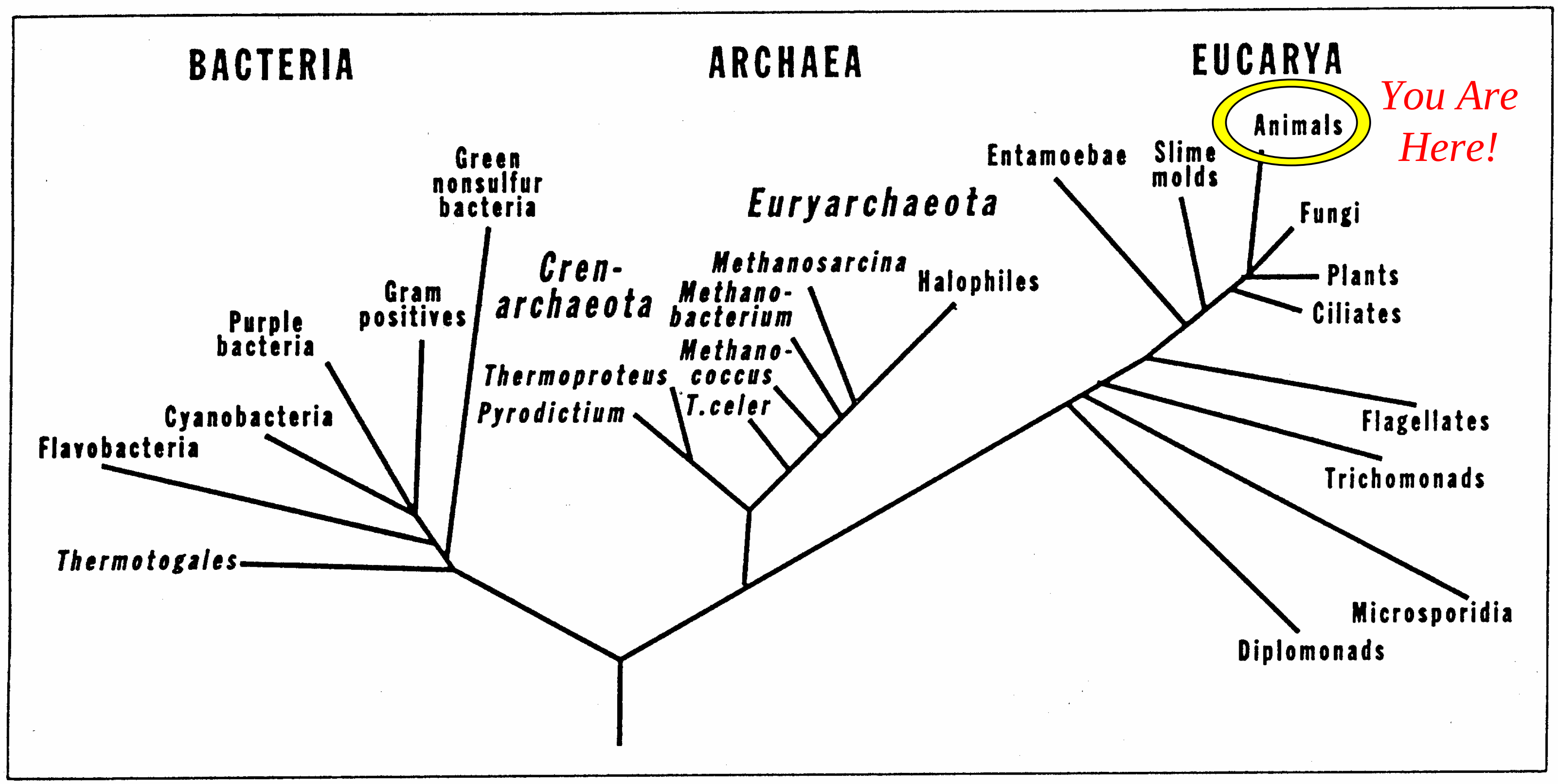
- 4.6 billion years to 544 million years.
- Represents 90% of all of the history of the earth.
- Referred to as the Cryptozoic Eon.
  - "hidden life"
- Used to be called Azoic Eon
  - "without life"



Early Life

- Single-celled Archea (ancient bacteria) appear in the fossil record very soon after rigid, cool earth crust formed.
- Why so soon?
  – Chemicals available
  – Water available
  – Lots of excess energy to power chemical reactions

Phylogeny of Cells



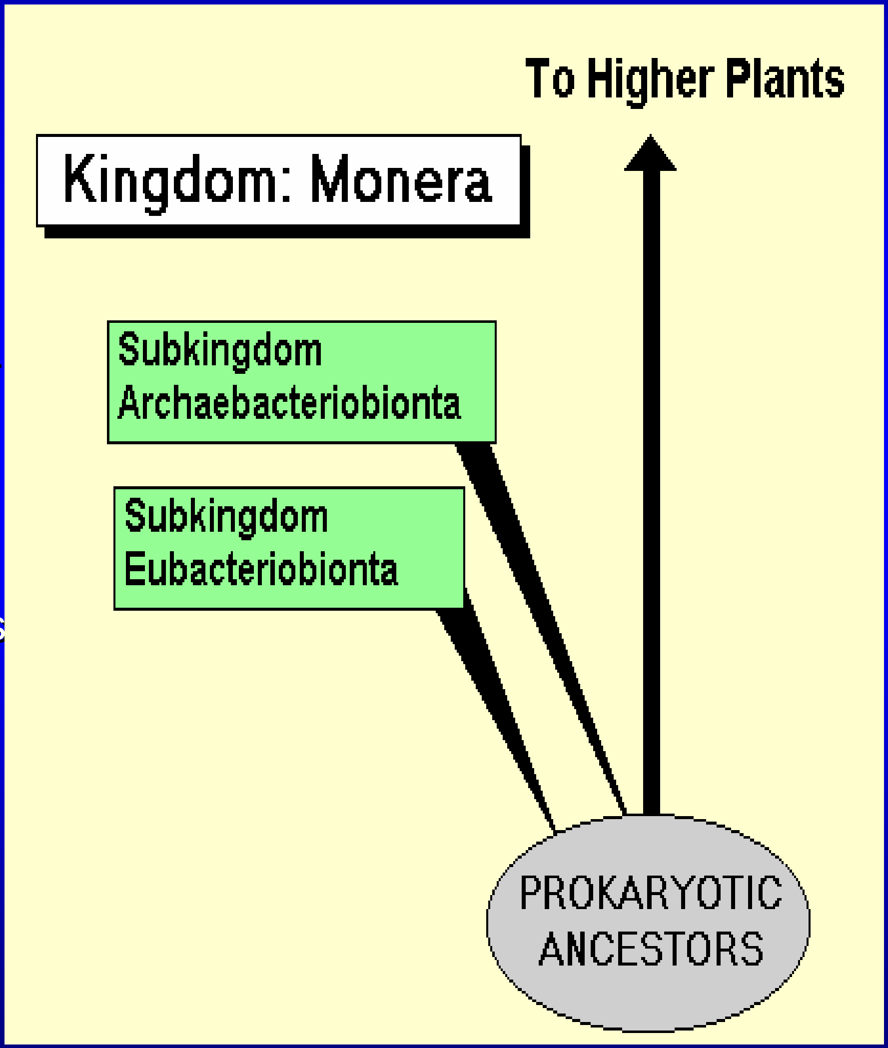
Experiments on Origin of First Cells

- 1950's and 1960's experiments combined atmospheric gases (NH_3, H_2, CH_4, water, electricity and heat to produced amino acids, formadehyde and cyanide.
  - Demonstrated abiotic processs could make precursors of life.
- Further experiments demonstrated that drying and re-wetting of these organic compounds could produce cell-like membranes and simple proteins.
  - Led to shallow water “primordial soup” theory.
- But organic compounds in shallow pools would have been instantly destroyed by ultraviolet radiation and oxidation in young, thin atmosphere.
- Life may have evolved far from sunlight in deep oceans around geothermal vents.

Stanley L. Miller, working in the laboratory of Harold C. Urey at the University of Chicago.

Origin of Archaebacteria

- Archaebacteria are the most primitive fossil life forms
  - Likely ancestors of all life.
- Primitive Archaebacteria are hyperthermophiles that thrive in boiling water.
  - Modern Archaebacteria live in deep-sea volcanic vents.
- Many Archaebacteria feed directly on sulfur (chemoautotrophs).
  - Archean life probably arose in deep oceans hydrothermal, volcanic vents that would have dotted the ocean floor near rifting zones.
  - Vents provide:
    - chemical and heat energy,
    - abundant chemical and mineral compounds, including sulfur
    - protection from oxygen and ultraviolet radiation.



Hydrothermal Origin of Archaebacteria

QuickTime™ and a
Sorenson Video decompressor
are needed to see this picture.

http://www.onr.navy.mil/focus/ocean/habitats/vents2.htm

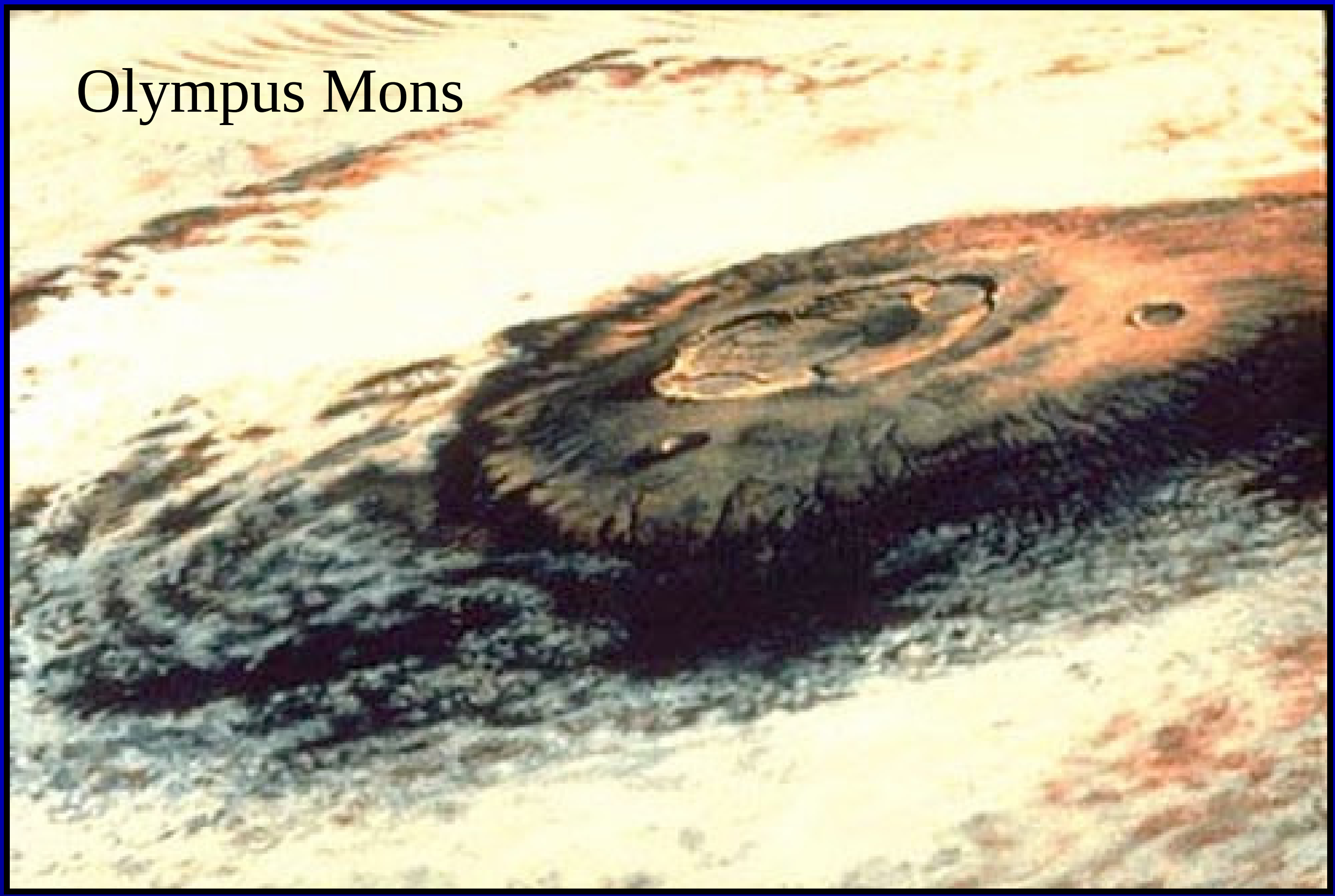
Modern hydrothermal vents support robust biota far from the sun!

Dan Fornari, WHOI

http://www.amnh.org/nationalcenter/expeditions/blacksmokers/smoker2.html

Possible Martian Habitats

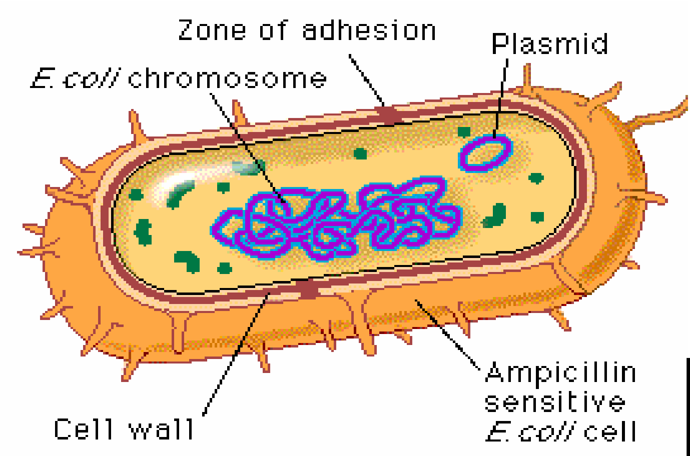
- Ancient Hydrothermal vent

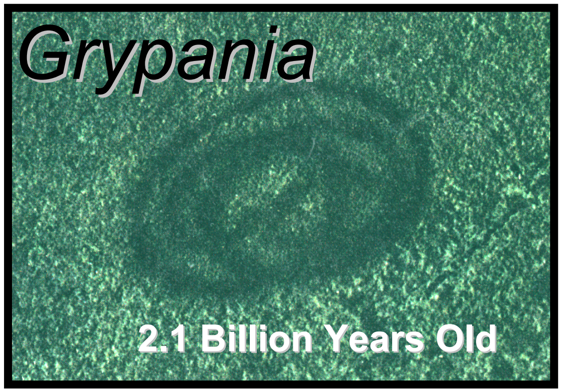


http://antwrp.gsfc.nasa.gov/apod/ap970915.html

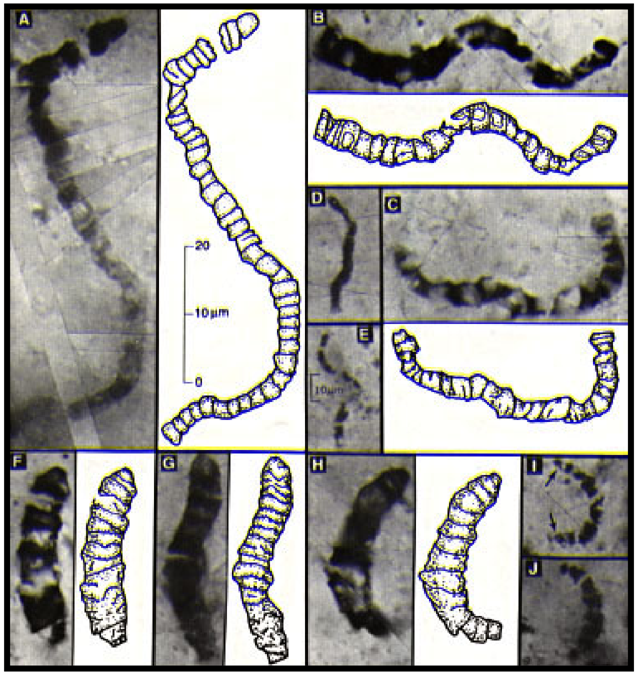
Fossil Bacteria

- Prokaryotic archaebacteria and eubacteria are dominant.
  - Eubacteria form stromatolites (photosynthetic).
  - More common in upper Archean as shallow water shelves began to form along margins of early continents.
  - Archean is the age of pond-scum.
- Molds of individual bacterial cells found in Precambrian cherts.





Used by permission of SEPM © 1968



Filamentous cyanobacteria, 3.46 Ga, Australia

Proterozoic Stromatolites Northwest Territories

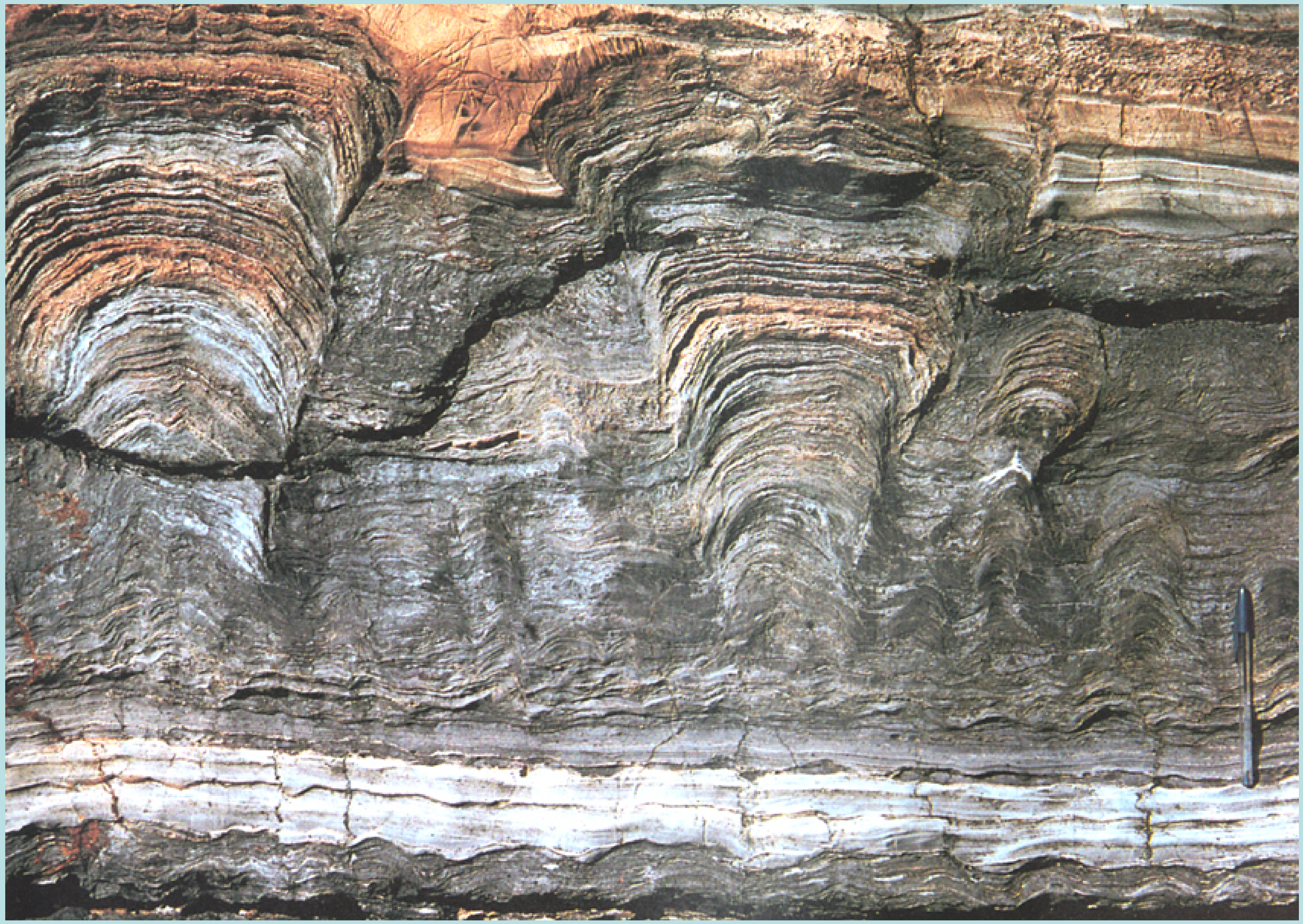


Photo from Paul Hoffman in James (1983)

Modern Stromatolites

Shark Bay Australia

Formed in hypersaline areas where grazing gastropods can not thrive.
Used to dominate the landscape in Precambrian and Early Cambrian.

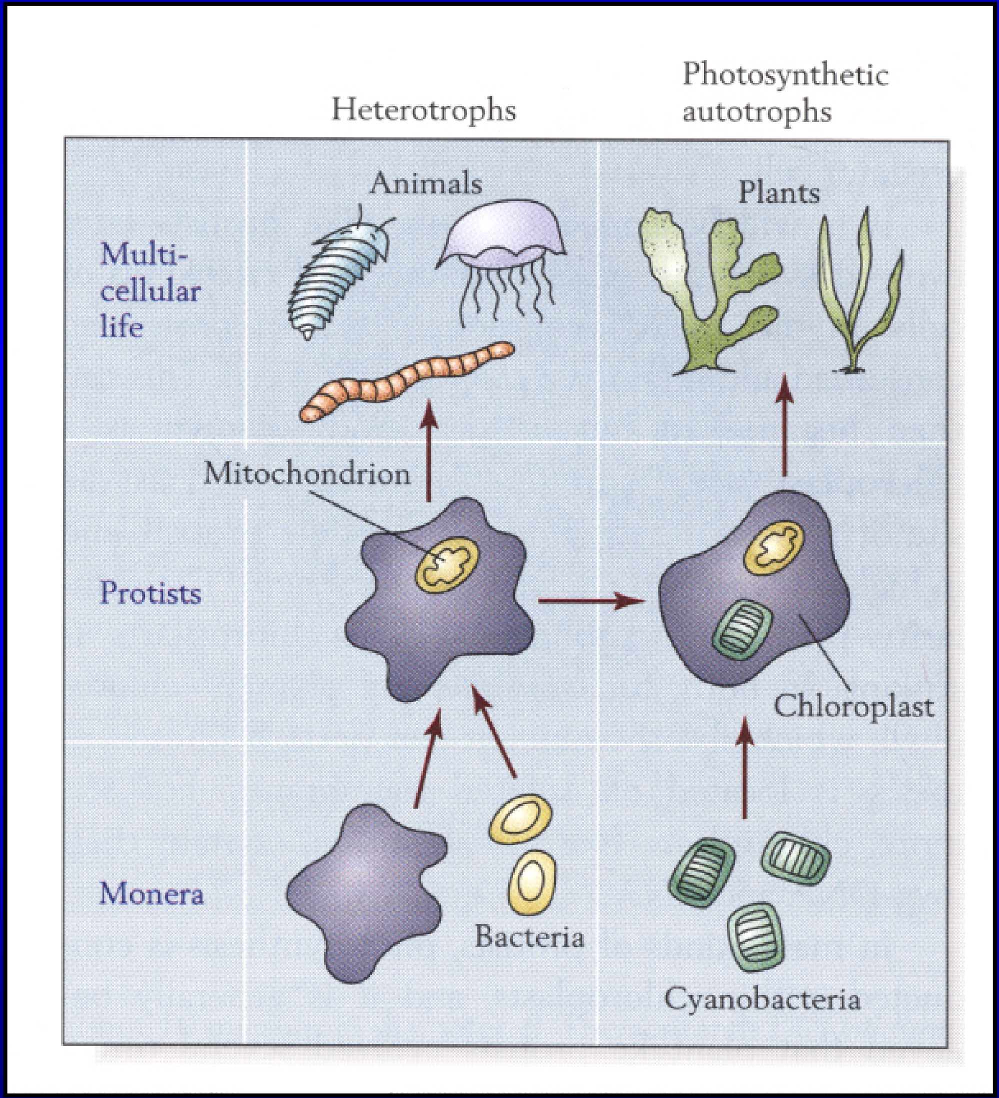
http://www.ucmp.berkeley.edu/bacteria/cyanofr.html

Habitable Martian Sedimentary Environments?

- Crater lakes
  - Long-standing or ephemeral?
- Shallow Seas
- Hydrothermal
- Back to Life Story

Evolution of Eukaryotes: c.1.8 Ga

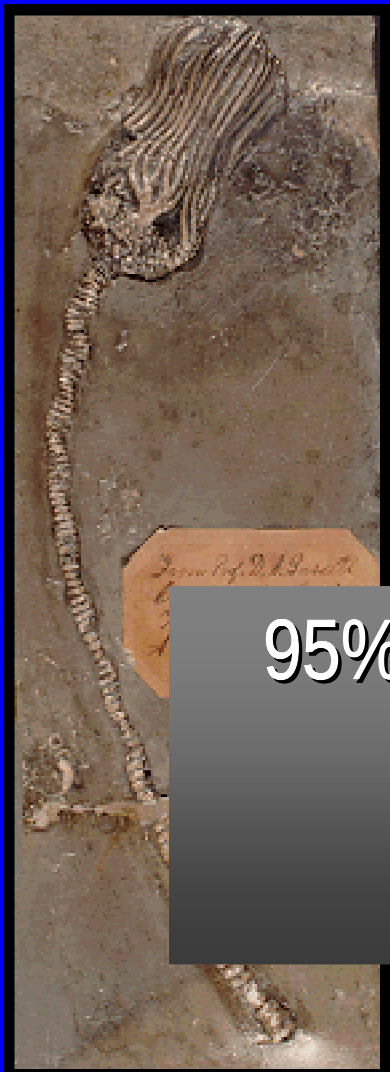
- Probably began as a symbiotic relationship between different prokaryotes.
- Early eukaryotes “ate” but could not digest a cell which became a mitochondria.
- Plant-like eukaryotic ancestors “ate” chlorophyll-bearing cyanobacteria.
- Once eukaryotes evolved, multi-cellular and colonial forms proliferated.

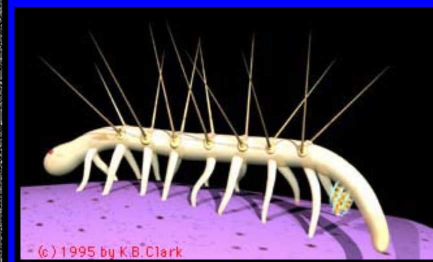


Appearance of Metazoans: 570 Ma

- Nothing more complicated on earth than bacteria for 4 Billion Years!
- First metazoans evolve about 570 million years ago.

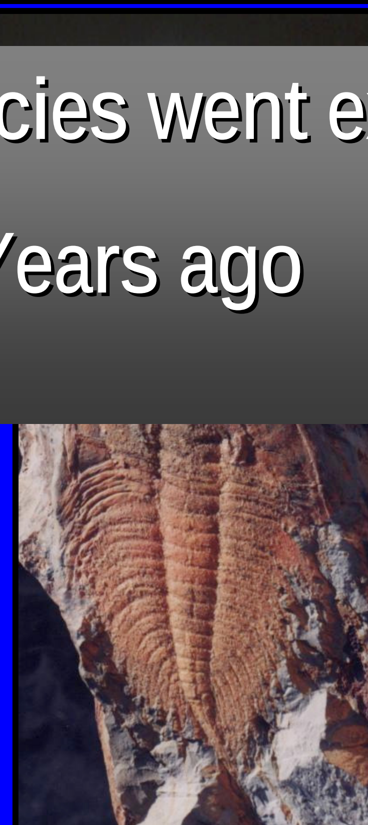
Paleozoic Life





95% of all marine species went extinct -

250 Million Years ago

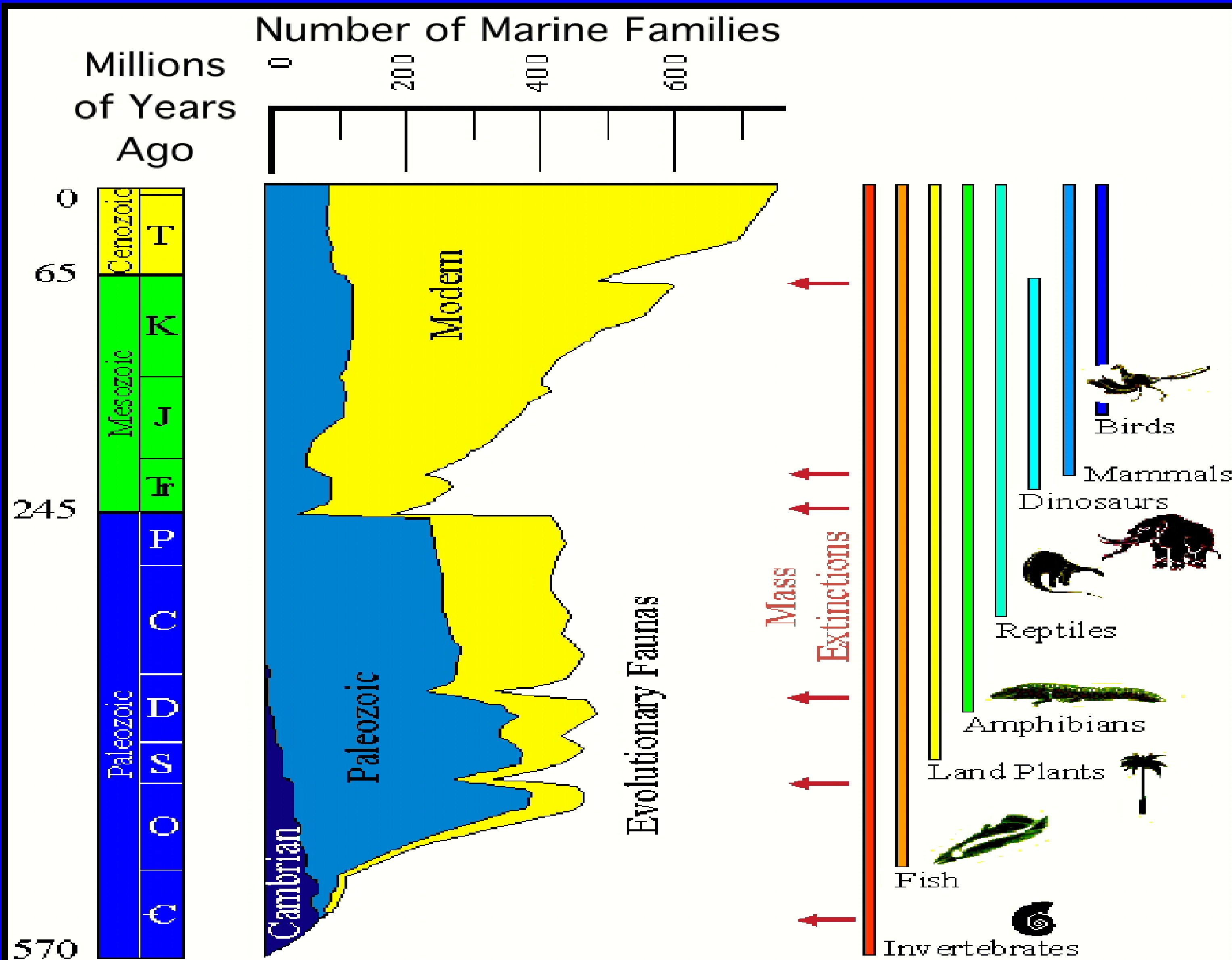


Mesozoic Life

Most of these creatures went extinct -

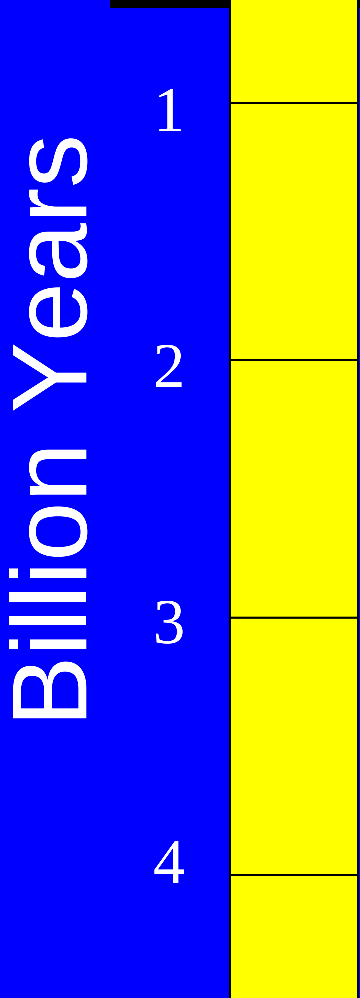
65 million years ago

Biologic Diversity Through Time



After J. John Sepkoski, Jr., 1981

Phanerozoic Diversity Through Time



Precambrian - dominated by bacteria and algae:

The Age of Pond Scum!

Hadean - No Fossil Evidence for life

After J. John Sepkoski, Jr., 1981

Non-Anthropoids

Anthropoids

Which event is unusual in Earth History

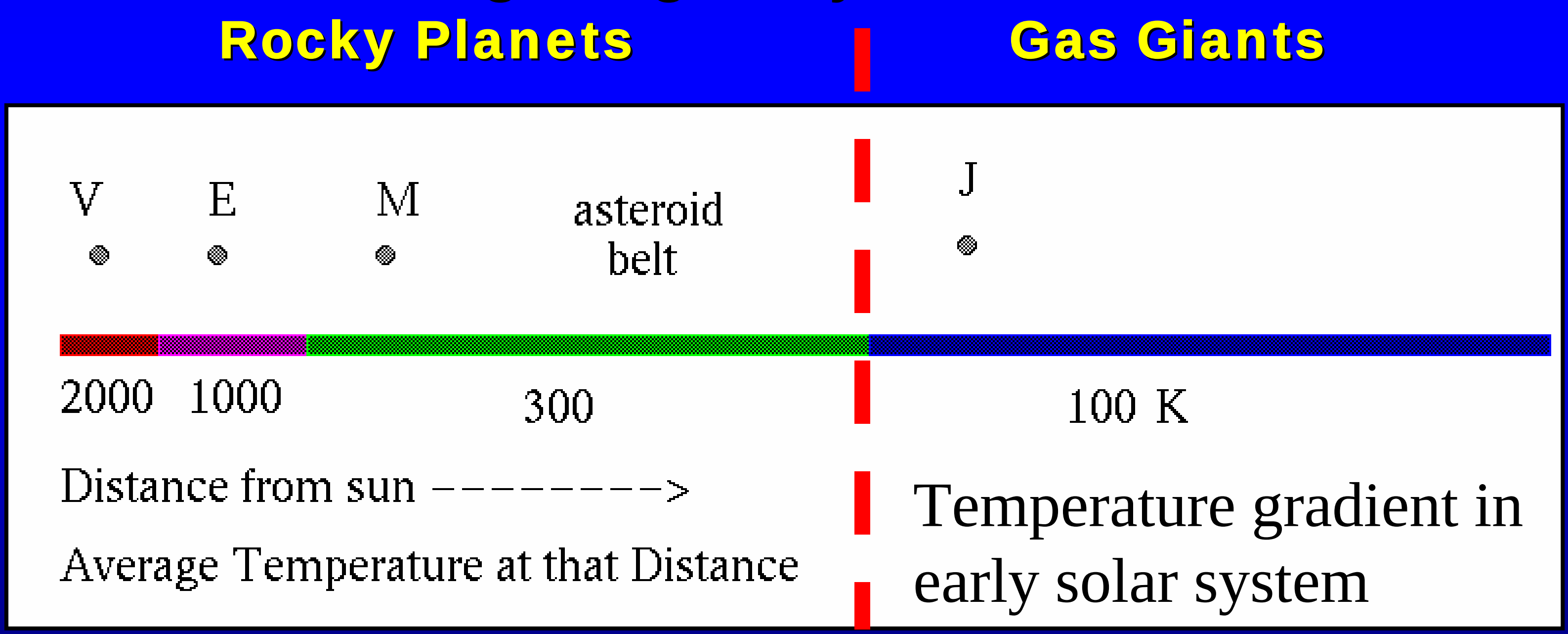
- Origin of Archea?
  – Inevitable?
- Rise of metazoans?
  – Took a *<u>long</u>* time
- Rise of vertebrates?
  – Followed soon after metazoans
- Appearance of language?
  – Only happened once, in 1 species in 4.6 billion years!

Which event is unusual in Earth History

- Origin of Archea?
  - Inevitable?
  - Look for evidence in solar system
- Origin of Language
  - SETI project

Comparison of Planets

- Because of temperature gradient, outer planets are icy and inner planets are rocky.
- Large planets also retain atmospheric gas because of higher gravity.



Temperature gradient in early solar system

http://zebu.uoregon.edu/1996/ph123/l10a.html

Searching for habitable environments on Mars: *"Follow the water"*

- Sedimentary Environments
  - Several have been found
  - Mars is a very layered planet
- Hydrothermal Environments
  - None identified to date (no active thermal events).
- Environments associated with groundwater or ice.
  - 2007 Phoenix Mission will sample polar ice.

AFL and Pathways

The following mission sequences were proposed by MSPSG (2003), as part of the Pathways planning process.

Pathway	2009	2011	2013	2016	2018	2020	NOTES
Search for Evidence of Past Life	MSL to Low Lat.	Scout	Ground Breaking MSR	Scout	Astrobio. Field Lab or Deep Drill	Scout	All core missions to mid-latitudes. Mission in '18 driven by MSL results and budget.
Explore Hydrothermal Habitats	MSL to Hydrothermal Deposit	Scout	Astrobiology Field Laboratory	Scout	Deep Drill	Scout	All core missions sent to active or extinct hydrothermal deposits.
Search for Present Life	MSL to N. Pole or Active Vent	Scout	Scout	MSR with Rover	Scout	Deep Drill	Missions to modern habitat. Path has highest risk.
Explore Evolution of Mars	MSL To Low Lat. (Netlanders)	Scout	Ground Breaking MSR	Aero-nomy	Network	Scout	Path rests on proof that Mars was never wet.

Outline

- Introduction
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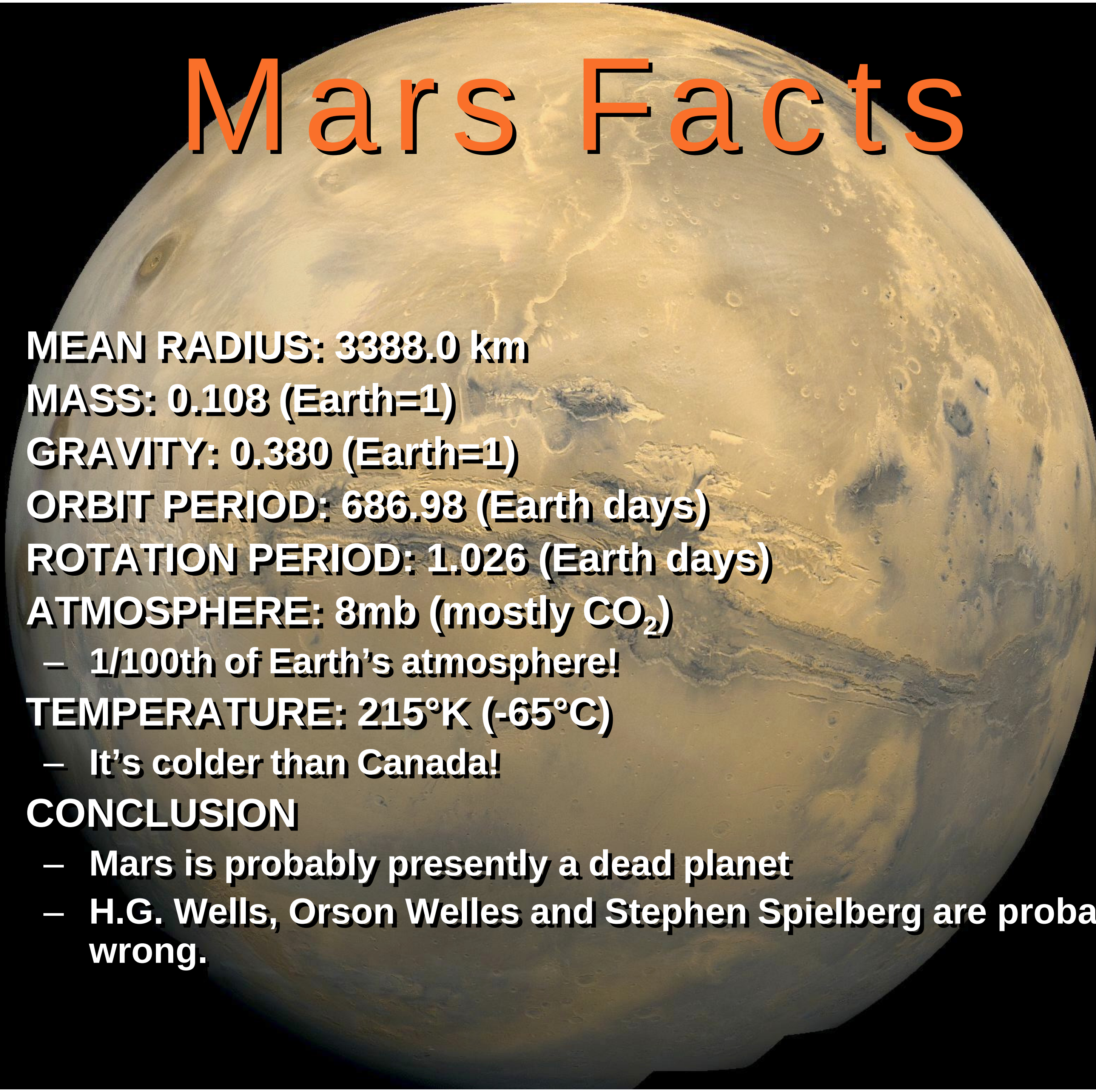
- Conclusion



Mars Facts

- MEAN RADIUS: 3388.0 km
- MASS: 0.108 (Earth=1)
- GRAVITY: 0.380 (Earth=1)
- ORBIT PERIOD: 686.98 (Earth days)
- ROTATION PERIOD: 1.026 (Earth days)
- ATMOSPHERE: 8mb (mostly CO_2)
  – 1/100th of Earth's atmosphere!
- TEMPERATURE: 215°K (-65°C)
  – It's colder than Canada!
- CONCLUSION
  – Mars is probably presently a dead planet
  – H.G. Wells, Orson Welles and Stephen Spielberg are probably wrong.

Was Early Mars Different?

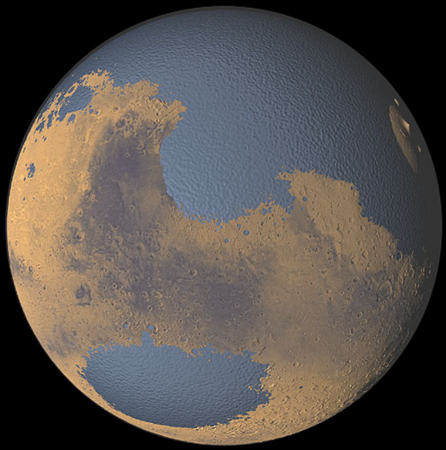
- **Mars may have been hotter and wetter in early history.**
- **Escape velocity of Mars much lower than Earth; so atmosphere has long since escaped.**
- **Could life have evolved on early Mars?**
- **Evidence for water compelling.**
- **Present NASA Missons have found evidence for water that could indicate potential habitats for life.**
  - **"Follow the water"**

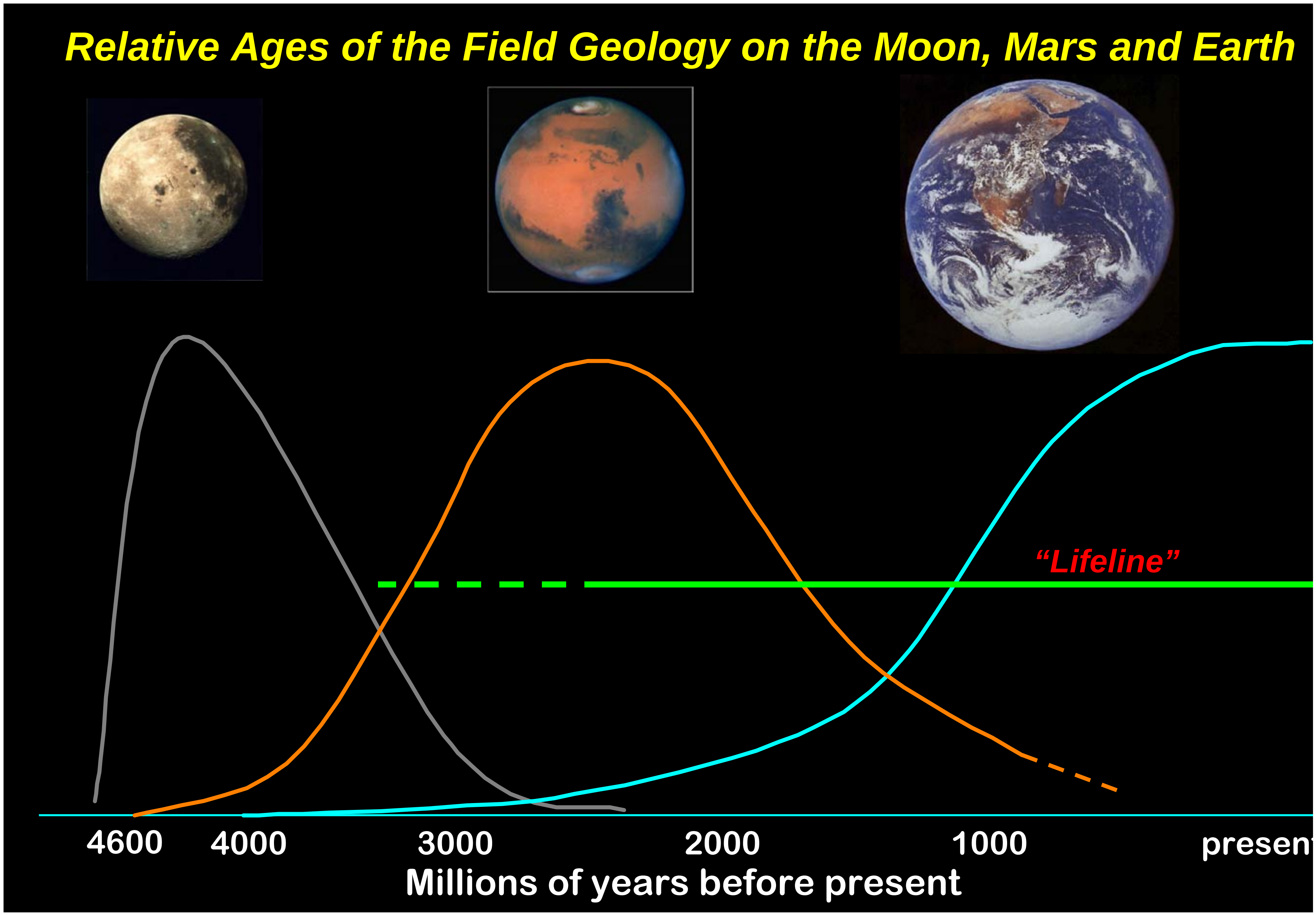
http://www.spaceref.com/tools/vi.html?id=166&cat=mars&imgs=mediumimage

Martian History

- Noachian: 4.5Ba - 3.5Ba
  - Heavy bombardment
- Hesperian: 3.5 - 2.0Ba
  - Moderate bombardment
- Amazonian: 2.0Ba - present
  - Light bombardment
- Mars is tectonically inactive and has been that way for most of its history.
- Near complete record of Archean.

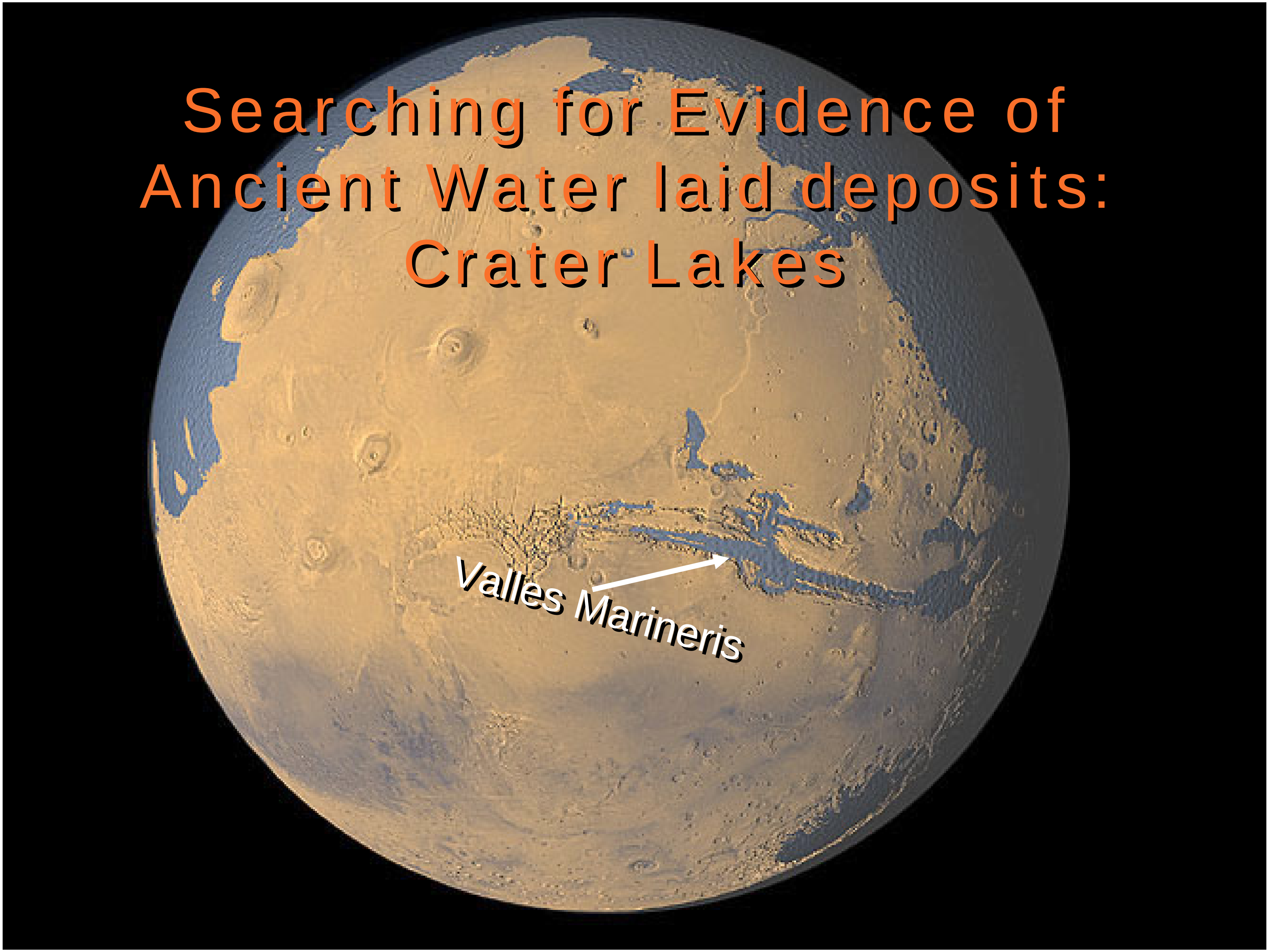
Views of hypothesized watery Mars
Goddard Space Flight Center, 2001



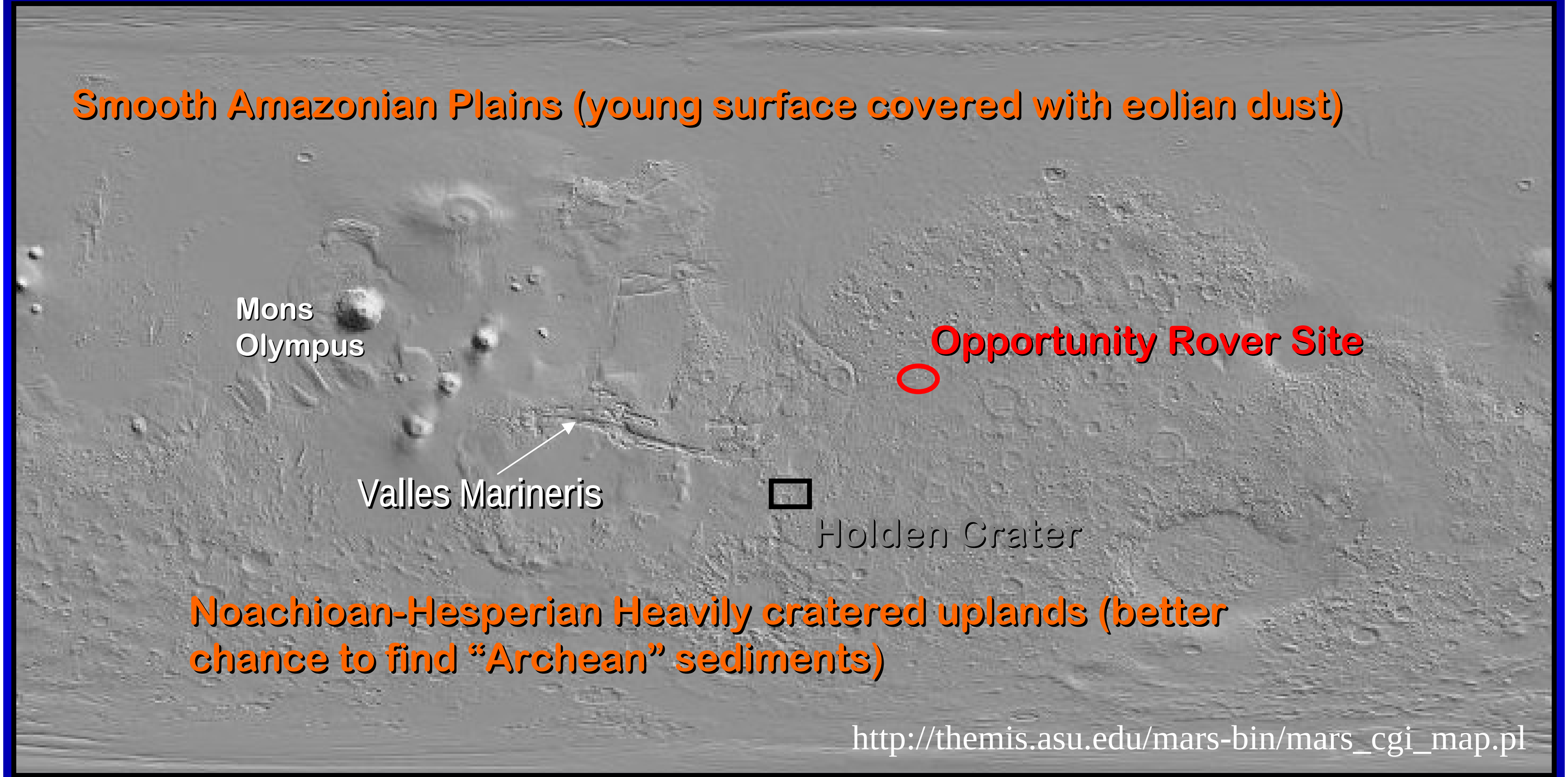


Courtesy of James Reilly, 2005

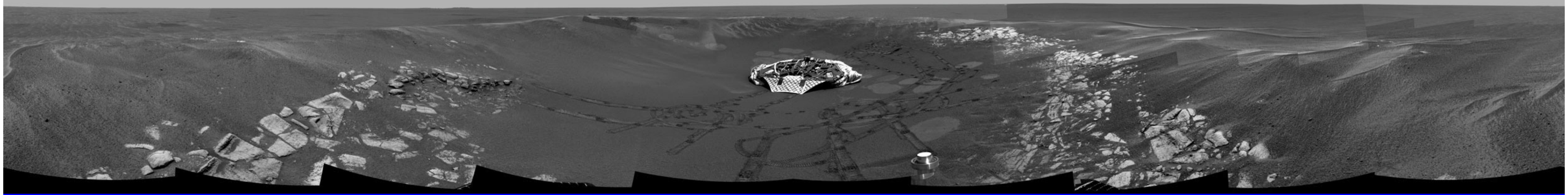
Searching for Evidence of Ancient Water laid deposits: Crater Lakes



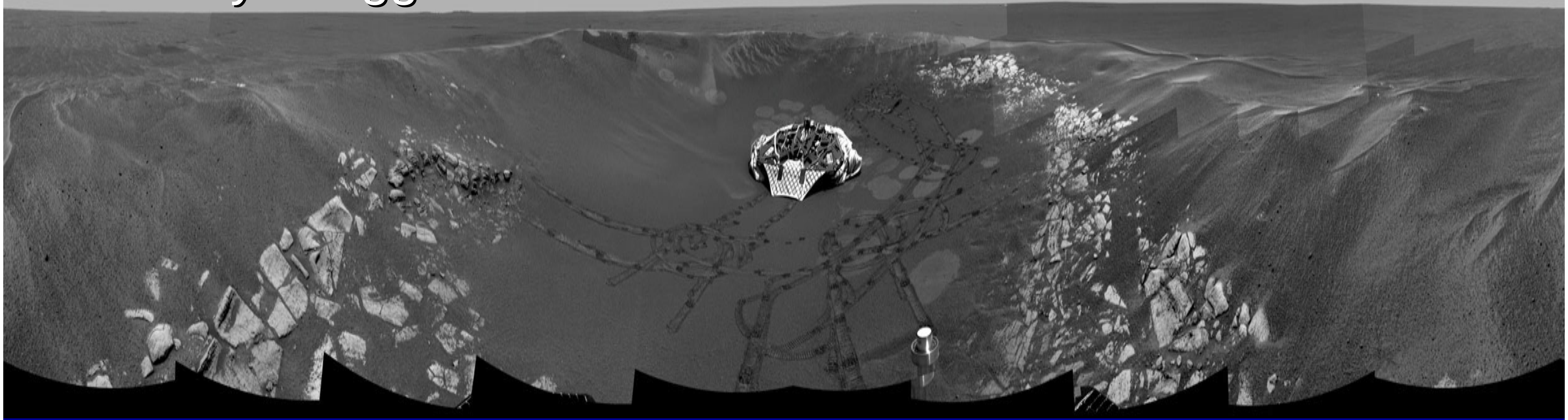
Themis Image Map of Mars



View Inside Opportunity Crater



Vertically Exaggerated

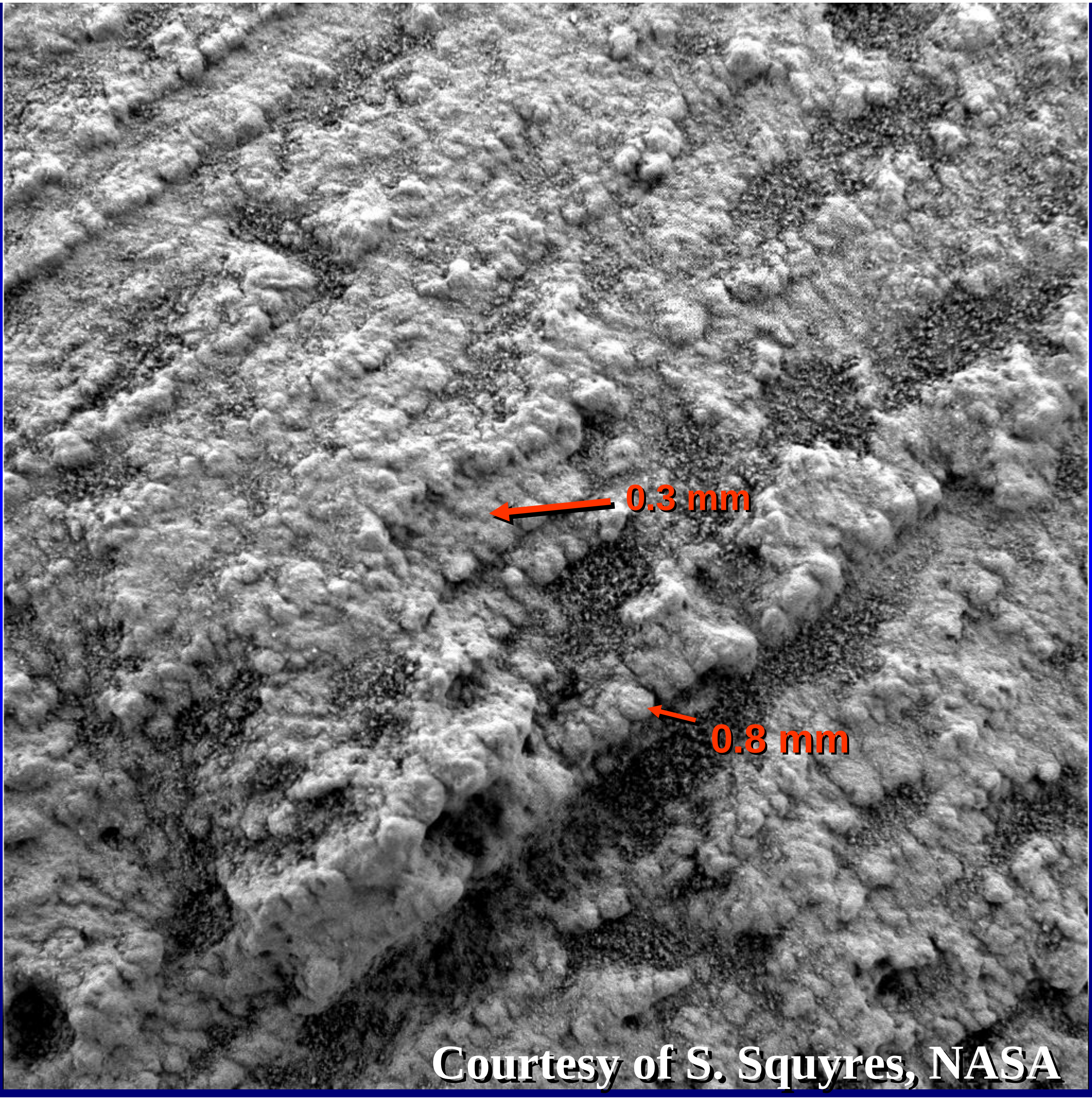


MI on Slickrock

Laminae Defined by Variable Grain Size

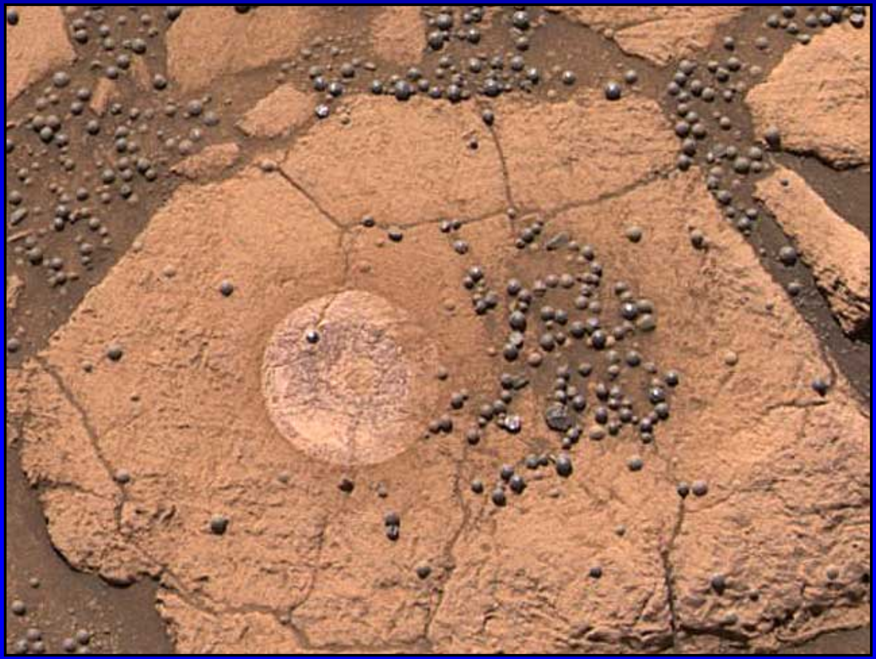
Medium Grain size

Well Rounded



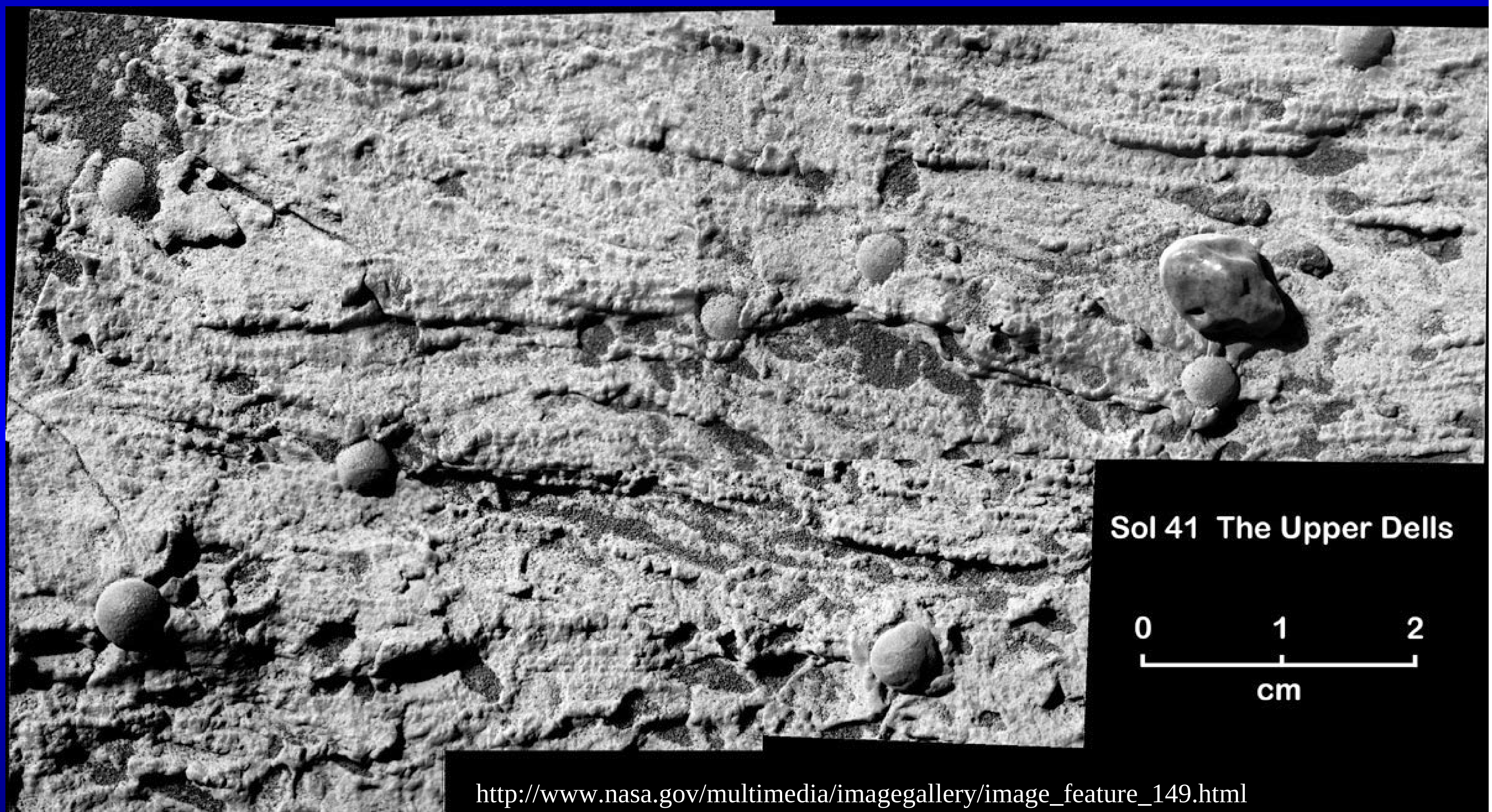
Mineralogy

- **Jarosite**
  - **$KFe_3(SO_4)_2(OH)_6$**
  - **an uncommon mineral on Earth, which forms in dilute sulfuric acid in ground water.**
  - **Probably formed in an acidic lake or an acidic hot springs environment.**
- **Hematite "blueberries"**
  - **$Fe_2 0_3$**
  - **Small (mm-diameter) concretions.**
  - **Probably formed in groundwater and later weathered out.**

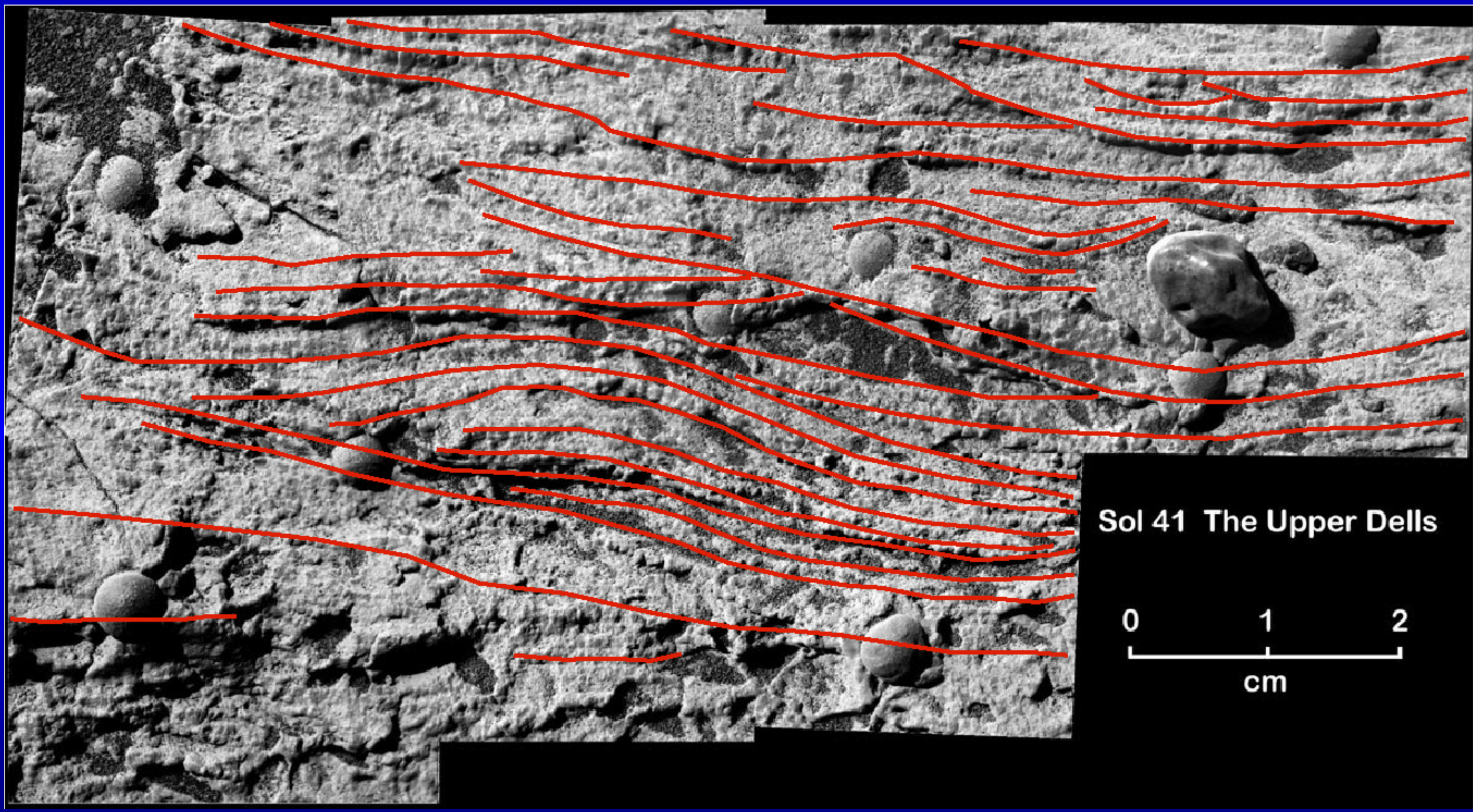


http://apod.gsfc.nasa.gov/apod/ap040405.html

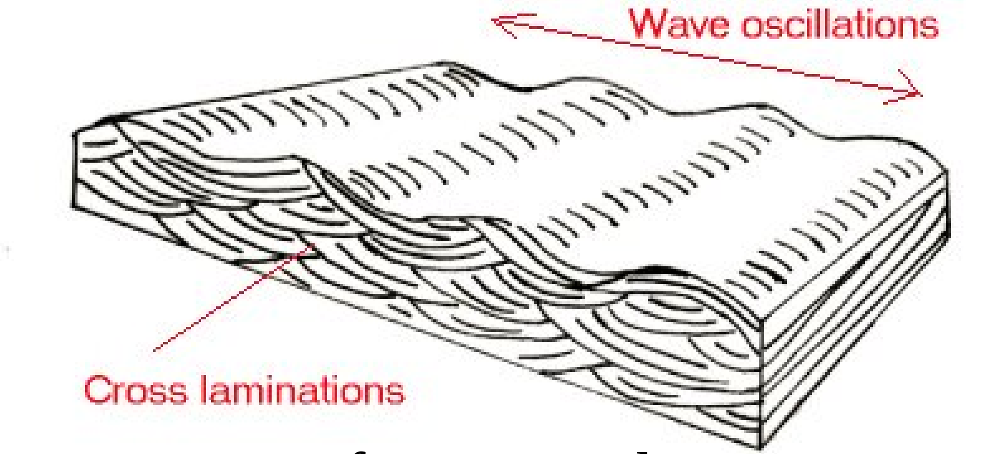
Ripple Cross Lamination on Mars



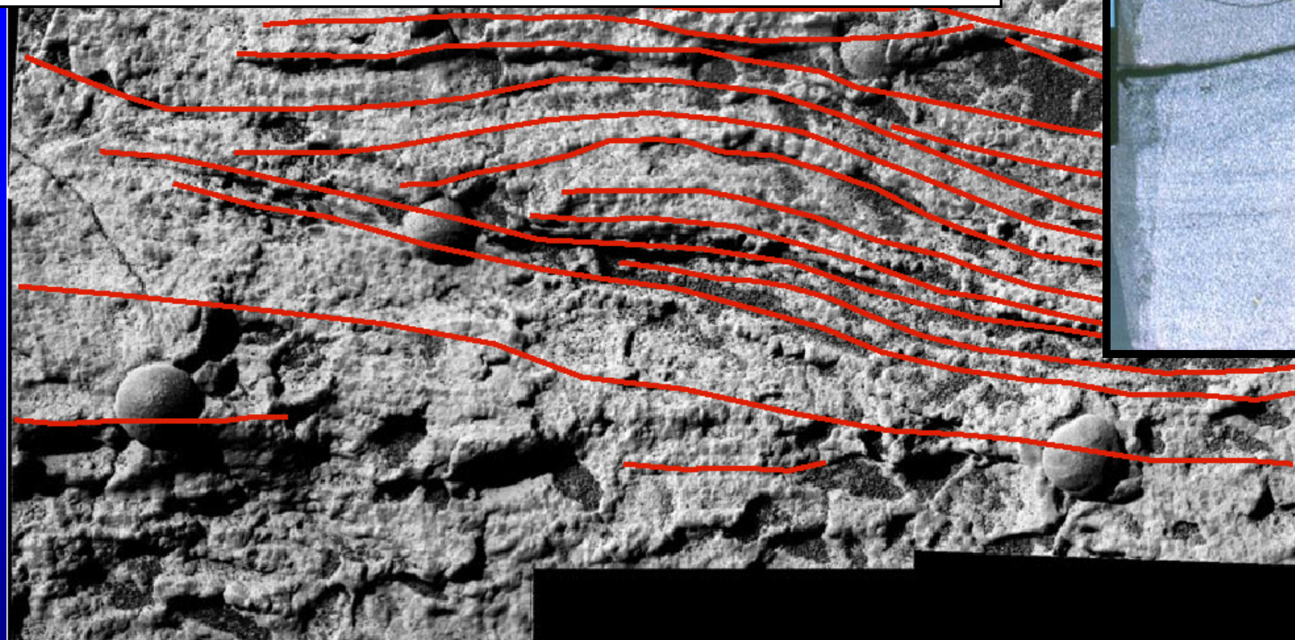
Ripple Cross Lamination on Mars

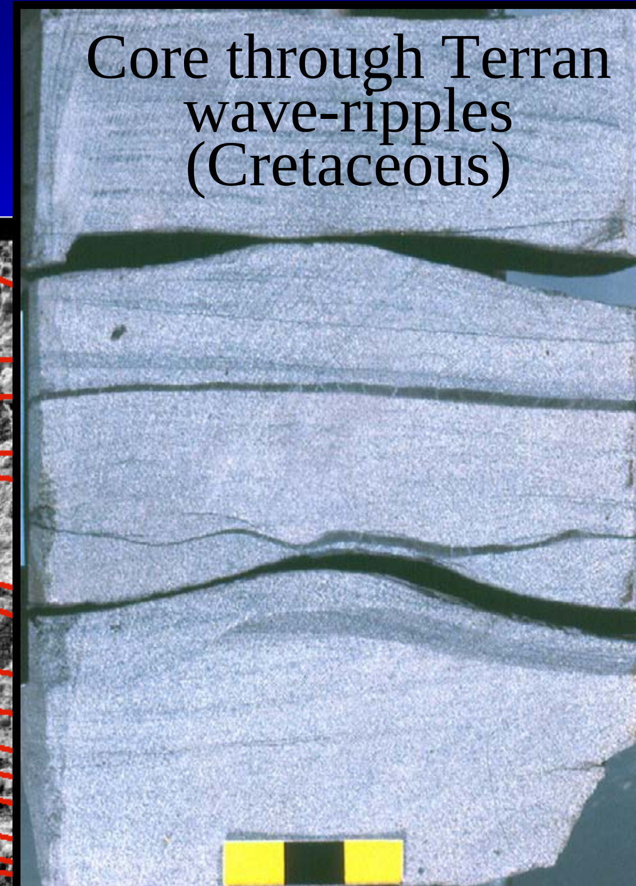


Ripple Cross Lamination



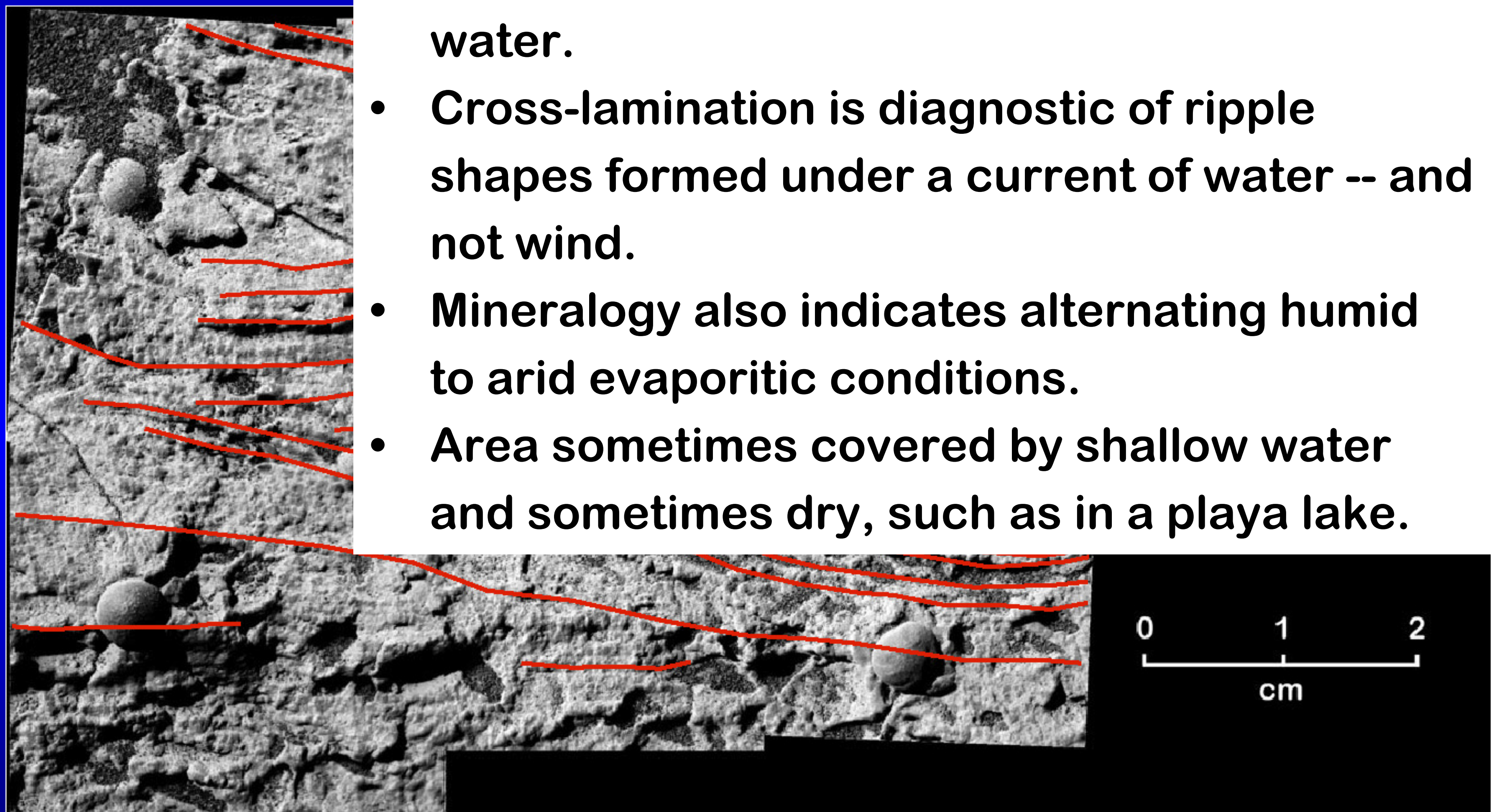
Formation of wave ripples.



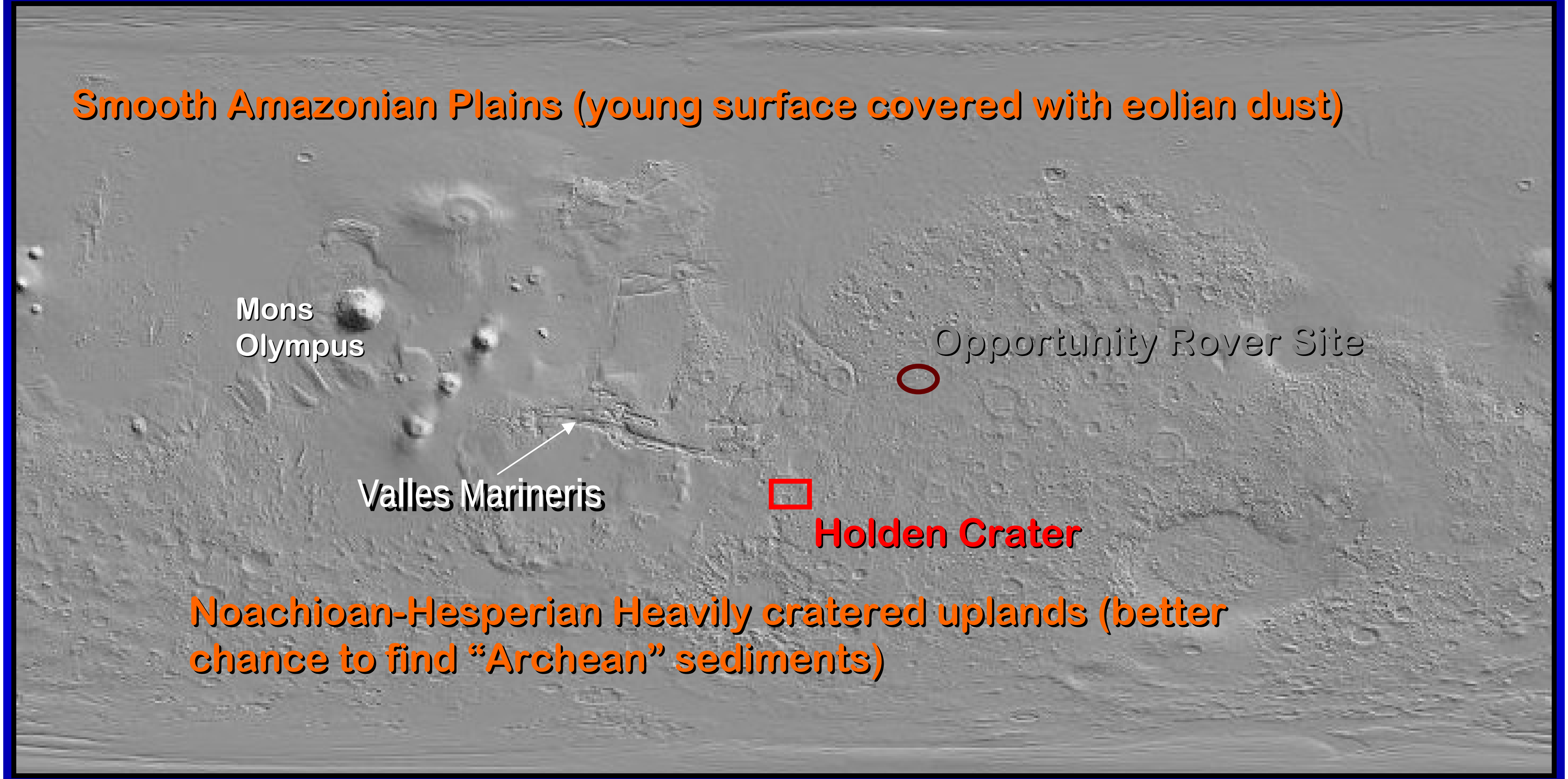


Ripples in Meridiani Planum

- Rippled patterns suggest a standing body of water.
- Cross-lamination is diagnostic of ripple shapes formed under a current of water -- and not wind.
- Mineralogy also indicates alternating humid to arid evaporitic conditions.
- Area sometimes covered by shallow water and sometimes dry, such as in a playa lake.

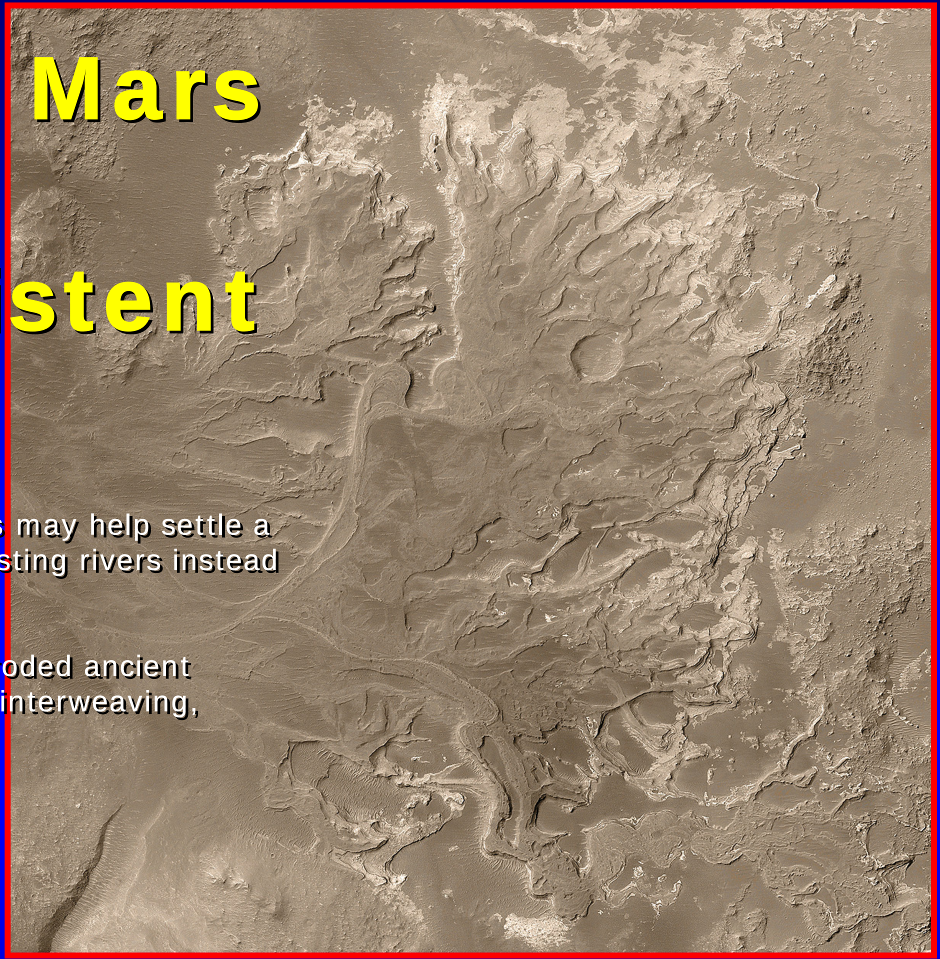


THEMIS Image Map of Mars



http://themis.asu.edu/mars-bin/mars_cgi_map.pl

Delta-Like Fan on Mars Suggests Ancient Rivers Were Persistent



NASA Asks, 'Did Rivers Once Run on Mars?'

Newly seen details in a fan-shaped apron of debris on Mars may help settle a decades-long debate about whether the planet had long-lasting rivers instead of just brief, intense floods.

Pictures from NASA's Mars Global Surveyor orbiter show eroded ancient deposits of transported sediment long since hardened into interweaving, curved ridges of layered rock

<u>Recent Papers:</u>

Malin, M.C., and Edgett, K.S., 2003

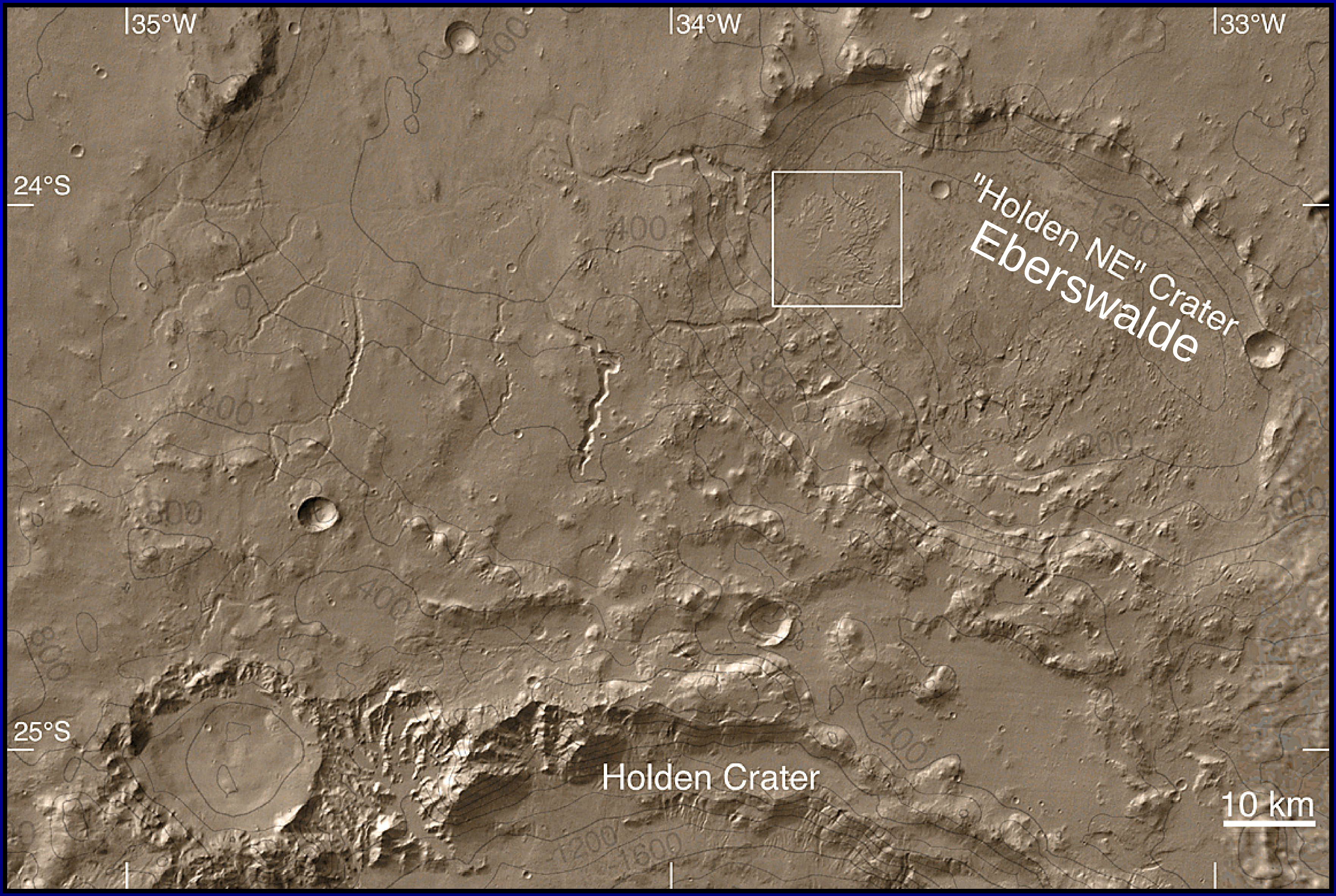
Moore, J.M., Howard, A.D., Dietrich, W.E., and Schenk, P.M., 2004

Lewis, K. and O. Aharonson, 2004

Jerolmack, D.J., D.M. Mohrig, M.T. Zuber and S. Byrne, 2004

Bhattacharya, J.P., Payenberg, T., Lang, S., and Bourke, M., 2005

Area NE Holden (Eberswalde) Crater

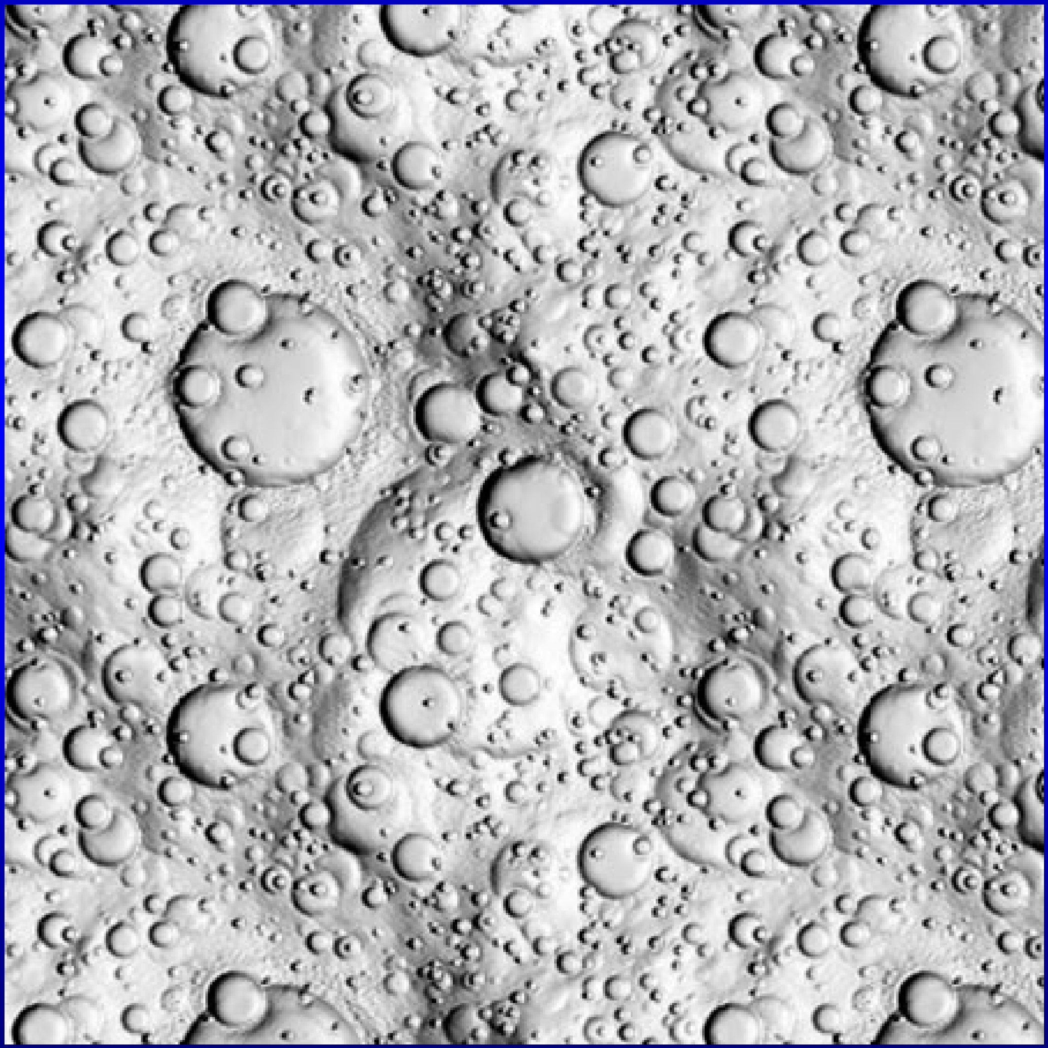


Martian Drainage

- How long-lived was drainage basin?
- How was drainage basin carved?
  - Rainfall?
  - Groundwater sapping?
    - Caused by bolide impacts that melt groundwater

Modeling of Martian geomorphology

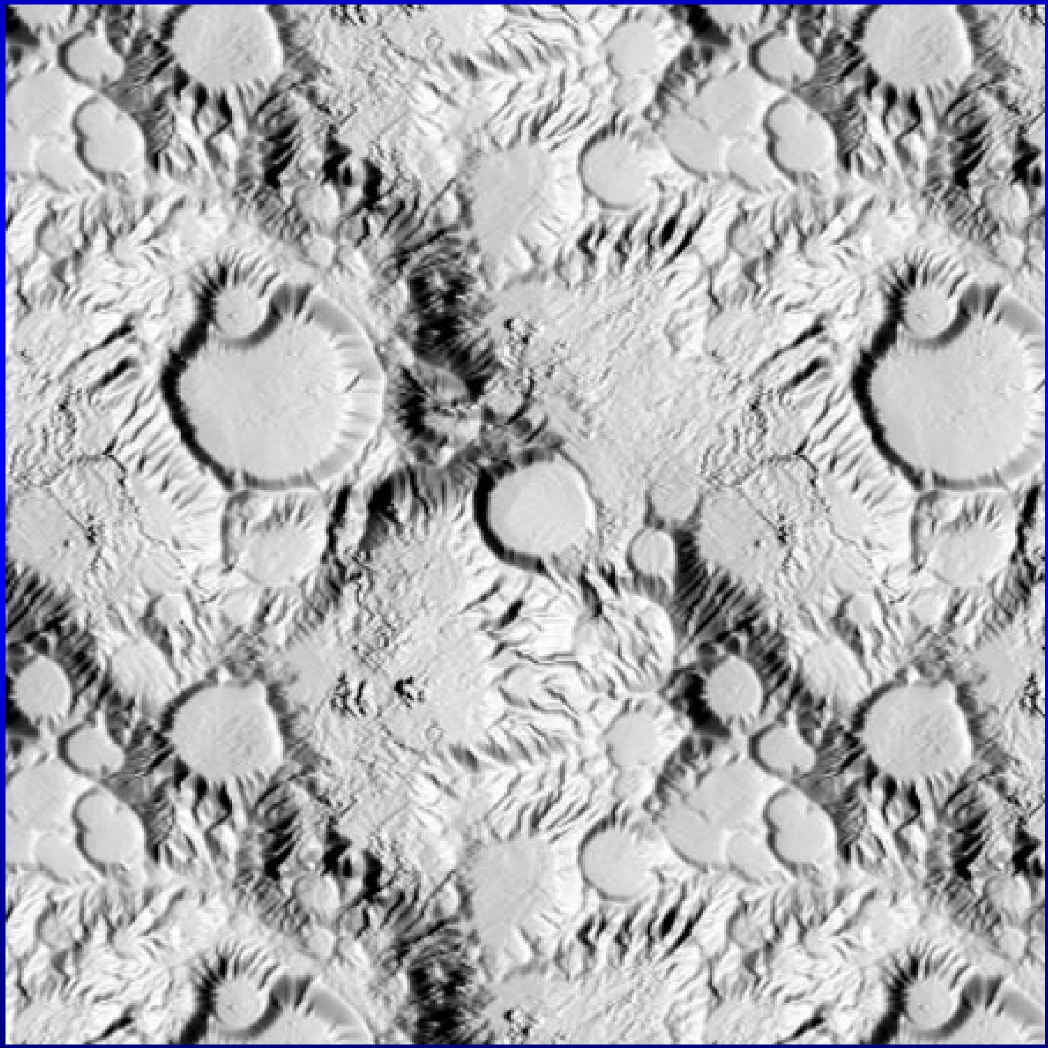
- Impacted surface.



Howard, 2005

Modeling of Martian geomorphology

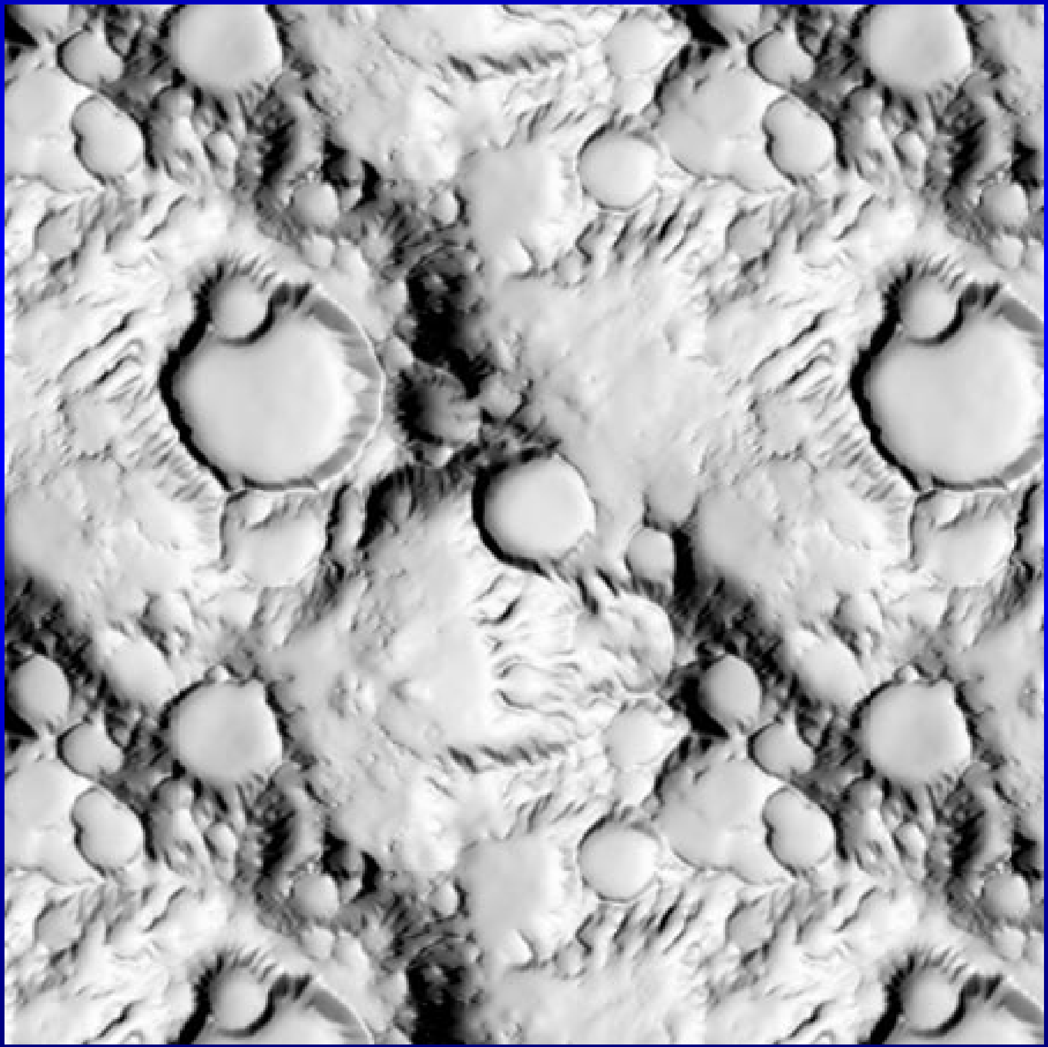
- Fluvial erosion



Howard, 2005

Modeling of Martian geomorphology

- Eolian reworking



Howard, 2005

Modeling of Martian geomorphology

- Initial Cratered Surface

http://erode.evsc.virginia.edu/marssap.htm Howard, 2005

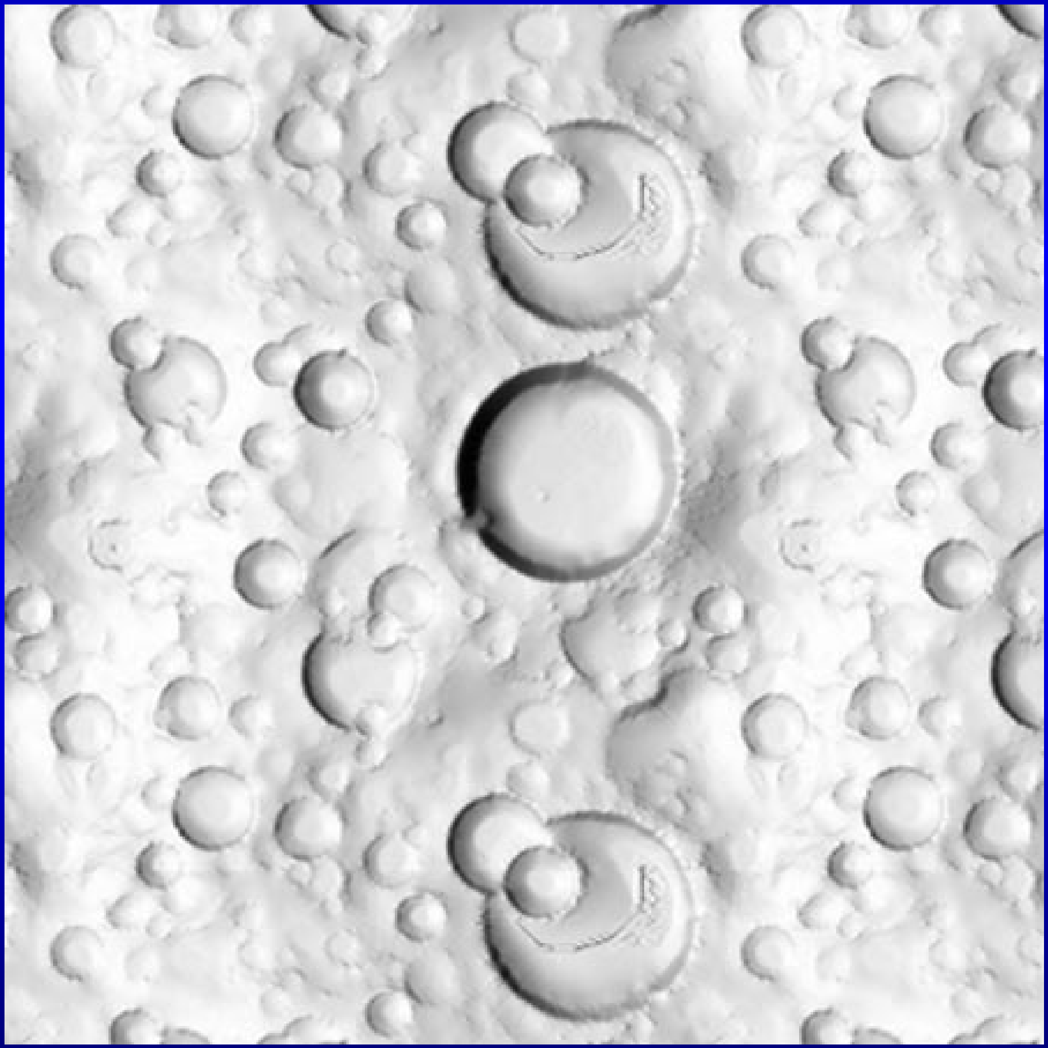
Modeling of Martian geomorphology

- Surface after groundwater sapping

http://erode.evsc.virginia.edu/marssap.htm Howard, 2005

Modeling of Martian geomorphology

- Initial surface with eolian reworking

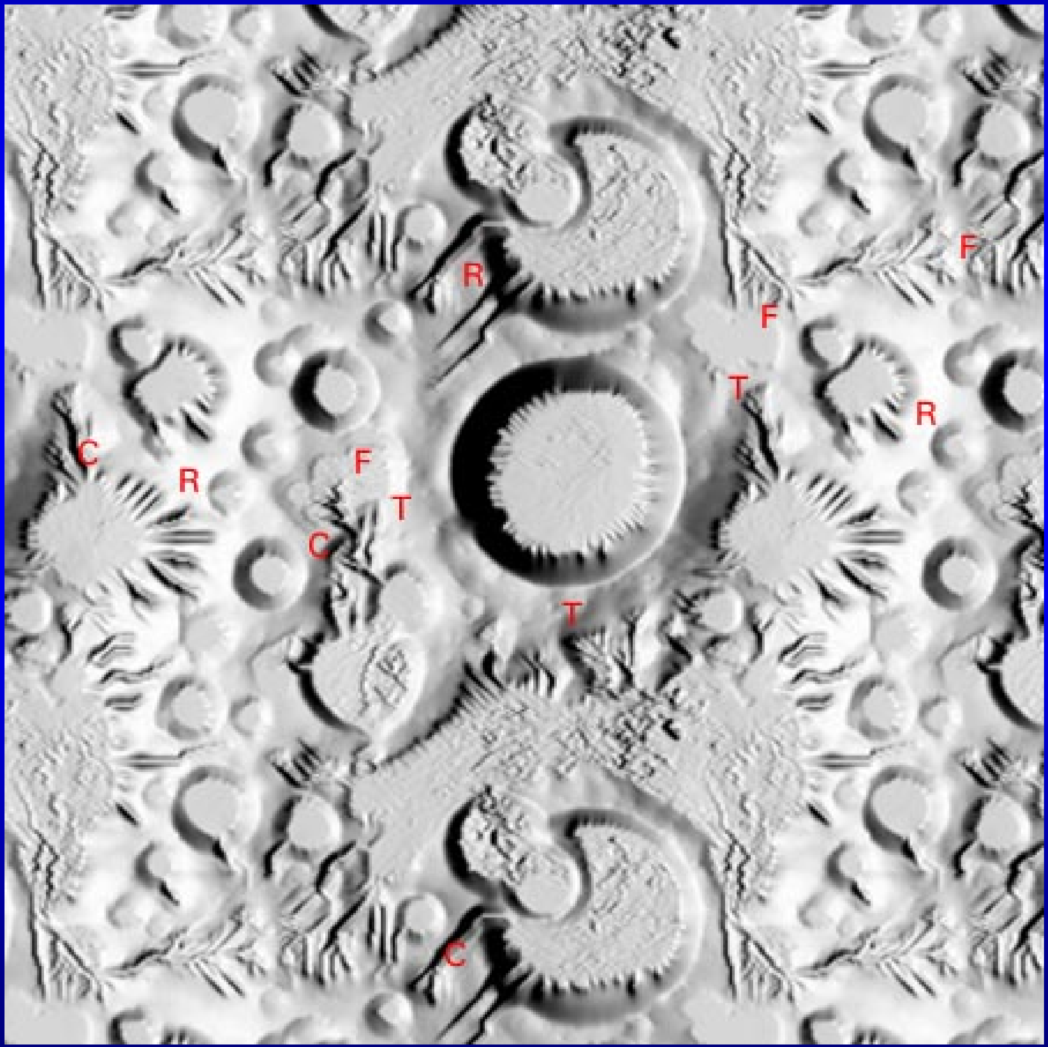


http://erode.evsc.virginia.edu/marssap.htm

Howard, 2005

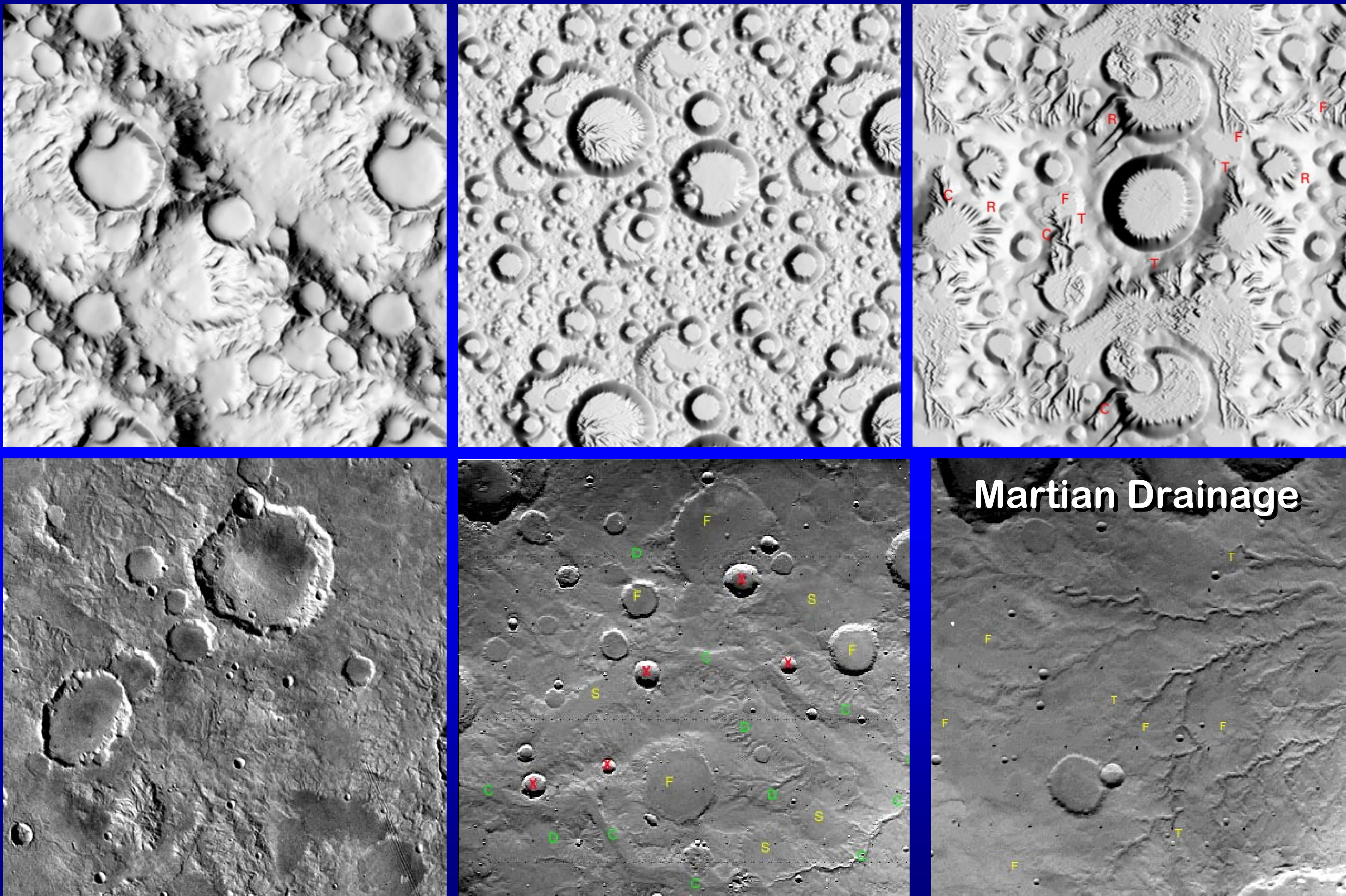
Modeling of Martian geomorphology

- Surface after groundwater sapping



http://erode.evsc.virginia.edu/marssap.htm Howard, 2005

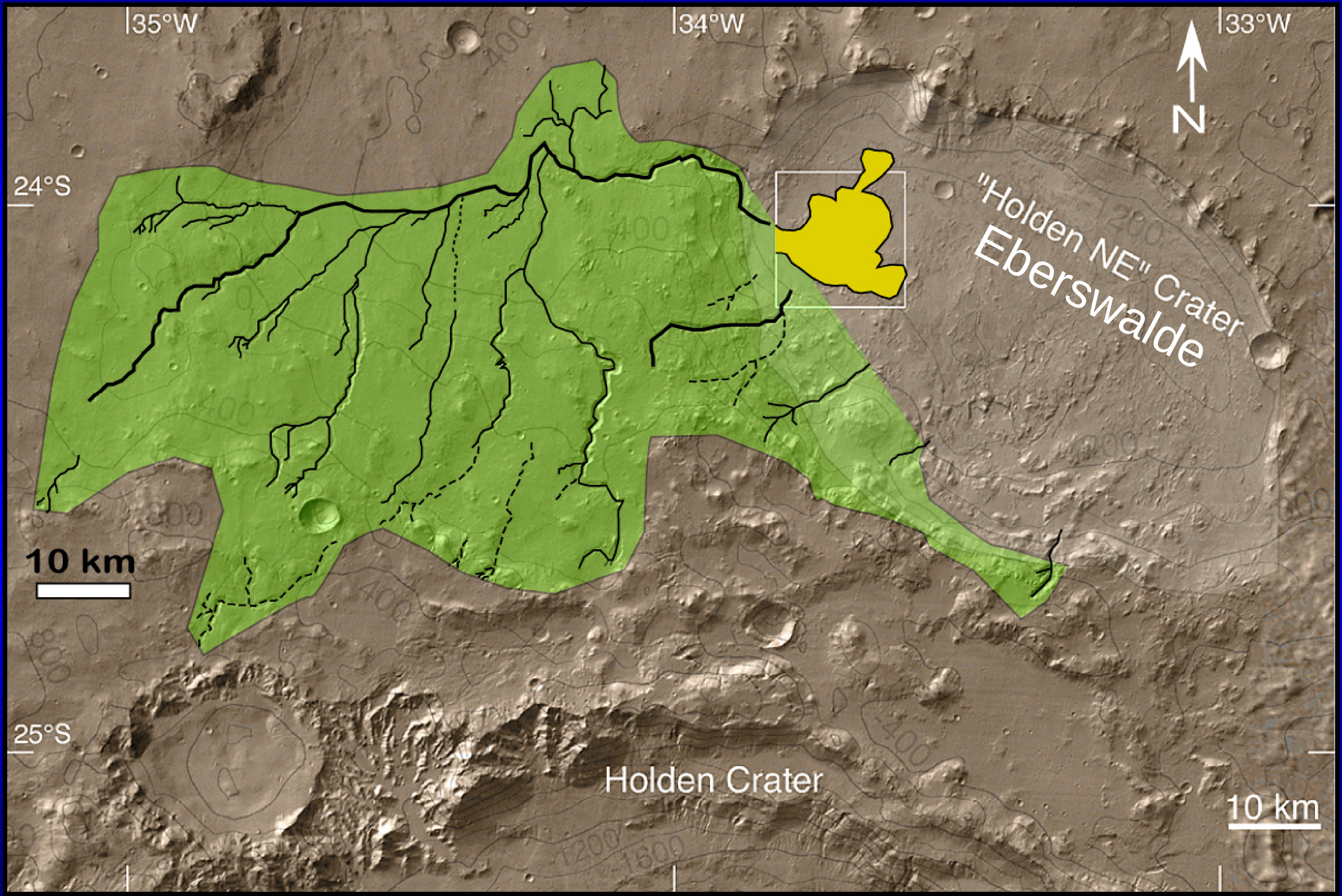
Models *versus* Reality



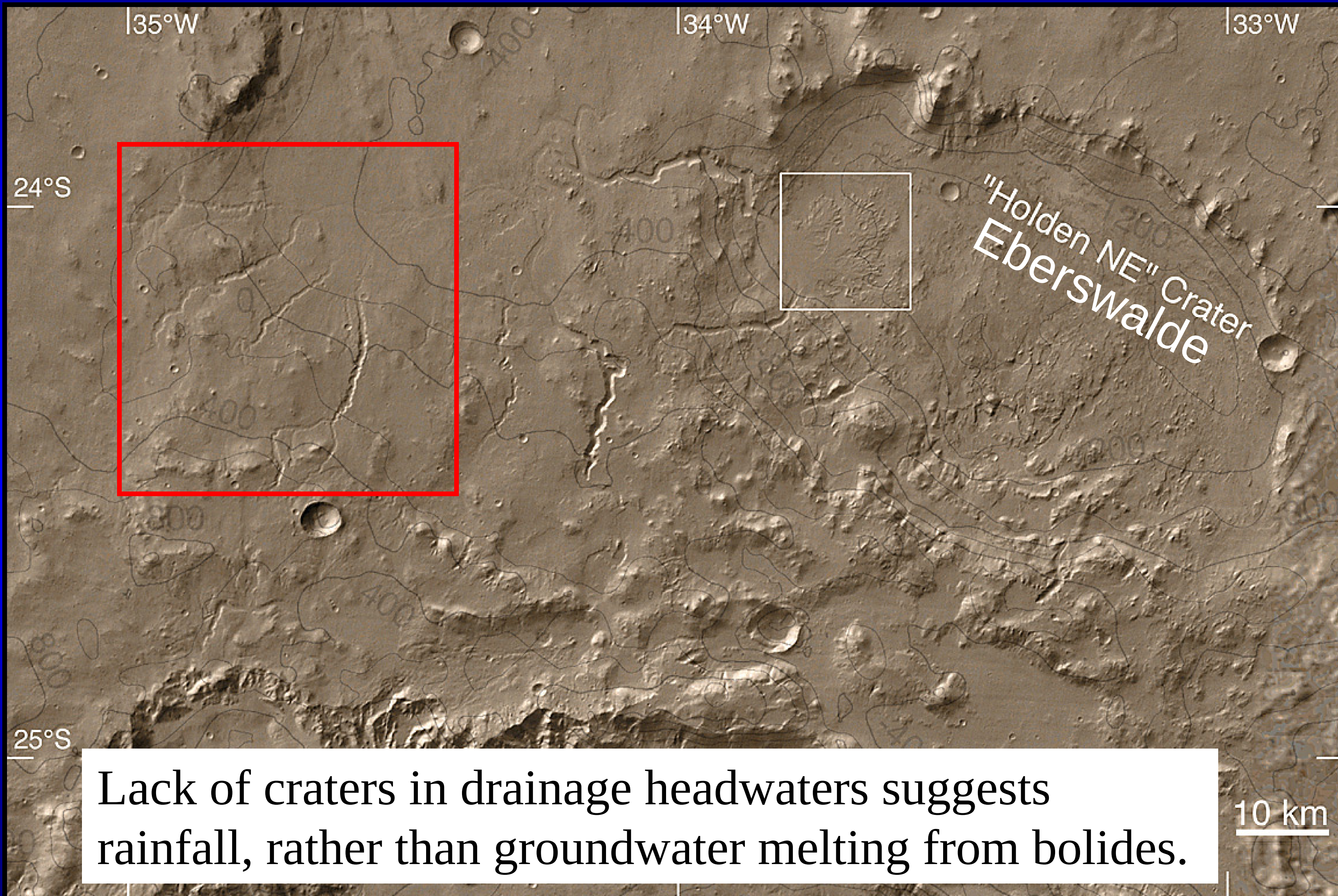
http://erode.evsc.virginia.edu/mars.htm

Howard, 2005

Map of Drainage basin

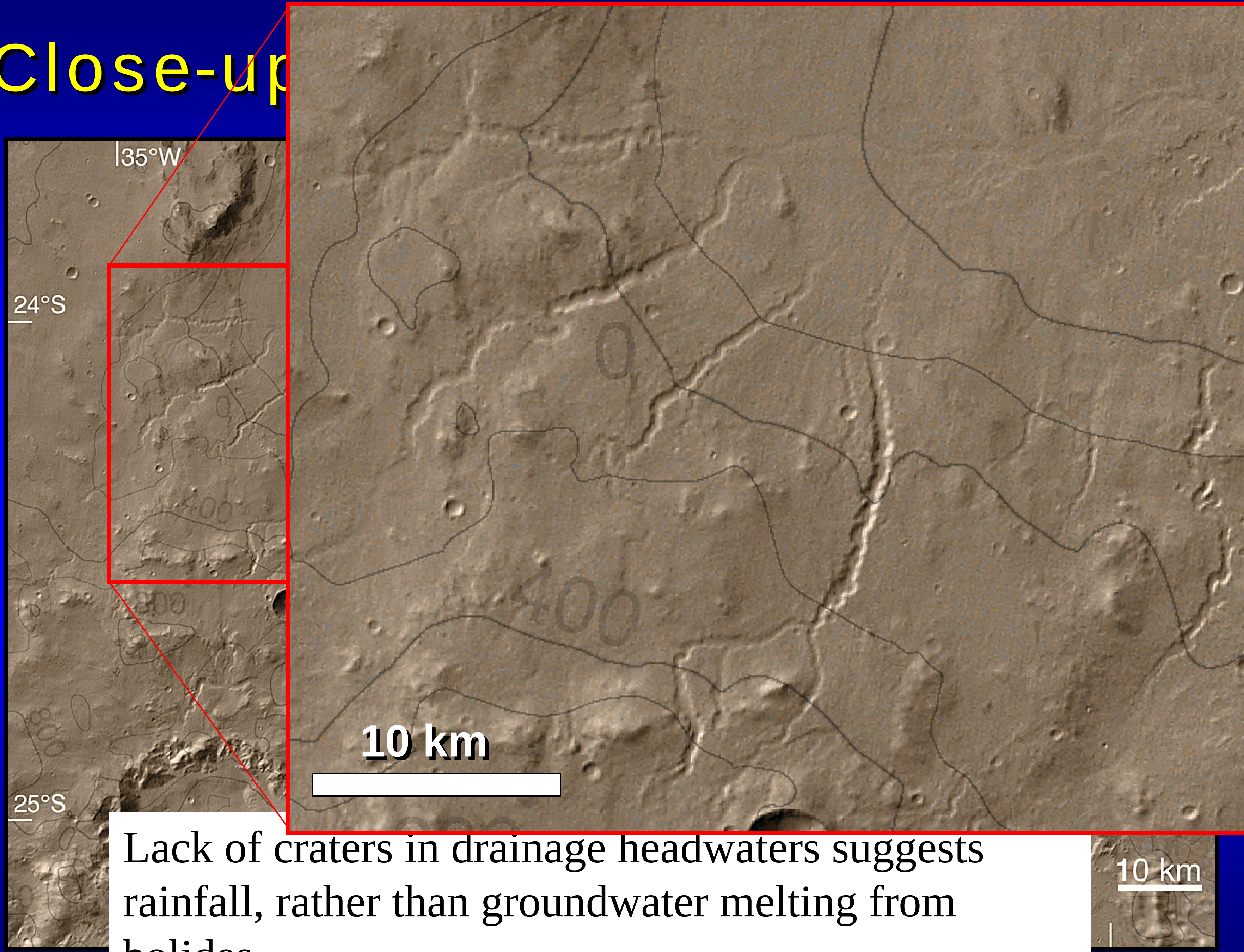


Close-up



Lack of craters in drainage headwaters suggests rainfall, rather than groundwater melting from bolides.

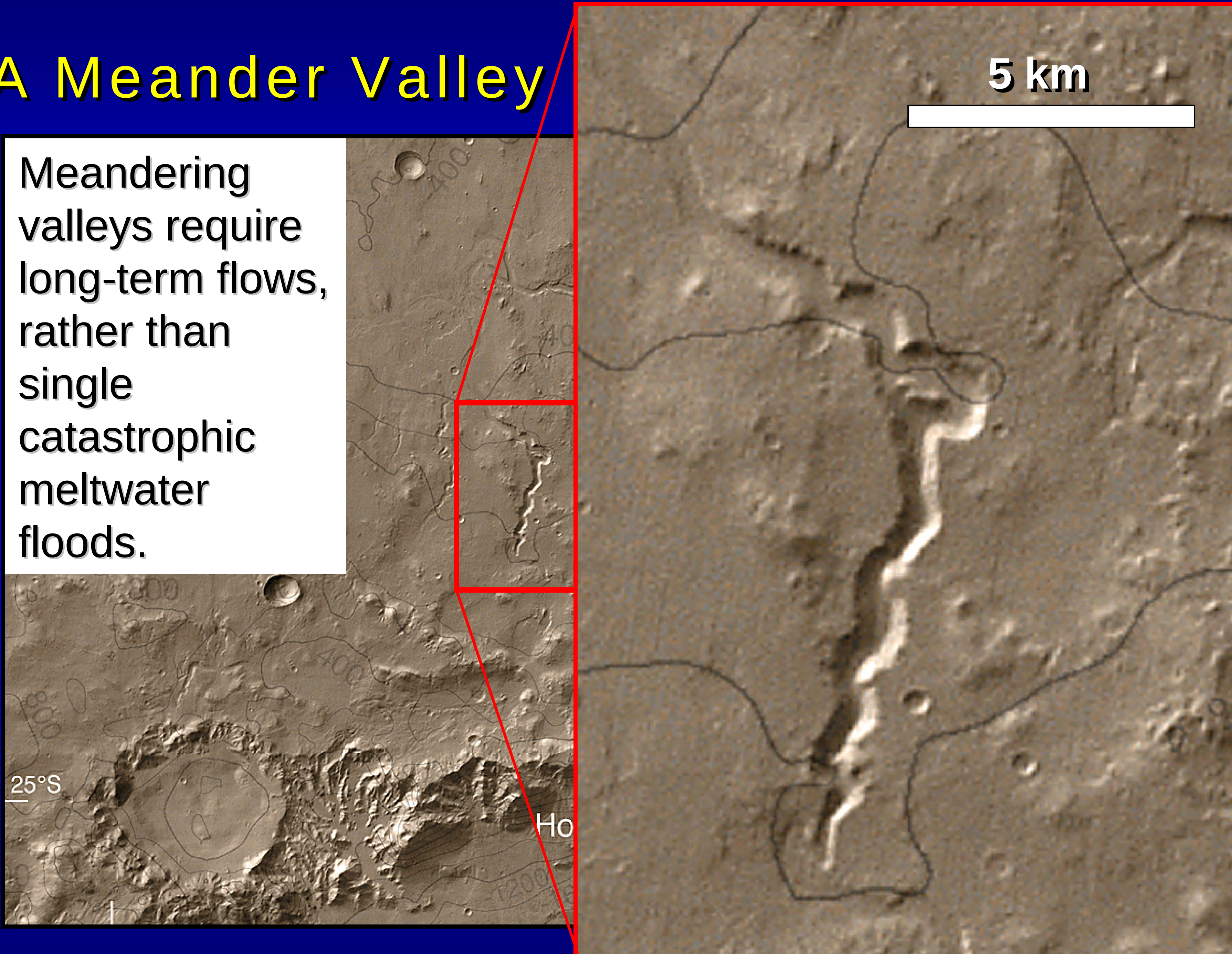
Close-up



Lack of craters in drainage headwaters suggests rainfall, rather than groundwater melting from bolides.

A Meander Valley

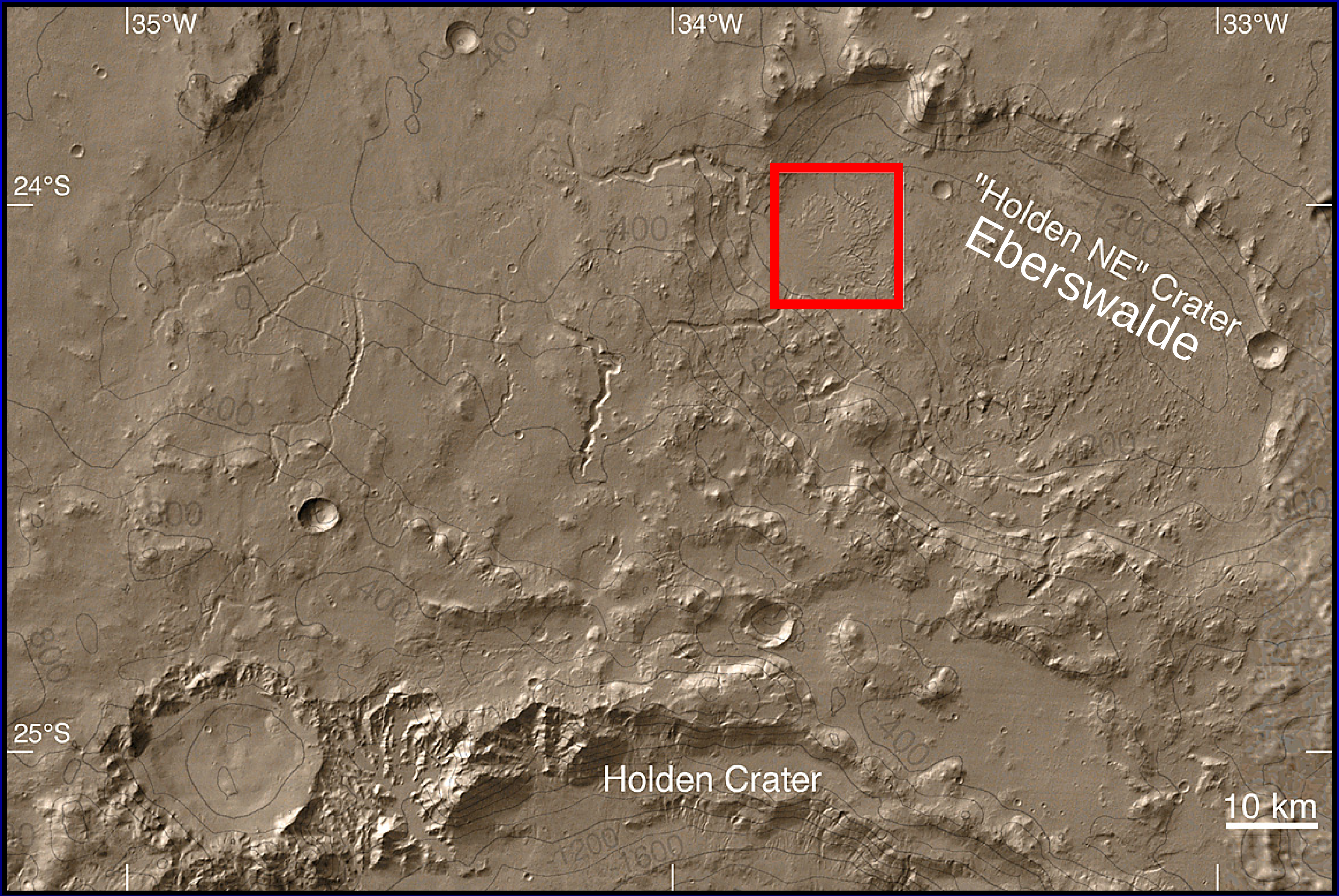
Meandering valleys require long-term flows, rather than single catastrophic meltwater floods.

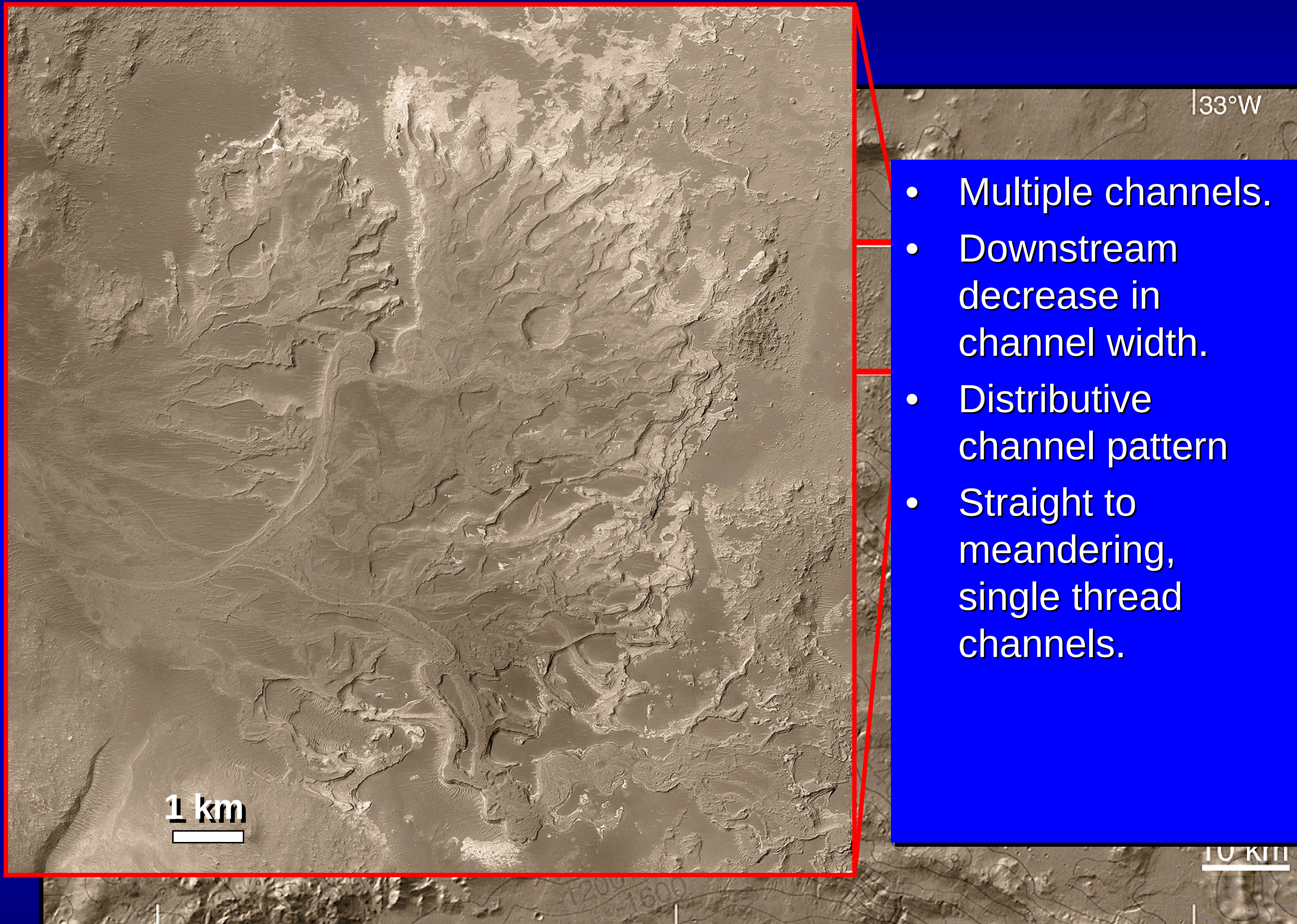


Incised Meander

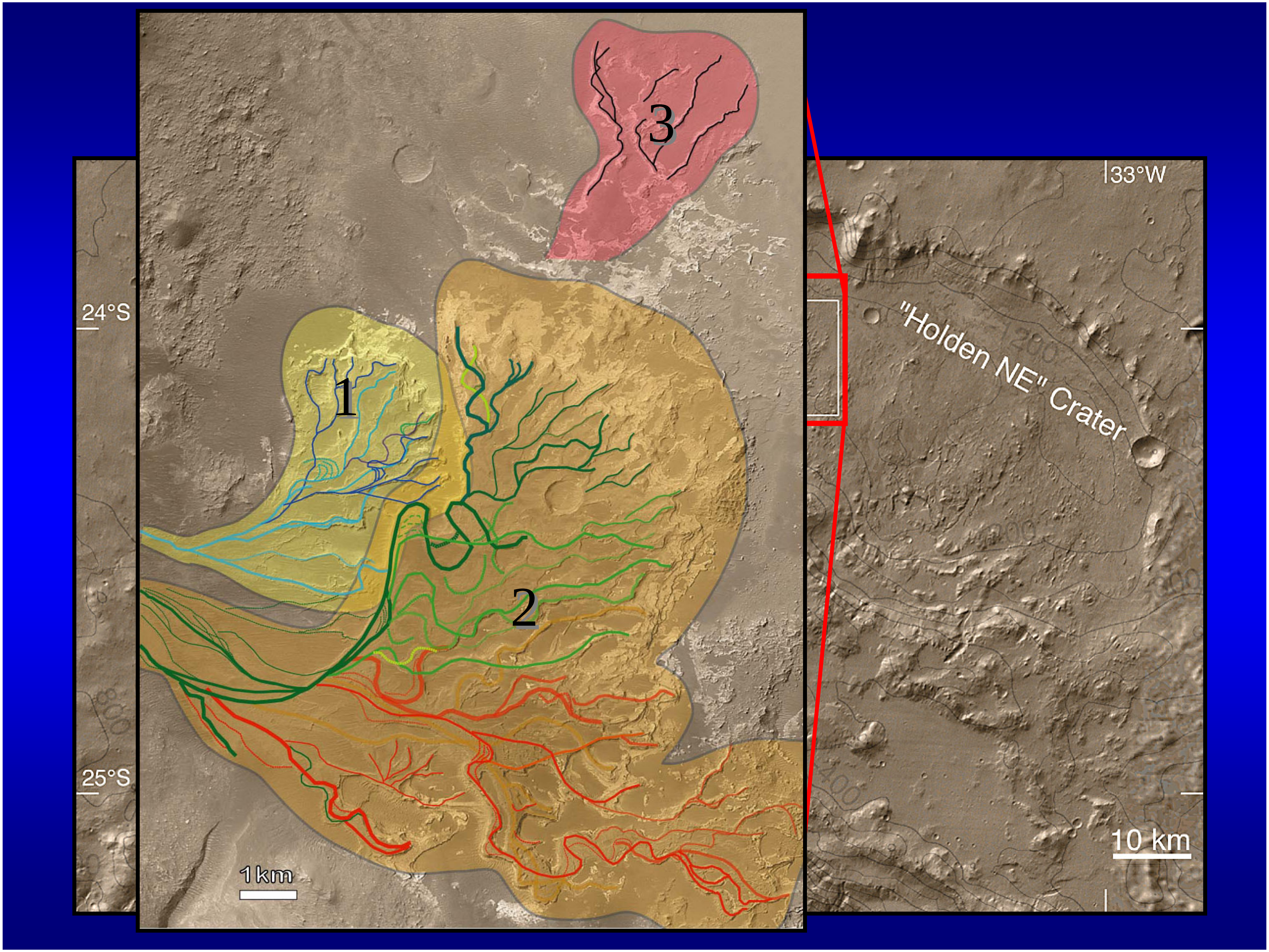
http://www.arctic.uoguelph.ca/cpe/environments/inland_water/rivers/meandering.htm; Photo 2002-319 Gooseneck stream meander, Prince Patrick Island Northwest Territories. Photographer unknown. Reproduced with the permission of the Minister of Public Works and Government Services Canada, 2006 and Courtesy of Natural Resources Canada, Geological Survey of Canada

Lets look at the crater fill!





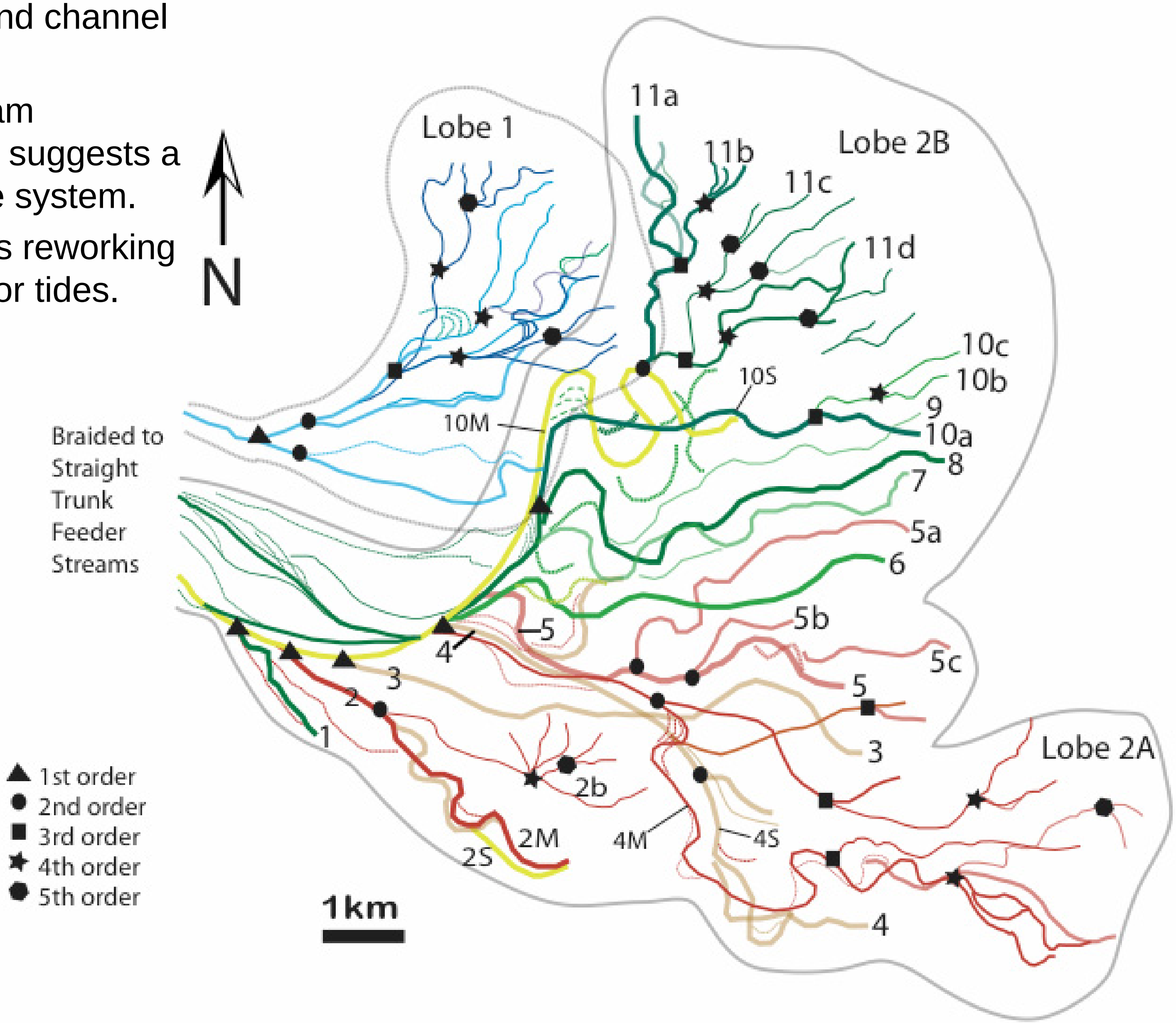
- Multiple channels.
- Downstream decrease in channel width.
- Distributive channel pattern
- Straight to meandering, single thread channels.



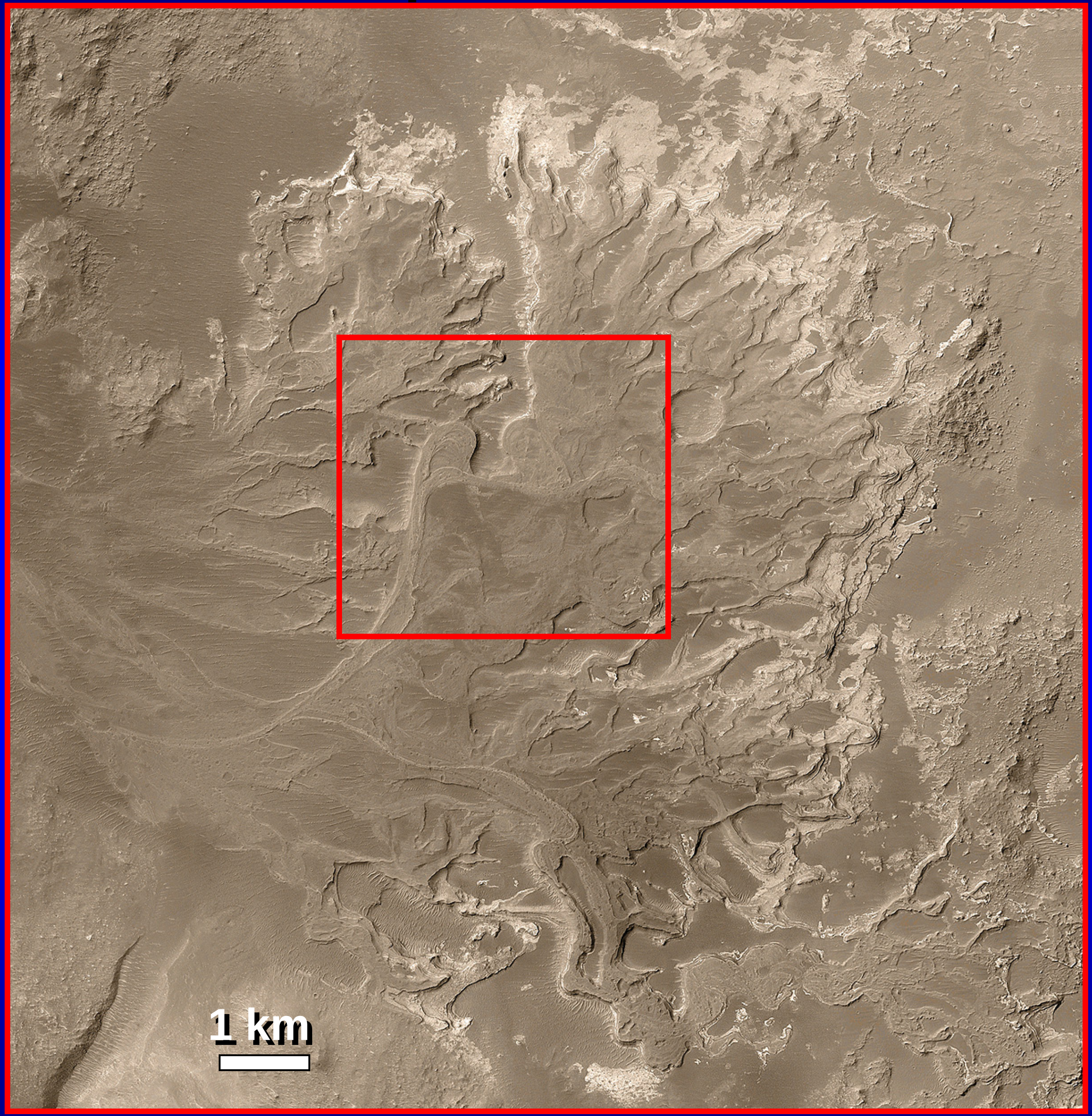
3
1
2
1 km
24°S
25°S
33°W
"Holden NE" Crater
10 km

Martian Delta Lobes

- Records complex history of fluvial avulsion and channel migration.
- Downstream bifurcation suggests a distributive system.
- No obvious reworking by waves or tides.



Close-up View of Meanders

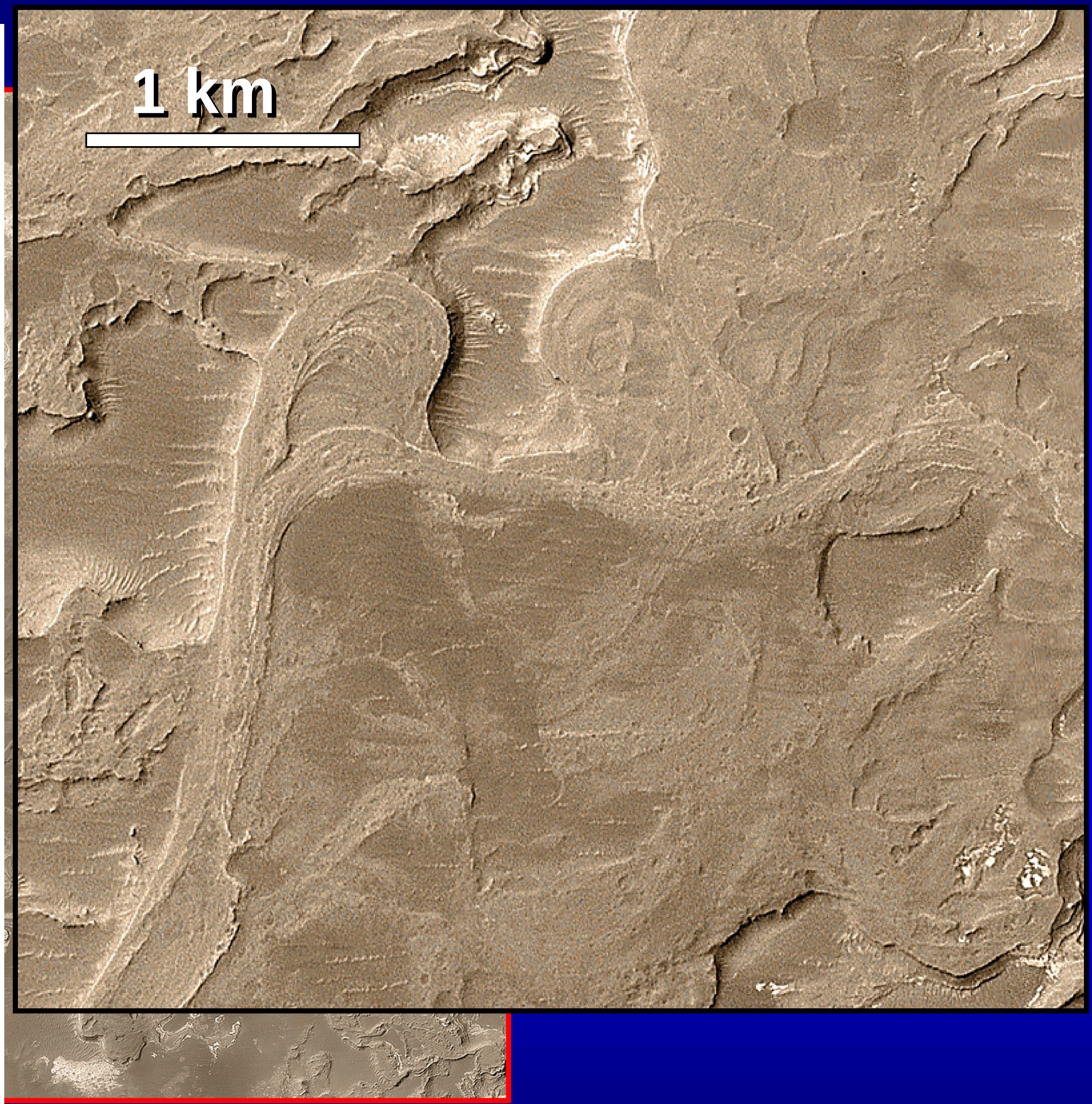


- Coarse-grained channel belt deposits are held high.
  - Finer-interchannel (floodplain) sediment is eroded by wind.
  - Inverted geomorphology.
- Channel belt surface is severely pock-marked, suggesting an extremely old (Noachian) age.
  - Over 3 Ga.

Modern Meandering River

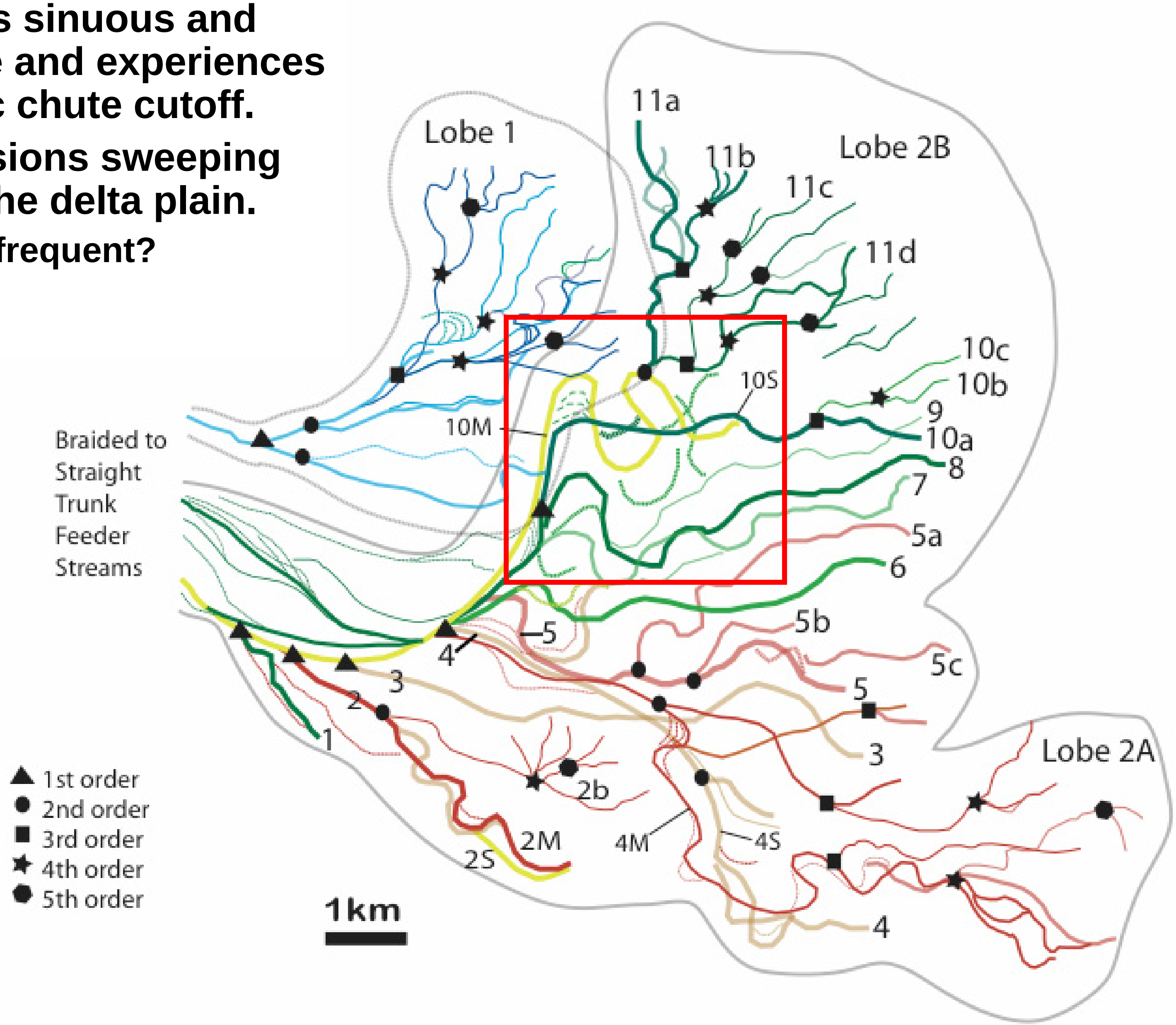
http://darkwing.uoregon.edu/%7Emillerm/meander.html
Courtesy of Marli Miller © Marli Miller millerm@uoregon.edu

- Channels about 100m wide.
- Cross-cutting relationships.
- Channels wander, meander, and avulse.
  - Scroll bars represent "frequent"floods.
  - Avulsions represent "infrequent" major-floods.
  - How frequent???

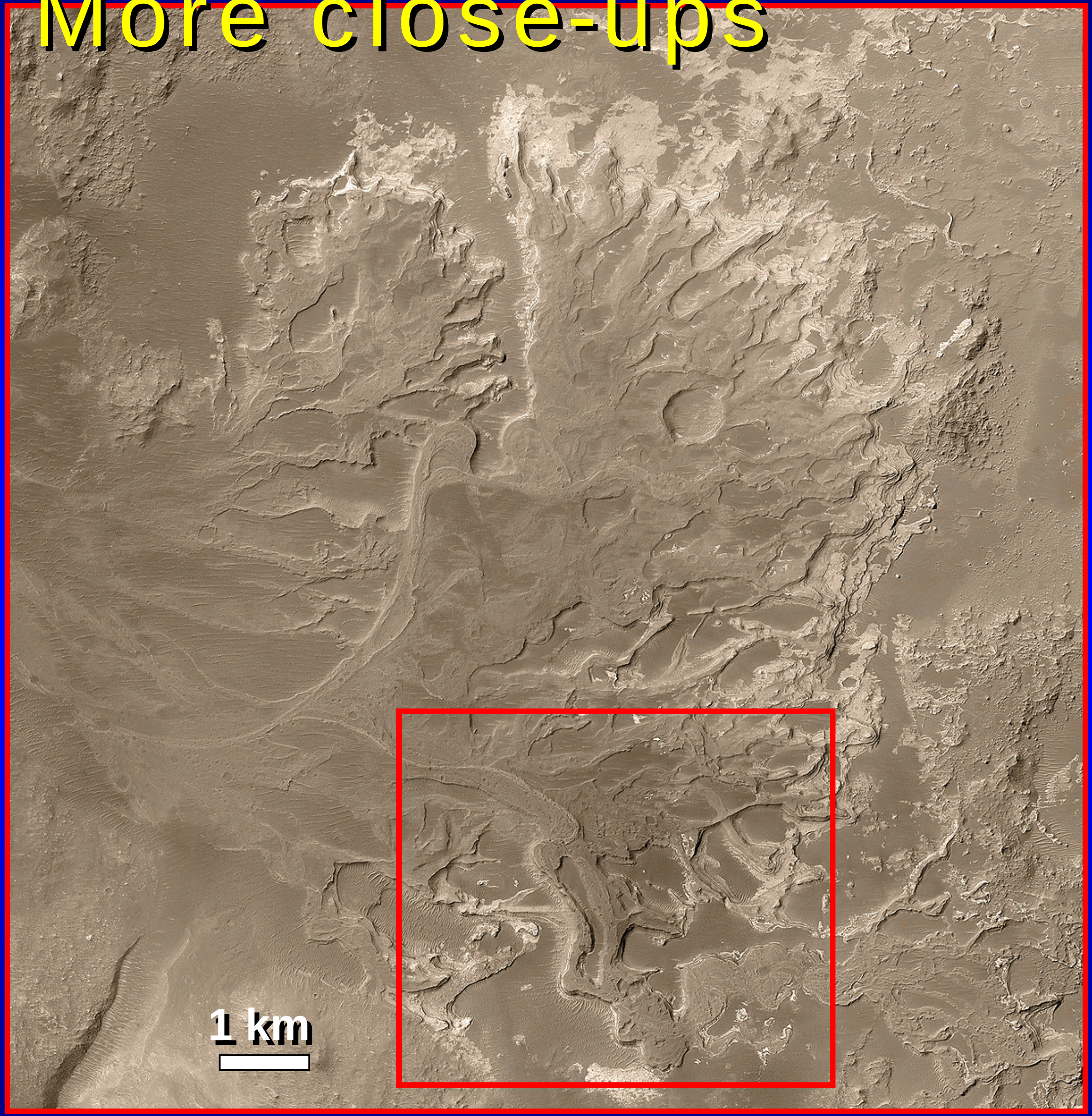


Martian Delta Lobes

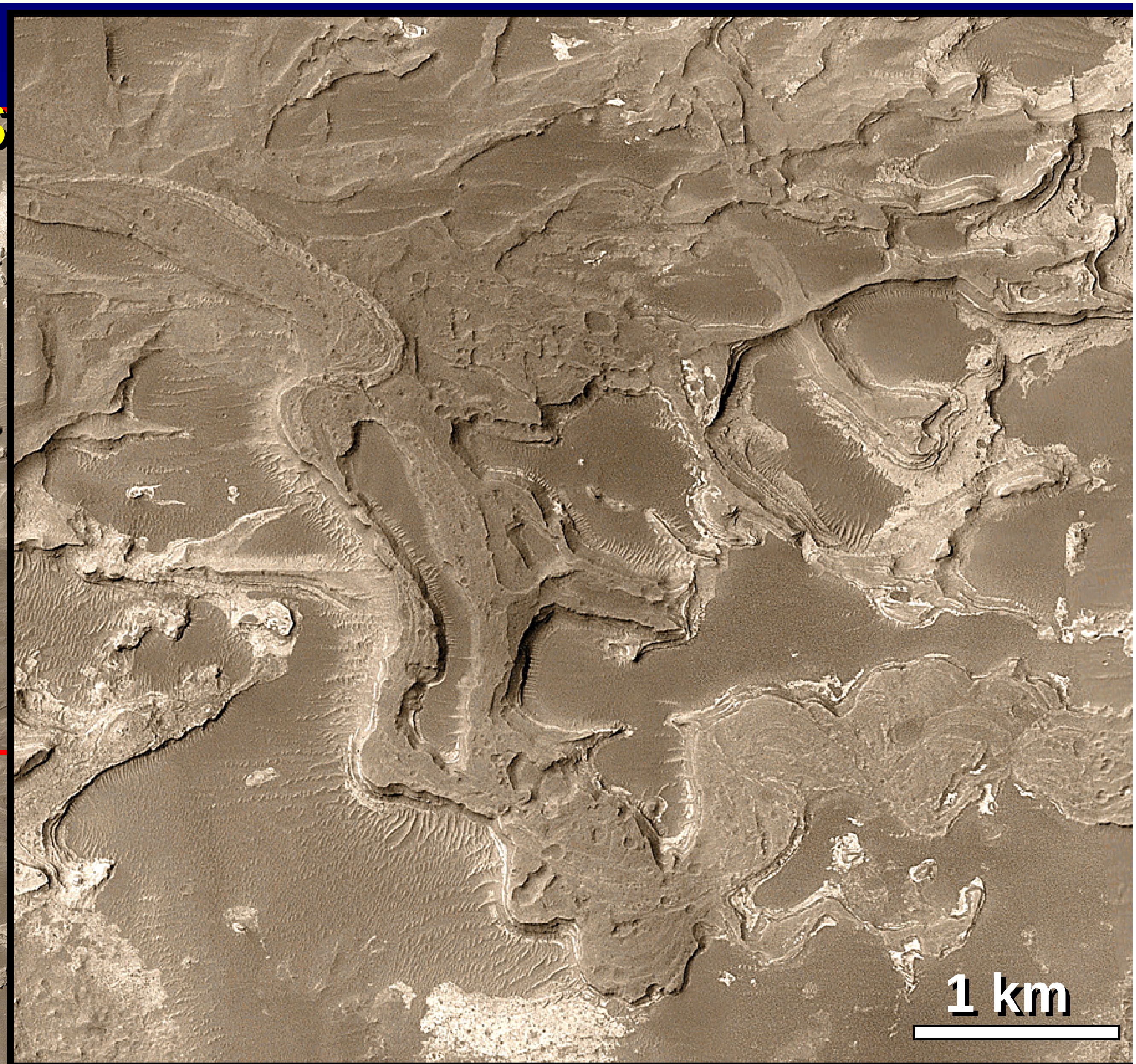
- **Original straight channel becomes sinuous and unstable and experiences a classic chute cutoff.**
- **11 avulsions sweeping across the delta plain.**
  - **How frequent?**

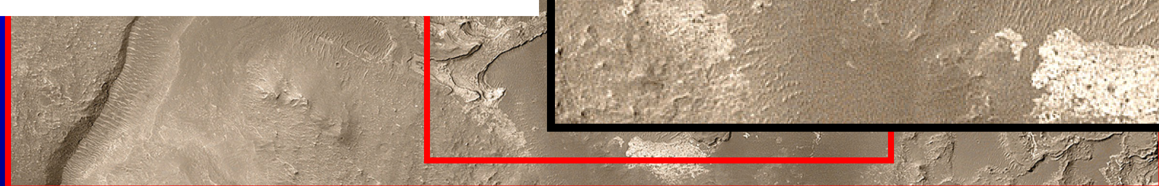


More close-ups



- Older channels are straight and then become more sinuous.
- Younger channels overlie older channels.
- Clear bifurcation downstream, suggesting distributary channels.

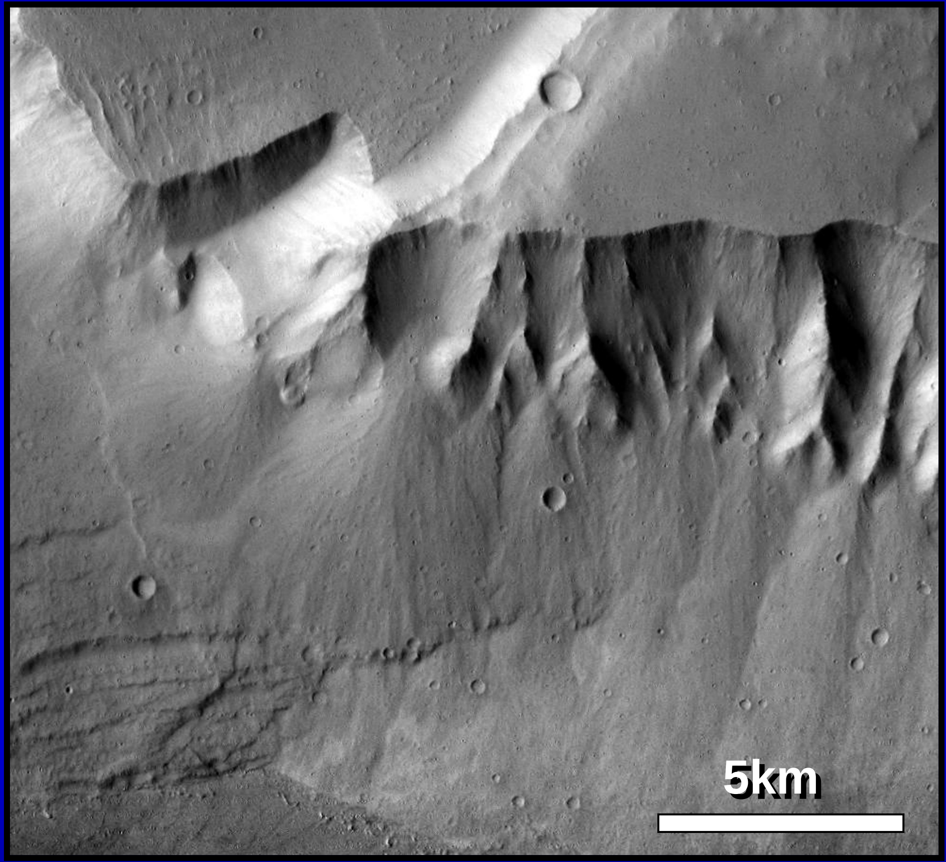




Delta versus Fan

- Alluvial fans are common on Mars.
- Numerous, straight to braided shallow channels.
- Strongly fan-shaped.
- Correlate with small drainage areas.

Alluvial Fans in Kasei Vallis

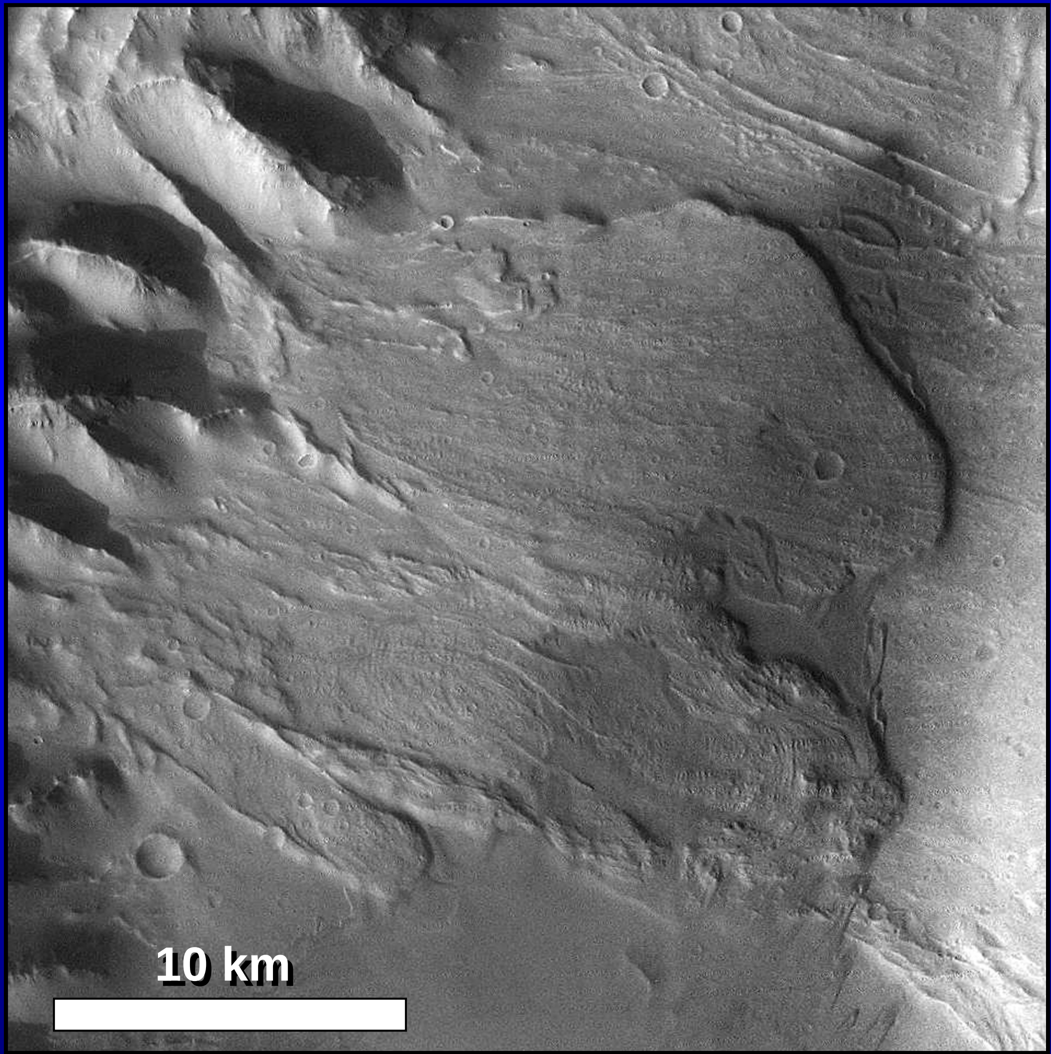


THEMIS image courtesy NASA/JPL/Arizona State University

Delta versus Fan

- Debris flows and landslides are also common on Mars.

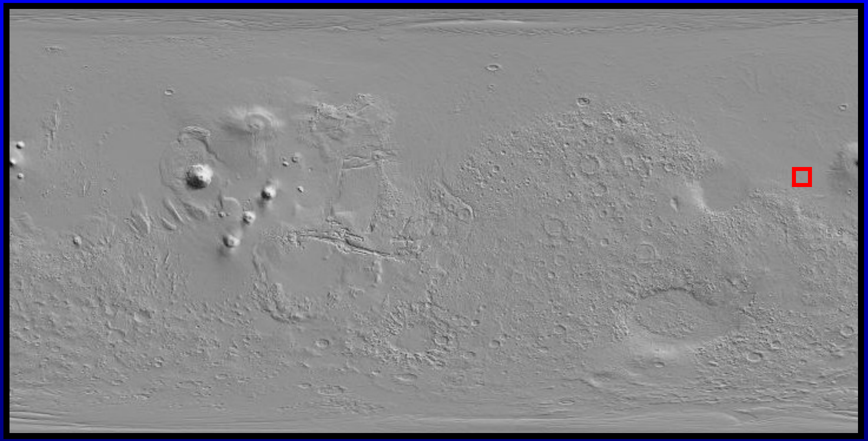
Debris flows, Orson Welles Crater



THEMIS image courtesy NASA/JPL/Arizona State University

Delta versus Fan

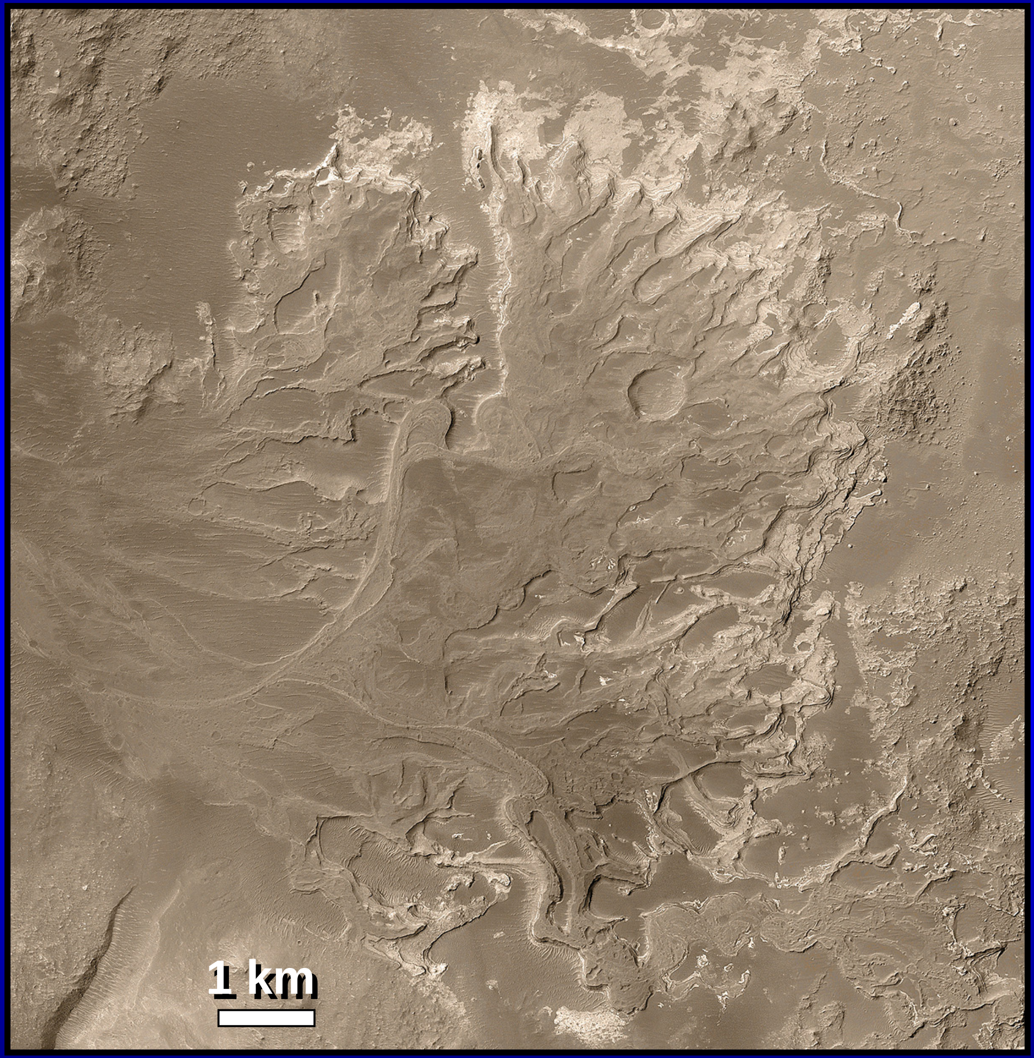
- Braided rivers are also common in Martian outwash valleys and northern plains.
  - these are very different from singe-thread, meandering channels in the Eberswalde delta.



THEMIS image courtesy NASA/JPL/Arizona State University

Delta versus Fan

- Highly organized single-thread, straight to meandering channels.
- Lack of debris flows or sheetflood deposits.
- Lack of braided channels
  - indicate lower slopes or lower discharge than might be expected on an alluvial fan.



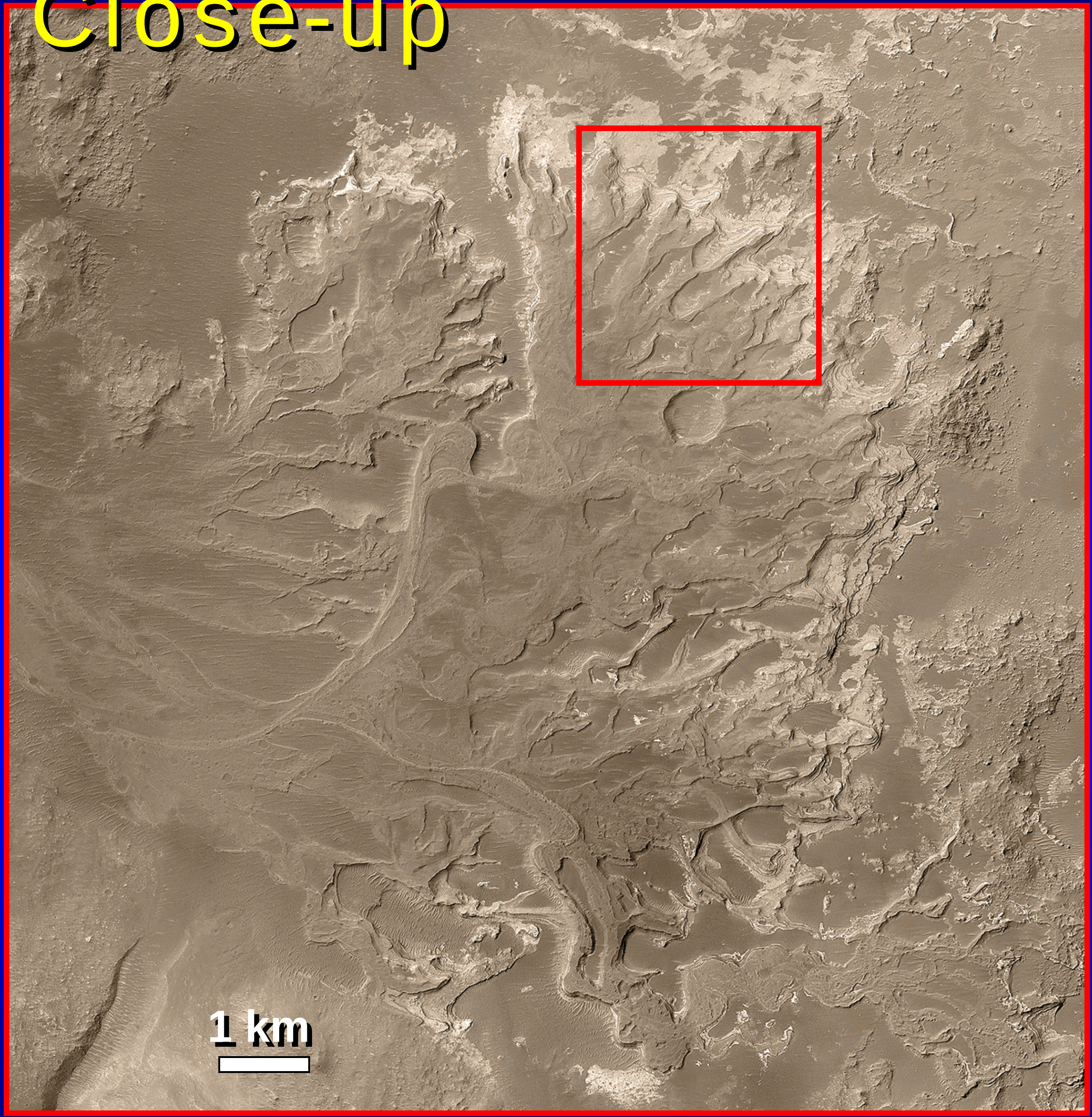
Estimating the duration of the delta

River	***Mean Avulsion Period (years)***
Mississippi	1400
Rhine-Meuse	945
Saskatchewan	670
Yellow	600
Po	490
Kosi (Mega-Fan)	28

Data compiled by Bridge, 2003

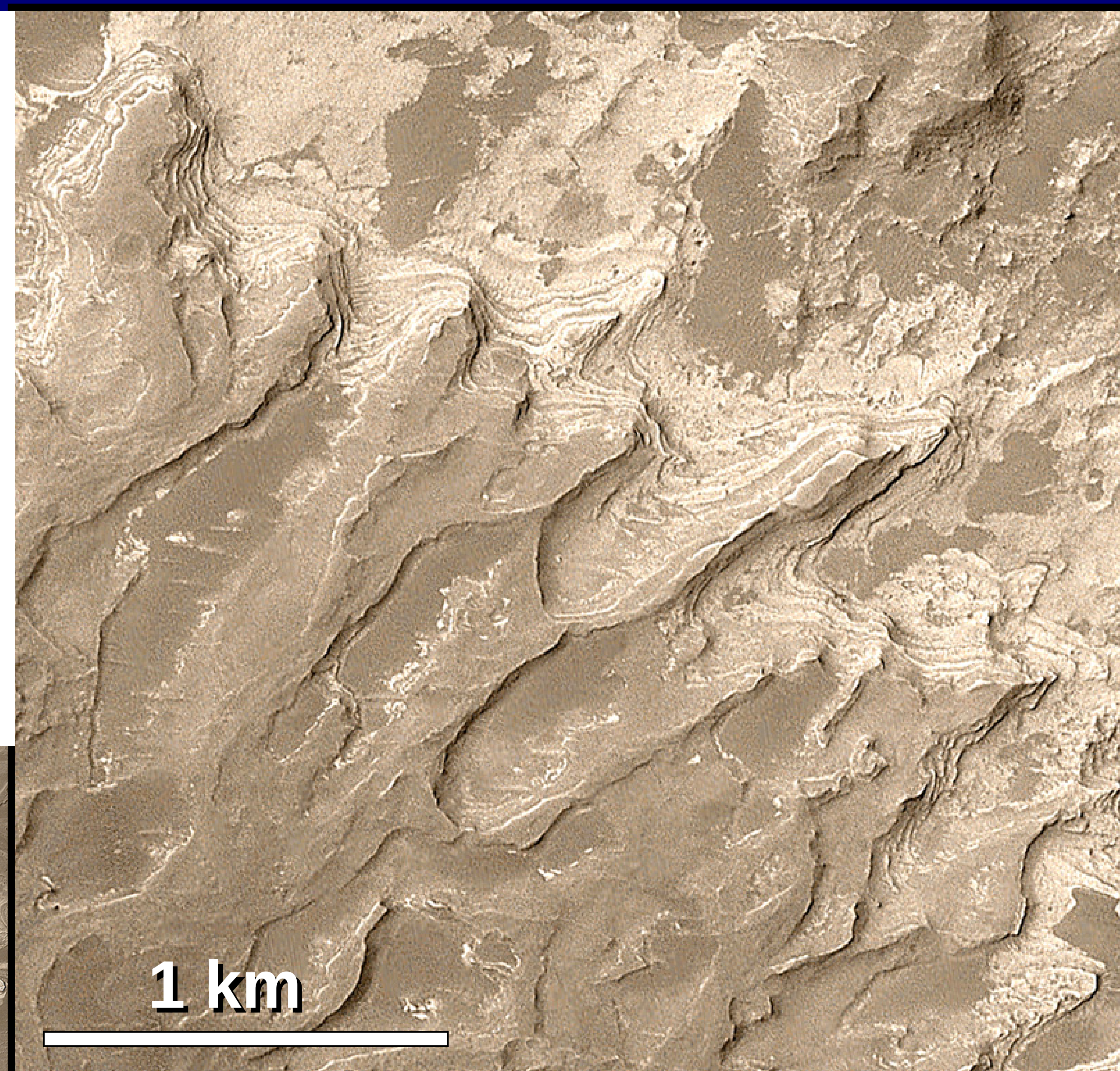
- **Deltaic versus fan numbers considered more likely**
  - **No vegetation on Mars, but floodplain may have been frozen much of the year: stable floodplain?**
  - ***Assume avulsion period of 100-500 years?***
- **11 avulsions = 1100 to 5500 years for topmost layer.**

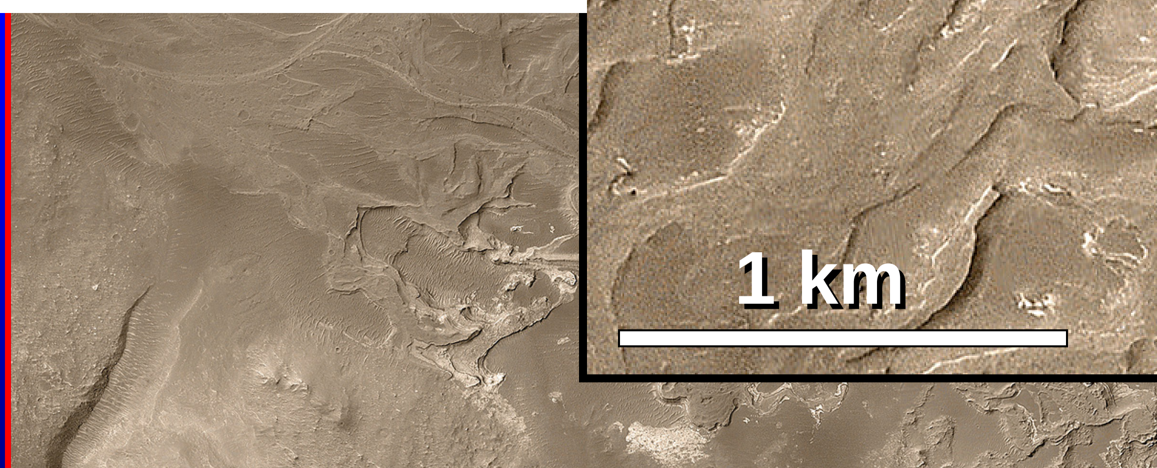
Close-up

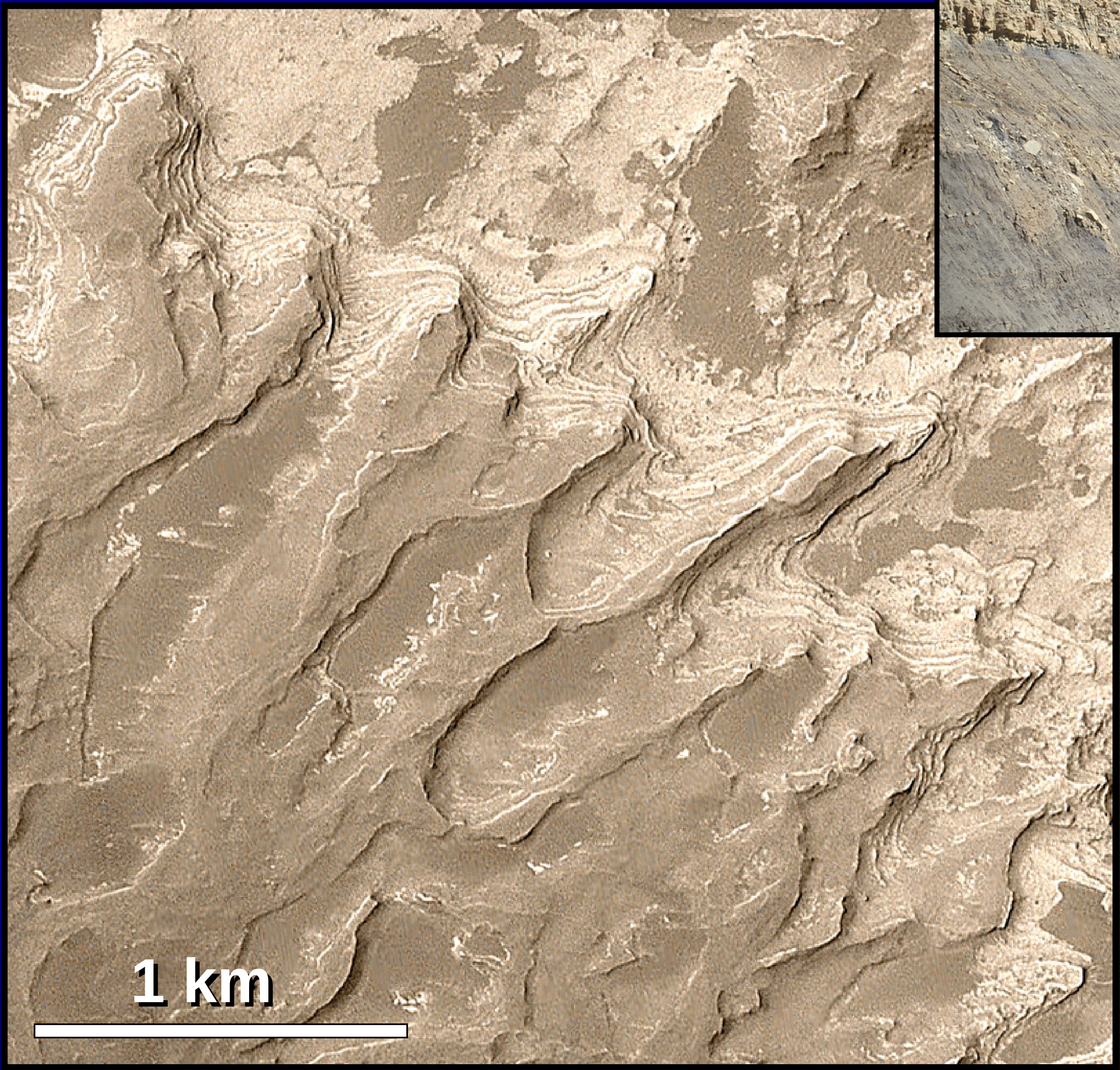


- Let's look at the distal end to get thickness.

- Examine edge of outcrop to get thickness.
  - 150 m thick
- Note lighter deeper layers
  - Prodelta bottomsets?
  - Evaporites?



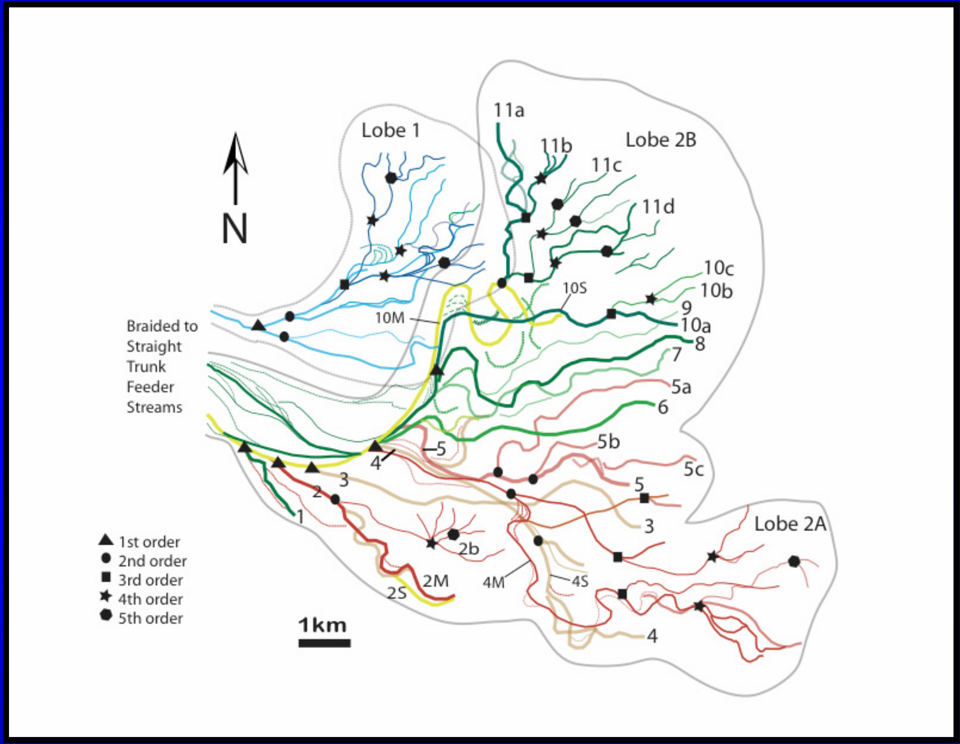




- Outcrops about 150m high.
- 1100 - 5500 years for upper layer.
- 150m x 1mm/year = 150,000 years for entire feature.

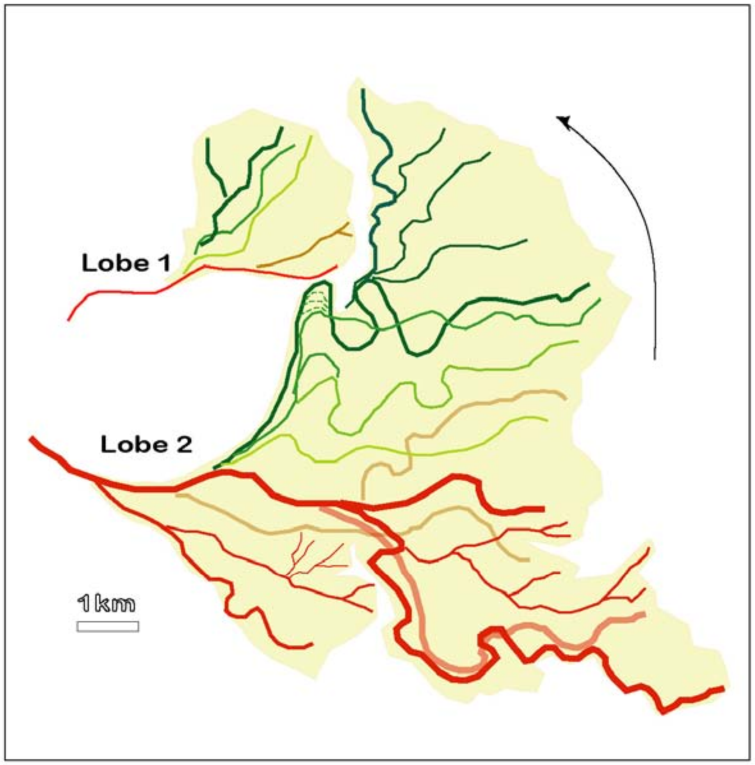
Conclusion

- Long-lived delta.
- Complex, dynamic history
  - Countless scroll-bar flood events
  - 11 avulsions in top layer
  - Feature may have formed over 10,000 to 100,000 years.
- Clearly not due to 1 major bolide-induced catastrophic groundwater melt episode.
- It was probably raining on Mars during the Archean.



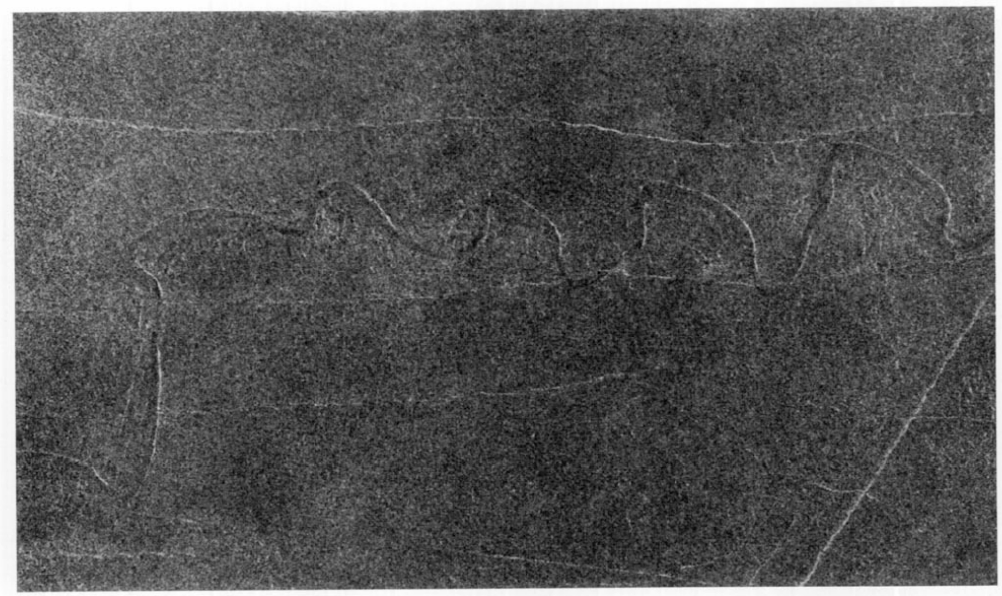
Conclusion

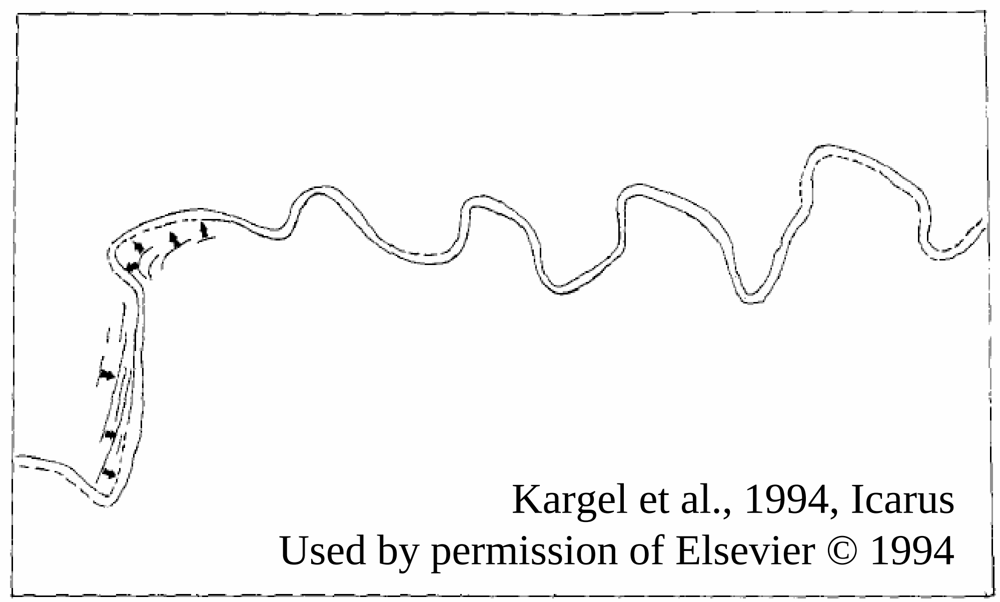
- Fluvial deposits and probable delta deposit on Mars.
- Preserve early sedimentary history.
- Candidate for preserving fossil evidence of life (biosignatures).



Meandering Channel on Venus

Feature interpreted to be formed by Carbonate-Sulfate Lavas, that have fluid properties similar to water on earth

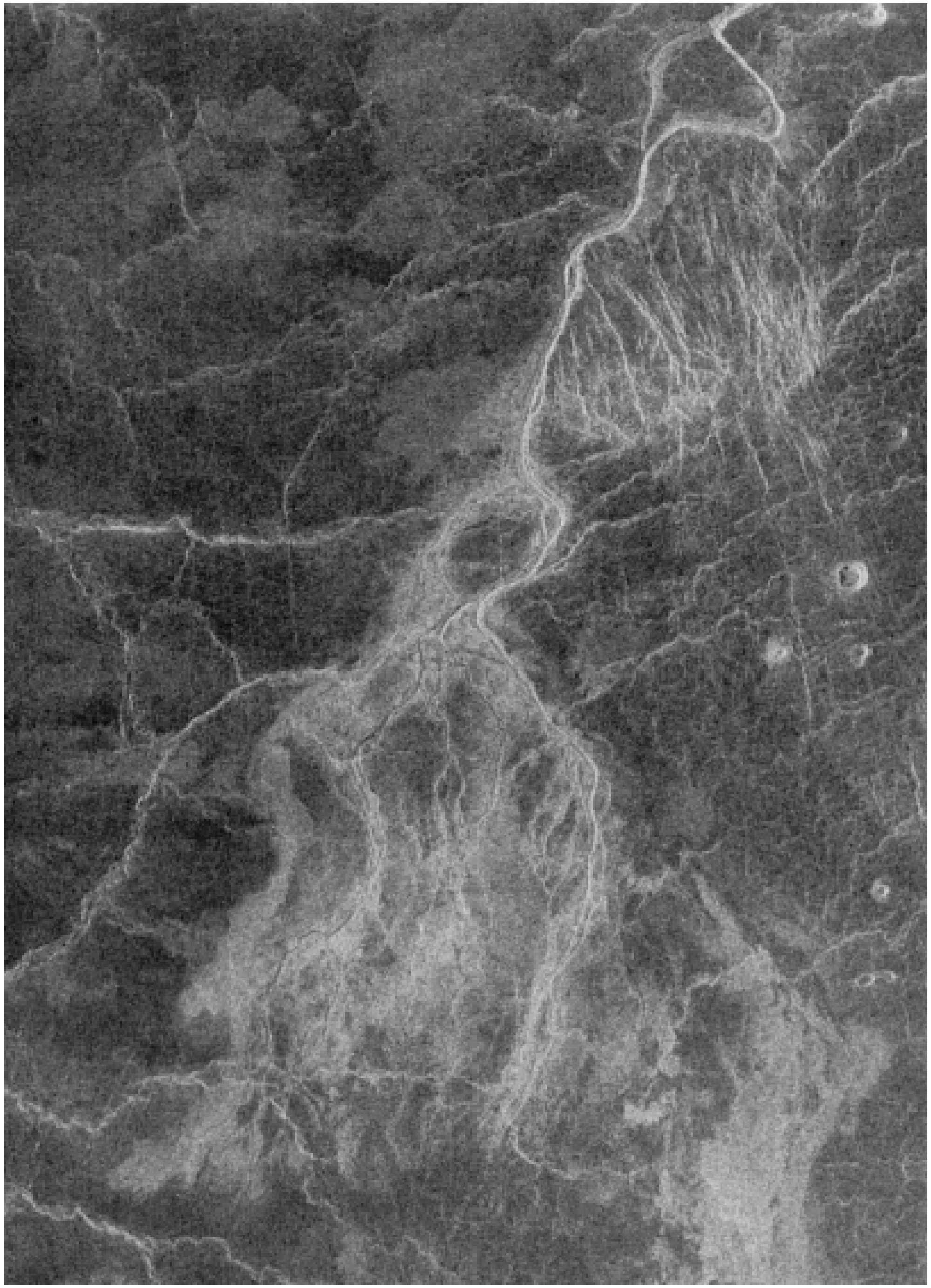




Kargel et al., 1994, Icarus

Lava Deltas on Venus

- "The universe is not only as queer as you suppose, but it is queerer than you can suppose." (*J.B.S. Haldane*)



Kargel et al., 1994, Icarus

Acknowledgements

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