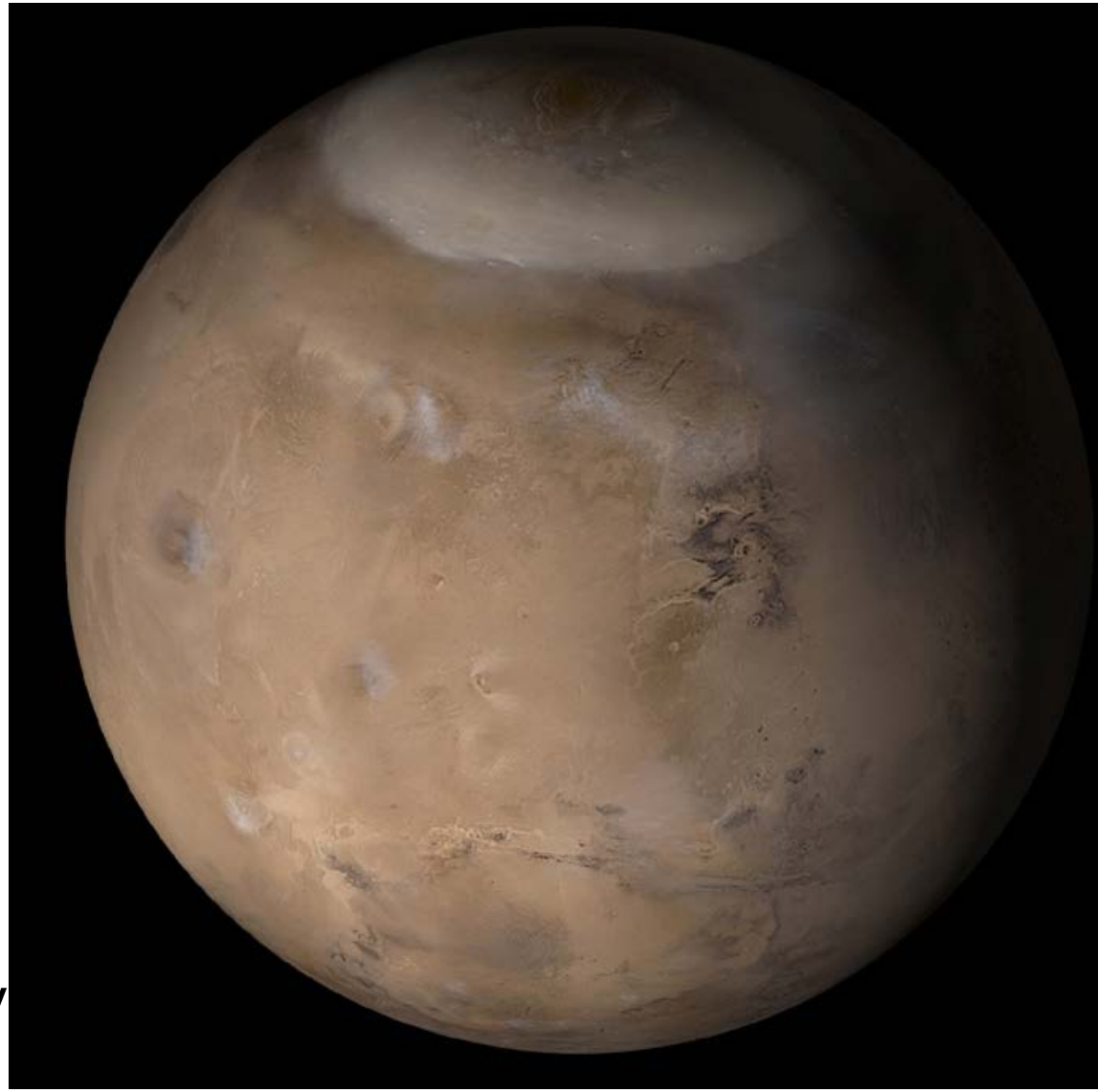
Mars' Polar Caps and Present-day Conditions

Shane Byrne (shane@lpl.arizona.edu)

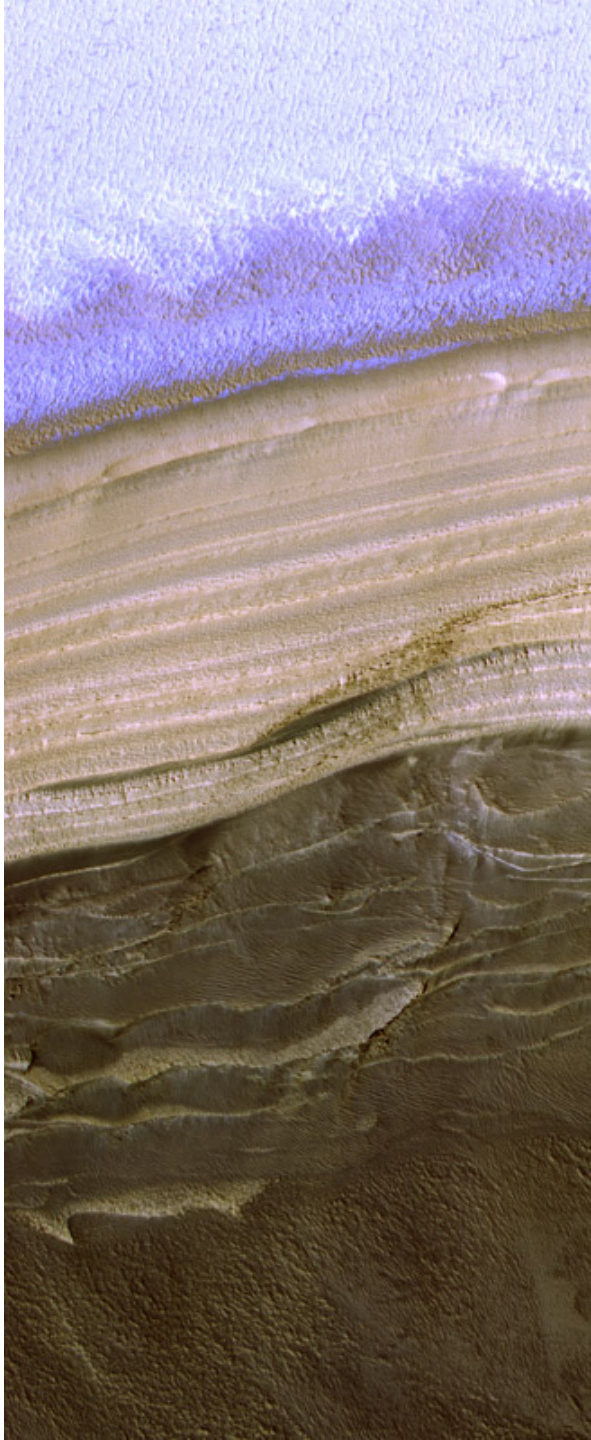
- Caps are thin bright coverings
- Seasonal frost on Mars
  - Major feature of martian seasons
  - Exotic CO_2 ice processes
  - Seasonal timescale of 686 days
- Polar Layered Deposits are where all the history is.



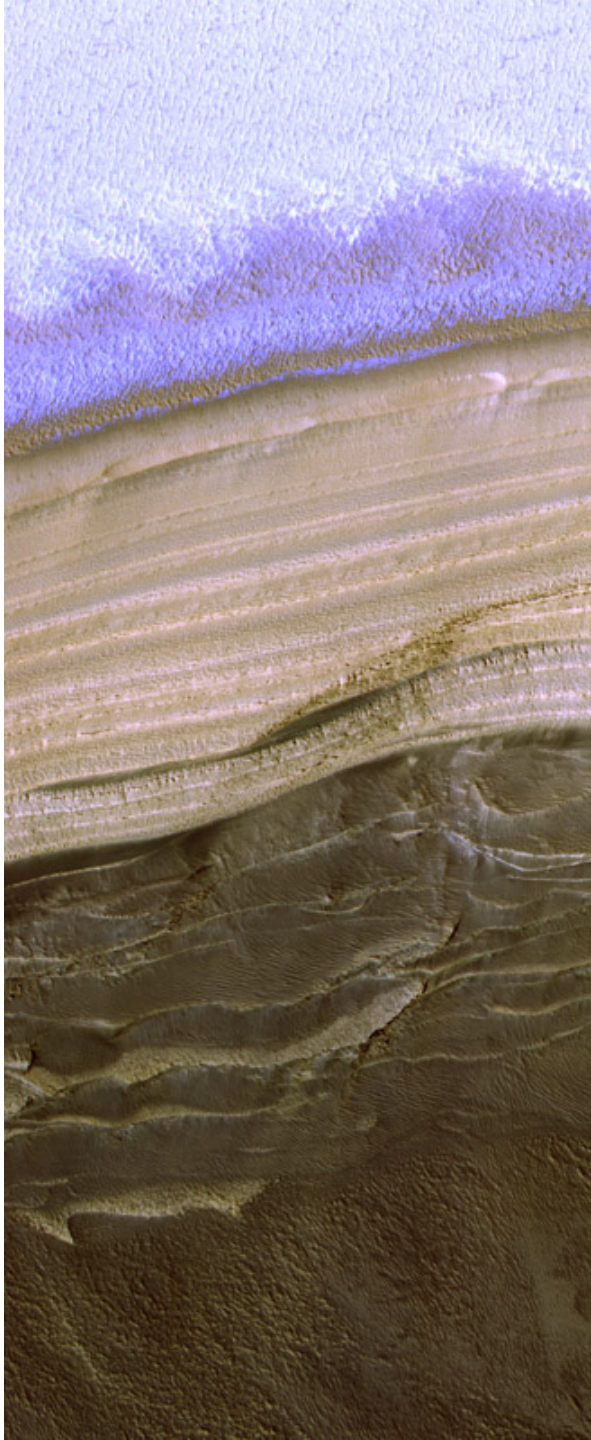
MOC wide angle, msss.com

- **Mars - An Earth-like planet**
  - **Earth-like Climate**
  - **Earth-like Geology**
  - **Use familiar techniques to analyze familiar features in an exotic locale**

- **Why bother?**
  - **Understand climate history of Mars over the Amazonian (most of martian history)**
  - **Understand climate variation on a simplified terrestrial planet**
    - **Lots more terrestrial planets are on the way**

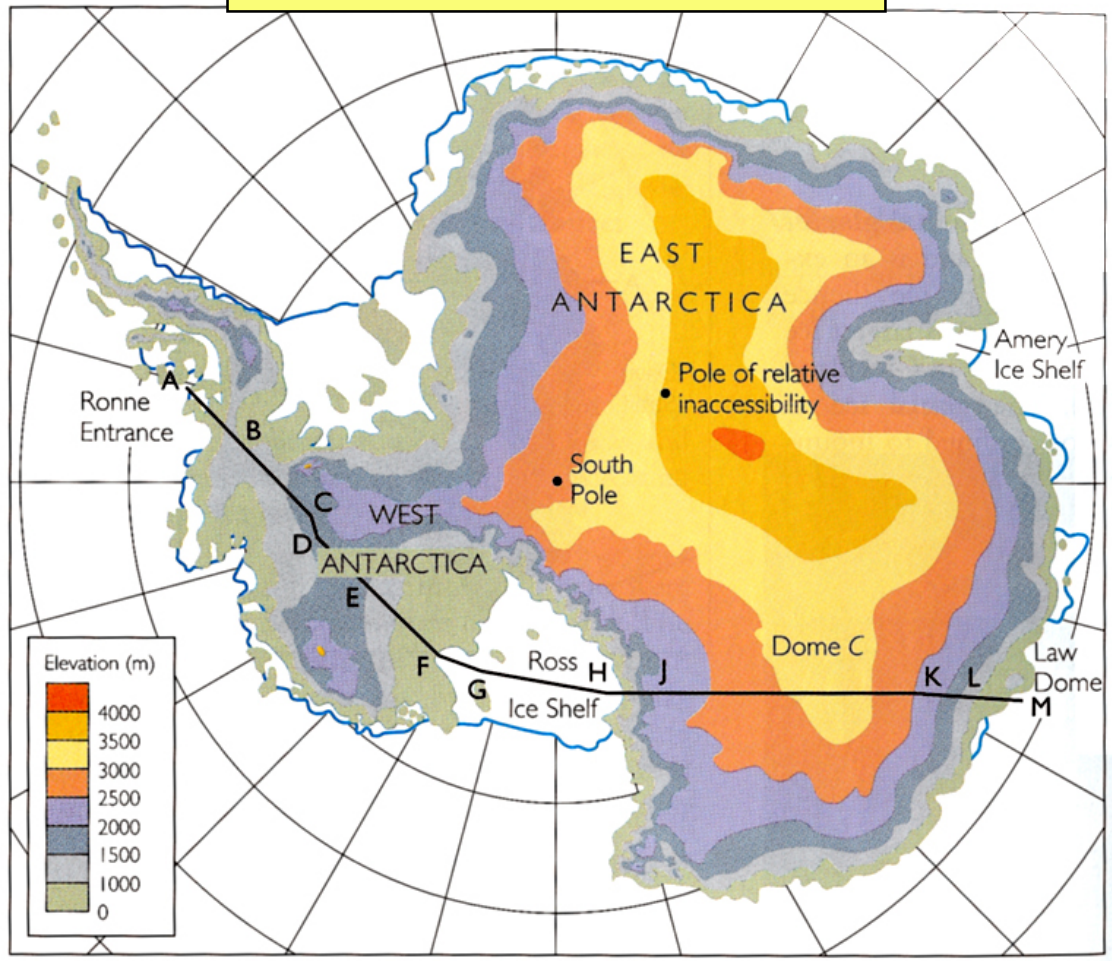


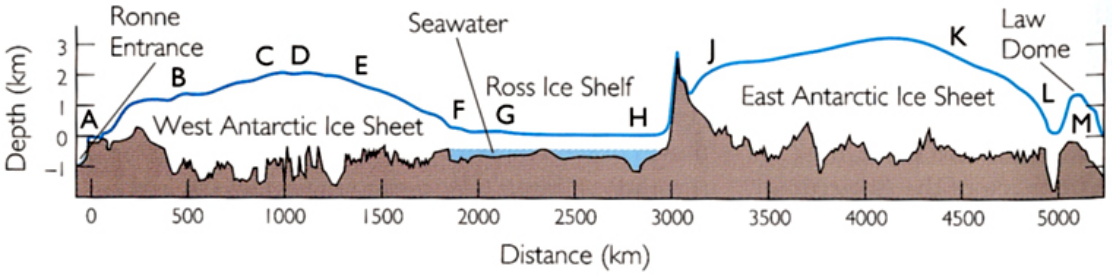
- **Overview**
  - What are the martian polar deposits?
  - What's their historical story?
- **More talks to look forward to:**
  - Patricio Becerra: Polar Stratigraphy
  - Melinda Kahre: Amazonian Climate Modeling
  - Christine Hvidberg: Terrestrial ice sheets in climate studies



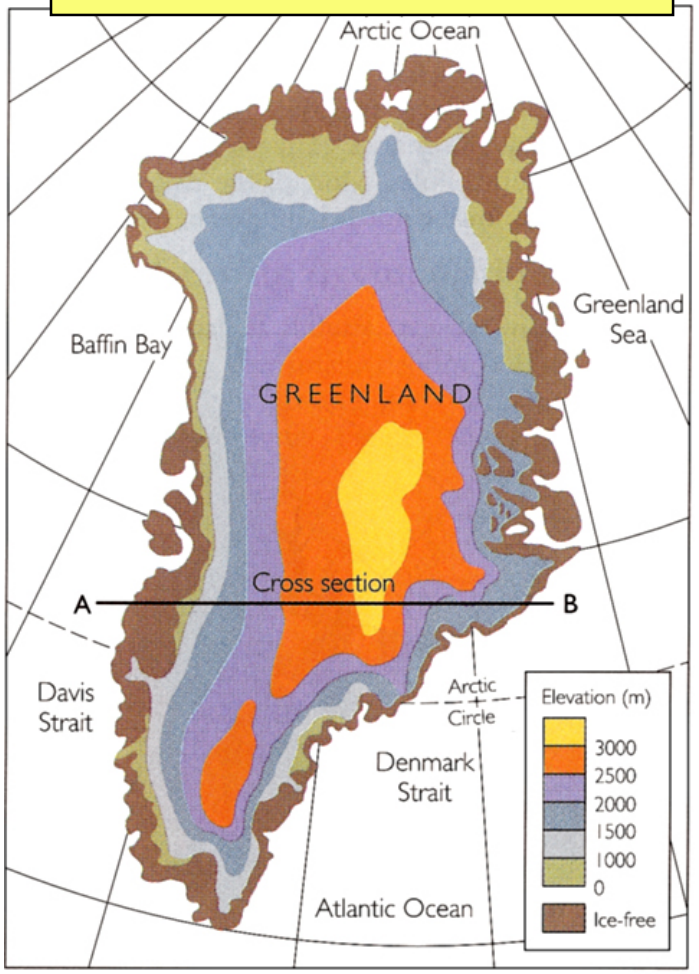
Big ice sheets of the inner solar system - Earth

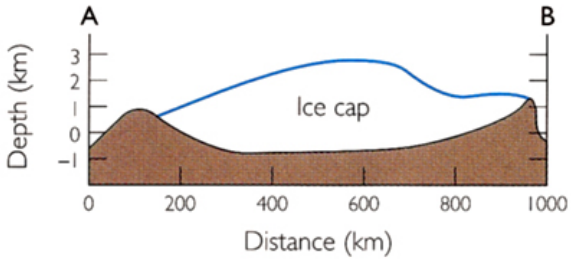
Antarctica: 30 million km³



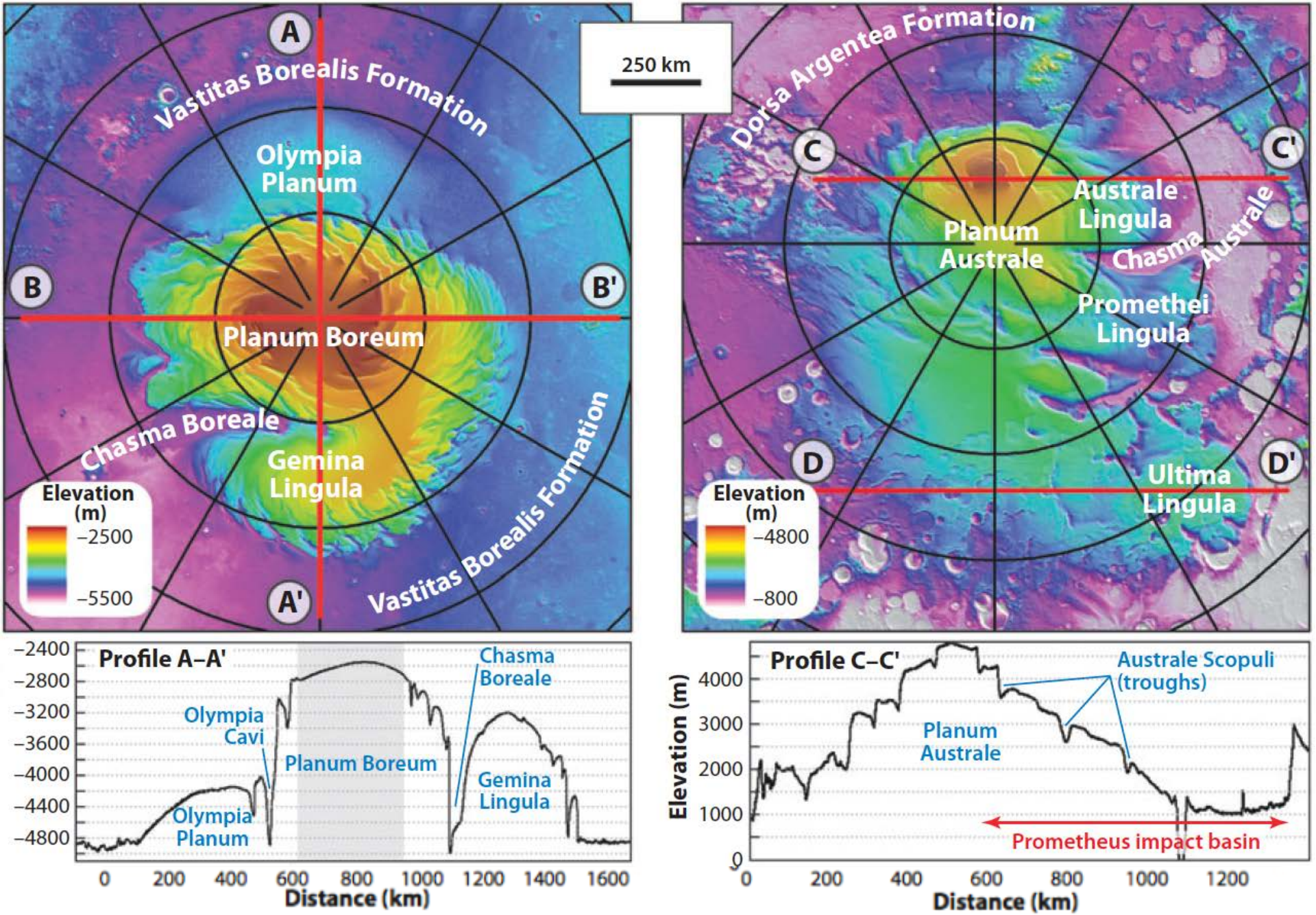


Greenland: 6 million km³

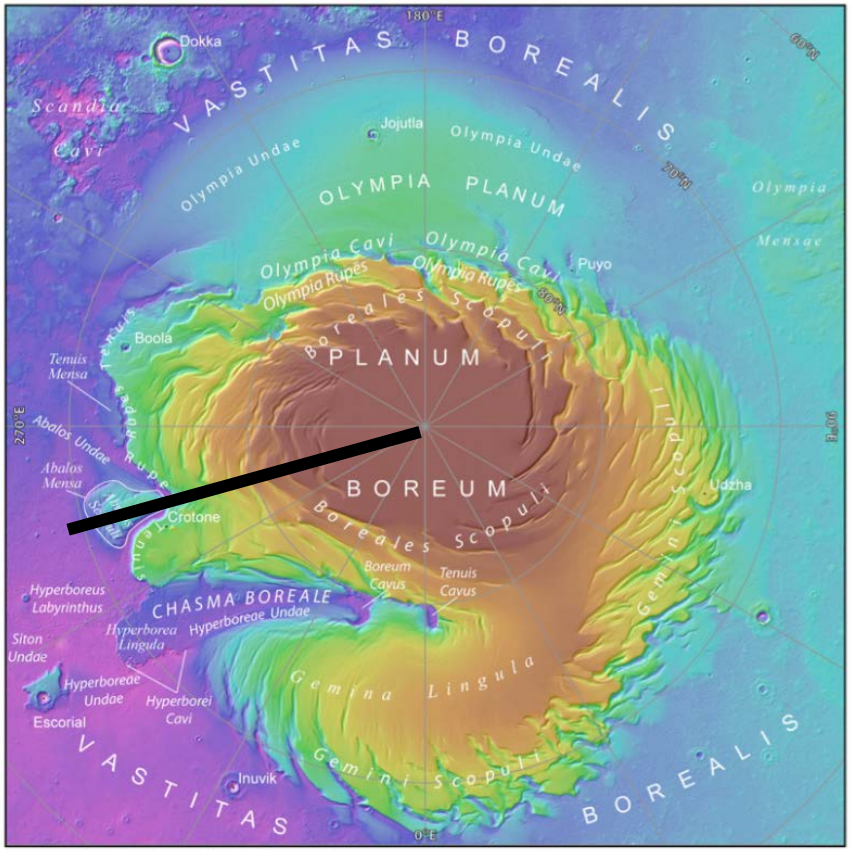


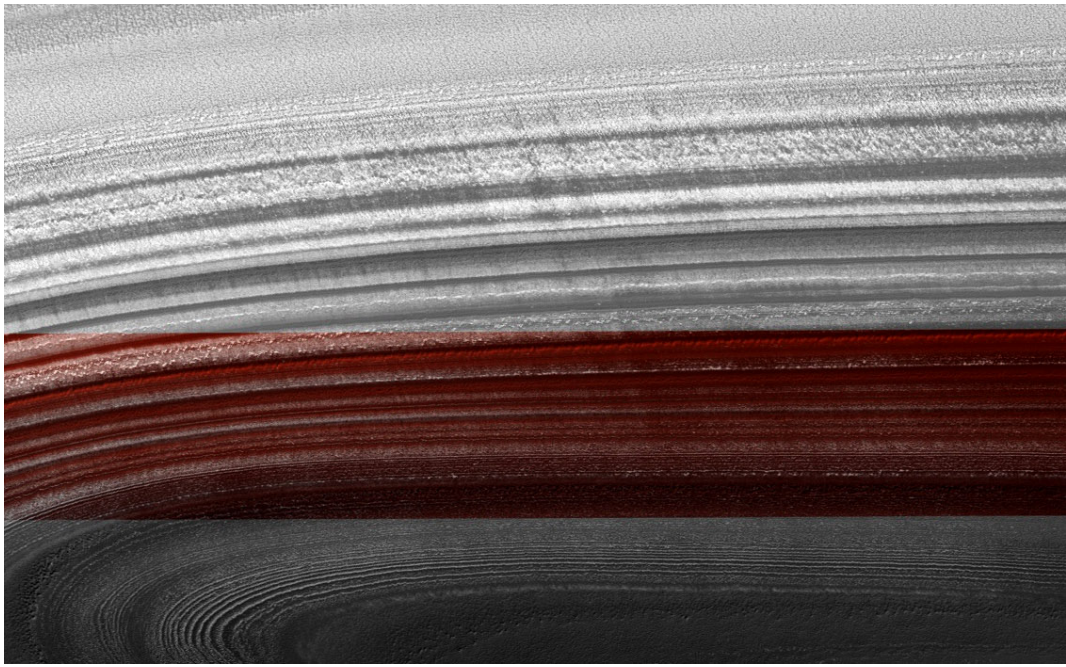


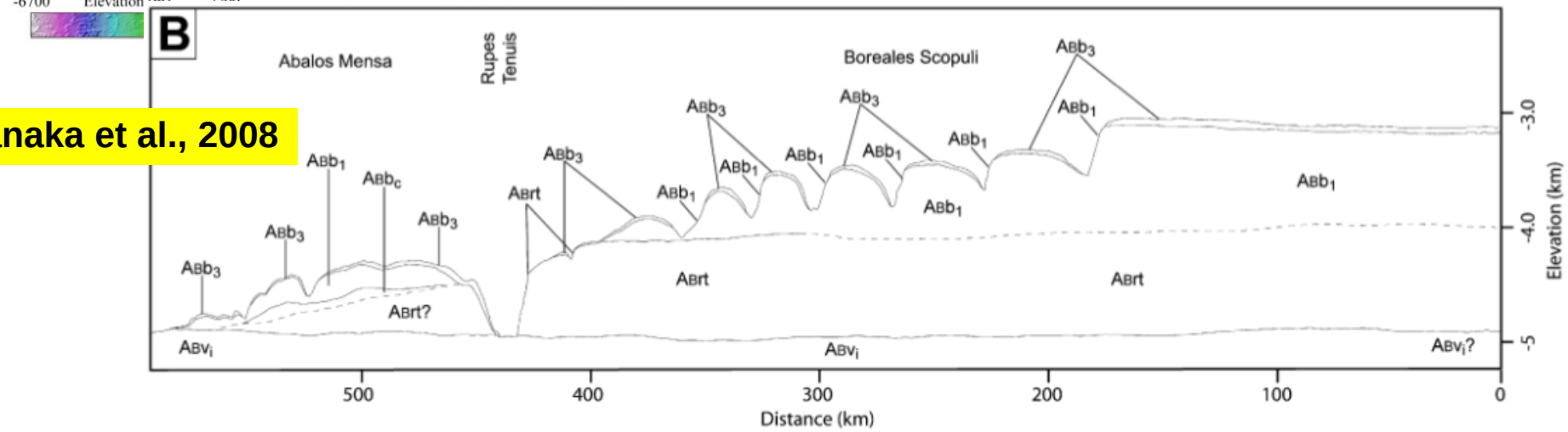
Big ice sheets of the inner solar system - Mars



- Internal layers exposed by asymmetric spiral troughs
- Typically only a few 100m in relief
- Slopes are low – 5-10 degrees

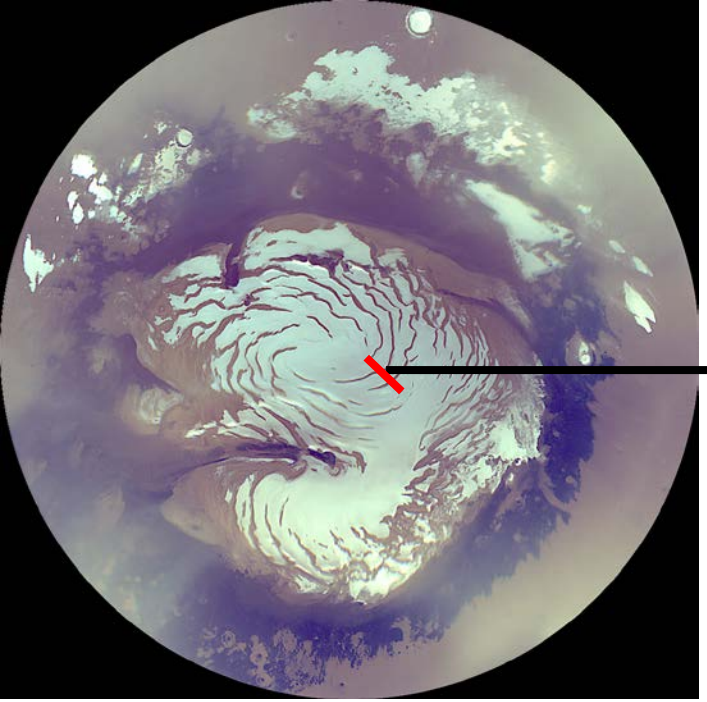


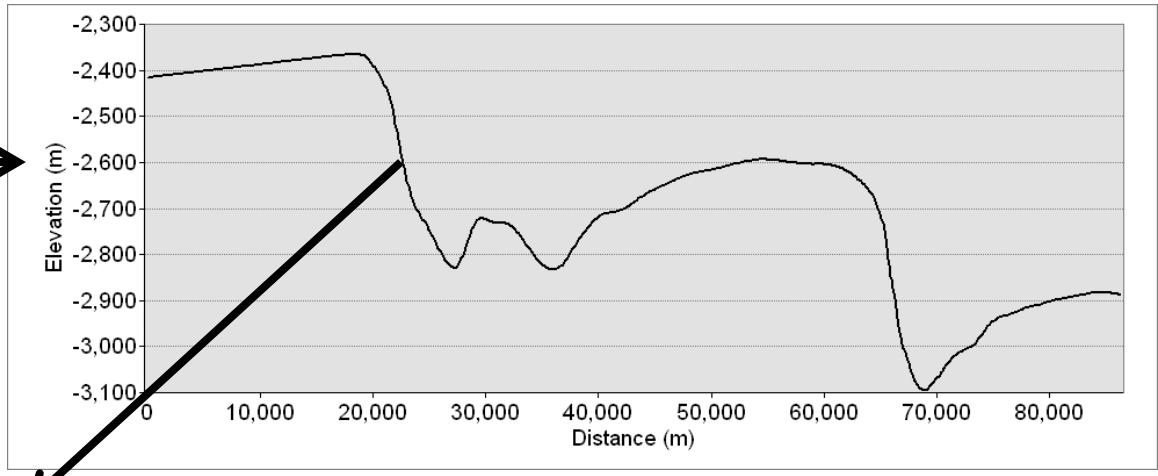


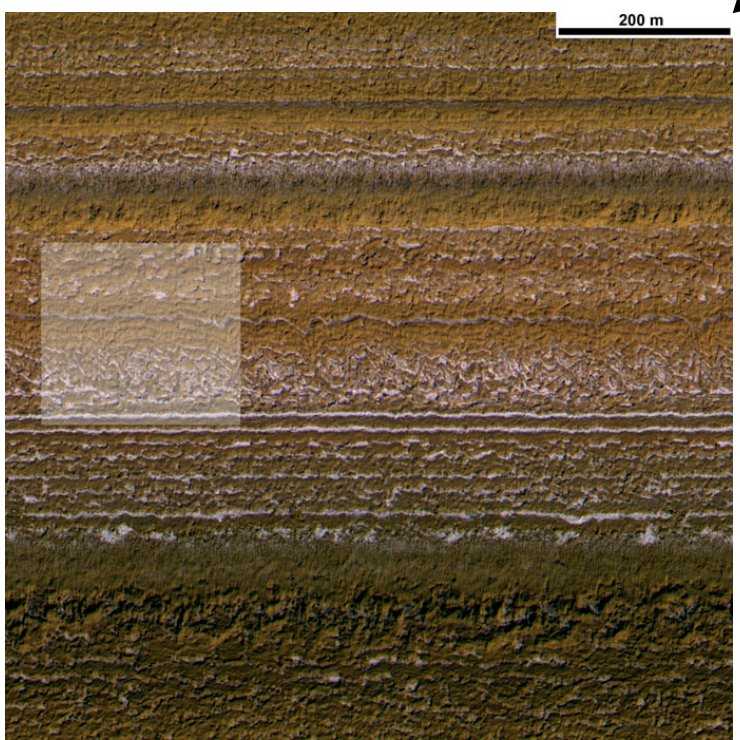


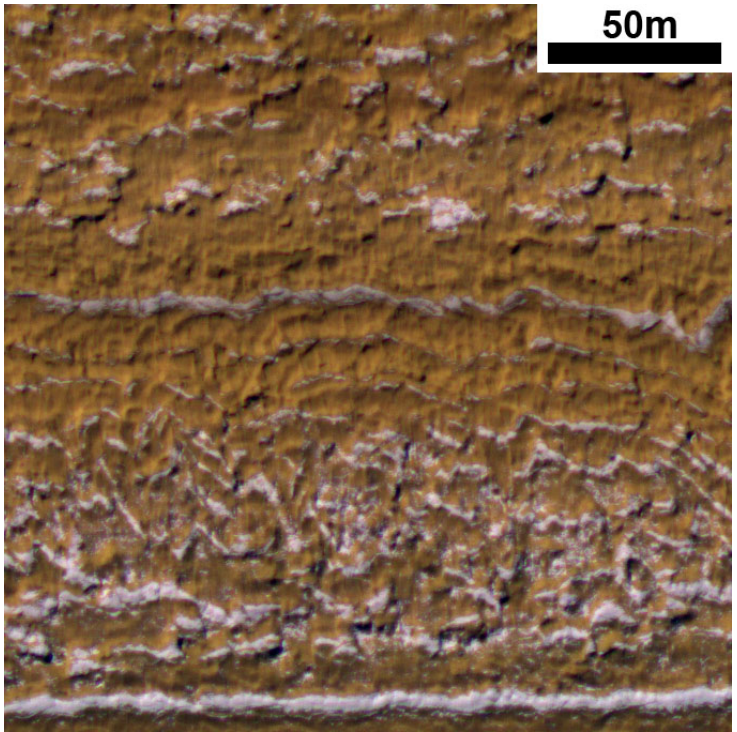
Tanaka et al., 2008

- Layers exposed by gently sloping troughs
- Thick lag deposits that slump downslope
- Thinnest layers observed ~10cm









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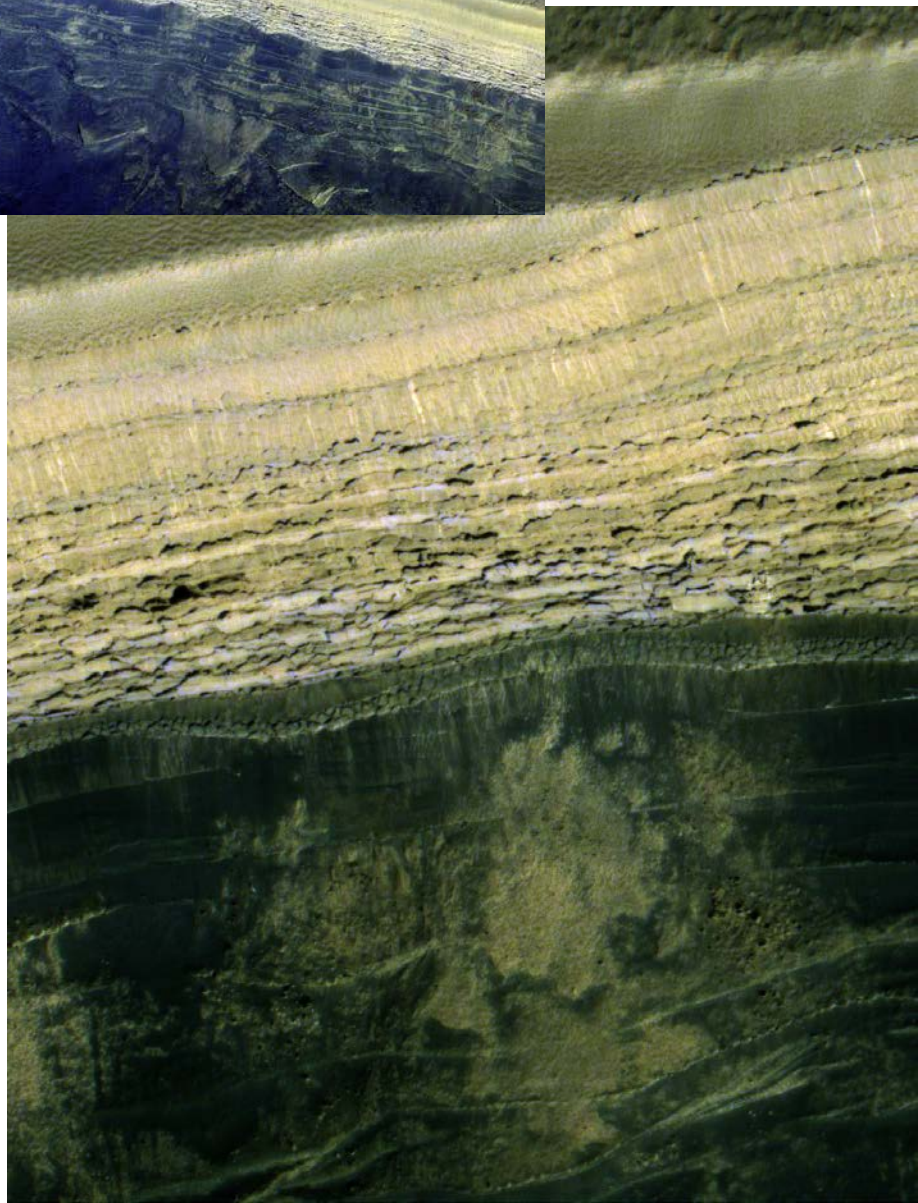
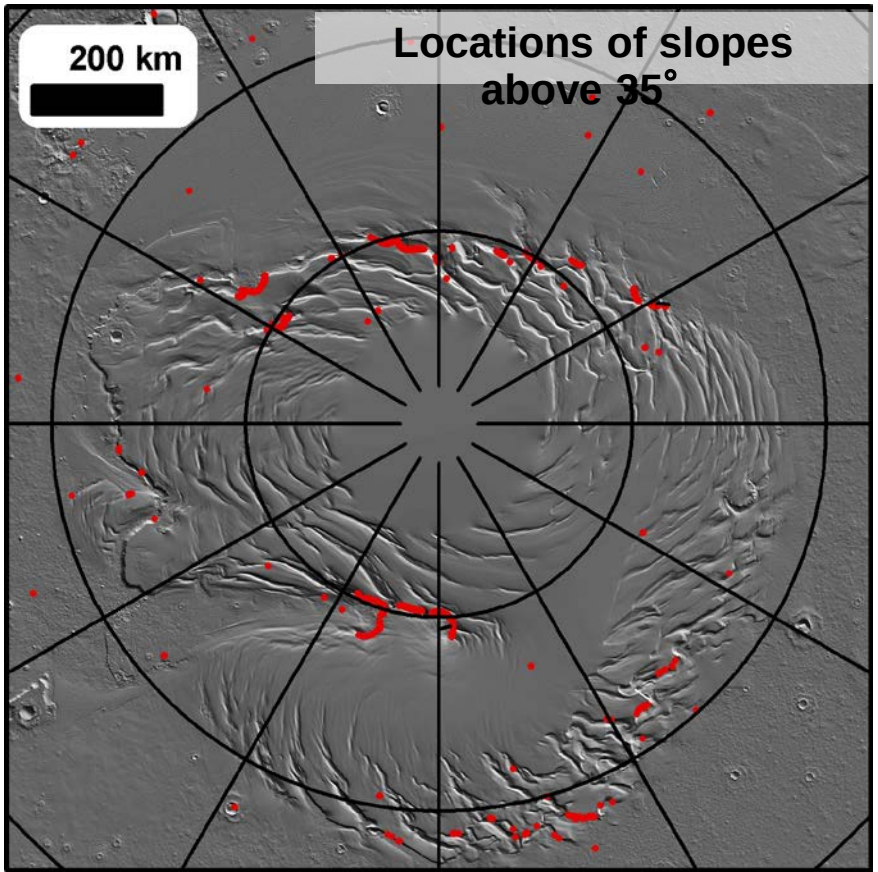
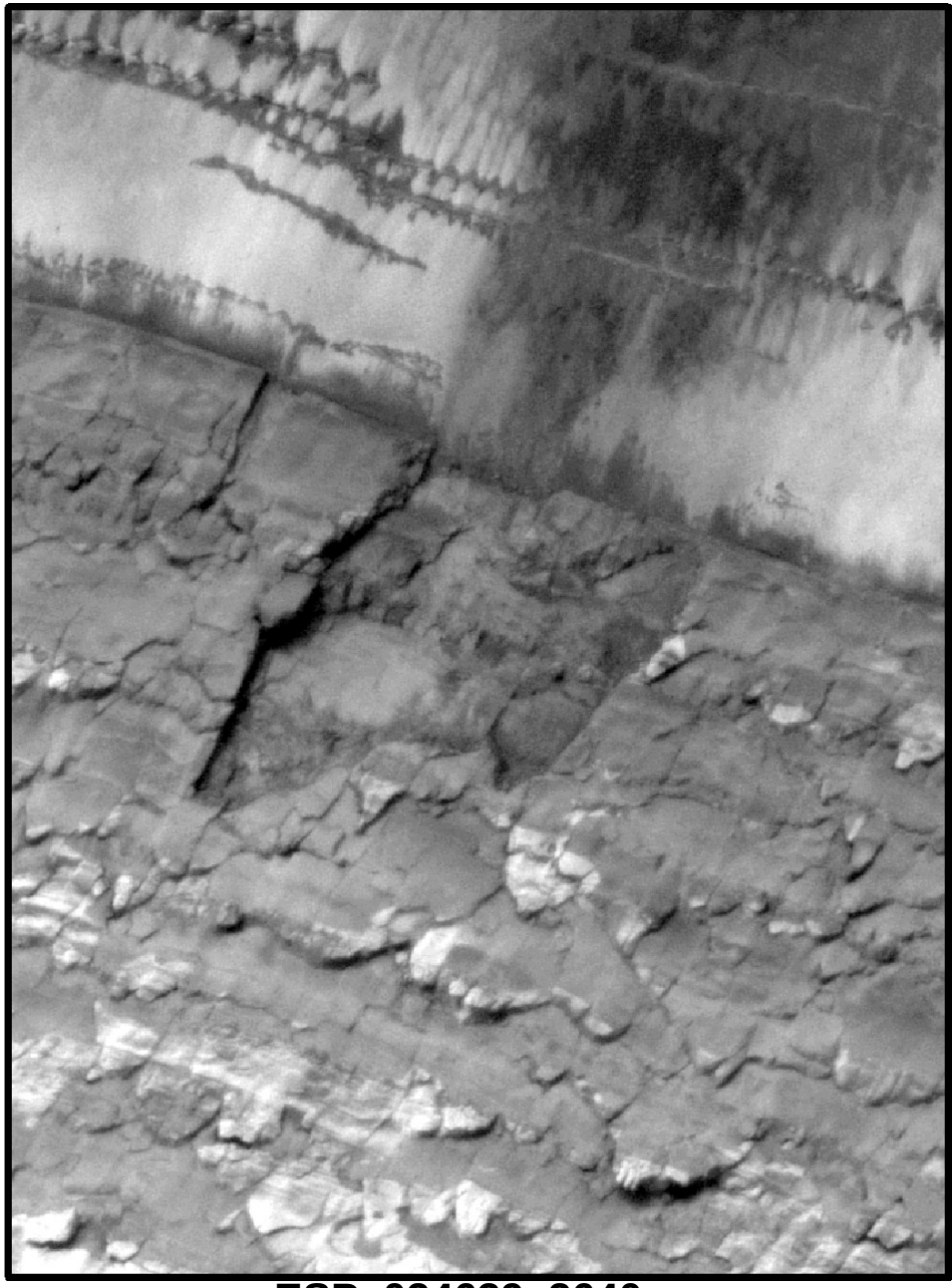


- Steep cliffs at the NPLD boundaries



Failure of a 70m wide section in late-summer or winter of MY 30…

ESP_016292_2640



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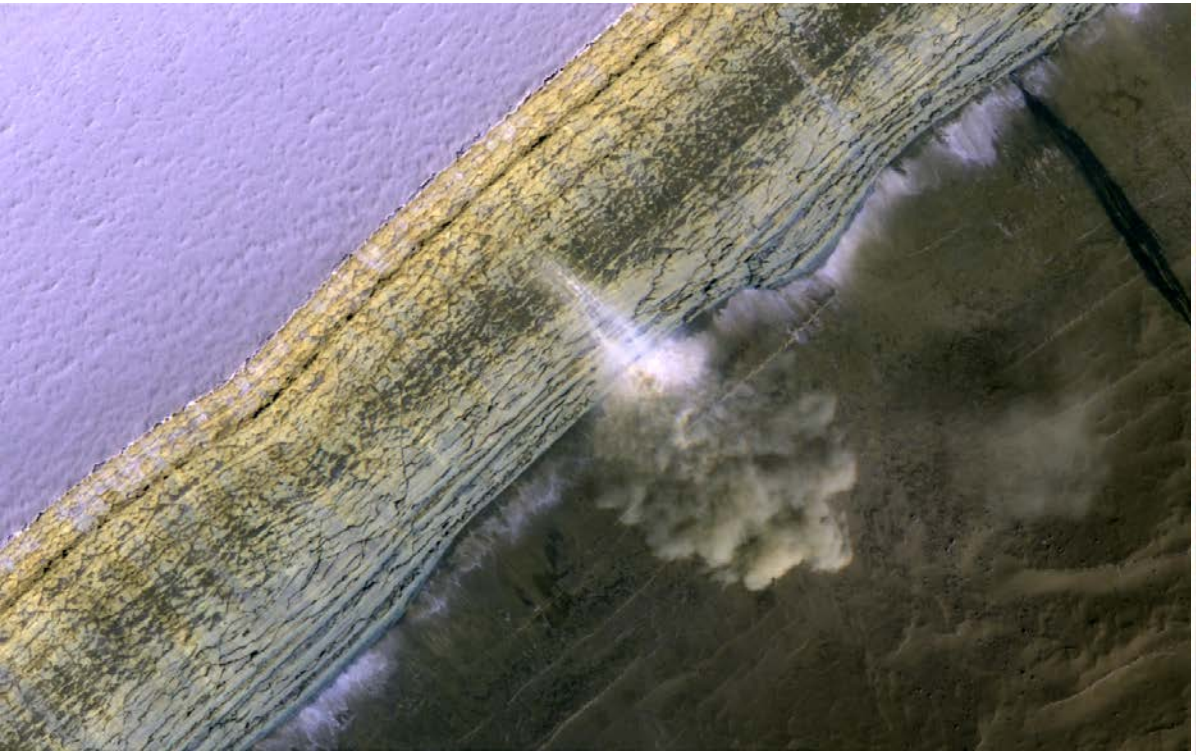
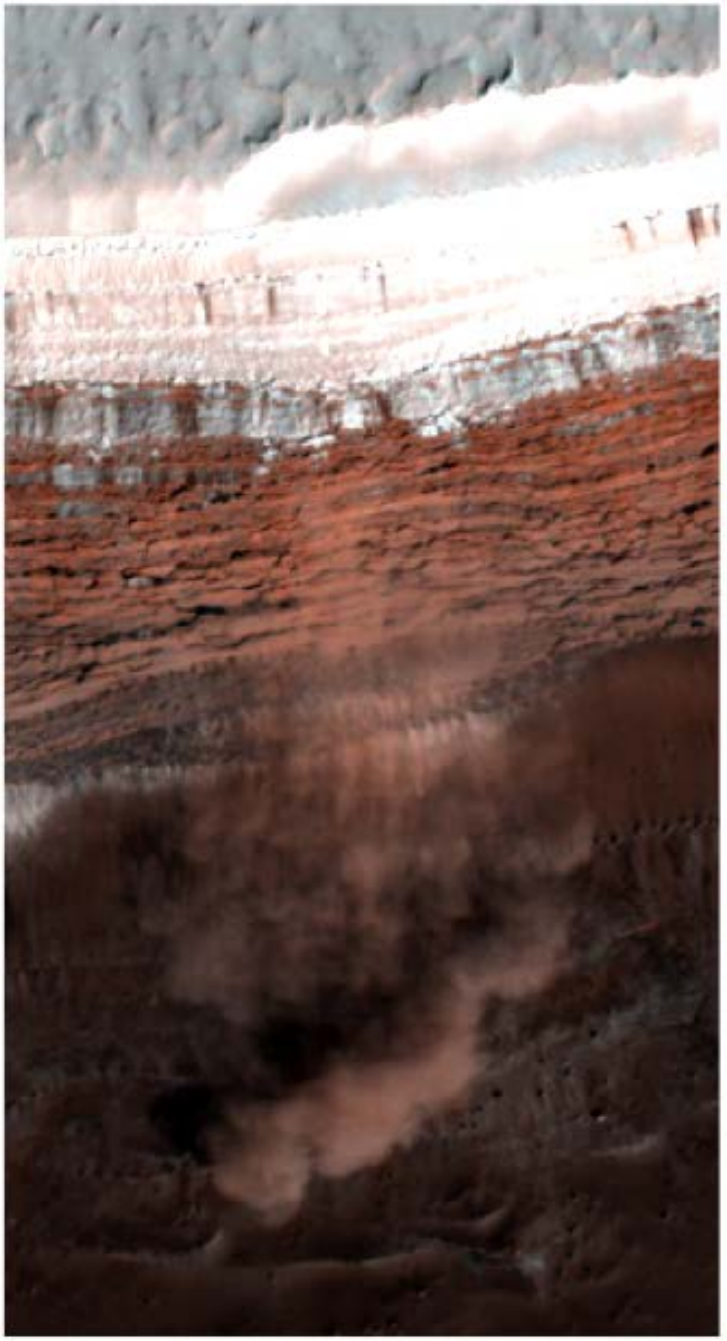
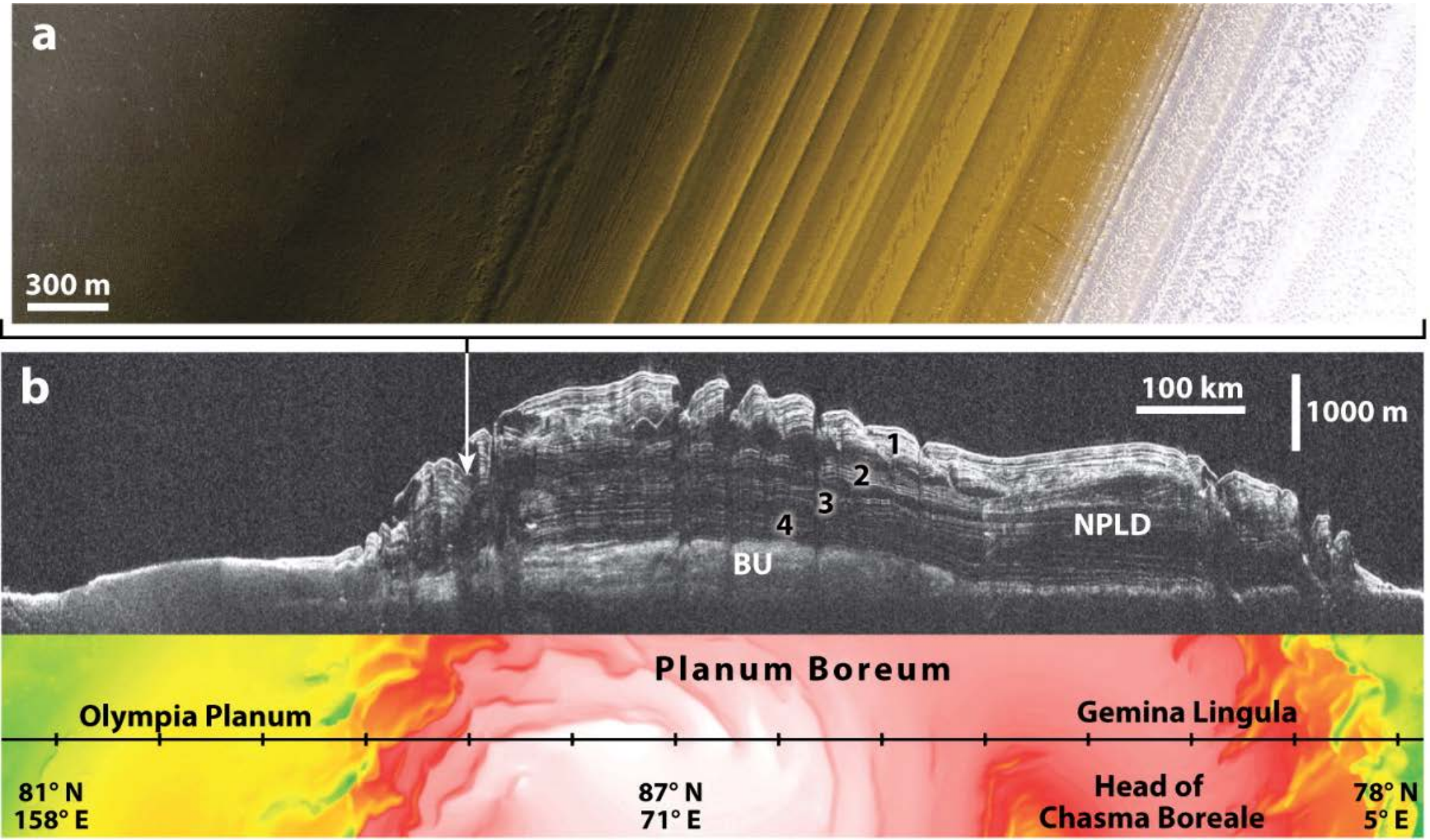
- Steep cliffs experience thermoelastic stresses and avalanches (probably related)



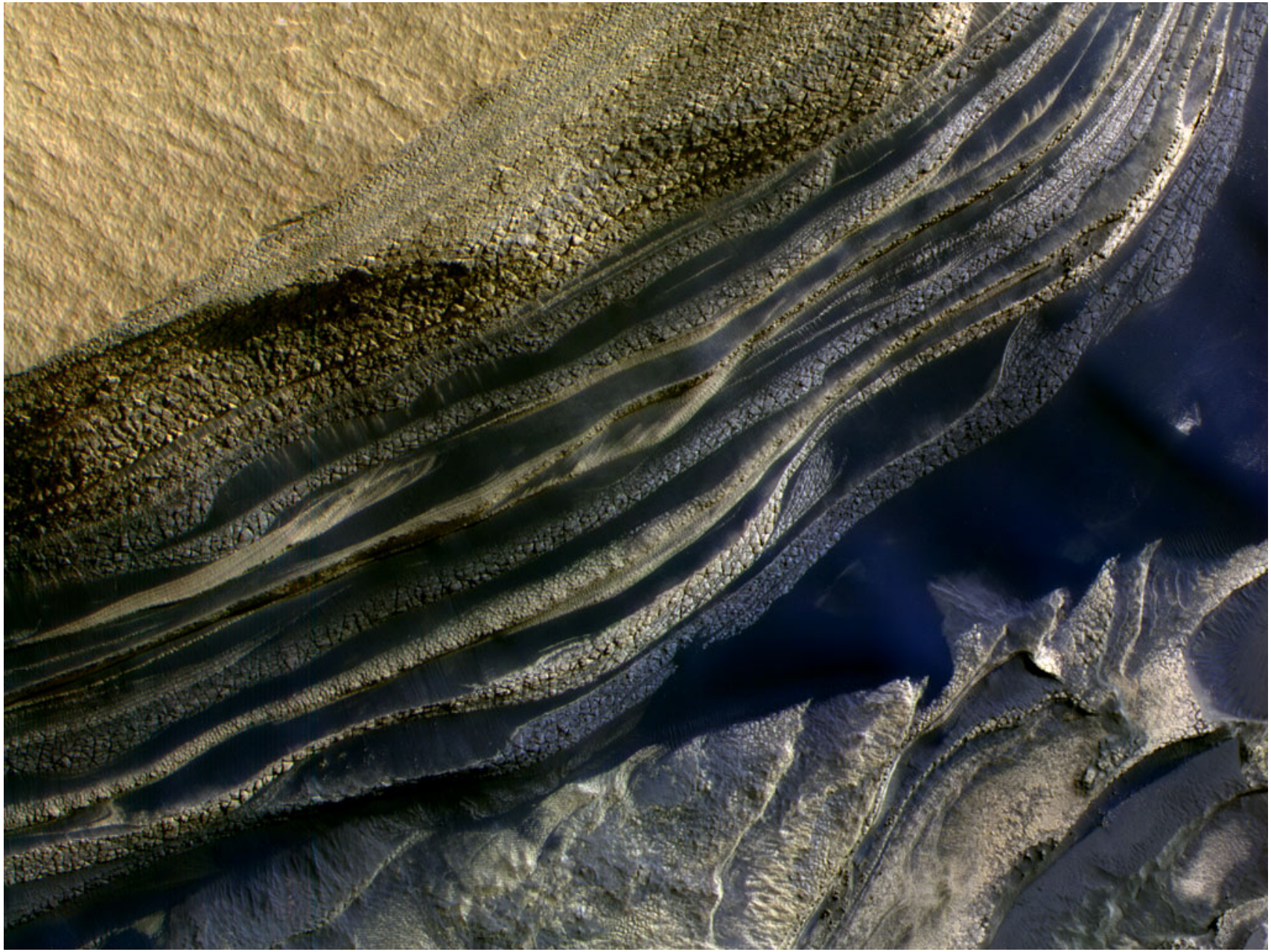


Russell et al., 2008

- Sharad shows layers extend across the whole polar cap – more on layers from Patricio

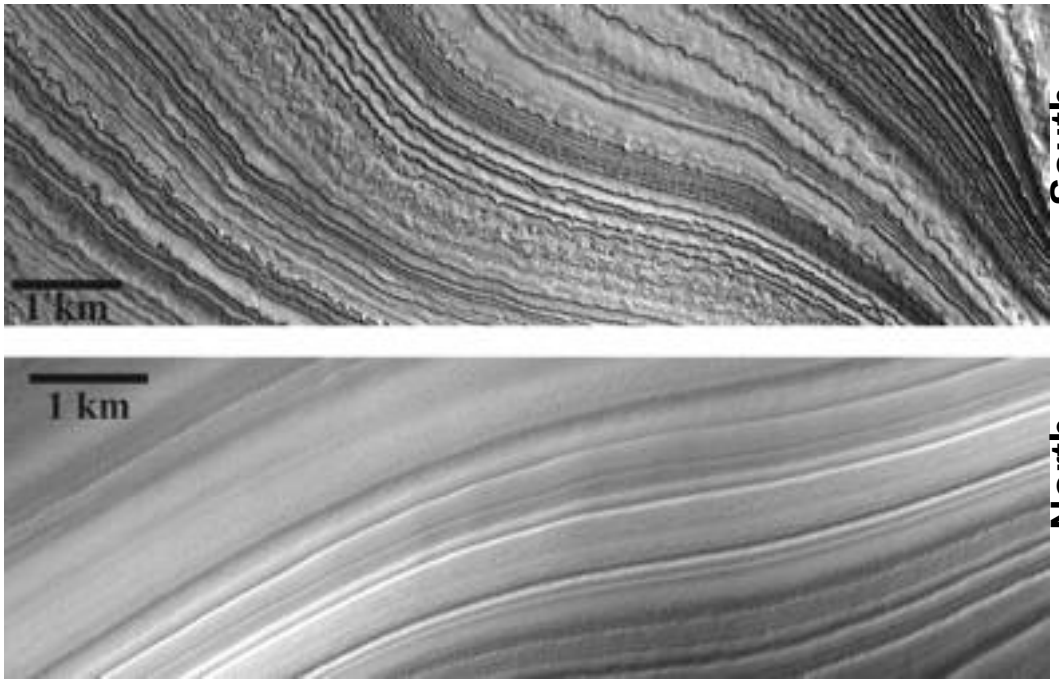


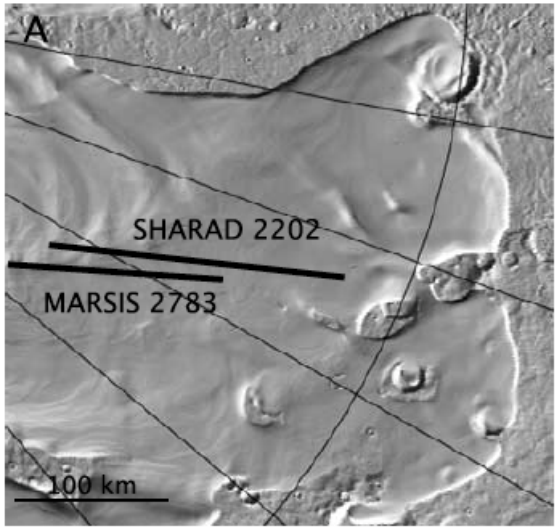
A basal unit of interbedded ice and sand underlies the NPLD

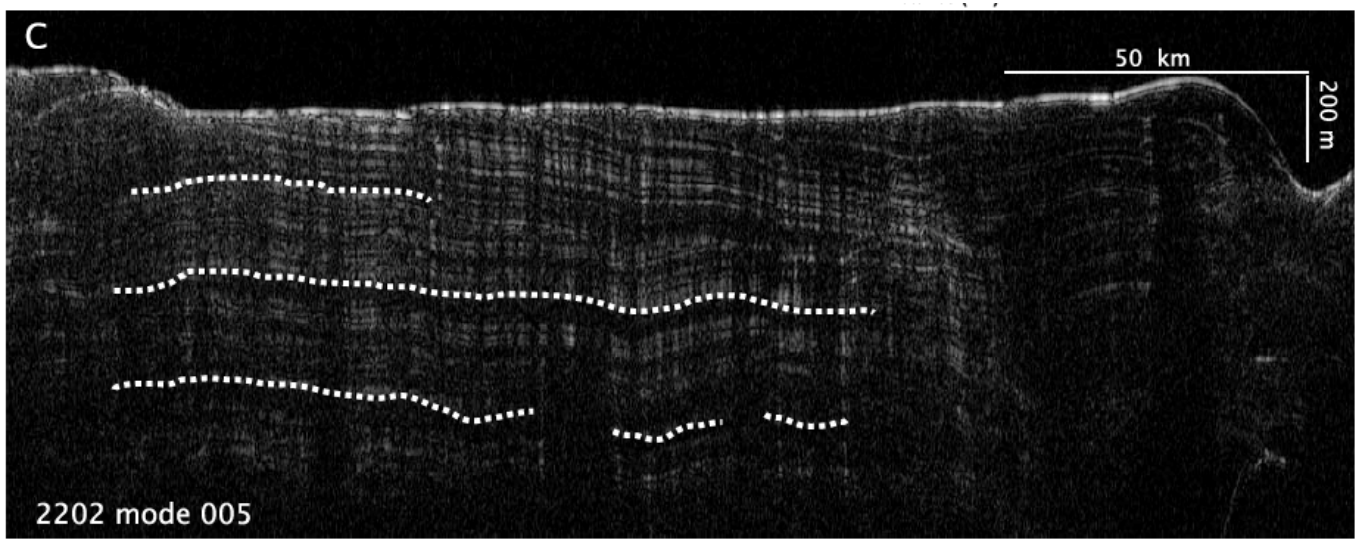


South polar differences

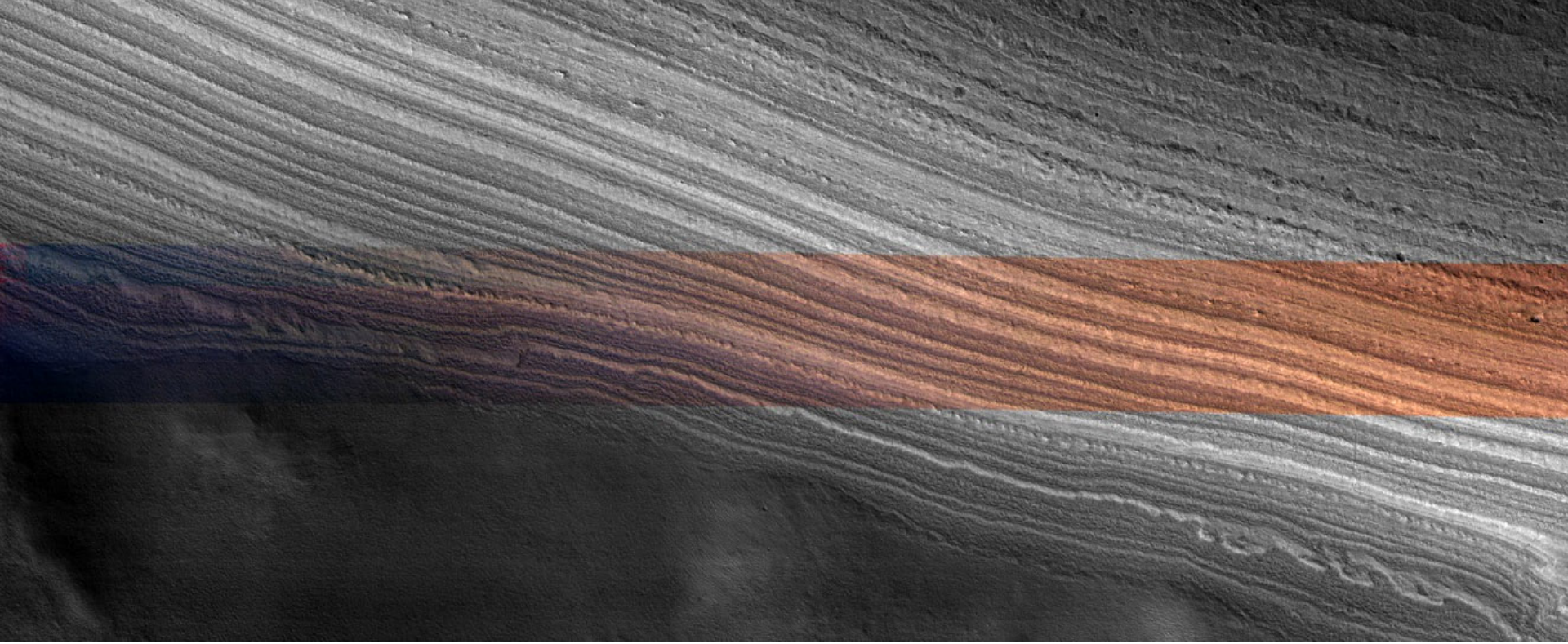
- Layers exposures appear more eroded
- Diffuse radar “fog” envelops a lot of the SPLD, although Promethei Lingula has discernable layers
- Radar reflection-free zones exist within the SPLD (more on this later)

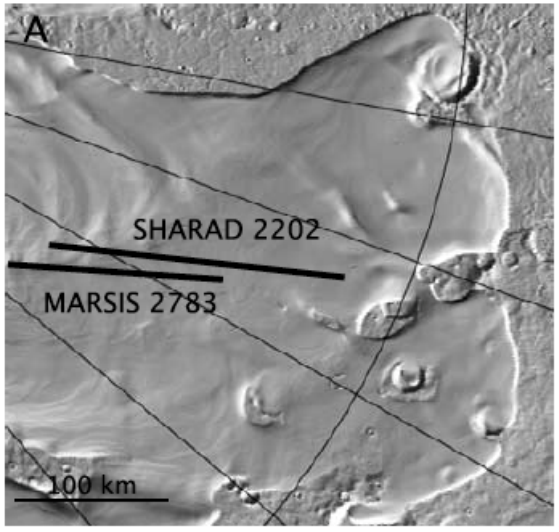


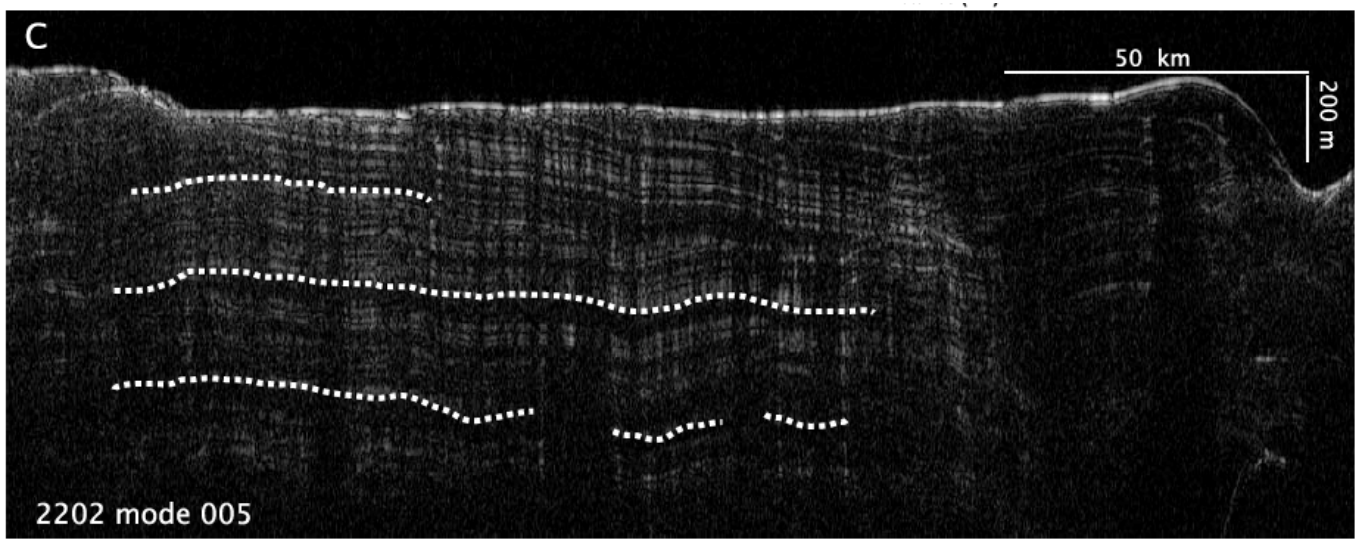




Milkovich et al., 2009

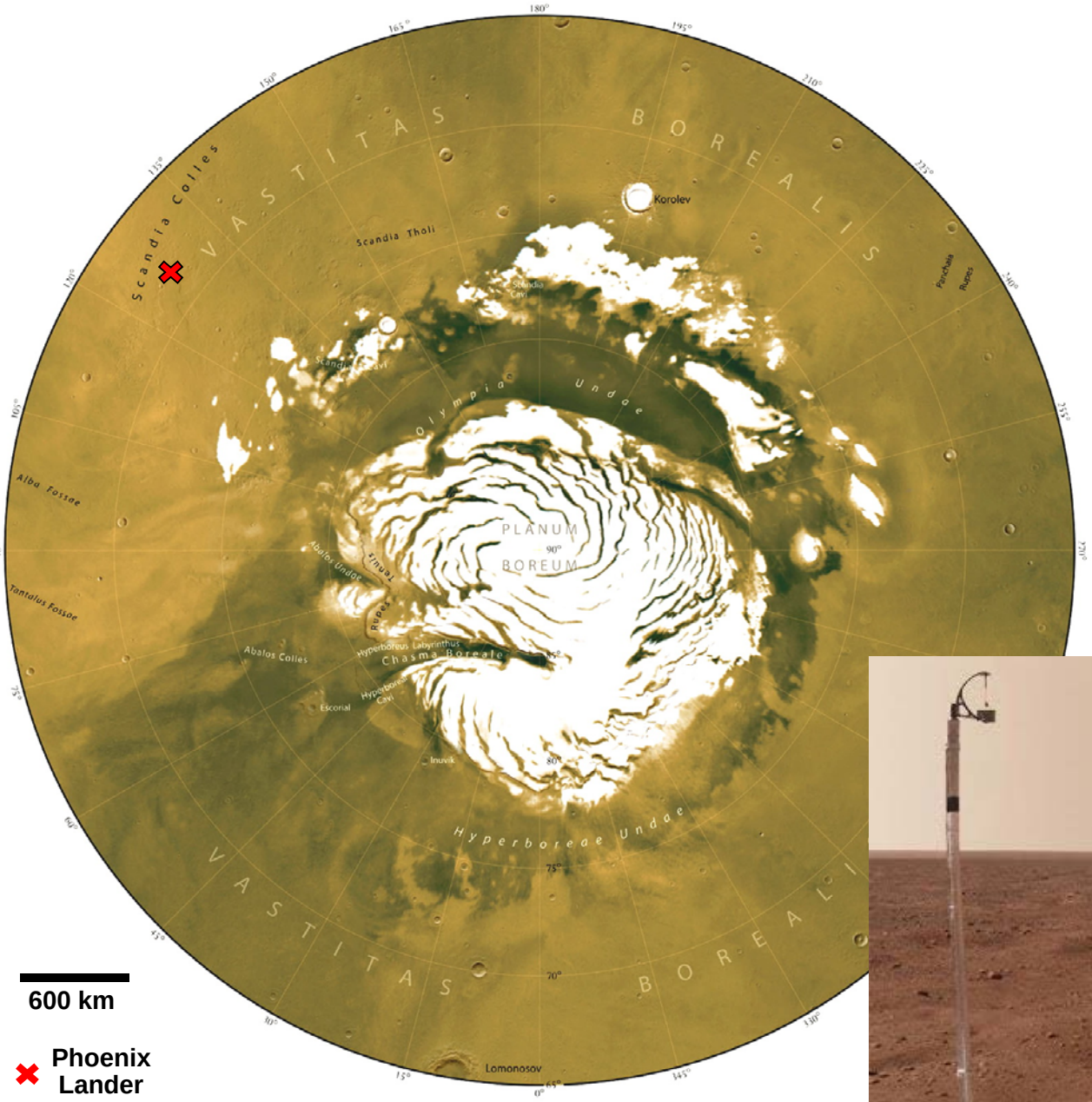


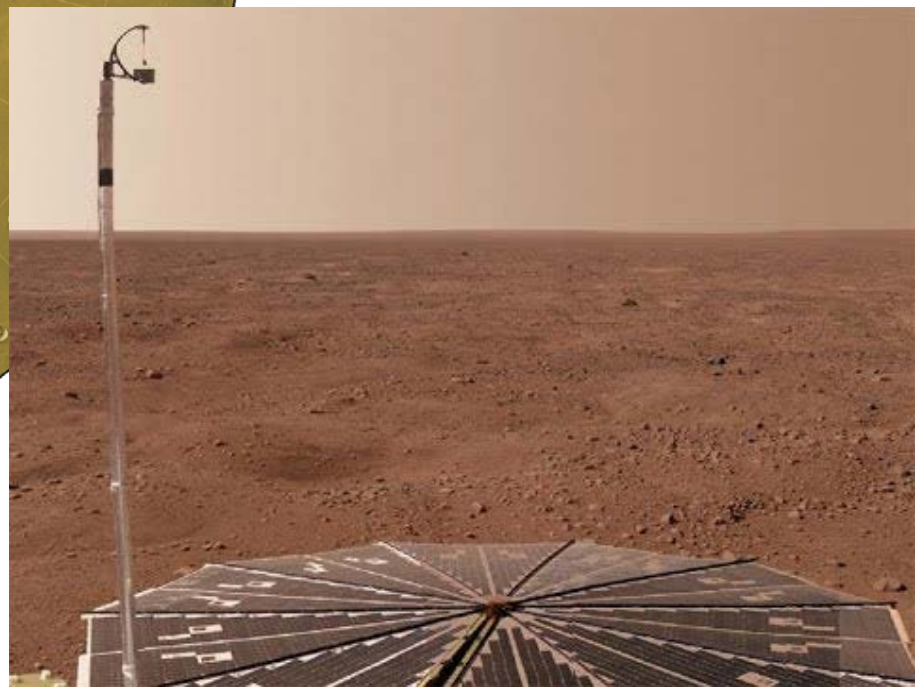

A
SHARAD 2202
MARSIS 2783
100 km


C
50 km
200 m
2202 mode 005

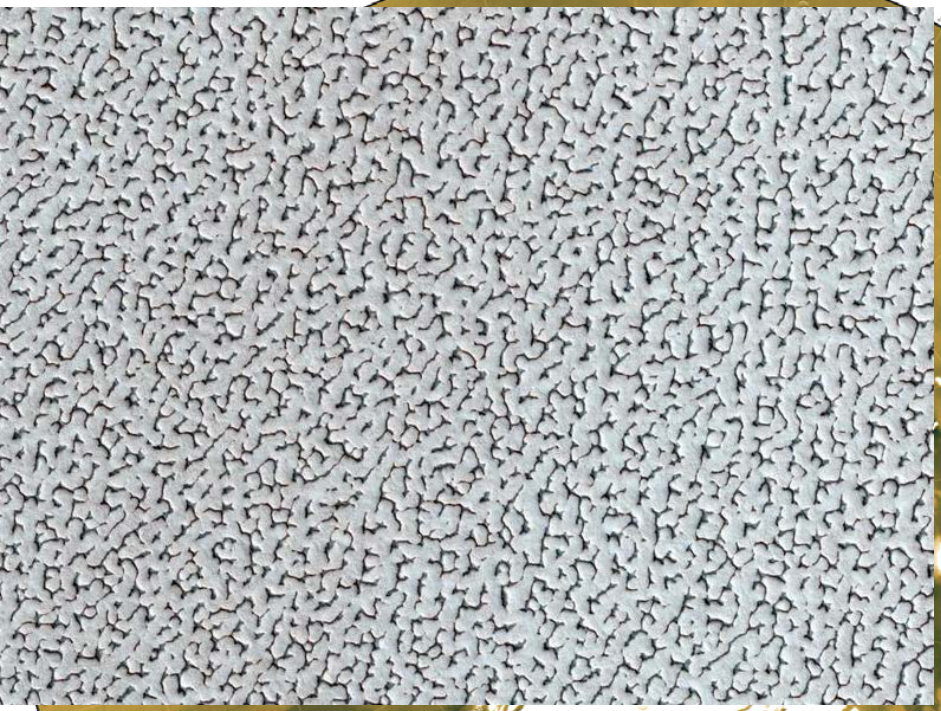
North polar layered deposits:

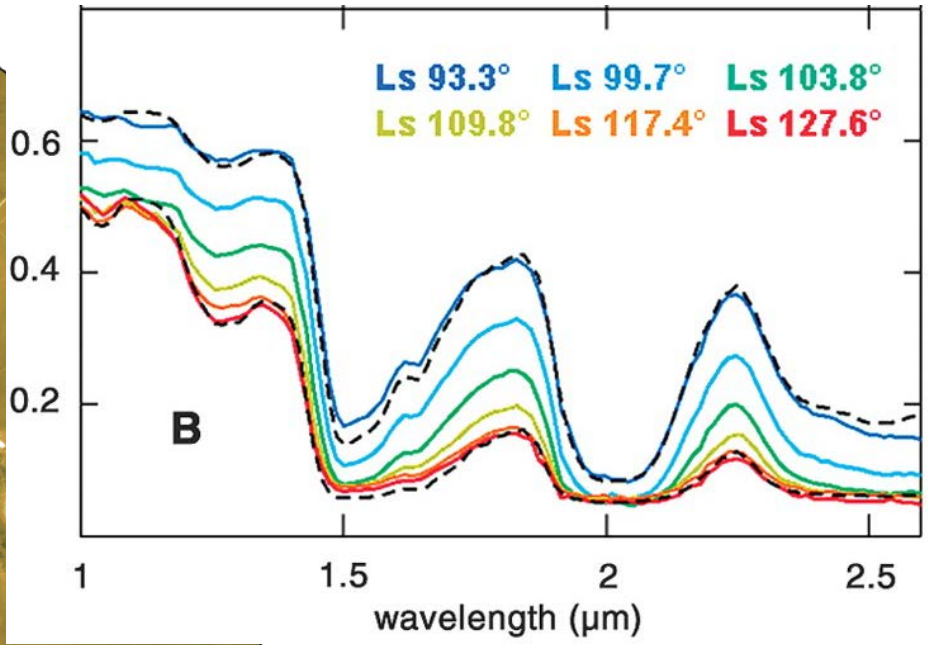
- Mostly covered by a residual water ice cap
- Surrounded by a large erg (sand sea)
- Sits on top of the Vastitas Borealis formation (visited by the Phoenix Lander)

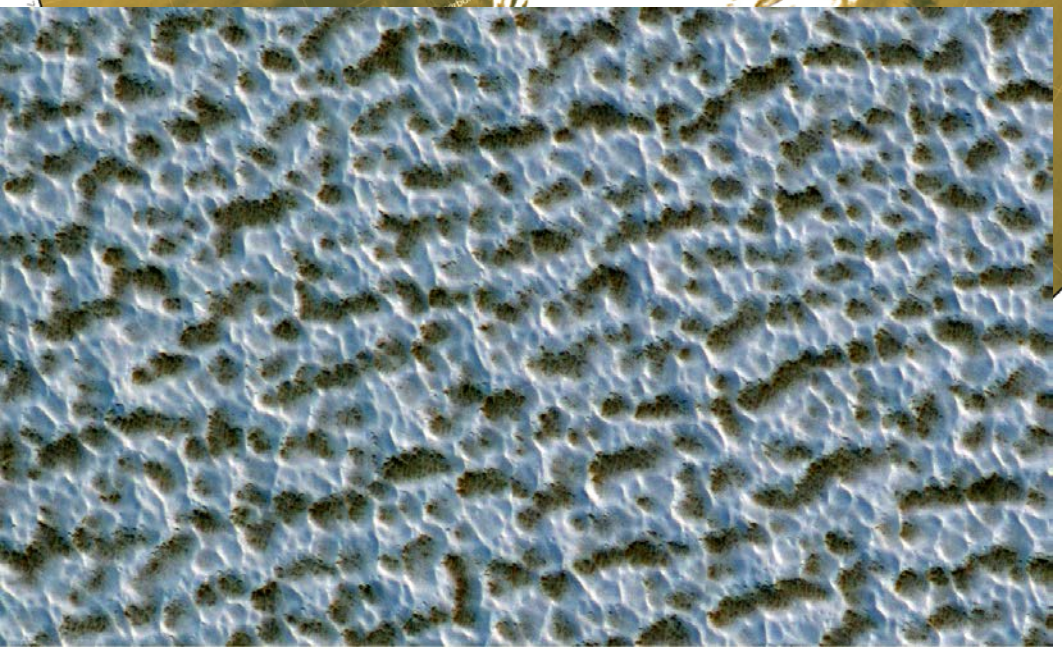


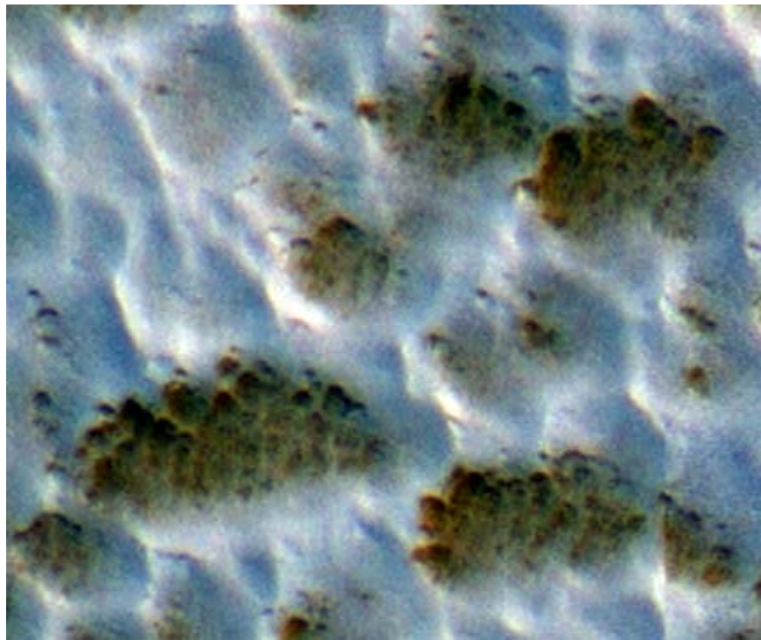


- Residual ice cap is dust-free large-grained water ice

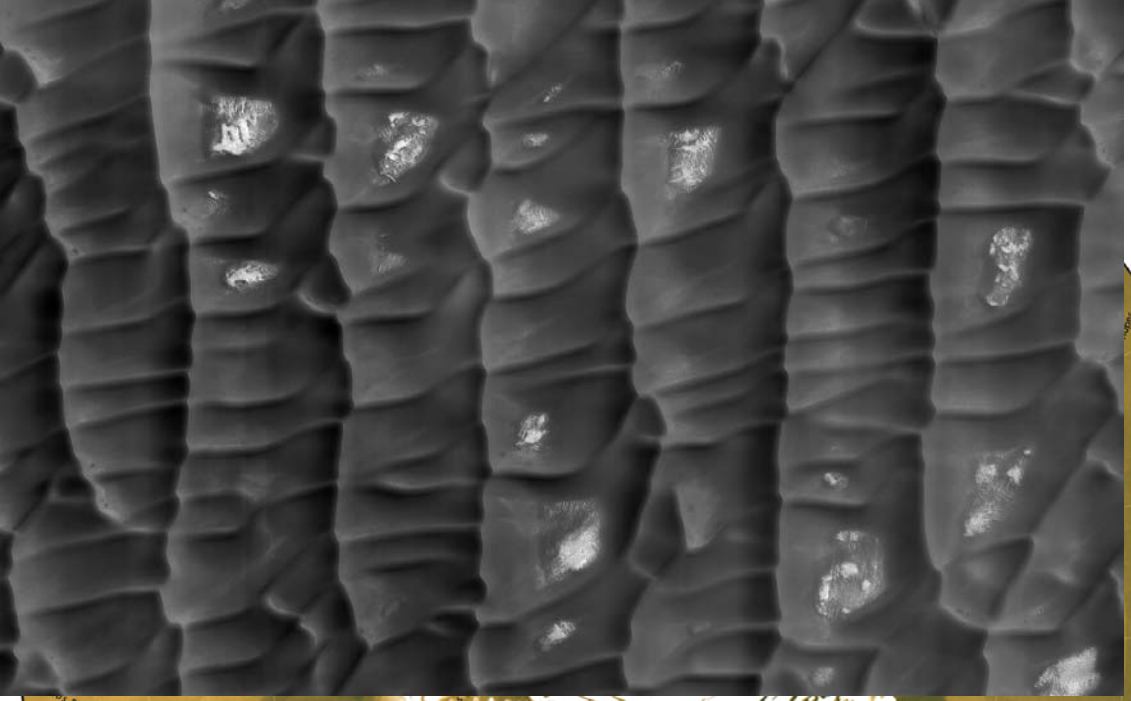


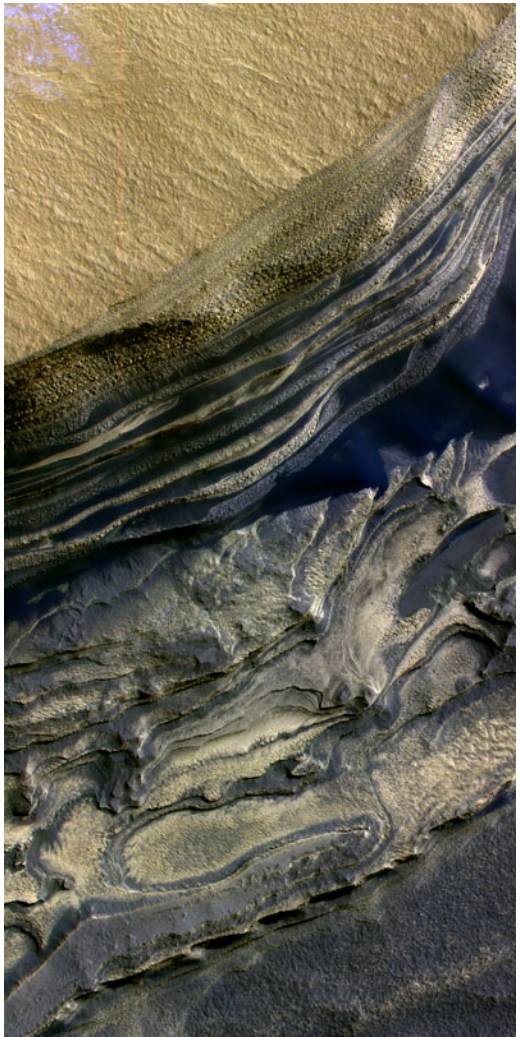




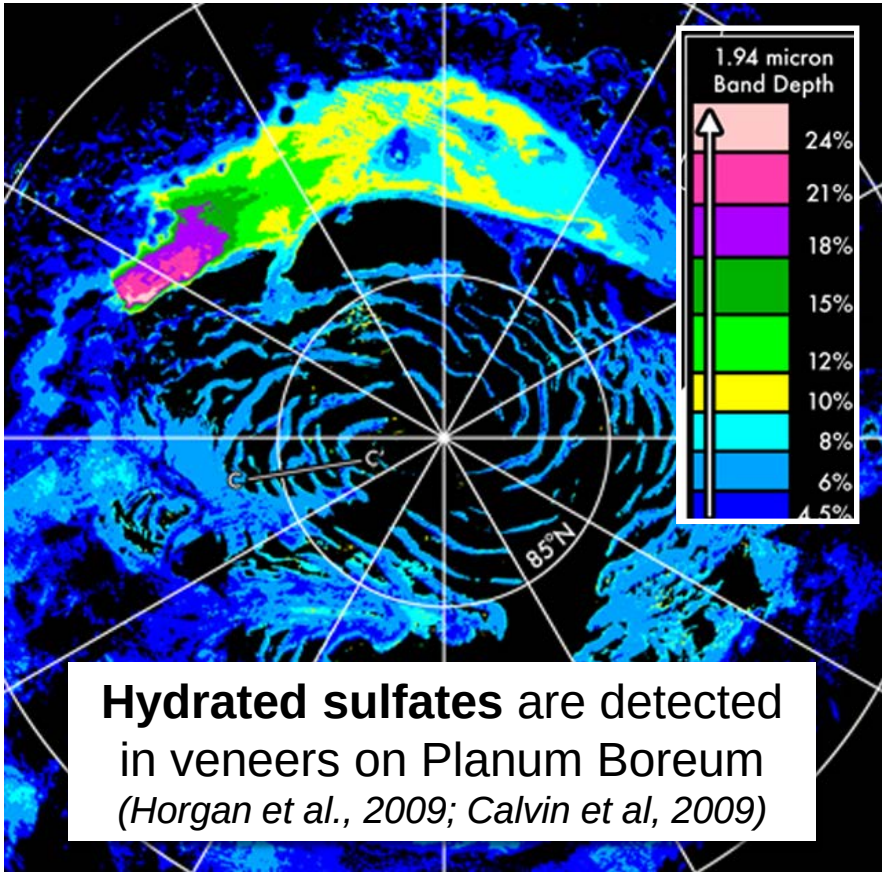


- Surrounding dunes are sourced from a unit beneath the polar layered deposits
- Thermal properties are consistent with normal basaltic sand overlying shallow ice-cemented sand.

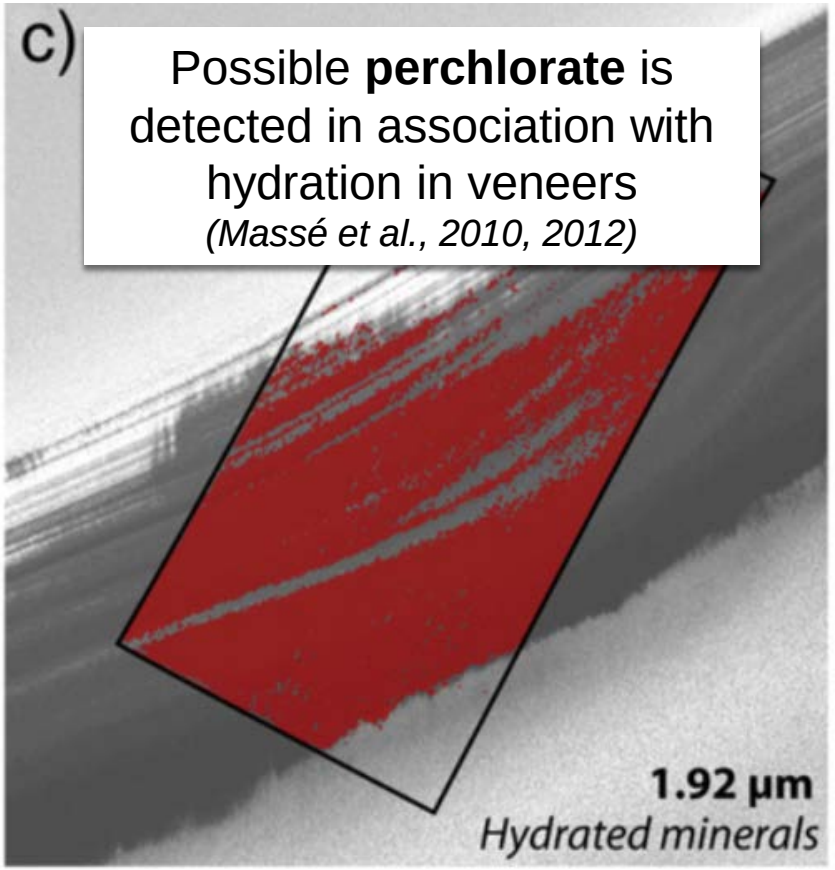




Sulfate and perchlorate salts have been detected within the PLD, but their origin is unclear

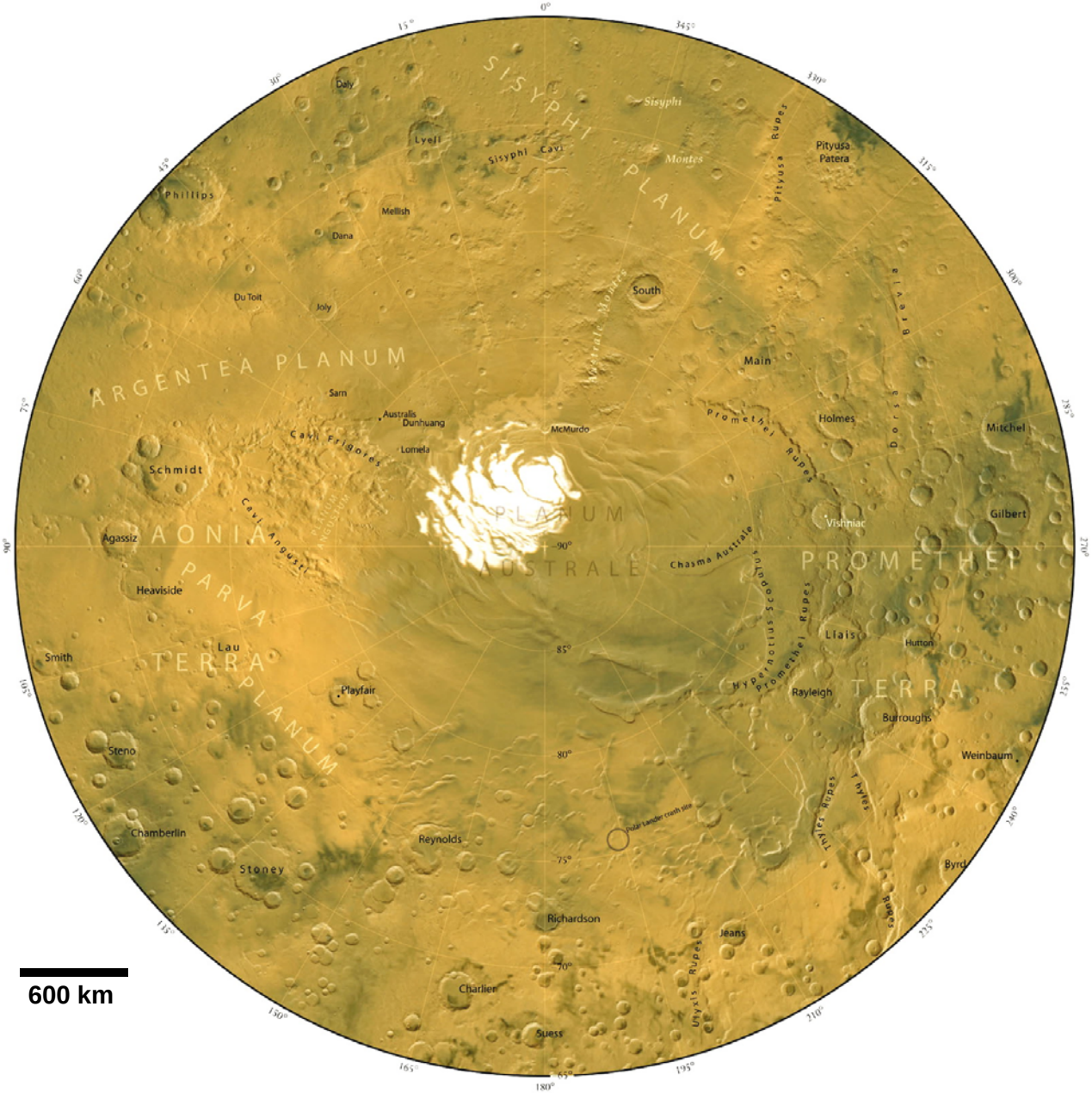


Hydrated sulfates are detected in veneers on Planum Boreum
(Horgan et al., 2009; Calvin et al, 2009)



Possible **perchlorate** is detected in association with hydration in veneers
(Massé et al., 2010, 2012)

Are these salts due to atmospheric deposition, alteration within the ice, or sub-aerial weathering? What can the PLD teach us about the origin of these minerals globally?



The Australe Quadrangle of Mars

Shaded Relief with Albedo Color

by

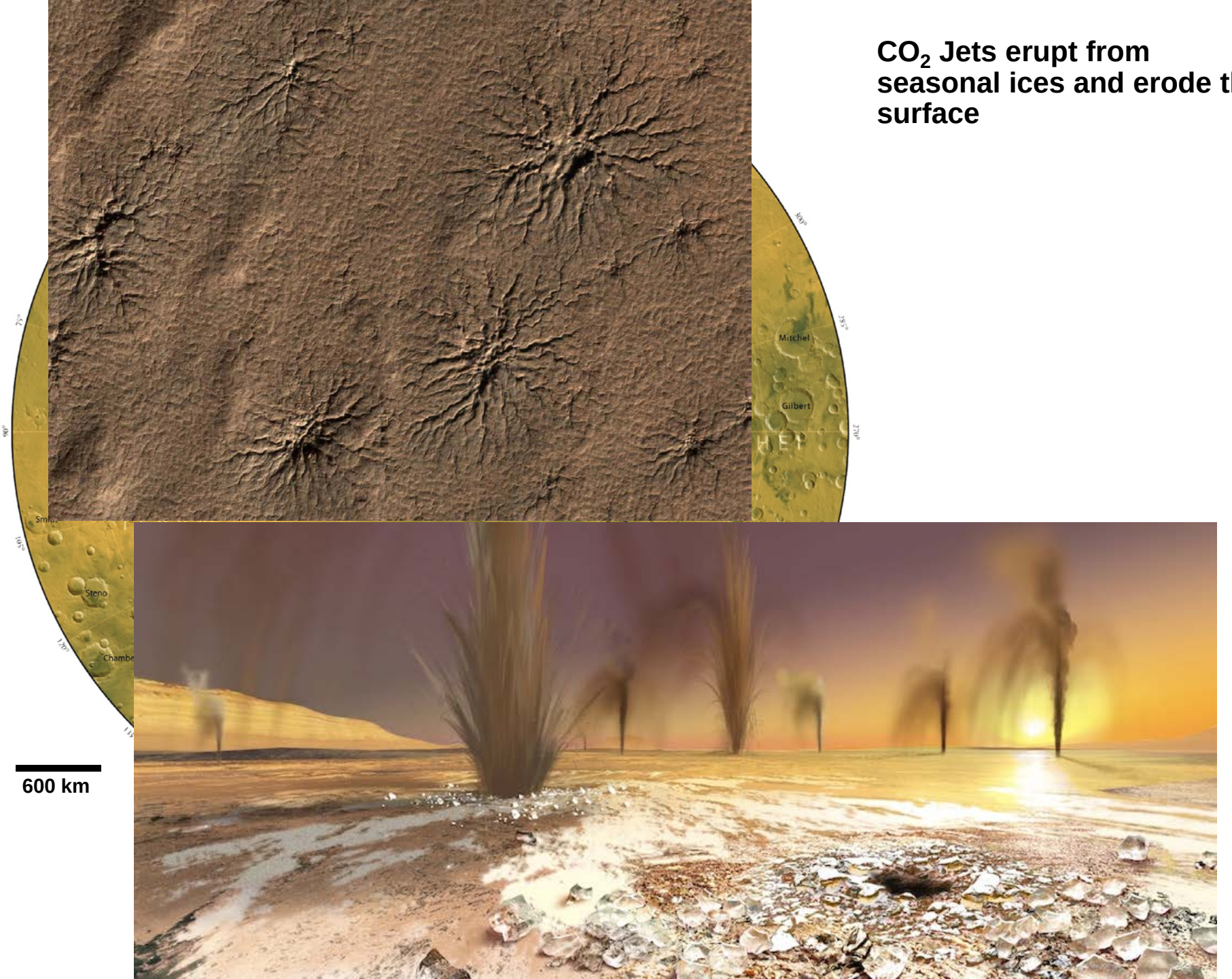
Ralph Aeschliman

Polar Stereographic projection

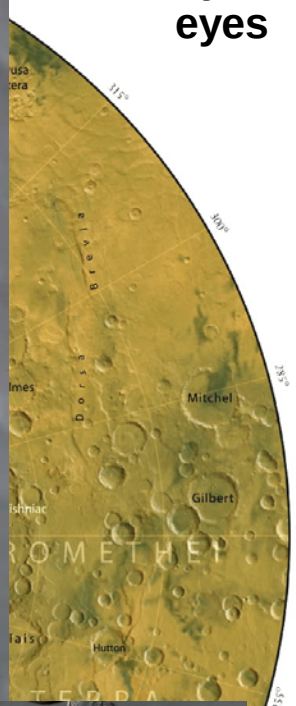
South polar layered deposits:

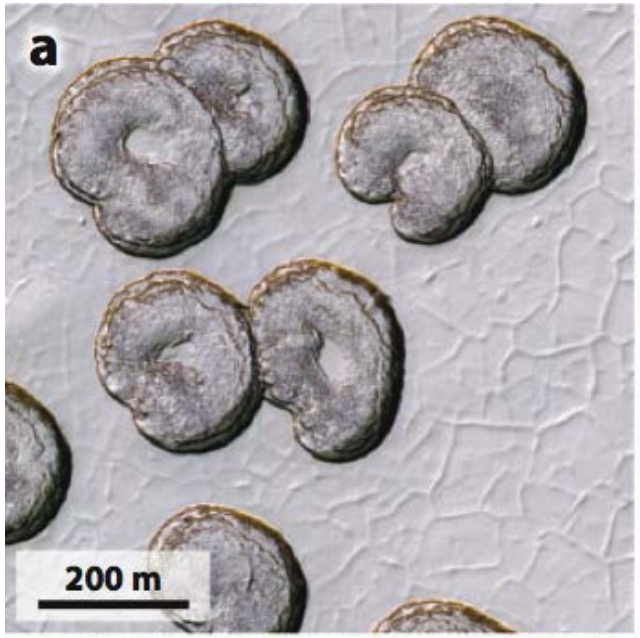
- Mostly covered by a dusty layer – same color and albedo as the surroundings
- Small high-albedo CO_2 ice deposit in current exchange with the atmosphere
- Sits on top of the cratered highlands

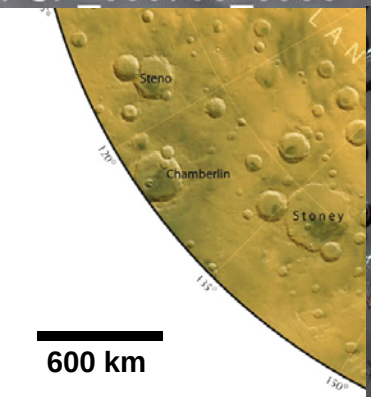
CO_2 Jets erupt from seasonal ices and erode the surface

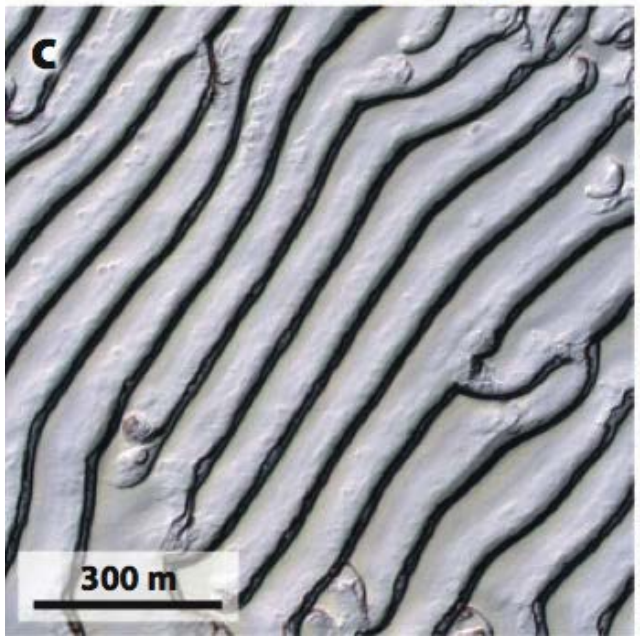


Southern Residual Cap is dynamically changing before our eyes

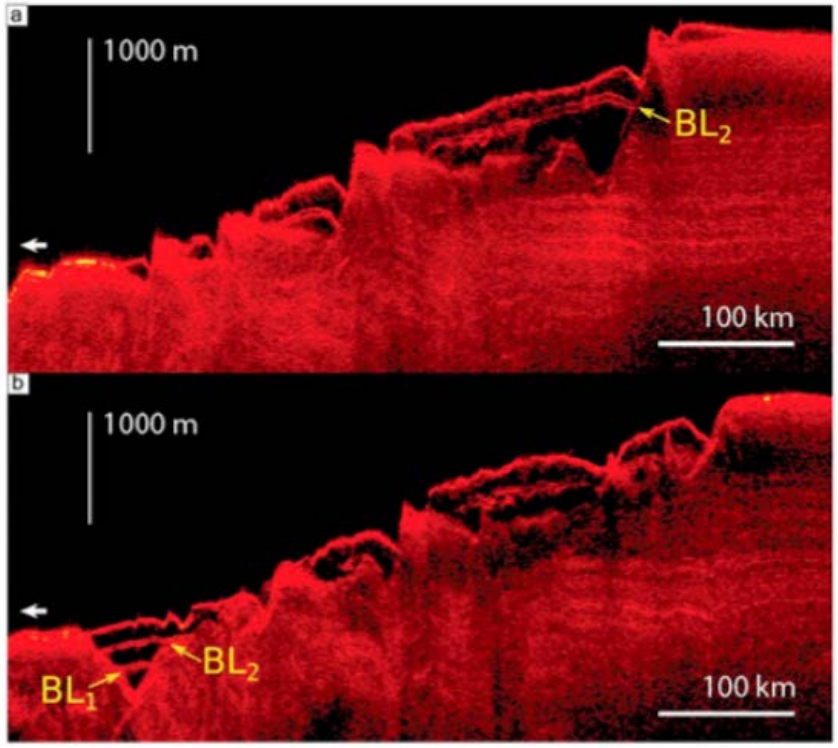


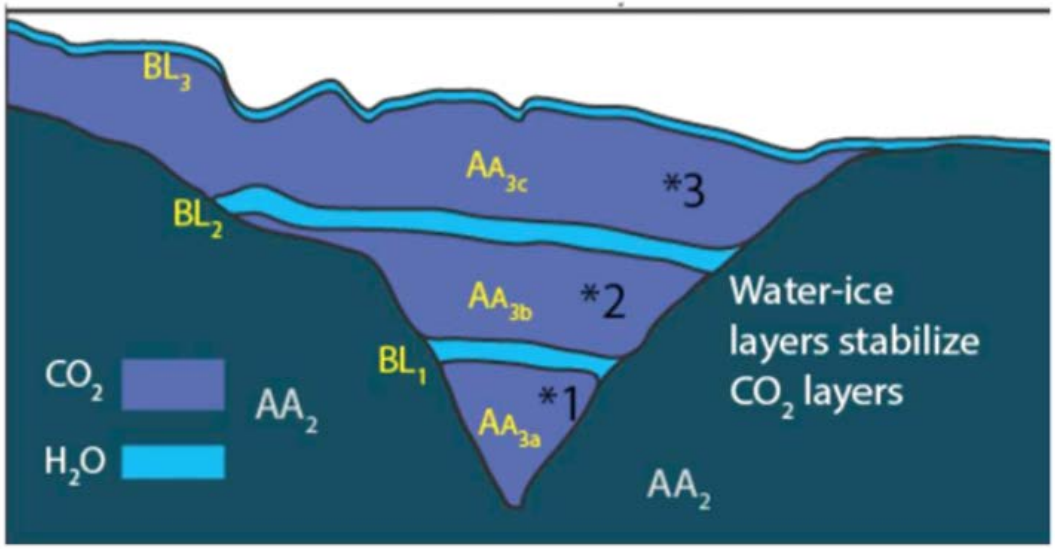






- **What about bulk composition?**
  - RADAR data of the NPLD suggests it is >95% water ice
  - Internal reflections tells us the composition varies with depth
  - Gravity analysis of the SPLD suggests densities of 1200-1300 kg m^{-3}
  - SPLD are more dust rich (~15%) than the NPLD or they're covered by a thick dust layer
  - Significant geographic variability though
- **SPLD radar reflection-free zones indicate several hundred meters of CO_2 ice in places**
  - Enough to at least double the current atmosphere

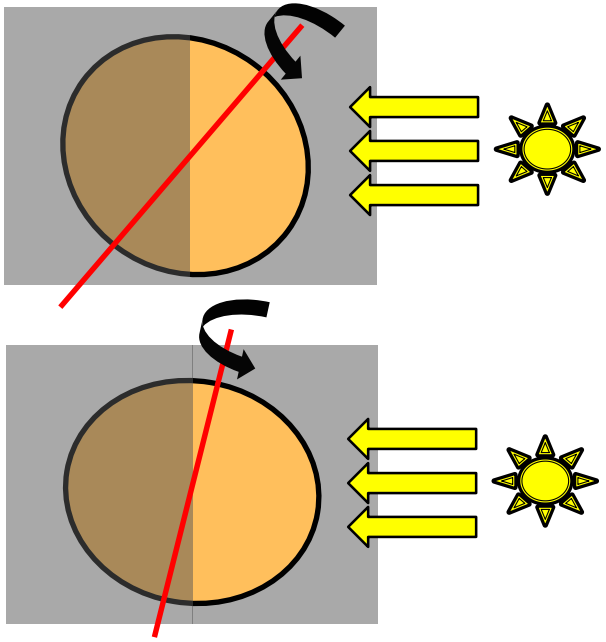




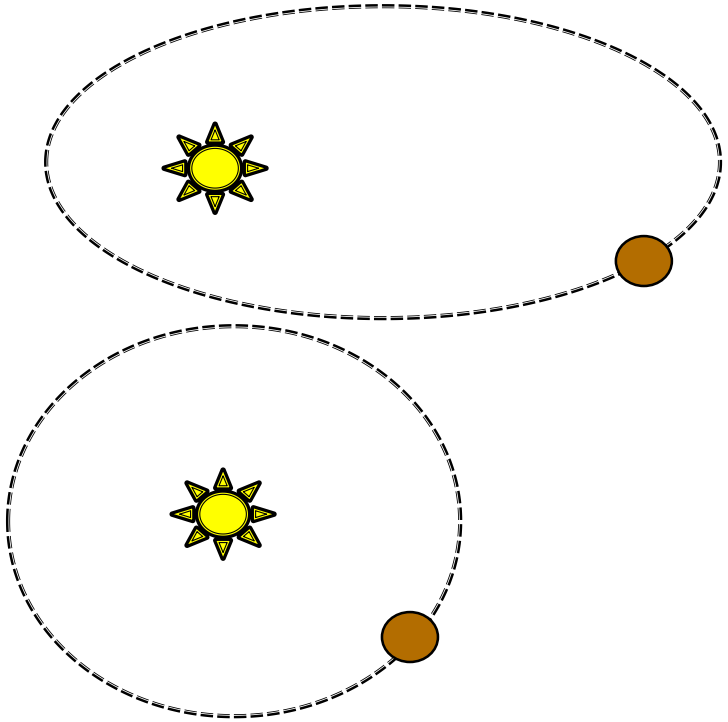
Bierson et al., 2016

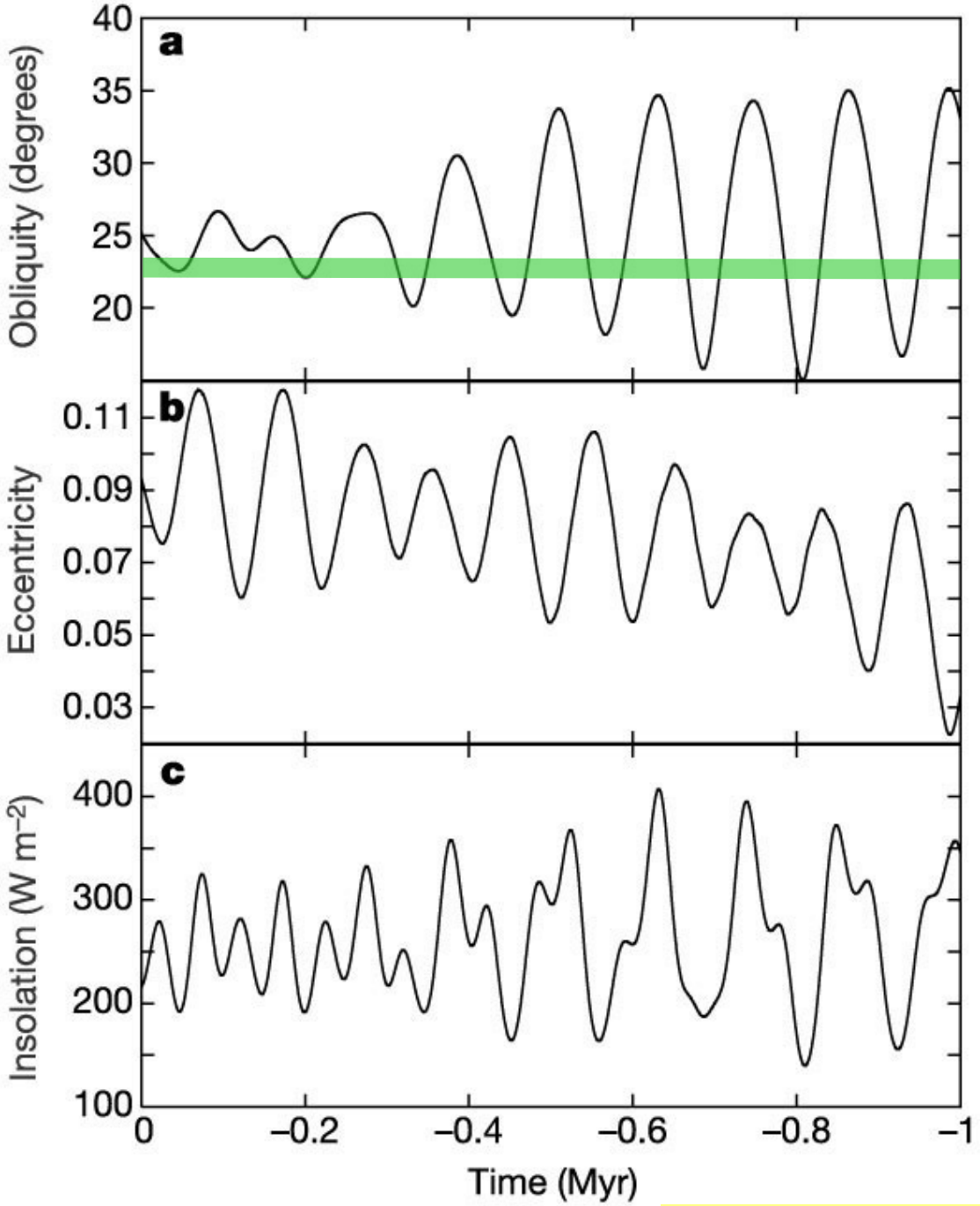
How did all this stuff get there?

- The canonical picture is that atmospheric deposition of water ice and dust in varying proportions built the PLD.
- Periods of sublimation are self-limiting in that ablation of ice builds up dust lags and dust is very insulating
  - Obliquity
    - Earth ~ 23 degrees
    - Mars today ~ 25 degrees



  - Eccentricity
    - Earth ~ 0 (circular)
    - Mars today ~ 0.1 (ellipse)

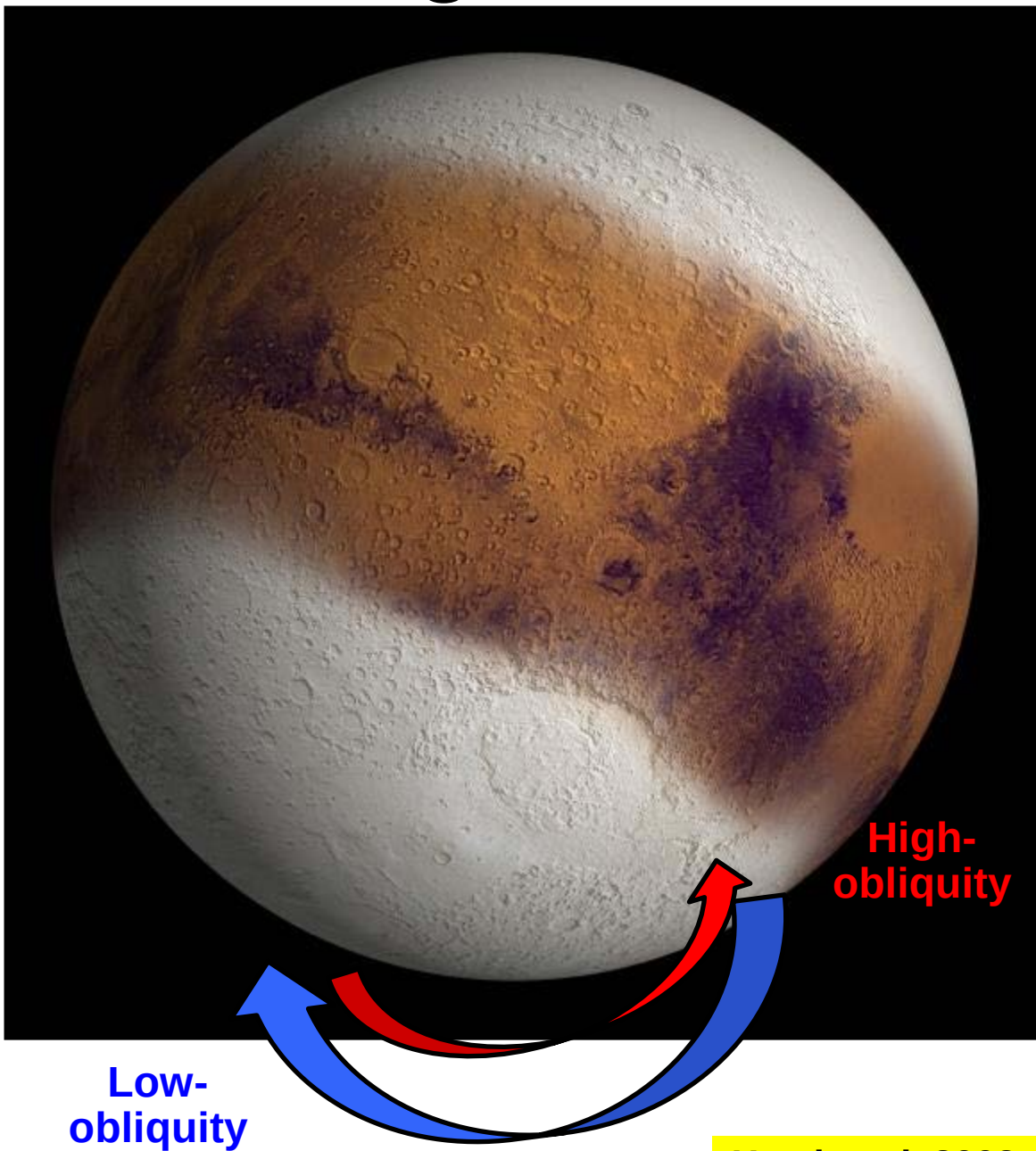




Laskar et al., 2003

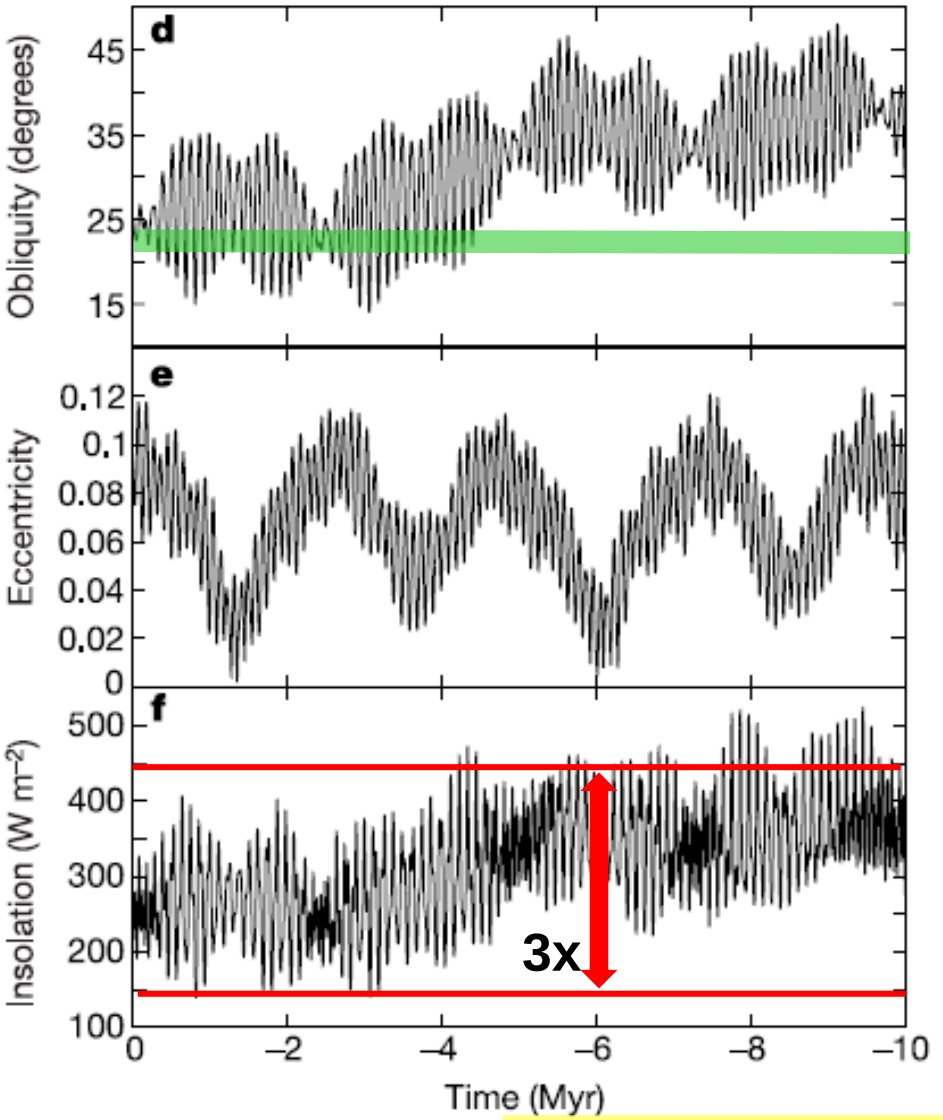
Martian “Ice Ages”

- **During high obliquities**
  - Ice is more stable in the mid-latitudes
  - Water ice sublimates from polar ice caps
  - Reaccumulates in the mid-latitudes
- **During low obliquities**
  - Ice is more stable at the poles
  - So water moves back…

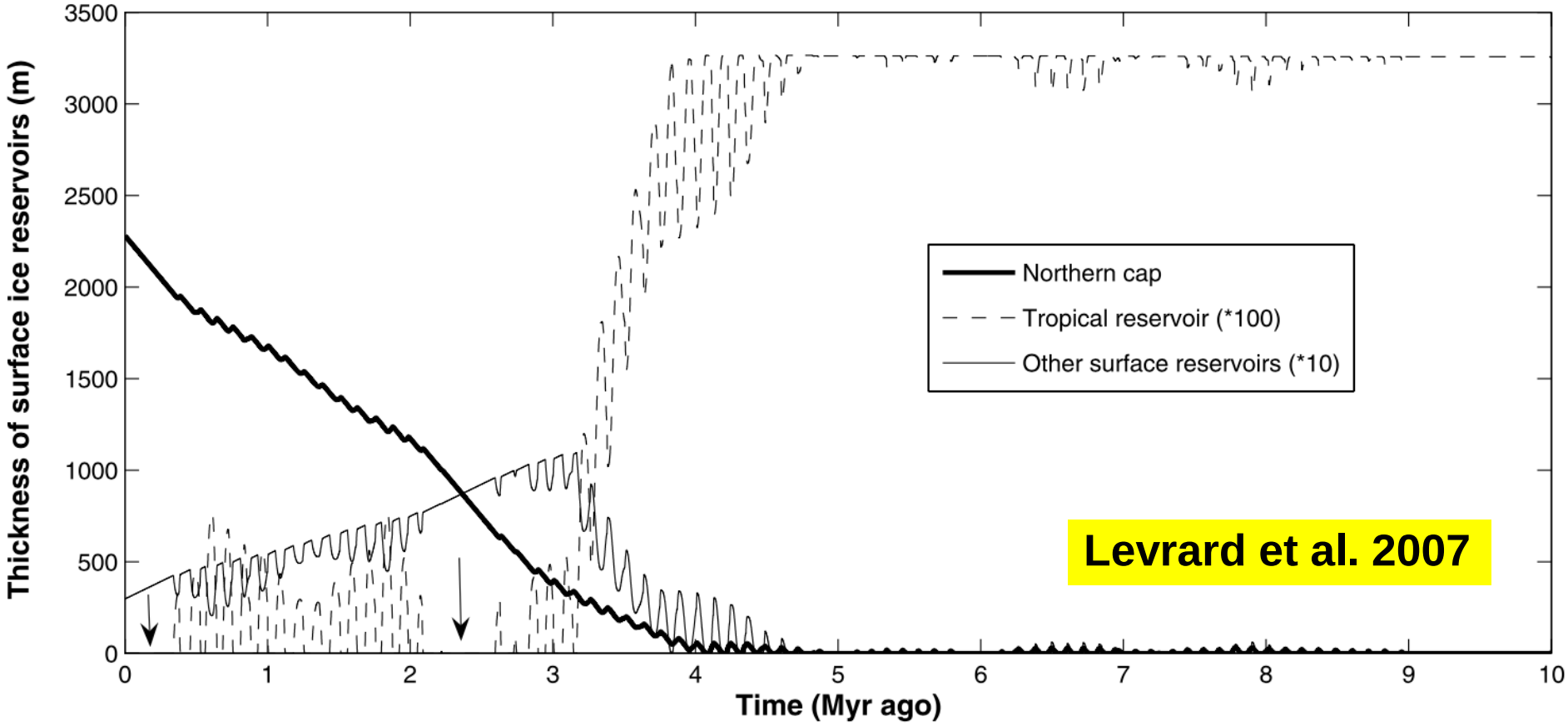


Head et al. 2003

- Even larger variations before that
  - Factor of 3 variation in solar power

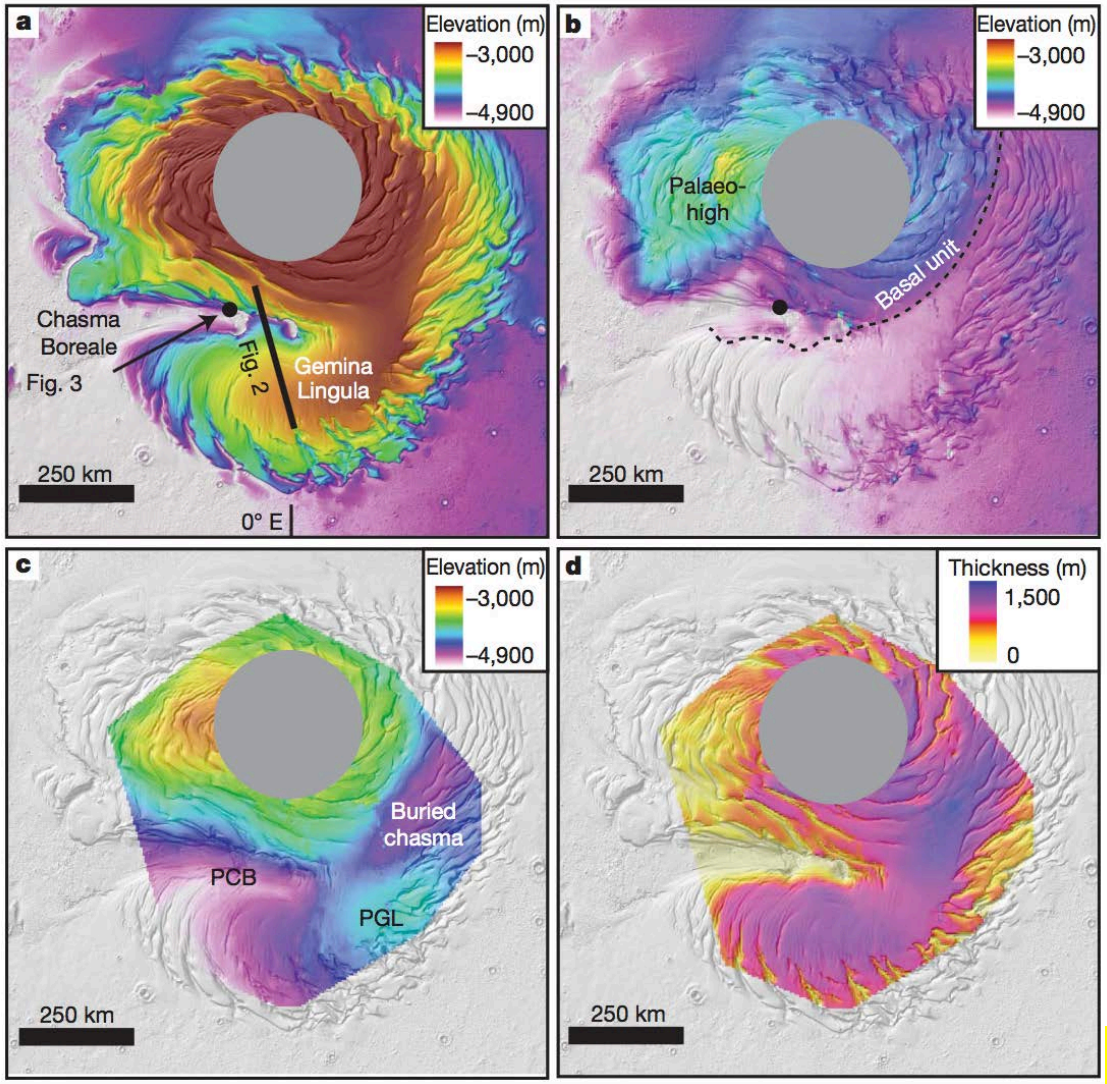


Laskar et al., 2003



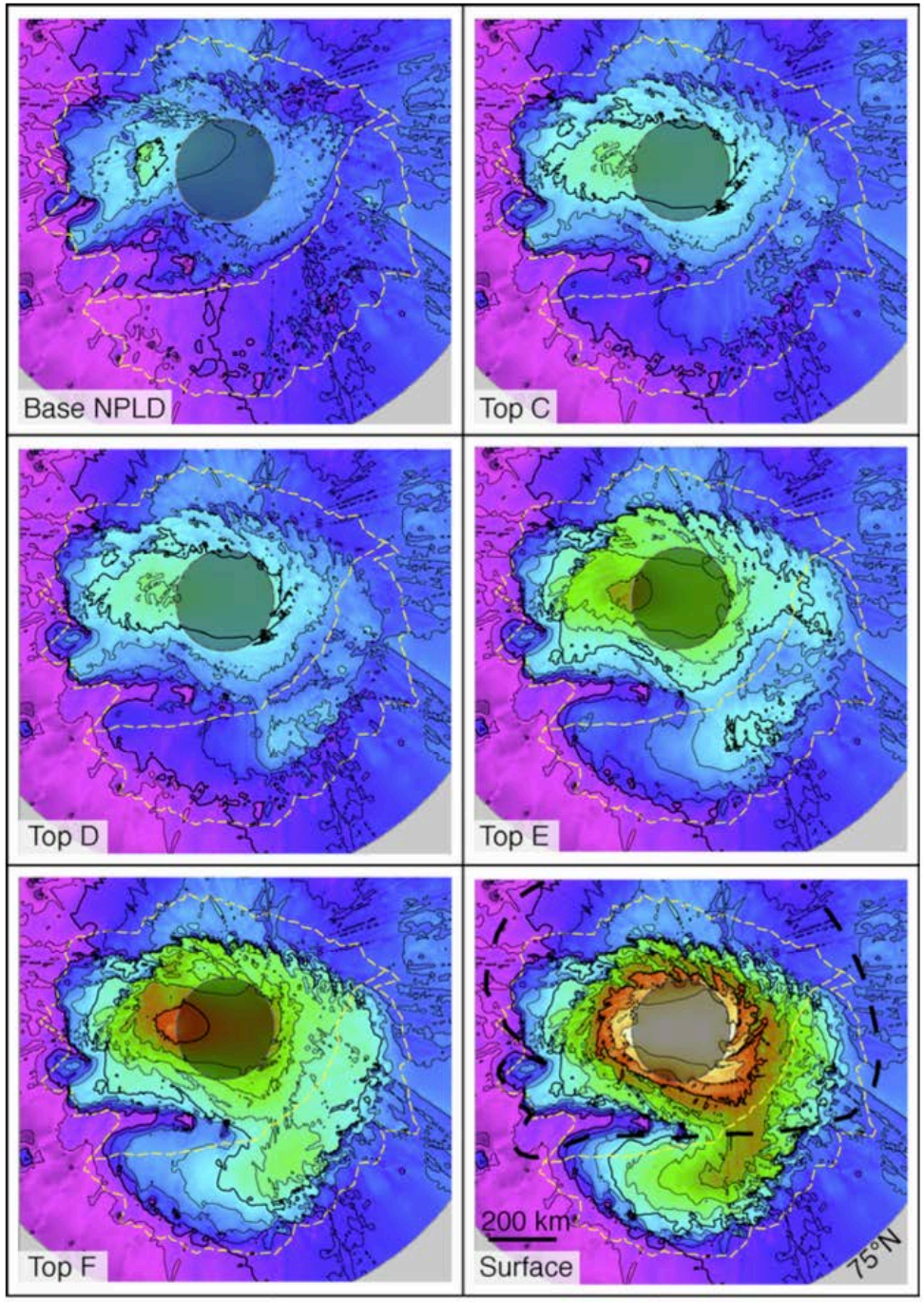
- **Jump to higher obliquity ~4-5 million years ago**
  - It's thought that pre-existing icy polar layered deposits could not survive that
  - Present NPLD may date from this epoch, but lag deposits are probably a key factor
- **This simple picture is probably naïve and conflicts with basic info like the cratering record of the SPLD (surface age of 10s of Myr)**
  - More on this later this week

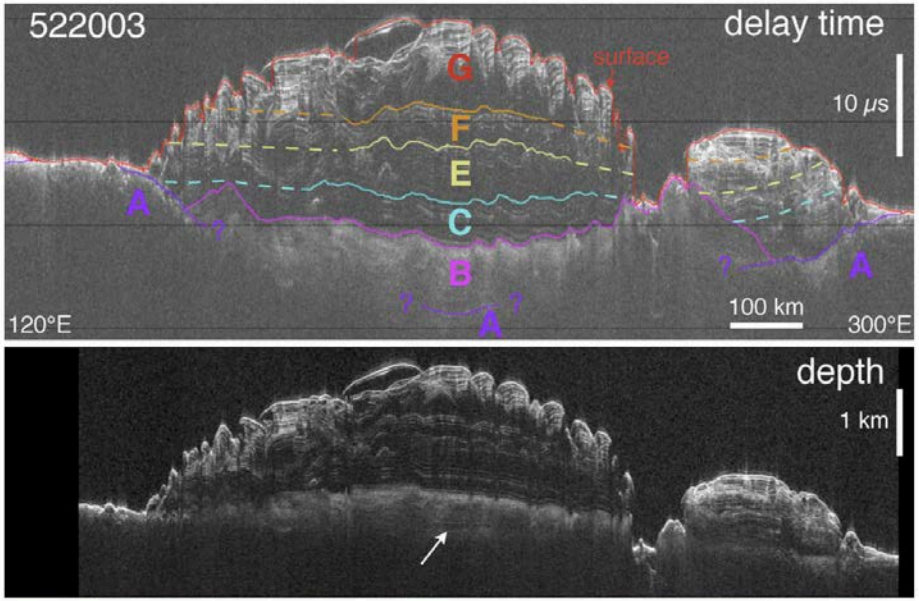
- Internal RADAR reflections map out paleo-surfaces and can tell us how the NPLD grew with time e.g.
  - Base of the polar layered deposits
  - Or a widespread unconformity



- Chasma Boreale is a long-lived feature that the polar deposits grew up around
  - Early ideas about melting a flood event turned out to be incorrect.
- Chasma Boreale wasn't the only large Chasma. Another Chasma disappeared due to faster ice accumulation in that area.

Holt et al., 2010

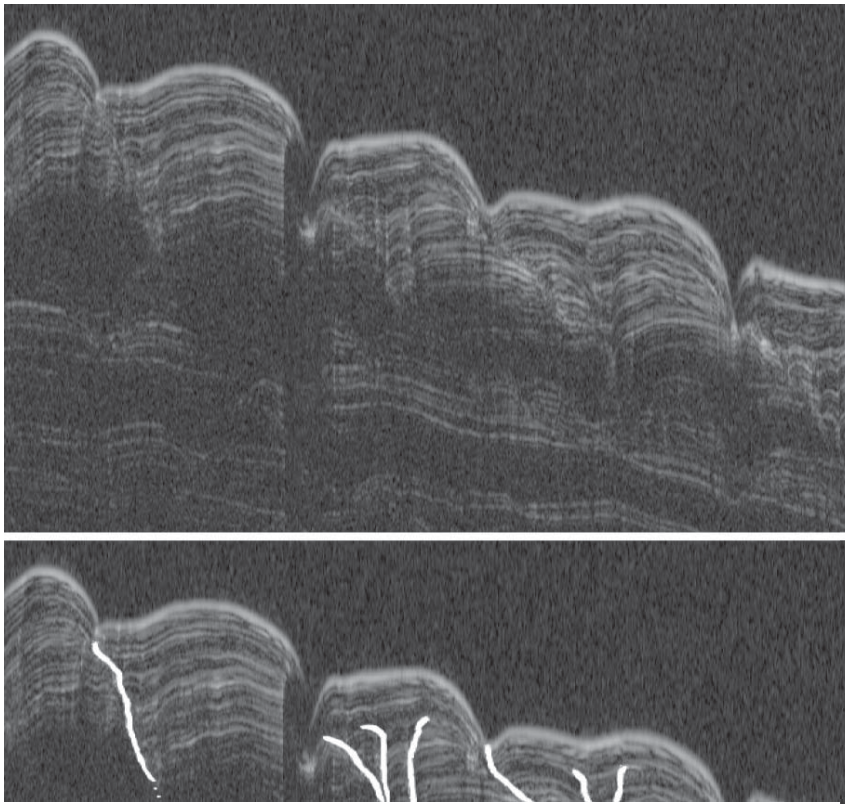


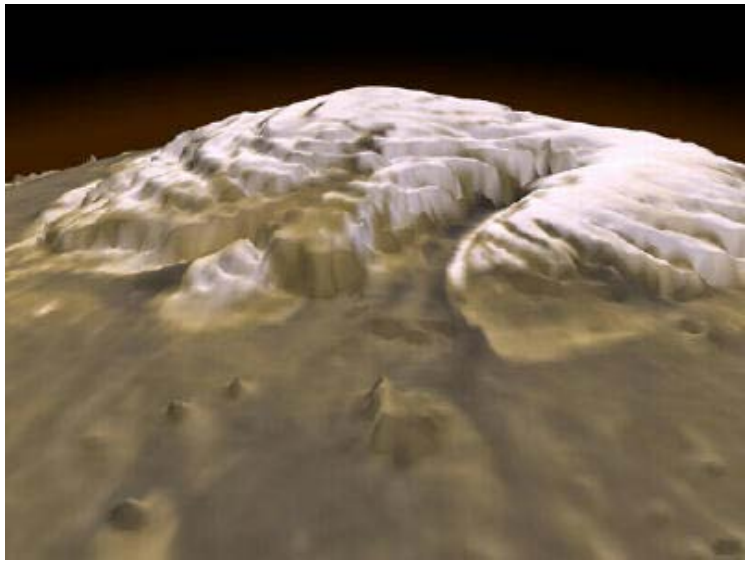


- Multiple radar units can be defined by packets of reflectors.
- The NPLD growth though time can be shown (without date labels)
- All trough-exposed stratigraphy occurs in the top unit

Putzig et al. 2009

What about the troughs?

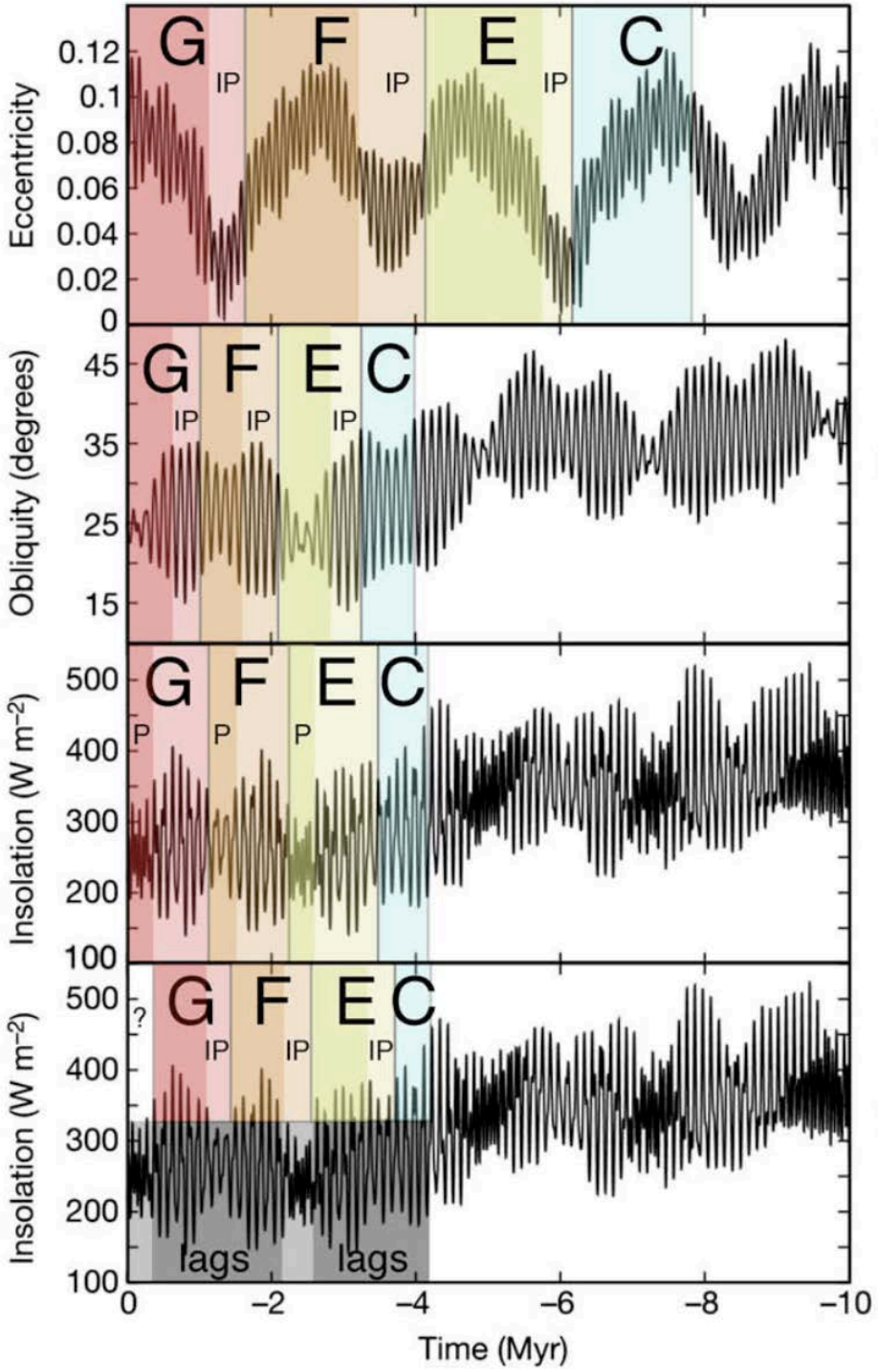




- Stratigraphic discontinuities show troughs migrating poleward as the NPLD accumulates.

- Troughs haven't always existed, they were initiated partway through NPLD history.
  - Perhaps when the NPLD grew thick enough to generate significant katabatic winds

Smith et al. 2010



Phillips et al., 2008
Scenario 1

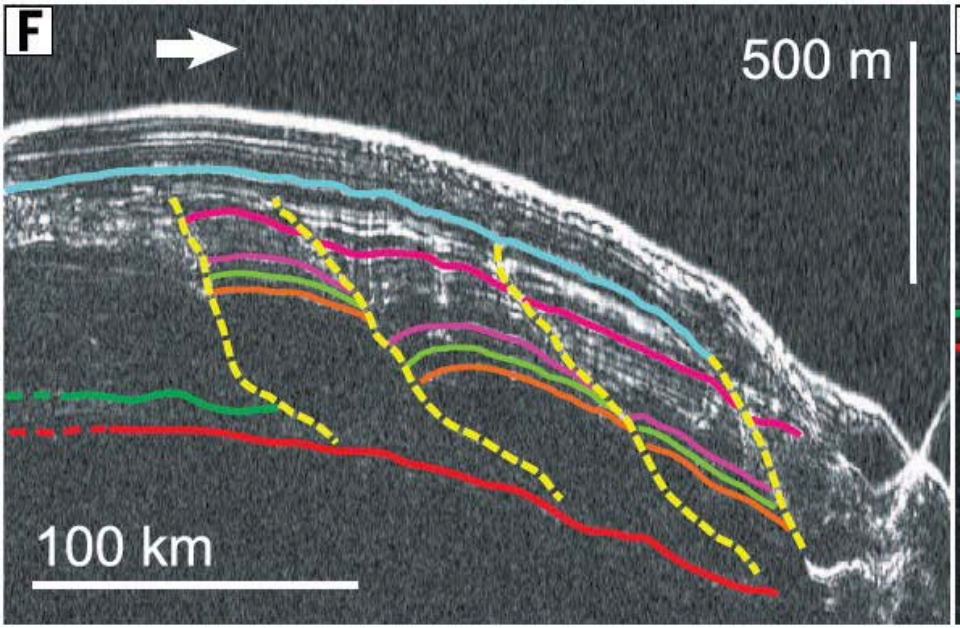
Phillips et al., 2008
Scenario 2

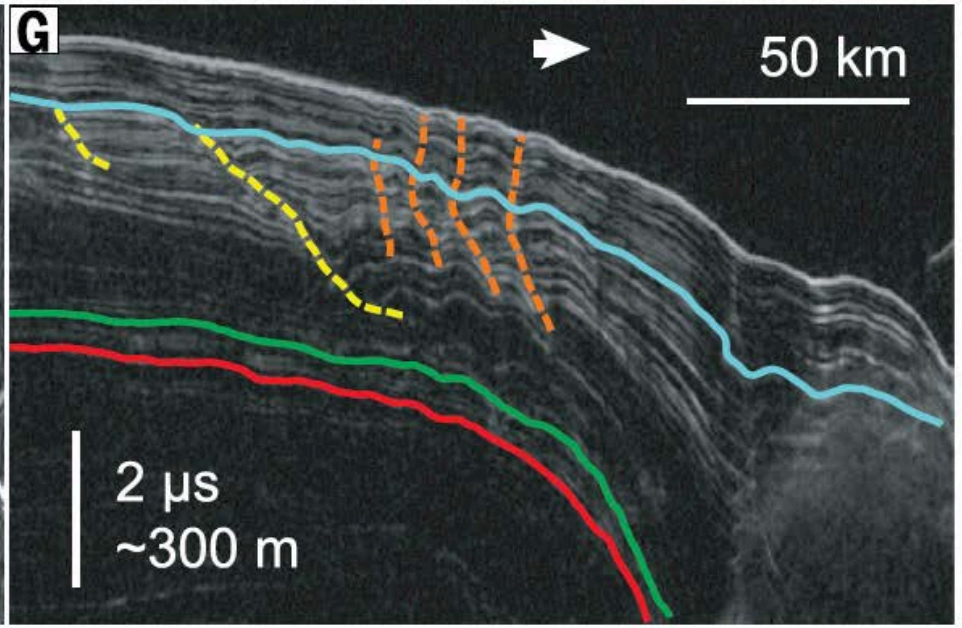
Putzig et al., 2009
(Figure 11)

Levrard et al., 2007

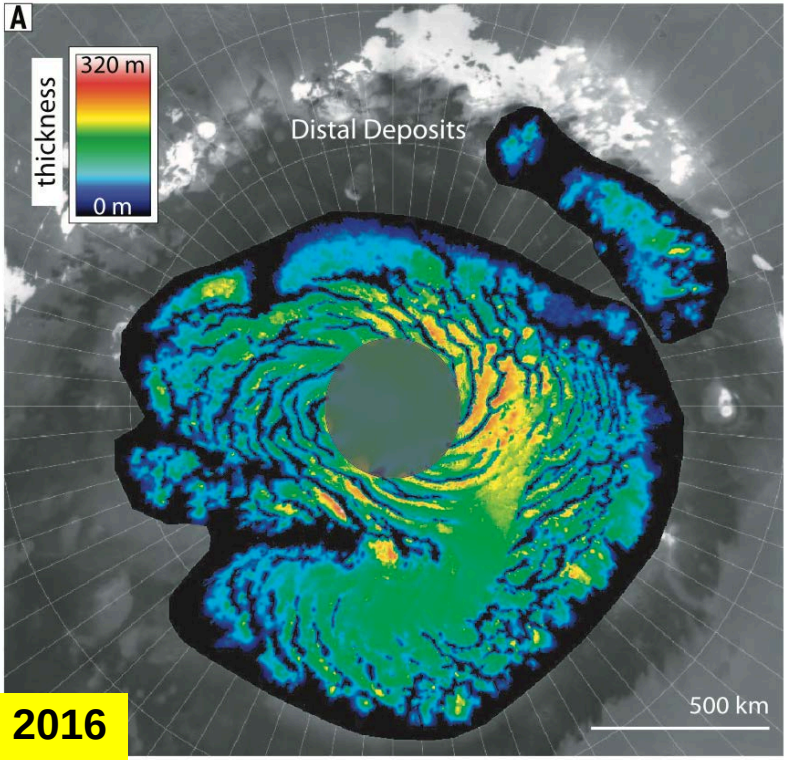
- Correlations between radar units and orbital periods have been attempted
- Correlations within the upper few hundred meters have produced more consensus
  - More from Patricio in following talks

Putzig et al. 2009





- The most recent accumulation buries some troughs
- Accumulation rates have peaked over the past ~100m (interpreted to be ~400kyr)

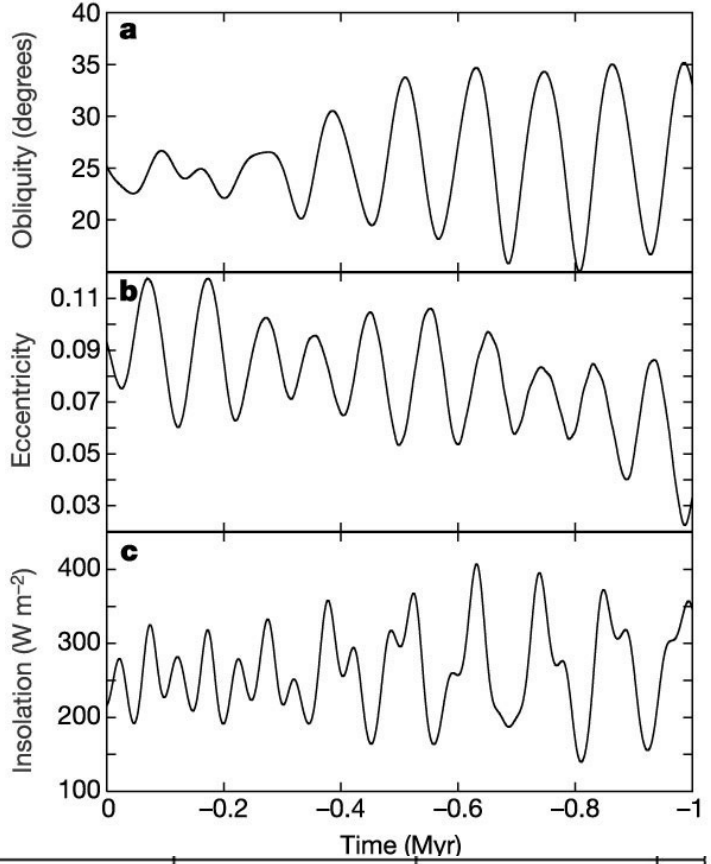


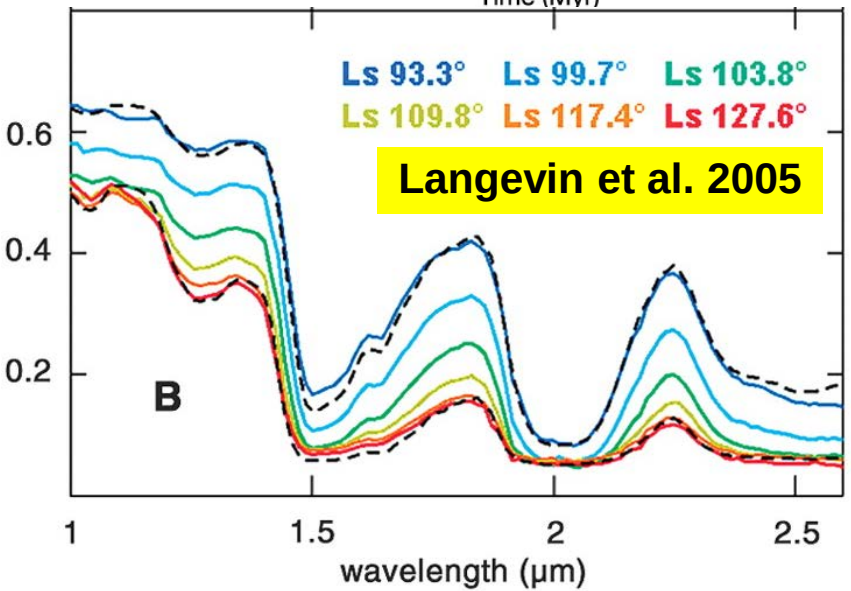
Smith et al. 2016

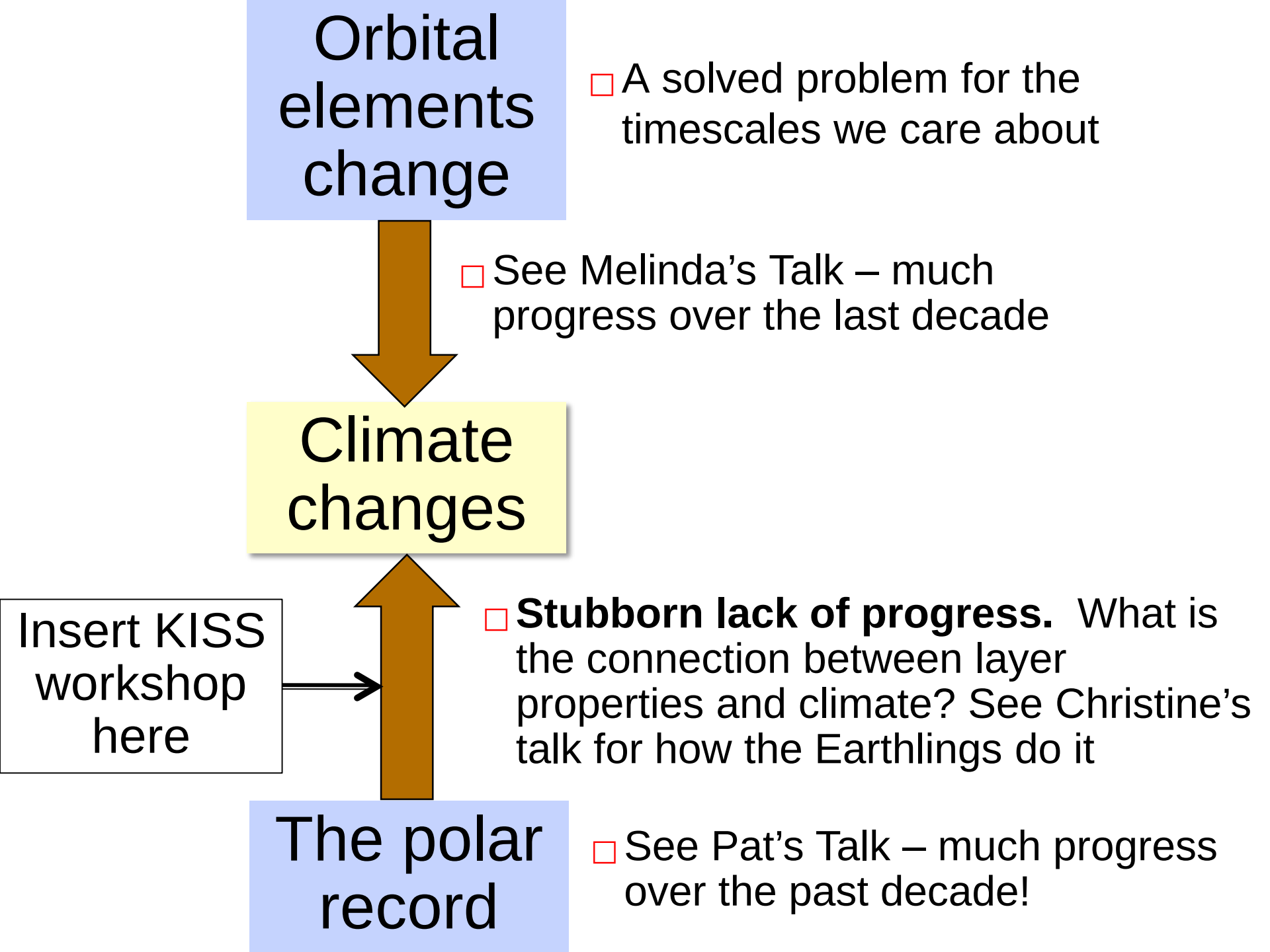
Are the PLD accumulating today? Expectations from orbital elements and models are ambiguous…

- The SPLD plainly isn't accumulating. Loosely consolidated dust covers the surface and craters dating has estimated (with many uncertainties) the age at 10s of Myr.
- NPLD accumulation?
  - Bright dust-free ice at the surface indicates recent accumulation and little ablation
  - Crater population that formed entirely within the past ~1000 years

  …but…
  - Large-grained ice is exposed each summer i.e. all the seasonal water frost is lost each spring so there's net loss each year
- NPLD accumulation may have recently ended






Orbital elements change
A solved problem for the timescales we care about
See Melinda's Talk – much progress over the last decade
Climate changes
Insert KISS workshop here
Stubborn lack of progress. What is the connection between layer properties and climate? See Christine's talk for how the Earthlings do it
The polar record
See Pat's Talk – much progress over the past decade!

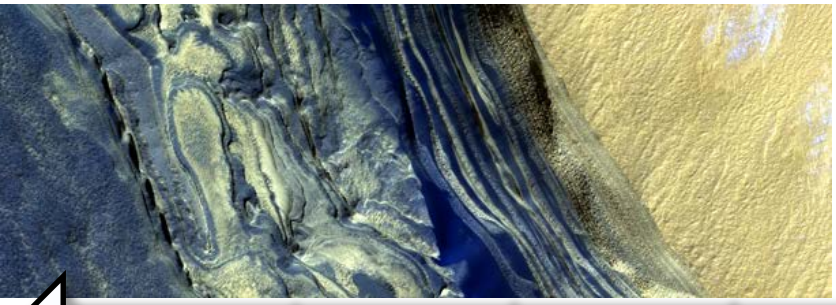
Summary

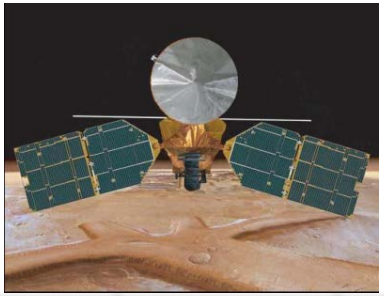
- Seasonal CO_2 and H_2O frosts sublimate away each spring to reveal thin residual ice caps that partly cover kilometers-thick polar layered deposits
- Martian Polar layered deposits record millions (perhaps10s of millions) of years of climatic history
  - ~10^4 layers
  - Unconformities and modeling suggests that this record is incomplete
  - Troughs and scarps are dynamic features
- Substantial progress over the past decade – but a critical step remains to be tackled!

RANDOM EXTRAS

Climatic Record

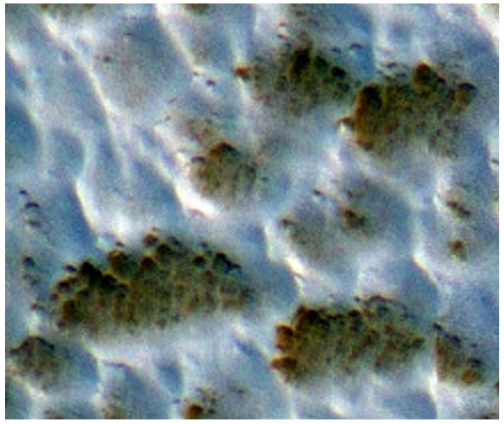
Spacecraft Record





YEARS

10^8 10^7 10^6 10^5 10^4 10^3 10^2 10^1 10^0



Recent climatic variations

Interannual variability of the current climate

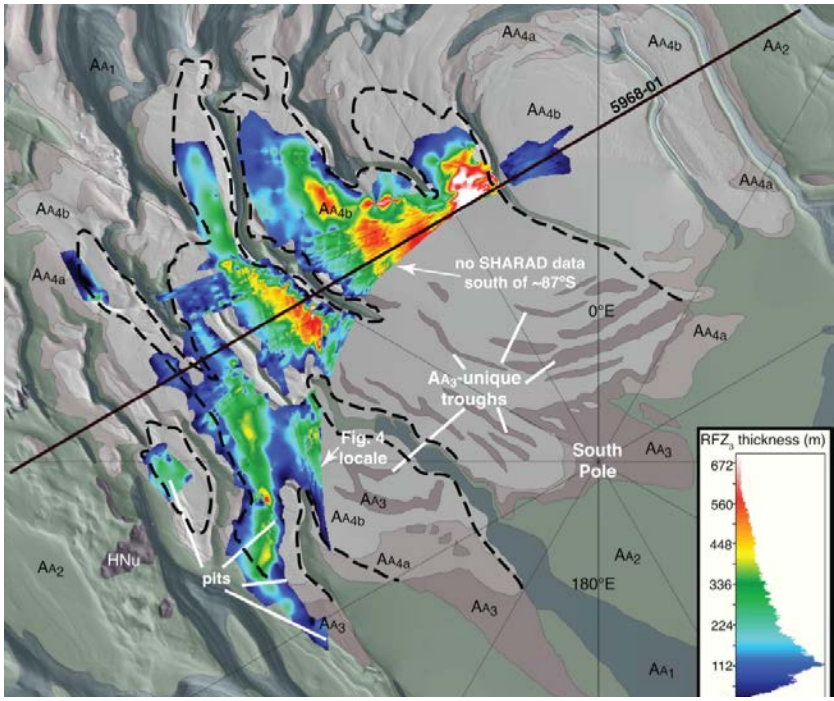
- More CO_2 ice buried below some H_2O ice
  - Accessible to the atmosphere in high obliquity periods
  - Could double atmospheric pressure
- Current residual cap stabilizes this larger deposit

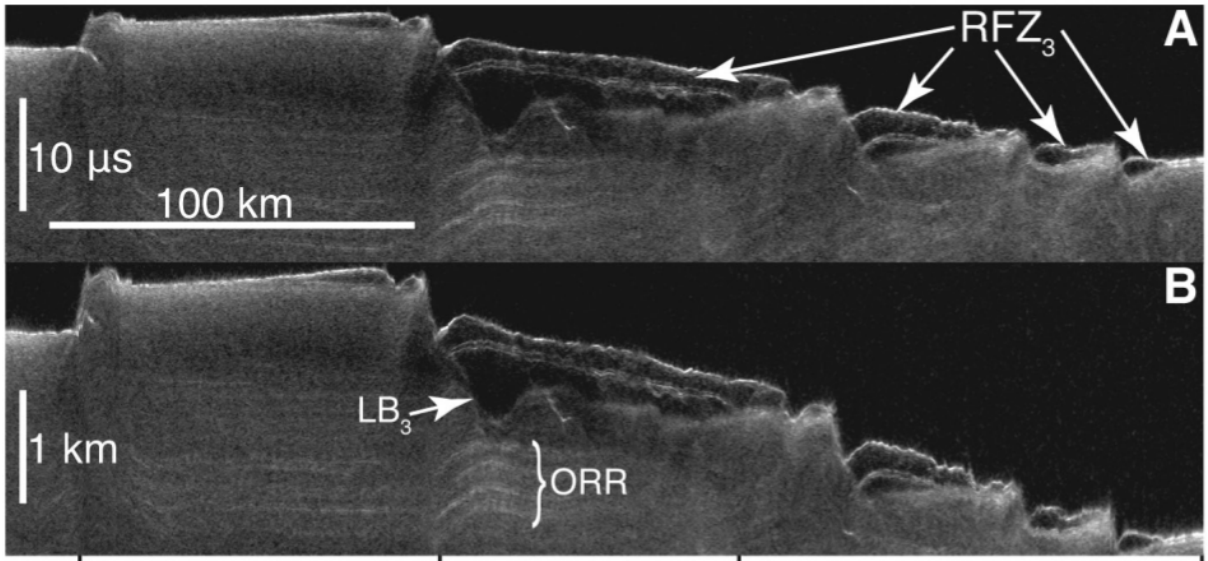
CO_2 ice, a few meters thick ← $10\text{-}10^2$yr timescales

H_2O ice, a few meters thick ← 10^4 yr timescales

Buried CO_2 ice
Up to 100s meters thick ← 10^5 yr timescales

Polar Layered Deposits
H_2O ice
Up to 4km thick ← $10^6\text{-}10^7$ yr timescales

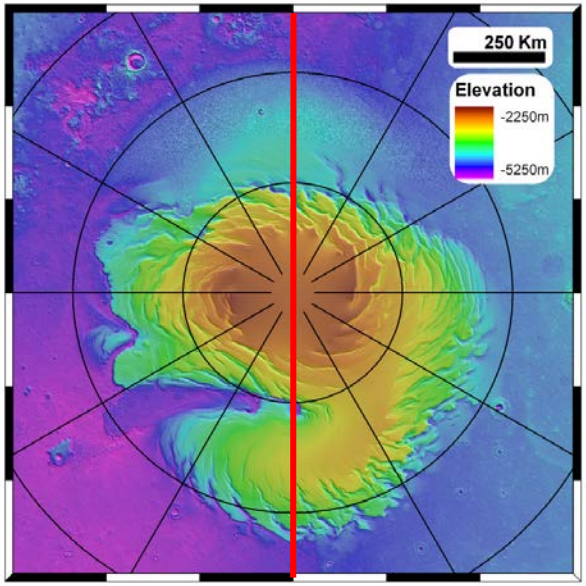




Phillips et al., 2011

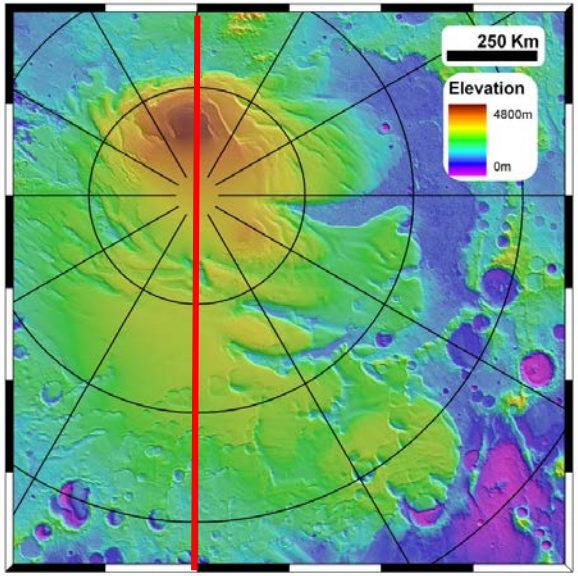
Mars North pole

1.1 million km³

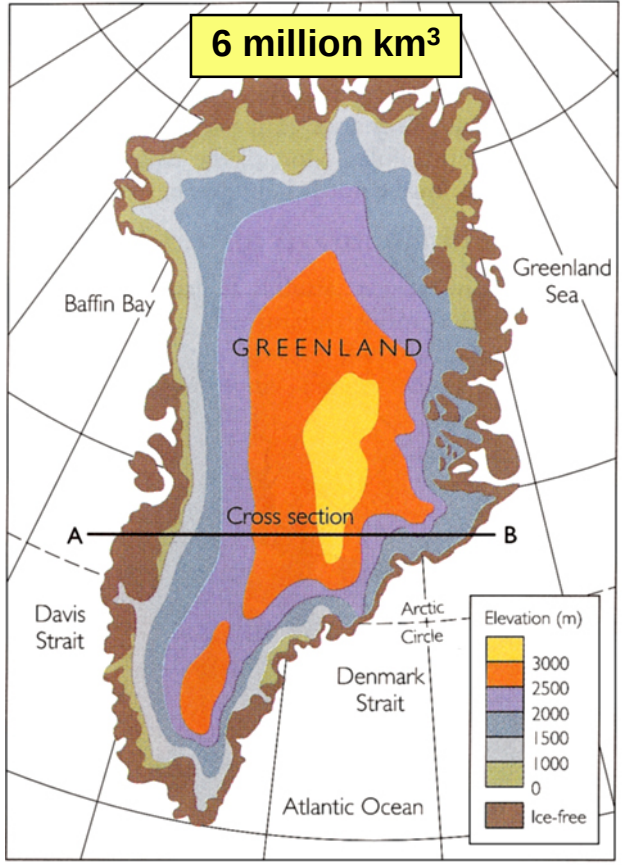


Mars South pole

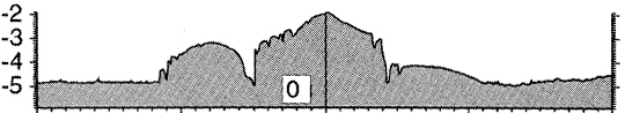
1.2 million km³

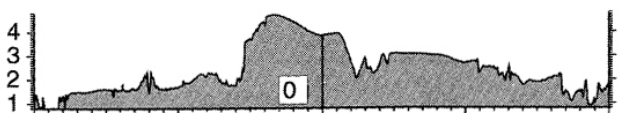


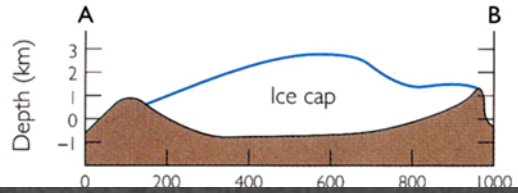
6 million km³

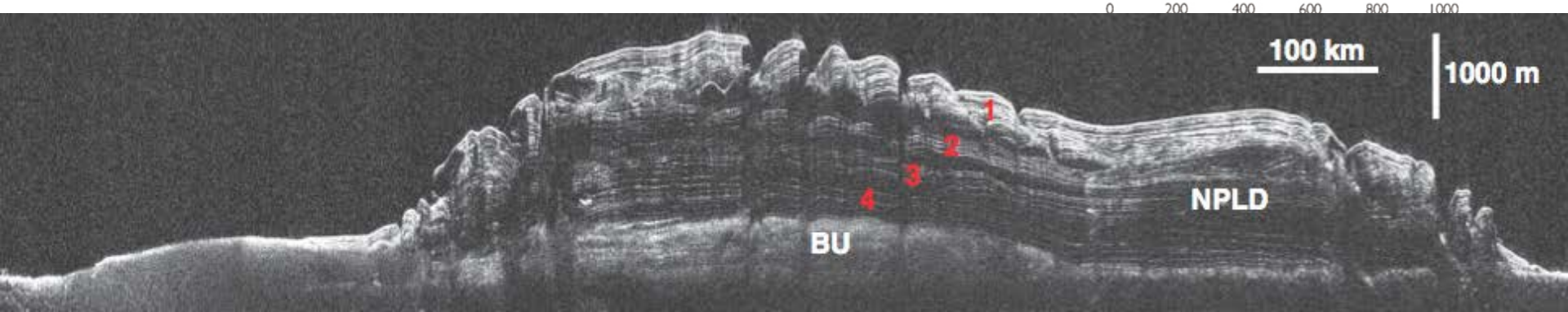


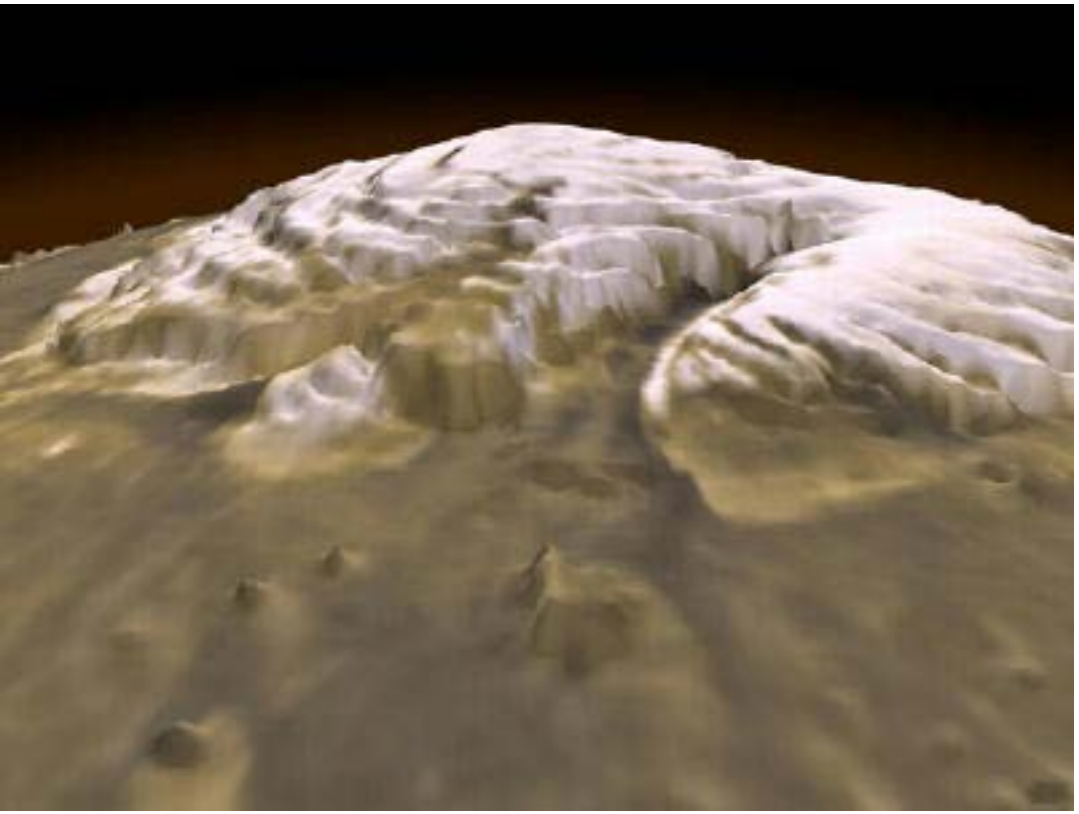
North V.E. 100:1 South

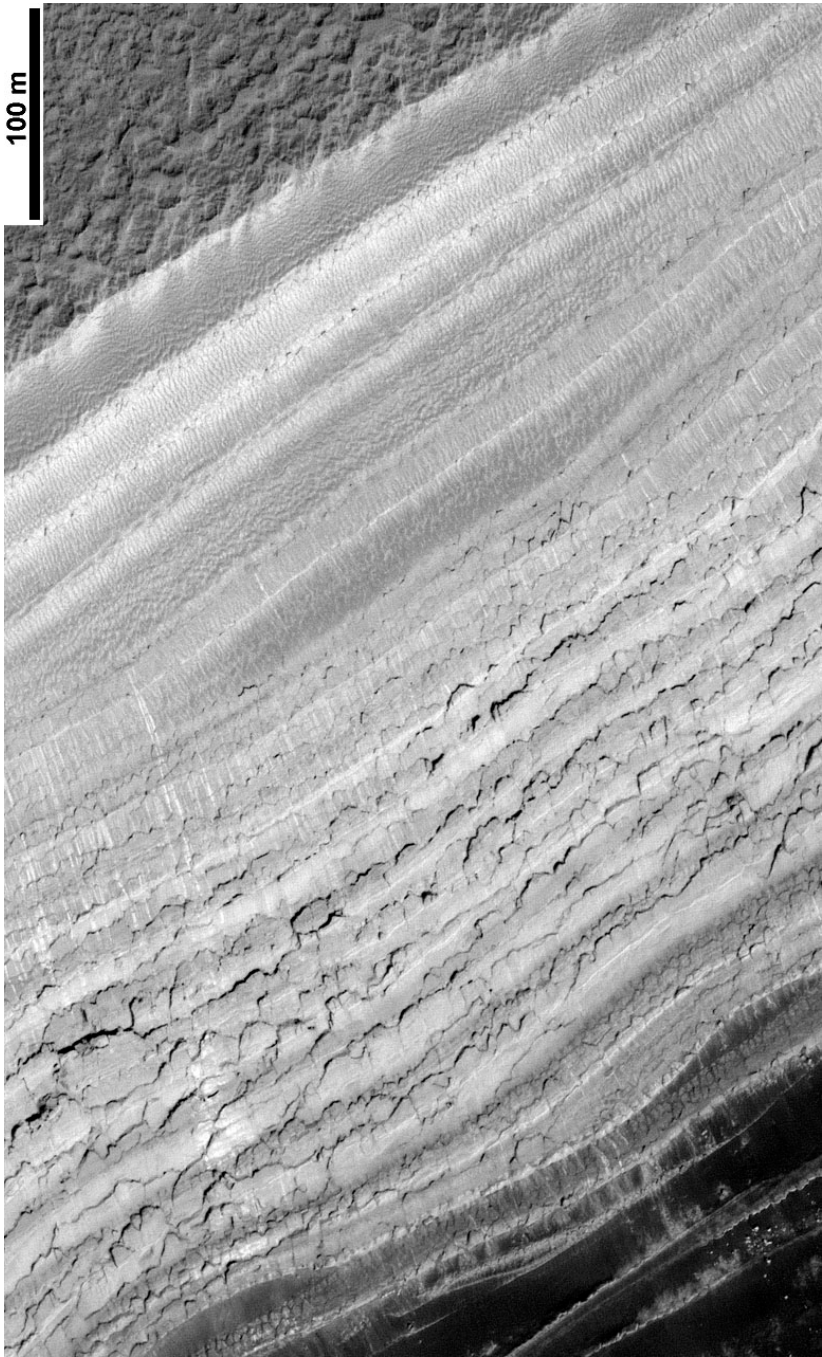






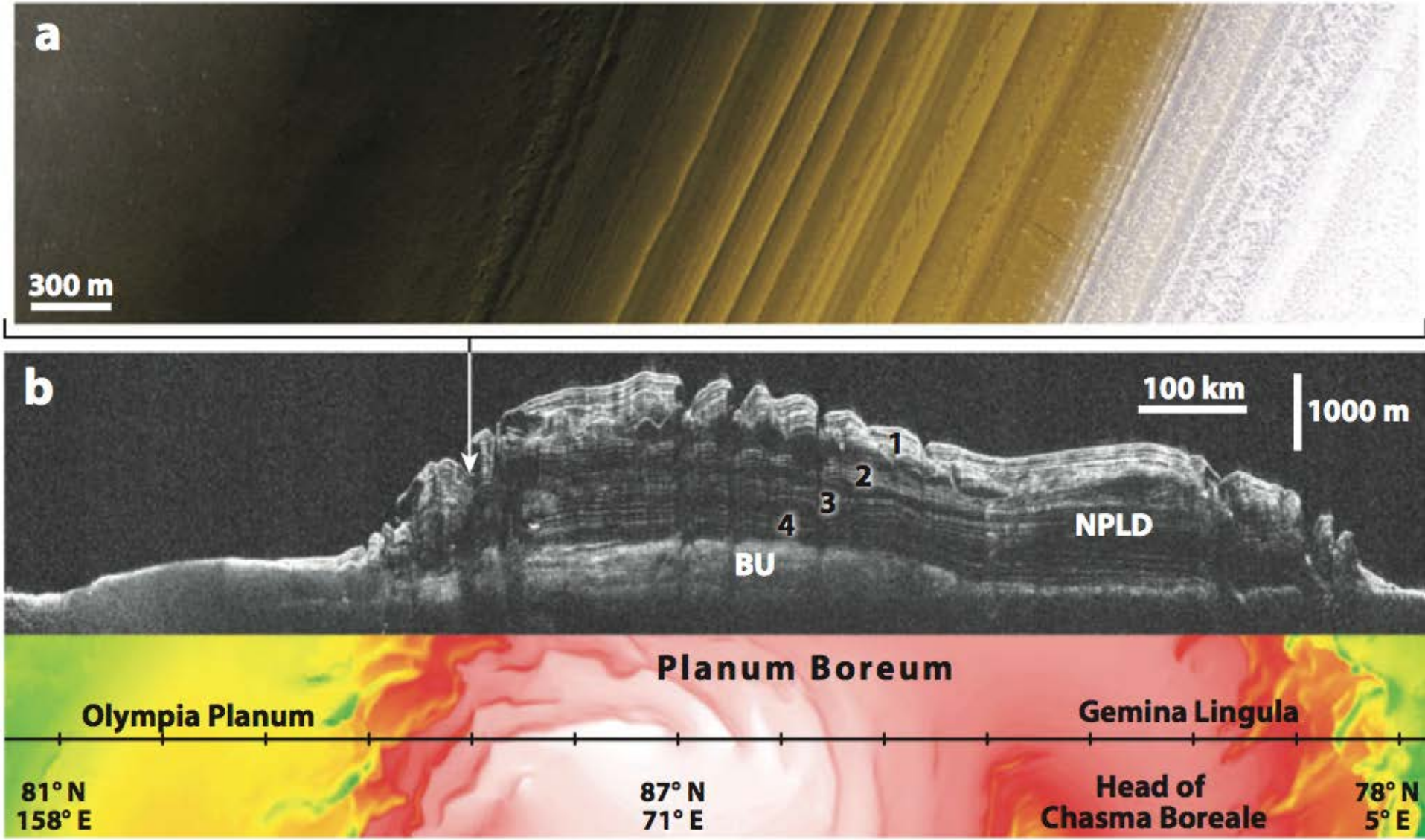




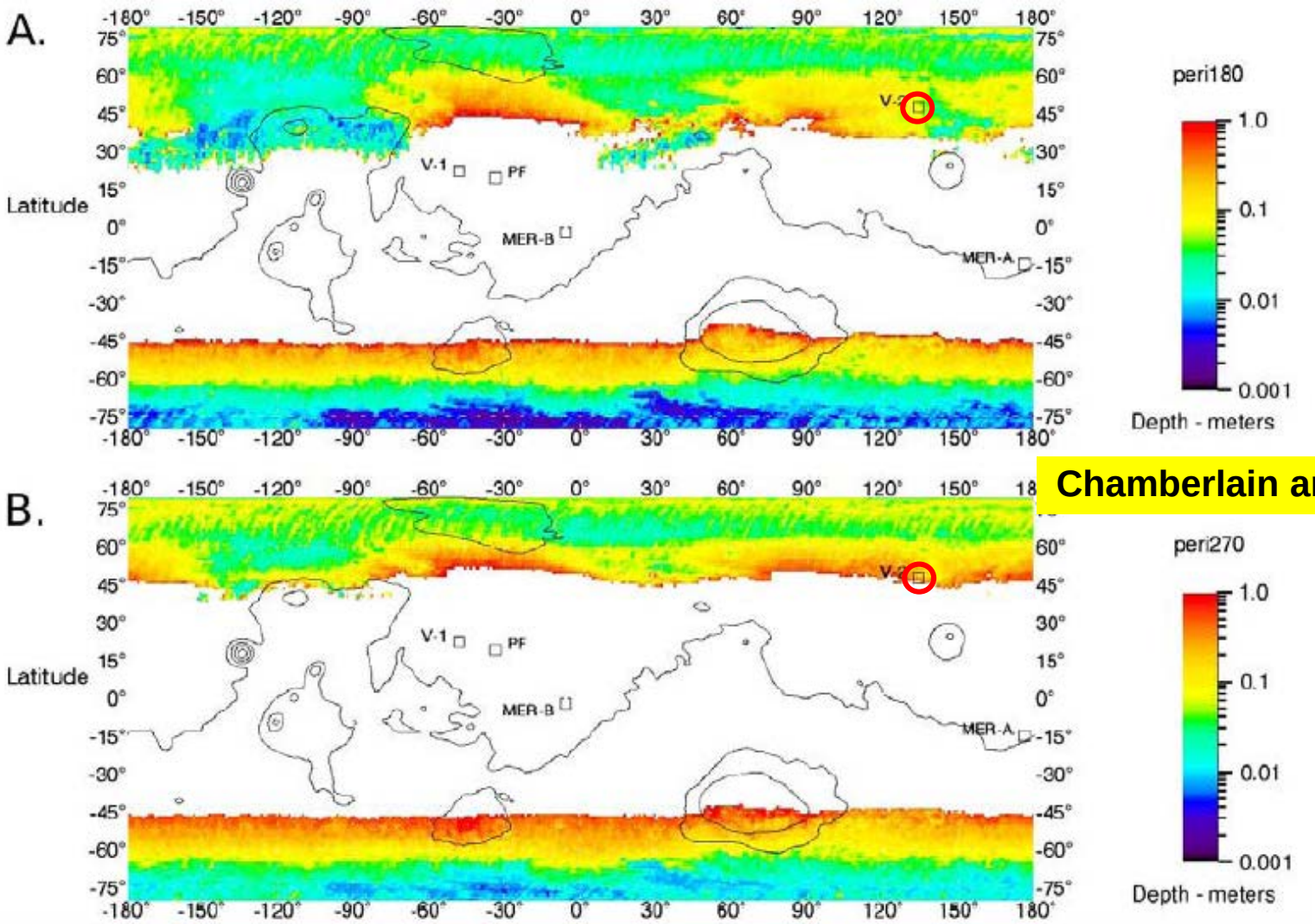


- Layers similar to those in ice-cores on the Earth
- Climate record of a few million years

- Radar layers look like they should correspond to the layers we see in images
  - This link has proven hard to nail down precisely though



- **Abrupt edge to ice table**
- **Edge of ground-ice extent is VERY sensitive to climate**

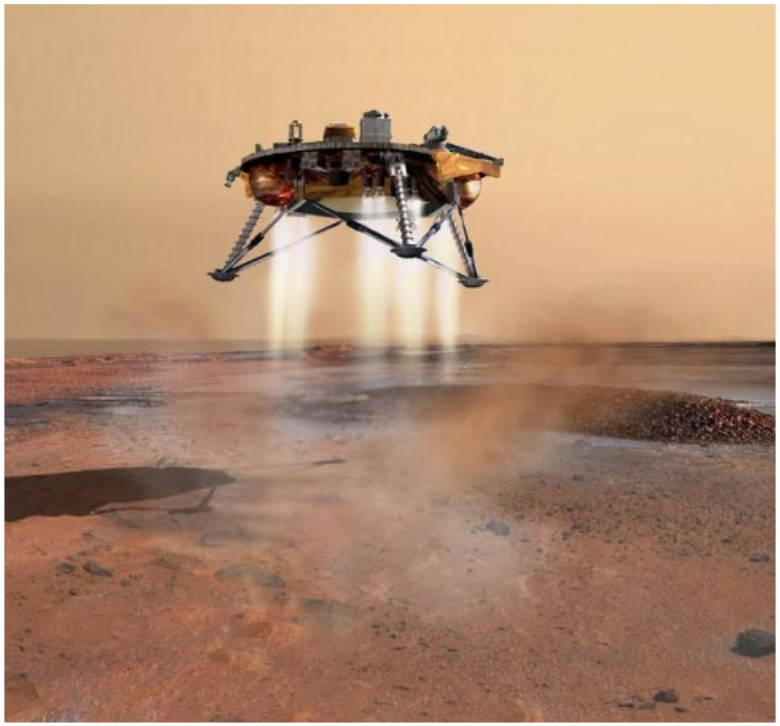


10,000 years in the past

Chamberlain and Boynton, 2007

3,000 years in the future

- **The Phoenix lander discovered very pure buried water ice**



Associated Press / NASA