Polar Ice on Mars

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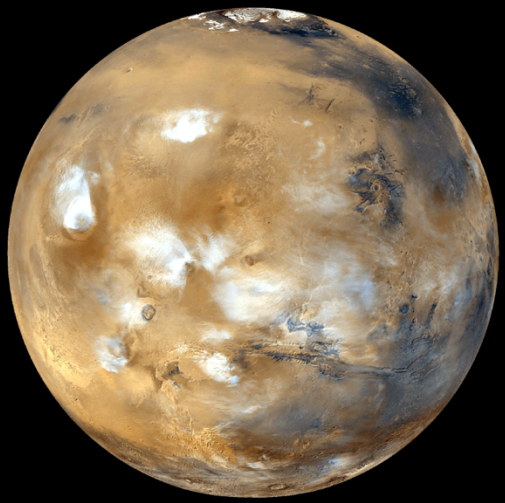
University of Washington



(scaled to eachother)

Phobos (Mars' Moon) from HiRISE camera

(**not** scaled to eachother)

	MARS	EARTH
Mean radius:	3390 km	6371 km
Semi-major axis:	1.523 AU	1 AU
Obliquity:	25.19° (NOW!)	23.45°
Length of day:	24 h, 37 m	24 h
Orbital period:	686 Earth days	365.2 days
Surface gravity:	3.7 m/s^2	9.78 m/s^2
Atmosphere:	95.3 % CO_2	78 % N_2
	2.7 % N_2	20.9 % 0_2
Surface Pressure:	5.6 mbar	1014 mbar

Ratio of total surface area on Mars to that on Earth (land): 0.976

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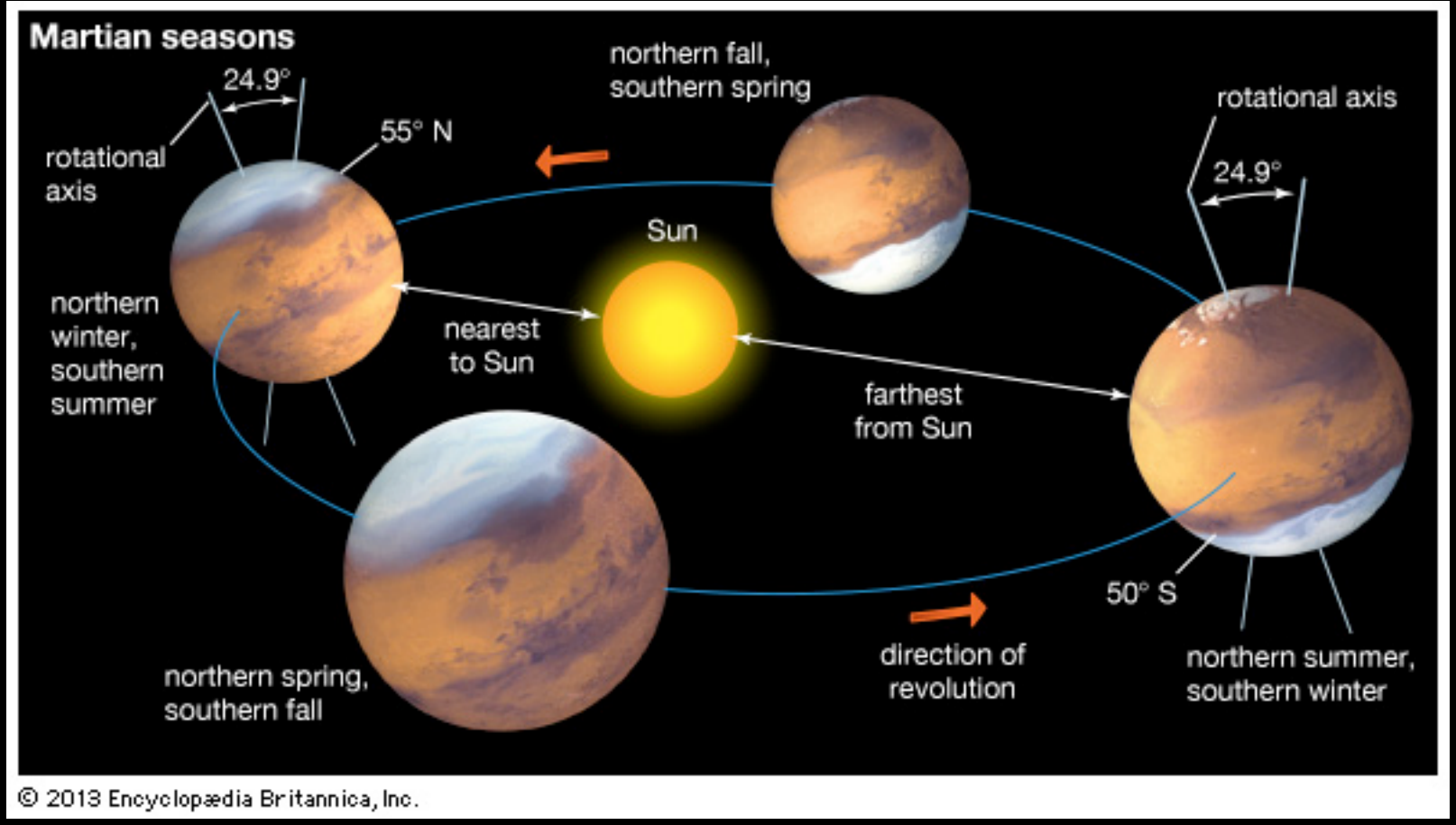
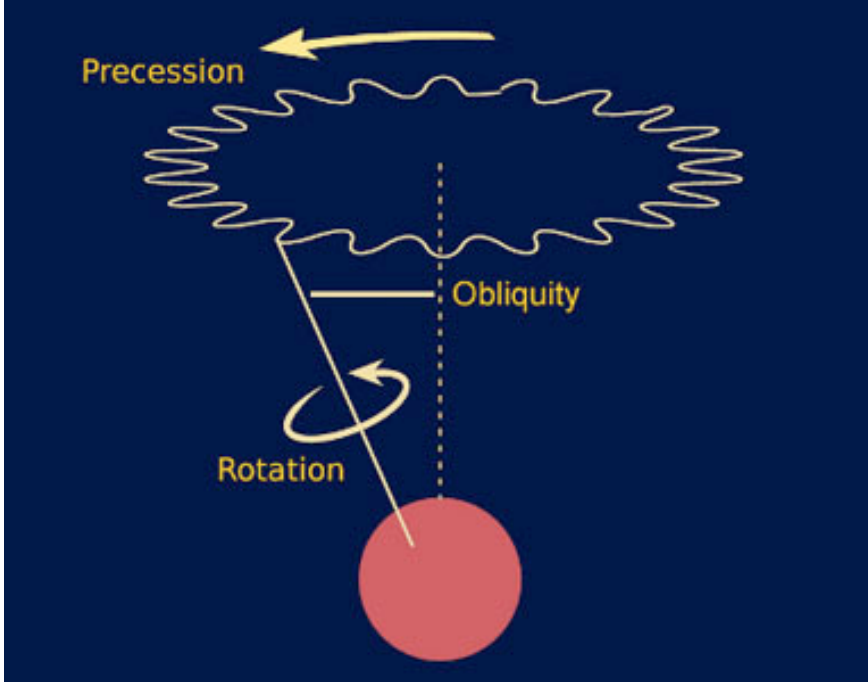


Season	*Earth*	*Mars*
Spring	93	171
Summer	94	199
Fall	89	171
Winter	89	146

Northern Hemisphere has a shorter and more "mild" winter while summer is longer and cool

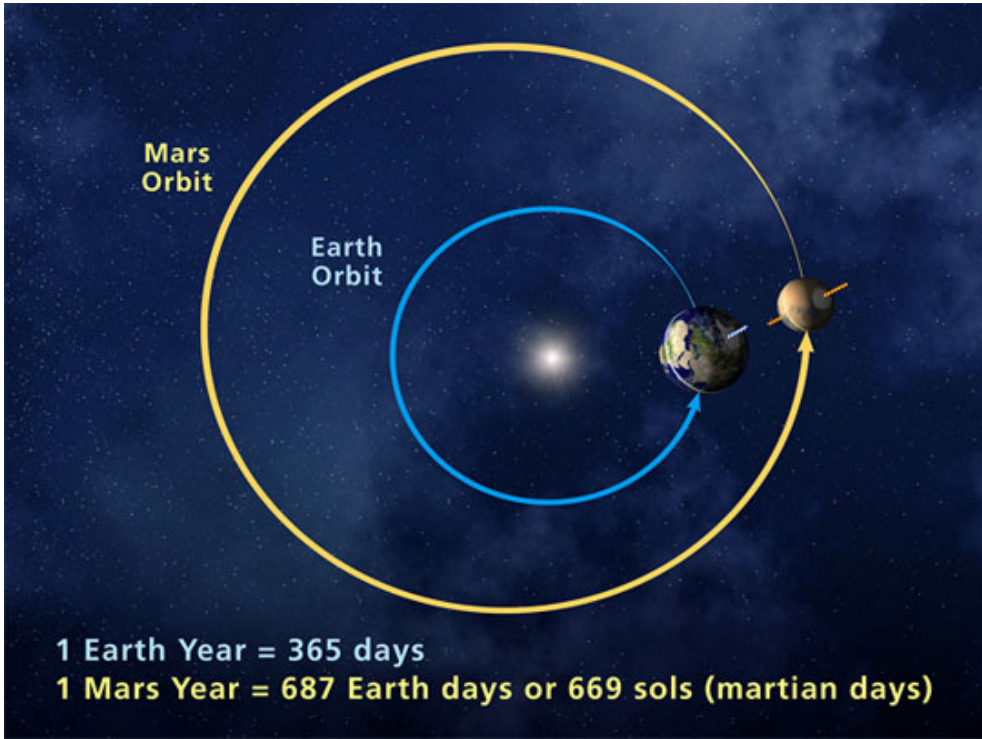
Southern Hemisphere has a shorter and "hot" summer while the winter is longer and cold

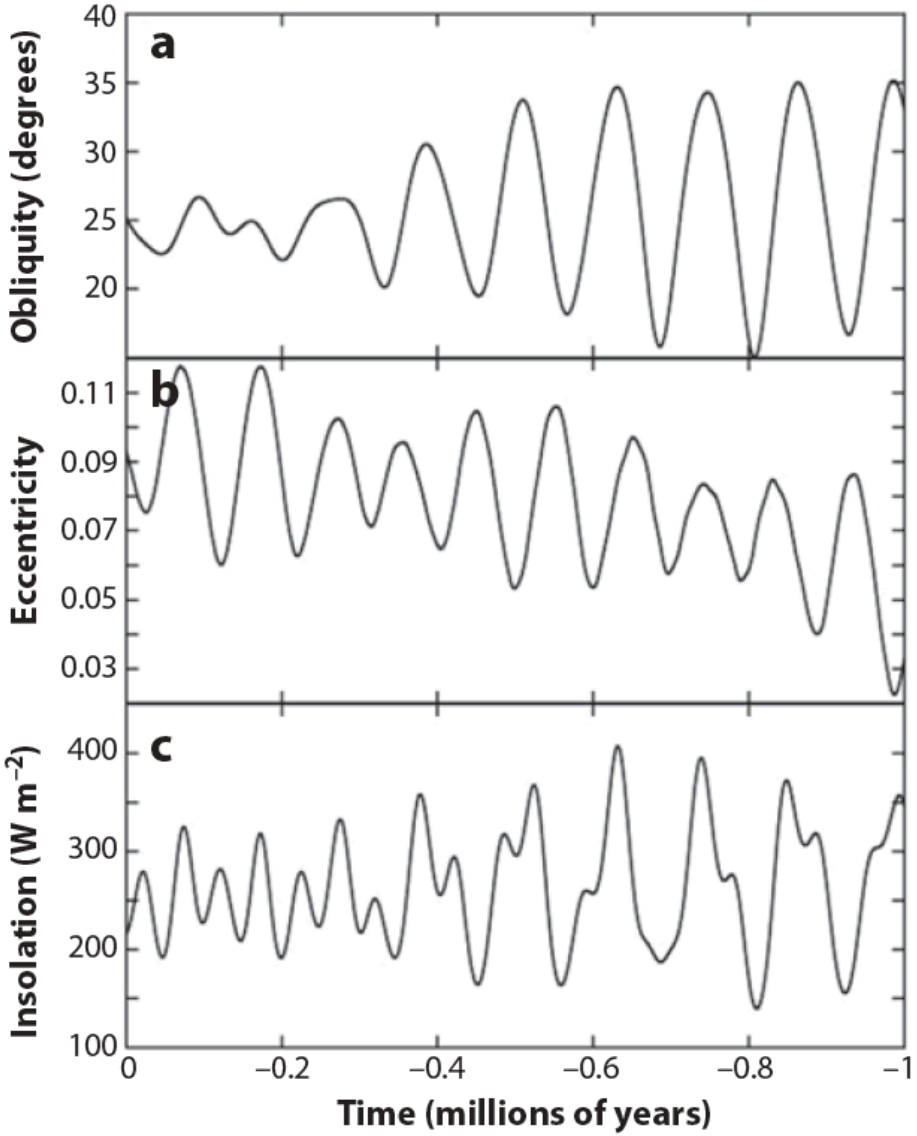
Martian Orbital Parameters

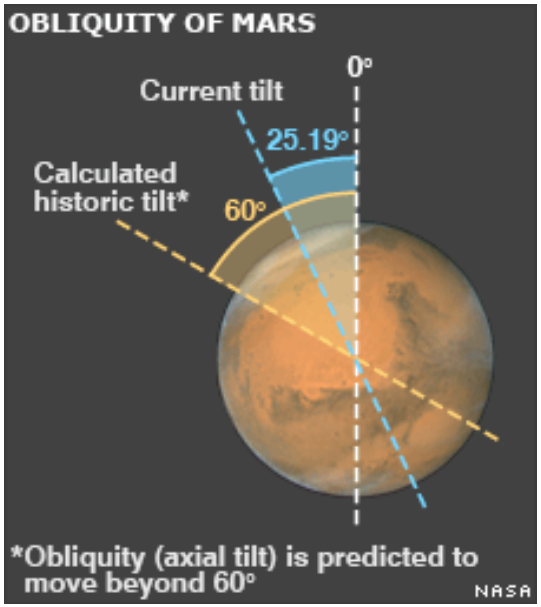


Obliquity cycle = 120,000 yr
Precession cycle = 51,000 yr
Eccentricity = 0.093

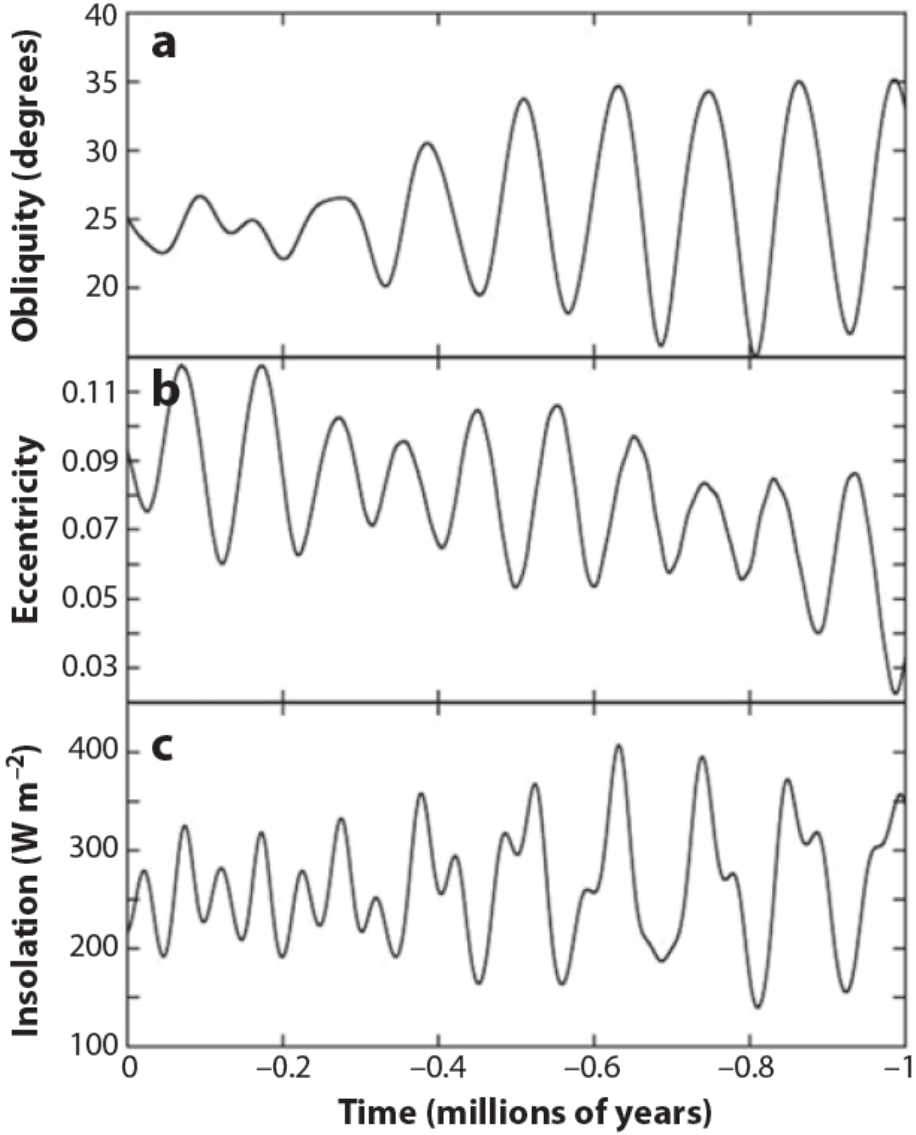
vs. Earth
Obliquity = 41,000 yr
Precession = 26,000 yr
Eccentricity = 0.017

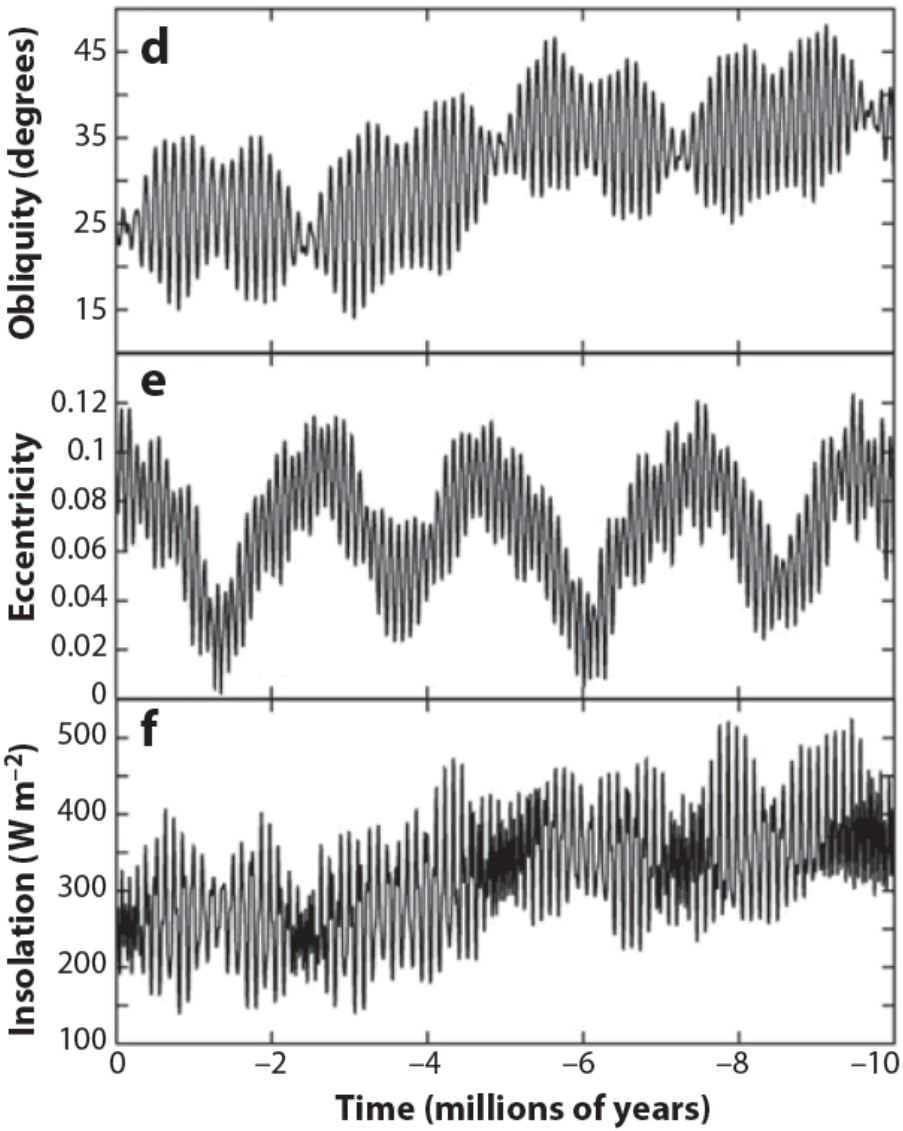



a
b
c
Obliquity (degrees)
Eccentricity
Insolation (W m^{-2})
Time (millions of years)
40
35
30
25
20
0.11
0.09
0.07
0.05
0.03
400
300
200
100
0
−0.2
−0.4
−0.6
−0.8
−1


OBLIQUITY OF MARS
0°
Current tilt
25.19°
Calculated historic tilt*
60°
*Obliquity (axial tilt) is predicted to move beyond 60°
NASA

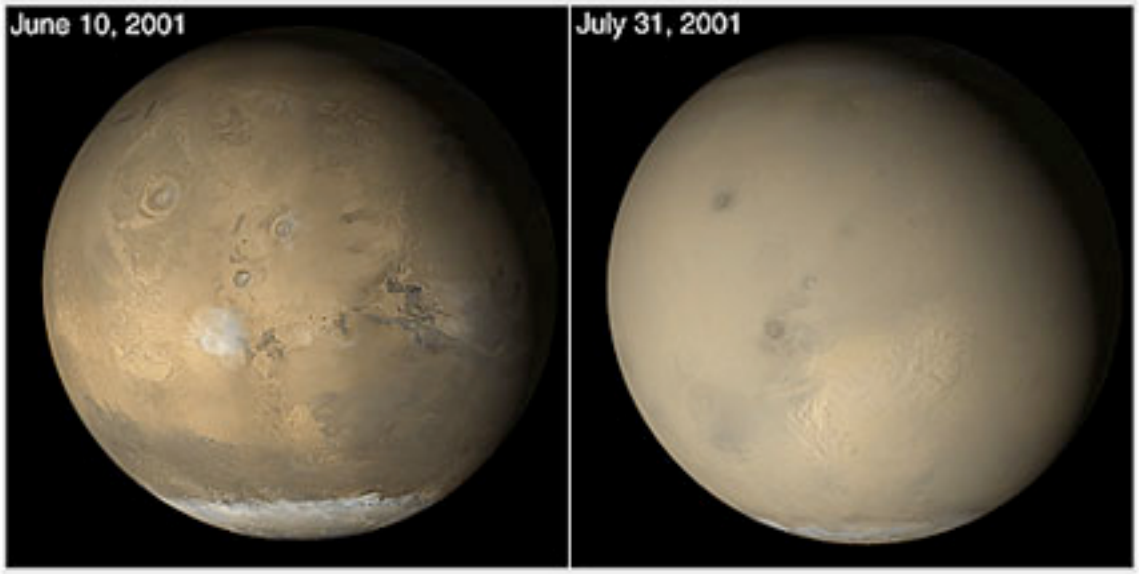
Byrne (2009)


a
Obliquity (degrees)
40
35
30
25
20
b
Eccentricity
0.11
0.09
0.07
0.05
0.03
c
Insolation (W m^{-2})
400
300
200
100
0
−0.2
−0.4
−0.6
−0.8
−1
Time (millions of years)


d
Obliquity (degrees)
45
35
25
15
e
Eccentricity
0.12
0.1
0.08
0.06
0.04
0.02
0
f
Insolation (W m^{-2})
500
400
300
200
100
0
−2
−4
−6
−8
−10
Time (millions of years)

Byrne (2009)

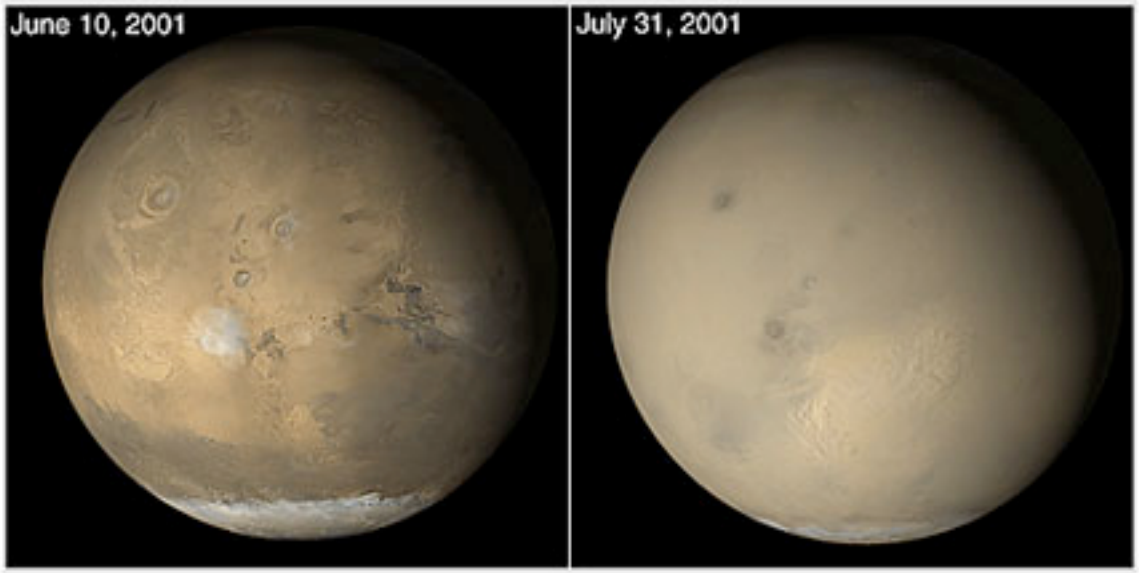
Dust storms on Mars



Sun gives energy source

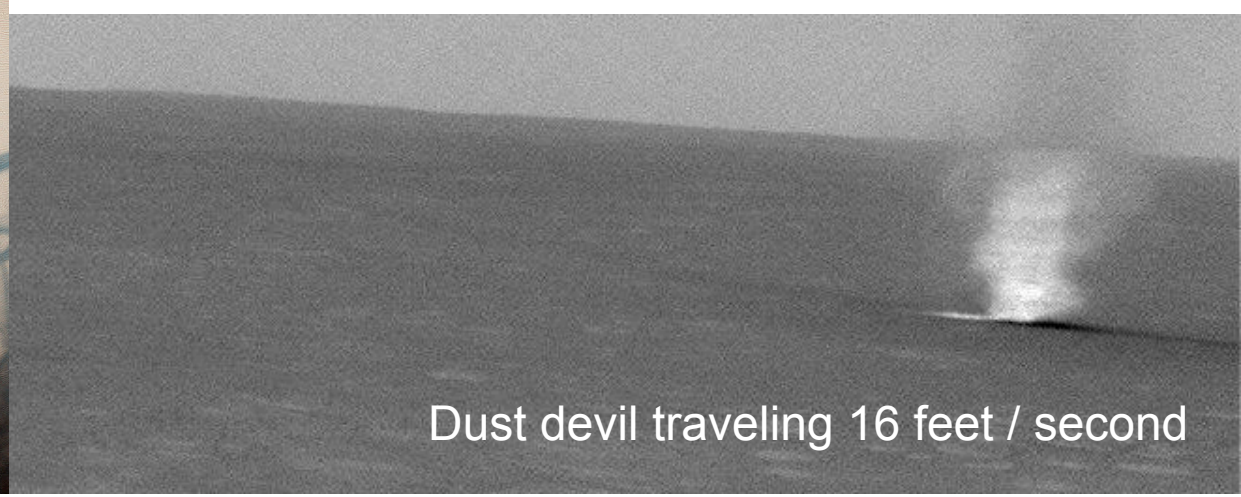
Big dust storms can last for weeks

Dust storms on Mars

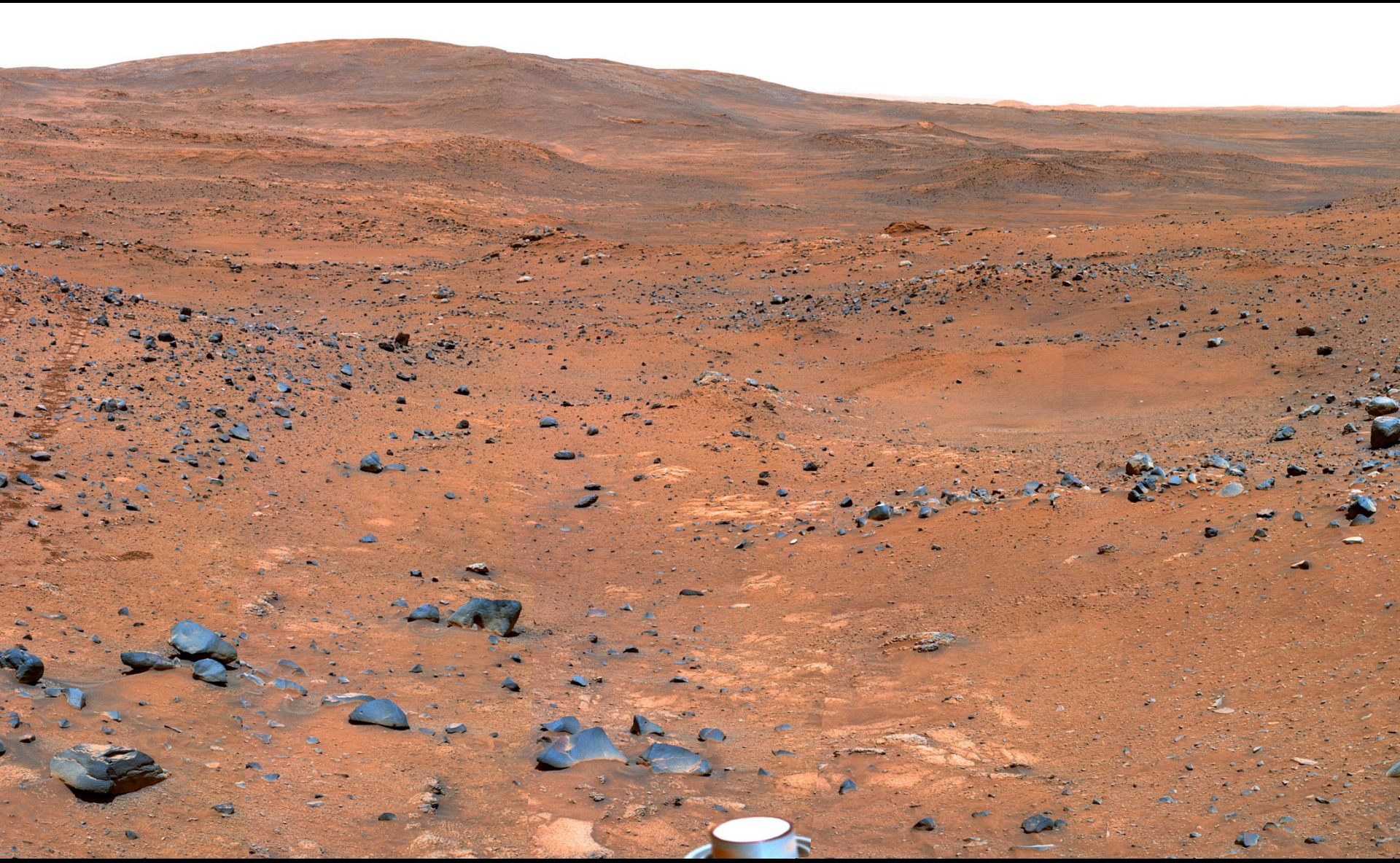


Sun gives energy source

Big dust storms can last for weeks



NASA/JPL

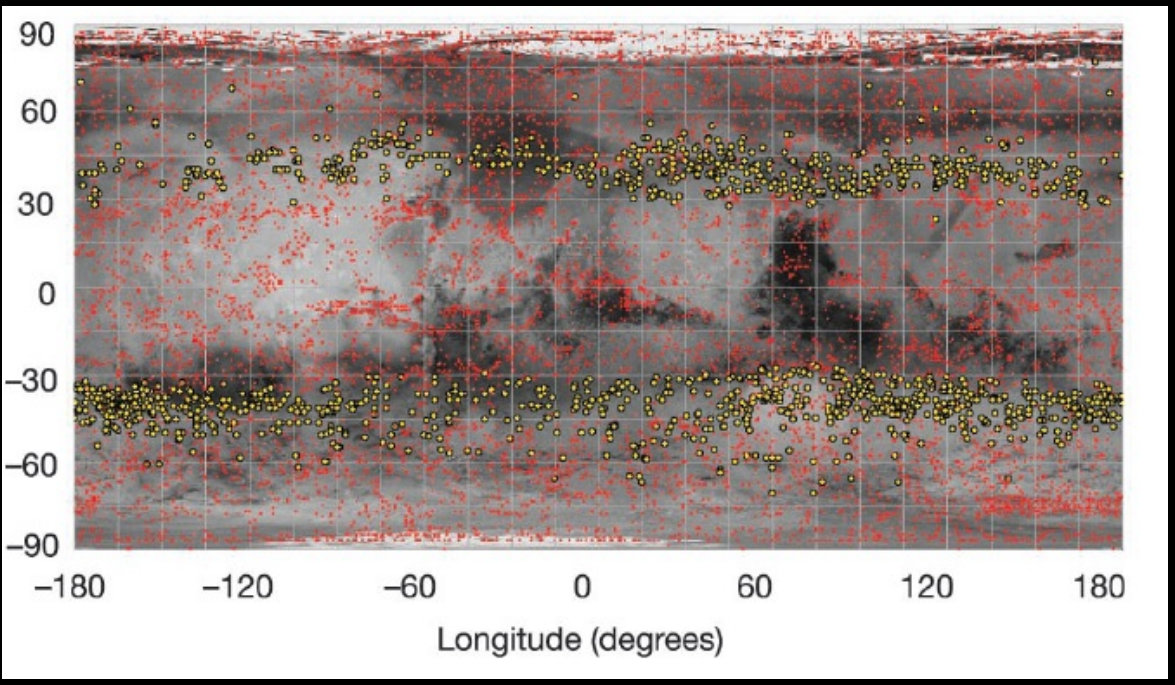


Mars Exploration Rover Spirit landing site (NASA/JPL-Caltech/Cornell)

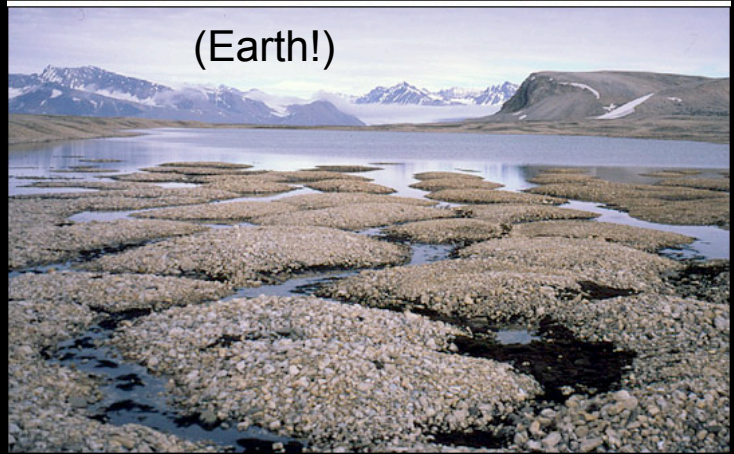
Evidence for exchange of volatiles and dust between the poles and mid-latitudes?

- Obliquity changes the stability of ice around the planet

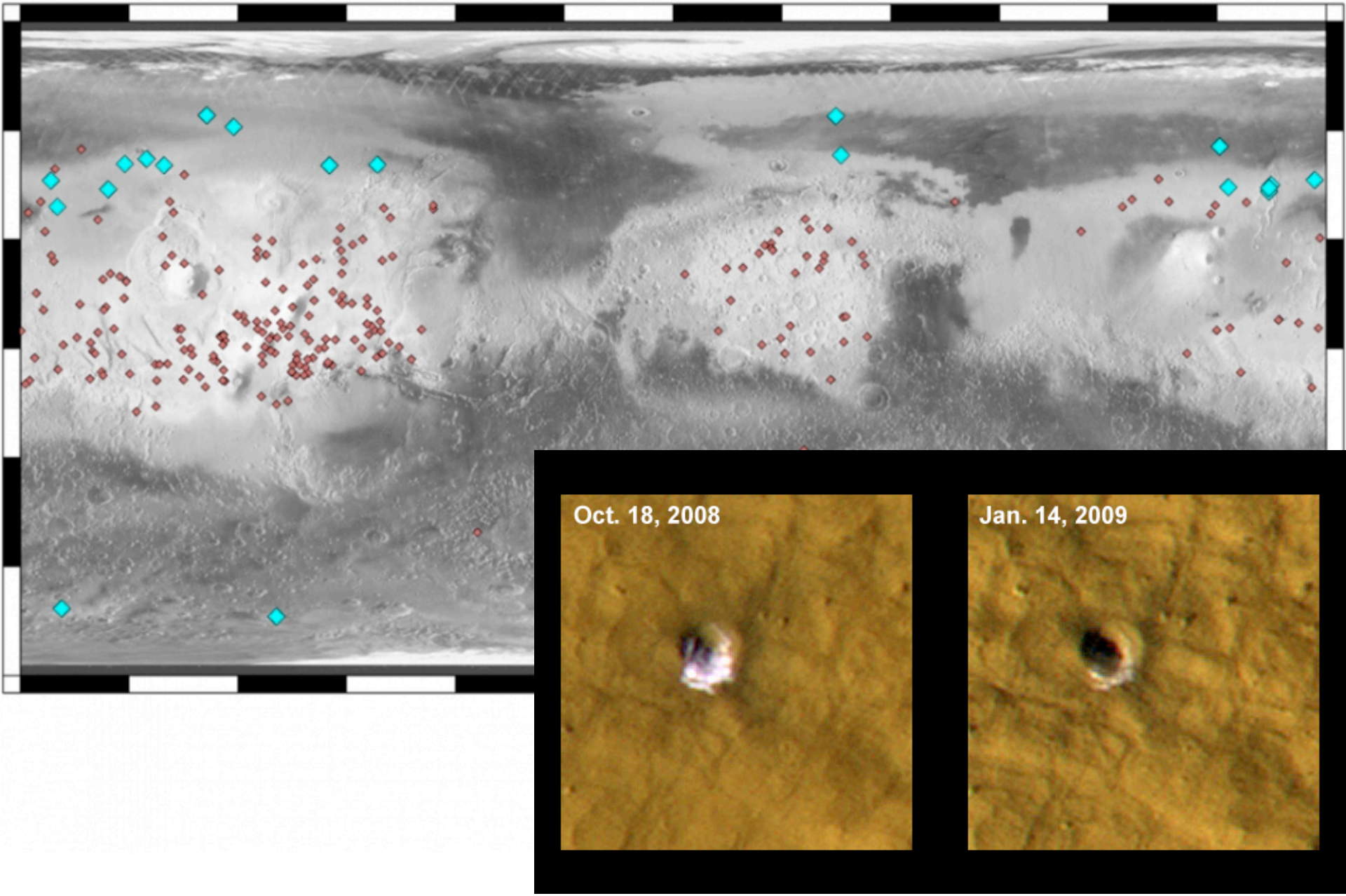
- Ground ice – polygons and other unique terrain; gullies



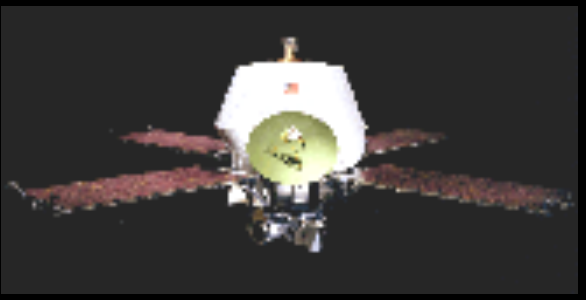
Head et al. (2002)



Distribution of fresh impact craters



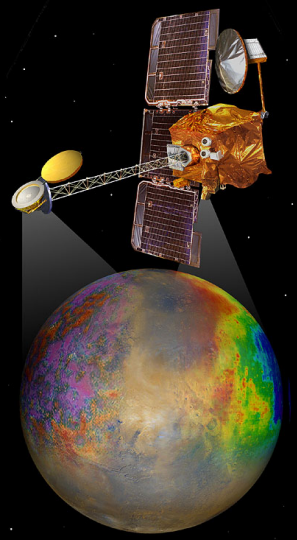
Brief history of spacecraft and landers…



Mariner 3-4, 6-9 (1964-1971)

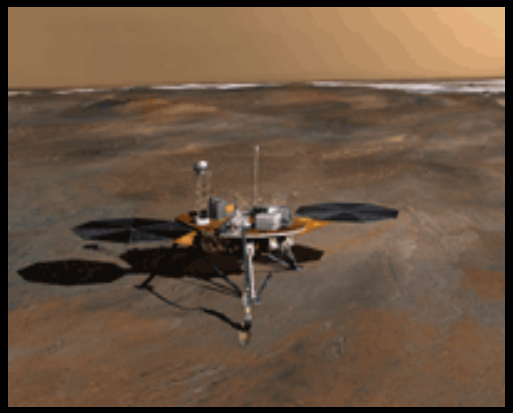
Viking 1-2 (1975)

Mars Global Surveyor (1996)

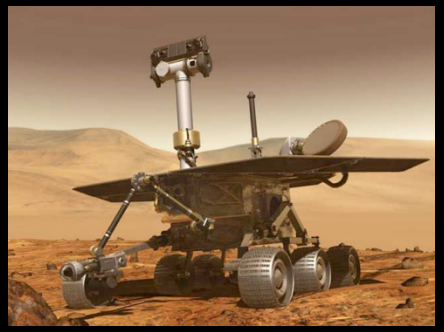


Mars Odyssey (2001)

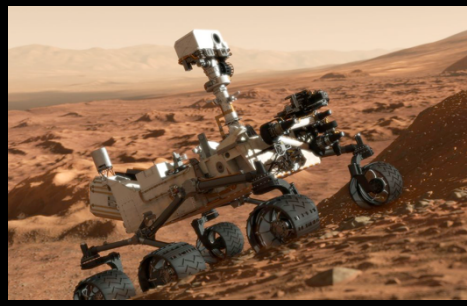
Mars Reconnaissance Orbiter (2003)



Phoenix Lander (2007)



Mars Exploration Rovers (2003)



Curiosity Rover Mars Science Lab (2011)

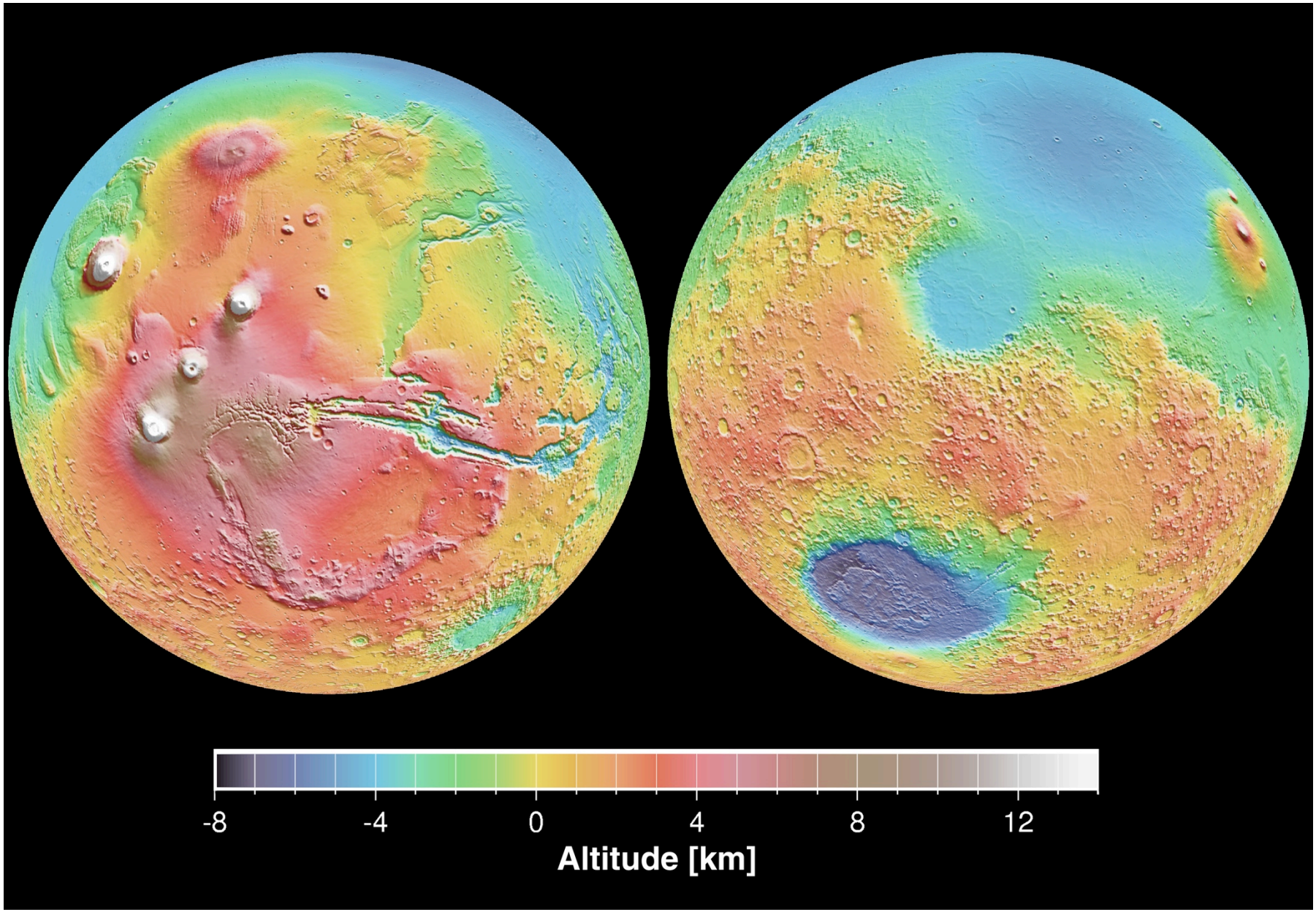
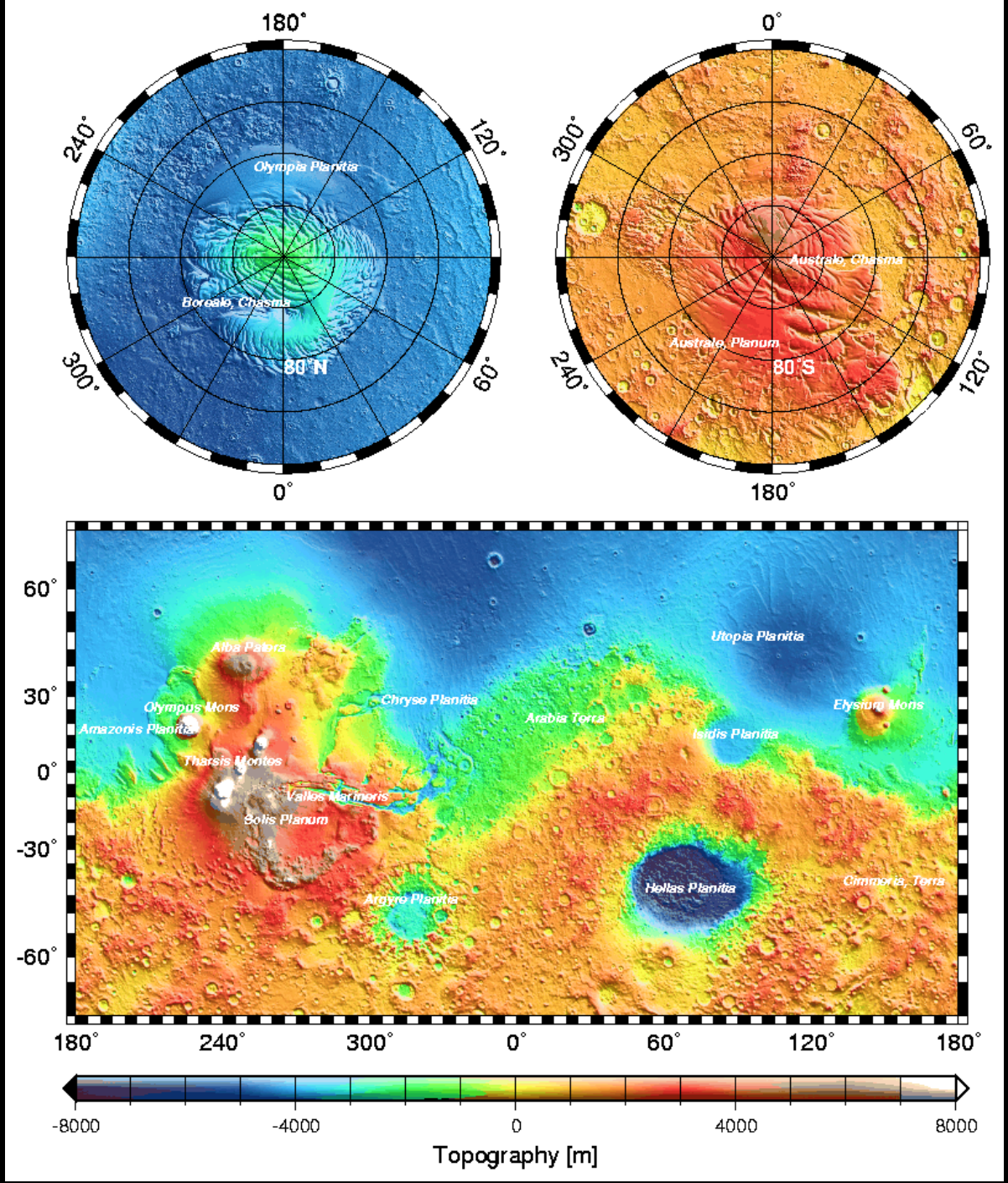


Image Credit: MOLA Science Team

North

South



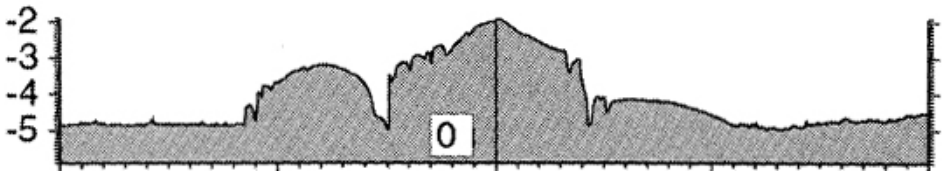
Southern Highlands about 6 km higher than Northern Lowlands

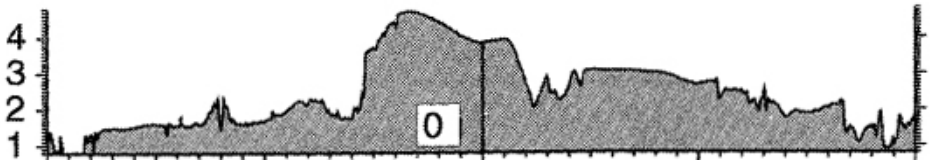
Image Credit: MOLA Science Team

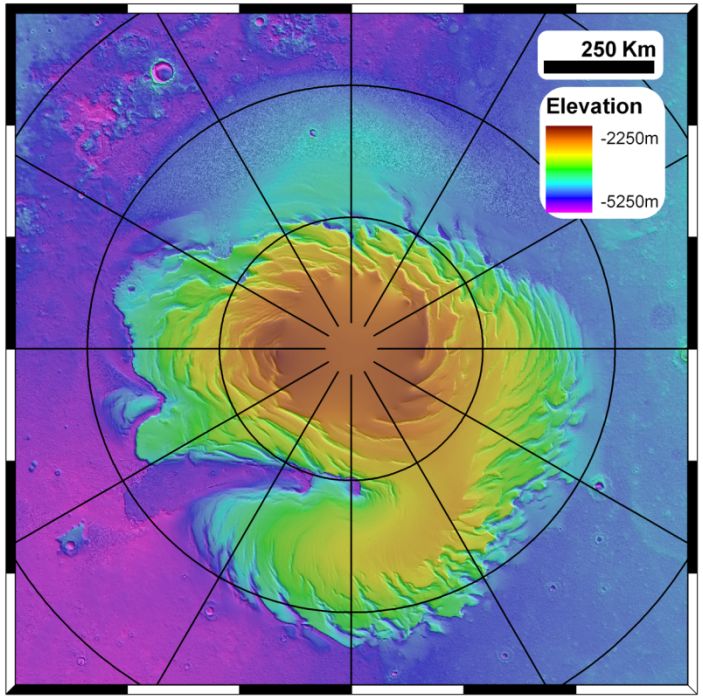
1.1 million km^3

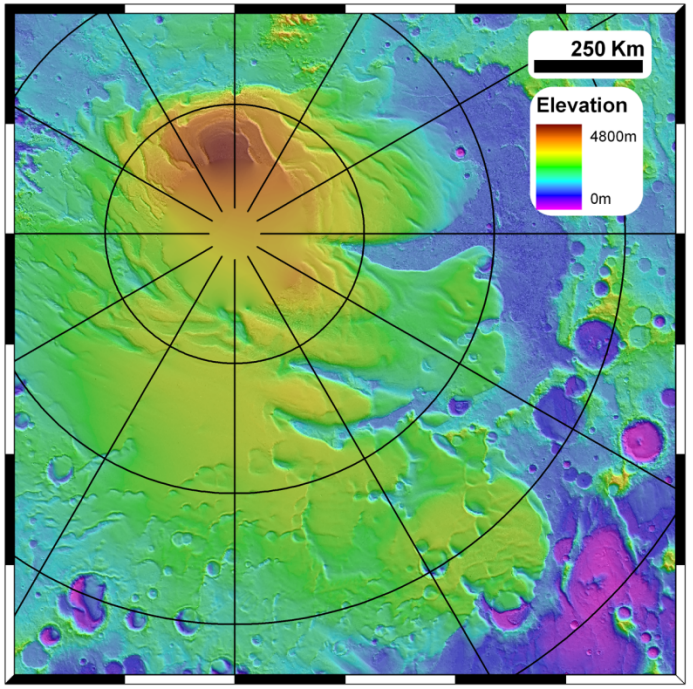
1.2 million km^3

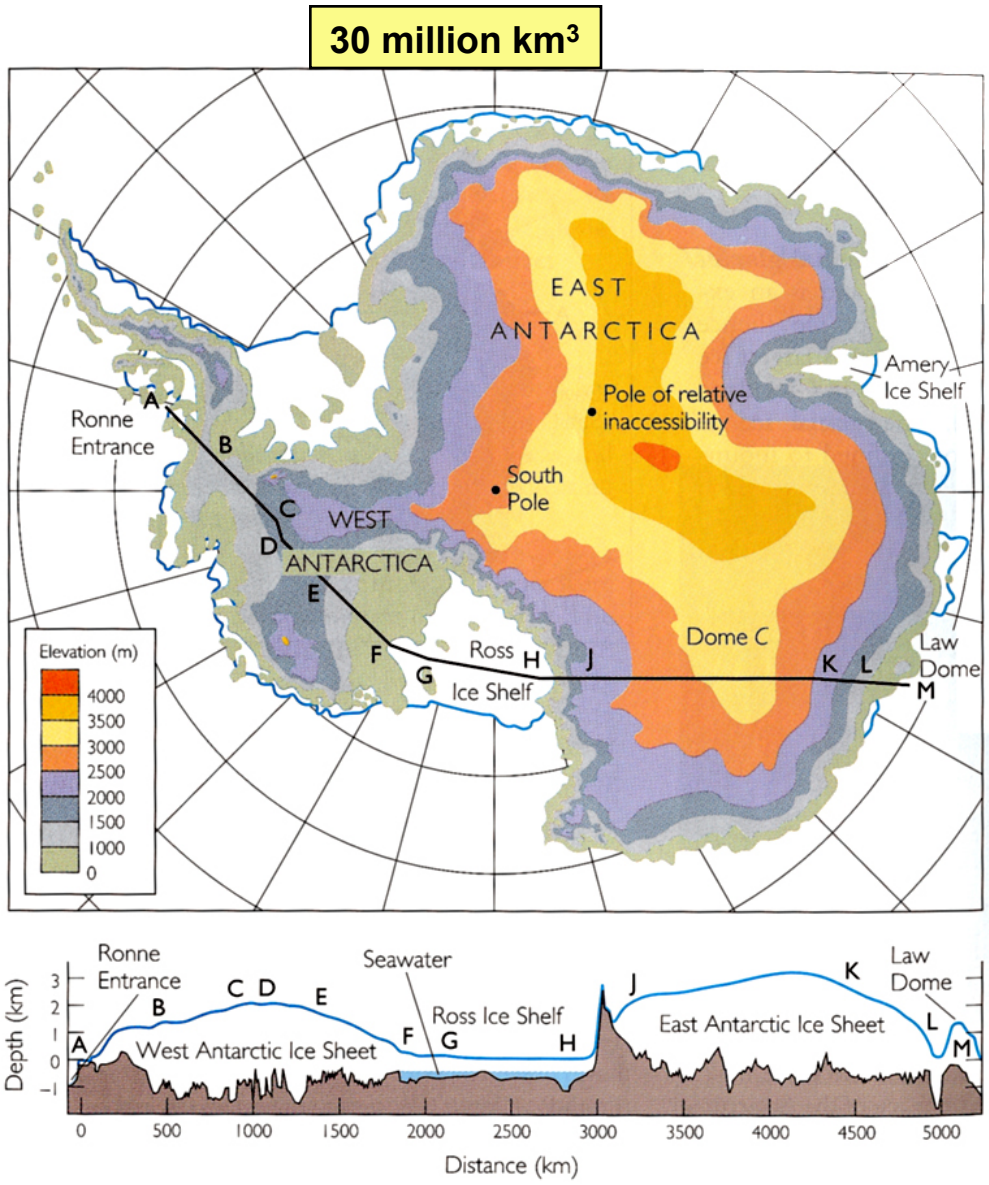
North V.E. 100:1 South

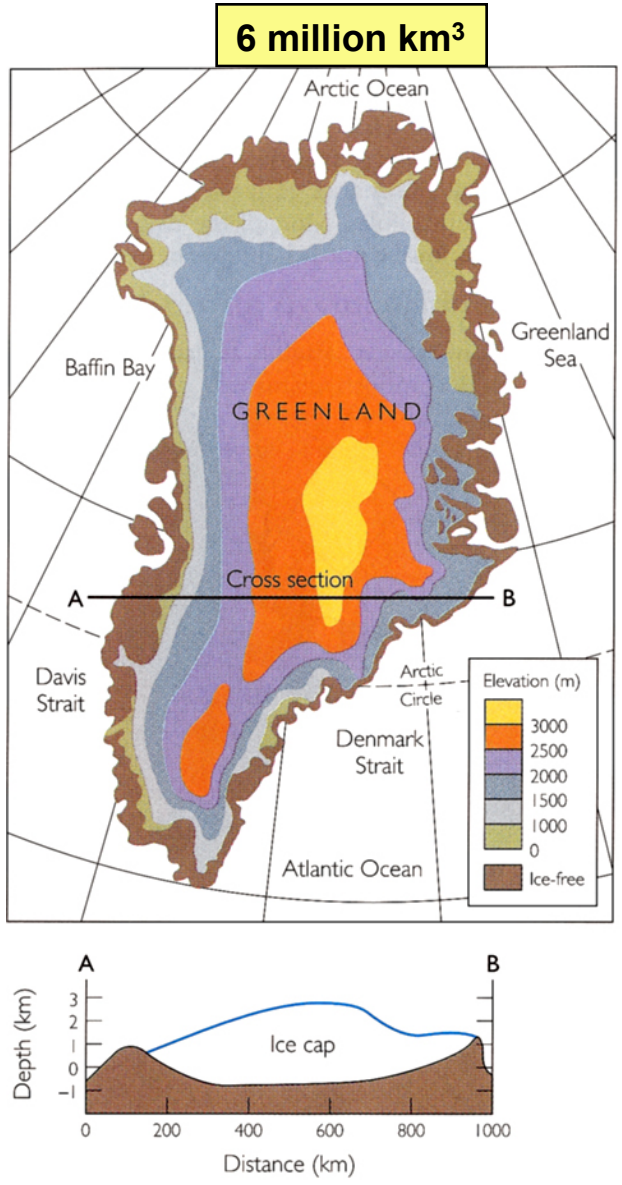




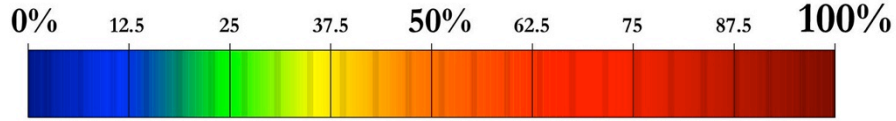




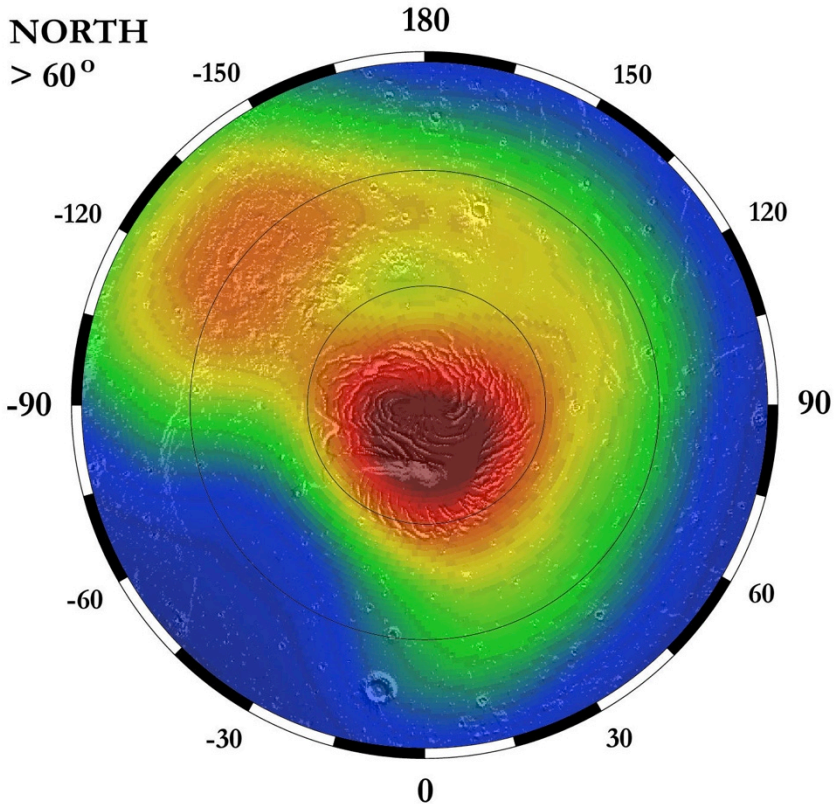

30 million km³
EAST
ANTARCTICA
WEST
ANTARCTICA
Pole of relative
inaccessibility
South
Pole
Dome C
Amery
Ice Shelf
Ronne
Entrance
Ross
Ice Shelf
Law
Dome
A
B
C
D
E
F
G
H
J
K
L
M
Elevation (m)
4000
3500
3000
2500
2000
1500
1000
0
Ronne
Entrance
Seawater
Ross Ice Shelf
Law
Dome
West Antarctic Ice Sheet
East Antarctic Ice Sheet
Depth (km)
Distance (km)

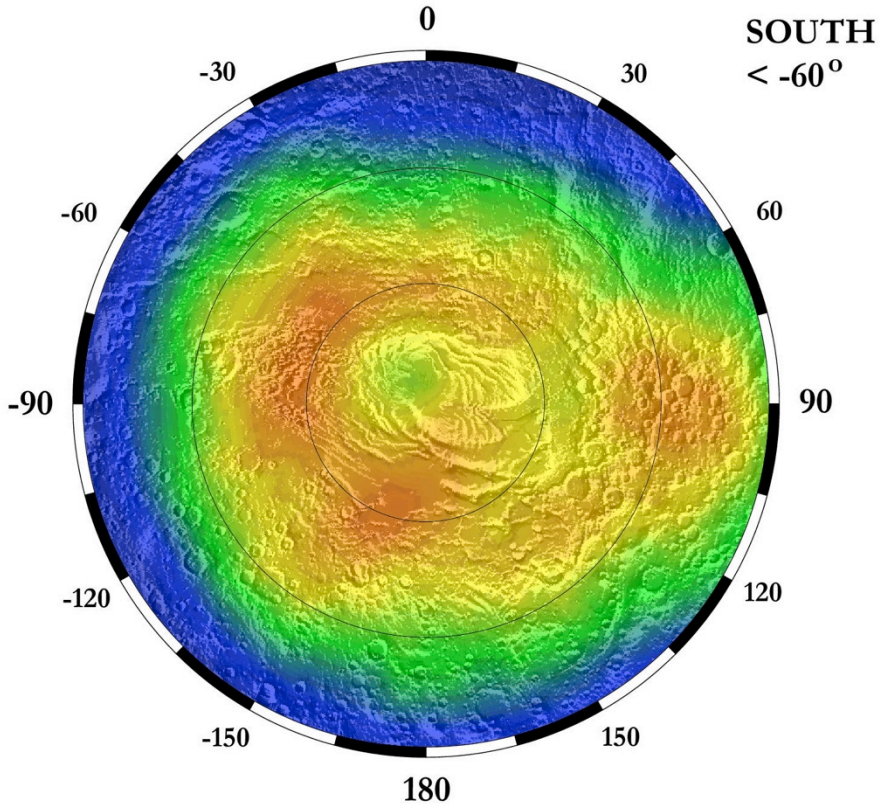

6 million km³
Arctic Ocean
Baffin Bay
Greenland
Sea
GREENLAND
Cross section
A
B
Davis
Strait
Arctic
Circle
Denmark
Strait
Atlantic Ocean
Elevation (m)
3000
2500
2000
1500
1000
0
Ice-free
Ice cap
Depth (km)
Distance (km)

Water Equivalent Hydrogen Abundance



Los Alamos NATIONAL LABORATORY



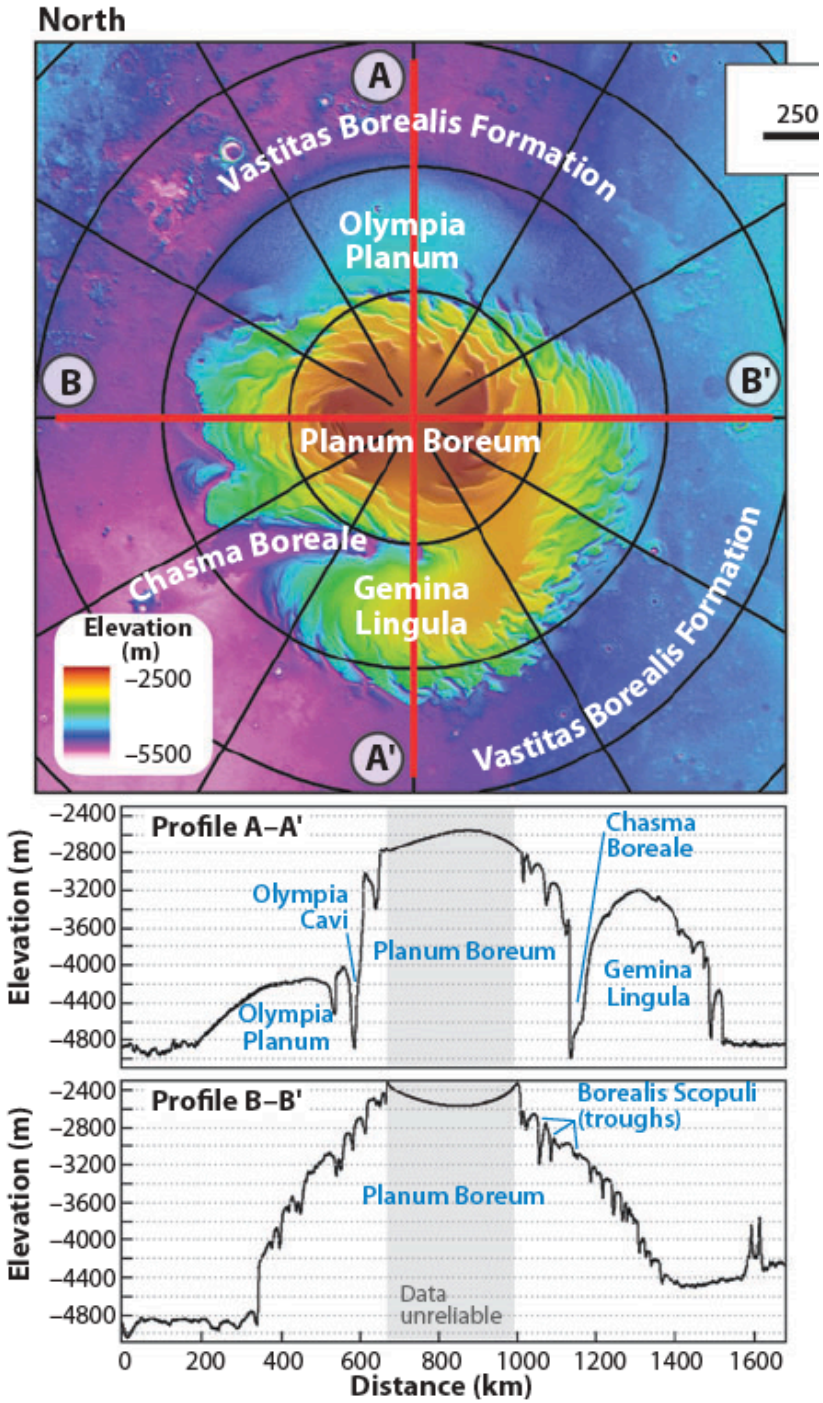


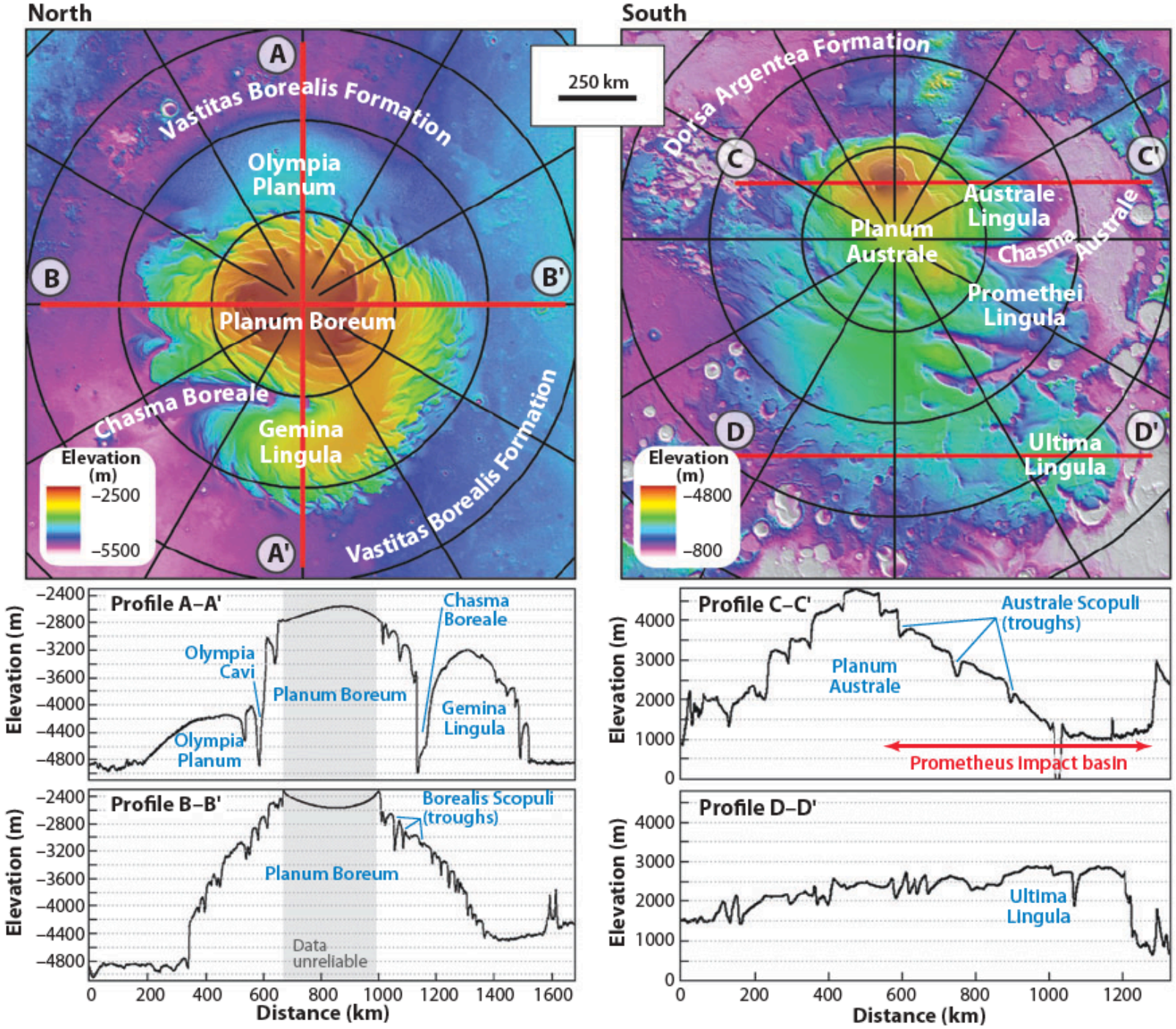
Distribution of Water on Mars: Overlay of water equivalent hydrogen abundances and a shaded relief map derived from MOLA topography. Mass percents of water were determined from epithermal neutron counting rates using the Neutron Spectrometer aboard Mars Odyssey between Feb. 2002 and Apr. 2003.

Reference: Feldman W. C., T. H. Prettyman, S. Maurice, J. J. Plaut, D. L. Bish, D. T. Vaniman, M. T. Mellon, A. E. Metzger, S. W. Squyres, S. Karunatillake, W. V. Boynton, R. C. Elphic, H. O. Funsten, D. J. Lawrence, and R. L. Tokar, The global distribution of near-surface hydrogen on Mars, *JGR-planets*, submitted July 2003.

These data were generated by the Planetary Science Team at Los Alamos: B. Barraclough, D. Bish, D. Delapp, R. Elphic, W. Feldman, H. Funsten, O. Gasnault*, D. Lawrence, S. Maurice*, G. McKinney, K. Moore, T. Prettyman, R. Tokar, D. Vaniman, and R. Wiens. * Also at Observatoire Midi-Pyrenees, France

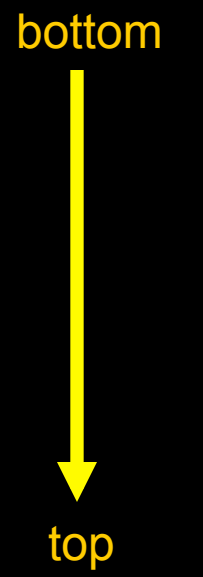
The neutron spectrometer aboard Mars Odyssey, a component of the Gamma-ray Spectrometer suite of instruments, was designed and built by the Los Alamos National Laboratory and is operated by the University of Arizona in Tucson. The Mars Odyssey mission is managed by the Jet Propulsion Laboratory.


North
A
A'
B
B'
250
Vastitas Borealis Formation
Olympia Planum
Planum Boreum
Chasma Boreale
Gemina Lingula
Vastitas Borealis Formation
Elevation (m)
–2500
–5500
Profile A–A'
Elevation (m)
–2400
–2800
–3200
–3600
–4000
–4400
–4800
Olympia Cavi
Olympia Planum
Planum Boreum
Chasma Boreale
Gemina Lingula
Profile B–B'
Elevation (m)
Borealis Scopuli (troughs)
Planum Boreum
Data unreliable
0
200
400
600
800
1000
1200
1400
1600
Distance (km)

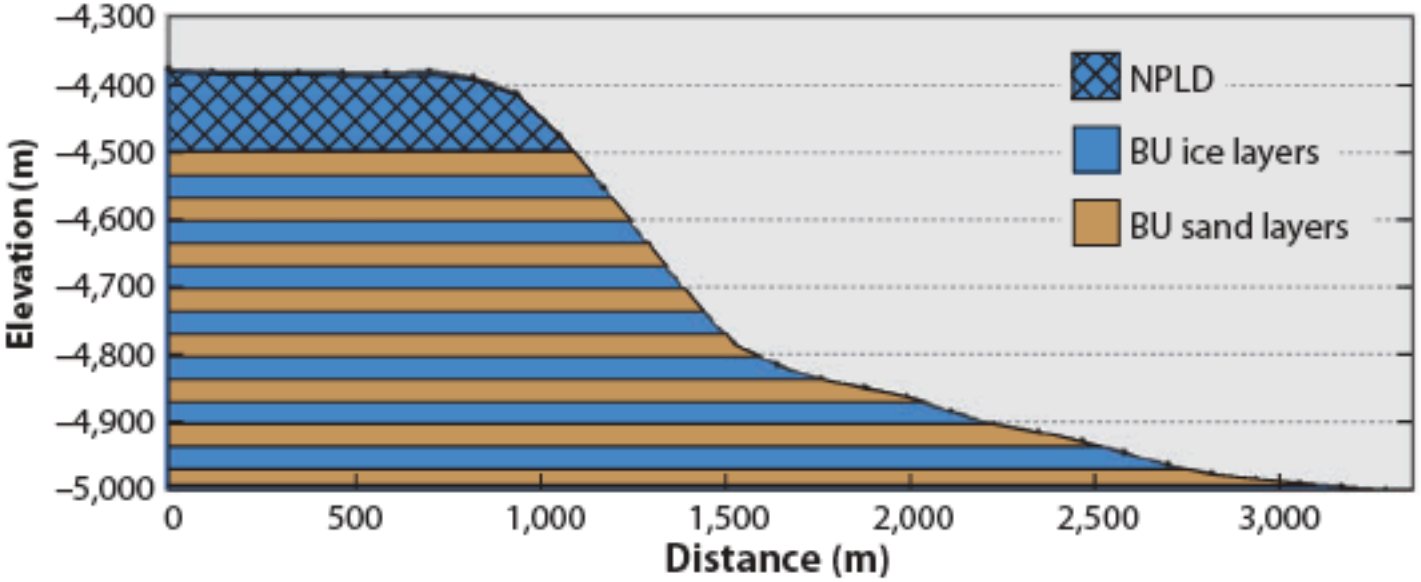

North
South
250 km
A
A'
B
B'
C
C'
D
D'
Vastitas Borealis Formation
Olympia Planum
Planum Boreum
Chasma Boreale
Gemina Lingula
Elevation (m)
−2500
−5500
Dorsa Argentea Formation
Planum Australe
Australe Lingula
Chasma Australe
Promethei Lingula
Ultima Lingula
−4800
−800
Profile A–A'
Olympia Cavi
Olympia Planum
Planum Boreum
Chasma Boreale
Gemina Lingula
Elevation (m)
Profile B–B'
Borealis Scopuli (troughs)
Data unreliable
Distance (km)
Profile C–C'
Australe Scopuli (troughs)
Planum Australe
Prometheus Impact basin
Profile D–D'
Ultima Lingula

1. Basal Deposits -- meters to hundreds of meters

North: basal unit and surrounding polar sand erg (10-50 m high)
South: "Dorsa Argenta" formation

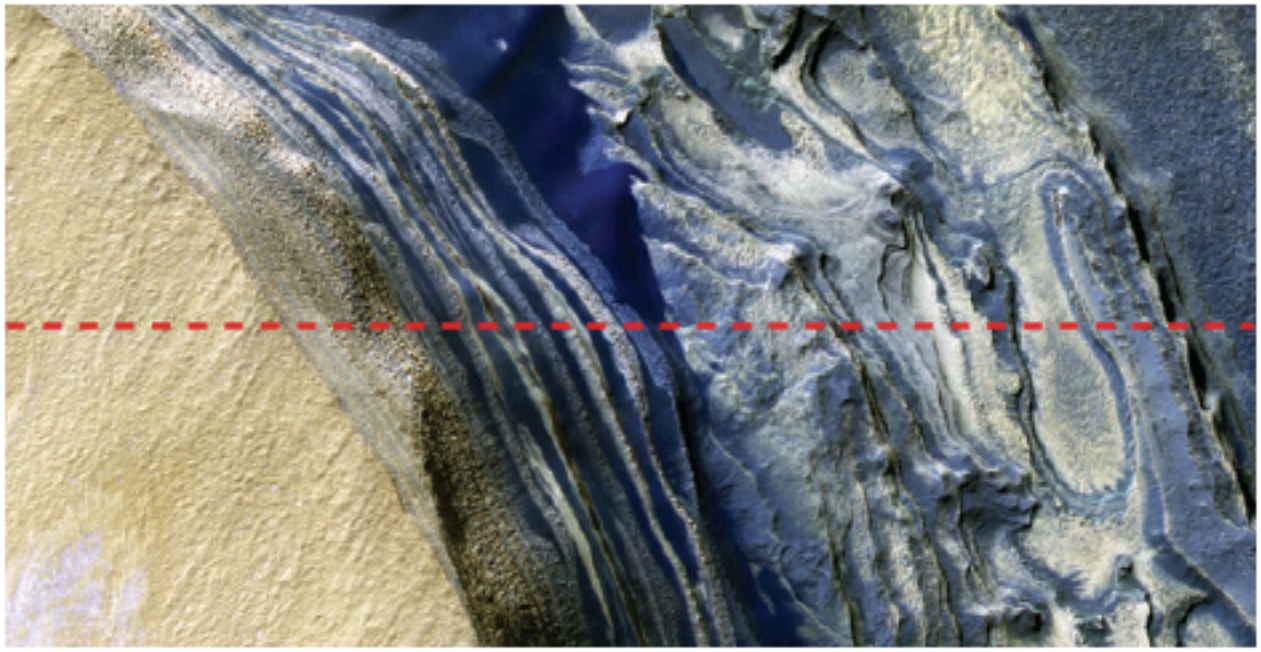


Basal Unit



But how does the layer brightness relate to material content …

How much ice is in a bright layer?



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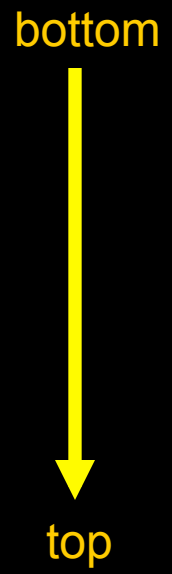

2. Polar Layered Deposits (polar ice caps) -- kilometers

Layers of ice/dust (possibly CO2 clathrate)
Troughs, scarps, chasmae

1. Basal Deposits -- meters to hundreds of meters

North: basal unit and surrounding polar sand erg (10-50 m high)
South: "Dorsa Argenta" formation

bottom

top

2. Polar Layered Deposits (polar ice caps) -- kilometers

Layers of ice/dust (possibly CO2 clathrate)
Troughs, scarps, chasmae

3. Residual Ices – meters to ten meters

North: water ice; over much of the cap, ~ m thick
South: CO2 ice – known from T_{sub} = 148 K; over small area, ~ 10 m thick

1. Basal Deposits -- meters to hundreds of meters

North: basal unit and surrounding polar sand erg (10-50 m high)
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bottom

top

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4. Seasonal Ice – centimeters to meters

CO_2 ice – slab ice deposits

How old are the polar layered deposits? What are their glacial, fluvial, depositional, and erosional histories?

- Crater counts – only have remote sensing data

- Ice flow? Modified only by wind and deposition?

- Stratigraphy: past atmospheric conditions

- Astrobiological implications

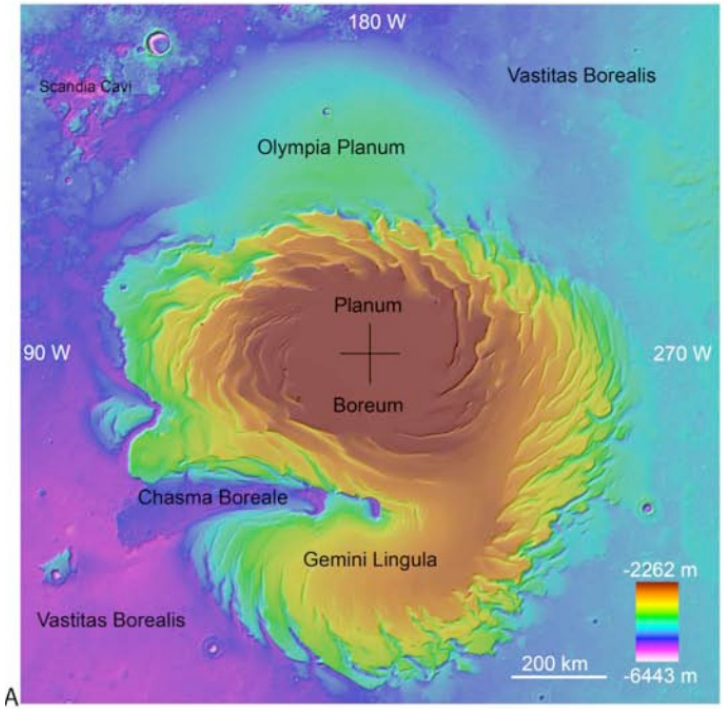
What chronology, compositional variability, and record of climate change is expressed in the stratigraphy?

- How to date internal layers?

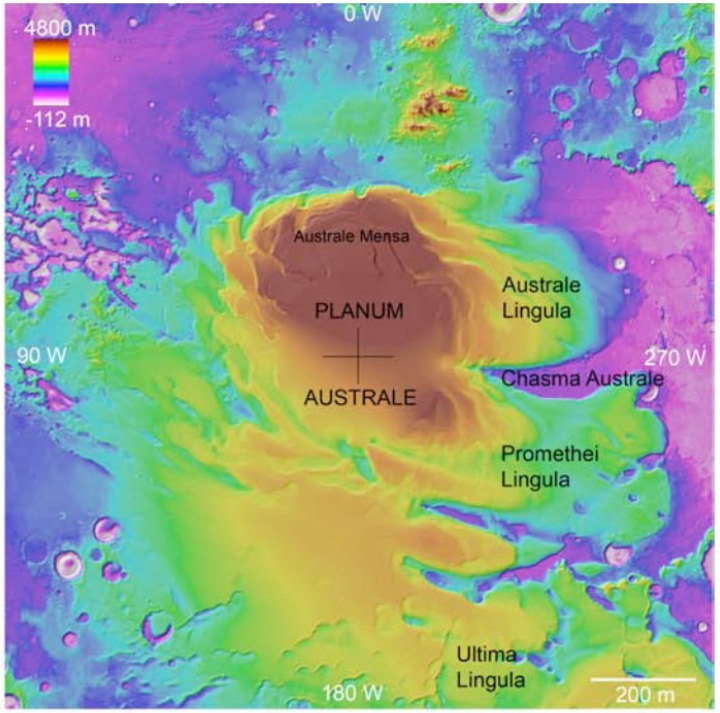
- Visible stratigraphy vs. radar stratigraphy – what are the layers?

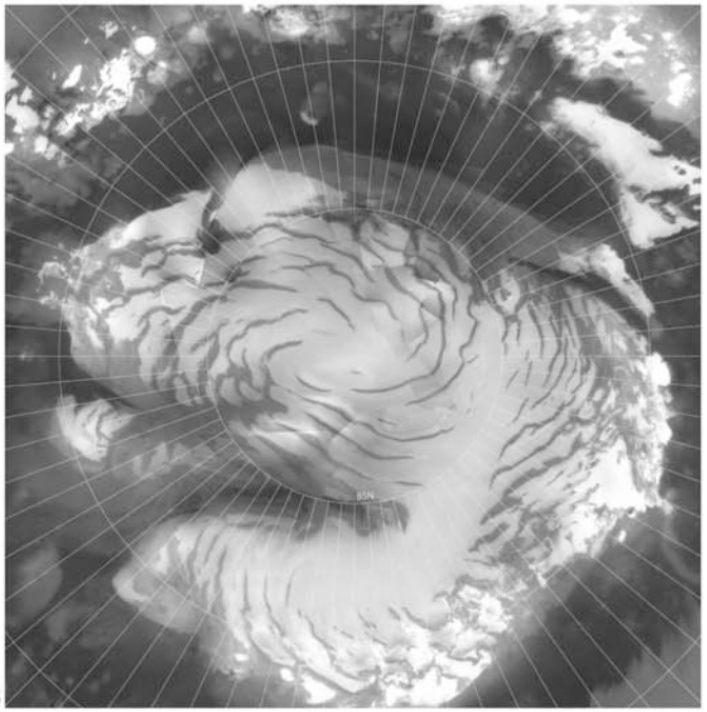
- Variations in obliquity and cycling of ice from poles to midlatitudes

- Can we see the same layer in the north and south?

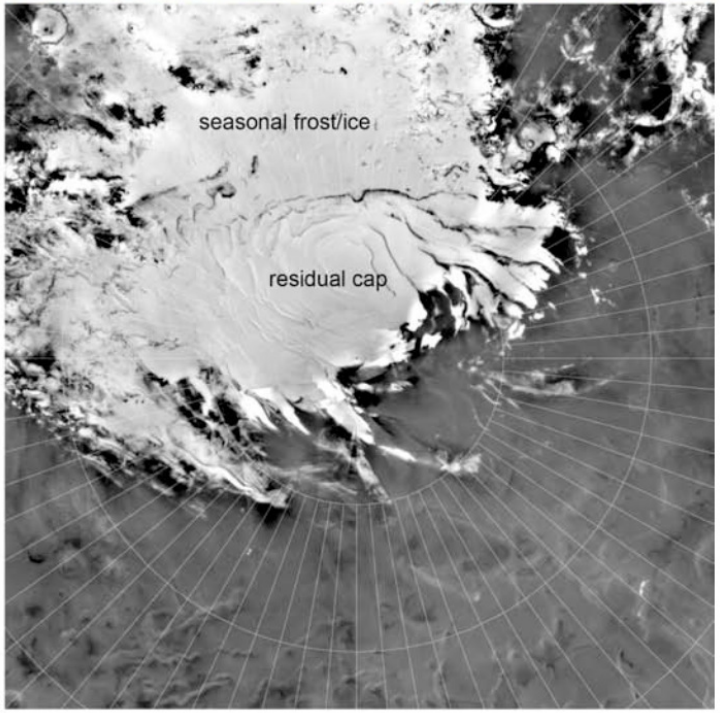

180 W
Scandia Cavi
Vastitas Borealis
Olympia Planum
Planum
Boreum
90 W
270 W
Chasma Boreale
Gemini Lingula
Vastitas Borealis
-2262 m
-6443 m
200 km

A


4800 m
-112 m
0 W
Australe Mensa
PLANUM
AUSTRALE
Australe
Lingula
90 W
270 W
Chasma Australe
Promethei
Lingula
Ultima
Lingula
180 W
200 m



B


seasonal frost/ice
residual cap

North Polar Layered Deposits

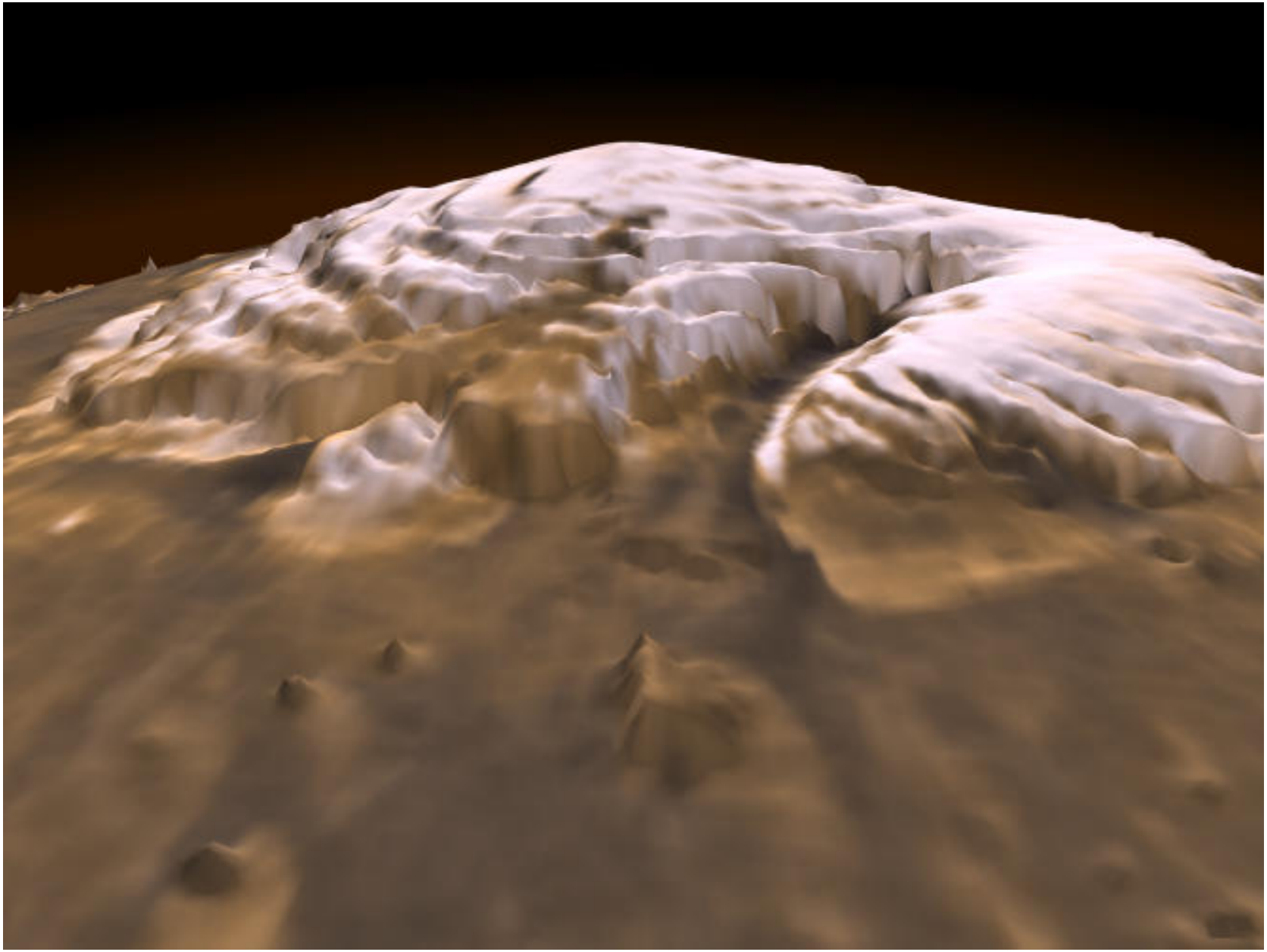
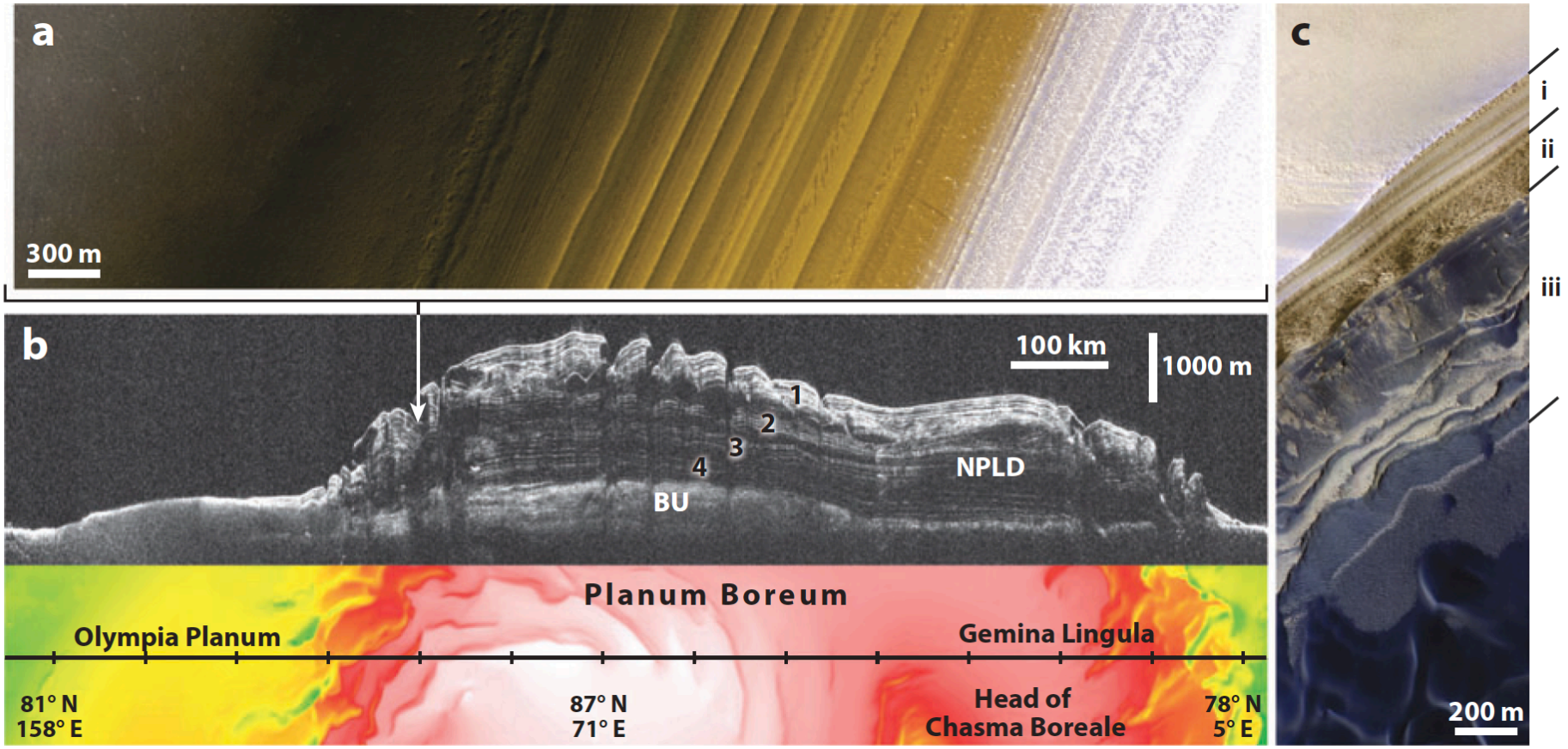


Image: MOLA Science Team

North Polar Layered Deposits

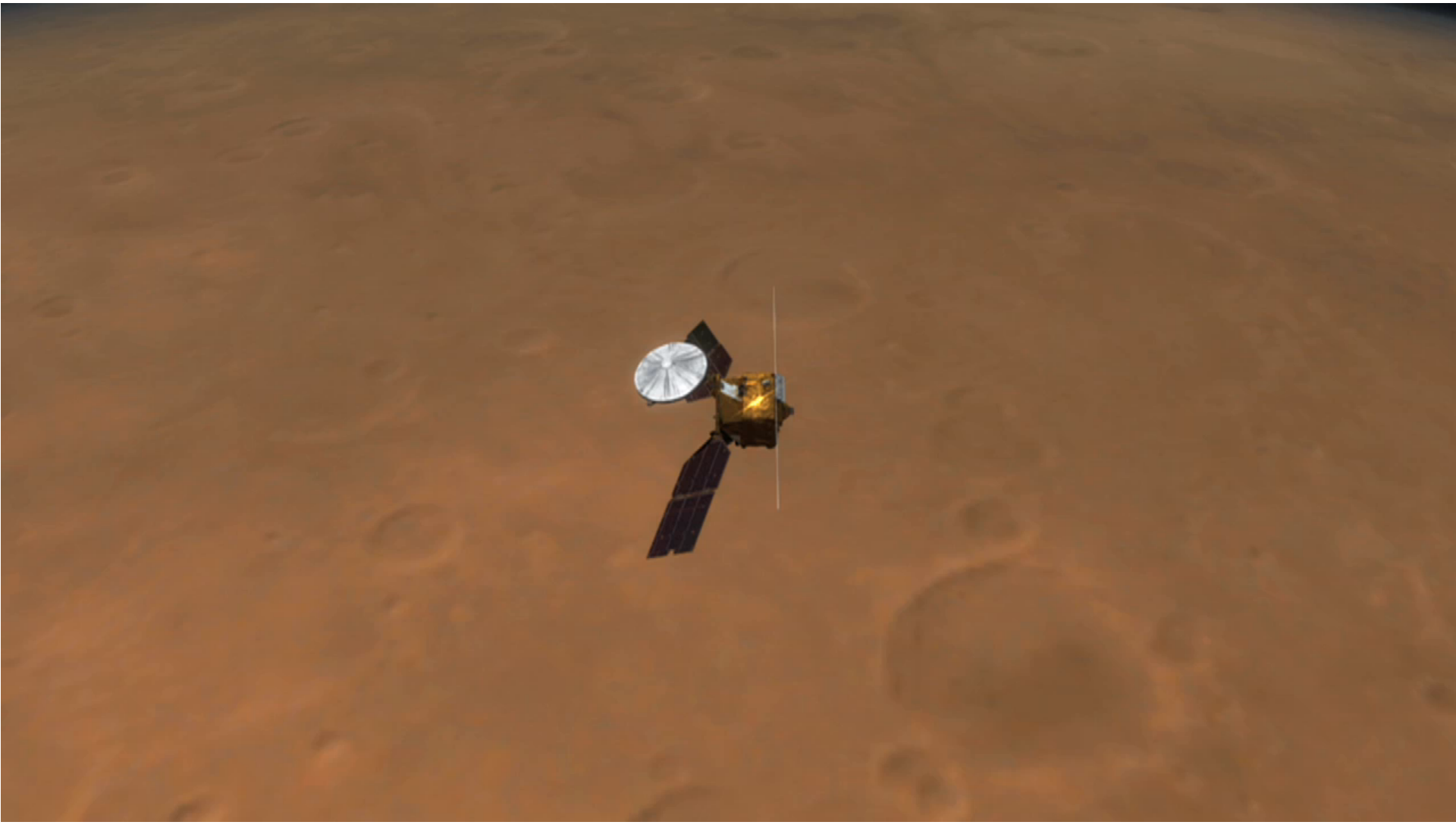


Byrne (2009)

(i) smooth layers
(ii) fractured
(iii) sand-rich unit

Interesting structures: troughs, pronounced layers, chasma –
We don't see these things in Antarctica or Greenland!

NASA Mars Reconnaissance Orbiter



North Polar Layered Deposits

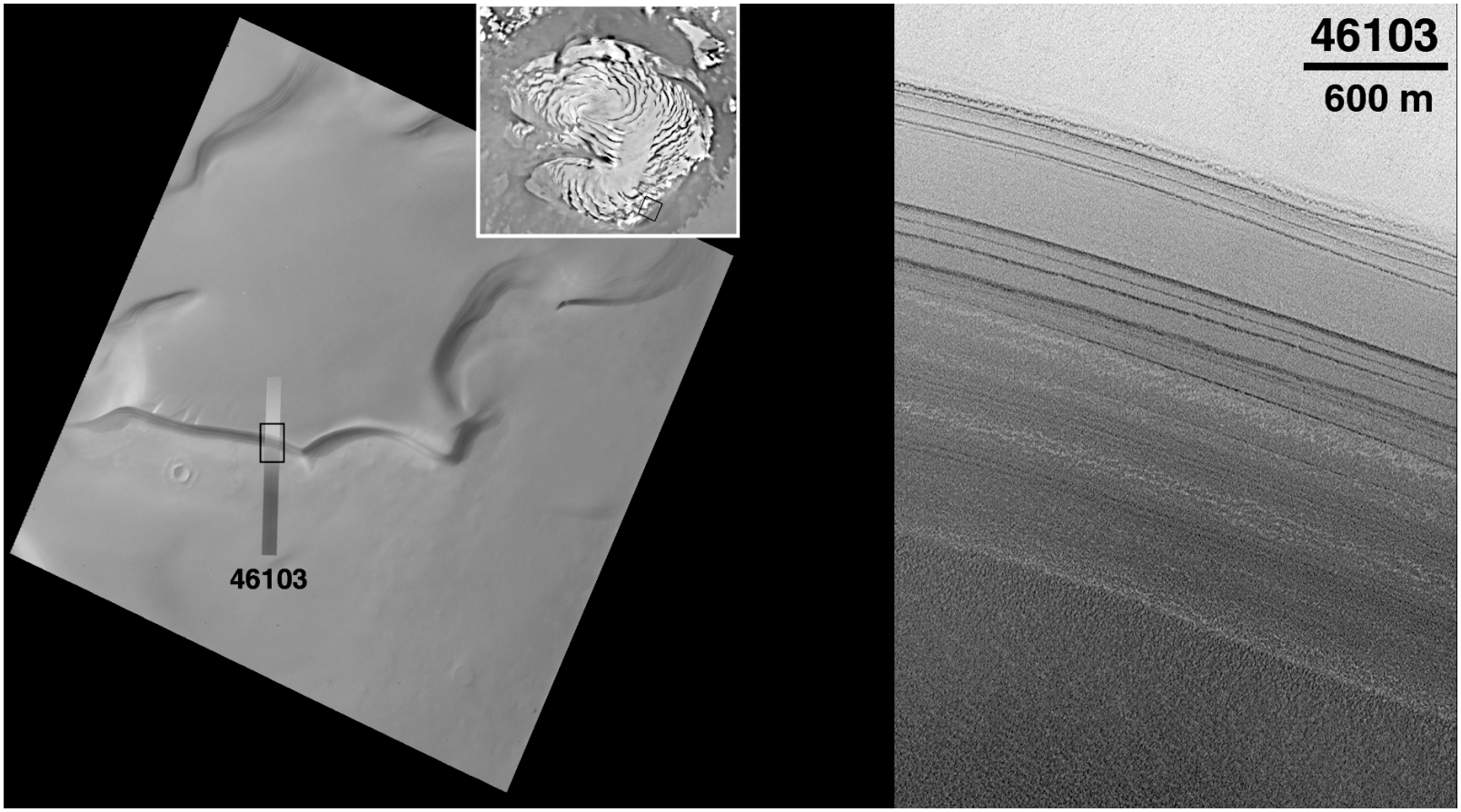


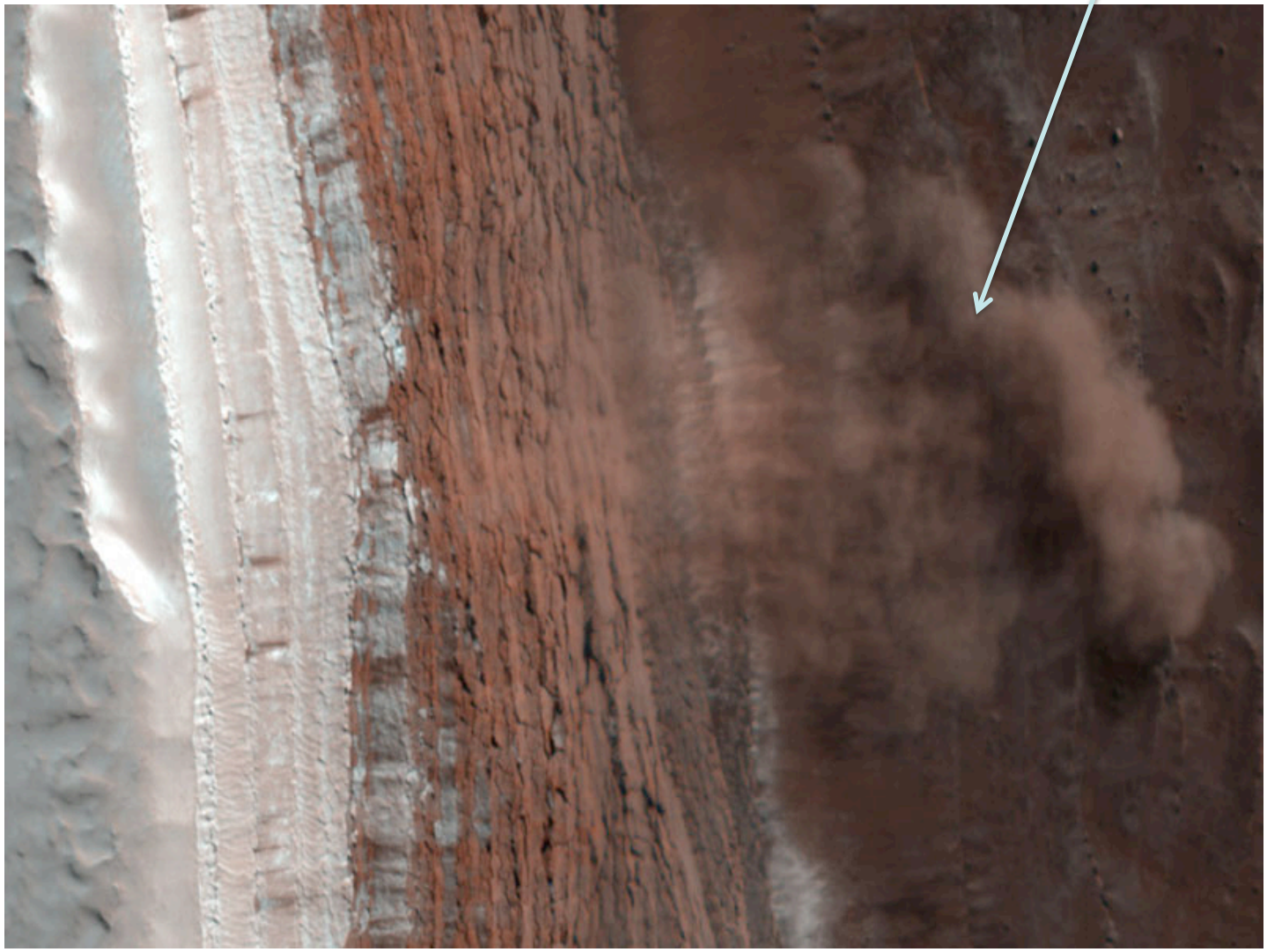
Image Credit: NASA/JPL/MSSS

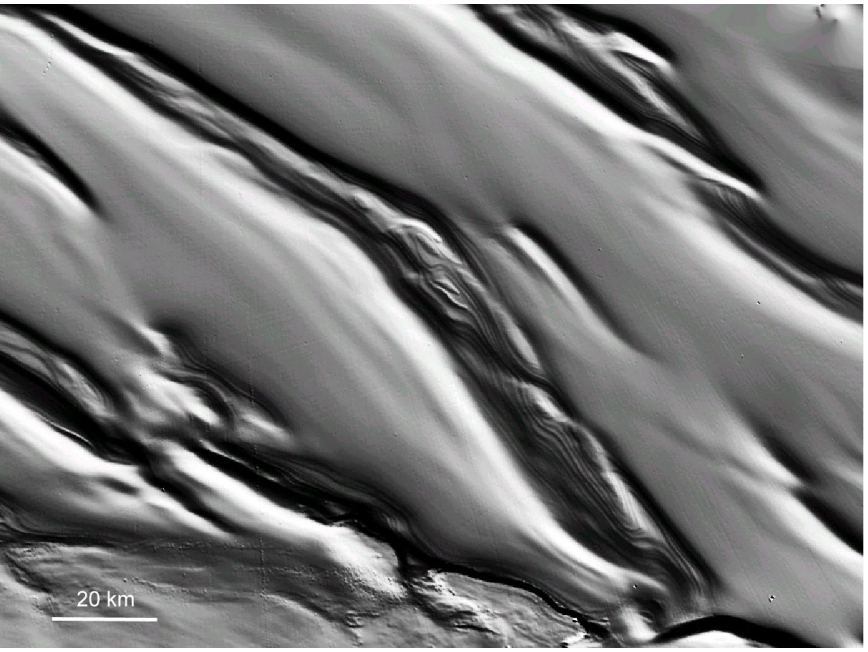
-Extremely regular, linear layered structure

-Composition: undetermined ratio of dust, ice, void space

- Exposed primarily in troughs

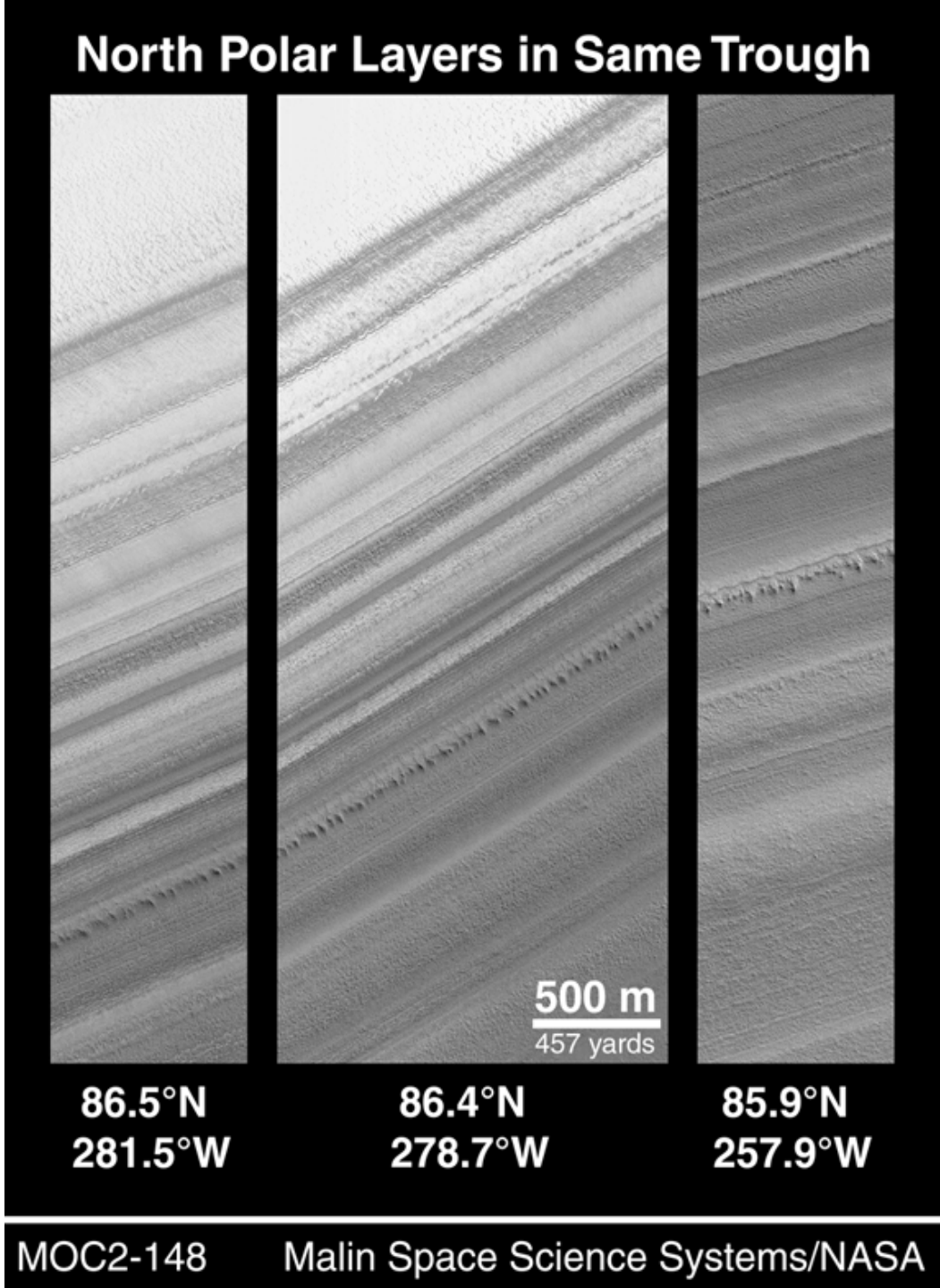
Slope failure --
dust avalanche

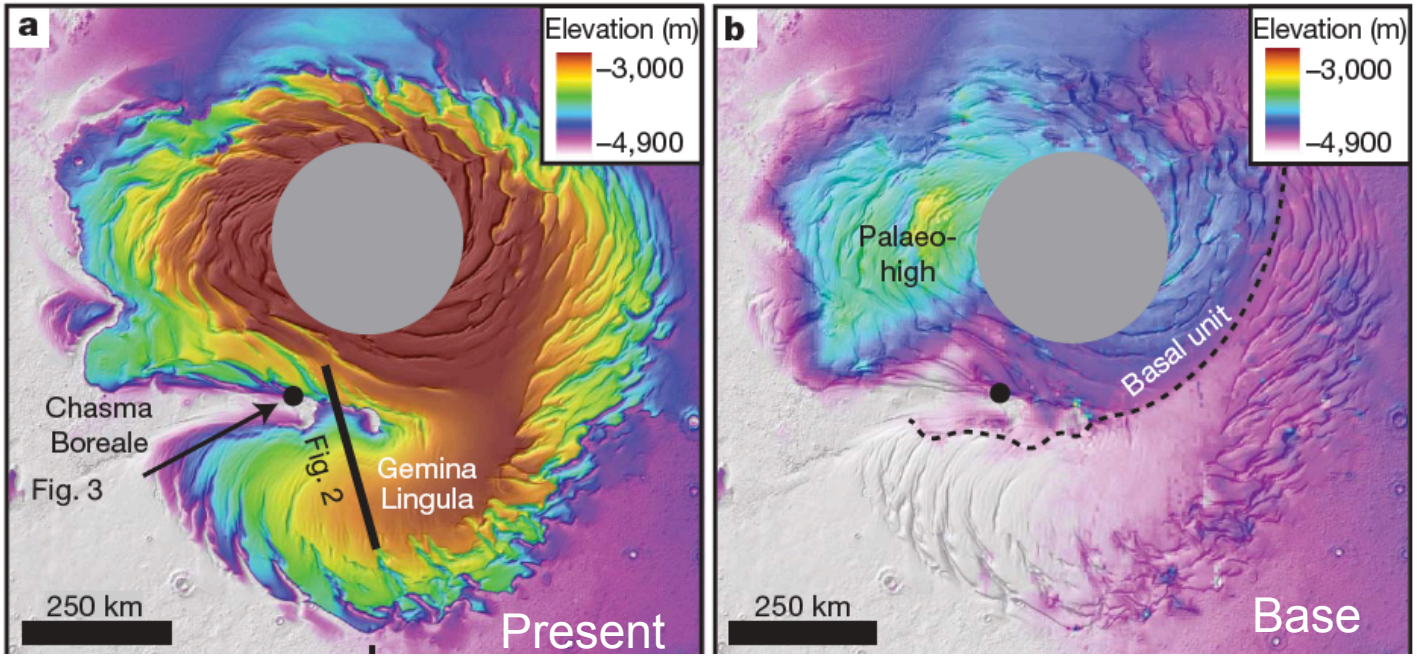




North Polar shaded relief showing exposed layers in troughs on a large scale

High resolution camera images resolve small scale layering features in individual troughs

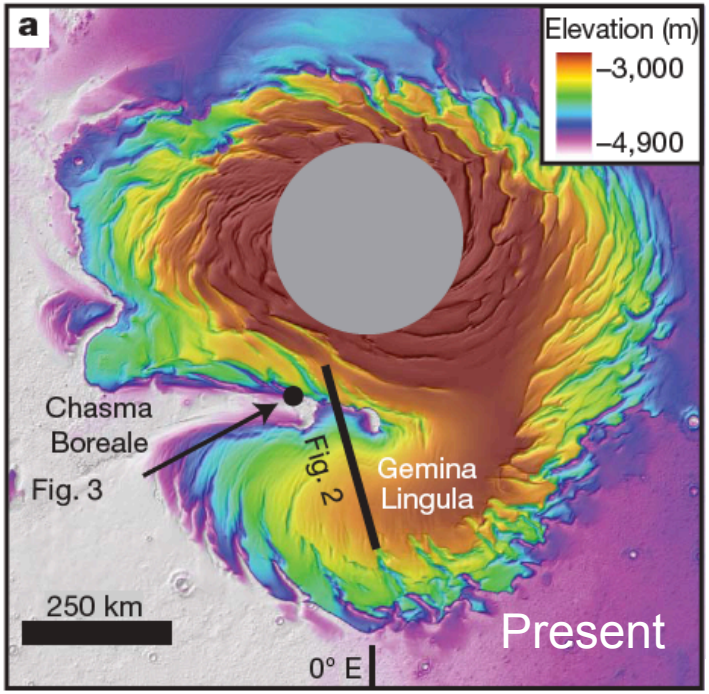


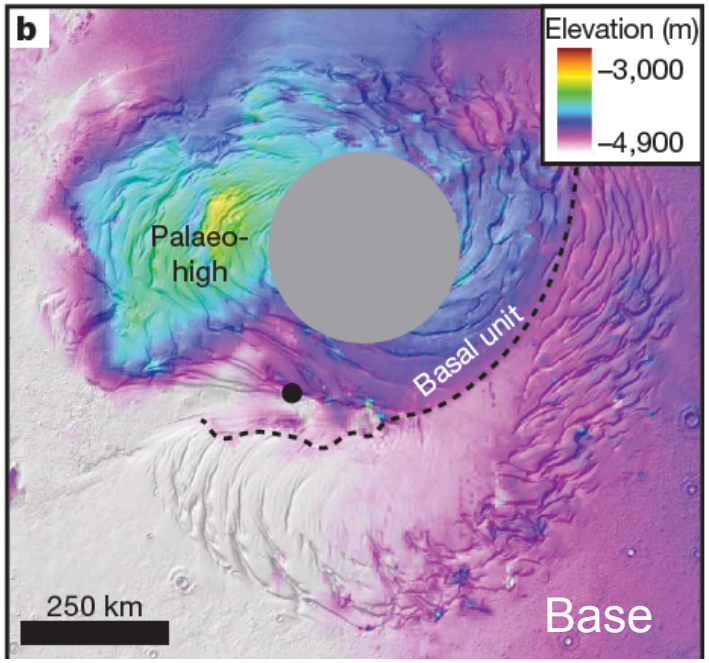


Hypothesis for formation of Chasma Boreale:

300 miles long
60 miles wide
1.2 miles deep

Holt et al. (2010)





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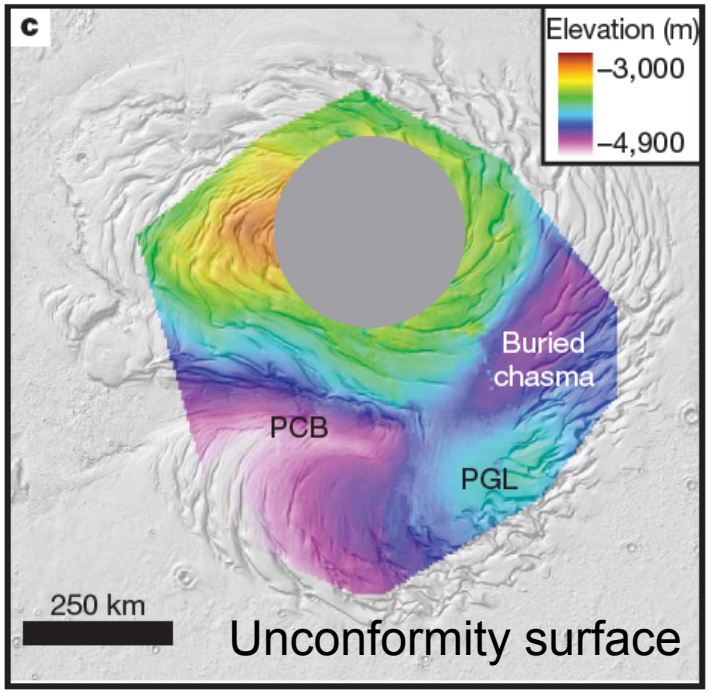
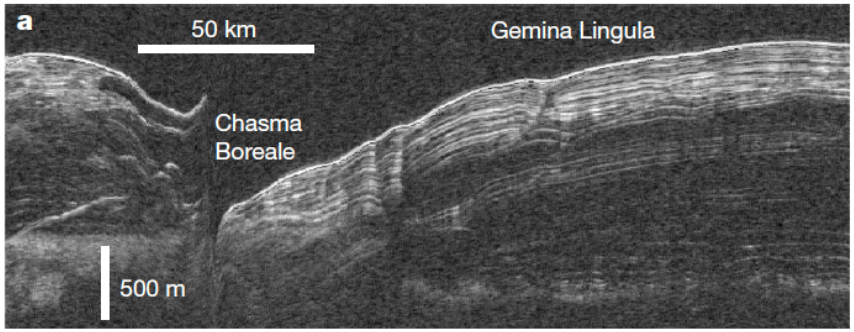
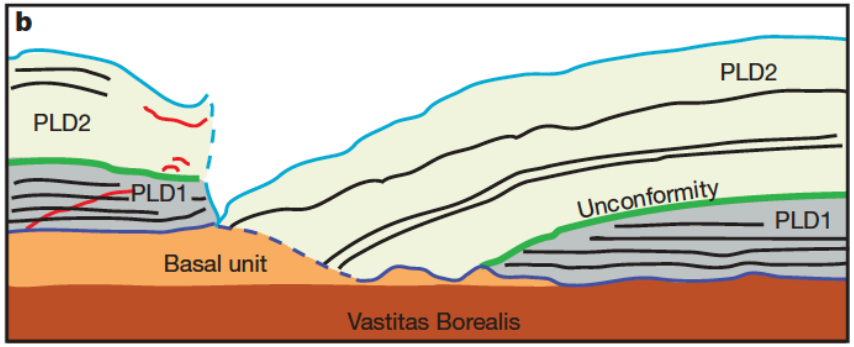






Holt et al. (2010)

Deposition

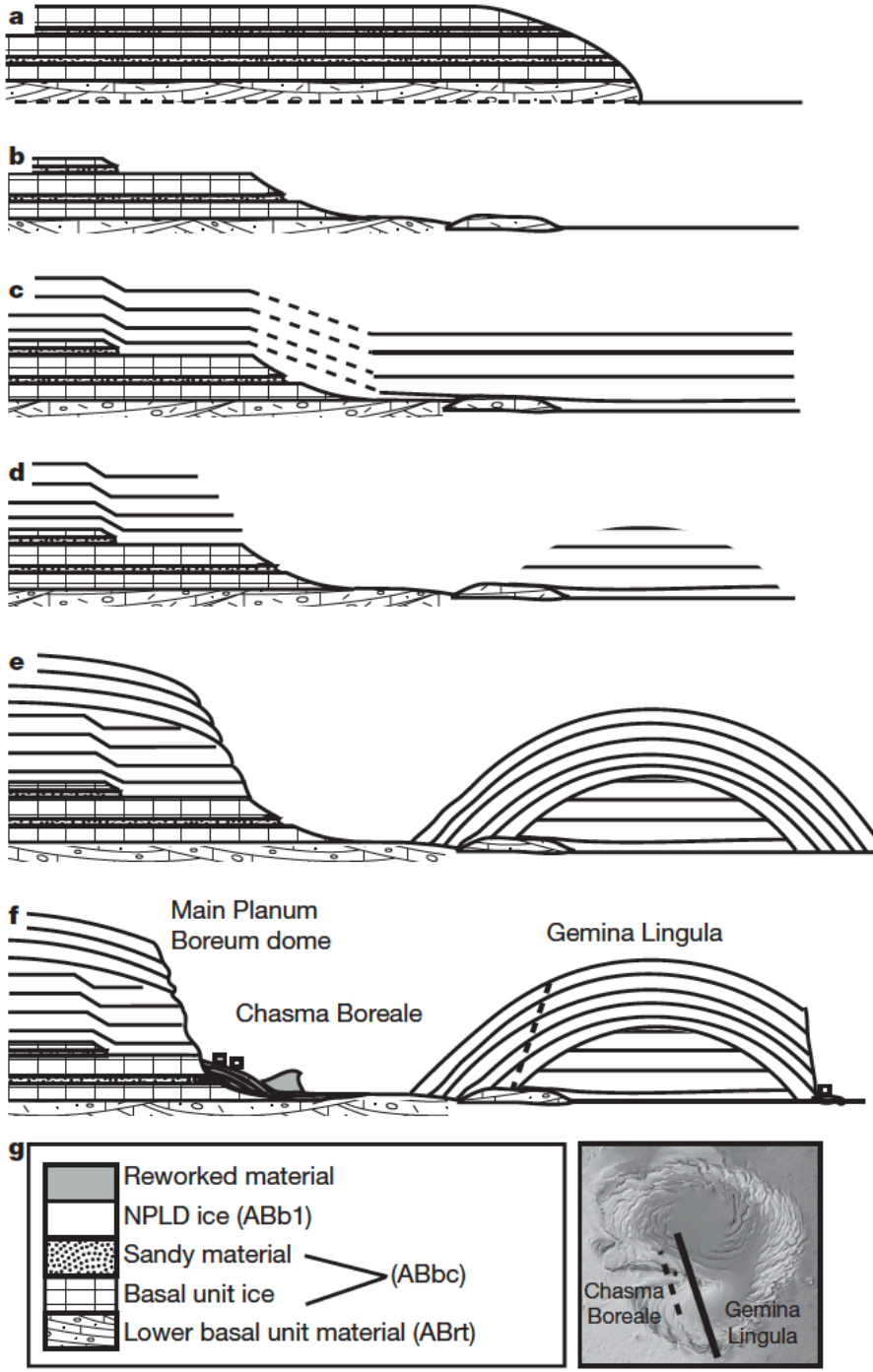
Erosion

Deposition

Erosion
(non-uniform)

Deposition
(non-uniform)

Recent erosion
(steepening slopes)



Hypothesis for formation of Chasma Boreale:

300 miles long
60 miles wide
1.2 miles deep

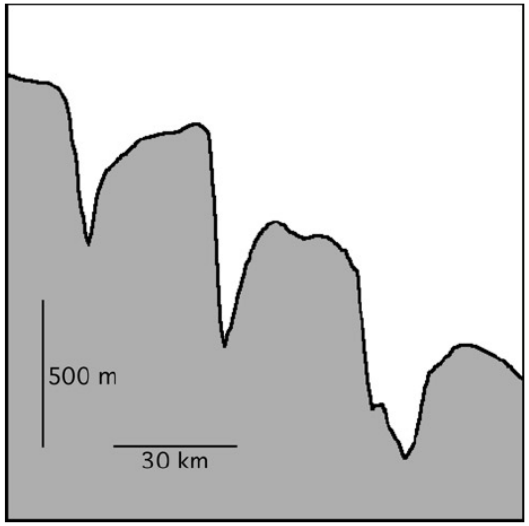
Holt et al. (2010)

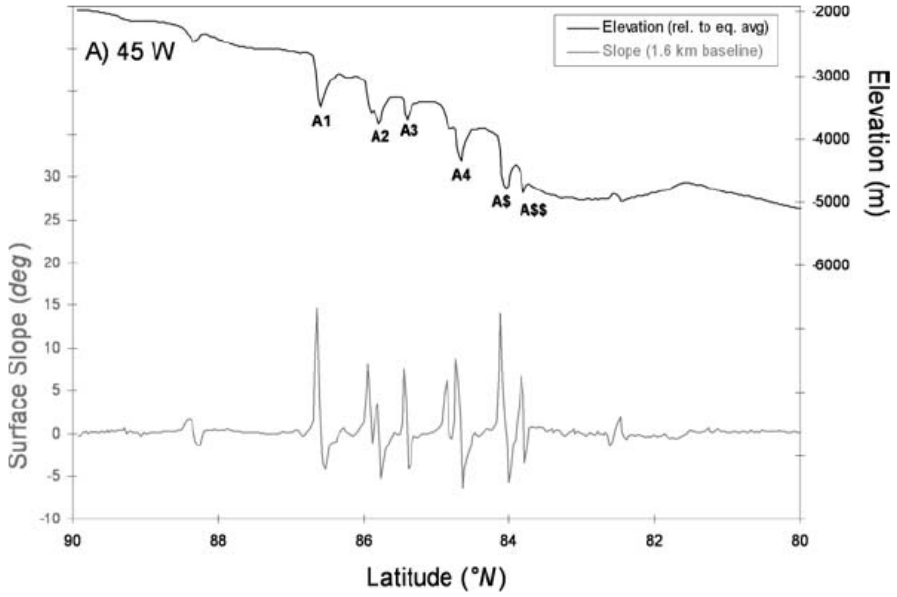
Troughs

Curvilinear structures, swirl outward counter-clockwise from the pole

Enhanced steepness with increased latitude not due to latitudinal variations in sublimation

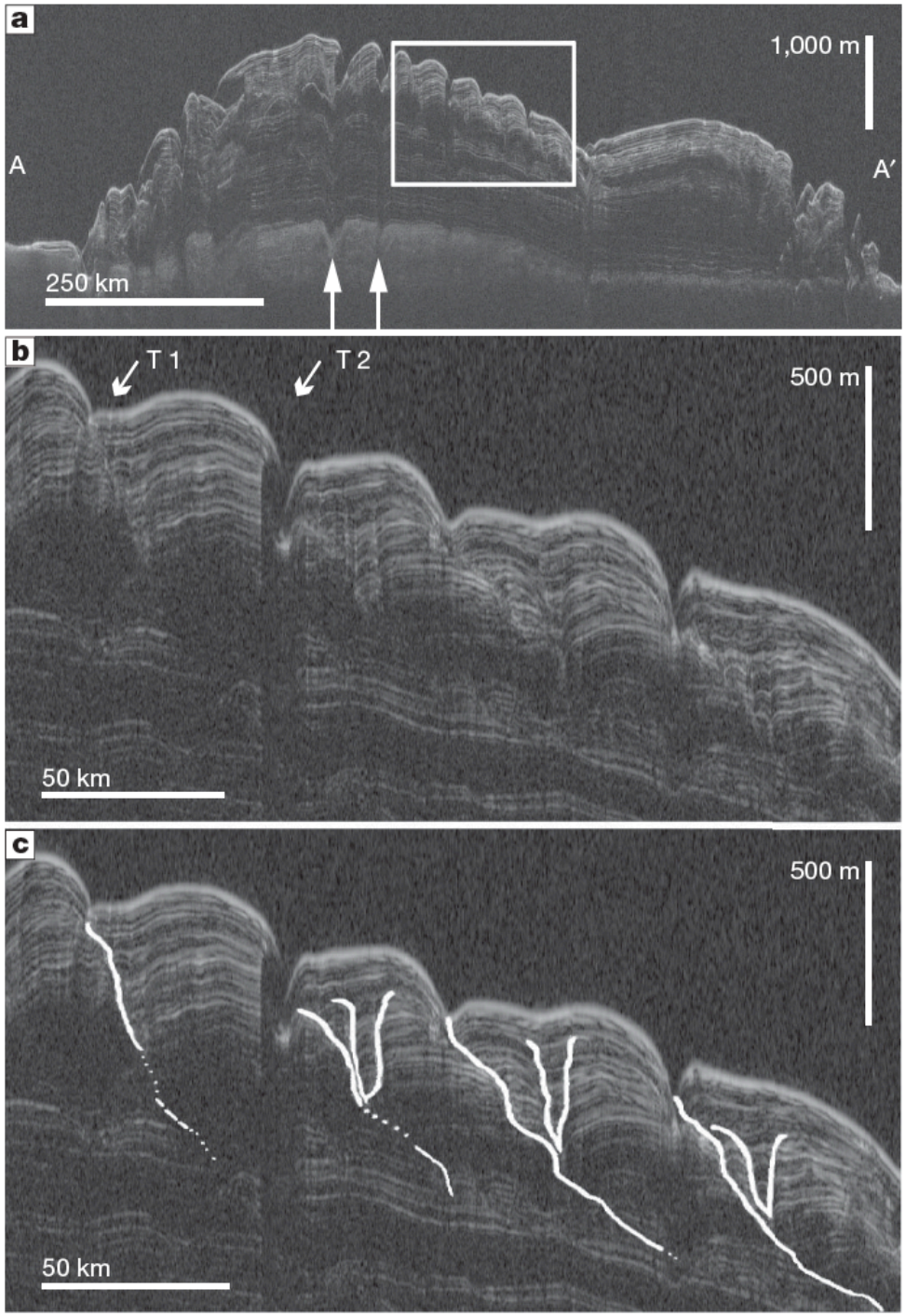
Equator facing slopes steeper than Pole facing slopes





Fishbaugh and Head (2002)

Pathare and Paige (2005)



Smith and Holt (2010):

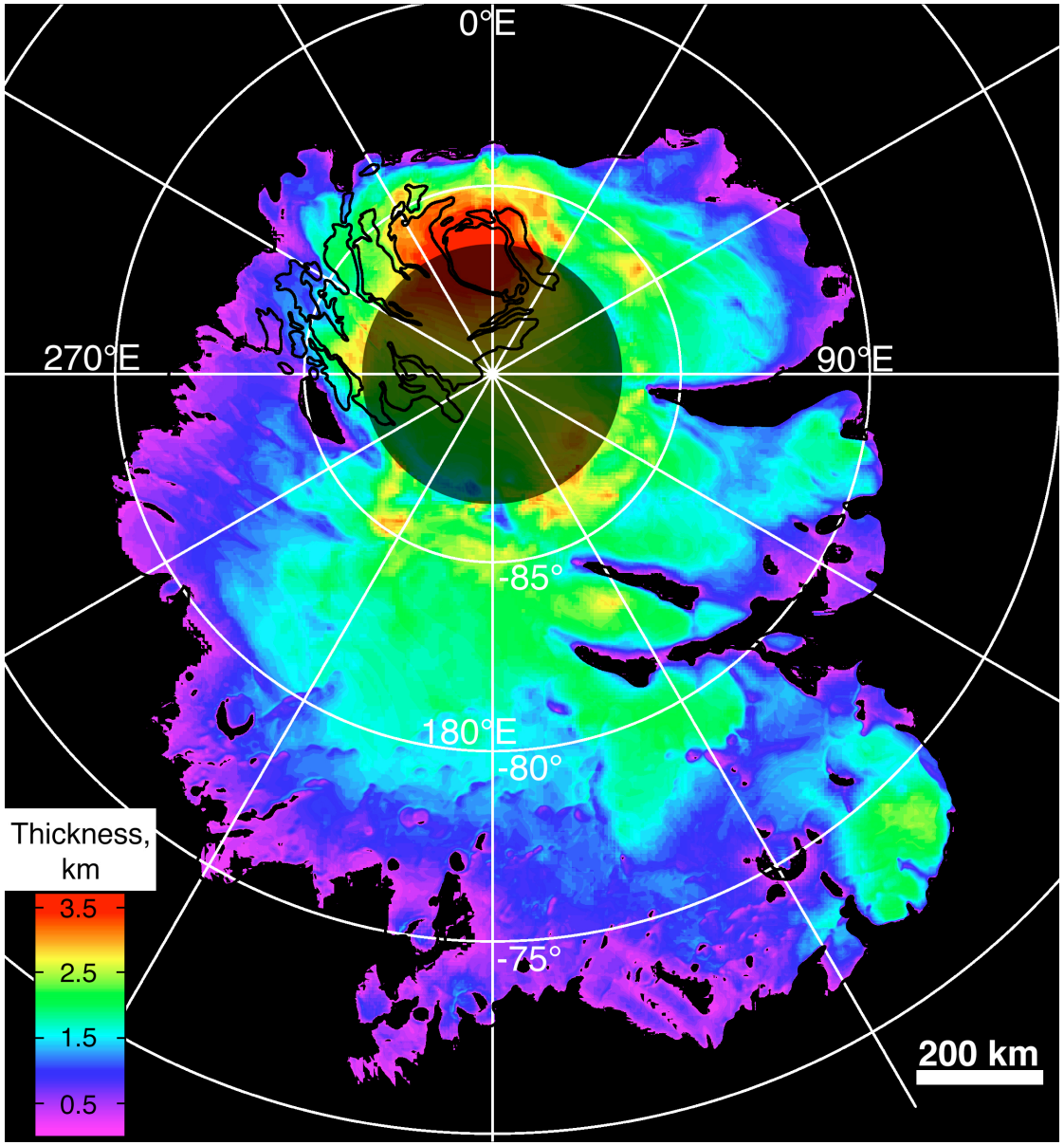
New hypothesis that troughs are constructional features

- Solar ablation, wind transport, and atmospheric deposition

Balance of these processes will cause more or less migration, deposition, or erosion

Traced for upper 600 meters

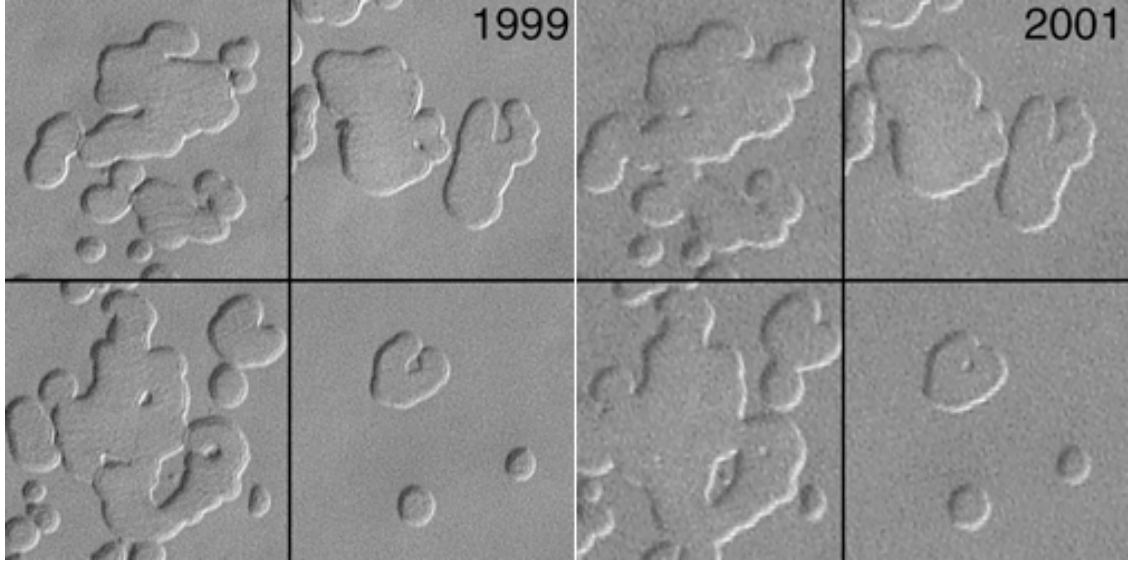
South Polar Layered Deposits

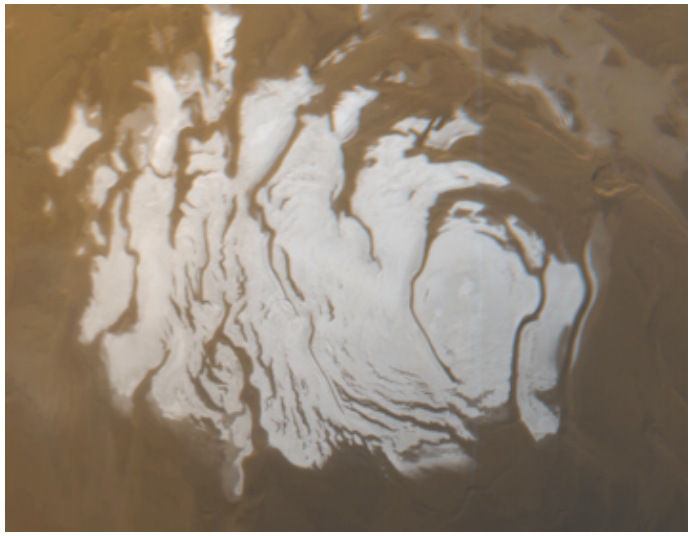


- SPLD to furthest extent ~72° S latitude

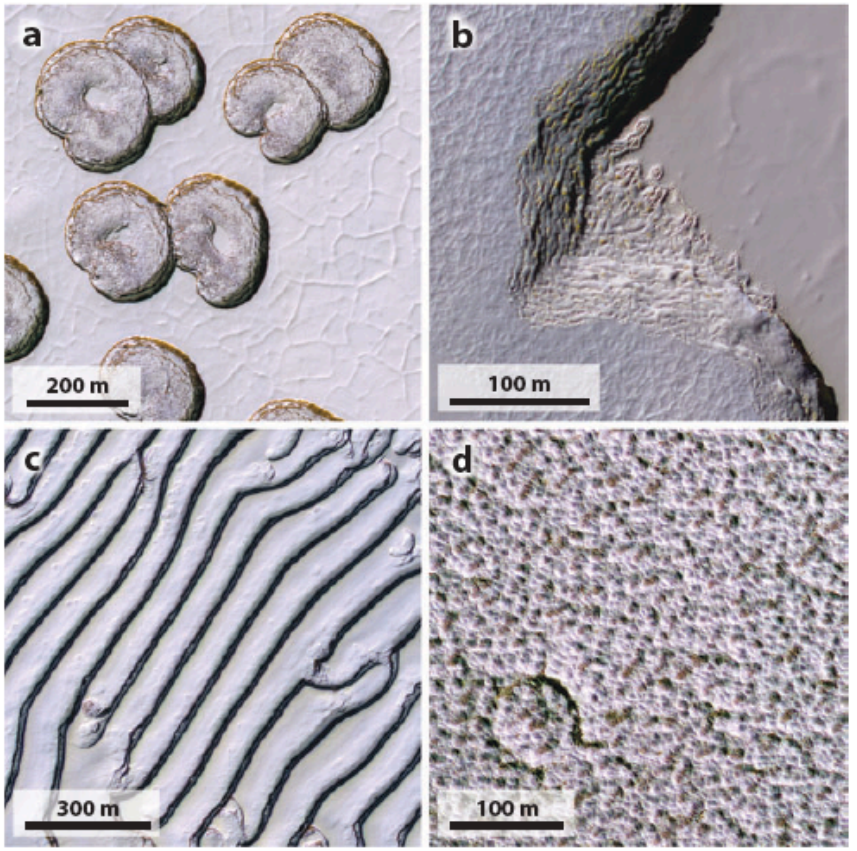
-Almost entirely considered layered deposits, not residual cap

Southern Residual Cap (CO_2 ice)

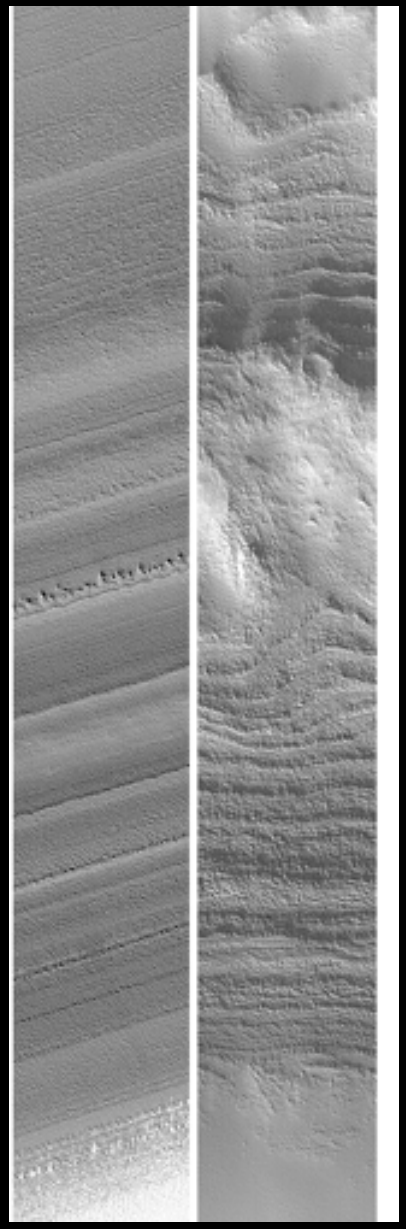




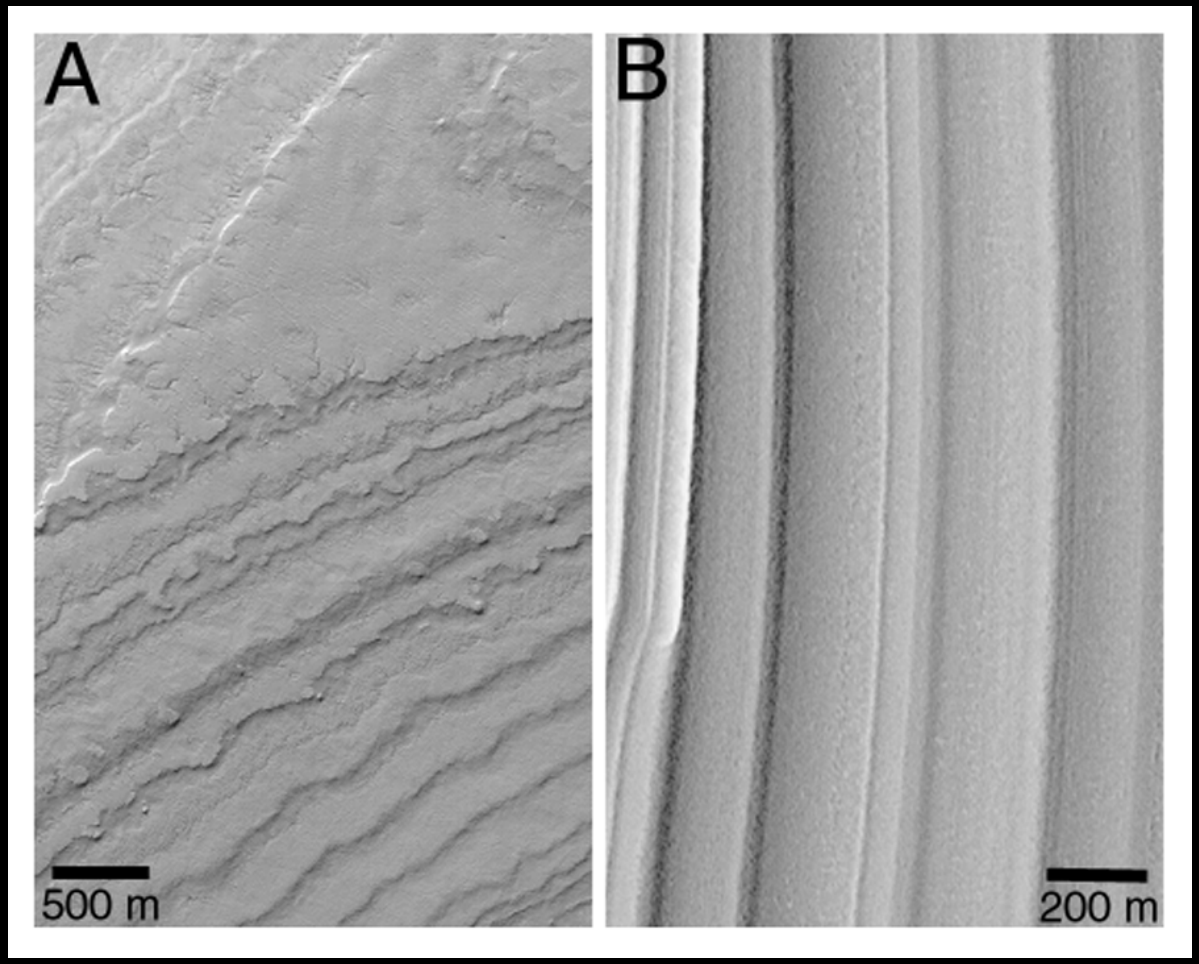
Martian South Polar Cap (Image: NASA/JPL/MSSS)



North vs. South Layer Comparison



North South



South North

Images: *Malin and Edgett*, JGR 2001

So, where are we at now?

Mars actually had a dynamic history and processes are active today, especially for polar ice

- Deposition and sublimation of CO_2
- Erosion by wind, ablation, and slope failure
- On longer timescales ice stability locations change

Imagery, topography, radar stratigraphy data abundant

New Mars missions providing new information

There are still big research questions:

- history of the polar ice
- climate conditions in the past – how warm was it?
- cycling of ice from poles to mid-latitudes