Water Ice on Mars and the Moon*

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Abstract

Water ice and other volatiles are not only vital to sustaining human settlement in space, but hydrogen and oxygen extracted from water by hydrogen-oxide reactions can also be used as propellants on interplanetary missions. Water ice occurs in abundance on Mars in polar ice caps, as well as in shallow permafrost. Martian polar caps, 2.7 and 3.1 km thick at the north and south poles, respectively, have an ice core overlain by carbon dioxide frost that sublimates during spring. The ice layers are interbedded with numerous thin dust layers that record global cycles of dust storms. Martian permafrost, which appears to hold more water ice than the poles, occurs in a wide variety of forms, including collapse structures, polygonal terrain, and pingoes with morphologies similar to those of terrestrial periglacial features.

Water ice may also occur on the Moon at the north and south poles, judging from hydrogen neutron scattering signatures from Clementine and Lunar Prospector missions. Given radar reflectivity signatures, lunar ice probably does not occur in extensive sheets at the surface, but, rather, in disseminated form in the shallow (<40 cm) regolith in floors of permanently shadowed craters. Estimates of the ice resource, hypothesized to have accumulated from meteoritic and cometary impacts, range from 10 to 300 million metric tons (3 to 90 billion gallons). An important objective of the Lunar Reconnaissance Orbiter mission, planned for launch in 2009, will be to map the distribution of, and quantify, the lunar ice resource.

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Water Ice on Mars and the Moon

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Denver, Colorado
June 9, 2009

HST

Bureau of Economic Geology

100 Years of Scientific Impact

1909-2009

Lick Observatory photograph

Outline

Strategic Importance

-Sustaining Human Settlement

-Manufacture of Propellants for Transportation

The Moon

-North and South Poles

Mars

-Atmosphere
-Ice Caps
-Permafrost
-Fluvial and Lacustrine Deltas
-Glacial Debris Aprons
-Gullies

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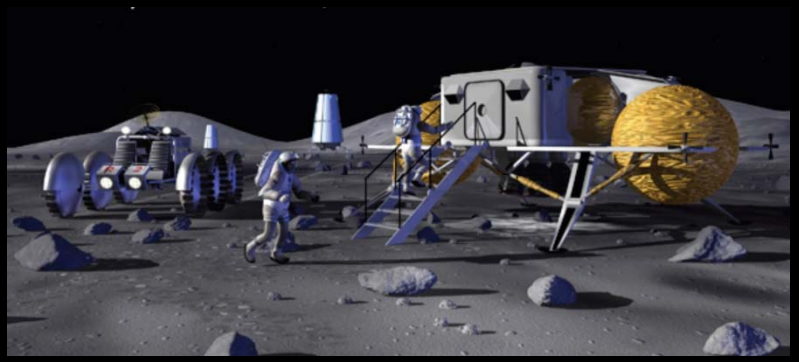
Strategic Importance

Support human settlement



Manufacture of propellants for transportation

Liquid hydrogen and oxygen
Nitrogen tetroxide
Hydrogen peroxide
Hydrazine
Nitrous oxide

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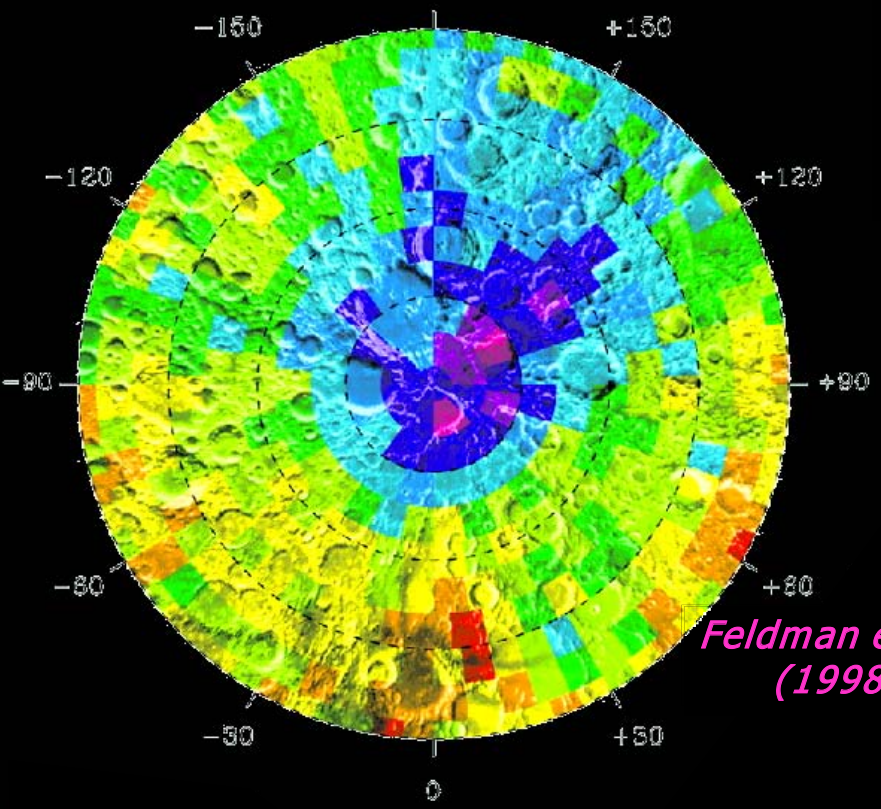
Lunar Energy Mineral Resources

Resource	Use	Occurrence
Helium-3	Energy	Mature regolith
Hydrogen	Propellant, water	Mature regolith, poles?
Oxygen	Propellant, air/water	Global
Nitrogen, carbon	Food and plastics	Breccias/regolith
Metals/bulk regolith Iron Titanium Aluminum	<u>Construction</u> Moon base Shielding Roads Solar power facility	Breccias/regolith

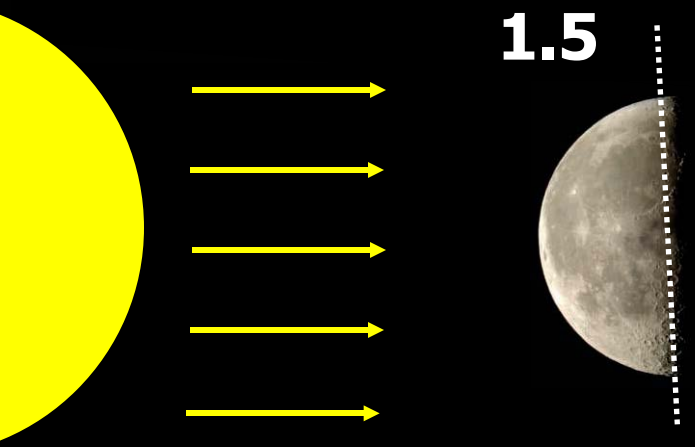
Lunar Hydrogen North Pole

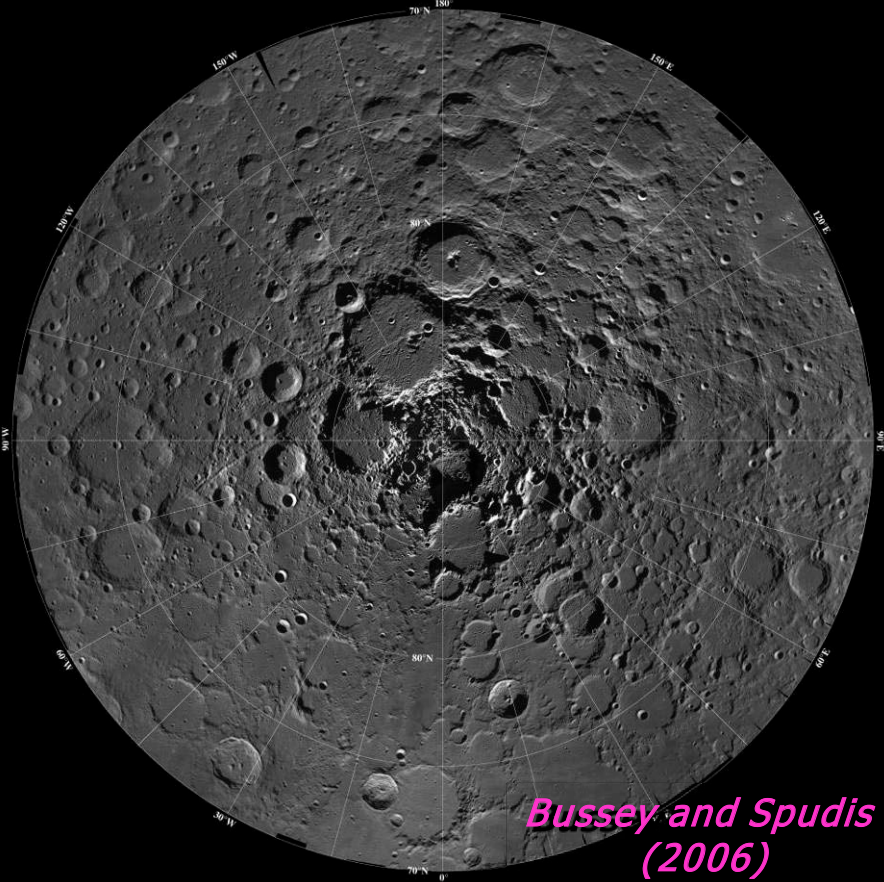
Both poles: ~6.6 billion tons of ice

Shadowed area within 12 latitude of north pole: 7,500 km²



Feldman et al. (1998)

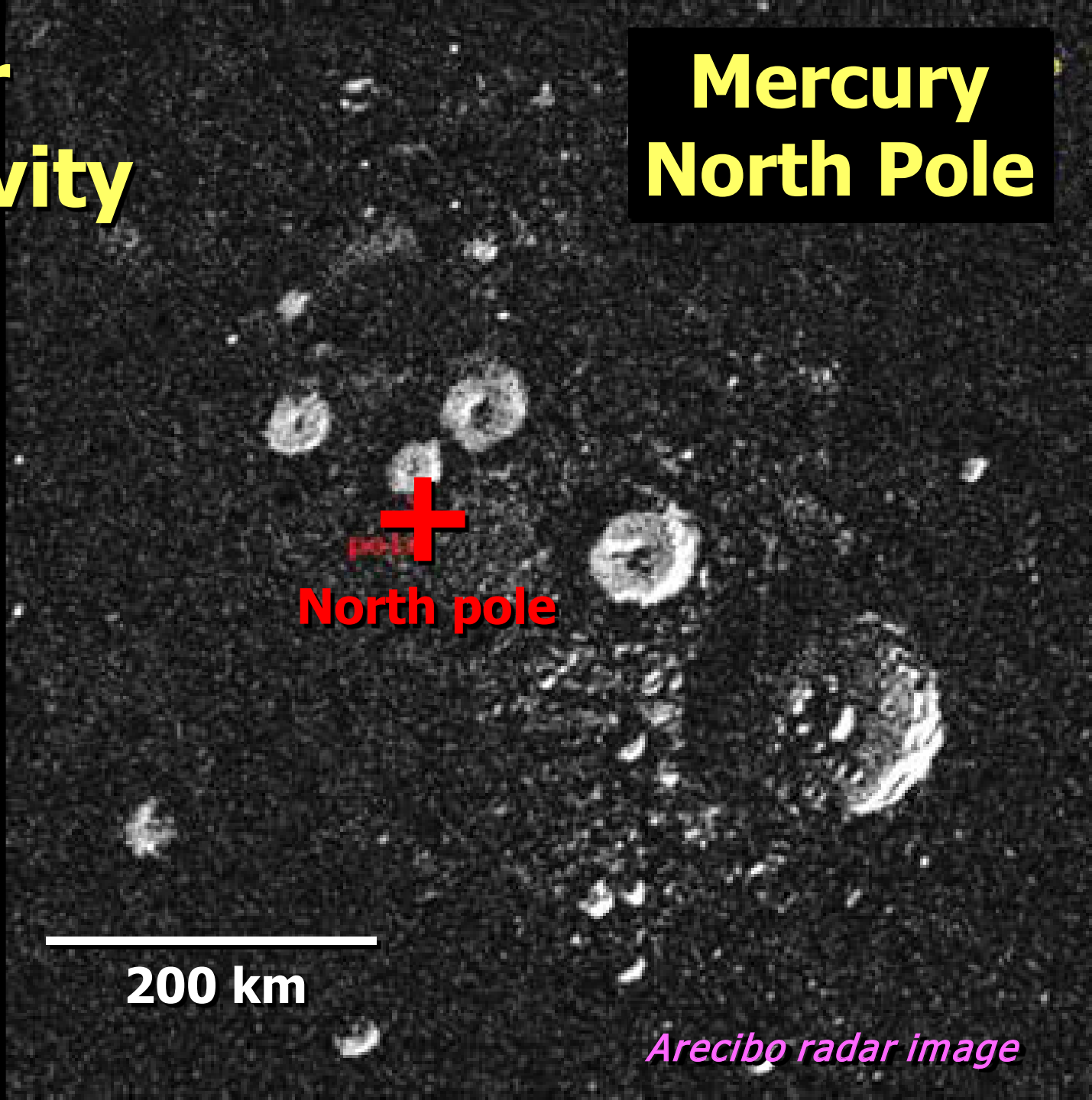




Bussey and Spudis (2006)

Radar Reflectivity

Mercury North Pole



Radar Reflectivity

Lunar Poles

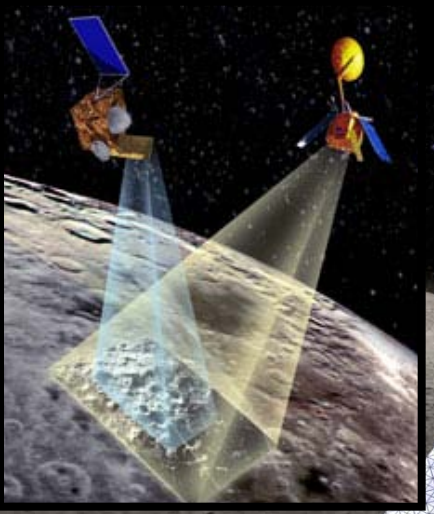
Arecibo radar images

North

South

Lunar Reconnaissance Orbiter

Mini-RF SAR



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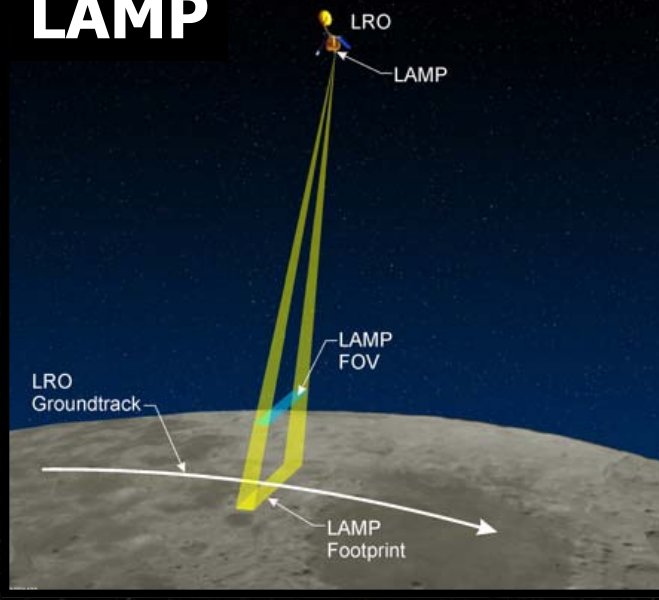
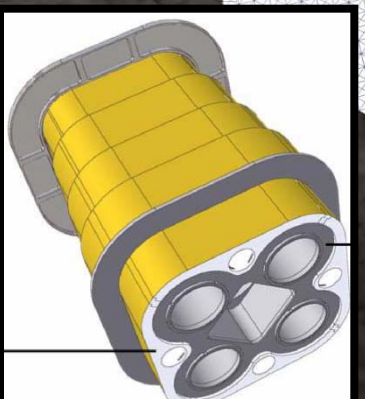


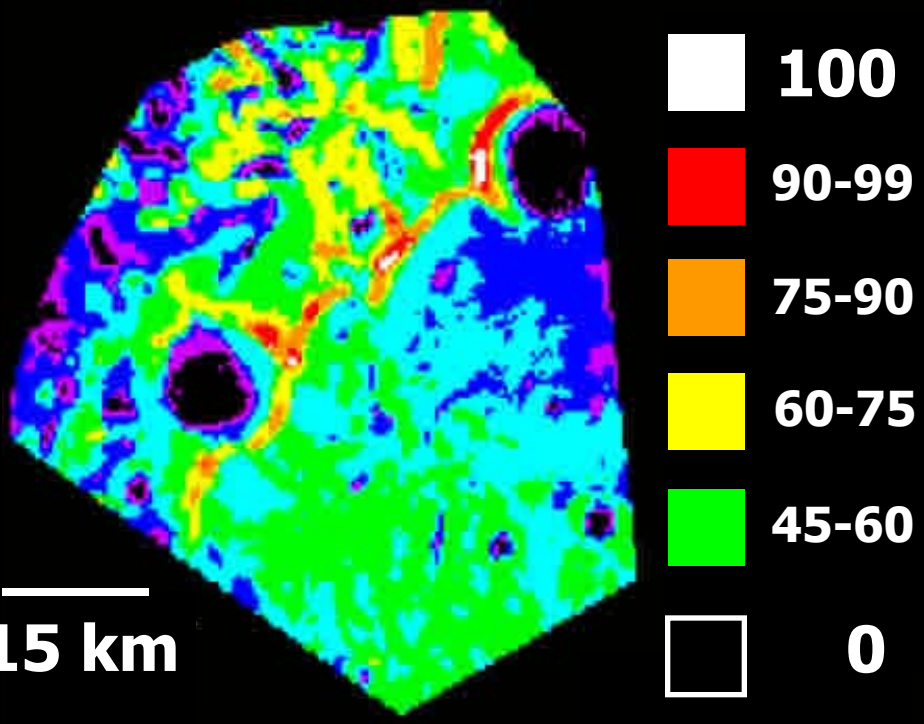
LEND



Solar Illumination North Pole

Solar power

% Illumination



100

90-99

75-90

60-75

45-60

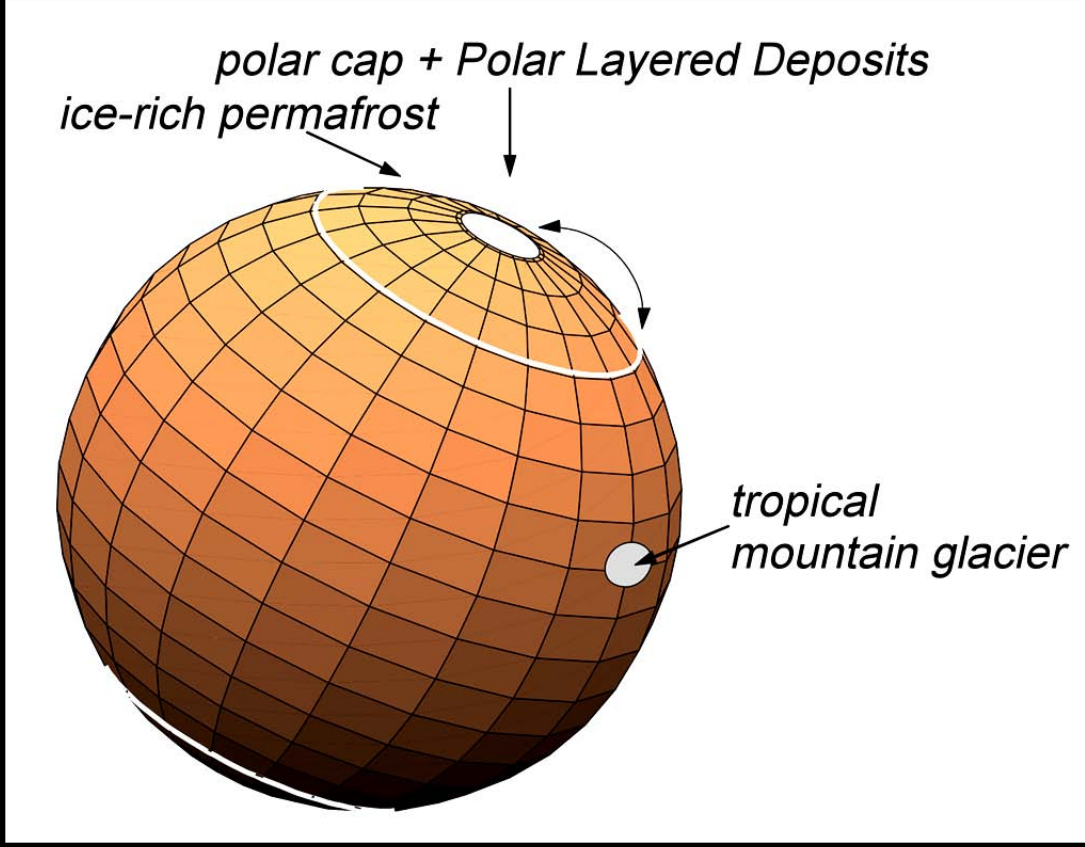
0

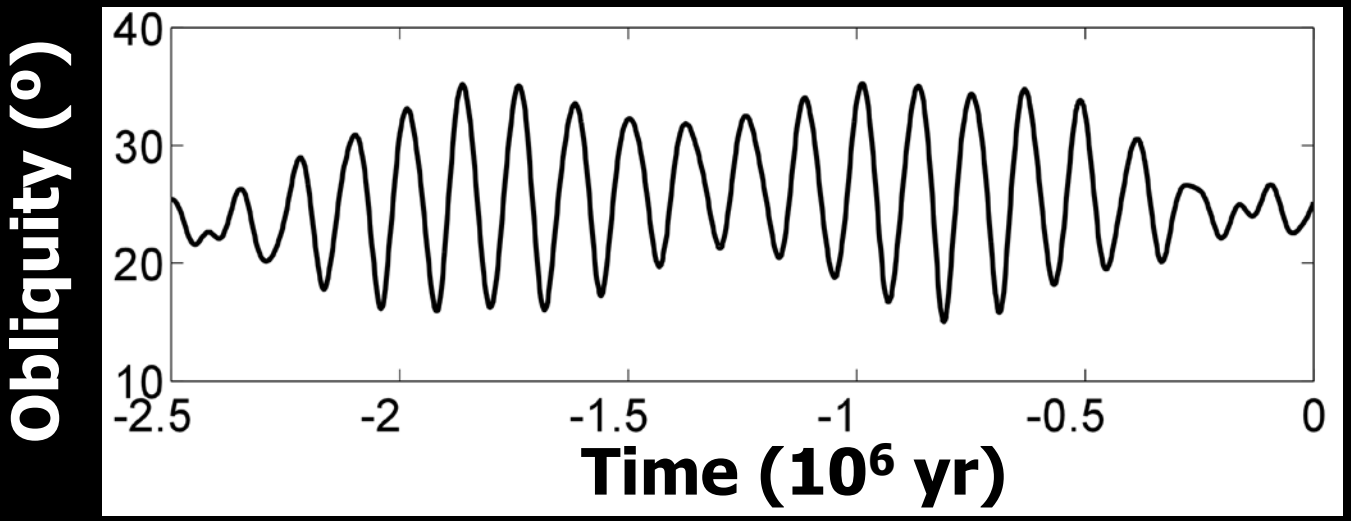
Bussey and Spudis (2006)

Mars

Water ice

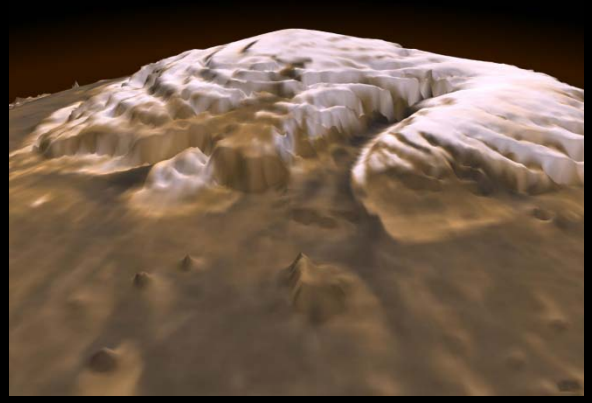
-Atmosphere
-Ice caps
-Permafrost
-Fluvial , lacustrine deltas
-Glacial debris aprons
-Gullies





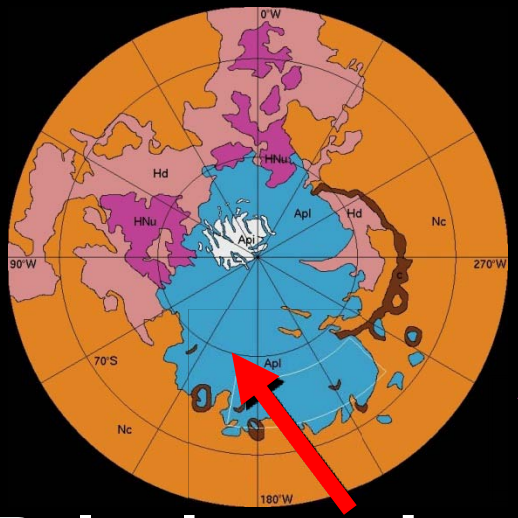
Schörghofer (2009)

Mars: Water Ice Distribution



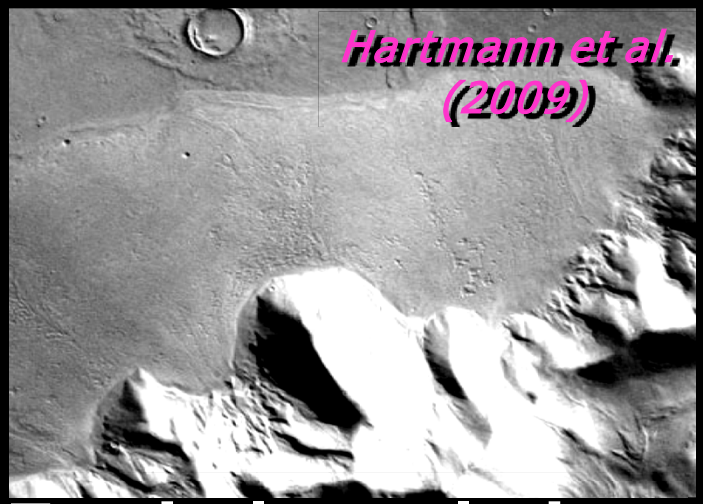
Kieffer et al. (1992)

Polar caps
0.925 x 10^6 km^2

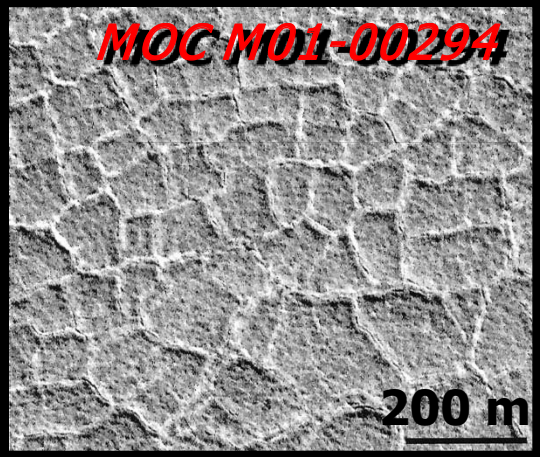


Tanaka (2005)

Polar layered terrain
1.8 x 10^6 km^2

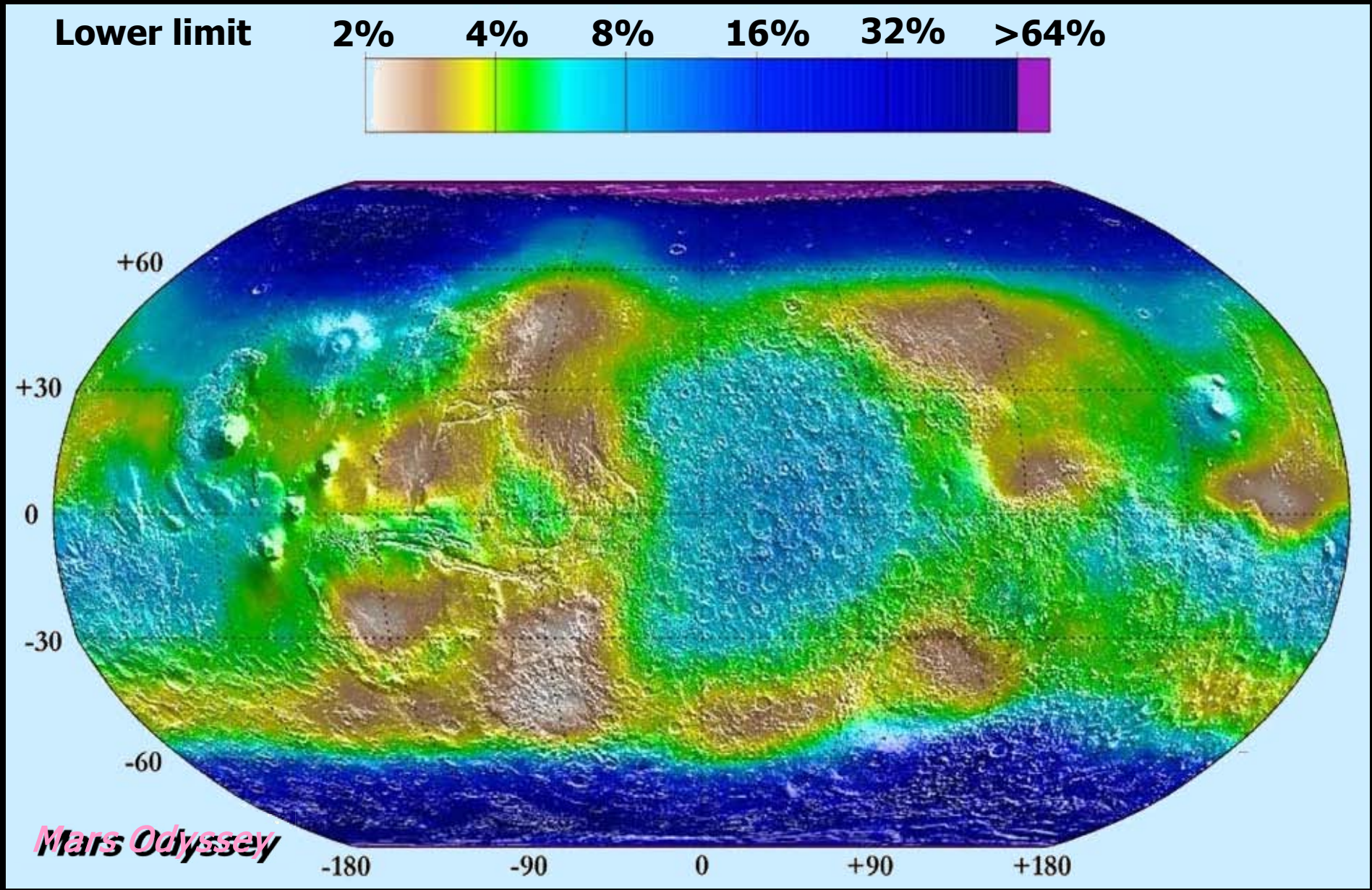


Tropical mt. glaciers
0.3 x 10^6 km^2

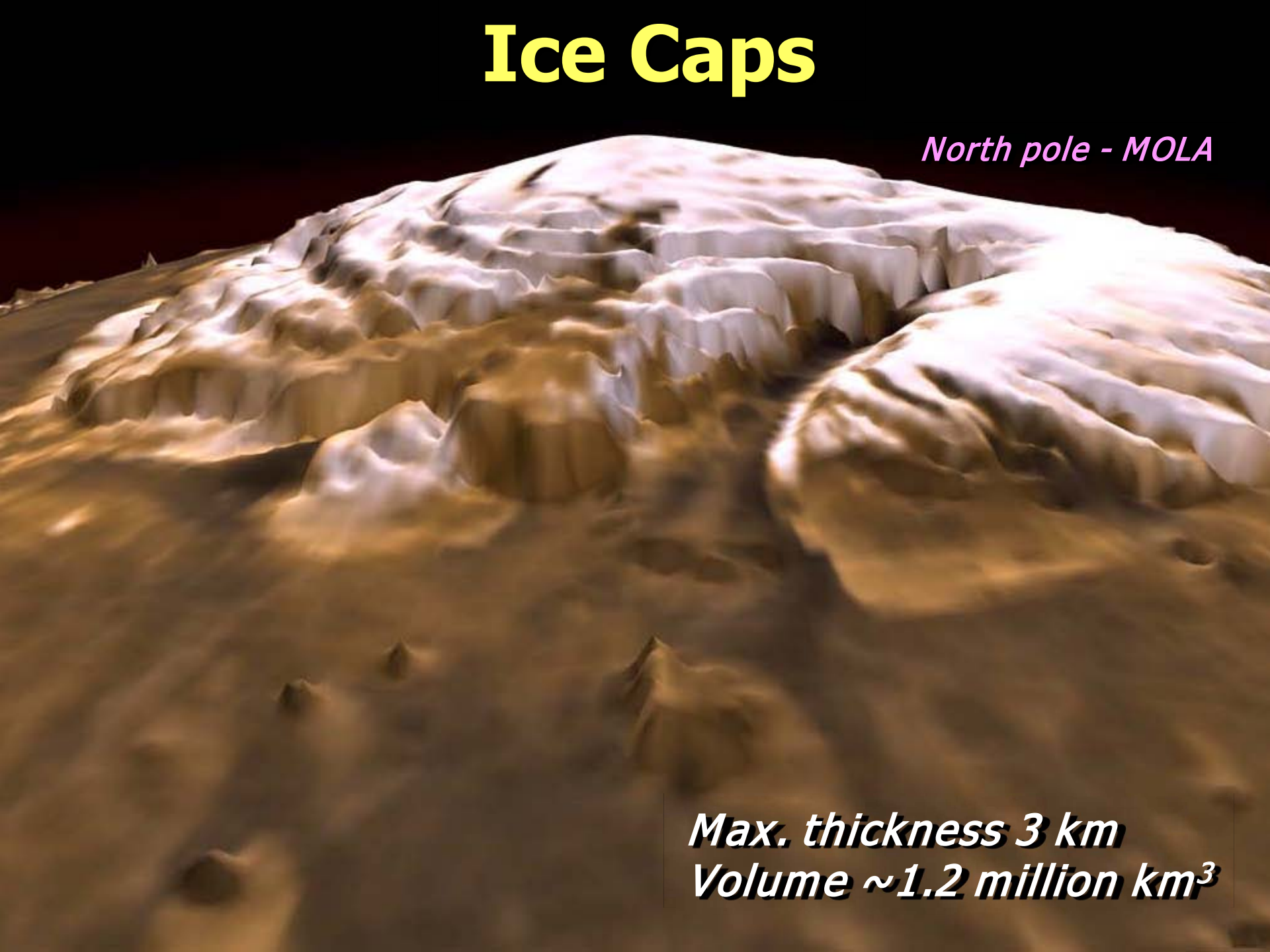


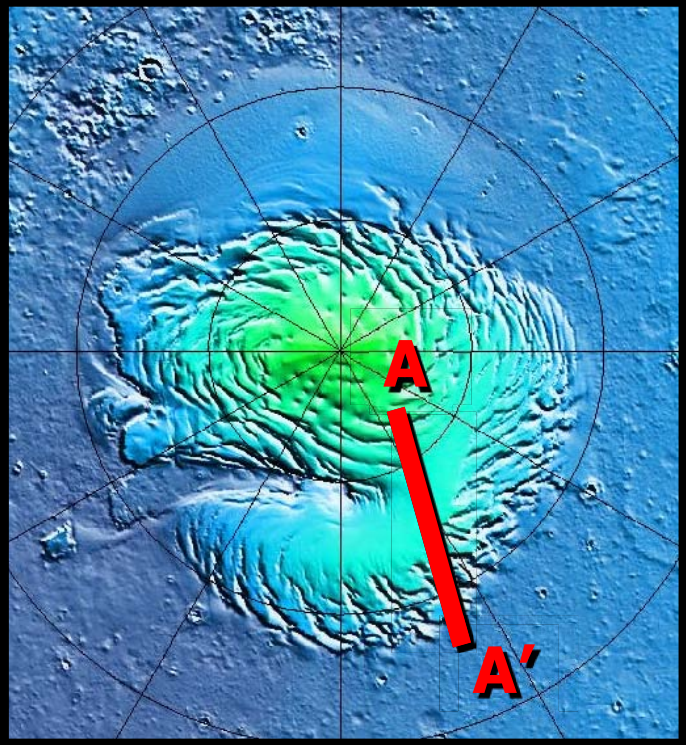
Subsurface ice
21 x 10^6 km^2

Mars: Global Water Distribution



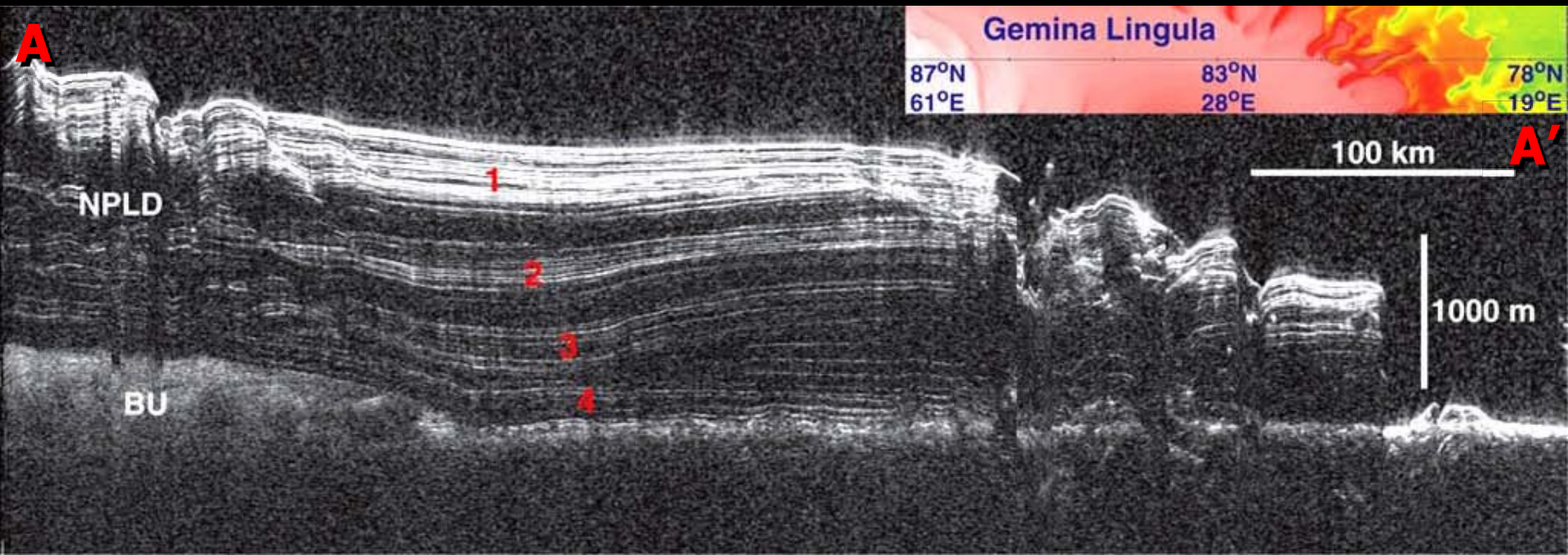
Ice Caps



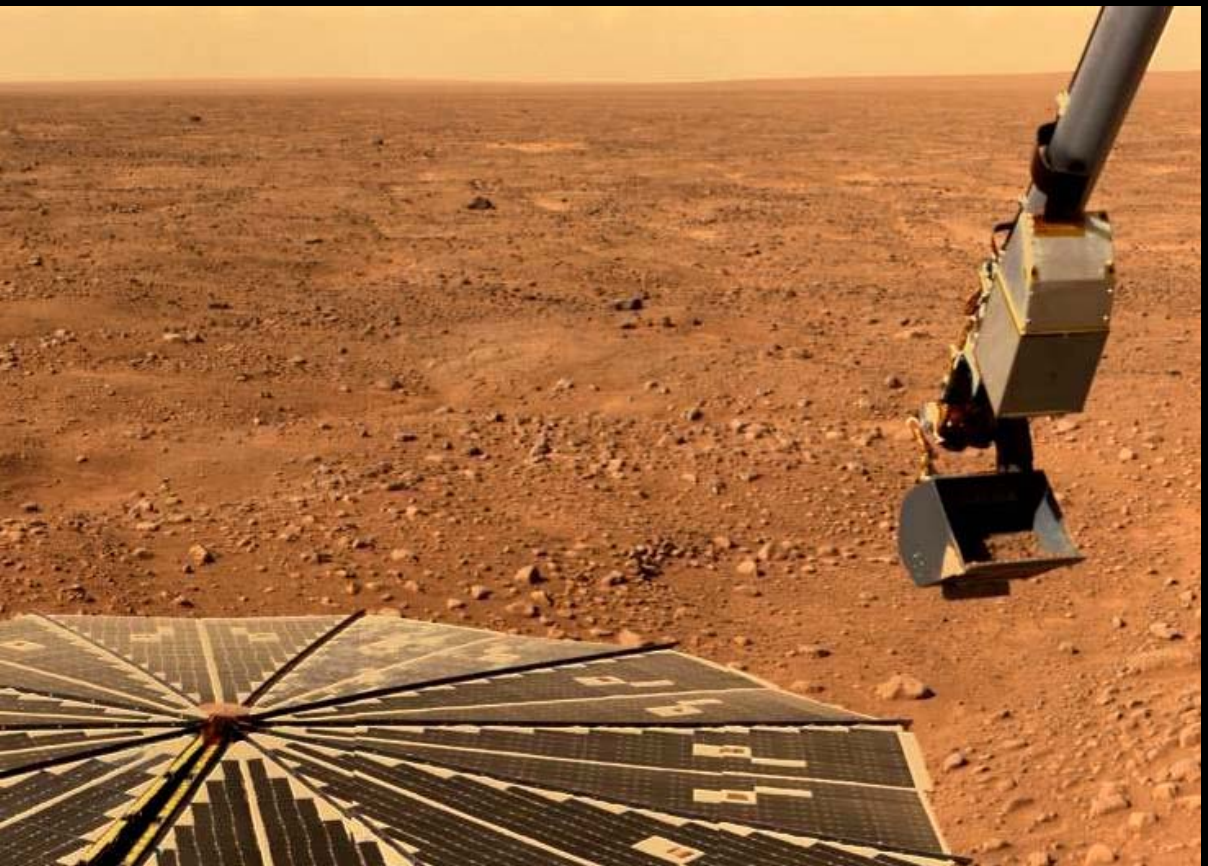


North Polar Cap Structure

Phillips et al. (2008)



Martian Permafrost
Phoenix Mission

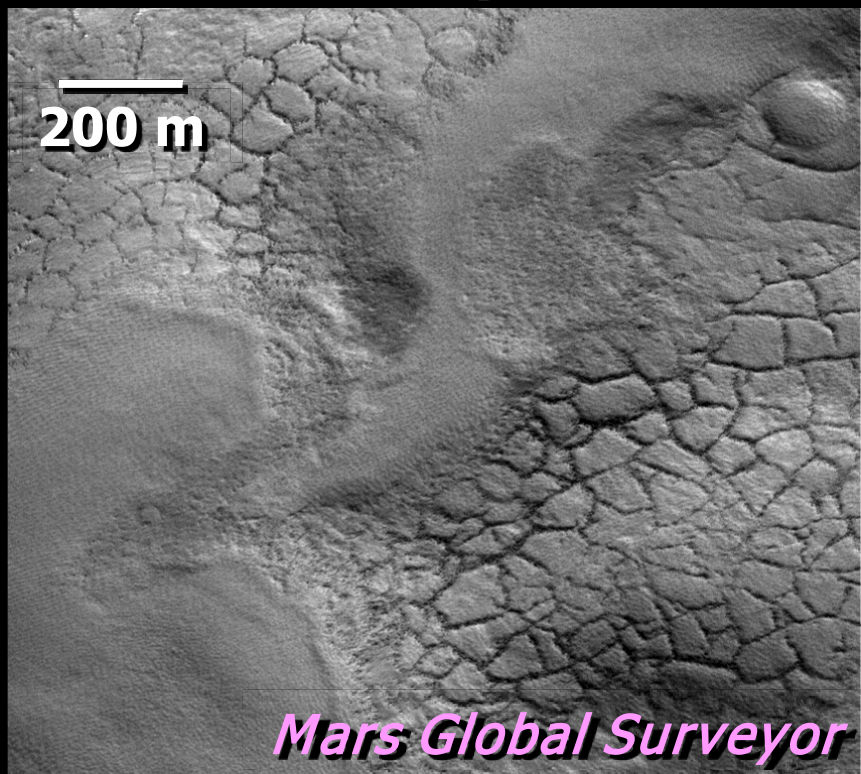


Patterned Ground

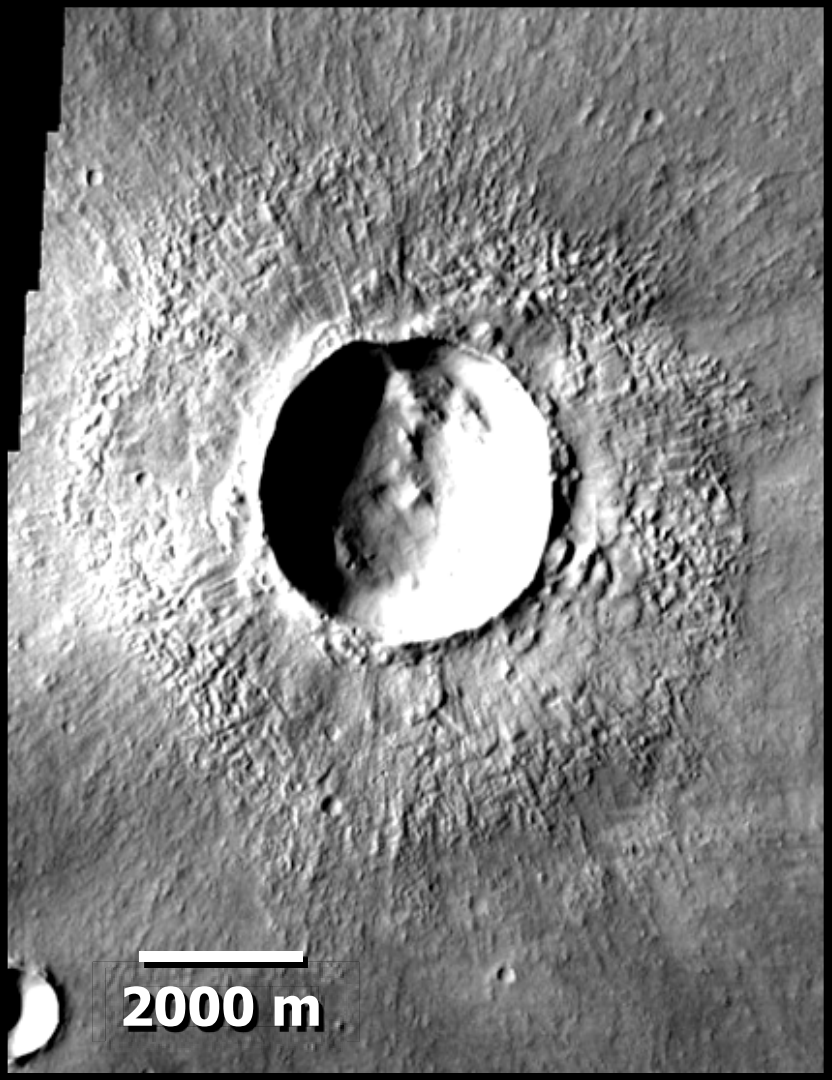
Exhumed Permafrost

Northwest territories

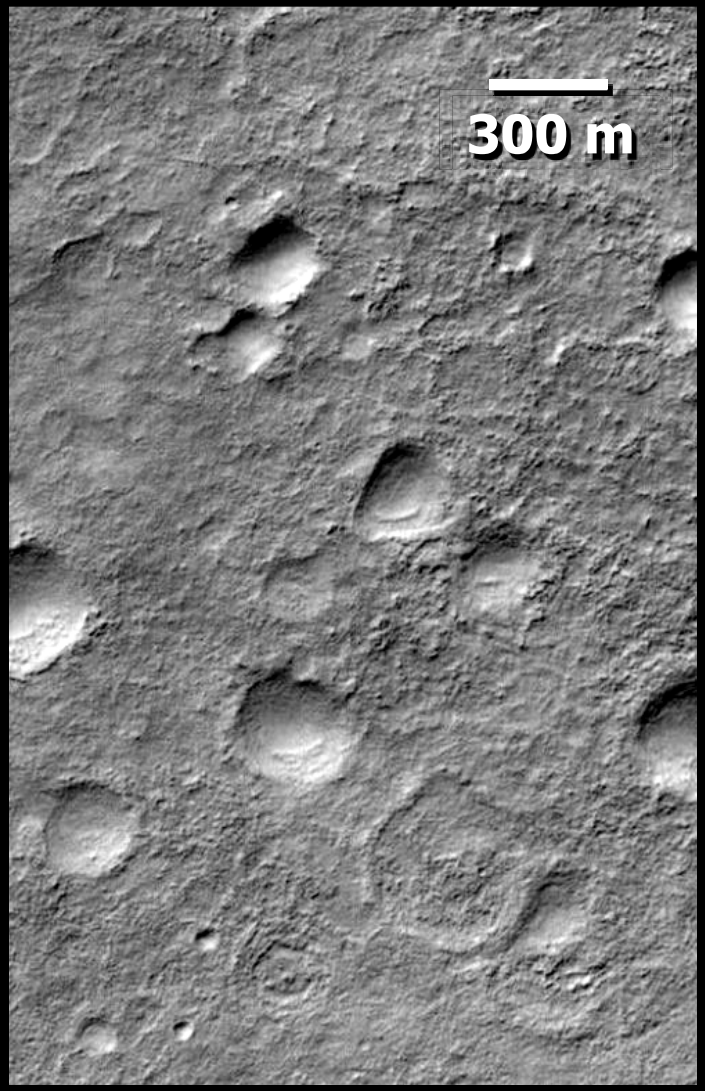
Plains near Lyot Crater



Impacts into Icy Substrates



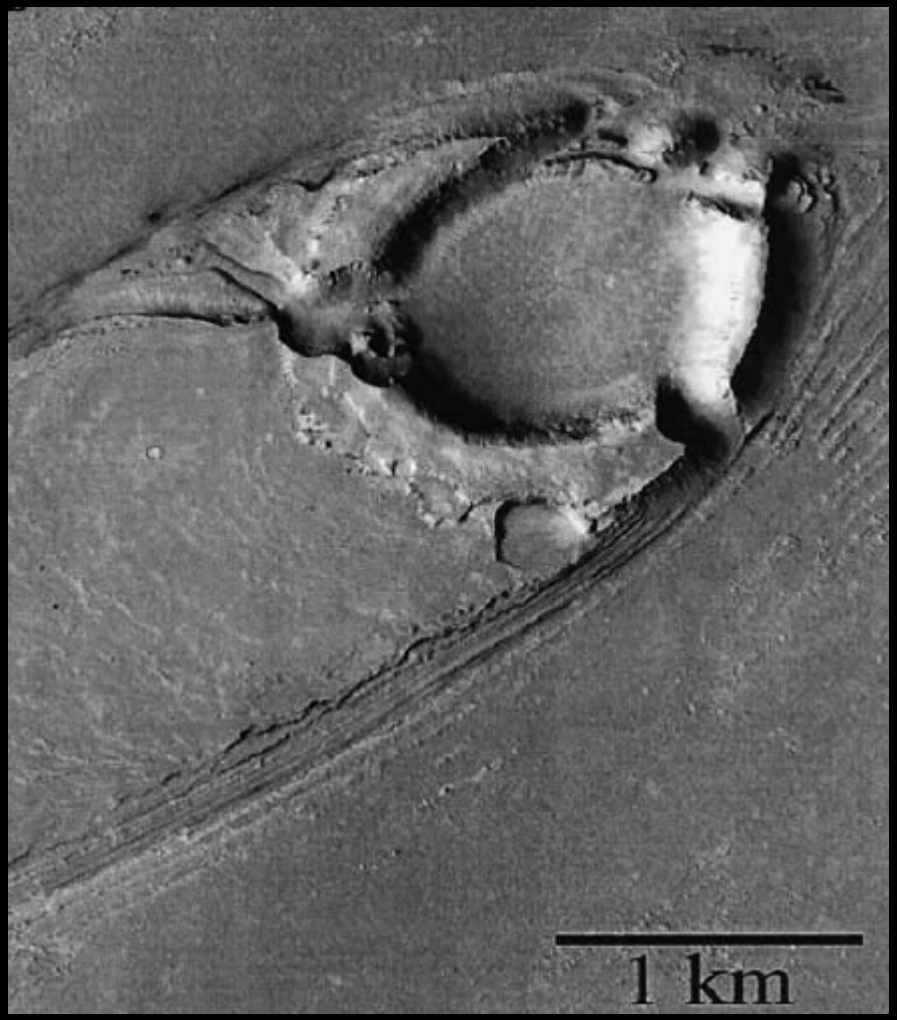
Themis SP2-43704



MOLA M20-00860

Fluvial Systems

Athabasca Valles

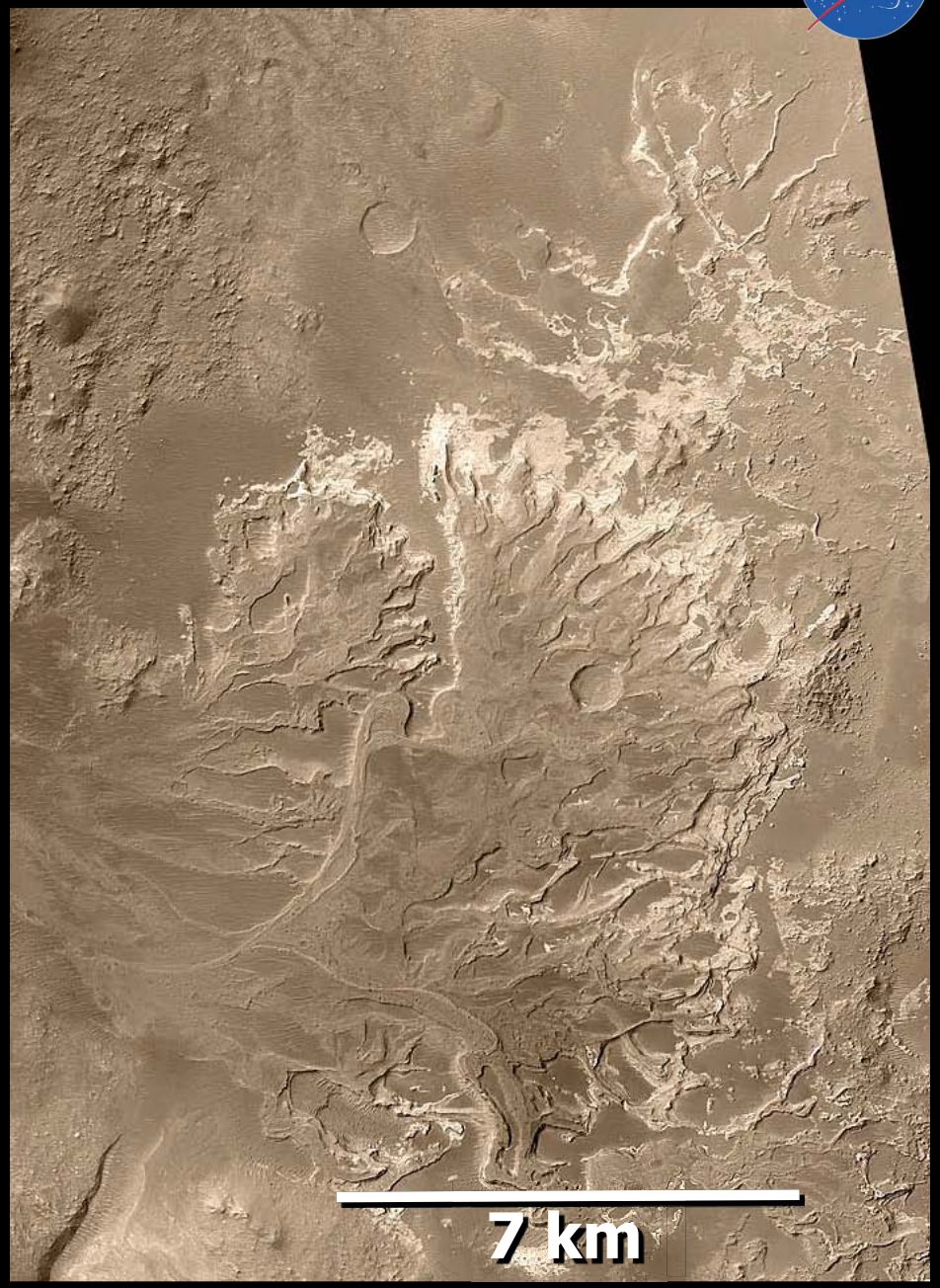


MOLA M07-00614

MOLA M21-01914

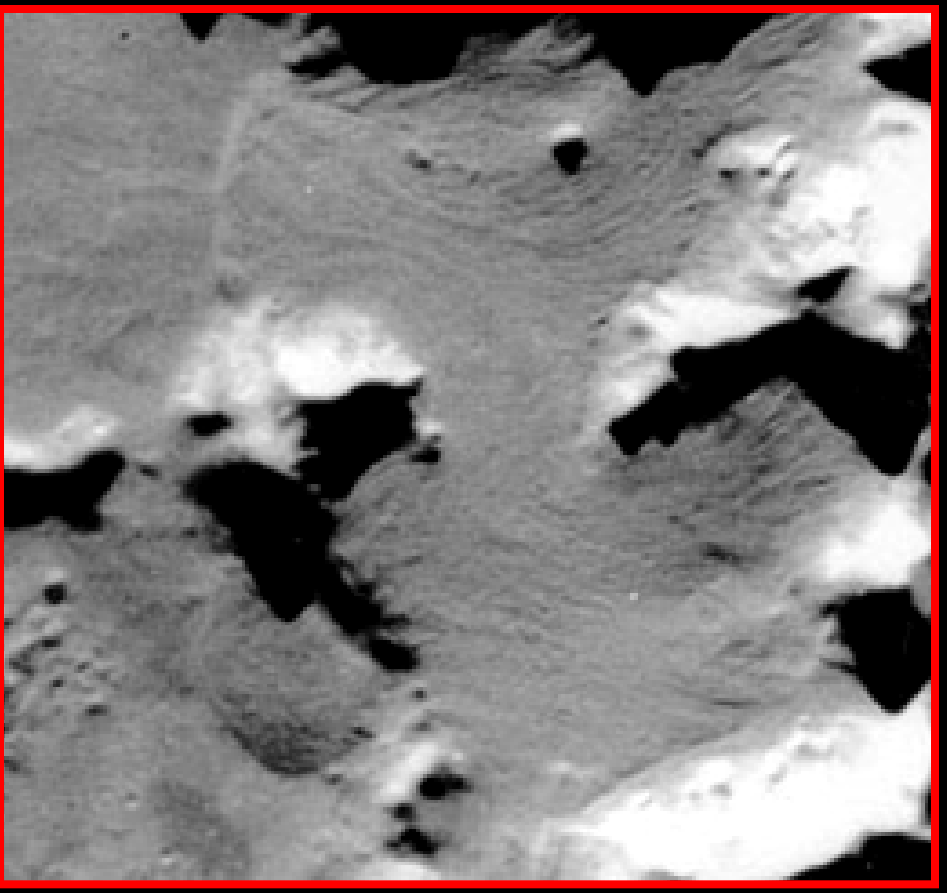
Deltas

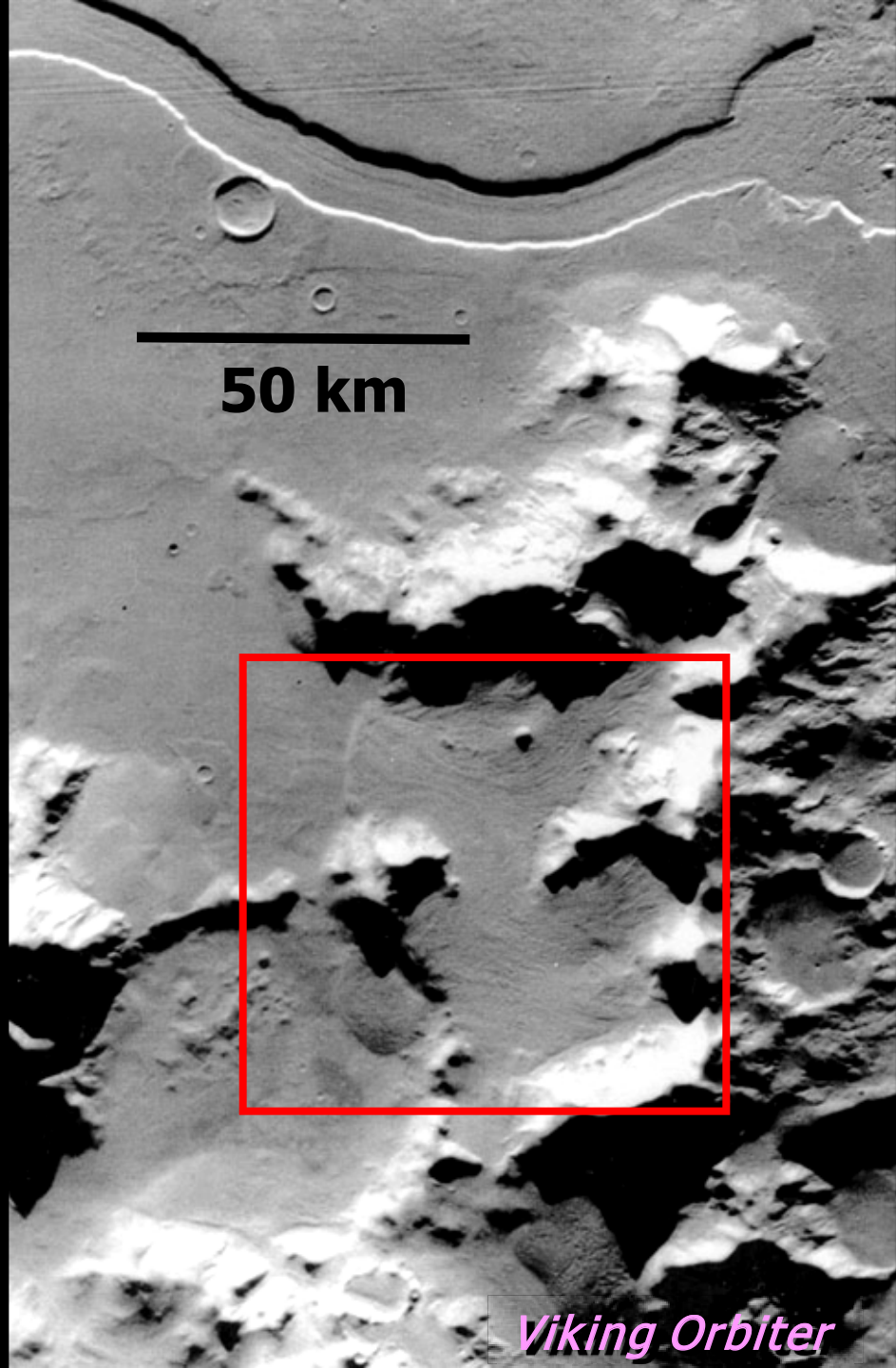
Holden Delta



Glacial Debris Aprons

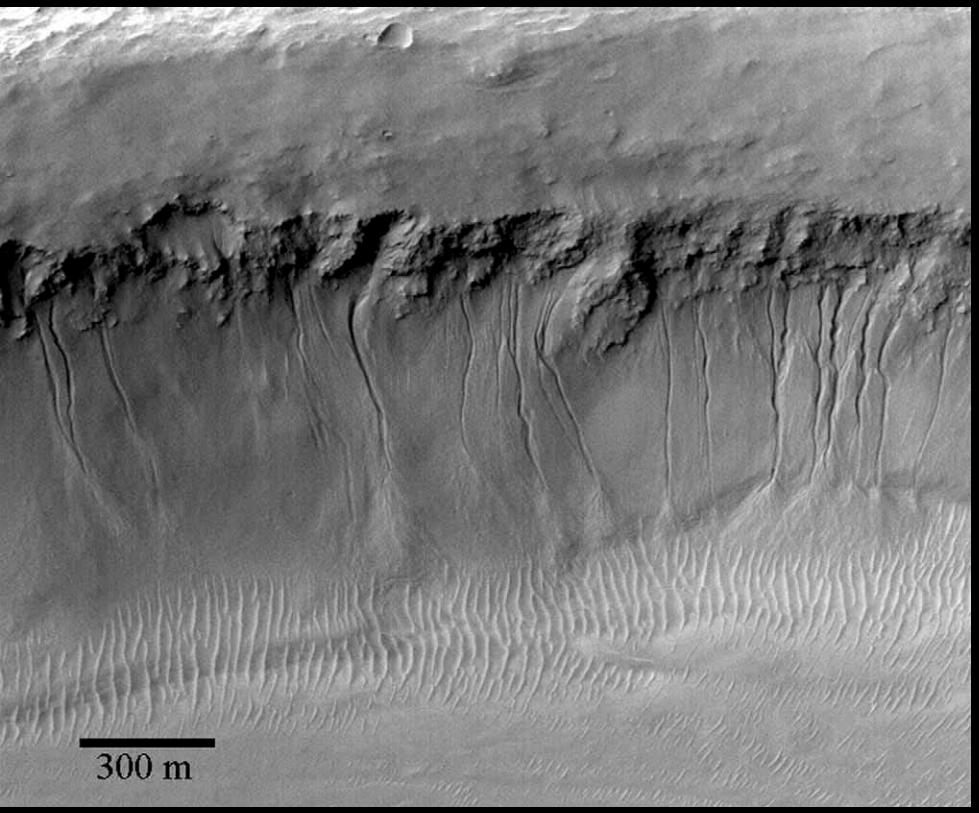
East of Hellas Planitia





Hillside Water Bursts

Mars



Hartmann et al. (2003)

Iceland

Recent Gully Fans

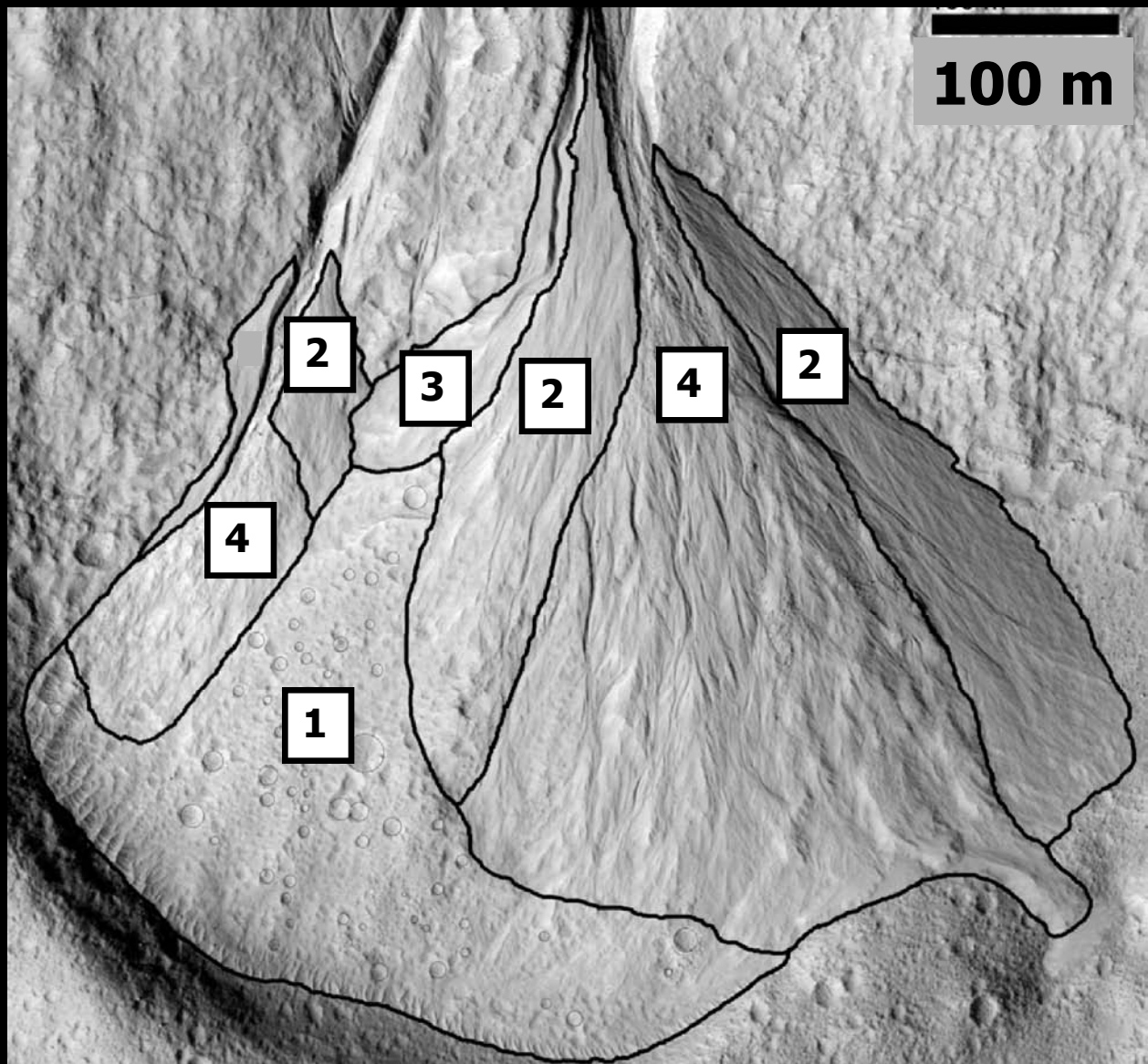
HIRISE PSP_002293_1450

Several sub-lobes

Lobes 2-4 uncratered

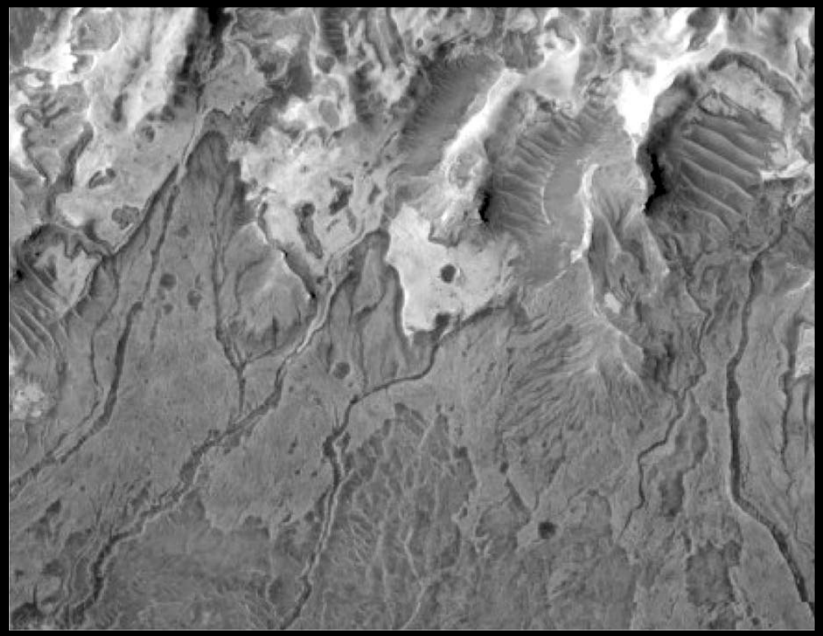
Episodic and recent formation implied

Modified from Schon et al. (2009)



Gullies: Salt Dehydration Origin

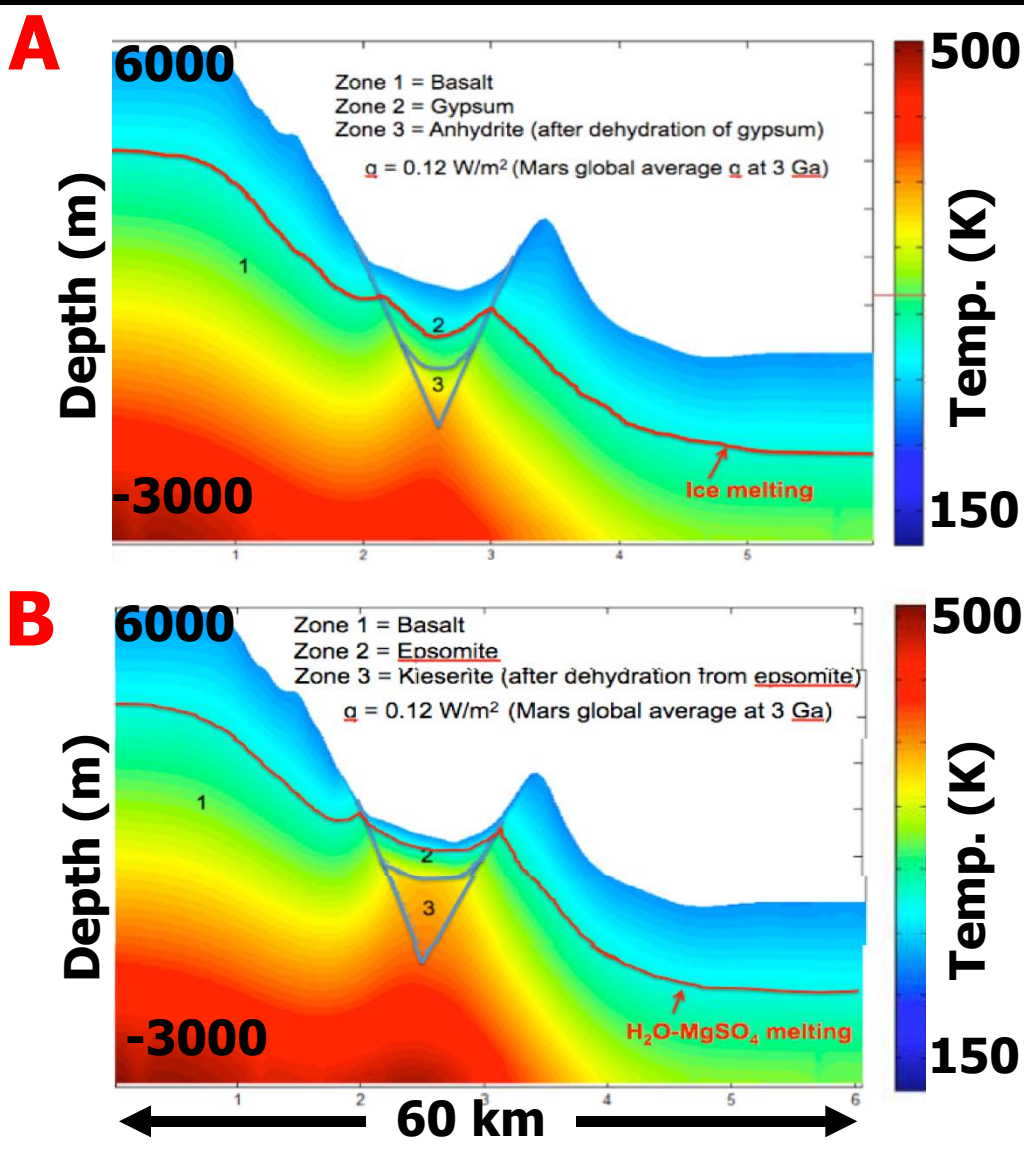
Melas Chasma



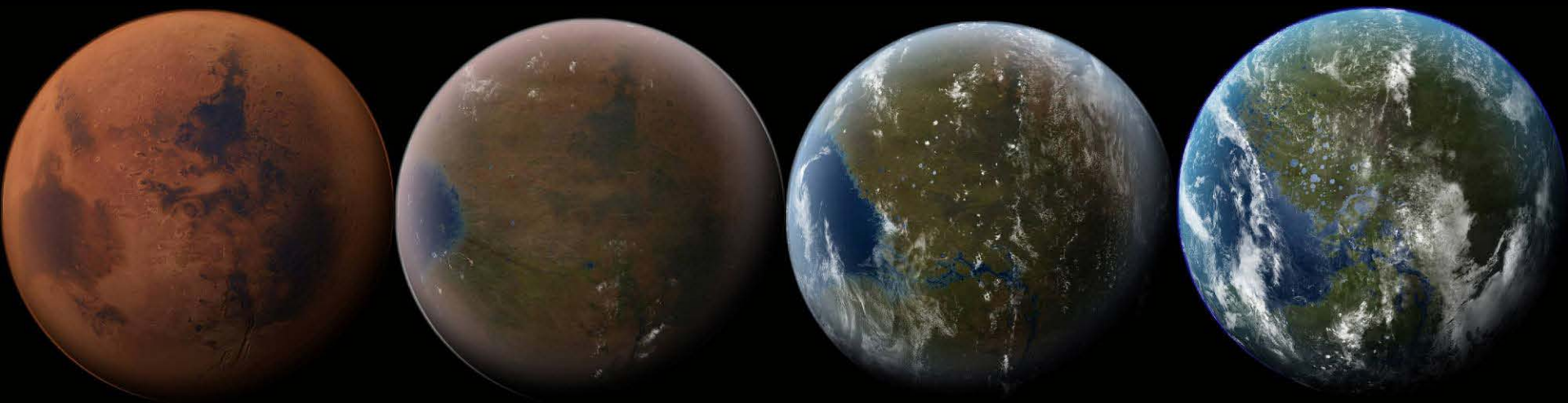
HIRISE PSP_005452_1700

Modified from Kargel et al. (2009)

Melting and dehydration model



Terraforming Mars



Daein Ballard

Reflection arrays

Rigel Woida

Greenhouse gas factories

Pbs.org

Summary

Water: Strategic Importance

-Sustaining Human Settlement

-Manufacture of Propellants for Transportation

The Moon

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