Mars Facts and Geology

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We did not go this way….

…but with robots

The saga of Mars Exploration

- Began in 1960 with the first attempts by USSR to launch 2 s/c designed for Mars flybys.
- Since then, more than 30 space missions to Mars were undertaken by USSR, USA, Europe, and Japan.
- 50 per cent of these missions performed successfully.

Origins of exploration

Mars Exploration has its roots in the 1950s

- The goal of many early rocket and space exploration pioneers
- The dream of von Braun in Germany/U.S. and Korolev in the USSR
- Enabled by the Cold War development of ICBMs
- Competition between the US and USSR

But it first got off the ground in 1960

- In 1959 Korelev had developed a 4-stage 'Molniya' planetary launch vehicle
  - derived from the 2-stage R-7 ICBM that had launched Sputnik in 1957
  - 3-stage 'Luna' version had been developed for lunar missions in 1958-60
- With success of Lunas 1-3, Korelev built a new planetary s/c for Mars and Venus.
- The first two were built for launch to Mars in Oct 1960
- New large 3rd stage failed on both launches

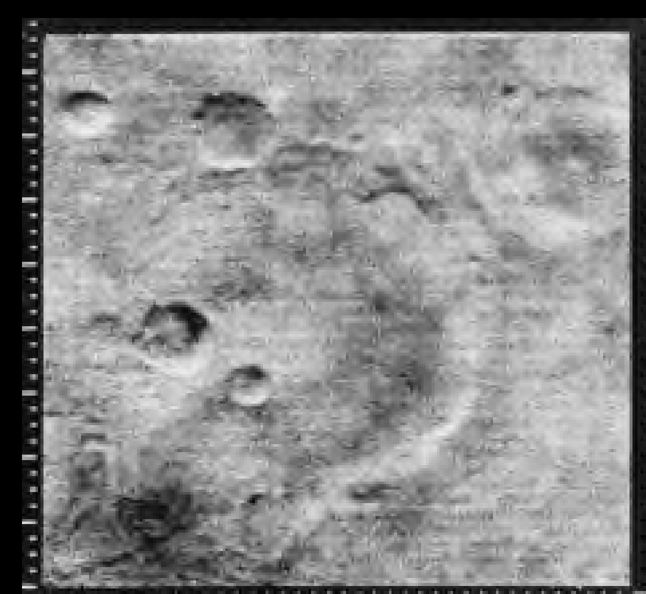
(by courtesy of W.T. Huntress)

1964: American succeed at Mars

Mariner 4

- First launch fails - Mariner 3
- Second launch succeeds Nov 28,1964
- Successful flyby on July 15, 1965
- Craters, not canals!

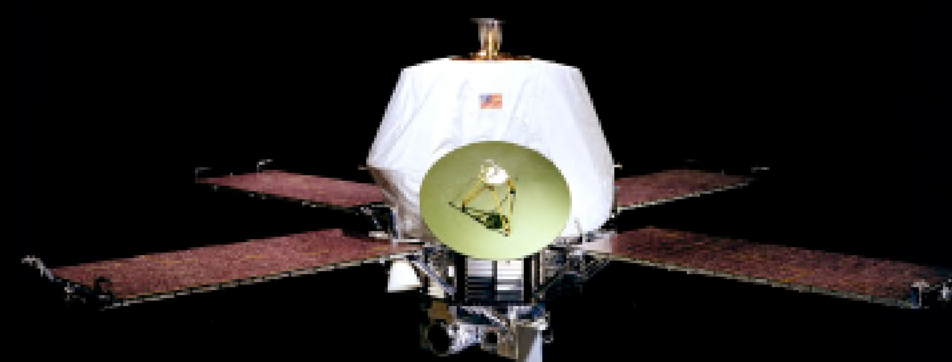
The famous picture No.11



First s/c image of Mars

1971: American Mariner 9 orbiter

- First Mars orbiter
- Mapped entire planet
- Discovered tectonic structures,
- Giant volcanoes and valleys
- Mars begins to look more Earth-like!



Mariner 9

Olympus Mons caldera

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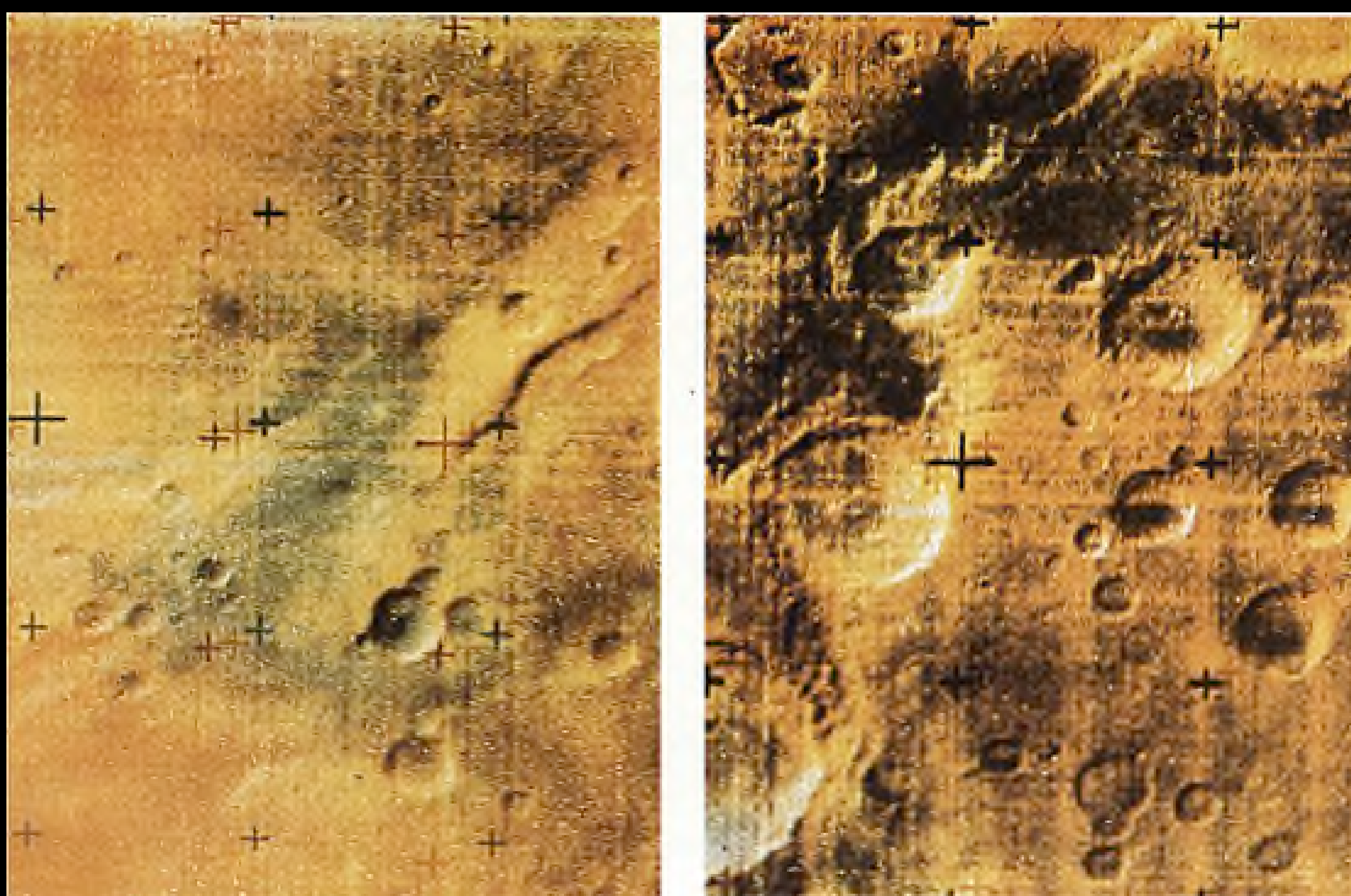
1973: USSR goes all out

Can’t fly orbiter/lander combination
Knows about plans for Viking lander (first 73 then 75)
Determined to beat US to land before Viking
Four large s/c! Use 71 vehicle designs to save money

Mars 4 flyby image

Mars 5 orbiter image



Mars 5 orbiter color images

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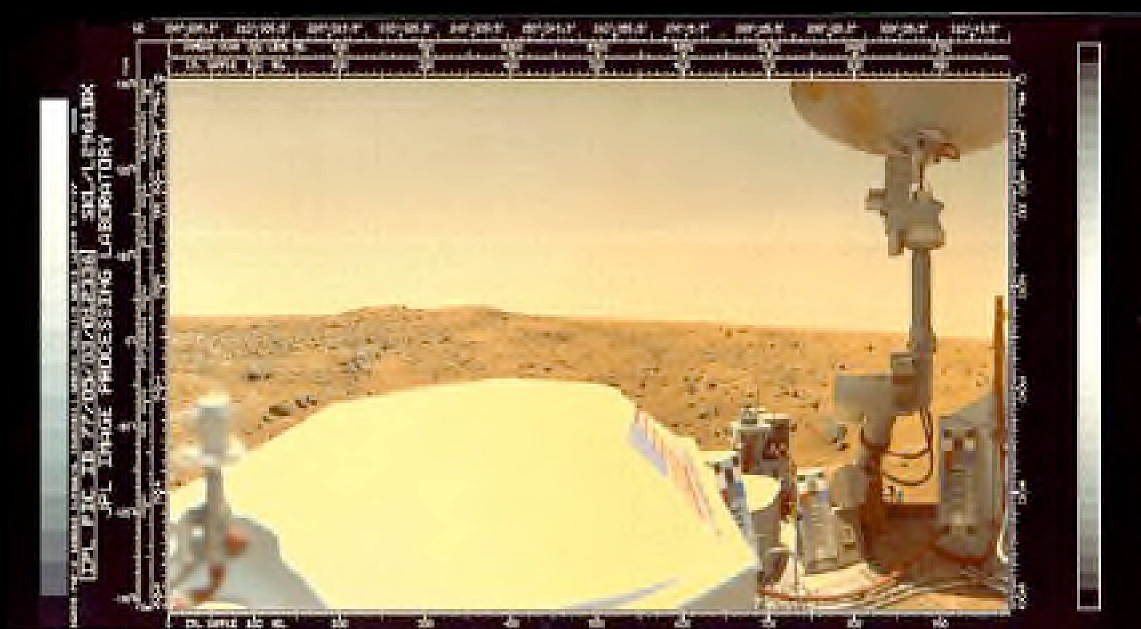
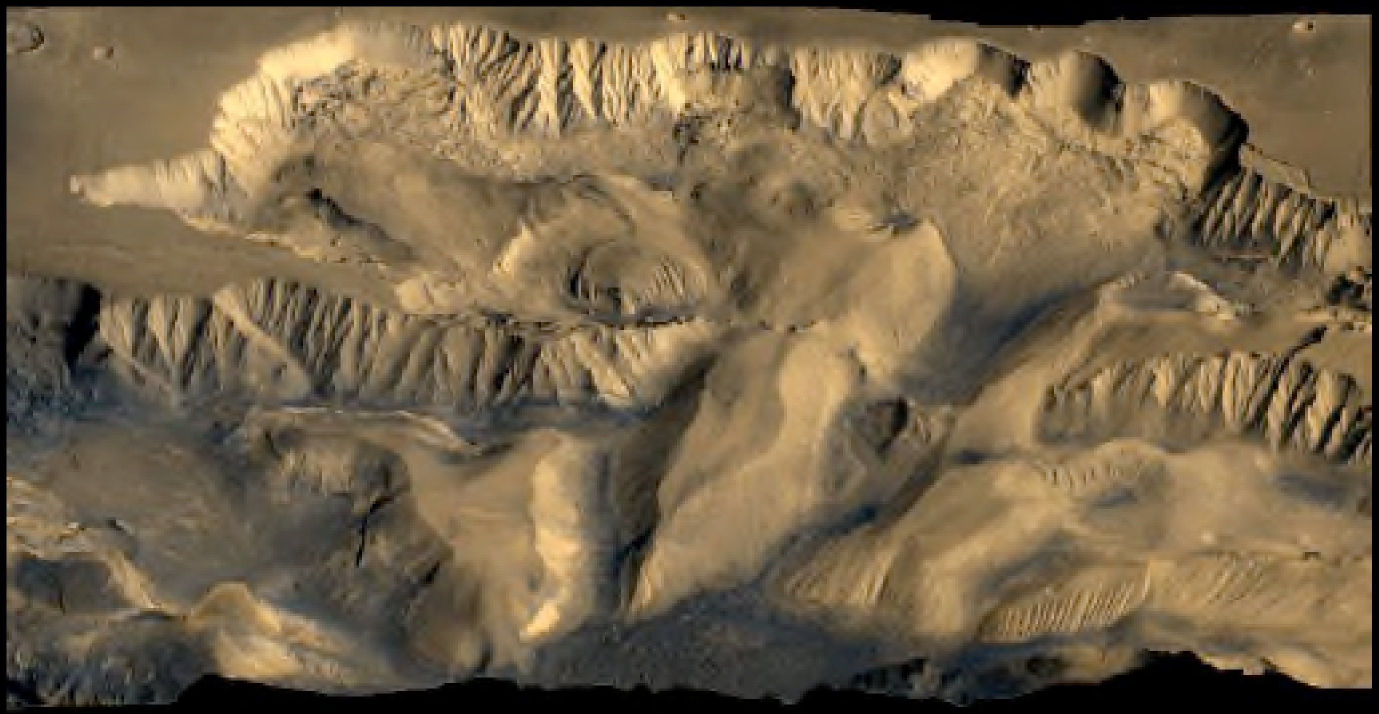
1975: the American Viking Lander



- Two orbiters & landers at Mars
- Spectacular images from orbit
- and from the surface
- First successful landers, but
- unsuccessful (?) search for life
- Interest in Mars wanes after Viking



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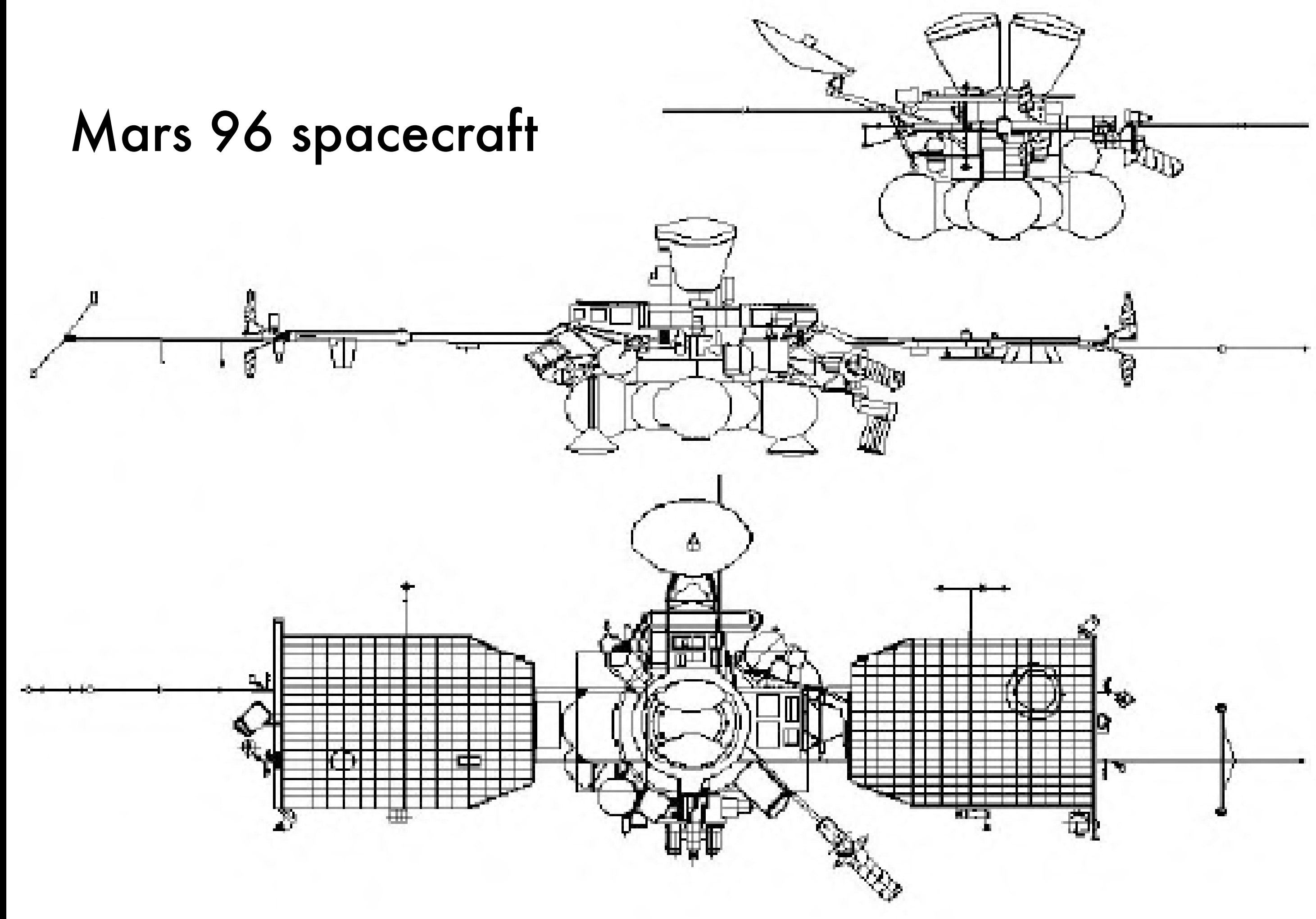
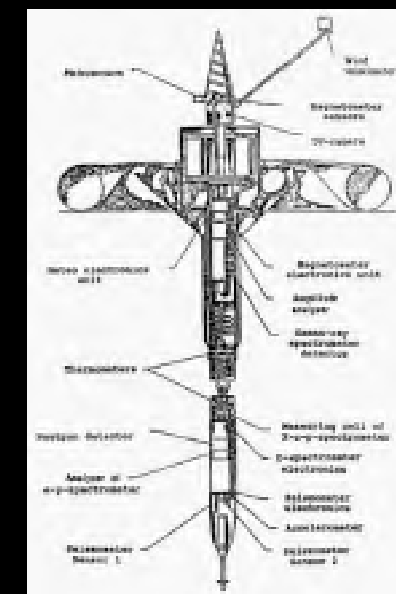
1996: Russia tries again

Mars 96

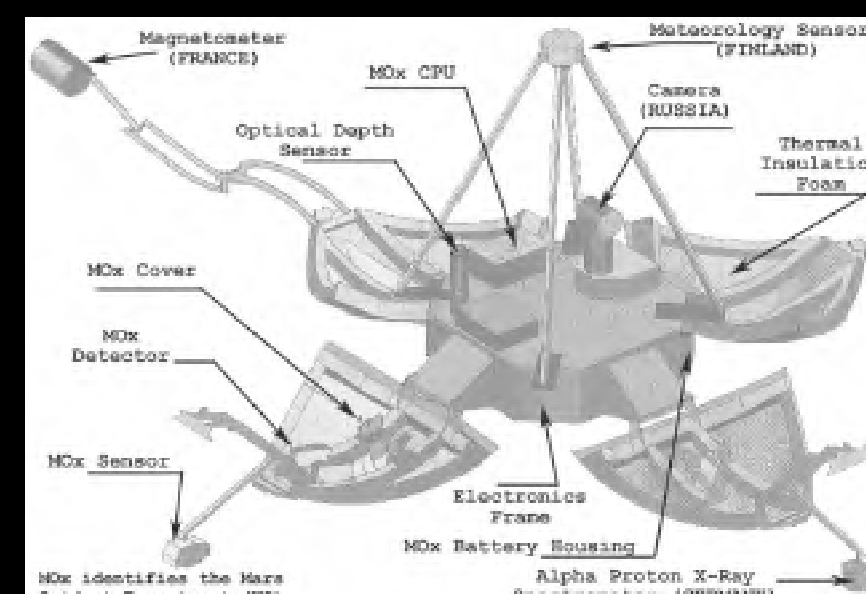
- an ambitious, comprehensive mission
- large orbiter with 2 landers, 2 penetrators
- rover and balloon abandoned in 1994
- heavy international investment
- launch fails in Nov 1996



Mars 96 spacecraft



Mars 96 penetrator



Mars 96 small lander

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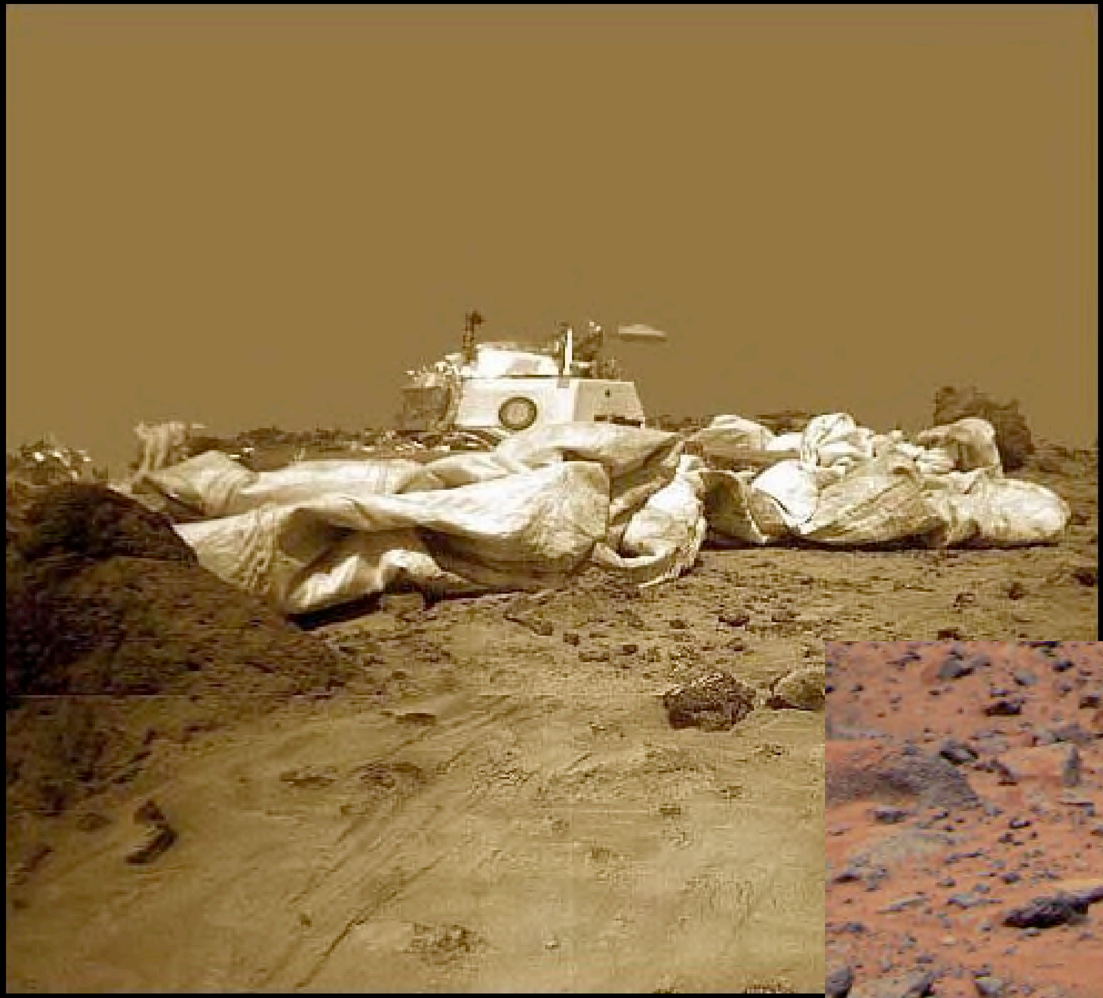
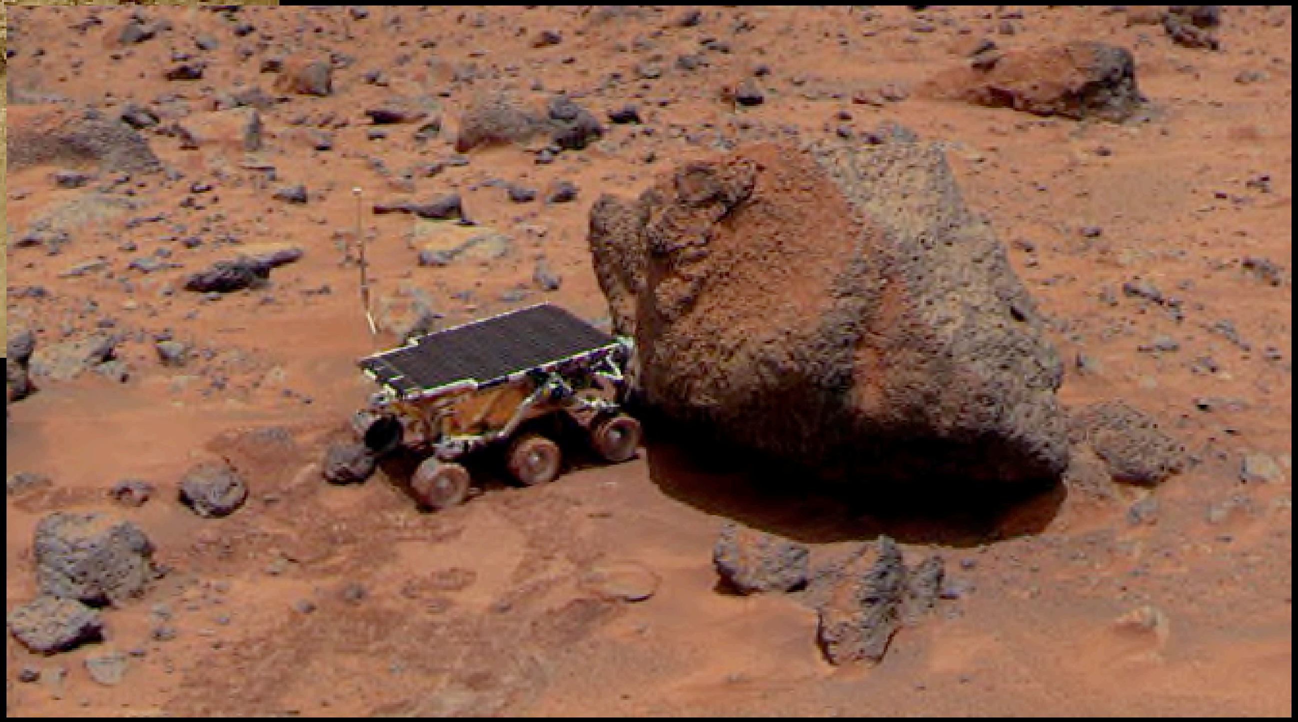
1996: New approach, lander & orbiter





Mars Pathfinder lander succeeds

- about 5% the cost of Viking
- pathfinds new approach to low-cost s/c
- more technology test than science
- including first successful rover on Mars
- revives public interest in Mars

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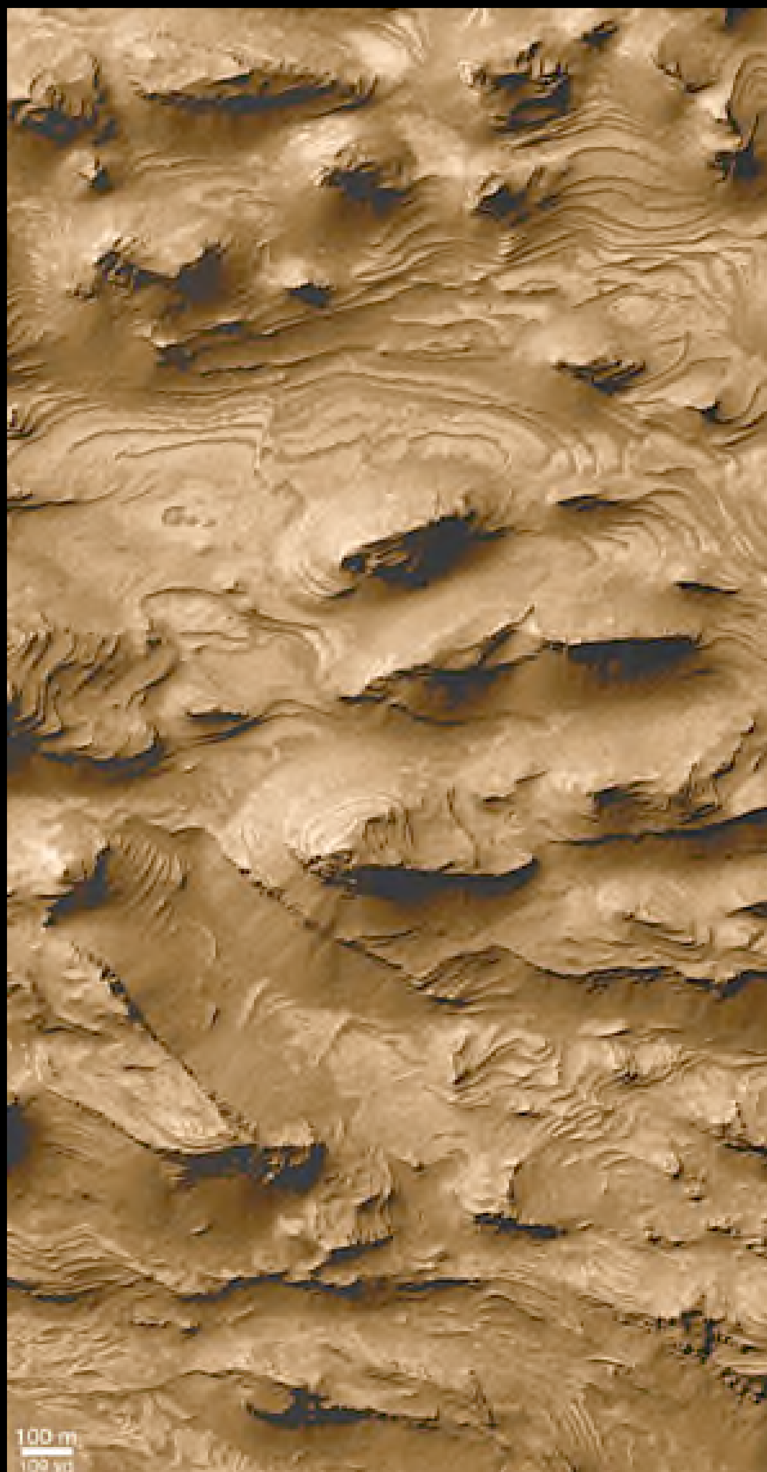
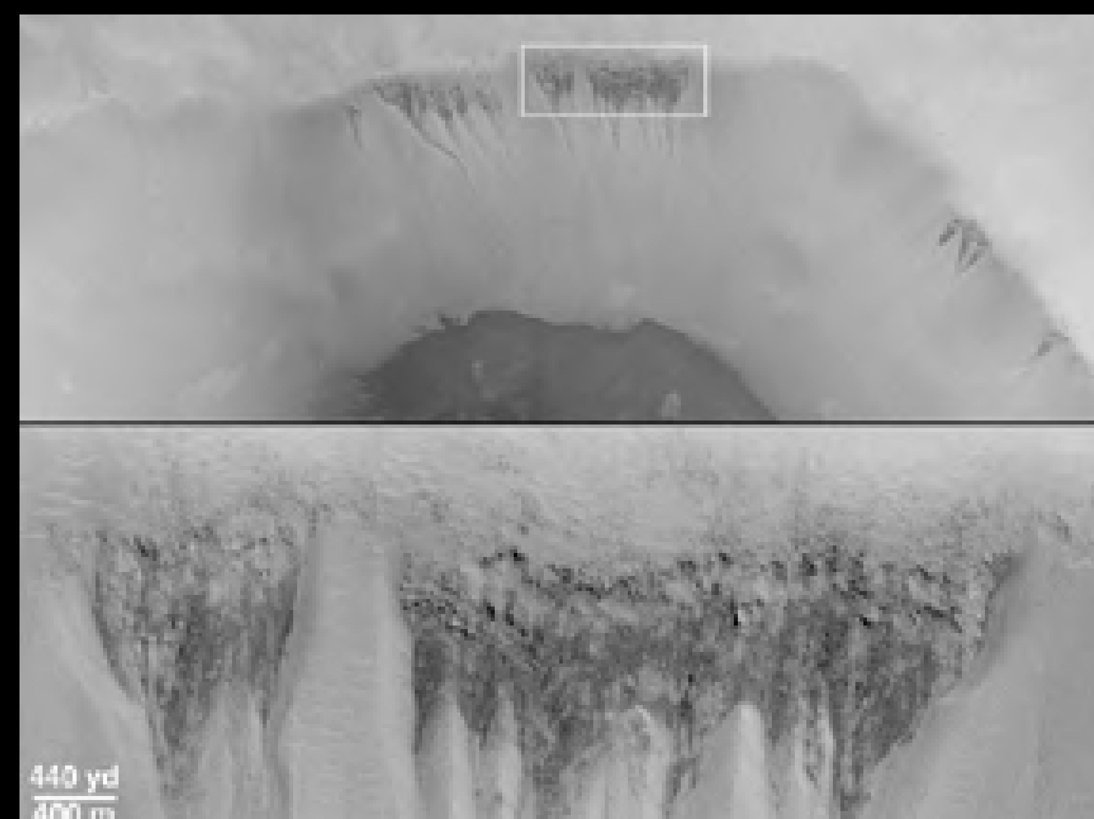
1996: Mars Global Surveyor orbiter

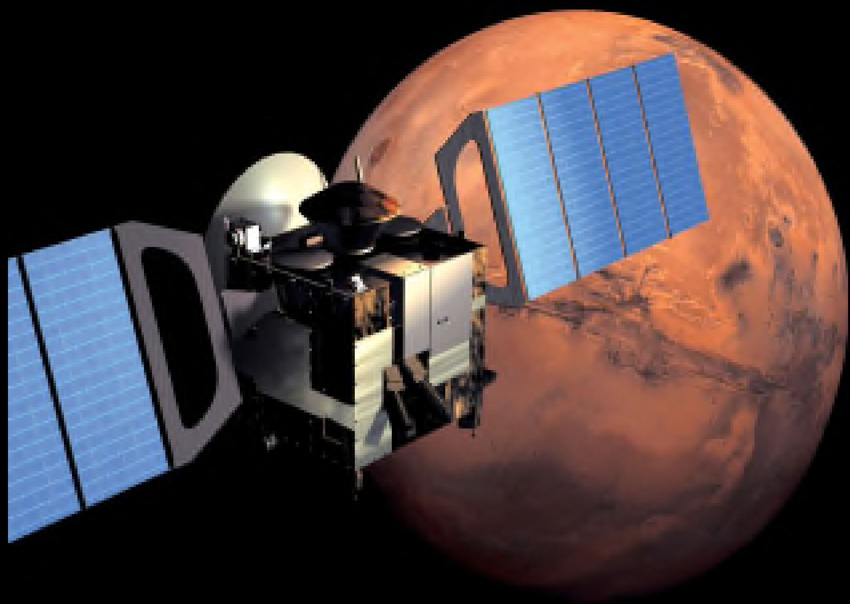


- Succeeds and keeps working until late 2006
- First science mission in new US Mars program
- Carries first third of lost Mars Observer payload
- Continuous science and lander data relay activity



Finds layering and signs of water!

2003: US/Europe/Japan



Mars Express

Mars Exploration Rovers

Nozomi

Mars is now the target of true international exploration!

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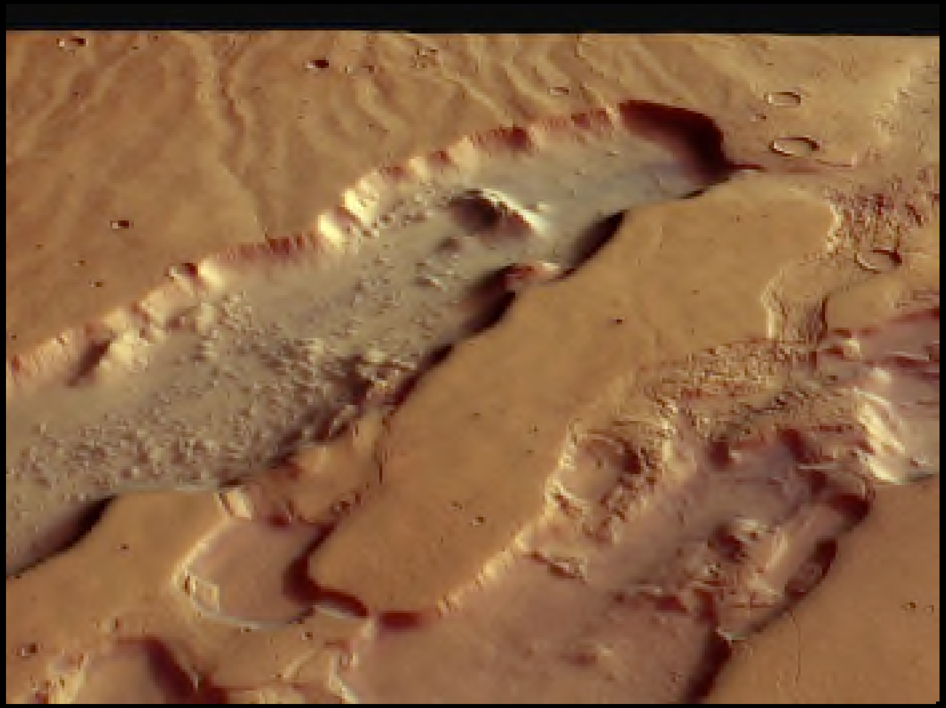
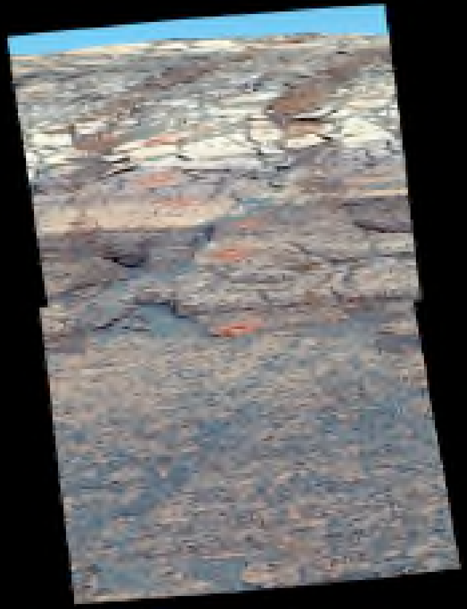
The major steps of Mars exploration

- Mariner 9 (1971)
- Viking Orbiters & Landers (1975)
- Mars Pathfinder (1996)
- Mars Global Surveyor (1996)
- Mars Odyssey (2001)
- Mars Express (2003)
- Mars Exploration Rovers (2003)
- Mars Reconnaissance Orbiter (2005)



Dao Vallis (HRSC MEX)



Endurance (MER)

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What's next?

- NASA Mars Exploration Program:
  - 2005: Mars Reconnaissance Orbiter
  - 2007: Phoenix
  - 2009: Mars Science Laboratory

  ...

- ESA Aurora Programme
  - ExoMars (2011)

  ....

  - Mars Sample return

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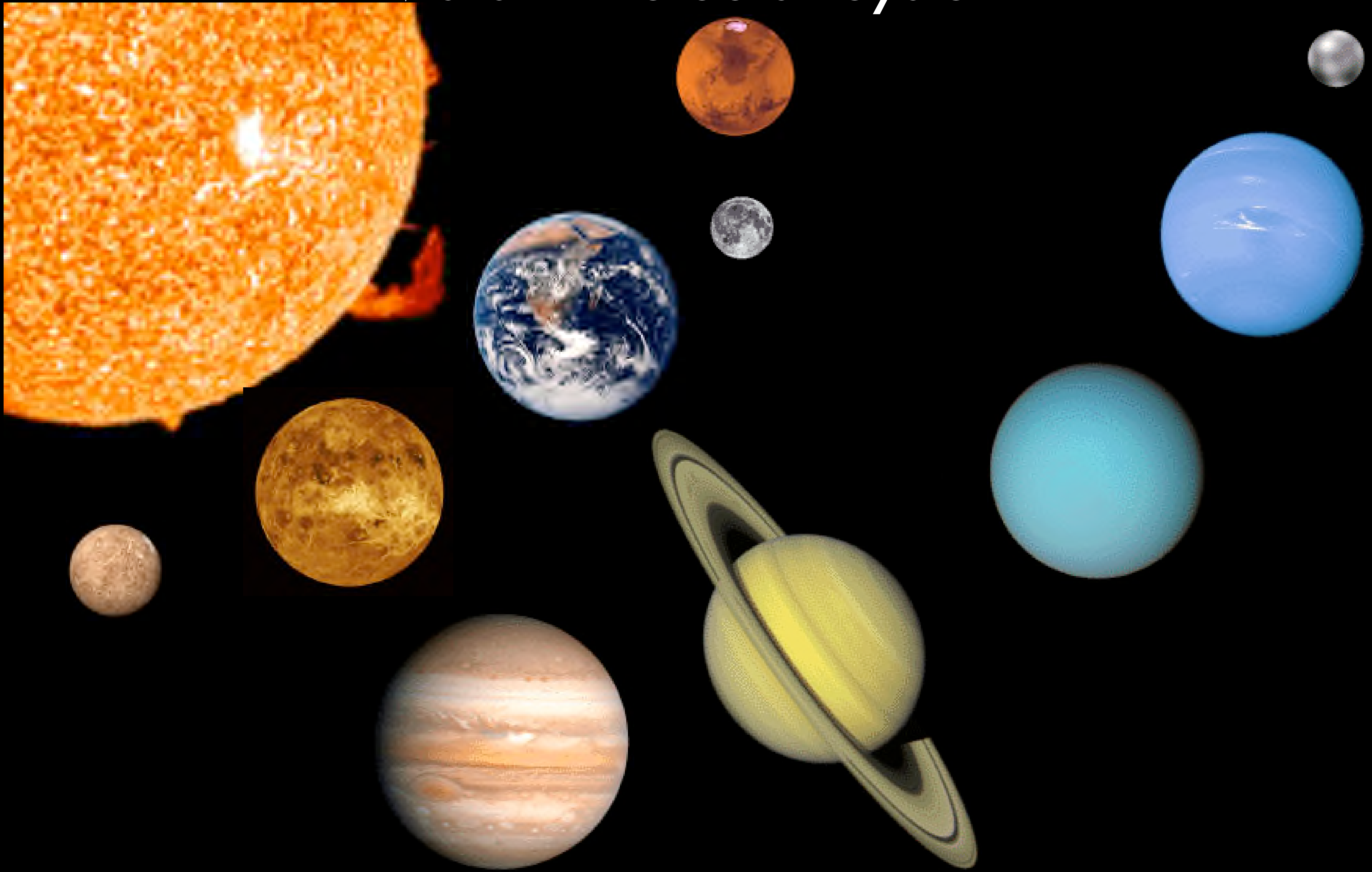
Mars in the Solar System



Mars facts

Distances:

1.52 AU from Sun

(or 227,940,000 km)

58,400,000 km to Earth

Dimensions:

Diameter: 6794 km

Mass: 6.41x1023 kg

Surface: 144x106 km2

Escape: 5.02 km.s–1

Temperatures:

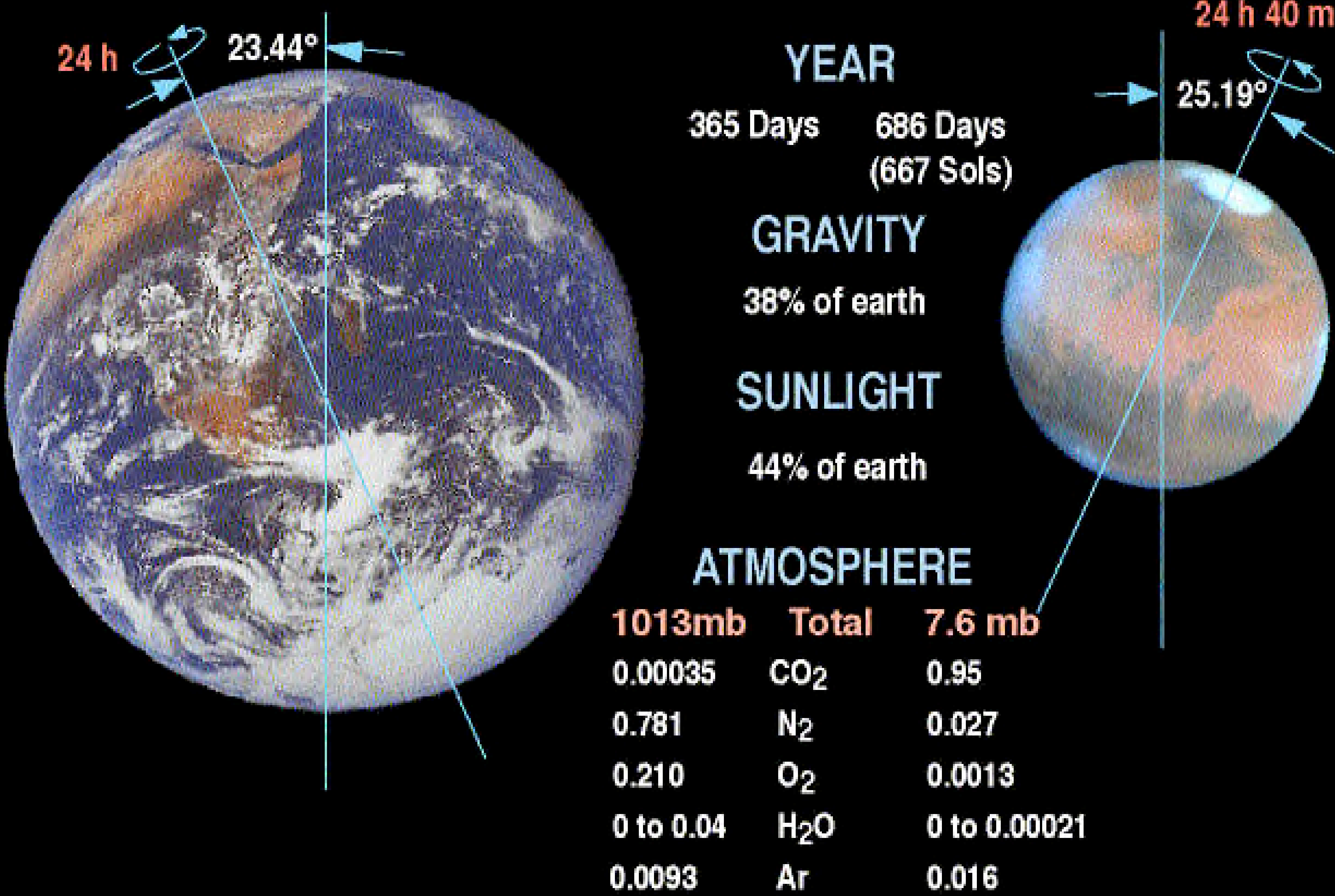
Min: –133°C (winter pole)

Max: +27°C (summer noon)

Average: –55°C (218K)

Albedo: 0.16 (darker)

Speed of sound: 235 m.s–1



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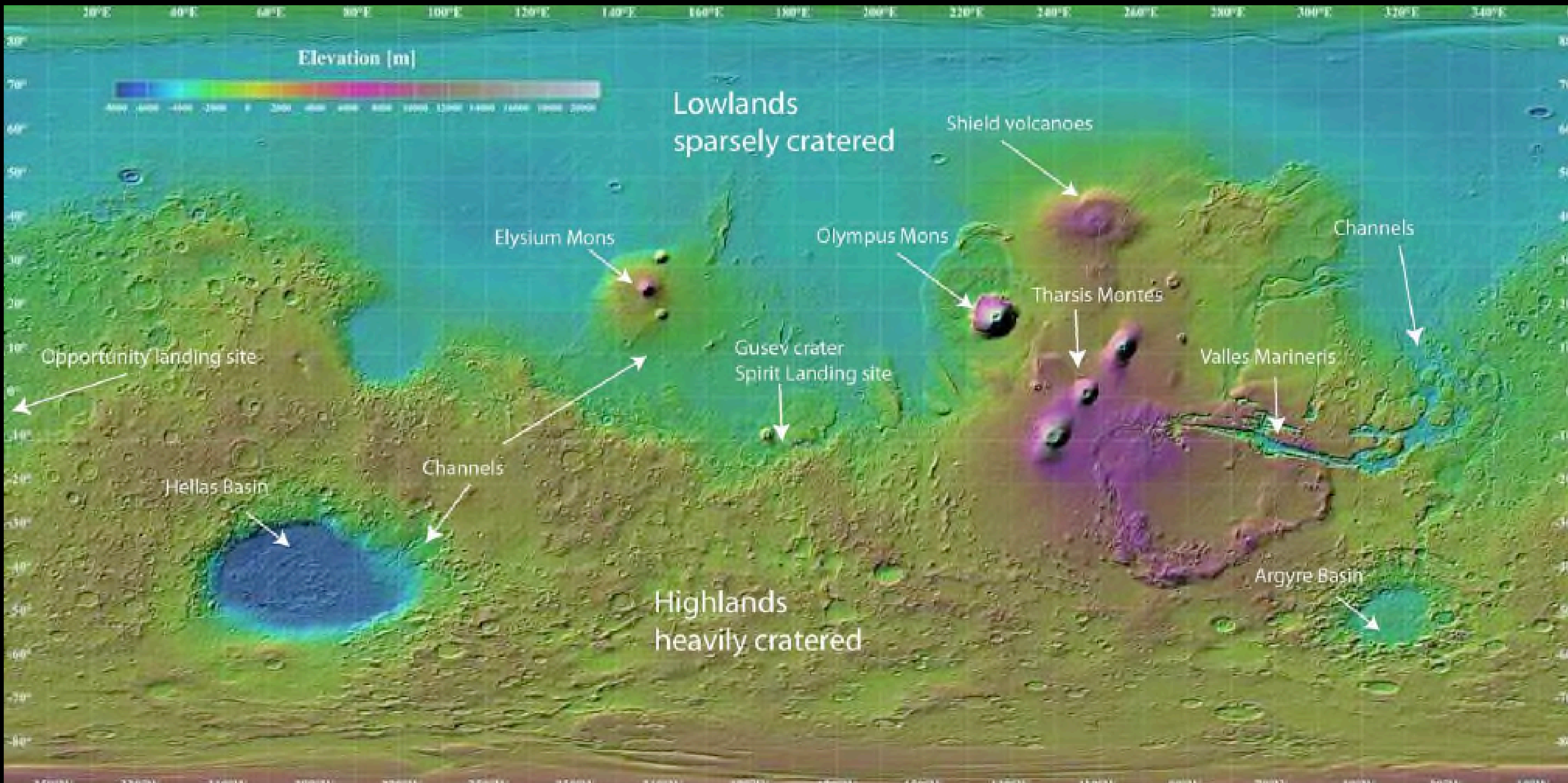
Main geological features on Mars



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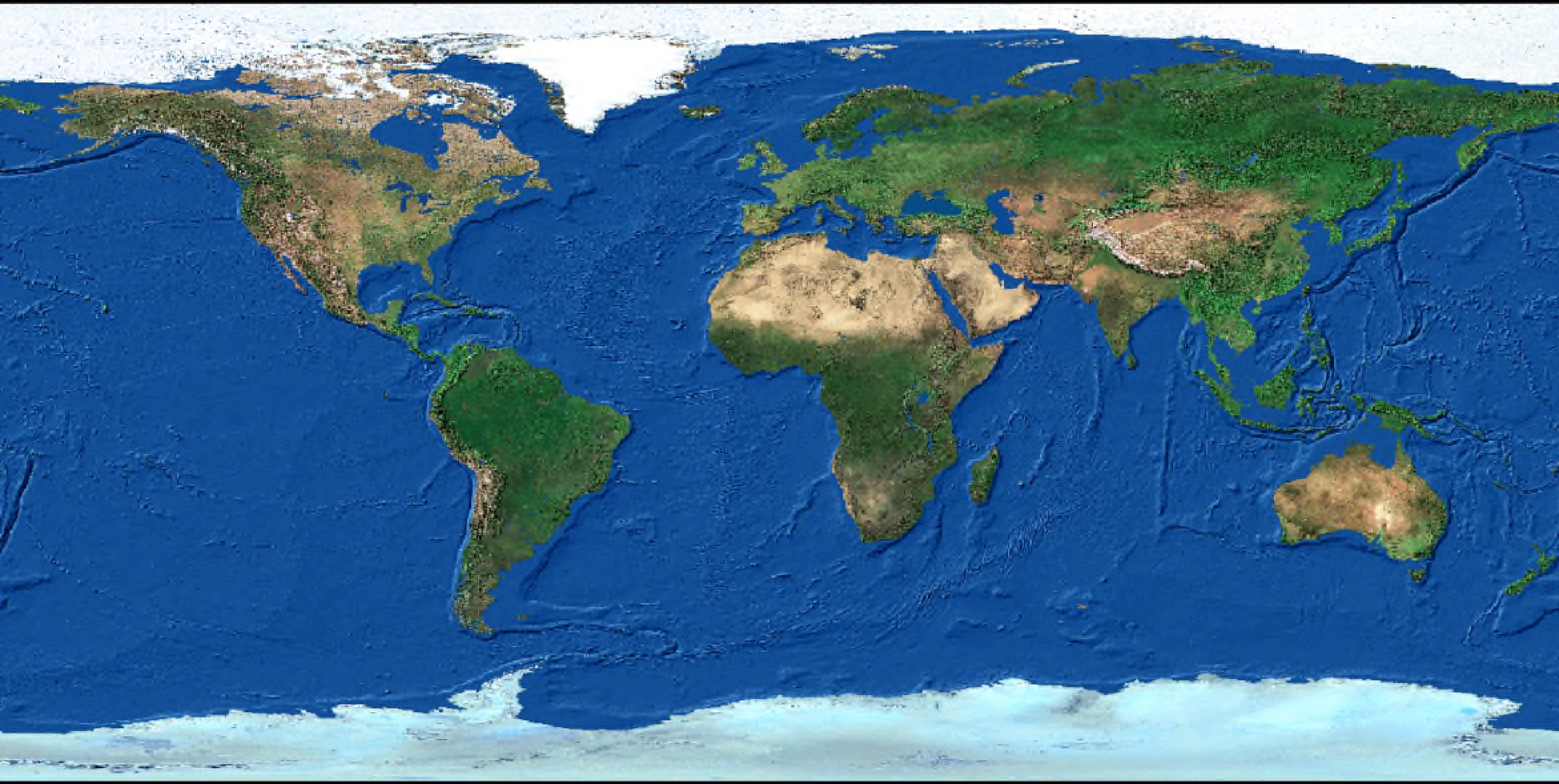
Earth physiography



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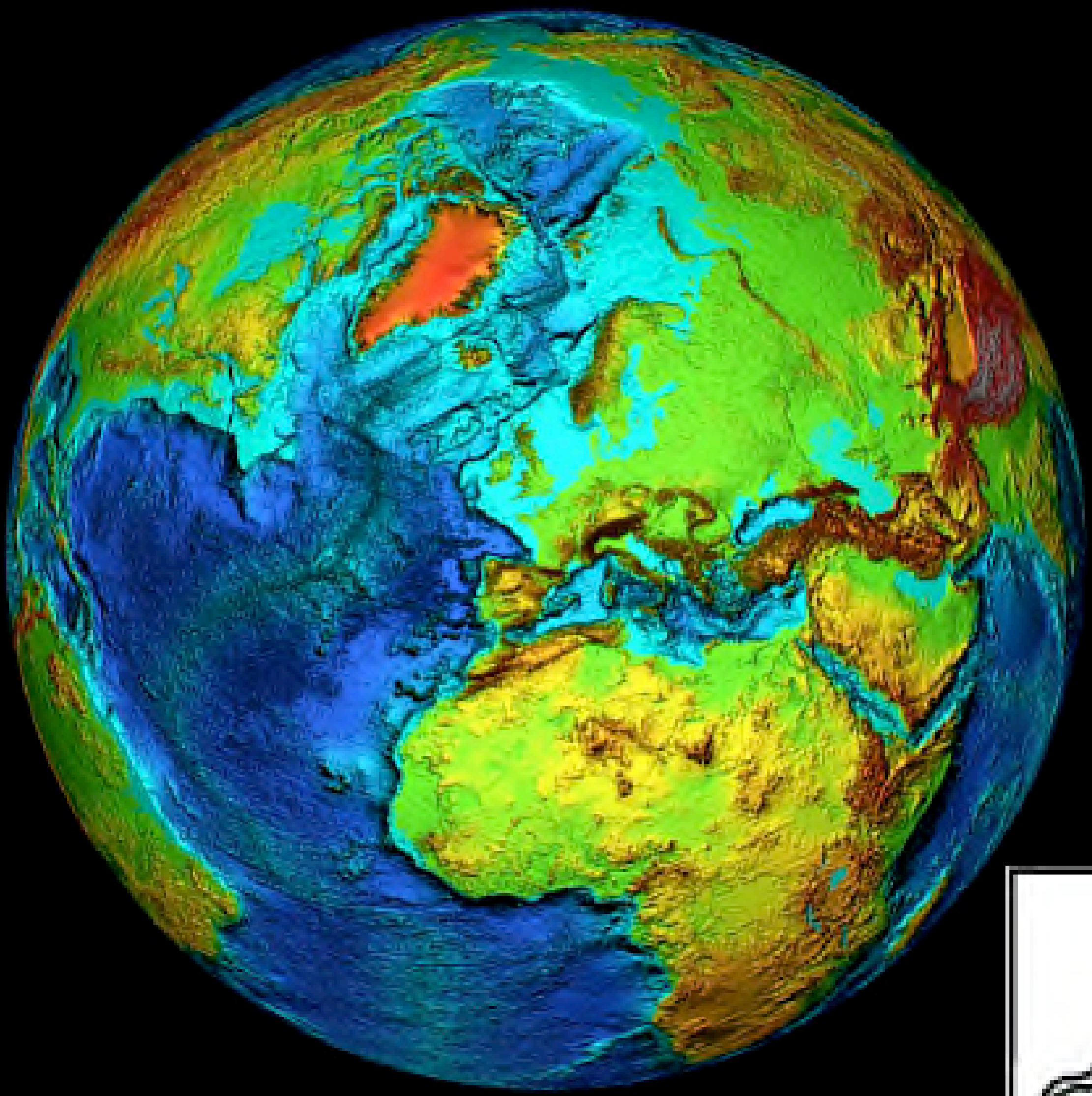
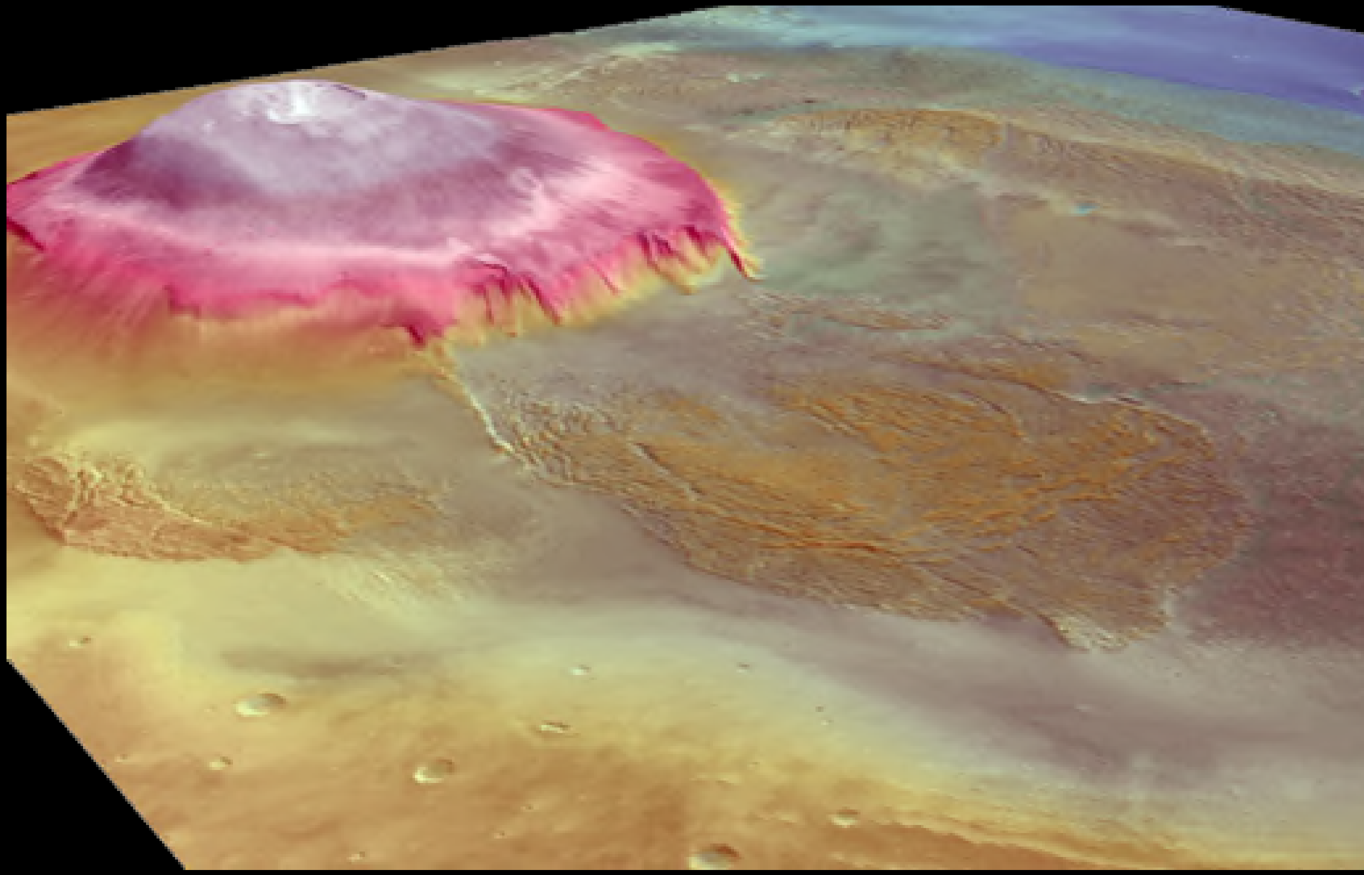
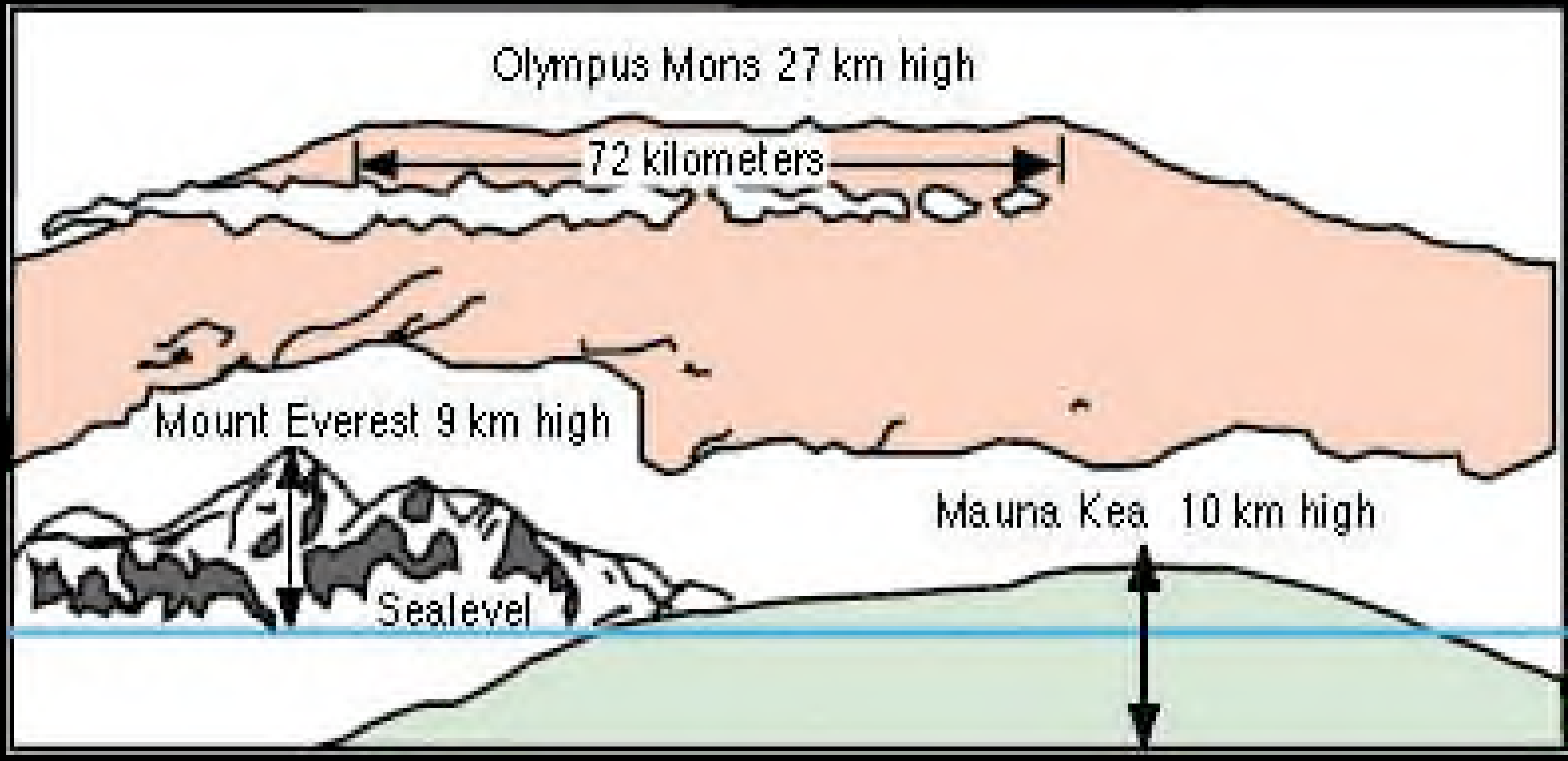
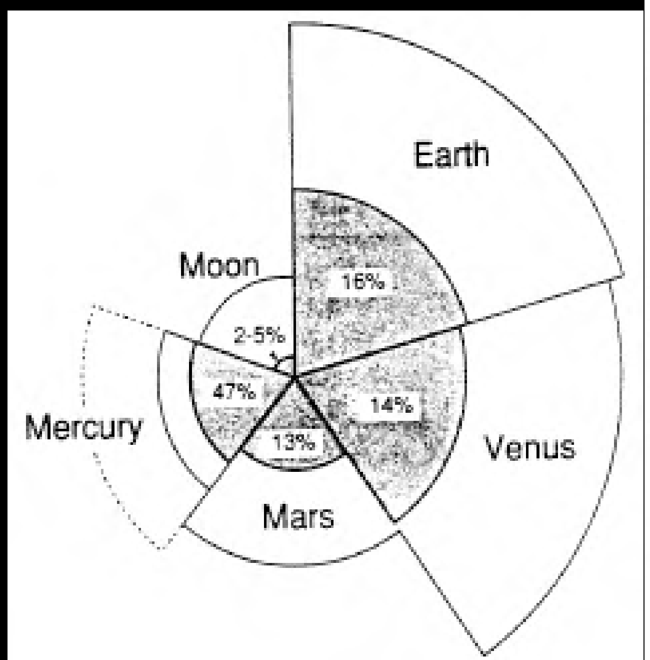
Large structural differences

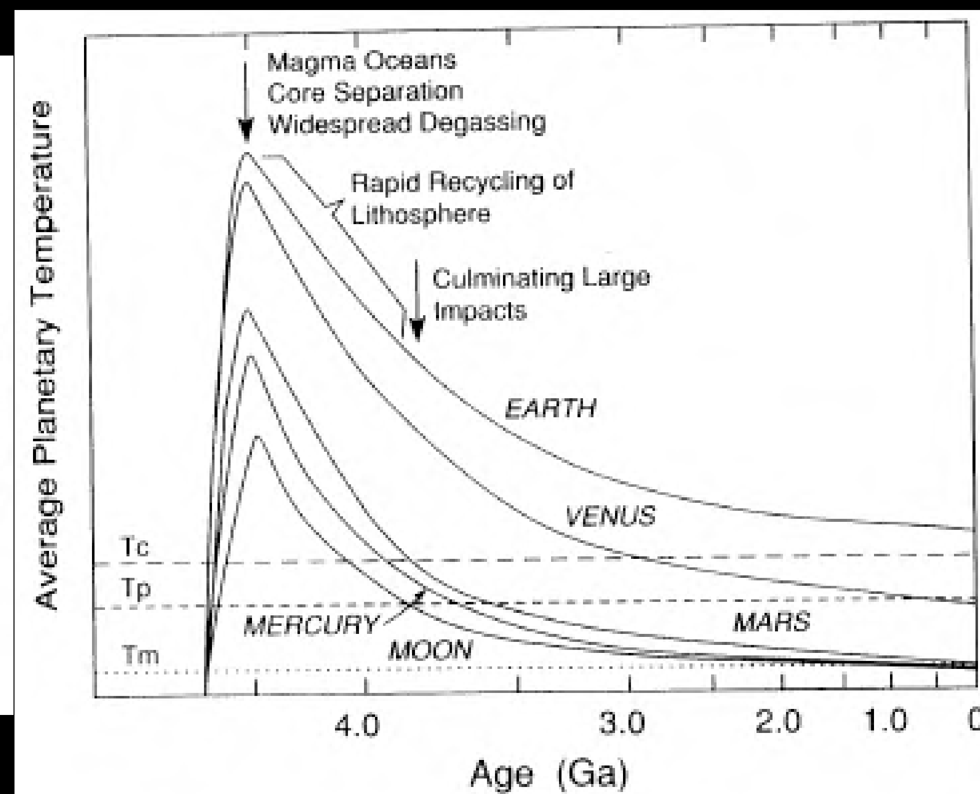


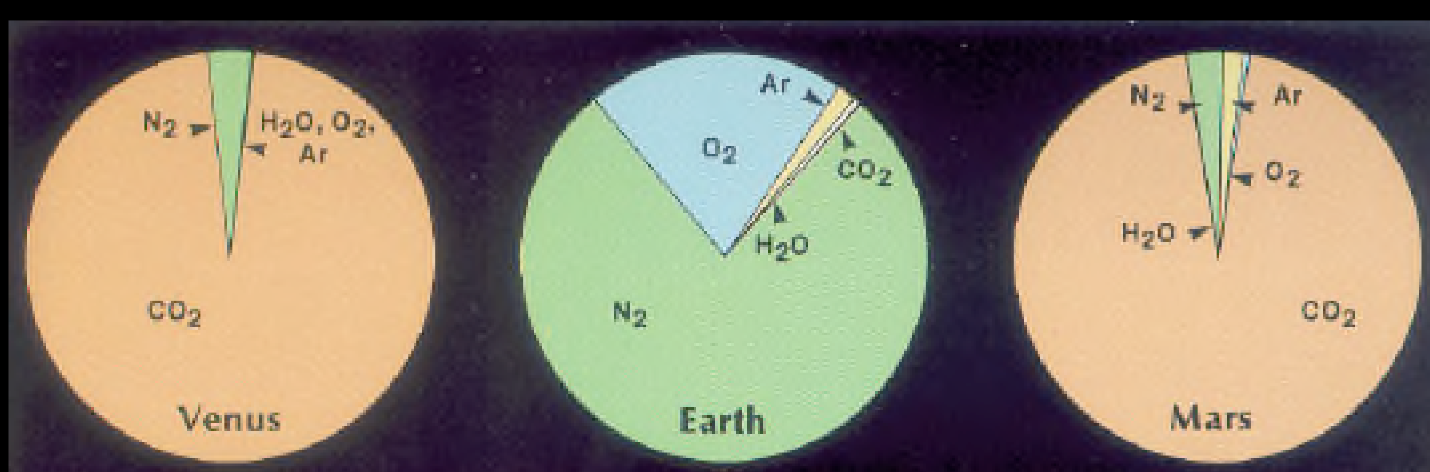




Terrestrial Planets - Atmosphere







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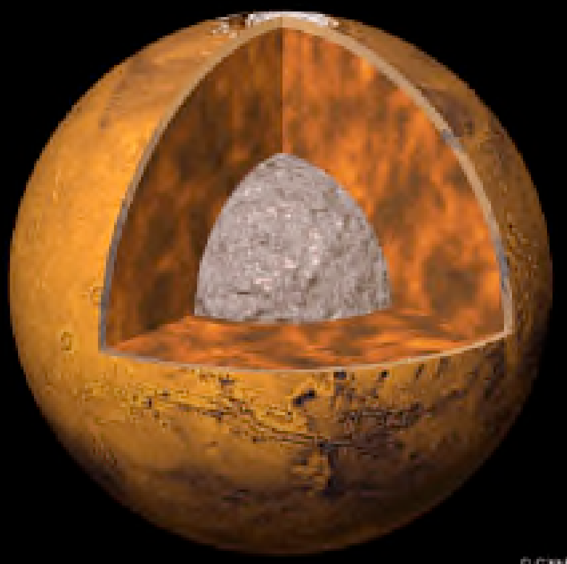
Mars

- Best known terrestrial planet
- $2/3^{rds}$ size of Earth
- Very large (>20 km) volcanoes
- Thin atmosphere (0.01 atm)
- Water-ice on surface
- Two very small moons
- Life???

Mars - Internal Structure

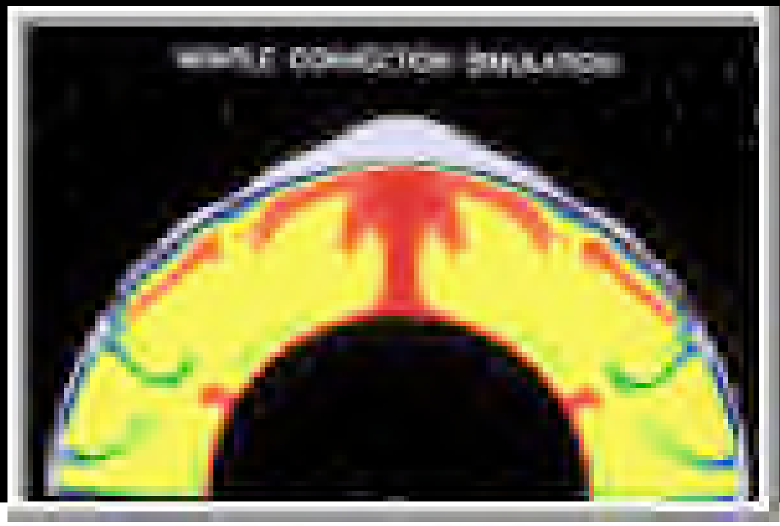


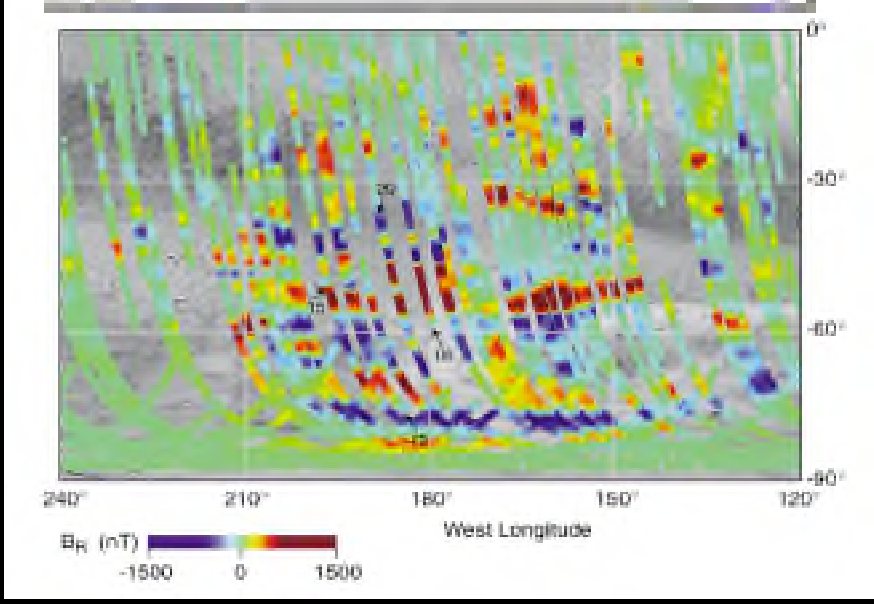
Background:

- Early global differentiation; heat-flux decline
- ~100 km thick crust uncorrelated with dichotomy
- North is not isostatically compensated
- Strong (1500 nT) paleomagnetic signatures (MD-Fe2O3)
- SNC's FeO content (~20%) > MORB (~10%)
- Lid convection at present (large volcanoes)

Questions:

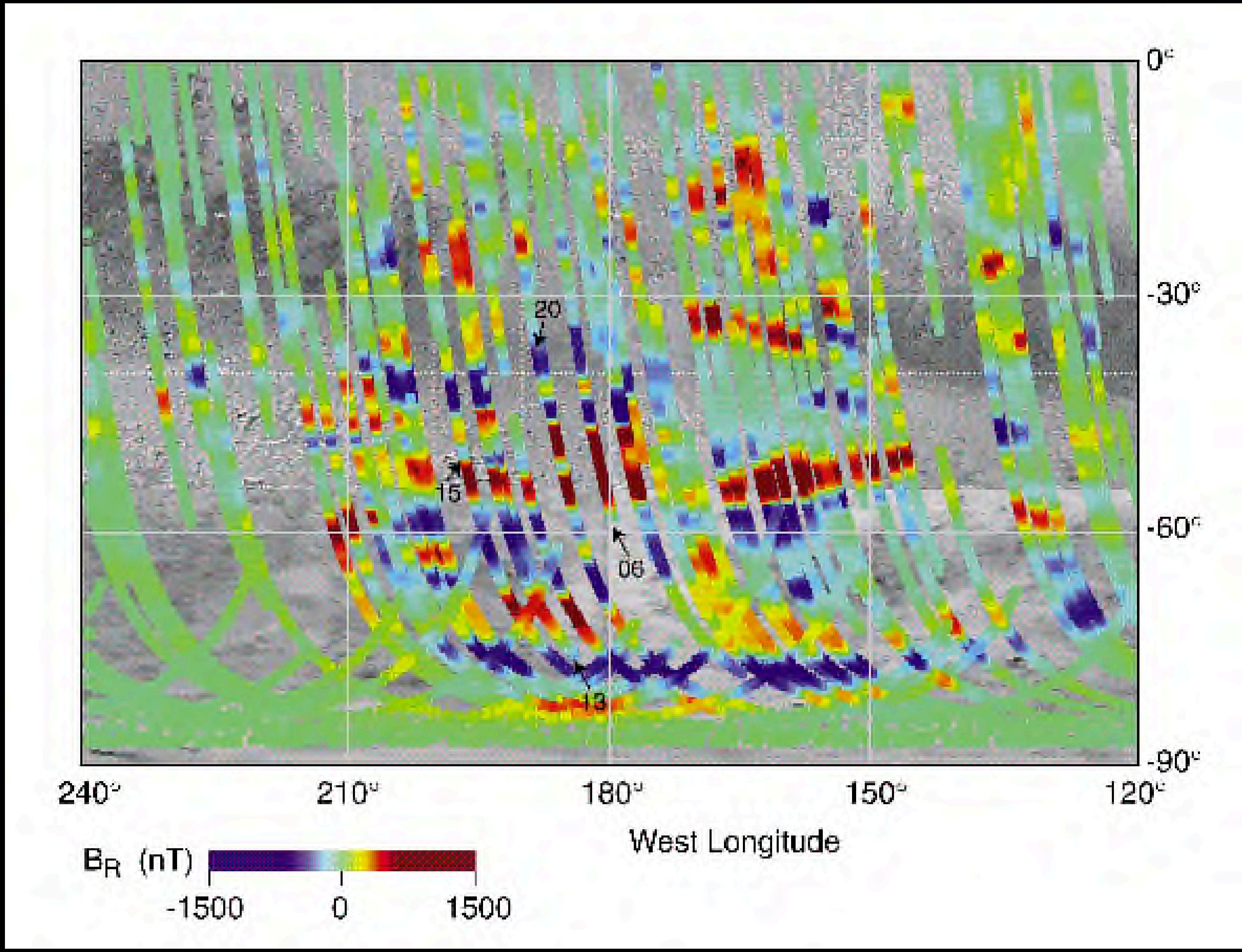
- Detailed internal structure, liquid core ?
- Current seismic activity ? North > South ?
- Why did magnetic dynamo stop after 500 Ma ?
- Initial plate tectonics ? Geothermal gradient ?





Magnetic anomalies

- Very strong magnetic anomalies in oldest highlands
- 10 x anomalies of Earth
- Remanent magnetism in crust
- Mars has no active magnetic field



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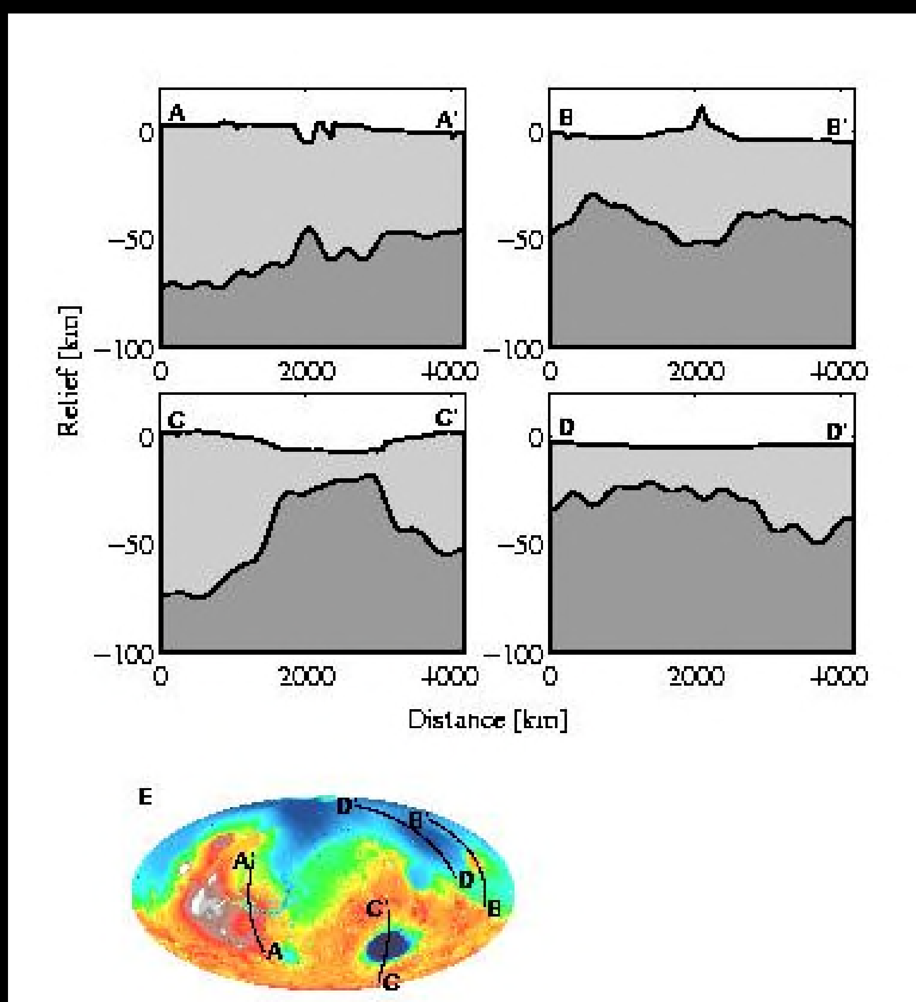
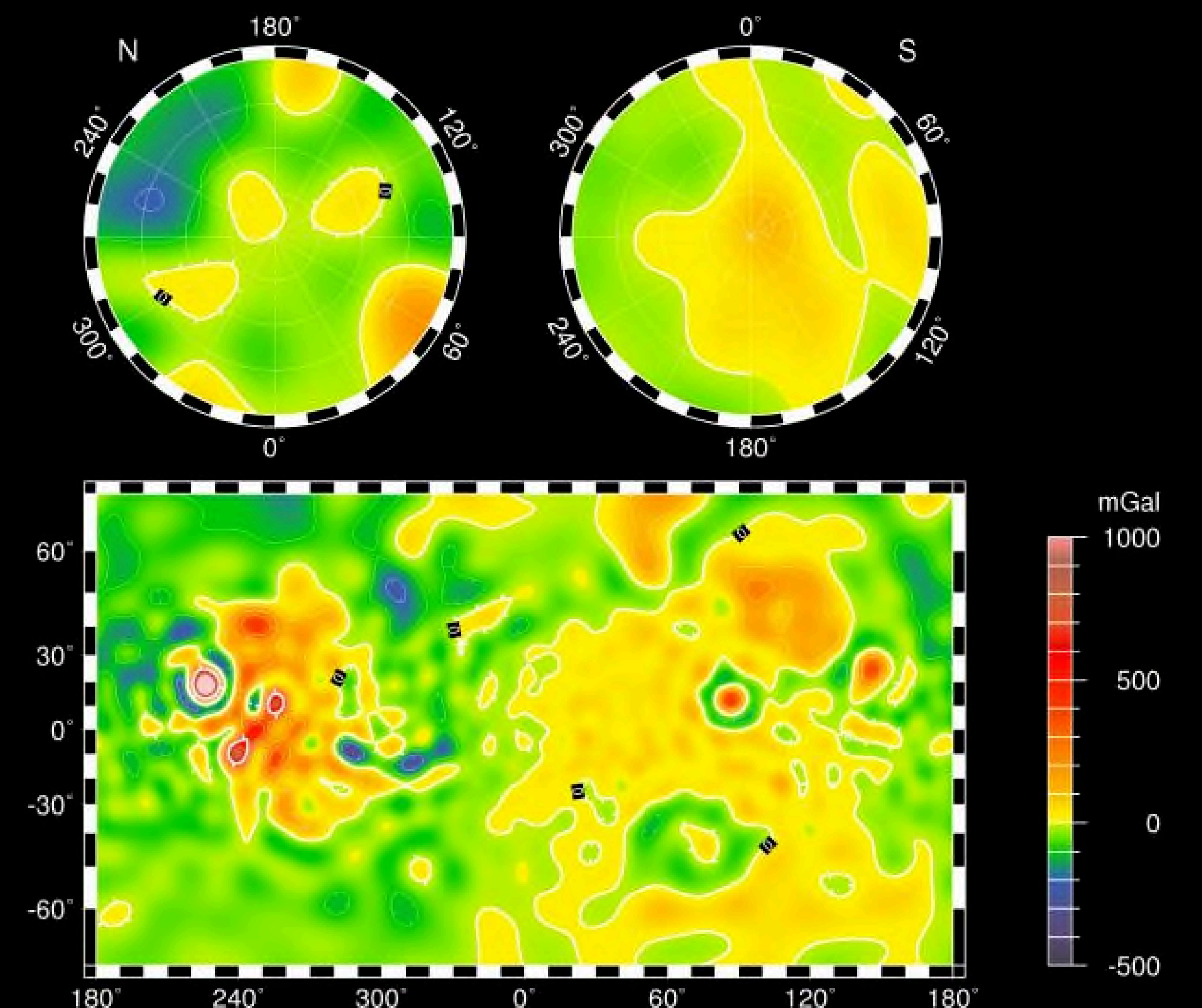
Gravity

- Gravity variations measured with radio tracking of the spacecraft (line of sight)





- Gravity profile + topography + assumption for crustal density => crustal thickness

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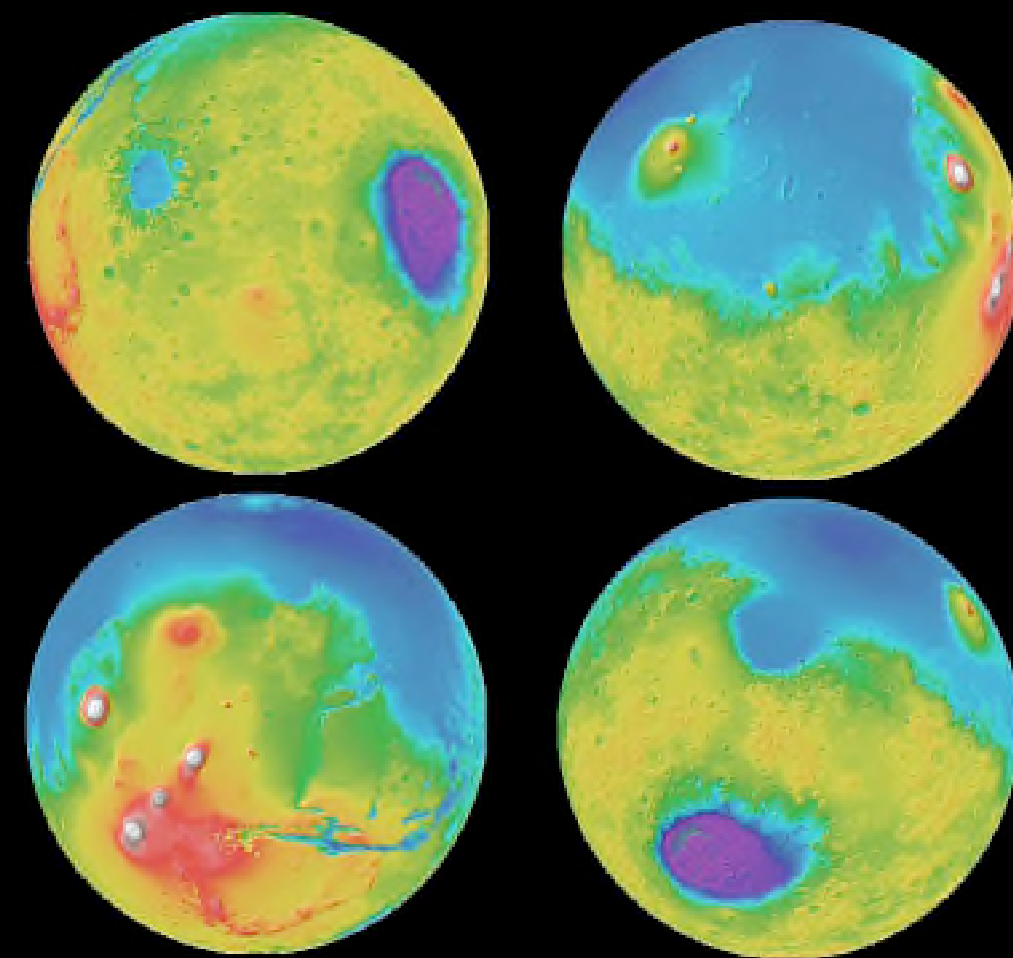
Topography

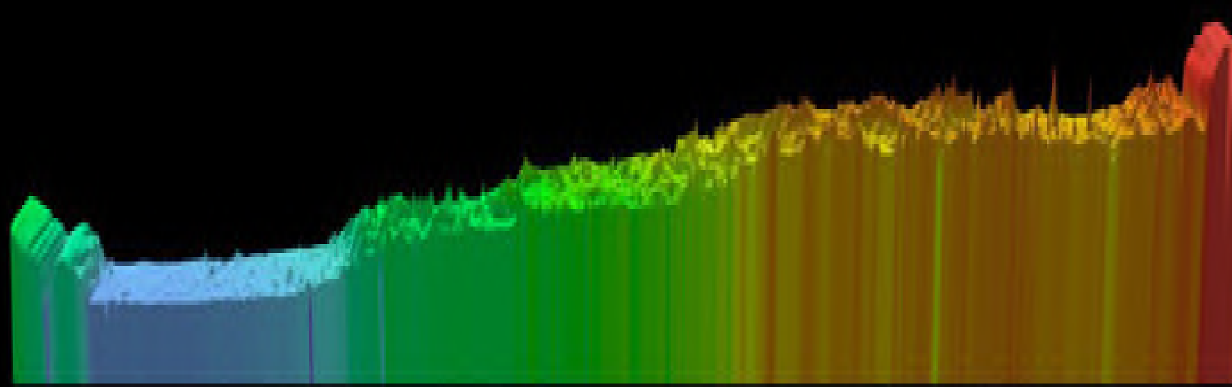
Background:

- S crater highlands, N smooth plains
- +22 km (Olympus) to -7 km (Hellas)
- S pole 6 km higher than N pole
- N lithosphere supports loads (+/-)
- 2 oceanic basins (Utopia, N pole)
- Numerous buried impact basins
- Tharsis uplift center is offset
- Valles Marineris radial to Tharsis

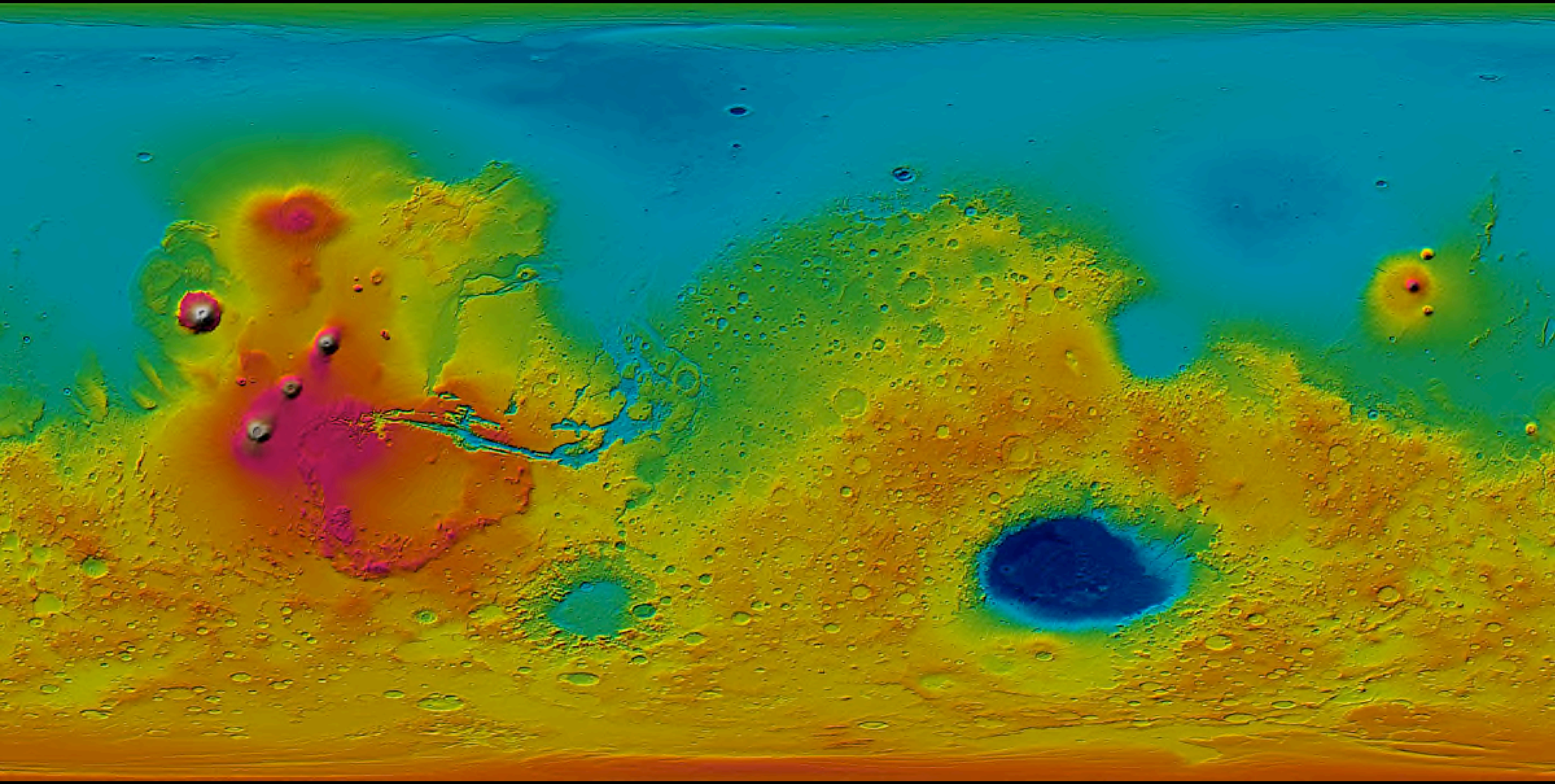


Questions:

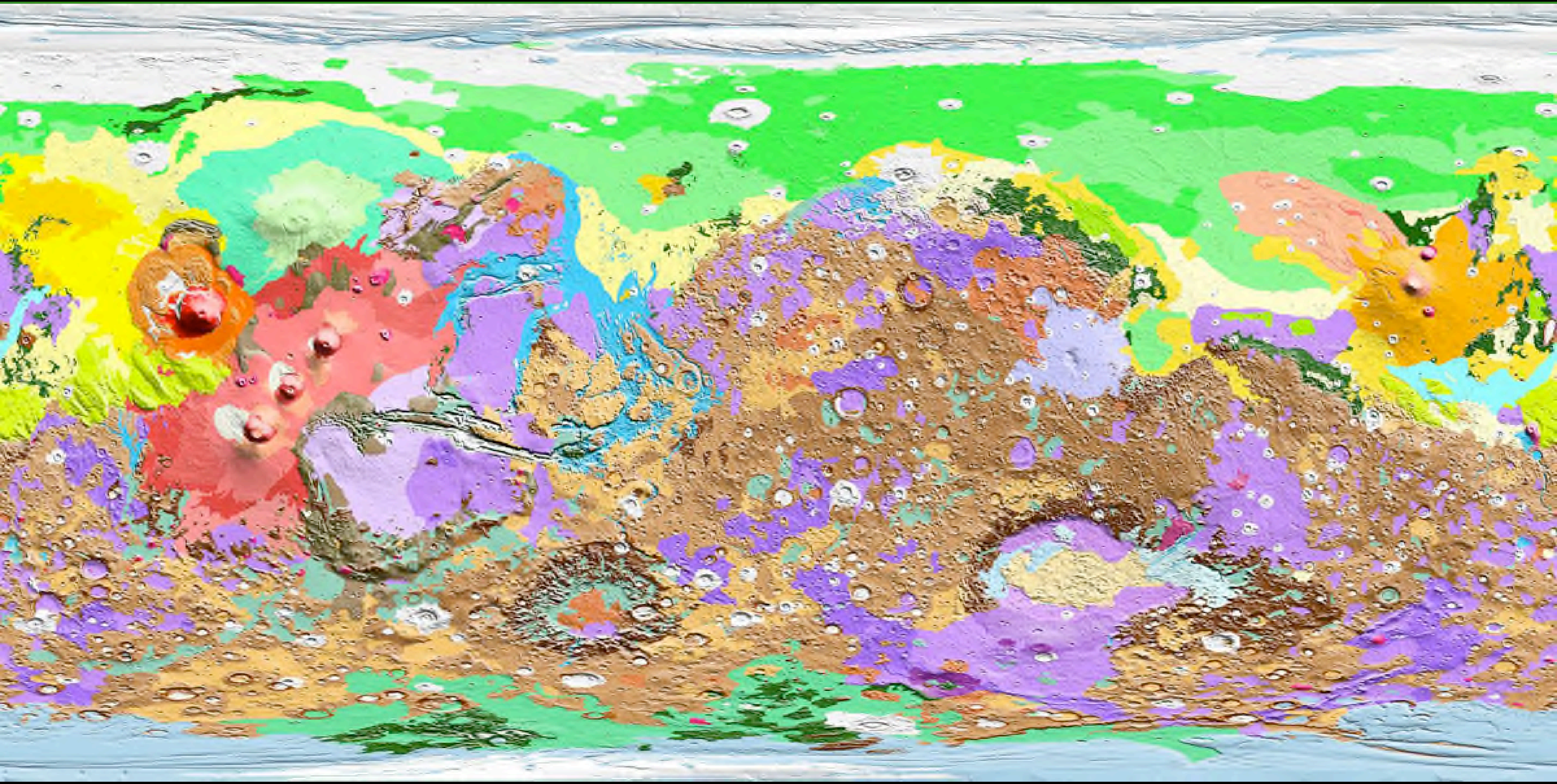
- Origin of crustal dichotomy ?
- Why N lowlands so flat (seabed) ?
- SÝN slope control aquifer flow ?



Mars topography



Mars Geology



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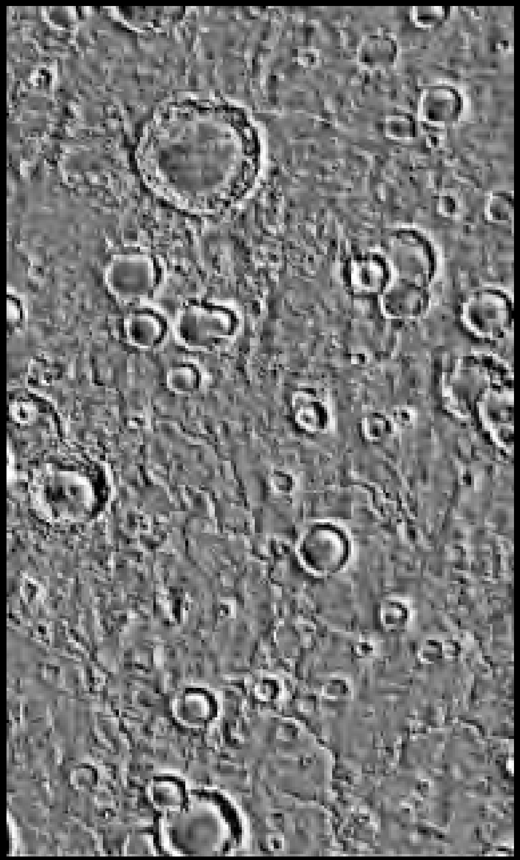
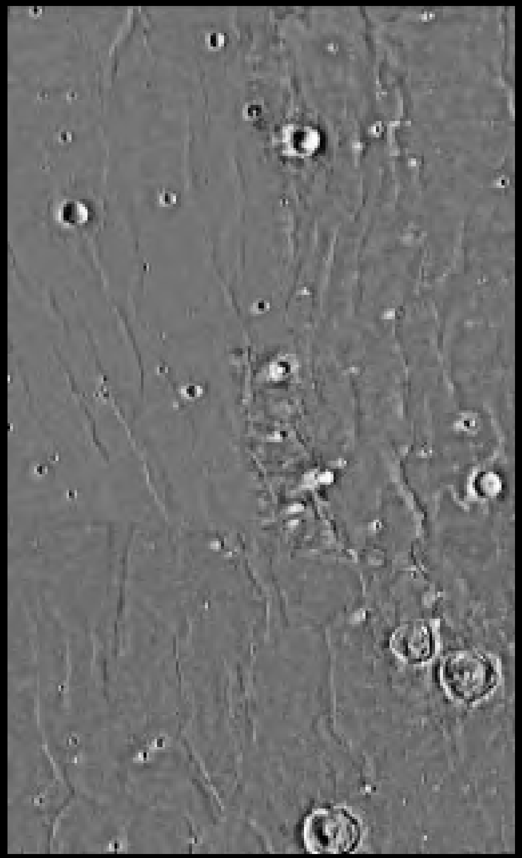
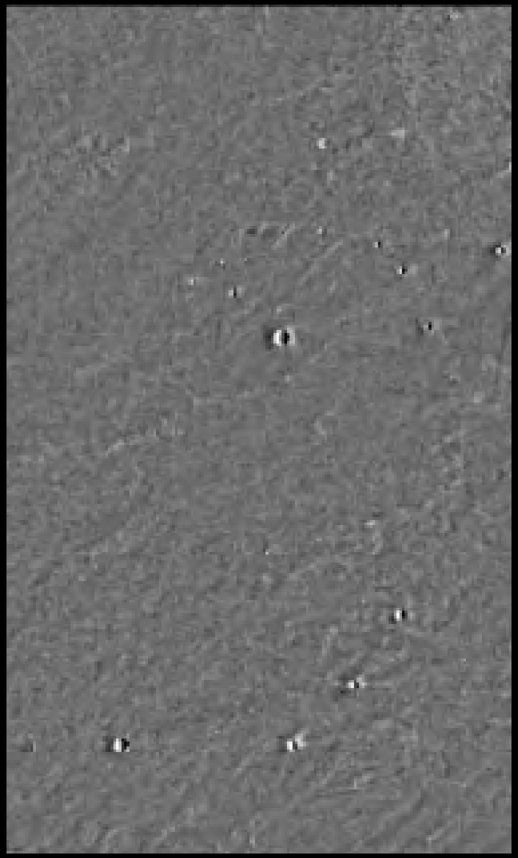
Major Martian epochs







Noachian	Hesperian	Amazonian
N(1)> 4800	1600-4800	< 1600 craters/10^6 km^2
> 3.7 Ga	3.7- 3.3 Ga	< 3.3 Ga

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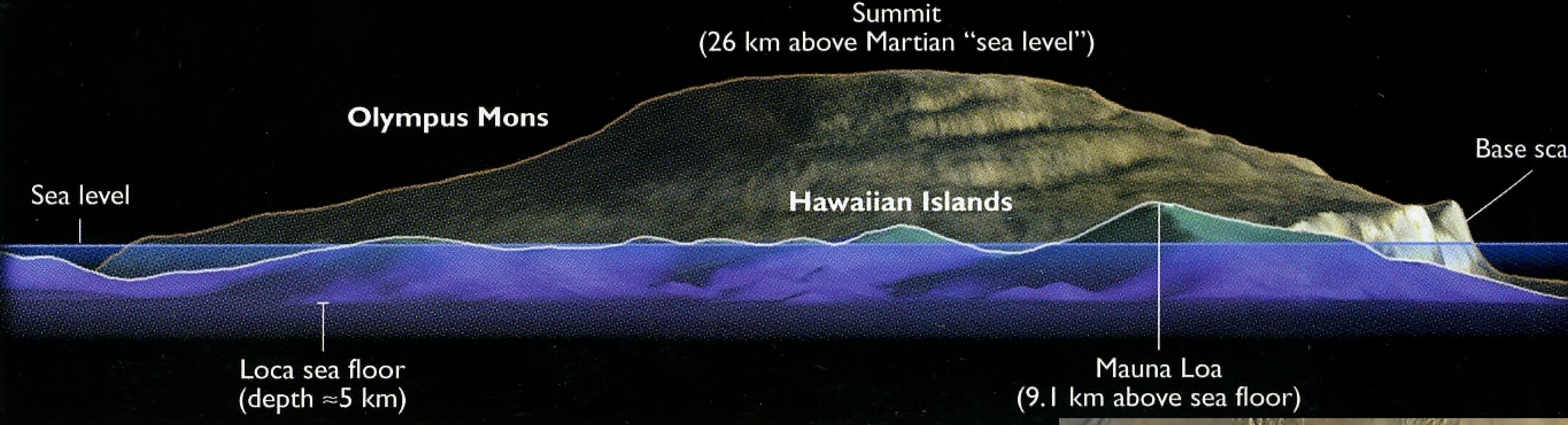
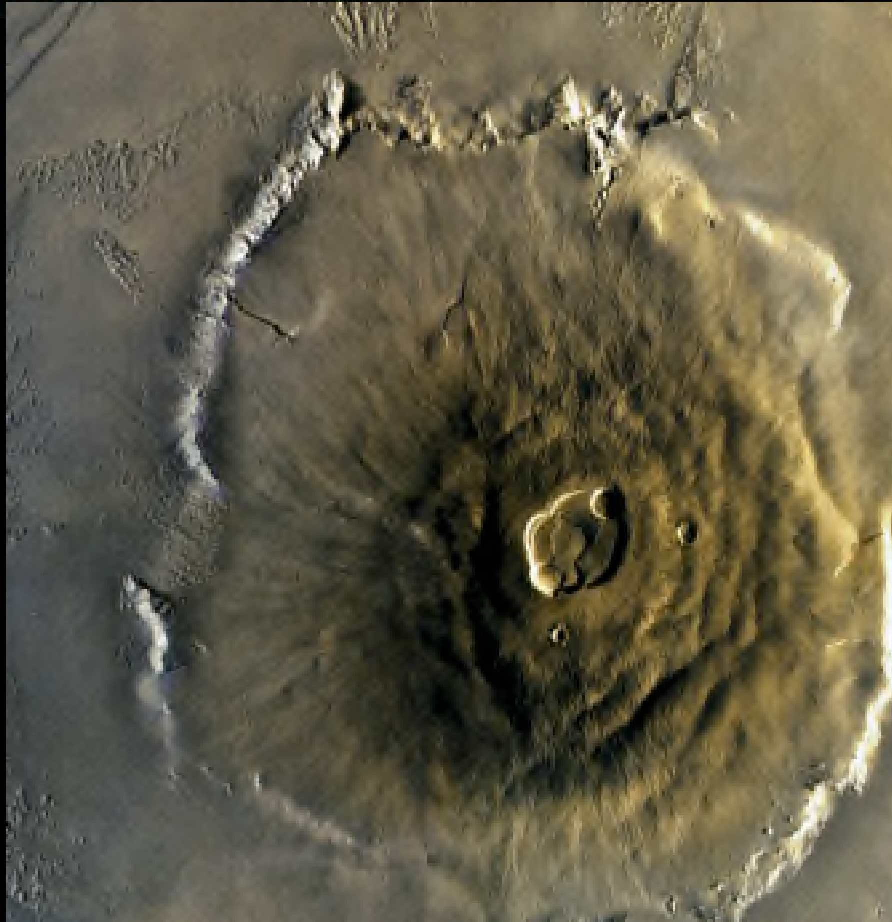
Volcanoes on Mars



- Large volcanoes ⟶ no plate tectonics
- Long lived mantle plume
- Stable crust
- Picture: Olympus Mons
- Caldera 90 km across
- Lava flows of 200+ km



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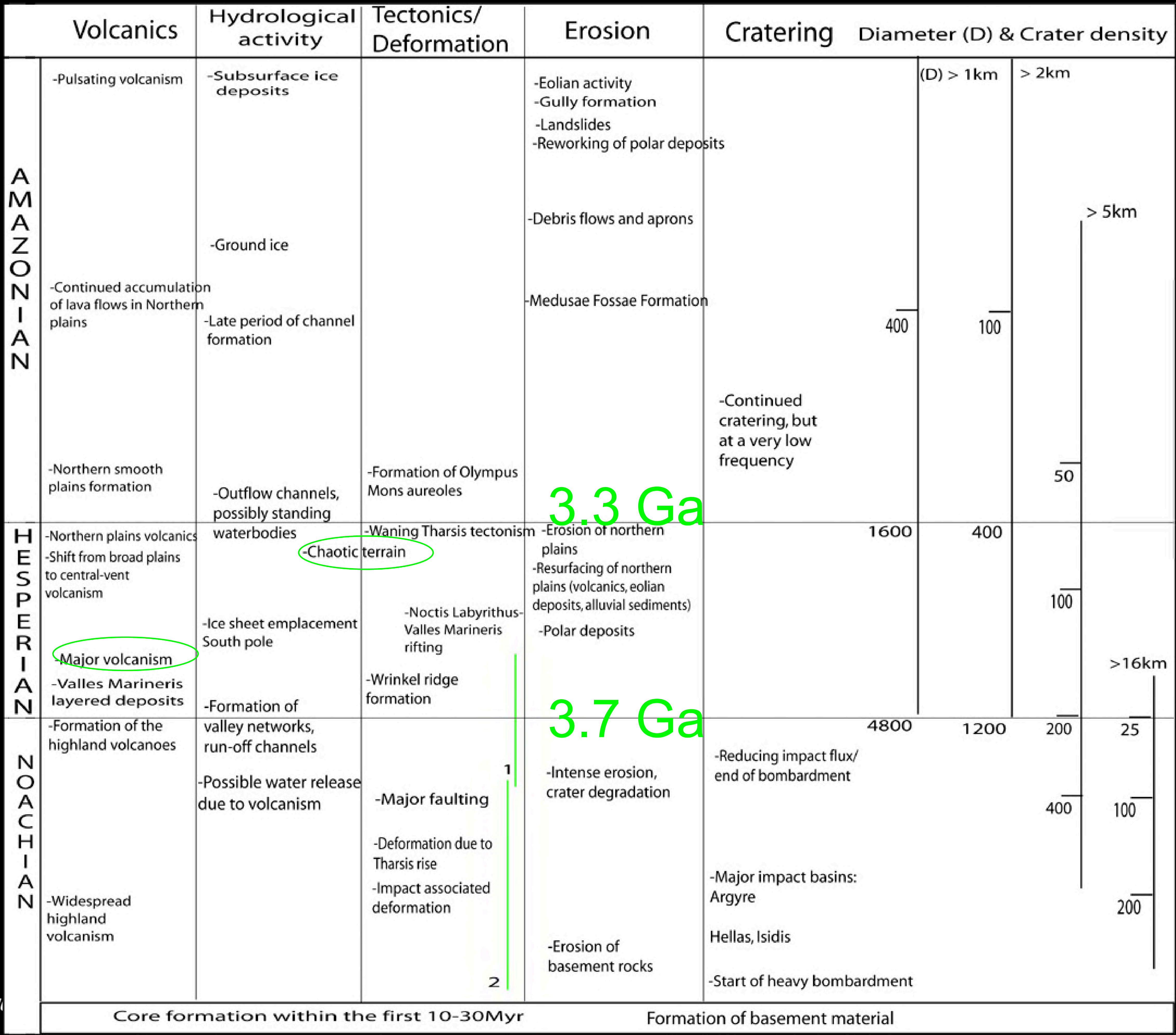
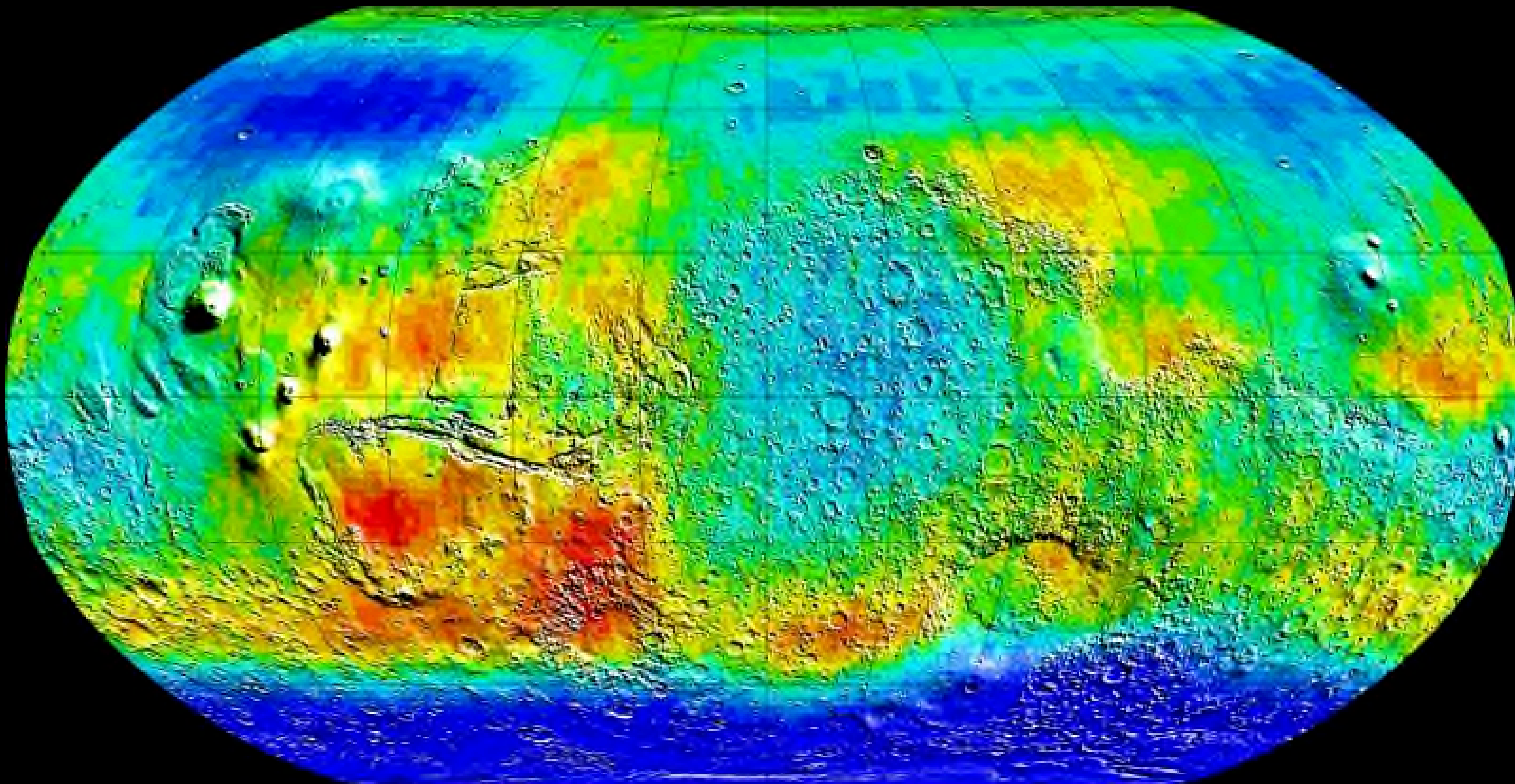
Mars Time



Volcanics
Hydrological activity
Tectonics/ Deformation
Erosion
Cratering
Diameter (D) & Crater density
(D) > 1km
> 2km
> 5km
>16km
AMAZONIAN
HESPERIAN
NOACHIAN
-Pulsating volcanism
-Continued accumulation of lava flows in Northern plains
-Northern smooth plains formation
-Subsurface ice deposits
-Ground ice
-Late period of channel formation
-Outflow channels, possibly standing waterbodies
-Formation of Olympus Mons aureoles
-Eolian activity
-Gully formation
-Landslides
-Reworking of polar deposits
-Debris flows and aprons
-Medusae Fossae Formation
-Continued cratering, but at a very low frequency
400
100
50
3.3 Ga
-Northern plains volcanics
-Shift from broad plains to central-vent volcanism
-Major volcanism
-Valles Marineris layered deposits
-Chaotic terrain
-Ice sheet emplacement South pole
-Formation of valley networks, run-off channels
-Waning Tharsis tectonism
-Noctis Labyrithus-Valles Marineris rifting
-Wrinkel ridge formation
-Erosion of northern plains
-Resurfacing of northern plains (volcanics, eolian deposits, alluvial sediments)
-Polar deposits
1600
400
100
3.7 Ga
-Formation of the highland volcanoes
-Widespread highland volcanism
-Possible water release due to volcanism
-Major faulting
-Deformation due to Tharsis rise
-Impact associated deformation
1
2
-Intense erosion, crater degradation
-Erosion of basement rocks
-Reducing impact flux/ end of bombardment
-Major impact basins: Argyre
Hellas, Isidis
-Start of heavy bombardment
4800
1200
200
25
400
100
200
Core formation within the first 10-30Myr
Formation of basement material

Ground ice



Below the surface, ice is stable at lower latitudes

Image shows epithermal neutron map of Mars Odyssey.

Dark blue indicates up to 50% water ice in top 1 m of soil

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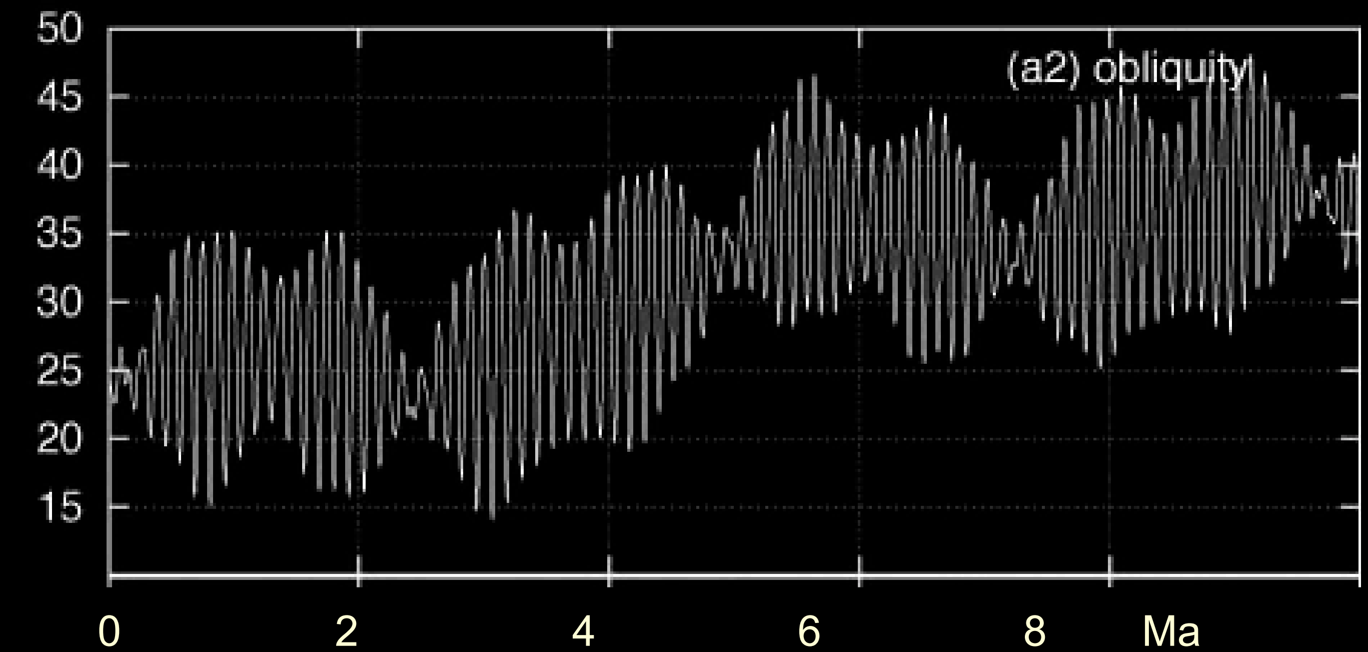
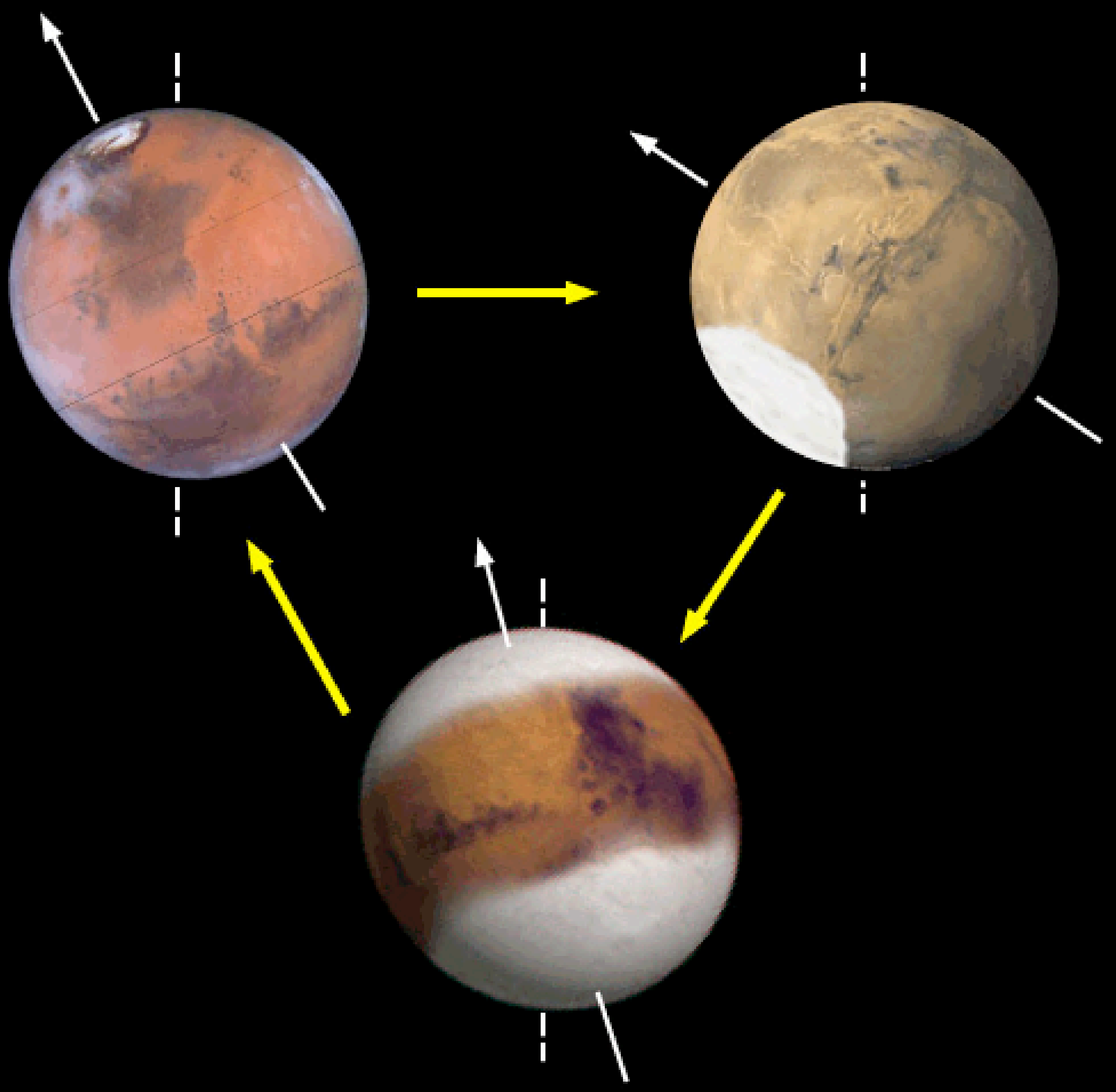


Paleoclimate

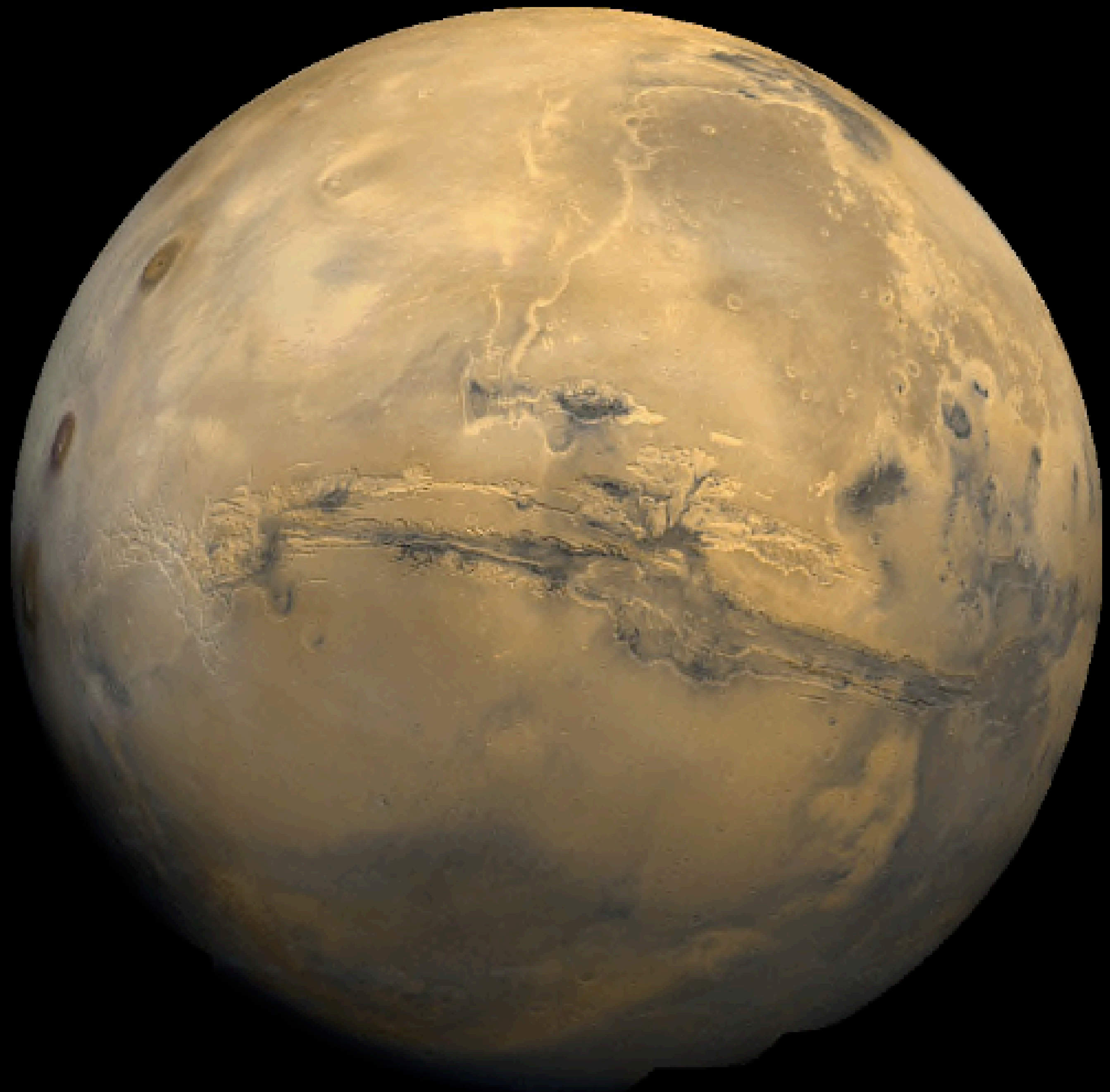
Laskar et al. (2004)



- Relatively young glacial activity (on equator) =>
- Climate on Mars has recently changed
- Related to change of obliquity

Valles Marineris

- 3000+ km long
- 600 km wide
- 8 km deep
- Formed by:
  - Faulting?
  - Fluvial erosion?
  - Landslides?
  - Or a combination of all three?
  - Not yet understood



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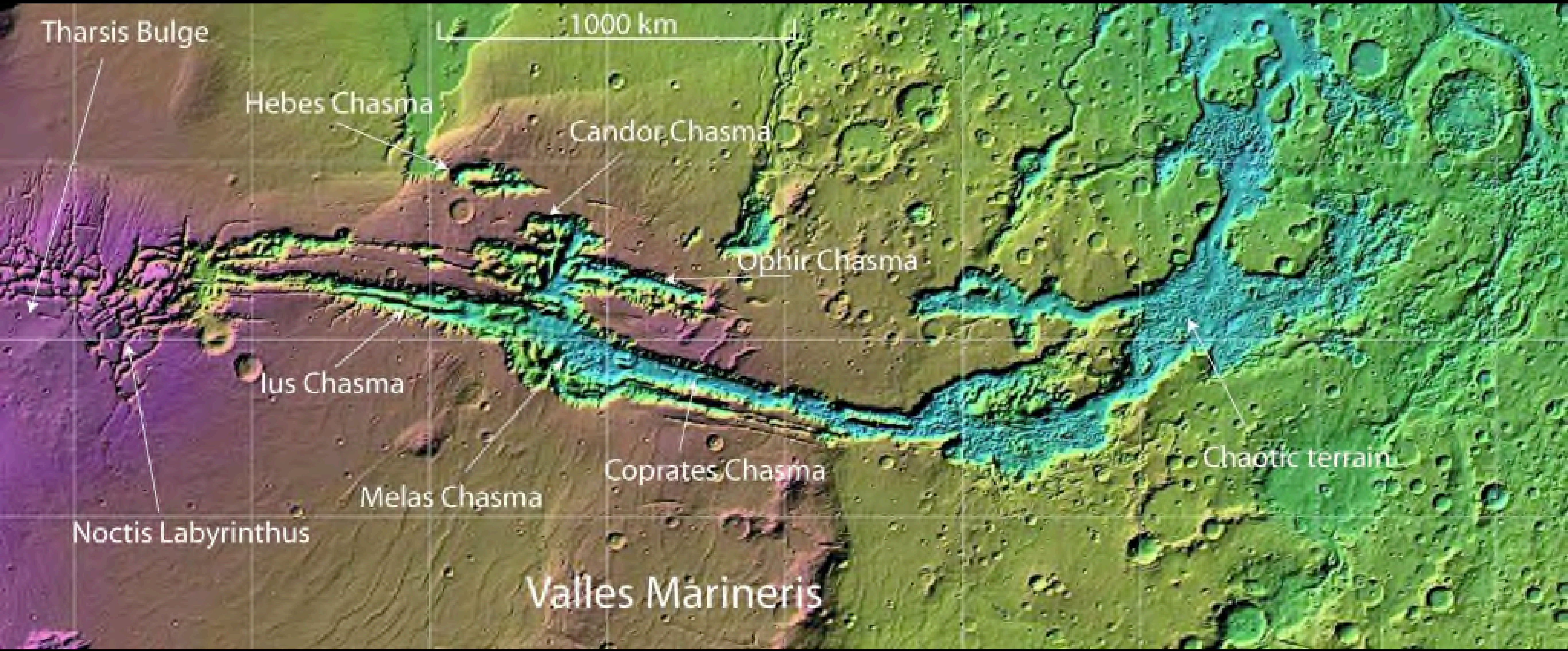
Valles Marineris



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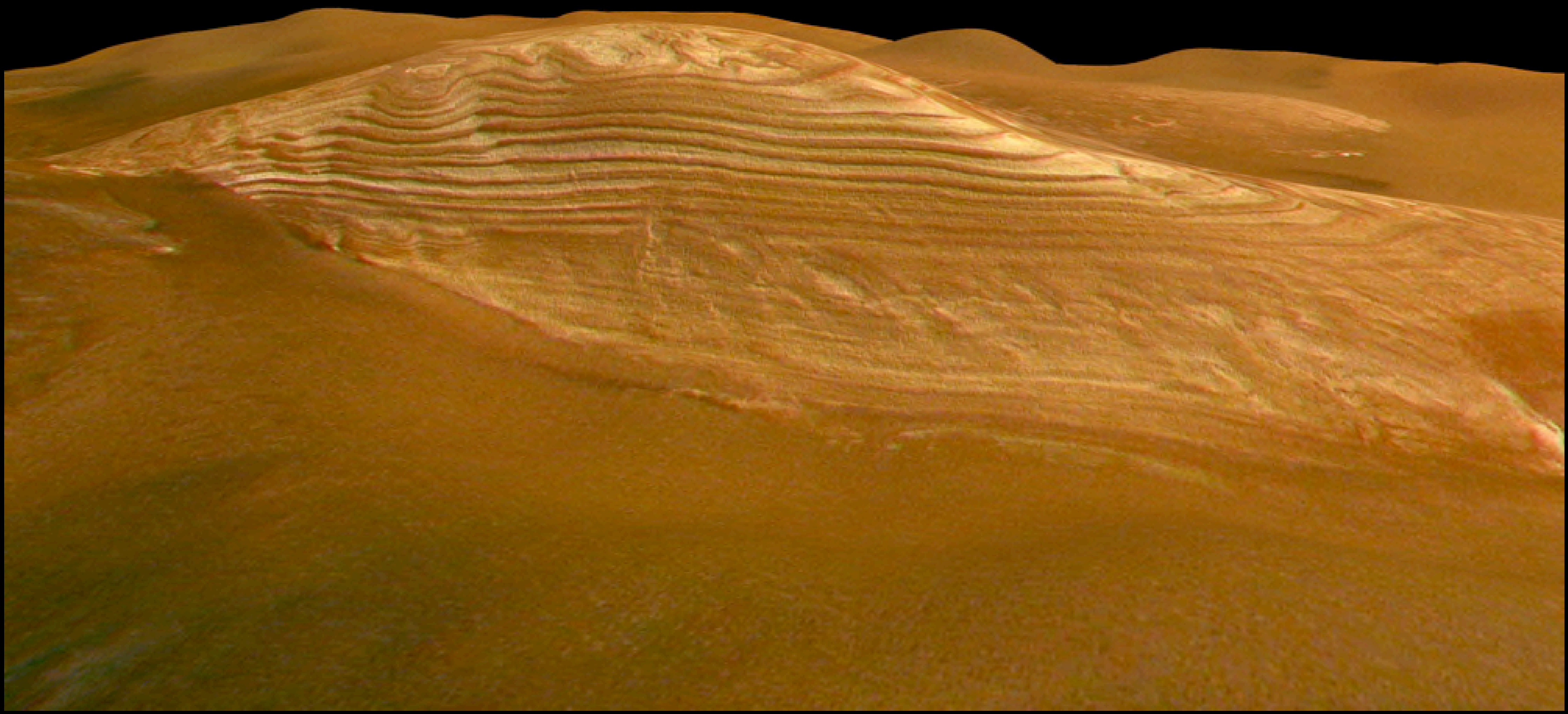
Interior Layered Deposits



- Juventae Chasma (Valles Marineris)
- ILD ~3.3 Ga (Neukum, LPSC 2006)

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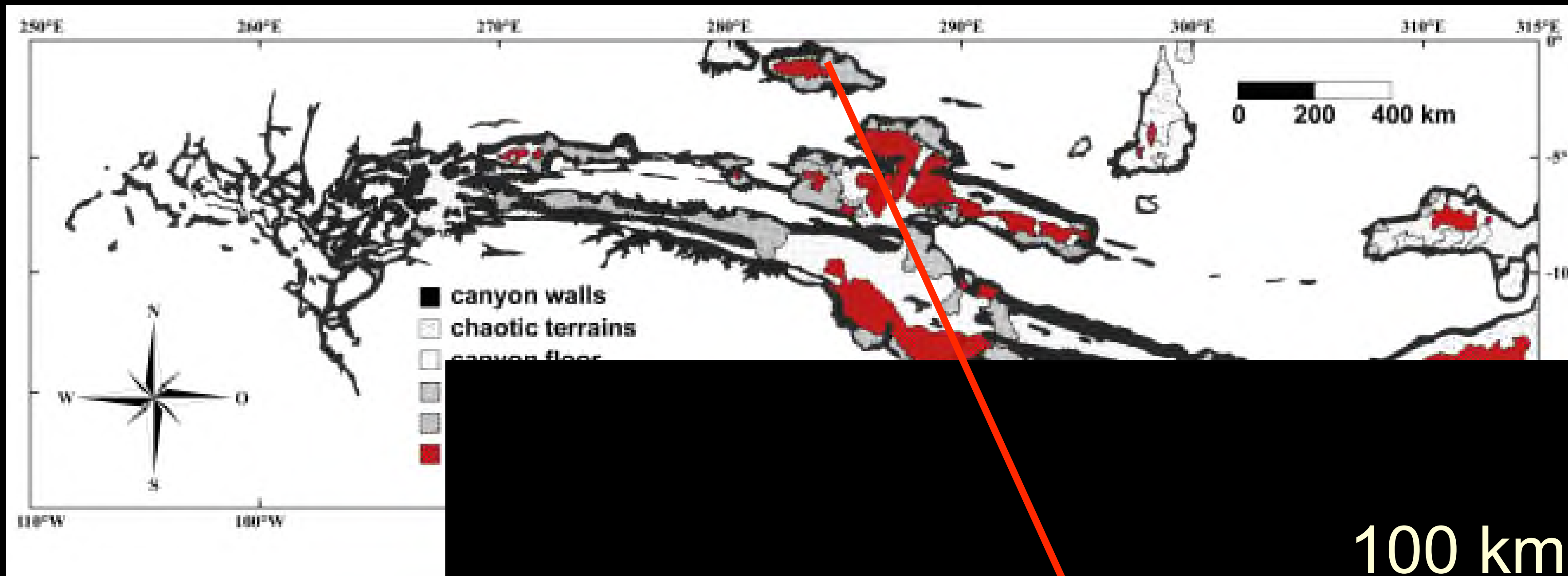
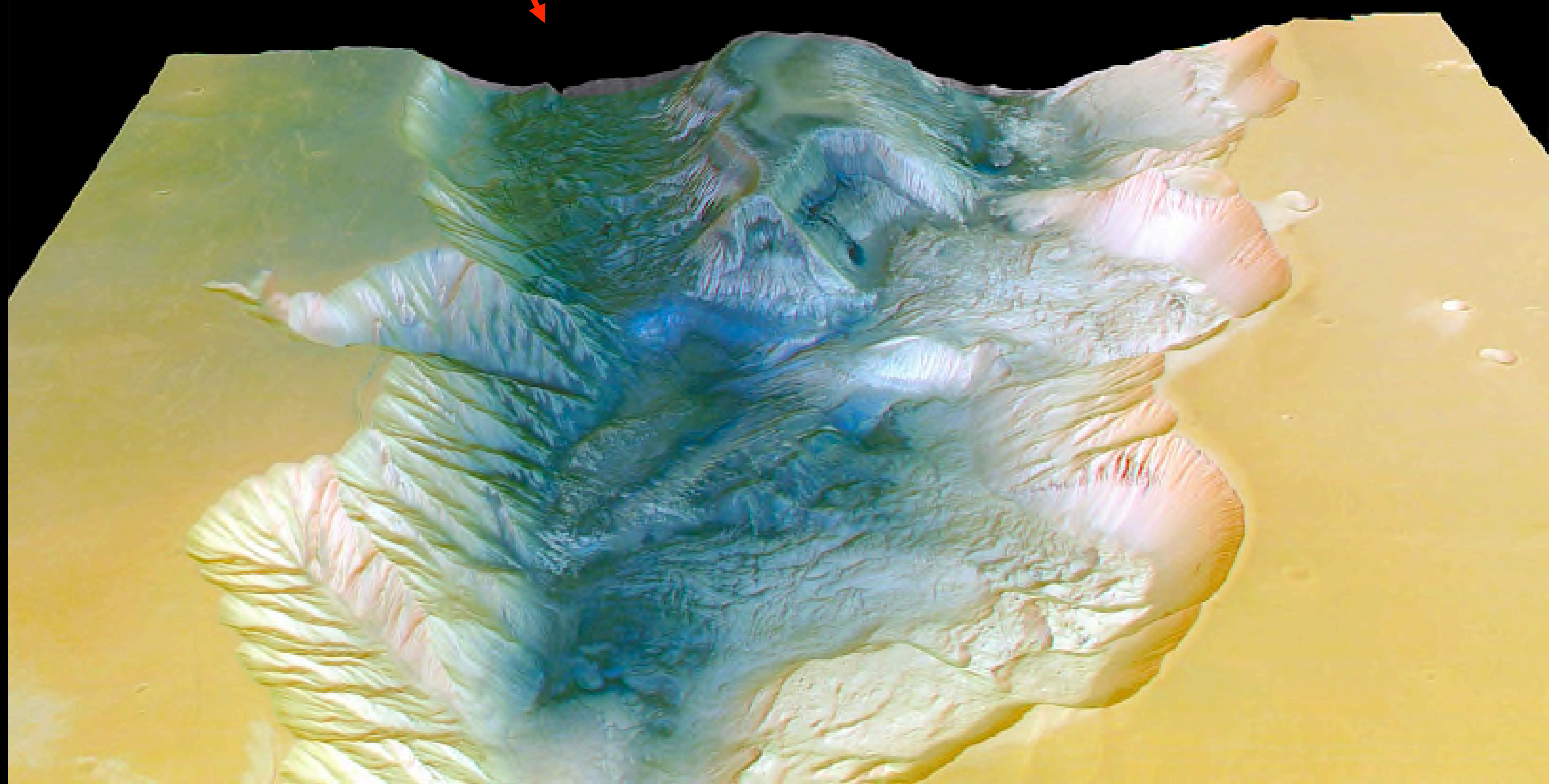
Hebes Chasma

Interior layered deposits ILD



- Hebes Chasma

Looking west



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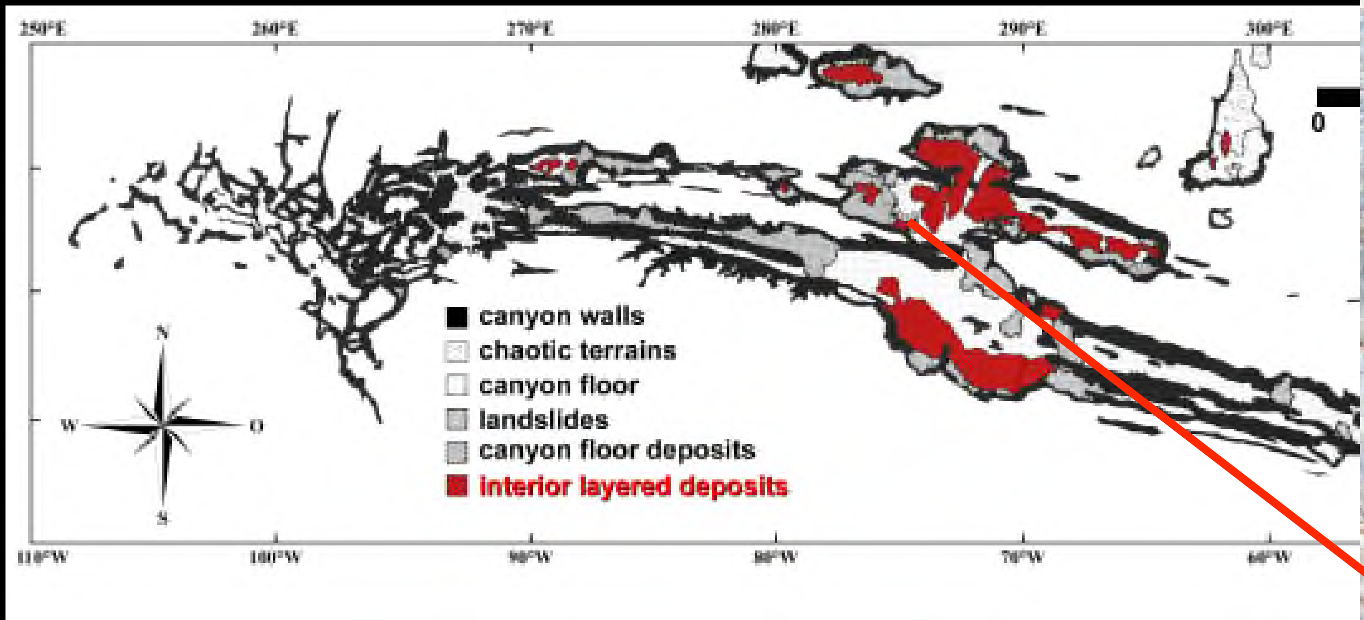
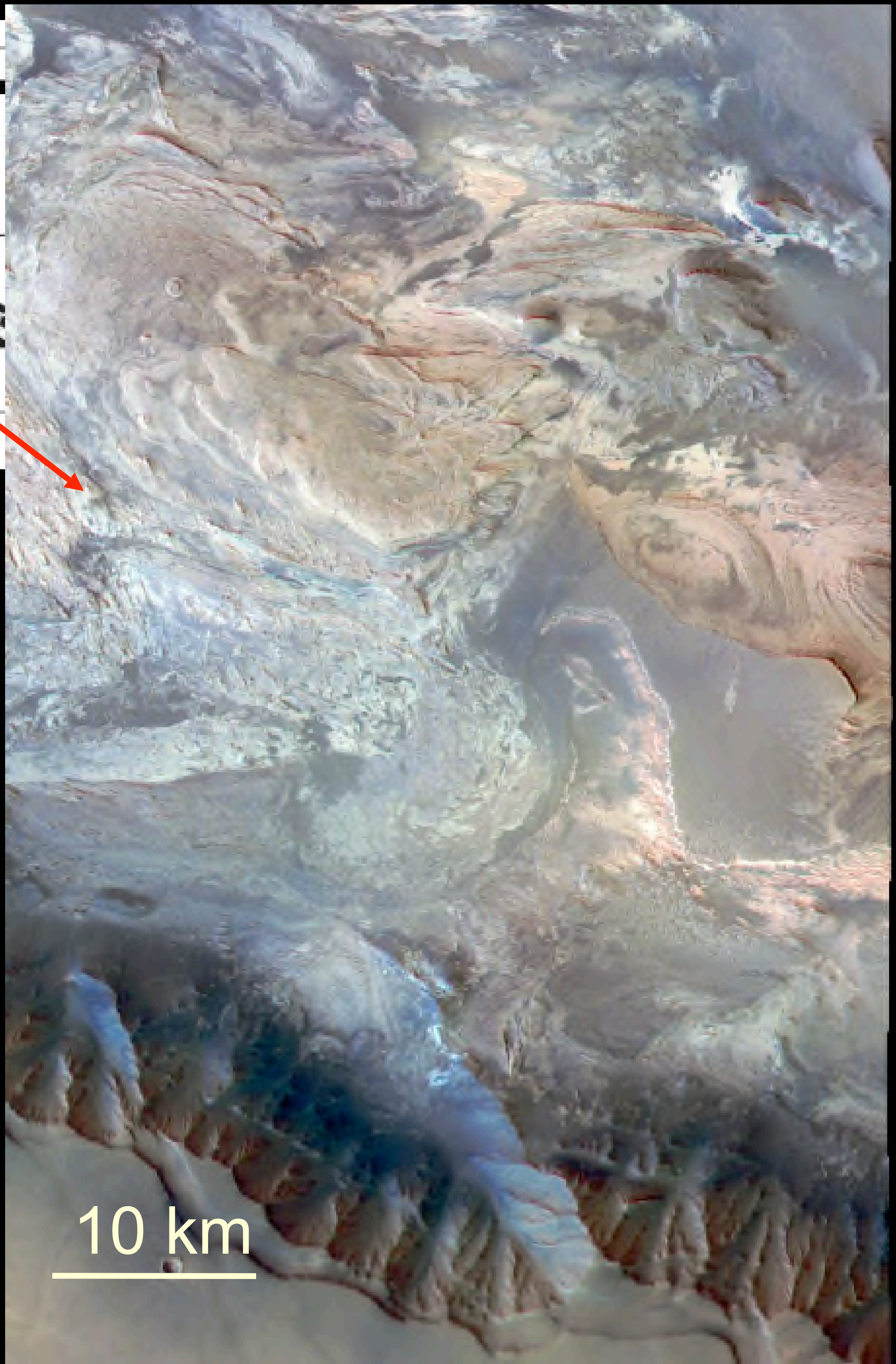
Candor Chasma





- Good layering
- Complex relation between topography and layering

=> Good for layer measurements

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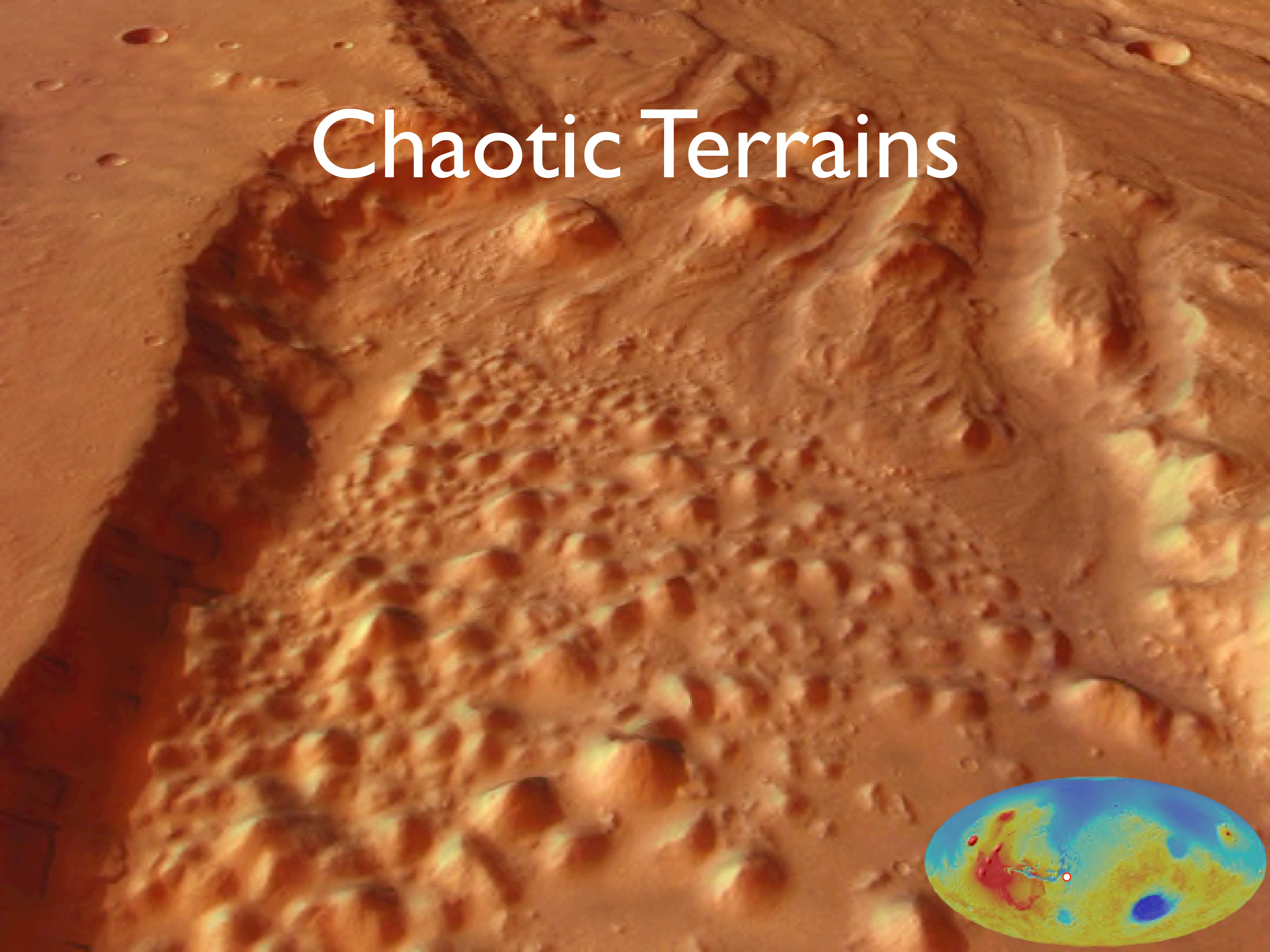
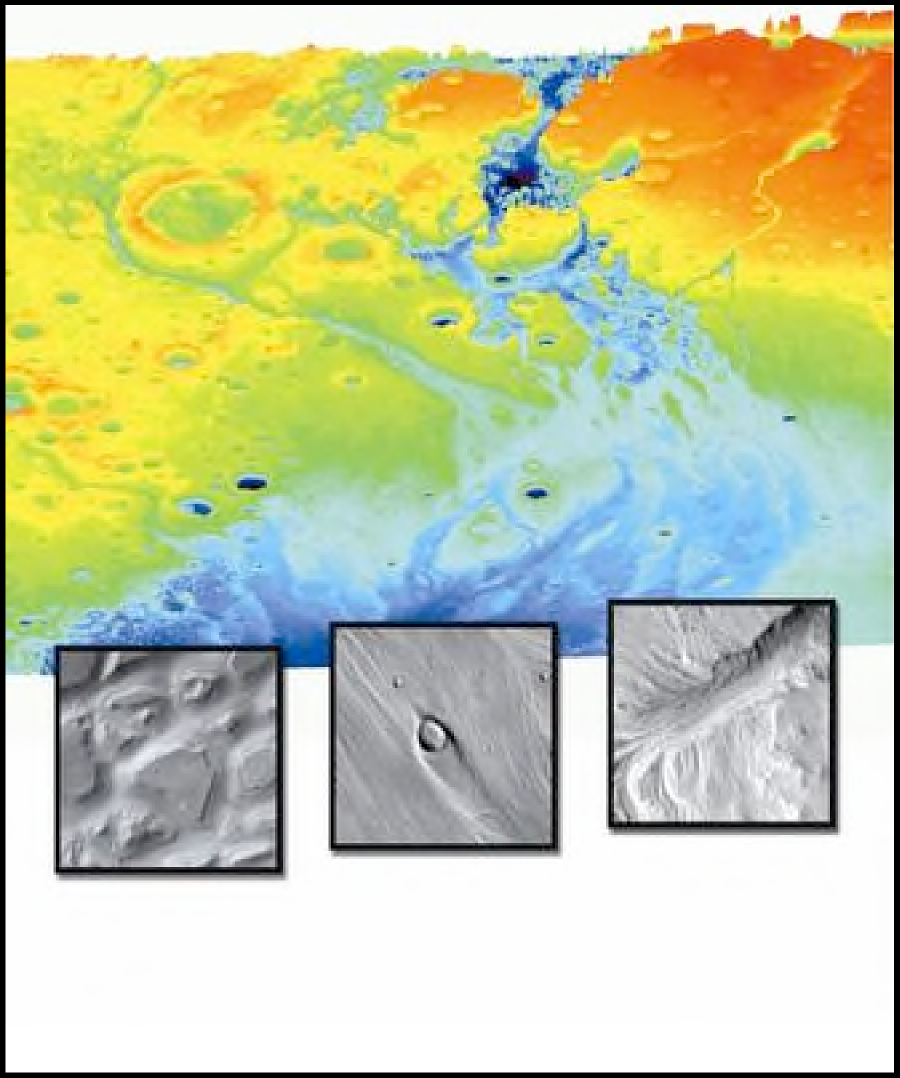
Candor Chasma

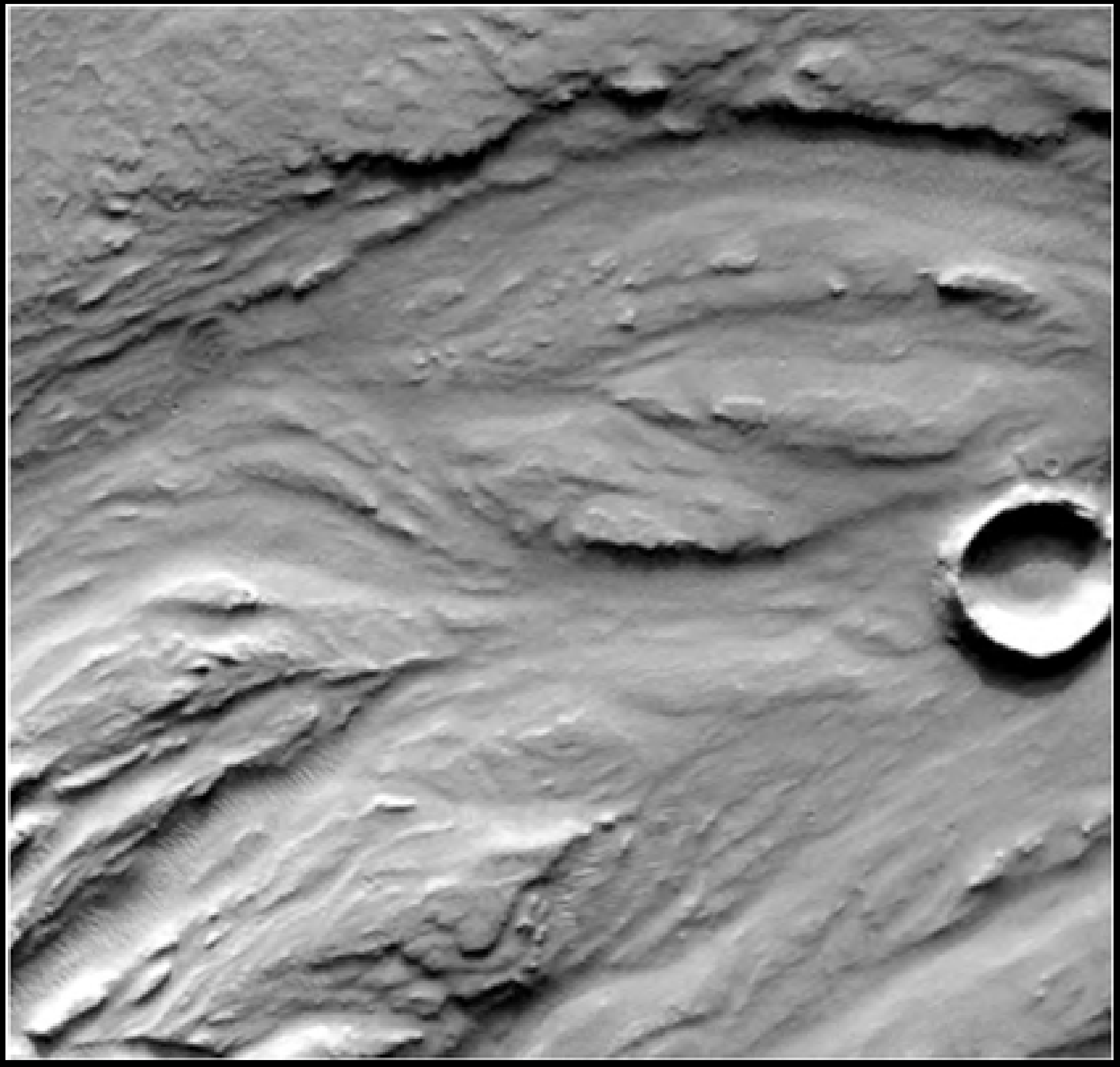
Chaotic Terrains

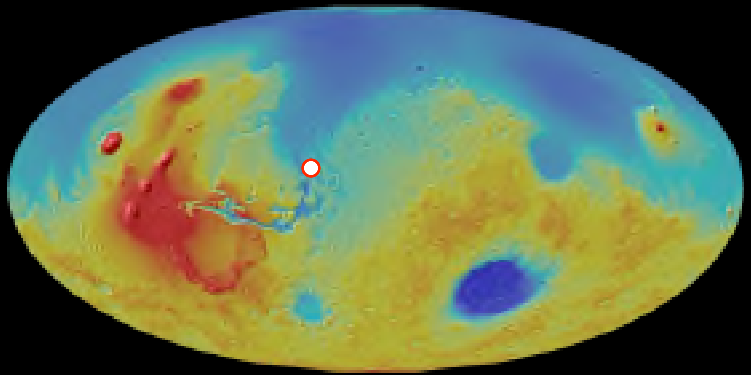


Outflow Channels

- Most channels are found at ‘exit’ of Valles Marineris, in Chryse Planitia.
- Abrupt beginning, lack of tributaries
- Sculpted terrains
- Formed by catastrophic outpourings of water?







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Valley networks

- Occur all over highland, very few in lowlands
- Evidence of warmer climate earlier on Mars?

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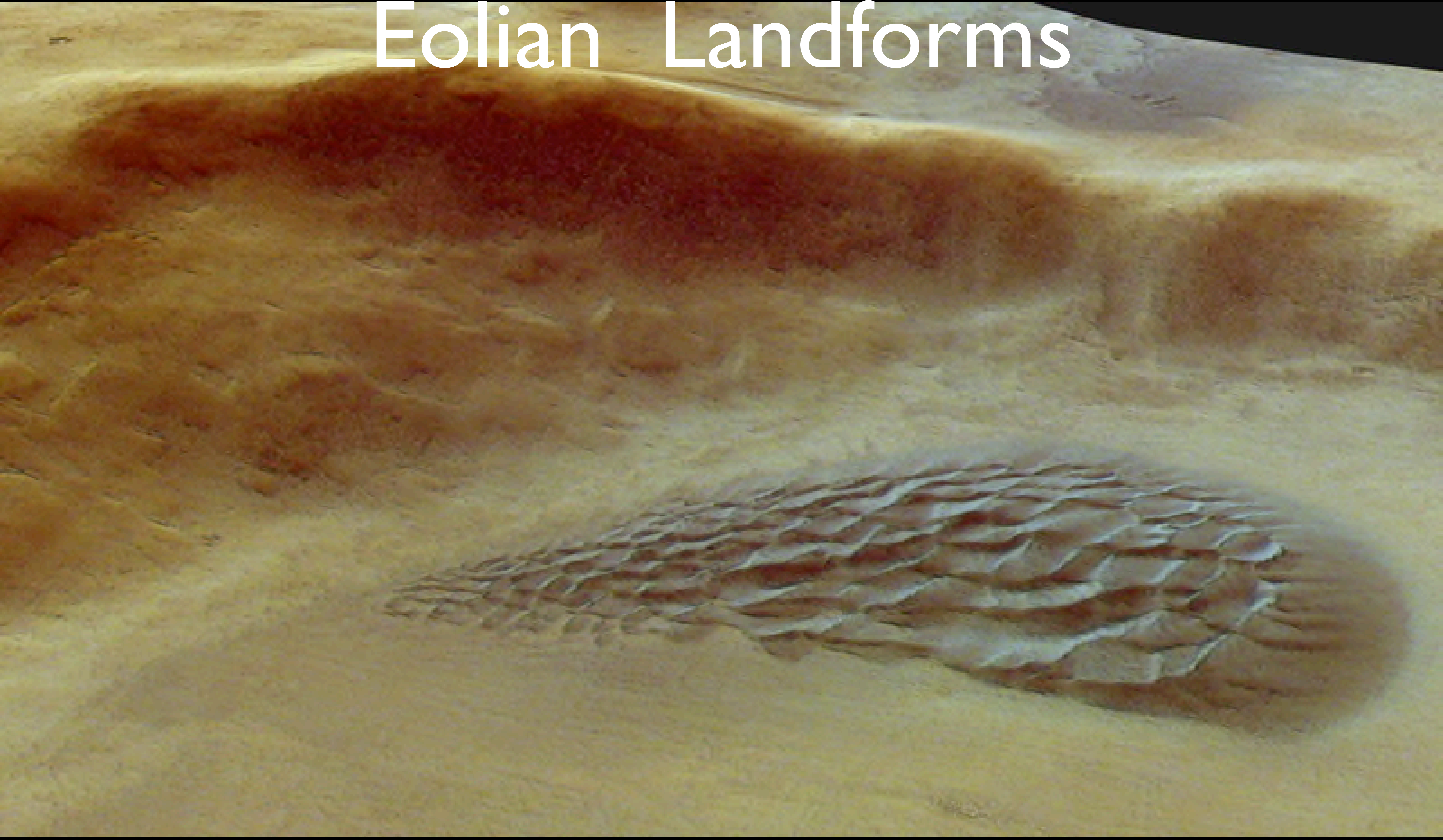
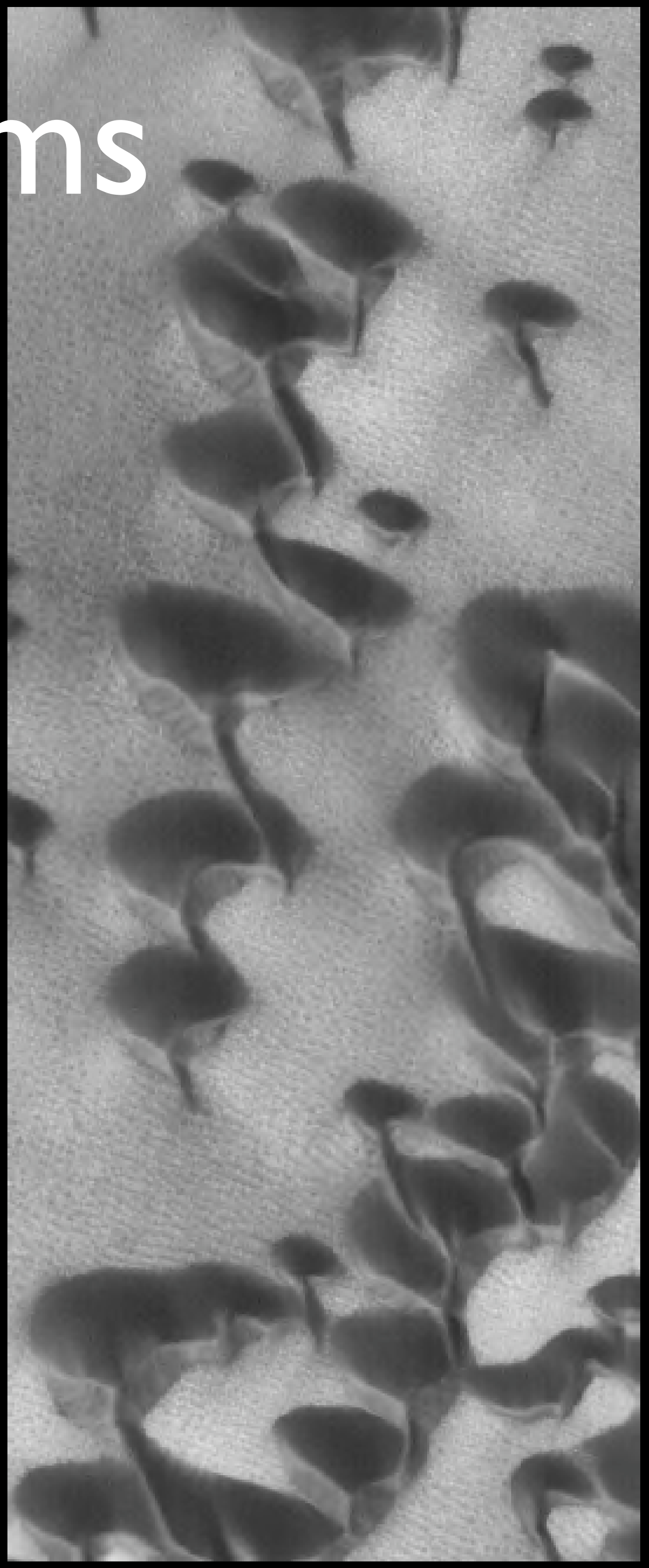
Eolian Landforms



Eolian Landforms



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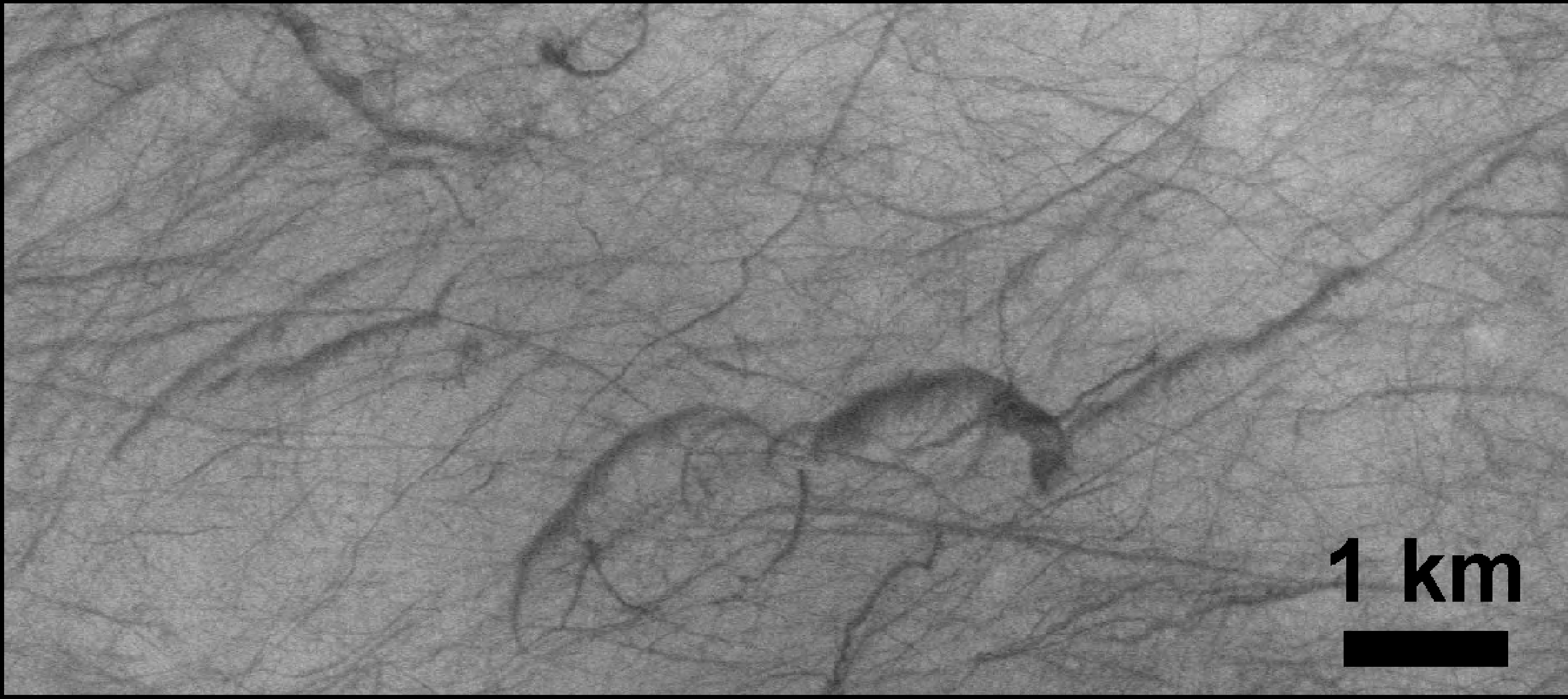
Dust devils & tracks on Mars



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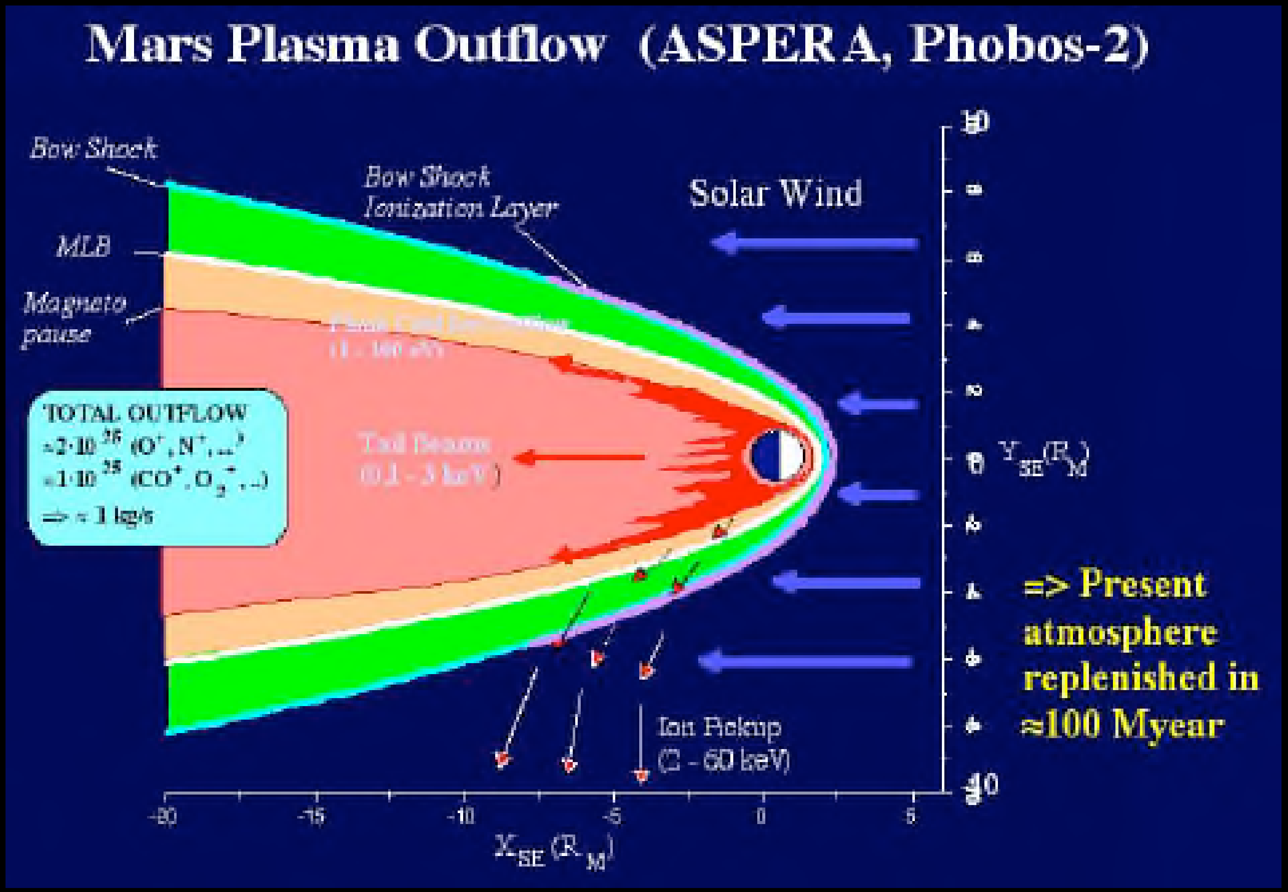
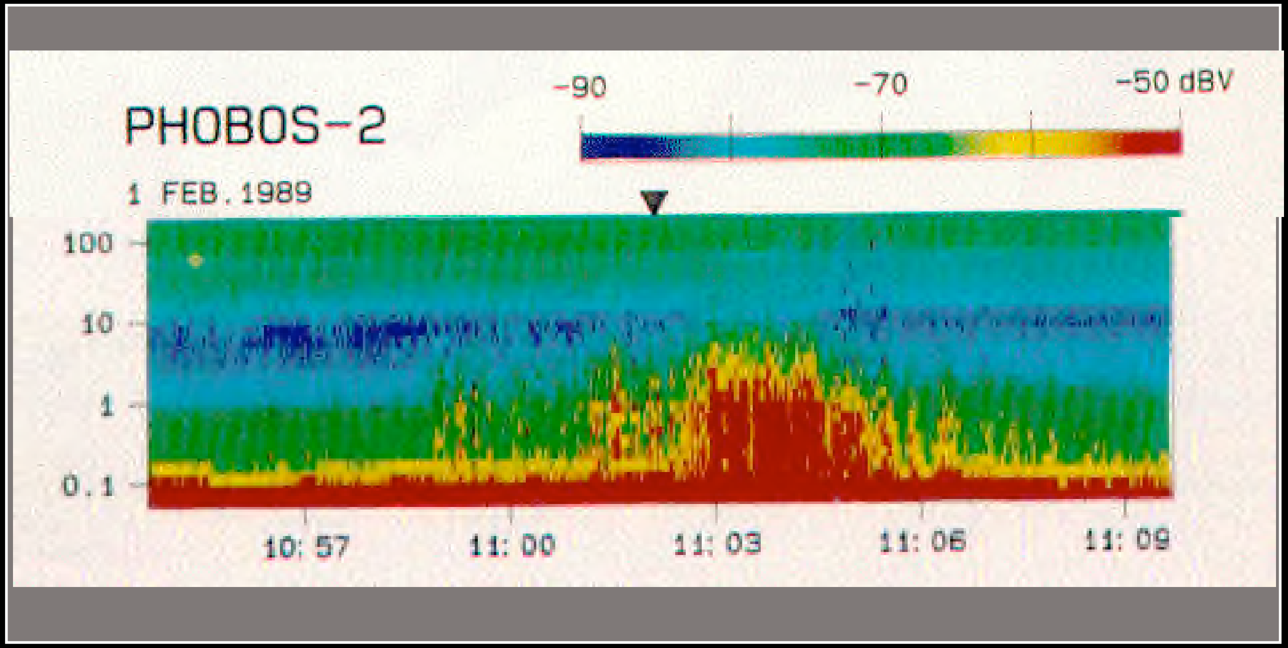
Ionosphere

Background:

- No magnetosphere, like on Venus
- Presence of tilted (4°) bow shock
- Foreshock similar to other planets
- Ionosphere develops on day side
- 10 m global water lost to impacts
- Loss of 75% current 40Ar level
- Current outgassing < on Earth (x15)
- High density atm/topo uncorrelated

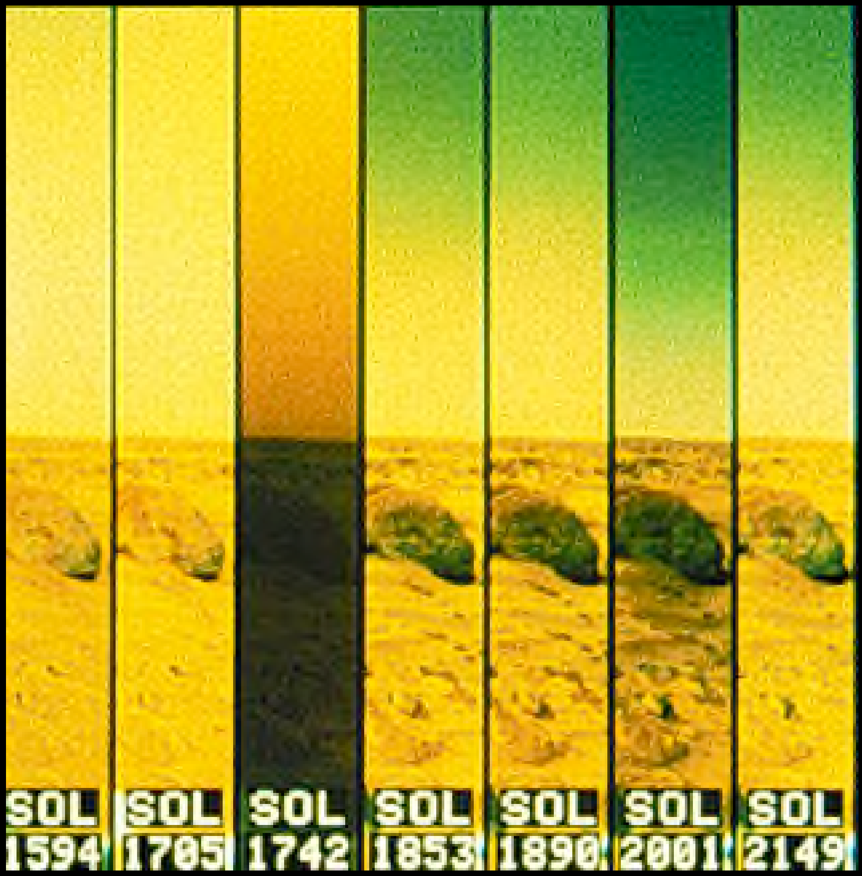


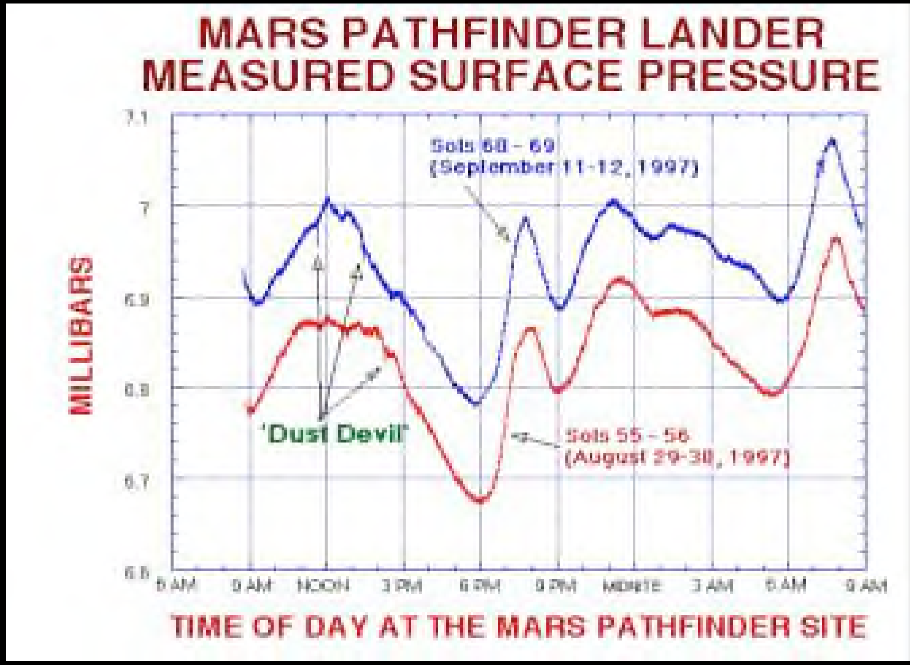


Questions:

- Intrinsic magnetic field ?
- Convection in upper atmosphere ?

Surface- Atmosphere interactions





Background:

- Surface Pressure: 6.8 mbar ó 10.8 mbar
- Surface Temperature: -140ºC ó +20ºC
- PBL between 0 km (night) ó 3 km (daytime)
- Average wind (5-10 m/s); wind gusts (100 m/s)
- High winds to set dust airborne (>25 m/s)
- Erosion rate: m/Ma (early) mm/Ma (late)
- UV (B/C) higher than on Earth today

Questions:

- Characterize PBL (thermal inversion) ?
- Regolith-atmosphere H2O exchange ?
- Mechanism to entrain dust and raise storms?

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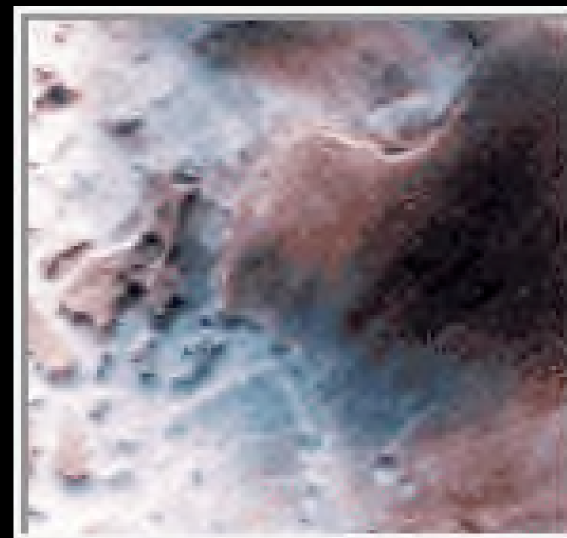
Atmosphere

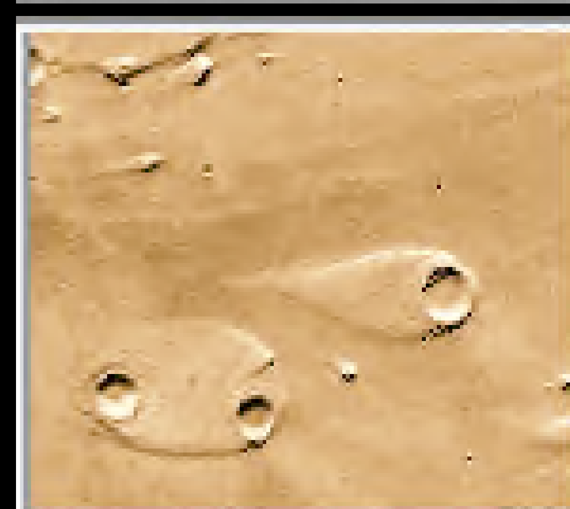
Background:

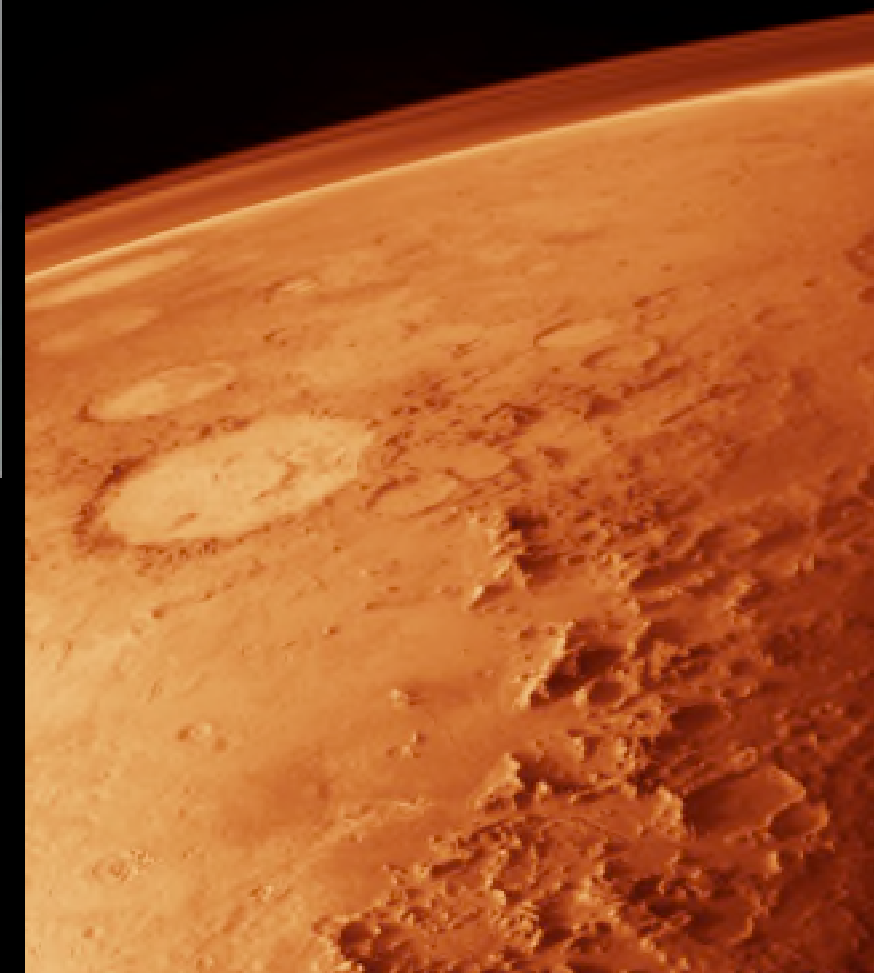
- CO_2 99, N_2 2.7, Ar 1.6, O_2 0.13 %
- Traces: CO, H_2O, Ne, Kr, Xe, O_3
- Thicker, warmer atm. 3.8 Ga ago
- No thermal reservoirs (oceans)
- Atm. waves (gravity, kelvin)
- Fog, frost, clouds, storms

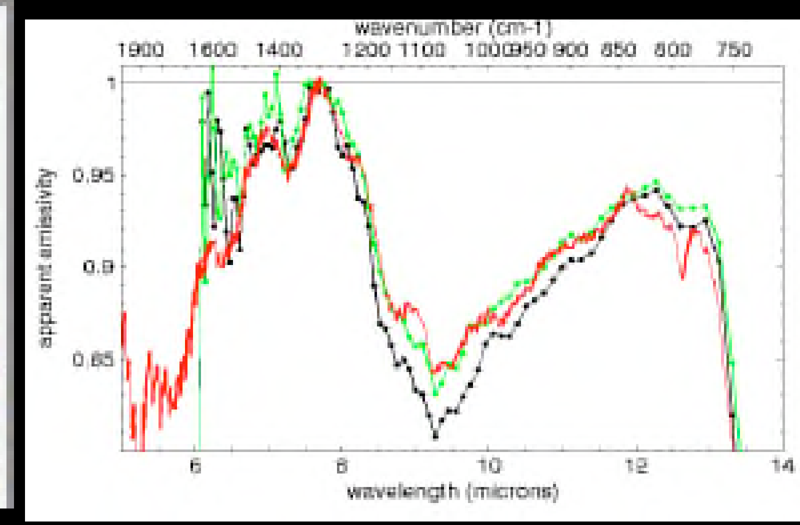
Questions:

- Atm. structure & dynamics ?
- Spatial & temporal variations ?
- Characterise H_2O, CO_2 cycles ?
- GCM validation (data points) ?









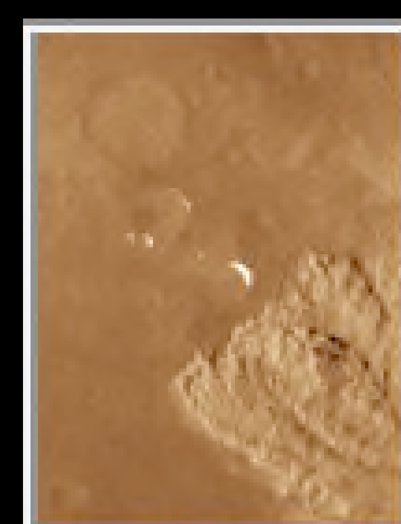
Dust, CO_2, Climate

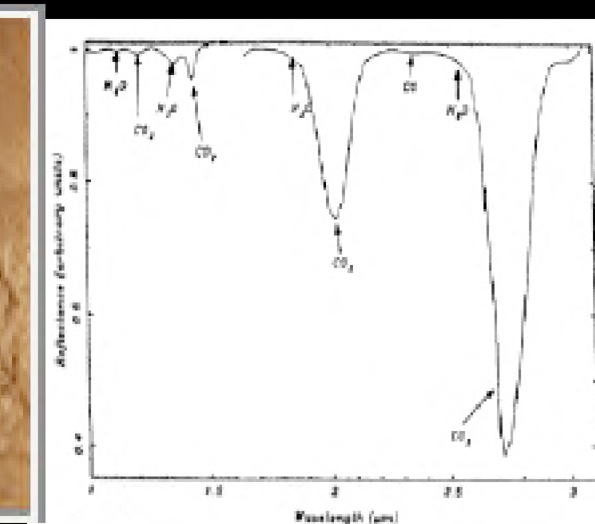
Background:

- Obliquity variations Þ polar ice loading
- Polar layered terrains seasonal cycles
- Global storms, dust, water to high latitudes
- Large dust storms every 3 y, local every year
- Dust storms create polar warming
- Thermal forcing by airborne dust
- Yellow clouds charged with dust
- Paleowinds more active than GCMs

Questions:

- Role of impacts in dust storm onset ?
- Dust storm electrostatic build-up ?





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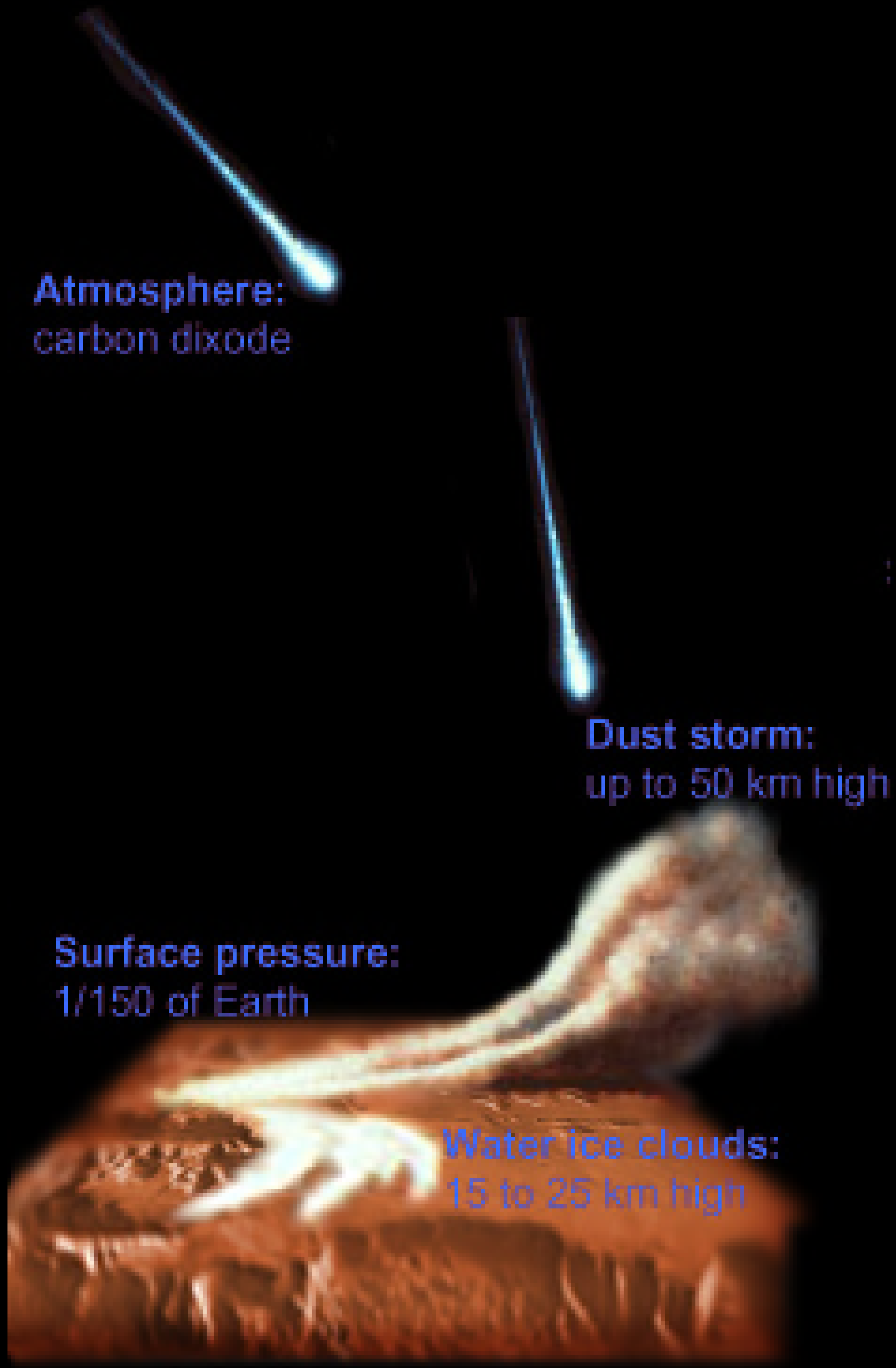
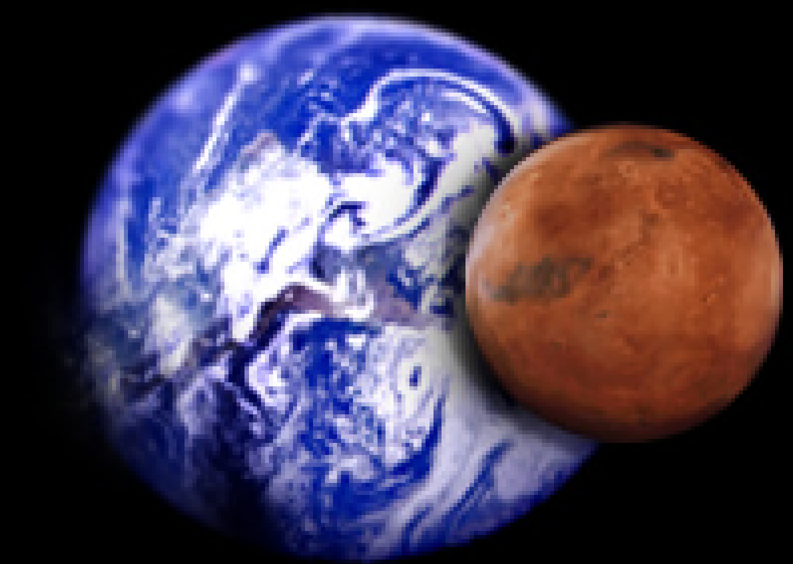
Dust, CO_2, Climate





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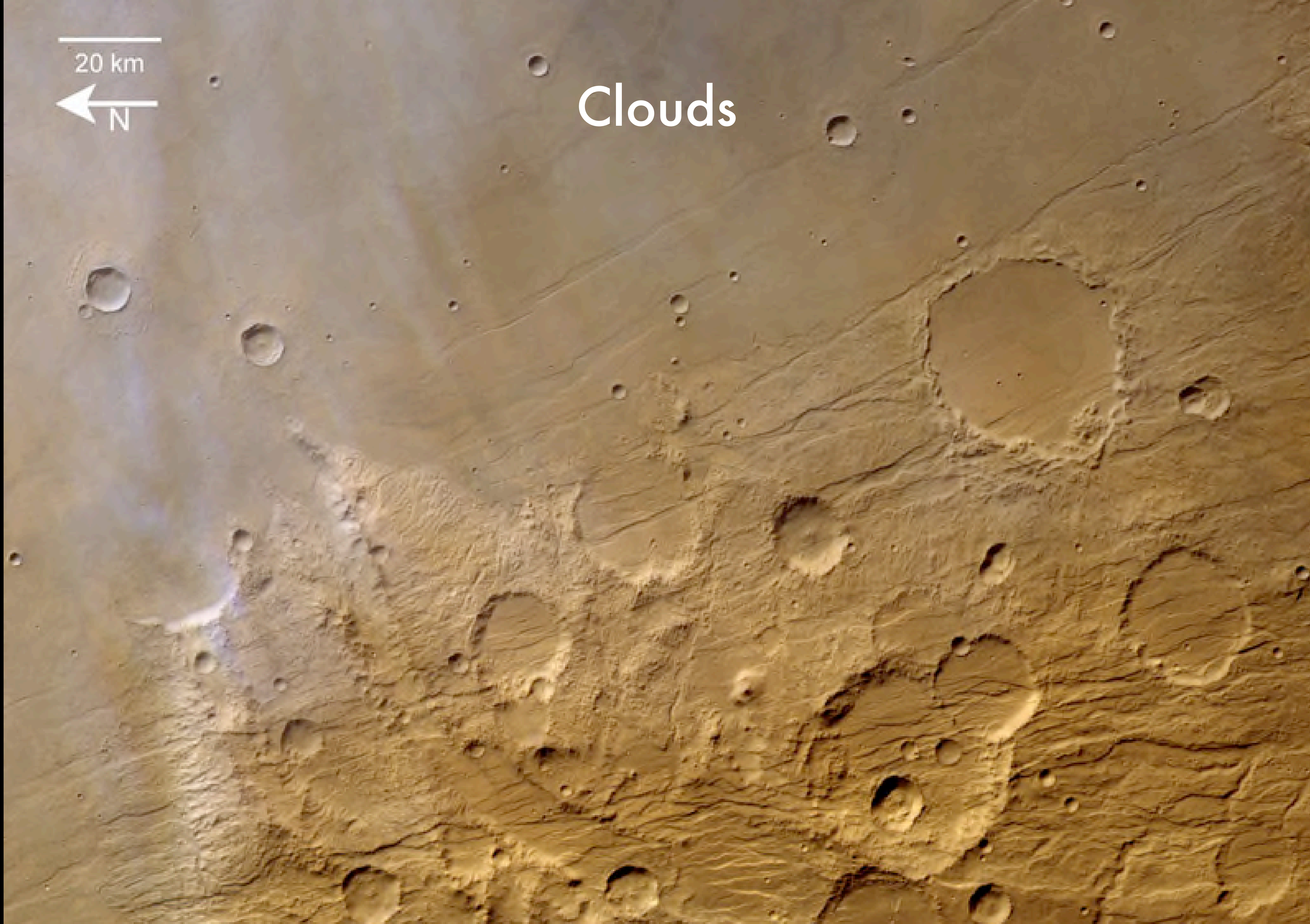
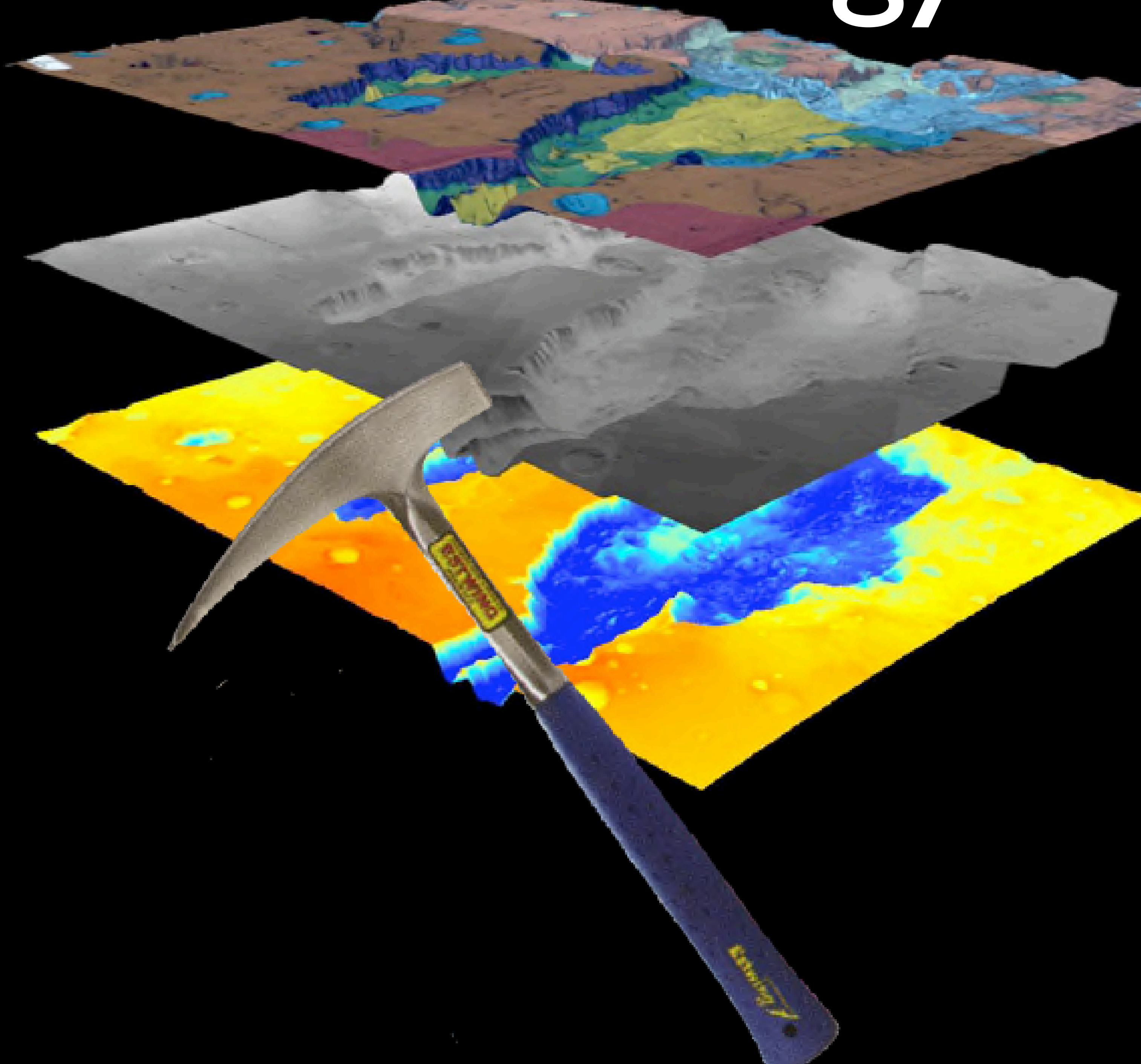
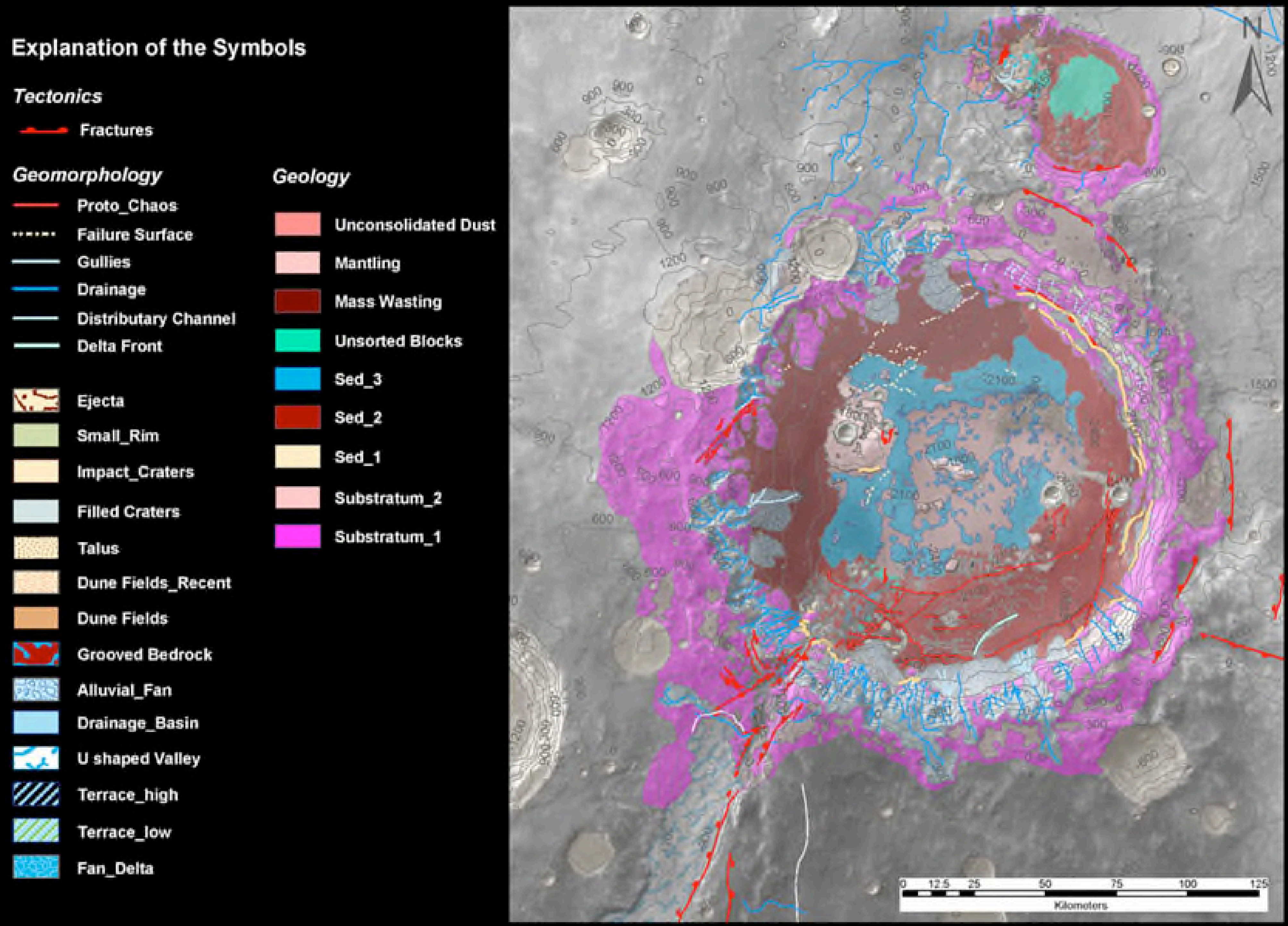

20 km
N
Clouds

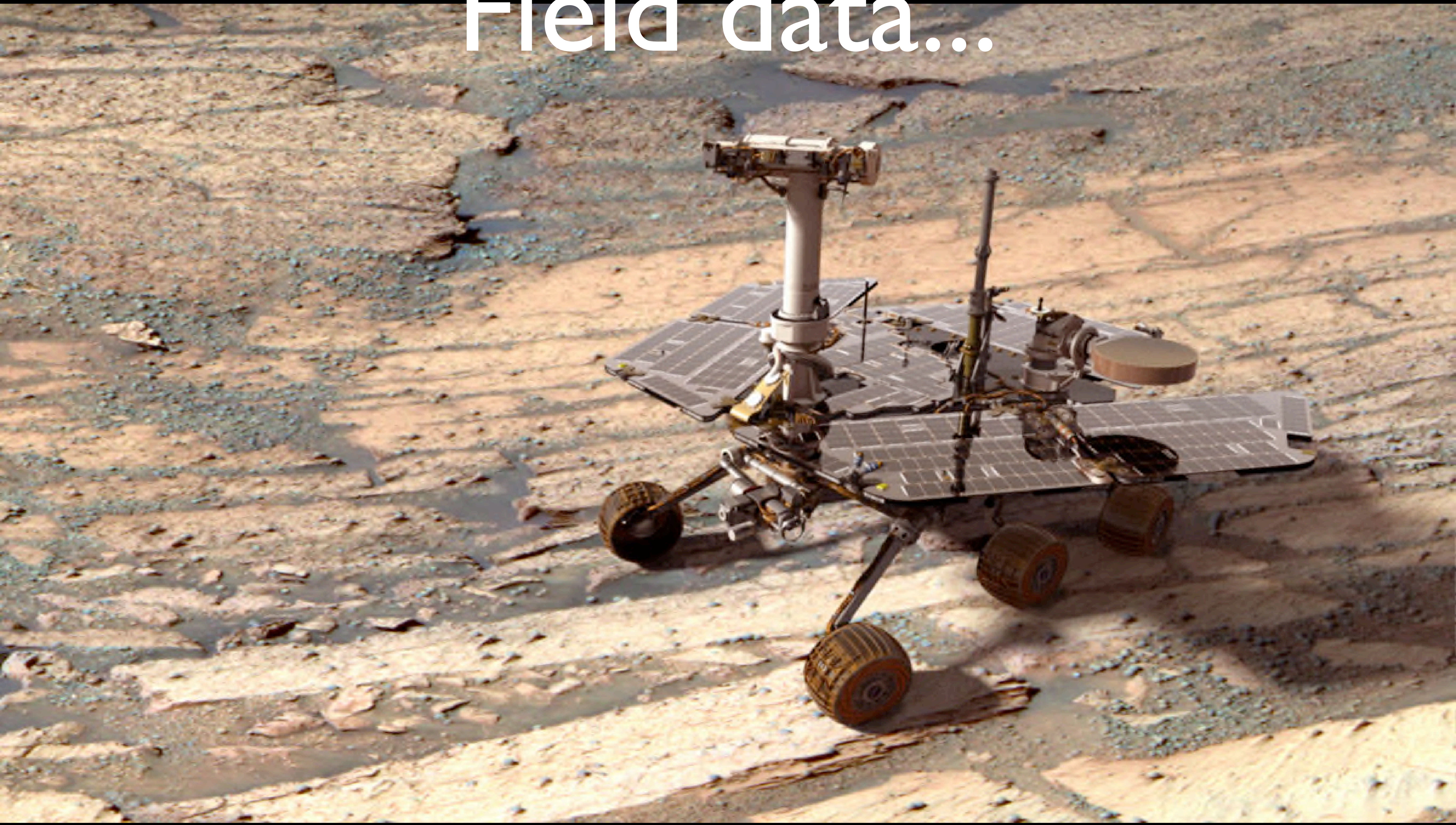
Geology on Mars?



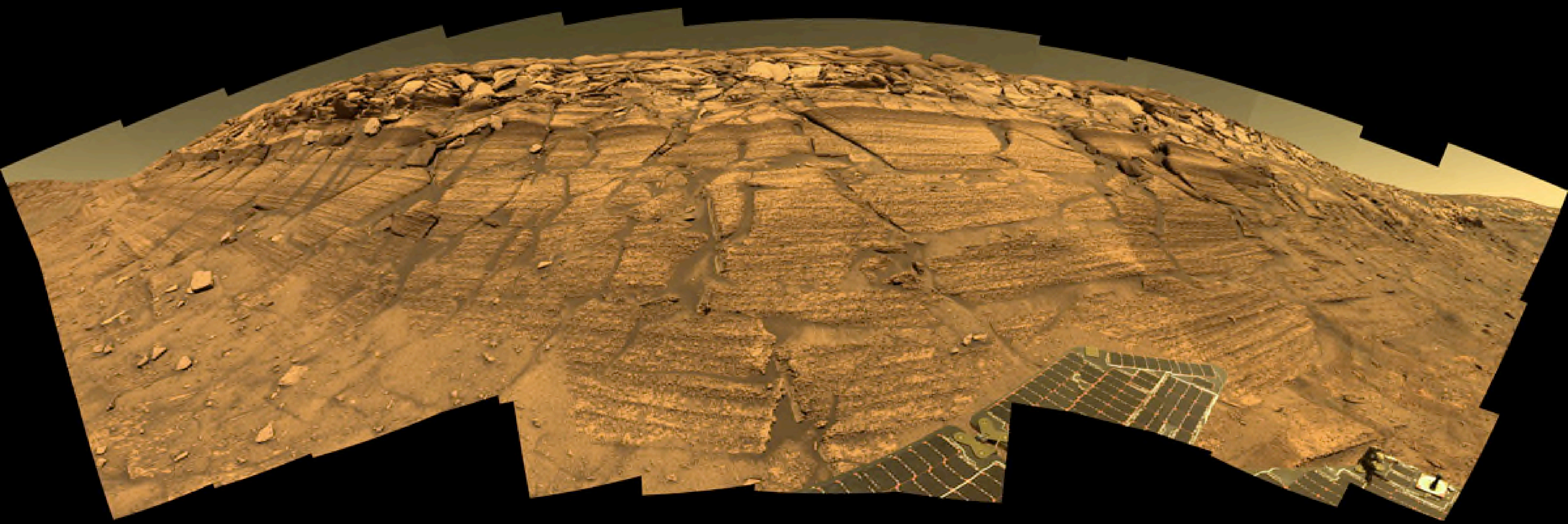
Geomorphological Mapping



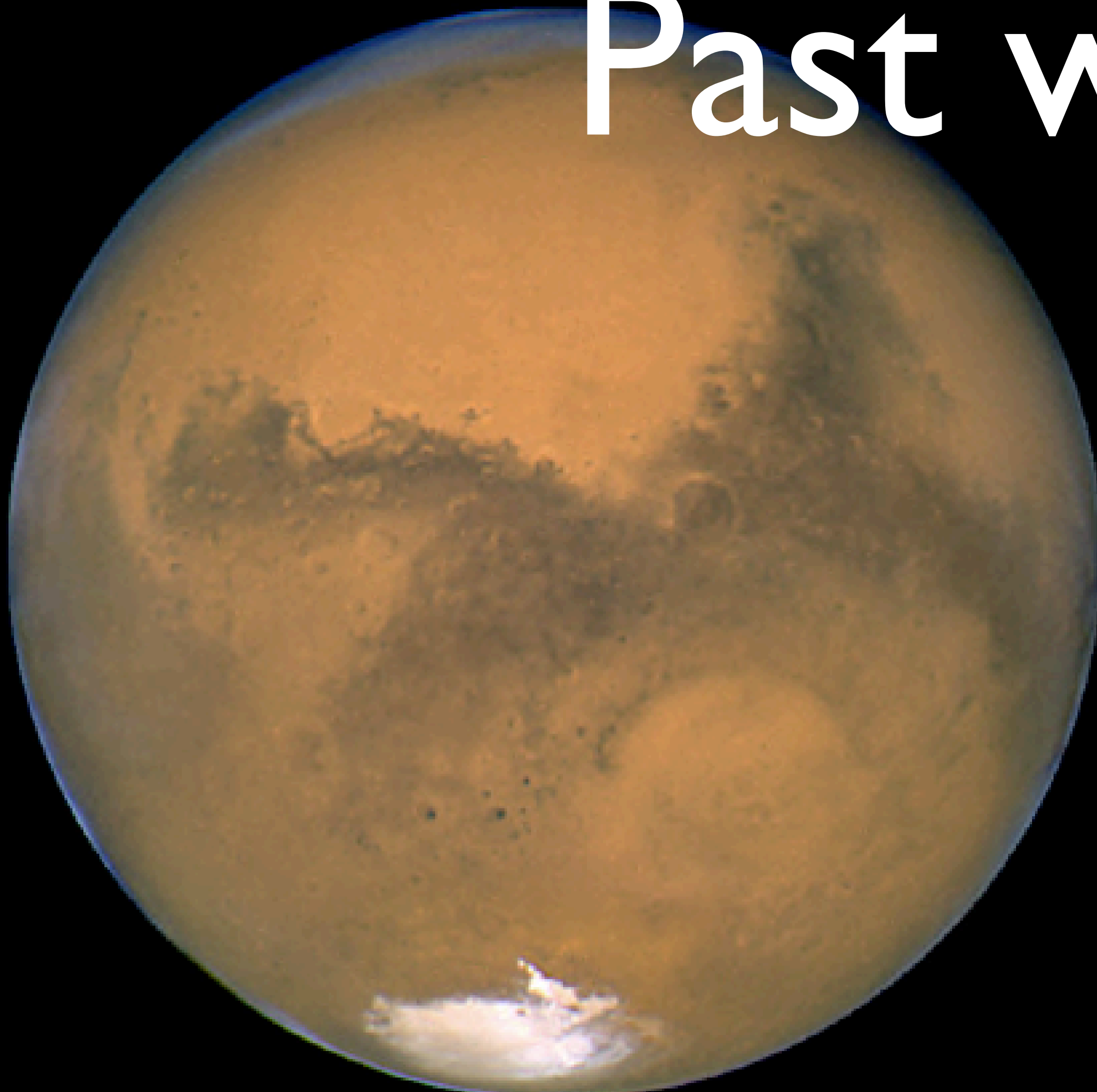
Field data...

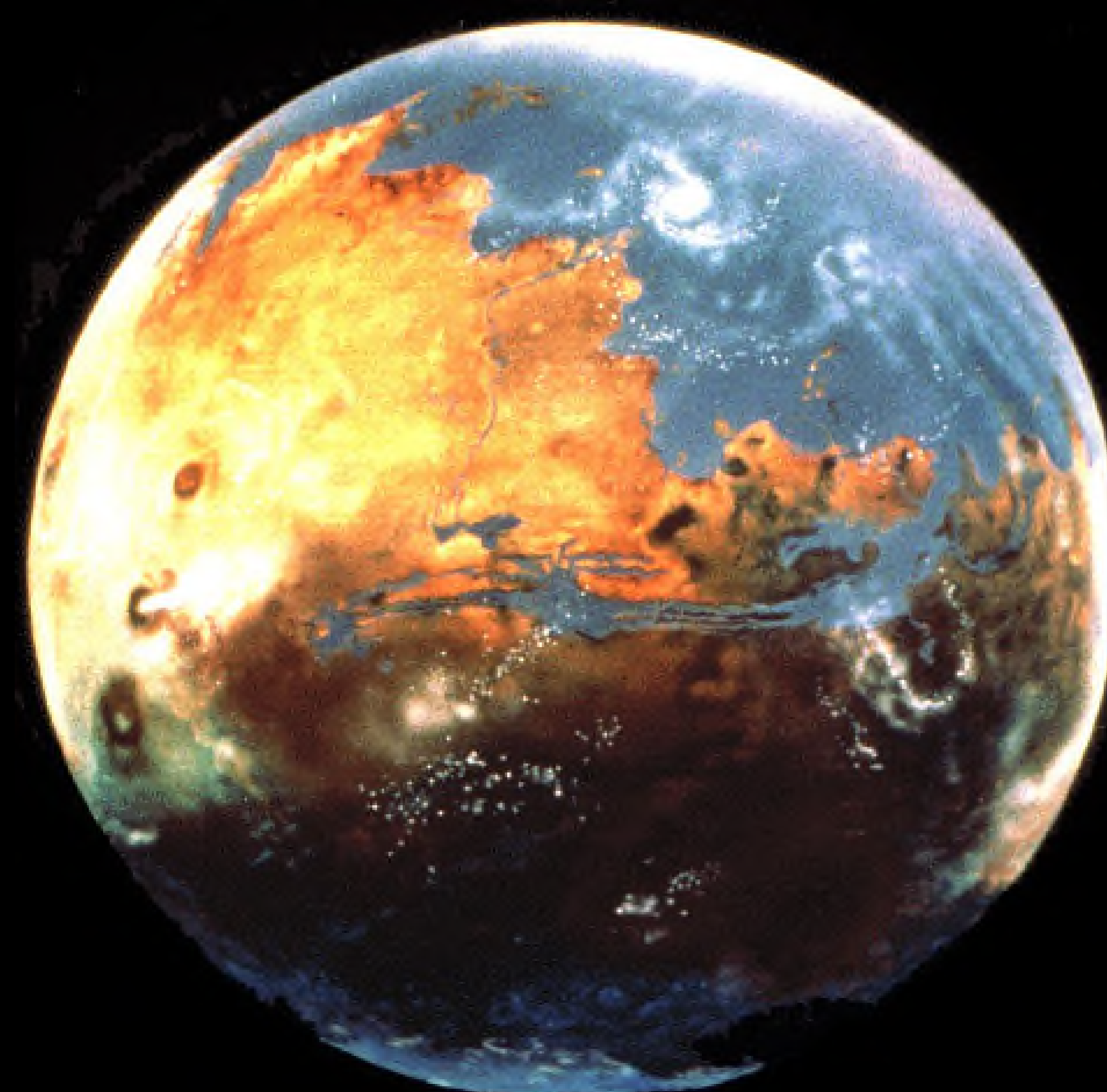


Outcrops



Past wet Mars?





Where is the water?

Estimates (in the Planetary Science community) of how much water there has ever been on the planet Mars:

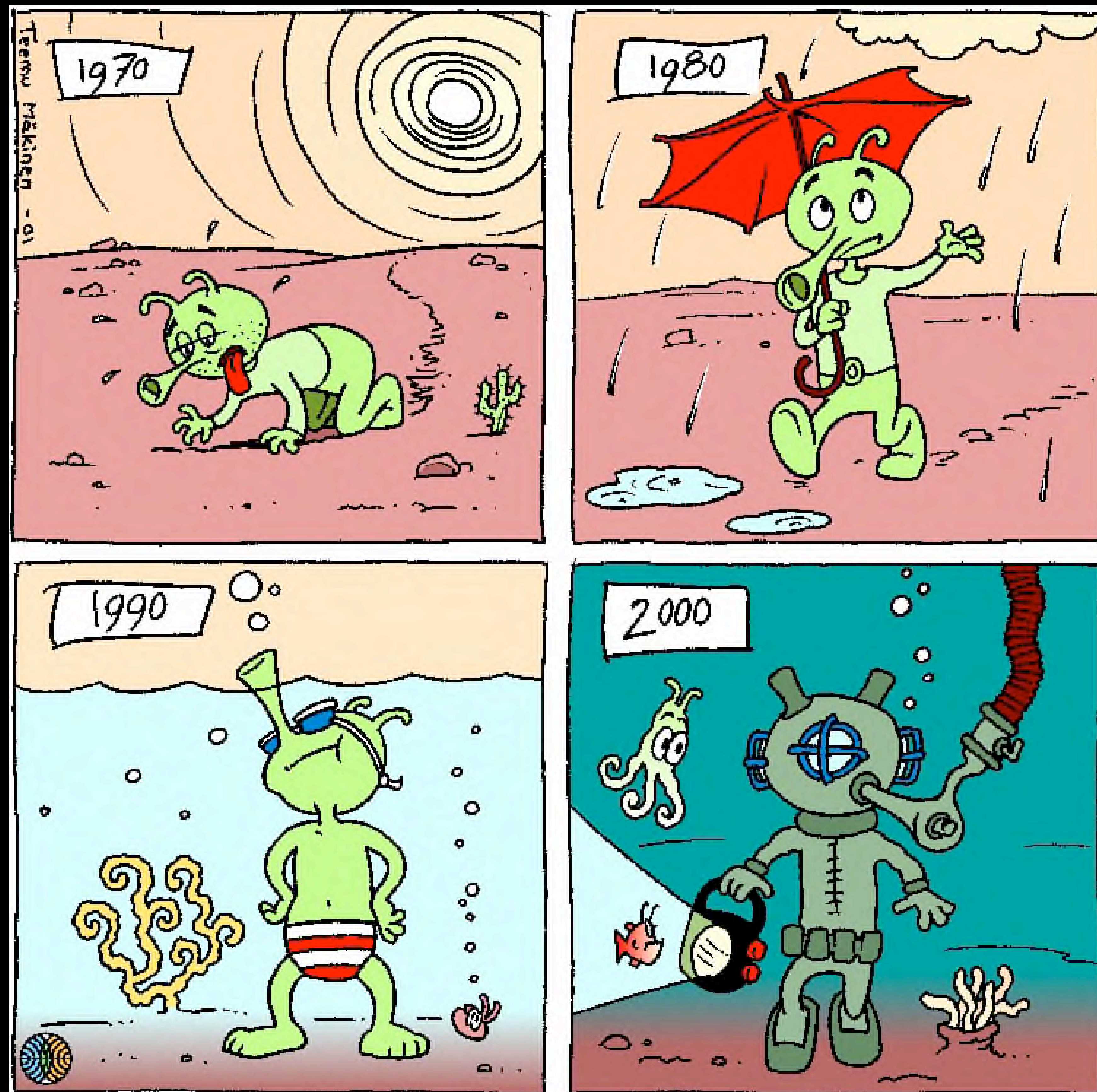
- 1970's: after Mariner-9

- 1980's: after Viking

- 1990's: after Pathfinder

- 2000's: after MGS

- Late 2000's after MEX???



ESA Solar System Missions

2013 - BEPI COLOMBO — Mercury

2005 - VENUS EXPRESS — Atmosphere & Surface

2004 - ROSETTA — Comet Orbiter & Lander

2003 - SMART-1 — Moon & Technology

2003 - MARS EXPRESS — Planetology & Exobiology

1997 - CASSINI-HUYGENS — Titan Probe

1986 - GIOTTO — Halley's Comet Fly-by

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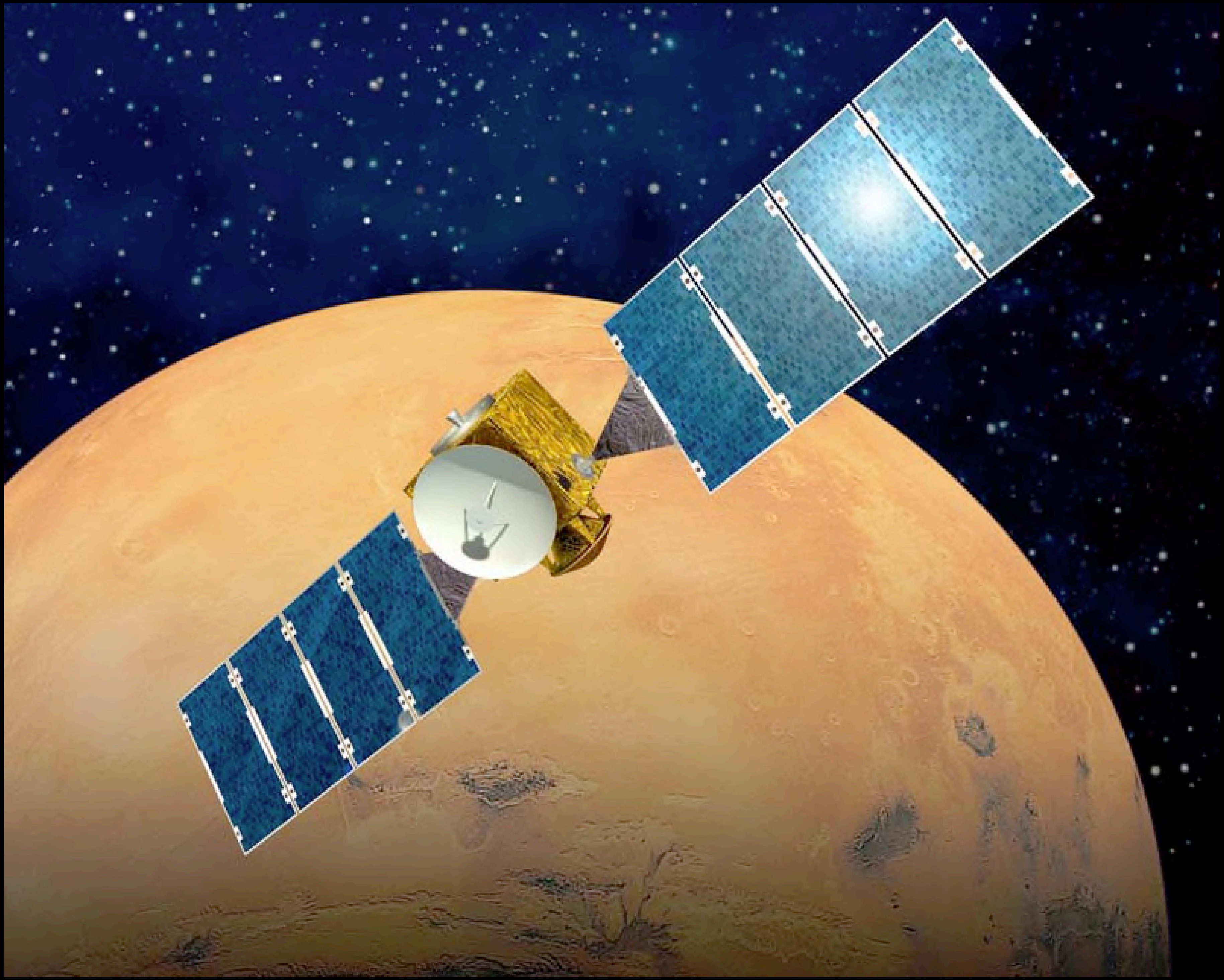
Mars Espress



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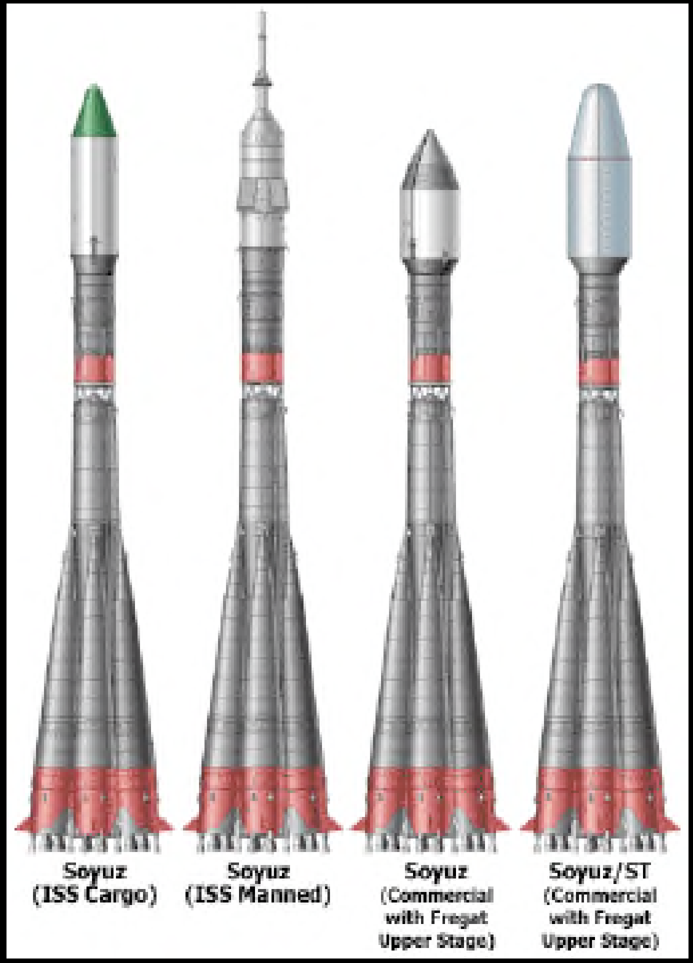
Soyuz rocket

- Overview
  - First launched in 1963
  - Used more than 1600 times (98%)
  - Manned and unmanned versions
  - Built in Samara, Russia
  - Assembled in Baikonur
- 3+1 Stages
  - S1: 4 boosters around central core
  - S2: cylindrical core
  - S3: payload adapter and fairing
  - S4: Fregat (tested) for use with MEX
- Characteristics
  - Lift-off weight: 304 tons (prop. 279 t)
  - Total height: 43.5 m
  - Figures include MEX mass (~1200 kg)



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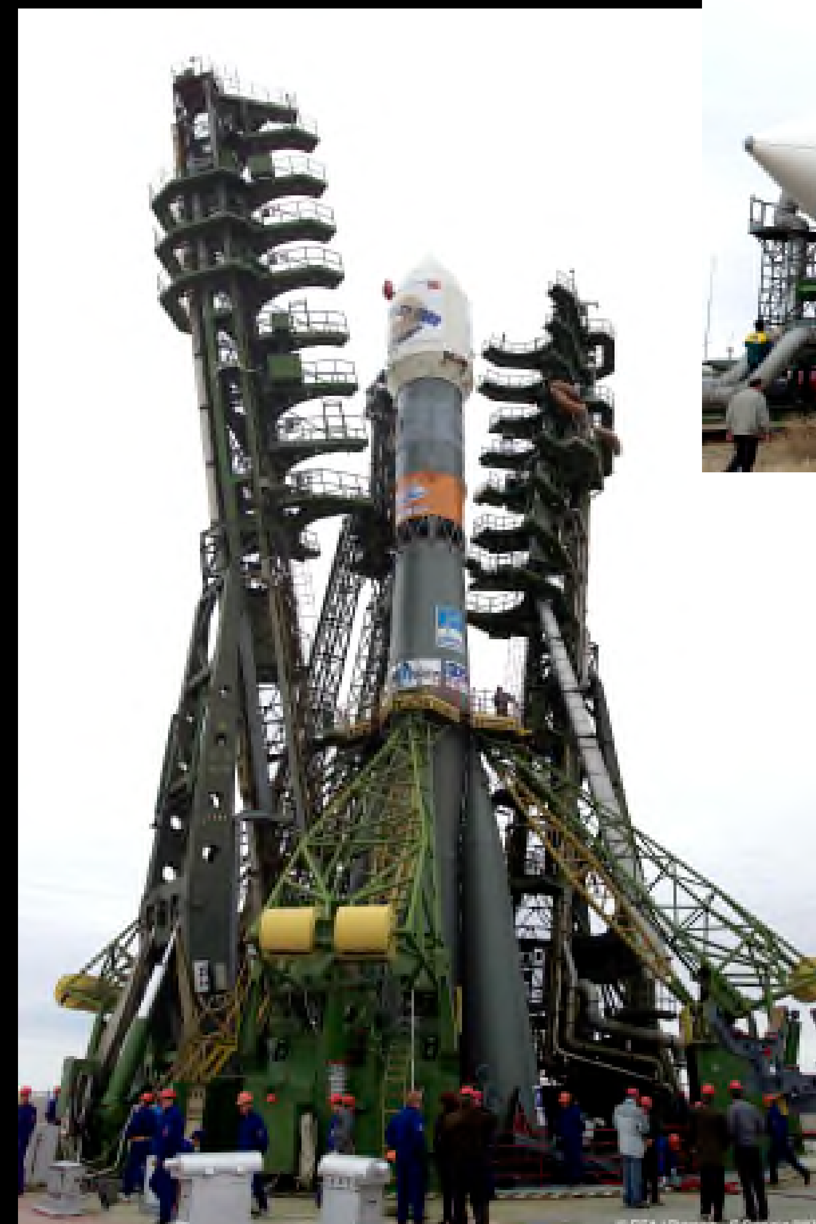
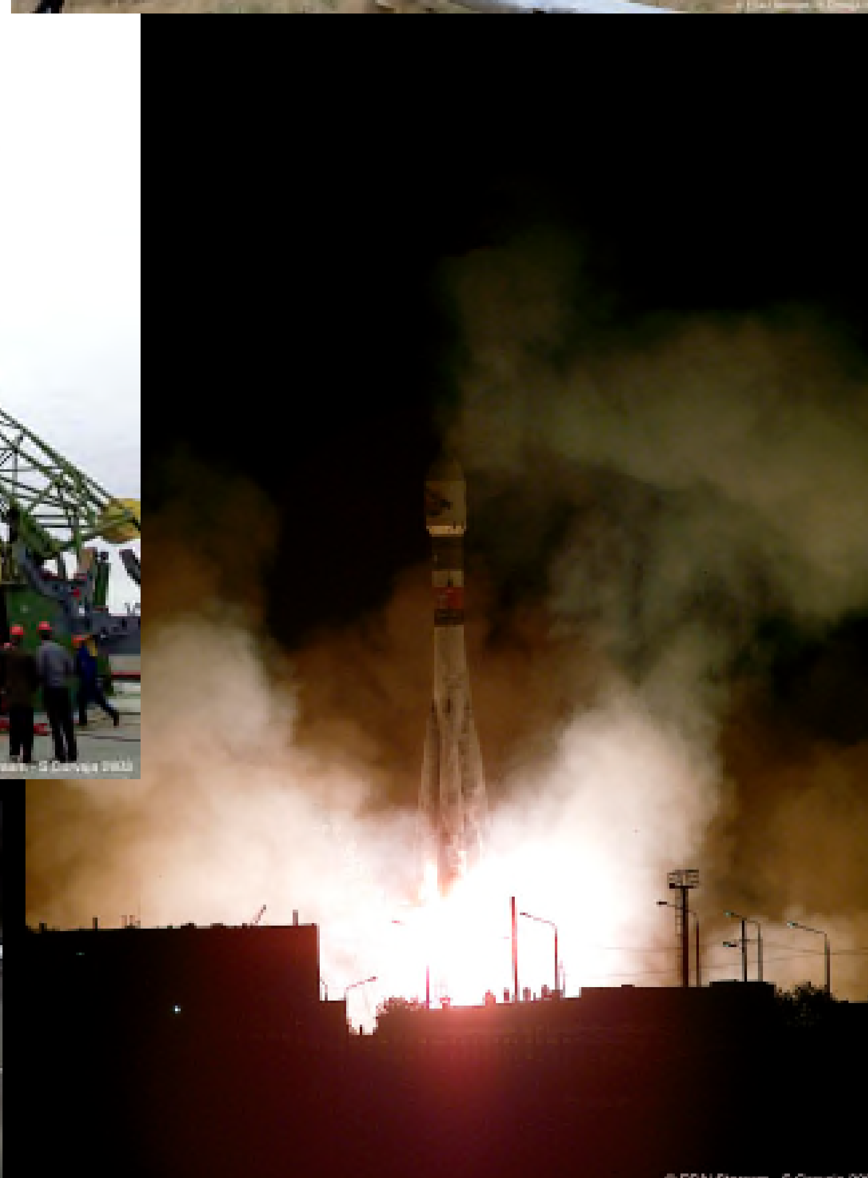
Launch

- Overview
  - Soyuz launch number 1677
  - Fregat stage use: 5th time
  - Roll-out: 4 days before launch
  - Tanks fill-up: 4 h before launch
- Time
  - Monday, 02 June 2003
  - 23:45:26 local (Kazakhstan)
  - Moscow time (-2h); CEST (-4h)
  - Fair weather, some wind
- Characteristics
  - MEX mass load: 1223 kg
  - Window up to 14/06 for mass load
  - Two launch slots (02-03/06)
  - All systems nominal (green)





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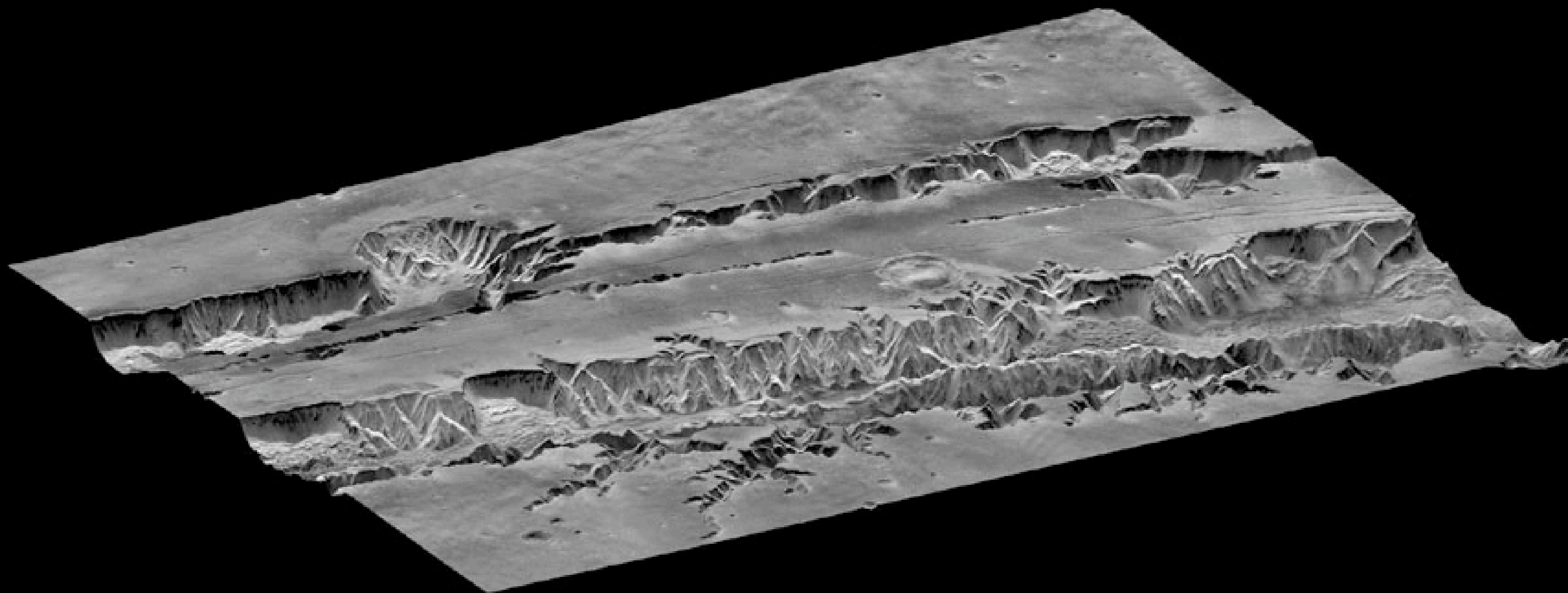
High Resolution Stereo Camera (HRSC)



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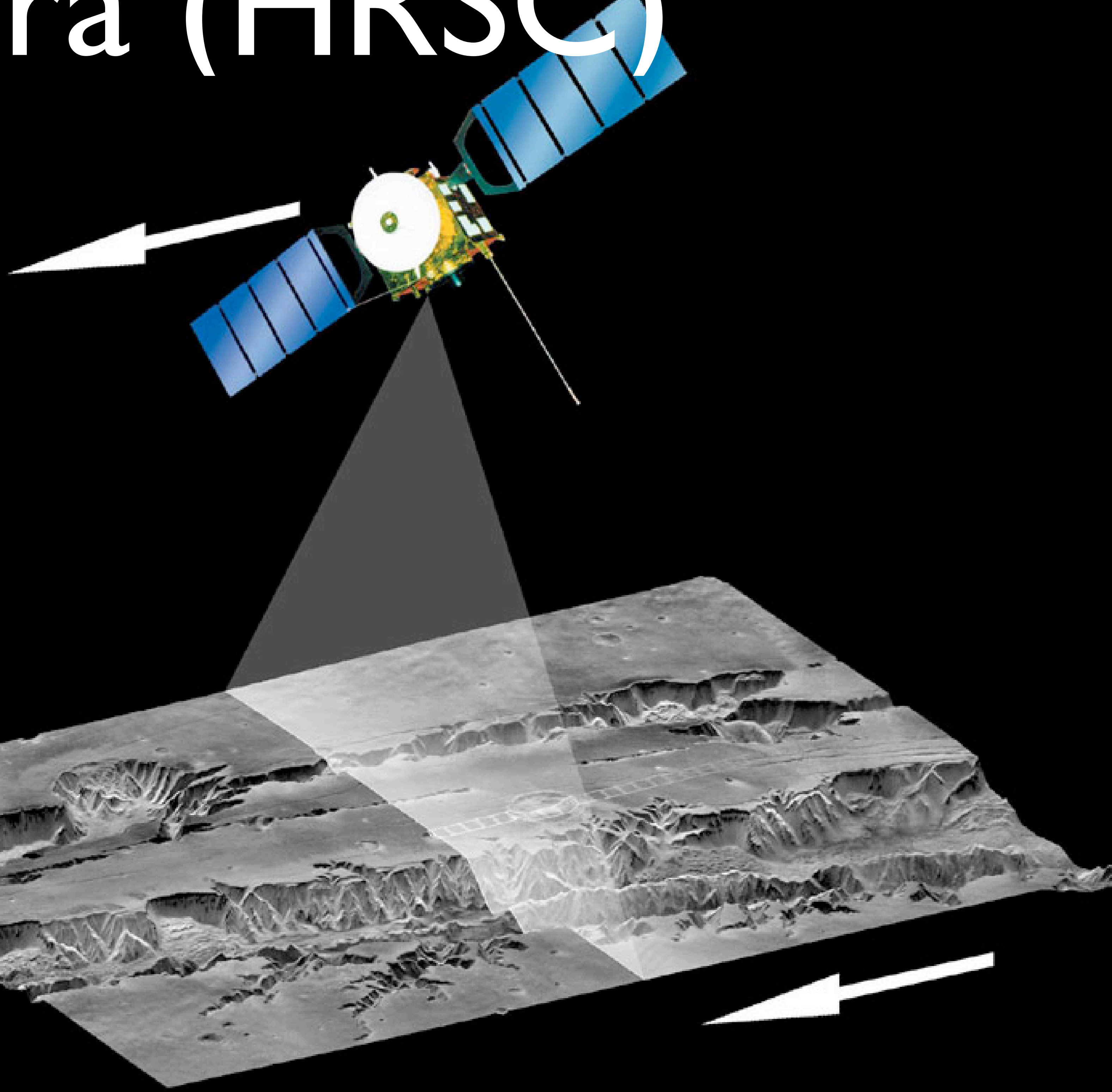
High Resolution Stereo Camera (HRSC)



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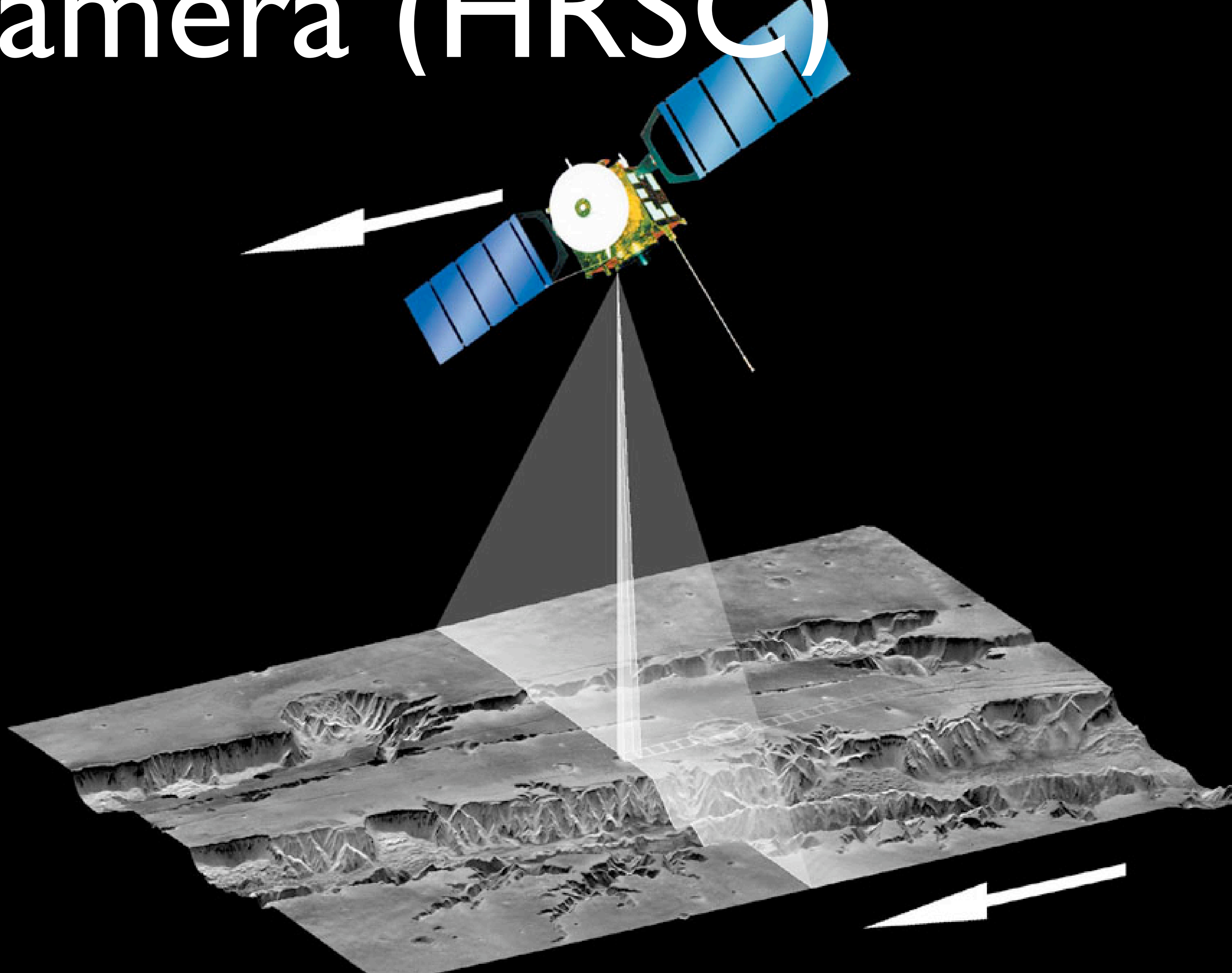

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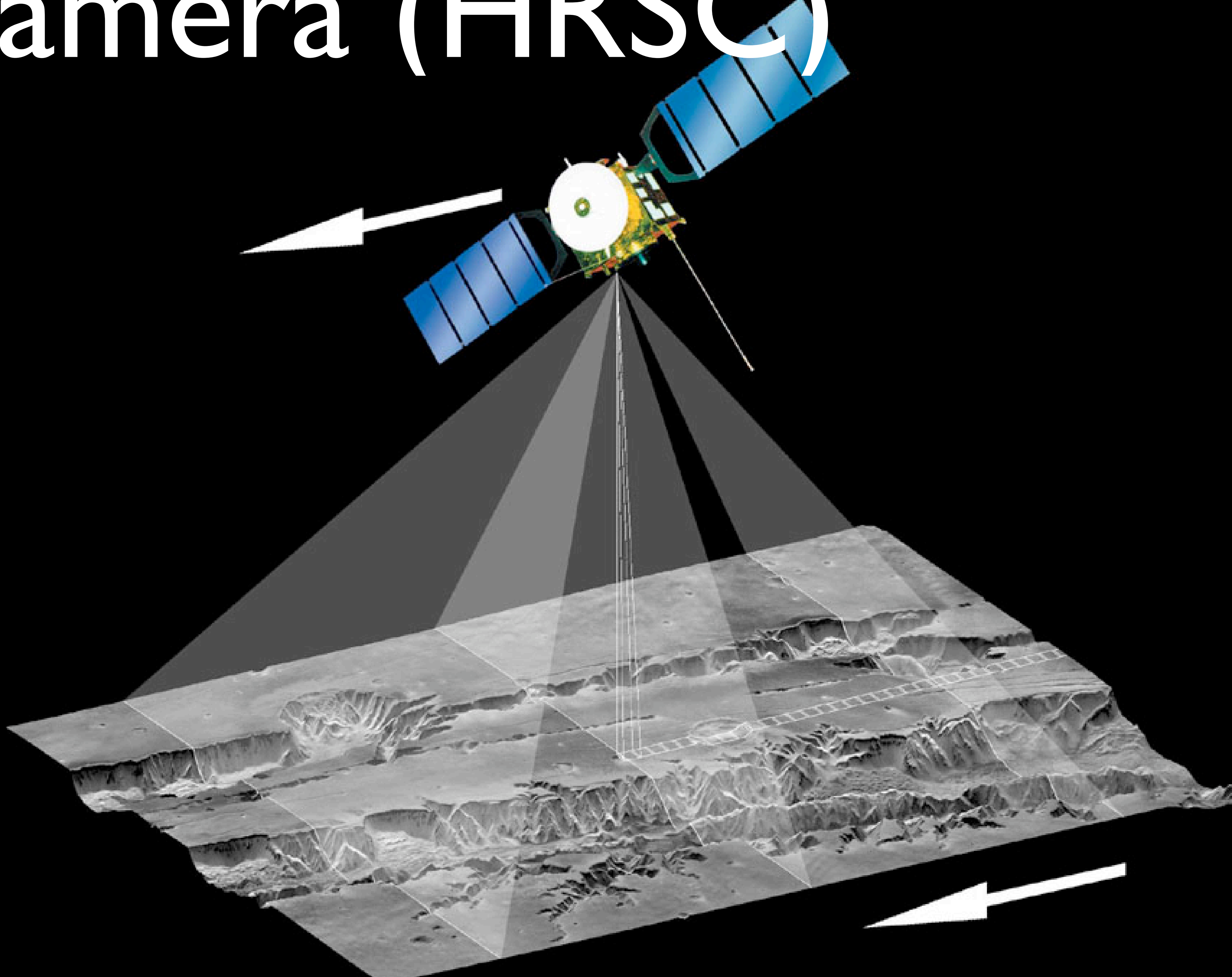
High Resolution Stereo Camera (HRSC)



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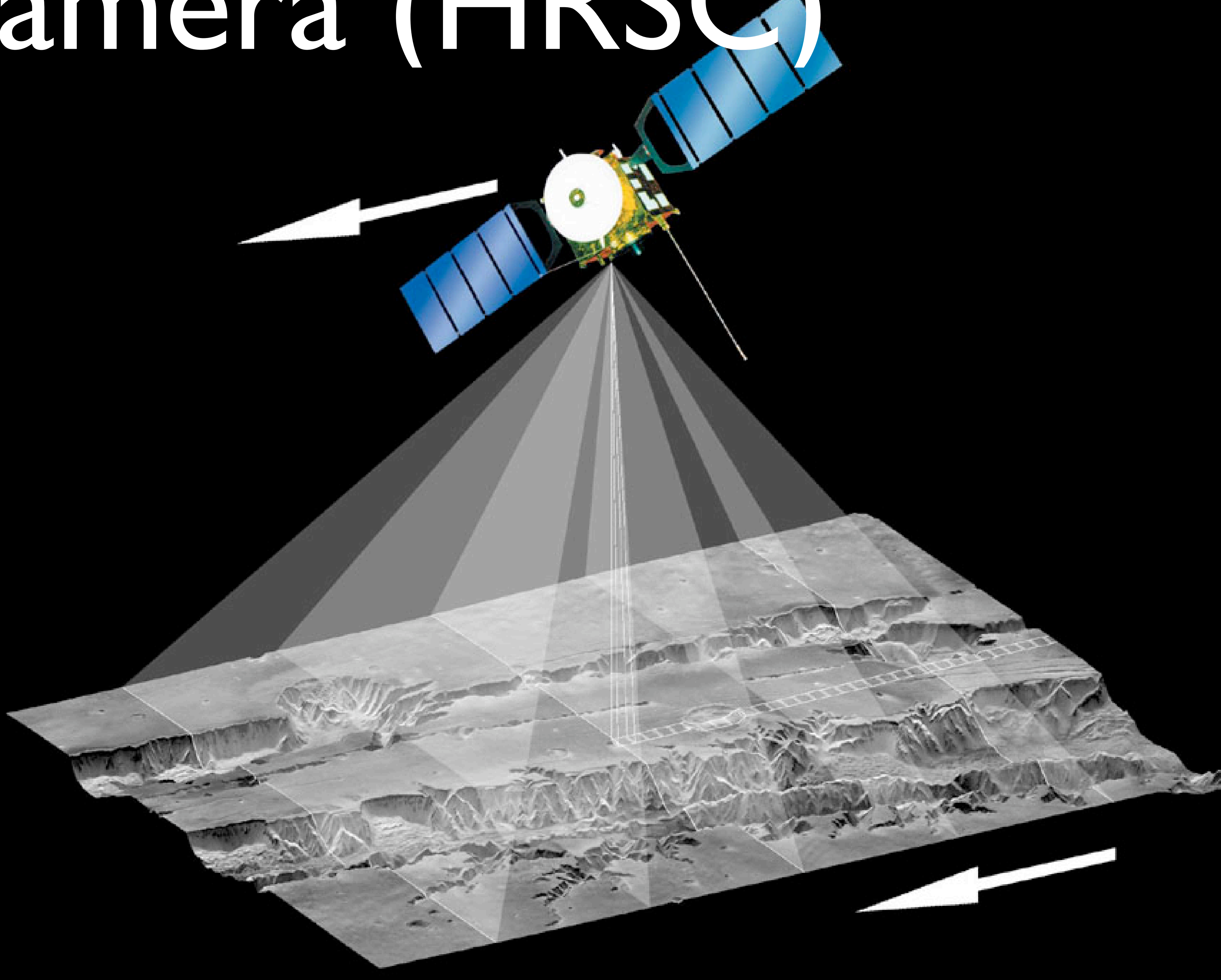
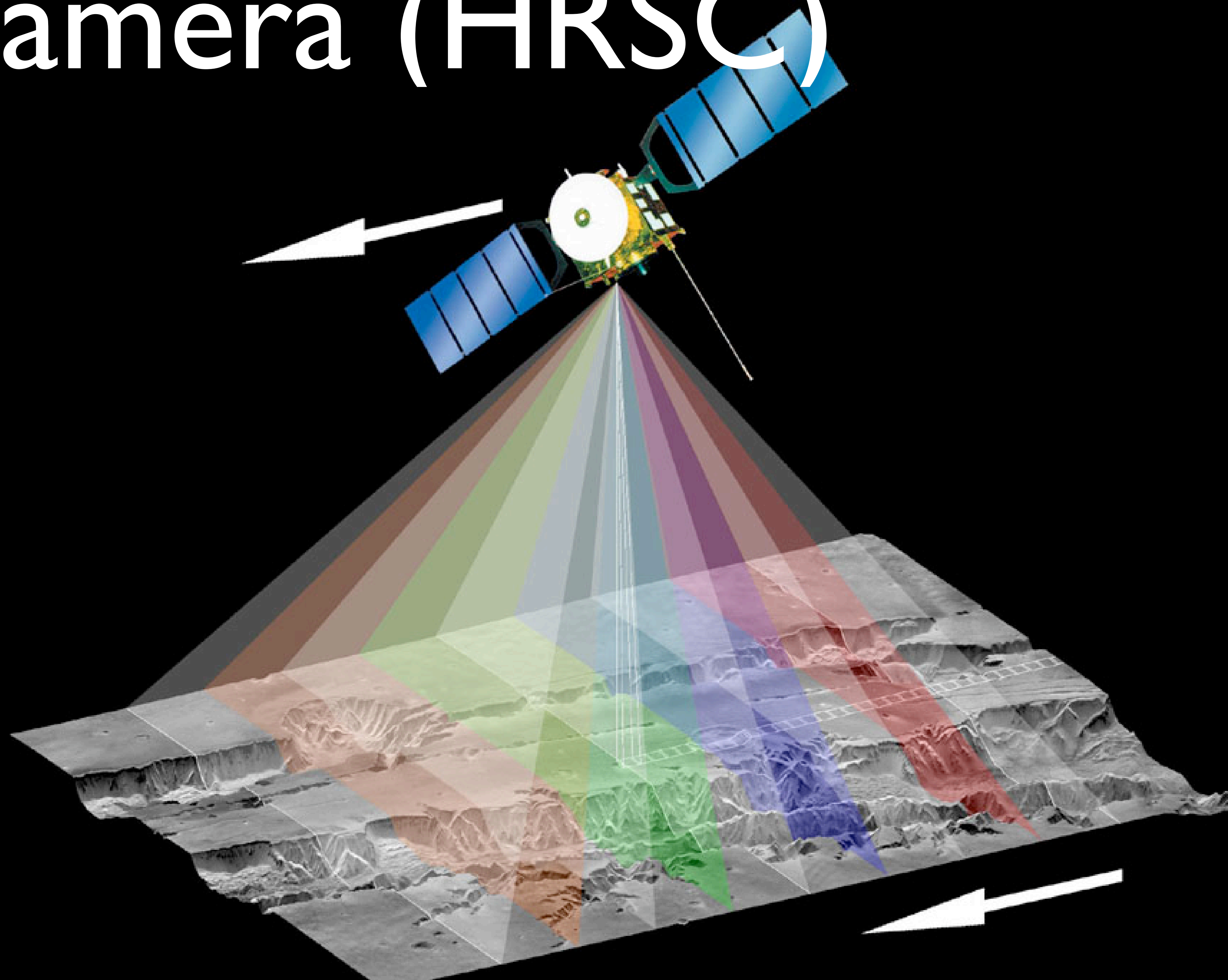


High Resolution Stereo Camera (HRSC)



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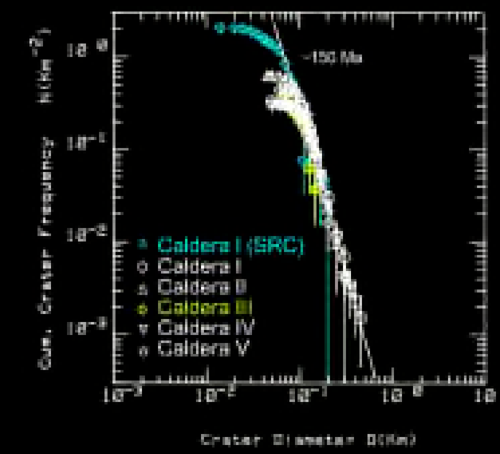
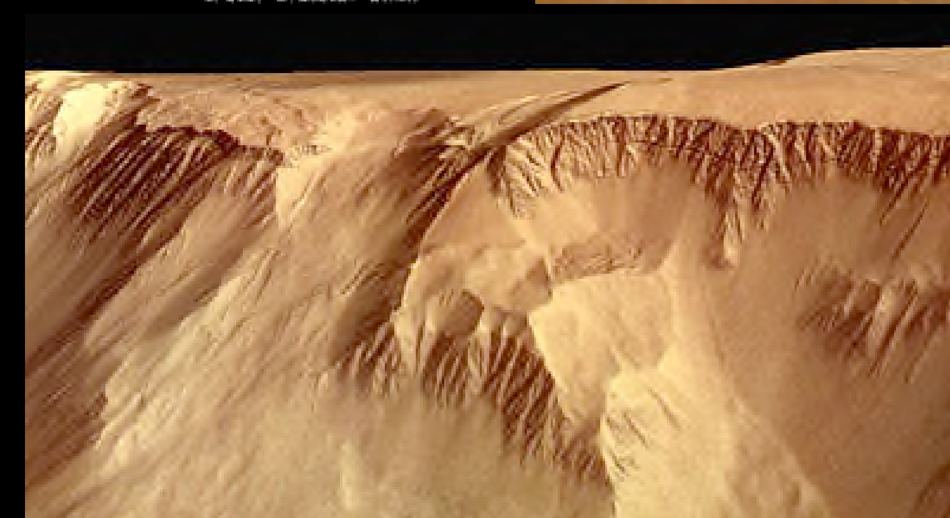
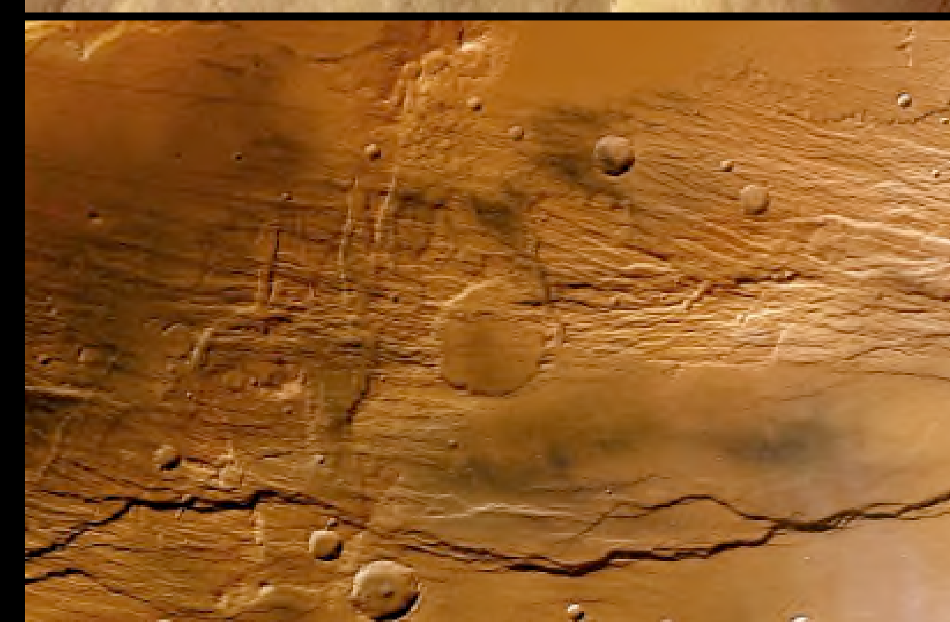
HRSC Results







HRSC

- Much more recent geological ages than previously estimated (one order of magnitude) for volcanic processes and glacial processes, which means that the planet is basically "active" today.
- Confirmation of glacial processes in current equatorial regions. Glacial, not fluvial activity, in combination with volcanic activity, seems to have dominated the evolution of the surface of Mars.
- No evidence of a large ocean in the Northern lowlands from HRSC data, as hypothesized in previous investigations.
- Climate change (cold/wet colder/dry) occurred early in Martian history.

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Valles Marineris

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Polar deposits

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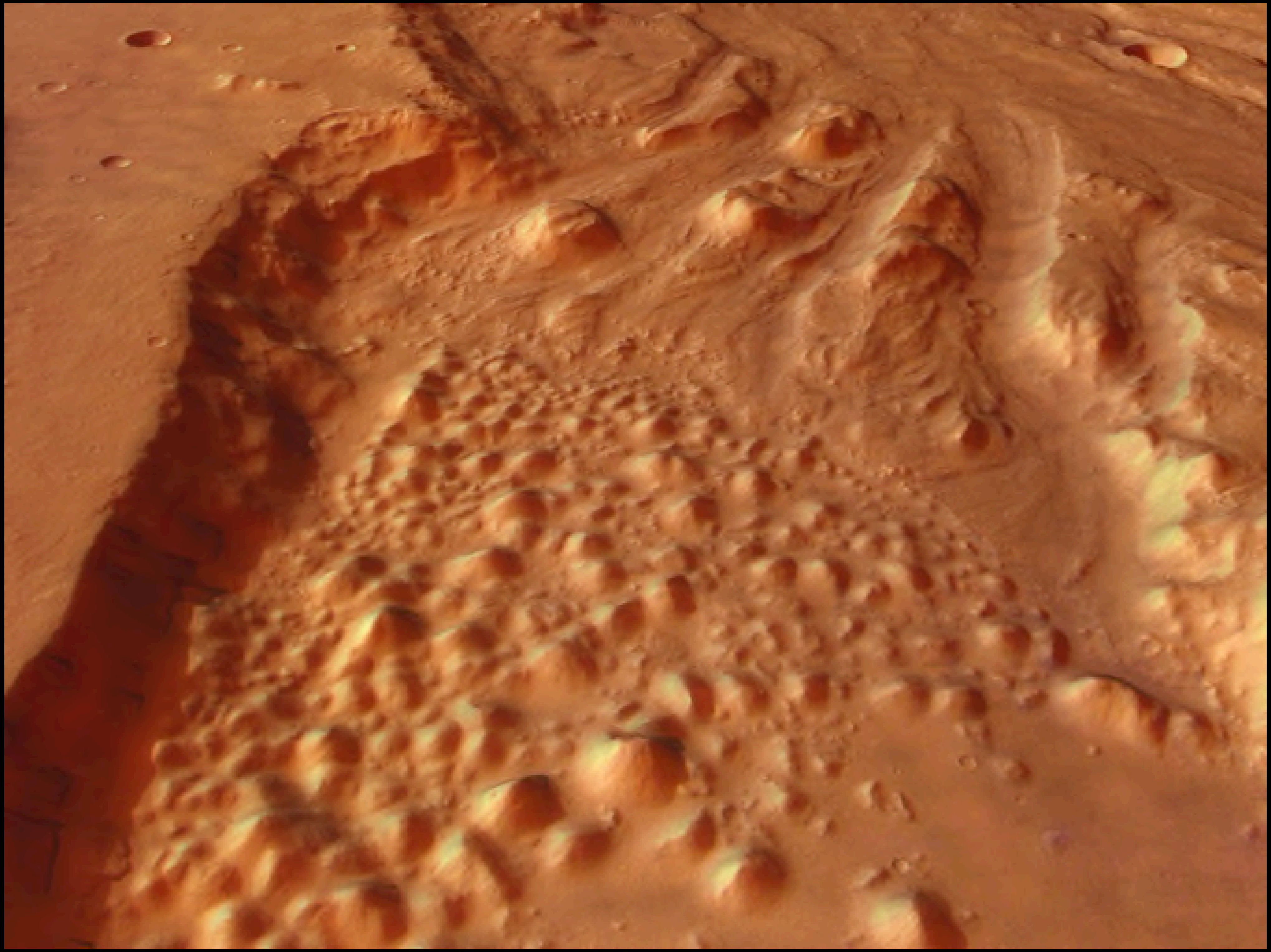
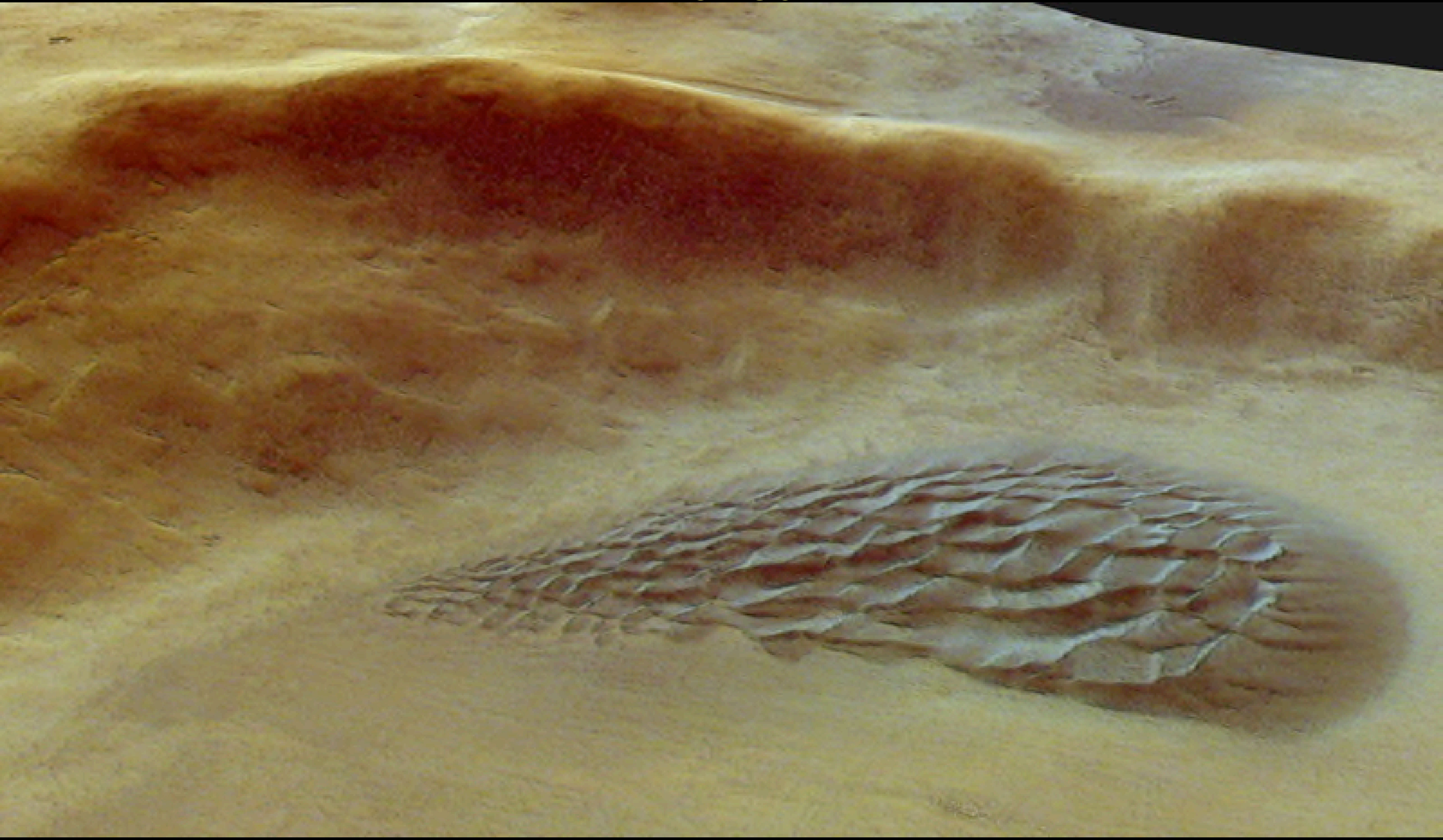
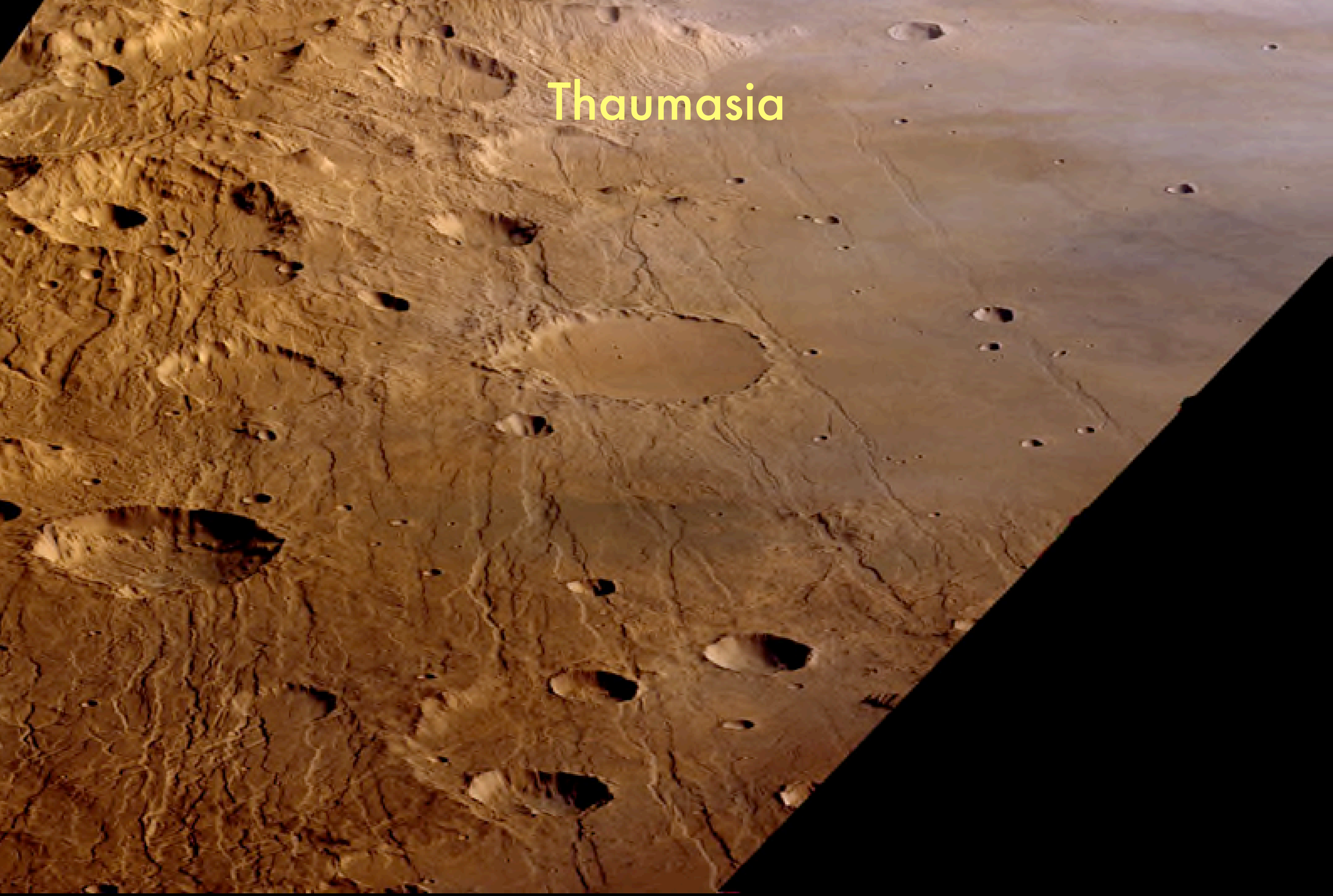
Chaotic terrains

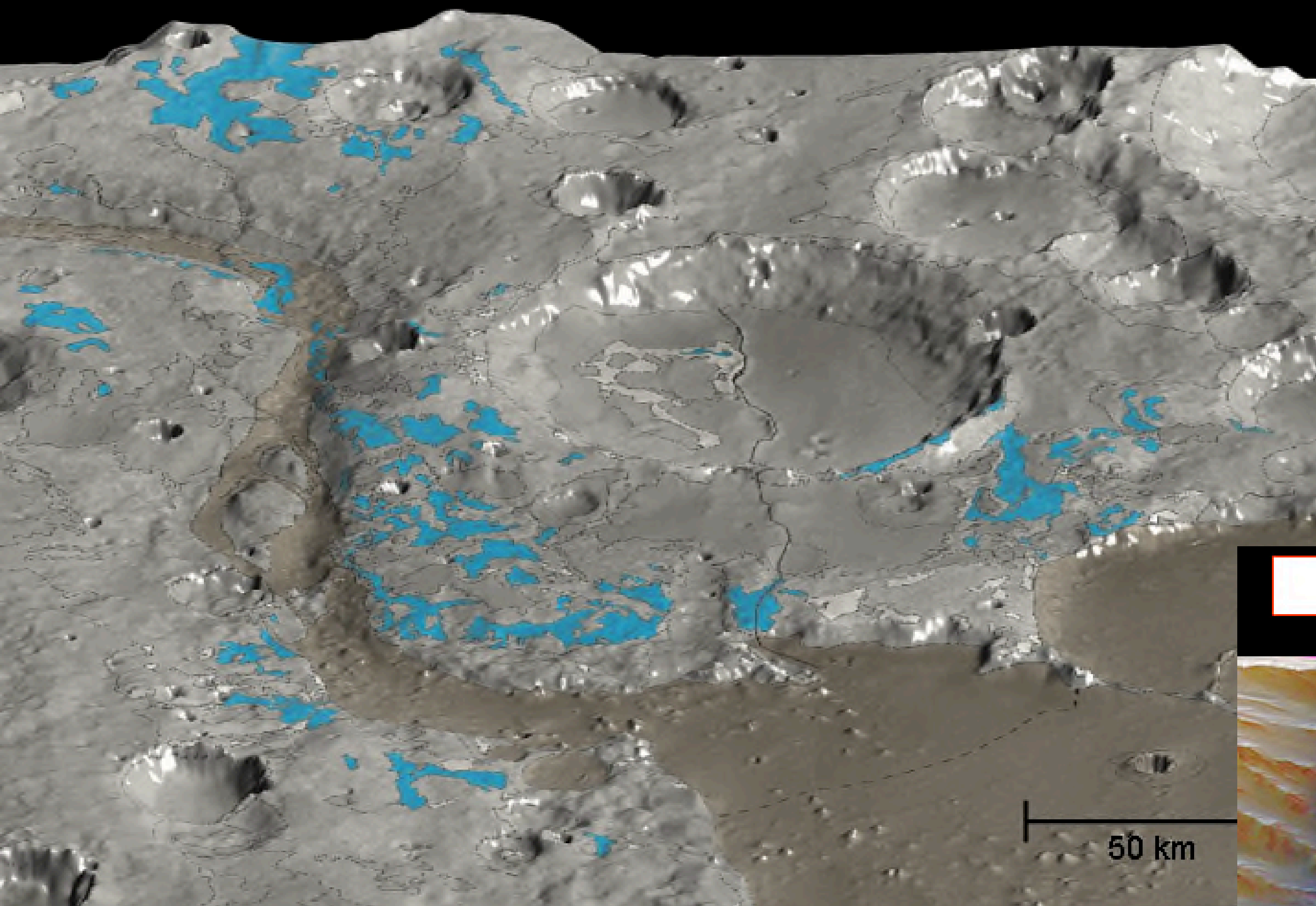


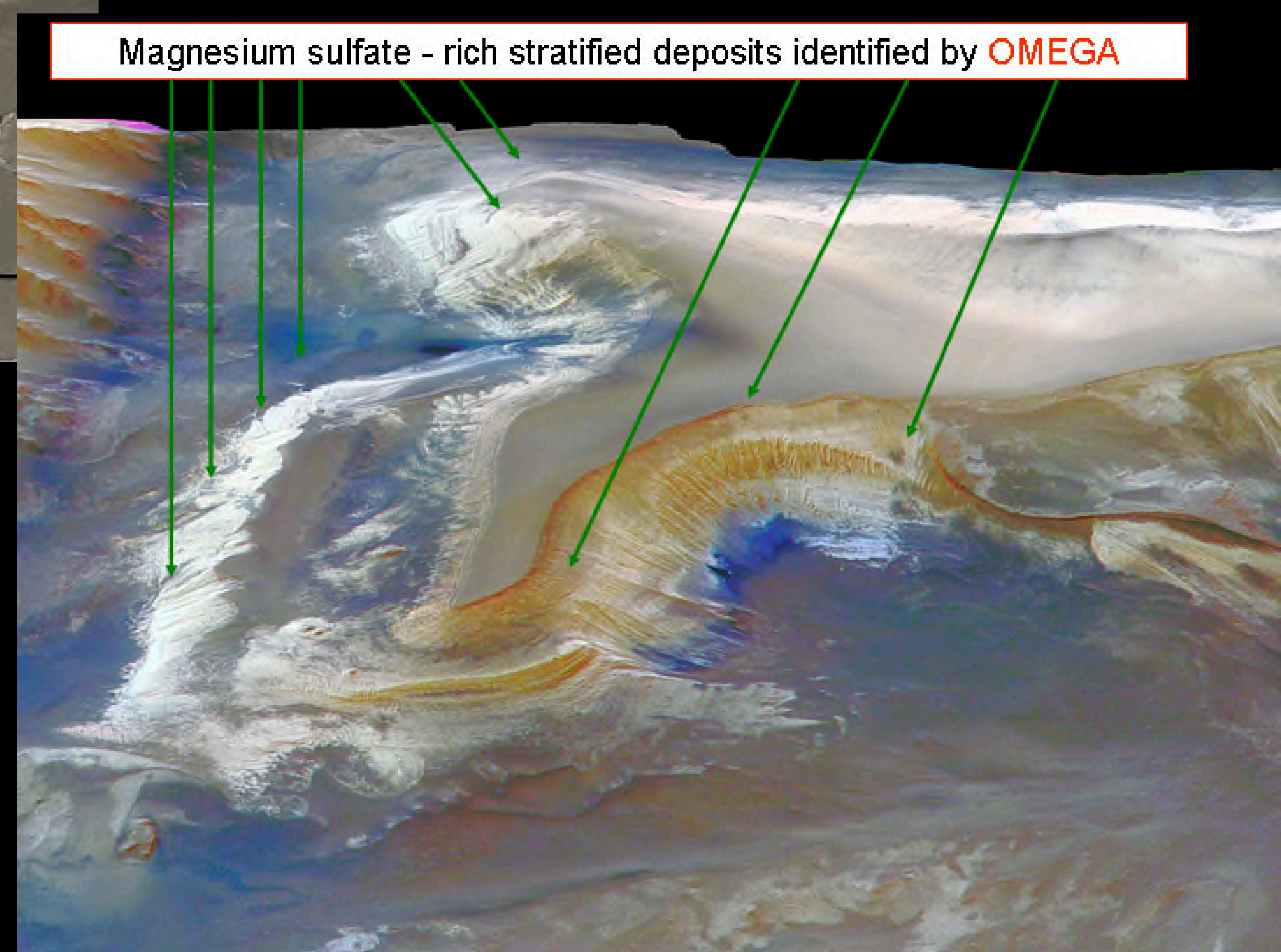
Dunes




Thaumasia

Minerals revealed on the surface (OMEGA)





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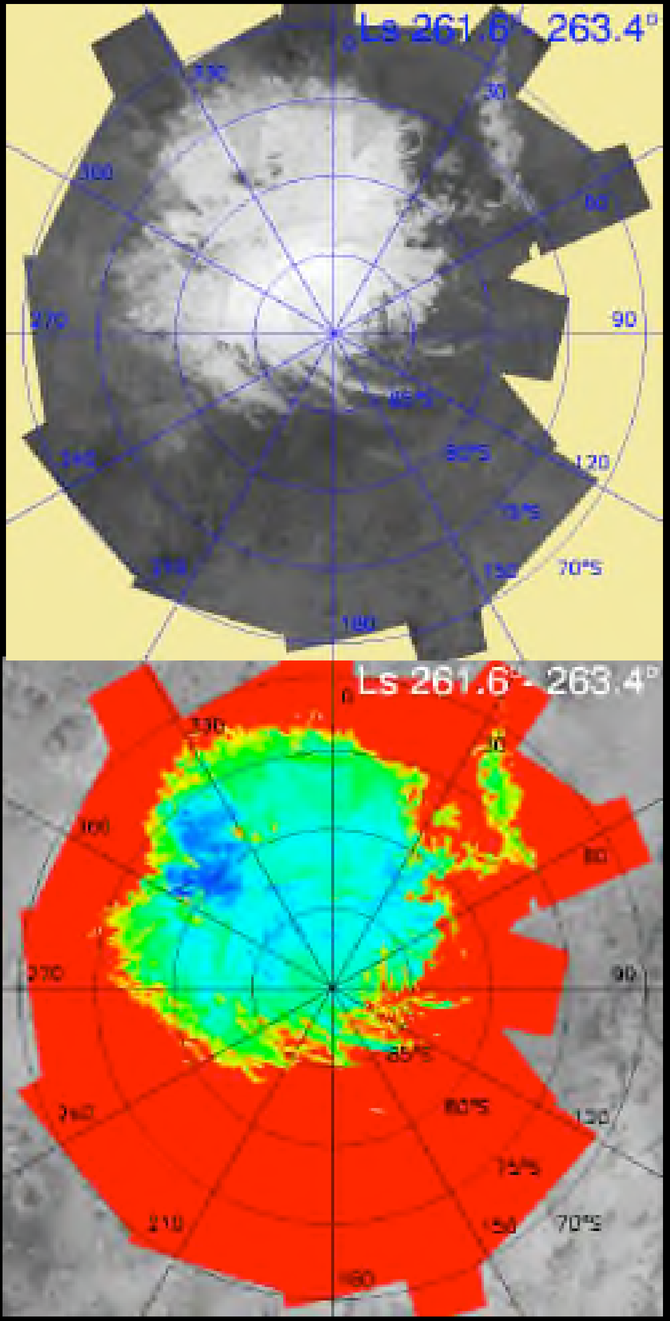
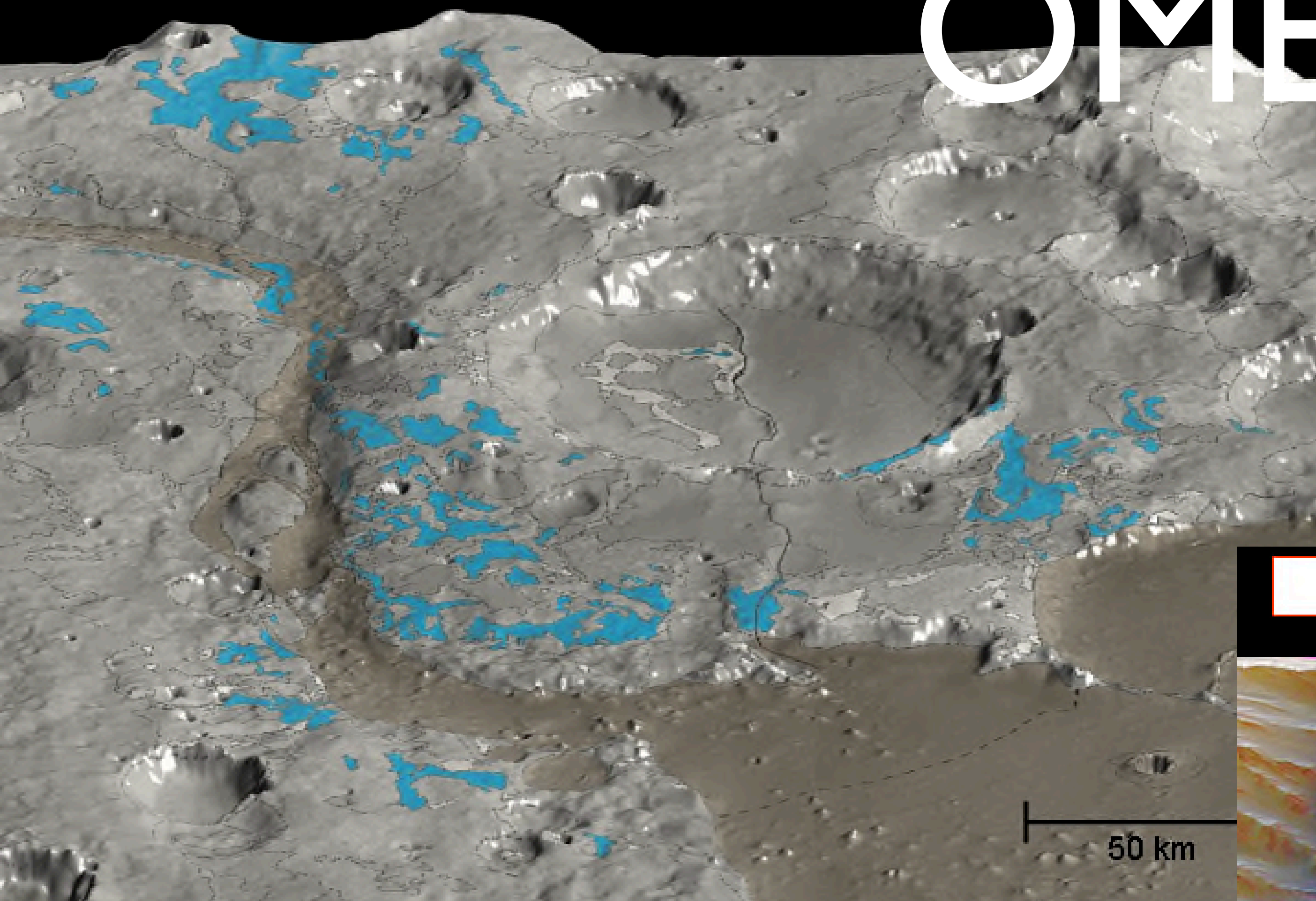
OMEGA results

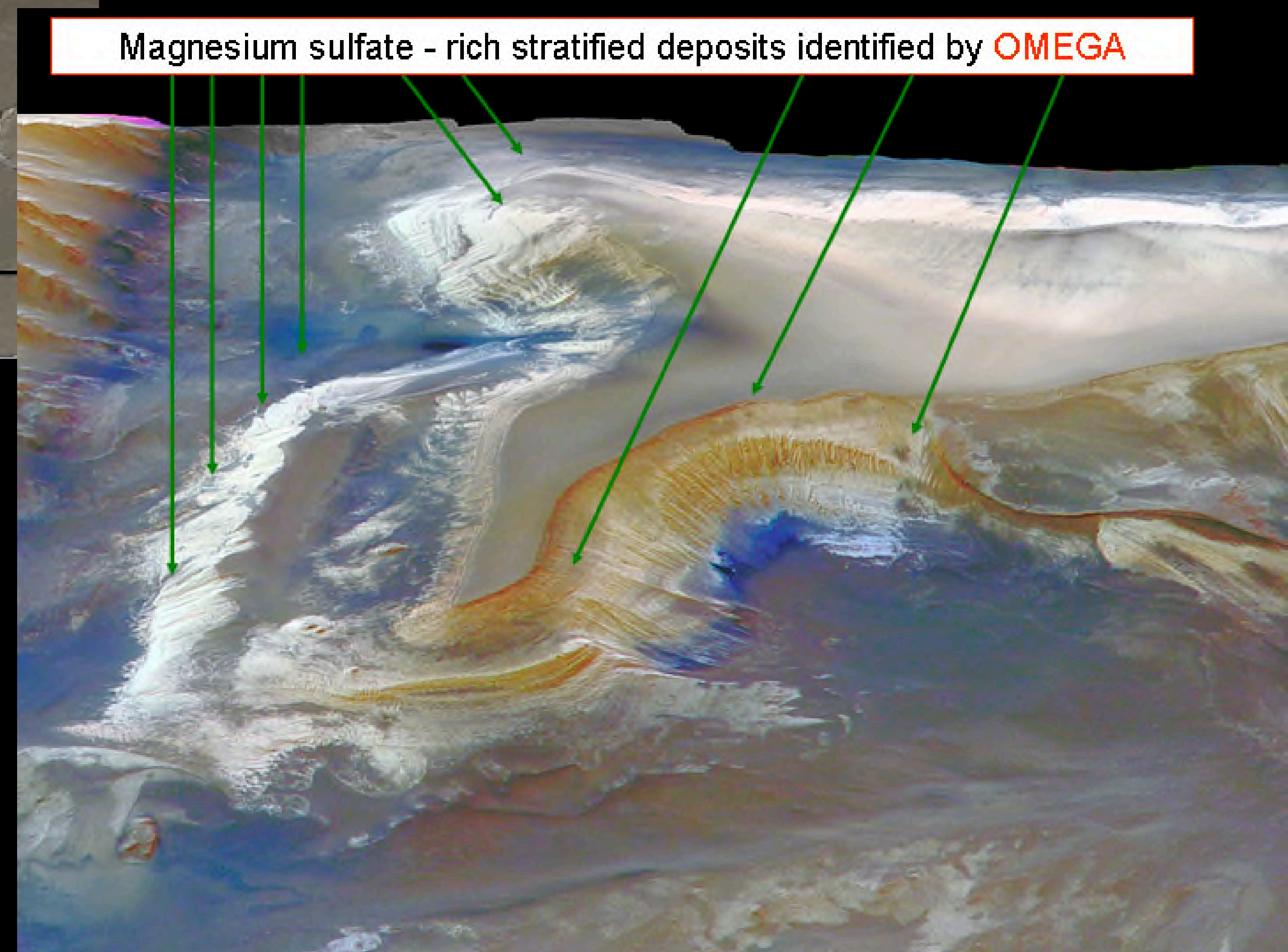
OMEGA

- Various types of ice (H_2O and CO_2), either mixed or distinct, mapped in polar regions.
- Lack of aqueous alteration of mafic minerals (olivine) in Northern plains suggests that large bodies of water, such as lakes or seas, have not existed for long periods on the Martian surface.
- Hydrated minerals (clays in Noachian, sulfates later) indicate alteration in varying amounts of water and climate regimes.
- Most of the Northern plains (volcanic origin) do not exhibit mafic minerals.
- At present, CO_2 is dominantly stored in the atmosphere, as no carbonates have been found.



Minerals Revealed by OMEGA





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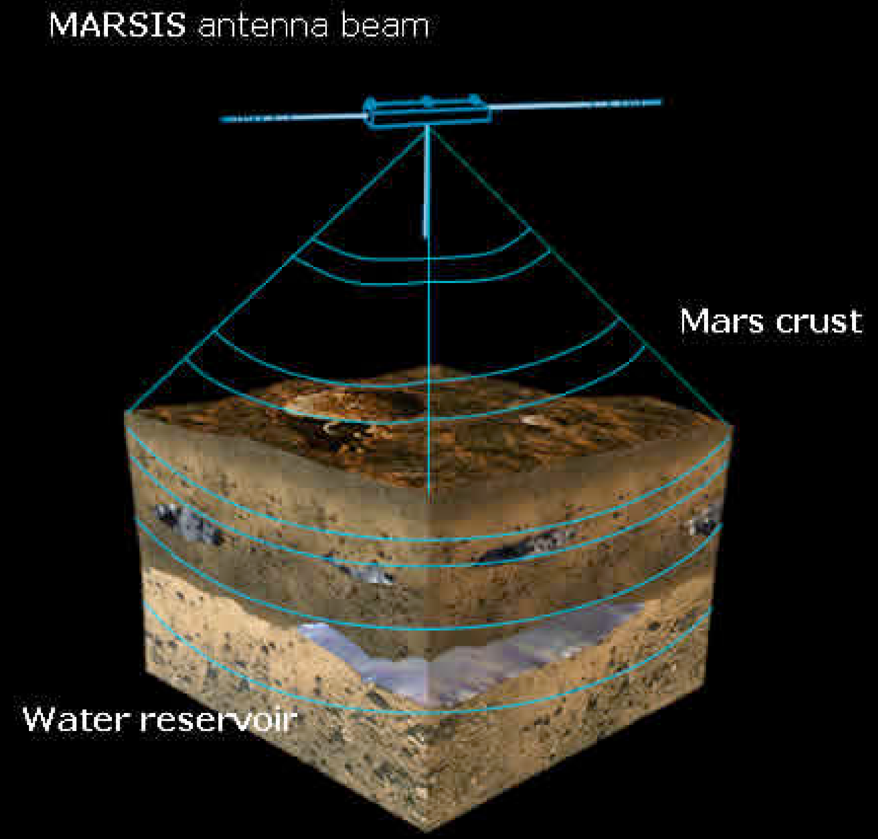
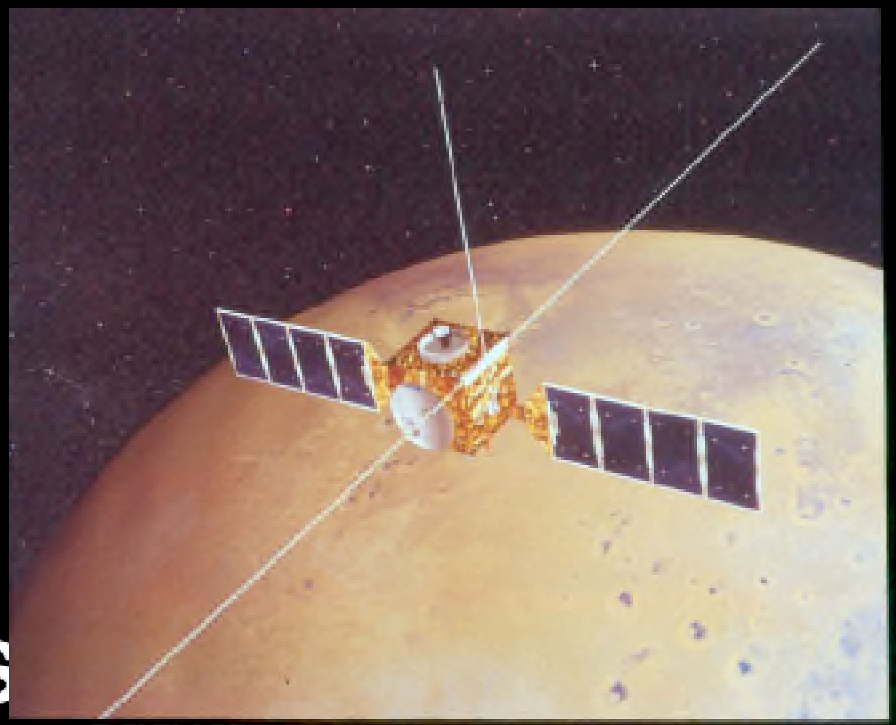
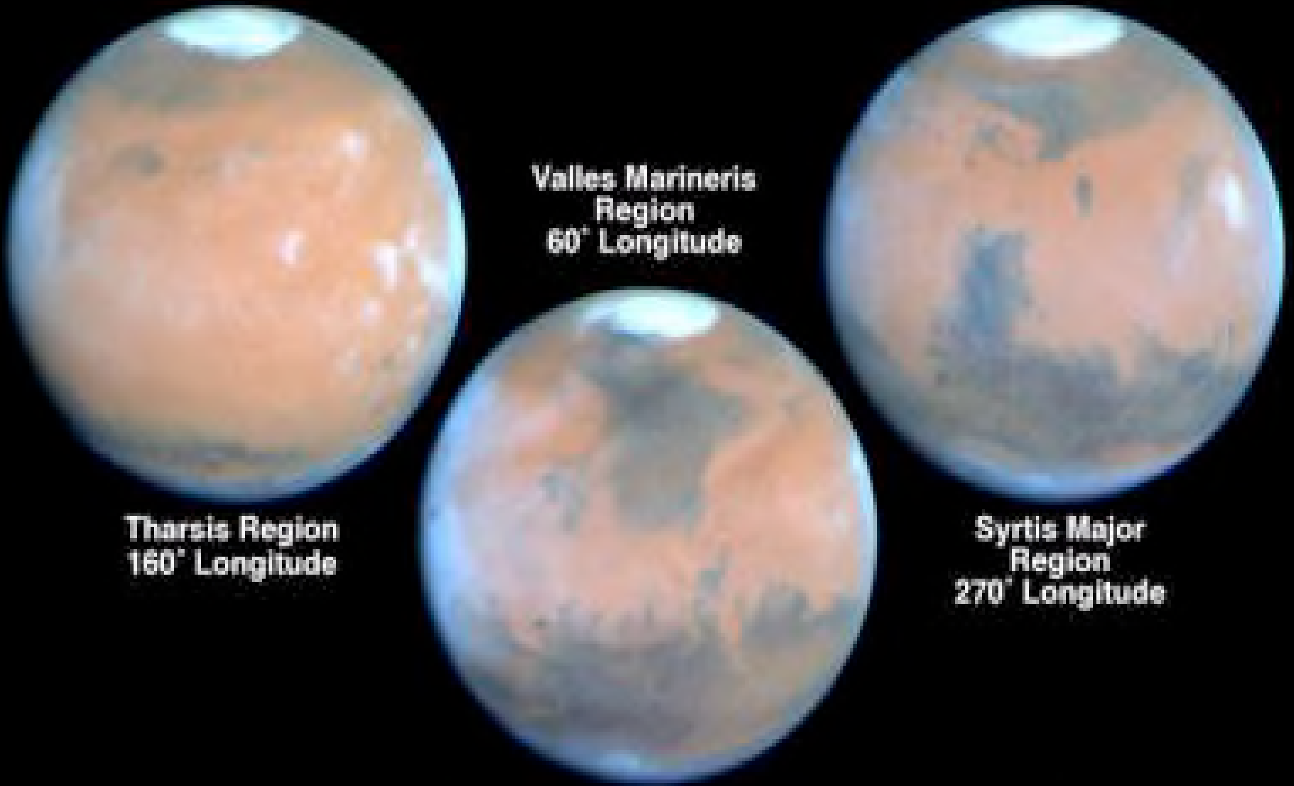
MARSIS radar

MARSIS

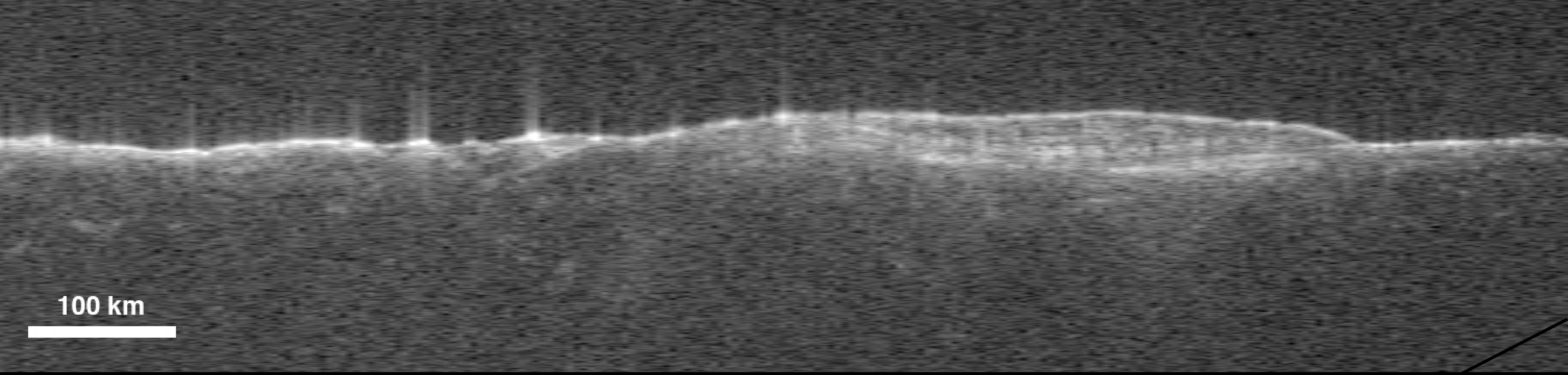
- Mapping the subsurface structure with micro waves.
- Current/past inventory of water.
- Study water transport, storage
- Evolution: geology, climate, life ?
- Surface roughness, topography.
- Ionospheric sounding: e^- density to H_2O and CO_2 cycles

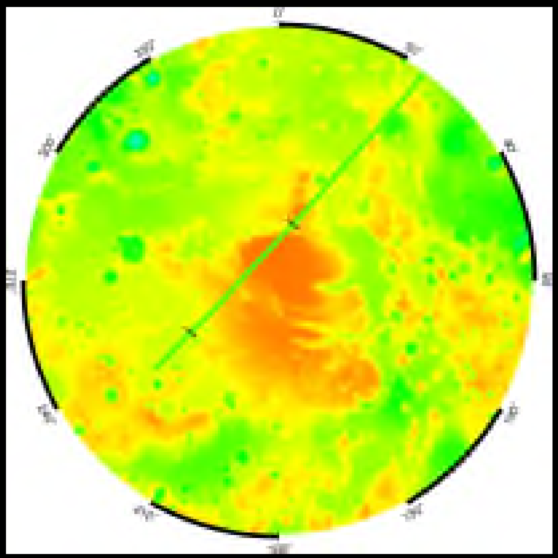


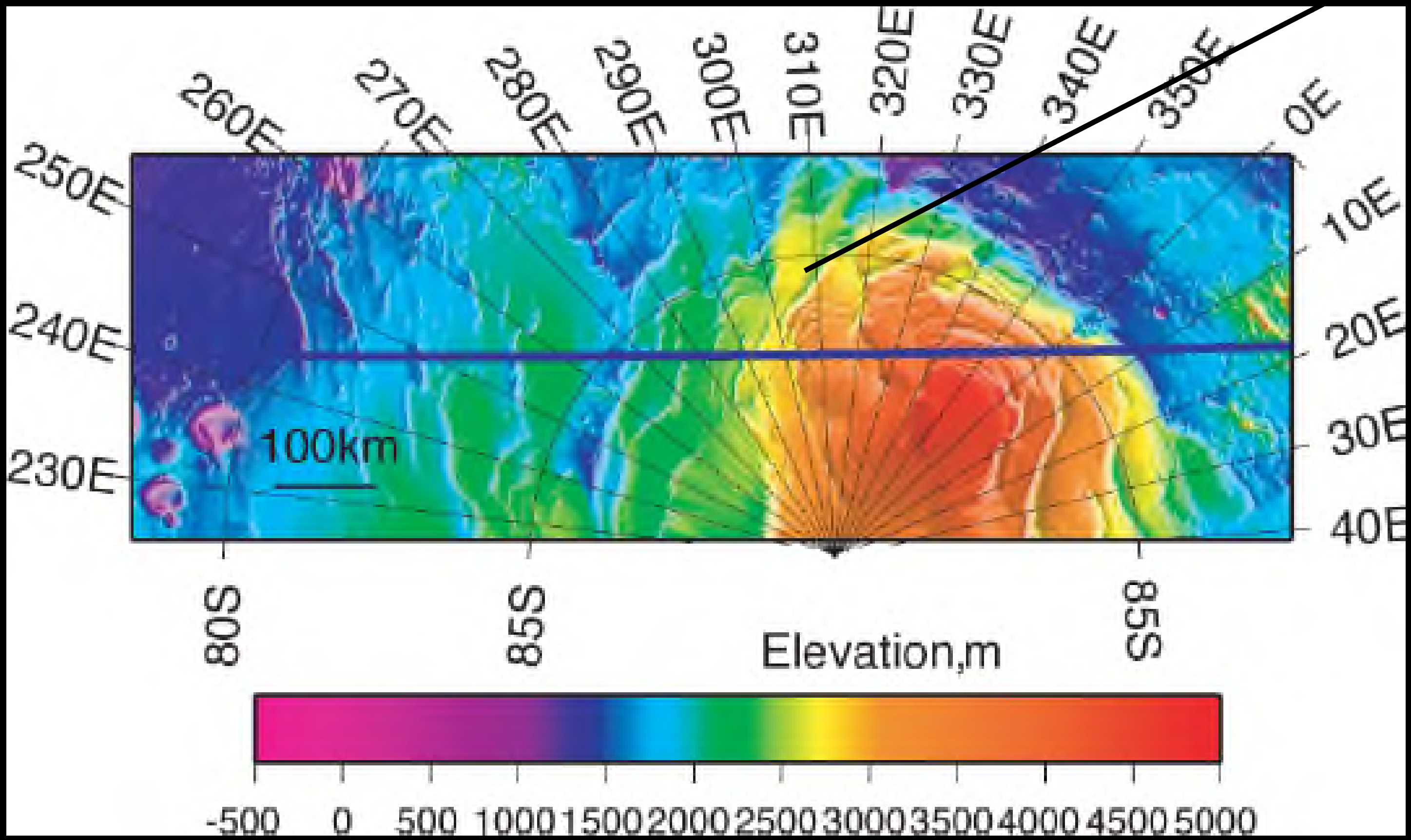




MARSIS Results



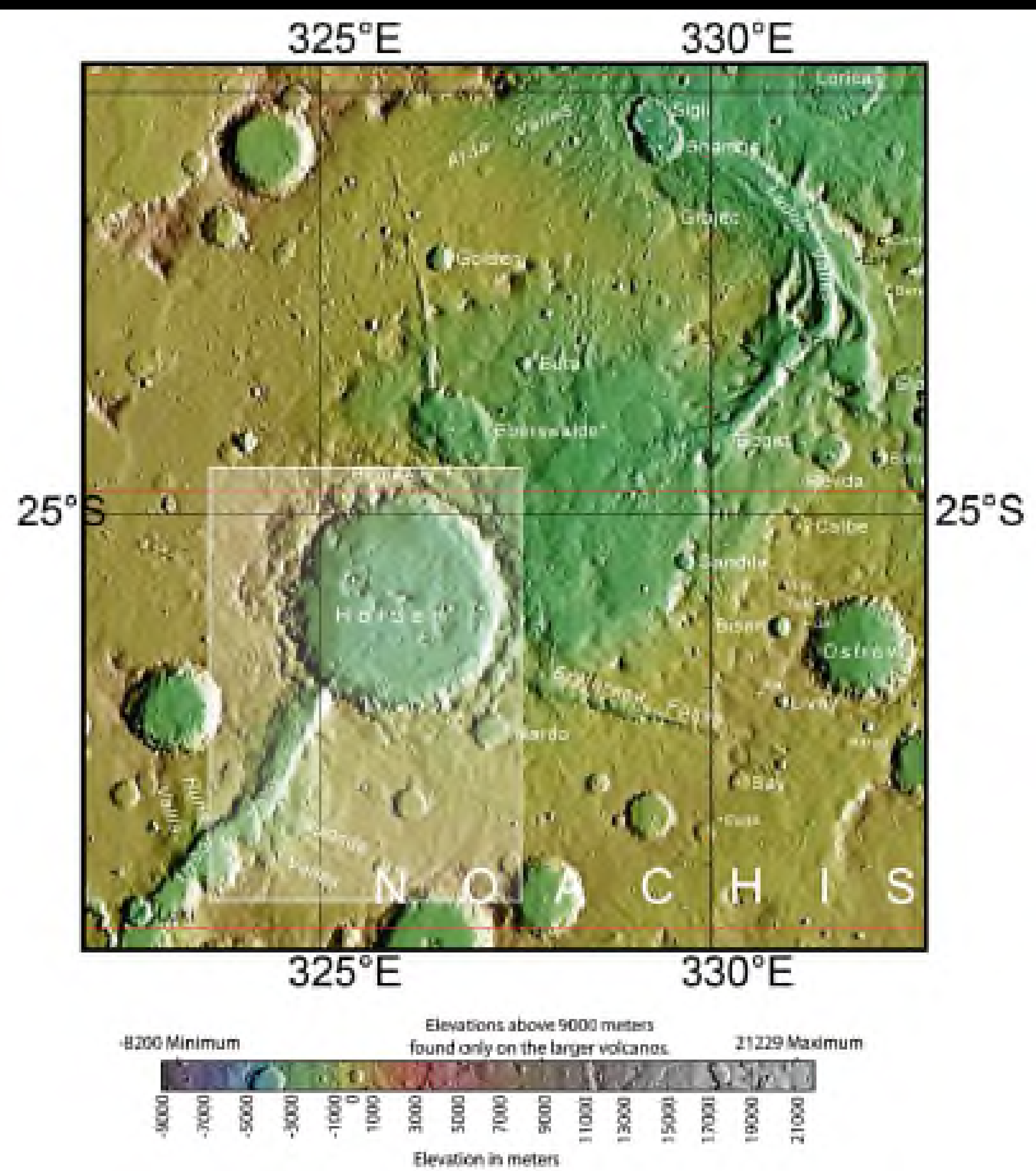


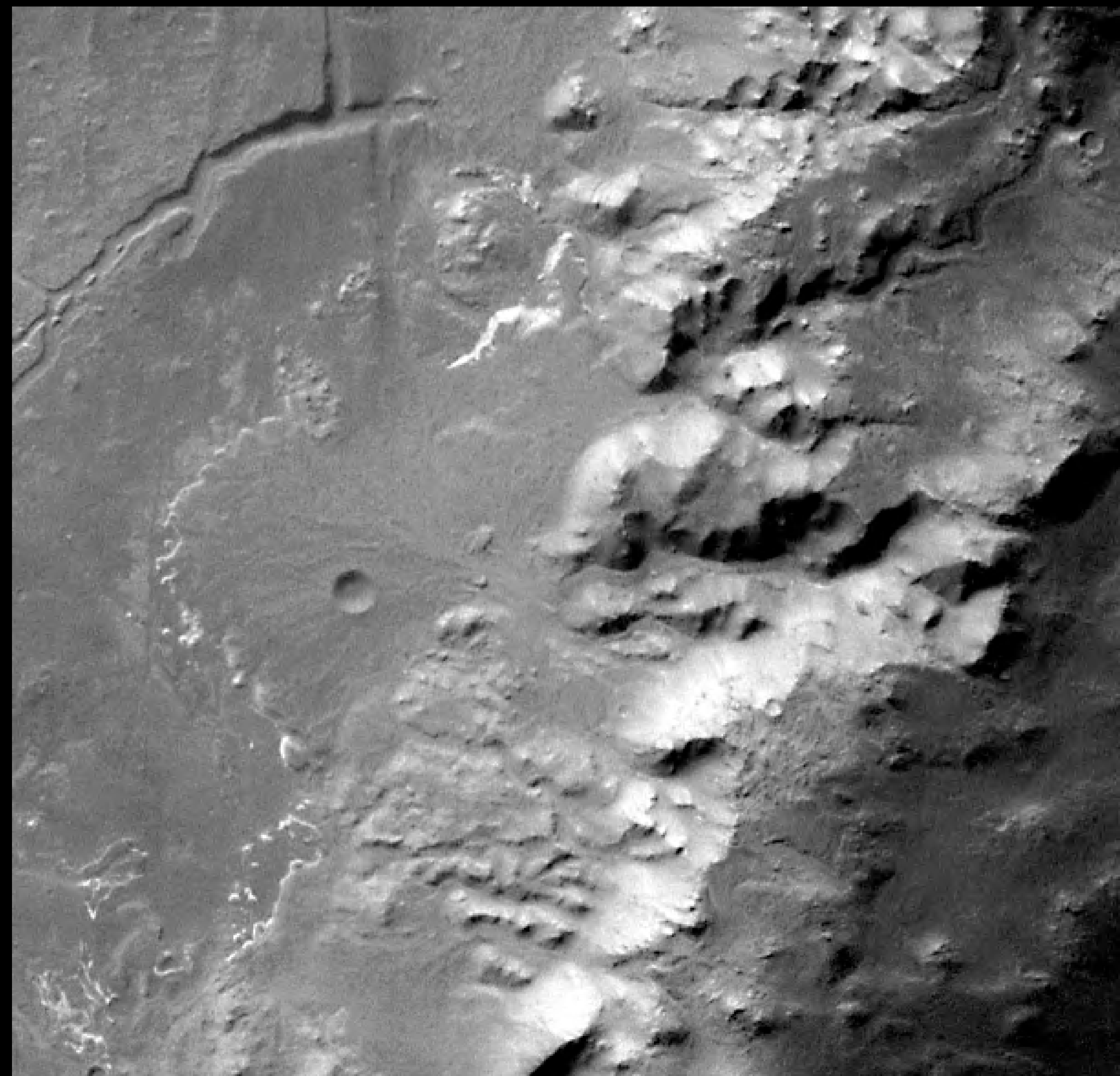


Holden Crater Paleolacustrine system

Courtesy M. Pondrelli

Fluvial features





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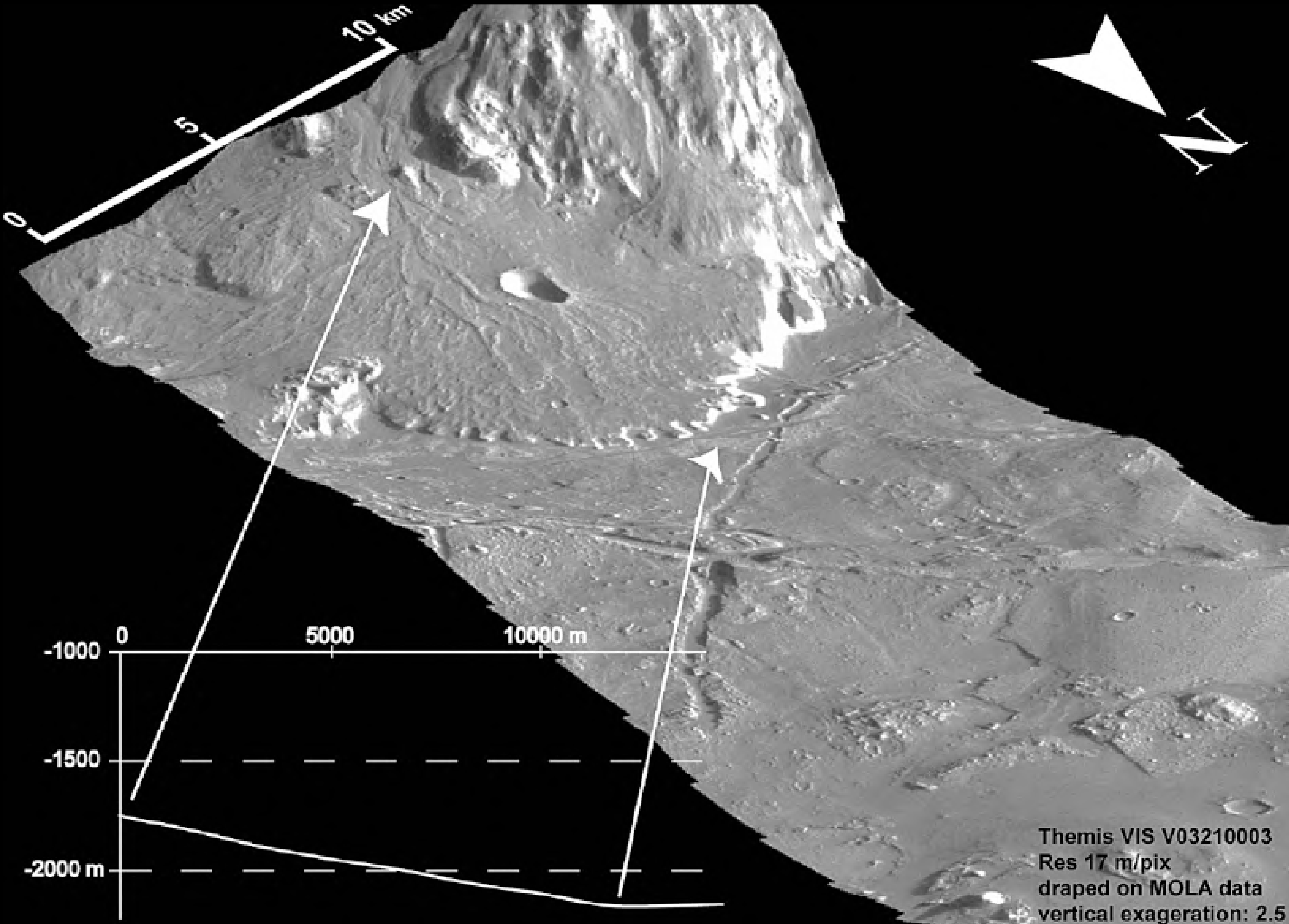
Alluvial fans on Earth and Mars



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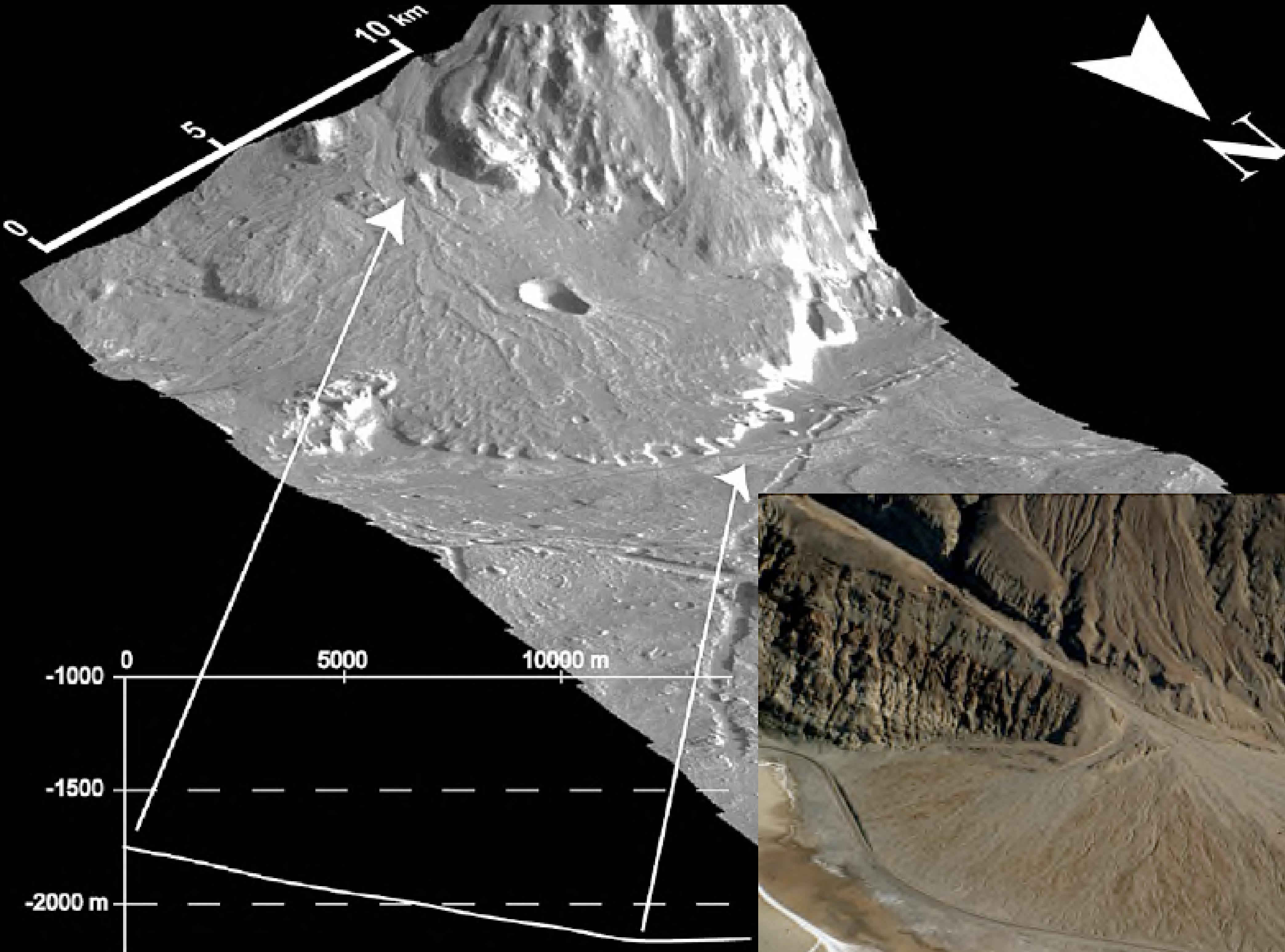
Alluvial fans on Earth and Mars



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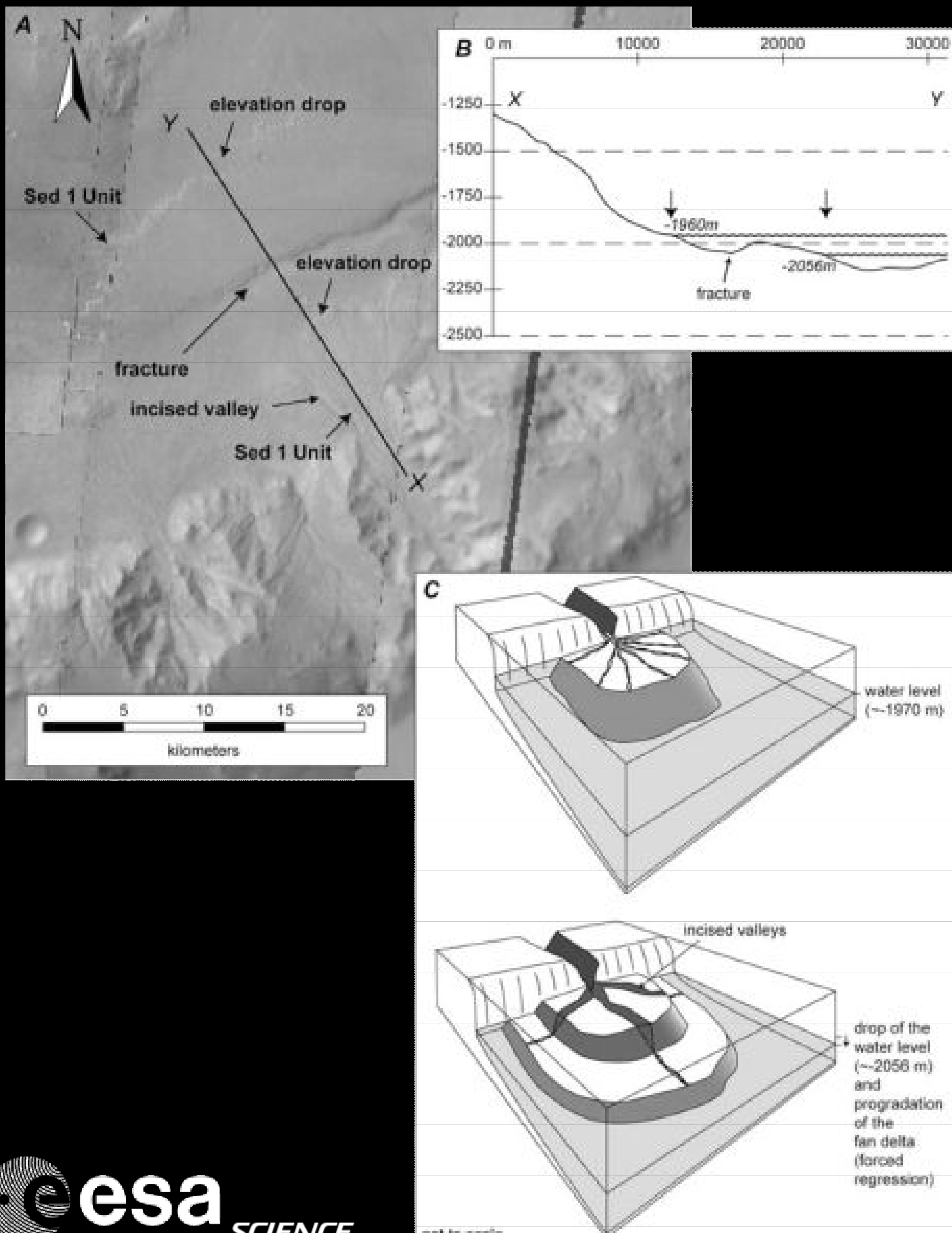
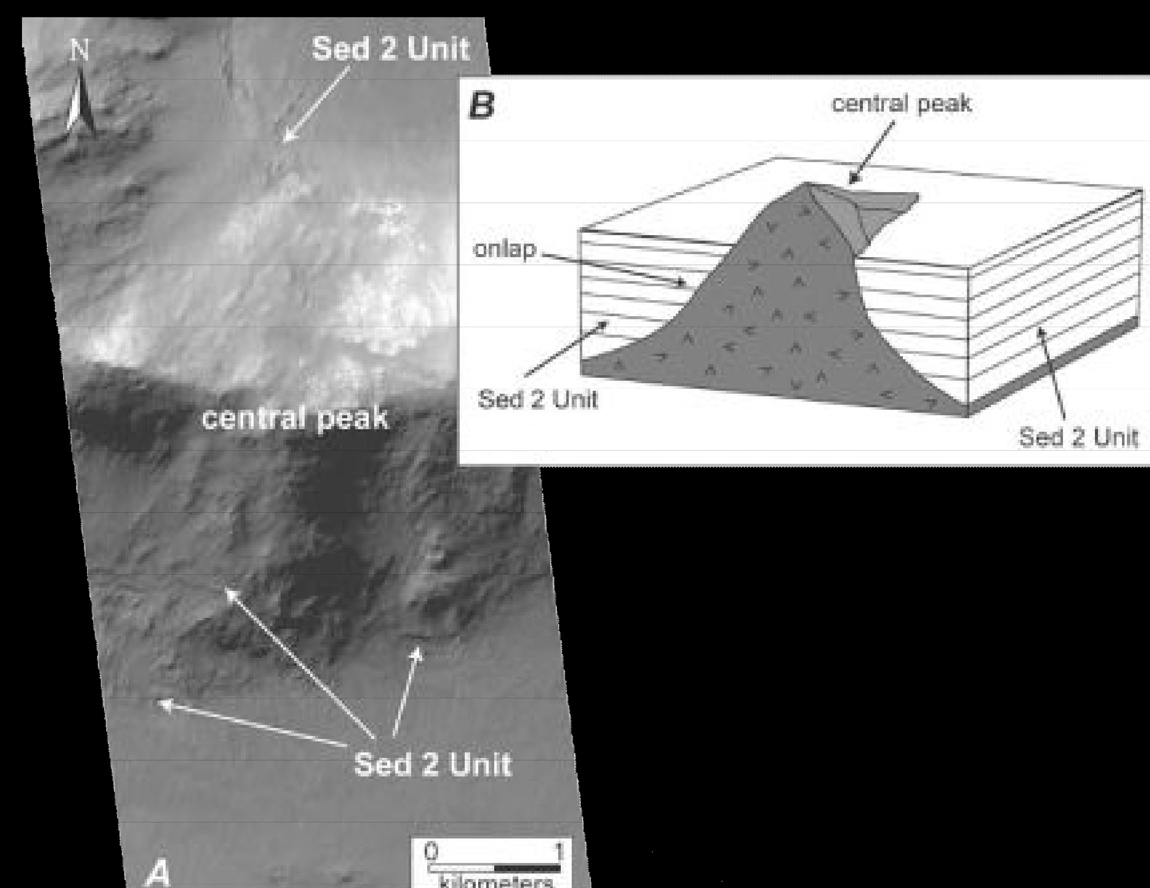
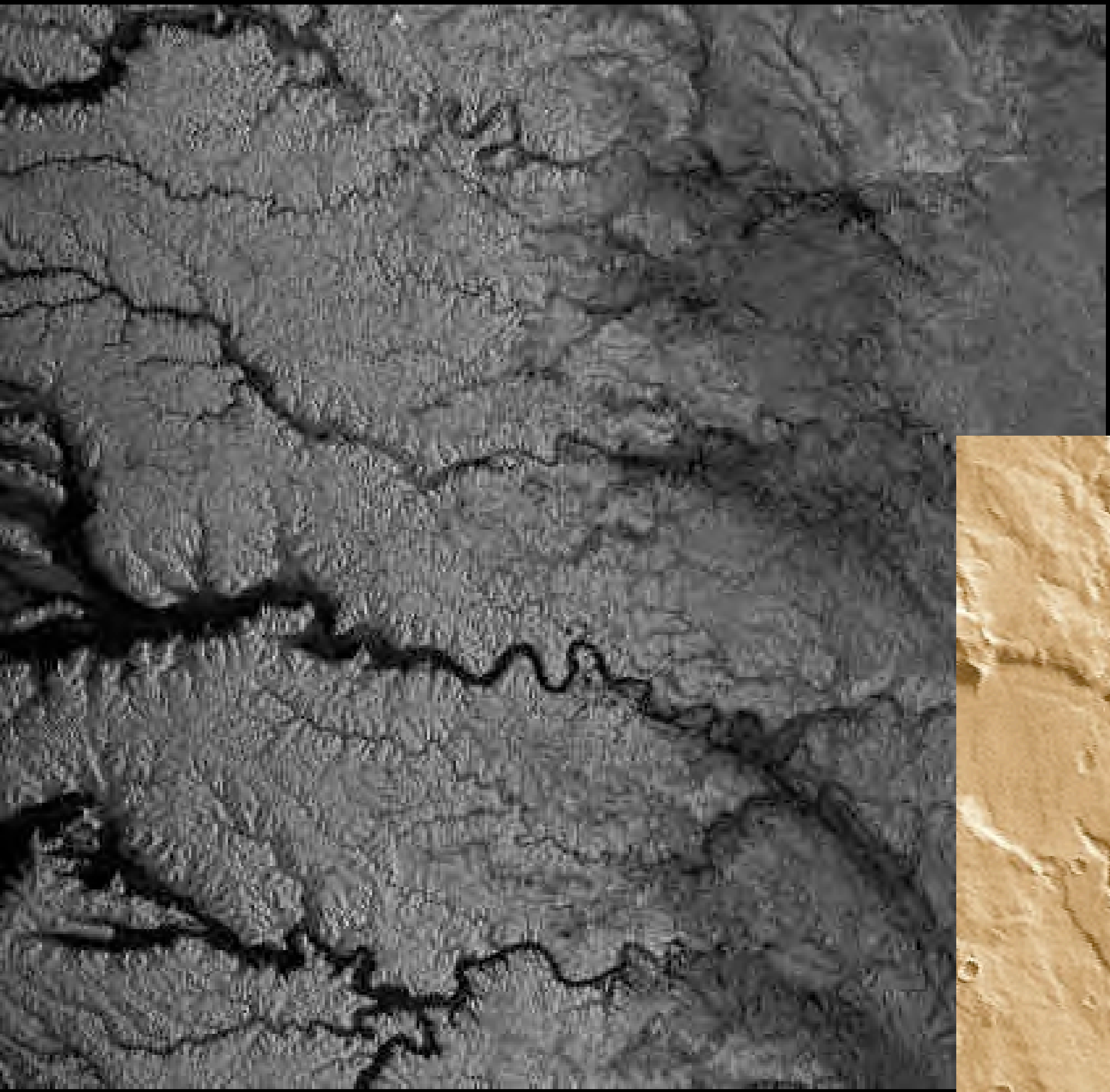
Holden crater: deposits

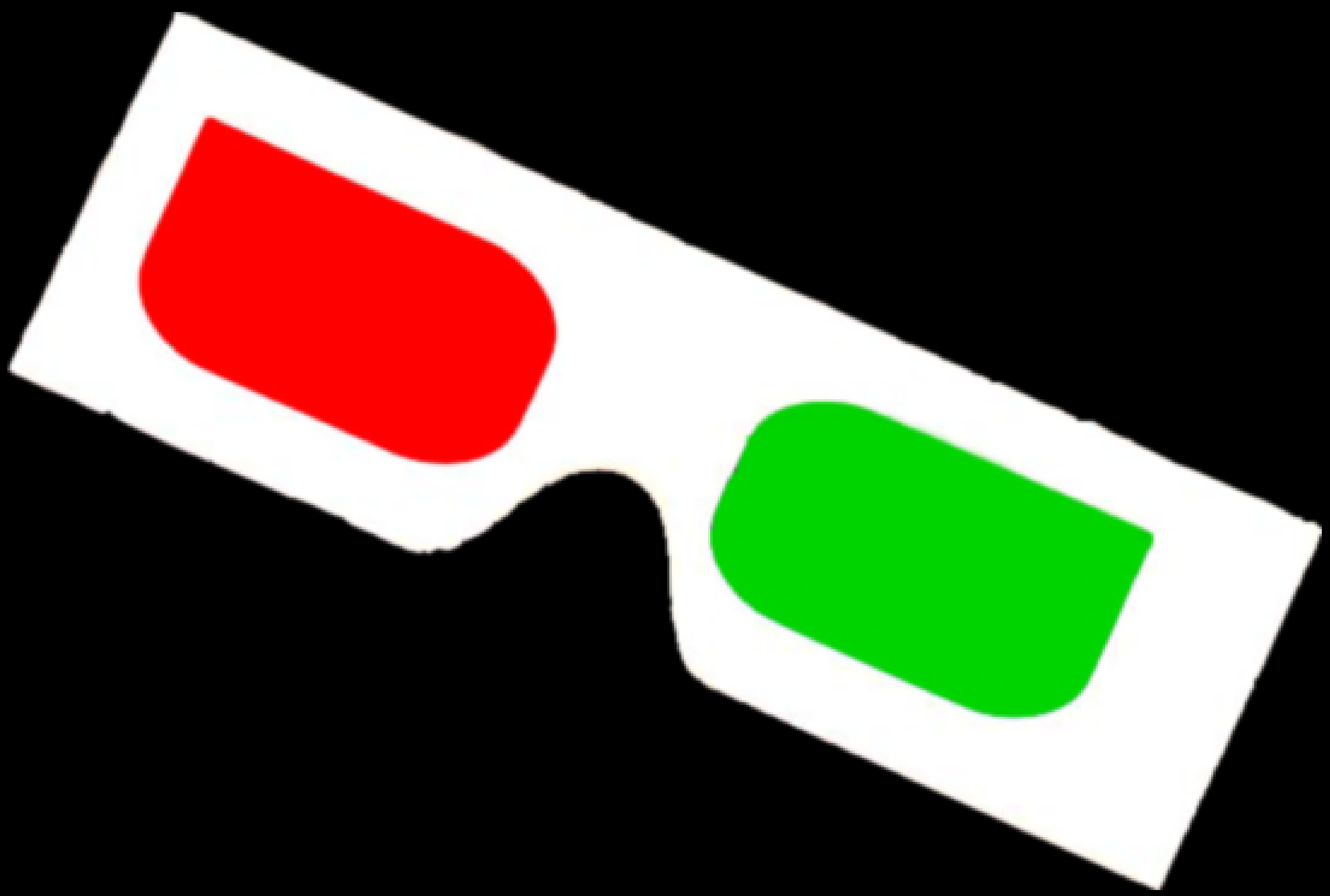


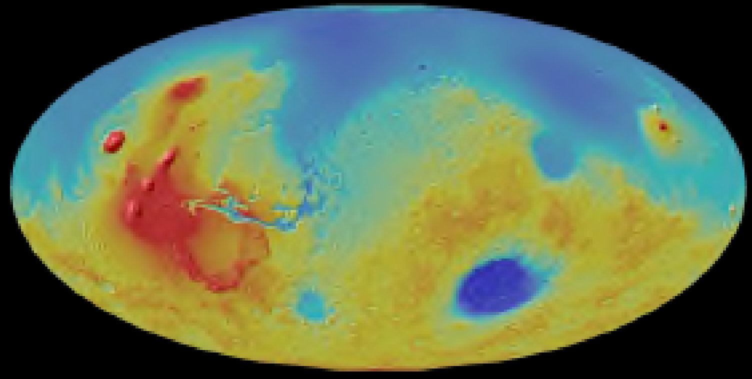


Earth desert environments as possible analogues

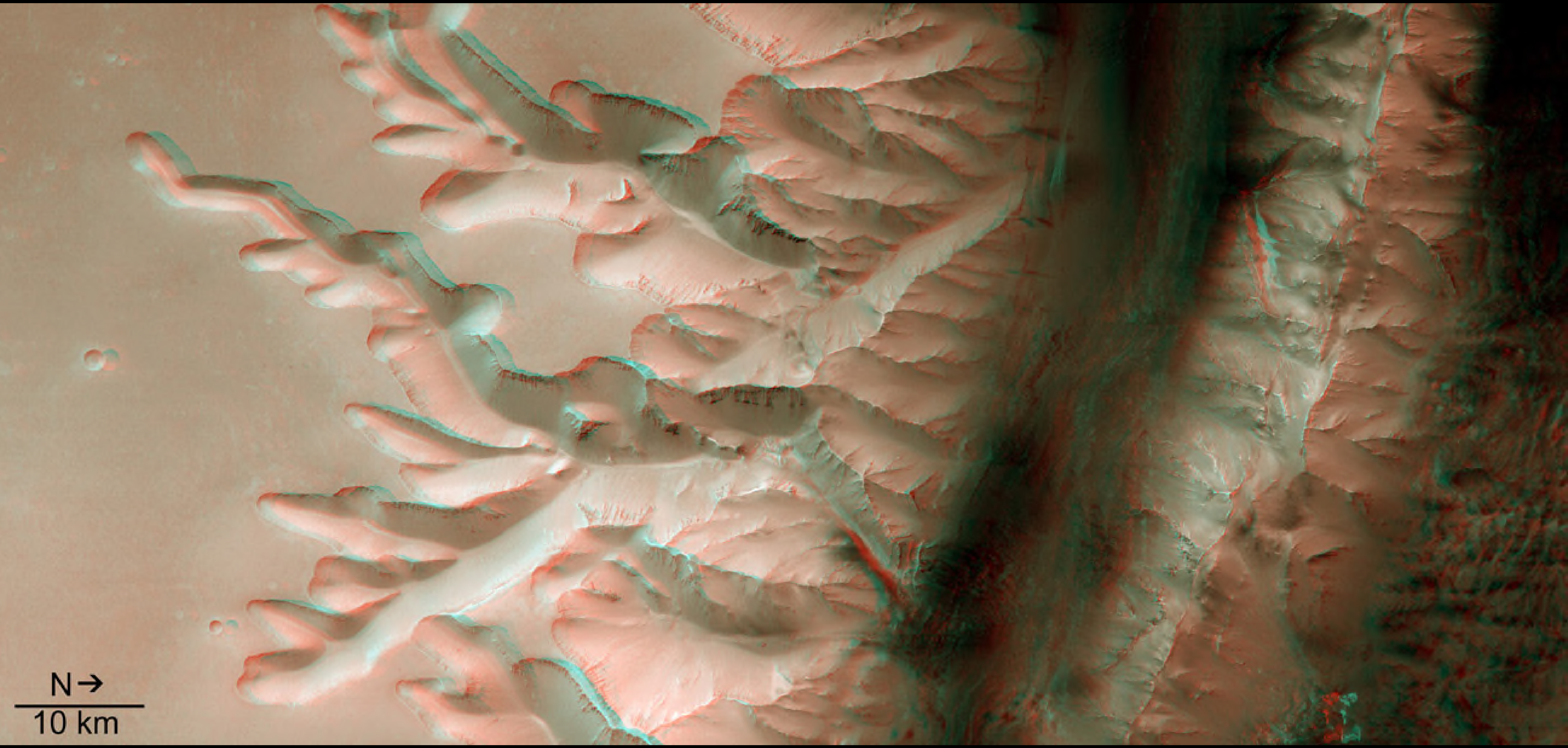


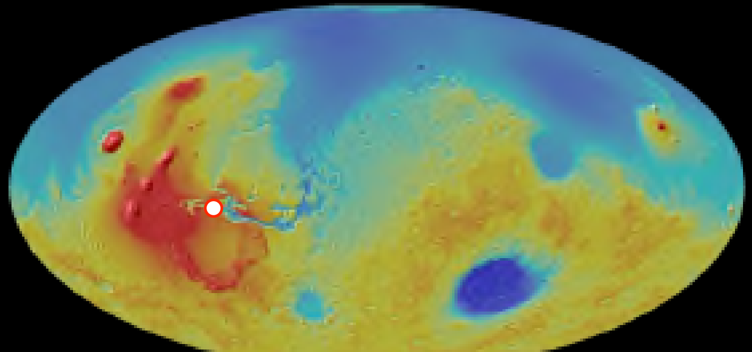
Mars in 3D





Valles Marineris





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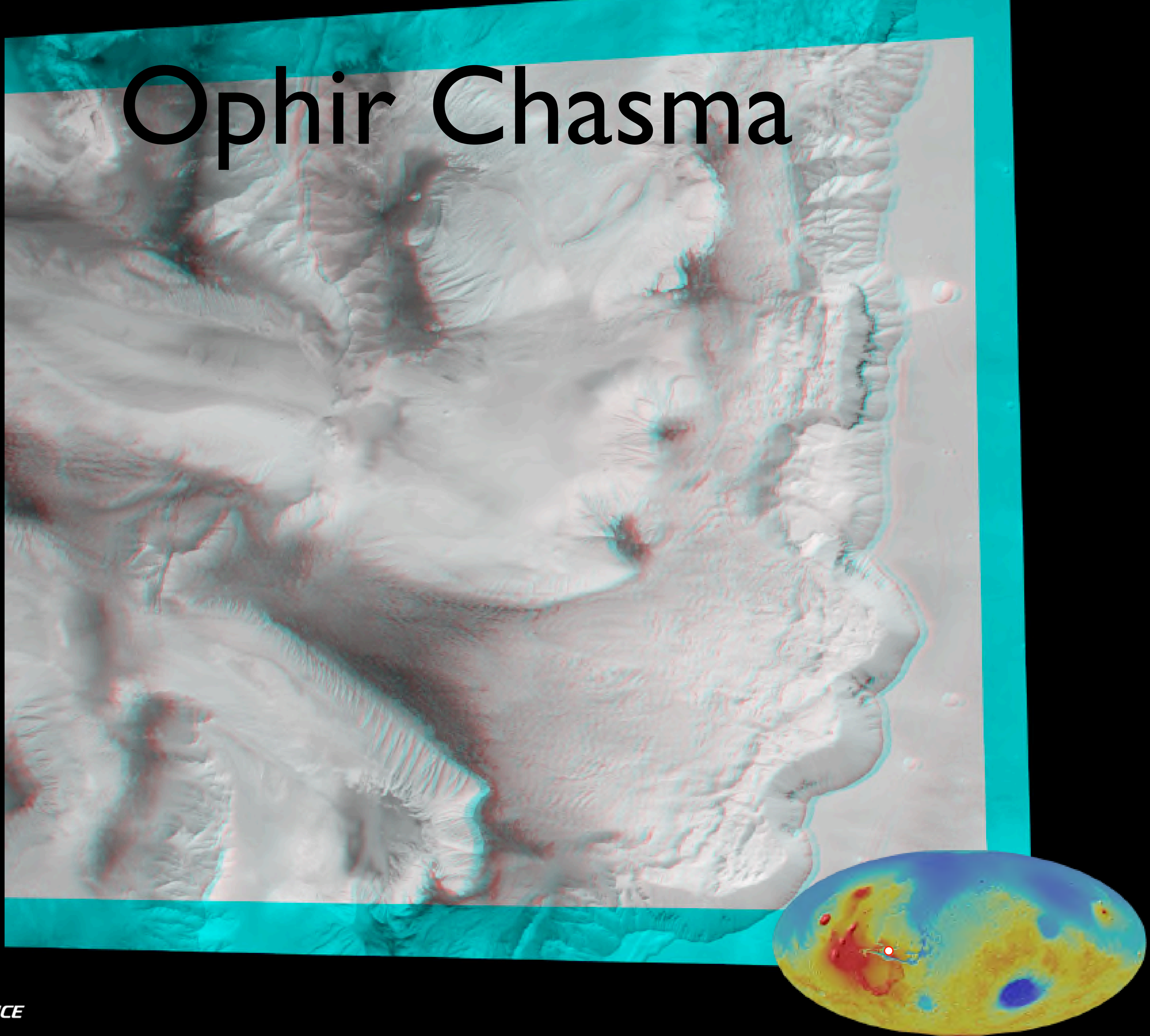
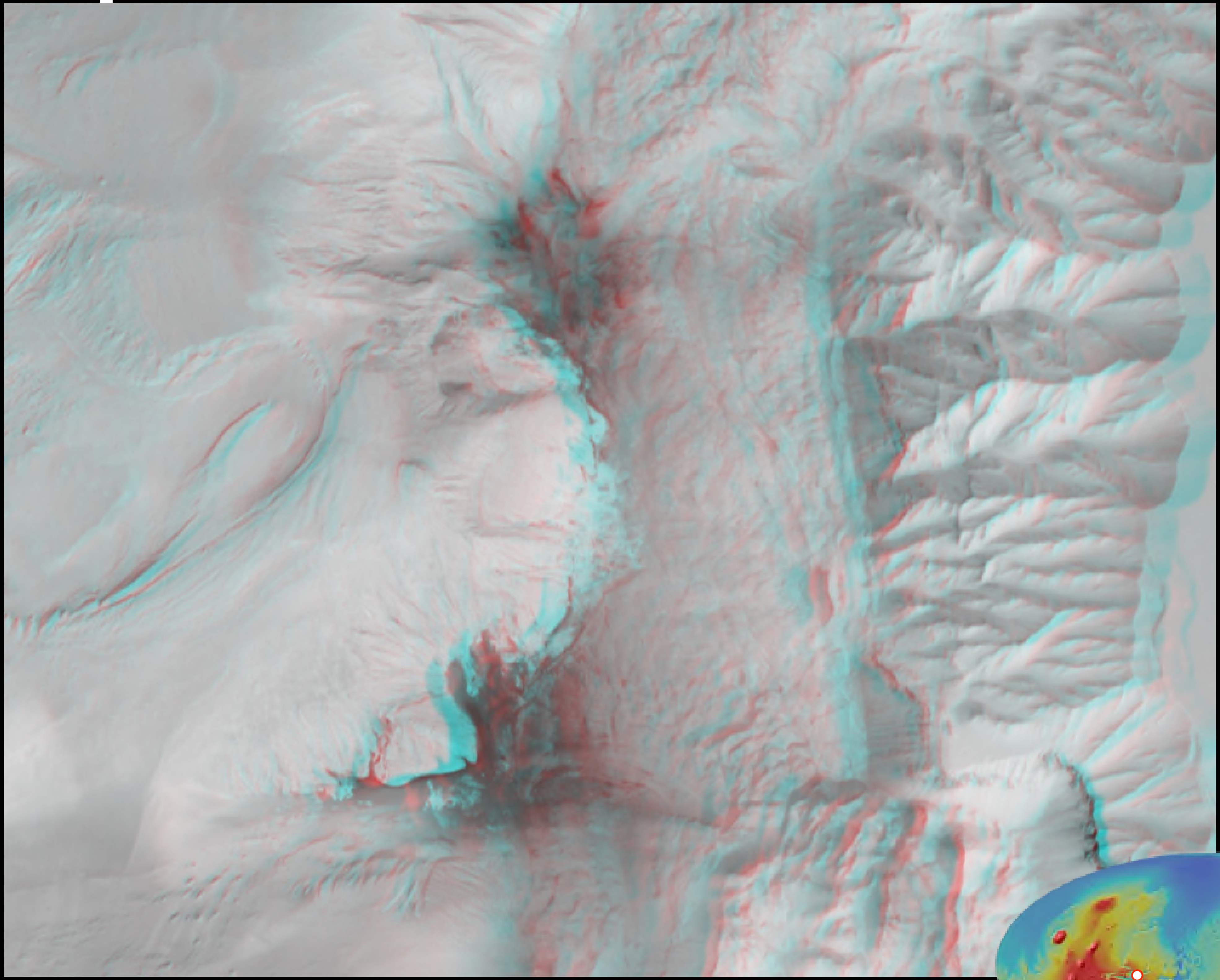
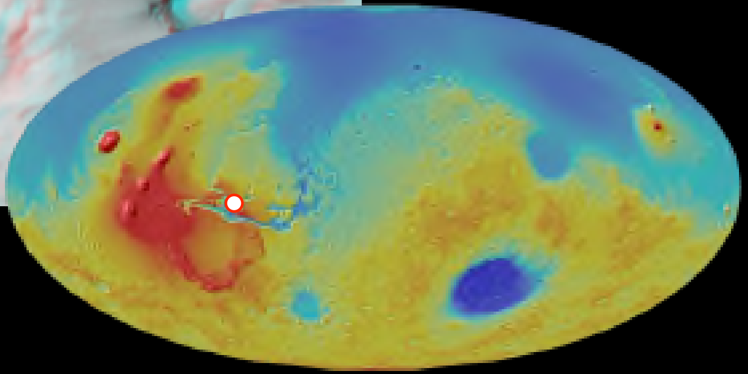
Ophir Chasma



Ophir Chasma - zoom





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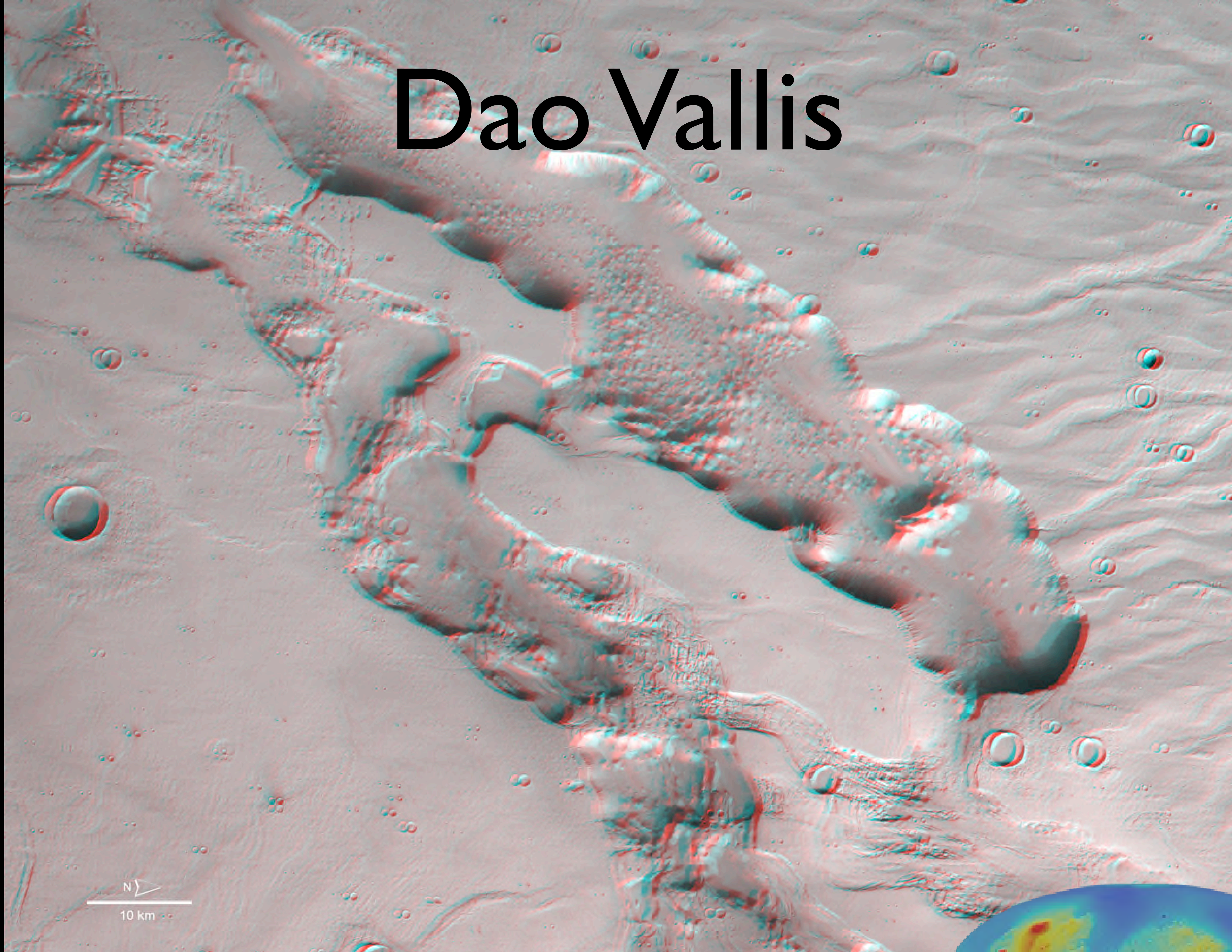
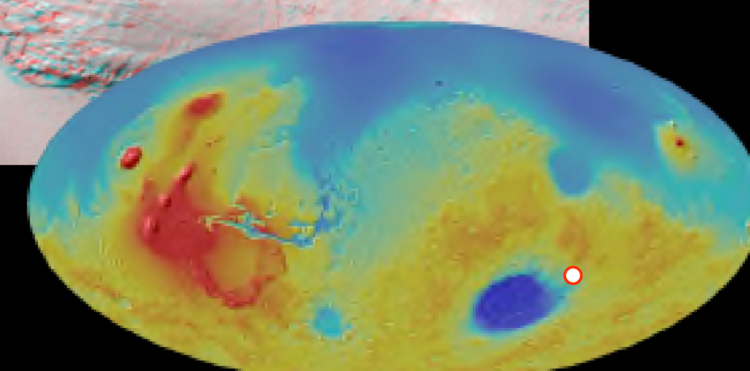
Dao Vallis





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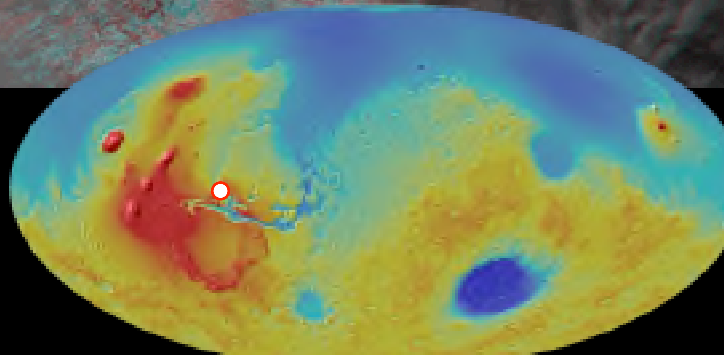
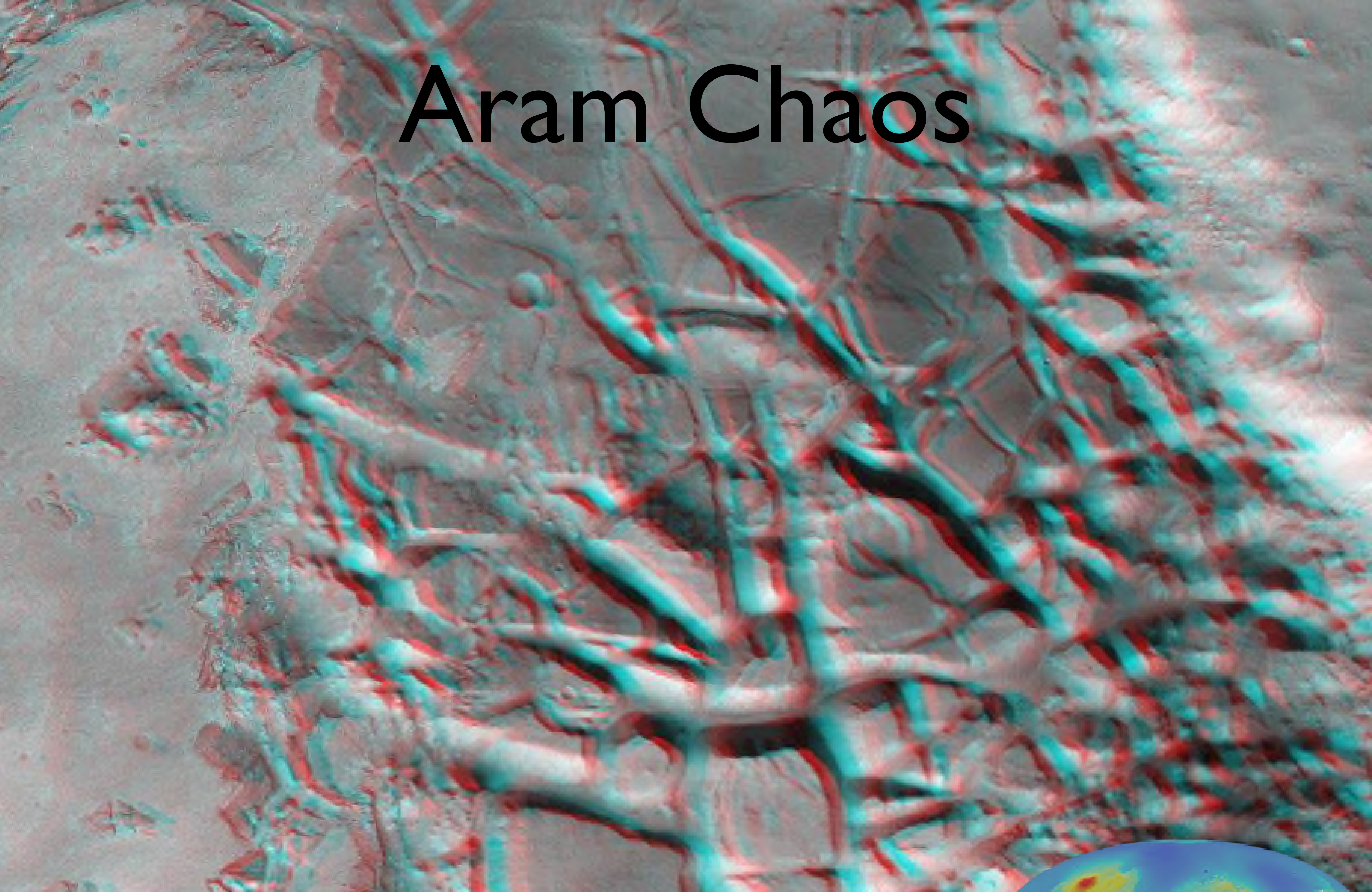
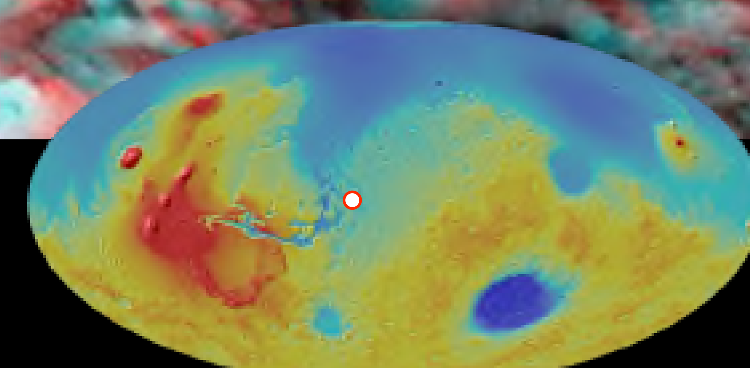
Hebes Chasma

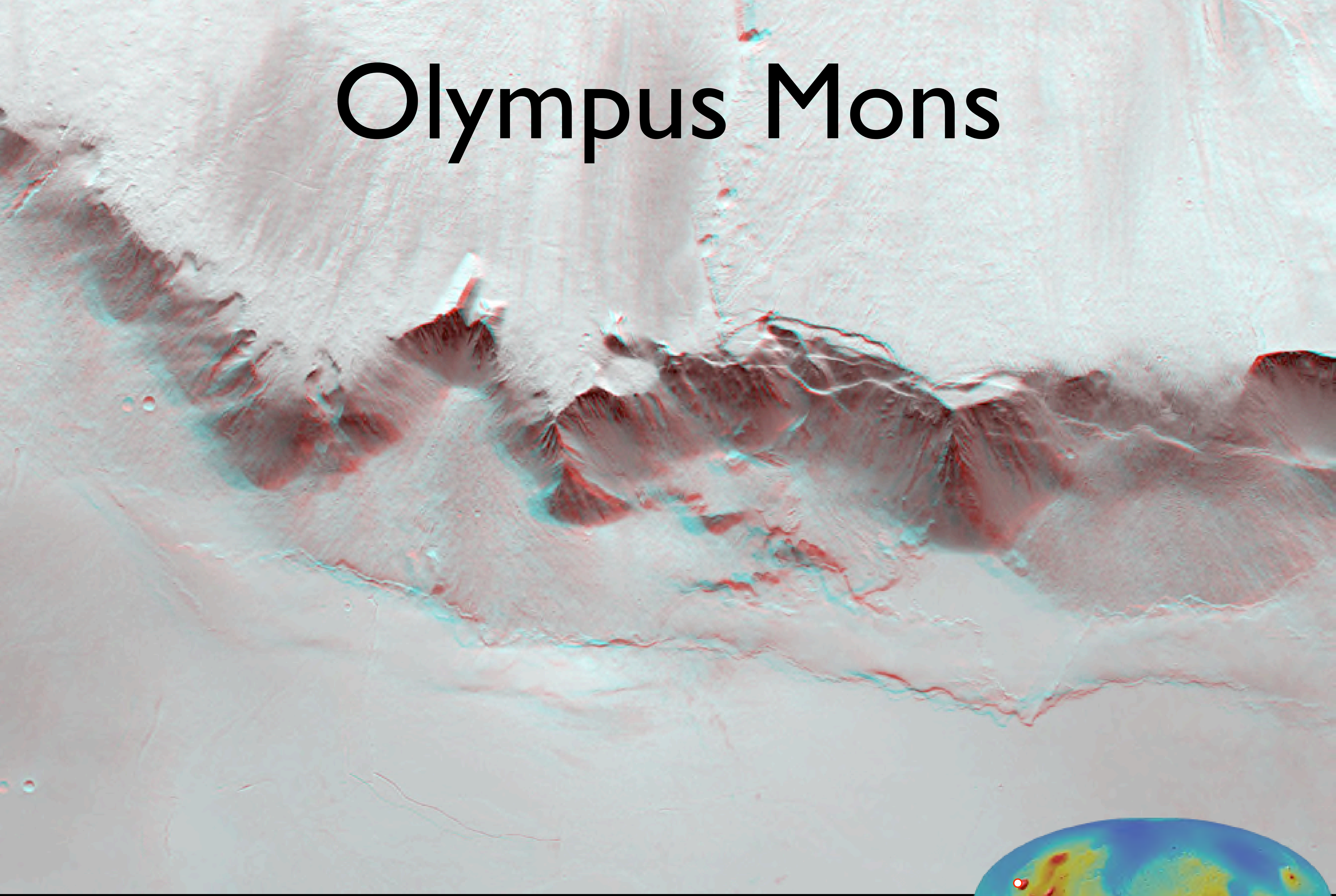


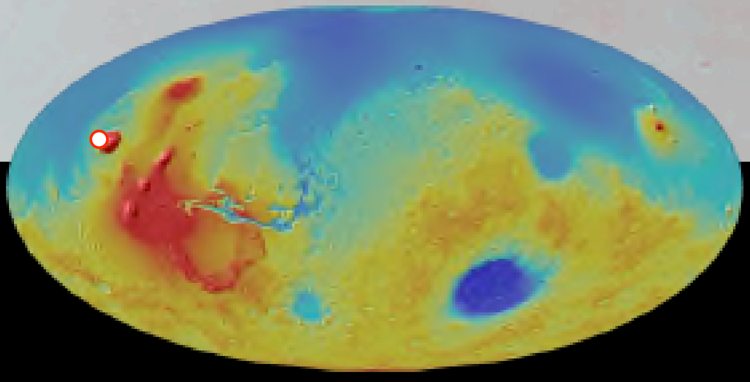
Aram Chaos



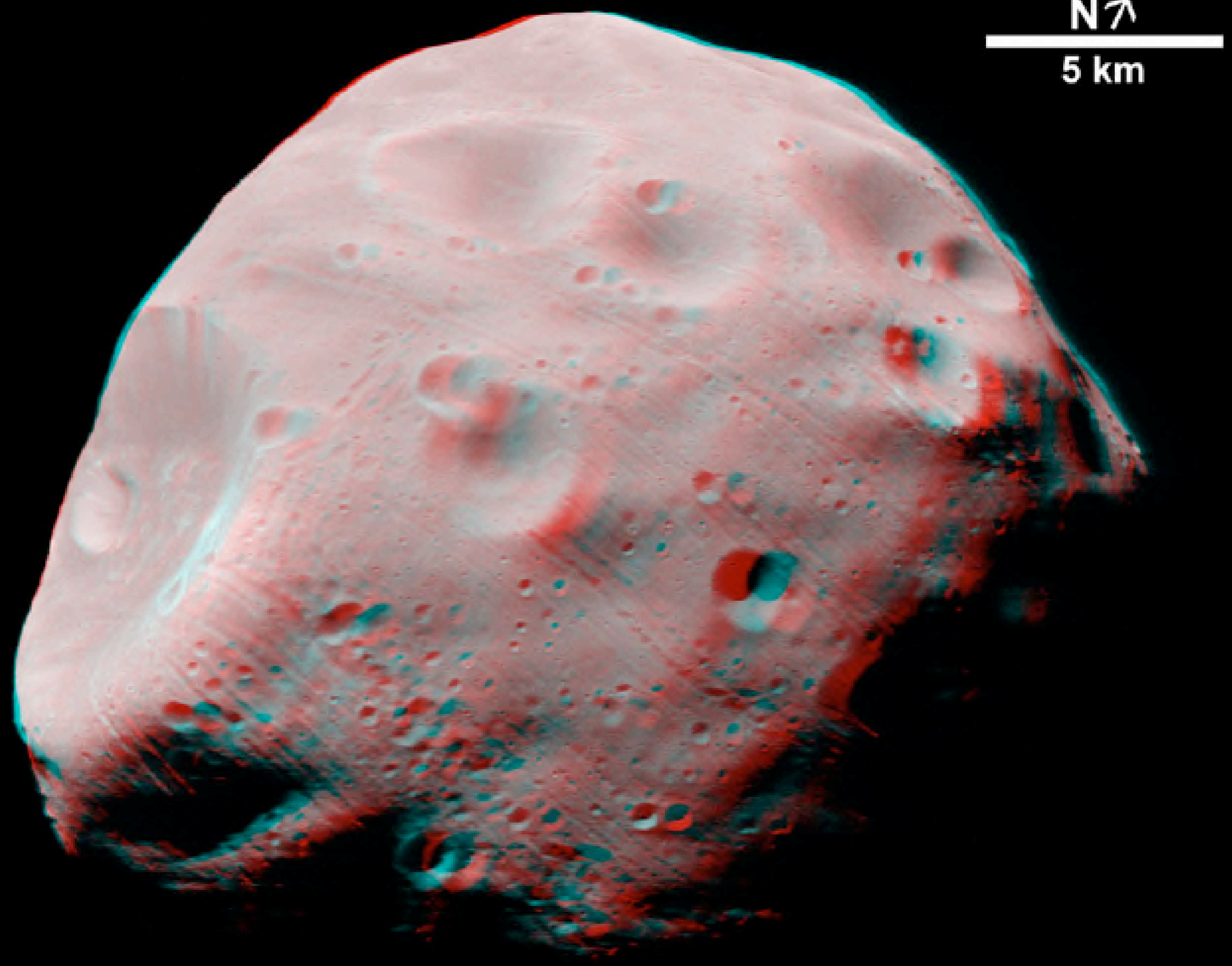


Olympus Mons





Phobos



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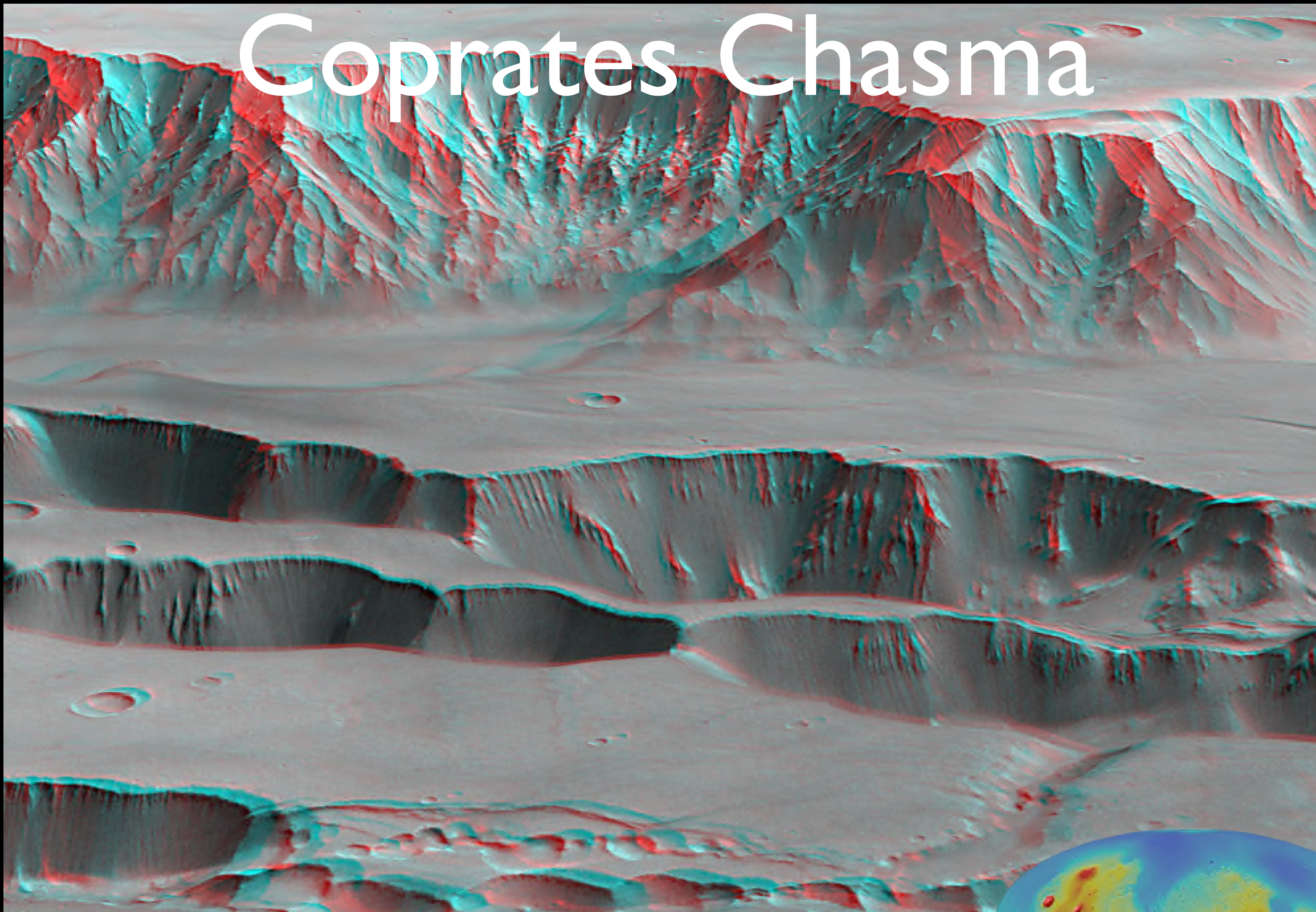
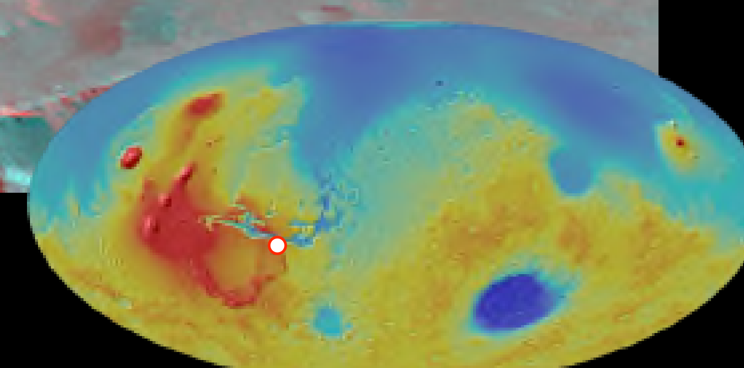
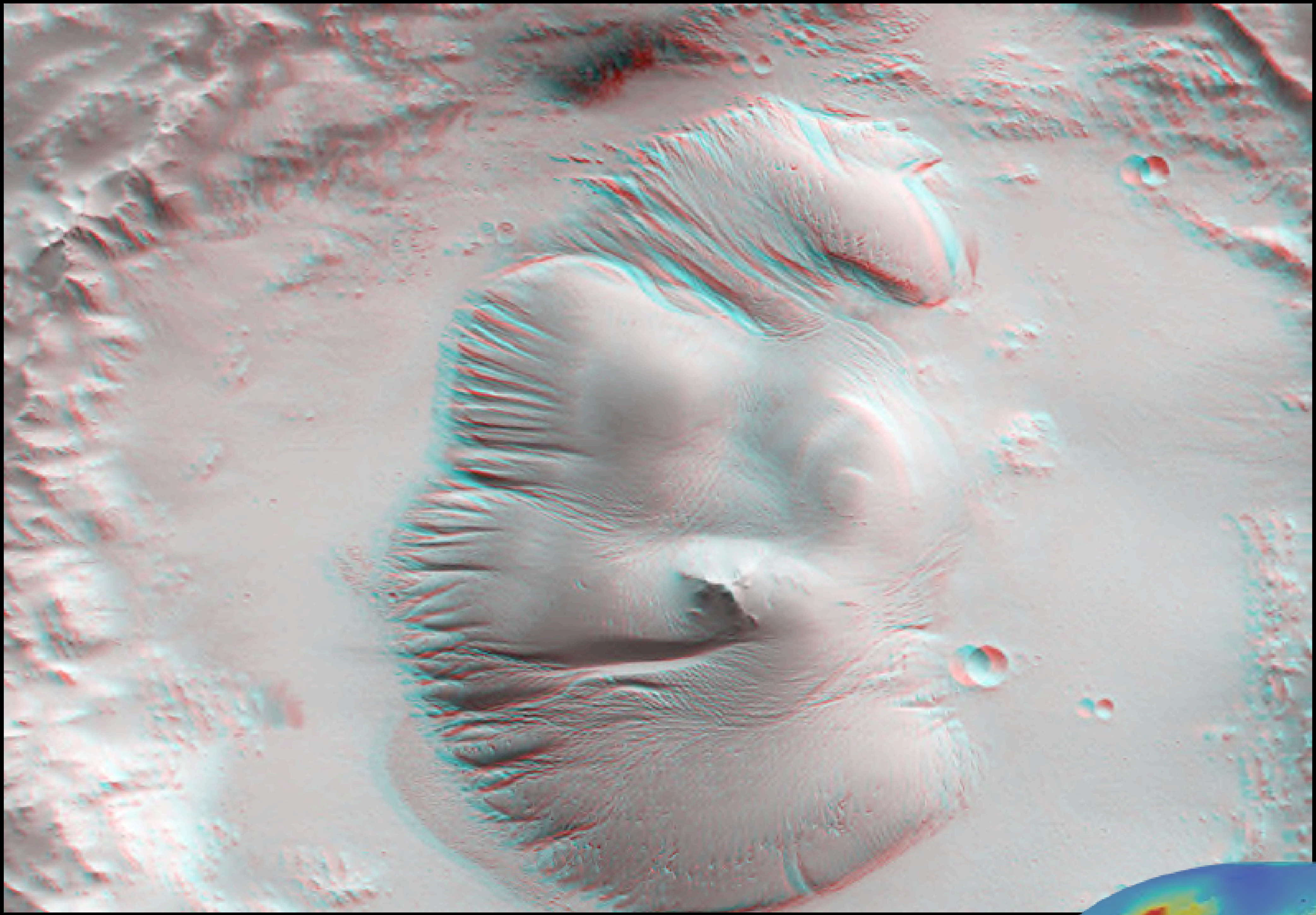
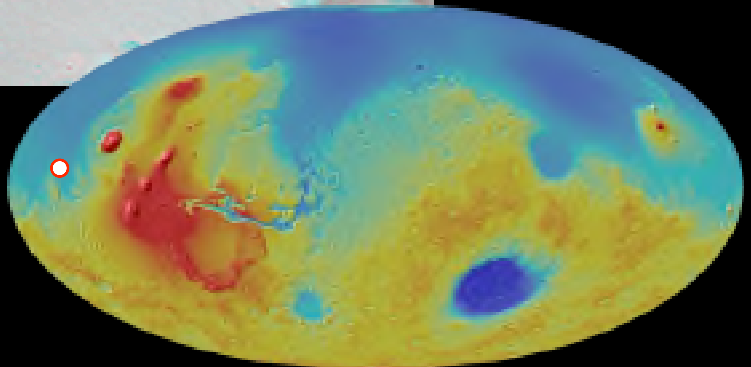
Coprates Chasma





Nicholson Crater





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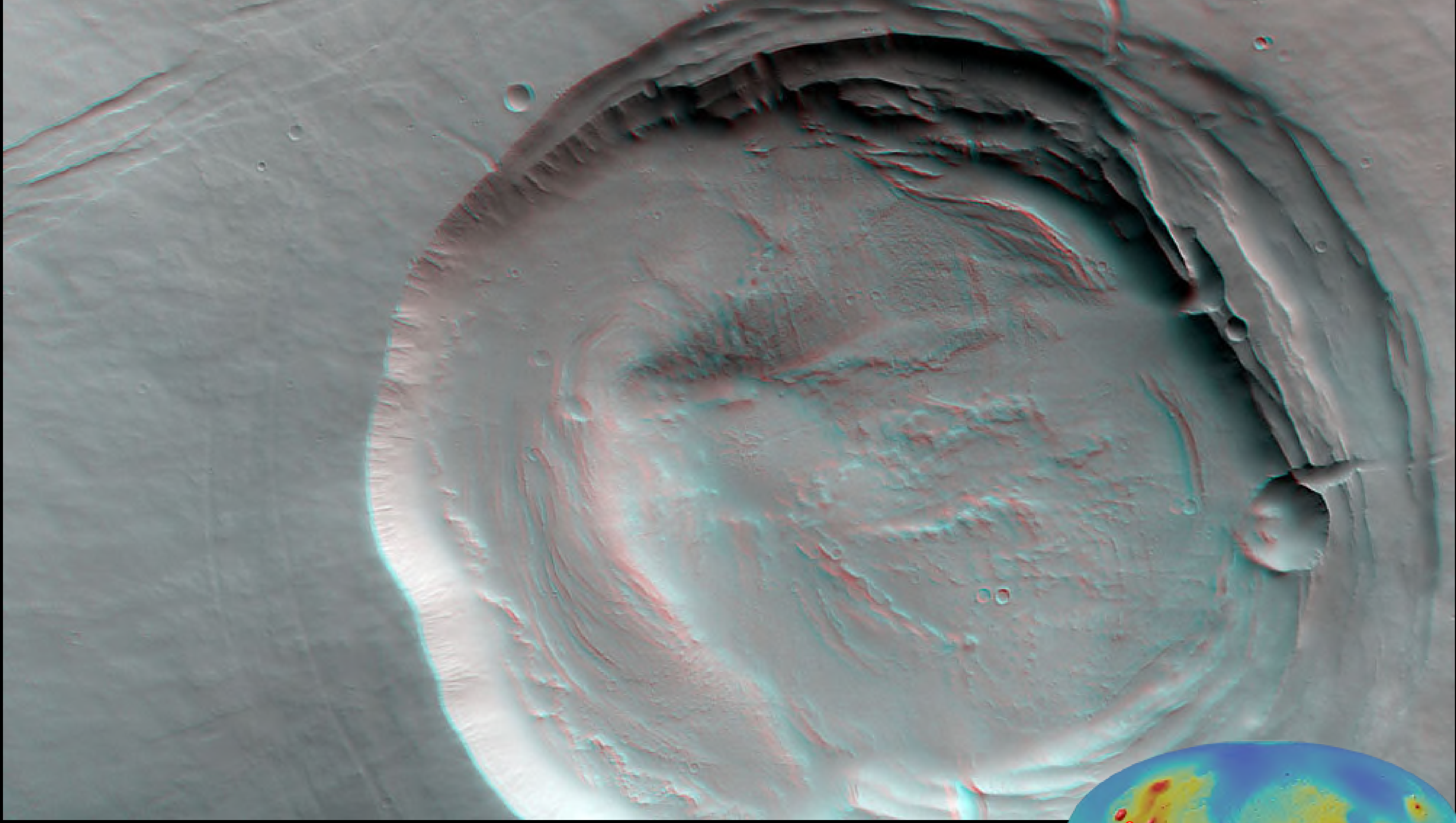
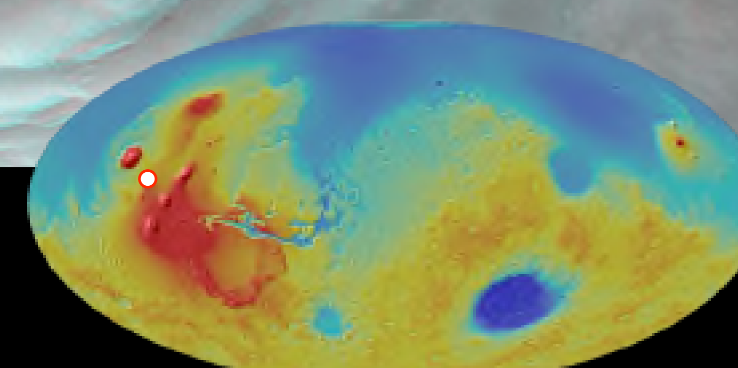
Biblis Patera





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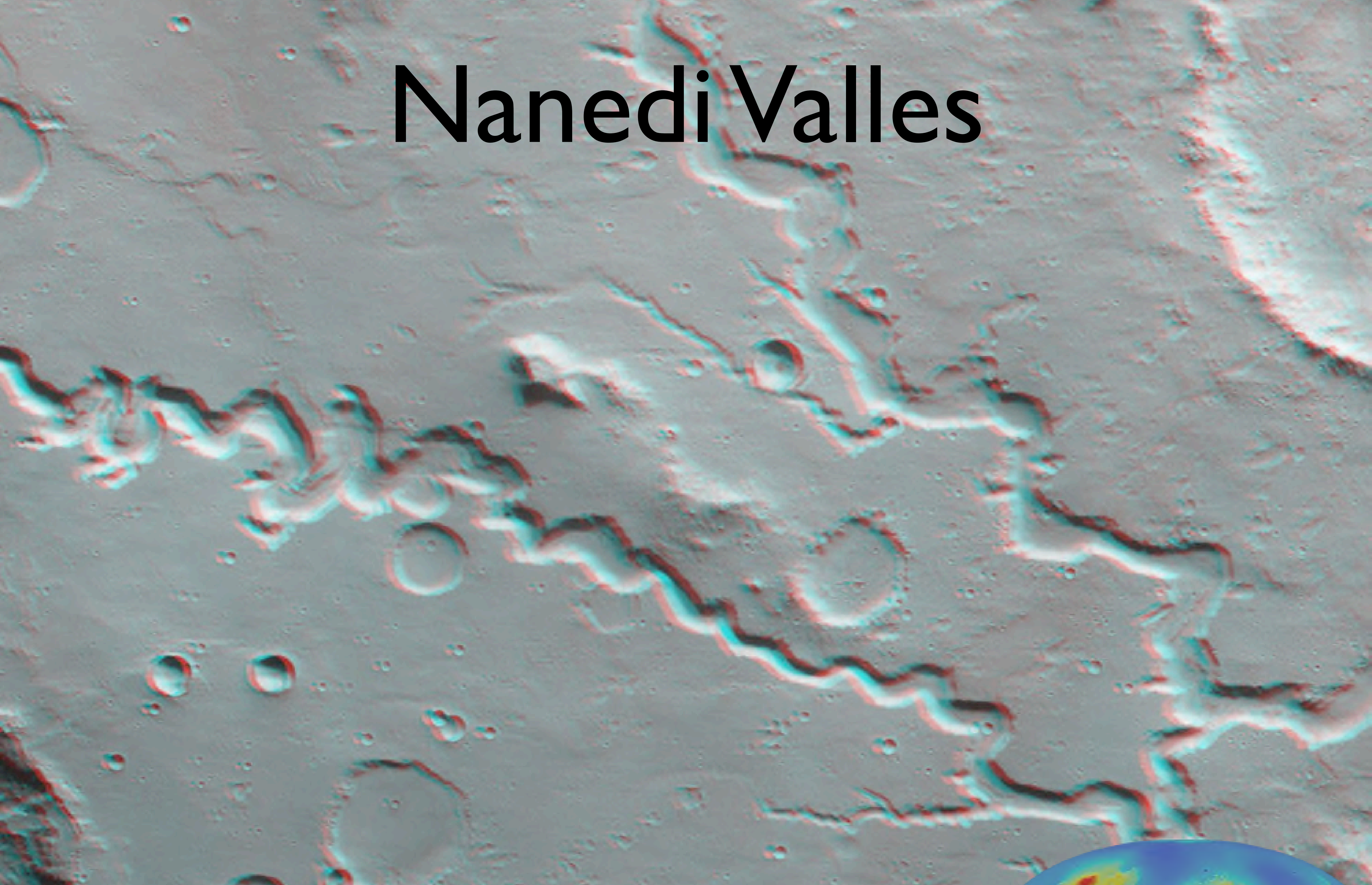
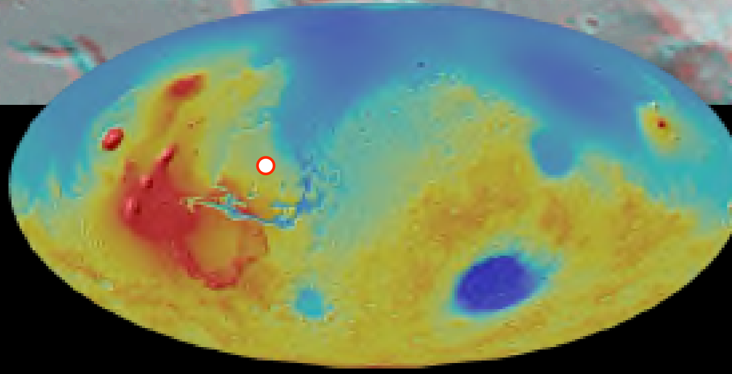
Nanedi Valles





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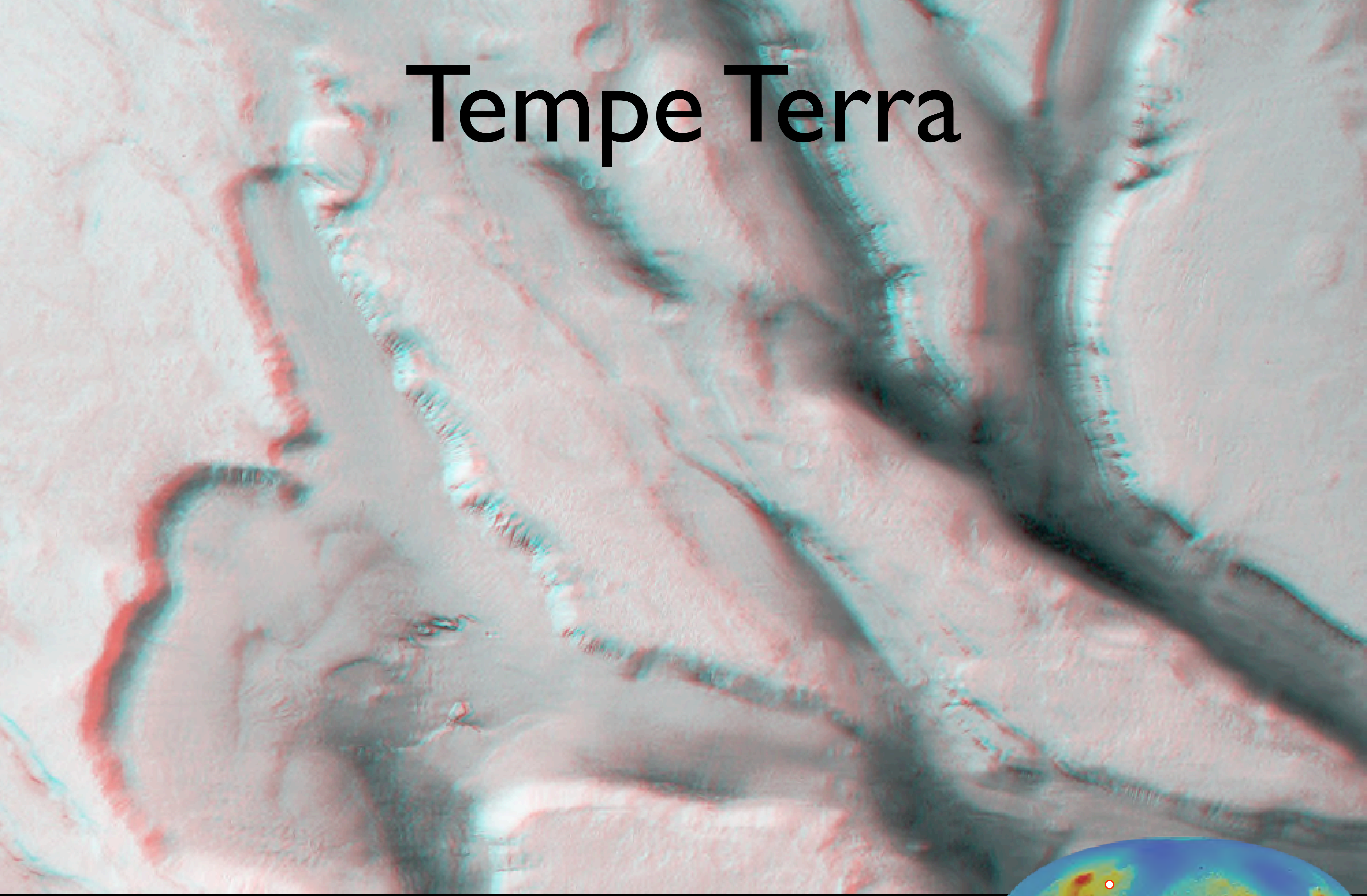
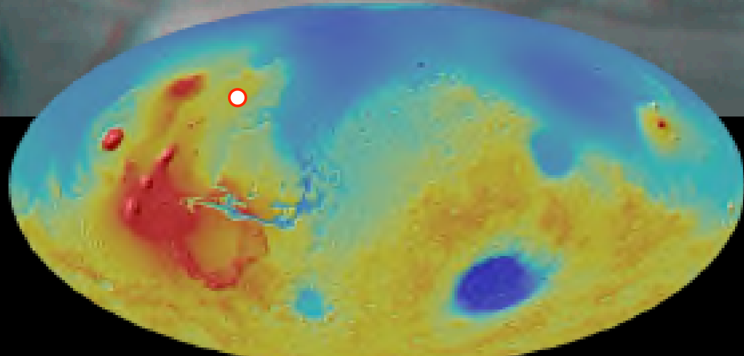
Tempe Terra





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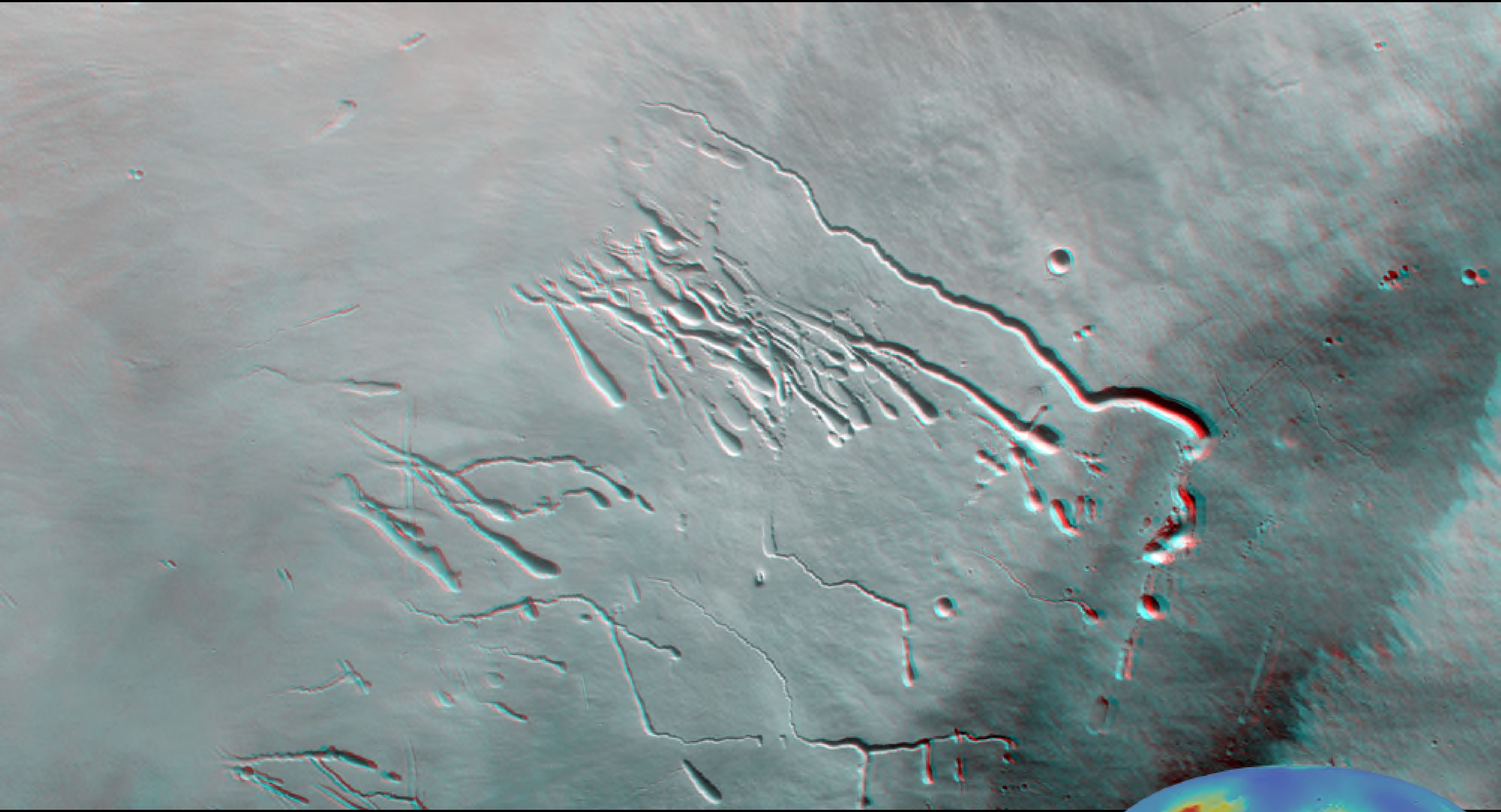
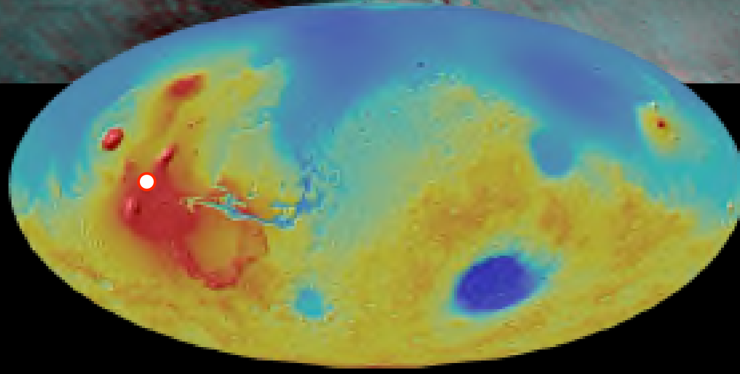
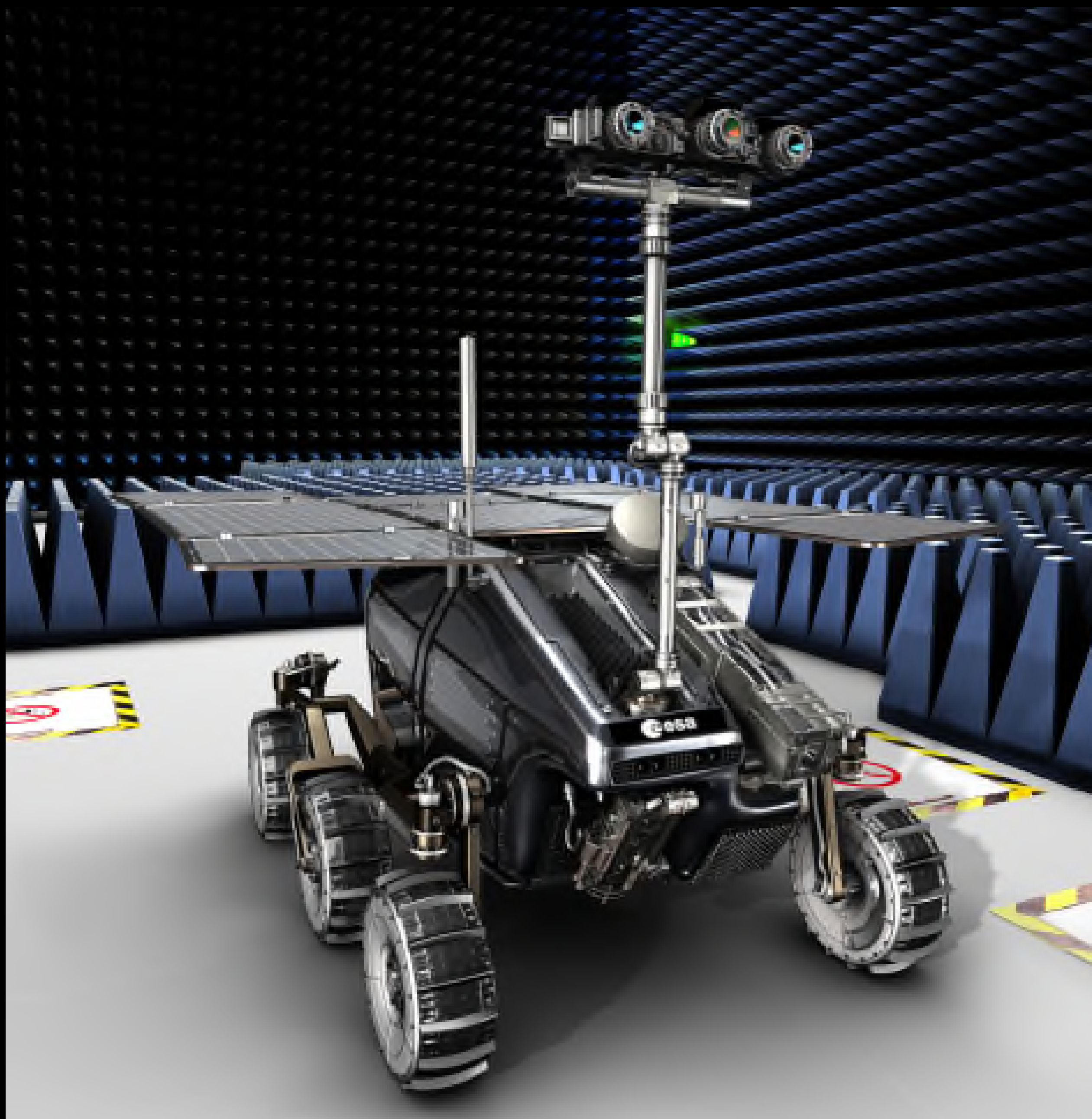
Pavonis Mons

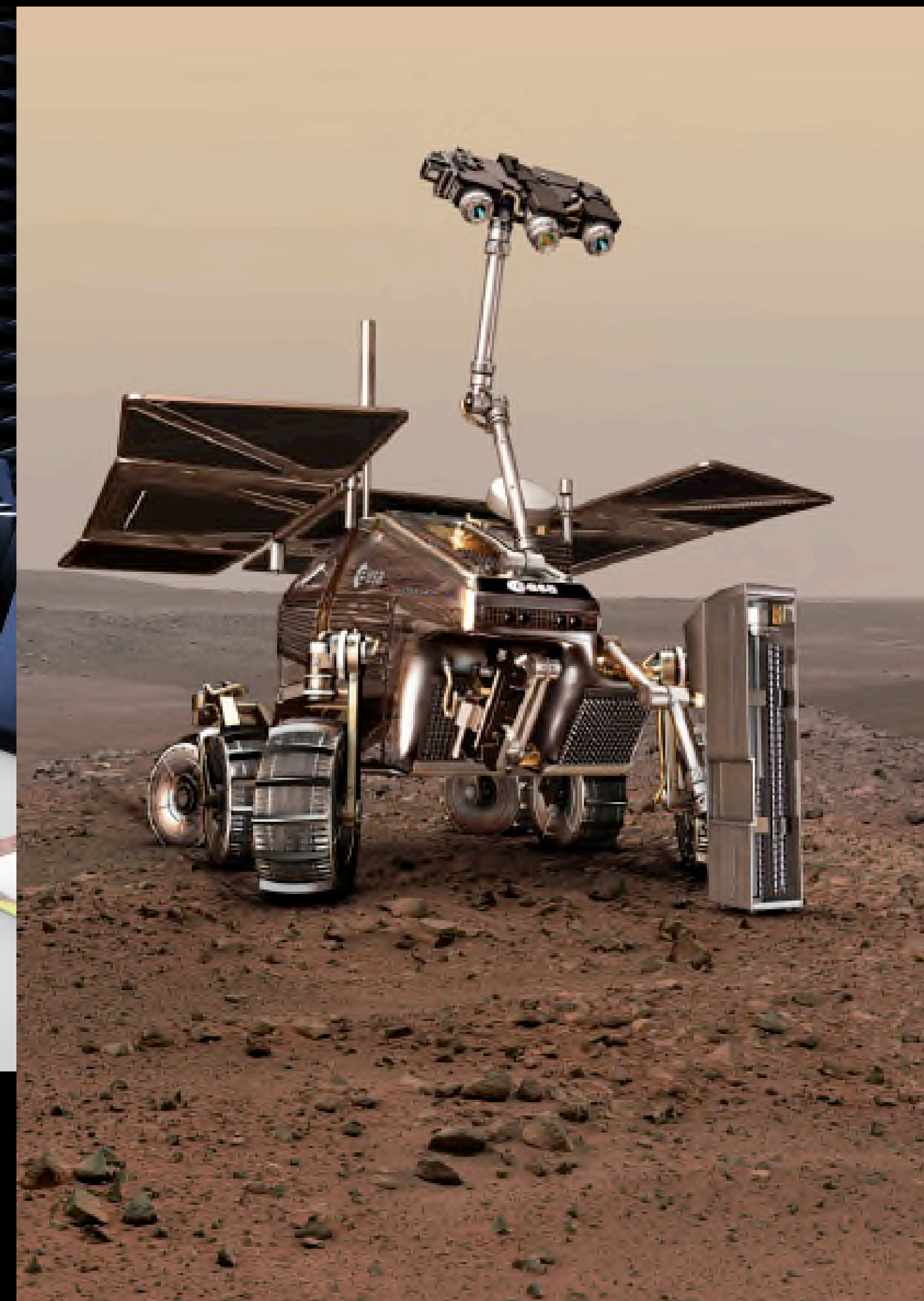




The future: ESA Aurora programme

ExoMars Rover





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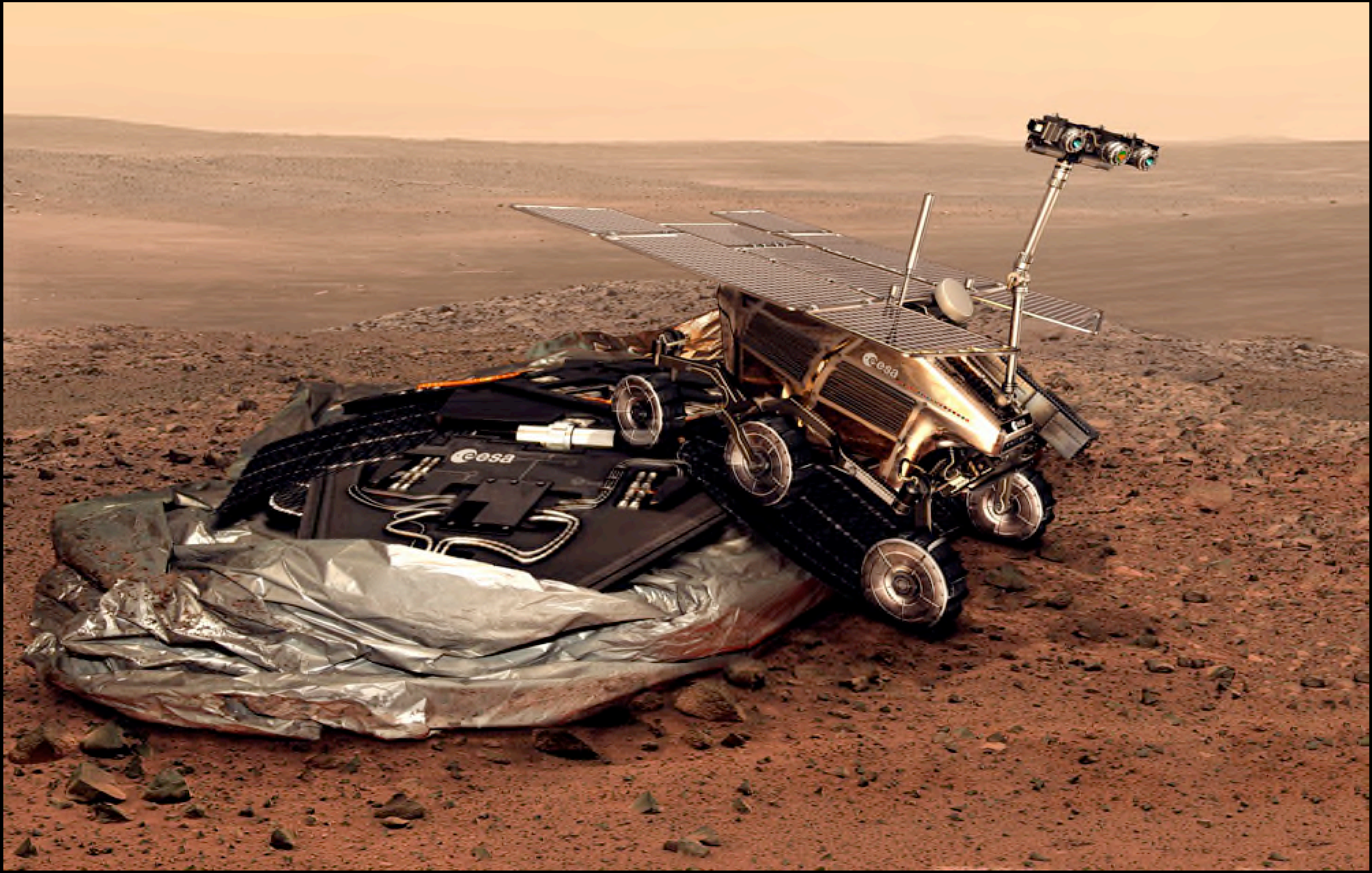
ExoMars



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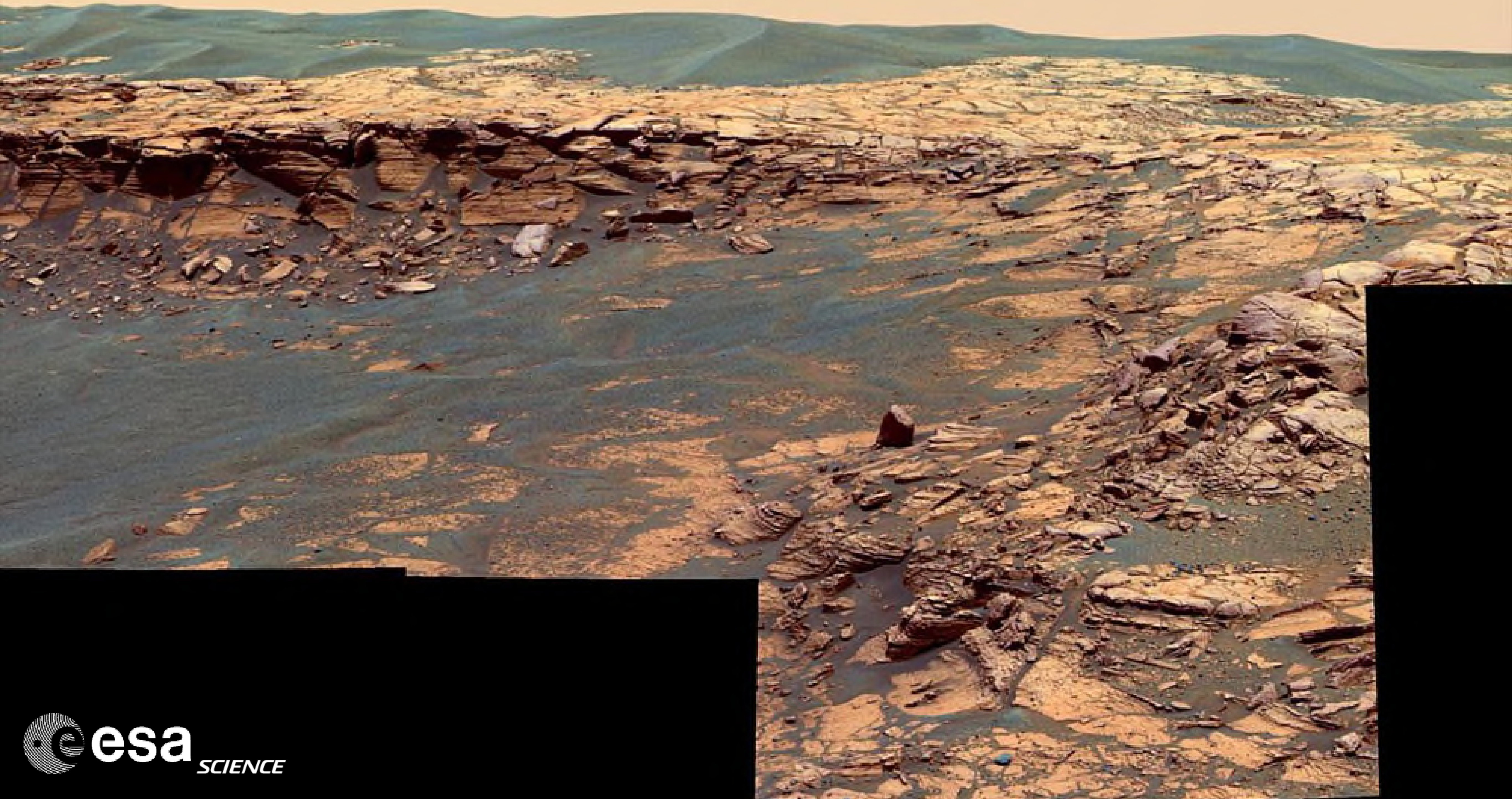
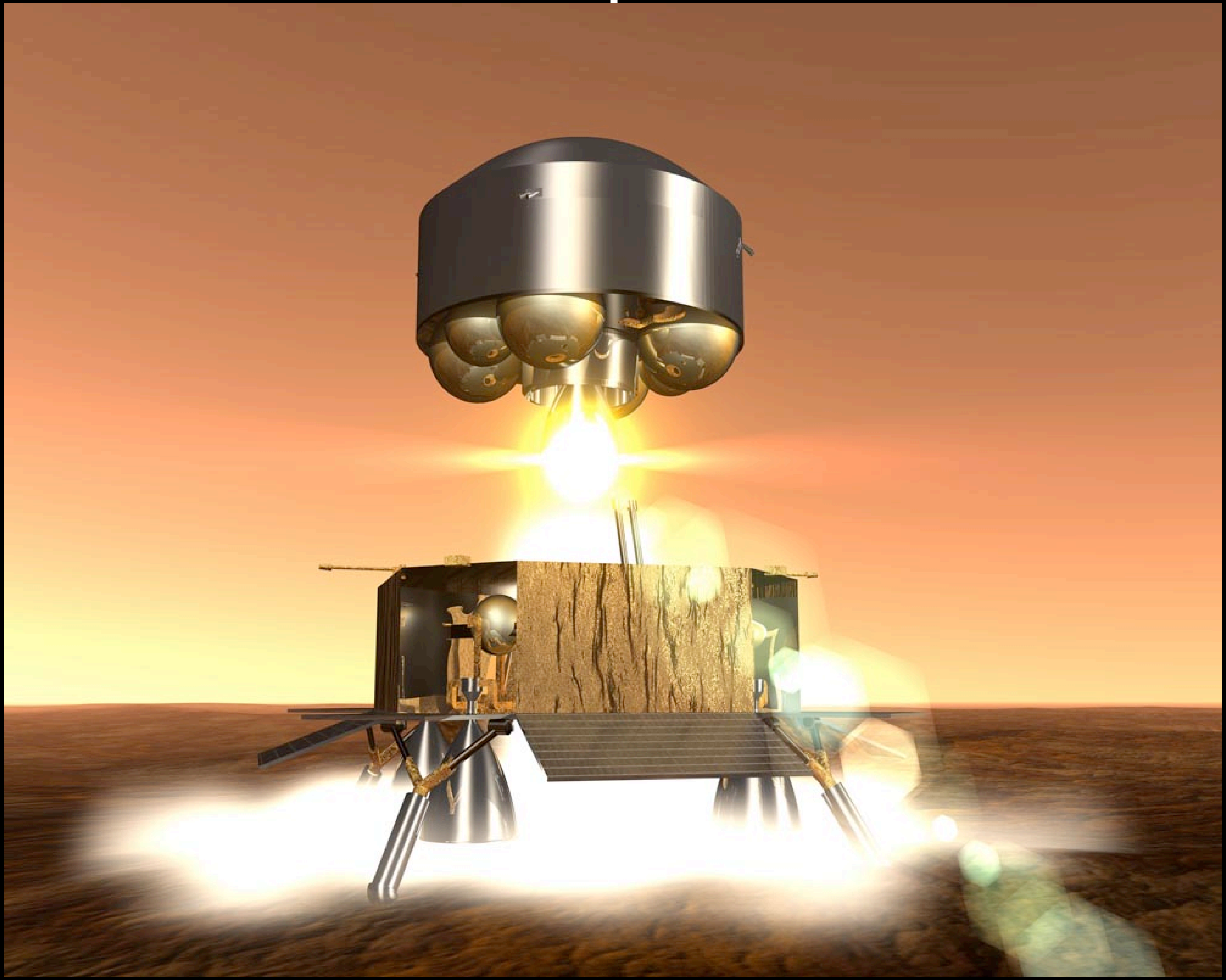
Where to drive…



Mars Sample Return



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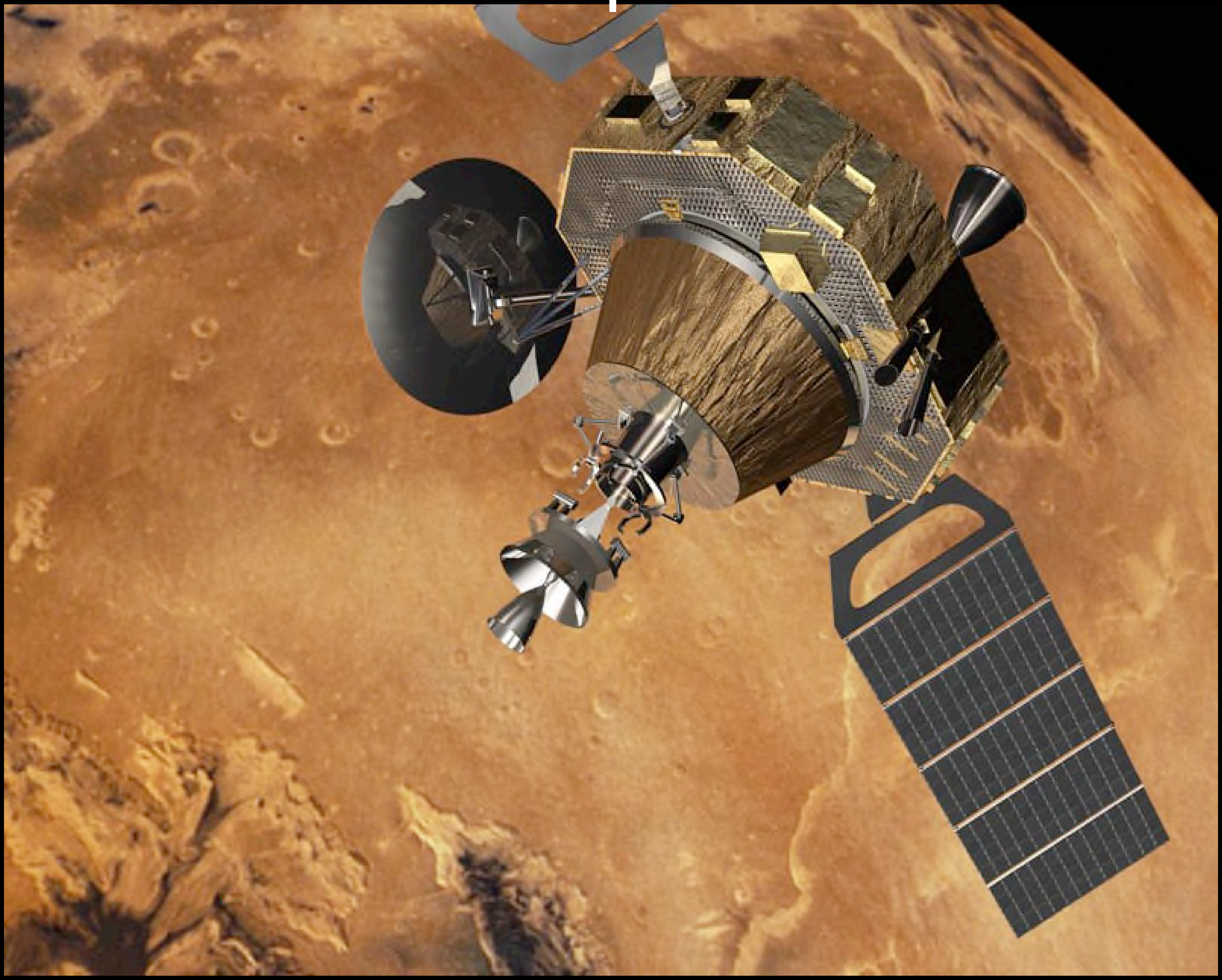
Mars Sample Return



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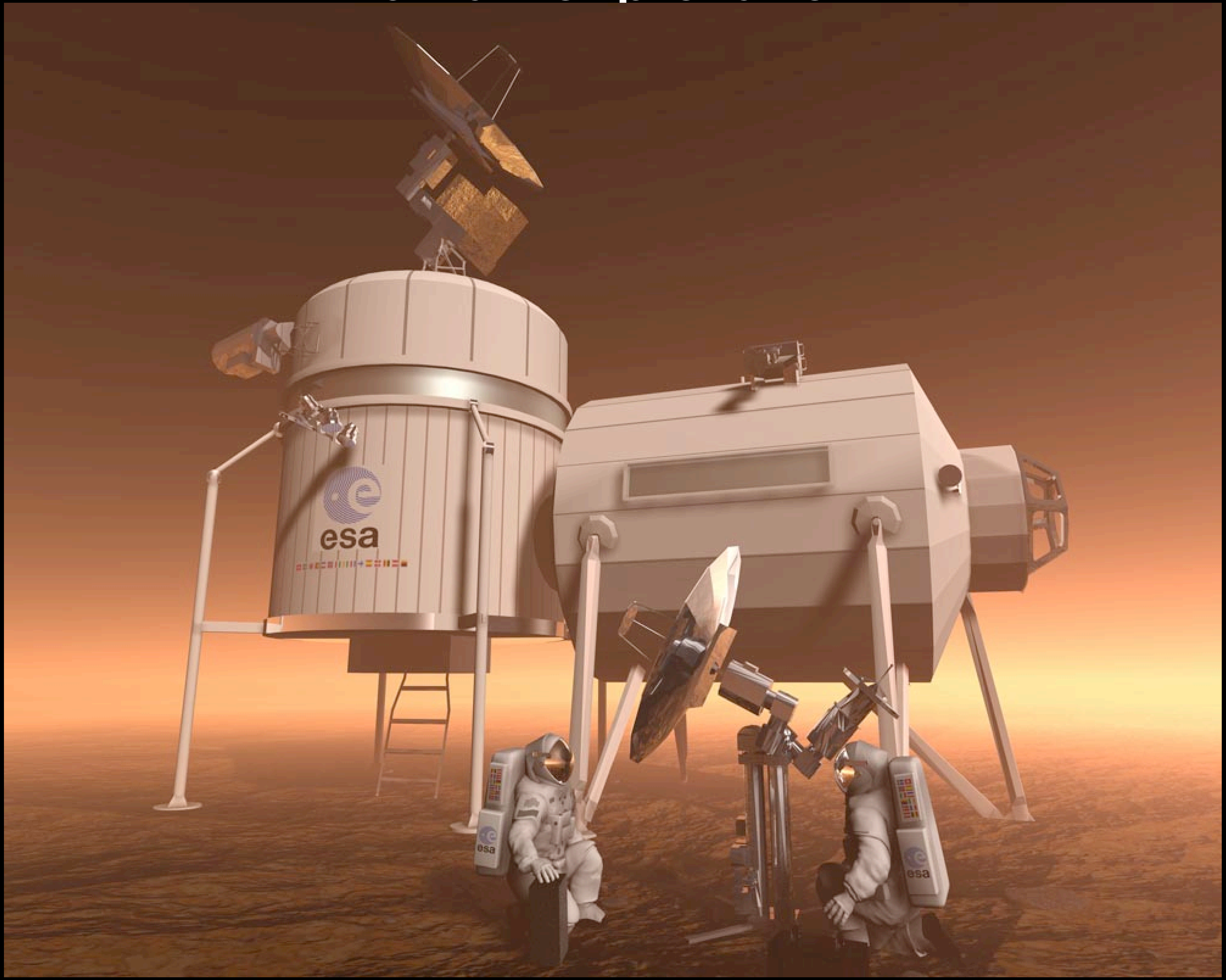
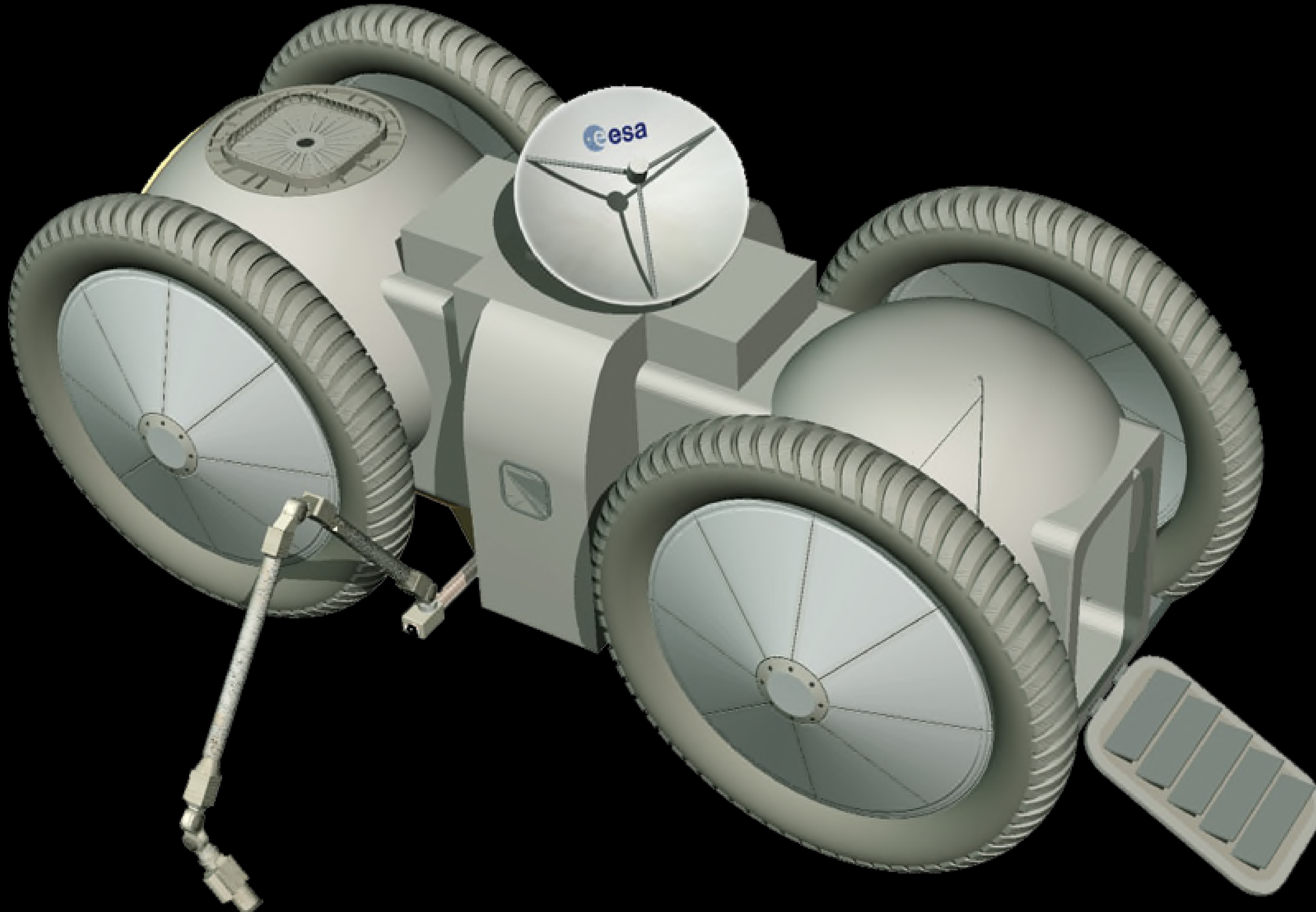
Human exploration



Human exploration



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