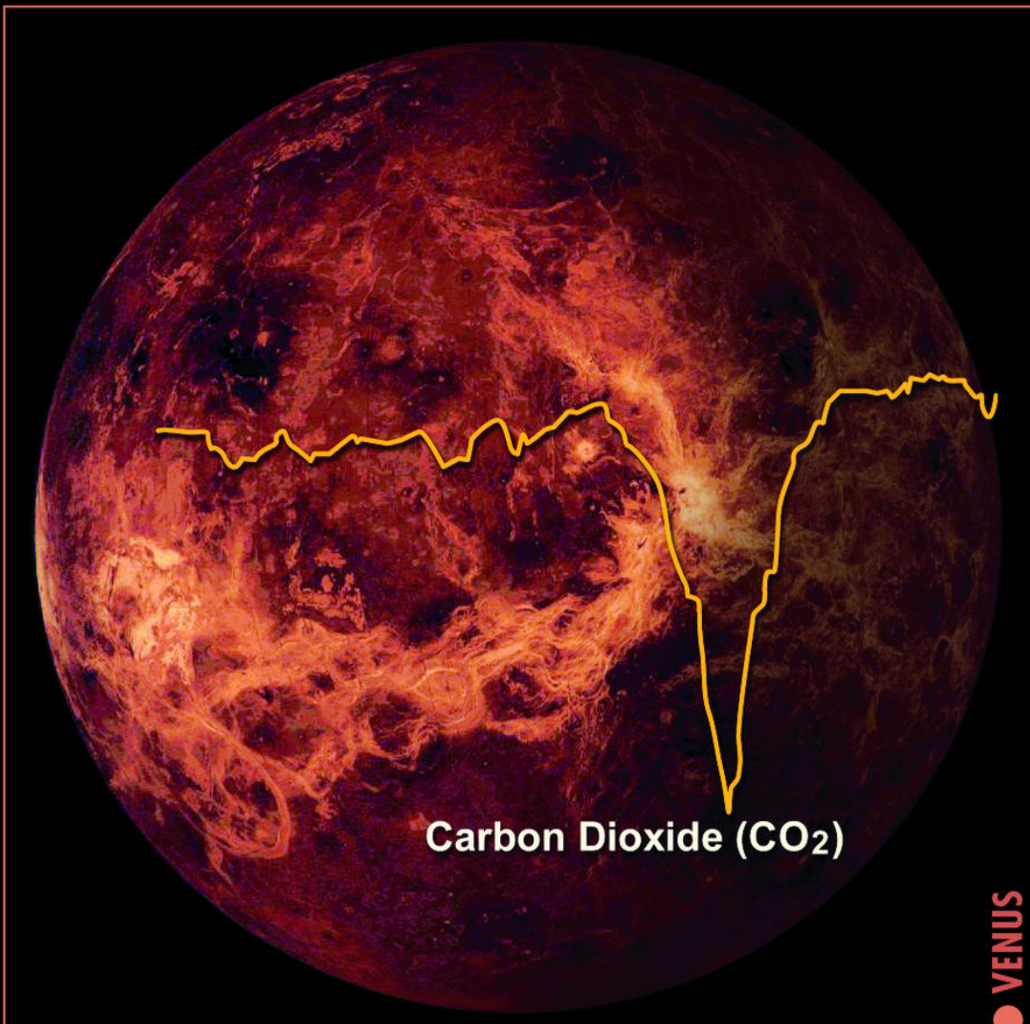
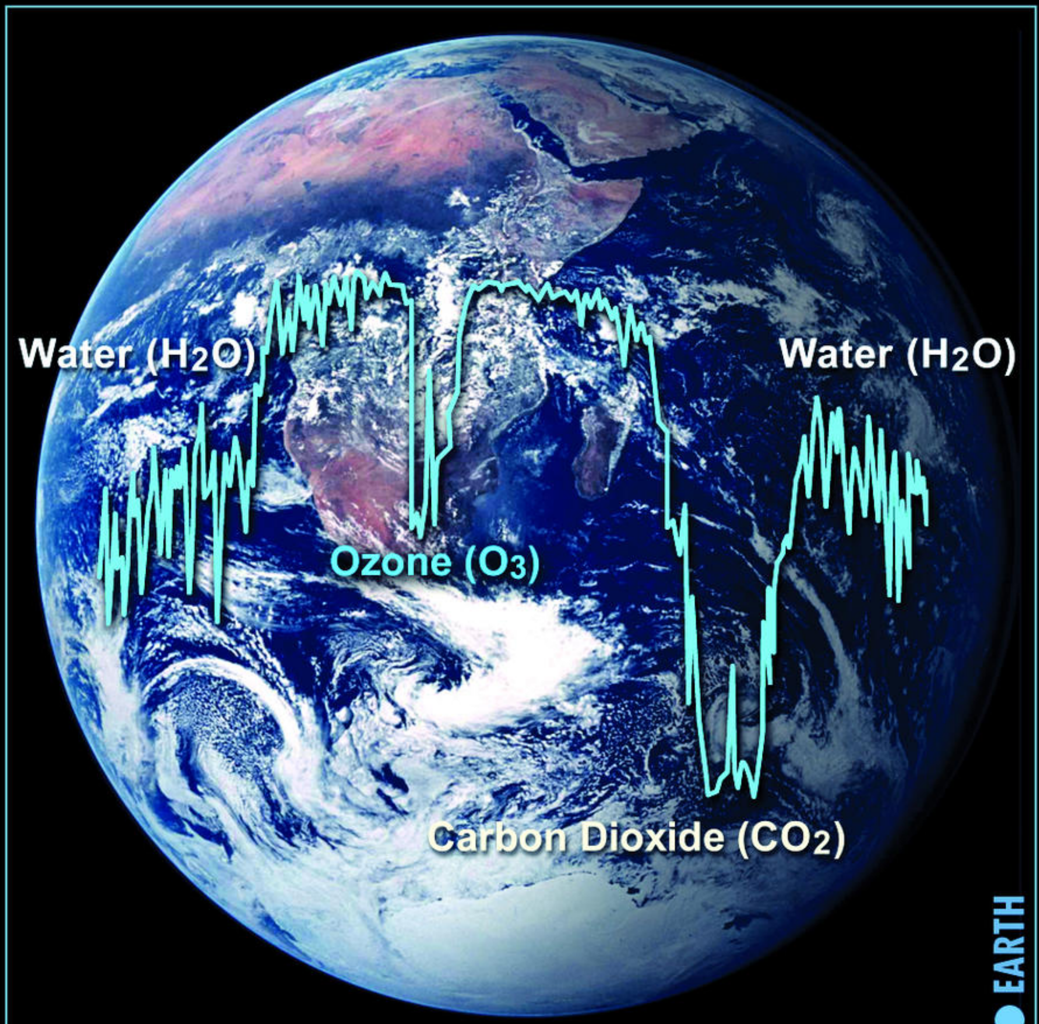
Planetary Habitability





Stephen Kane

UNIVERSITY OF CALIFORNIA
UC RIVERSIDE

Topics

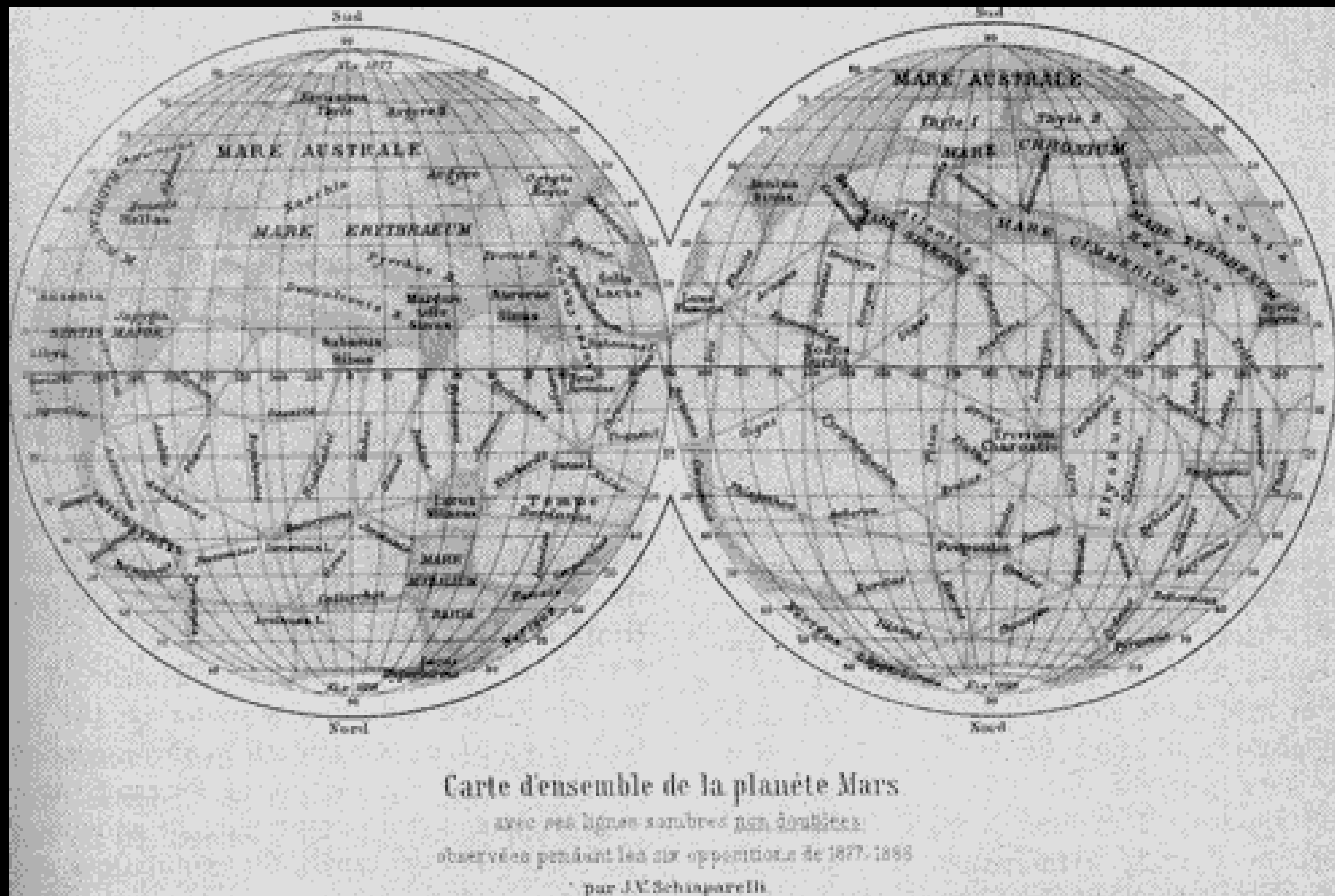
- Lecture 1 – Introduction
- Lecture 2 – Habitability Factors
- Lecture 3 - Stars
- Lecture 4 – Planetary Atmospheres
- Lecture 5 – Planetary Interiors
- Lecture 6 – Planetary Energy Balance
- Lecture 7 – Habitable Zone I
- Lecture 8 – Habitable Zone II
- Lecture 9 – Earth as a Living Planet
- Lecture 10 – Mars
- Lecture 11 – Icy Moons
- Lecture 12 – Venus
- Lecture 13 – Mercury & the Moon
- Lecture 14 – The Role of Giant Planets
- Lecture 15 – Stellar Influences
- Lecture 16 – Magnetic Fields
- Lecture 17 – Milankovitch Cycles
- Lecture 18 – Geological Cycles
- Lecture 19 – The Next Steps
- Lecture 20 – Summary/Discussion

Mars' Habitability

- Evolution of prevailing thoughts on Mars life.
- Attributes of Mars.
- Evidence for water.
- Atmospheric loss.
- Mars' orbital variations.

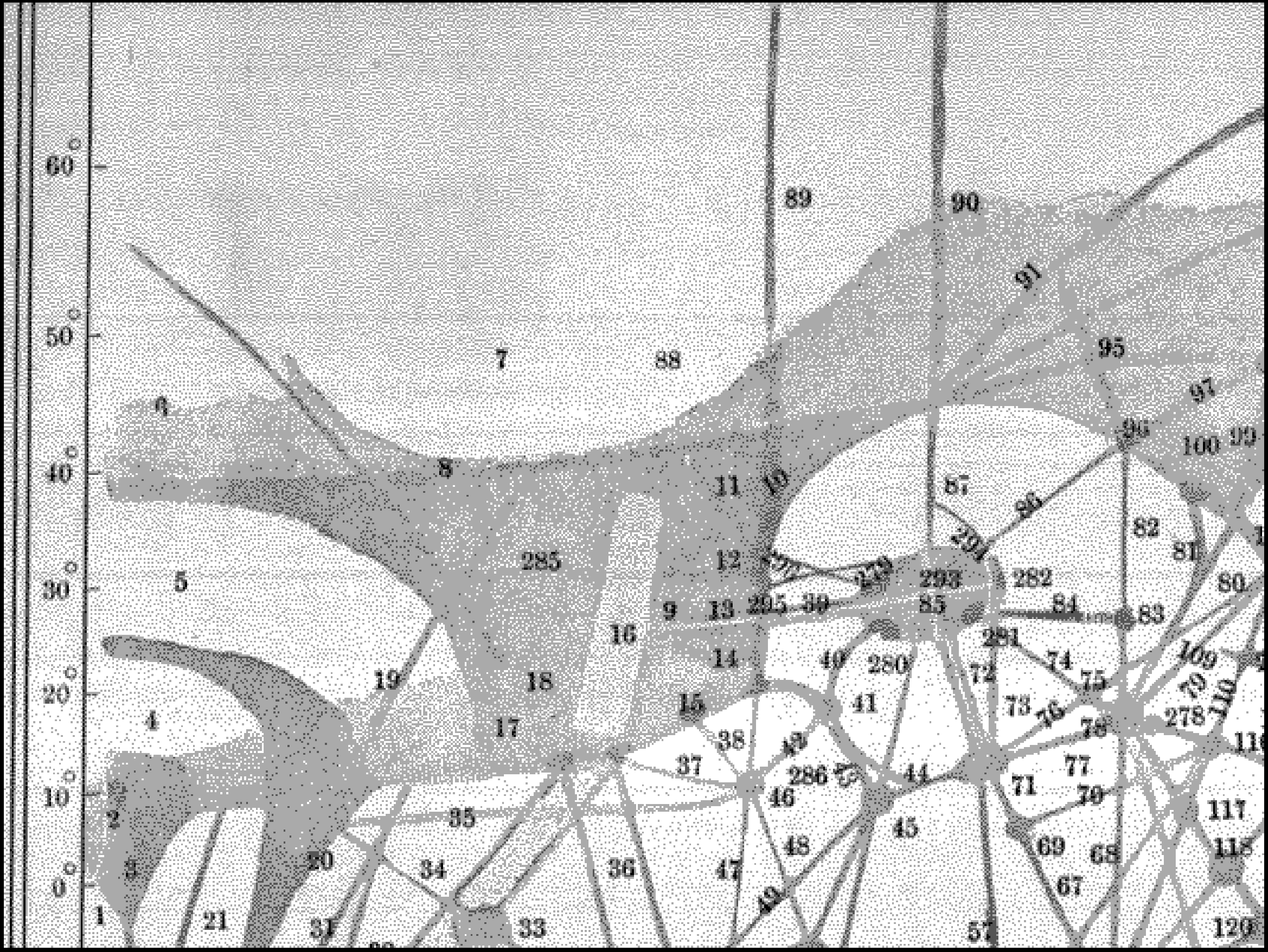
Life on Mars?

Giovanni Schiaparelli published a map (1877) of *canali* (channels)



Life on Mars?

Percival Lowell founded the Lowell Observatory to follow up.



Life on Mars?

No one would have believed in the last years of the nineteenth century that this world was being watched keenly and closely by intelligences greater than man's and yet as mortal as his own; that as men busied themselves about their various concerns they were scrutinised and studied, perhaps almost as narrowly as a man with a microscope might scrutinise the transient creatures that swarm and multiply in a drop of water.

H. G. WELLS   THE WAR OF THE WORLDS
Radio broadcast: Orson Welles; October 30 1938

A Summary of Mars

- White polar caps
- Seasonal reflectivity changes
- Dust storms
- 24^h37^m day; 25^o axial tilt

A Summary of Mars

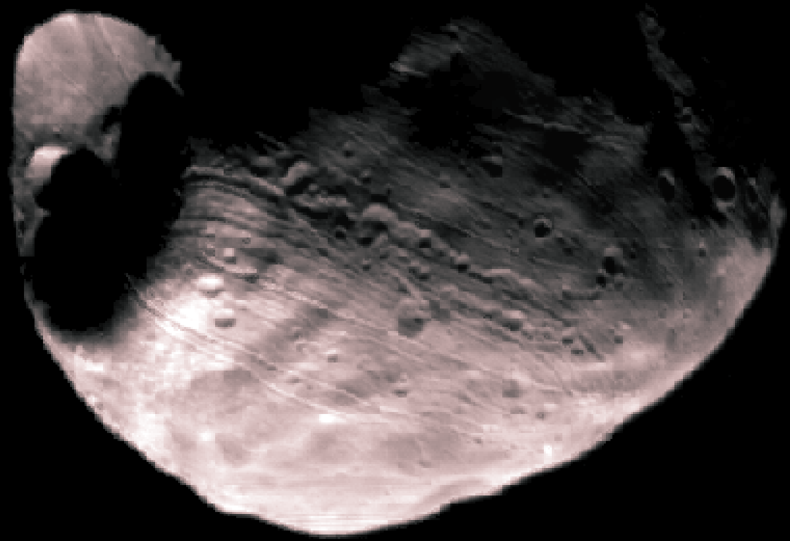
Table 12.1 Basic planetary parameters for Mars and its present atmosphere.

Parameter	Value on Mars
Mass relative to Earth's 5.97×10^{24} kg	$0.107 \approx 1/9$
Mean radius relative to Earth's 6371 km	$0.532 \approx 1/2$
Orbital eccentricity	0.093
Semimajor axis of orbit (AU)	1.523 66 (ranges 1.3815 to 1.666)
Obliquity (°)	25.19
Mean orbital period (a Mars year)	669.60 Mars solar days (sols) 686.98 Earth days ≈ 1.88 Earth years
Gravitational acceleration, equator ($m\ s^{-2}$)	3.711
Mean solar day (noon-to-noon period, sol)	88 775.2 s ≈ 24.66 hr
Sidereal day (axial rotation period)	88 642.7 s ≈ 24.6229 hr
Mean atmospheric surface pressure[a] (Pa)	≈ 600 Pa
Mean global surface emission temperature[b] (K)	215
Near-surface scale height[c] (km)	10.3
Atmospheric composition[d] (by volume) below 120 km (ppm = parts per million ppb = parts per billion)	CO_2 95.7±1.6%, N_2 2.03±0.3%, Ar 2.07±0.02%, O_2 0.173±0.006%, CO 749±26 ppm, H_2O 0.03% (varies), H_2 15±5 ppm, He 10 ppm, Ne 2.5 ppm, Kr 0.3 ppm, Xe 0.08 ppm, O_3 0.04-0.2 ppm (varies), H_2O_2 0–40 ppb, NO <1.7 ppb, SO_2 <0.3 ppb, HCl <0.2 ppb
Column dust content of the atmosphere[e]	0.1–5 visible optical depth

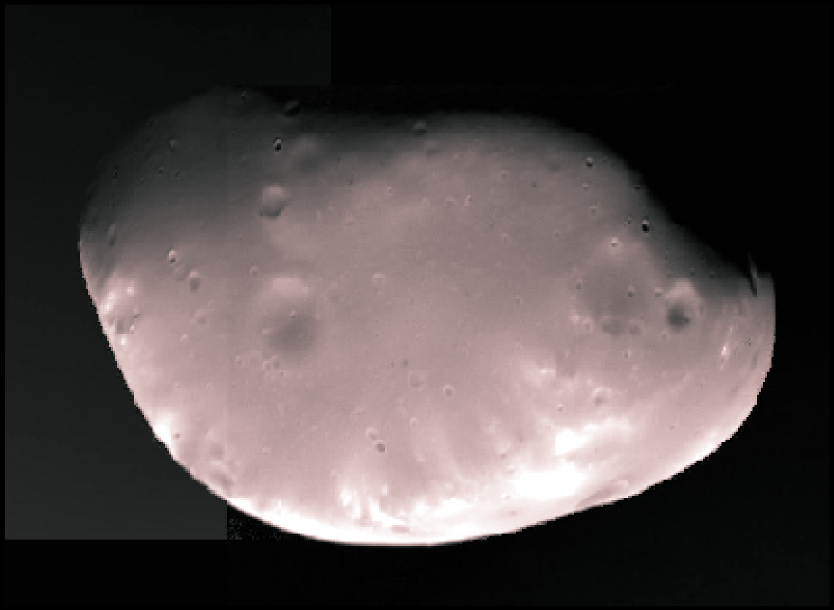
[a] Haberle *et al.* (2008). [b] Haberle (2013). [c] Leovy (2001). [d] Main constituents from Mars Science Lab results in Franz *et al.* (2015); see also Owen *et al.* (1977) and Krasnopolsky (2011), and references therein. [e] Kahn *et al.* (1992).

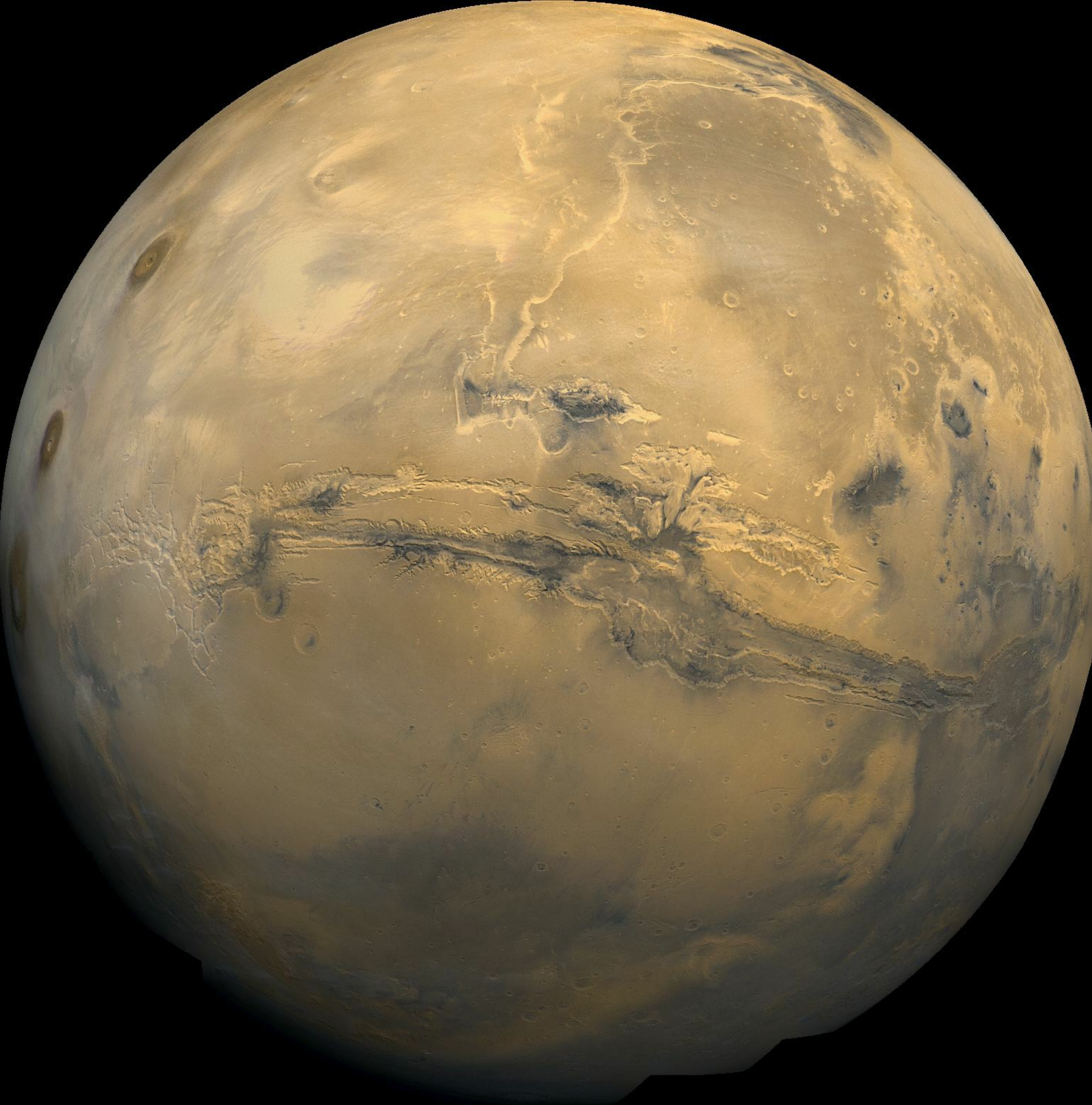
Moons of Mars

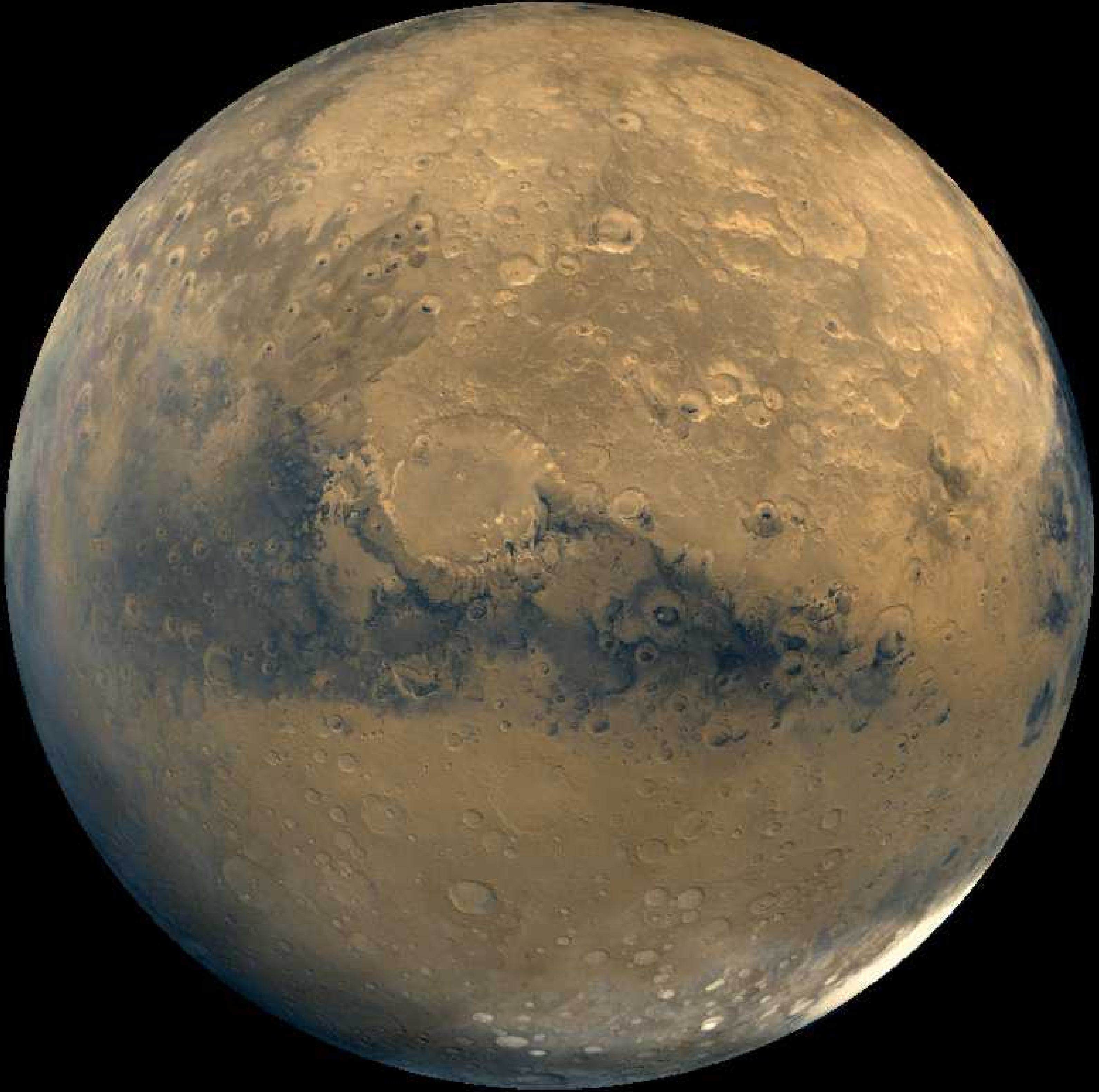
Phobos (Fear)
13x11x9 km



Deimos (Terror)
8x6x5 km







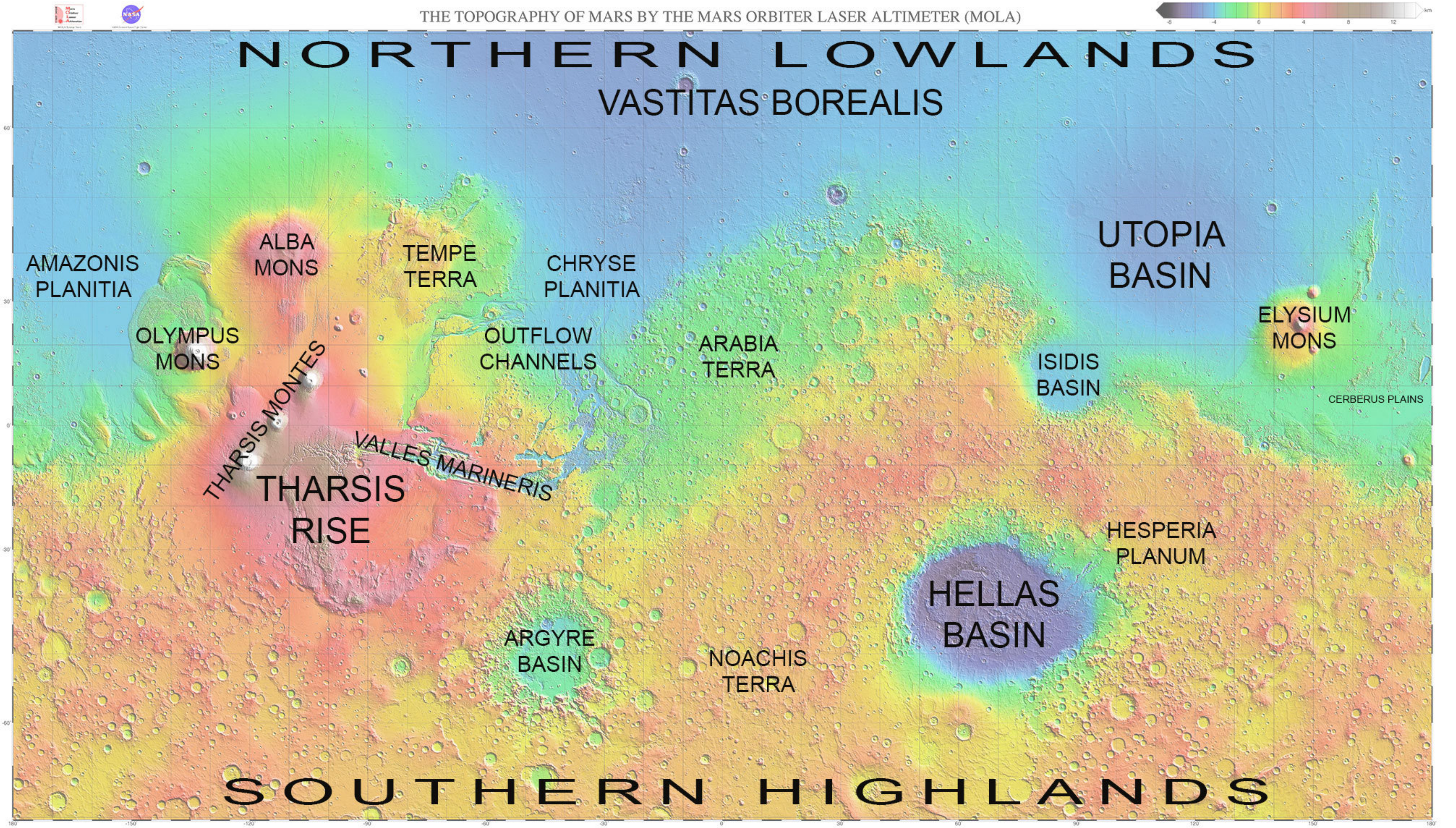

THE TOPOGRAPHY OF MARS BY THE MARS ORBITER LASER ALTIMETER (MOLA)
NORTHERN LOWLANDS
VASTITAS BOREALIS
AMAZONIS PLANITIA
ALBA MONS
TEMPE TERRA
CHRYSE PLANITIA
UTOPIA BASIN
ELYSIUM MONS
OLYMPUS MONS
THARSIS MONTES
OUTFLOW CHANNELS
ARABIA TERRA
ISIDIS BASIN
CERBERUS PLAINS
VALLES MARINERIS
THARSIS RISE
HESPERIA PLANUM
HELLAS BASIN
ARGYRE BASIN
NOACHIS TERRA
SOUTHERN HIGHLANDS

Table 12.3 Important spacecraft missions to Mars since the 1970s.

Mission	Operational at Mars	Most notable results
Mariner 9	1971–72	imaged volcanoes and apparent fluvial features, such as channels and valley networks
Viking (two Viking Orbiters (VOs), two Viking Landers (VLs)	1976–78/80 (VO-2, VO-1) 1976–79/82 (VL-2, VL-1)	VOs mapped the surface (visually to 200 m resolution) and atmosphere; VLs failed to find organics; VLs measured surface physical properties, soil elemental geochemistry, and atmospheric properties
Mars Pathfinder	1997	engineering demo; additional soil and rock elemental chemistry
Mars Global Surveyor (MGS)	1997–2006	topography, magnetic data, images down to 1.5 m $pixel^{-1}$; thermal infrared mineral mapping.
Mars Odyssey	2001–present*	mapped subsurface water ice in high latitudes; found halide salts
ESA Mars Express	2003–present*	revealed layered sulfates and clay minerals; measured hydrogen and oxygen ion escape rates
2 Mars Exploration Rovers (MERs): *Spirit* and *Opportunity*	2004–2010 (*Spirit*) 2004–present*	identified sulfate-rich sedimentary rocks, concretions indicative of groundwater, fossilized ripples from small streams, mud cracks, hydrated silica, and a carbonate-rich outcrop
Mars Reconnaissance Orbiter (MRO)	2006–present*	found outcrops of sulfates and carbonates and widespread clay minerals; ice exposed in new, mid-latitude craters. Images to 20 cm $pixel^{-1}$
Phoenix Lander	May–Nov. 2008	subsurface ice confirmed; first identification of soluble soil salts, including low eutectic perchlorate (ClO_4^-) salts
Curiosity Rover (Mars Science Laboratory)	2012–present*	found mudstone lakebed deposits, including clay minerals deposited in near-neutral pH fluid; found stream deposits; first *in situ* radiometric dating; first *in situ* detection of organics and nitrogen oxides (likely nitrates) in surface samples
Mars Atmosphere and Volatile EvolutioN (MAVEN) orbiter	2014–present*	enhanced ion escape and production of diffuse aurora by solar storms; *in situ* measurement of thermosphere; detection of infalling interplanetary dust particles
Mars Orbiter Mission (India)	2014–present*	yet to report major results*

* At present time of writing, 2016.

Is There Water on Mars?

Frost

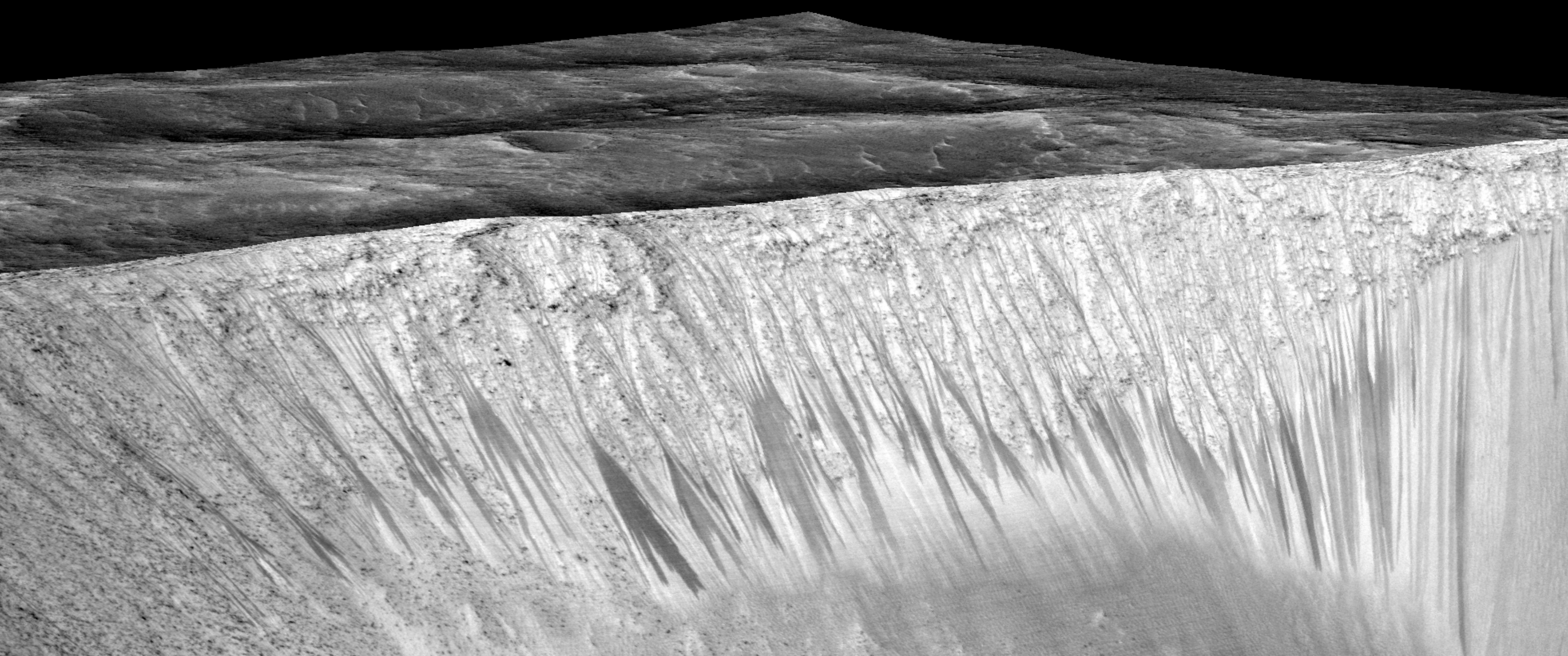
Frost in Lowell crater➔

🡐Frosty morning in Utopia Planitia

(Viking lander, 1976)

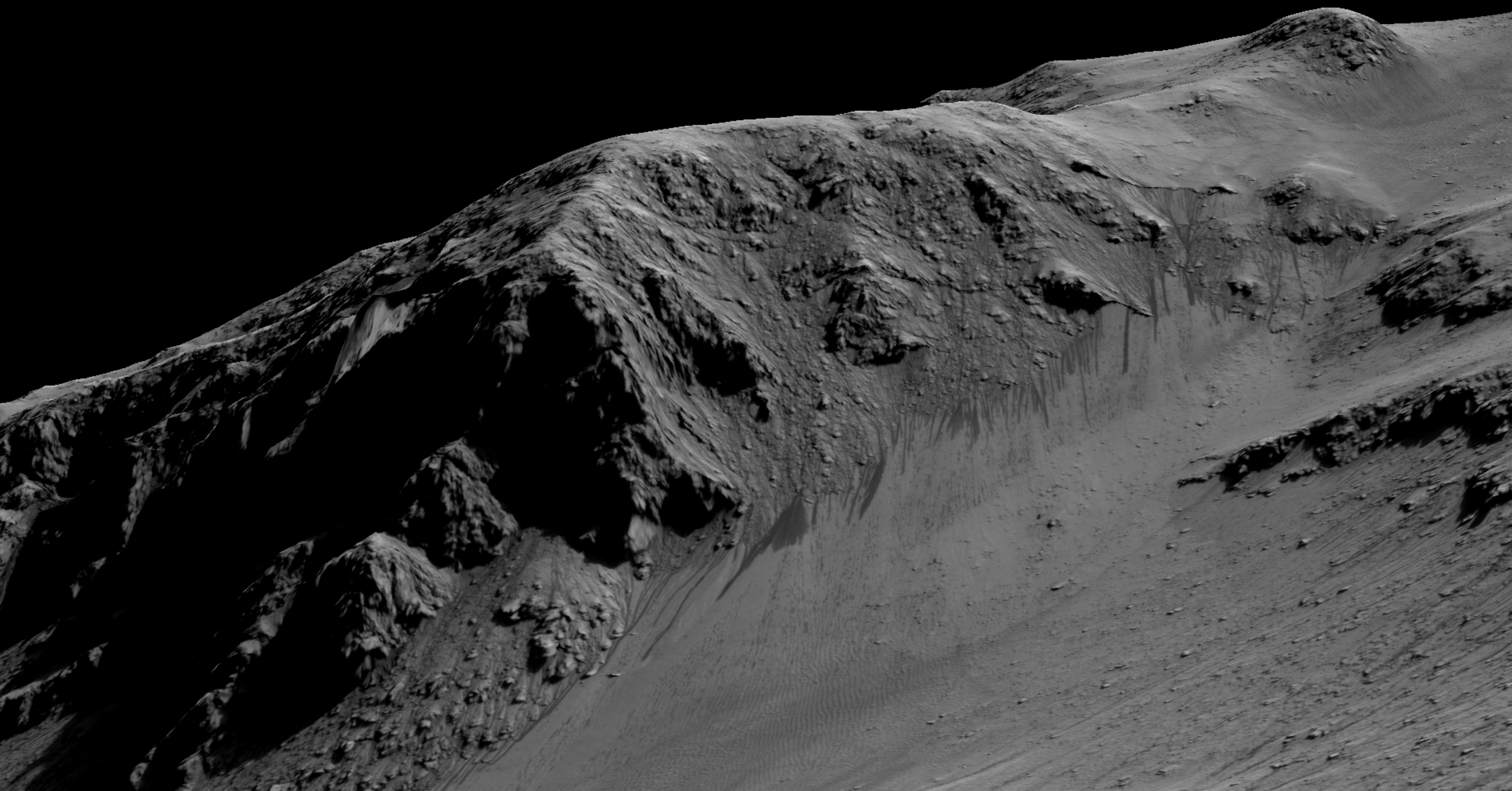
Recent Channels

New Evidence: Water on Mars

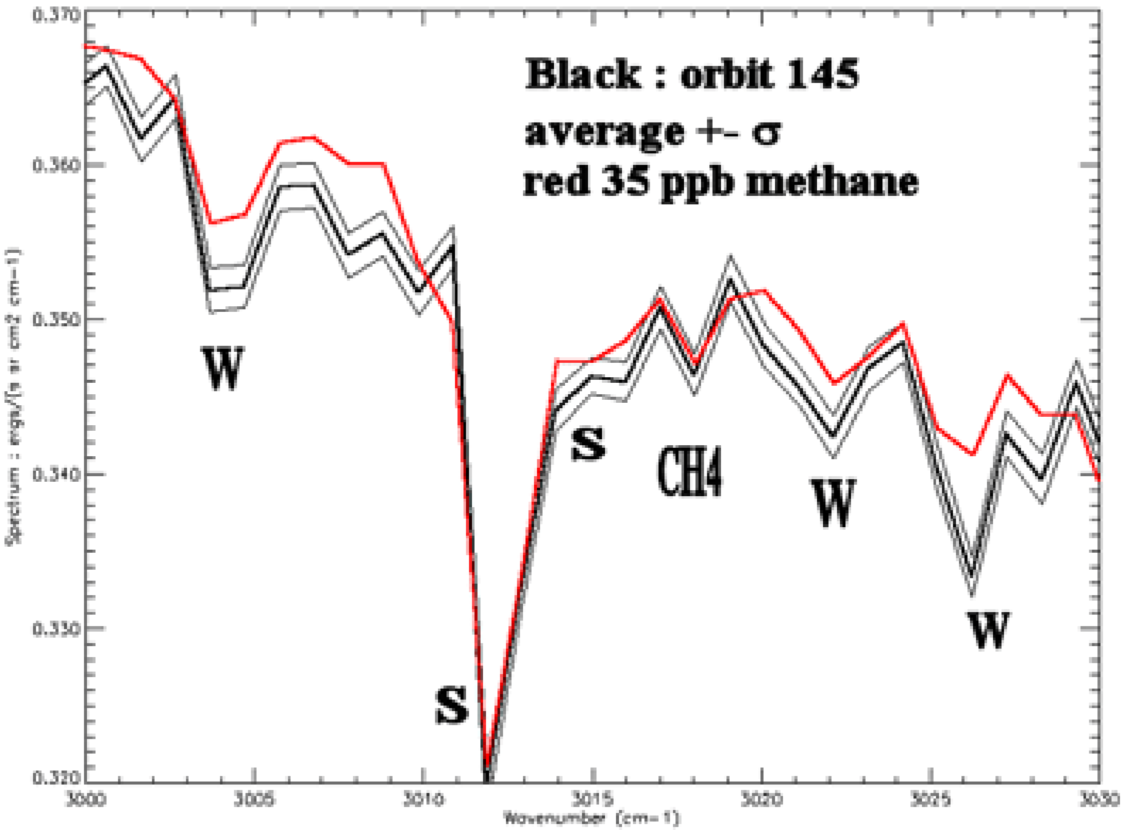


New Evidence: Water on Mars

Spectroscopic evidence for hydrated salts
-Magnesium perchlorate
-Magnesium chlorate
-Sodium perchlorate

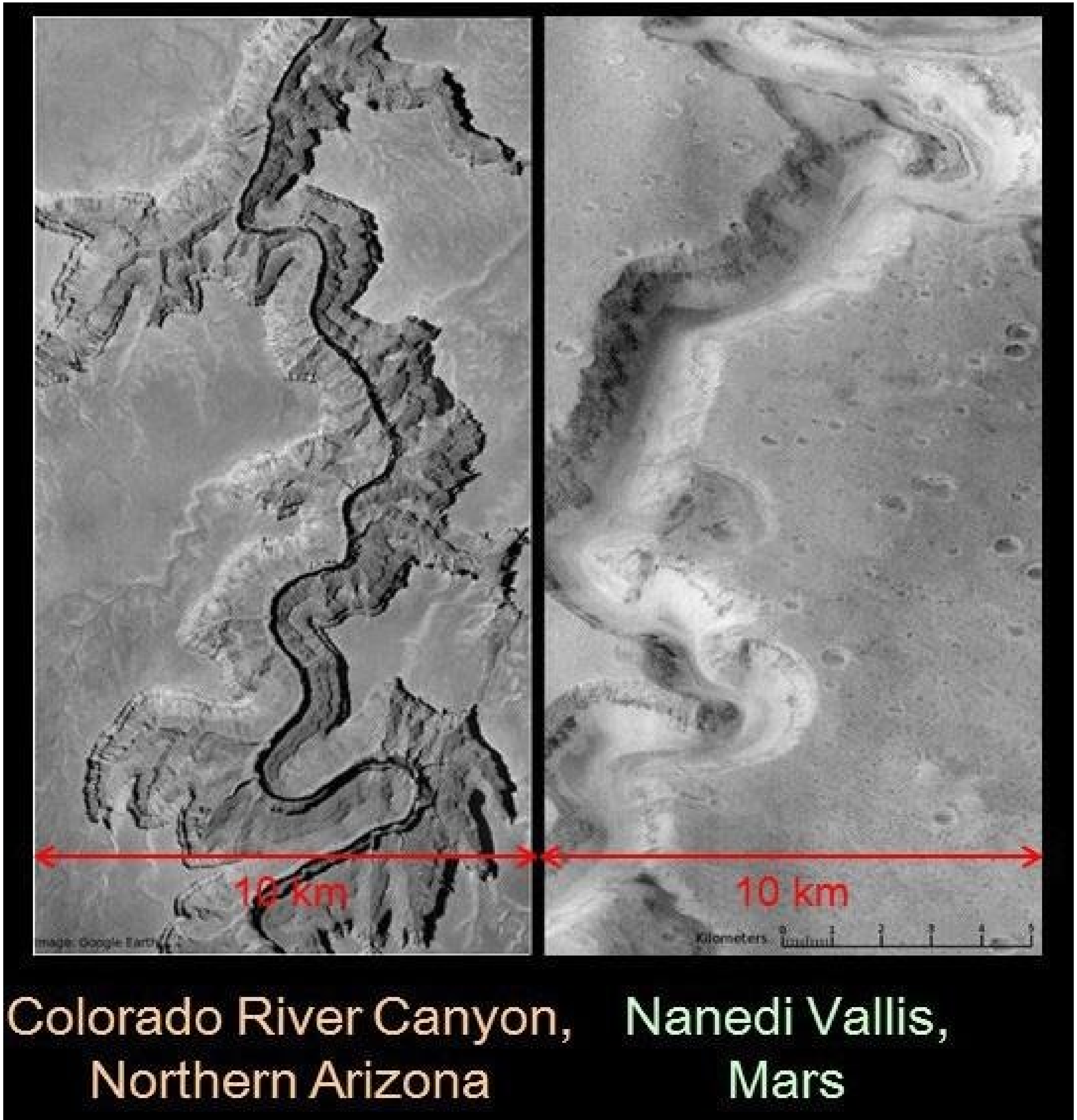


Methane on Mars

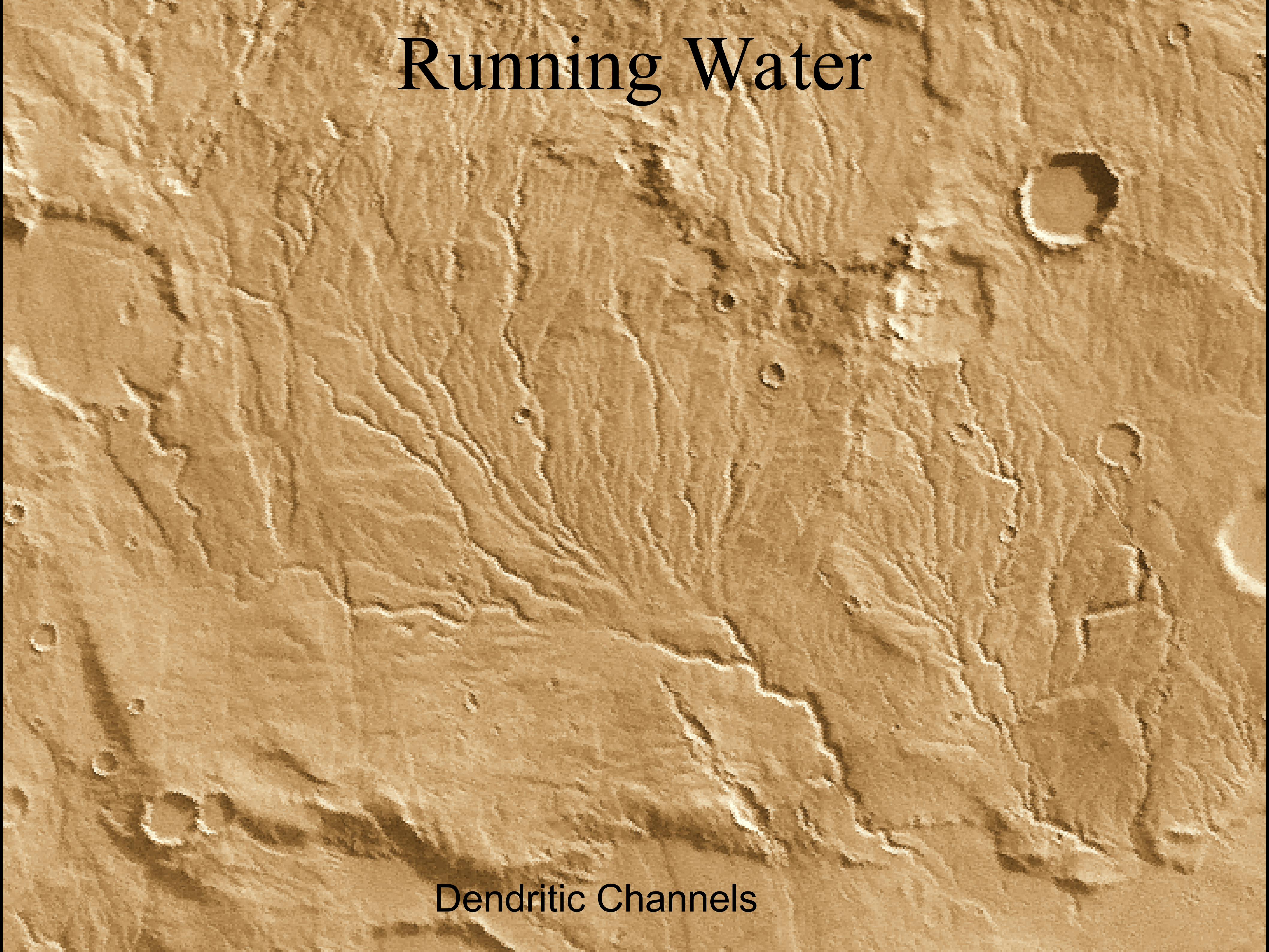


- Discovered in near-IR spectra; 60 ppb in atmosphere
- Destroyed by UV radiation: lifetime about 300 years
- Methane on Earth is produced by methanogens
- Co-spatial with water vapor
- Could be from clathrates (gas/ice mixtures)

Evidence for Past Water



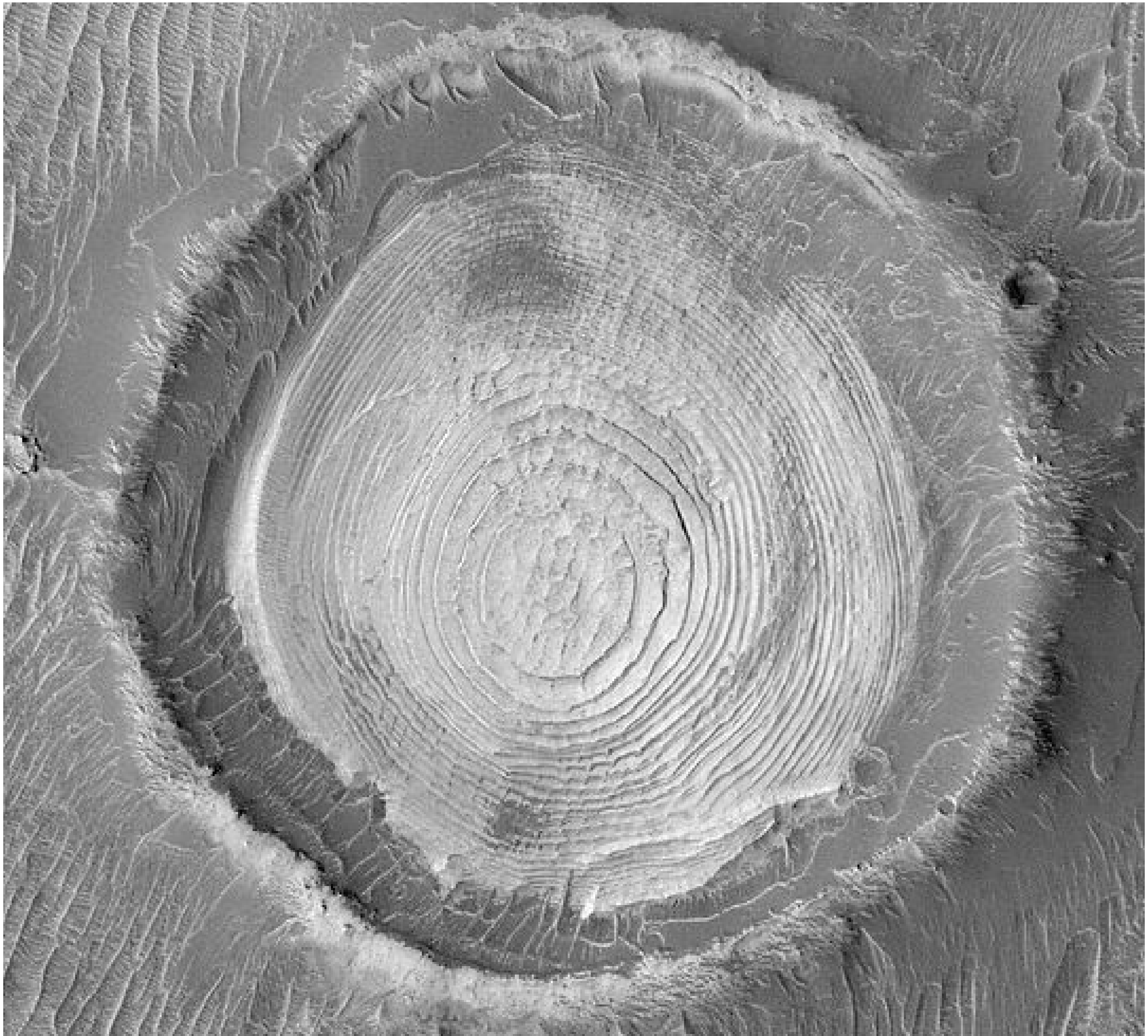
Running Water



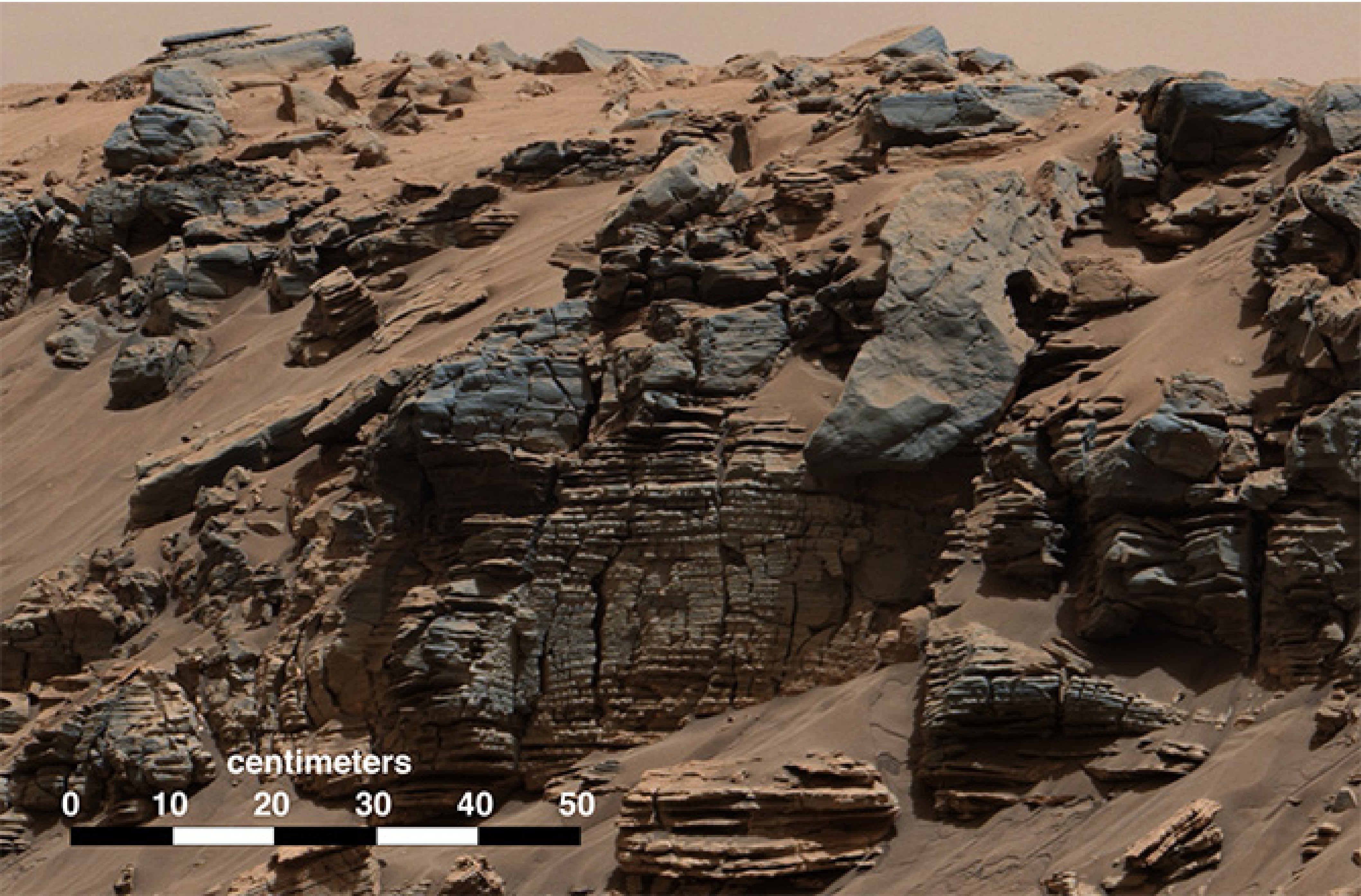
Dendritic Channels

Fossilized Icebergs?

Bathtub Rings
(Sedimentation)



Sedimentary Rocks on Mars



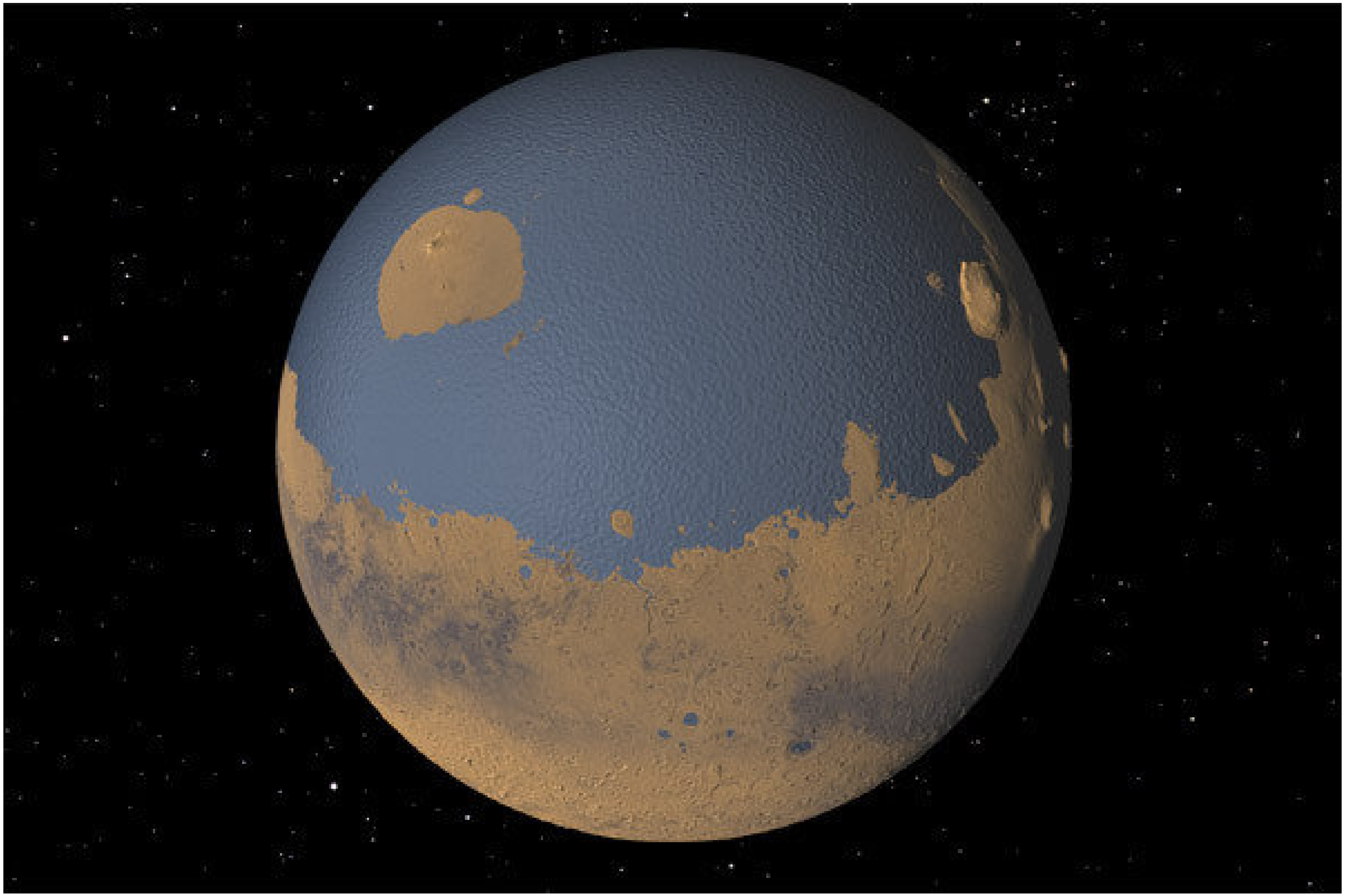
Sedimentary Rocks on Mars

Running Water Requires

- Temperatures > 0 C
- Pressures > 30 millibars

Estimate current inventory and mass loss from observations

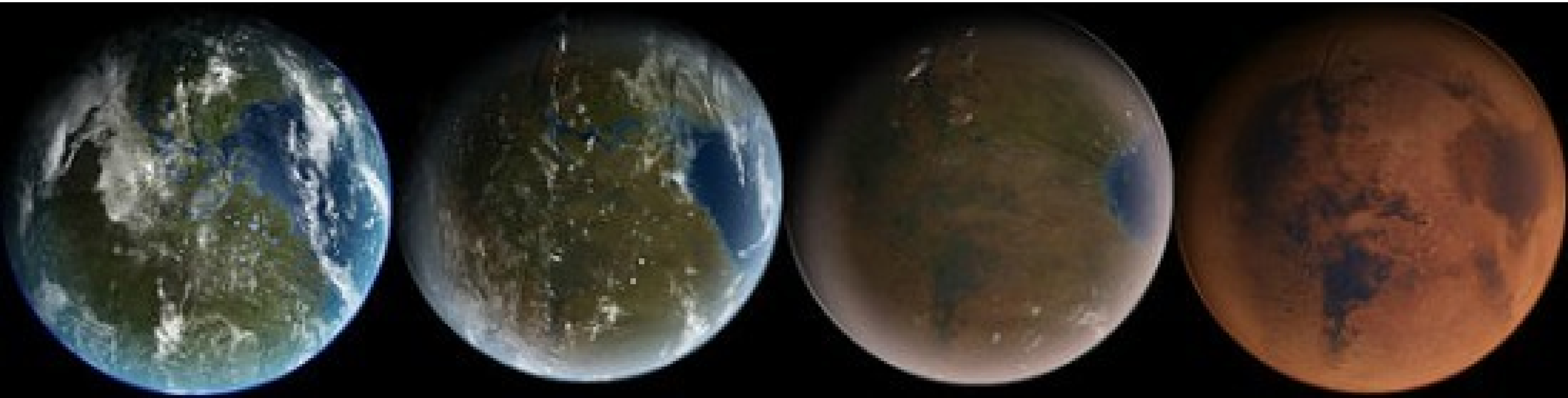
Mars @ 4 Gya

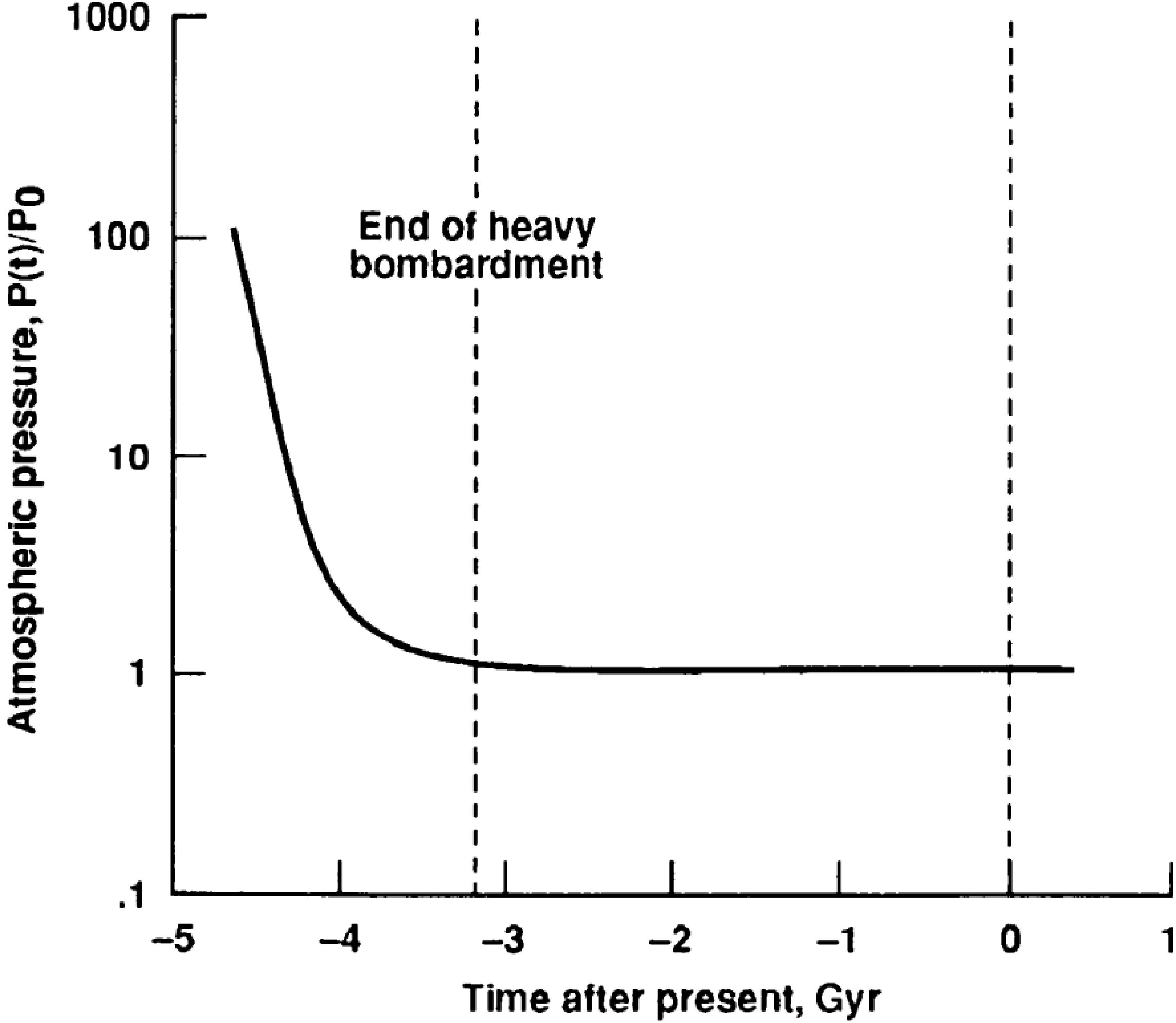


Estimated water lost would cover all Mars to 450 feet

Evolution of the Martian Atmosphere

- Noachian era (4.5 – 3.7 Gya)
  - Abundant volcanic activity
  - Riverbeds and deltas form
- Hesperian era (3.7 – 3 Gya)
  - Rivers dry up
  - Lava plains form
- Amazonian era (3 Gya – now)
  - Atmosphere lost





1000
100
10
1
.1
Atmospheric pressure, P(t)/P0
End of heavy bombardment
–5
–4
–3
–2
–1
0
1
Time after present, Gyr

Clouds

Mist in Valles Marineris➔

Ice clouds

Atmospheric Loss on Mars

Milankovitch Cycles on Mars

Table 12.10 The orbital elements of Mars and the Earth and their variability.

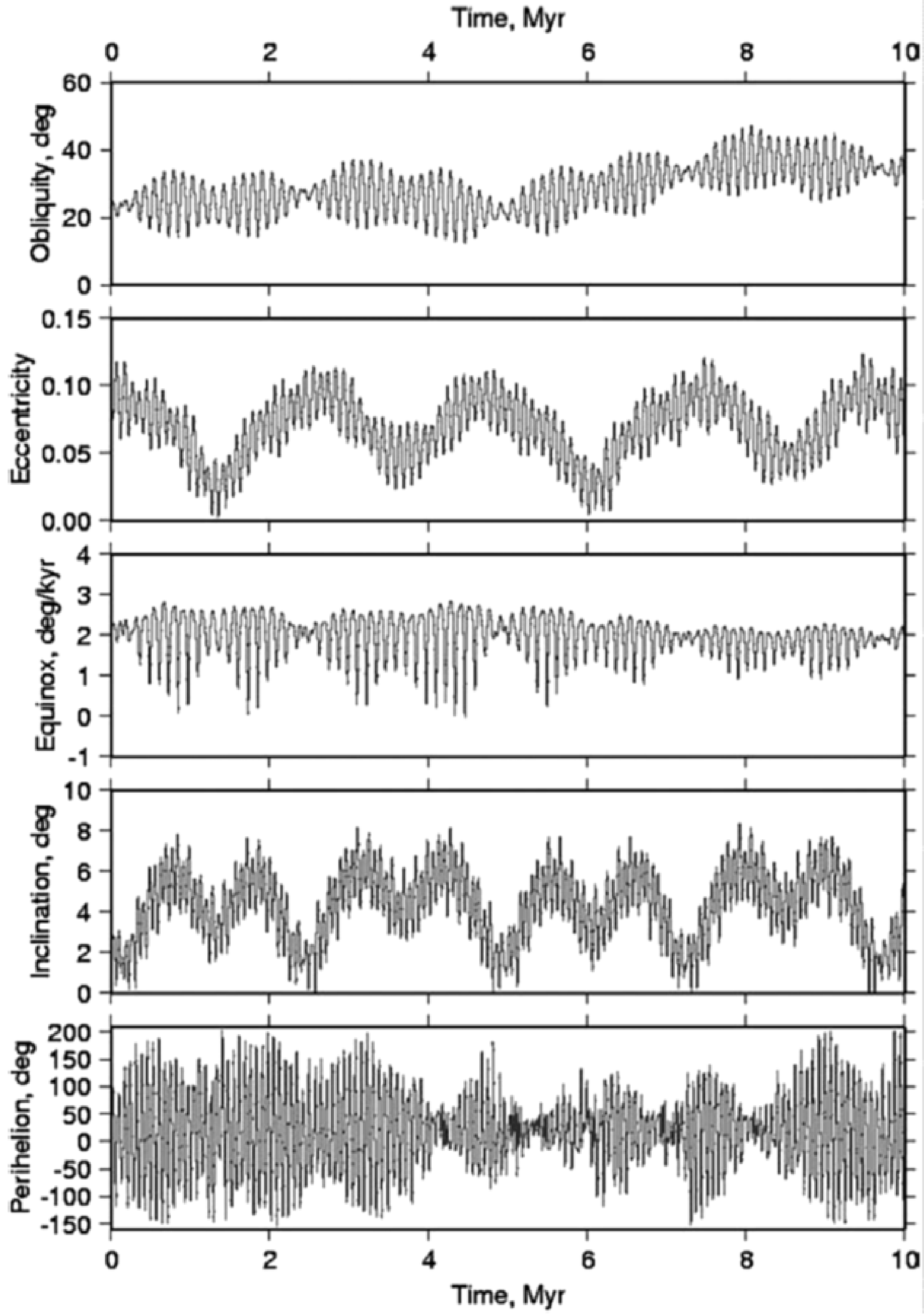
		Martian variability			Terrestrial variability	
Parameter	Present Mars	Range	Cycle (years)	Present Earth	Range	Cycle (years)
Obliquity (°)	25.19	0–85*	120 000**	23.45	22–24	41 000
Eccentricity	0.093	0–0.12	120 000***	0.017	0.01–0.04	100 000
Longitude of perihelion (°)	250	0–360	51 000	285	0–360	21 000

* Before ~10 Ma, obliquity variations are chaotic. While unpredictable at an exact time, statistically they would have varied between 0 and 85° (Laskar *et al.*, 2004; Touma and Wisdom, 1993).

** The amplitude of obliquity oscillation is modulated with a ~1.2 Myr period envelope.

*** The amplitude of eccentricity oscillation is modulated with a ~2.4 Myr period envelope.

- **Milankovitch cycles on Mars are significantly more extreme than on Earth.**
- **Obliquity may reach as high as 80 degrees.**
- **Changes in insolation cause carbon dioxide ice and water ice to migrate.**



Time, Myr
Obliquity, deg
Eccentricity
Equinox, deg/kyr
Inclination, deg
Perihelion, deg
Time, Myr