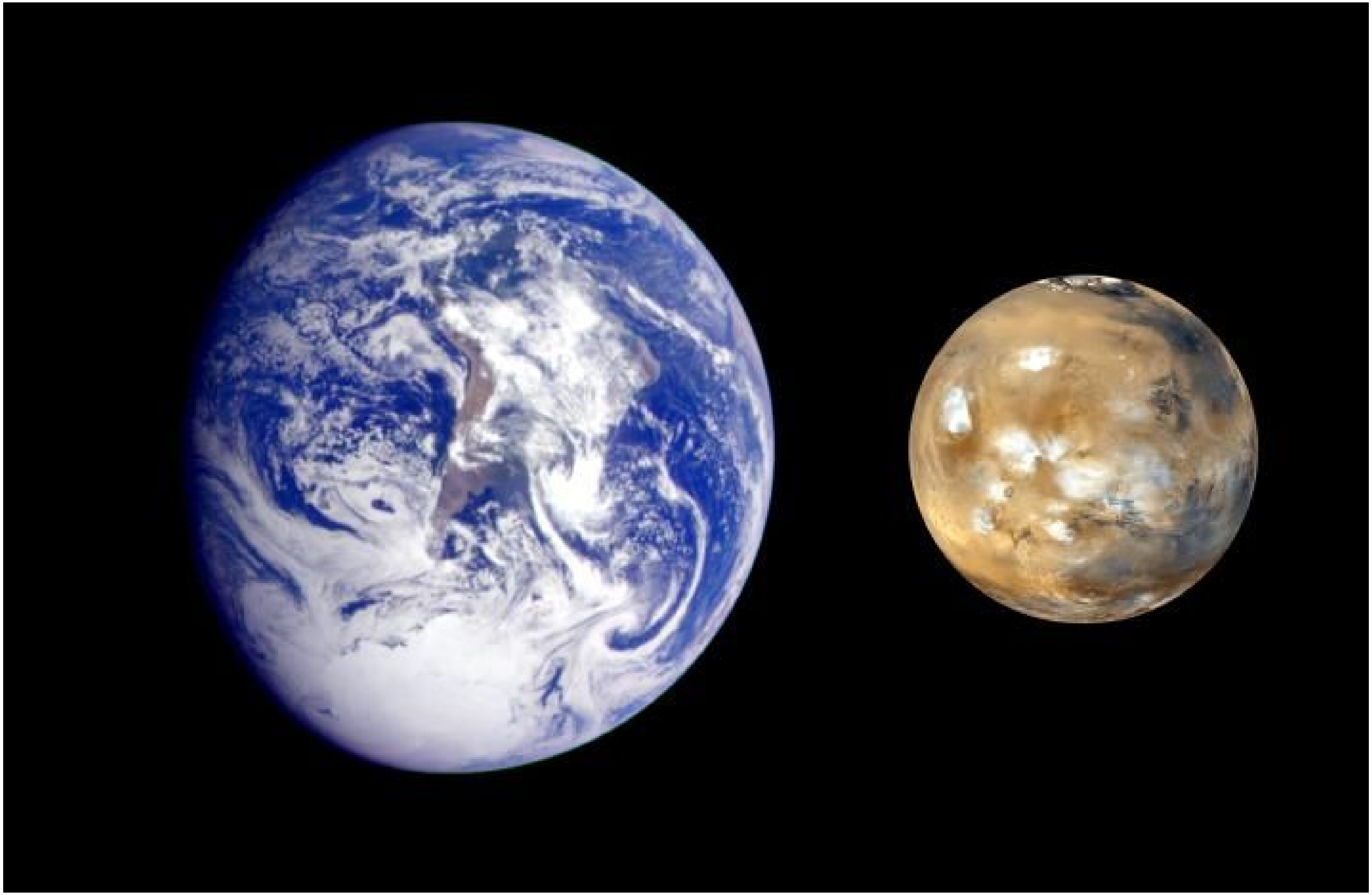
Mon. Nov. 20, 2017

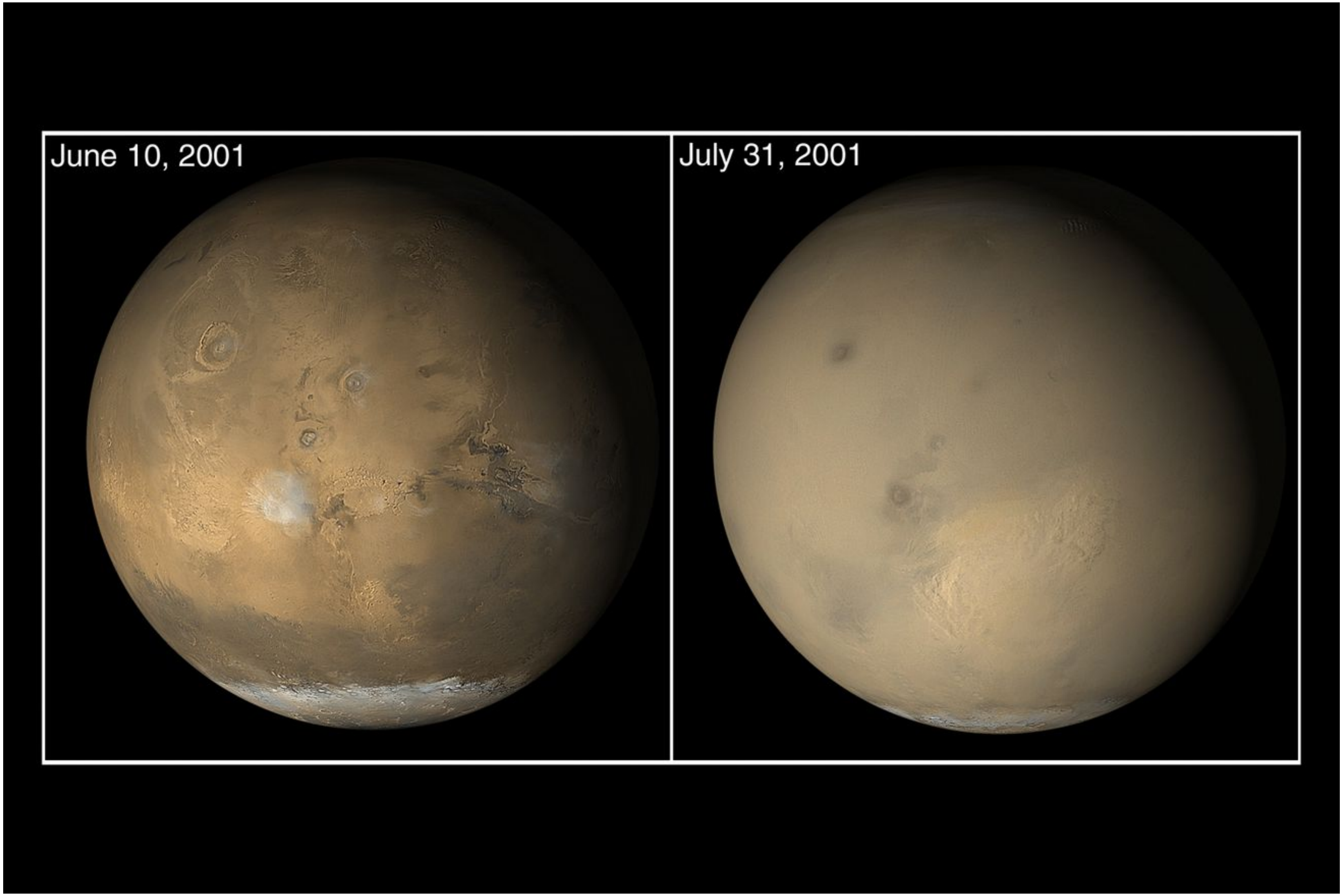
Mars Overview Part 1

- Mars Overview
  - Hemispheric dichotomy, overall ages, volcanism
  - Evidence for past water and other volatiles
  - Overview of missions
  - Global mapping of mineralogy and changing climate with time
  - Atmospheric effects
  - Volatile locations and inventory
  - Martian Meteorites, select rover results

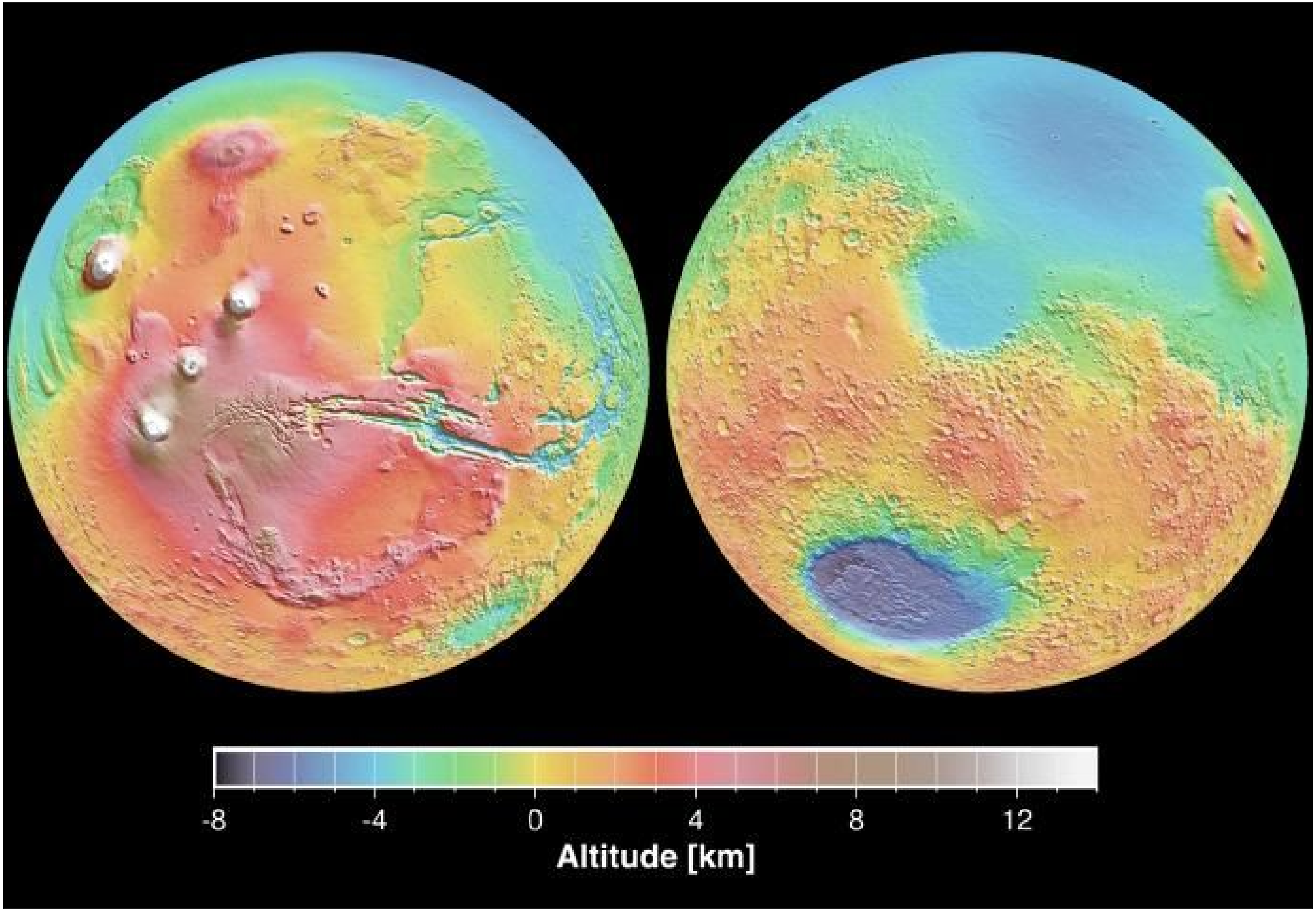
Mars Earth Comparison



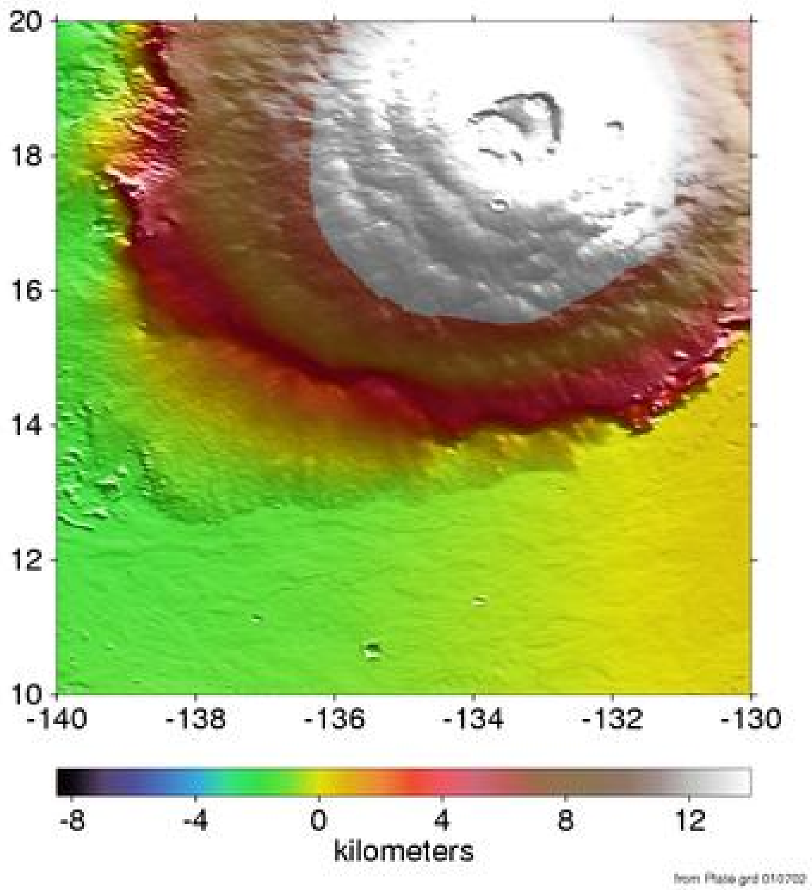
Mars atmosphere effects – dust storms



General topograph of Mars



MOLA: Mars Orbiter Laser Altimeter



1.064 µm

10 Hz pulse rate

48 mJ per pulse (at Mars)

Laser spot: 0.4 mrad ⇒ 130 m

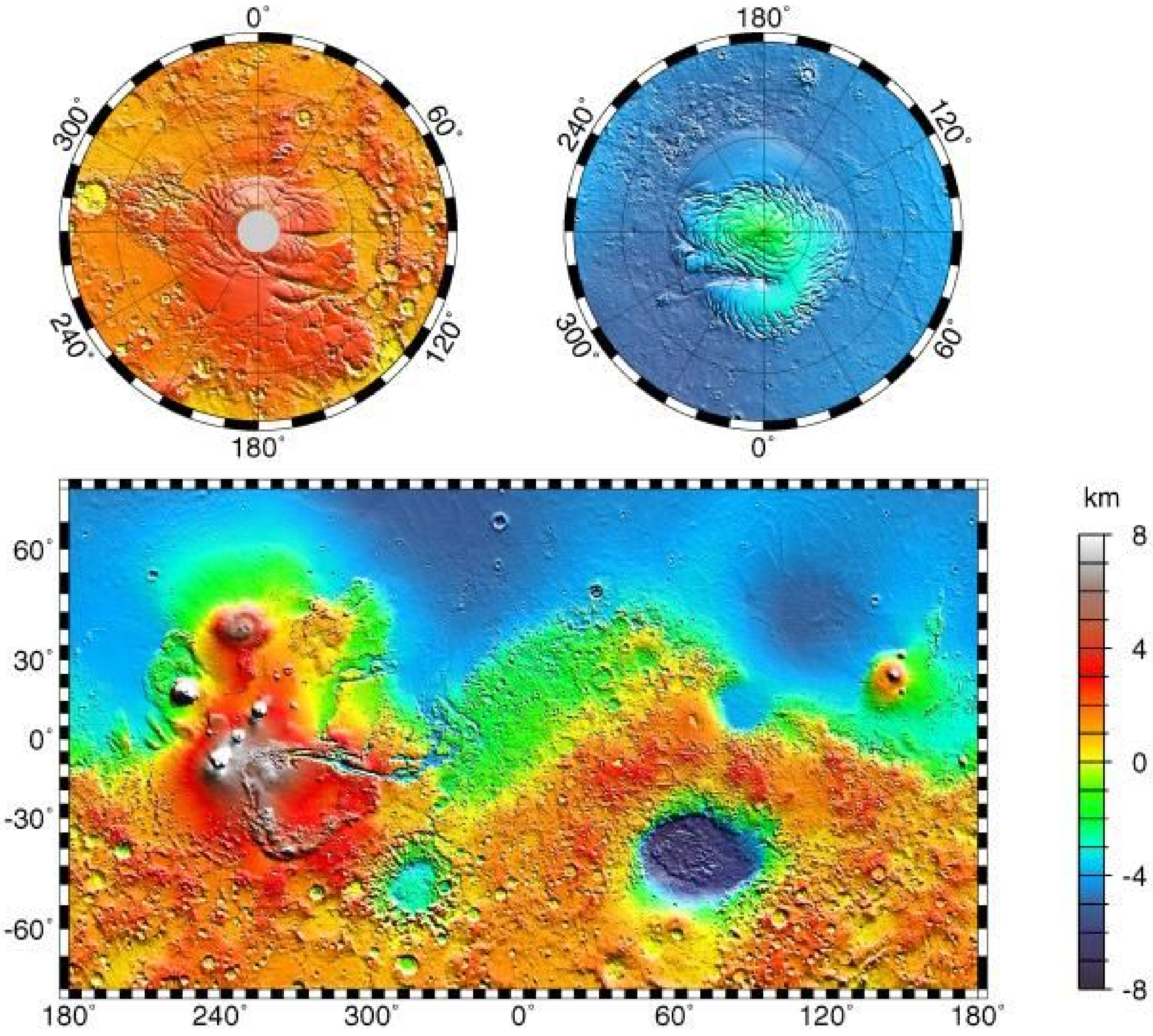
Receiver IFOV: 0.85 mrad

Vertical precision: 37.5 cm

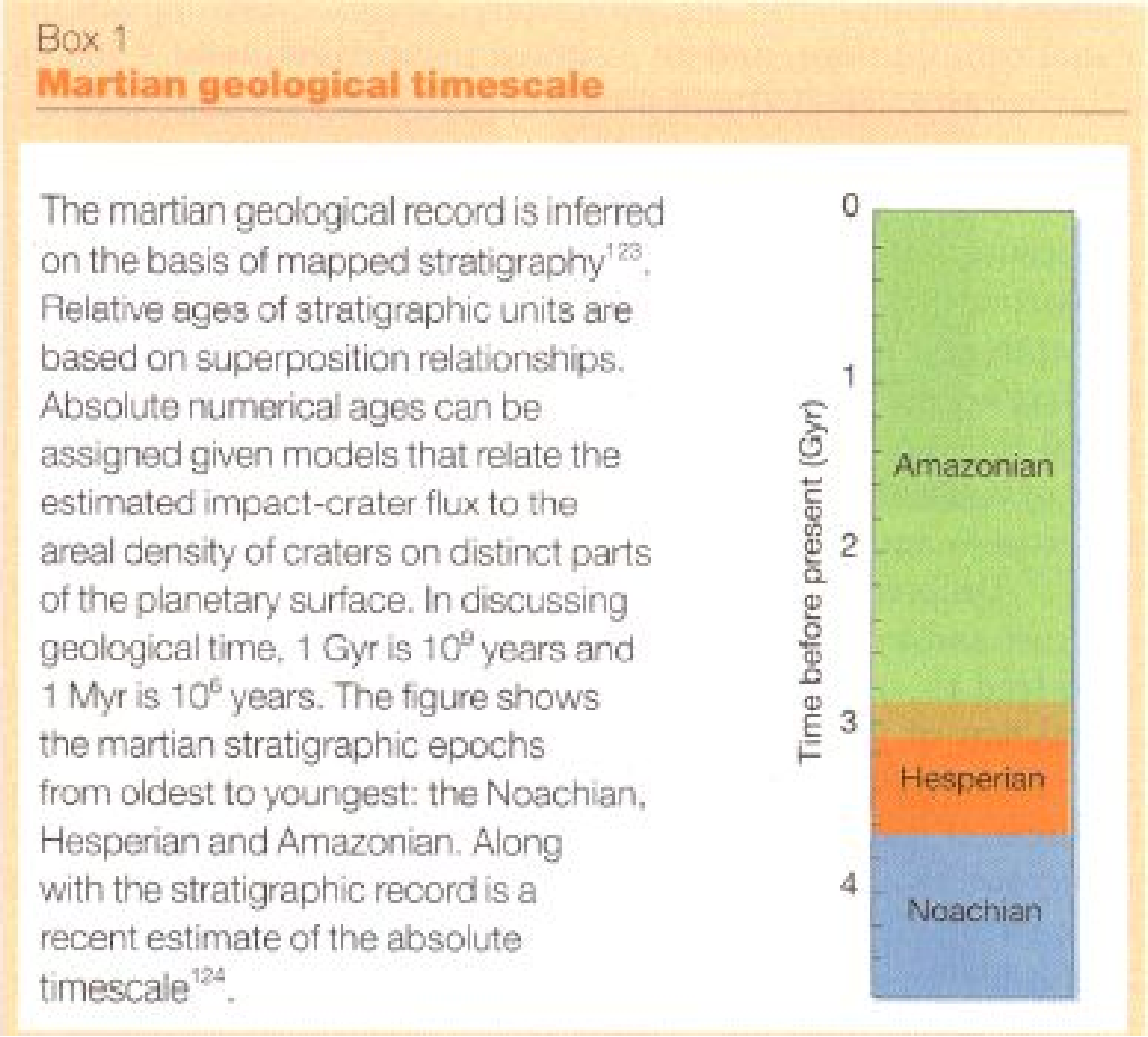
Vertical accuracy: 10m

http://ssed.gsfc.nasa.gov/tharsis/Mars_topography_from_MOLA.new/

General topograph of Mars



Martian geological timescale

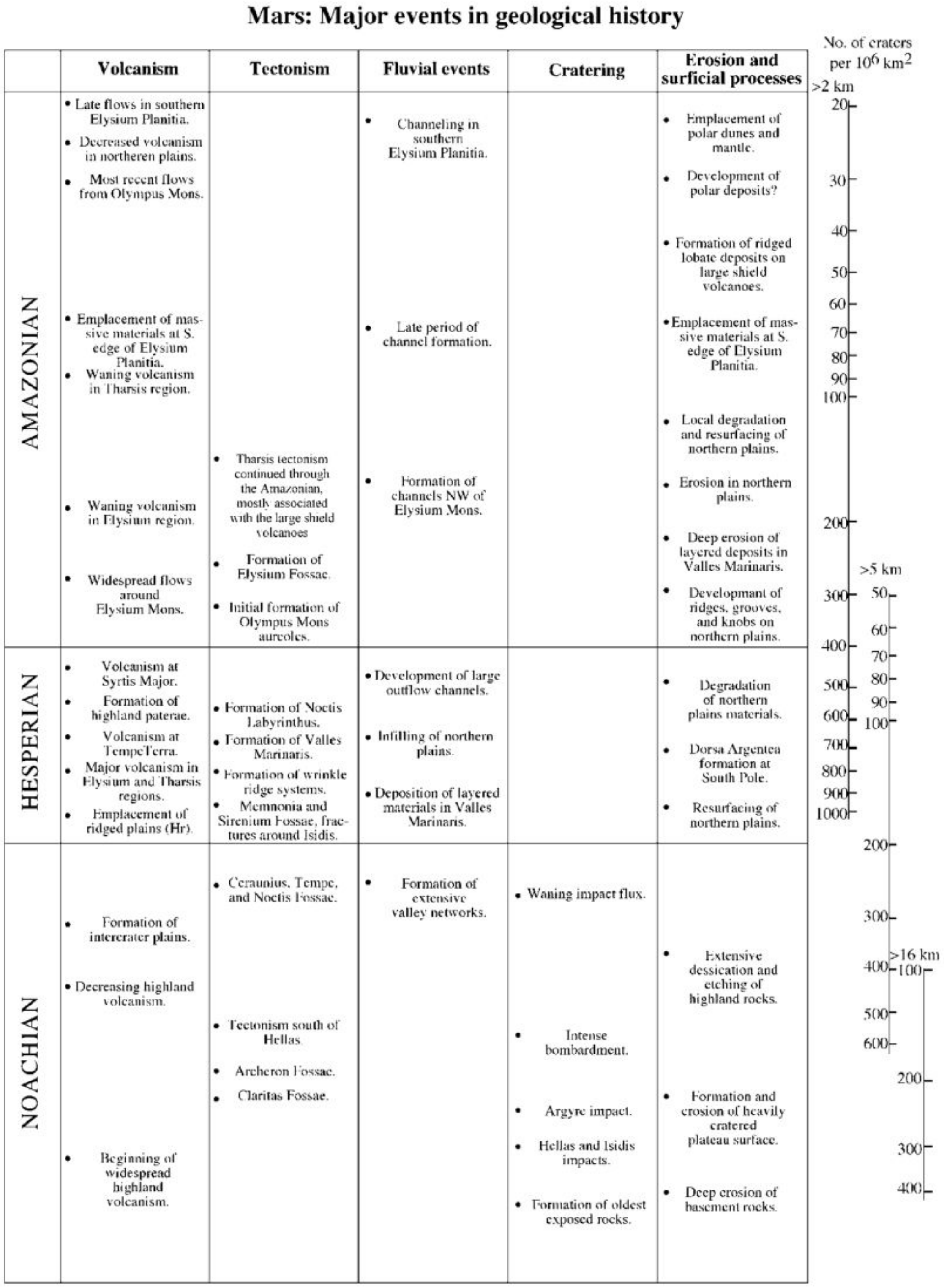


Box 1

Martian geological timescale

The martian geological record is inferred on the basis of mapped stratigraphy[123]. Relative ages of stratigraphic units are based on superposition relationships. Absolute numerical ages can be assigned given models that relate the estimated impact-crater flux to the areal density of craters on distinct parts of the planetary surface. In discussing geological time, 1 Gyr is 10^9 years and 1 Myr is 10^6 years. The figure shows the martian stratigraphic epochs from oldest to youngest: the Noachian, Hesperian and Amazonian. Along with the stratigraphic record is a recent estimate of the absolute timescale[124].

Overview of Mars Geological History



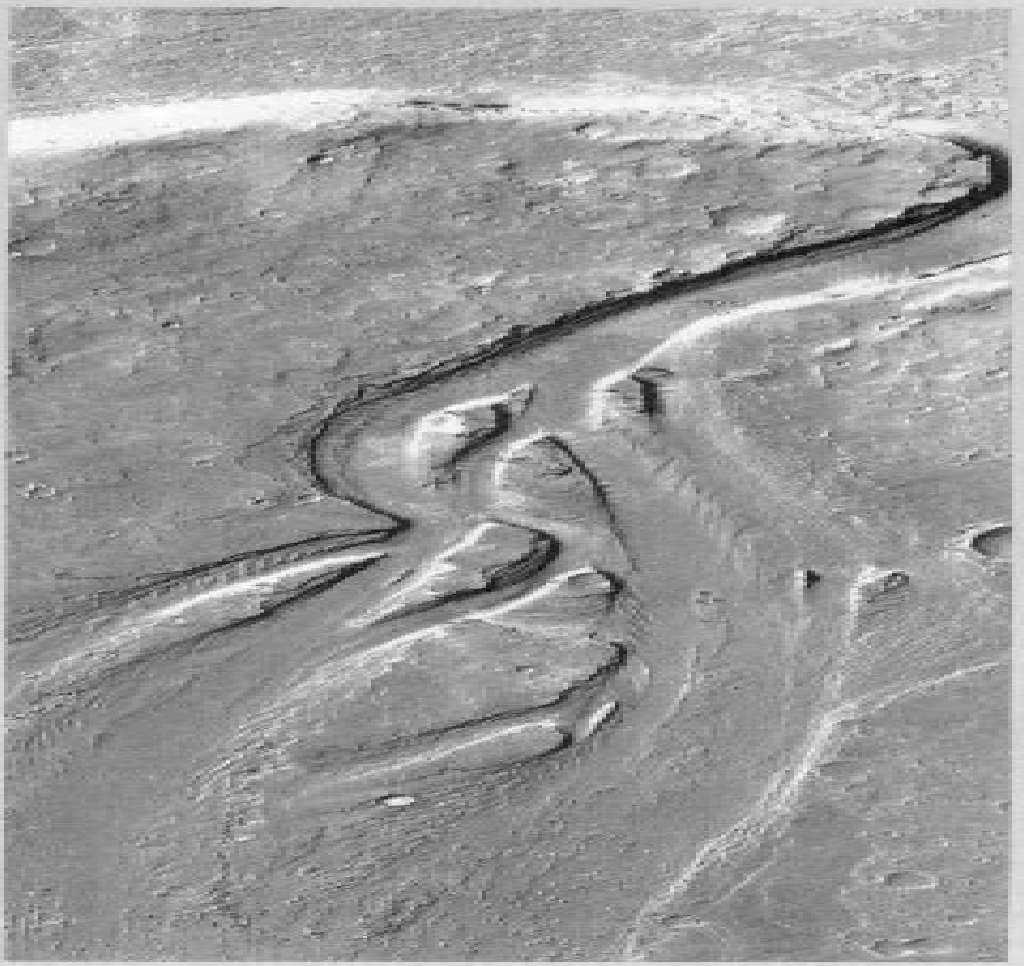
Mars: Major events in geological history

	Volcanism	Tectonism	Fluvial events	Cratering	Erosion and surficial processes
AMAZONIAN	• Late flows in southern Elysium Planitia. • Decreased volcanism in northeren plains. • Most recent flows from Olympus Mons. • Emplacement of massive materials at S. edge of Elysium Planitia. • Waning volcanism in Tharsis region. • Waning volcanism in Elysium region. • Widespread flows around Elysium Mons.	• Tharsis tectonism continued through the Amazonian, mostly associated with the large shield volcanoes • Formation of Elysium Fossae. • Initial formation of Olympus Mons aureoles.	• Channeling in southern Elysium Planitia. • Late period of channel formation. • Formation of channels NW of Elysium Mons.		• Emplacement of polar dunes and mantle. • Development of polar deposits? • Formation of ridged lobate deposits on large shield volcanoes. • Emplacement of massive materials at S. edge of Elysium Planitia. • Local degradation and resurfacing of northern plains. • Erosion in northern plains. • Deep erosion of layered deposits in Valles Marinaris. • Developmant of ridges, grooves, and knobs on northern plains.
HESPERIAN	• Volcanism at Syrtis Major. • Formation of highland paterae. • Volcanism at TempeTerra. • Major volcanism in Elysium and Tharsis regions. • Emplacement of ridged plains (Hr).	• Formation of Noctis Labyrinthus. • Formation of Valles Marinaris. • Formation of wrinkle ridge systems. • Memnonia and Sirenium Fossae, fractures around Isidis.	• Development of large outflow channels. • Infilling of northern plains. • Deposition of layered materials in Valles Marinaris.		• Degradation of northern plains materials. • Dorsa Argentea formation at South Pole. • Resurfacing of northern plains.
NOACHIAN	• Formation of intercrater plains. • Decreasing highland volcanism. • Beginning of widespread highland volcanism.	• Ceraunius, Tempe, and Noctis Fossae. • Tectonism south of Hellas. • Archeron Fossae. • Claritas Fossae.	• Formation of extensive valley networks.	• Waning impact flux. • Intense bombardment. • Argyre impact. • Hellas and Isidis impacts. • Formation of oldest exposed rocks.	• Extensive dessication and etching of highland rocks. • Formation and erosion of heavily cratered plateau surface. • Deep erosion of basement rocks.

From Head et al. 2001

Evidence of water – outflow channels

Figure 2 High-resolution Mars Orbiter Camera (MOC) image of a fluvial channel system at latitude 7.9° N, longitude 205.8° W, south of Cerberus Rupes (MOC Image M21-01914). The scene shows an area about 4 km across. A complex of anastomosing channels and streamlined uplands reveals a history of differential fluid erosion of layered bedrock and progressive degradation that produced terrace levels and abandoned spillways. Regularly spaced (about 60-m wavelength) rib-like bedforms are developed transverse to the direction of fluid flow in some of the channels. All these features are best explained by large-scale water flow. The lack of impact craters on the flood-scoured surfaces indicates that this flow occurred very recently in martian geological history. (Image provided courtesy of Malin Space Science Systems.)



Evidence of water – valley networks and gullies

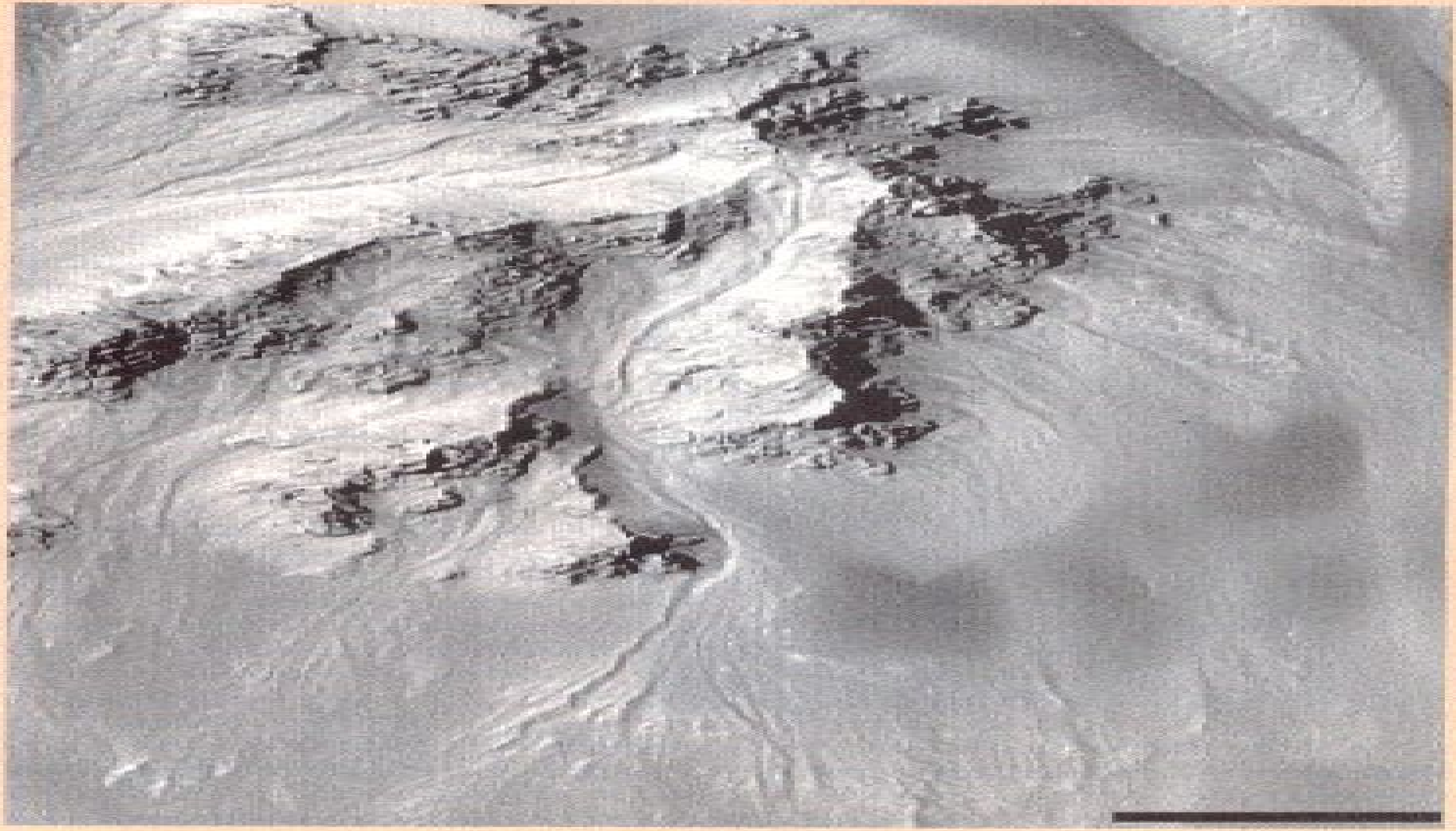
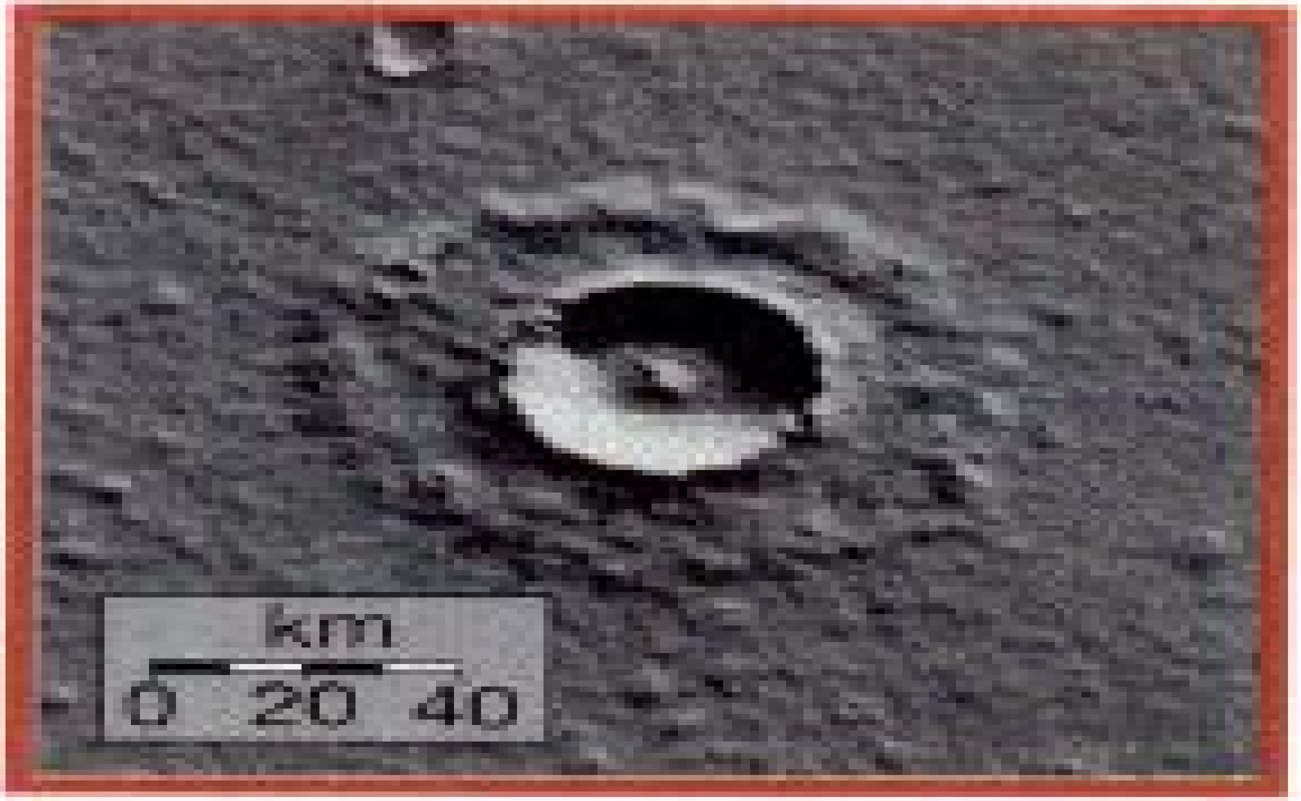


Figure 6 MOC image (M09-04718) of small gullies and other hillslope features in the central peak area of Hale Crater (latitude 36° S, longitude 37° W). Scale bar, 200 m.

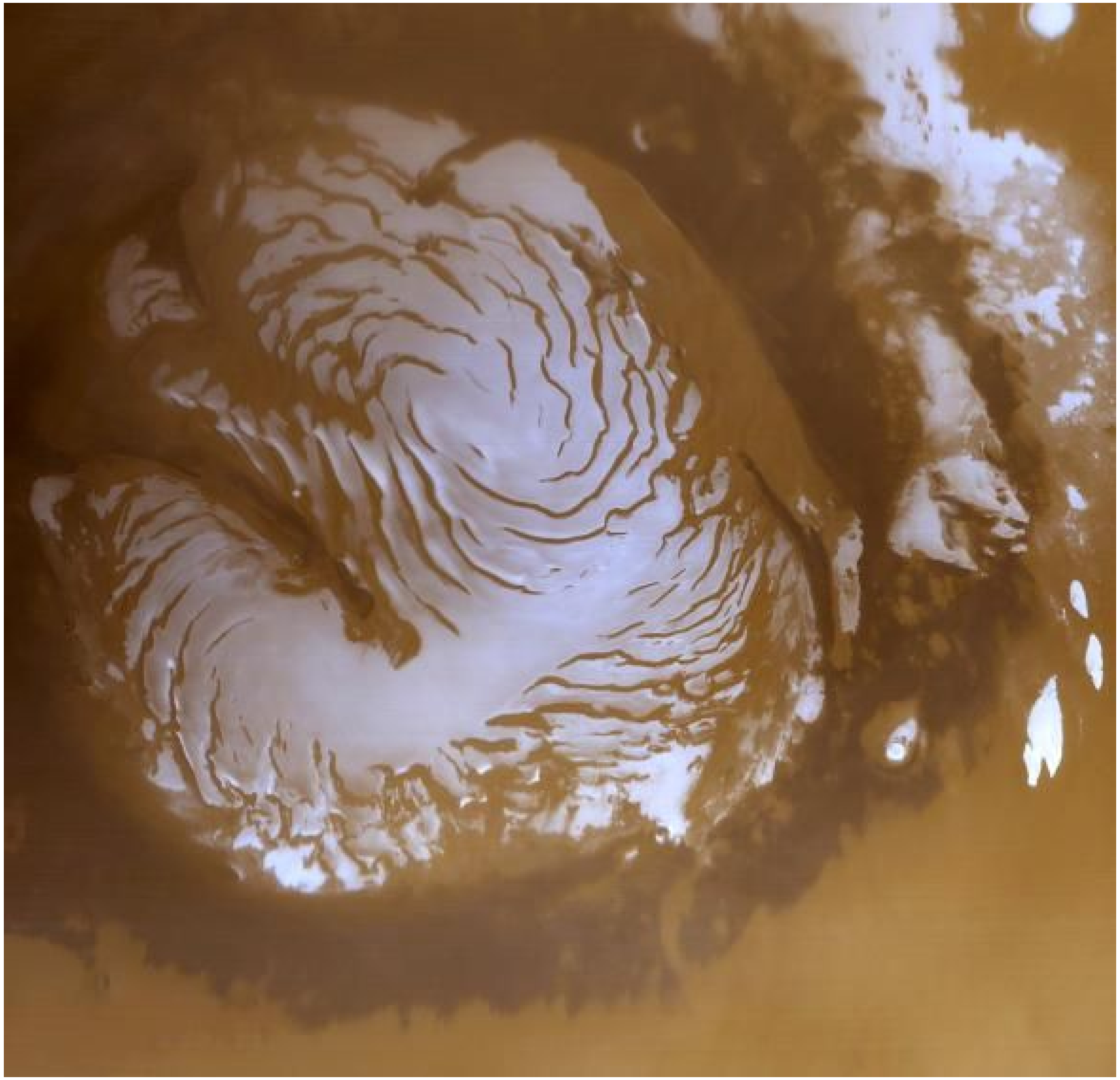
Evidence of subsurface water/ice

Evidence of water – rampart craters

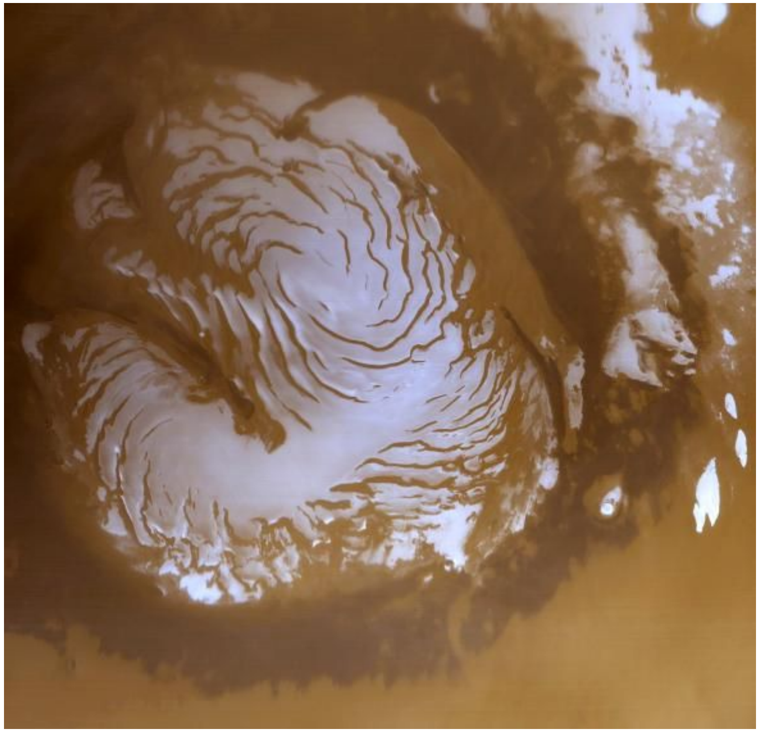


'Rampart' crater

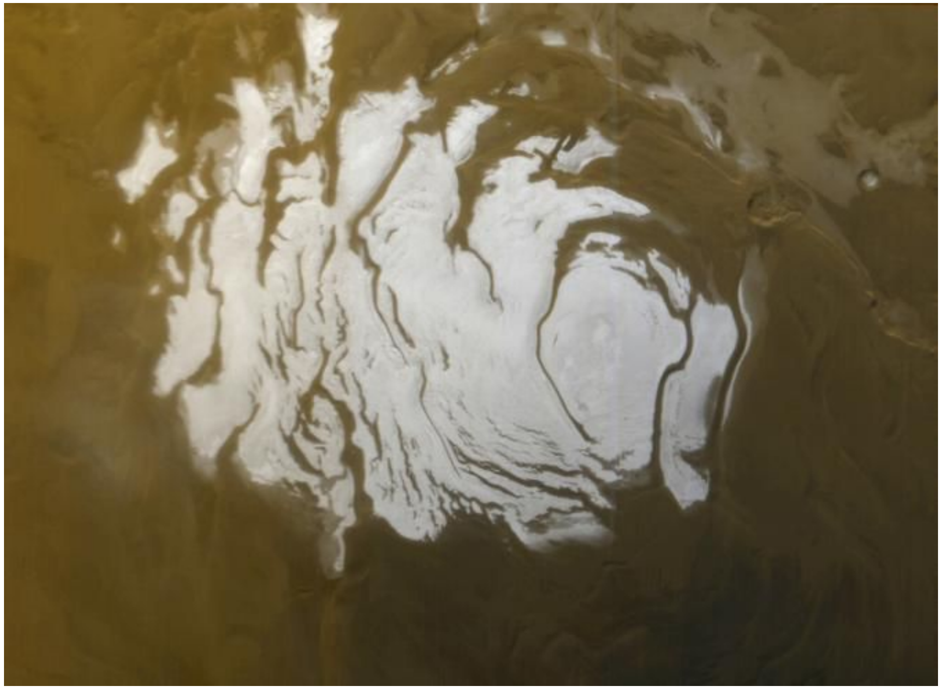
Mars polar caps



Mars polar caps



N Polar Cap



S Polar Cap

Swirl pattern related to solar illumination and sublimation of frost.

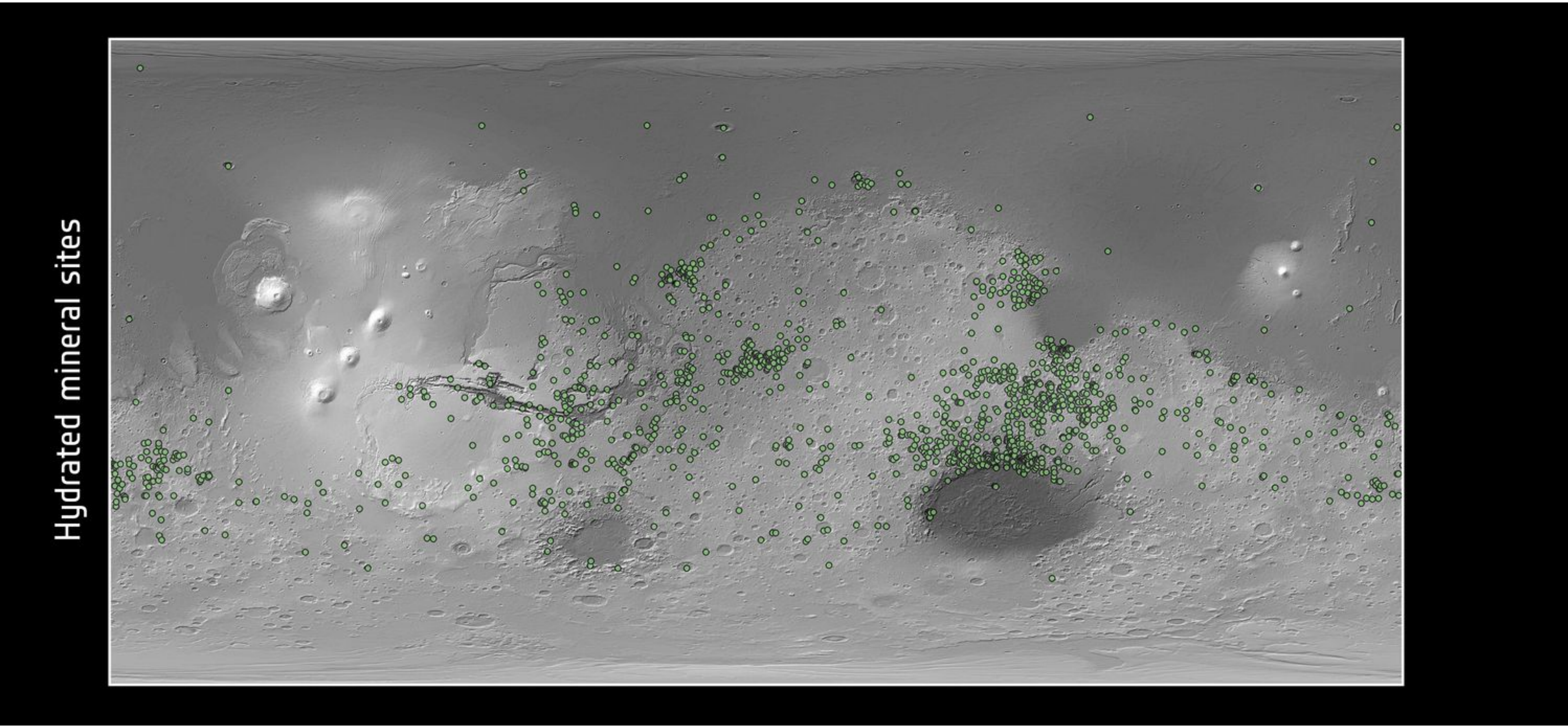
Recent Rover and Lander Results

- Early missions
  - Mariner 4 (1964) flyby
  - Mariner 6&7 (1969) flyby
  - Mariner 9 (1971 ... orbiter)
  - Viking I and II orbiters and Landers 1976 ...
- Modern missions
  - Landers
    - Pathfinder (prototype) 1997
    - Spirit and Opportunity 2004
    - Phoenix (N. Polar Lander) 2008
    - MSL (Curiosity) Rover 2012
  - Orbiters
    - Odyssey 2001
    - Mars Express (Europe) 2004
    - Mars Reconnaissance Orbiter (MRO) 2005
    - MAVEN Launched 2013, Arrived in Mars Orbit Sept. 22, 2014
    - Mangalyaan (Indian Space Agency) Launched 2013, arrived Sept. 24, 2014

Mars Express (European orbiter 2004--)

- OMEGA: 0.35 - 5.1 μm Mapping Spectrometer
  -

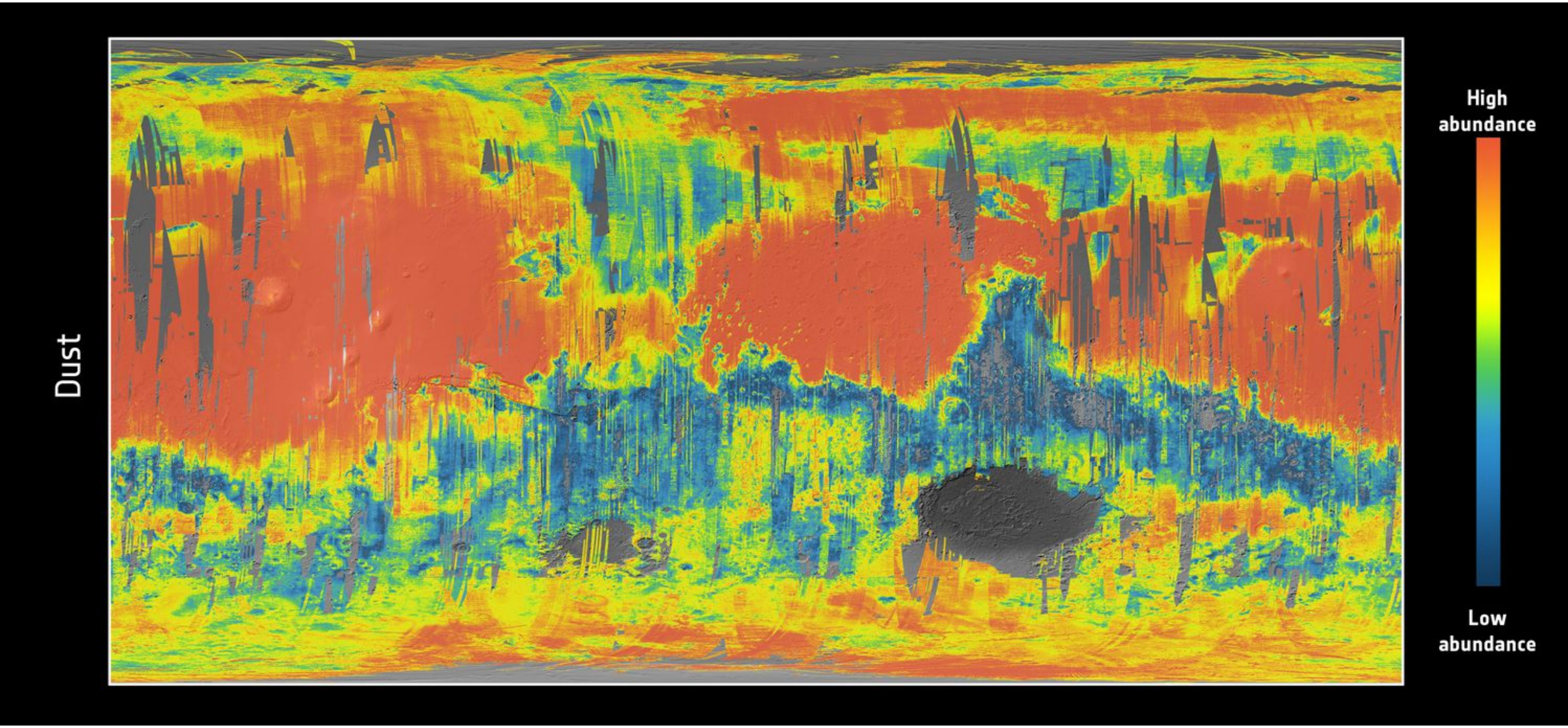
Mars Express OMEGA Mapper Results: Hydrated Minerals



- Hydrated Mineral Sites:
  - 50% Are impact sites which have excavated older sediments -- presumably indicating formation of hydrated minerals was more common in distant past
  - Most common in the older southern highland. Rare in the younger morthern volcanic plains
  - Also more common closer to the equator

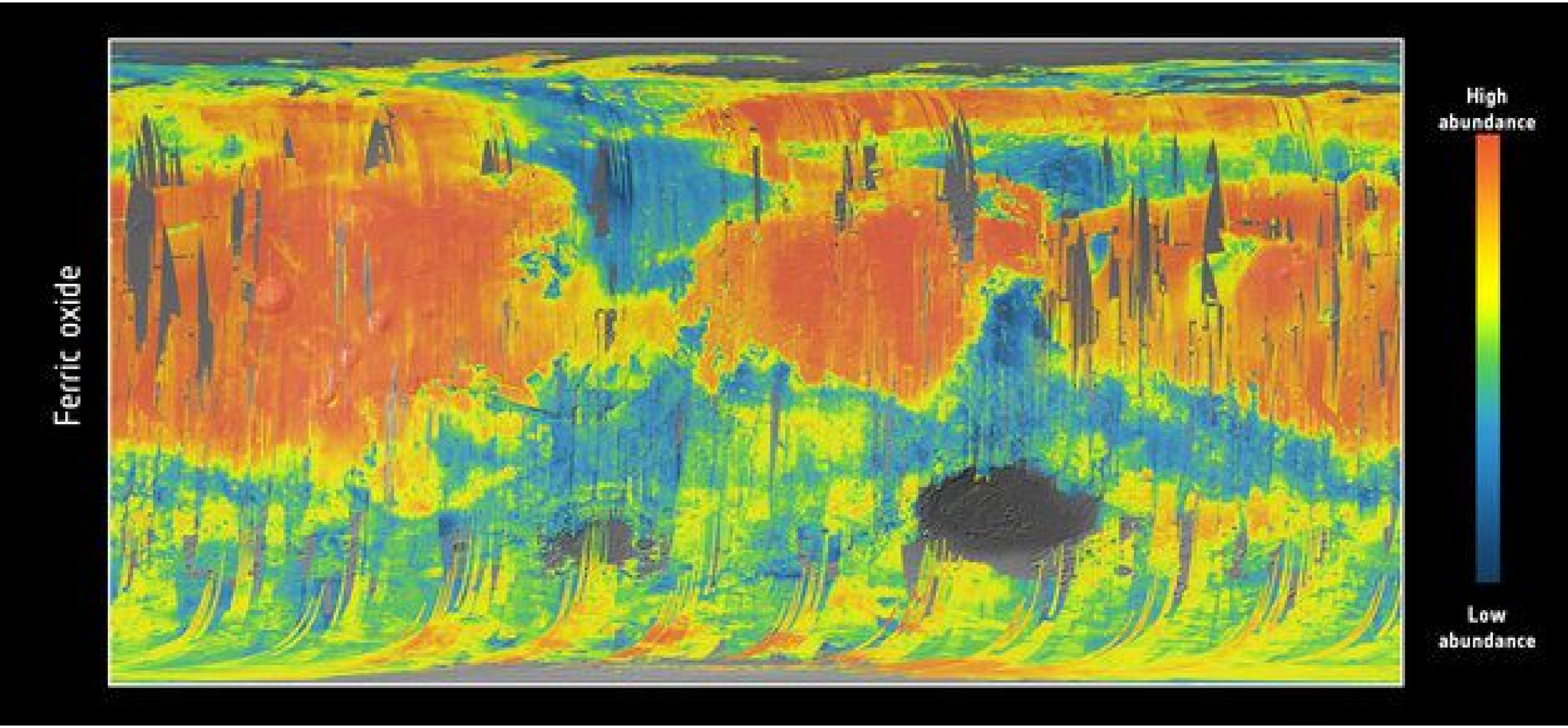
http://spaceinimages.esa.int/Images/2013/05/Mars_hydrated_mineral_map

Mars Express OMEGA Mapper Results: Dust



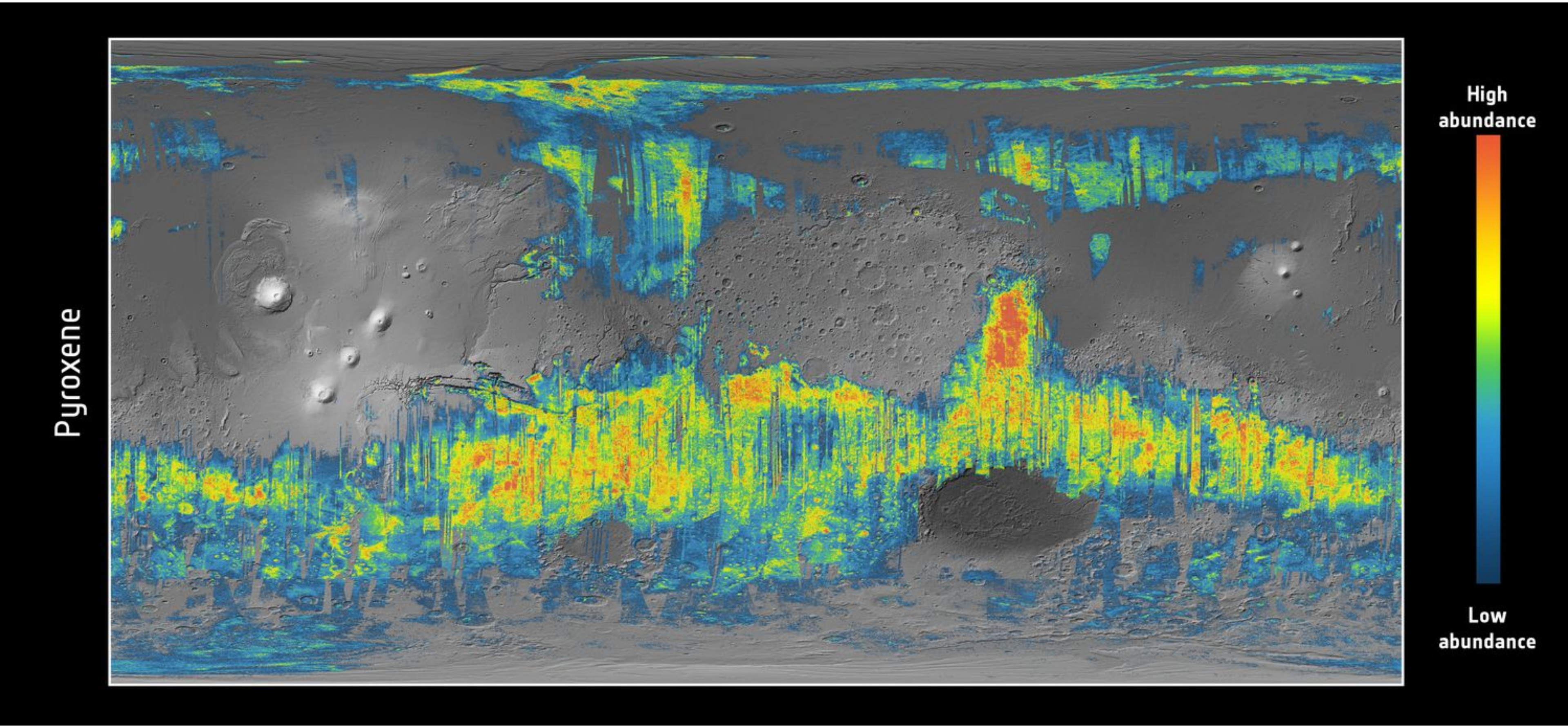
- Mars dust mapped here is mostly ferric iron nanoparticles (“rust”, few nanometer diameter)
- Thick dust can mask mineralogy of underlying surface

Mars Express OMEGA Mapper Results: Ferric Oxide



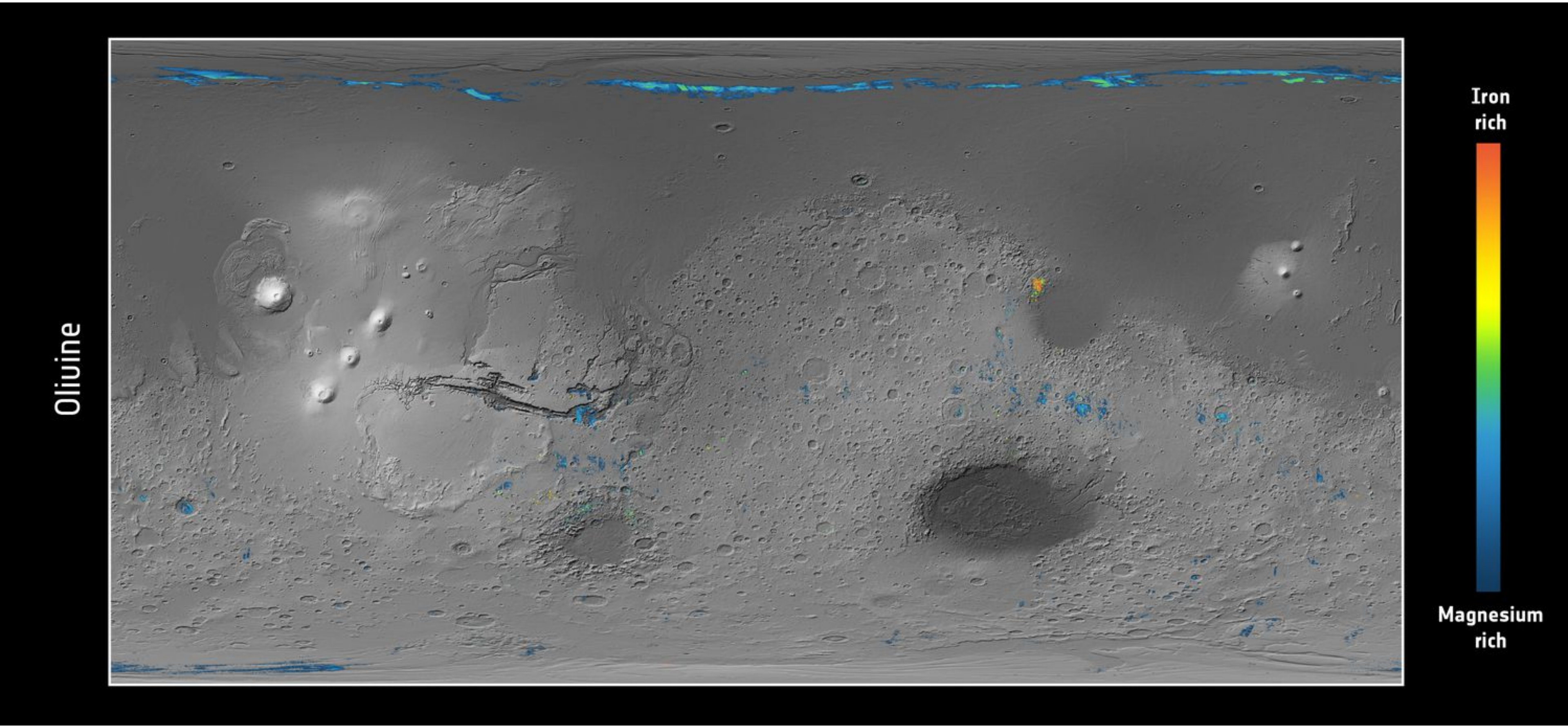
- Overall Ferric Oxide abundance -- Clearly mimics dust abundance.
- Partly related to dust deposition, but also suggests oxidizing conditions

Mars Express OMEGA Mapper Results: Pyroxene



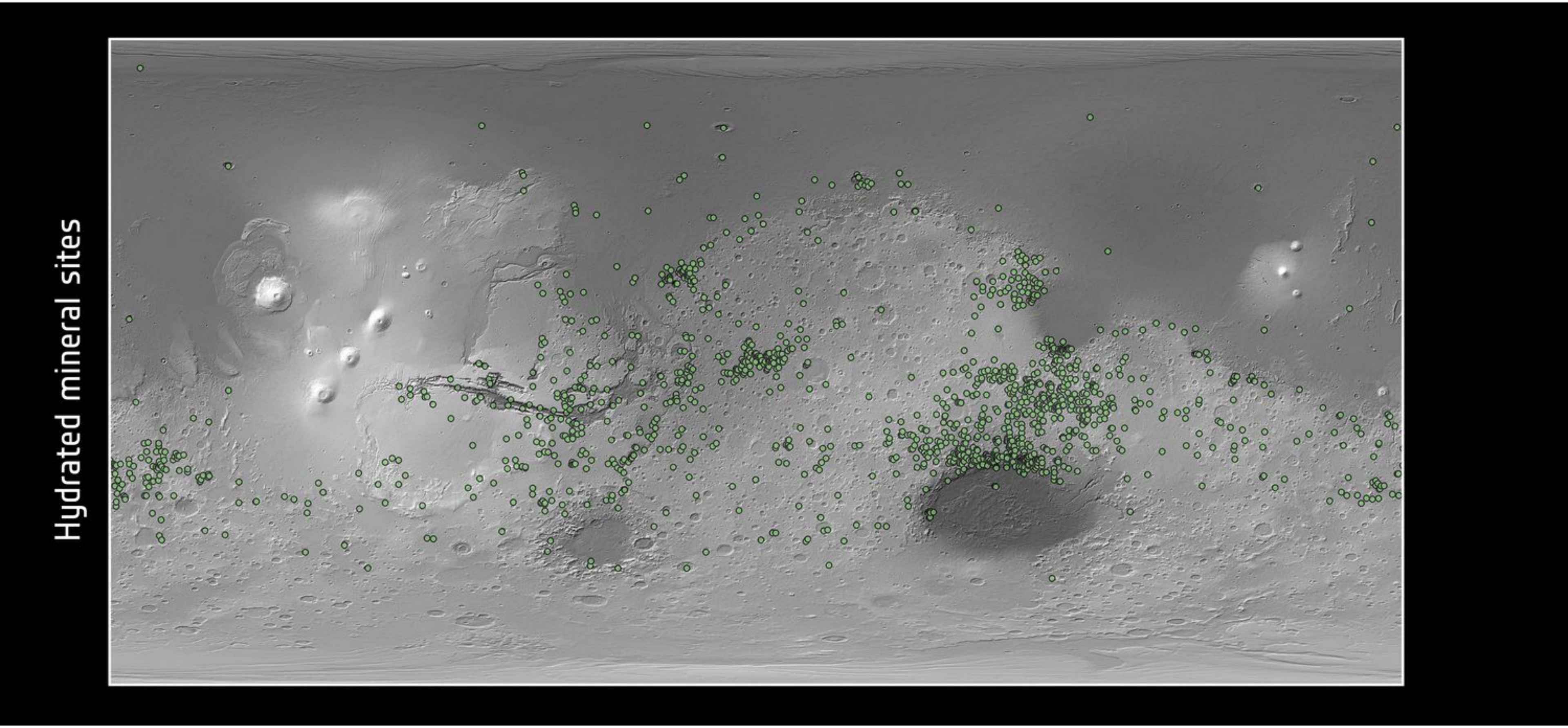
- Partly masked by dust
- Despite that -- clearly more common in the southern highlands than northern lowlands

Mars Express OMEGA Mapper Results: Olivine



- Partly masked by dust
- Mg/Fe, Abundance, and Grain Size are not completely separable in OMEGA measurements. The region of “high Fe” olivine near Nili Fossae might actually be larger grain size or higher olivine abundance

Mars Express OMEGA Mapper Results: Hydrated Minerals



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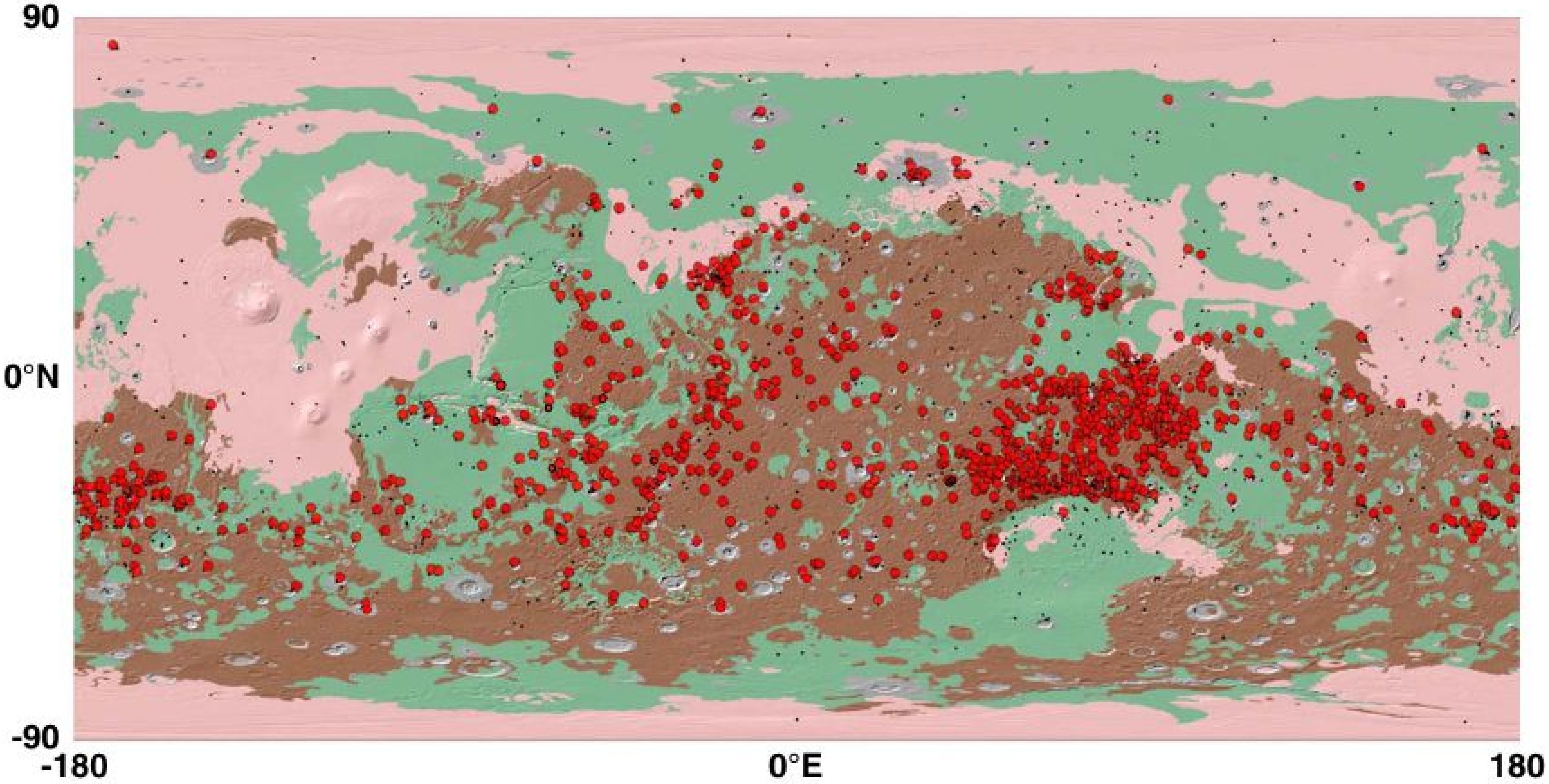
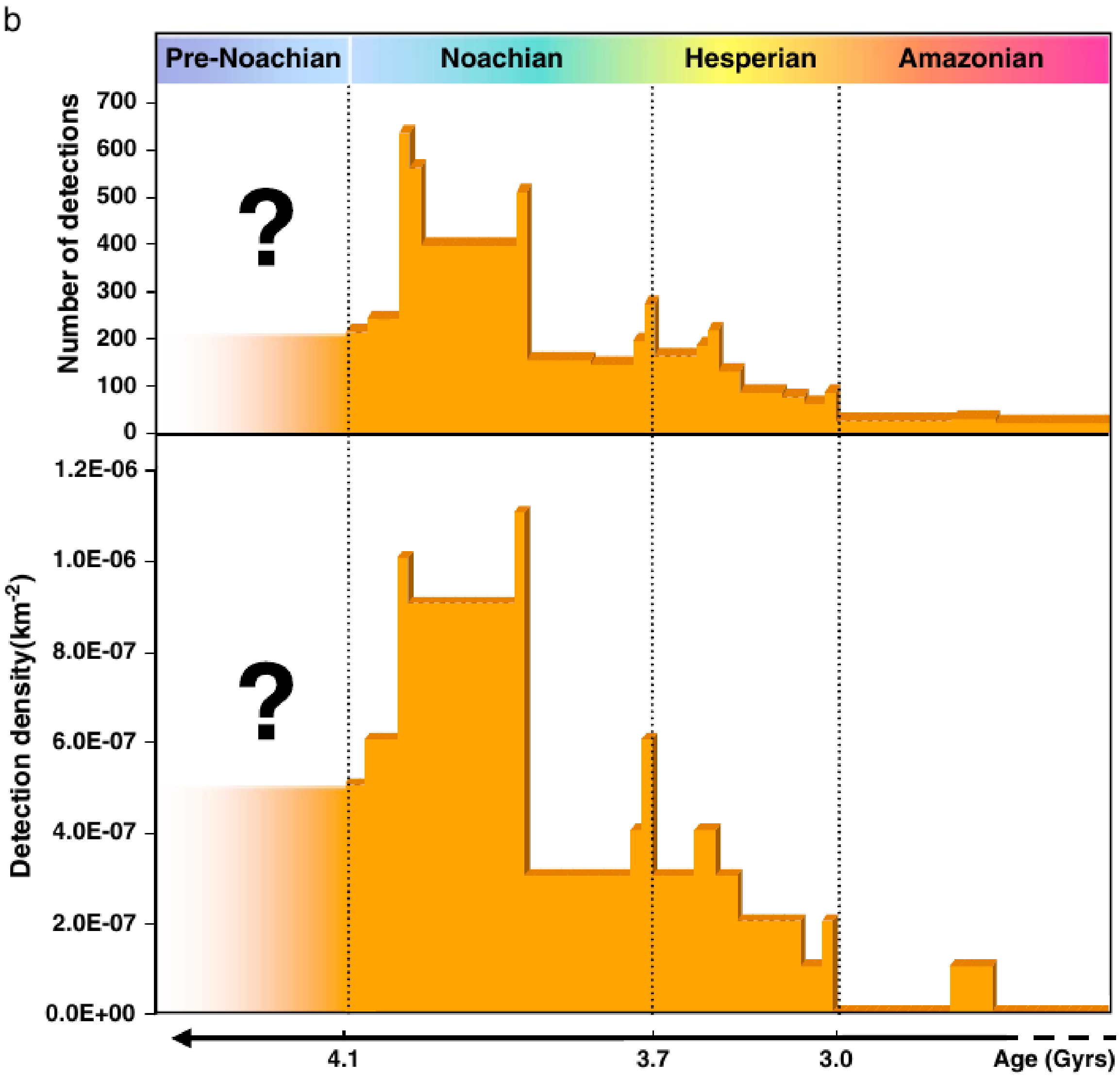
Carter et al. 2013: Hydrated minerals vs time (OMEGA and CRISM)



- Brown = Noachian		Green = Hesperian		Pink = Amazonian
- OMEGA on Mars Express
- CRISM on MRO

Carter et al. 2013: Hydrated minerals vs time (OMEGA and CRISM)

- Using previous slide's information to estimate formation vs. time

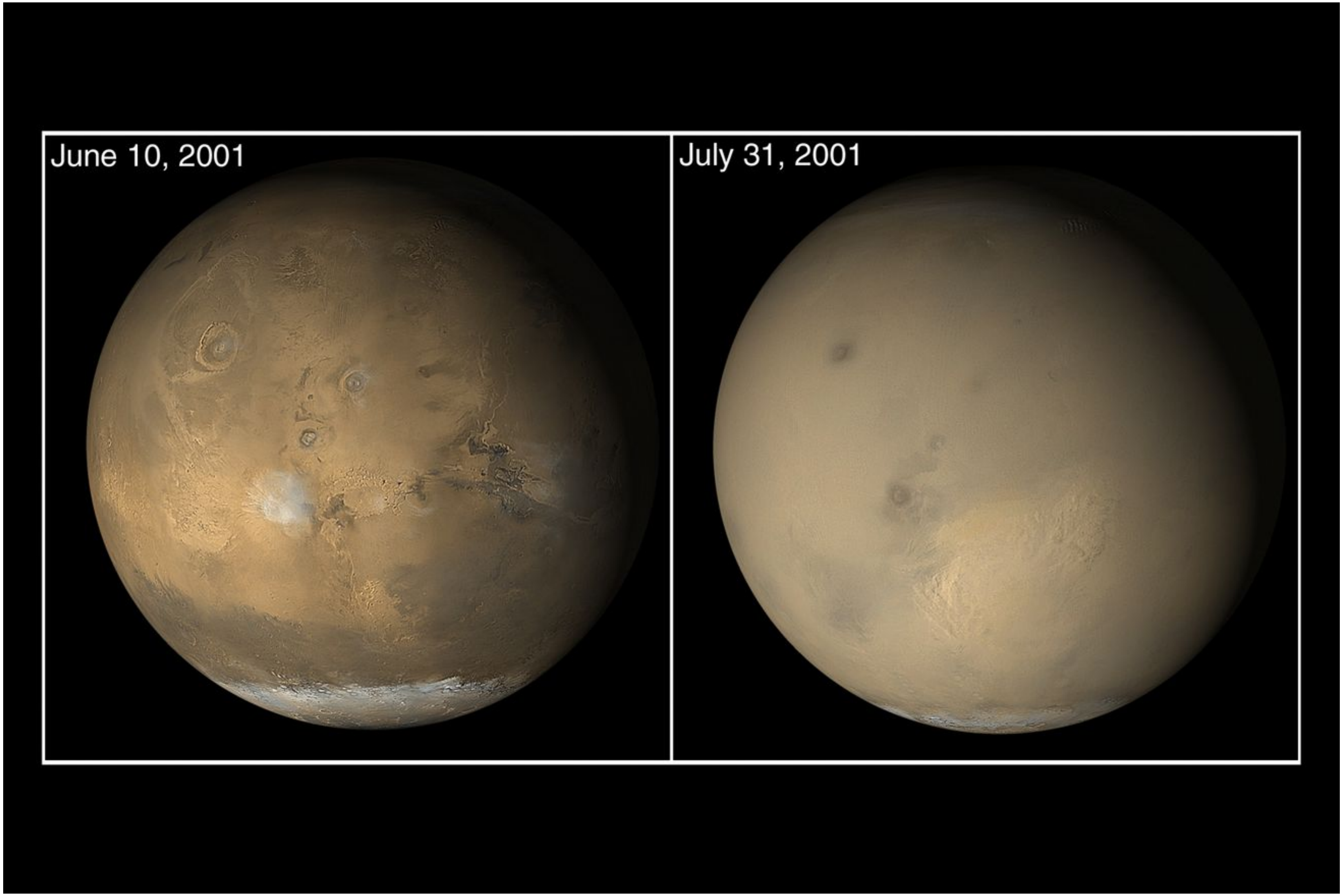


Importance of Atmosphere for Mars

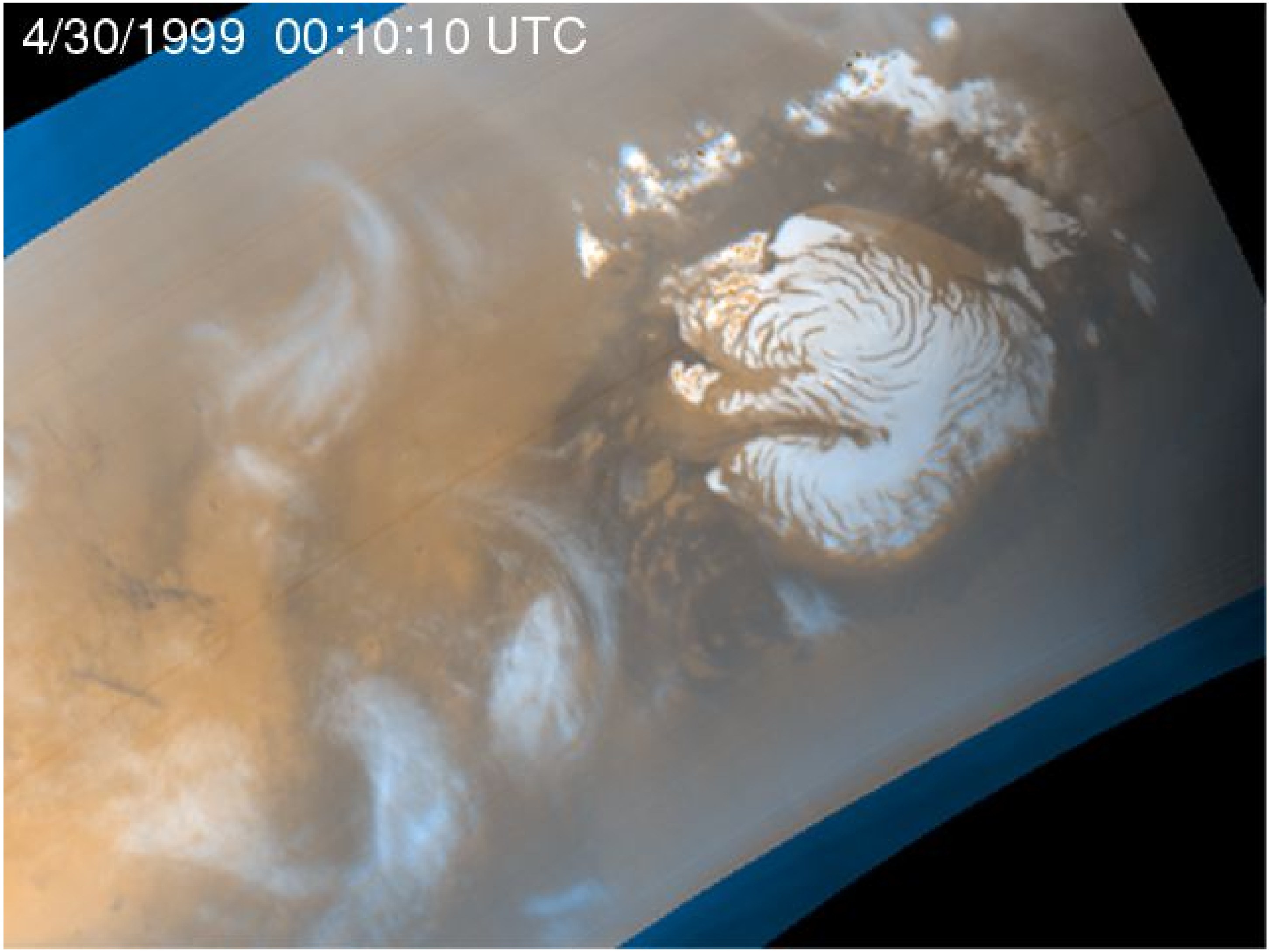
- Mars atmospheric pressure only ~1% of Earth’s
  - Still important in determining properties of Mars
    - Eolian erosion/deposition dominates in many places
    - Atmosphere transports water vapor

- Atmosphere mostly CO_2
  - Can condense at the winter poles

Mars atmosphere effects – dust storms



Mars cyclones



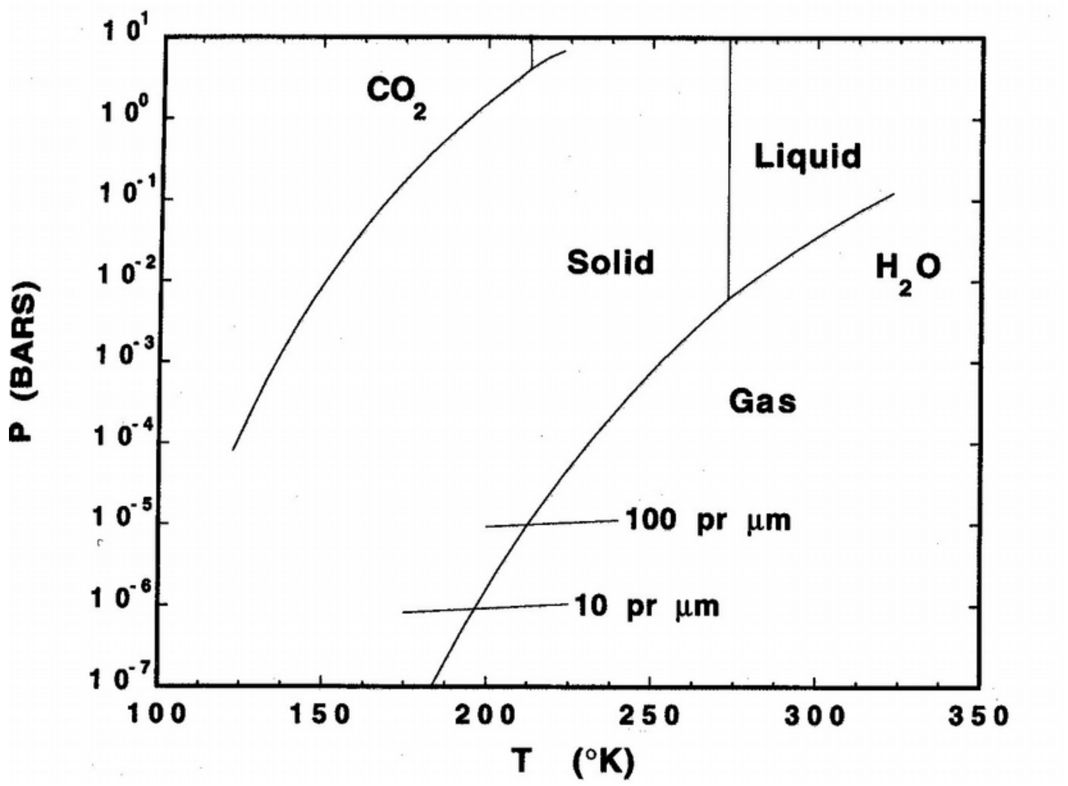
Phase Diagrams for H_2O, CO_2

At equator

T_{mean} ~ 215K

T_{peak} ~260-280K

T_{night} ~ 160 – 180K



- P_{triple} = 6.1 mbar for H_2O some parts of Mars above this, some below
- This 6.1 mb “elevation” is used as the “sea level” datum for Mars
  - Above this, water unstable (even if T high enough) (water ice is a dry ice here)
  - Below this, water stable in the sense it won’t immediately boil
    - Still can evaporate (or freeze if T low enough – which it almost always is)

- P_{triple} for CO_2 is several bars – could get liquid CO_2 if pressure this high
  - Some people have proposed running CO_2 in past – but not widely accepted

Atmospheric Escape

- Thermal escape (Jeans escape)

  - Hydrodynamic escape -- usually H, with other entrained gasses
- Photochemical escape
- Solar wind sputtering
  - Magnetic field can protect planet
- Impact Escape

- Isotopic Fractionation
  - D/H is ~8 times terrestrial value
  - Gives fraction of "accessible" H that has escaped
  - Uncertainty about what part is "accessible"
  - Recent $^{36}Ar/^{38}Ar$ results also imply significant loss

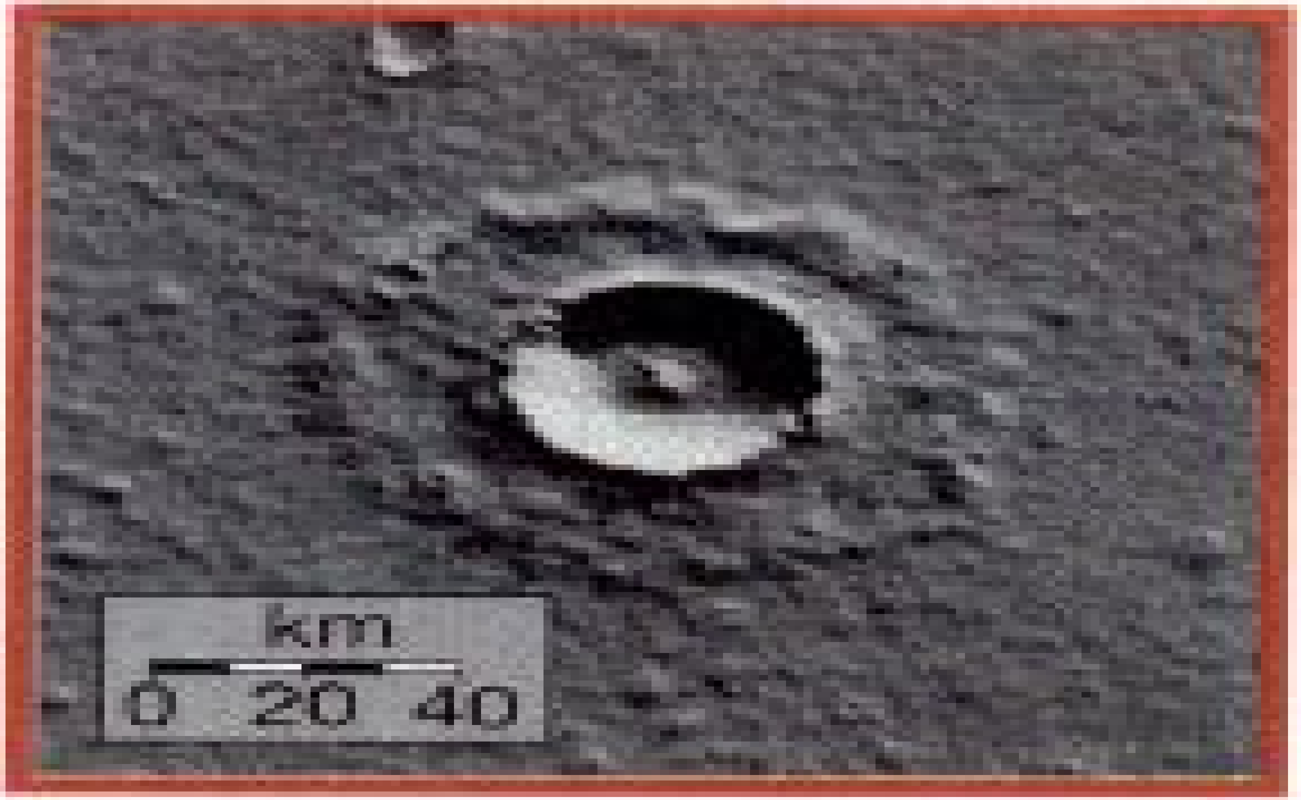
Long term vs. Short Term climate change

- Long term means gradual over age of solar system
  - Volatile escape
  - Decreasing heat flow
  - Decreasing impact rate
  - Permanent sequestration of volatiles
- Short term means related to orbital cycles or intermittent volatile release
  - Milankovitch cycles – more severe than on Earth
    - Variation in eccentricity, obliquity (diagrams on “chalk” board)

- All effects magnified by CO_2 and H_2O greenhouse
- Complicated by early faint sun

Where is ground ice stable?

'Rampart' crater



More on detailed mapping later

Mapping ground ice – based on rampart craters

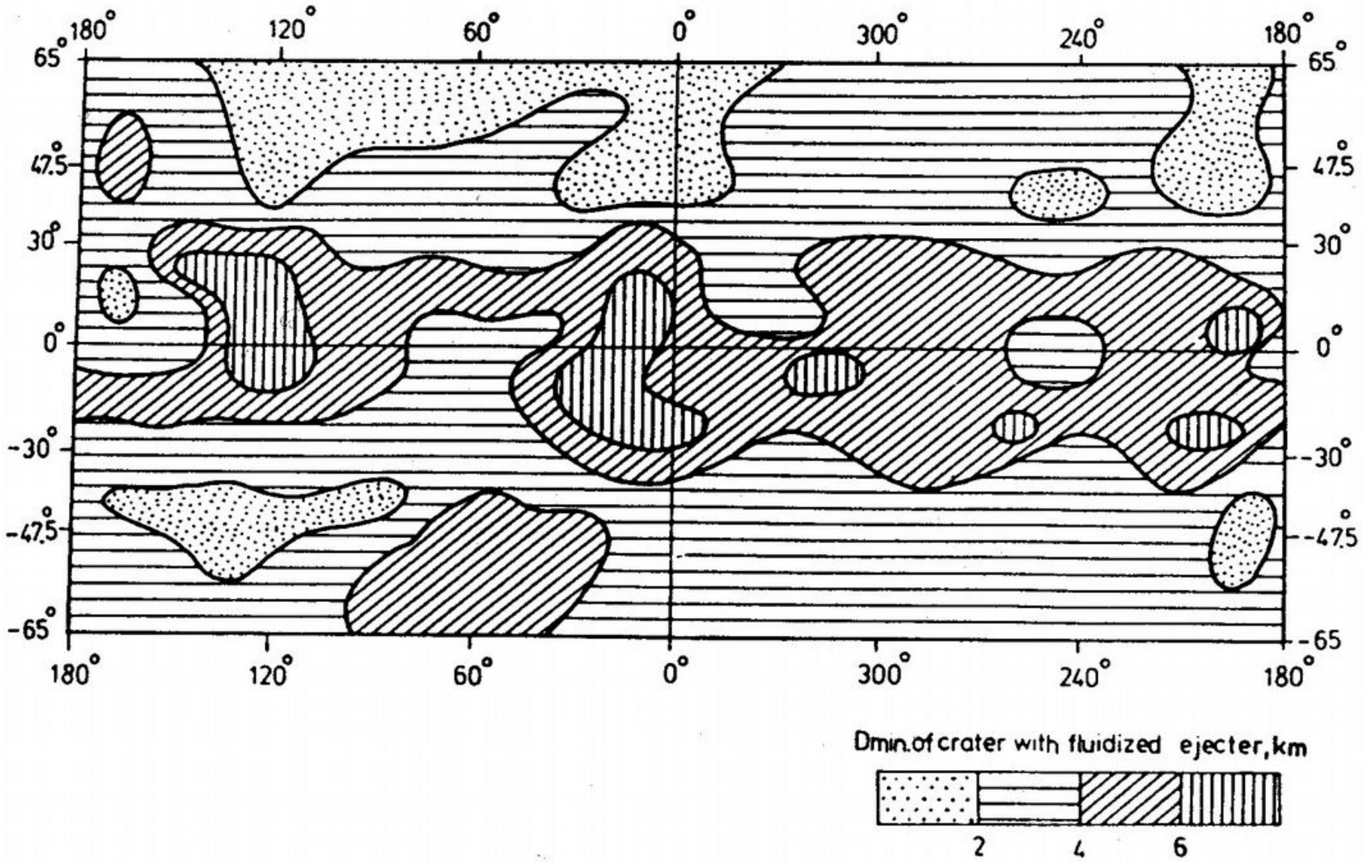
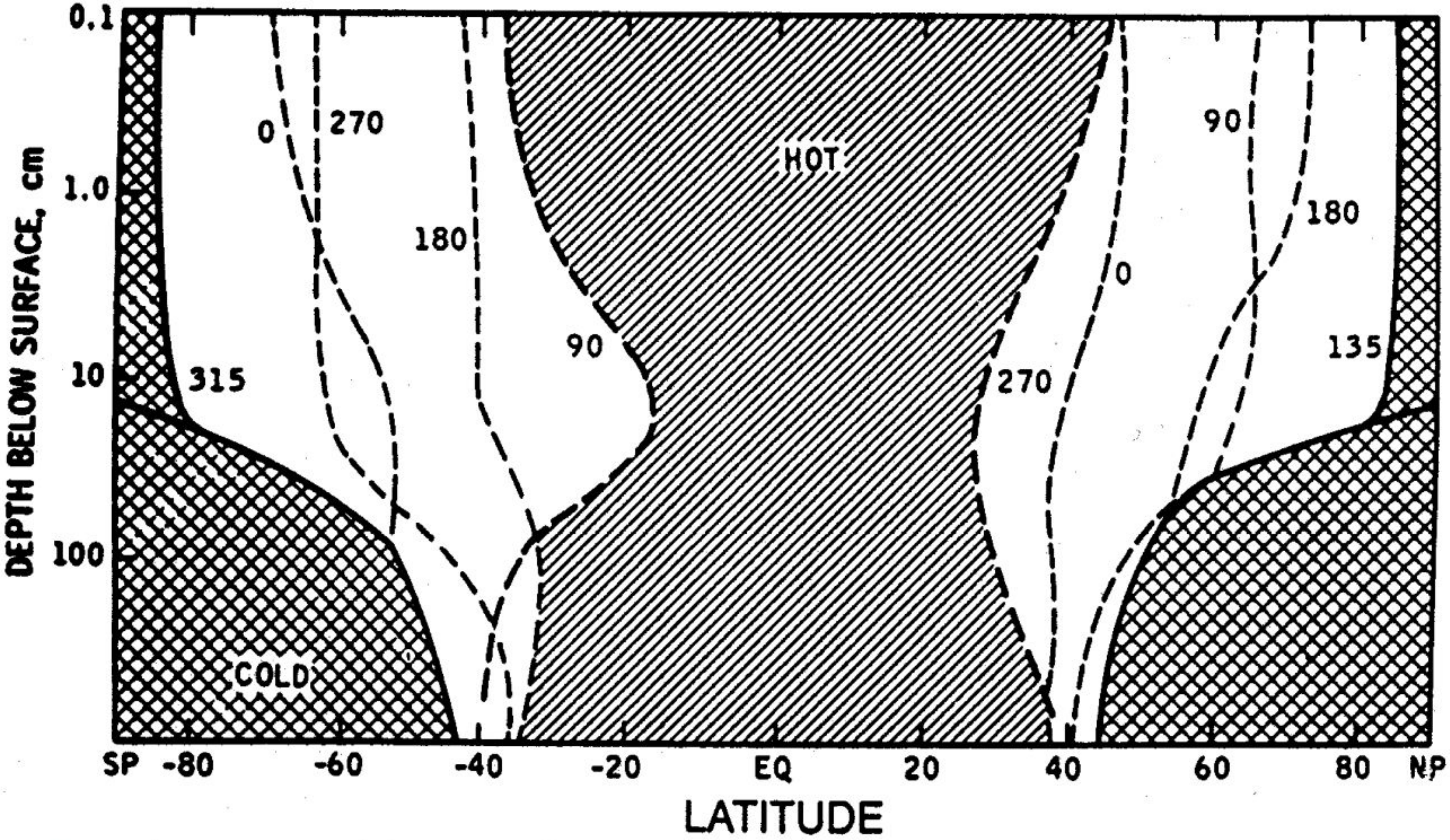


Figure 5-10. Onset diameter for craters with lobate ejecta patterns as a function of location. Craters smaller than the onset diameter do not have lobate patterns. Onset diameters are larger at the equator, suggesting the depth to ground ice is greatest at low latitudes. (From Squyres et al., 1992. Reproduced with permission from the University of Arizona Press.)

From Carr 1996 *Water on Mars*

Ice Stability as function of depth and latitude



- Clear: Unstable part of year
- Hashed: Completely stable or completely unstable

Theoretical models of H2O location: Regolith

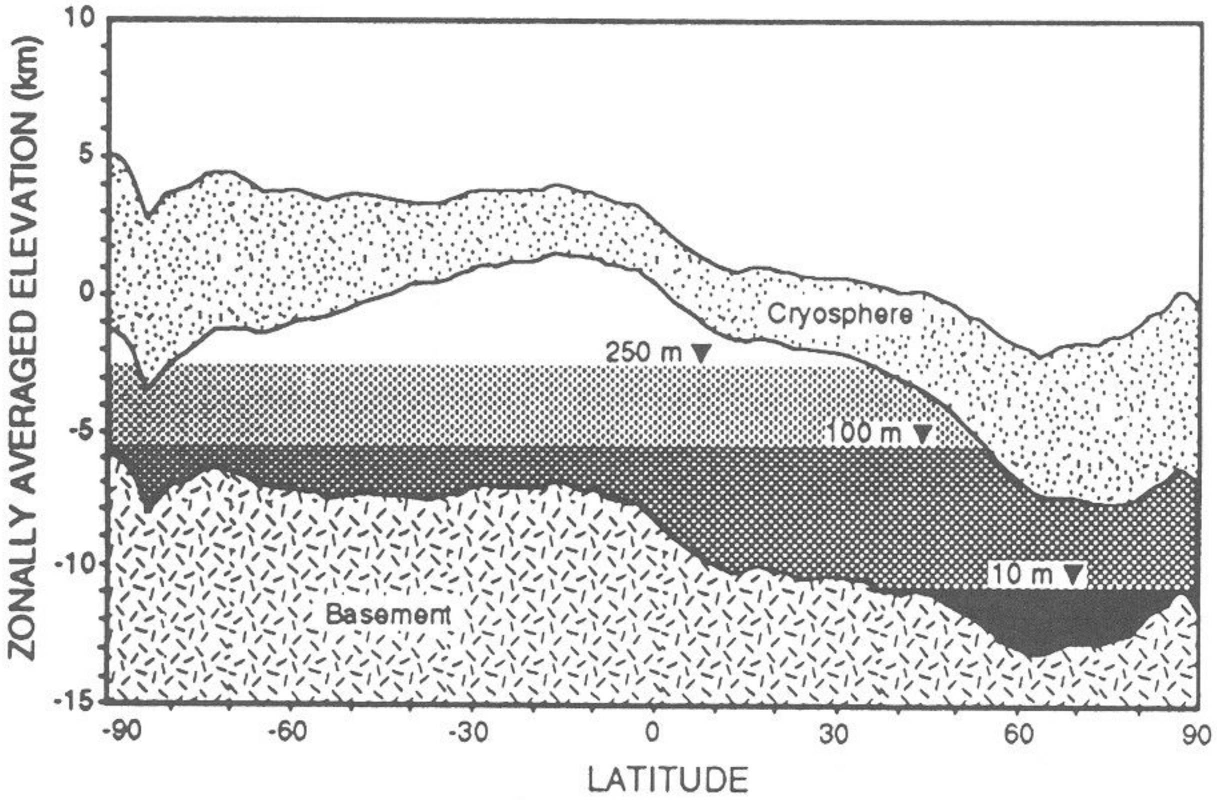


Figure 2-8. Model of the martian cryosphere and underlying hydrosphere. The upper surface shows the latitudinally averaged mean elevations. The surface of the basement is 10 km below the ground surface. The thickness of the cryosphere is taken from the values shown in Table 1-1. The water capacities shown are for the 50% surface porosity model. (From Clifford, 1993. Copyrighted by the American Geophysical Union.)

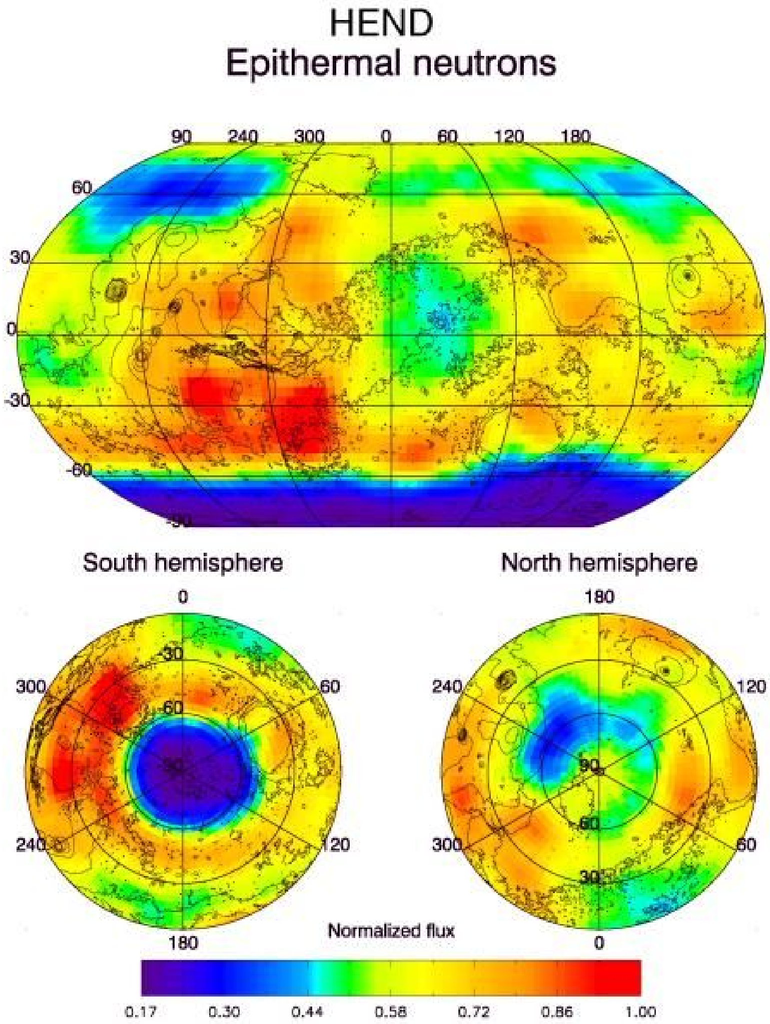
From Carr 1996 *Water on Mars*

Erosion rates over time: Constraints

- Require low overall rates of erosion to preserve any craters
- Require high rates during period of heavy bombardment to produce subdued crater morphology

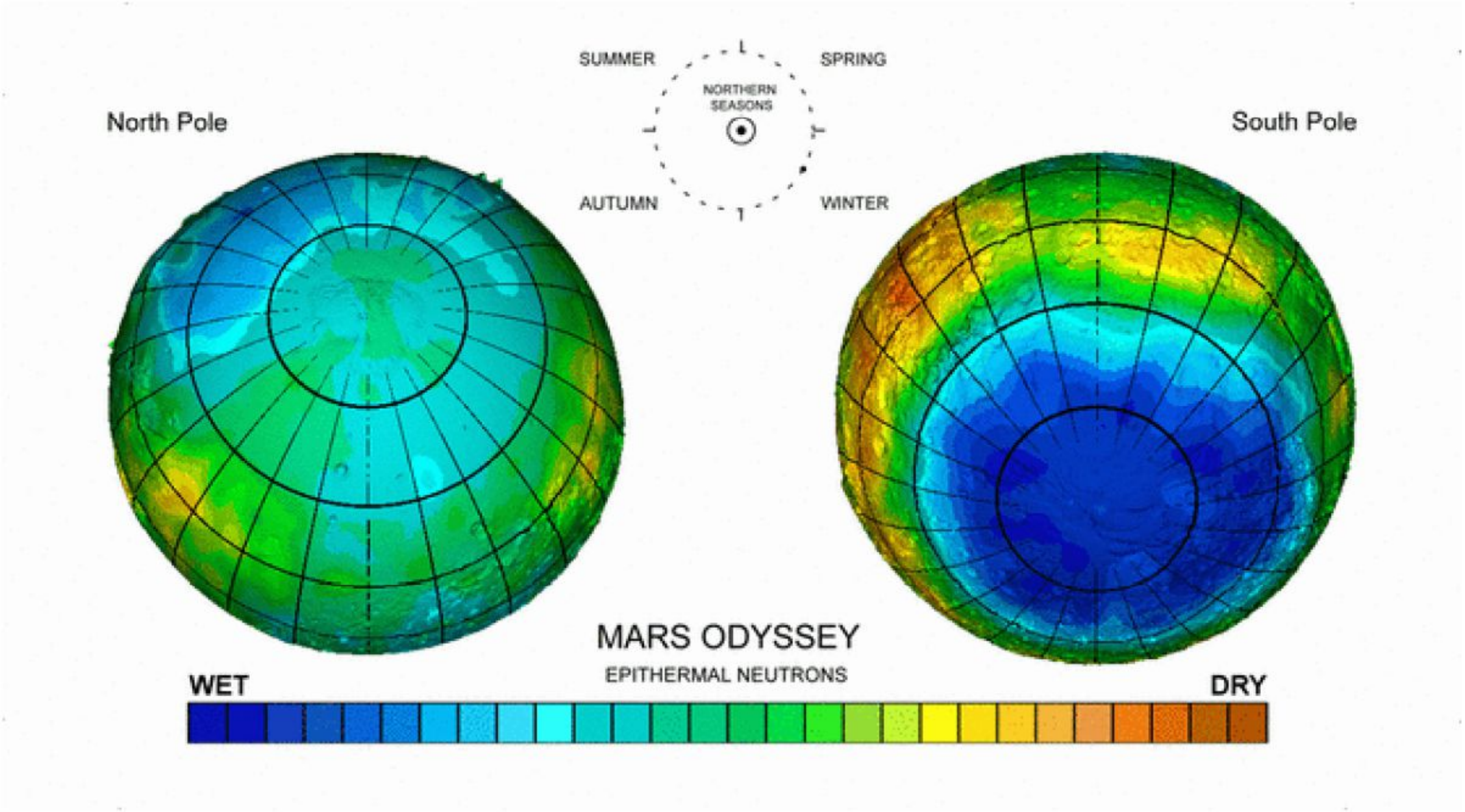
- Timing of outflow channels
- Timing of river valleys

Mars Odyssey Neutron Maps



- Hydrogen does good job of slowing down the high speed neutrons created by decay or cosmic ray interactions.
- More slow (=epithermal) neutrons means more H_2O
- H_2O concentrated at S pole, some at N pole, with lower, varying amounts at lower latitudes.

Epithermal Neutron Movies



- H_2O appears to disappear during the winter not because it is gone but because it is buried under the temporary CO_2 cap

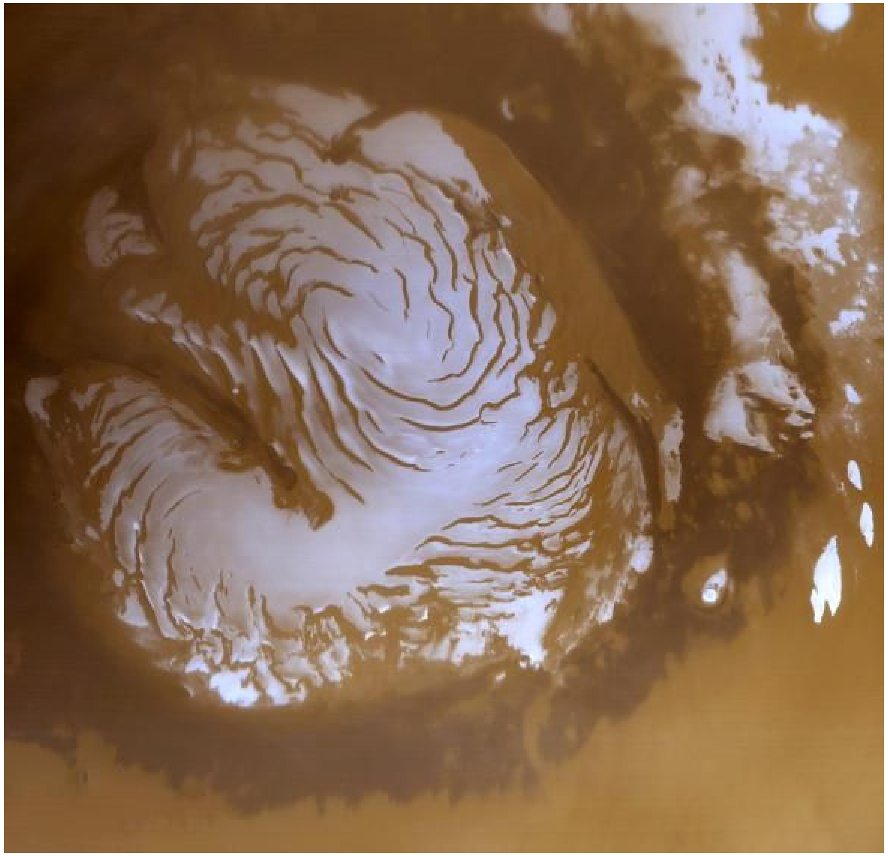
Approximate Size of Volatile Reservoirs

	H_2O (kg m^{-2})	CO_2 (kg m^{-2}	H_2O Uncertainty Factor	CO_2 Uncertainty Factor
Atmosphere	0.01	150	0.3	0.1
Seasonal Polar Caps	0.01	40	2	0.2
Permanent N Polar Cap	5800	0	4	---
Permanent S Polar Cap	600	8	5	10
Polar Layered Deposits	6200	0?	3	--- (?)
Upper "exchangable" Regolith	10	1000	10	+6 -20
Total Regolith	100,000	2000	10	10

Data from Kieffer & Zent 1992 in Mars book.

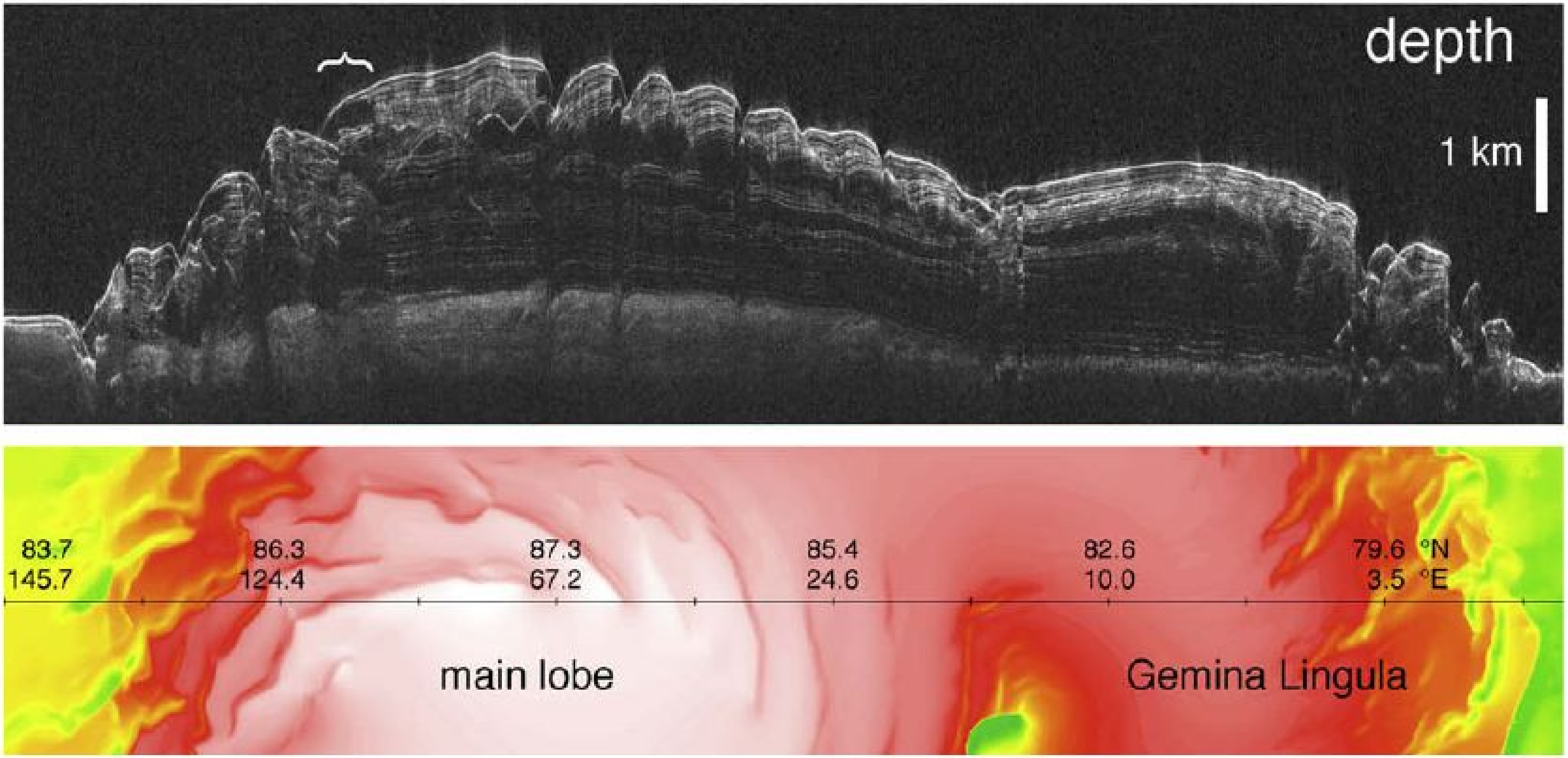
To convert water kg m^{-2} to equivalent global meters, divide by ρ=1000 kg m^{-3}

Mars Polar Deposits



- Unusual terrain not just at poles but surrounding them
- H_2O CO_2 ice/frost
- Layered Polar Deposits
  - light region just outside cap itself
- Dune fields
  - dark region outside layered deposits
- All geologically young – from small crater counts

Mars polar caps



Putzig et al. 2009 SHARAD (SHAllow RADar)
on the Mars Reconnaissance Orbiter 15 to 25 MHz

Viking view of layered deposits

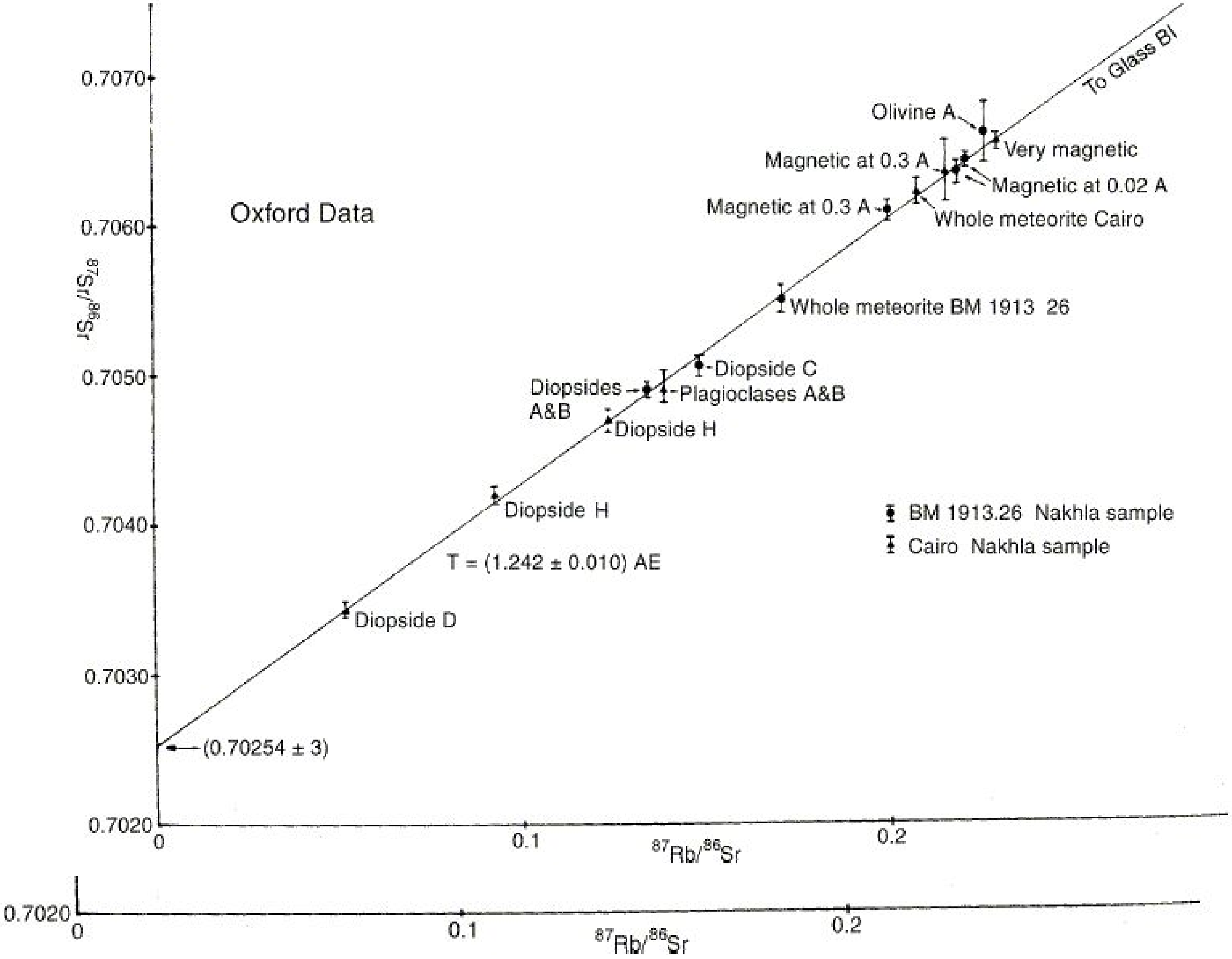
From Thomas et al. 1992

- Scale bar is 20 km
- Bright areas are residual frost
- Albedo of deposits much less than frost, but could be mix of dust and ice
- Larger layers presumably related to Mars’ extreme Milankovitch cycles
- MGS sees layers down to much smaller scale (meters)

Martian "SNC" Meteorites

- 3 unusual meteorite classes (9 members in 1996, more now)
  - Shergotty (basalts)
  - Nakhla (pyroxenites)
  - Chassigny (dunite)
- Crystallization ages: 170 Myr -- 1.3 Gyr
  - Need <u>planet</u> to have activity then
- Gas abundances match Viking
- Allows detailed examination of isotopic ratios
  - Similar Oxygen isotope pattern so common source
- Core formation time
  - Fractionation effects in H and other volatiles
    - Atmospheric plus interior water component
  - Allows examination of mineralogy
- Carbonates present – details of hydrothermal system
- Don't have source locations for these samples

SNC Rb-Sr ages (Nakhla)



- Crystallization age = 1.24 Gyr (Gale et al. 1975)
- Cosmic Ray Exposure Age 11 My

SNC – Oxygen Isotope evidence

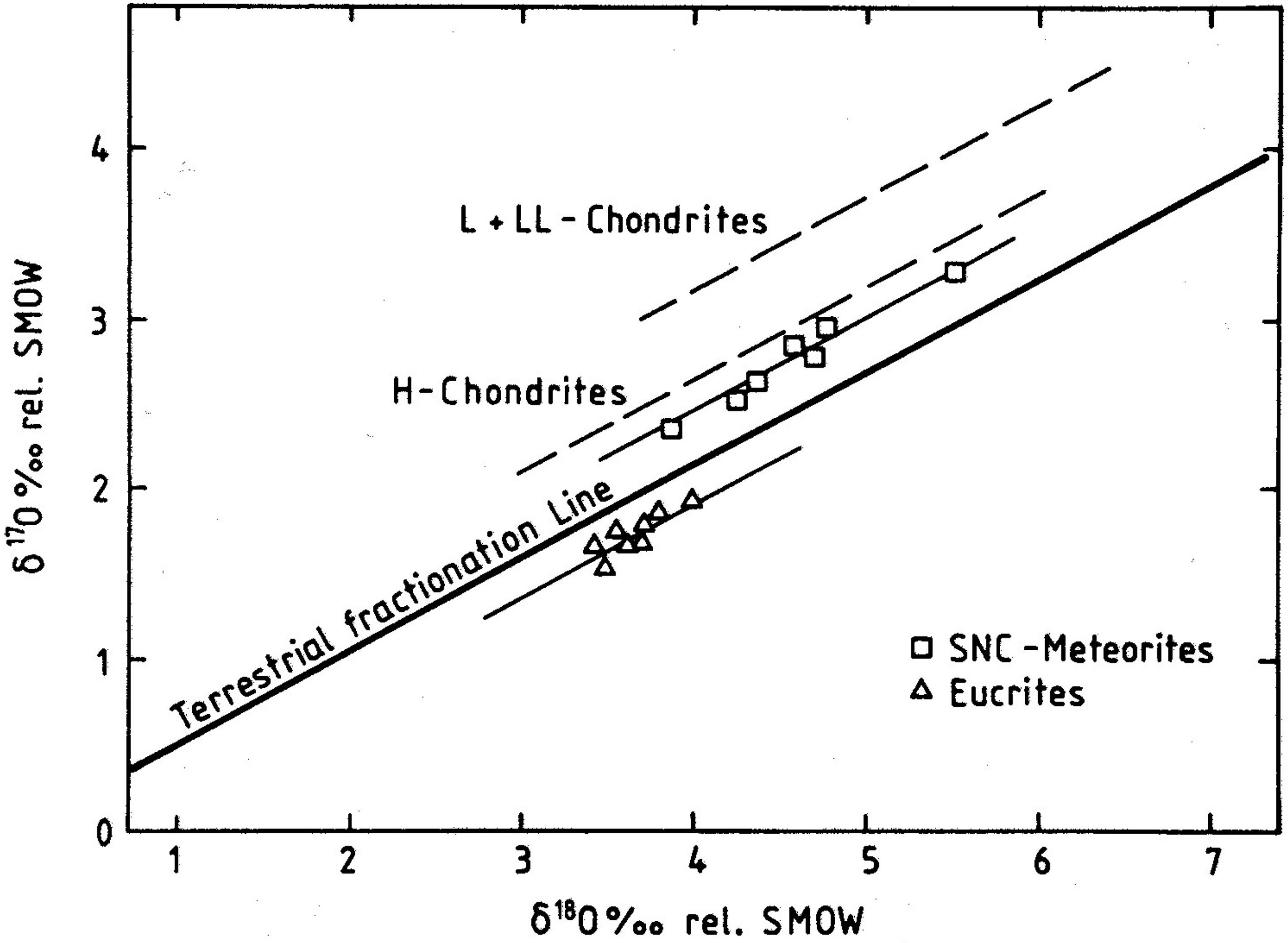


Figure 1-12. Oxygen isotope variations in terrestrial rocks and various meteorites. The SNC meteorites form a distinct coherent class with isotopic patterns different from other meteorites or terrestrial rocks. (From Clayton and Mayeda, 1983. Reproduced with permission from Elsevier Science.)

From Carr 1996 "Water on Mars"