



● Announcements

■ Use Priyanka Sharma as TA

- ◆ psharma@lpl.arizona.edu
- ◆ Office hours: Tuesday 10.30am-12.30pm
Room 316, Kuiper Building

■ Thursday office hours?

- ◆ Can only stick around for ~1 hour today
- ◆ ...but these office hours are under-utilized in general
- ◆ Do away with these hours?

■ Calculate your expected grade...

- ◆ Add HW1 and HW2 percentages together, multiply by 0.15
- ◆ Add the two in-class activity marks (out of 5) together, multiply by 2
- ◆ Take your mid-term score (out of 45), multiply by 1.111
- ◆ Add these three things together.... And compare to grade table

90-100%	A
75-89%	B
60-74%	C
50-59%	D
0-49%	E

- ◆ This is a REALLY rough guess, you can easily move up/down a grade

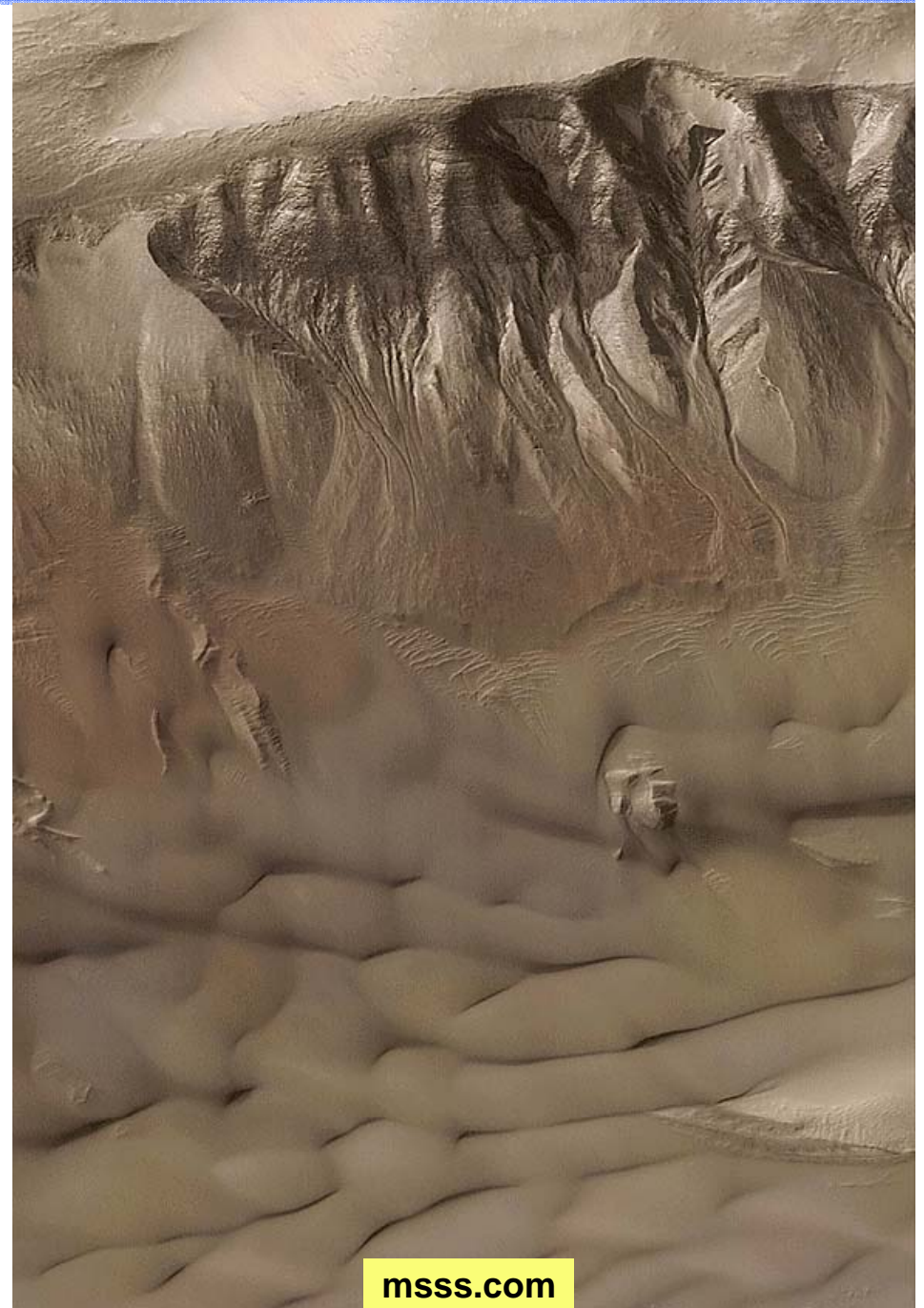
Mars – Recent History

PTYS/ASTR 206 – The Golden Age of Planetary Exploration

Shane Byrne – shane@lpl.arizona.edu

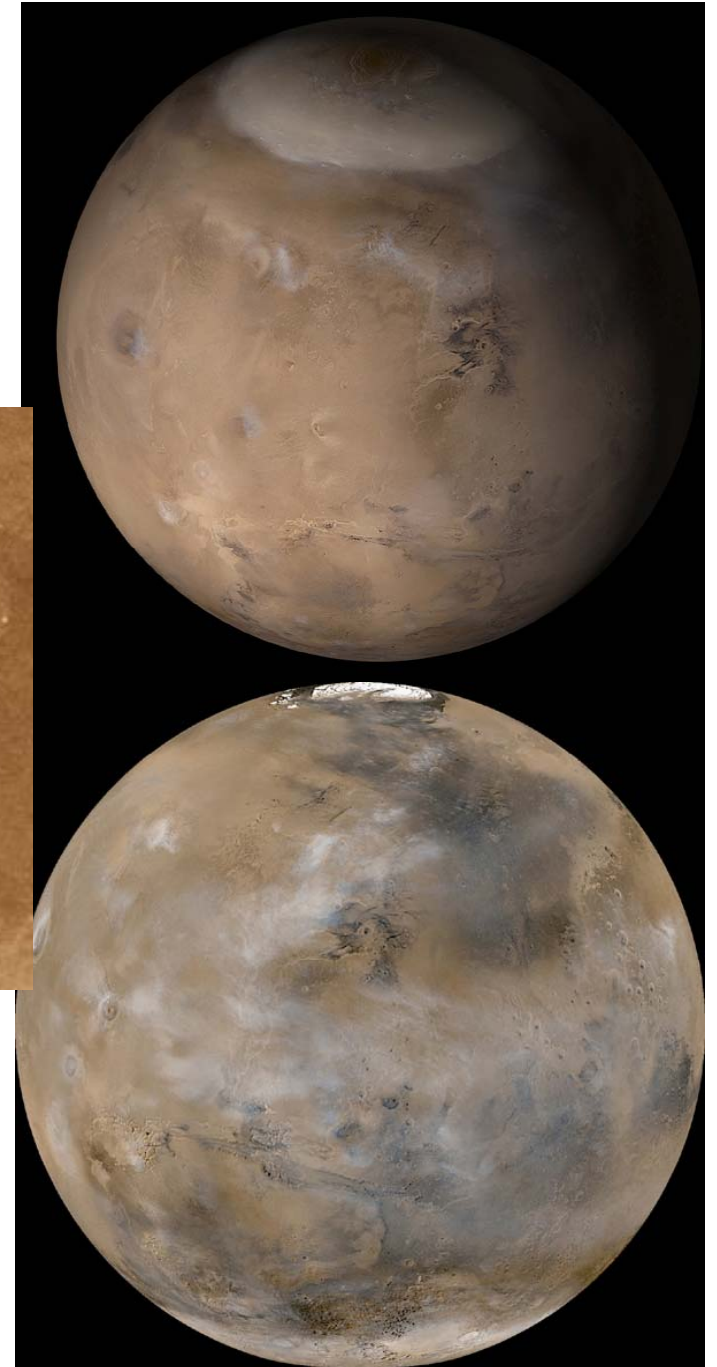
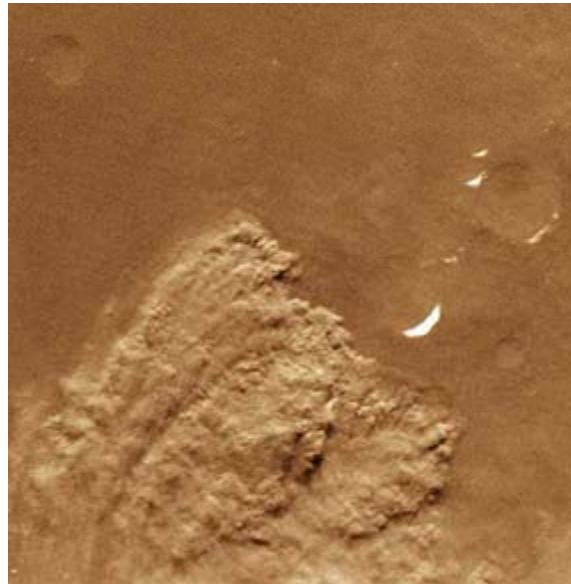
In this lecture...

- **Martian weather today**
 - Seasonal frost
 - Ice clouds
 - Dust storms
- **Recap**
 - Ancient Mars
 - Transition to cold dry conditions
- **Giant Floods**
 - Outflow channels
- **Climate change on Mars**
 - Polar ice caps
 - Orbital variations
- **Running water today?**
 - Gullies
 - Flowing ice
- **Volcanism and life?**
 - Methane in the atmosphere



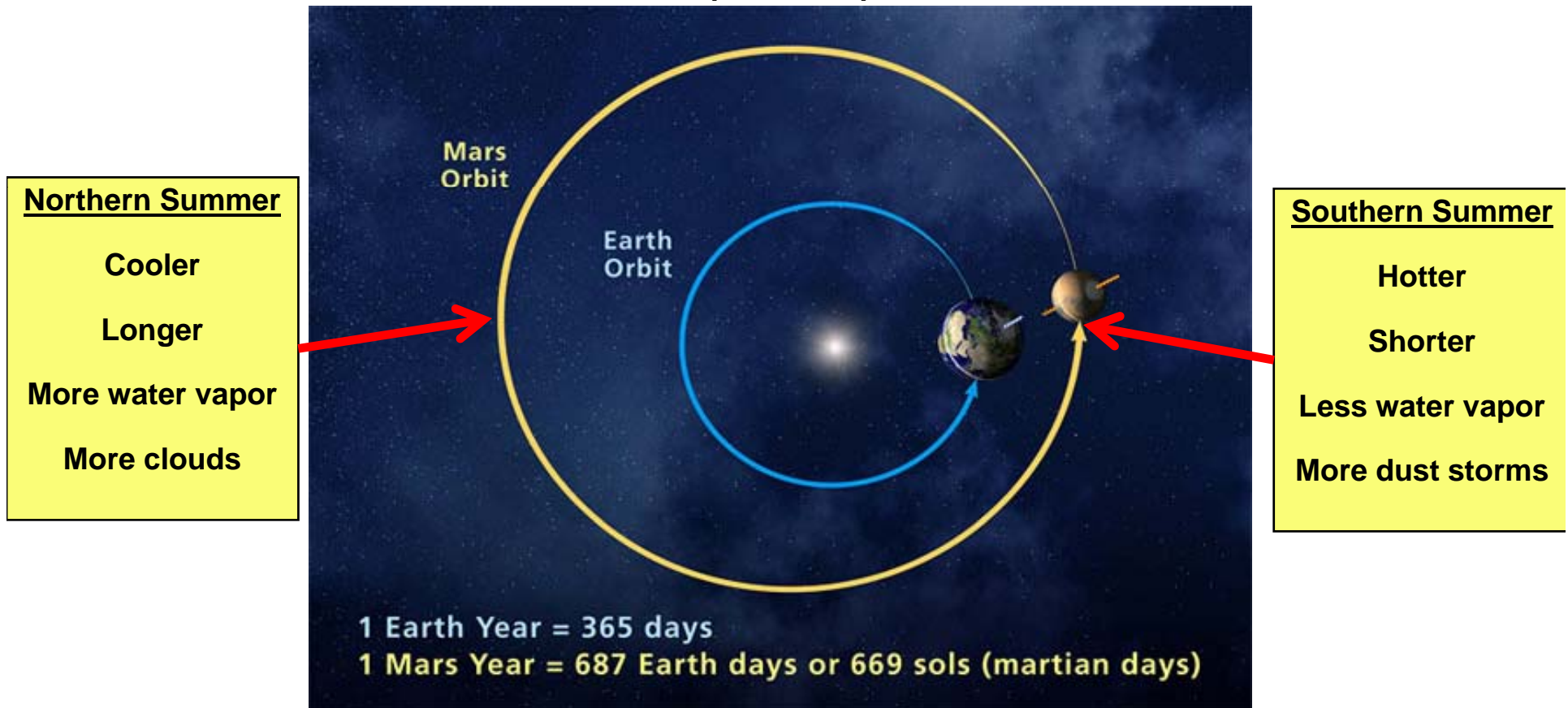
Current Climate

- Mars has seasonal ice caps
- Mars has dust-storms
 - Dry dusty southern summer
 - Warmer
- Mars has water ice clouds
 - Wetter northern summer
 - cooler

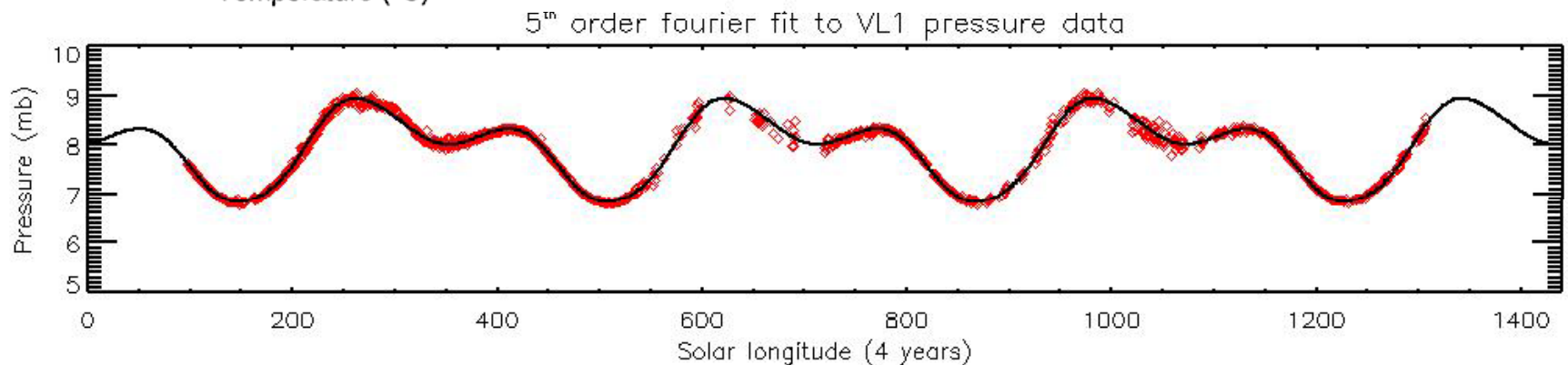
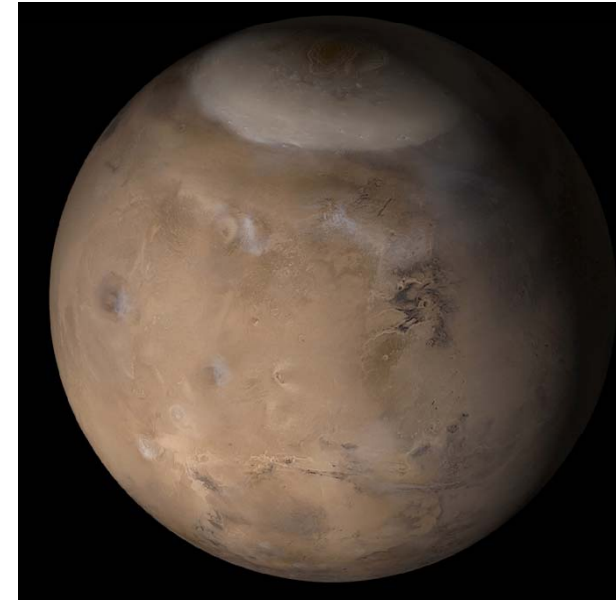
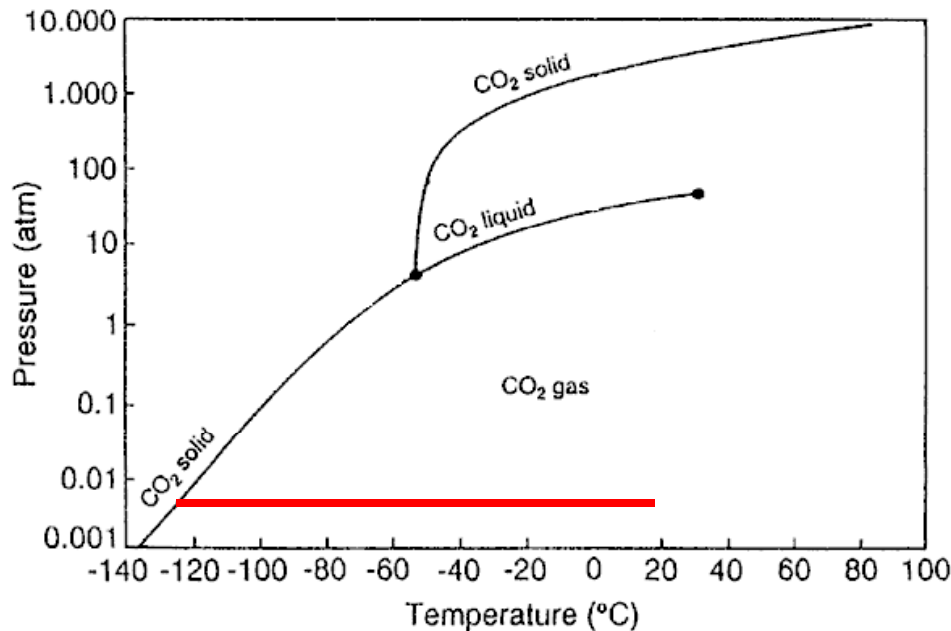


- **Earth-like seasons – but with a twist**

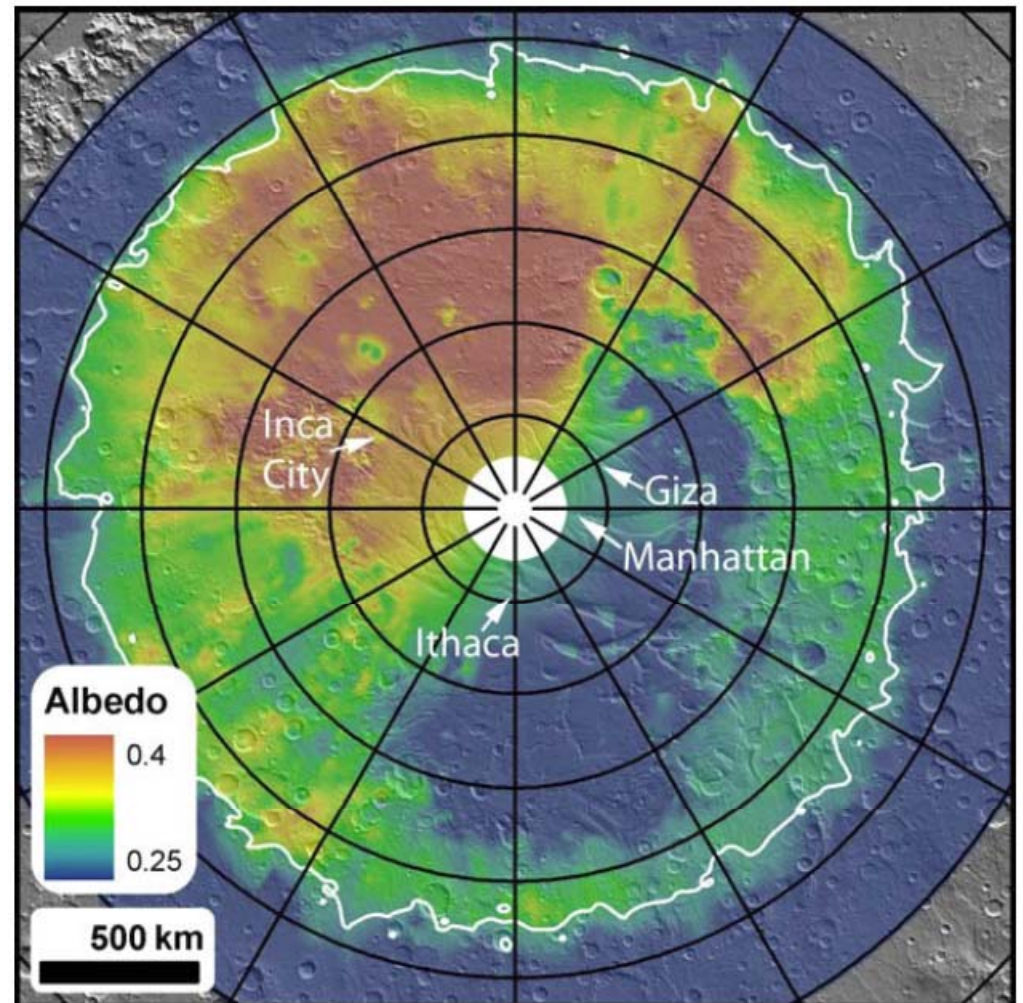
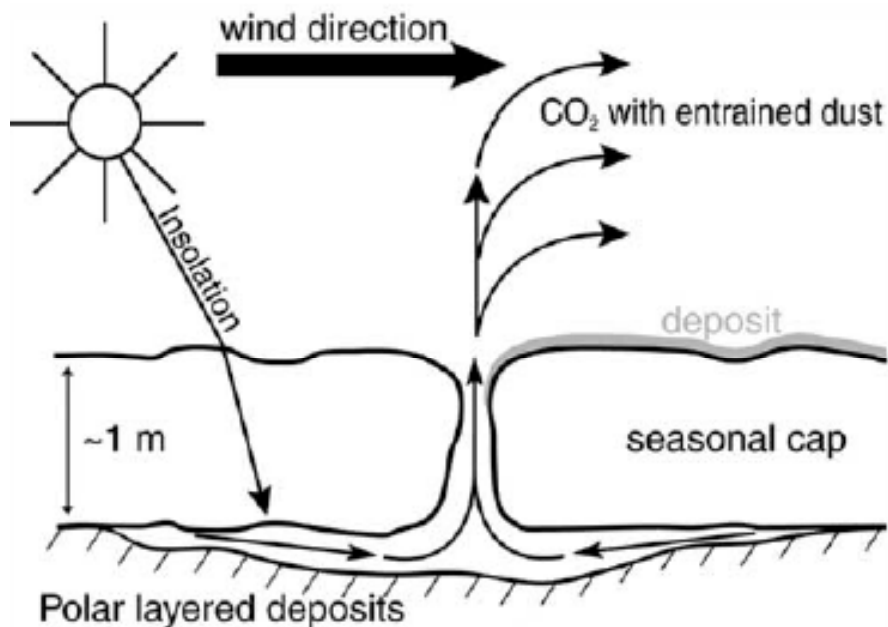
- Martian orbit is eccentric (eccentricity ~ 0.1)
- Mars is farther from the Sun in the northern summer (1.37 AU)
- Closer in the southern summer (1.67 AU)



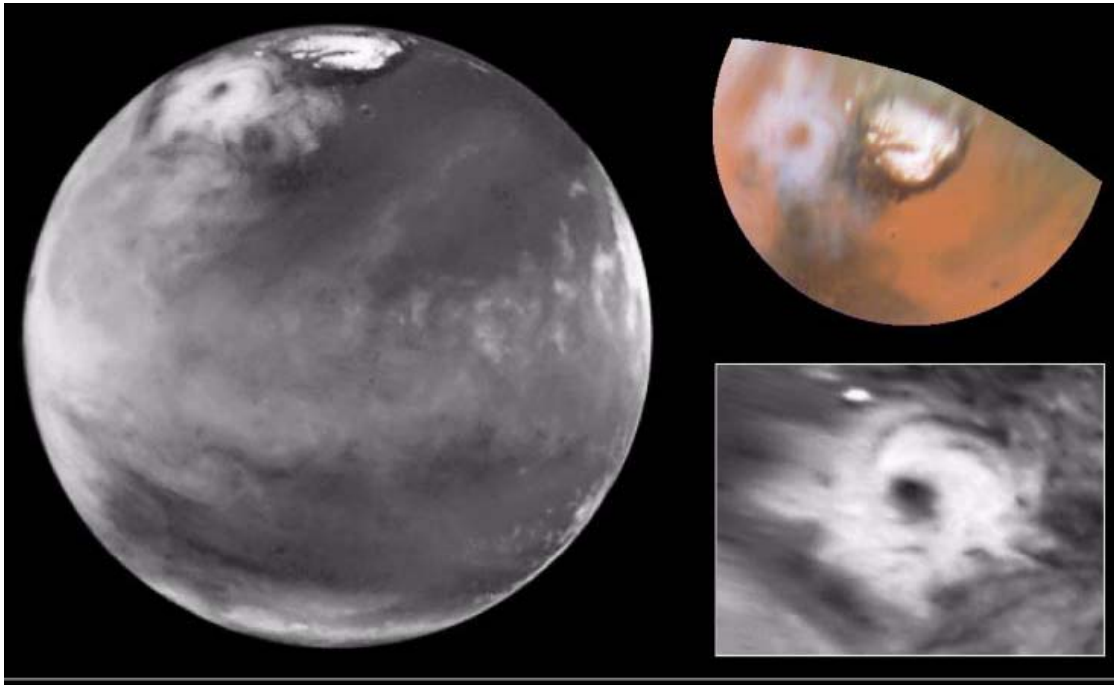
- Mars has a similar obliquity (25°) to the Earth.
 - Ensures seasons with periods of permanent polar darkness and daylight.
- Mars has a low pressure CO_2 atmosphere.
 - Permits seasonal icecaps of CO_2 ice to form -Leighton and Murray (1966)



- **Not every part of the ice cap is frosty**
 - Low albedo region inside the CO₂ cap
 - Spectral indicators of large grain size
 - Large areas anneal into a transparent slab in 100's of days

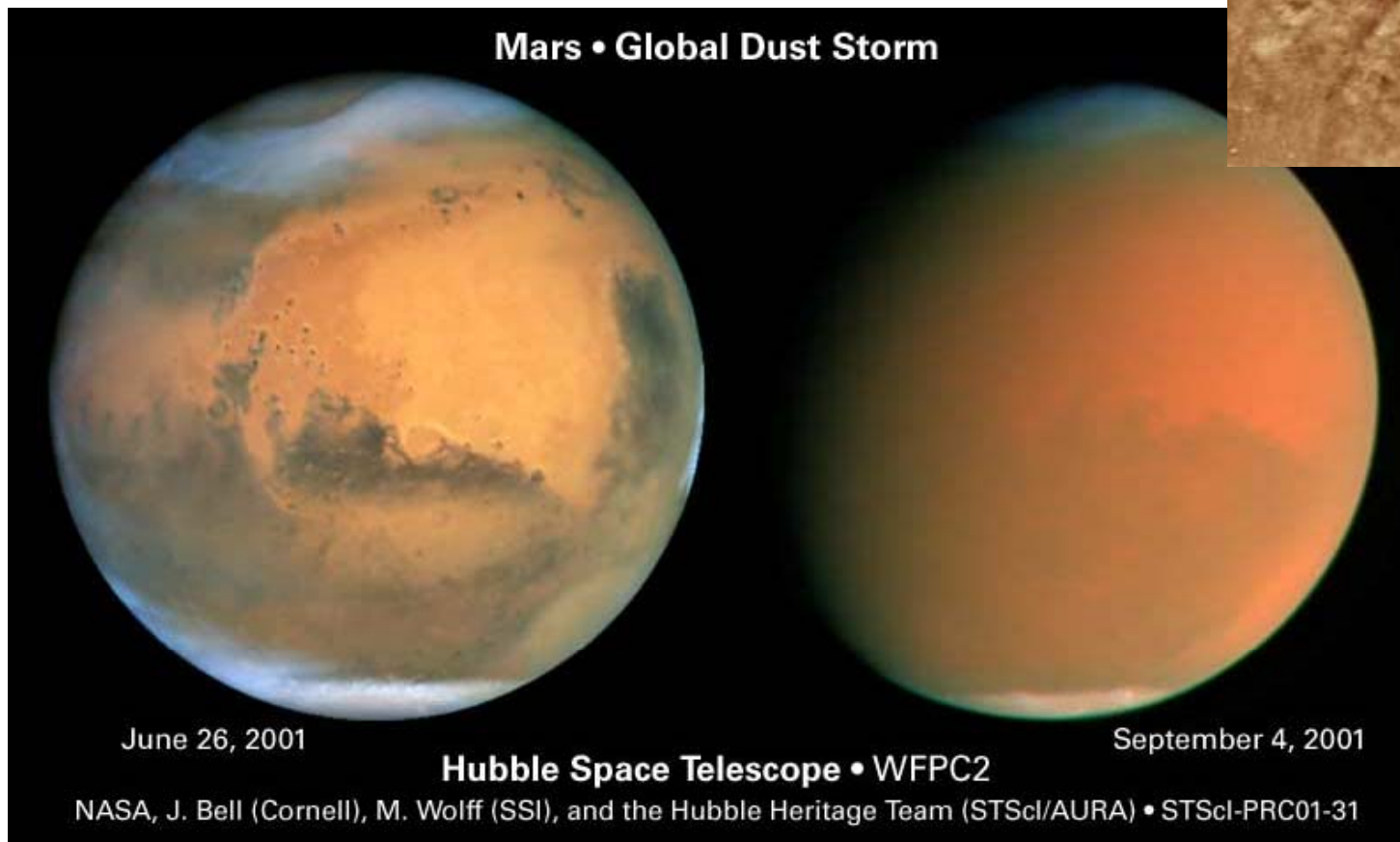
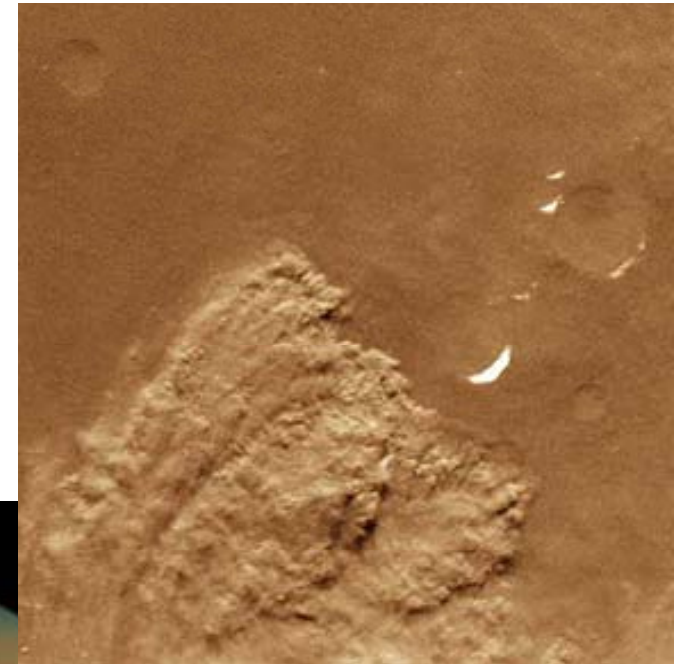


- **Clouds are common**
 - In the northern summer...
 - Especially over volcanoes
 - Lifting of air over obstacles cause water to condense



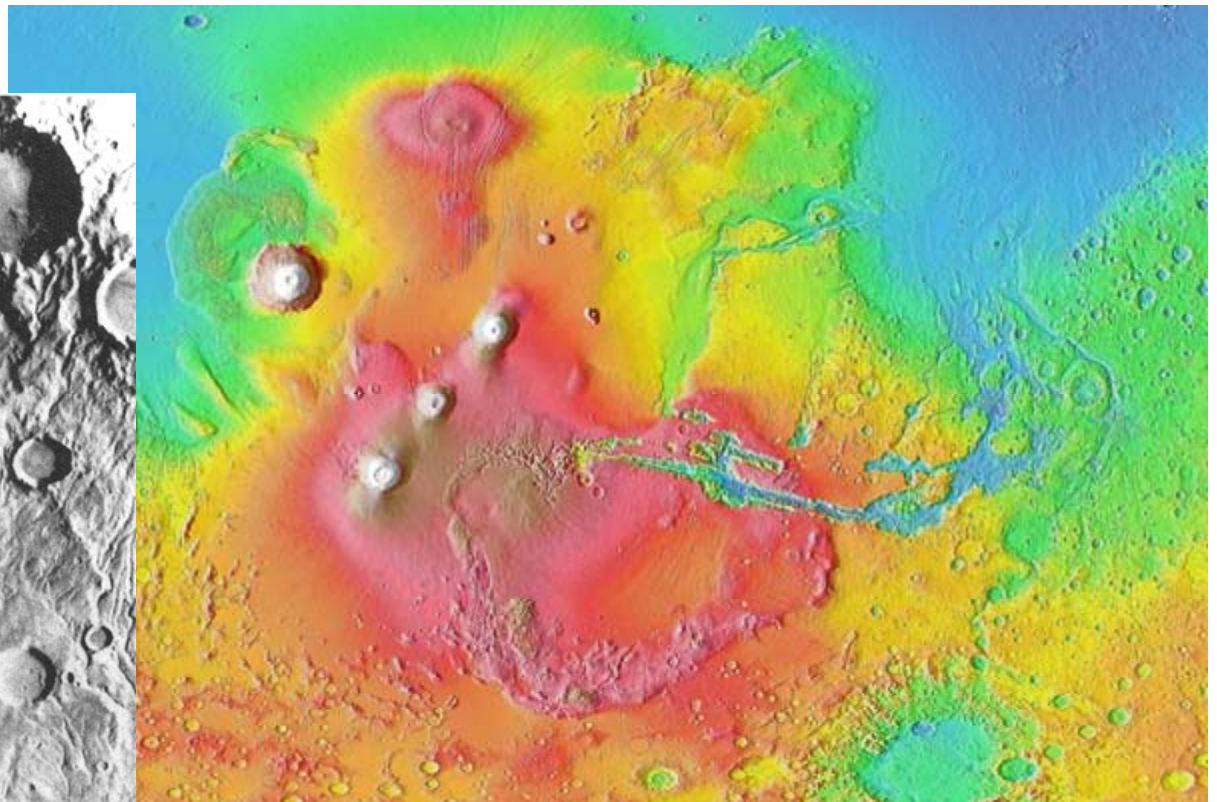
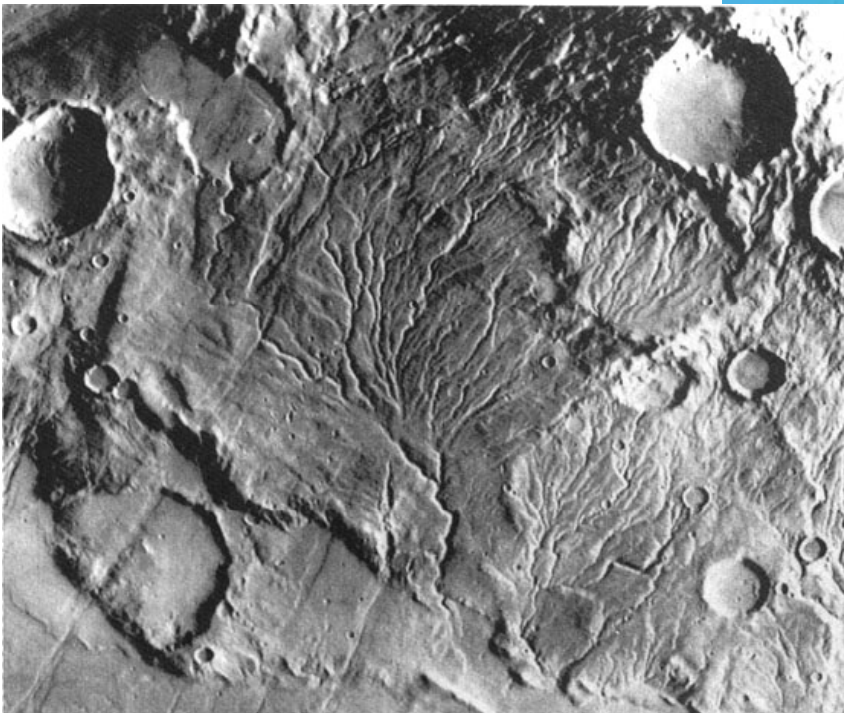
• Dust Storms

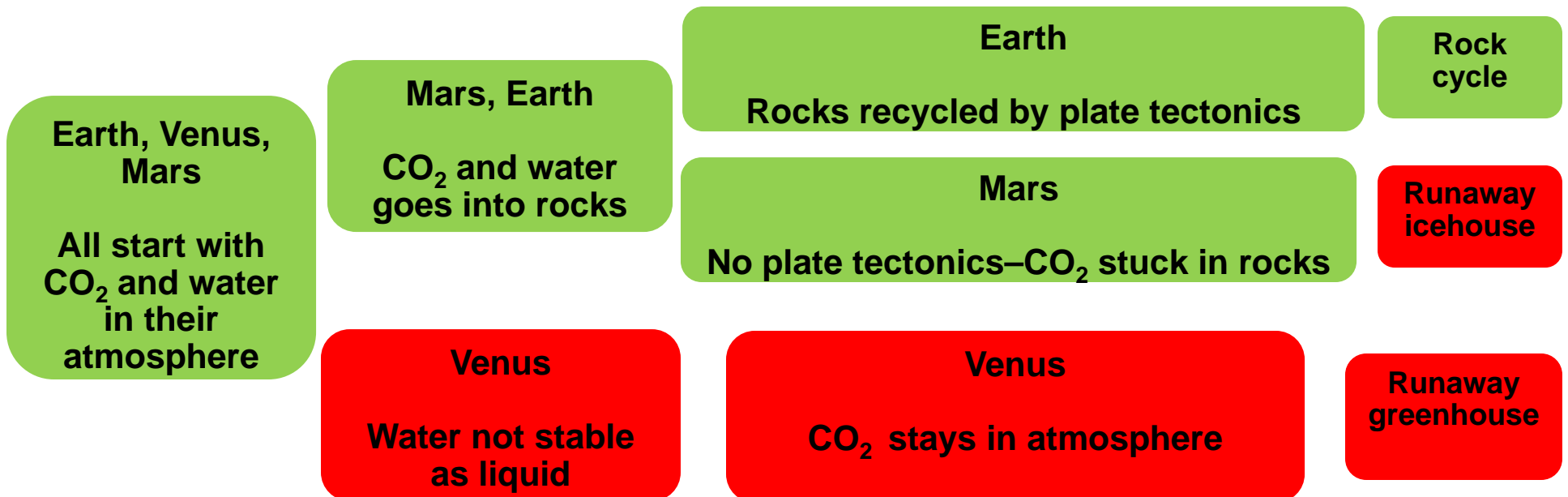
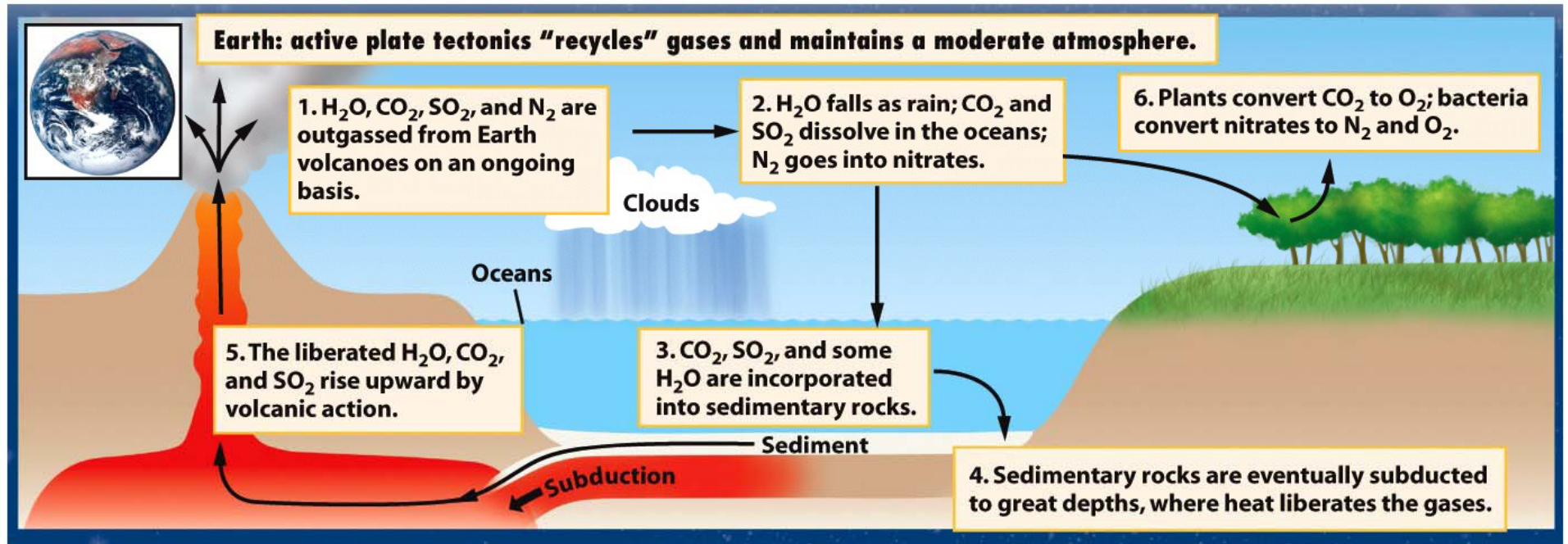
- Regional dust storms common in southern summer
- Global dust storms occur every few years
 - ◆ Reasons for interannual variability not well understood



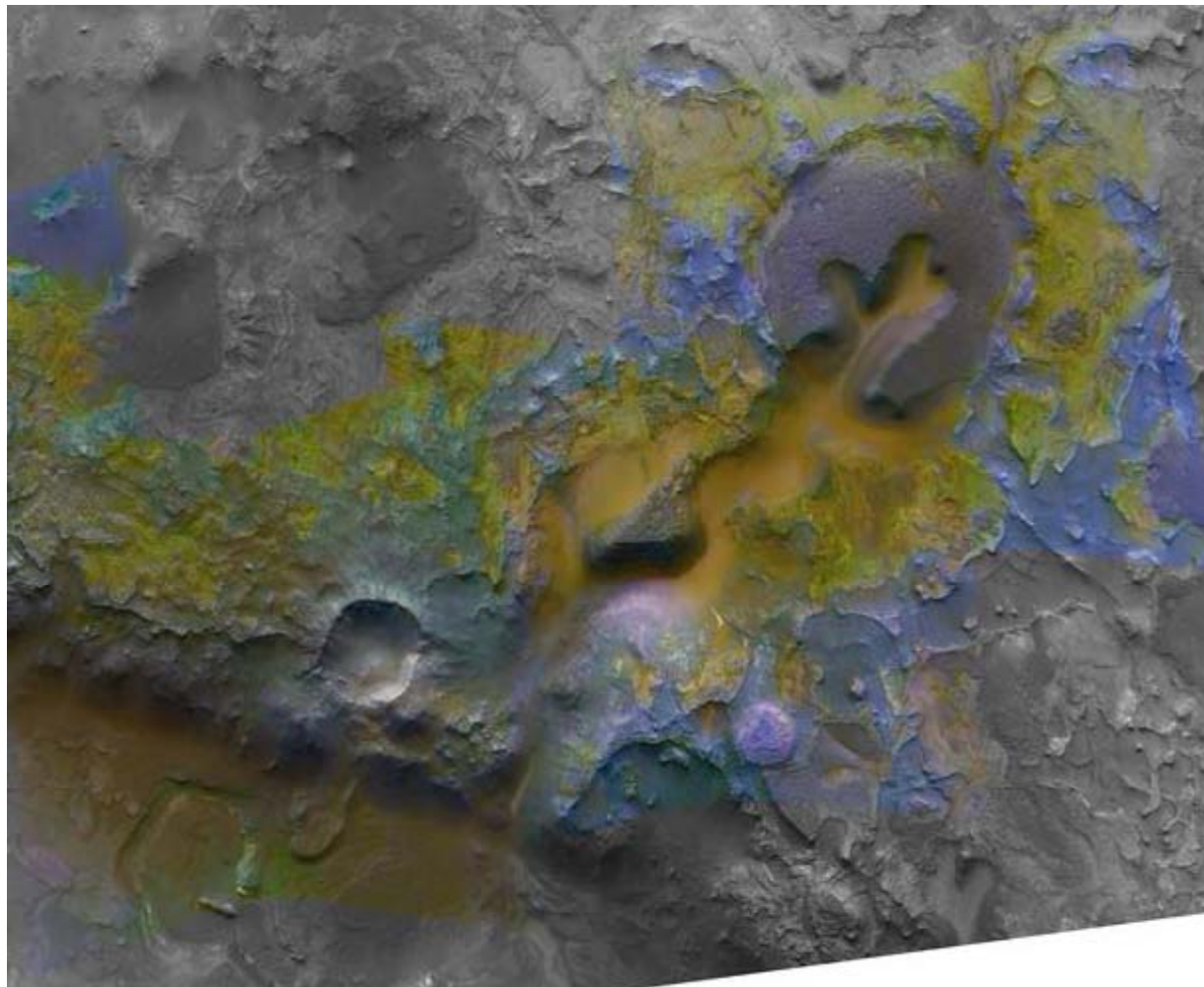
How Mars became cold and dry

- The Tharsis volcanic bulge formed
 - Thick (>8 kilometers thick) sequence of volcanic rocks
- Outgassing of a lot of volcanic gas changed the climate
 - Warmer conditions allowed more liquid water

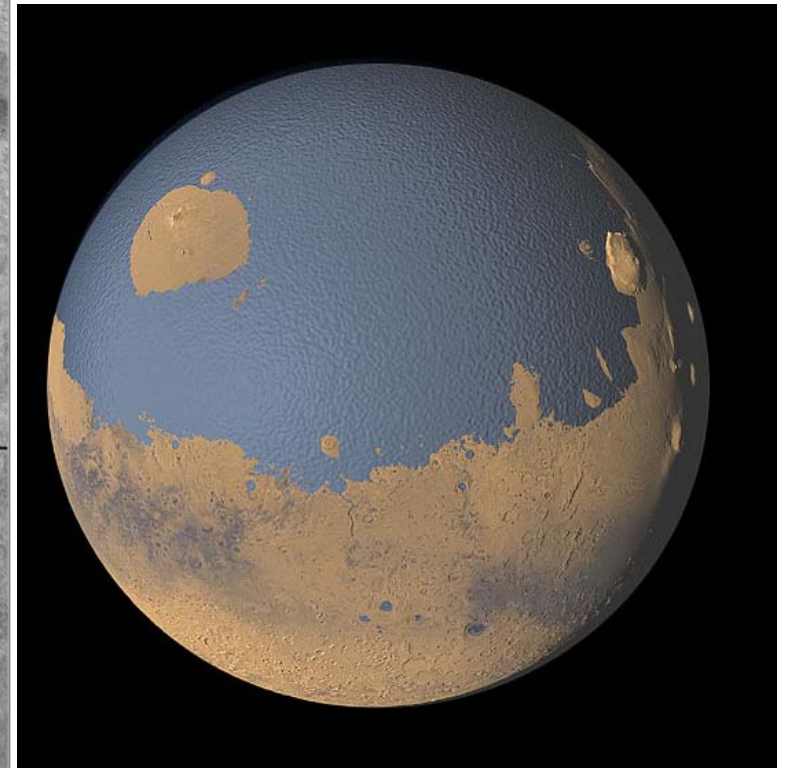
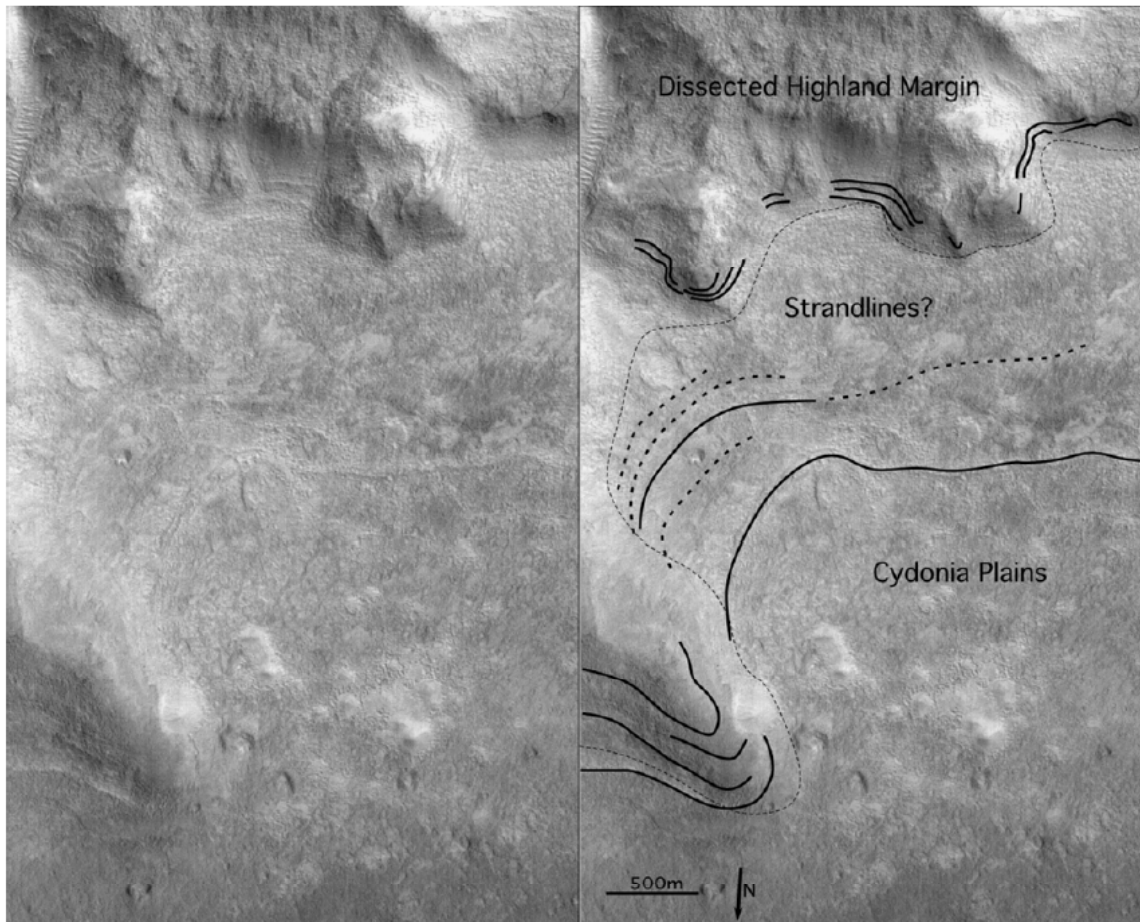




- **There's just one problem**
 - **We can't find these CO₂ bearing rocks (carbonates)**
 - **Some recent progress on this...**
 - **Spectral evidence of carbonates discovered and announced 2 months ago**



- Mars at the end of the warm period
 - Maybe an ocean?
 - Some evidence of former shorelines – but this is still controversial



- Former shorelines should be all the same elevation
 - “sea-level” on Mars
 - One shoreline matches this...
- Shorelines have been altered
 - By subsequent volcanoes
 - By polar wander

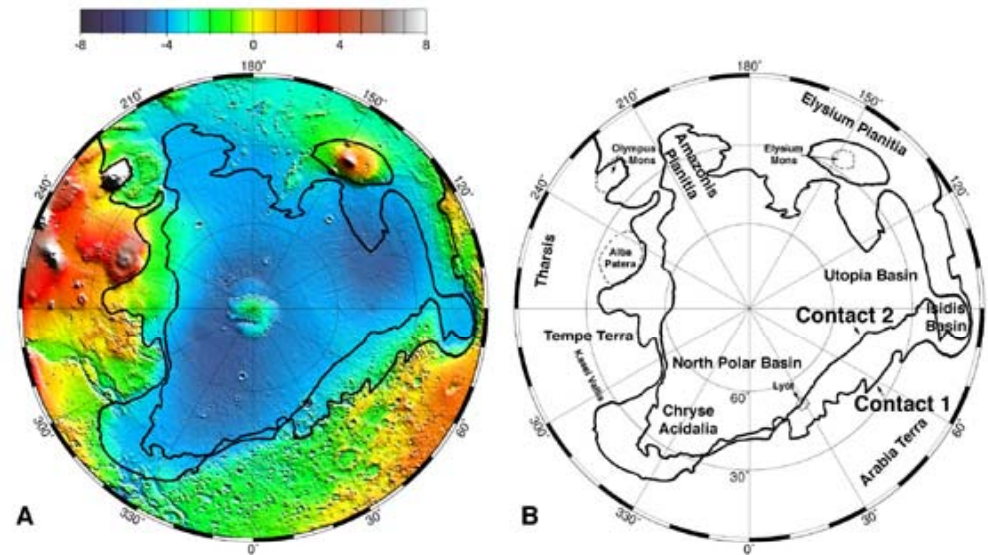


Figure 1

Head et al., 1999

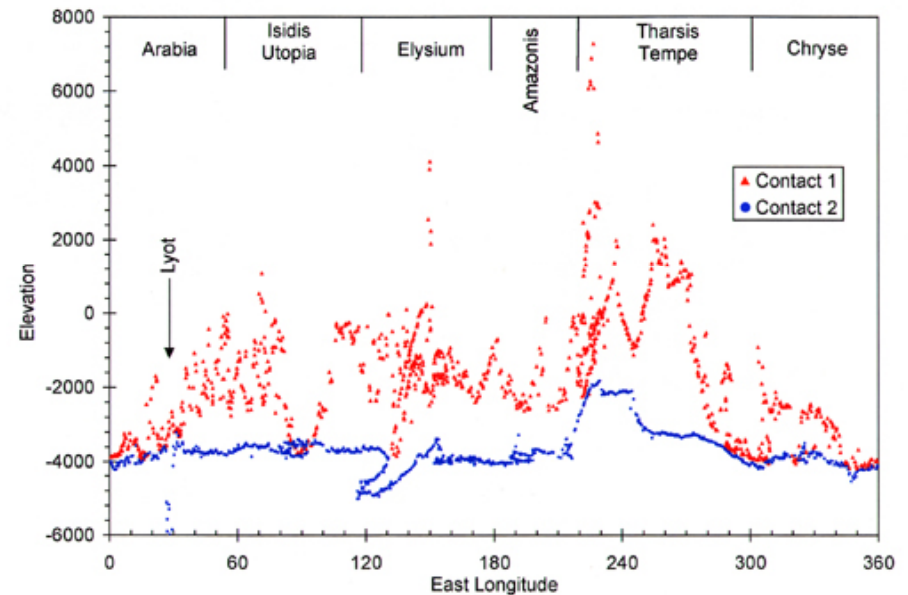
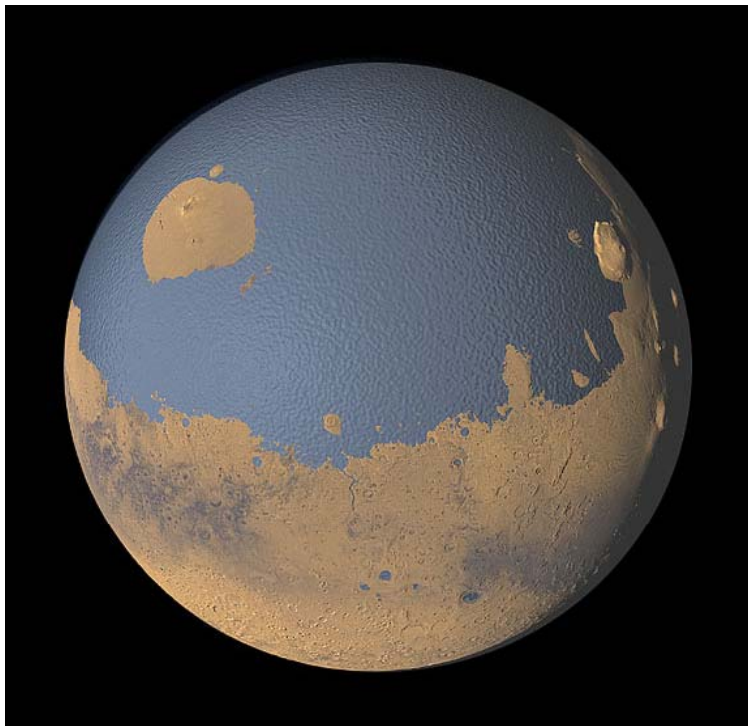
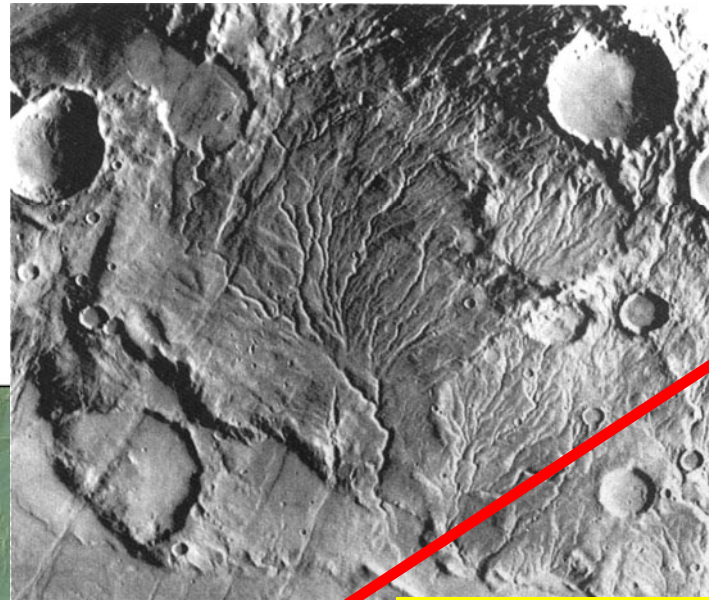


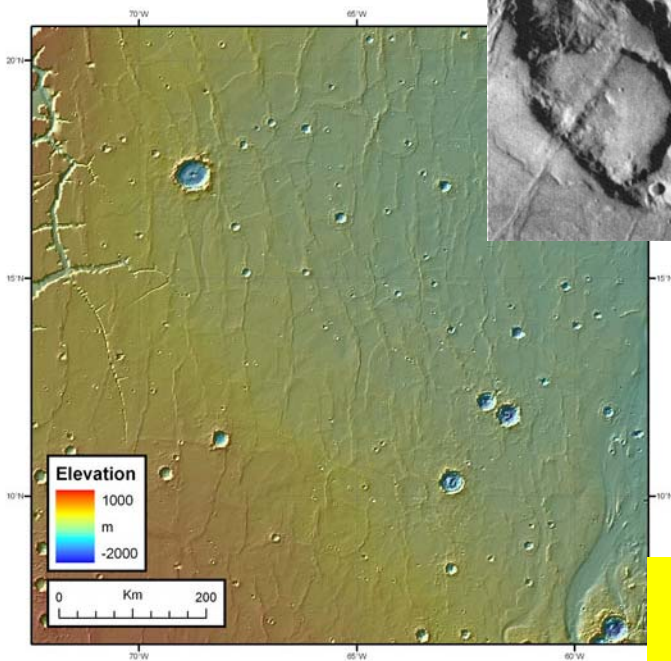
Figure 2

A Changing Planet

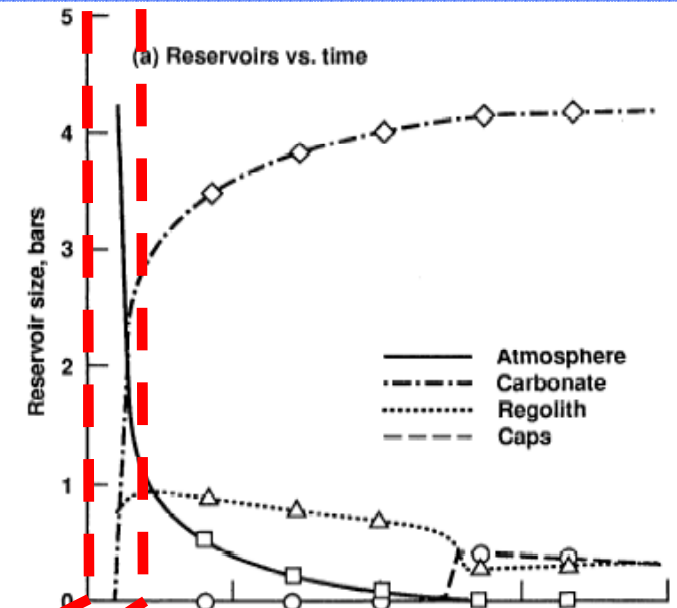
- Early greenhouse atmosphere quickly removed
 - Warm-wet transition to cold-dry



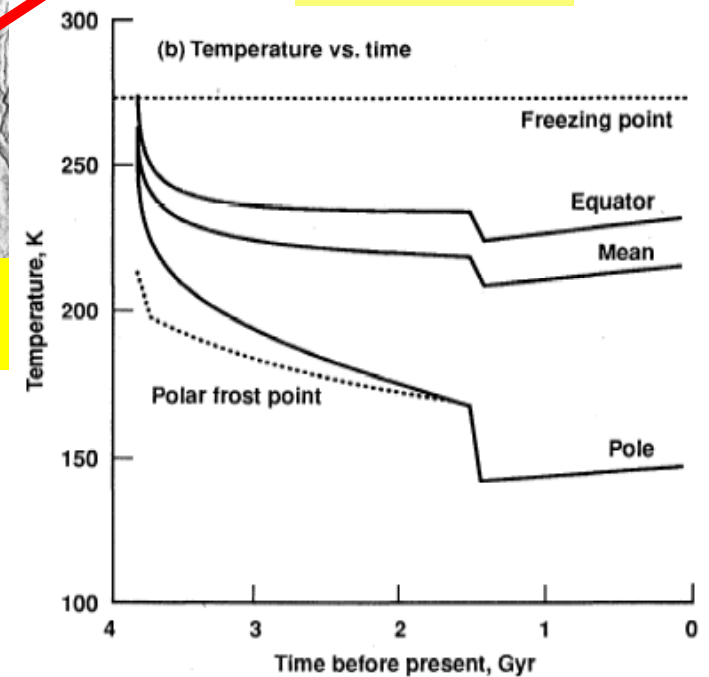
Lots of fluvial erosion



Not much fluvial erosion



Haberle, 1998

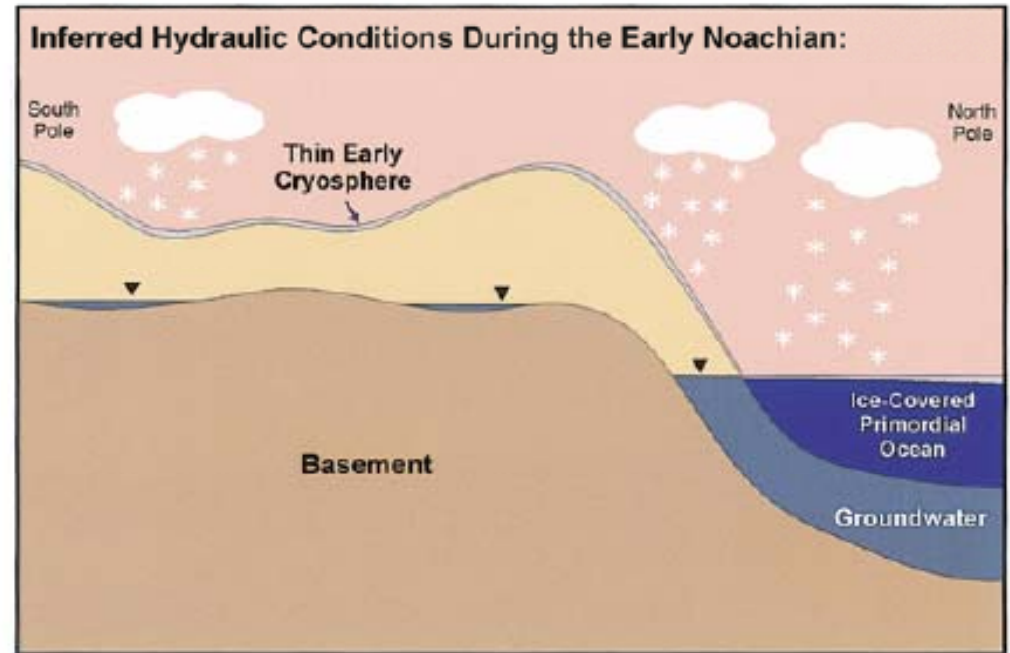


Giant floods...

- **Mars starts to freeze**
 - From the surface downwards
 - Ocean starts to freeze

- **Cryosphere forms**
 - Ground is frozen to some depth
 - Cryosphere gets thicker as planet gets colder

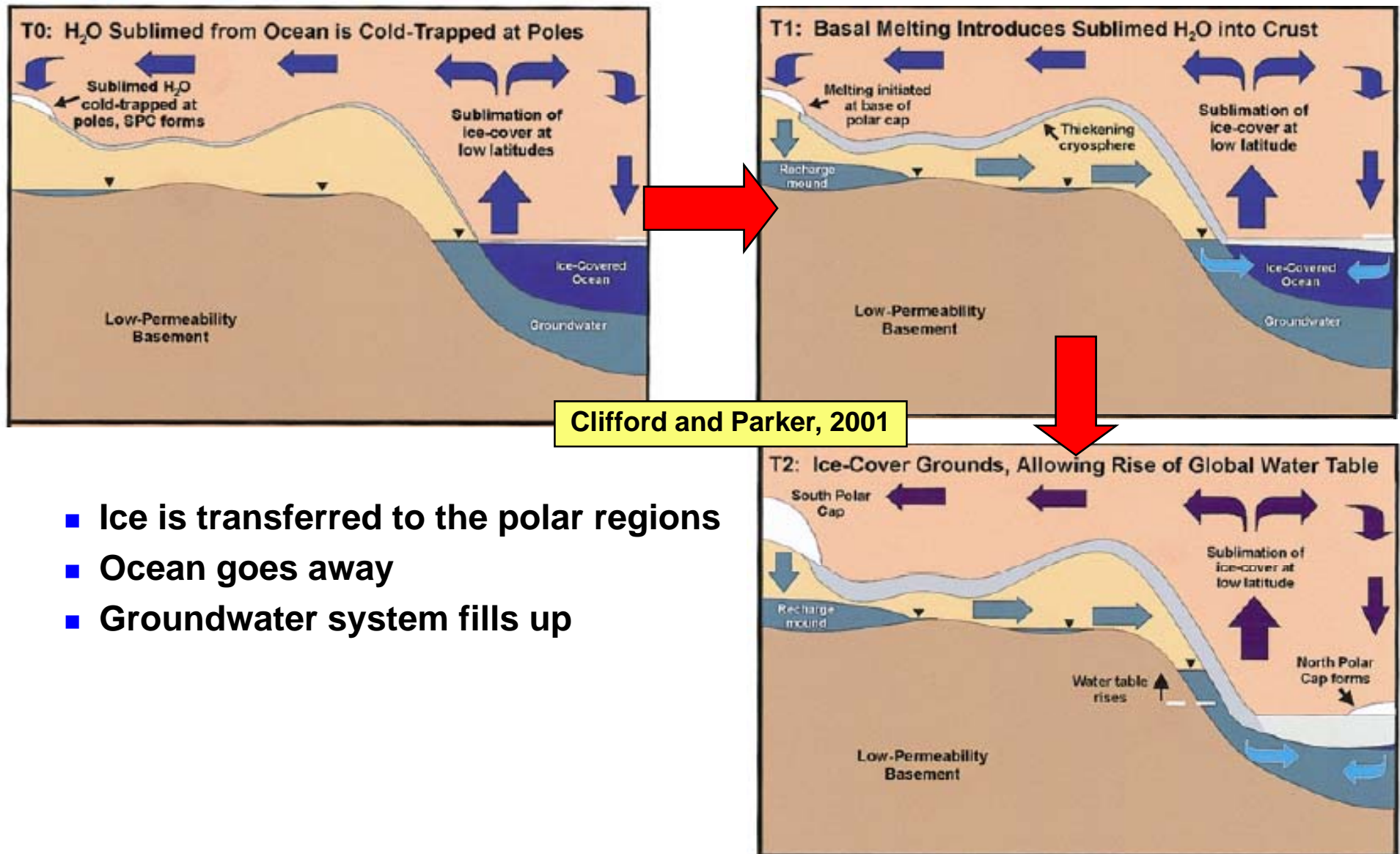
 - Groundwater exists between cryosphere and basement



Clifford and Parker, 2001

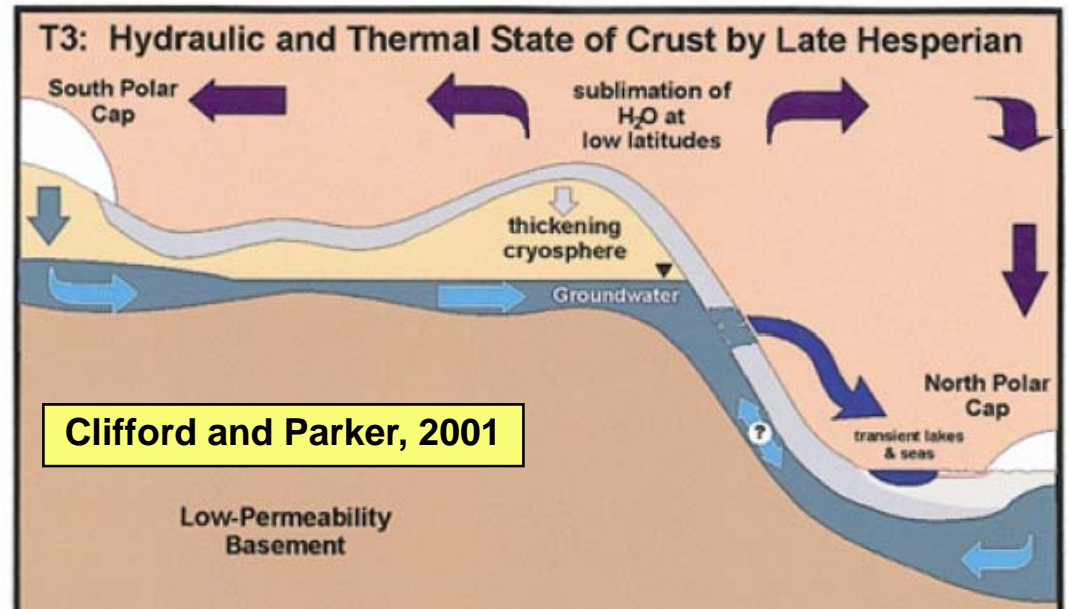
- What happens next?

- No ice covered ocean in the northern lowlands today



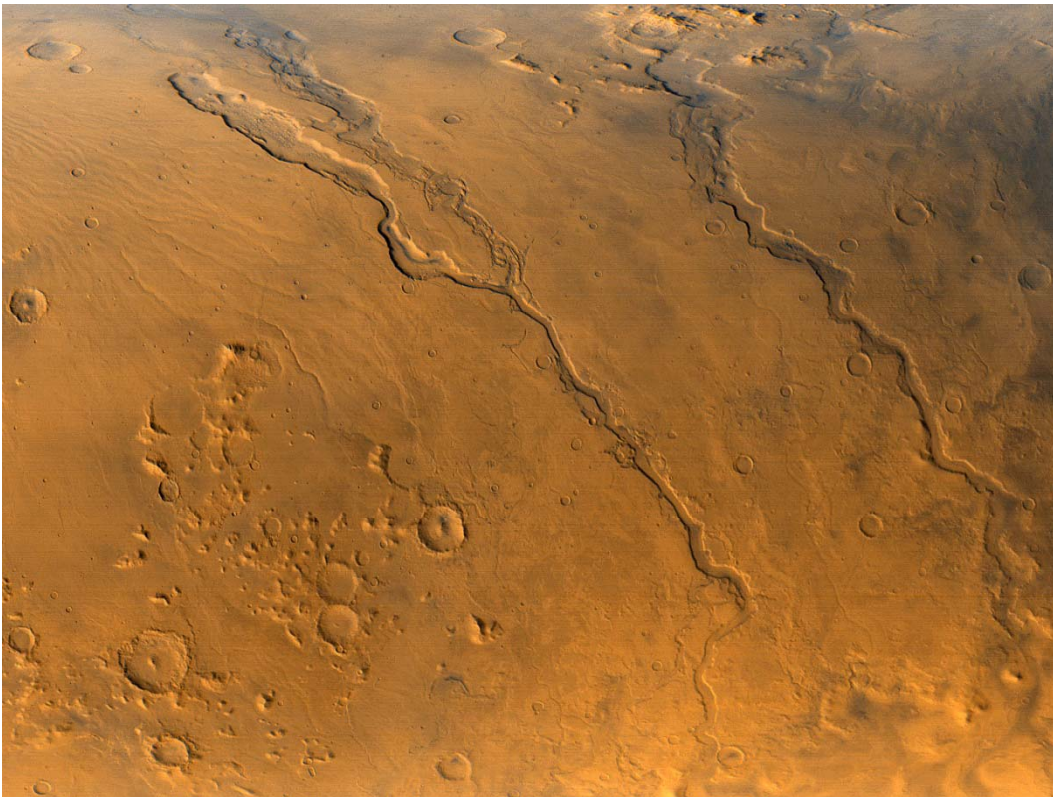
- Ice is transferred to the polar regions
- Ocean goes away
- Groundwater system fills up

- Accidents can happen
 - Cryosphere could break
 - Ground water can flood out



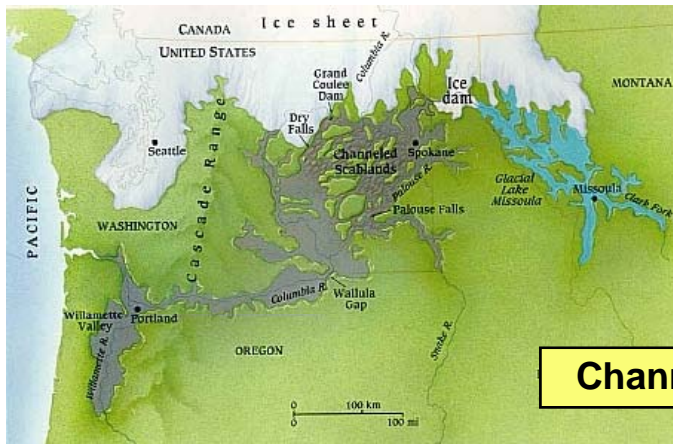
- **Outflow channels on Mars**

- **Ground water outbreaks - Carves huge flood channels**
- **Floods 100's of meters deep at ~25 m/s**
- **Discharge rates of $\sim 10^7 \text{ m}^3\text{s}^{-1}$**
 - ◆ **Enormous by terrestrial standards!!**
 - ◆ **Mississippi river $\sim 3 \times 10^4 \text{ m}^3\text{s}^{-1}$**

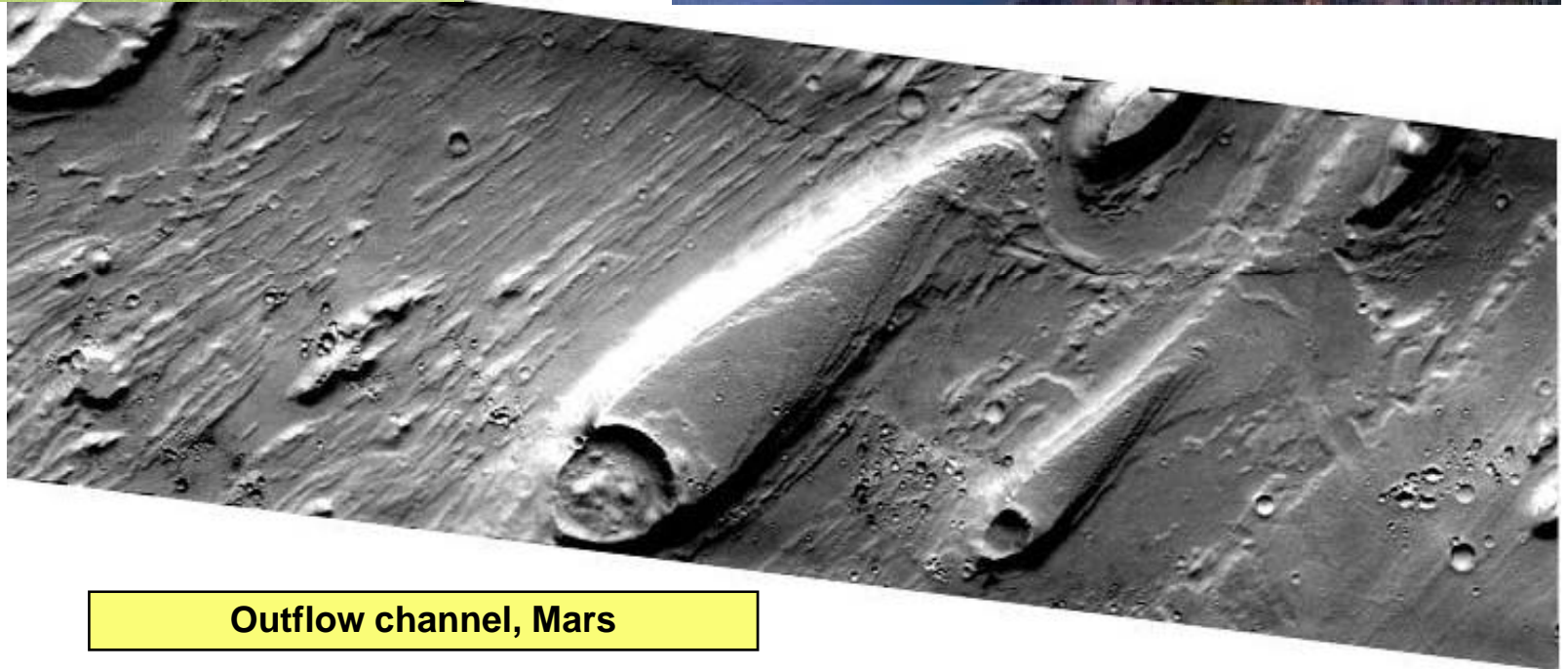


- **Terrestrial analogue**

- End of the last ice-age
- Glacial lake Missoula- Ice-dam breaks



Channeled scablands, Washington



Outflow channel, Mars

Climate change and ice caps

- About 20% of the size of the Greenland ice-sheet

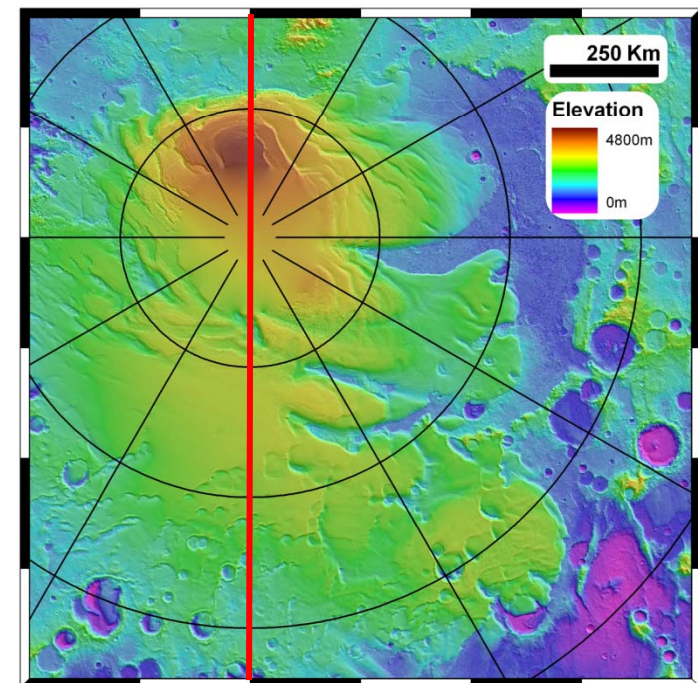
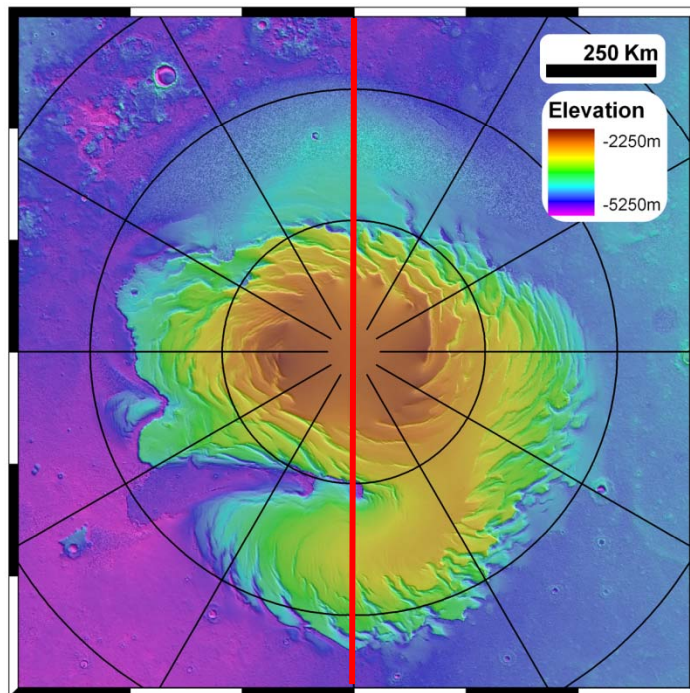
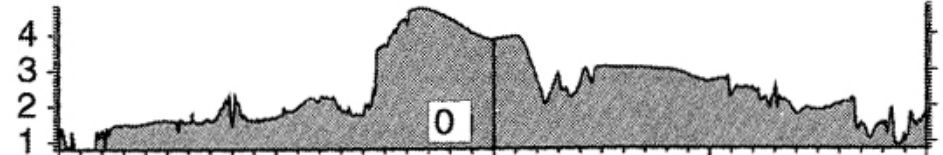
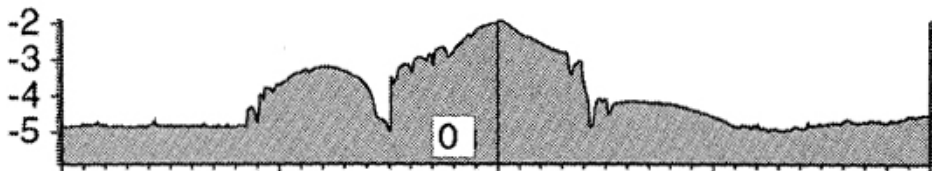
1.1 million km³

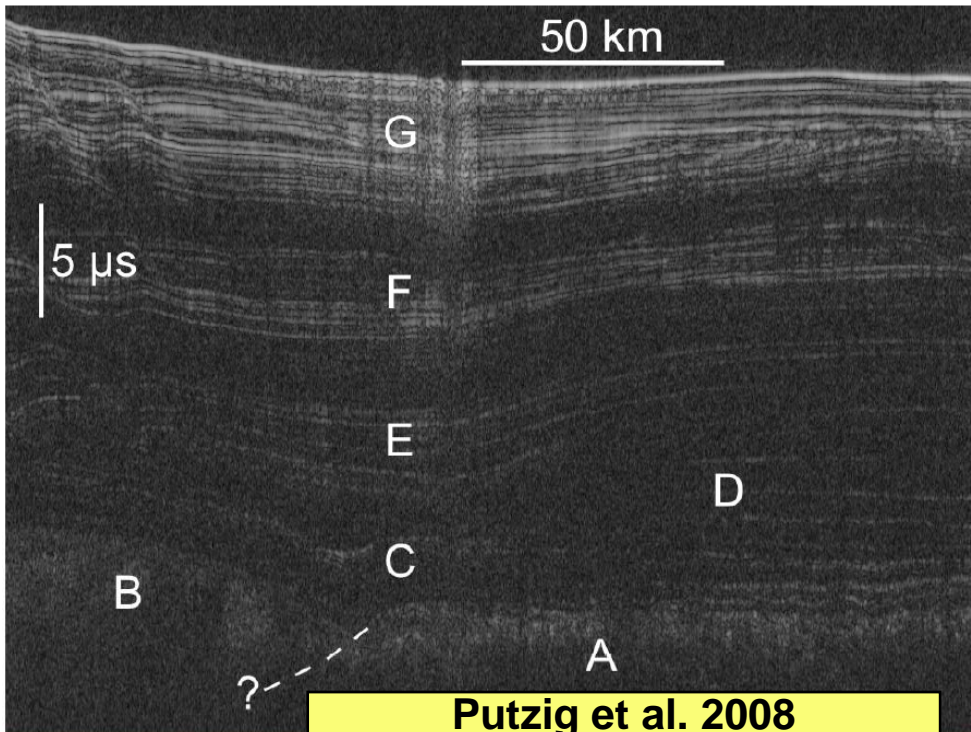
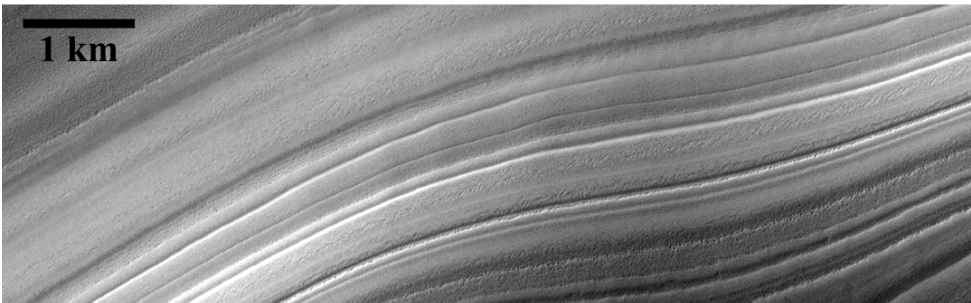
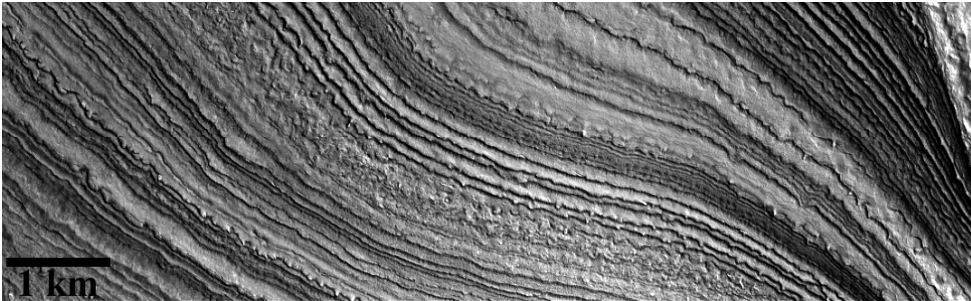
North

V.E. 100:1

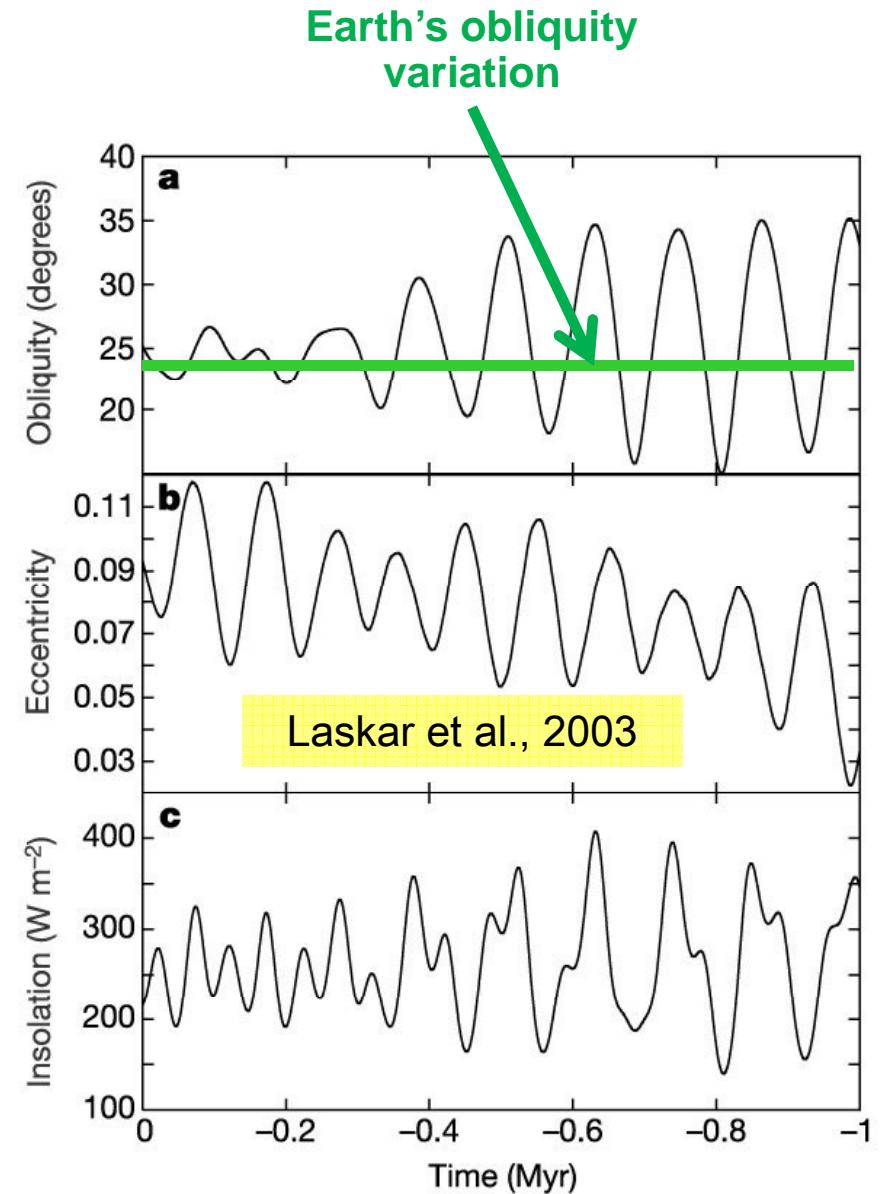
1.2 million km³

South



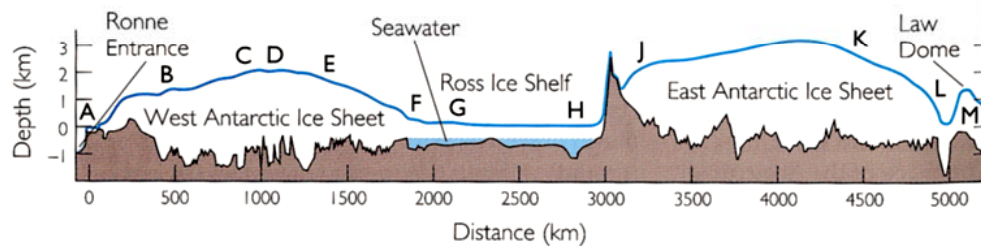
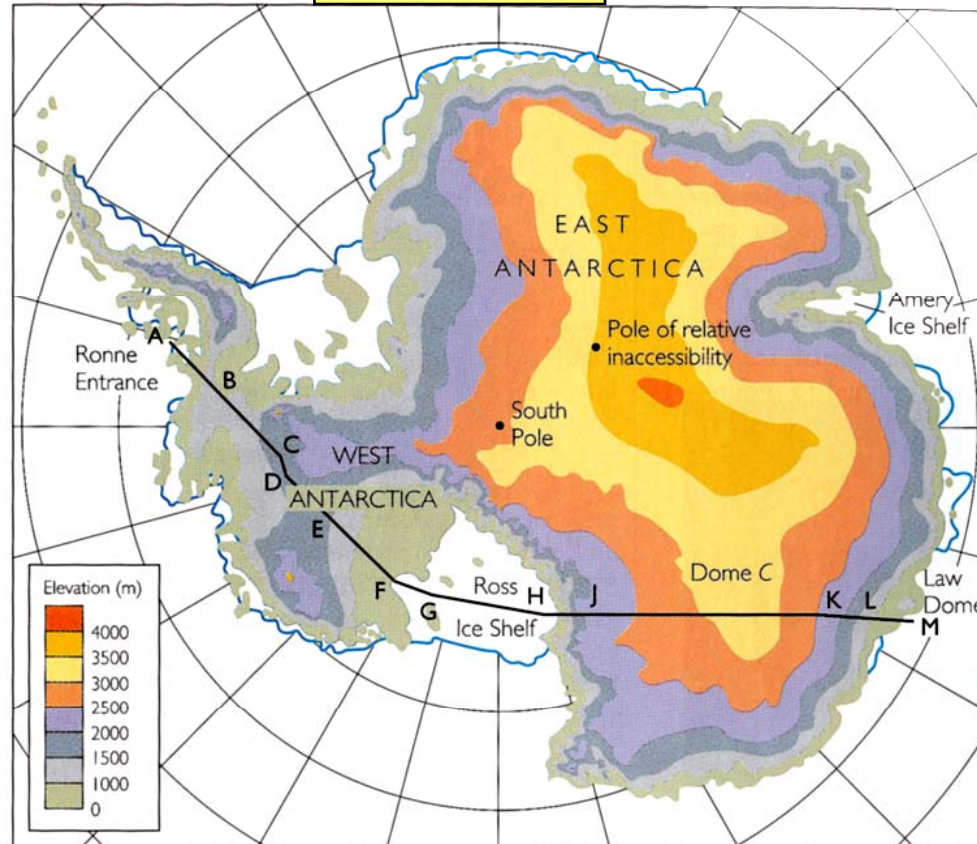


- Orbital changes create layers

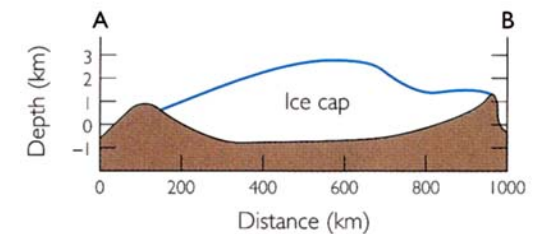
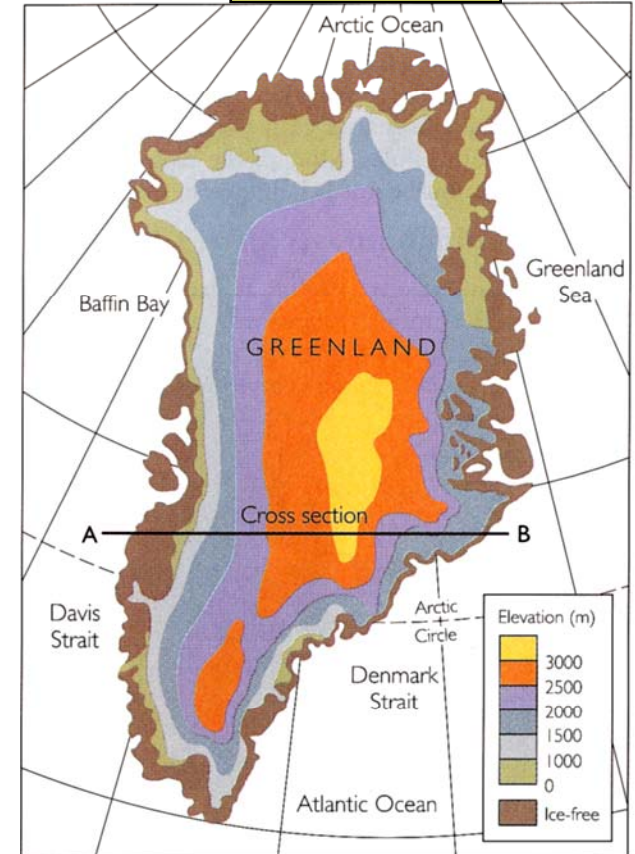


Big ice sheets of the inner solar system – Earth

30 million km³



6 million km³



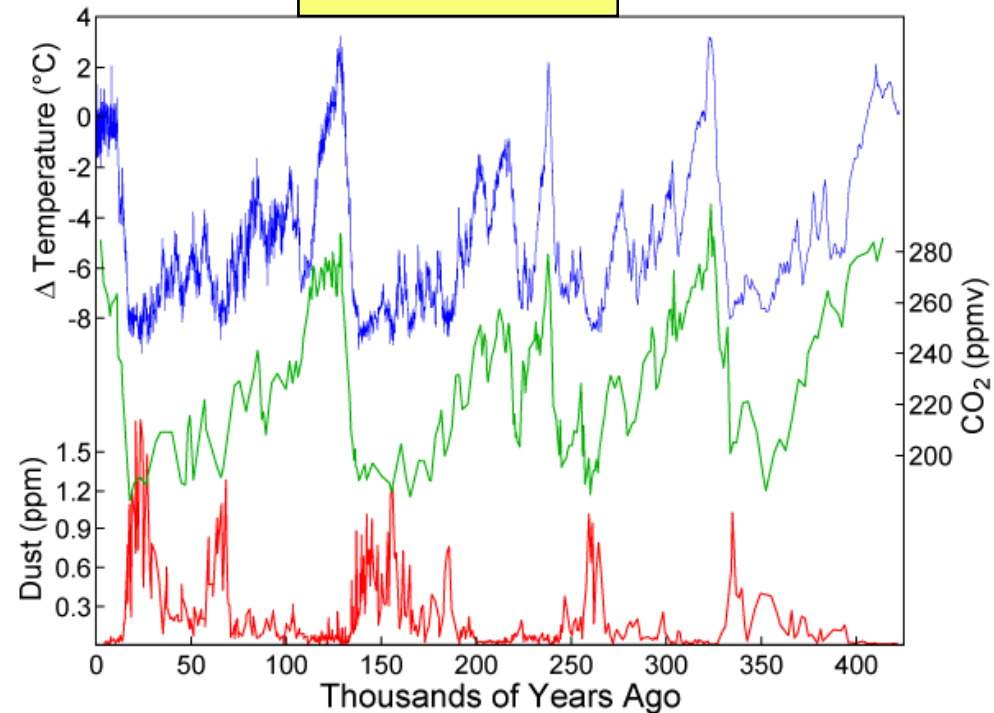


- These layers could tell us a lot about martian climate over the past few million years
- Similar to terrestrial ice cores

Mars: north pole

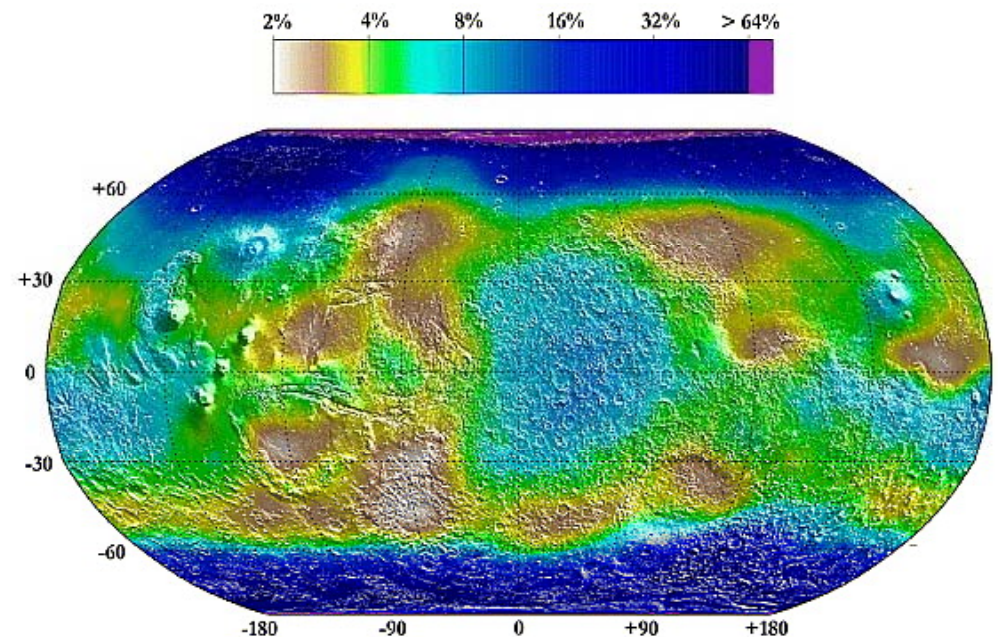
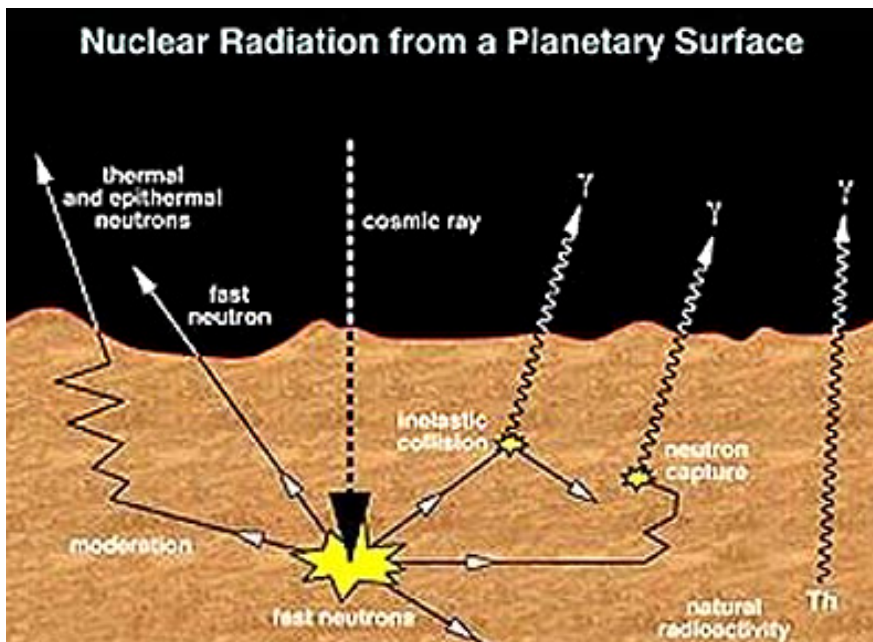
Earth: Greenland

Earth: Antarctica



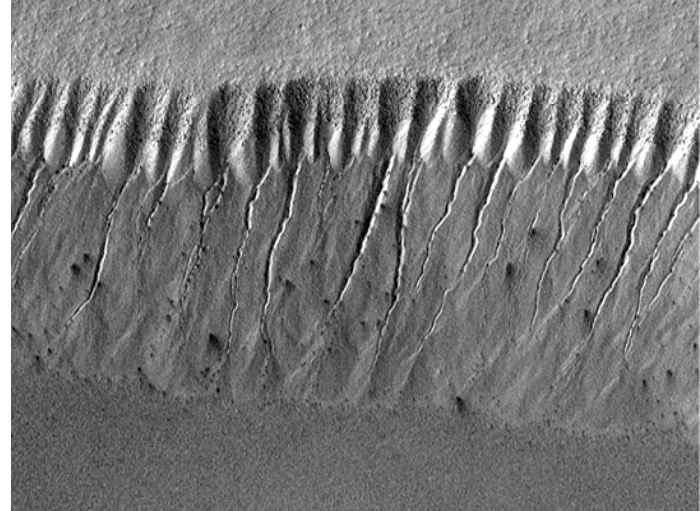
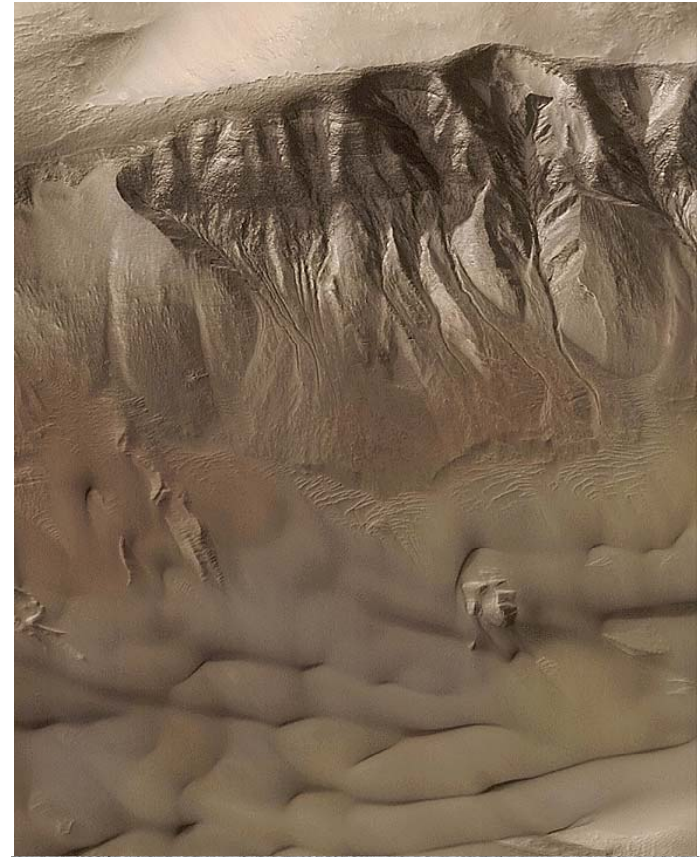
Running water today and non-polar ice

- **Mars isn't as cold and dry as we once suspected**
- **Neutron spectrometer on Mars Odyssey spacecraft has detected hydrogen in near surface.**
 - **Several 10's percent by volume at high latitudes**
- **New ideas about exchange of ice between the polar caps and the mid-latitudes**
- **Vapor diffusion models alone cannot explain these quantities of ice**
 - **Surface ice sheets that are thinly buried are probably required**

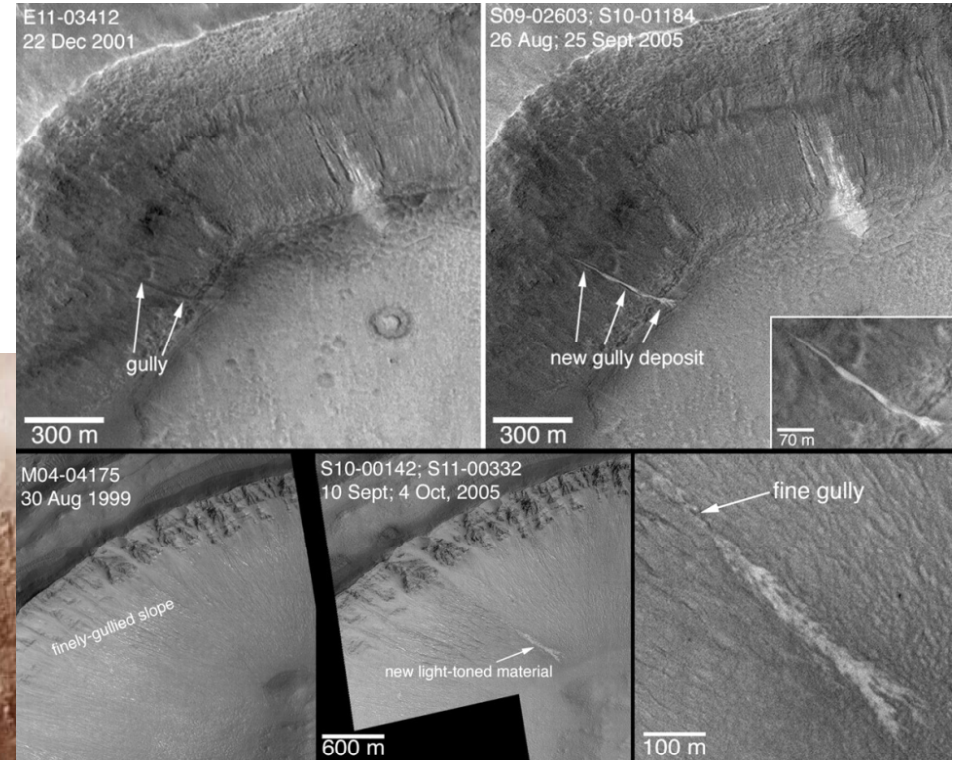
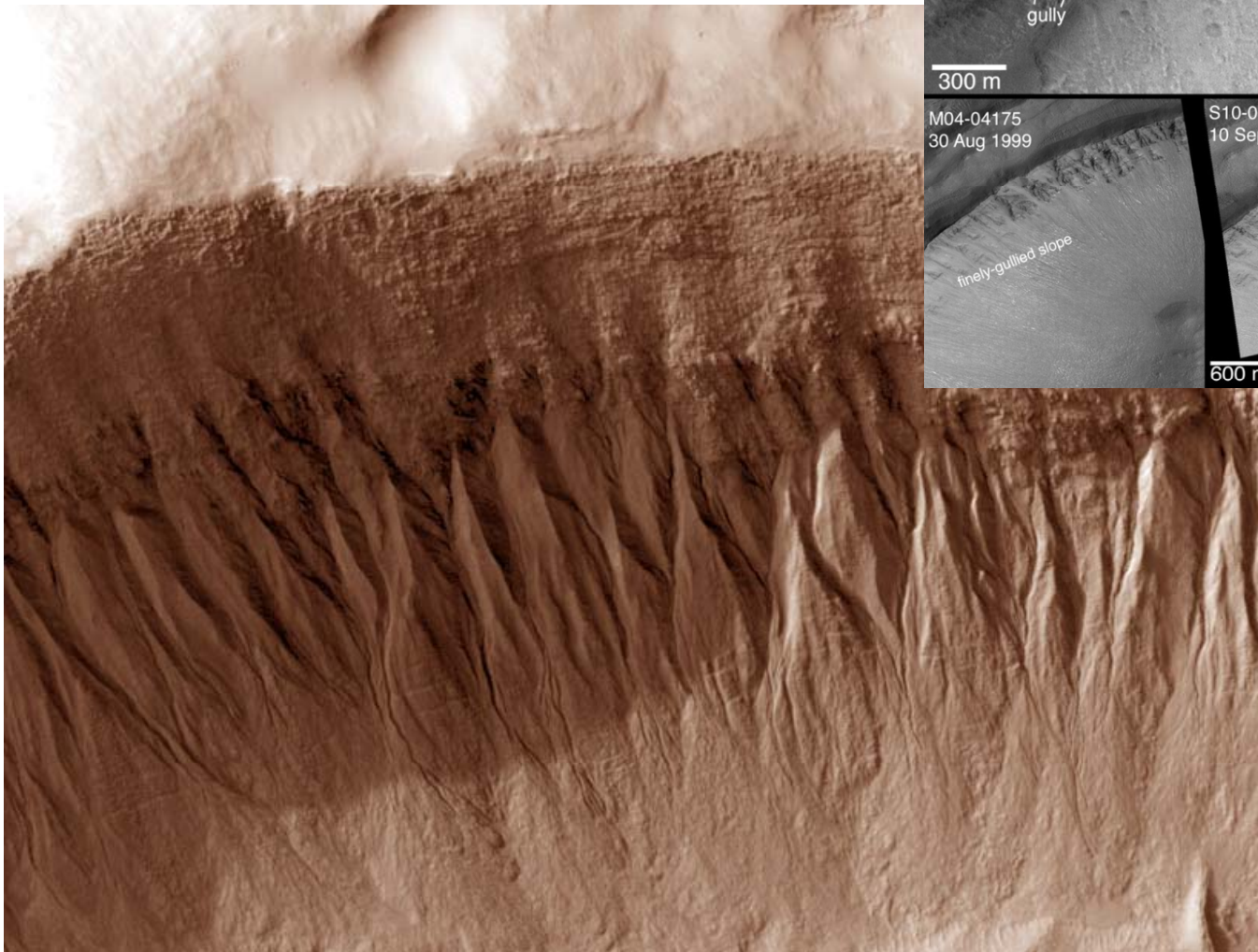


Gullies

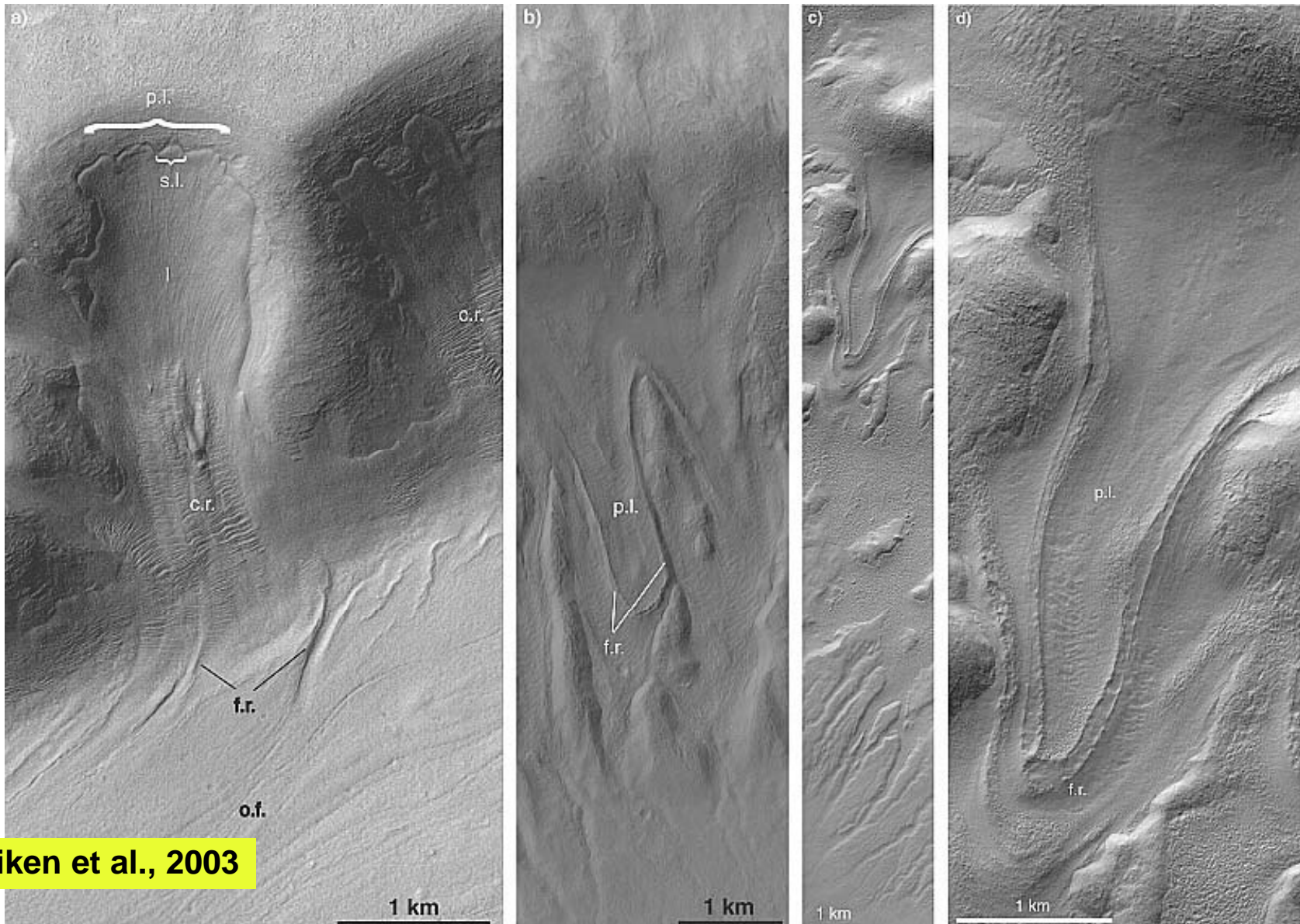
- Recently carved gullies observed on crater walls
 - Occur preferentially on poleward facing slopes in the mid-latitudes
- Almost certainly carved by liquid water
 - Liquid CO₂ people have given up
- Water is not currently stable on the Martian surface, theories:
 - Gully formed beneath snowpack
 - ◆ Under a recently deposited mid-latitude snow layer
 - Local or deep pressurized aquifer



- Recent activity?
 - New bright deposits

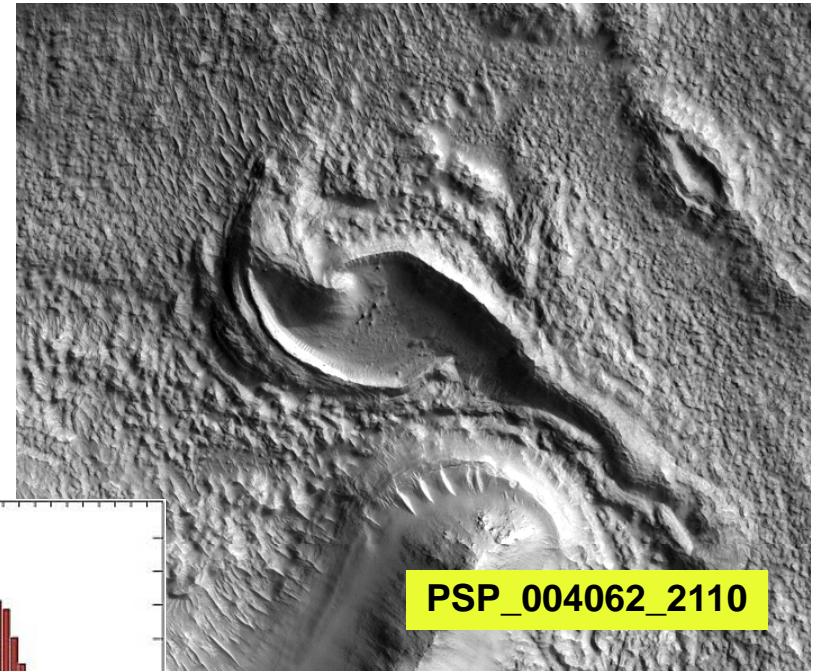


- Apparent flow of icy terrain
 - Mars is much more dynamic than people thought

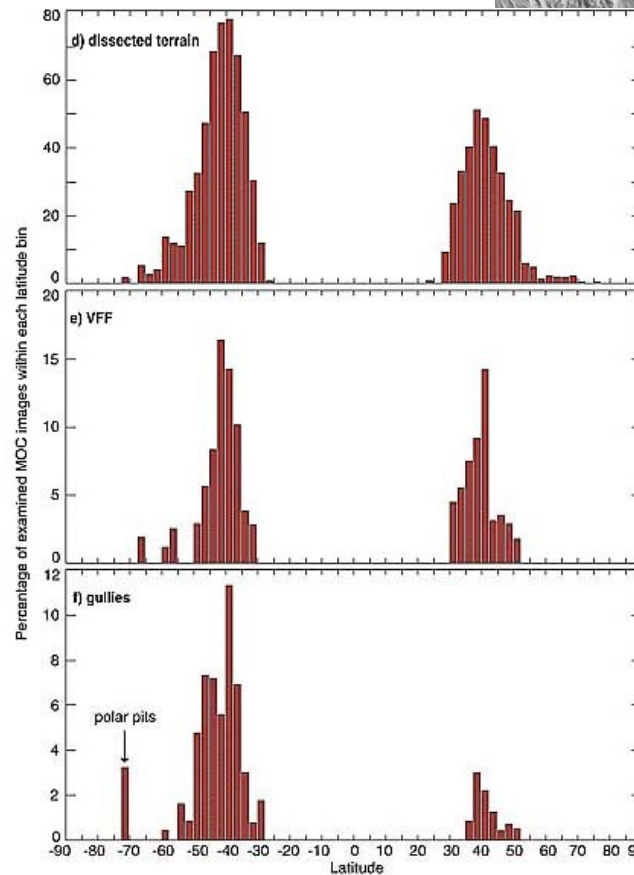
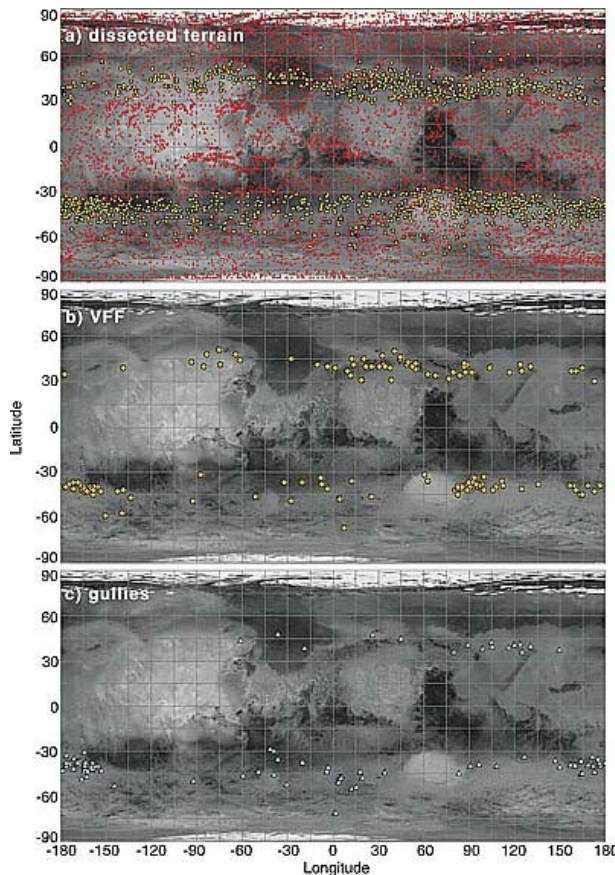


Milliken et al., 2003

- Near surface ice related to
 - Gullies
 - Viscous flow features
 - Dissected terrain – basketball
- Obliquity variations can move ice back and forth between the poles and mid-latitudes

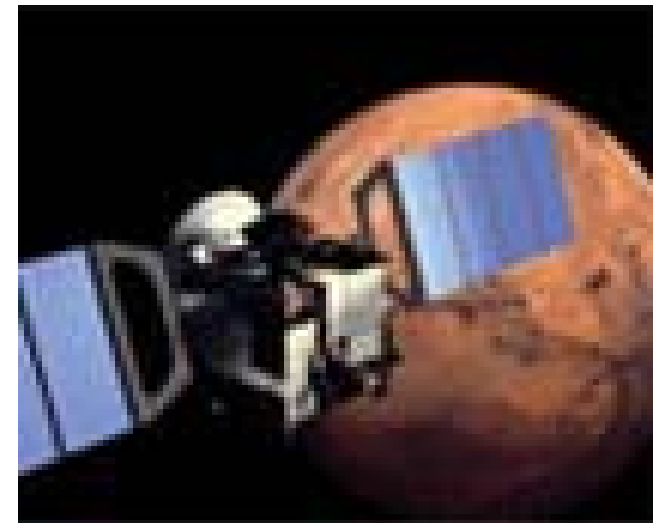


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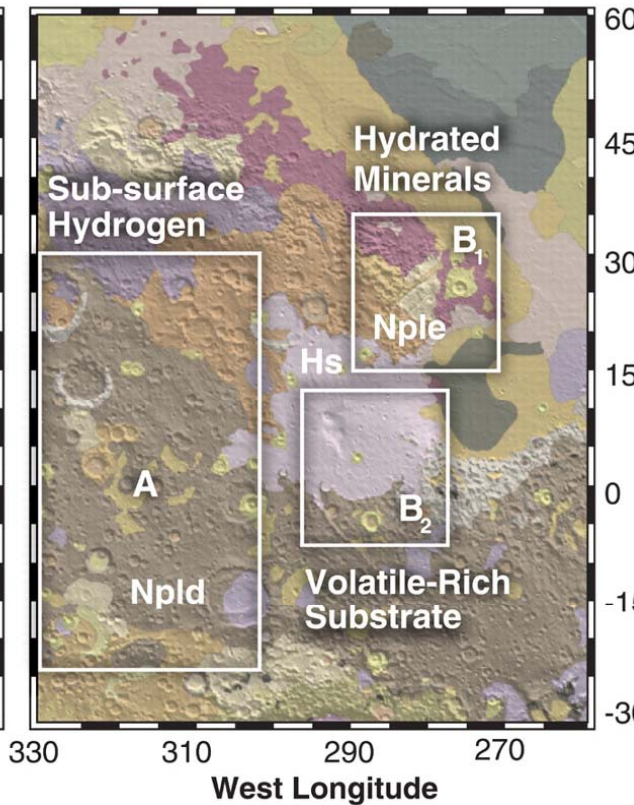
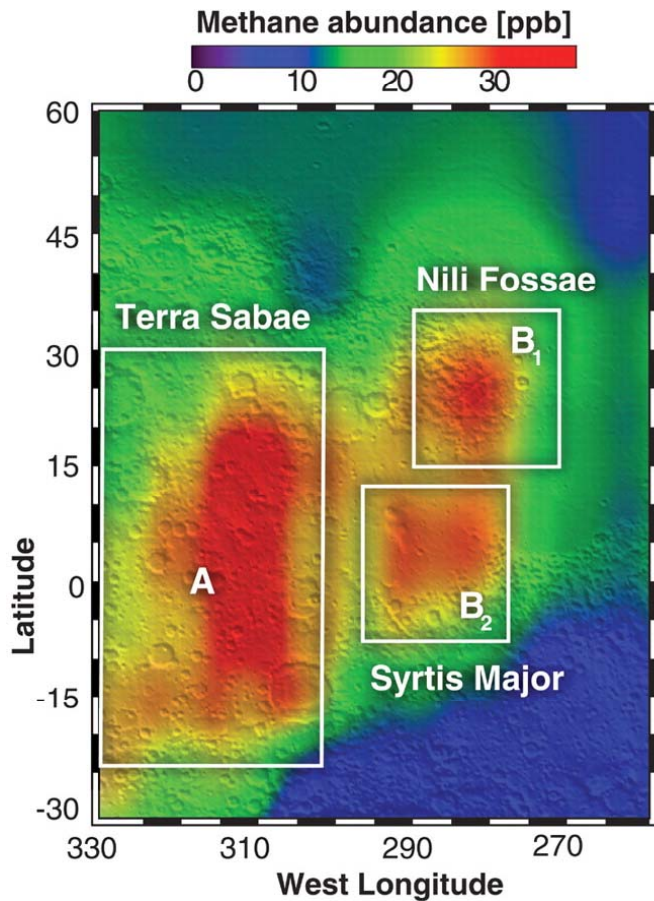
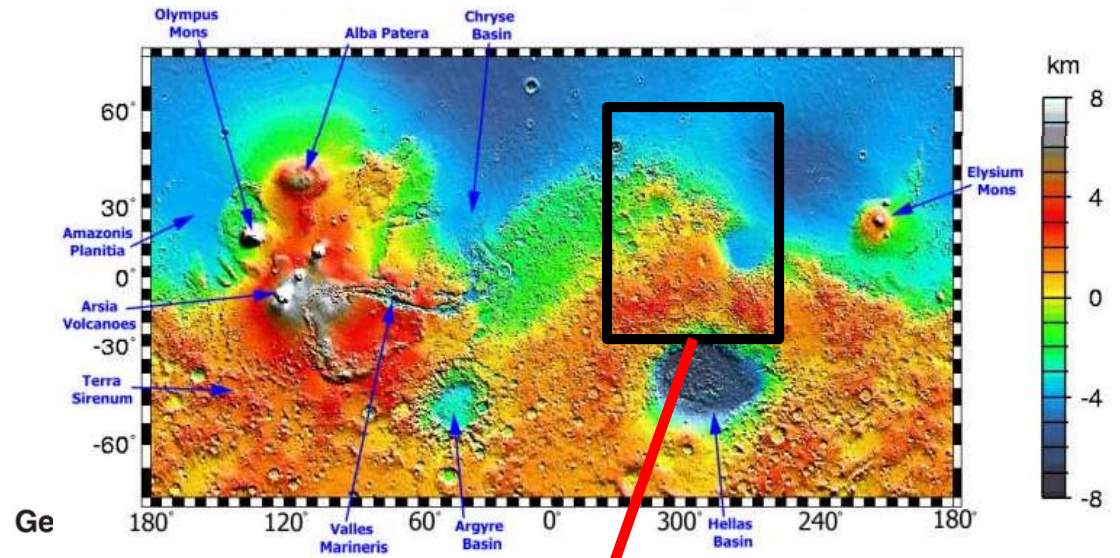


Methane

- **Methane on Mars**
 - CH_4
 - Detected by telescopes and Mars Express
- **Why we care...**
 - Methane is destroyed quickly
 - Lifetime of only a few centuries
 - Implies continuous production
- **So what's making it?**
 - **Life**
 - ◆ Cows? Unlikely...
 - ◆ Chemolithotrophic microbial ecosystems
 - **Hydration of rocks**
 - ◆ Serpentinization – a geologic process
 - ◆ Warm volcanic rock combines with water – releases methane

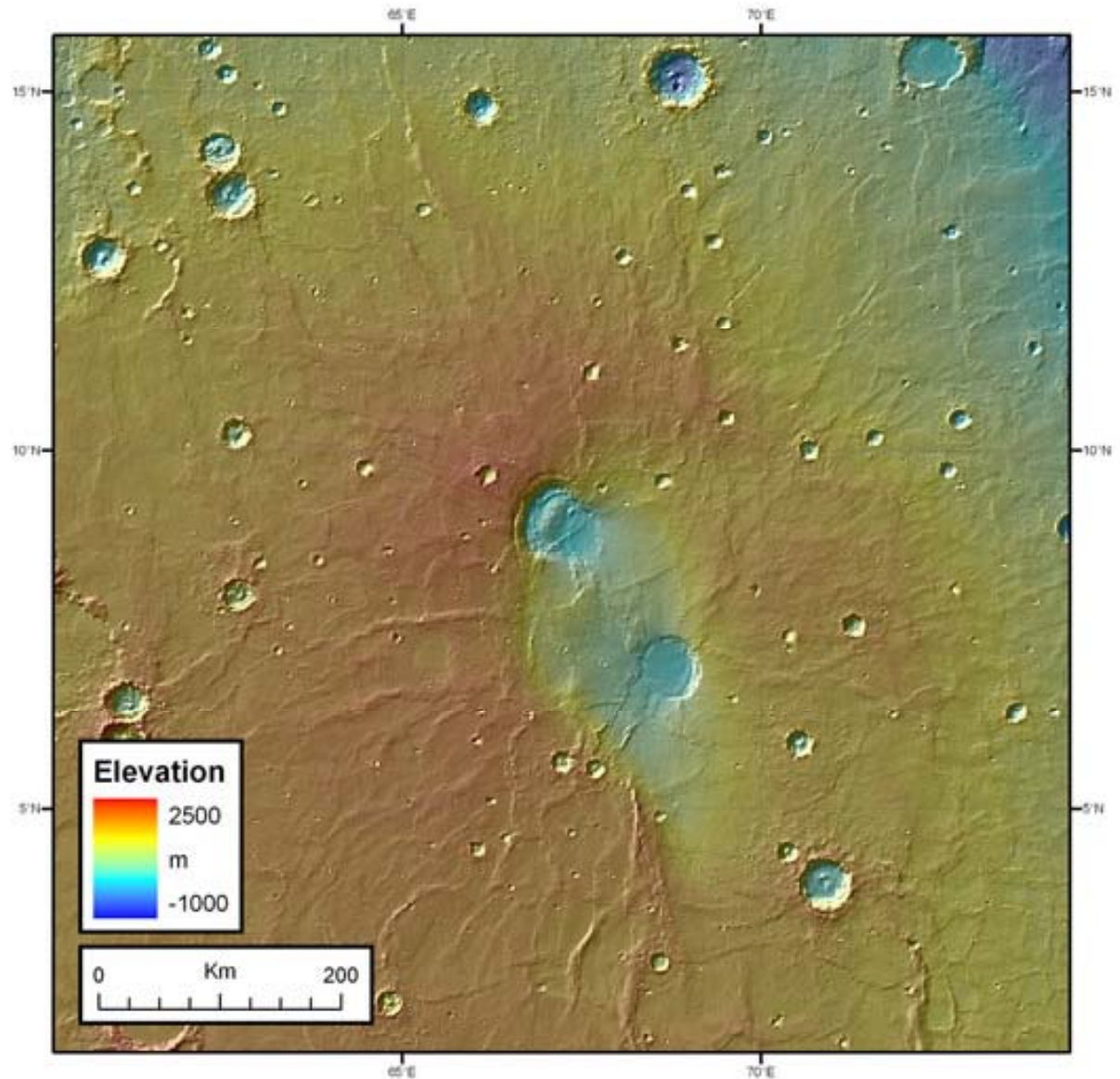
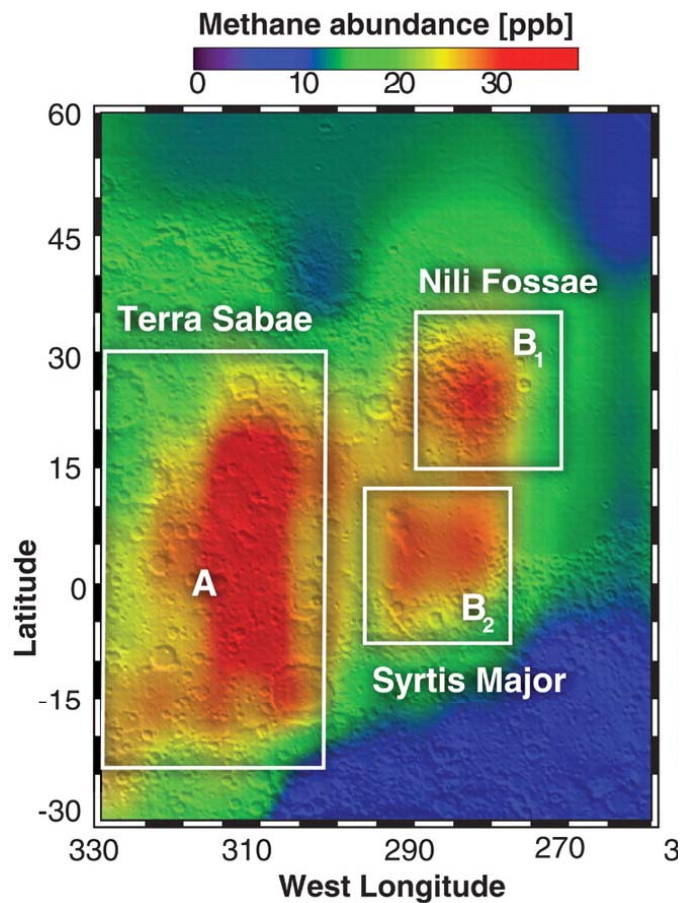


- Methane comes from...
 - a certain region

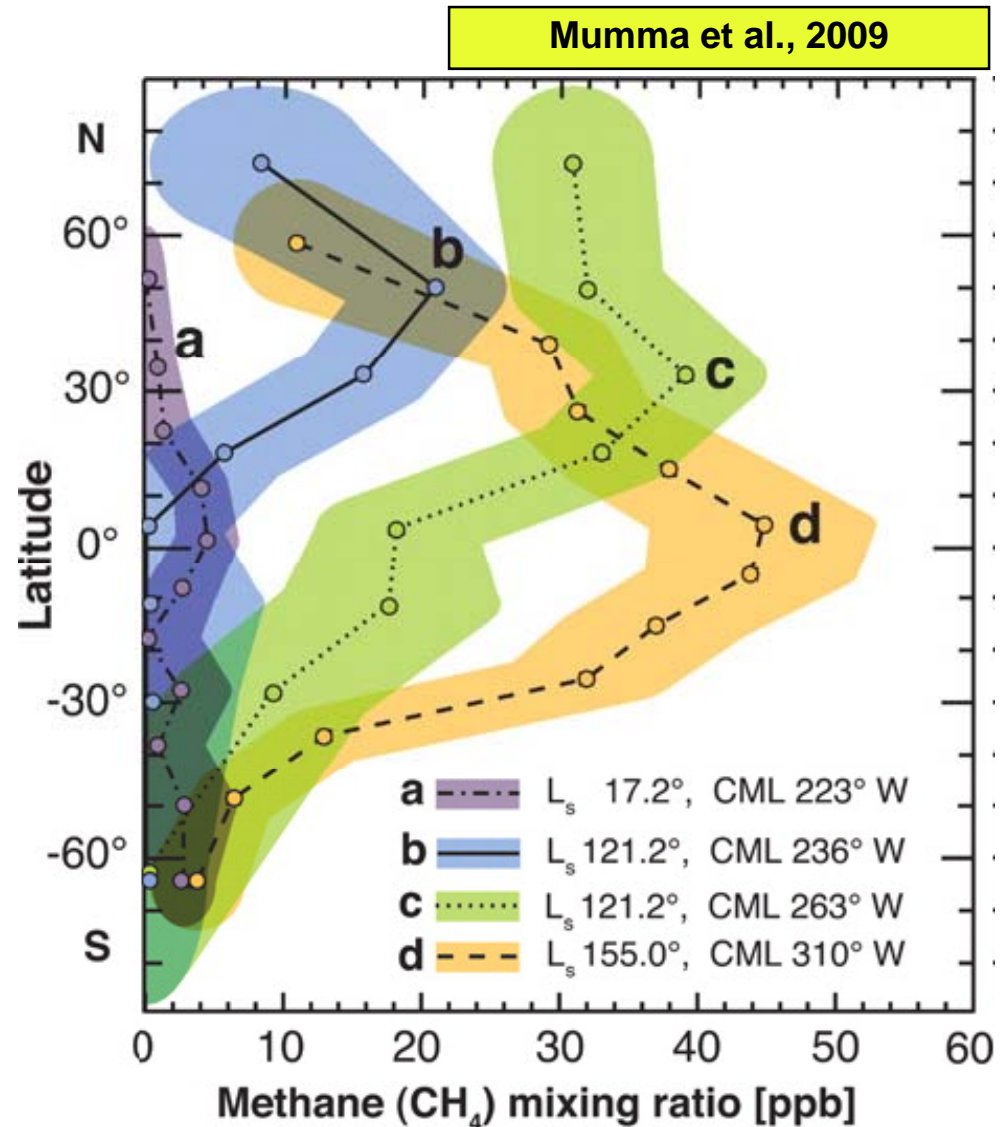
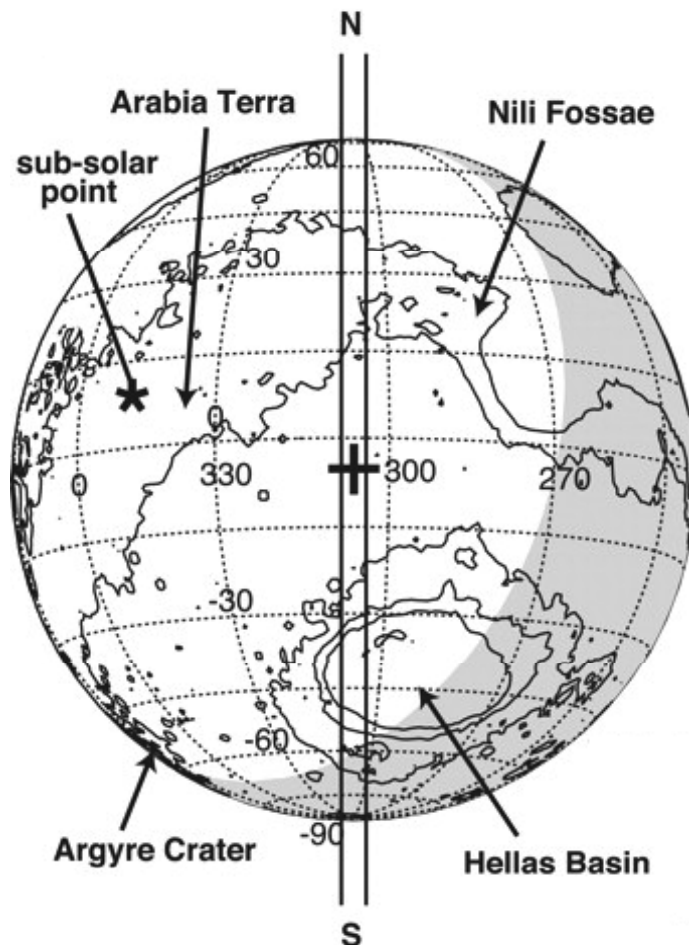


Mumma et al., 2009

- Source region includes Syrtis Major volcano

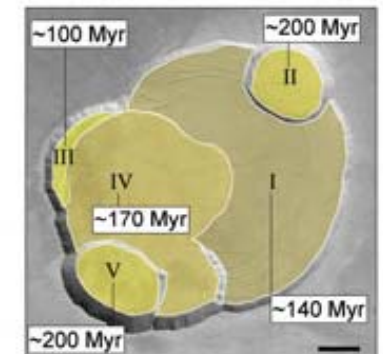
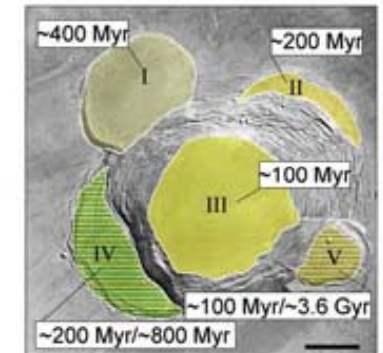
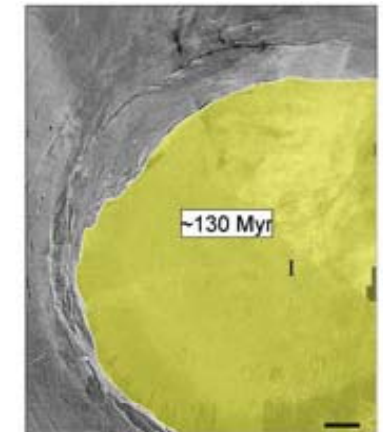
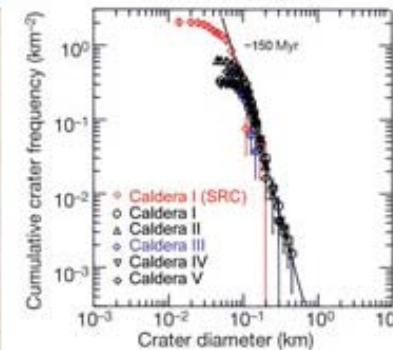
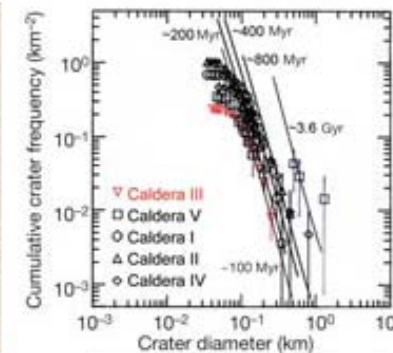
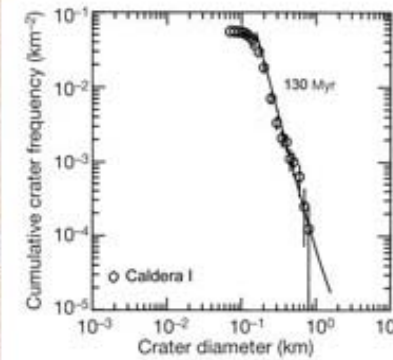
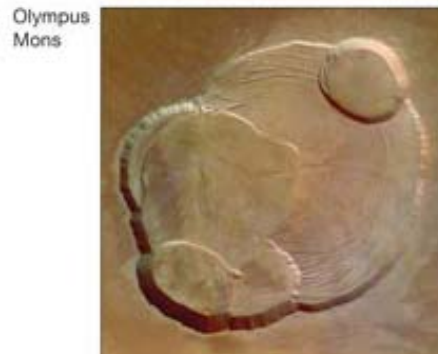
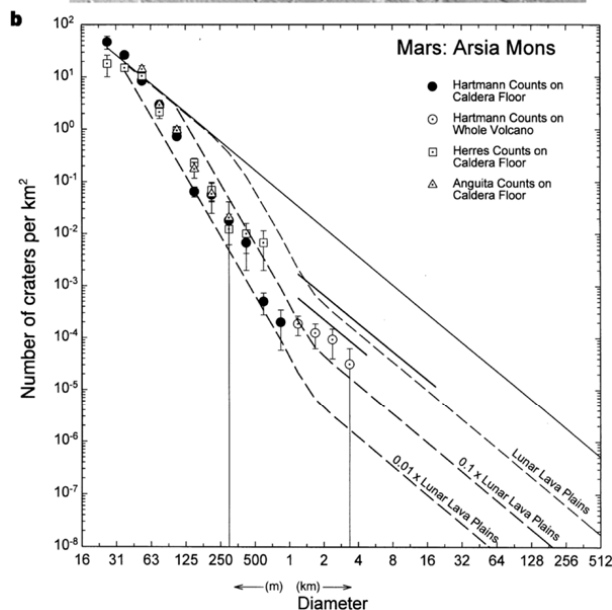


- Methane is released at a certain time of year
 - This part is hard to understand



- Volcanism continues up to the present day
- Surge of activity 100 & 200 Myr ago

Hartmann et al., 1999



Neukum et al., 2004



In this lecture...

- **Martian weather today**
 - Cold and dry with a dusty southern summer and a cloudy northern summer
- **Recap Transition to cold dry conditions**
 - Oceans and cryospheres
 - Giant Floods - Outflow channels
- **Climate change on Mars**
 - Polar ice caps
 - Orbital variations
- **Running water today?**
 - Gullies
 - Flowing ice
- **Volcanism and life?**
 - Methane in the atmosphere

Next: Mars - Early History

- **Reading**
 - Chapter 11-Mars sections to revise the last two lectures
 - Chapter 9 for the next lecture