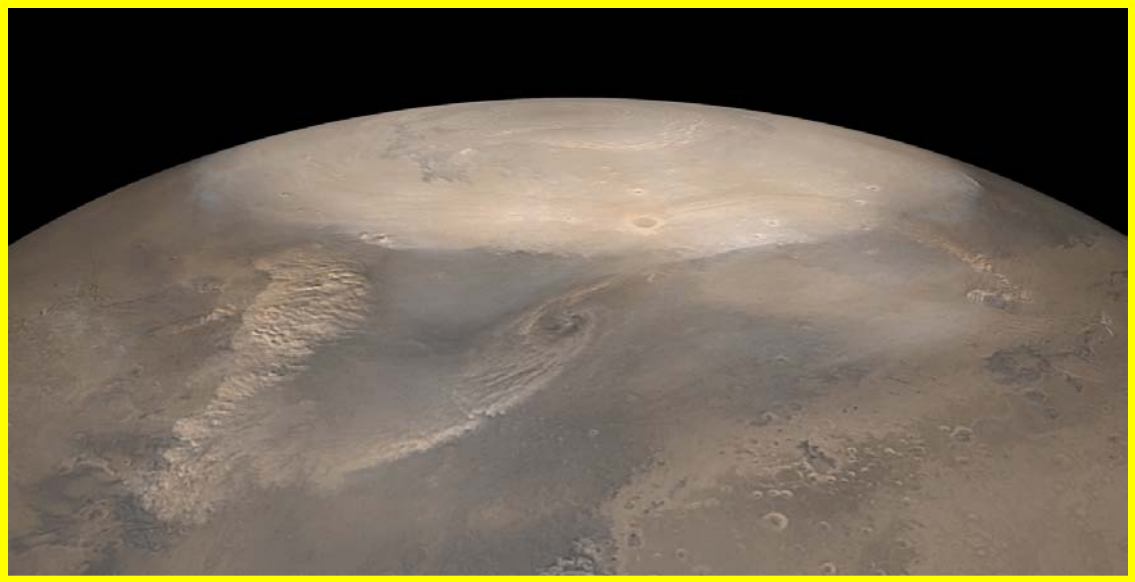
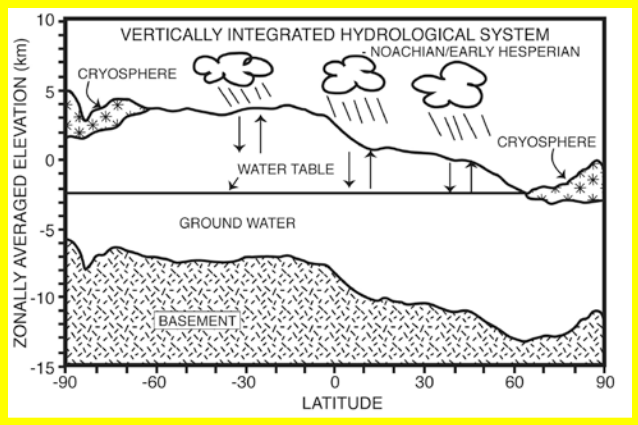
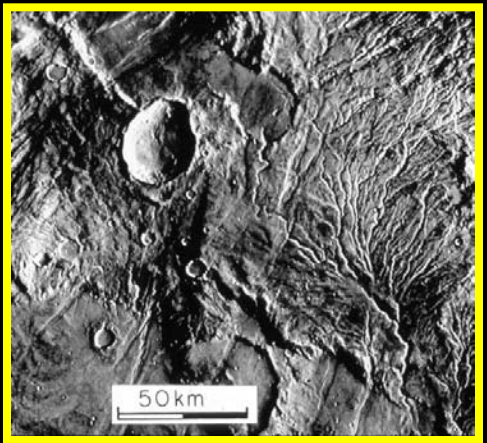
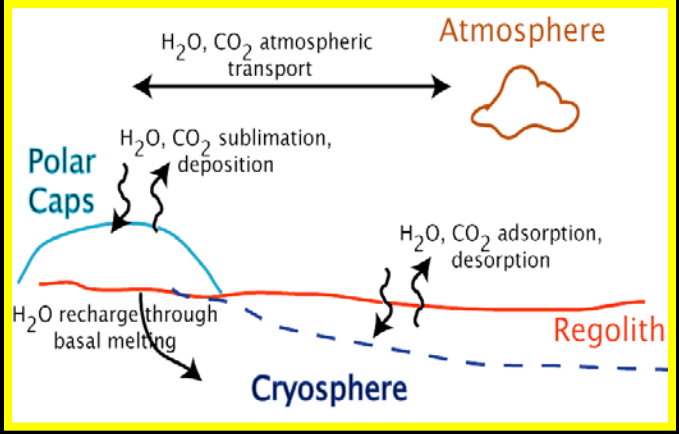
Liquid Water on Mars:
When, where, how much and where does it come from?



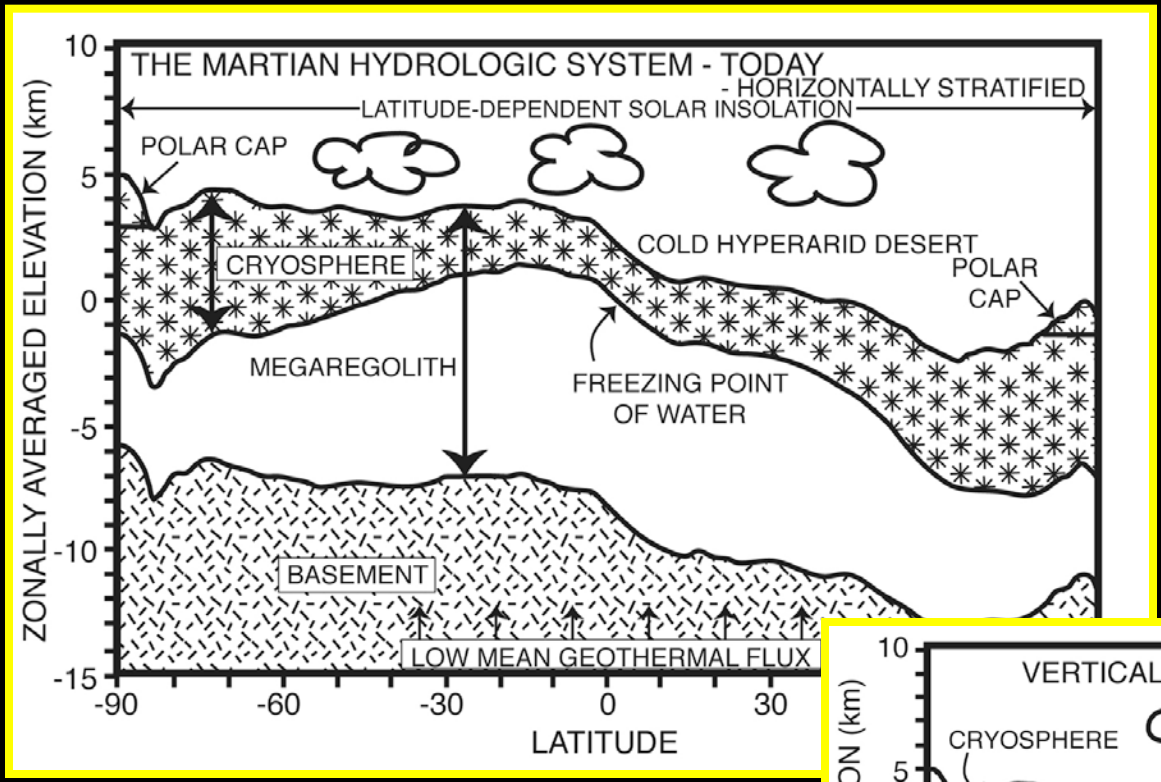






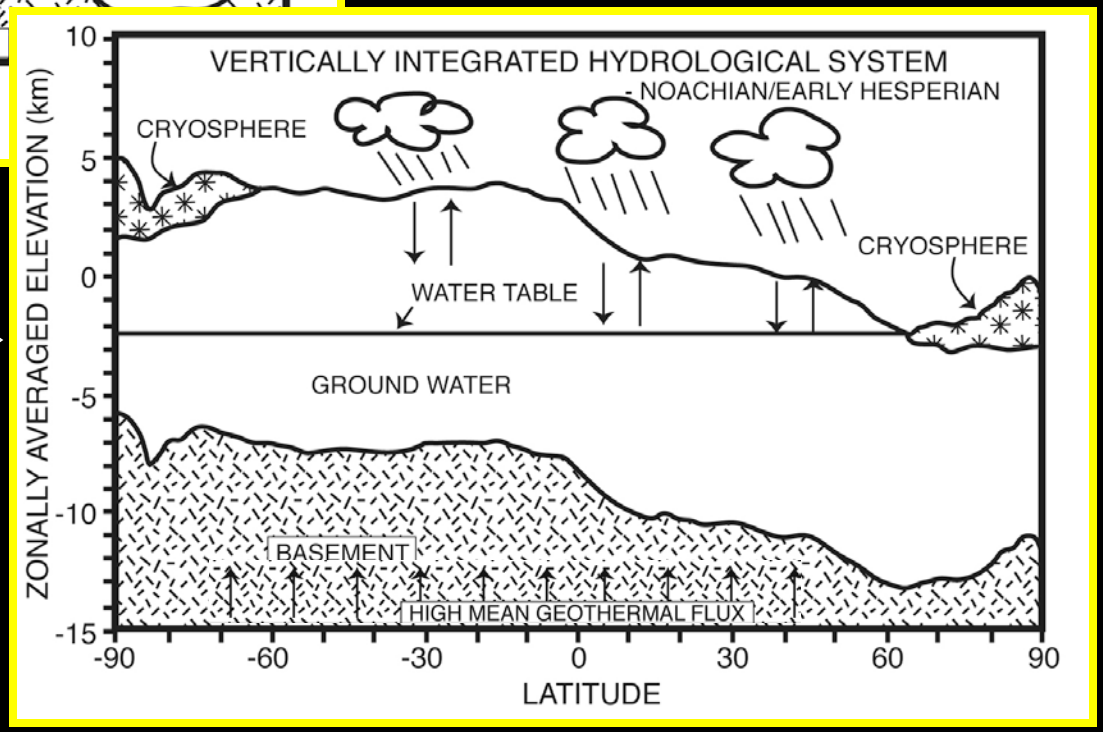
James W. Head
Department of Geological Sciences, Brown University, Providence, RI USA
Santander Astrobiology Summer School, Universidad Internacional Menéndez Pelayo, June, 2011

What is the Nature of the Hydrological Cycle on Mars?

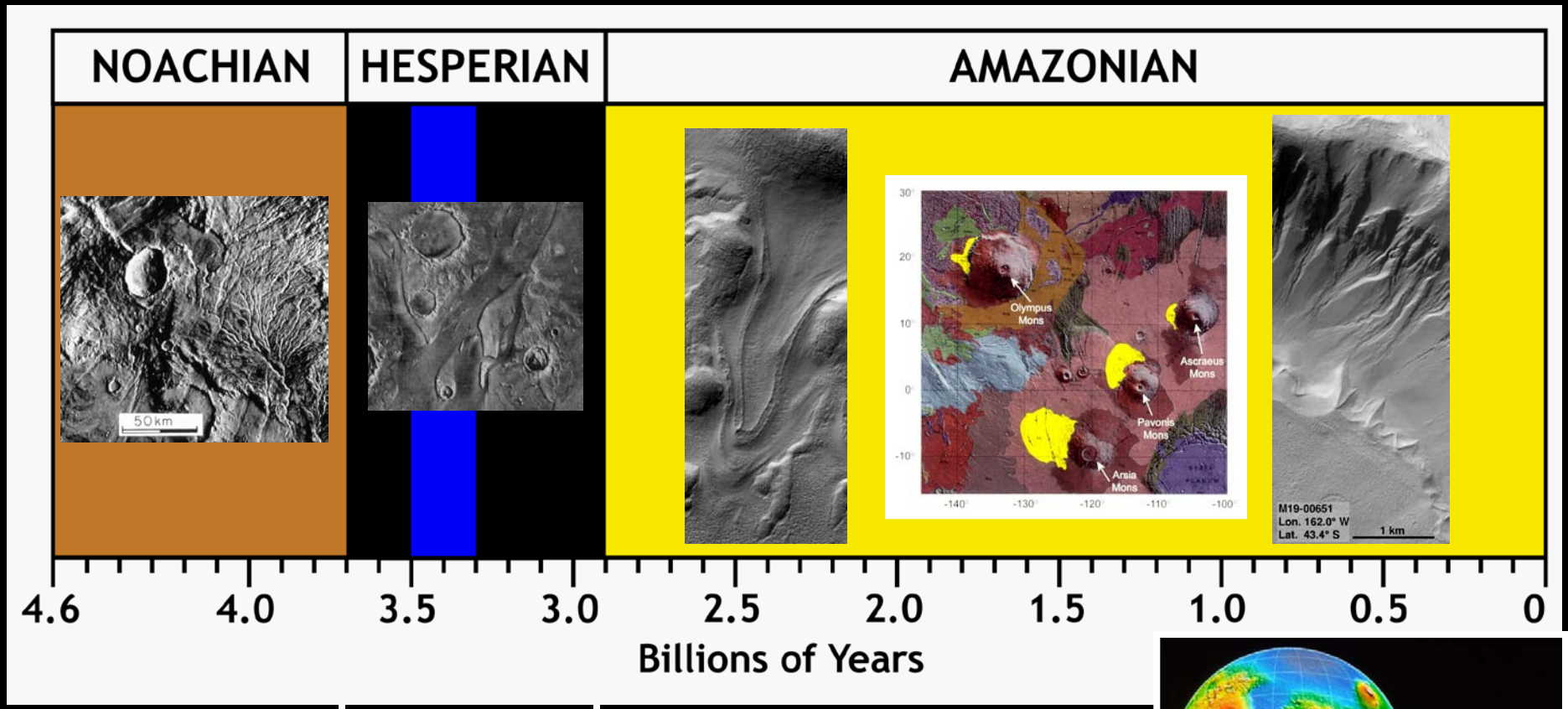


TODAY:
-Cold, Hyperarid Desert.
-Low Geothermal Heat Flux.
-Global Cryosphere.
-Horizontally Stratified Cycle.

NOACHIAN:
-High Geothermal Flux.
-Warmer and Wetter (?).
-Vertically Integrated Cycle (?).



Water and Climate on Mars: Relation to Geologic History



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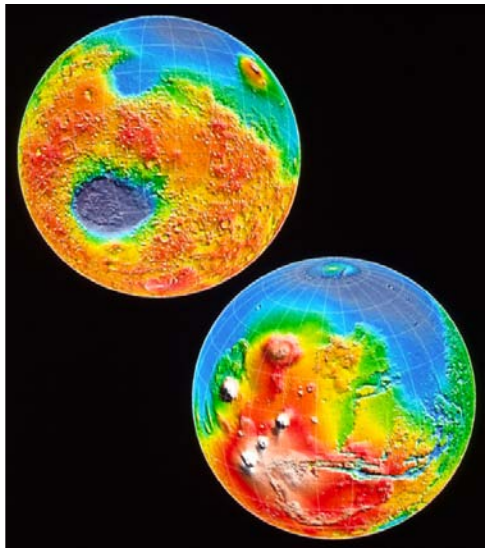

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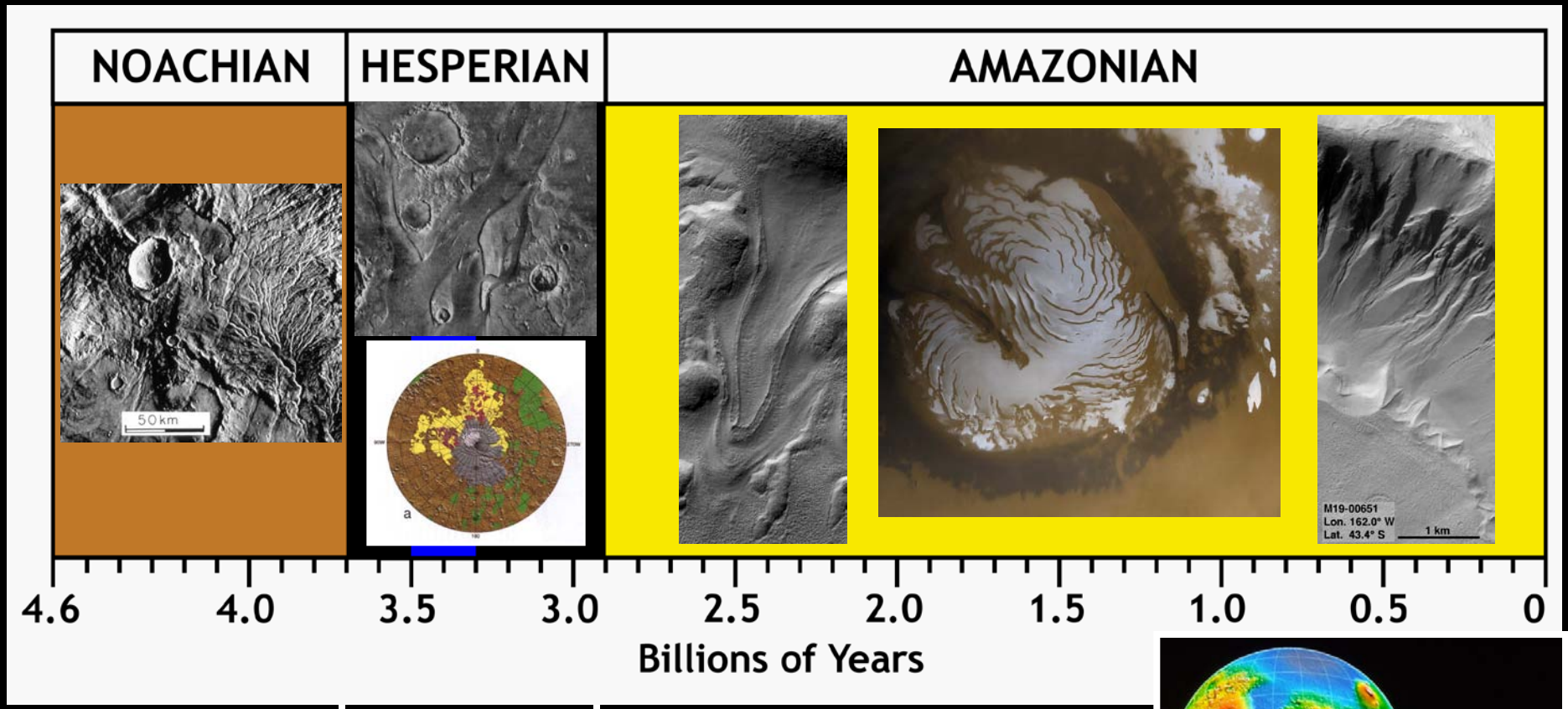
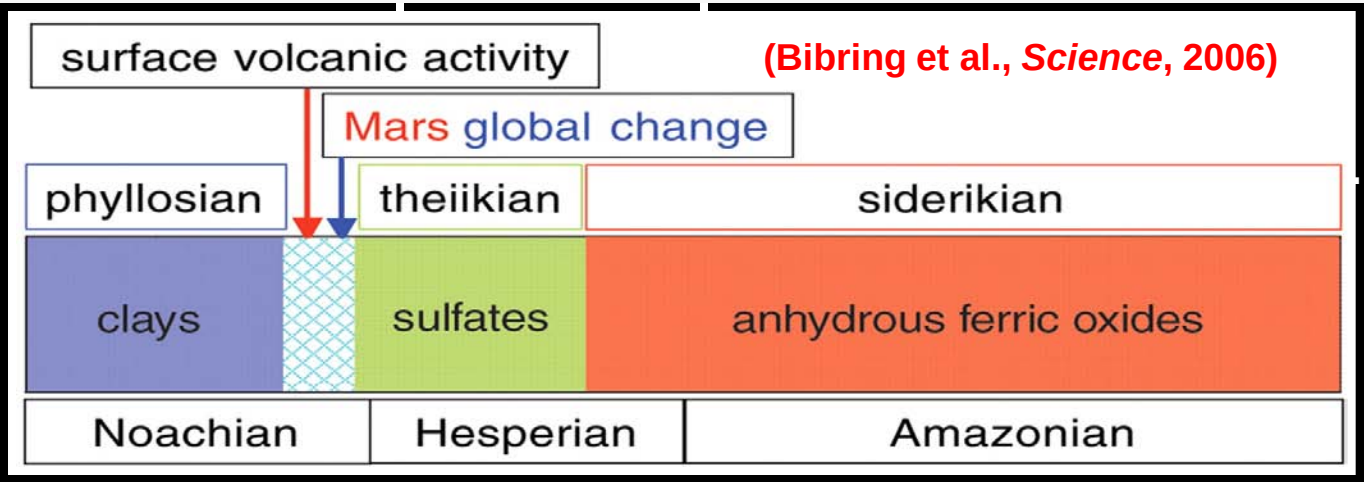
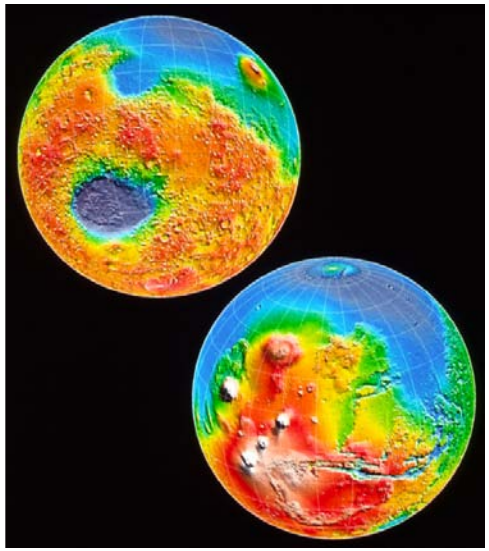
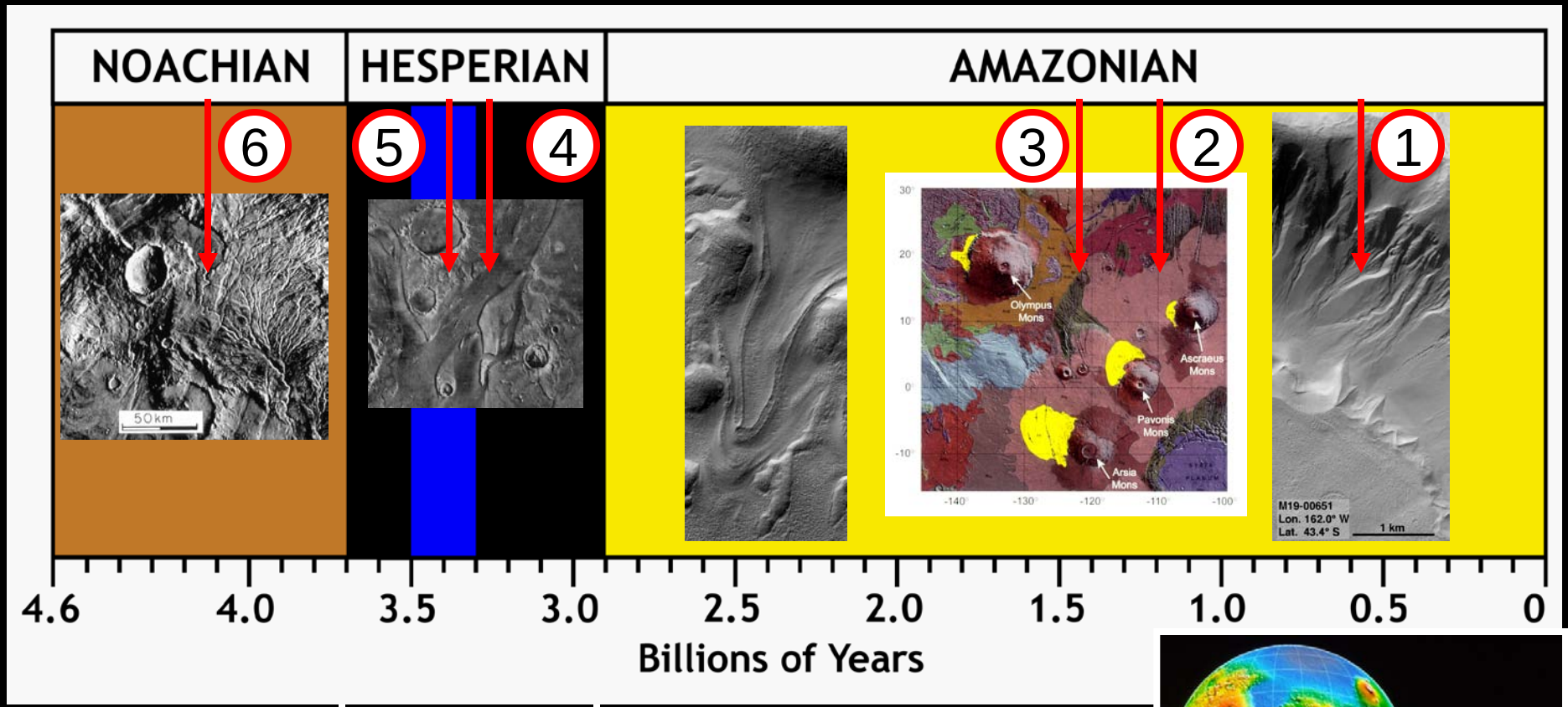




(Bibring et al., *Science*, 2006)



Water and Climate on Mars: Relation to Geologic History



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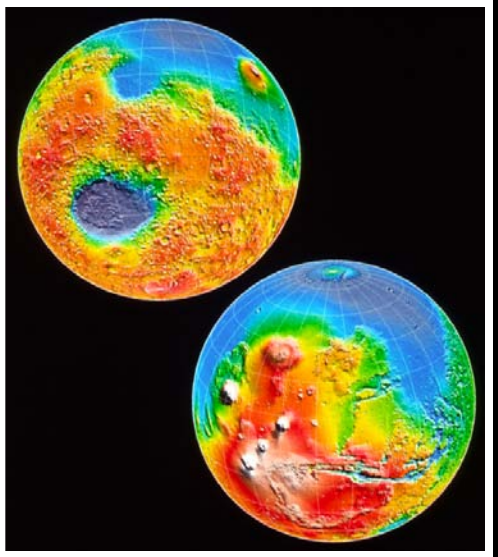
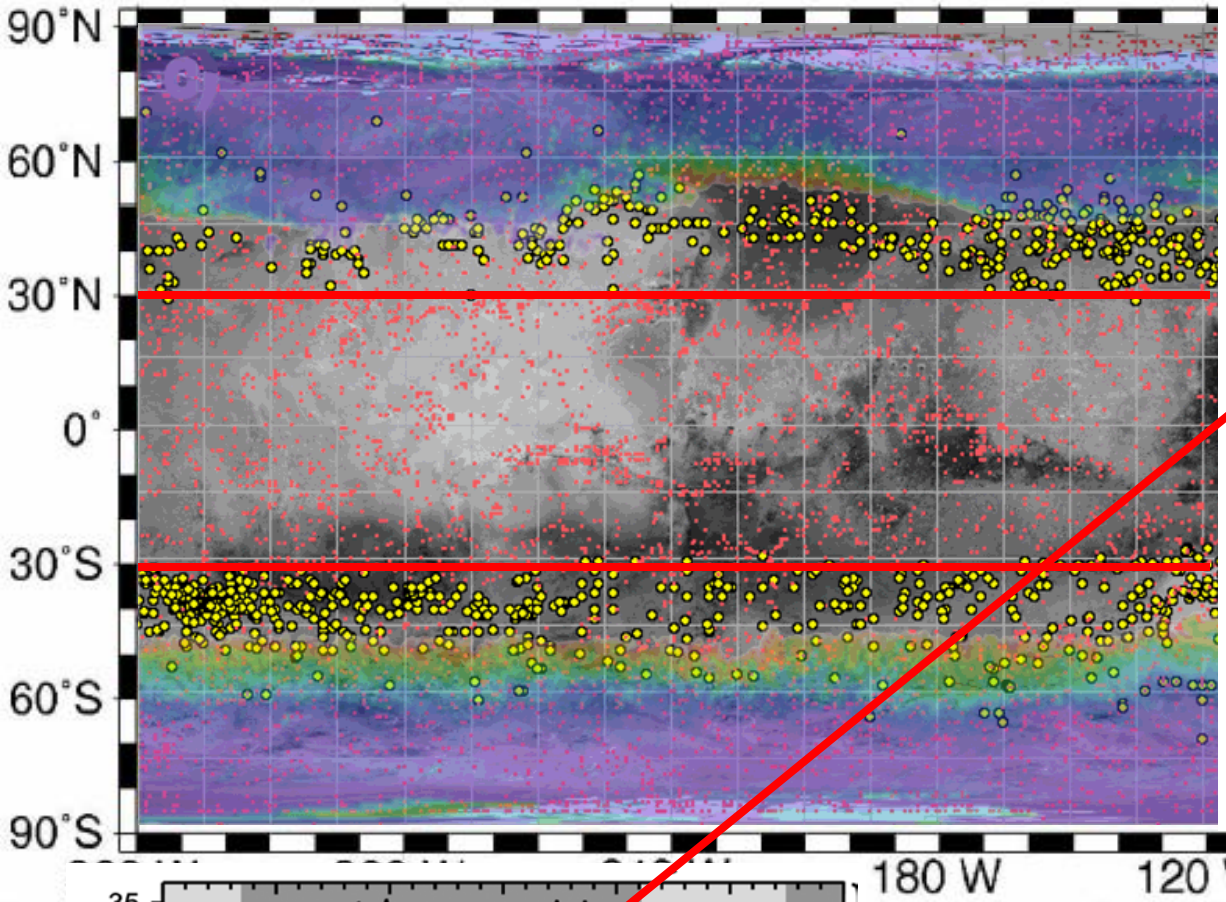
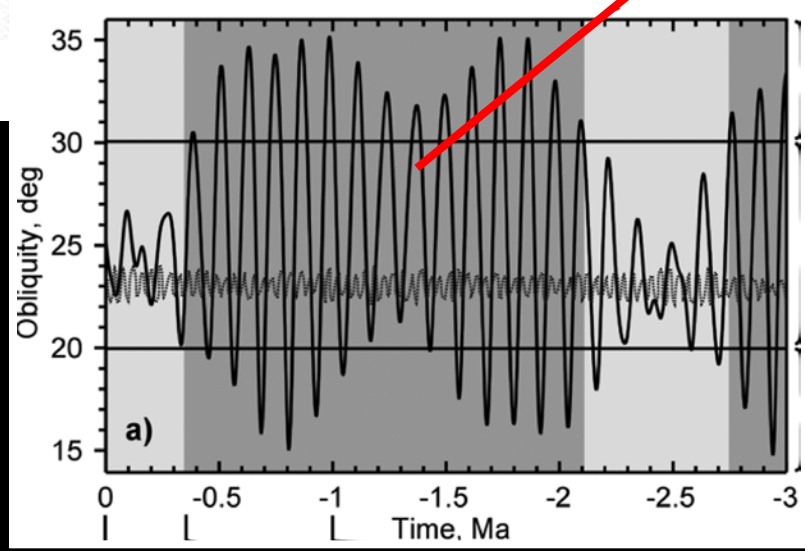
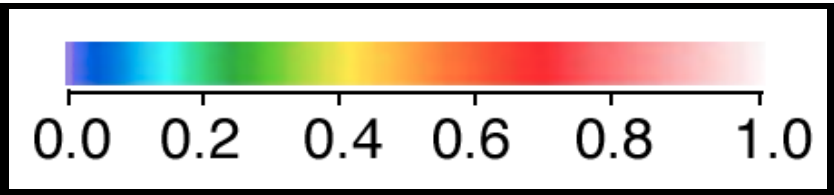




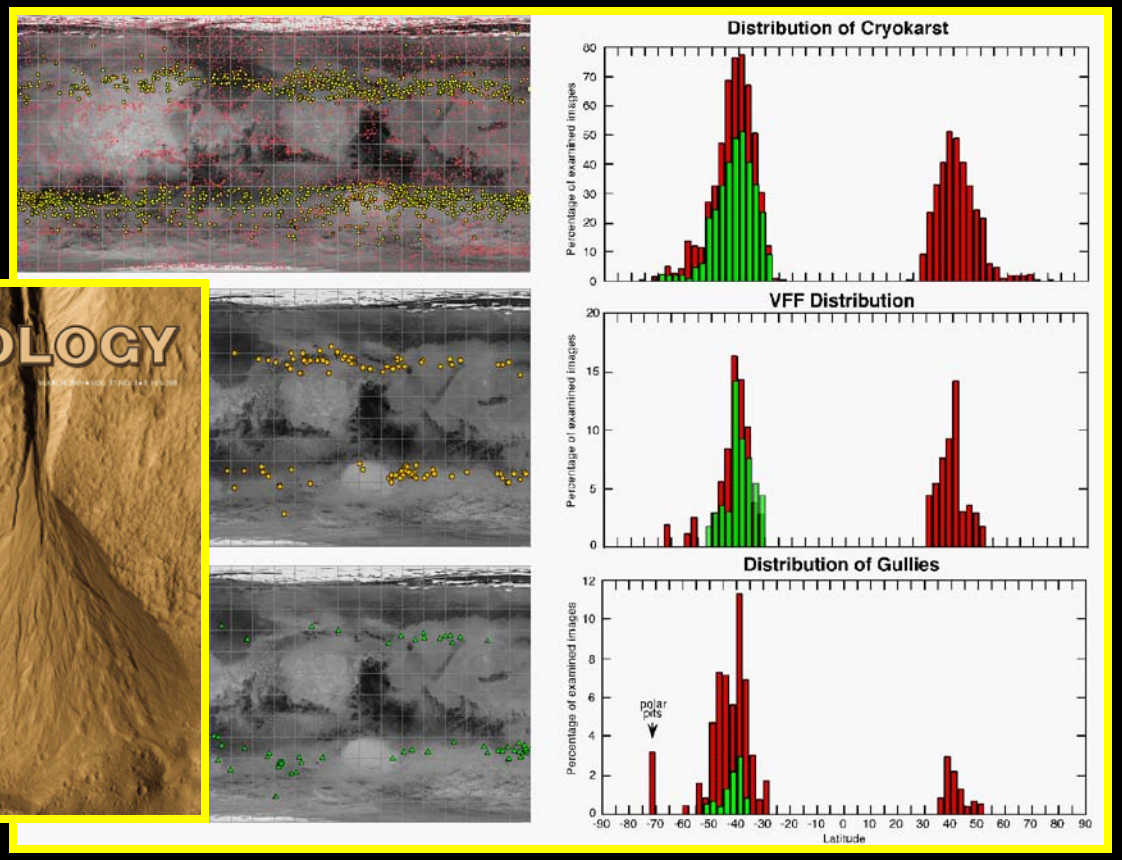
(Head et al., 2003)





Ice Table Depth [m]
Mellon, LPSC 34

What is Relation of Mars Gullies to Regional Mantling Deposit?

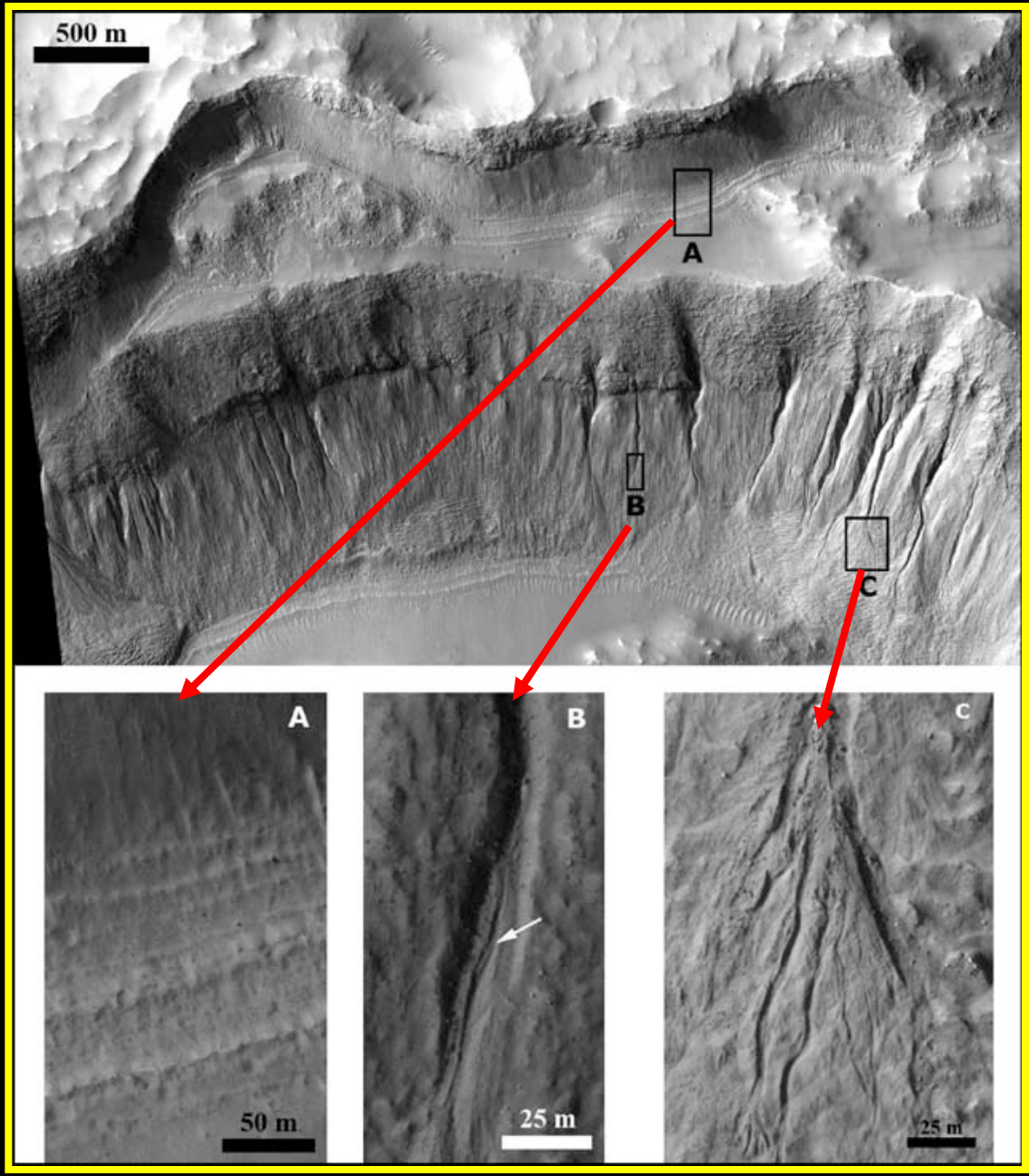


Mustard et al., 2000; Milliken et al., 2003; Head et al., 2003.

-What is the association of the recent ice-rich latitude-dependent climate-related mantle deposits and correlative features and structures?

- **Gullies.**
- **Dissected Terrain (cryokarst) and Mantle Layering**

Correlation of Ice-Rich Latitude-Dependent Mantle and Related Gully Features.

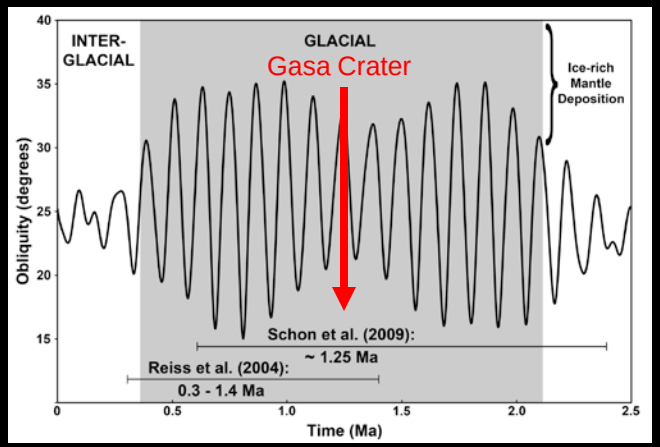


Exposed Layered mantle = A
Gully alcoves and channels = B
Gully channels and fans = C

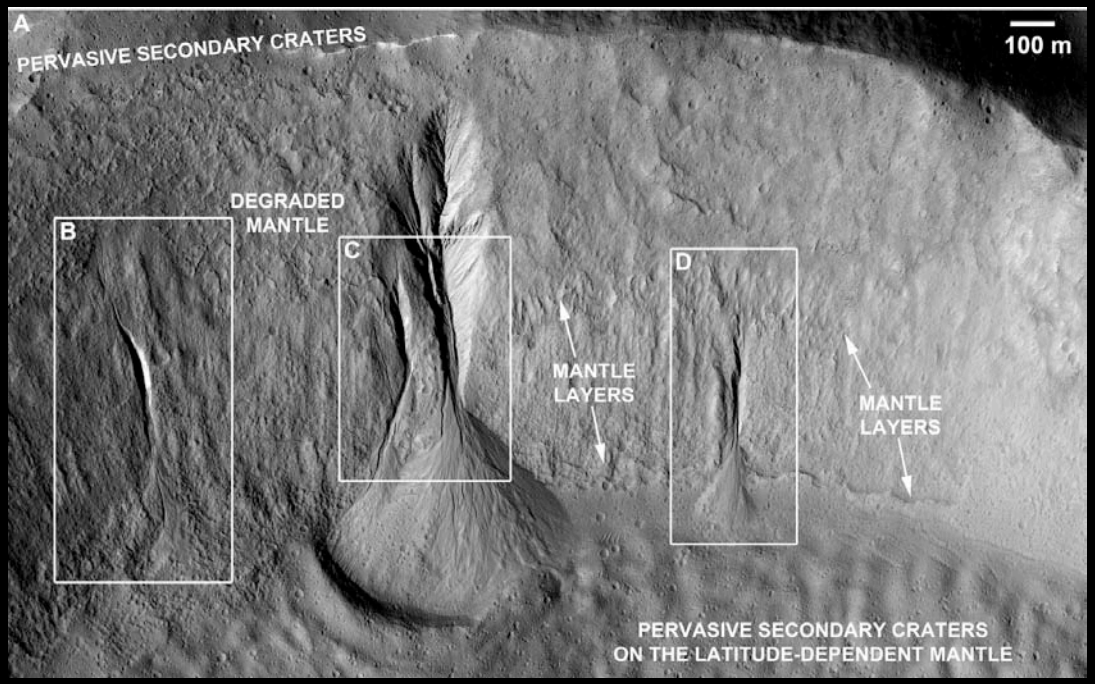
Dickson et al., 2007, 2009;
Schon and Head, 2007

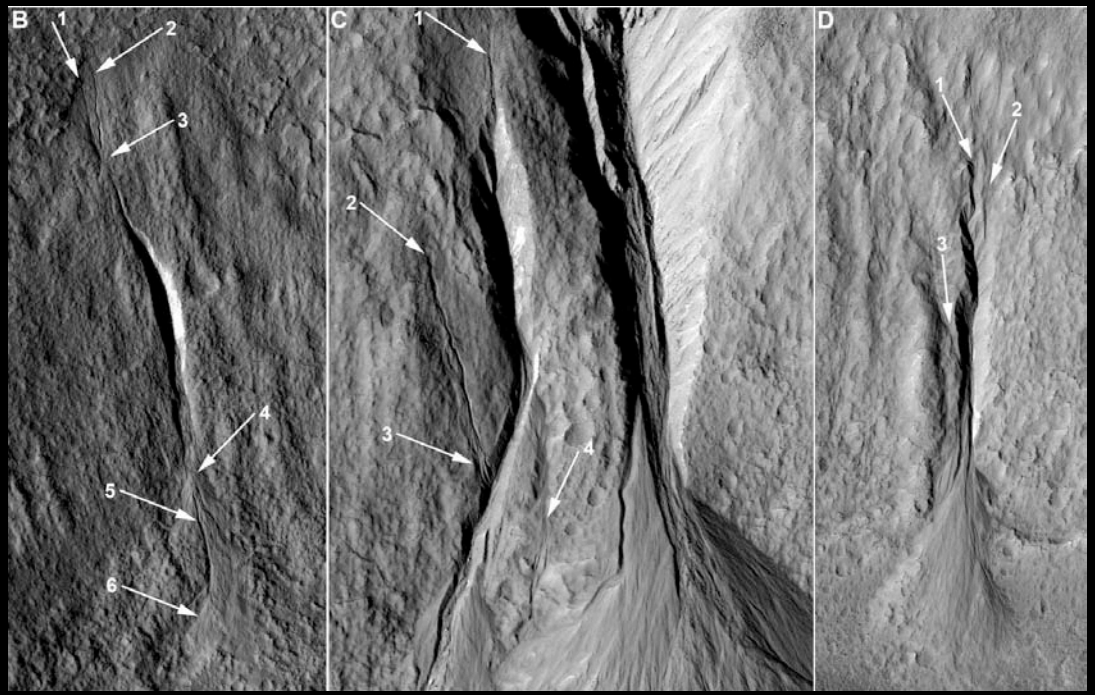
1. Gullies are Very Young.

2. Gullies are Associated with and Derived From the Ice-Rich Latitude-Dependent Mantle.



(Schon and Head, 2009, 2011)





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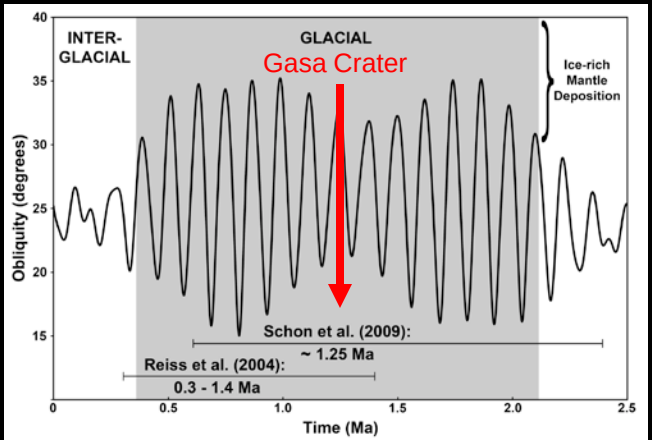

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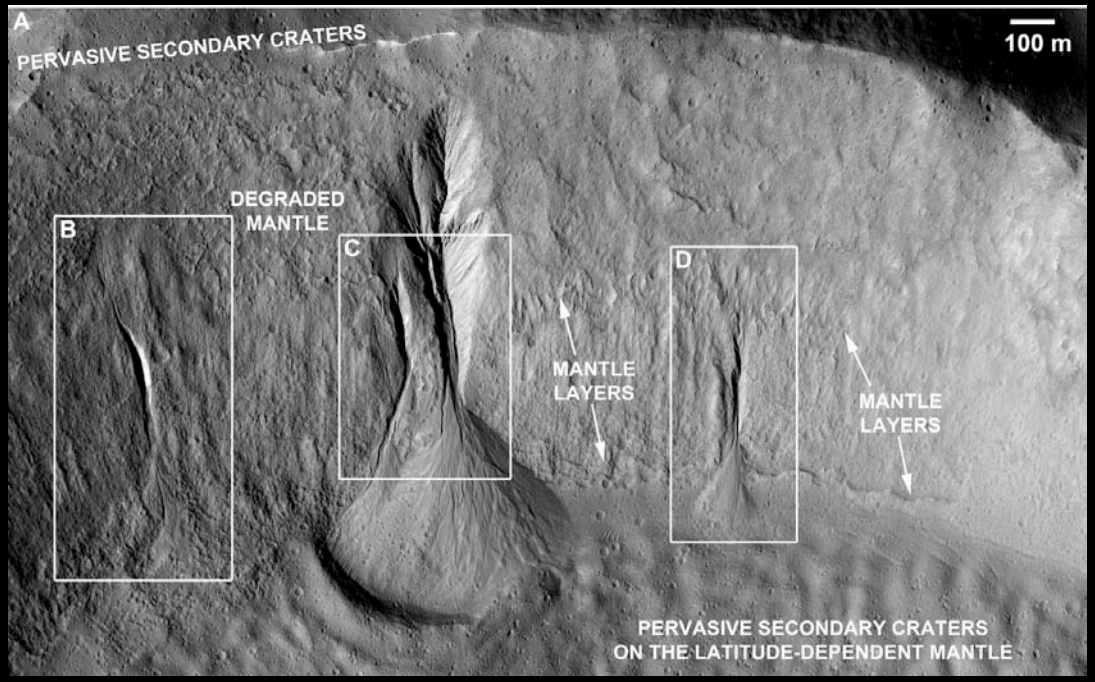
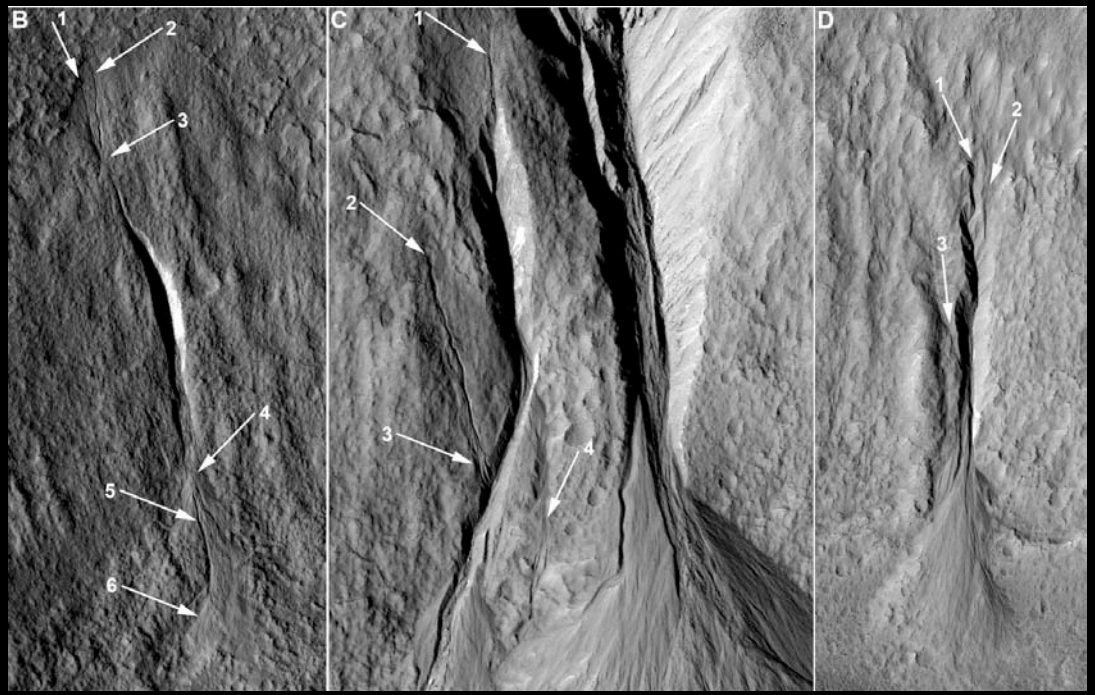
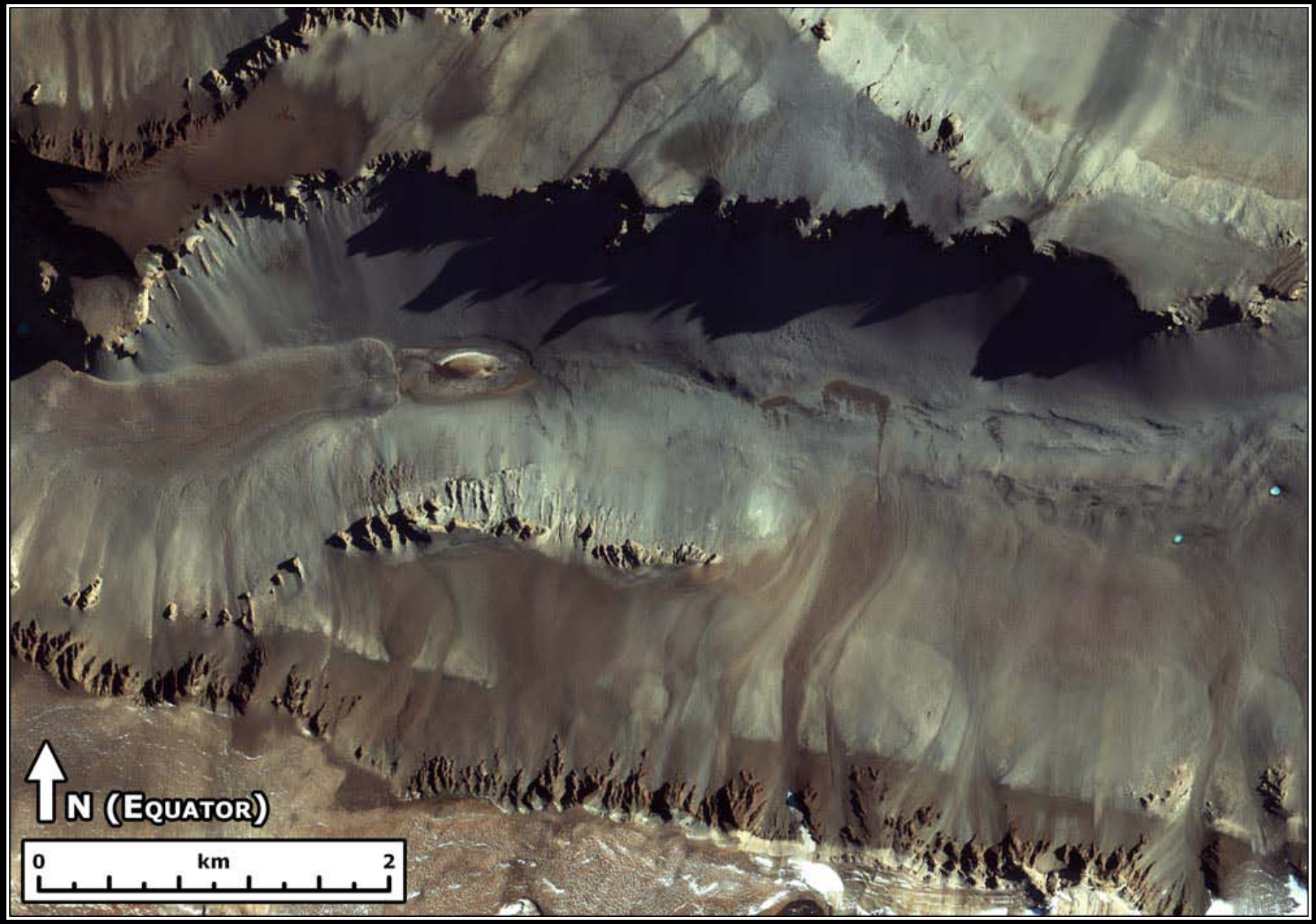




McMurdo Dry Valleys – Upper Wright Valley



McMurdo Dry Valleys – South Fork

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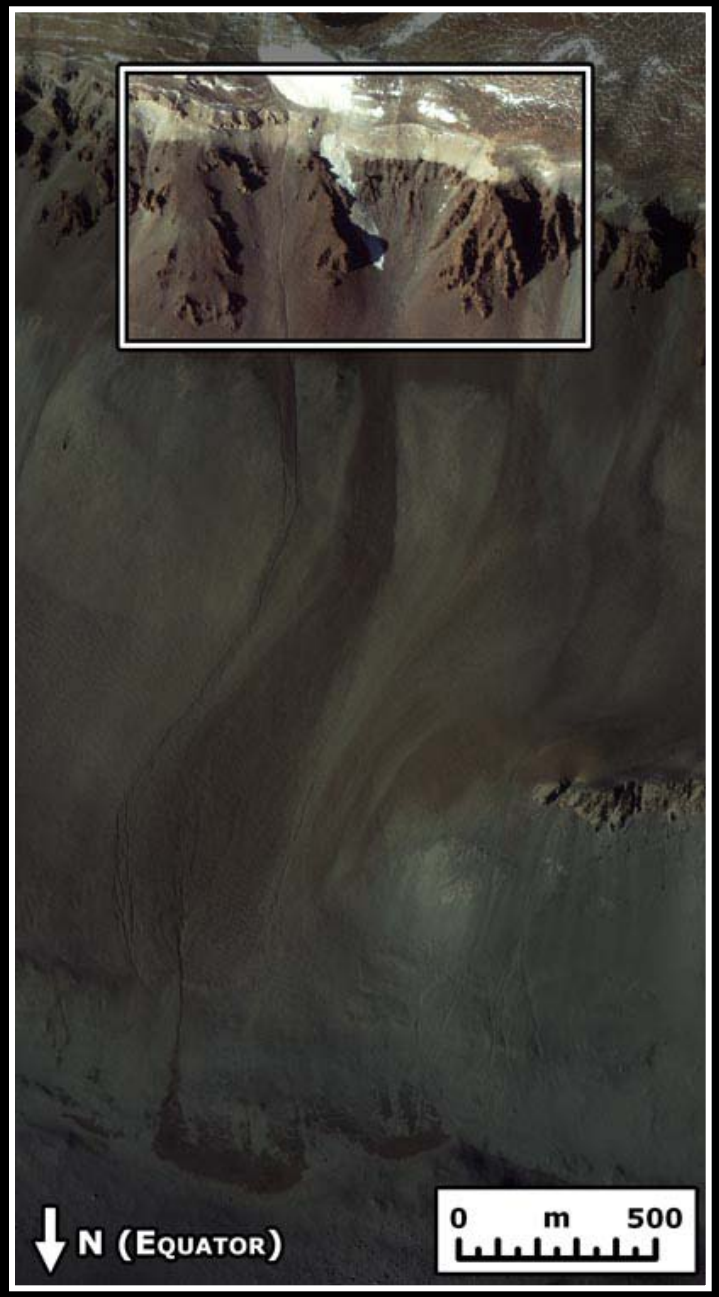
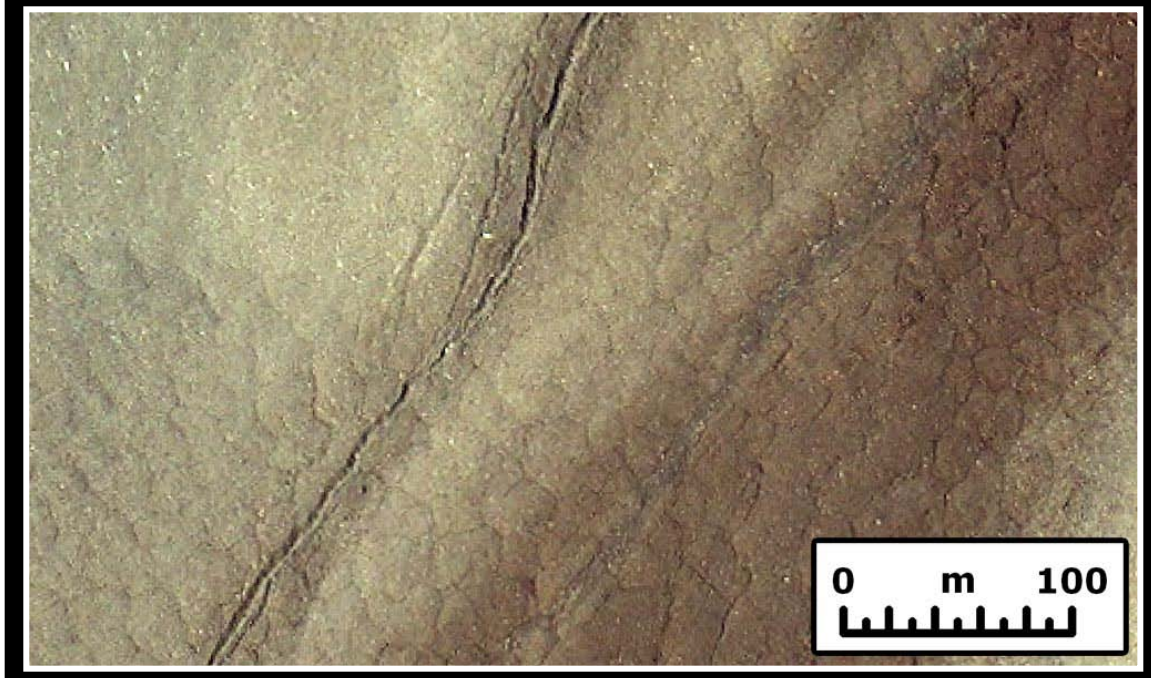


Alcoves

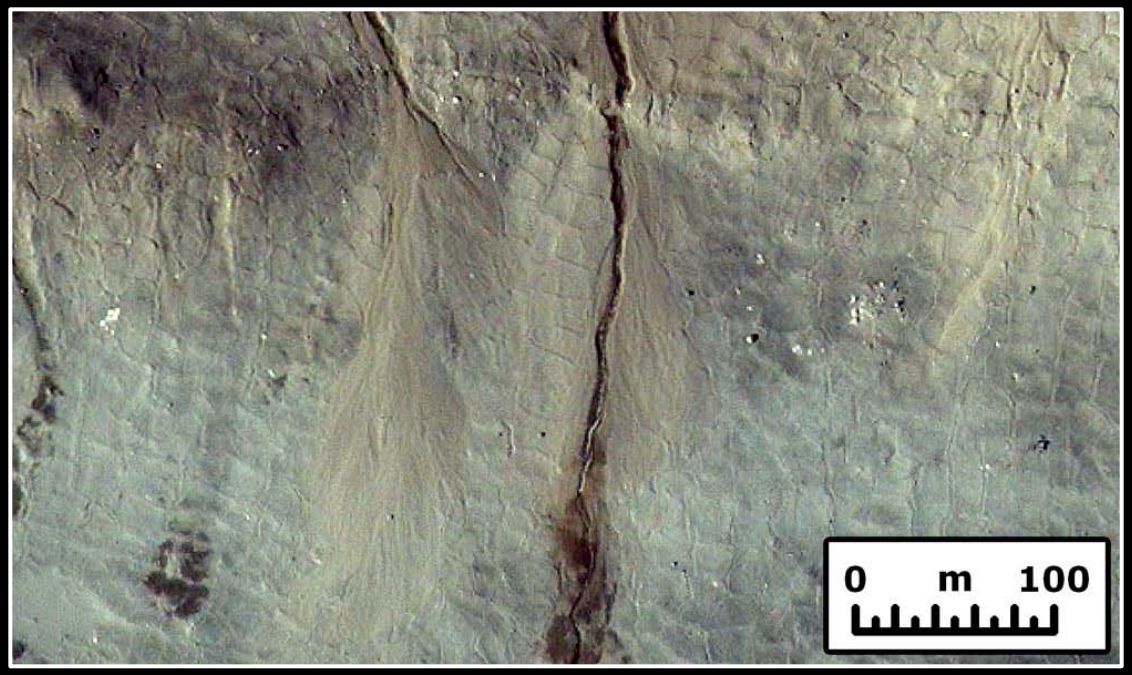
McMurdo Dry Valleys – South Fork

Channels

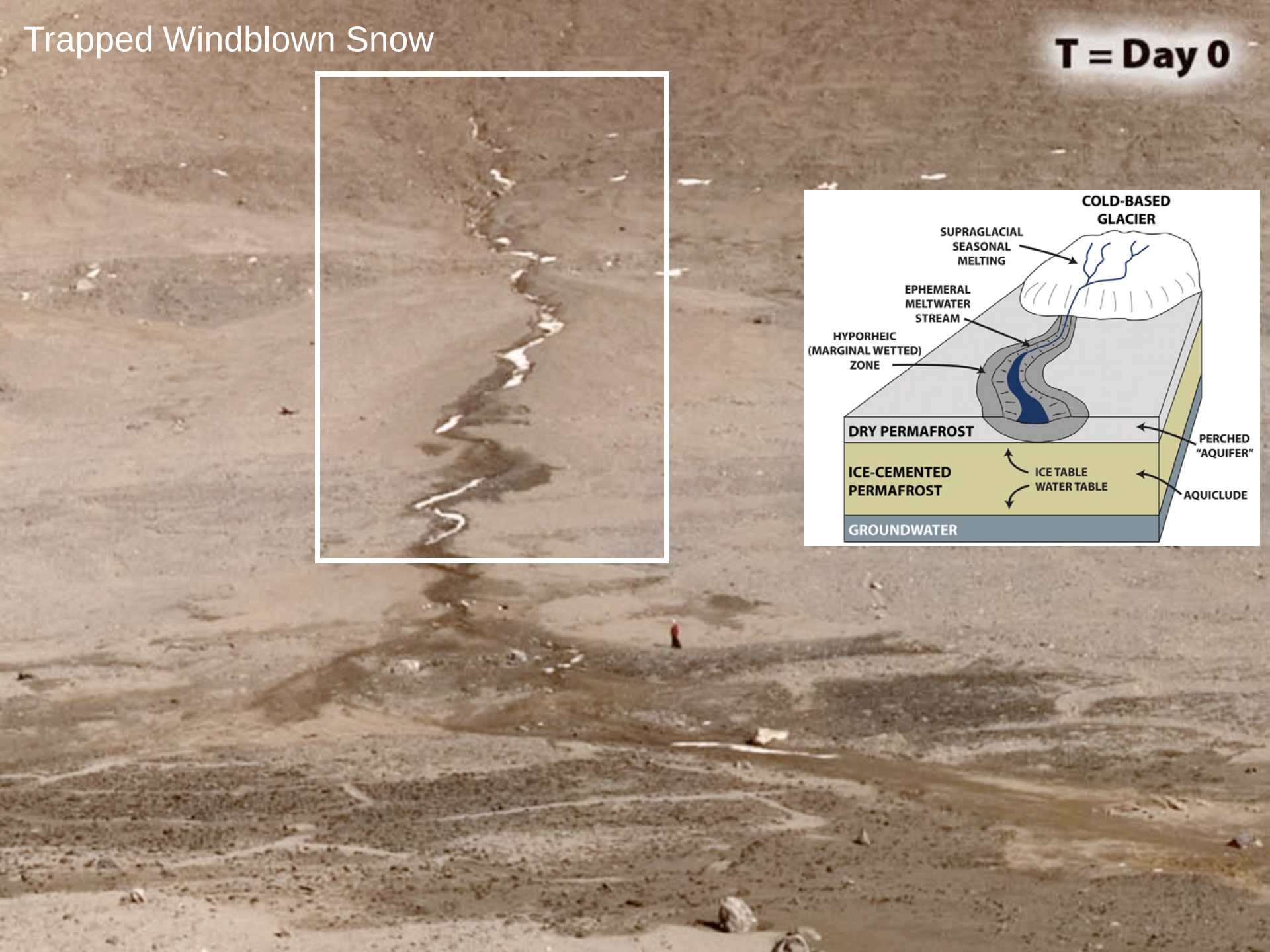


McMurdo Dry Valleys – South Fork

Fans



Trapped Windblown Snow



T = Day 2

T = Day 4

T = Day 6

T = Day 8

T = Day 10

T = Day 12

Surface Water Flow

Hyporheic Zone

Hyporheic Zone

Hyporheic Zone

Hyporheic Zone

Hyporheic Zone

Hyporheic Zone

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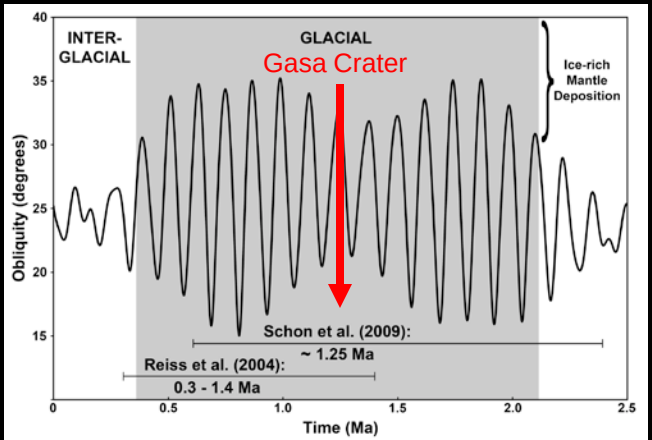

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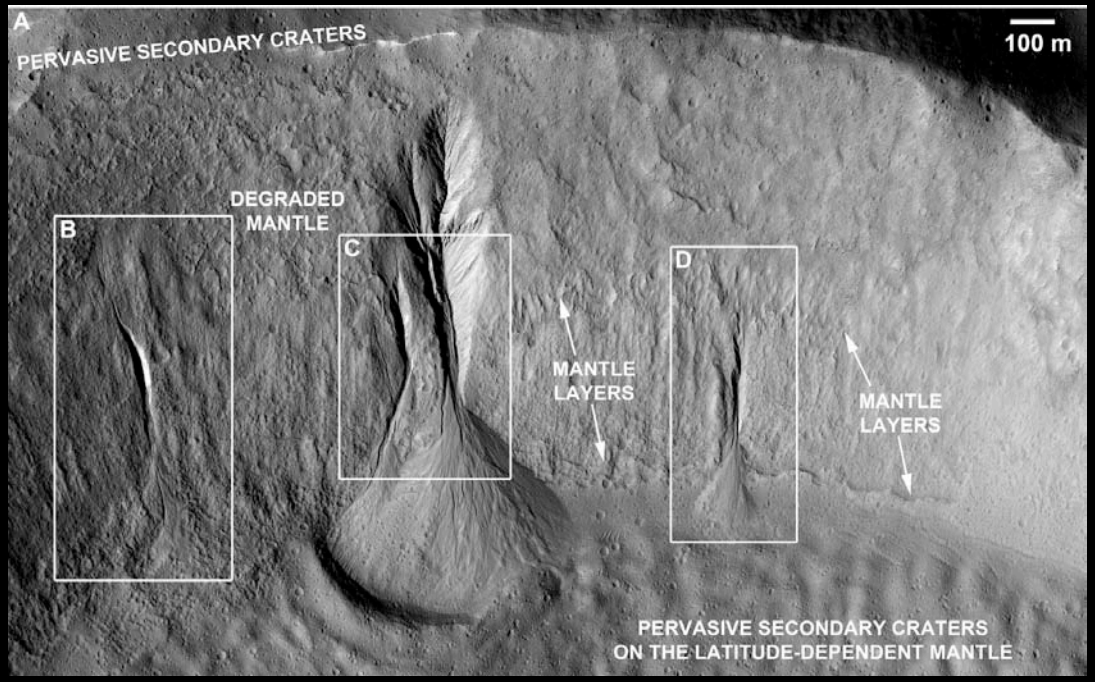
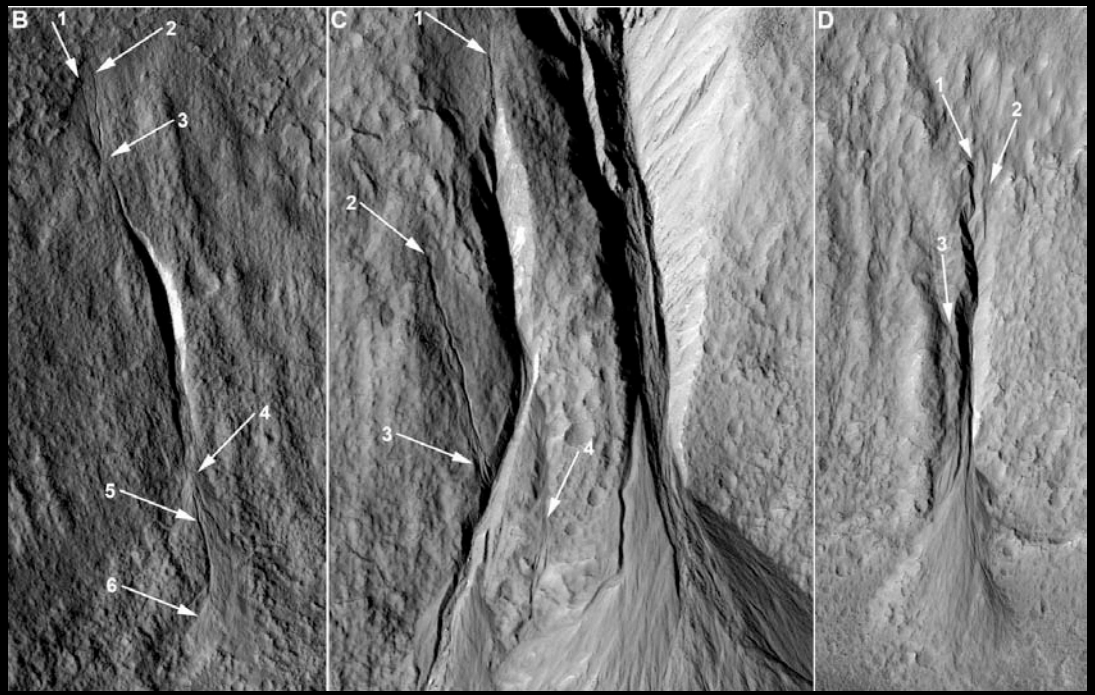
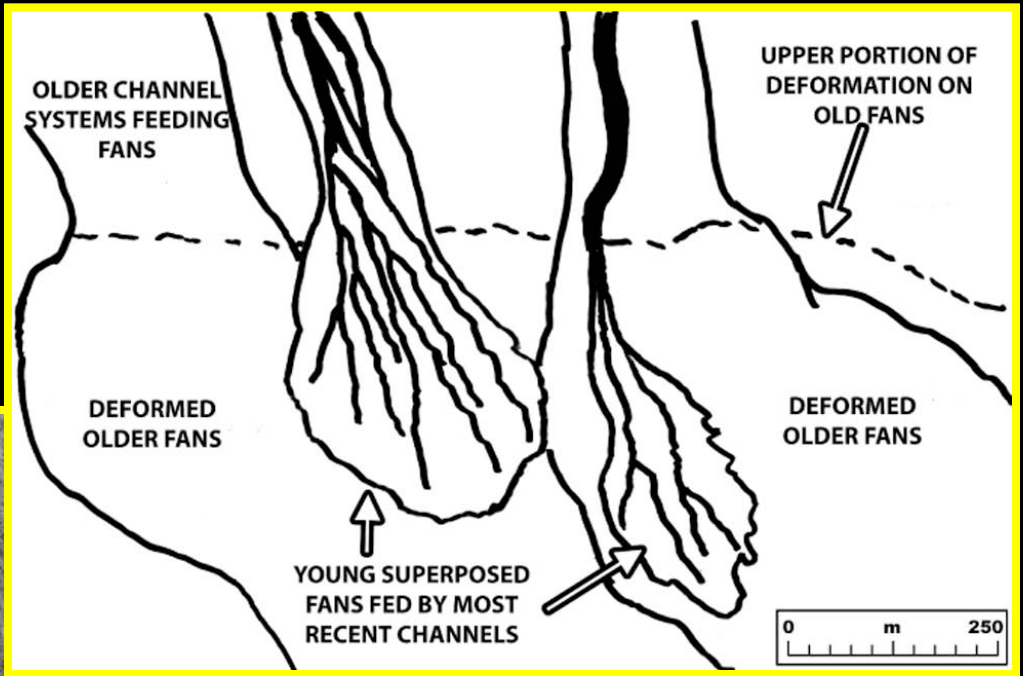


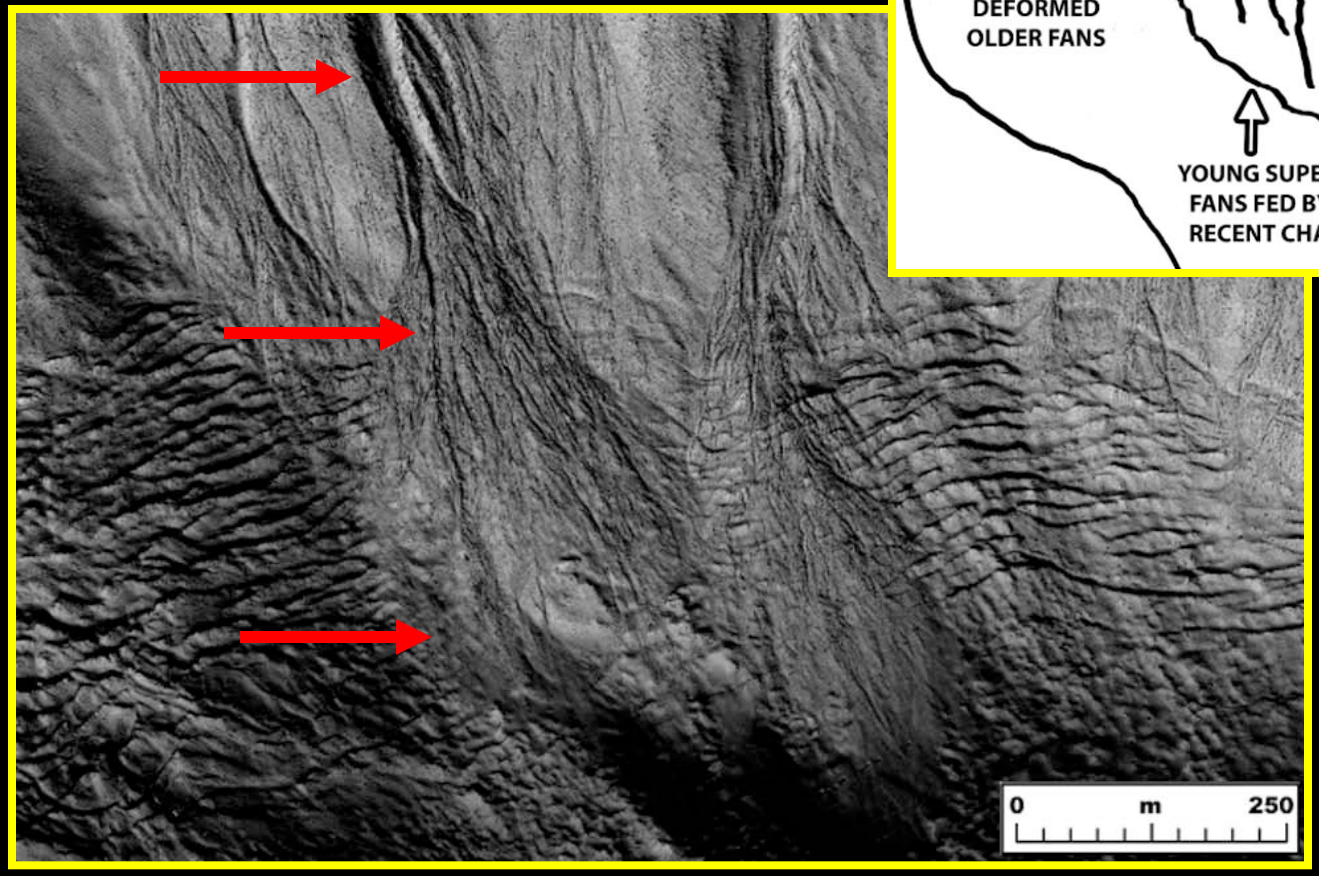


Gullies Are Active Over Extended Period

-Bases of earlier fans are deformed, but later fans are not.

-Youngest fans have superposed distributary fans.

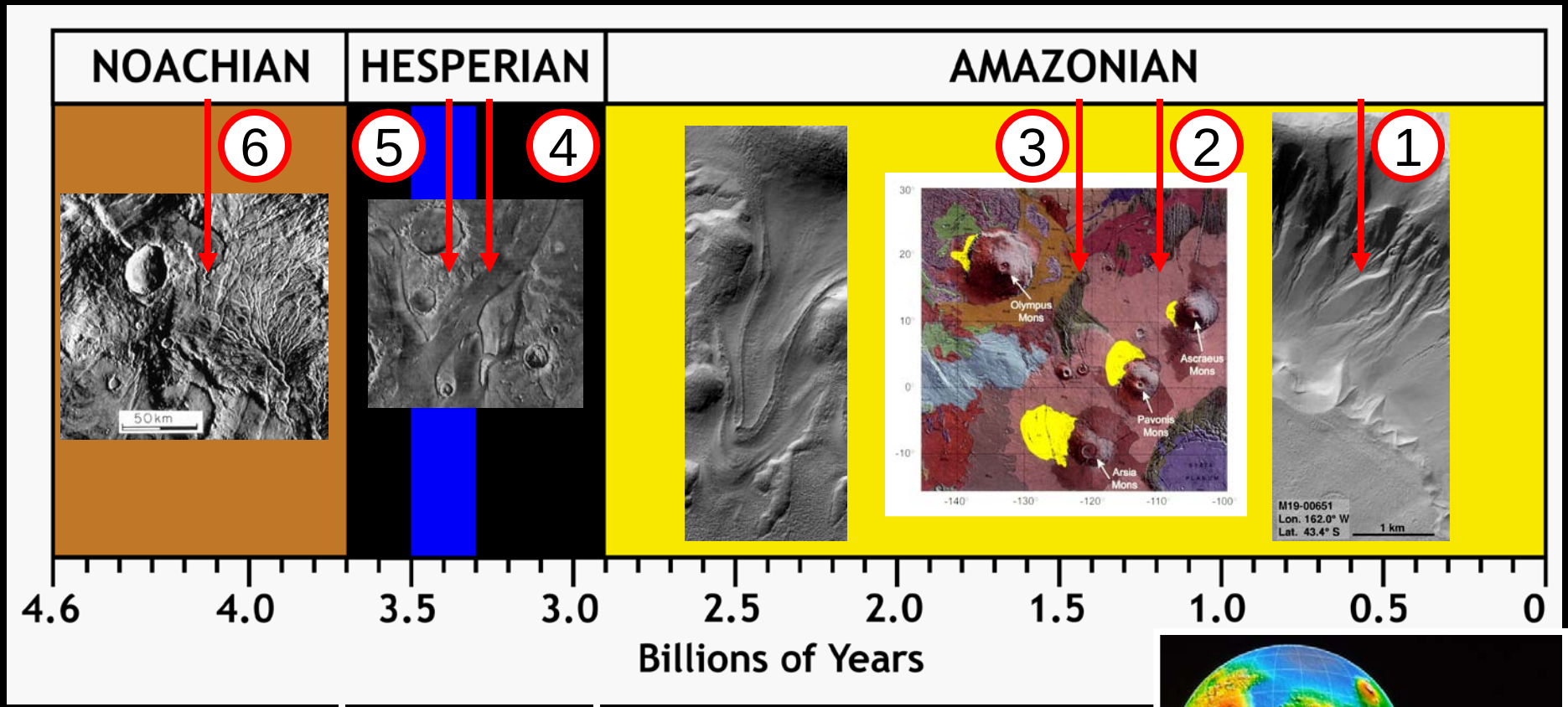




-These relationships favor multiple, smaller-scale events in gully and fan formation.

-As in Antarctica, the latest gully activity reflects erosion of earlier fan deposits.

Water and Climate on Mars: Relation to Geologic History



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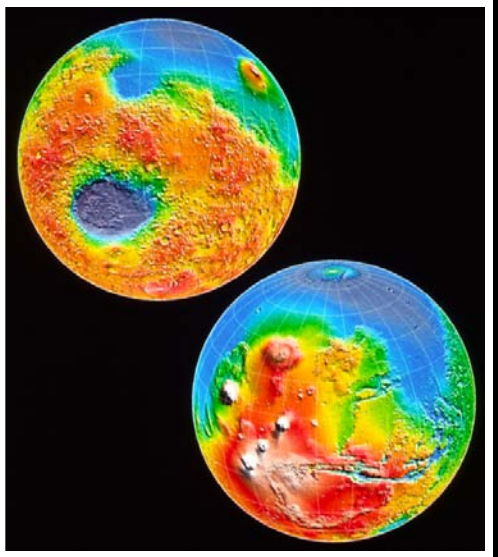
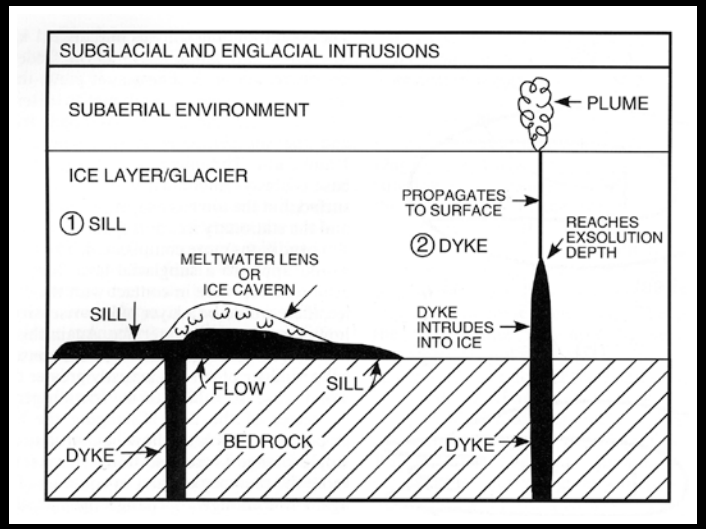
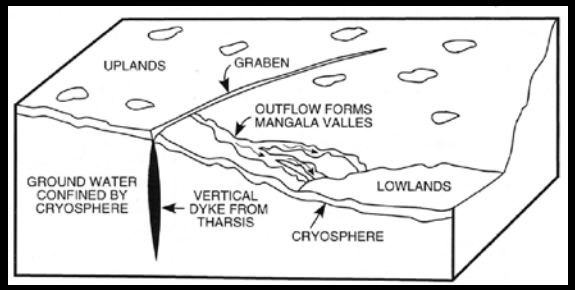


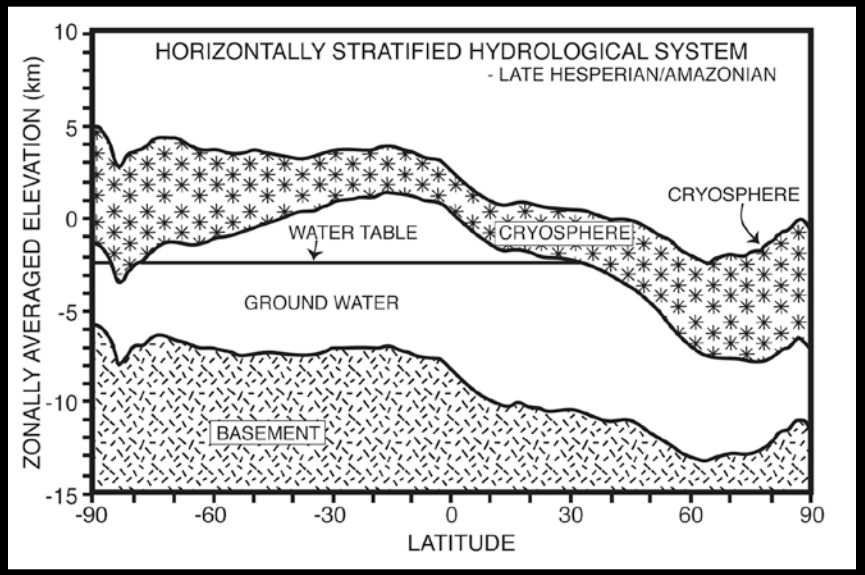
Volcano-Ice Interactions on Mars:

- **<u>Glaciers and Polar Ice Sheets</u>:**
  - Englacial eruptions (dikes).
  - Subglacial eruptions (sills, flows, tuyas).
  - Supraglacial eruptions, marginal chilling.
  - Jokulhaups, postglacial eruptions.

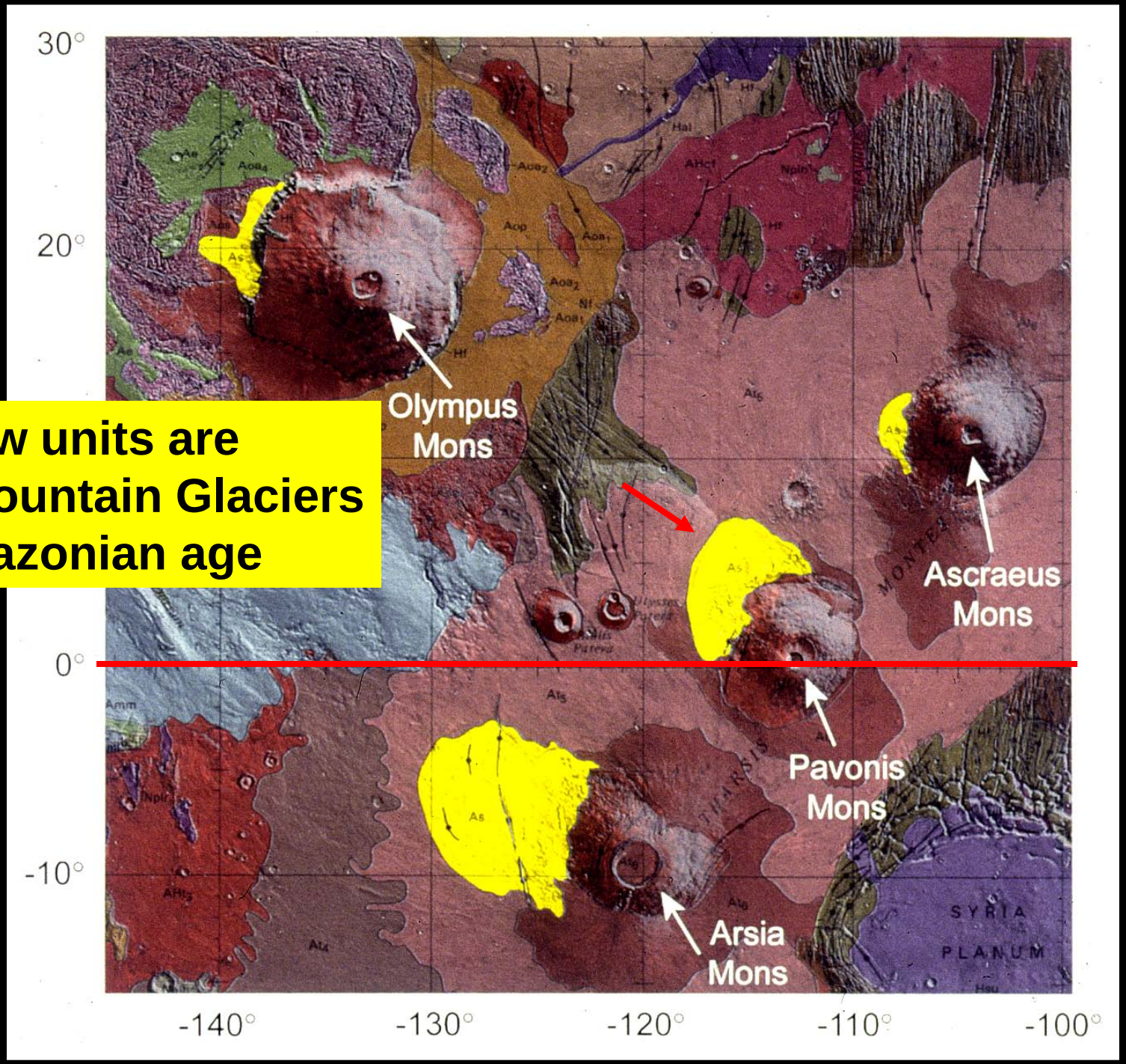




- **Global Cryosphere:**
  - Dike-induced cracking.
  - Phreatomagmatic eruptions.
  - Effusive eruptions.
  - Mega-lahars.
  - Sill emplacement.
  - Catastrophic release of groundwater under hydrostatic head ("groundwater jokulhaups").



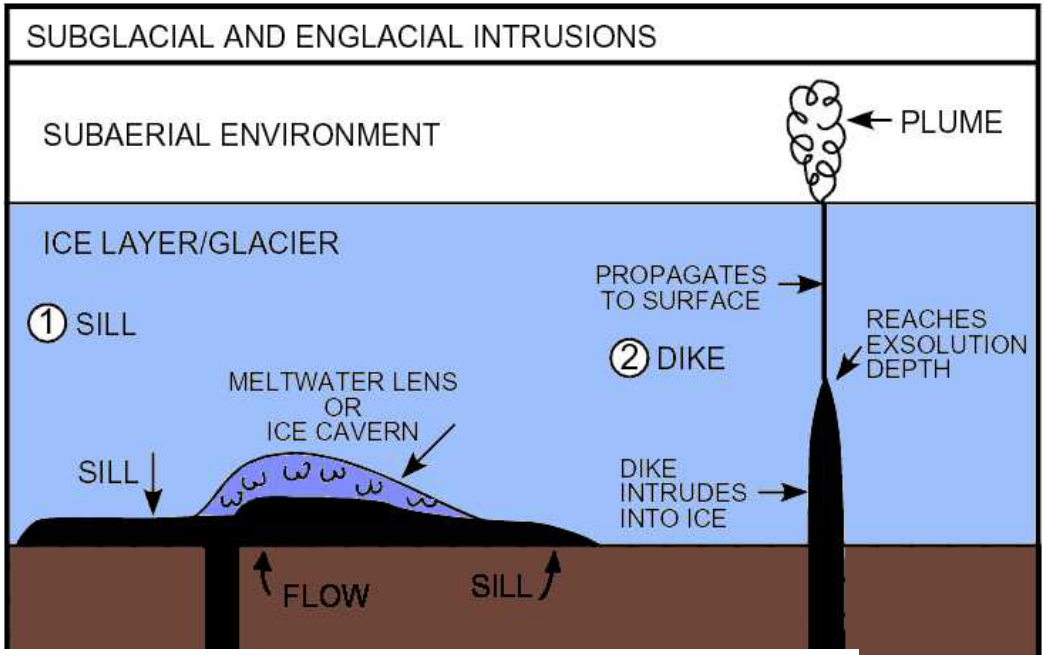
(Wilson and Head; Head and Wilson, 2002)

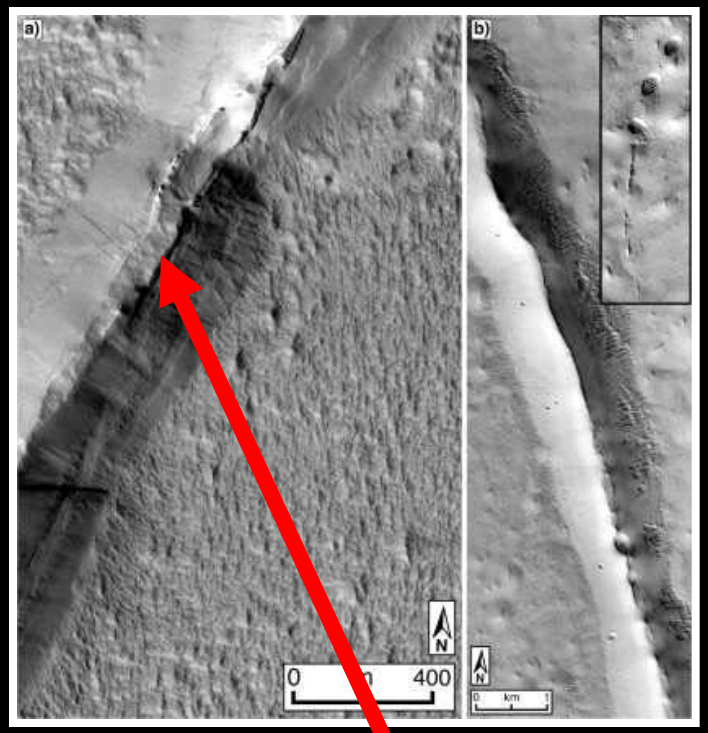


Yellow units are Tropical Mountain Glaciers of Amazonian age

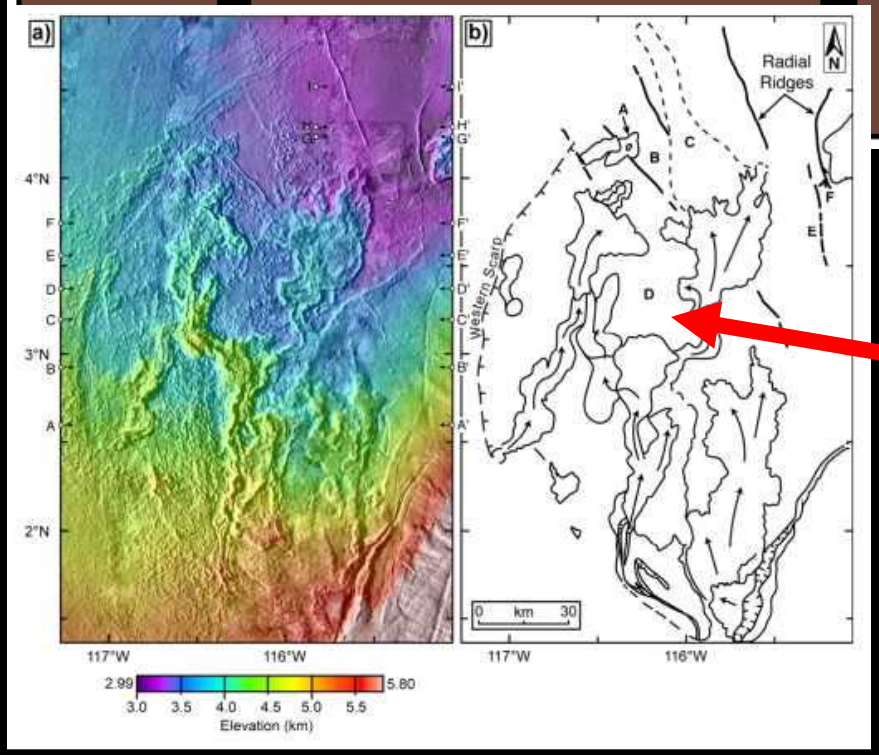
Equator

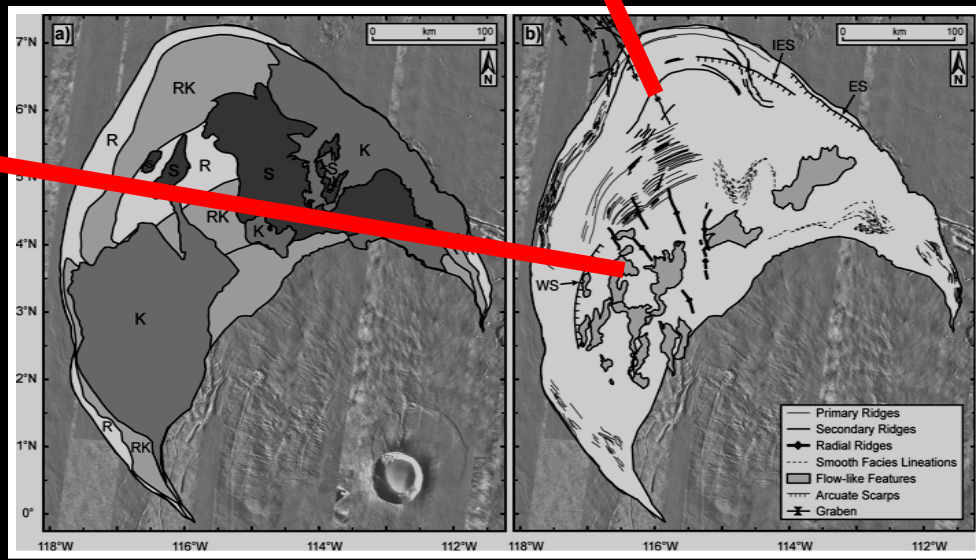
Subglacial dikes and lava flows



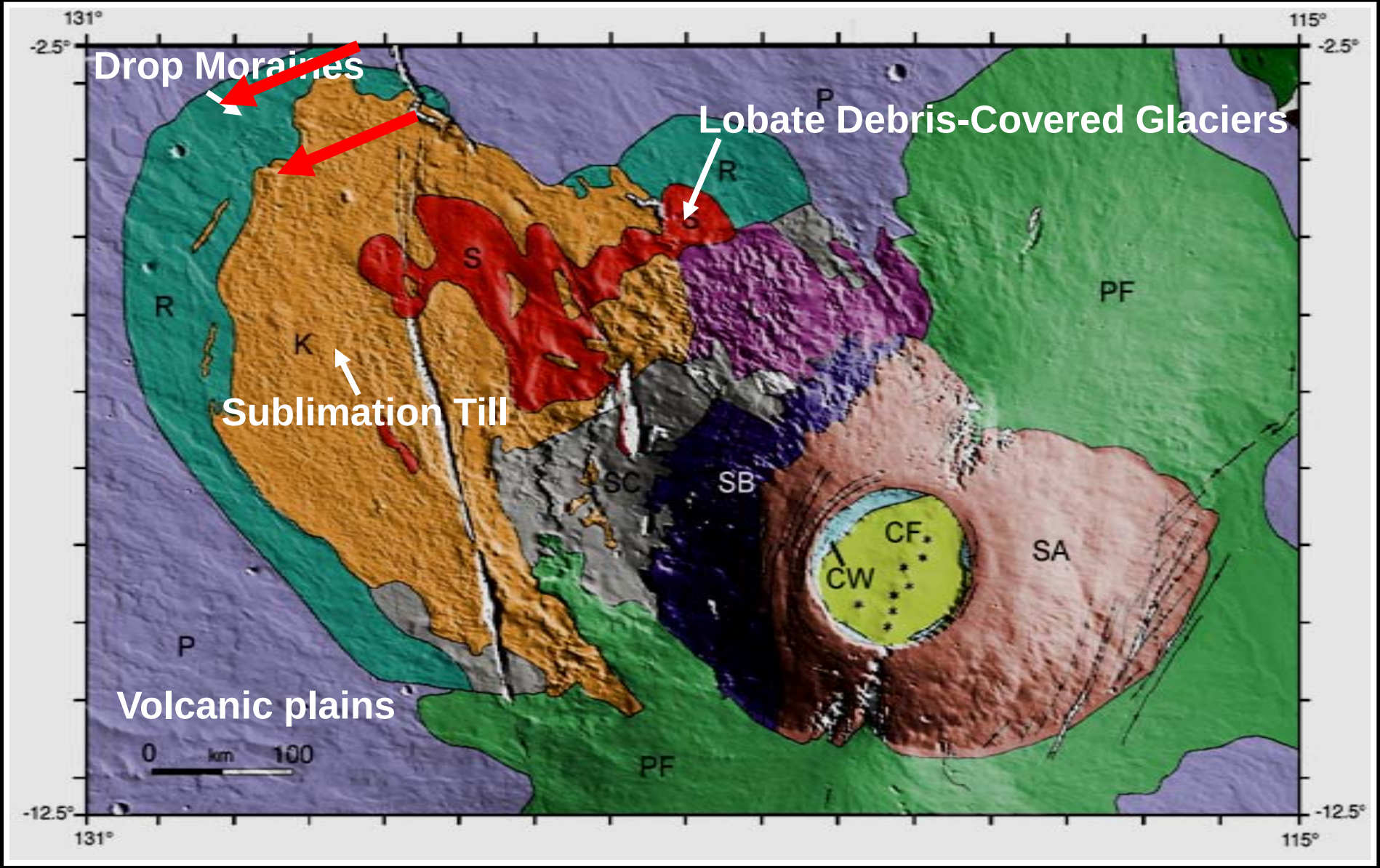


(Shean et al. 2006)



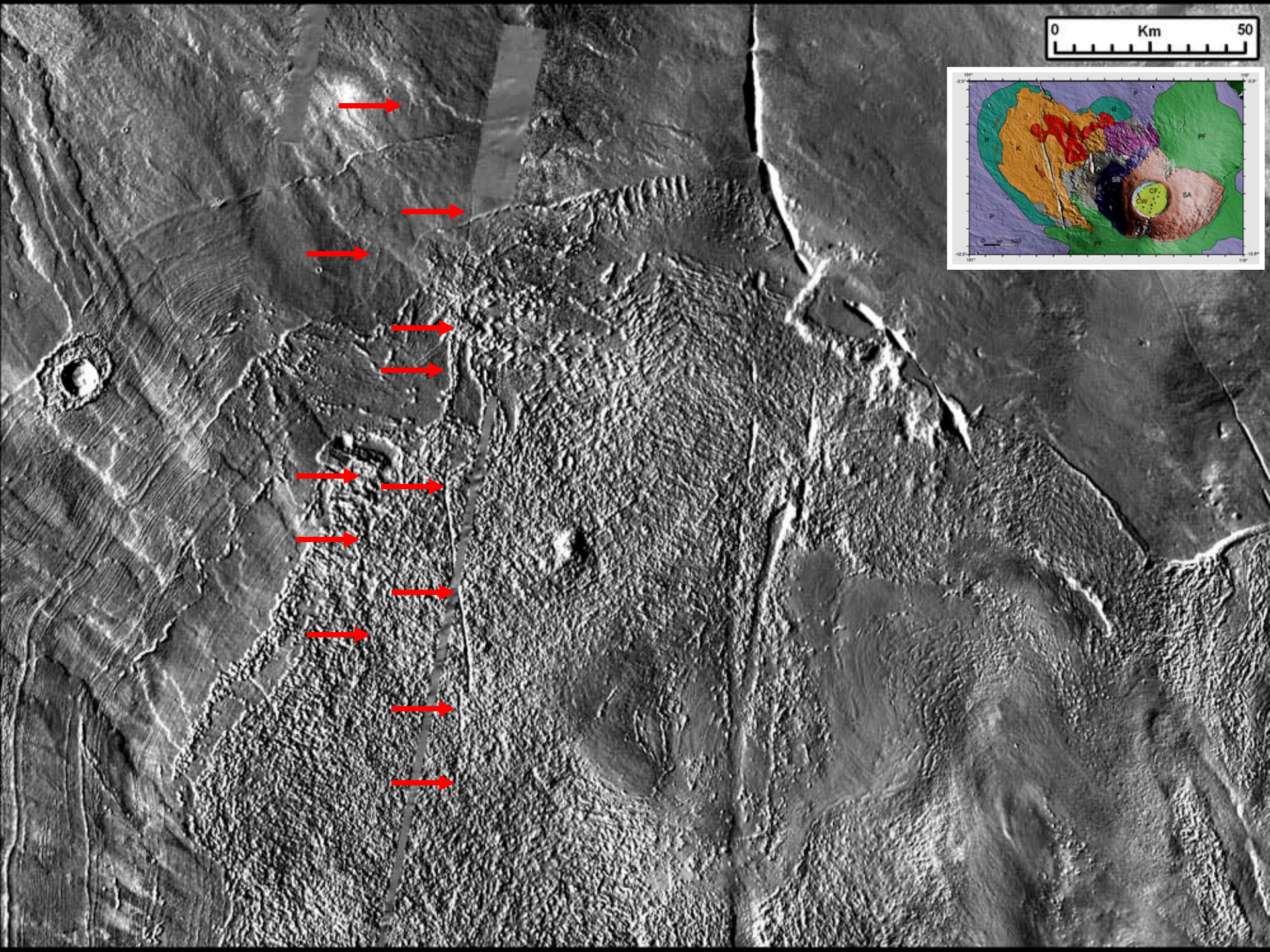


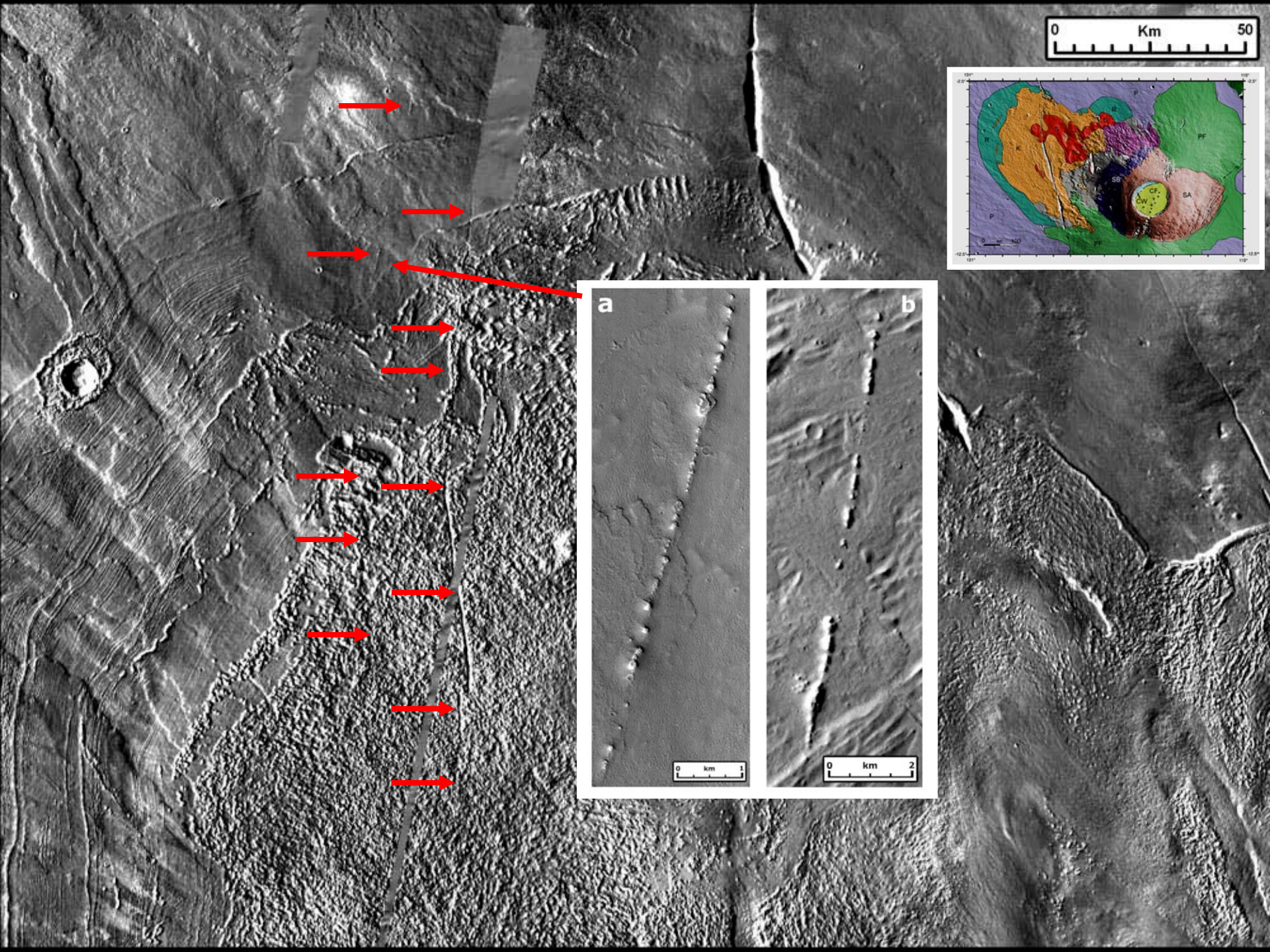
Subglacial Intrusion - Meltwater Generation - Polyphase Glaciation



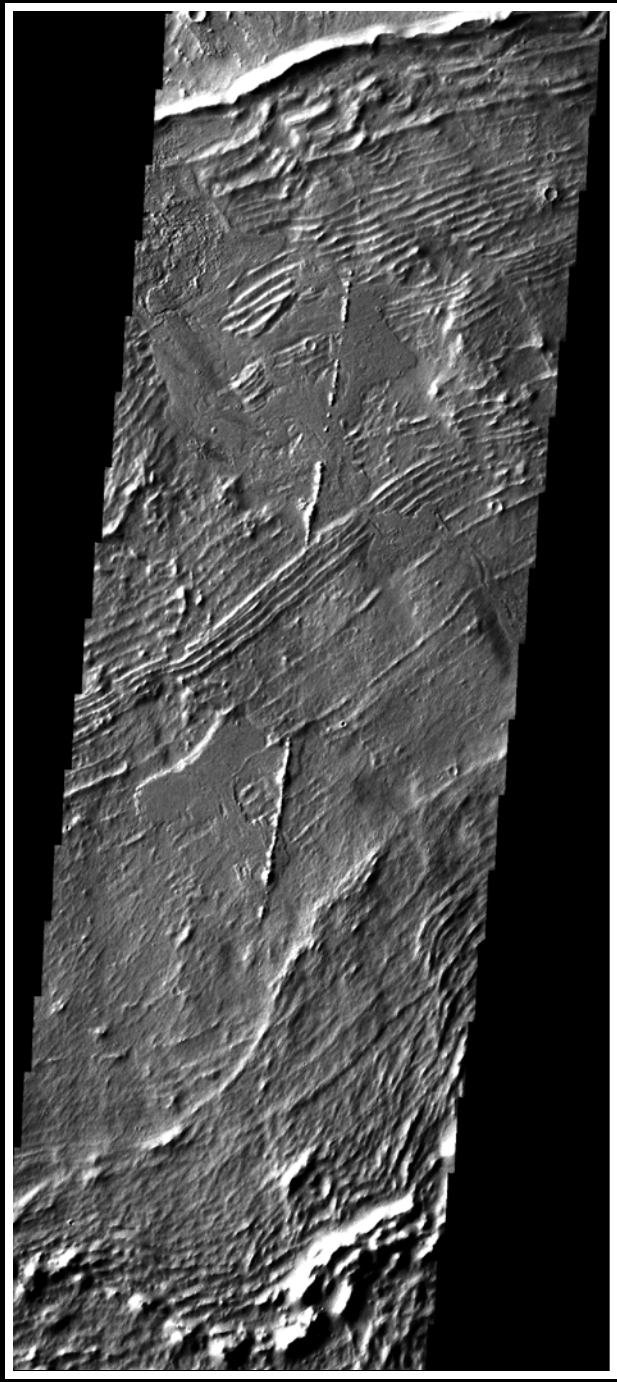
Head and Marchant, 2003, *Geology*

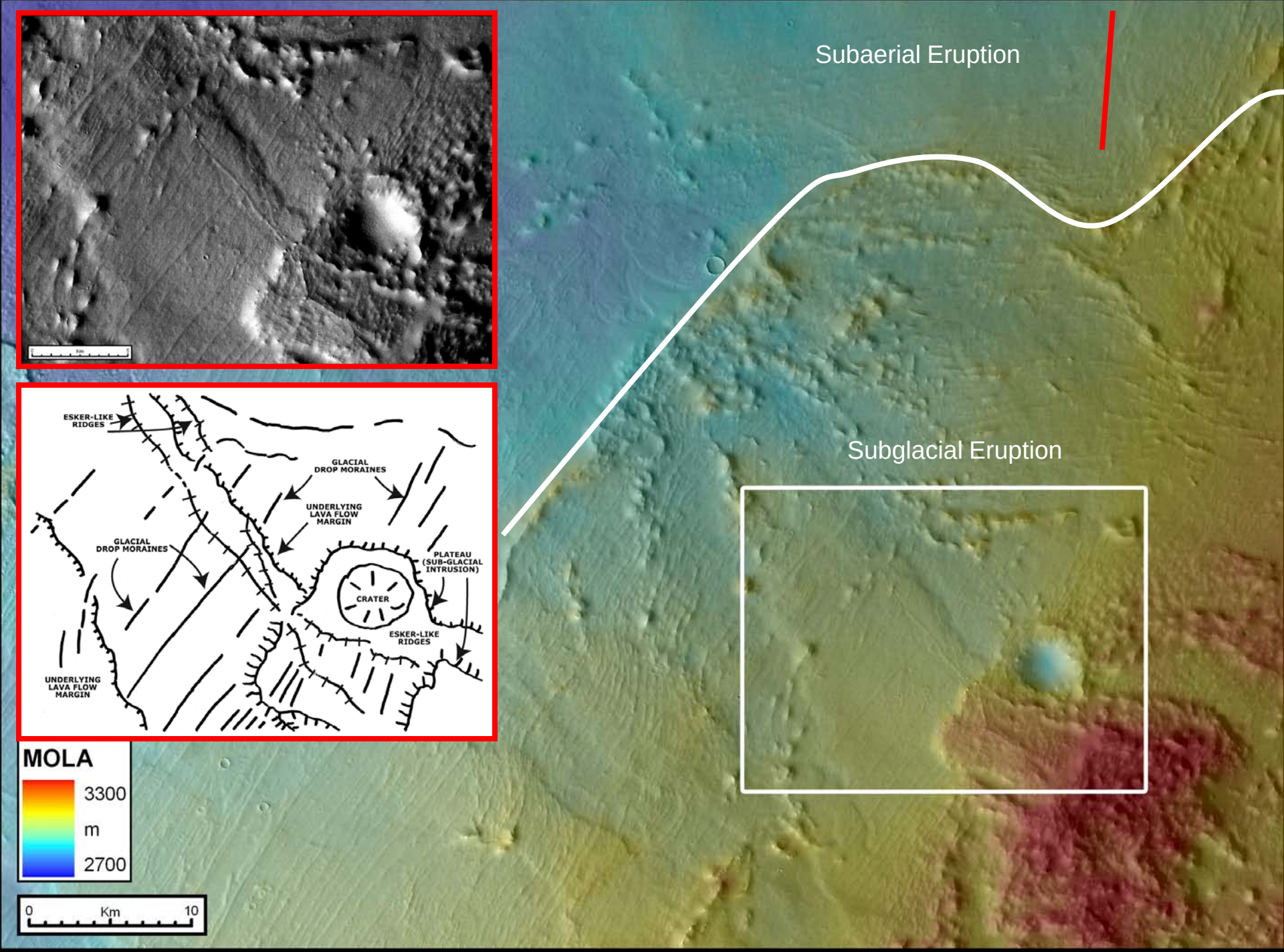
Map after Zimbelman and Edgett (1992)

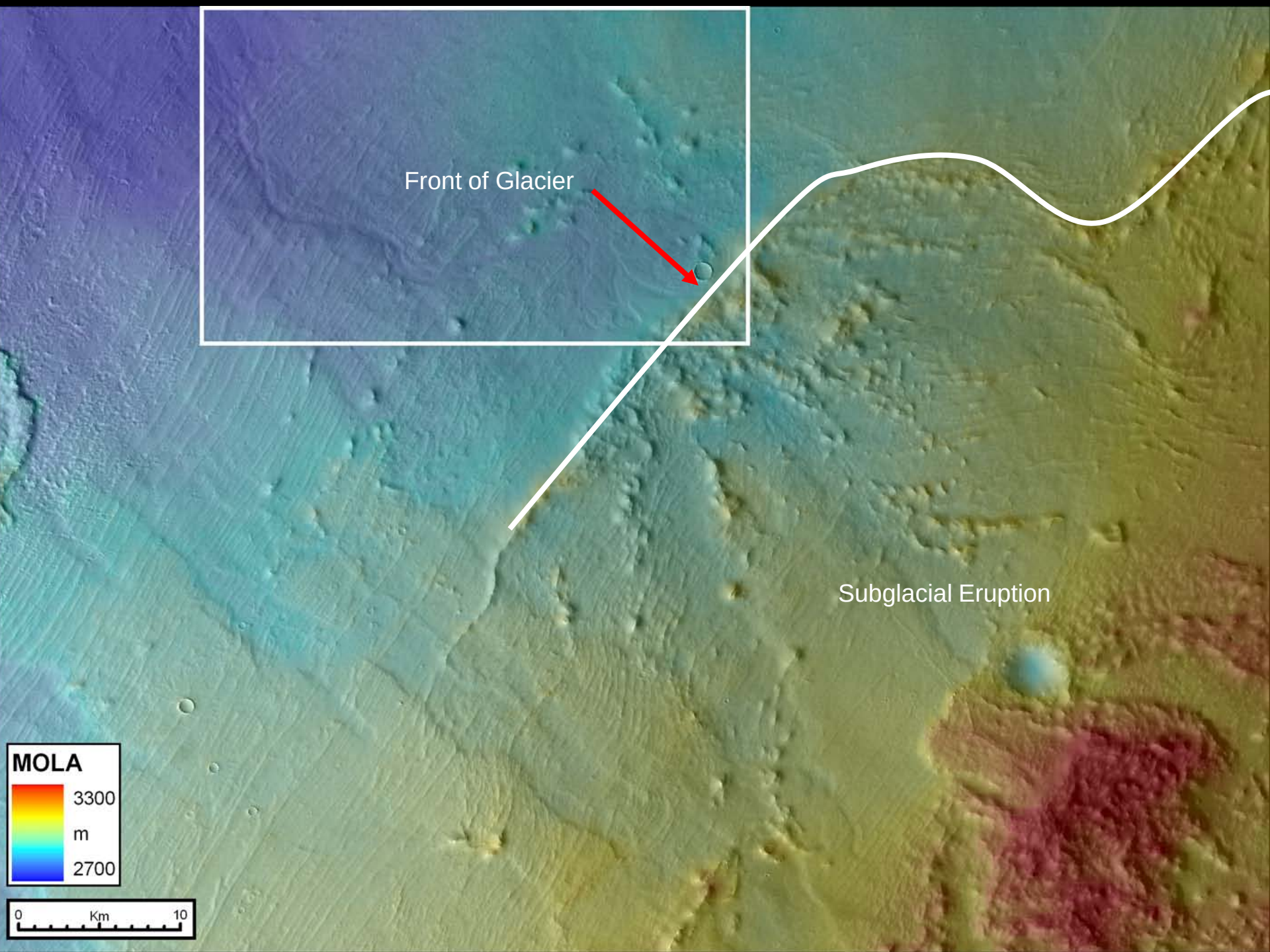

0
Km
50
R
P
PF
K
SB
CF
CW
SA
P
PF


0
Km
50
a
b
0
km
1
0
km
2

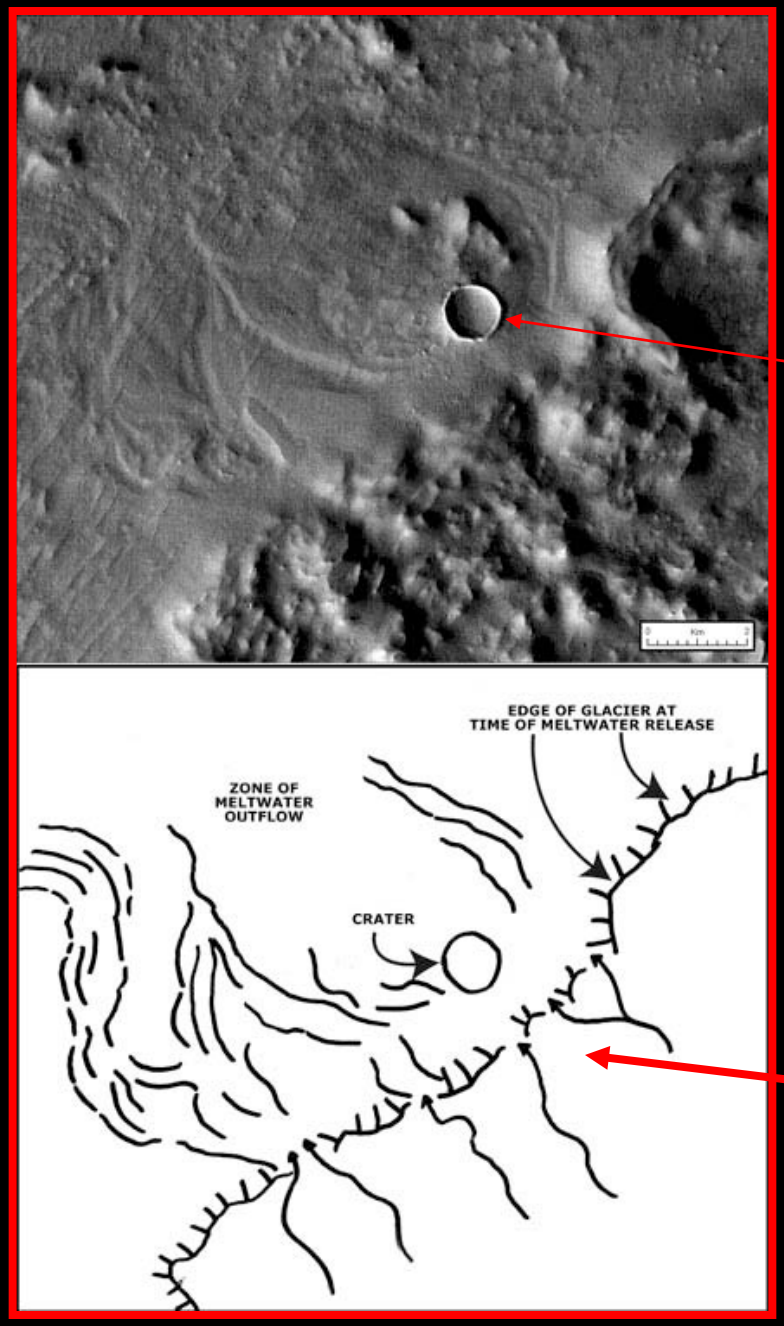
Post-Tropical Mountain Glacier Volcanism



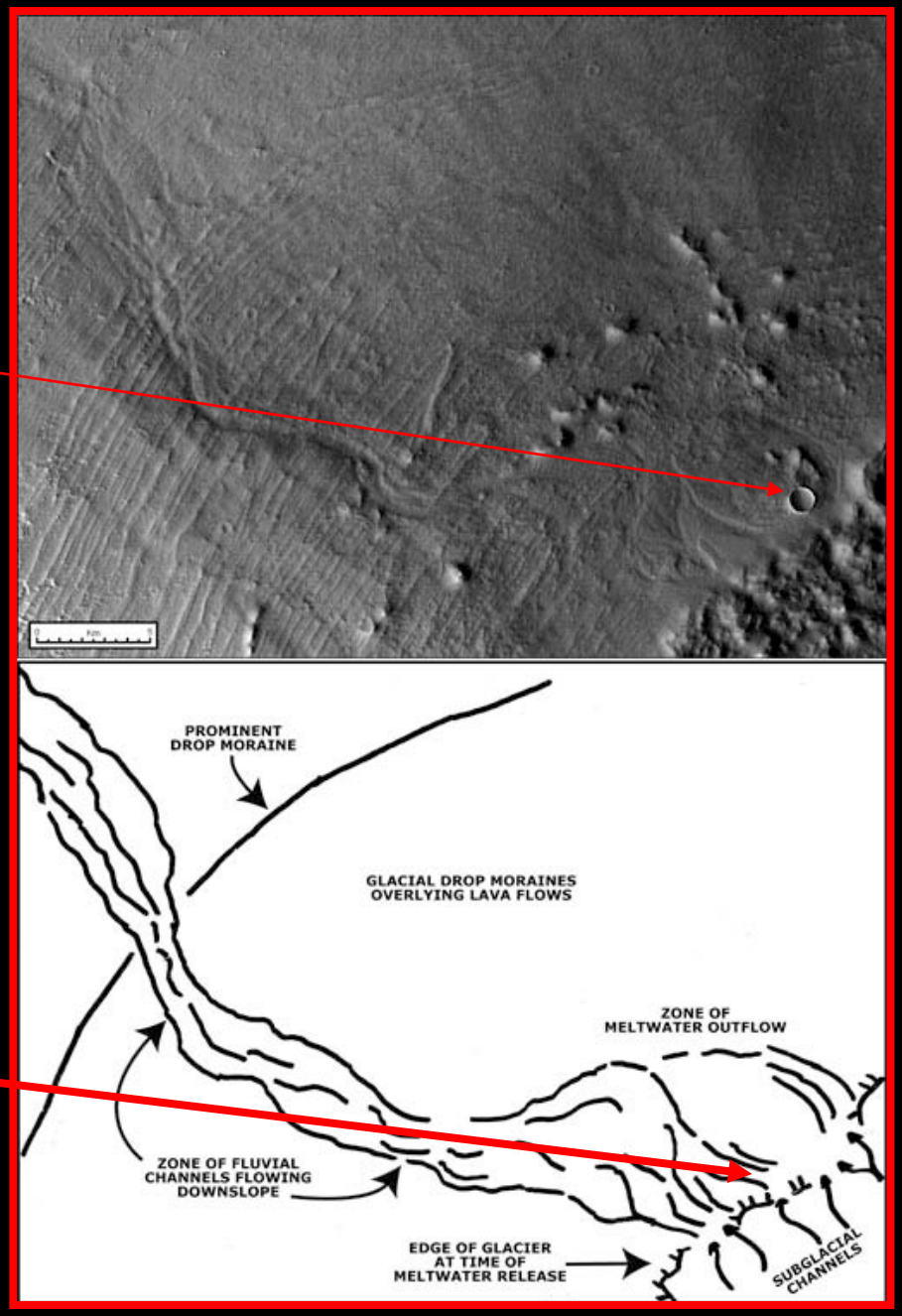

Subaerial Eruption
Subglacial Eruption
ESKER-LIKE RIDGES
GLACIAL DROP MORAINES
UNDERLYING LAVA FLOW MARGIN
GLACIAL DROP MORAINES
PLATEAU (SUB-GLACIAL INTRUSION)
CRATER
ESKER-LIKE RIDGES
UNDERLYING LAVA FLOW MARGIN
MOLA
3300
m
2700
0
Km
10

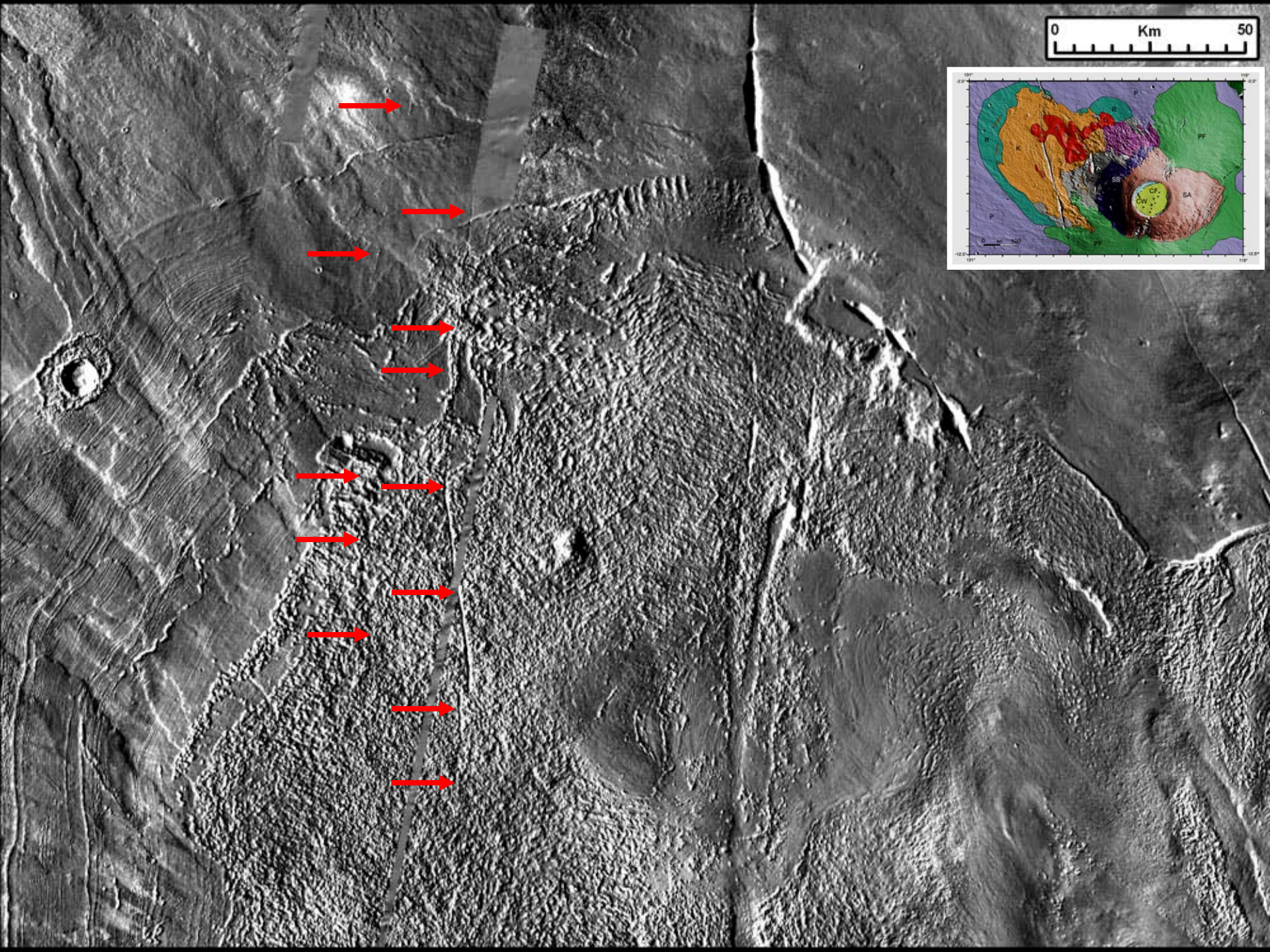

Front of Glacier
Subglacial Eruption
MOLA
3300
m
2700
0
Km
10

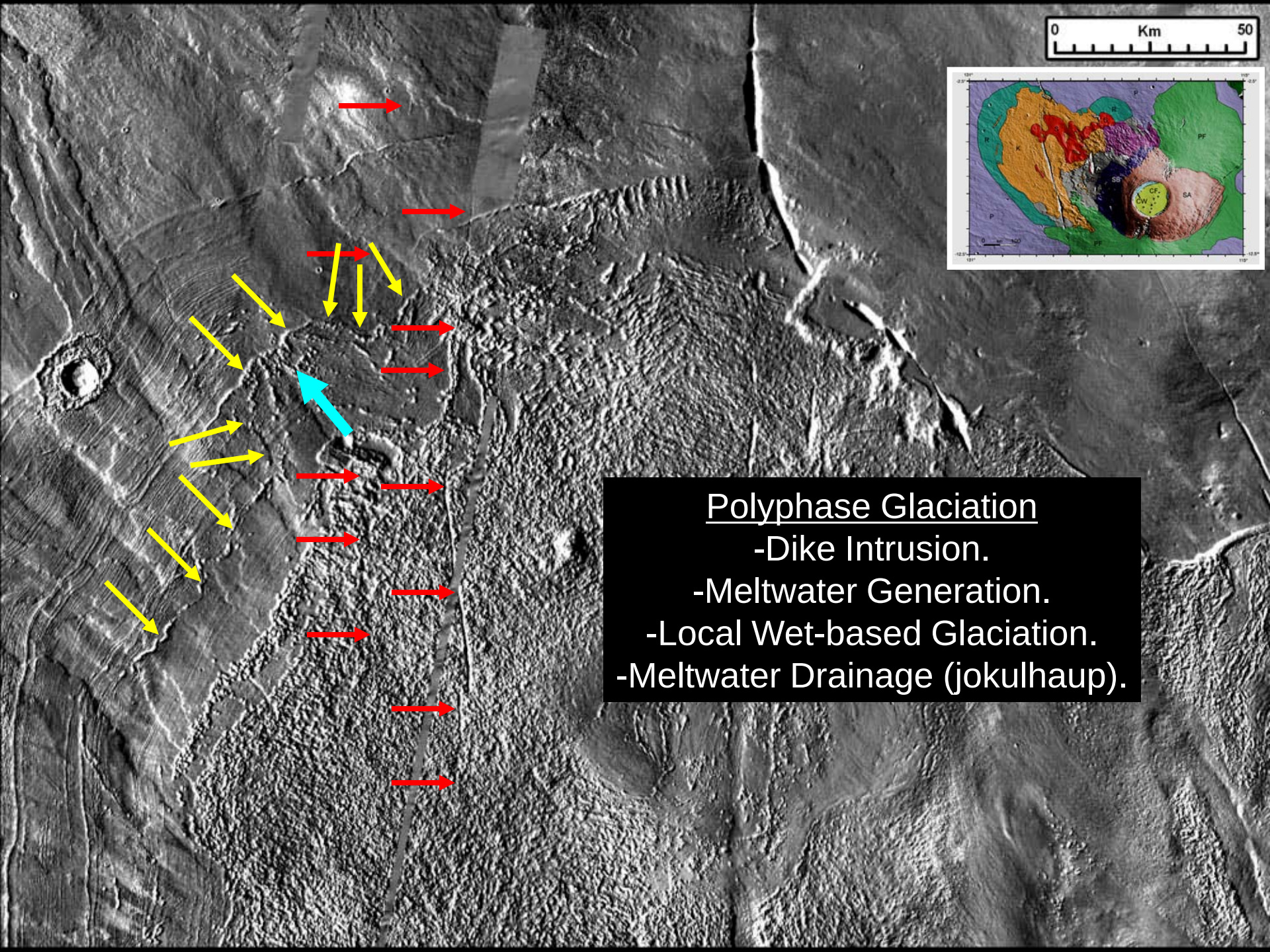
Proglacial Meltwater Outburst



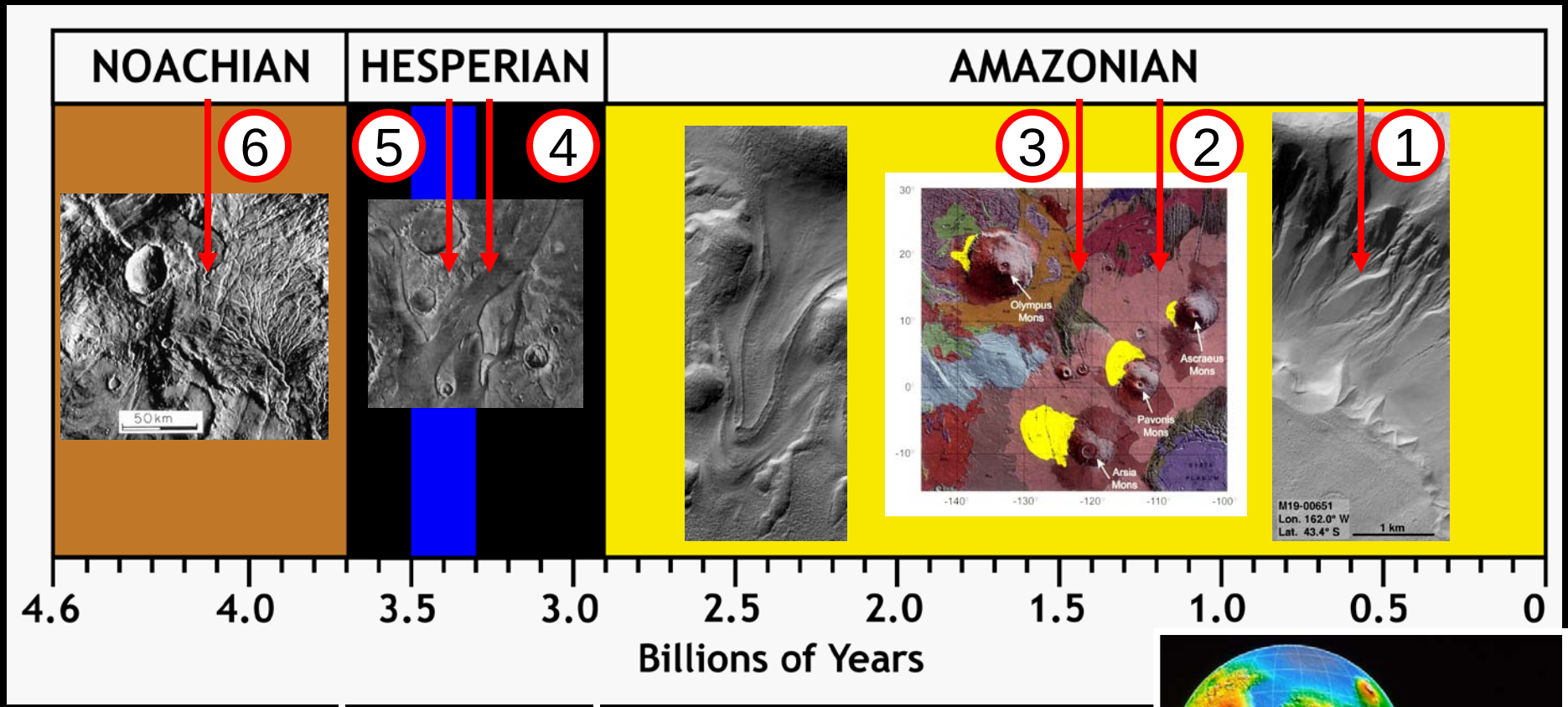
Proglacial Meltwater Drainage




0
Km
50
R
P
PF
K
SB
CF
CW
SA
P
PF


0
Km
50
Polyphase Glaciation
-Dike Intrusion.
-Meltwater Generation.
-Local Wet-based Glaciation.
-Meltwater Drainage (jokulhaup).

Water and Climate on Mars: Relation to Geologic History



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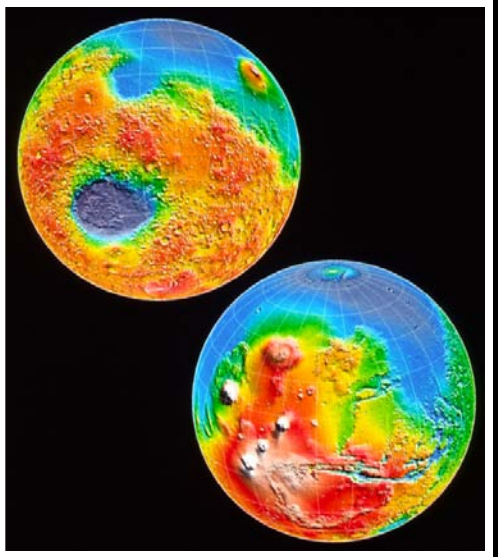

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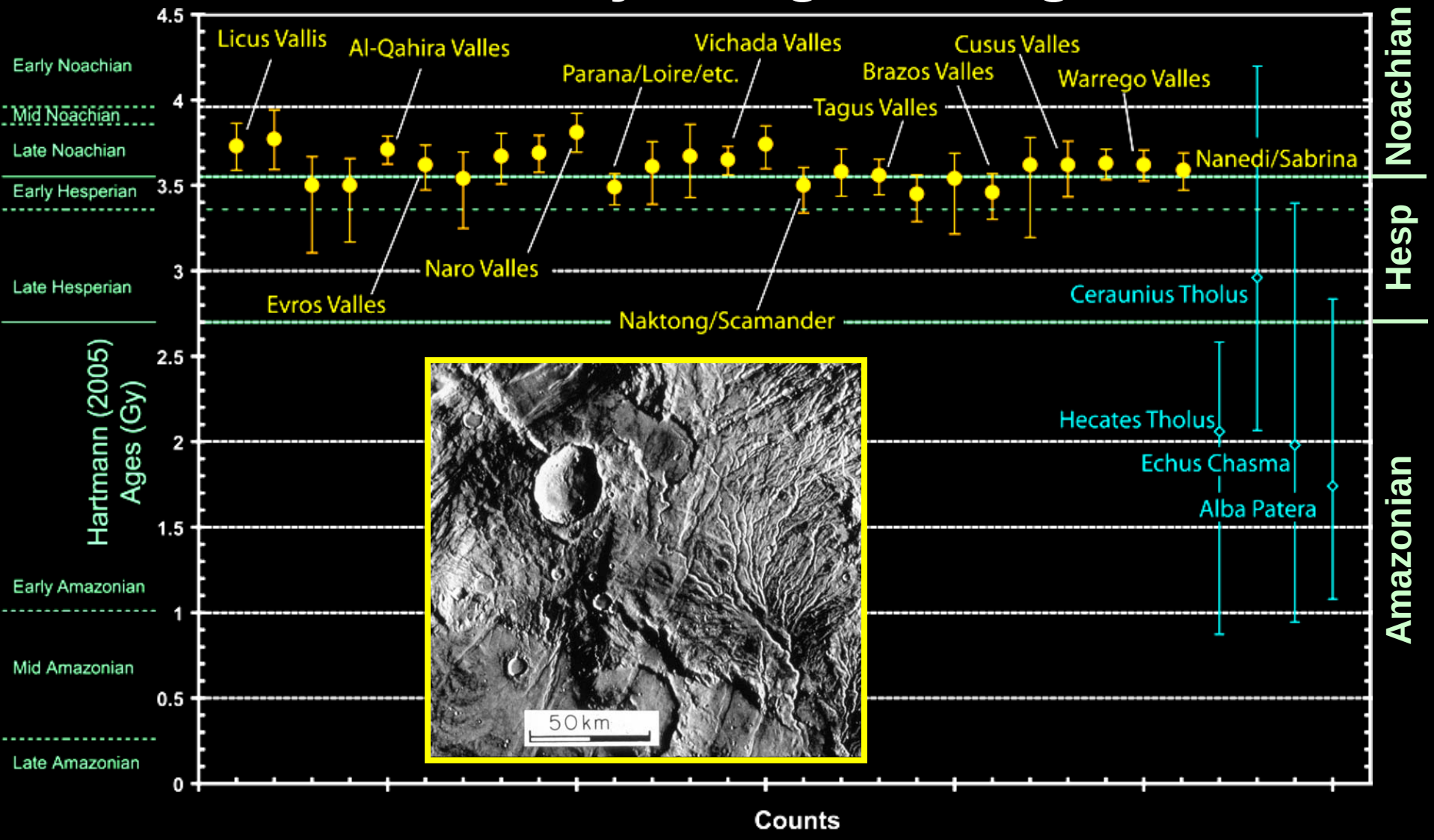
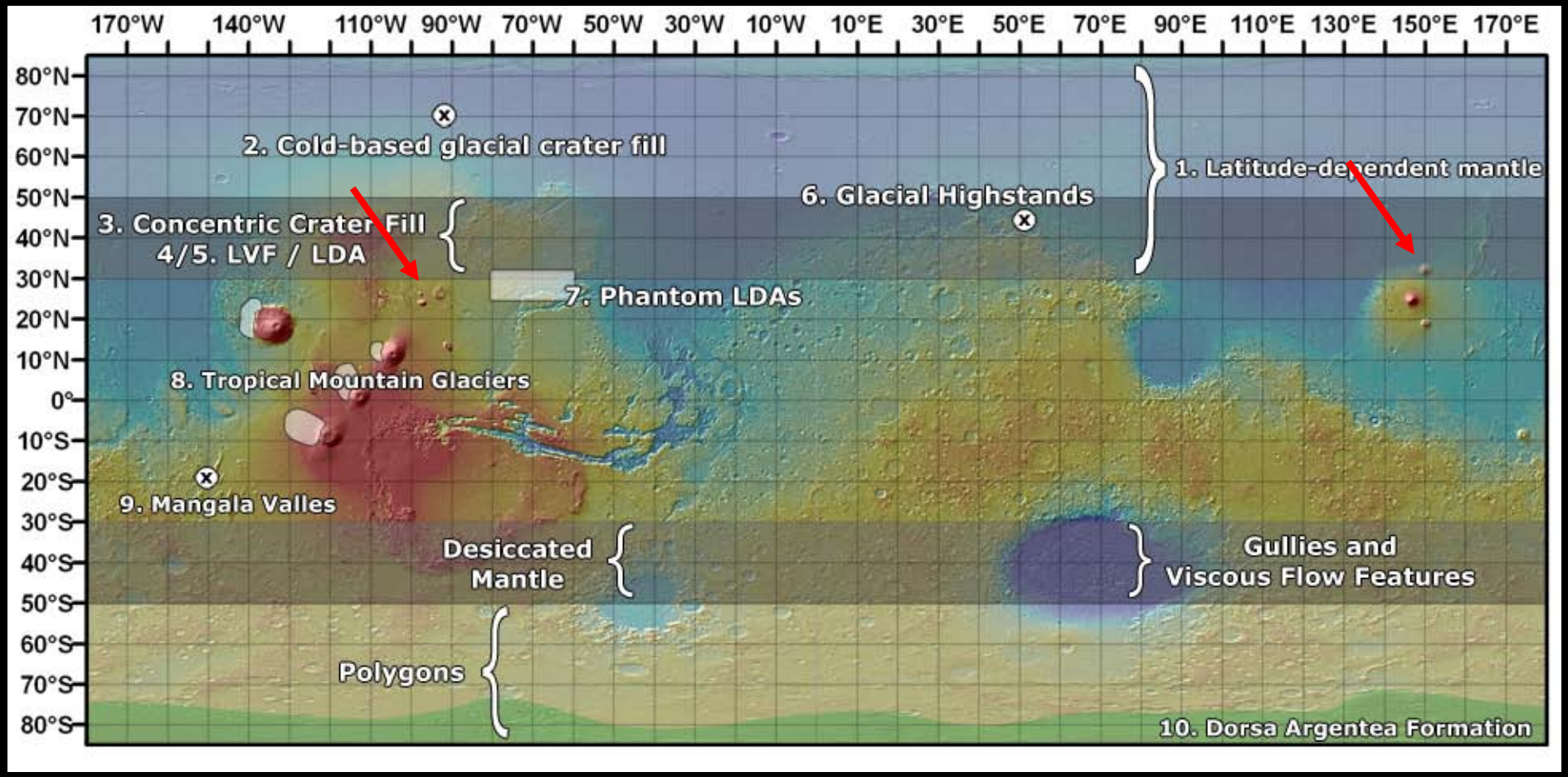


Fassett and Head, 2008, Icarus.

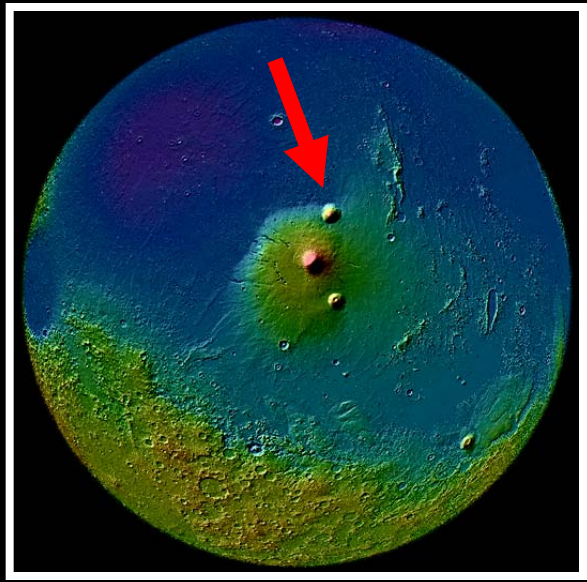
Candidate Latitude-Dependent Glacial/Ice Deposits

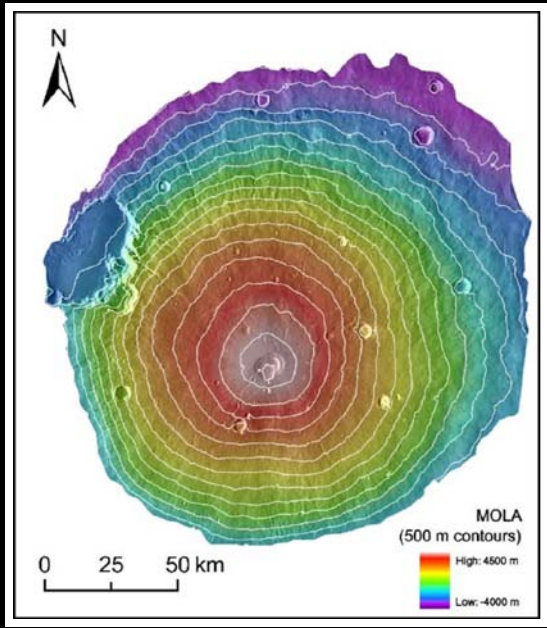


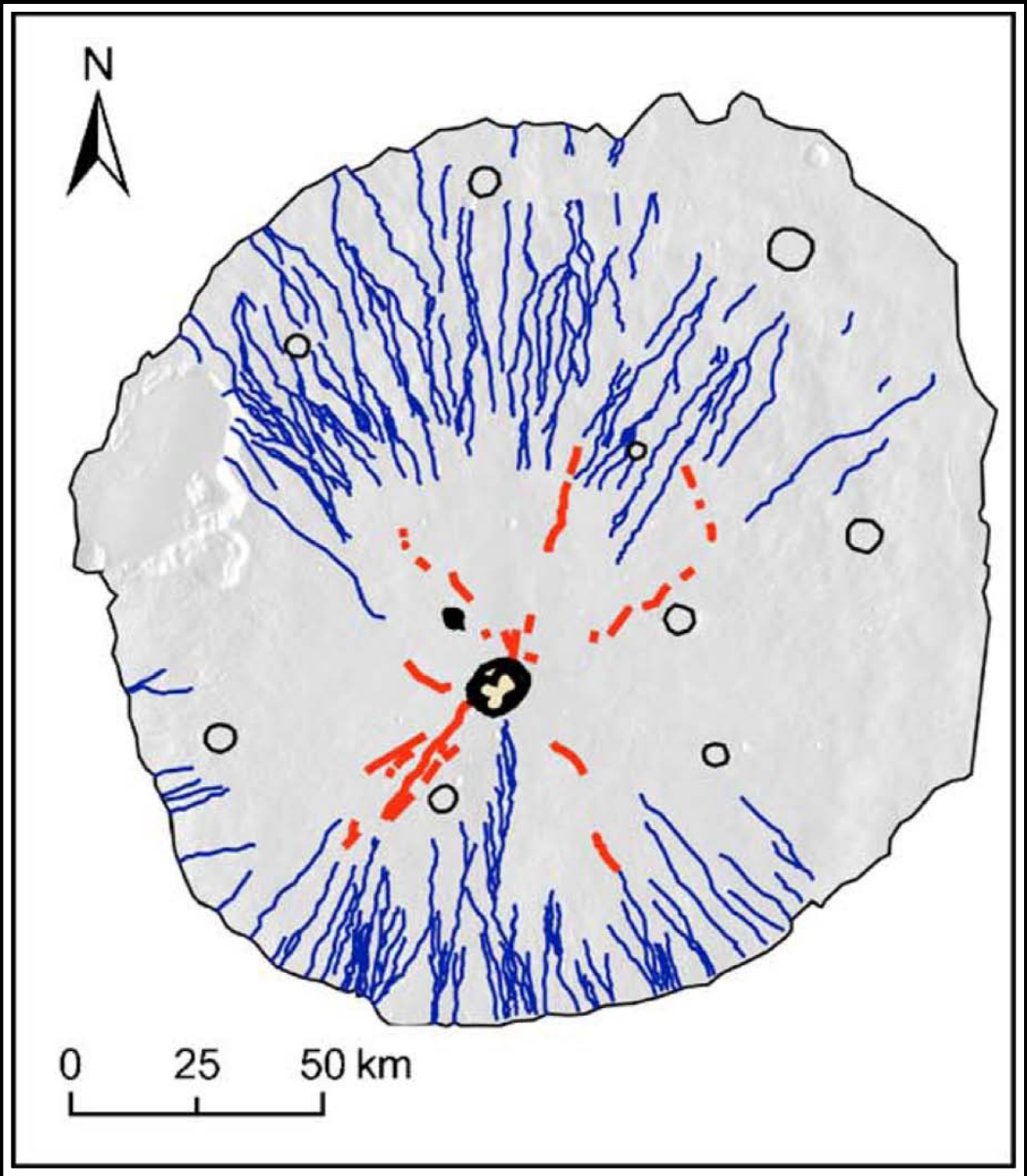
Magmatic Heating and Melting of Edifice Summit Snowpack

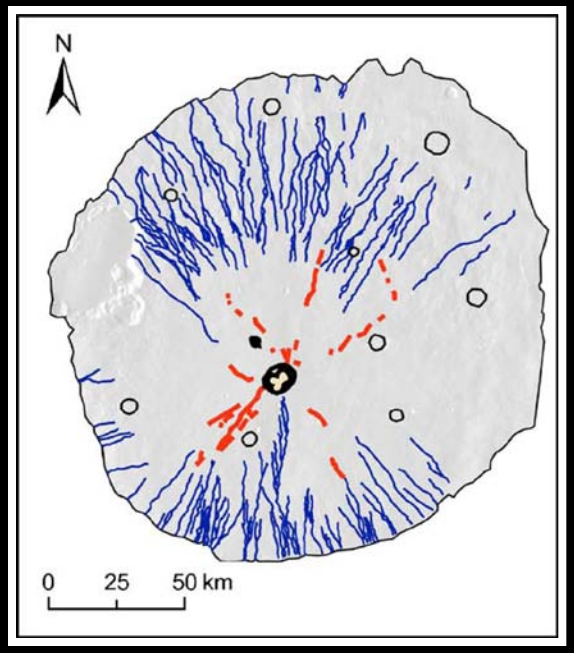
(Fassett and Head, 2006, 2007)

Basal Melting of Summit Snowpack: Hecates Tholus Volcano





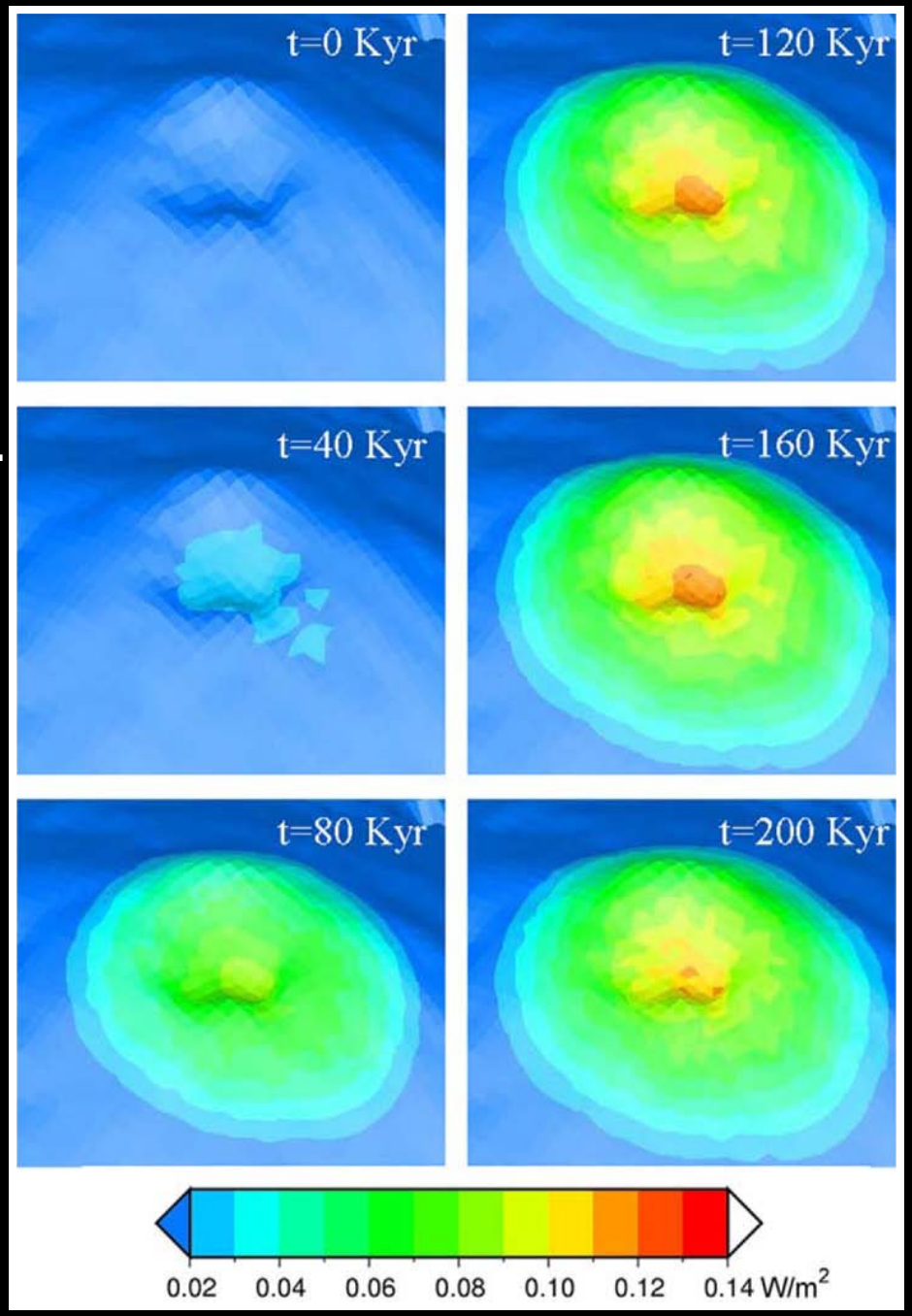




Hecates Tholus

Two necessary conditions:
-Climate change, snow accumulation.
-Intrusion, raising summit heat flux.

Mount St. Helens TIR/MASTER data



(R. G. Vaughan et al., 2005)

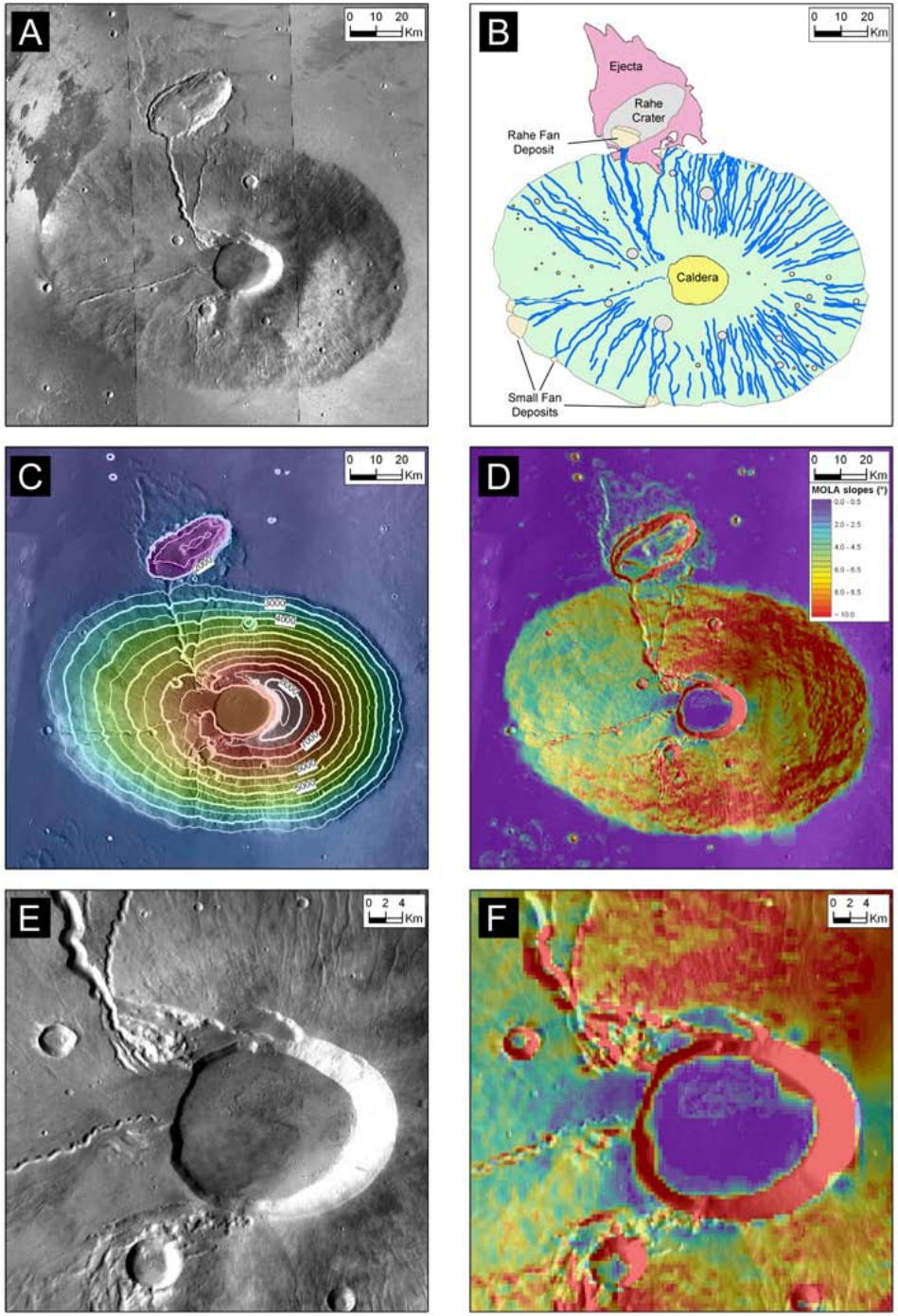
Ceraunius Tholus

-Contains radial channels, like Hecates.

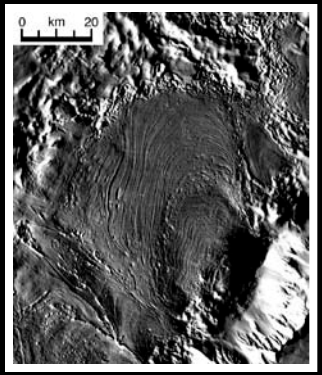
-Also contains several much larger channels extending from the summit caldera to the base in the north.

-What is the origin of this second set of channels?

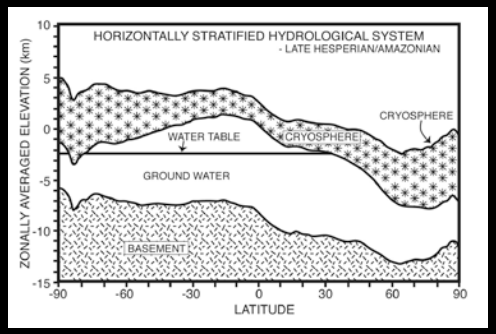
-We interpret these to be from melting of summit snowpack, filling of the caldera, and then drainage down side into surrounding plains (or crater).



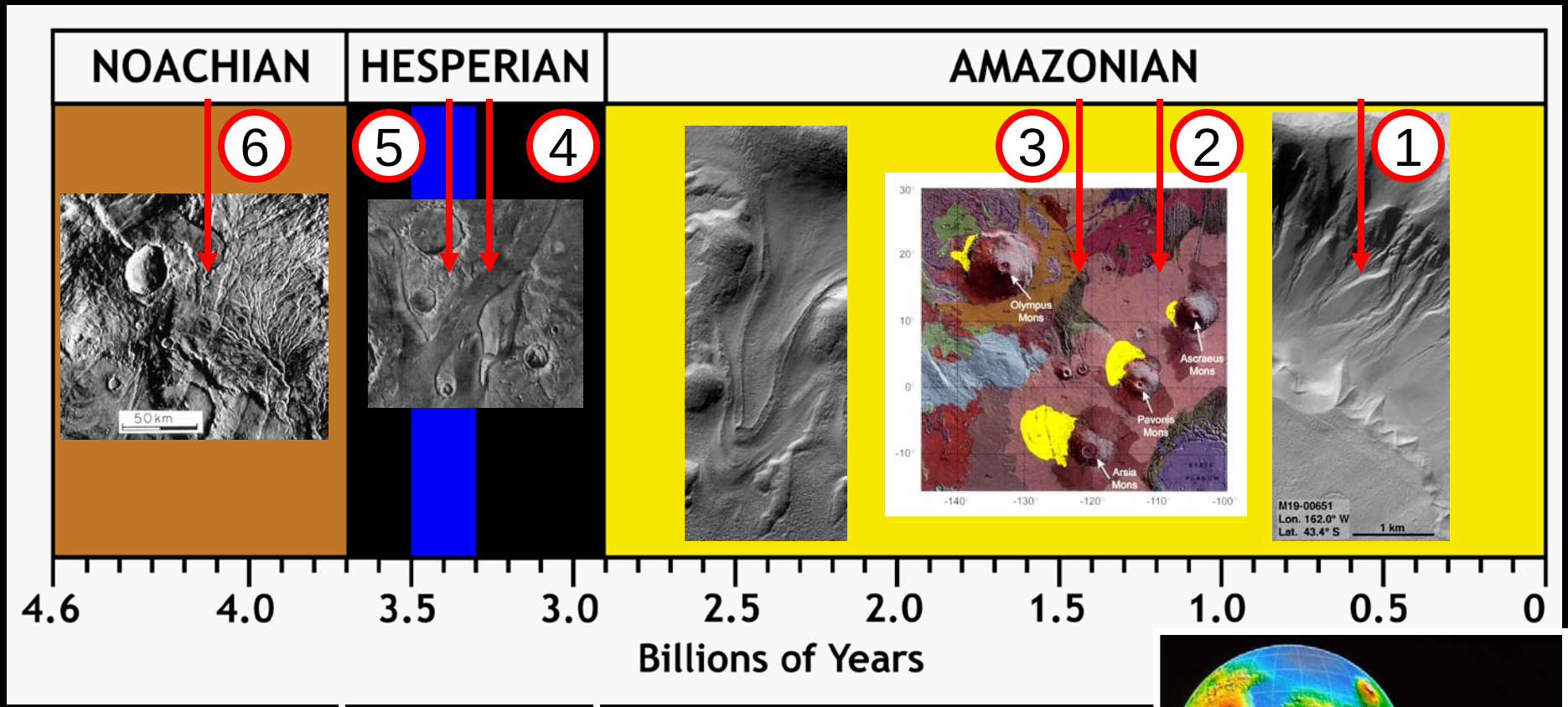
Volcano-Ice Interactions on Mars



- **Glaciation is widespread on Mars, ranging from valley glaciers to huge circumpolar ice sheets.**
- **Glaciation on Mars is typically cold-based; Volcano-ice interactions provide key mechanism for melting, leading to a wide range of landforms.**
- **Global Cryosphere provides a fundamental interface between magma source regions and the surface.**
- **Magma-Cryosphere interactions are very common (dikes, sills) and control the transfer of groundwater to the surface.**
- **Mars is a key laboratory for the study of Volcano-Ice interactions.**



Water and Climate on Mars: Relation to Geologic History



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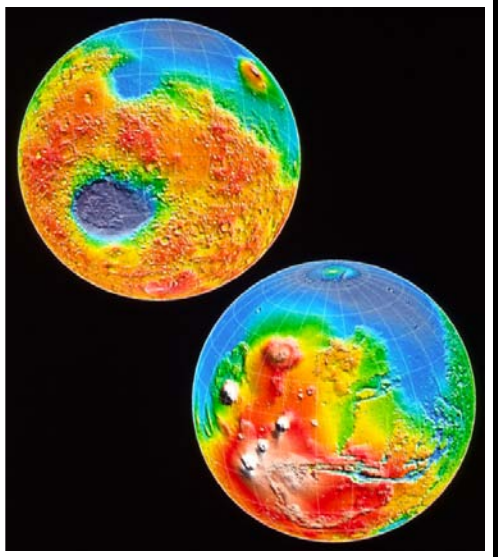
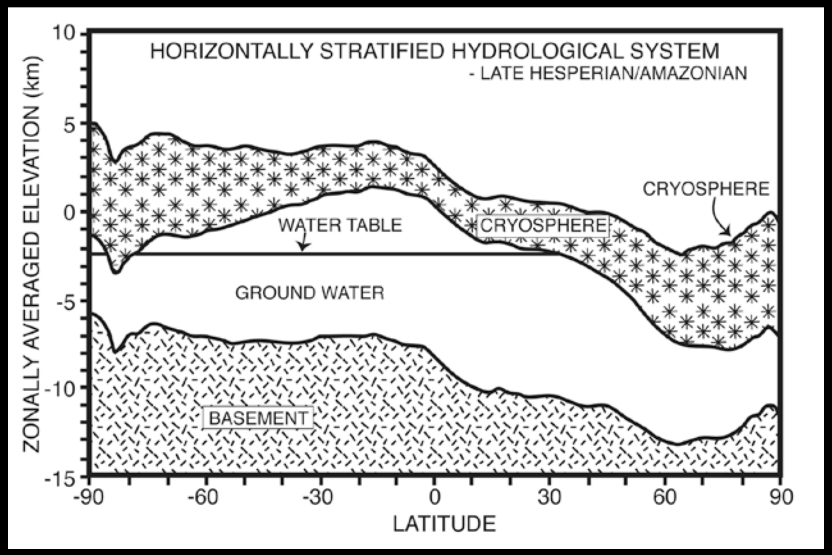
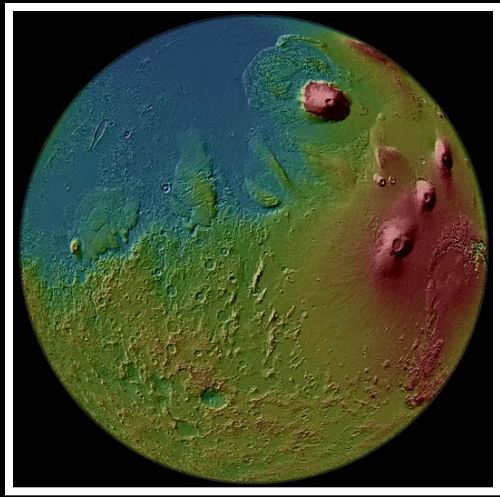


Mangala Valles:
Dike-Induced Cryospheric Cracking, Phreatomagmatic Eruption, Massive Groundwater Release from Aquifer Under Hydrostatic Pressure.

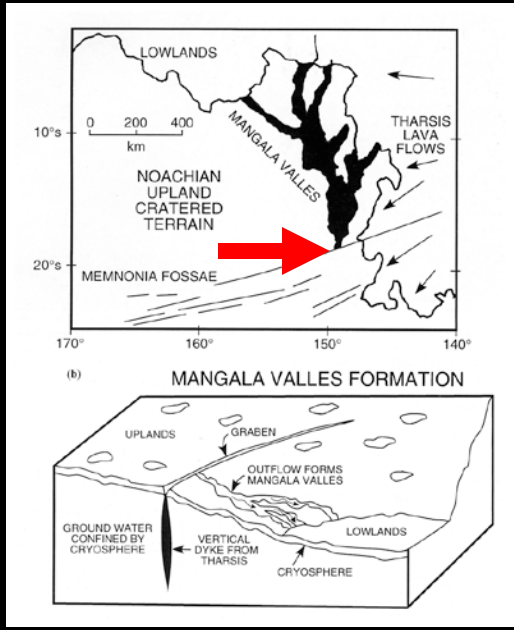


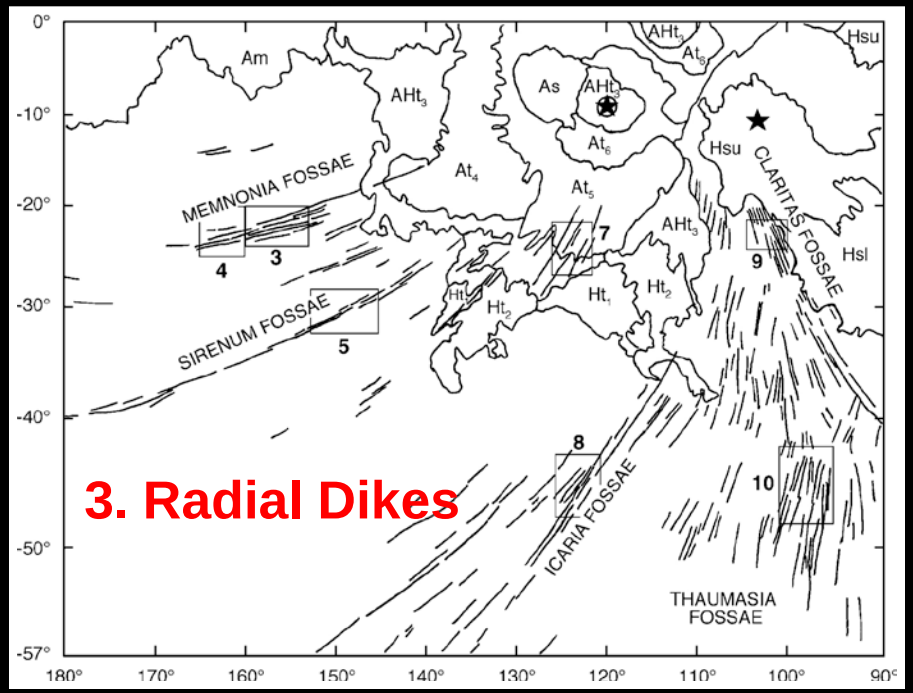
1. Global Confined Aquifer



2. Tharsis Volcanic Province

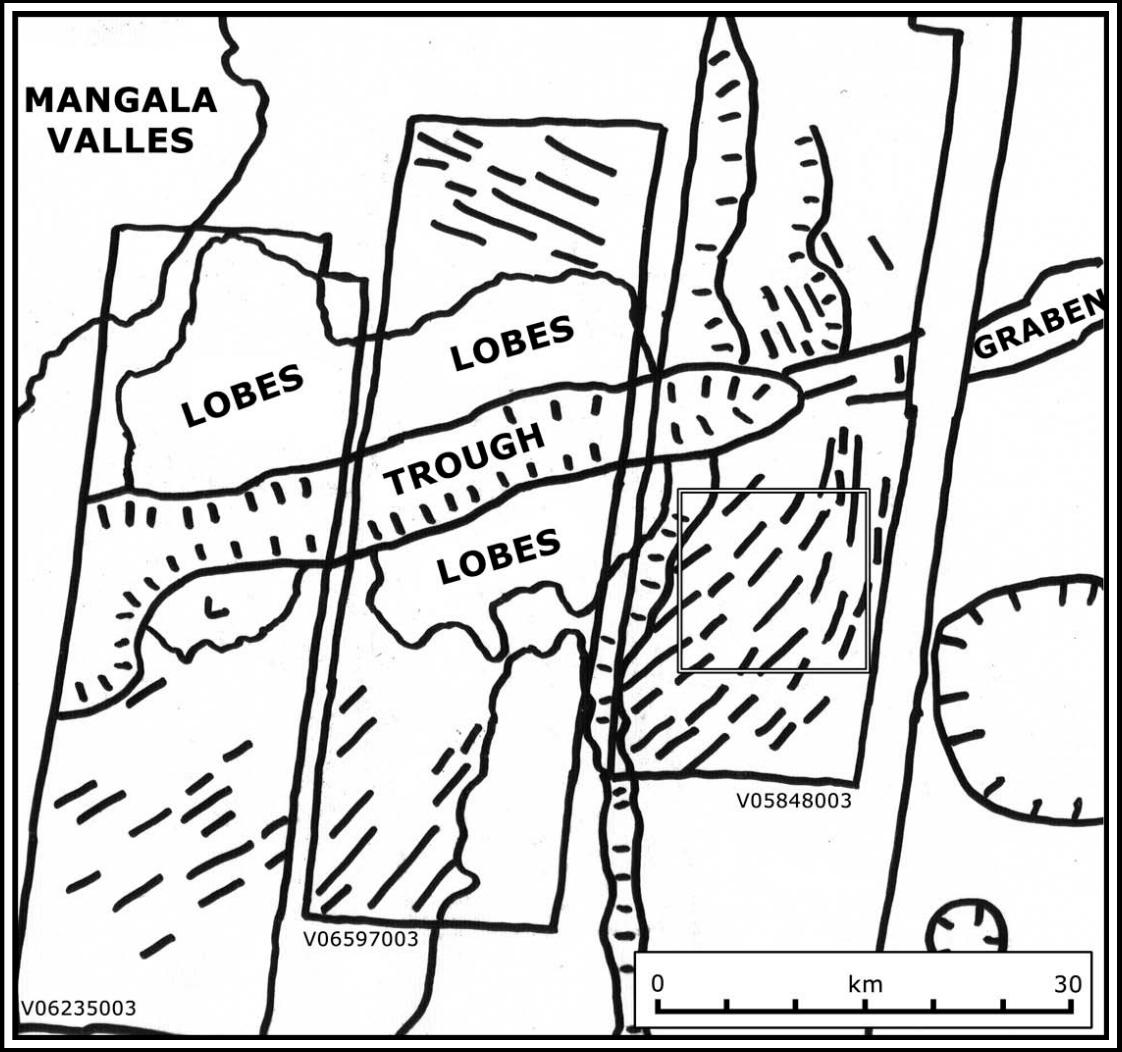
4. Dikes Crack, Heat Cryosphere, Release Pressurized Groundwater.

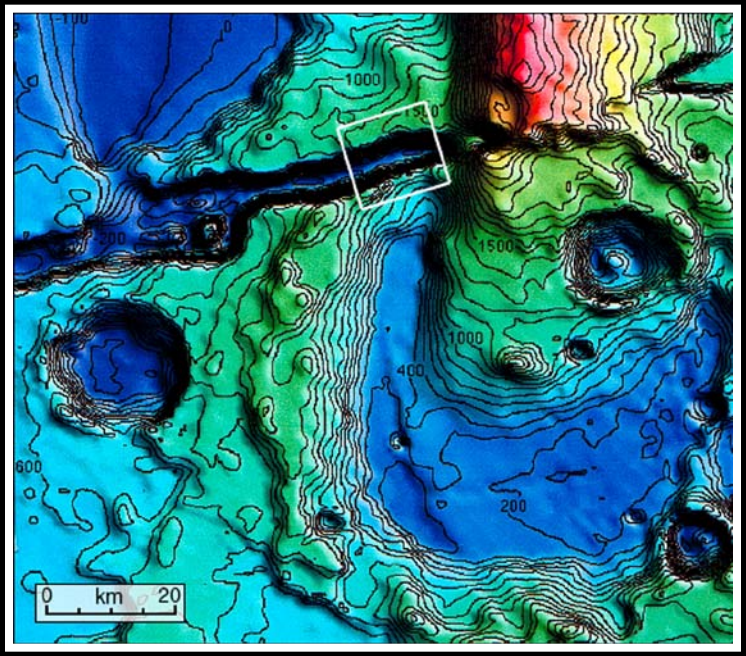


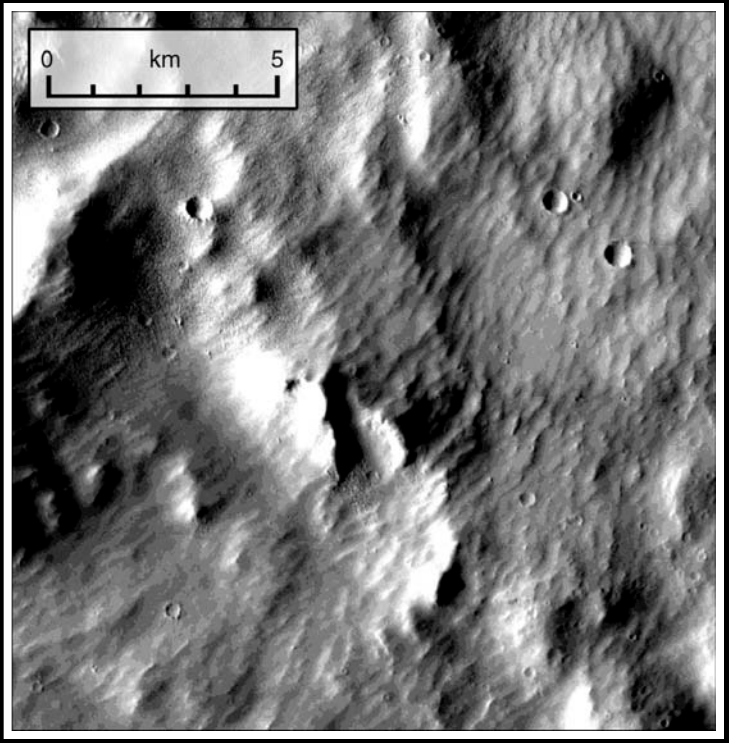


3. Radial Dikes

Dike-Induced Cryospheric Cracking, Magmatic Heating of the Cryosphere, Associated Phreatomagmatic Eruption and Massive Groundwater Outflow

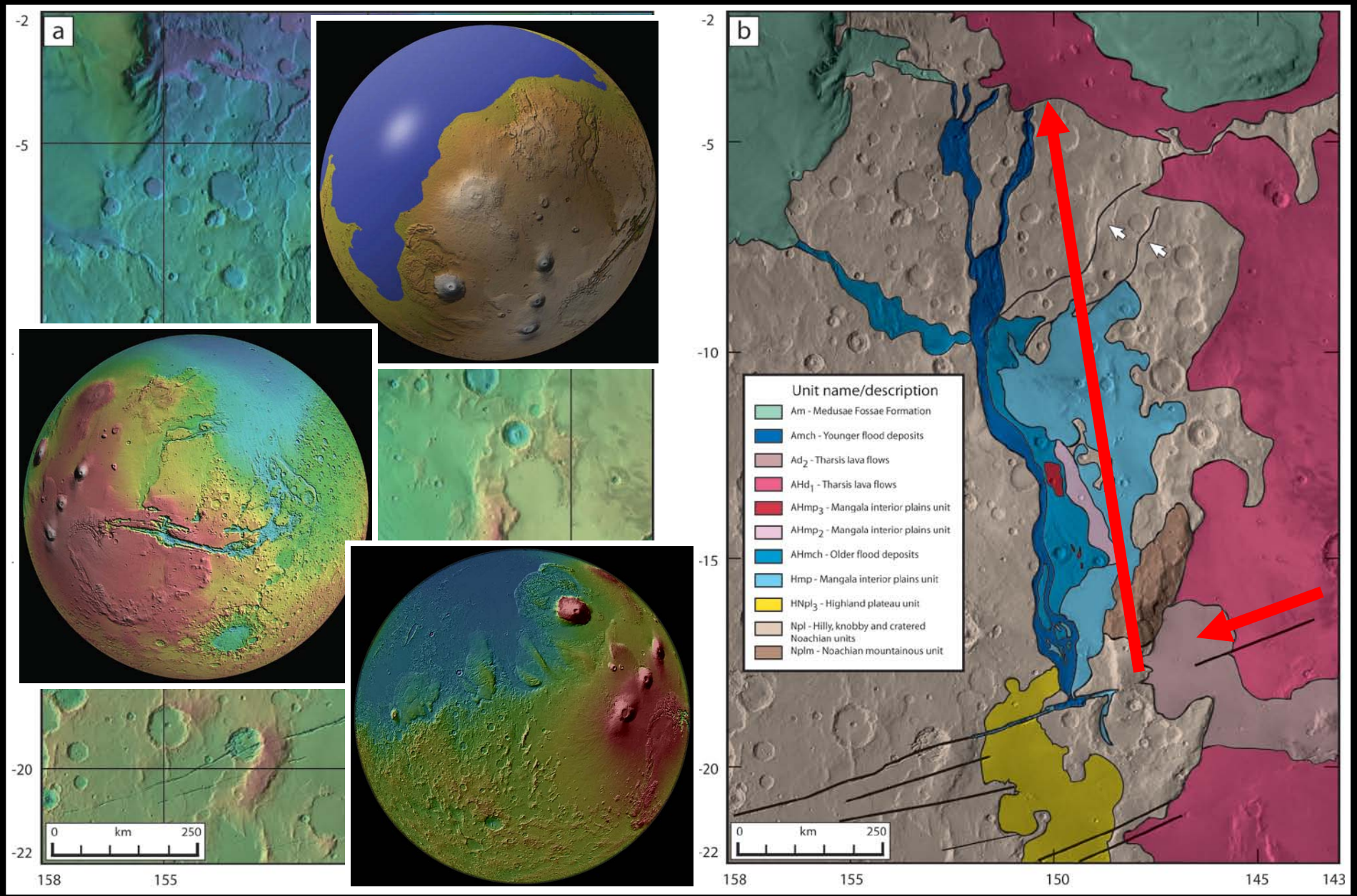






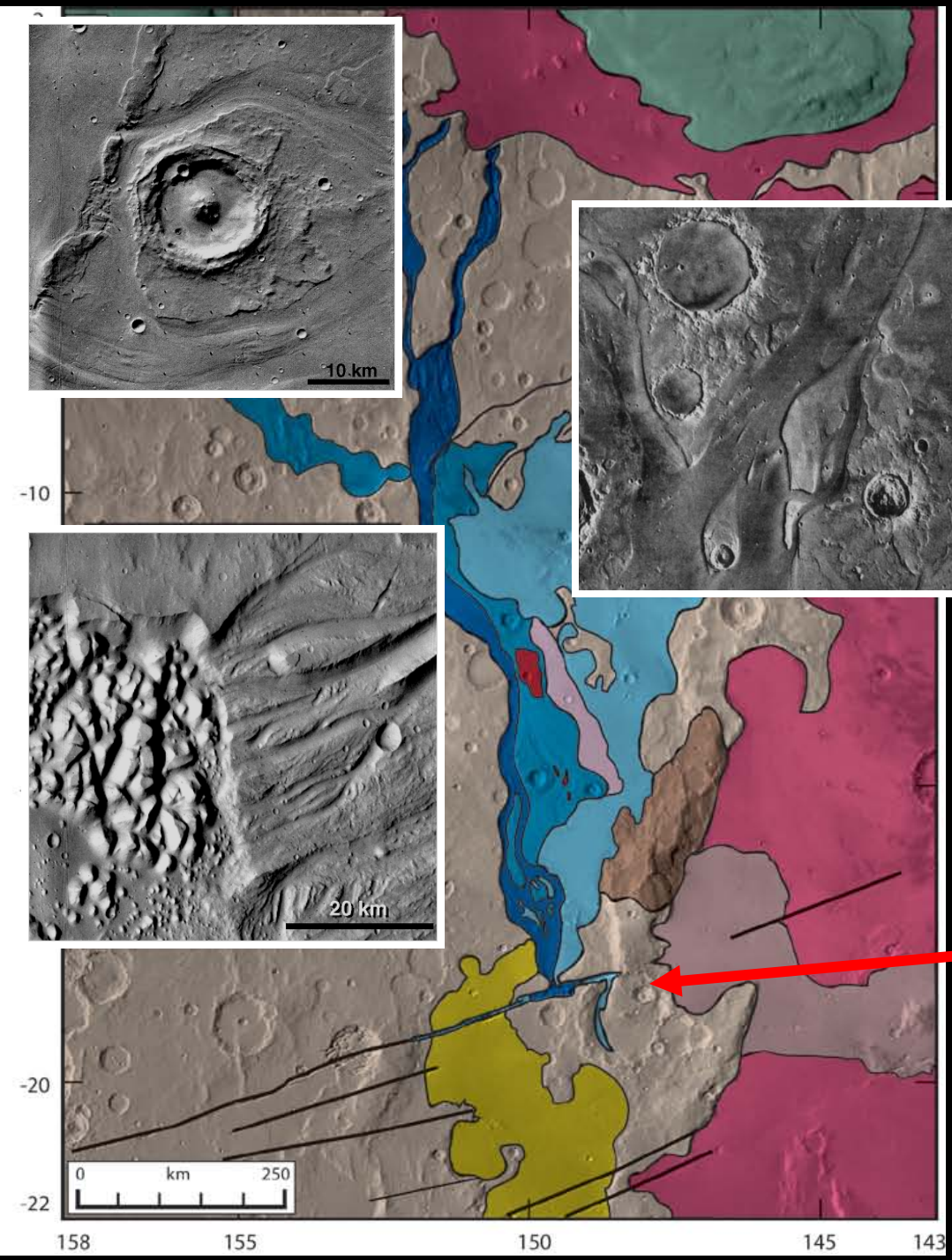
Concentric dunes from outward expansion of phreatomagmatic eruption plume.

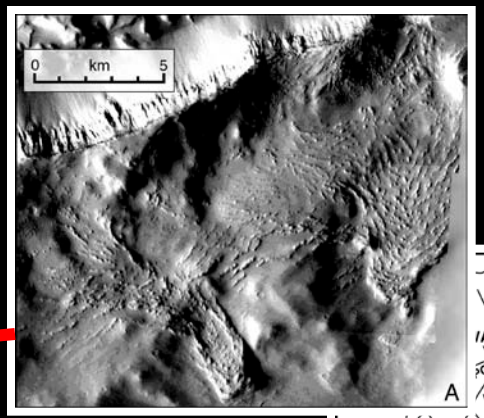
Mangala Valles:
“Pressurized Groundwater-Release Jokulhlaup”



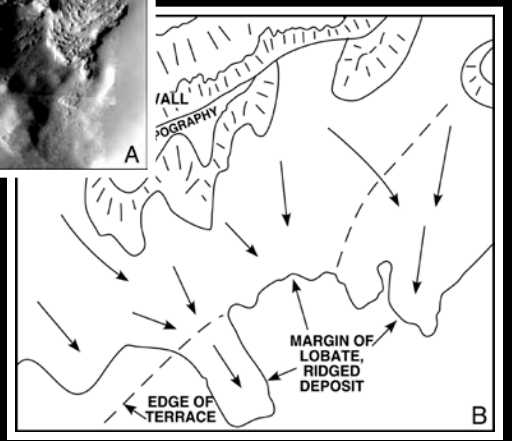
Outflow Channels

- Catastrophic floods emerging from subsurface.
- Dikes crack cryosphere, release groundwater under hydrostatic pressure.
- Produce channels up to a few 1000 km long, a few 100 km wide.
- Start full-size at discrete sources.
- <u>What is the climate at the time</u>?
- <u>How does event effect climate</u>?

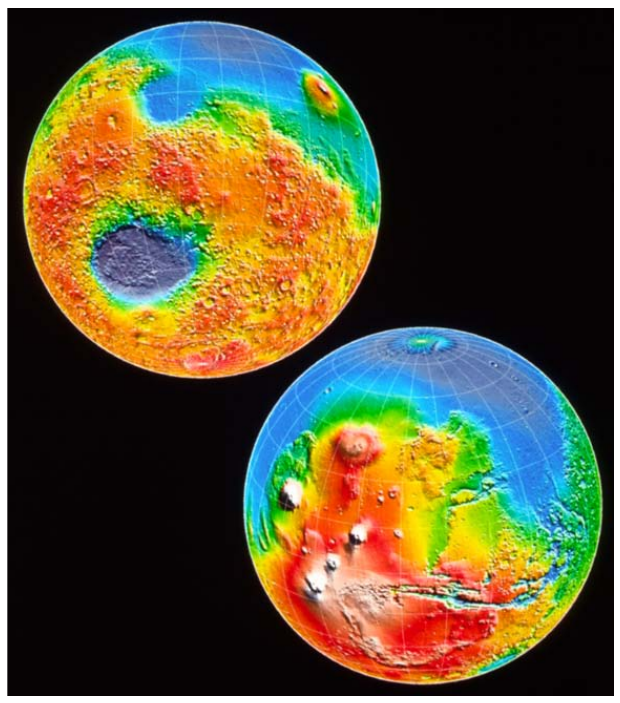


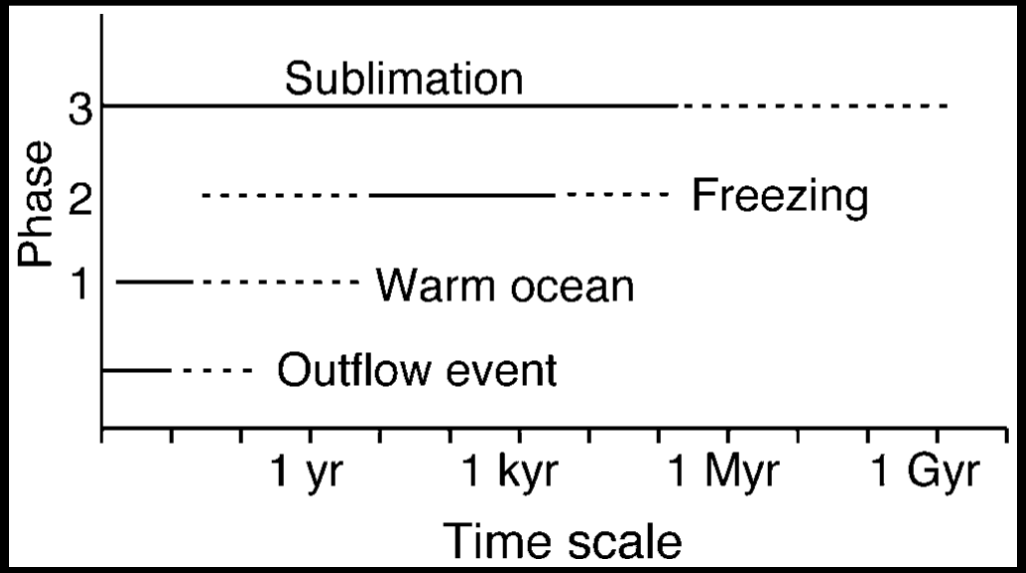


(Head et al, GRL, 2005)

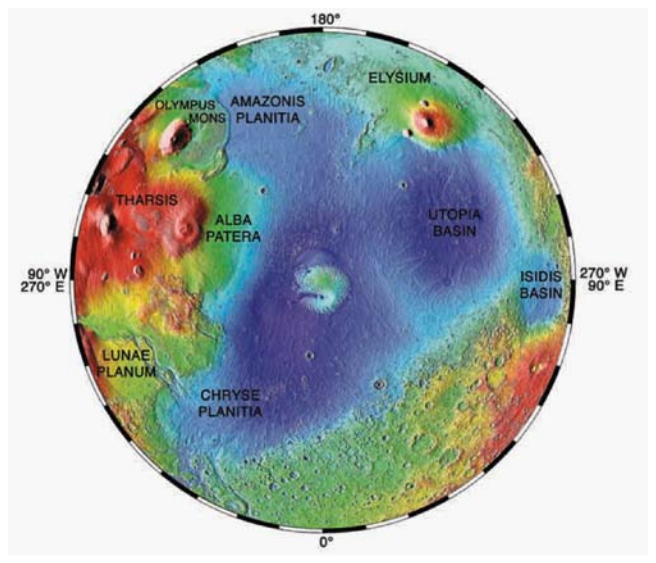


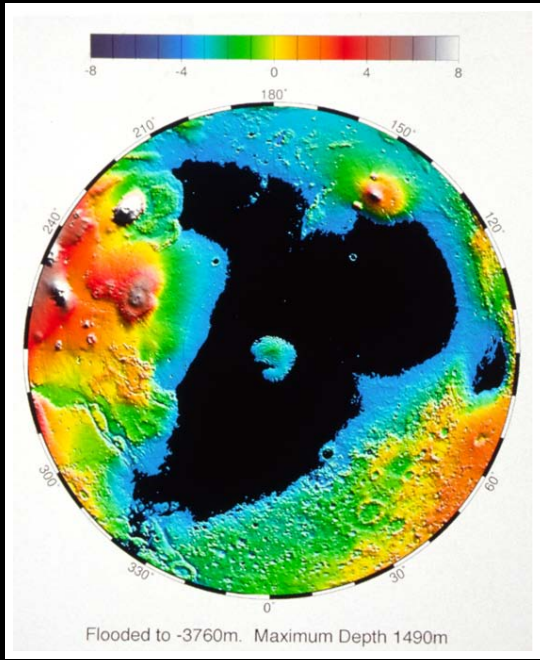
Fate of Outflow Channel Effluent

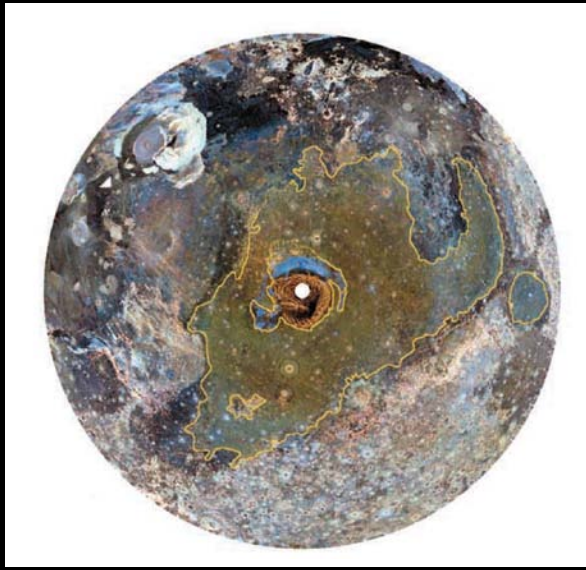




(Kreslavsky and Head, 2002)

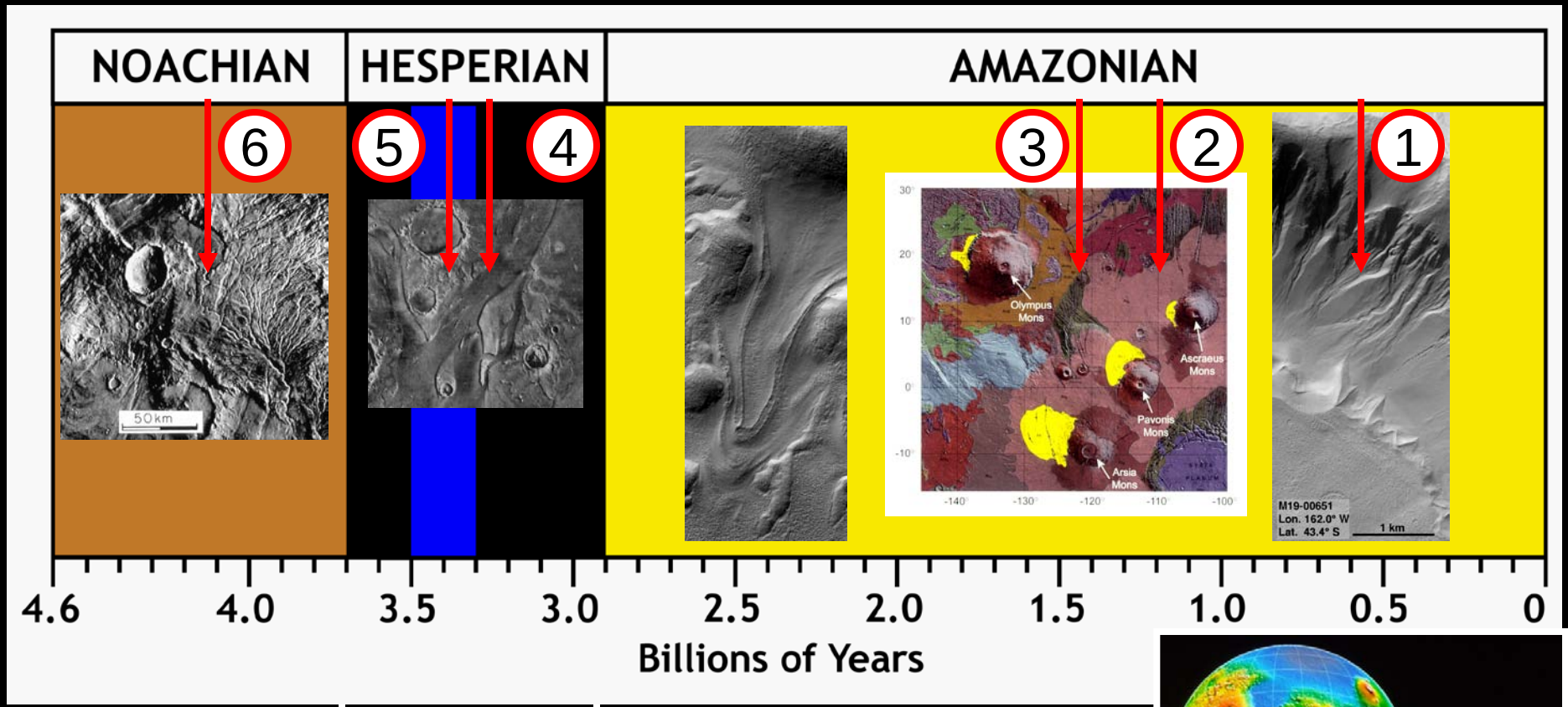






Vastitas Borealis Formation; Sublimation residue of effluent?

Water and Climate on Mars: Relation to Geologic History



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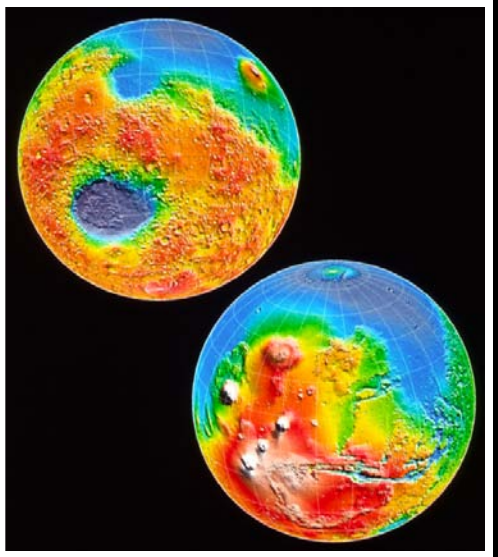
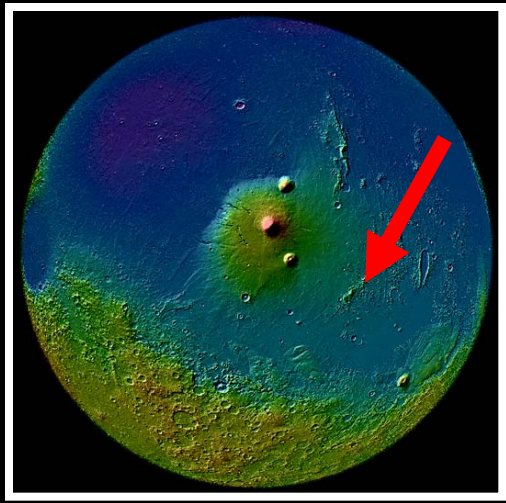
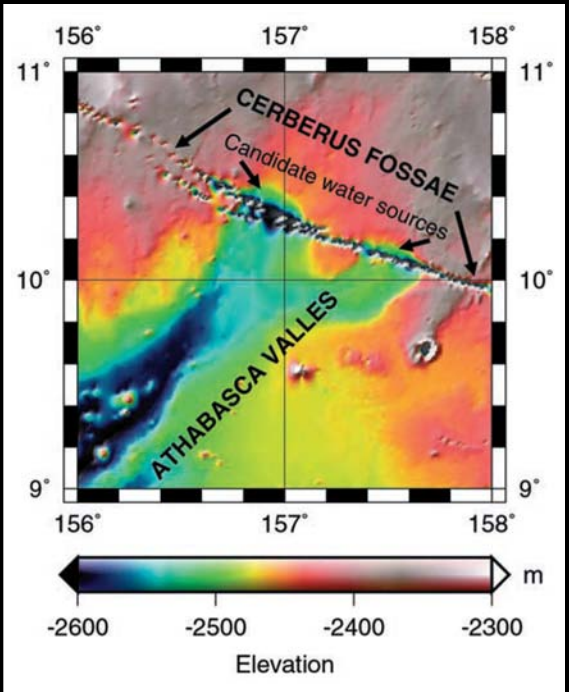
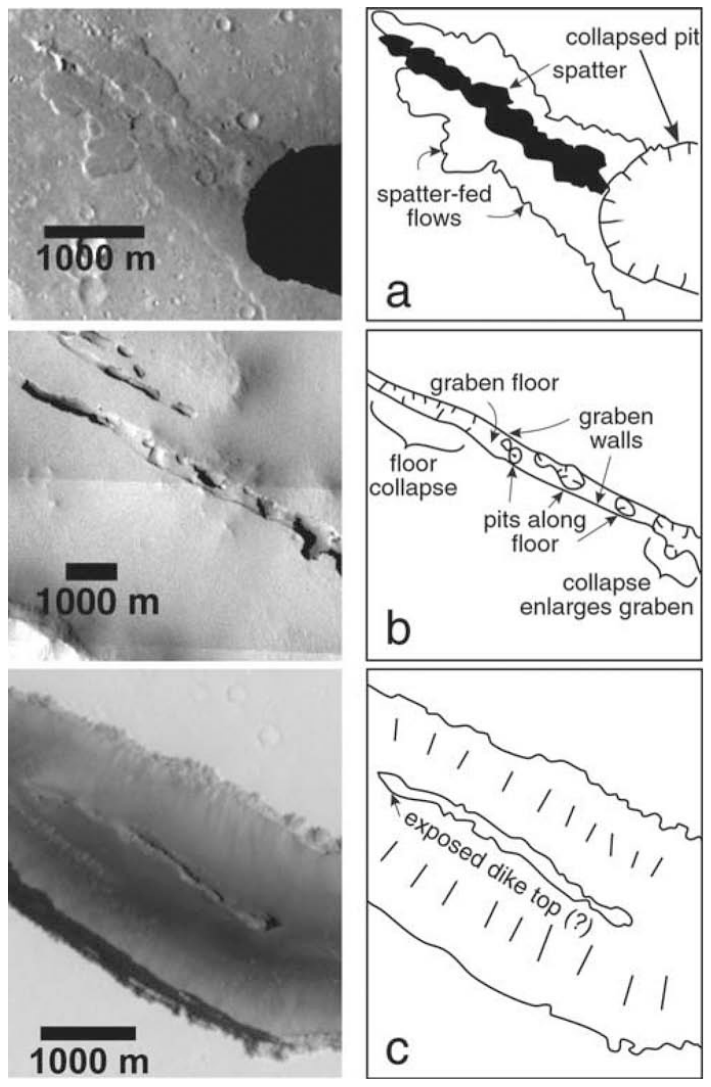
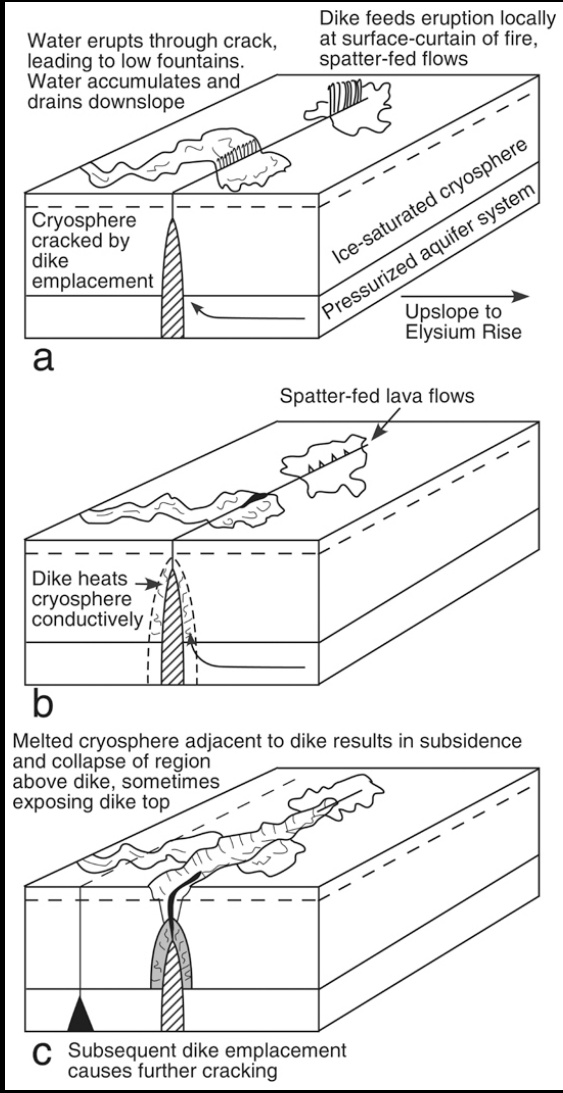


Cerberus Fossae: Dike-Induced Cryospheric Cracking, Associated Effusive Volcanism and Massive Groundwater Outflow









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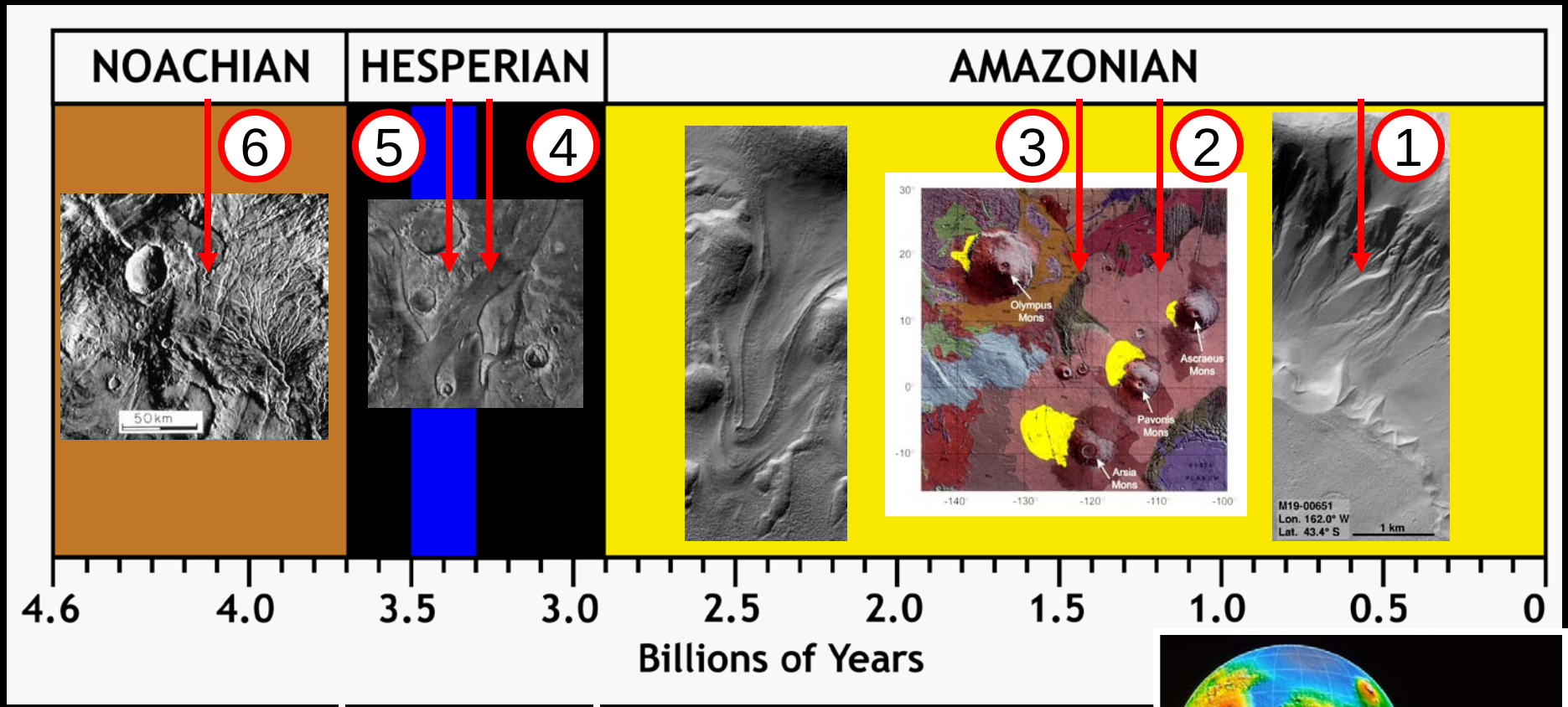

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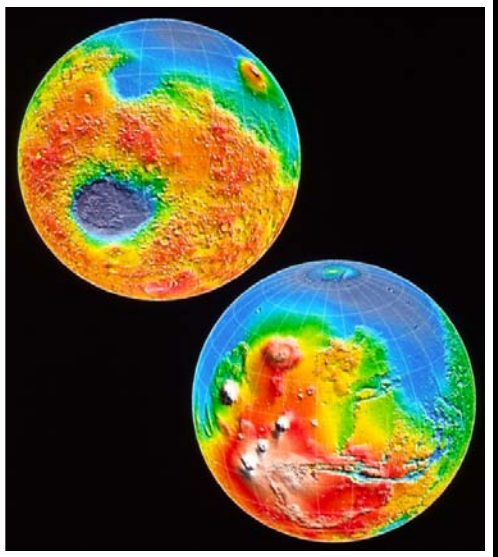
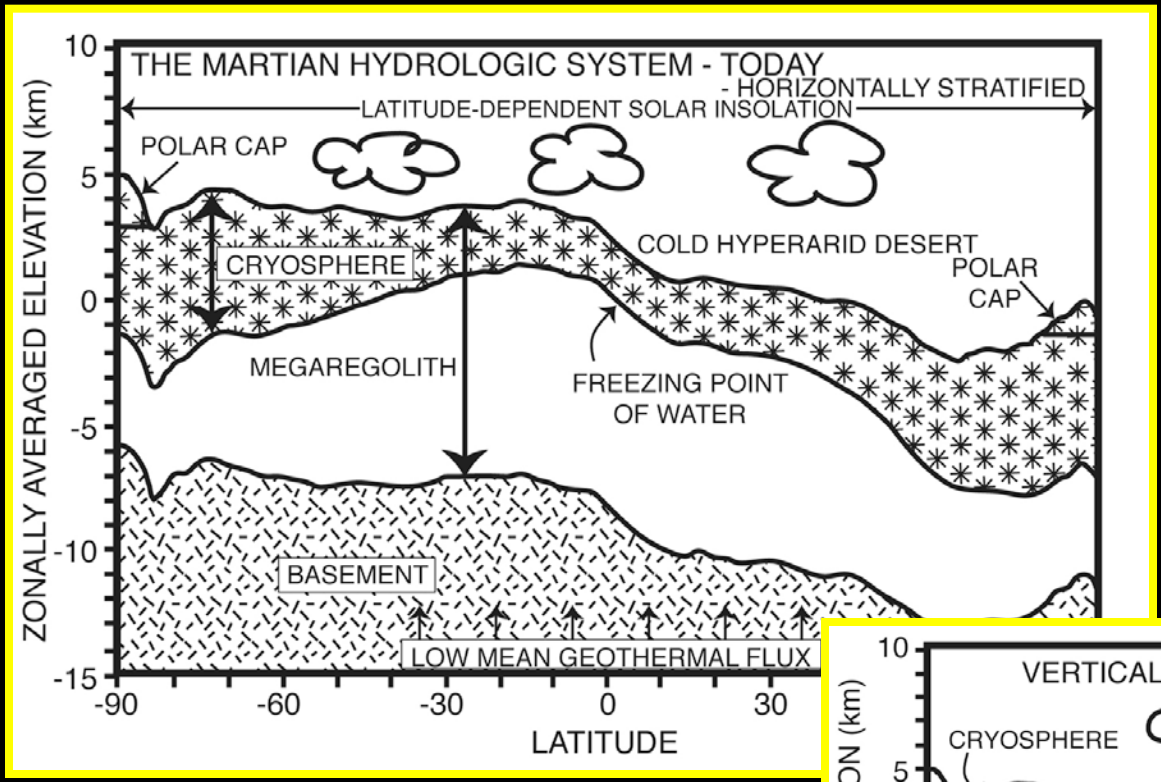
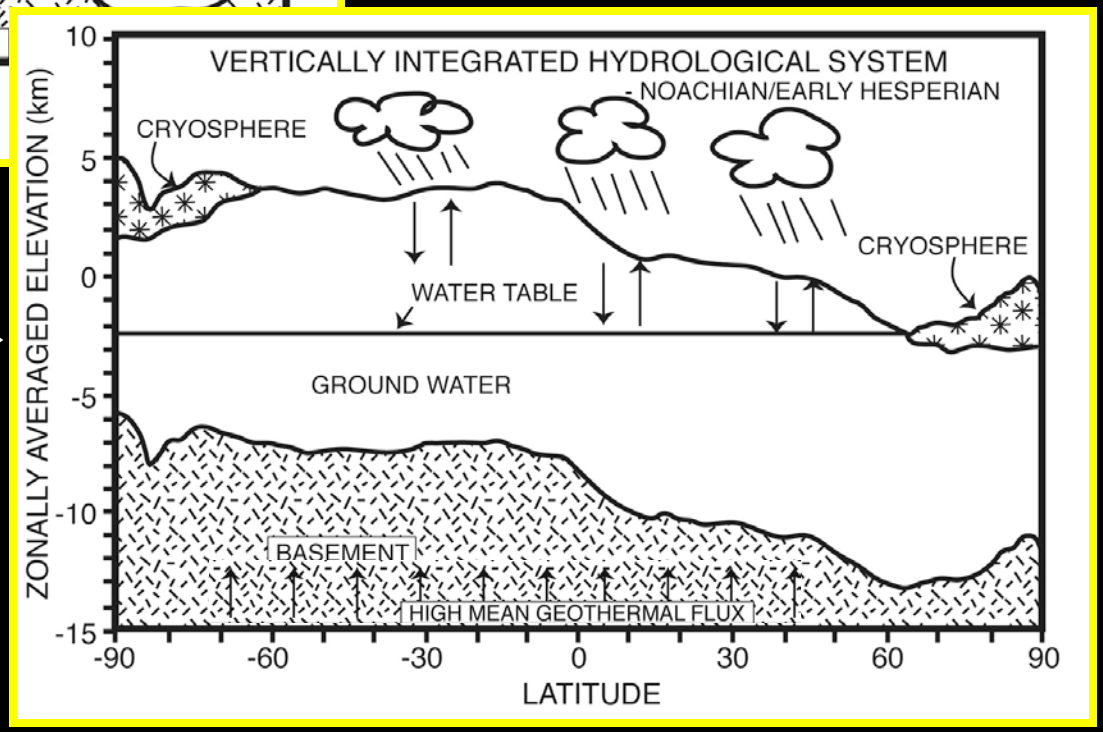


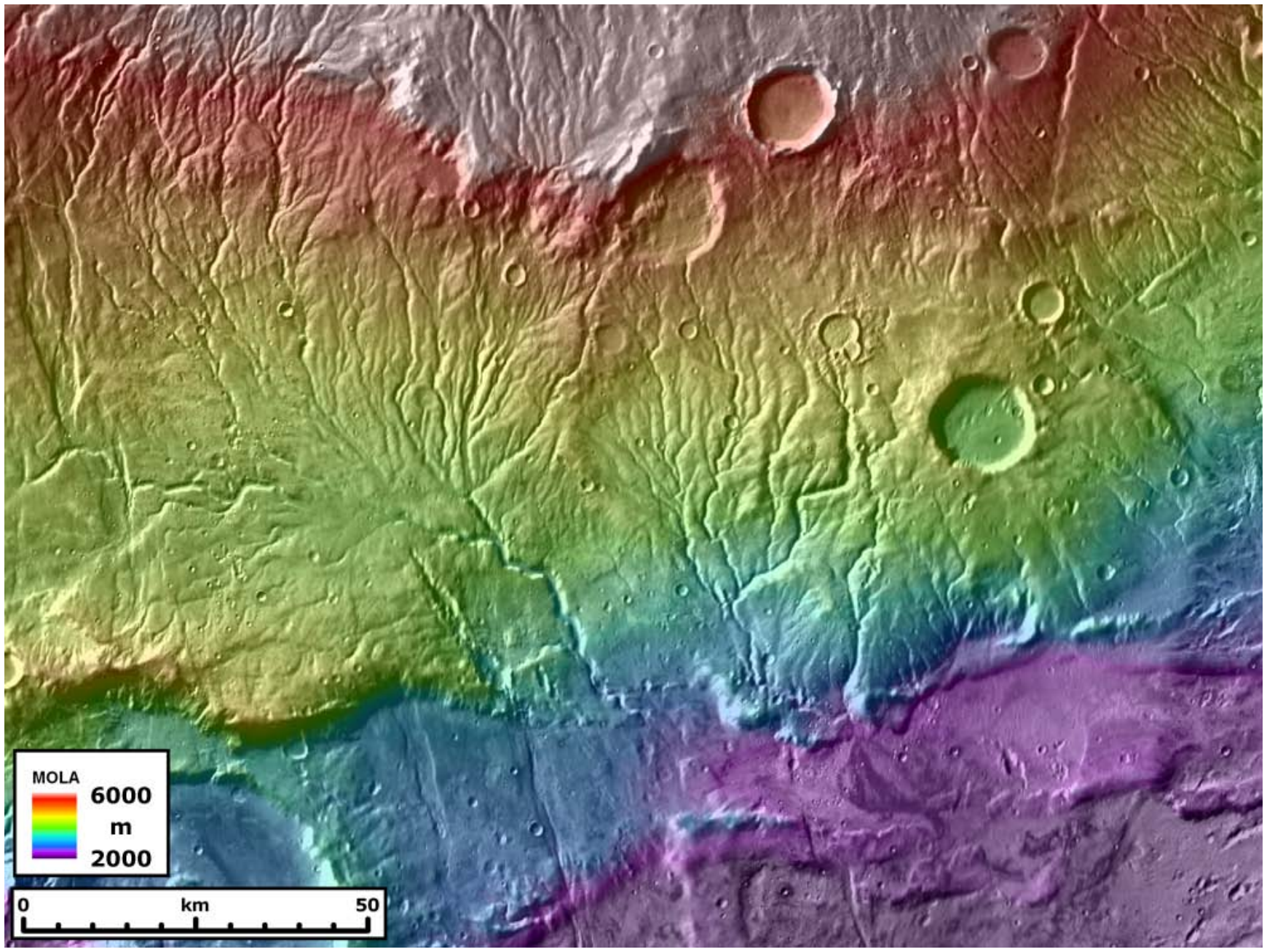
What is the Nature of the Hydrological Cycle on Mars?



TODAY:
-Cold, Hyperarid Desert.
-Low Geothermal Heat Flux.
-Global Cryosphere.
-Horizontally Stratified Cycle.

NOACHIAN:
-High Geothermal Flux.
-Warmer and Wetter (?).
-Vertically Integrated Cycle (?).




MOLA
6000
m
2000
0
km
50

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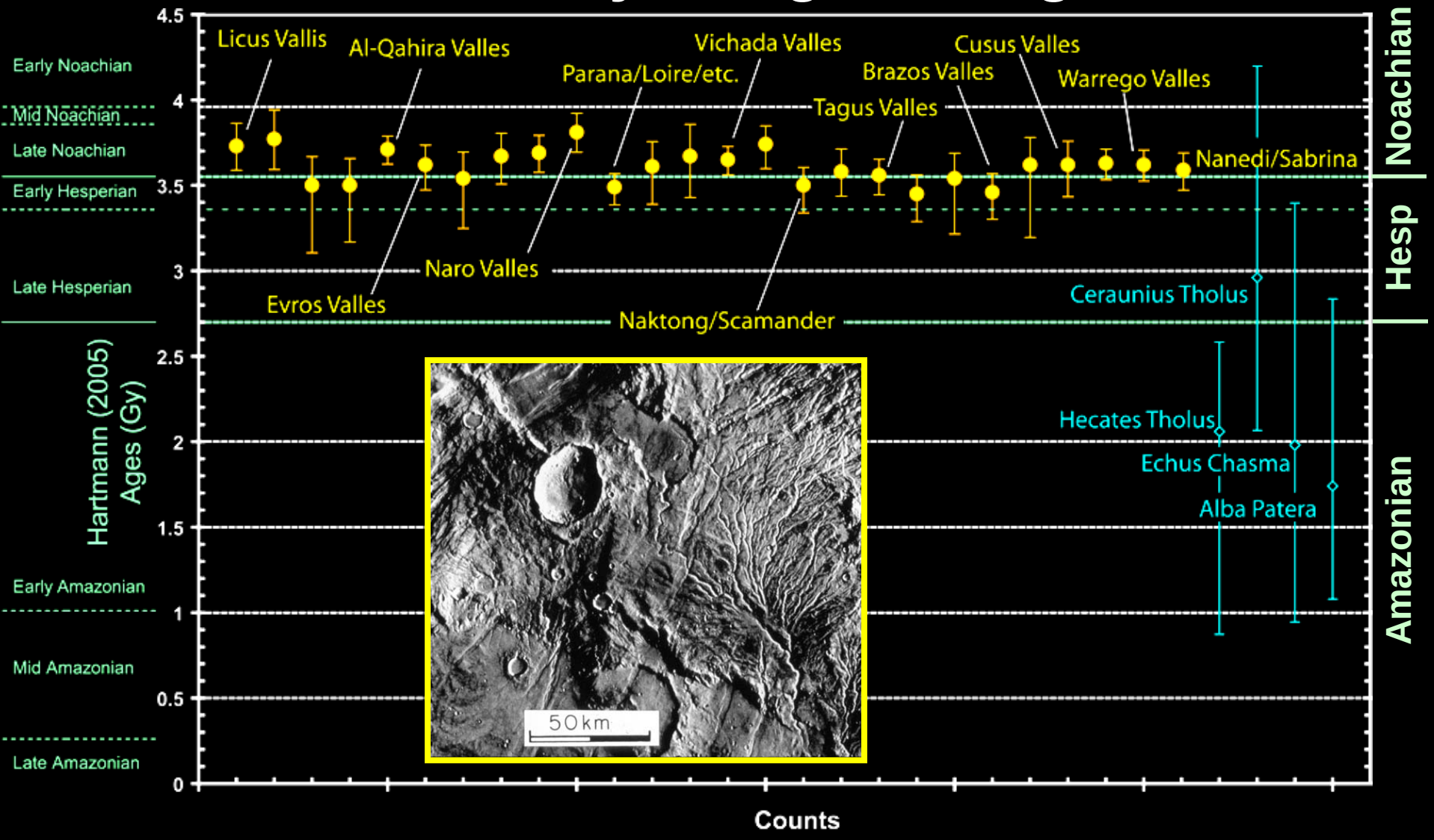
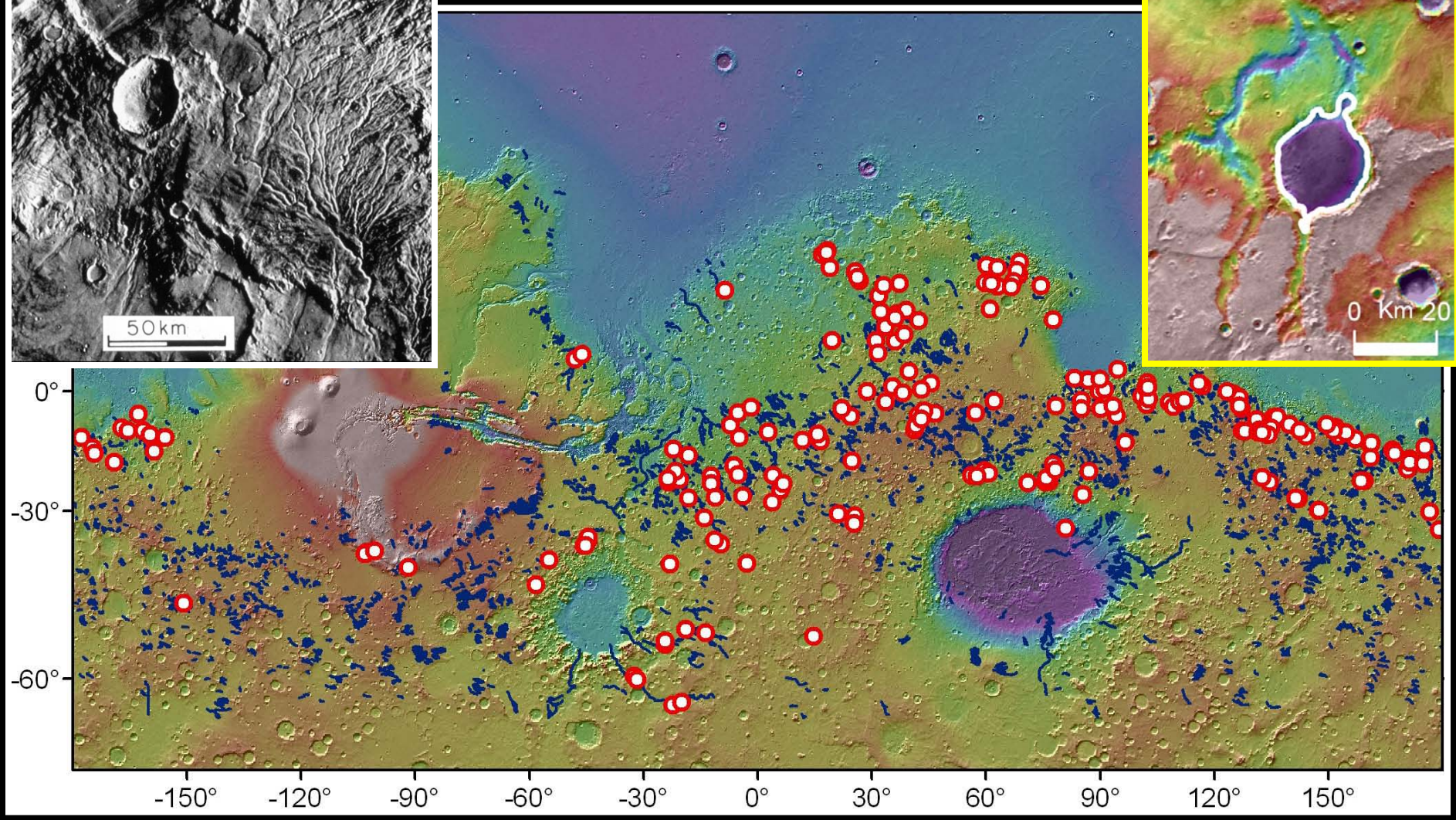


Fassett and Head, 2008, Icarus.

Noachian Valley Networks and Open Basin Lakes

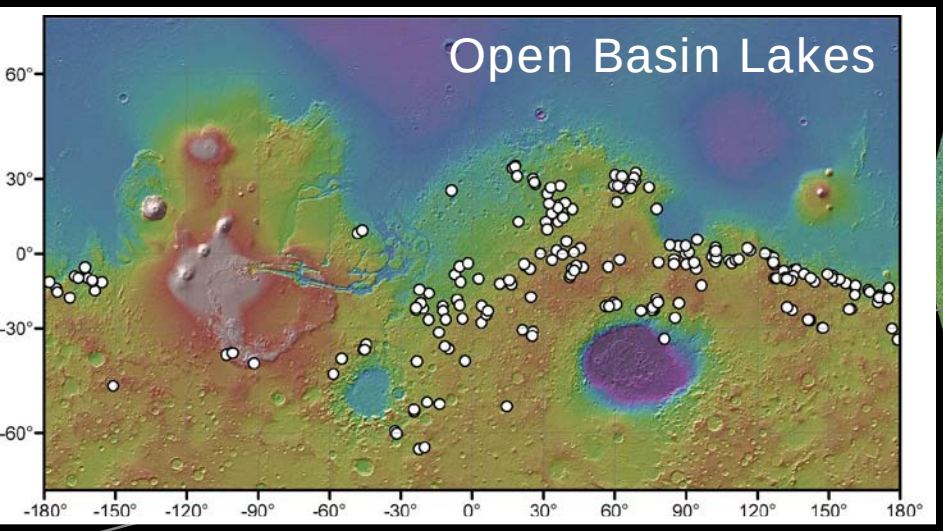


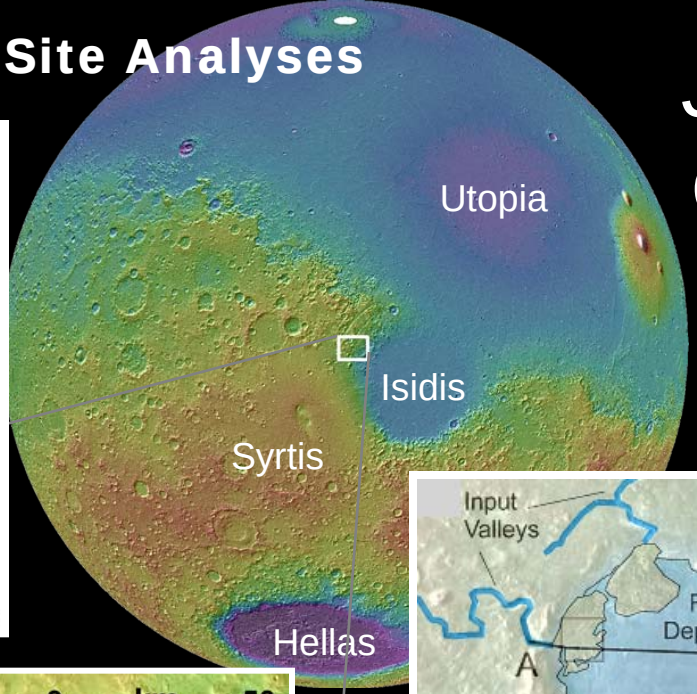
Fassett and Head, 2008a,b

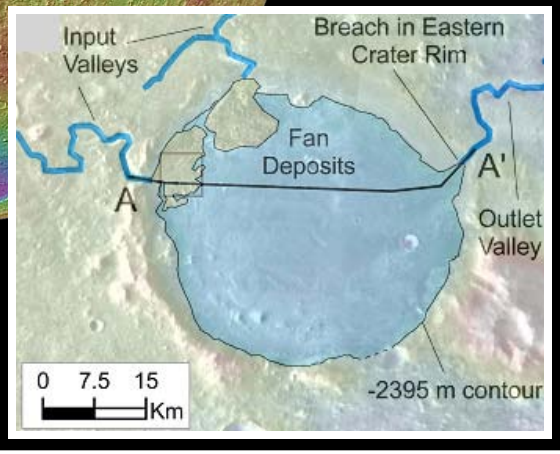
Open Basin Lakes
N=>210 (~65% newly recognized)

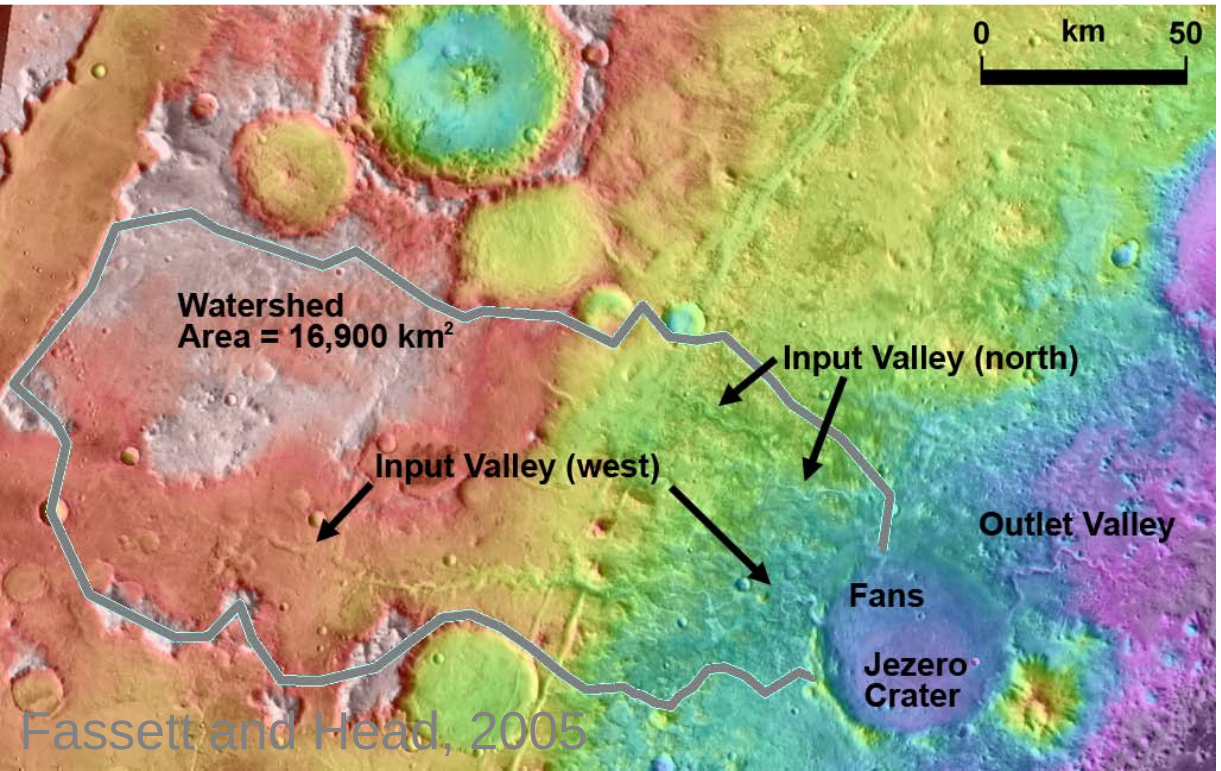
Mars Science Laboratory Landing Site Analyses

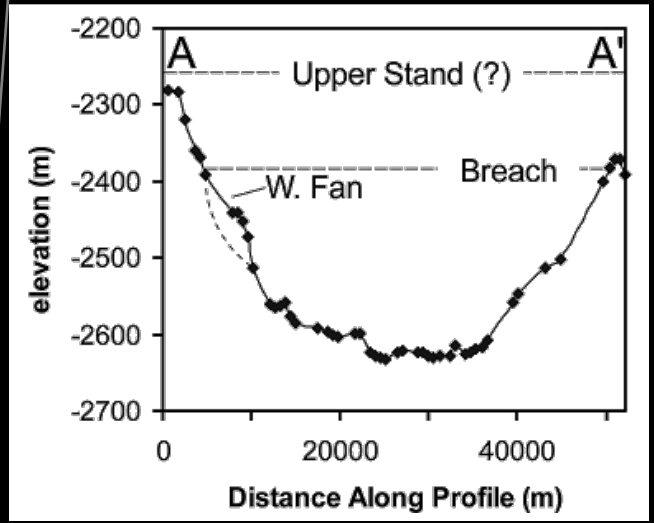
Jezero Crater



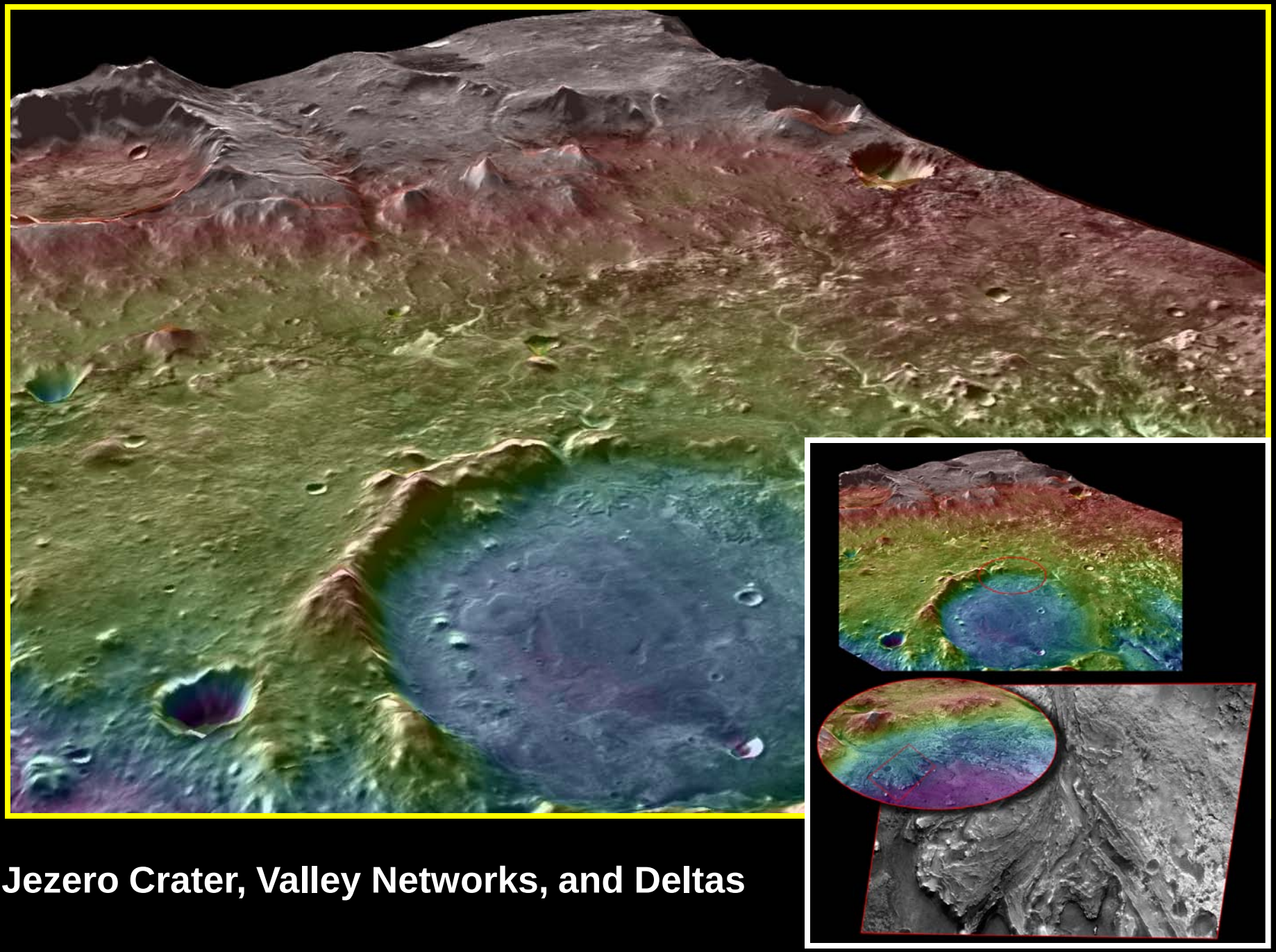








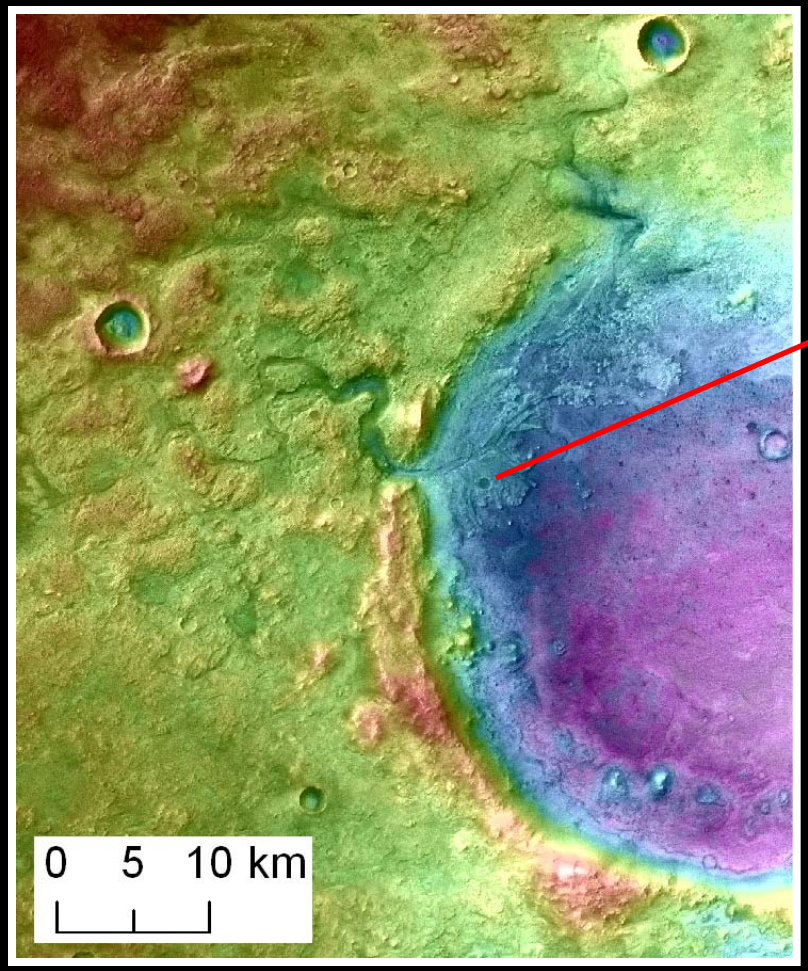
Fassett and Head, 2005

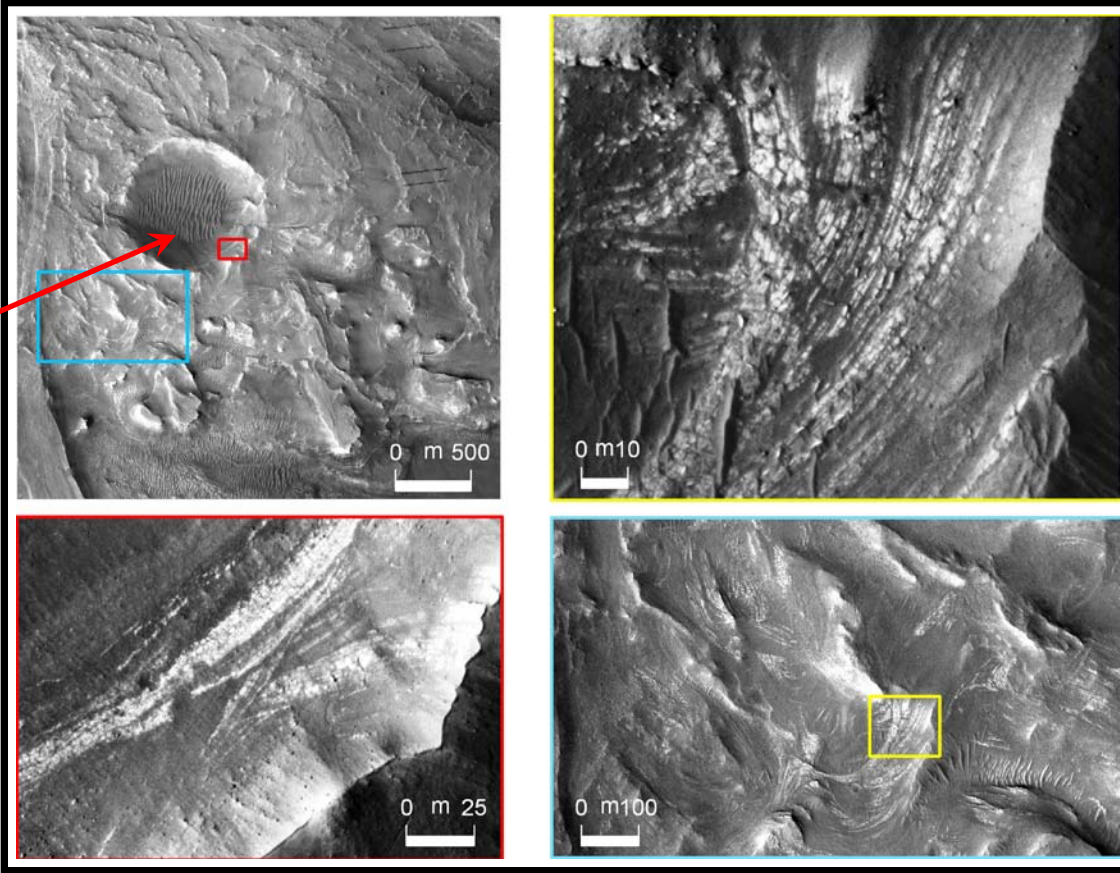


Jezero Crater, Valley Networks, and Deltas

Jezero Crater:

1. Valley network formation. 2. Crater breaching. 3. Crater flooding.
4. Crater filling. 5. Delta formation. 6. Delta migration.
7. Crater breaching to produce open basin lake and throughgoing system.
8. Steady-state open basin lake (?). 9. Water input ceases; desiccation.

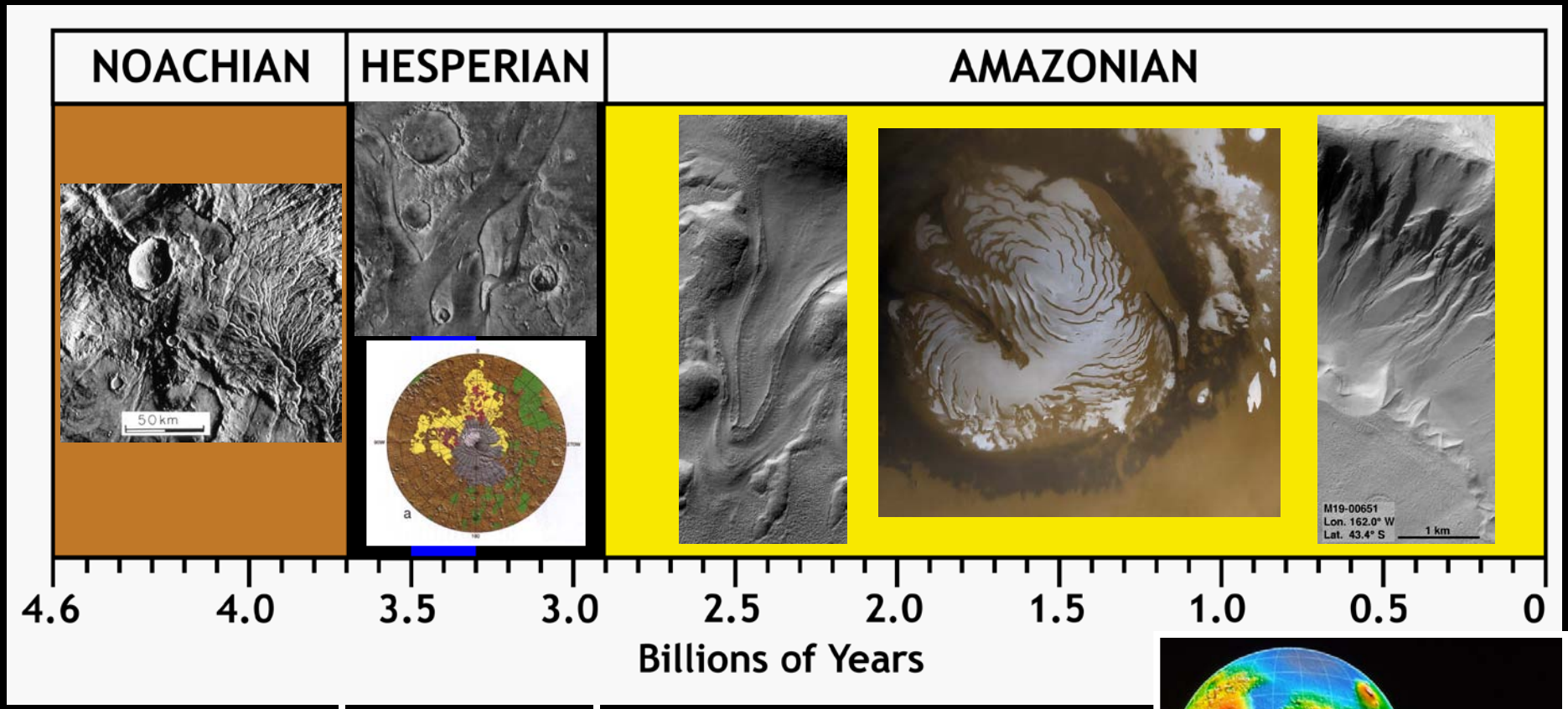


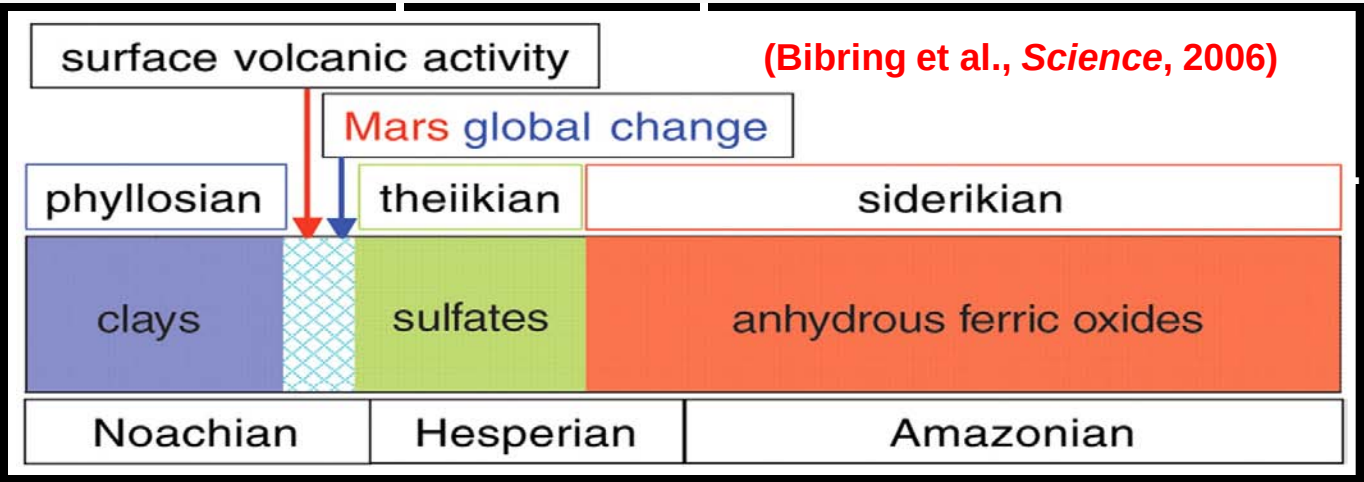


HRSC 988, High quality stereo DEM (75 m/px) & Nadir image (12.5 m/px)
Jezero Crater 75E 18 N

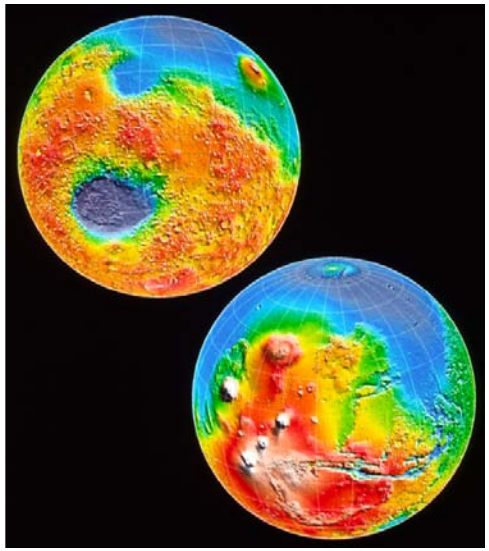
HiRISE

Water and Climate on Mars: Relation to Geologic History

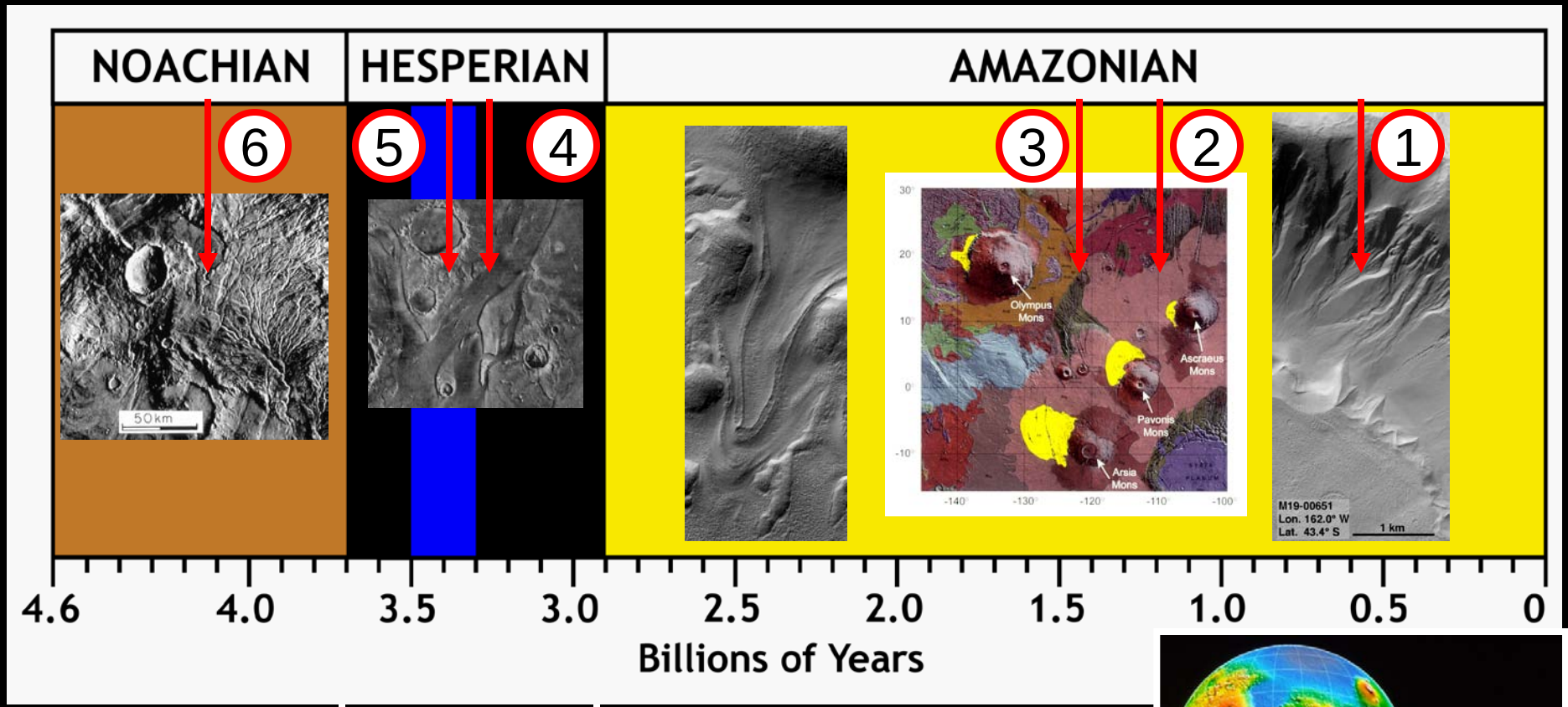




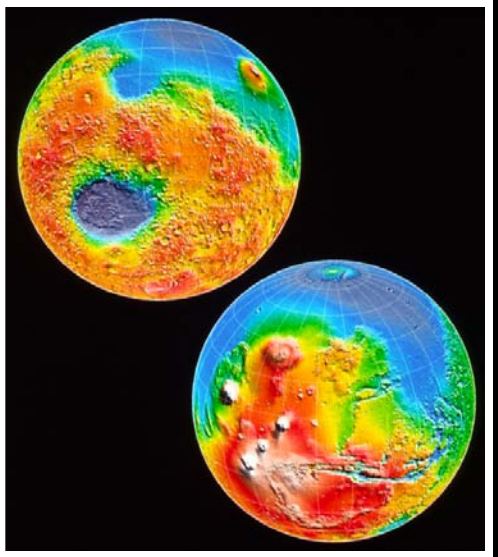
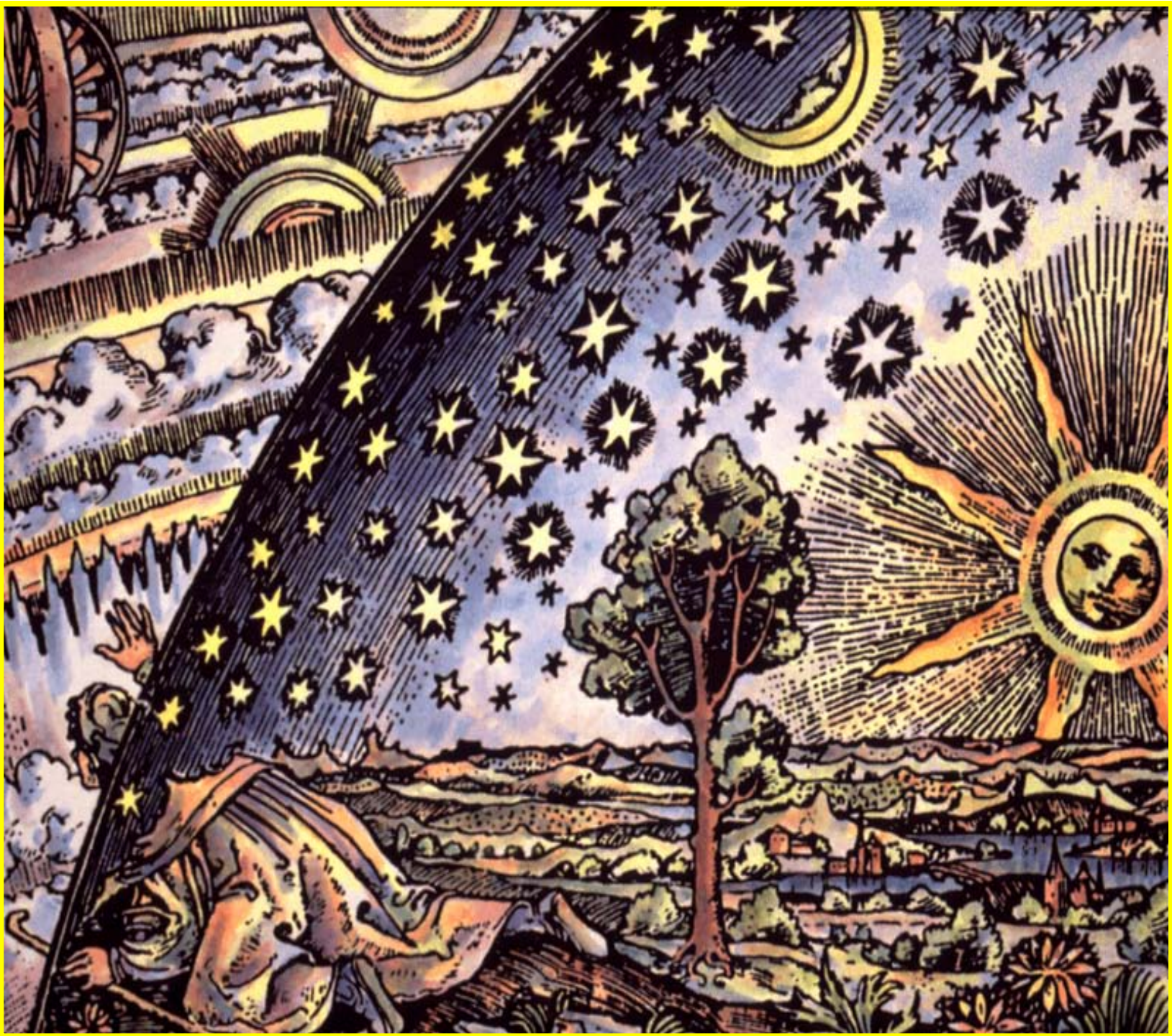
(Bibring et al., *Science*, 2006)



Water and Climate on Mars: Relation to Geologic History



- Heavy impact bombardment.
- Valley networks.
- "Warm/Wet" early Mars?

-Volcanism.
- Outflow channels.
- Oceans?
- South circumpolar deposits.

- Low impact rates.
- Tharsis volcanism continues.
- Outflow channels continue.
- Late-stage polar caps.
- "Cold/Dry" late Mars.