PLANETARY GEOLOGY

Lecture 1 – Solar System and Introduction to Mars Geology

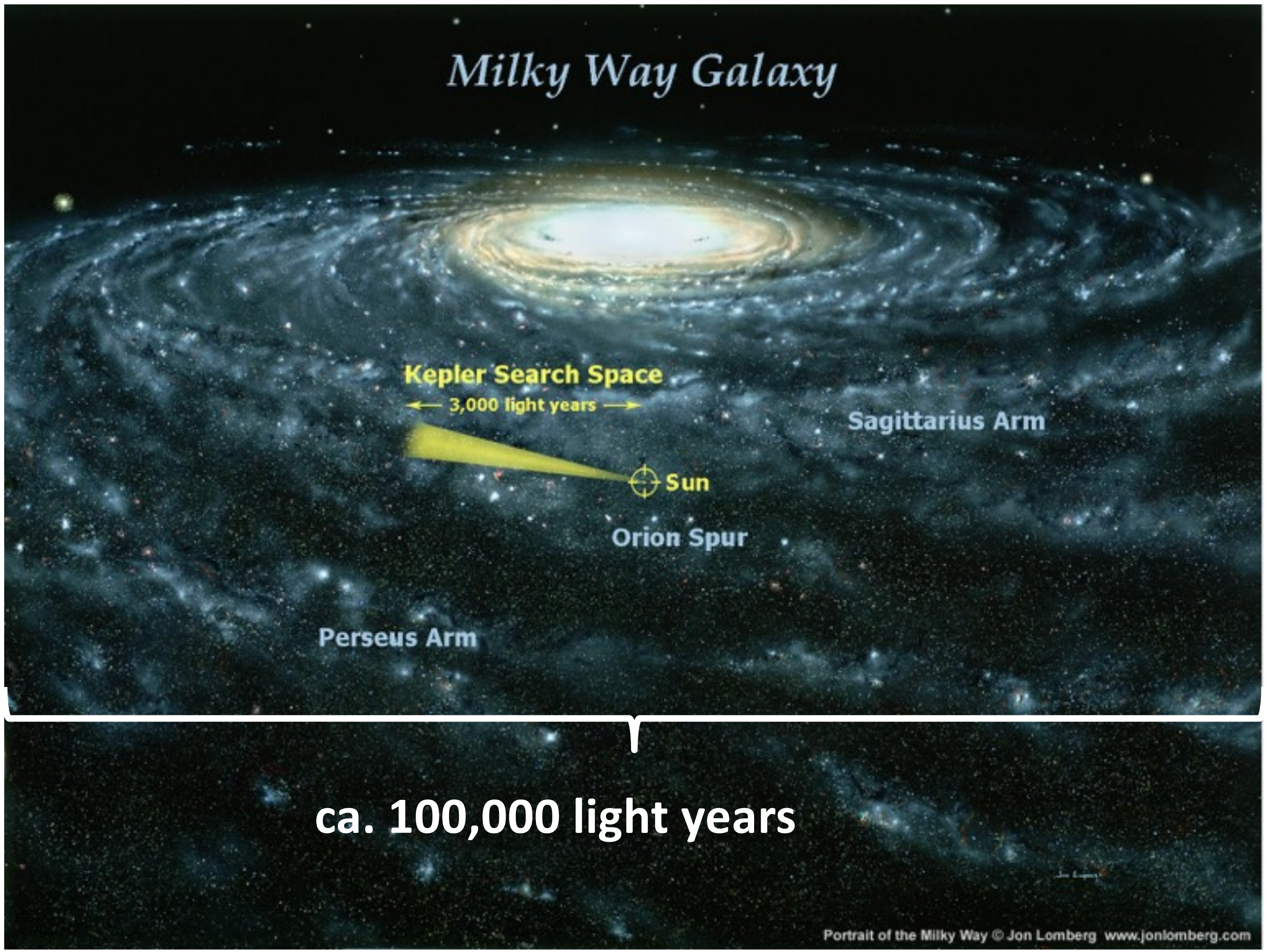
Prof. Fulvio FRANCHI

Solar System and Mars Geology

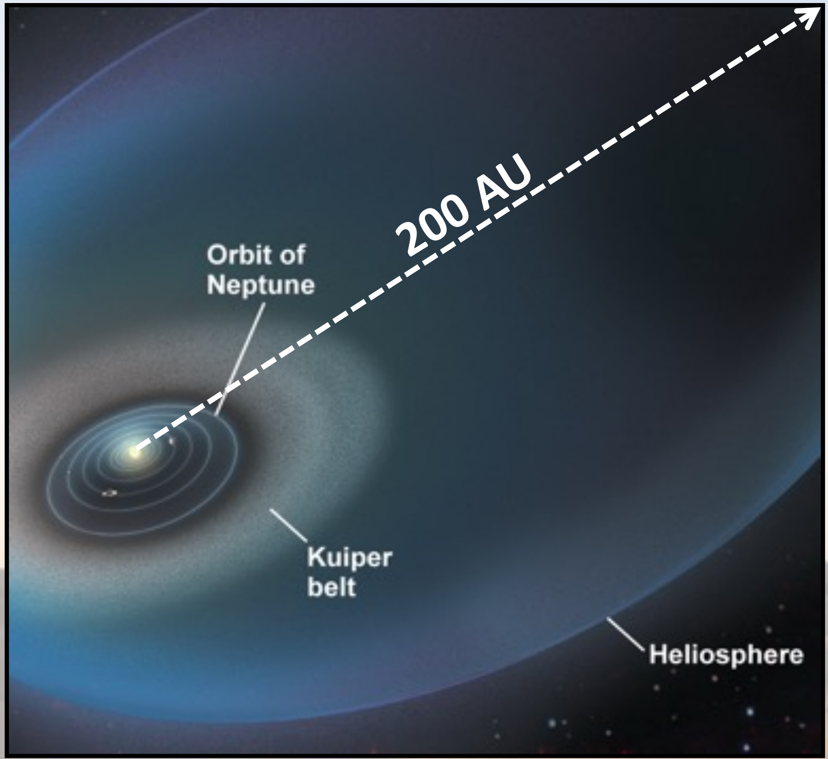
TOPICS TO BE COVERED:

- The Solar System
- Mars Geology (Pt. 1):
  - Mars interior
  - Mars tectonics
  - Ages and (Mars) stratigraphy
  - Craters
  - Volcanoes on Mars
  - Polar caps

Our Galaxy

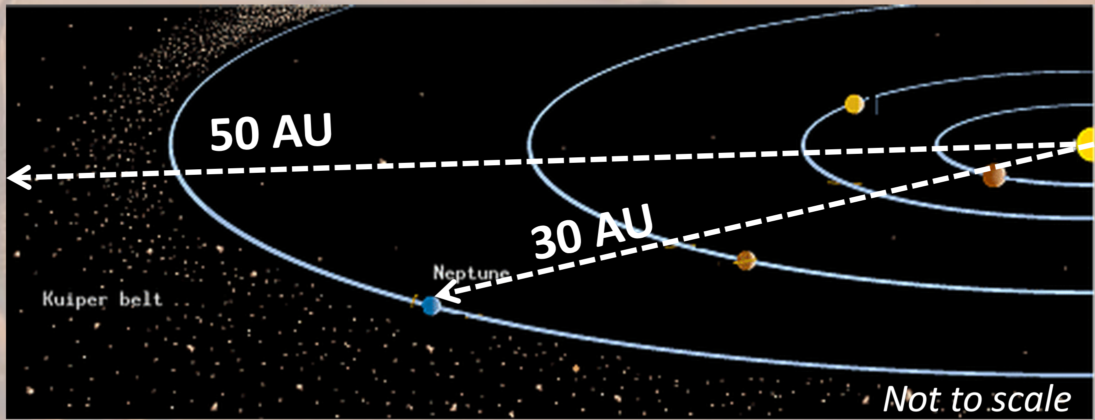

Milky Way Galaxy
Kepler Search Space
3,000 light years
Sagittarius Arm
Sun
Orion Spur
Perseus Arm
ca. 100,000 light years
Portrait of the Milky Way © Jon Lomberg www.jonlomberg.com

The Solar System



Heliosphere: is the outer reach of the solar wind (highly energetic electrons and protons released from the upper atmosphere of the Sun).

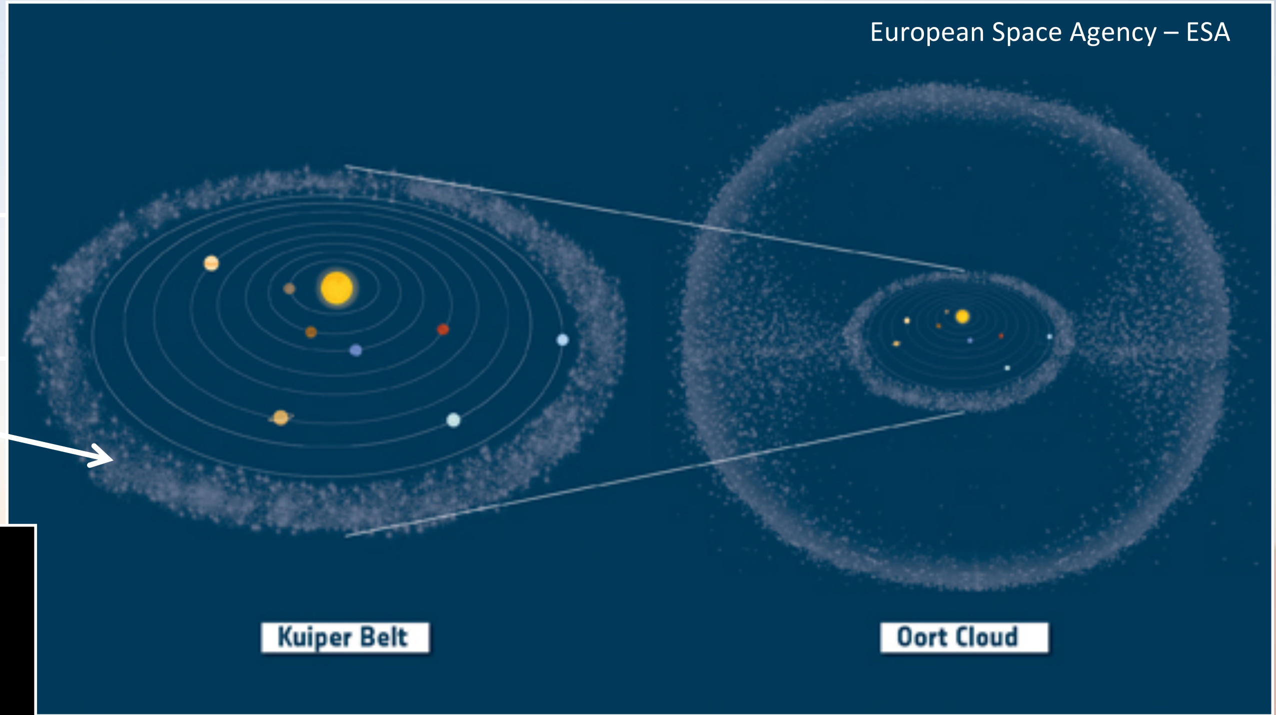
10 billion of small objects including comets (icy) and asteroids (metals and rocks)



→ ***One AU, an astronomical unit, is the distance between Earth and the Sun, 93 million miles***

The Solar System

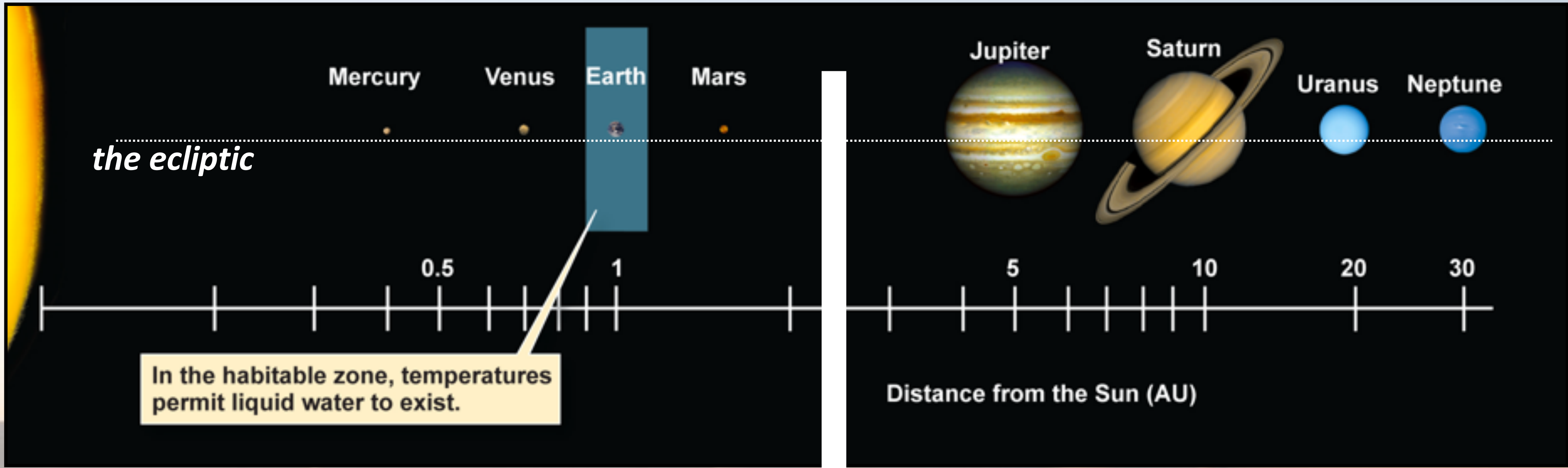
Comet 67P/Churyumov–Gerasimenko



Comets are icy planetesimals that orbit the Sun, mostly made of H_2O, CO_2, CH_4, NH_3 and other volatiles, organic compounds (?) and dust

Rosetta experiment sent a lander on the 67P/Churyumov–Gerasimenko.

The Solar System



TERRESTRIAL PLANETS

GAS-GIANT PLANETS

OUTER ICE-GIANT PLANETS

ASTEROIDS BELT

→ *A planetesimal is an object formed from dust, rock, and other materials.*

Acknowledgements

Some of the original material presented here comes from the work of the following individuals, to whom I'm very grateful:

Monica Pondrelli, Angelo Pio Rossi, Stephan van Gasselt, Barbara Cavalazzi, Ernst Hauber, Gaetano di Achille, Andrea Pacifici, Mihaela Glamocljia, Simone Silvestro.

Introduction: Mars vs Earth

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

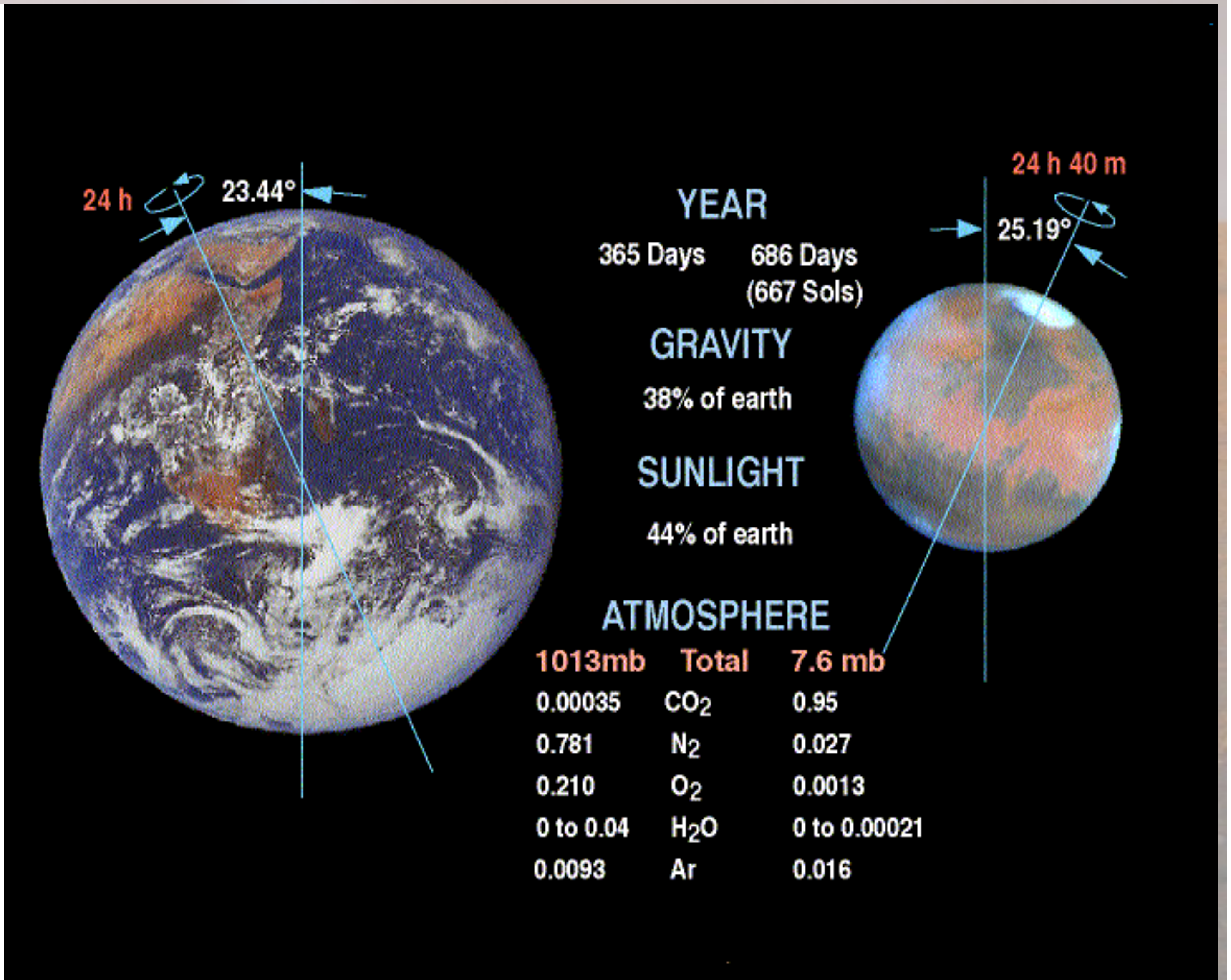
Escape: 5.02 km.s–1

Temperatures:

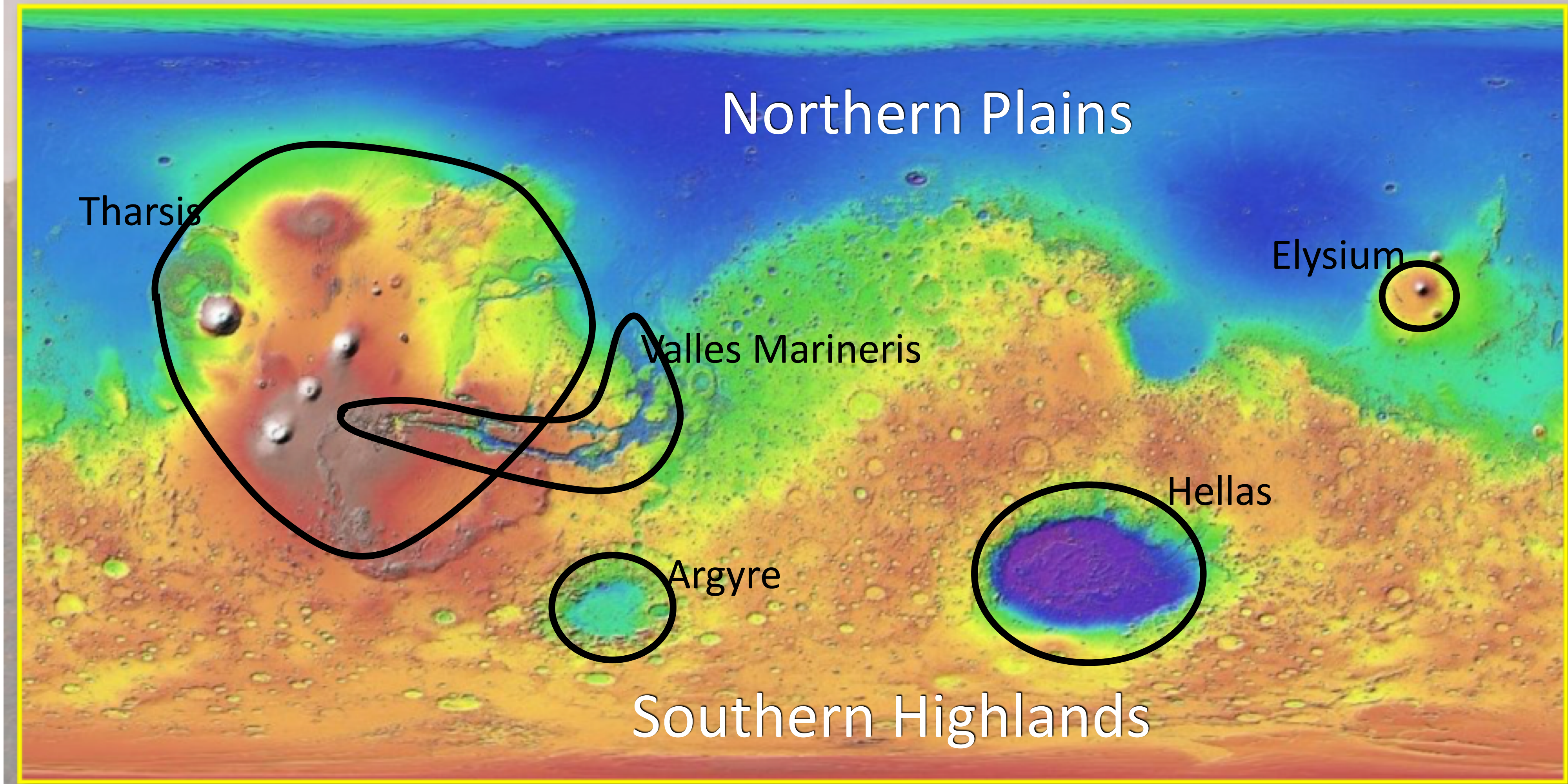
Min: –133°C (winter pole)

Max: +27°C (summer noon)

Average: –55°C (218K)

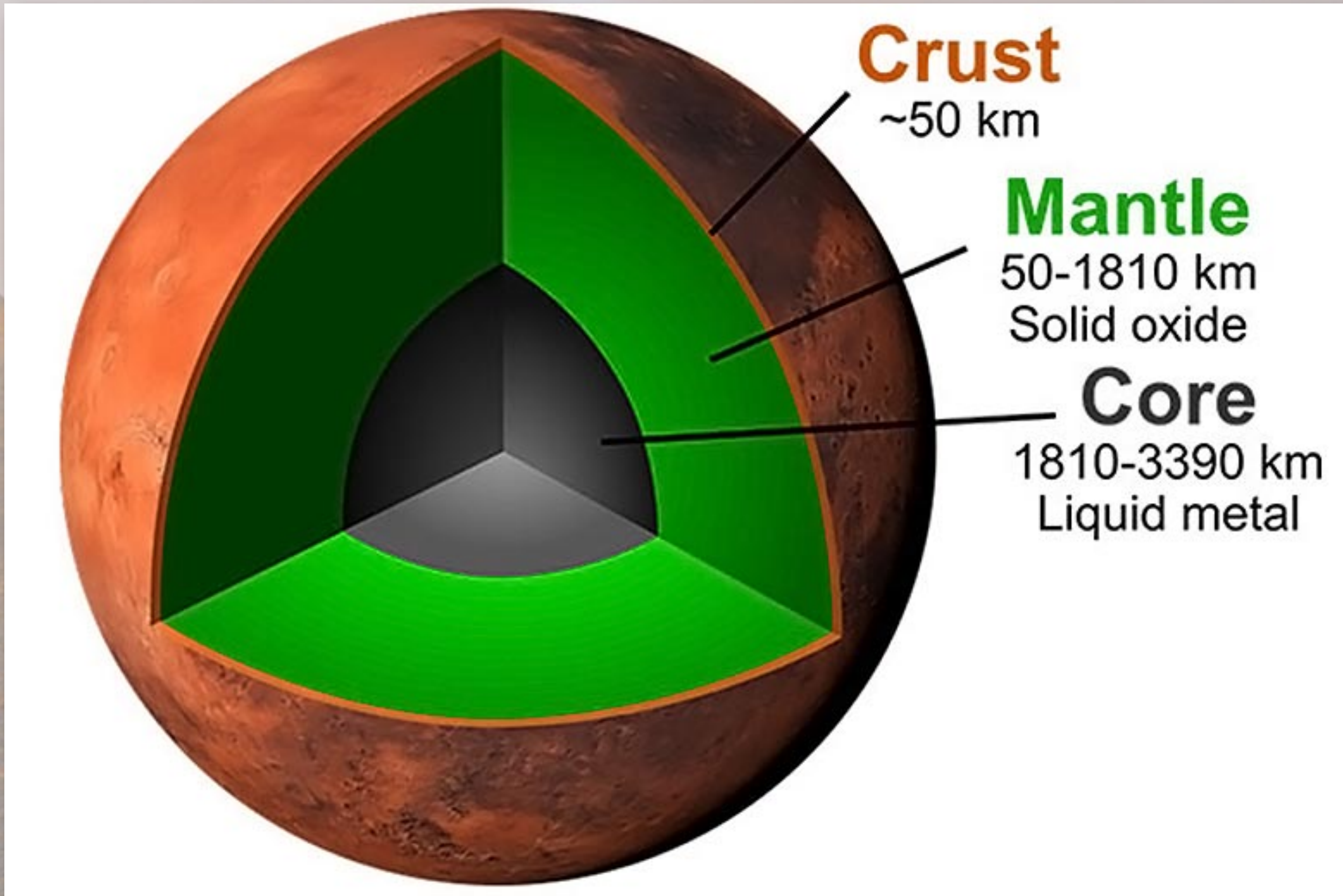


Introduction
Mars physiography



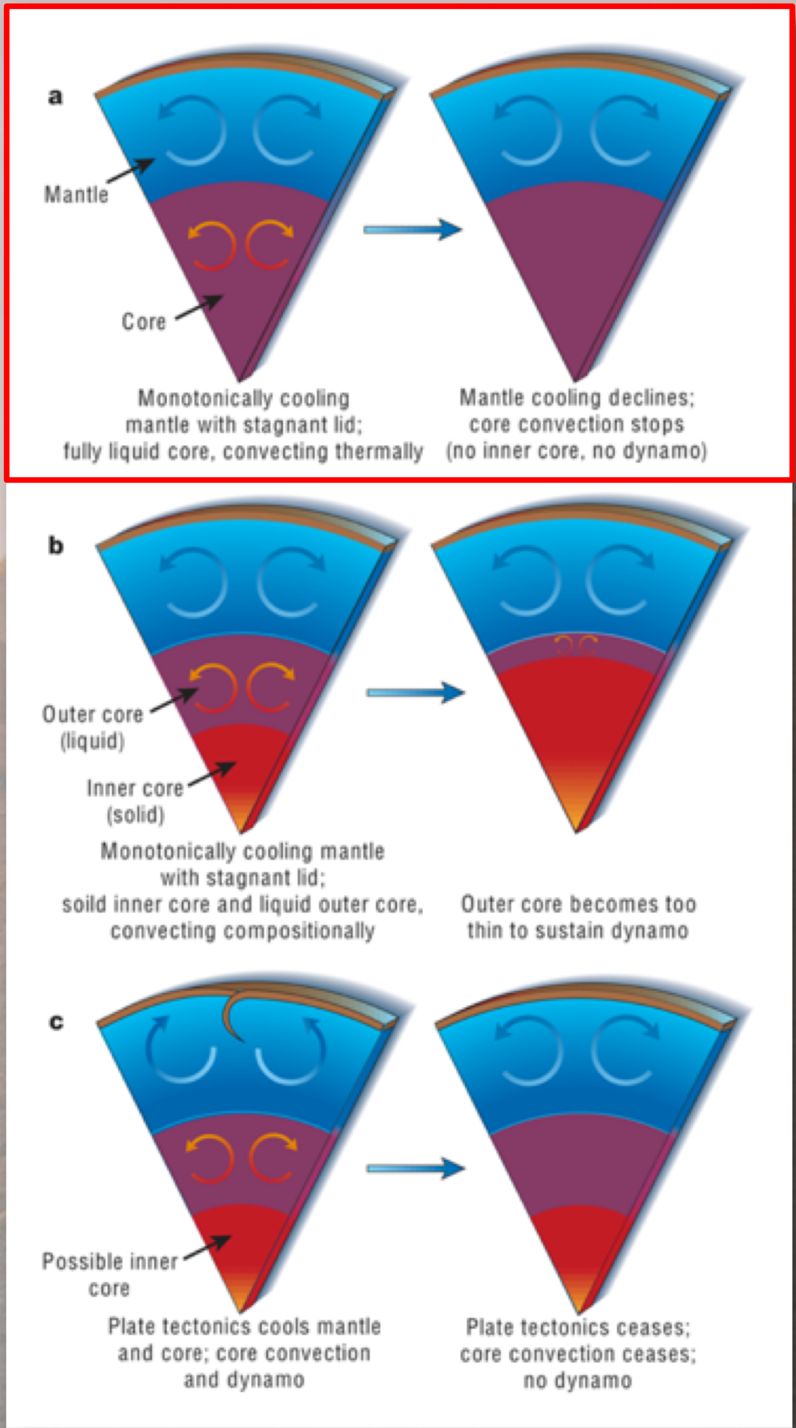
MGS MOLA Global Colorized Hillshade 463m

Mars Interior structure



"The composition of Mars" by Takashi Yoshizaki and William F. McDonough, 21 January 2020, Geochimica et Cosmochimica Acta.

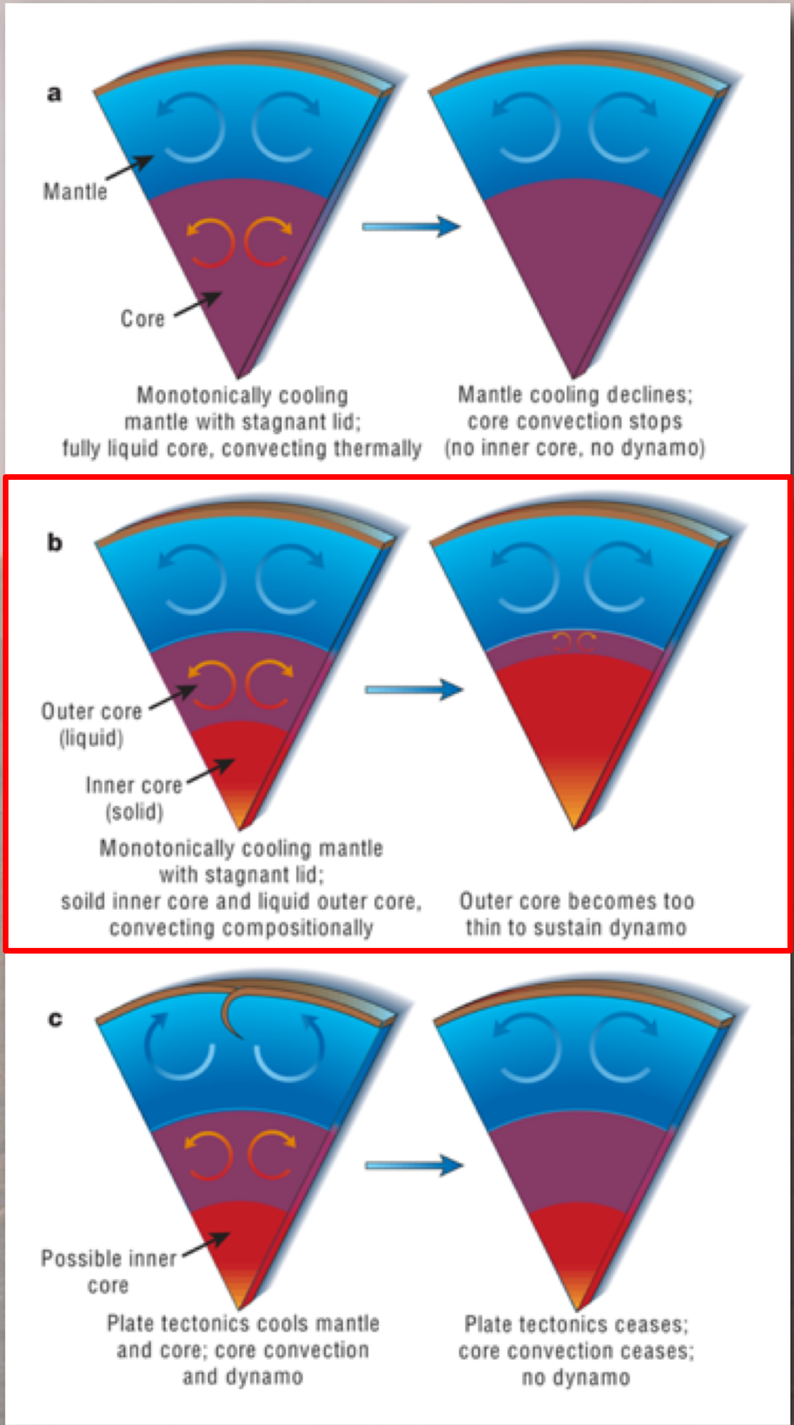
Mars Core Evolution



a) Completely liquid core whose convective motions generated a global magnetic field. The mantle was also subject to convection, but the Martian crust did not break up into floating plates and no plate tectonics ever occurred. As the planet cooled down, the liquid core's convection decreased and finally stopped, leading to the disappearance of Mars' magnetic field.

Source: *Stevenson (2001) Nature, 412*

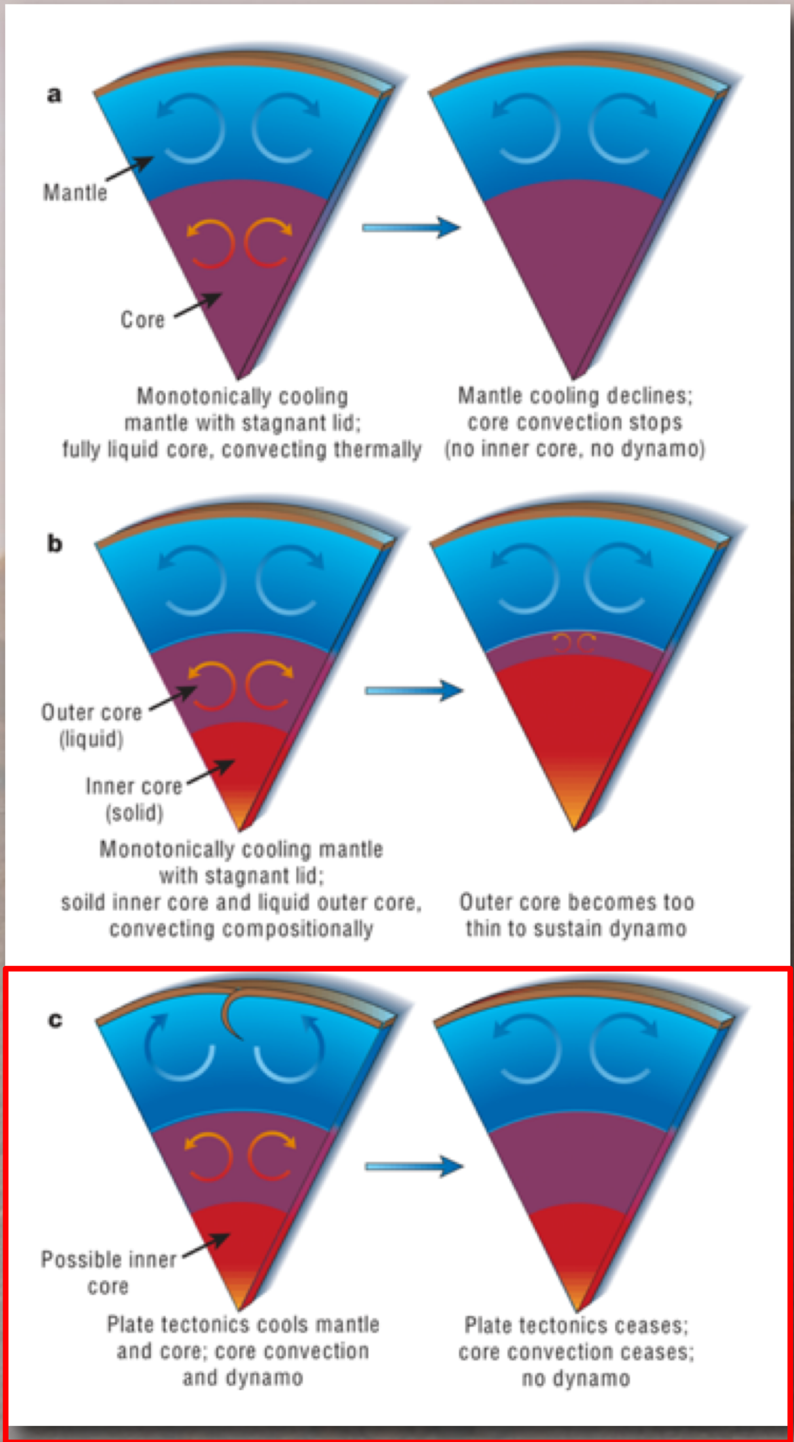
Mars Core Evolution



b) a crust comprising a single plate covering the whole of the planet and a mantle subject to convective motions. Instead of being completely liquid, the core in this scenario has an external part that is liquid and whose convection is sufficient to create a global magnetic field, and an inner part that is solid due to the crystallization of the initial molten metal. The difference between this model and the first one is based on the hypothesis that, following the planet's cooling, the core rapidly continued to gain mass, only leaving a liquid layer too thin to be able to host convective cells able to generate a magnetic field.

Source: *Stevenson (2001) Nature, 412*

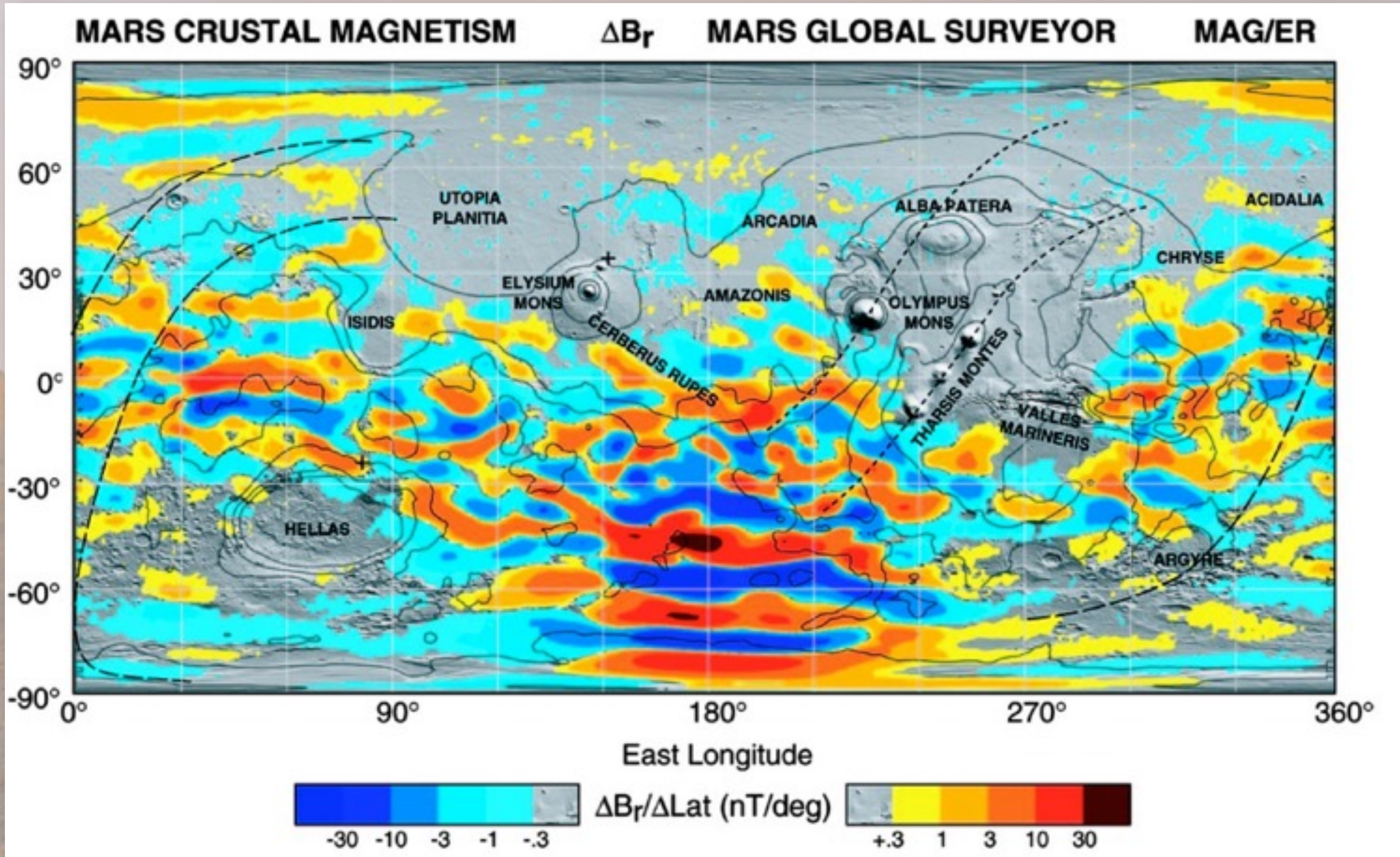
Mars Core Evolution



c) involves the appearance of plate tectonics, that allows the planet's internal heat to be evacuated efficiently. Under the crust, the mantle is subject to convective motions that contribute to plate movements. The core is composed of a convective liquid outer core and a solid inner core. Following the efficient cooling of the planet's interior, or due to a specific event such as a major collision, the mantle's convection stops. This automatically leads to the cessation of plate tectonics and has a dramatic effect on the mantle's convection, which also stops. The domino effect leads convective motions of the outer core's molten metal to stop, leading to the disappearance of the global magnetic field.

Source: *Stevenson (2001) Nature, 412*

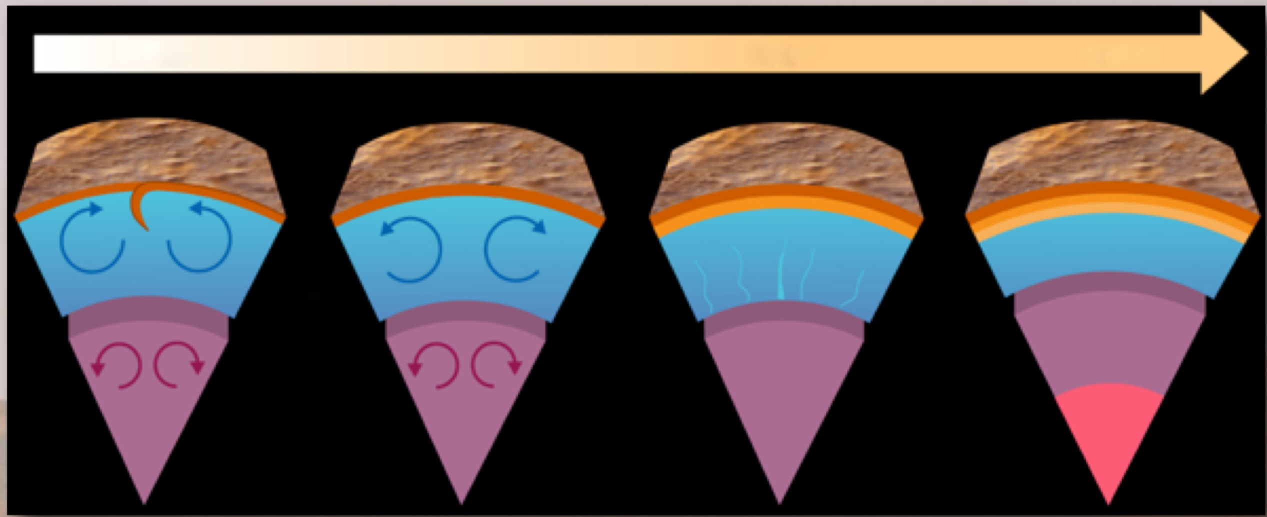
Mars magnetism



Magnetic map of Mars. Credit: NASA

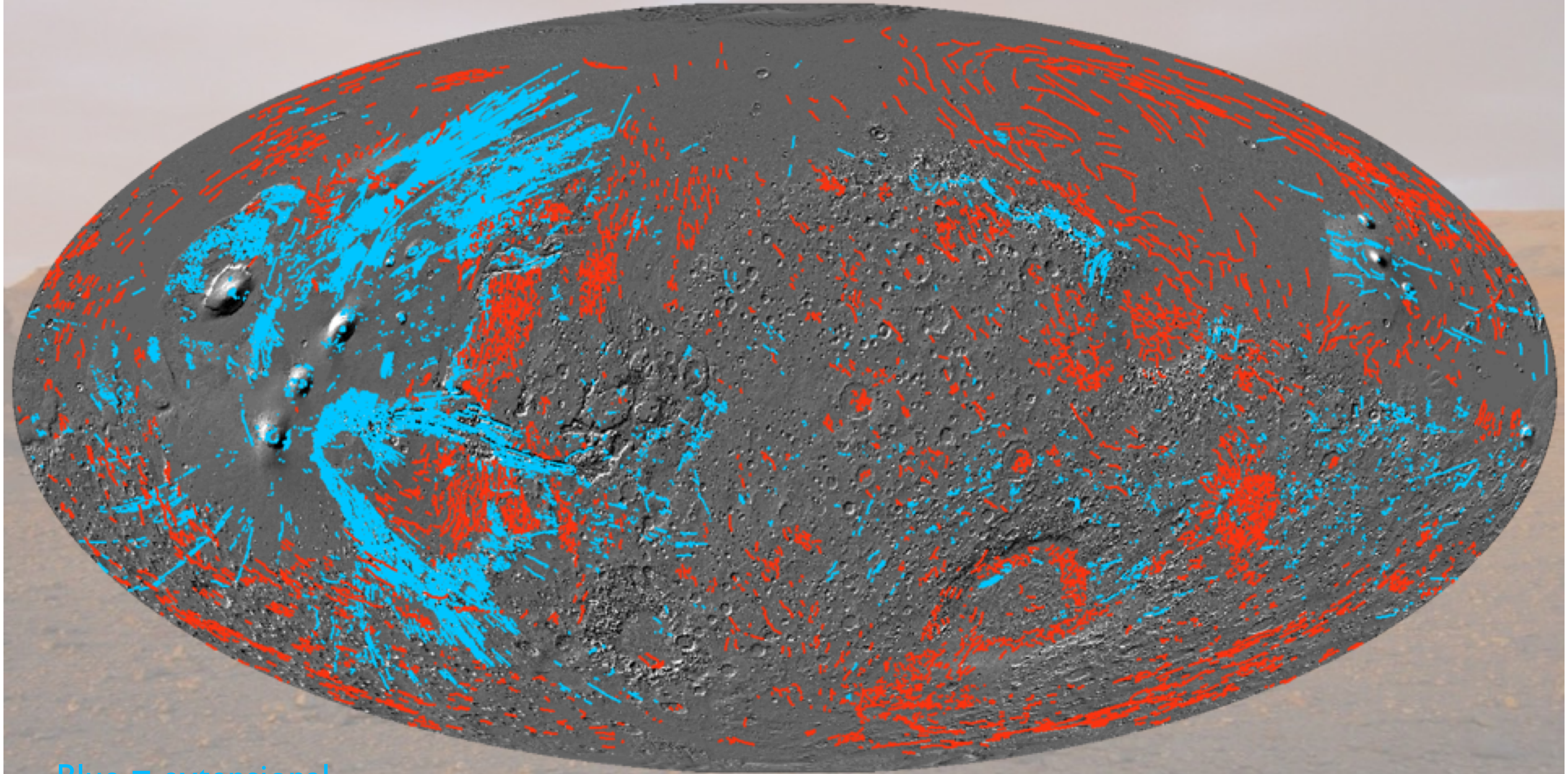
No Global Field (Localized Magnetic Fields)
Non-random Distribution of Local Fields
"Noise" (this is due to variable solar magnetic field)
A core dynamo operated much like Earth's current dynamo, but was probably limited in duration to several hundred million years.

Mars Interior:
Open Questions



- Did plate tectonics ever occurred on Mars?
- What is the water/volatile content of the Martian mantle and its outgassing history?
- What is the present heat flux?
- What is the present volcanic and tectonic activity?
- What is the timing of the geological evolution?
- How does such evolution impact on the habitability of the planet?

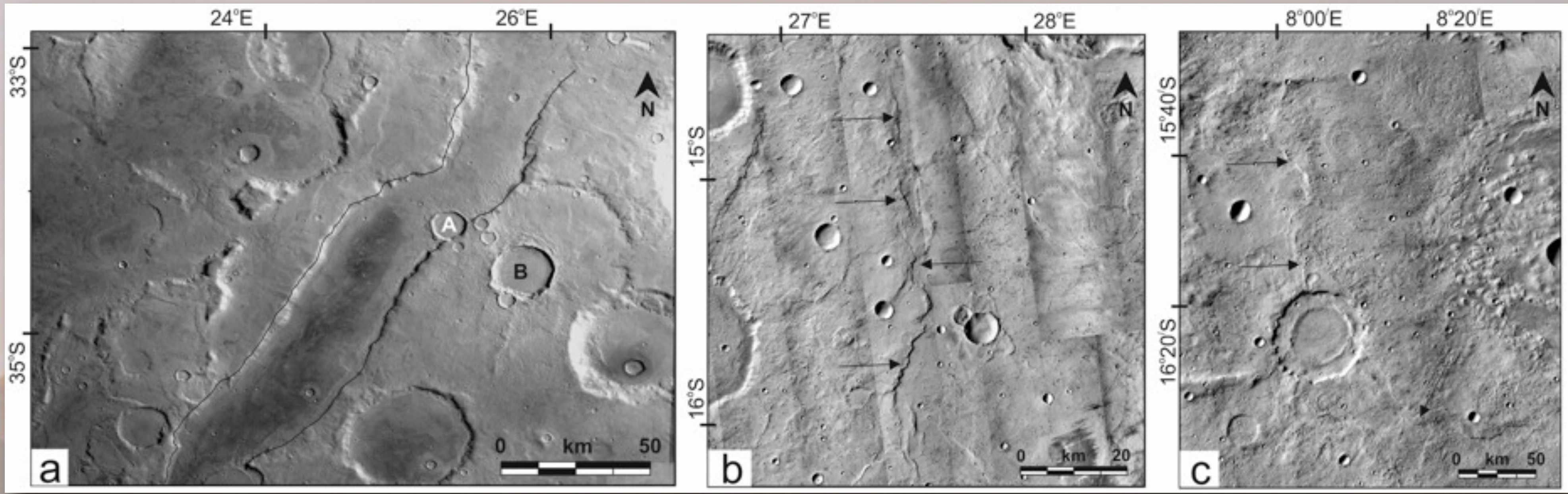
Mars Tectonics



Blue = extensional
Red = compressional

Source: Anderson et al. (2008), Icarus, 195, 537-546

Mars Tectonics



Source: Ruj et al. (2019), Geoscience Frontiers, 10, 1029-1037

(a) Graben

(b) Wrinkle ridge is marked with arrowheads.

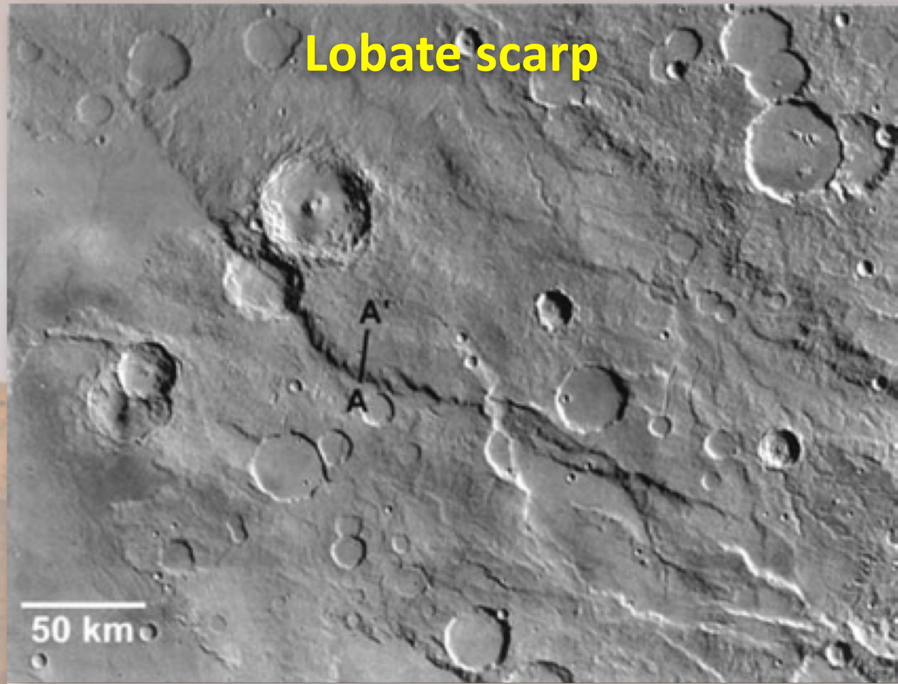
(c) Lobate scarp in the Terra Sabaea region.

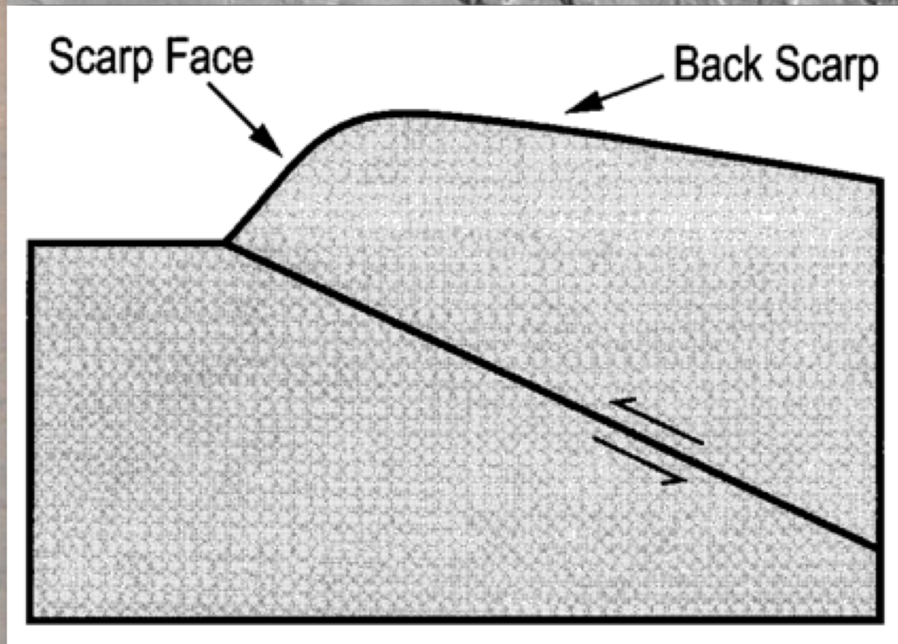
- The extensional structures are interpreted to be products of crustal stretching in Late Noachian.
- The compressional structures correspond to the global Martian contractional phase due by planetary cooling.

Mars Tectonics

Schematic cross-sectional view of a **lobate scarp**.

Lobate scarps consist of two morphologic features, a steeply sloping scarp face and a gently sloping back scarp. The proposed kinematic model for the formation of lobate scarps involves deformation over a buried thrust fault that propagates upward and eventually breaks the surface





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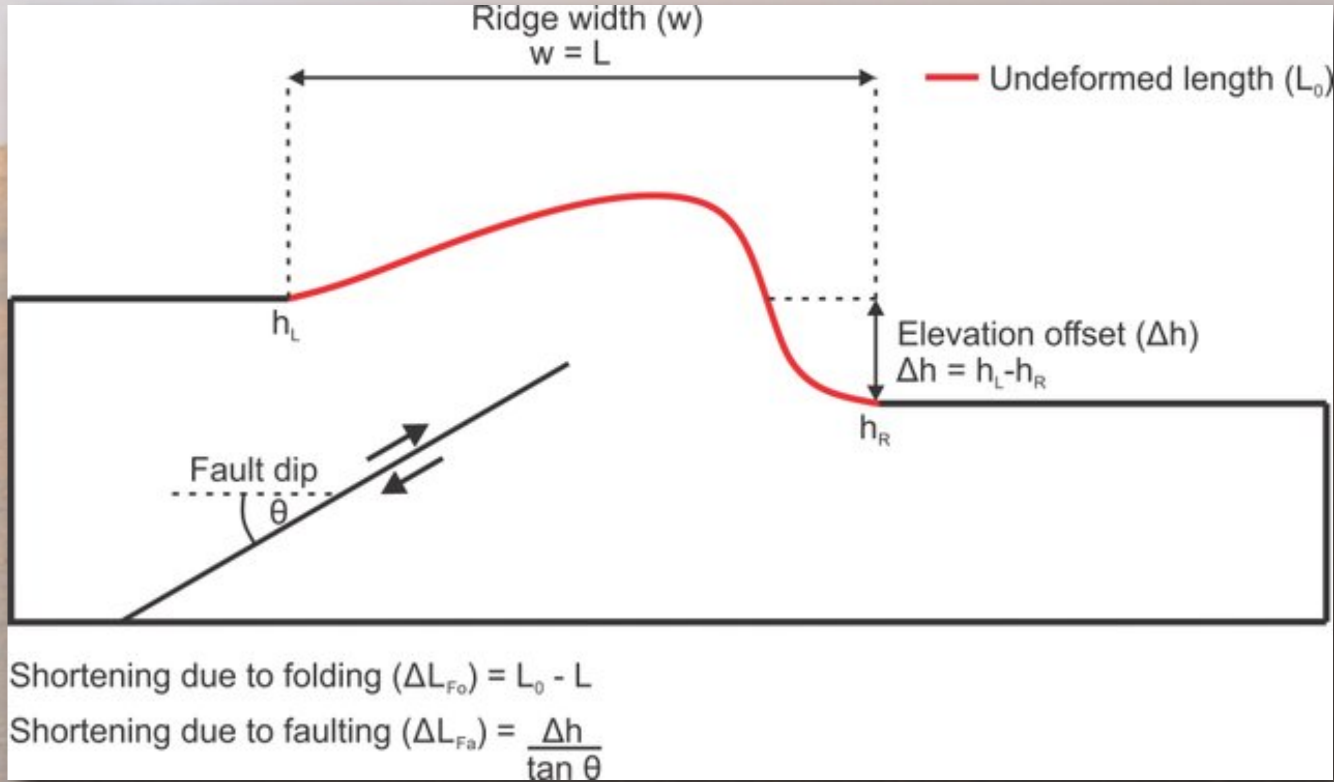
Mars Tectonics



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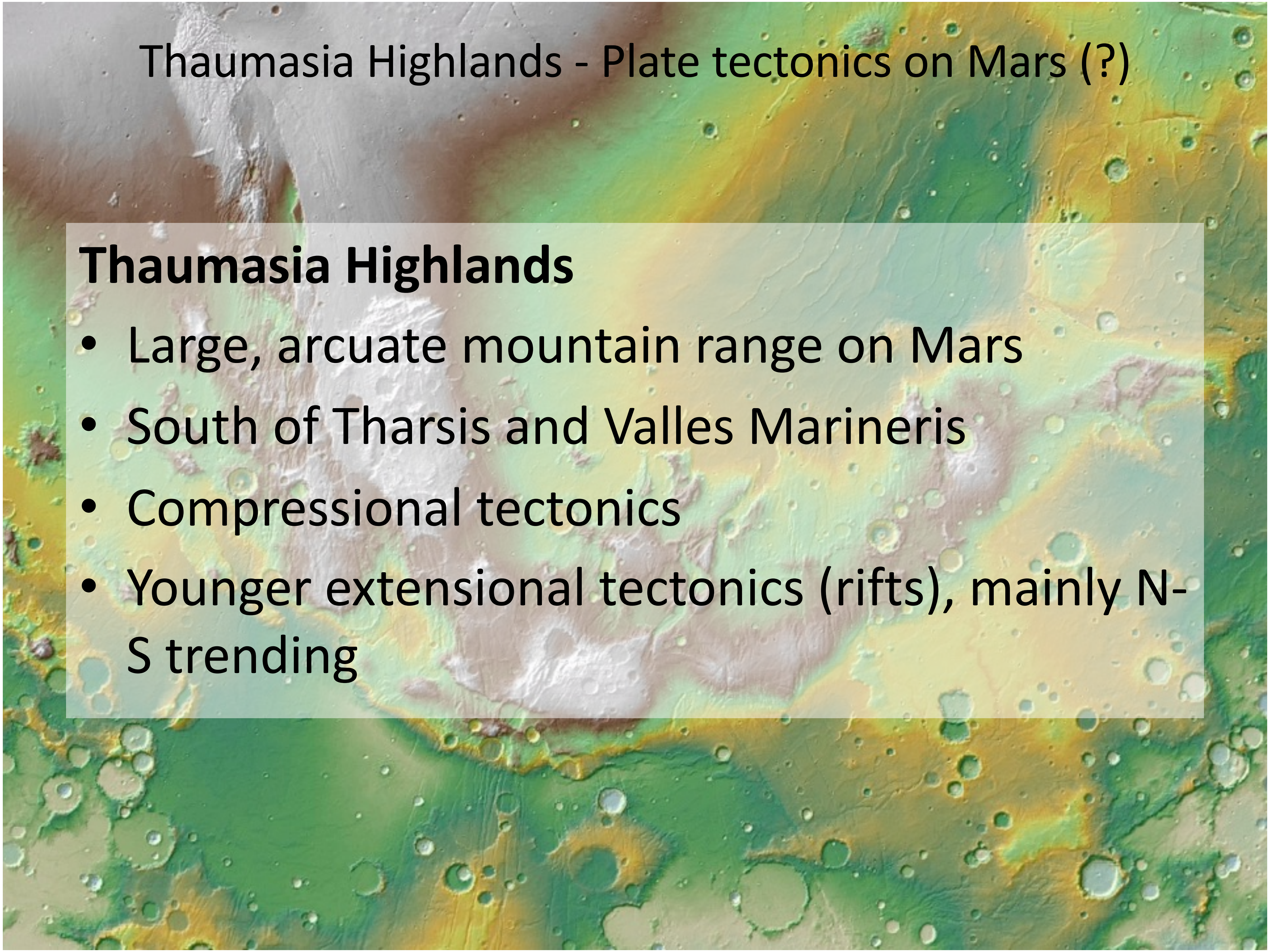
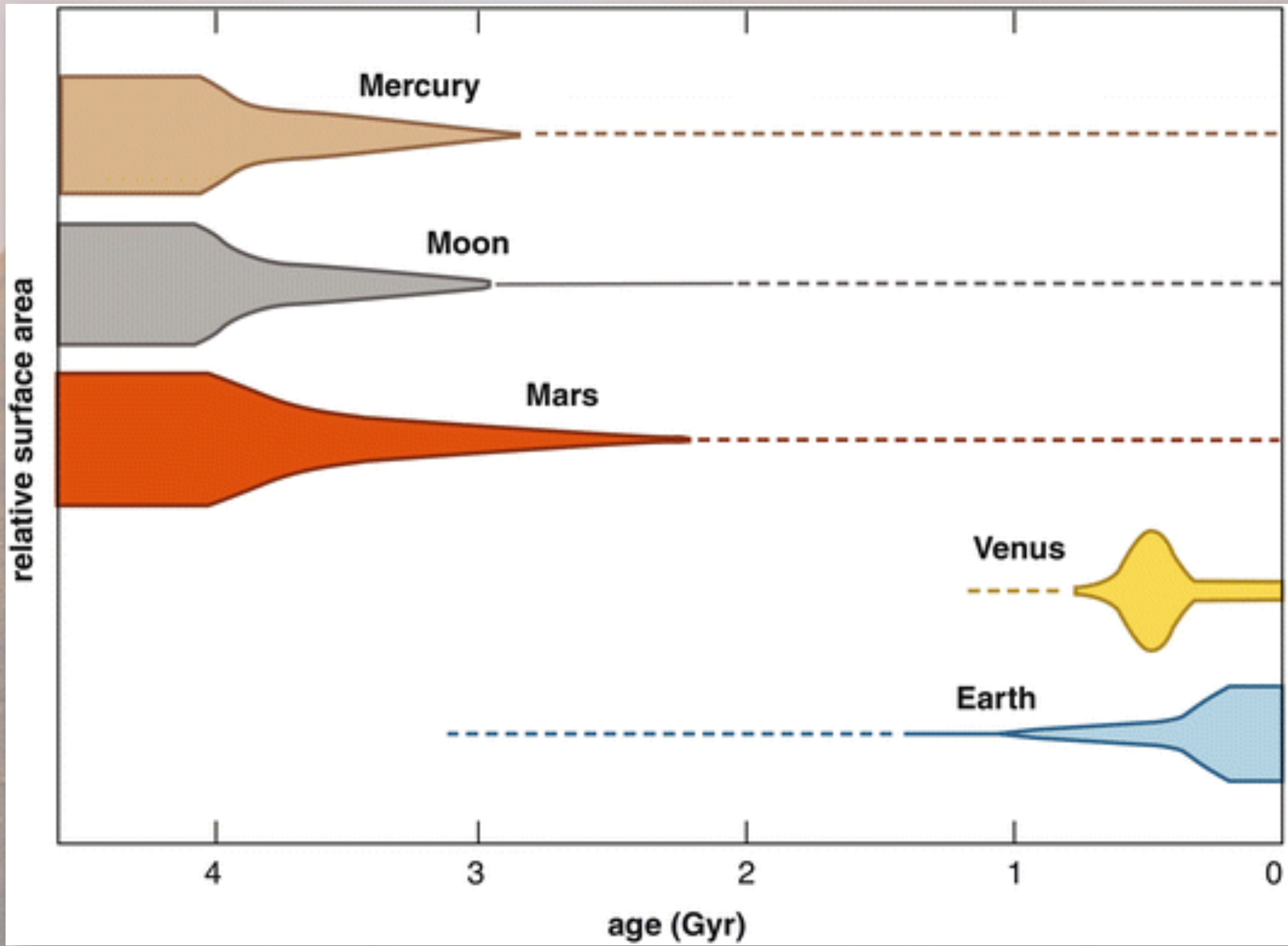


Thaumasia Highlands - Plate tectonics on Mars (?)

Thaumasia Highlands

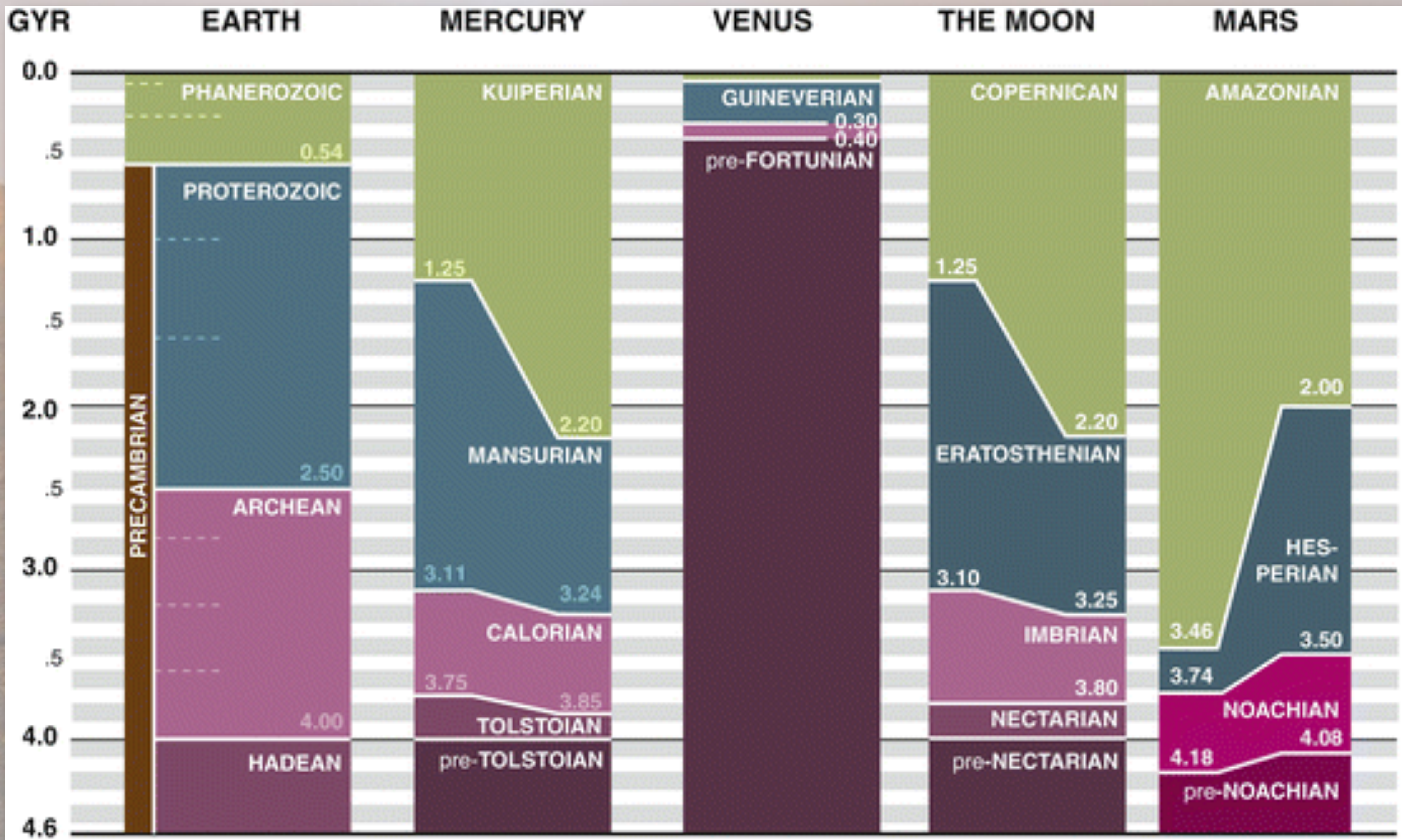
- Large, arcuate mountain range on Mars
- South of Tharsis and Valles Marineris
- Compressional tectonics
- Younger extensional tectonics (rifts), mainly N-S trending

Ages and Stratigraphy
Terrestrial Planets (and Moon)



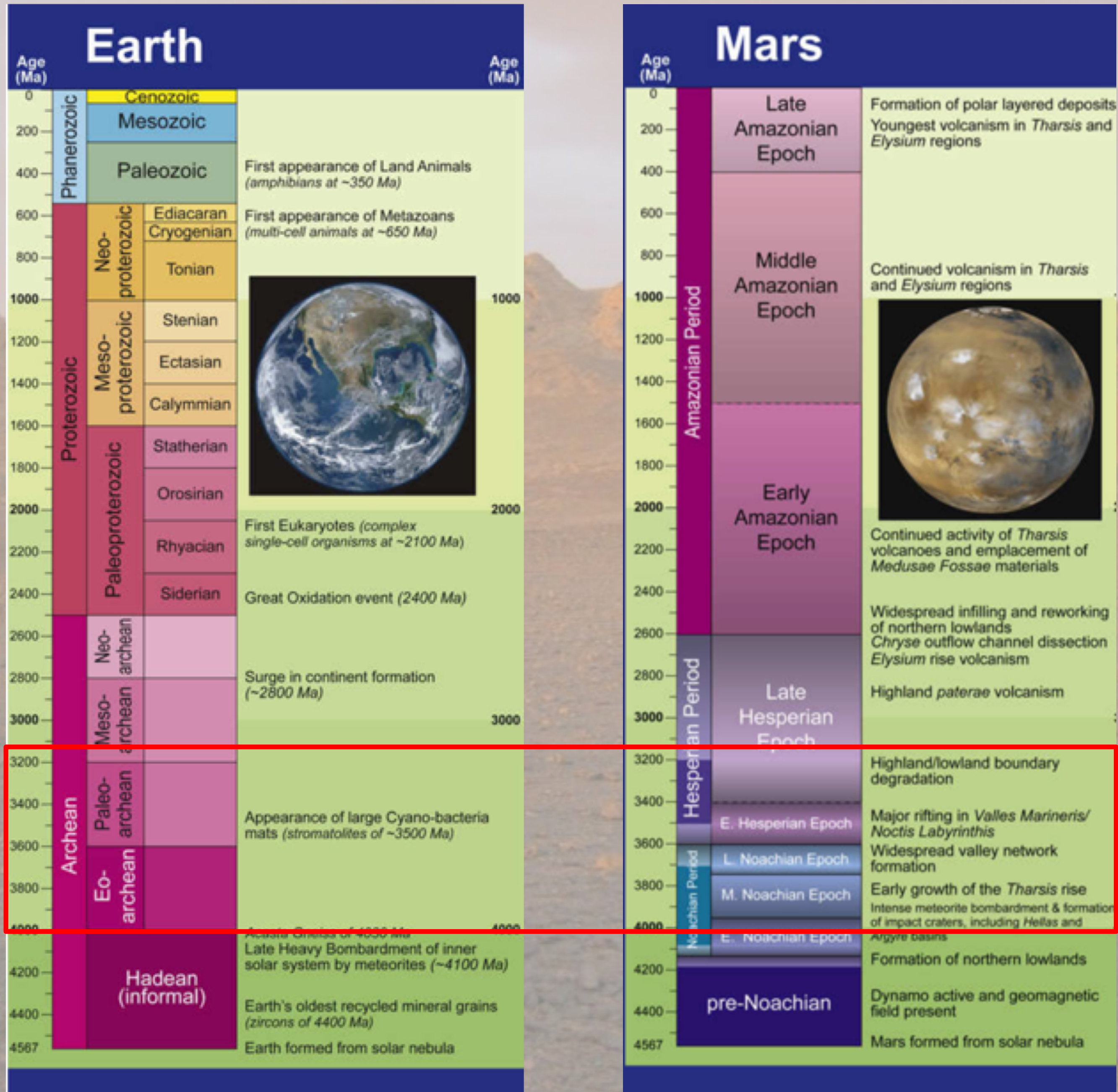
Head, 1999; Rossi et al., 2018

Ages and Stratigraphy
Terrestrial Planets (and Moon)



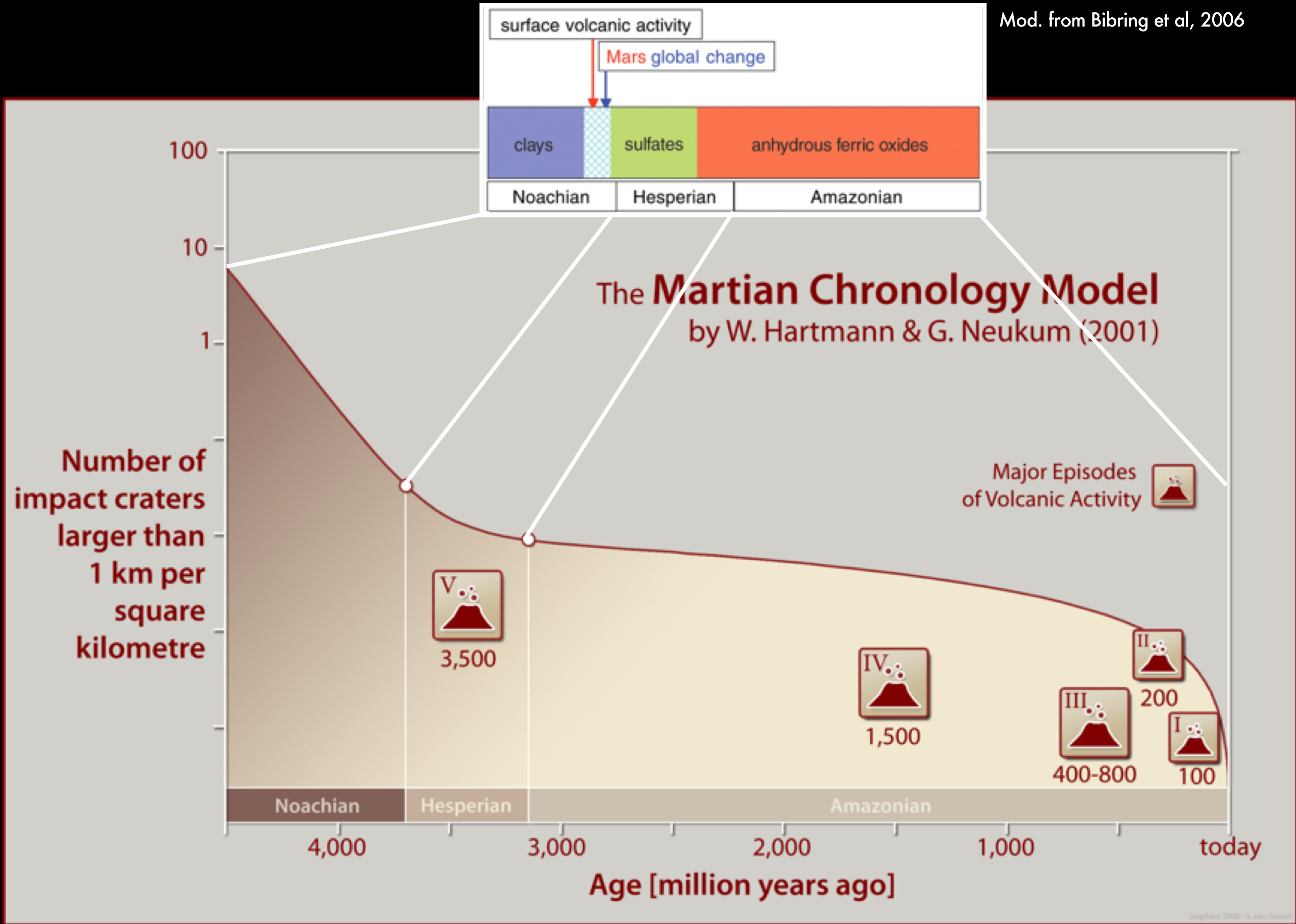
van Gasselt and Neukum (2011)

Geological time scale: Earth vs Mars



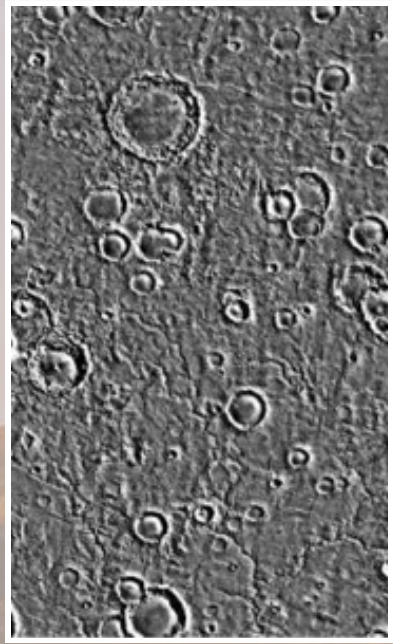
Tanaka and Hartmann 2016

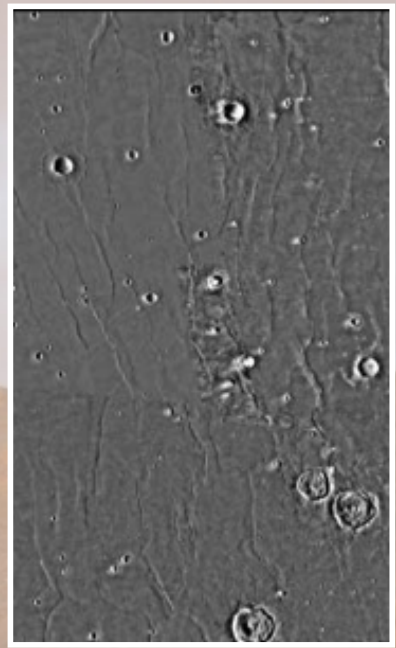
Mod. from Bibring et al, 2006

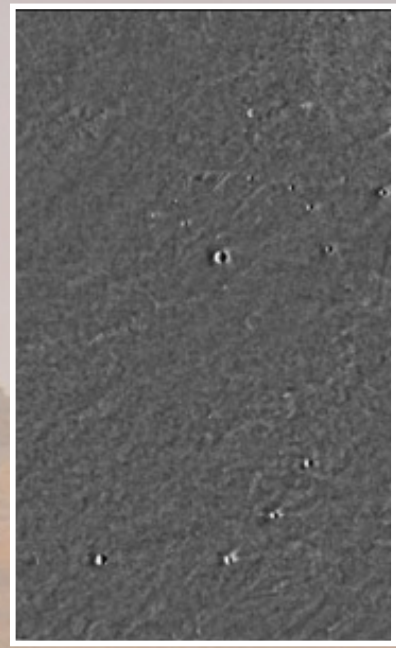


Courtesy S. van Gasselt/A.P. Rossi

Major Martian periods





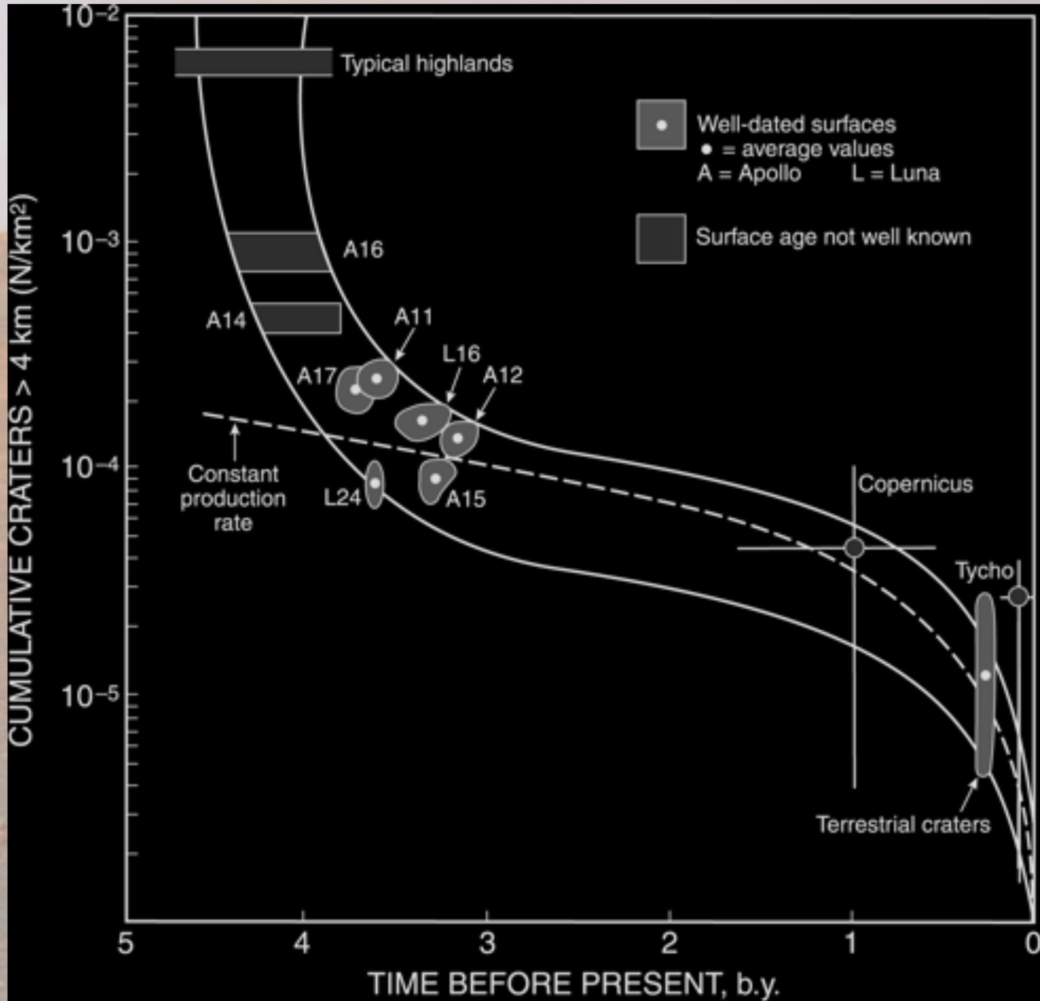


Noachian	Hesperian	Amazonian
N(1)> 4800	1600-4800	< 1600craters/10^6 km^2
> 3.7 Ga	3.7- 3.3 Ga	< 3.3 Ga

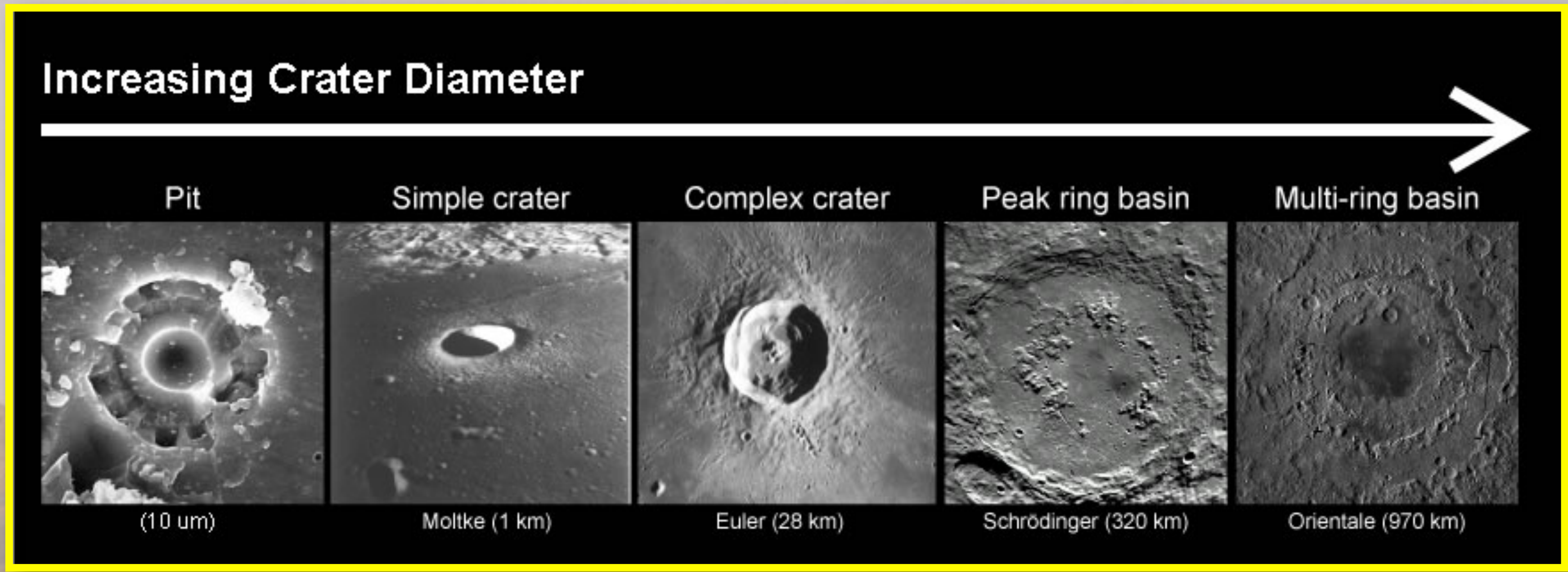
GLOBAL CHRONOLOGY ⇢ CRATER-BASED AGE

The older a planetary surface is, the more meteorite impacts suffered.

Moon rocks have been dated radiometrically as well ⇢ calibrated CHRONOLOGY MODEL



Crater Morphology

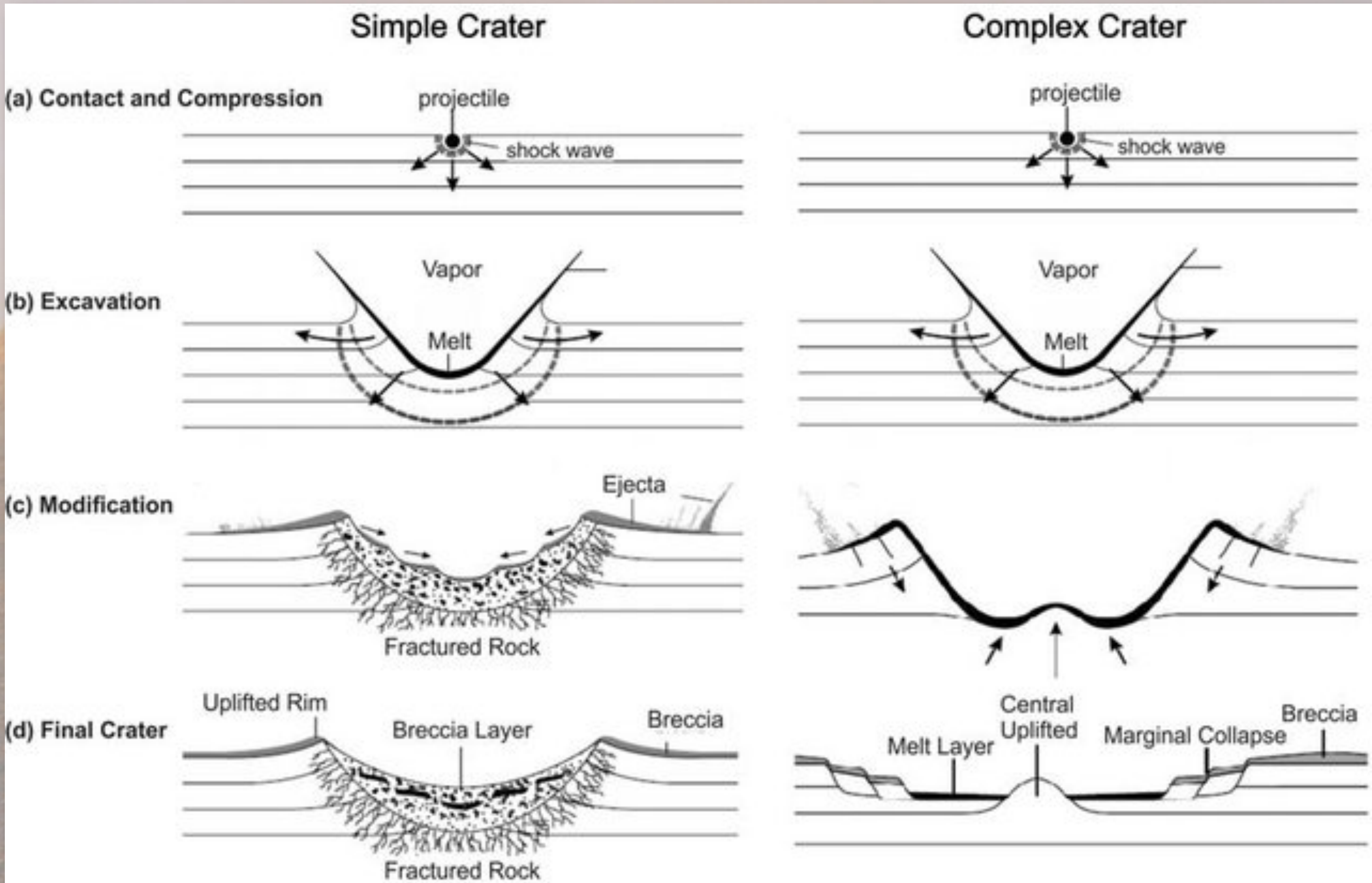


Impact Crater Sizes of the Moon

- Impact craters on an airless body like the Moon range in size from pin-size structures to continent-size structures.
  - (a) 10 micron-diameter crater on a glassy, ~465 micron diameter lunar spherule from the Luna 16 landing site (Hartung, Hörz, McKay, and Baiamonte, 1972);
  - (b) 1 kilometer diameter simple crater called Moltke;
  - (c) 28 kilometer diameter complex crater called Euler;
  - (d) 320 kilometer diameter peak-ring impact basin called Schrödinger;
  - (e) 970 kilometer diameter multi-ring impact basin called Orientale.

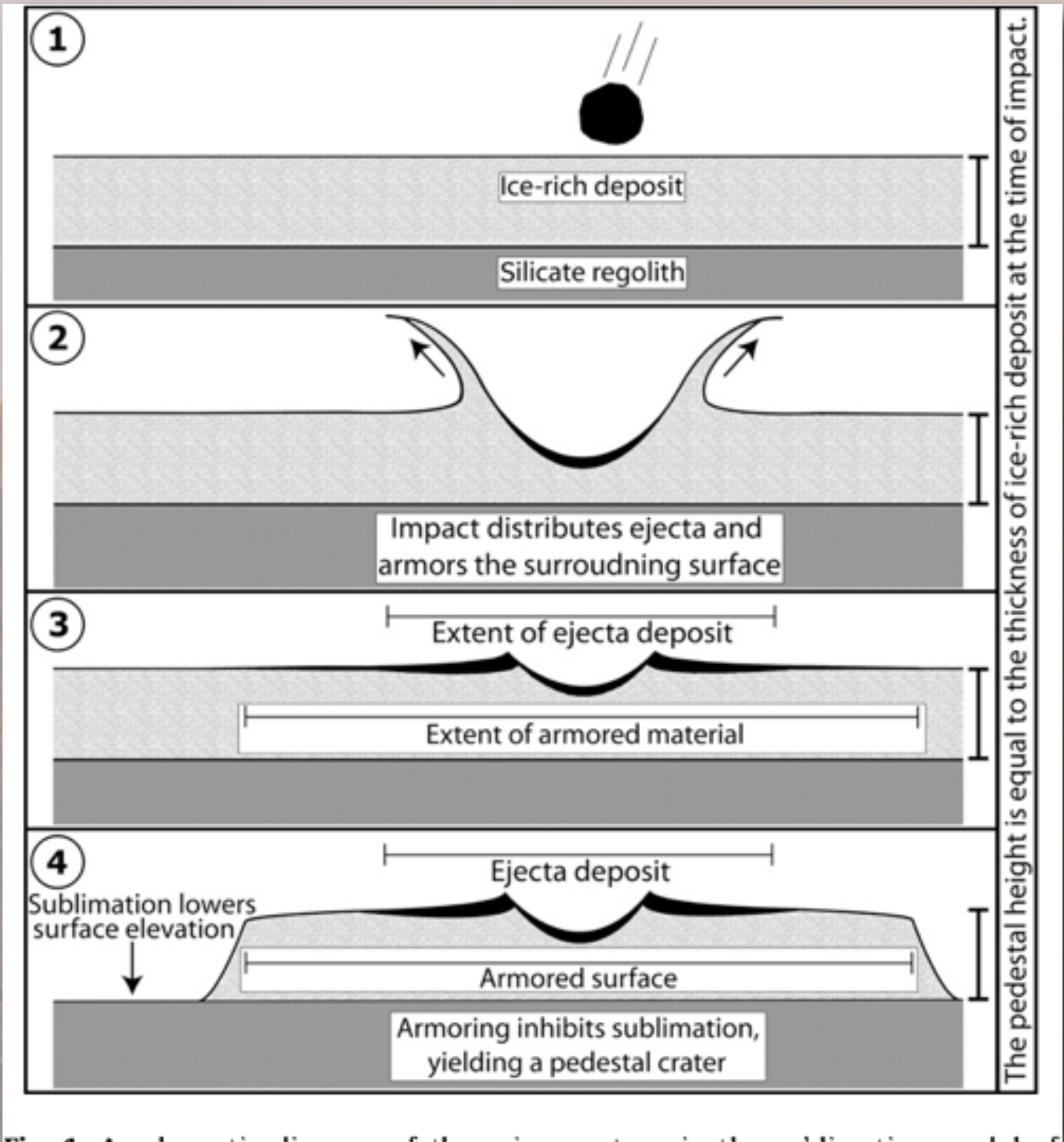
Image Credit: LPI (Priyanka Sharma)

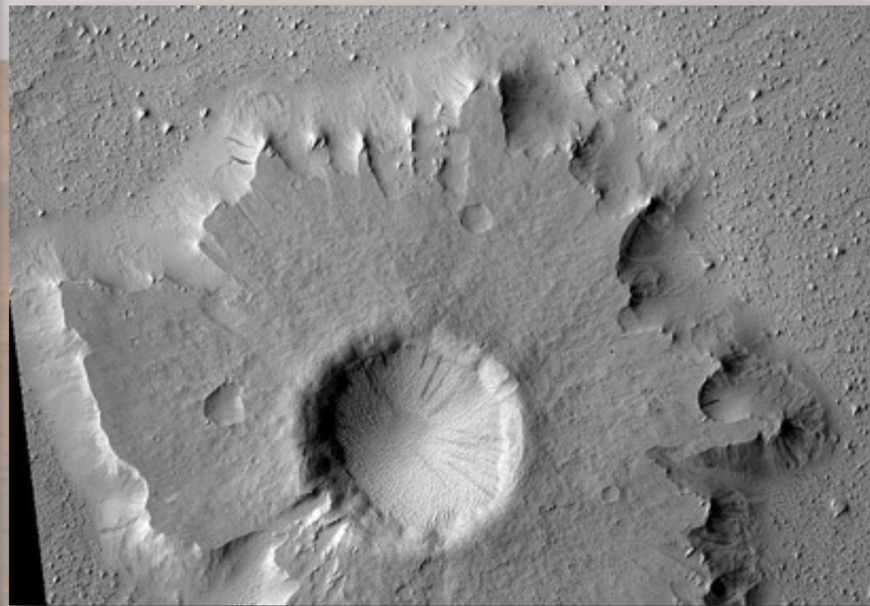
Simple and Complex craters



Stages of simple and complex craters formation (French, 1998).

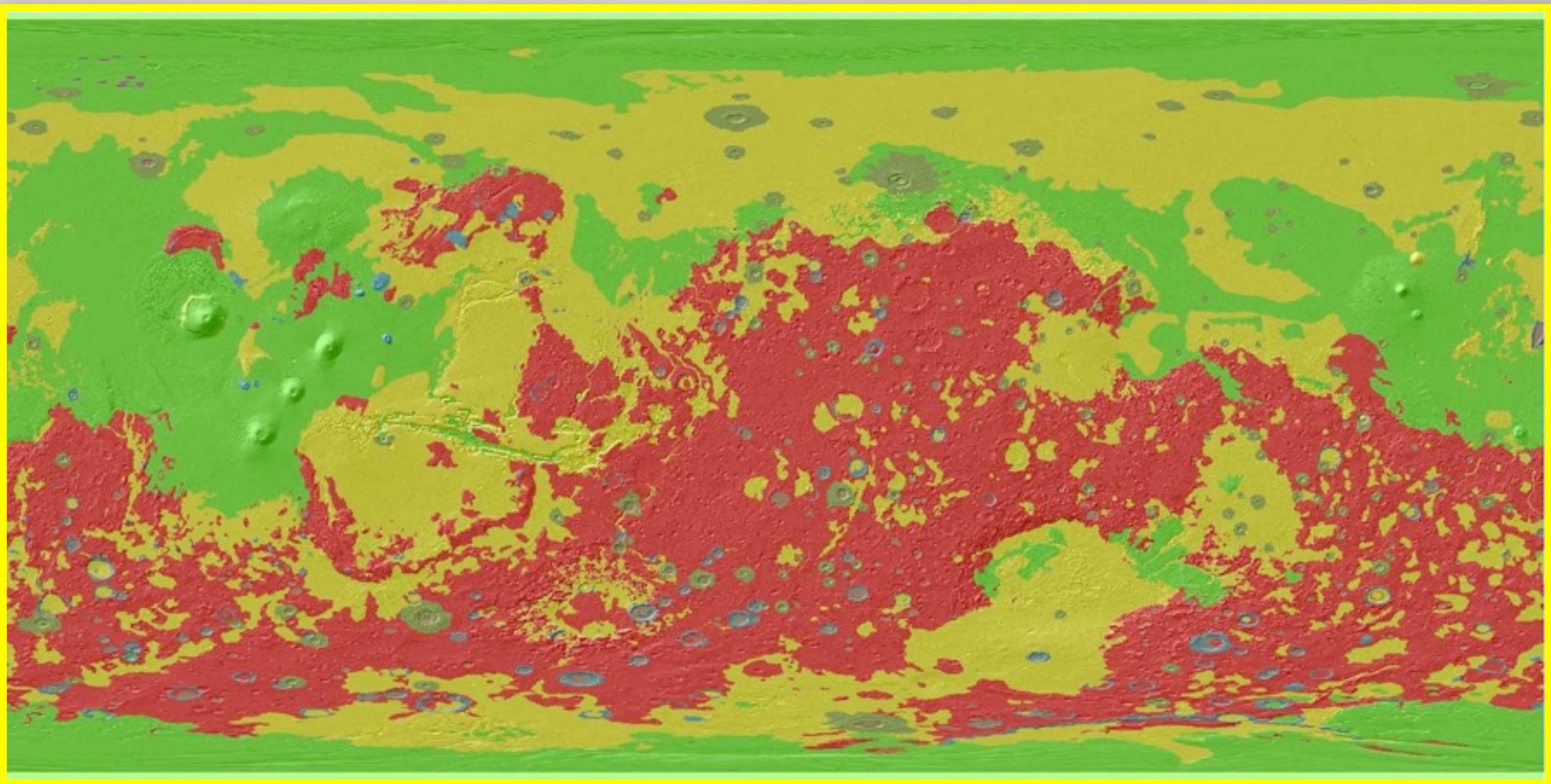
Pedestal craters



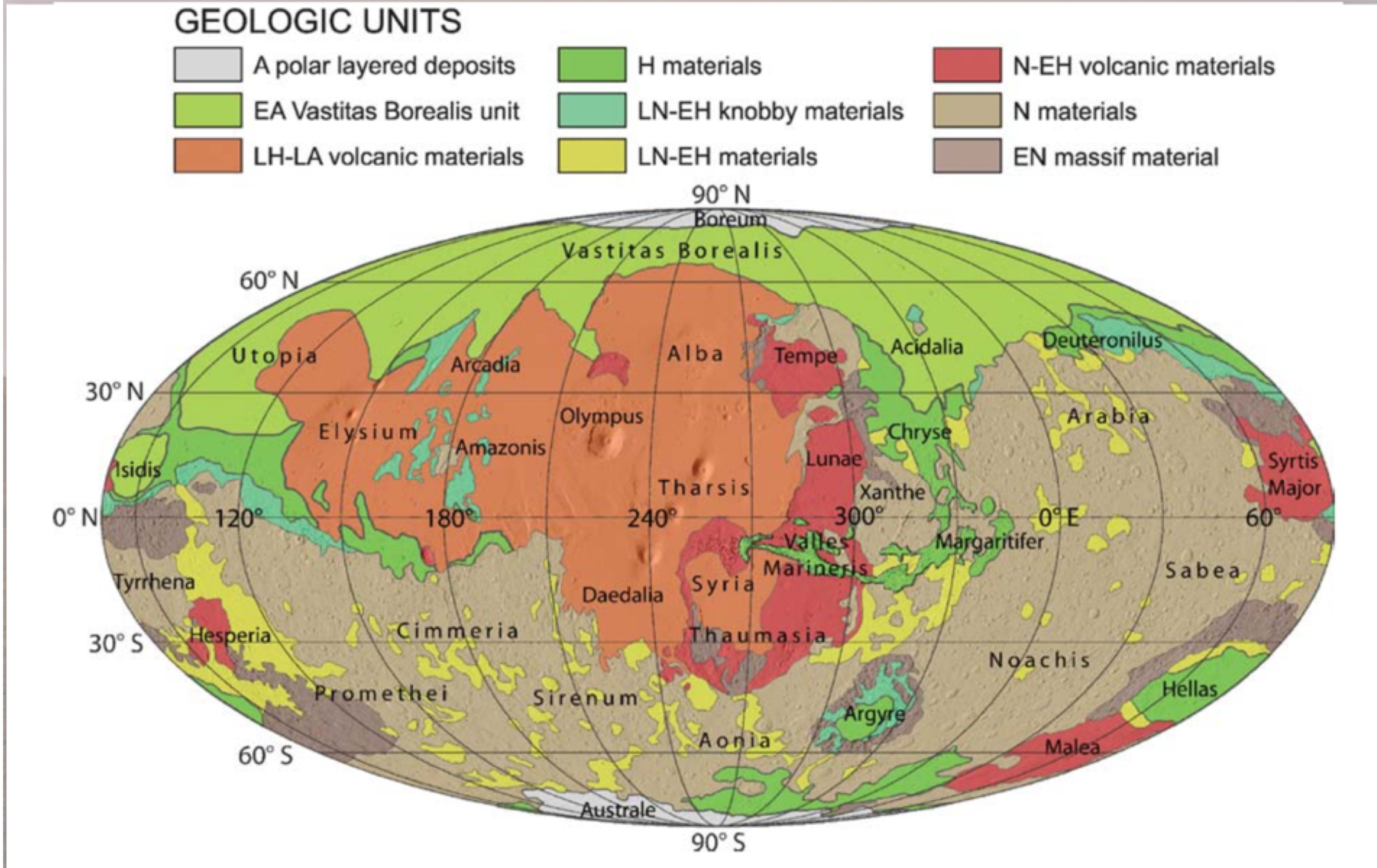


Seth J. Kadish, James W. Head, Nadine Gail Barlow, 2010. Pedestal crater heights on Mars: A proxy for the thicknesses of past, ice-rich, Amazonian deposits.

Major Martian periods

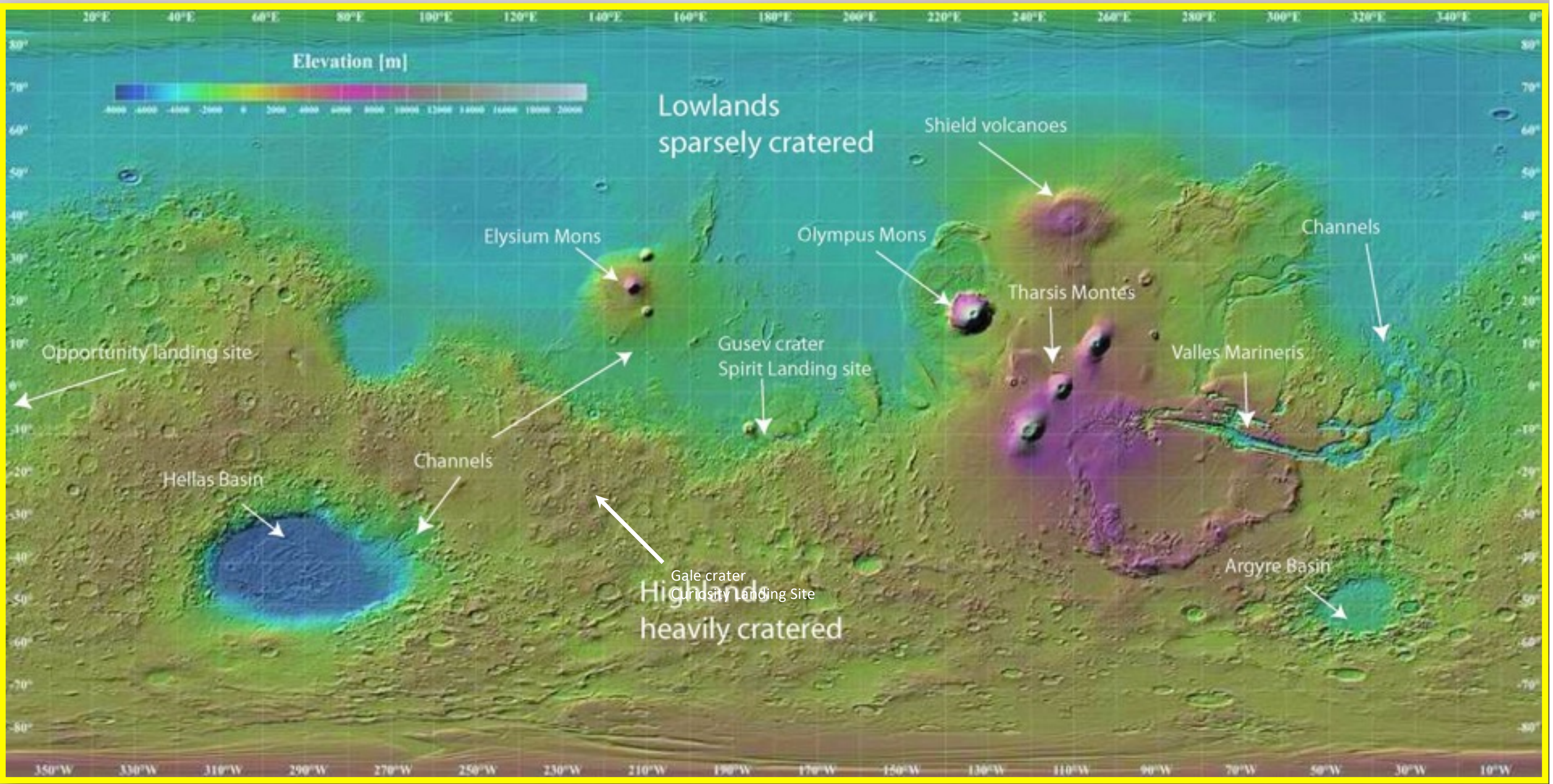


Noachian Hesperian Amazonian



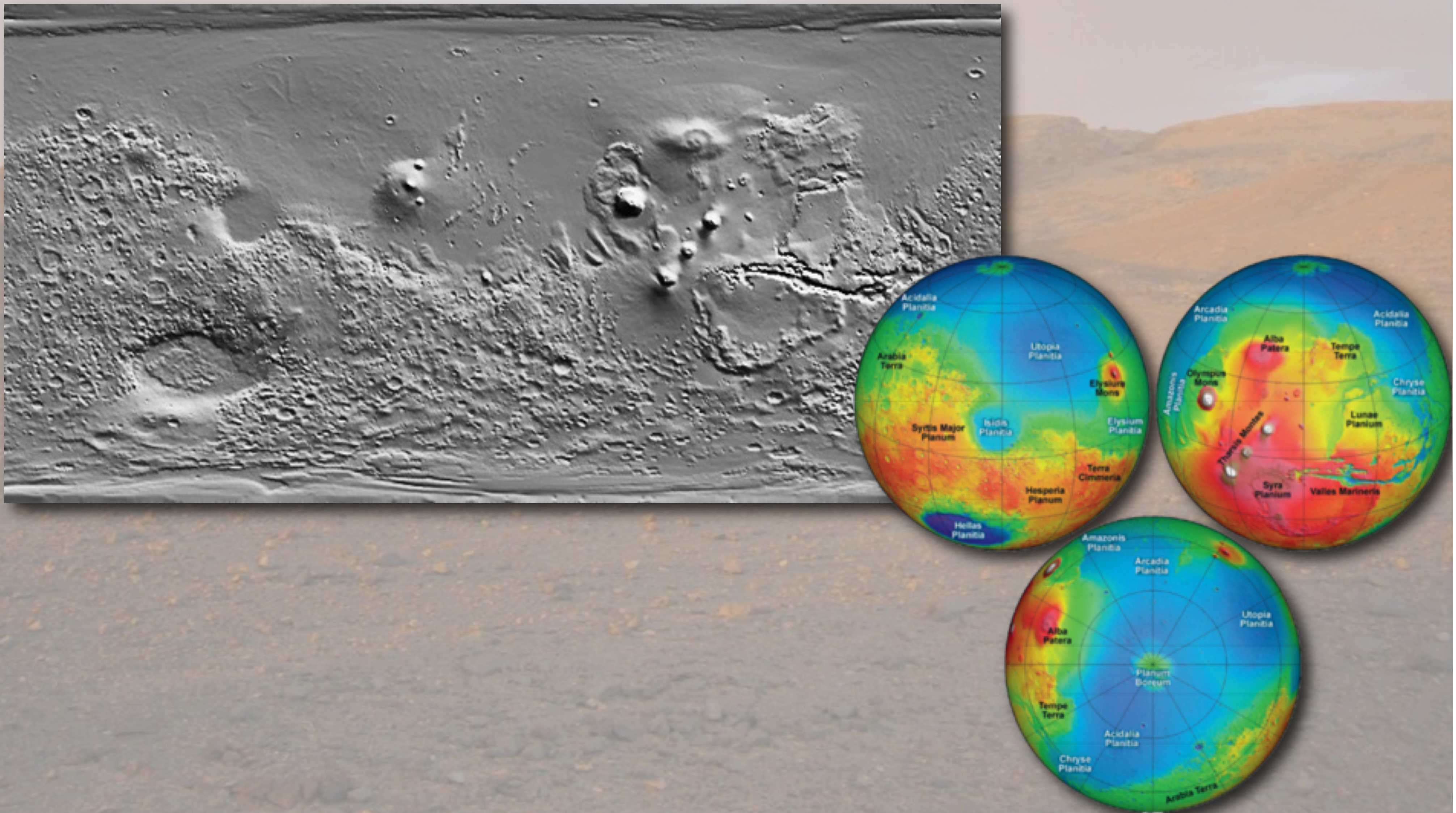
Source: *Nimmo and Tanaka (2005), Annu. Rev. Earth Planet. Sci.. 33:133–6*

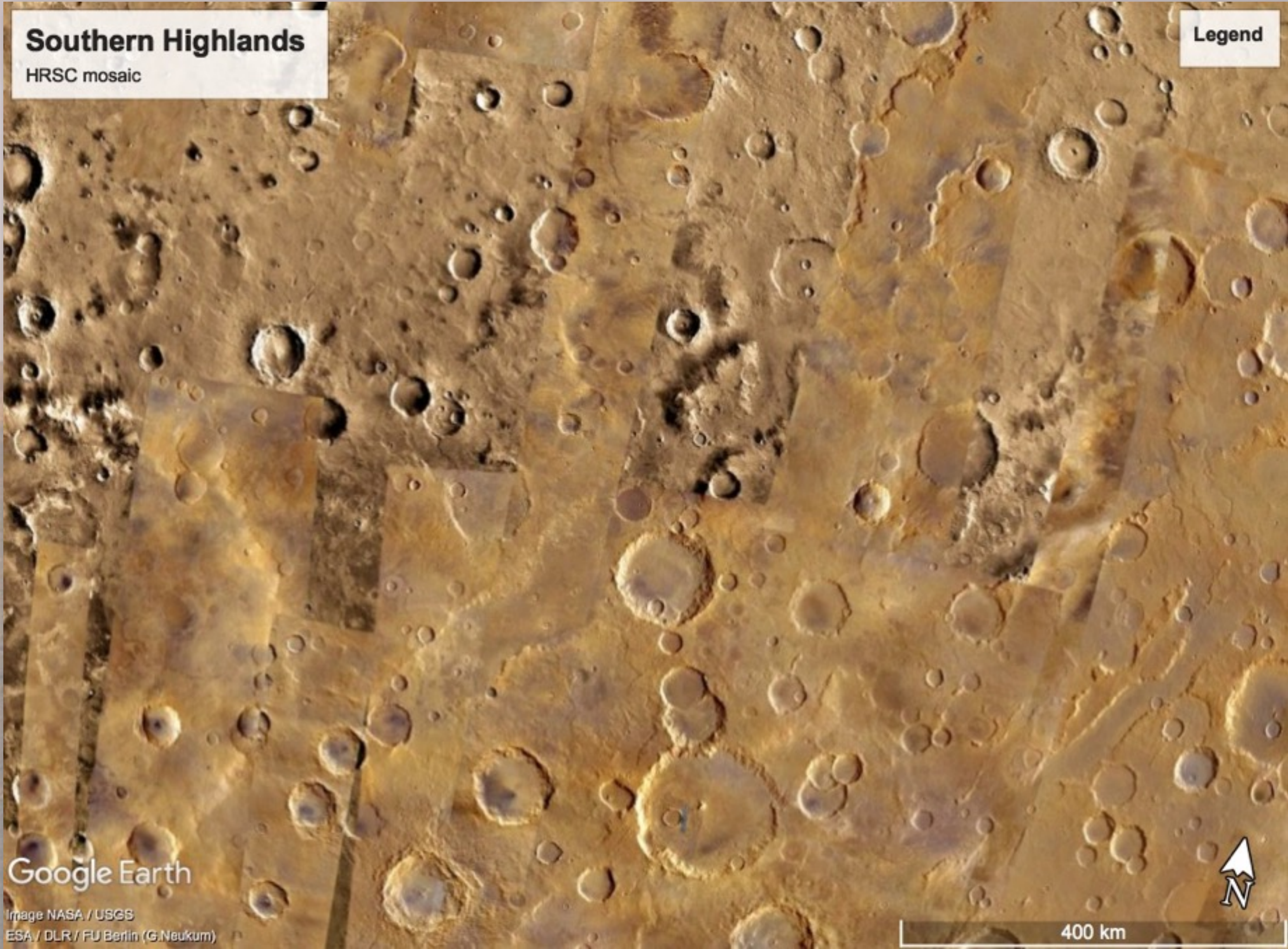
Main Geological Features on Mars

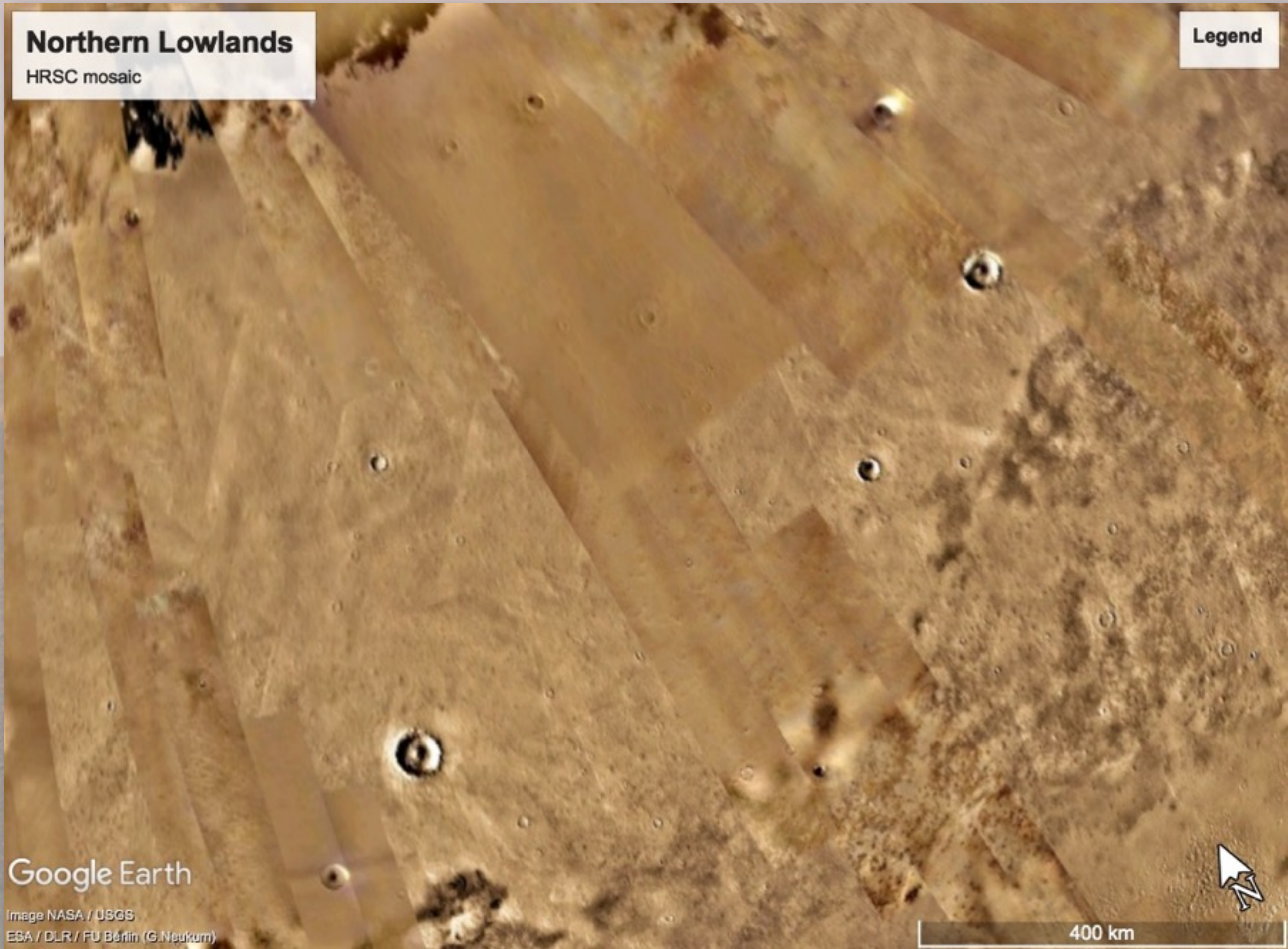


Mars Dichotomy

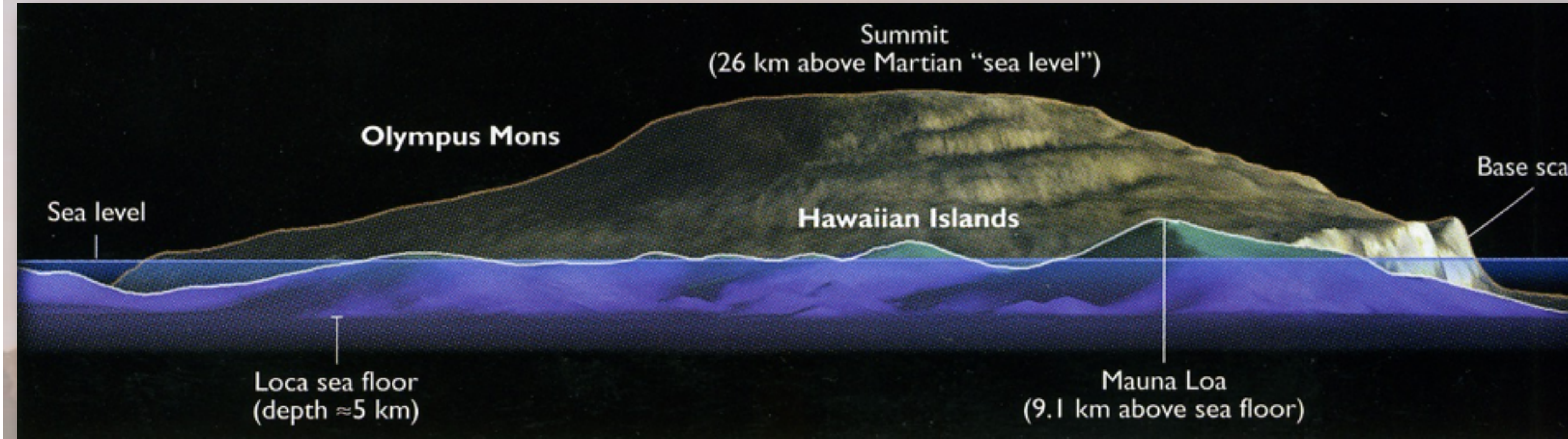
The **dichotomy boundary** divides the southern highlands and the northern lowlands




Southern Highlands
HRSC mosaic
Legend
Google Earth
Image NASA / USGS
ESA / DLR / FU Berlin (G.Neukum)
400 km
N

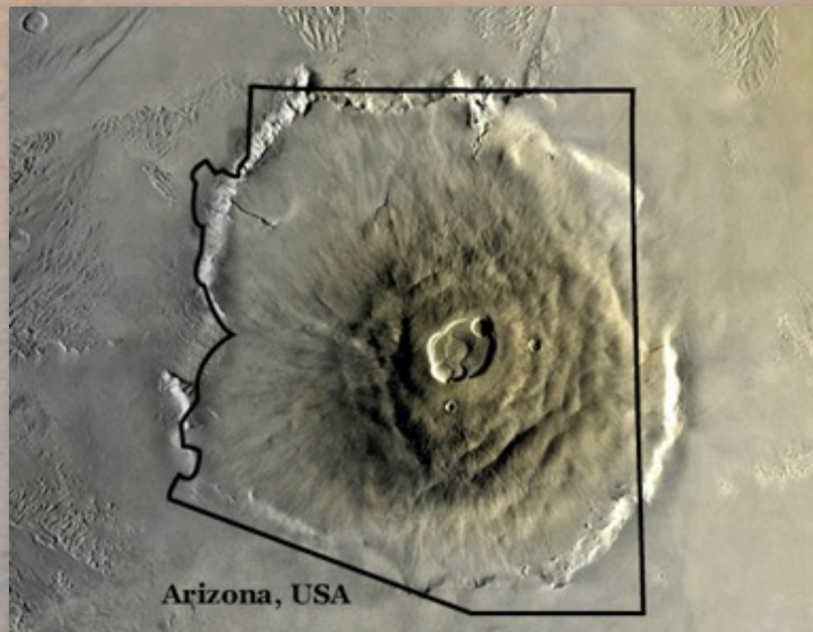

Northern Lowlands
HRSC mosaic
Legend
Google Earth
Image NASA / USGS
ESA / DLR / FU Berlin (G.Neukum)
400 km

Volcanoes on Mars



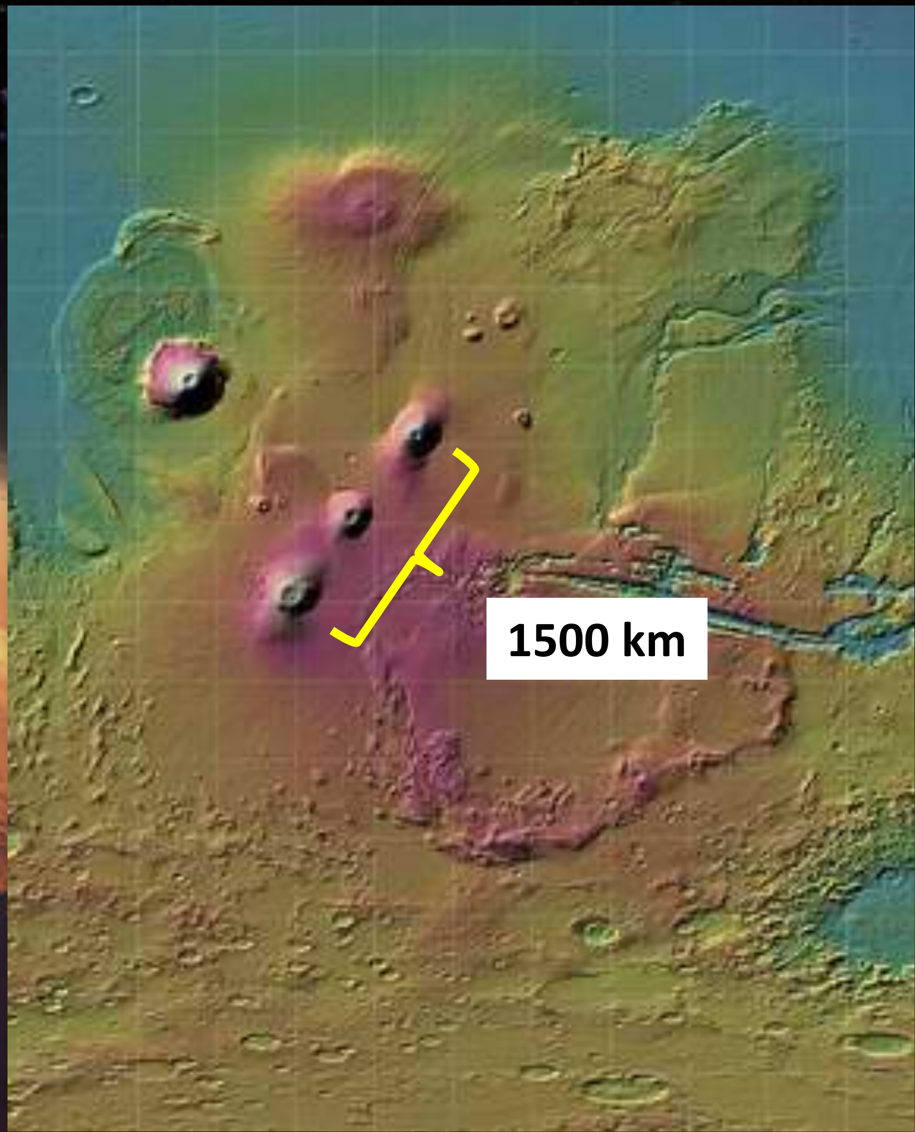
- Large volcanoes ⇢ no plate tectonics
- Long lived mantle plume
- Stable crust

- Olympus Mons
- Caldera 90 km across
- Lava flows of 200+ km



Tharsis Bulge

- The larges volcanic province on Mars
- Consists of 5 main volcanic edifices and several smaller ones
- Very long lasting activity: dates back to Noachian until Late Amazonian



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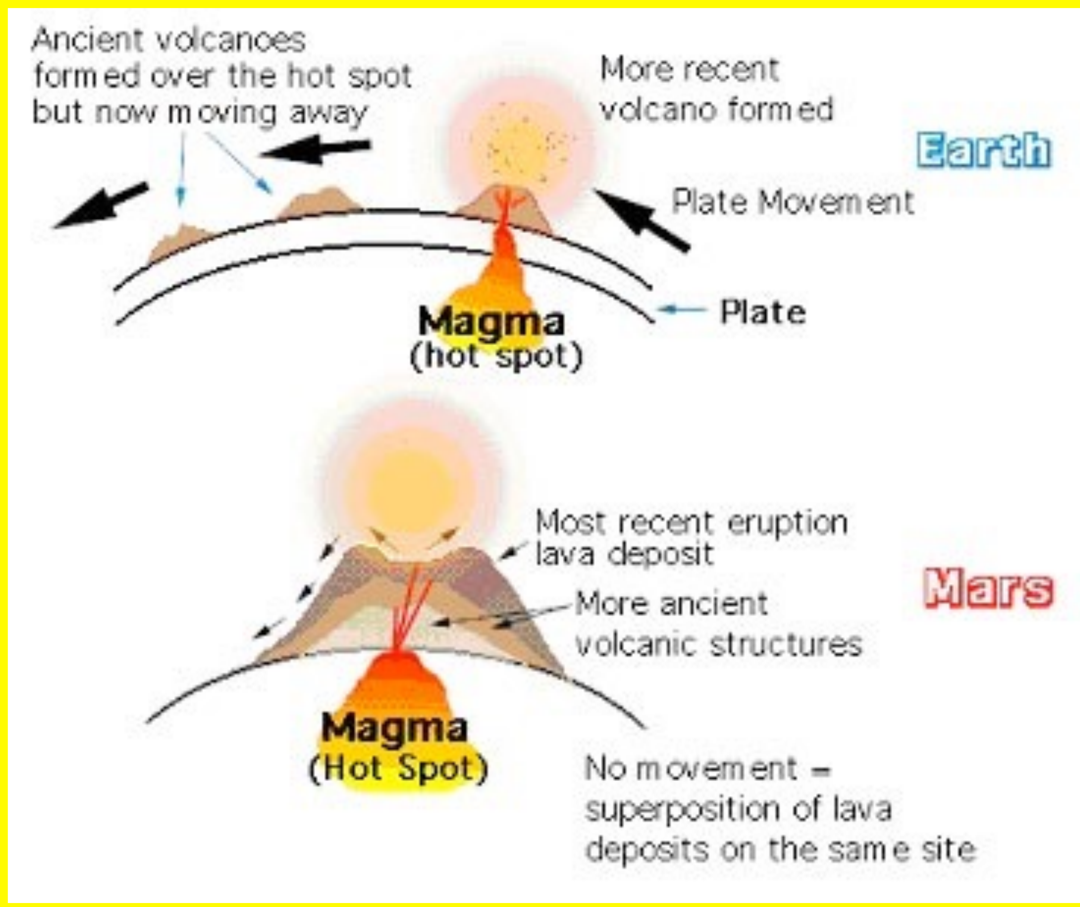
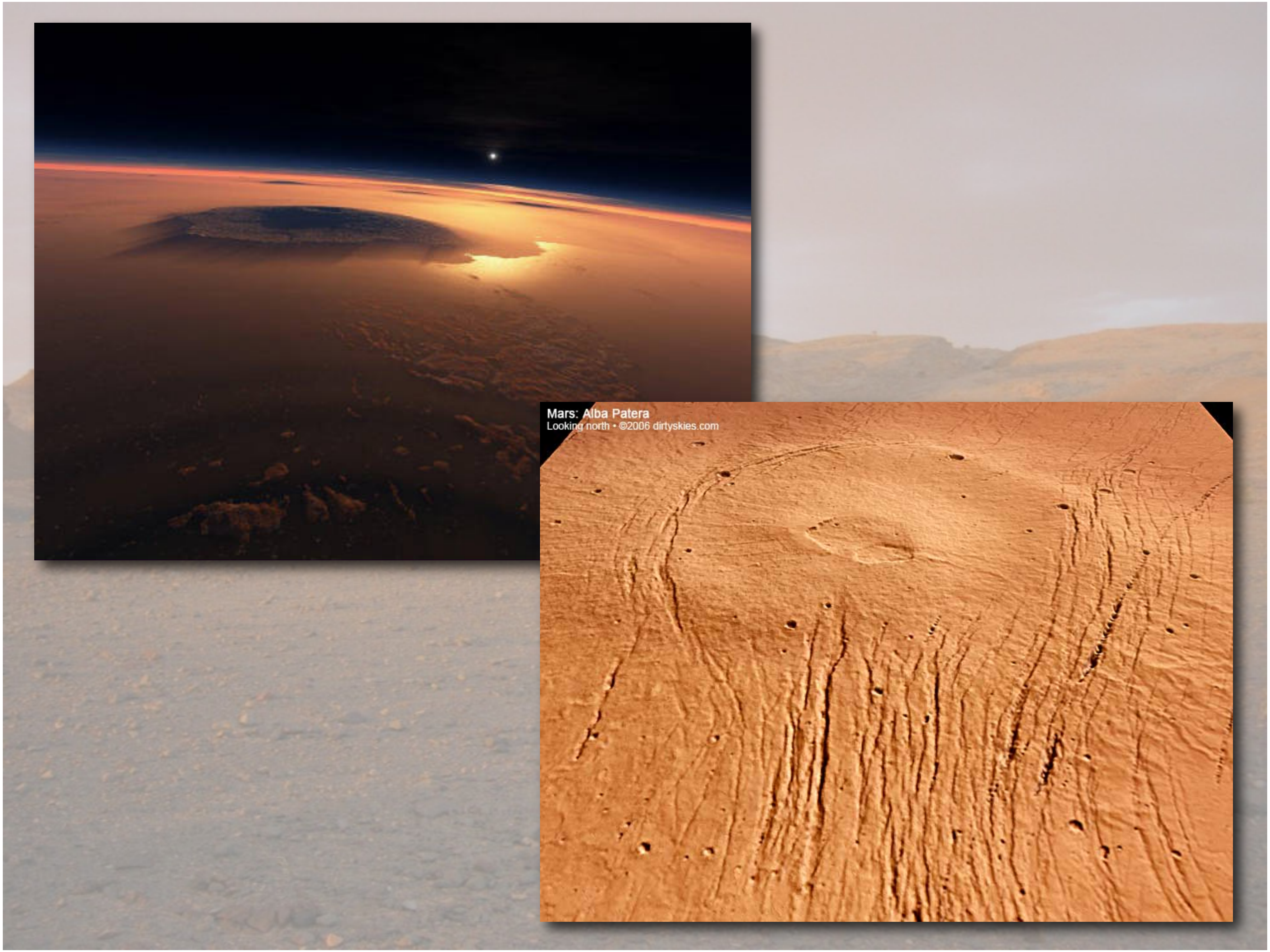


Tharsis bulge:
Earth and Mars

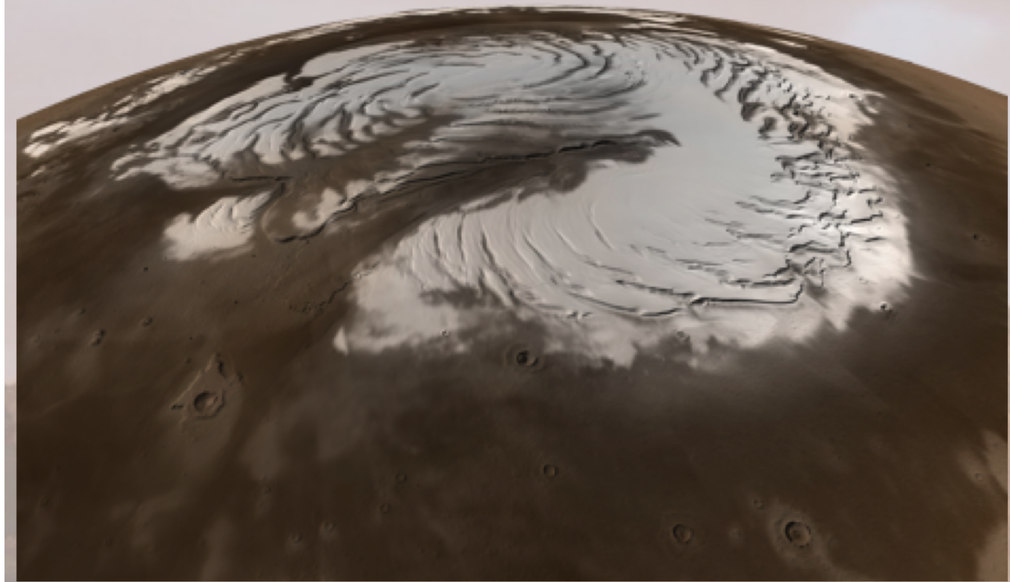
Shield Volcanoes and Paterae

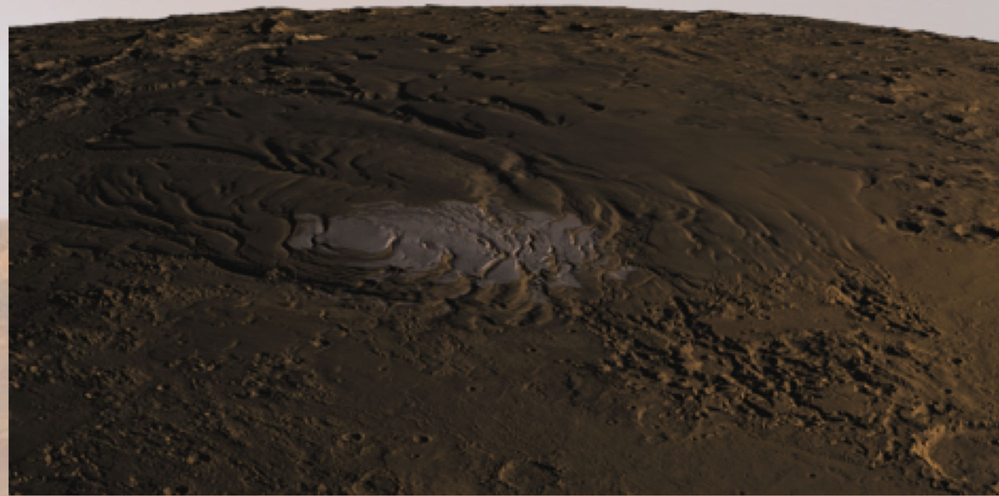
Paterae

- Unique features
- Mostly in the Cratered Uplands far from other large volcanoes
- Older than the Tharsis and Elysium shields.
- No sign of actual lava flows. Central calderas are surrounded by sets of radial furrows.
- Very flat. They typically are only 1-2 km high and 200-300 km across. Sometimes called ash shields.
- Piles of easily eroded volcanic ash composed of basalt.
- Formed when magmas met underground water and exploded?


Mars: Alba Patera
Looking north • ©2006 dirtyskies.com

Polar Caps





- Seasonally varying polar caps
- Formed largely by water ice (and very minor dust)
- Seasonal cap formed by carbon dioxide ice
- One of the largest current reservoirs of water on Mars

Polar Caps

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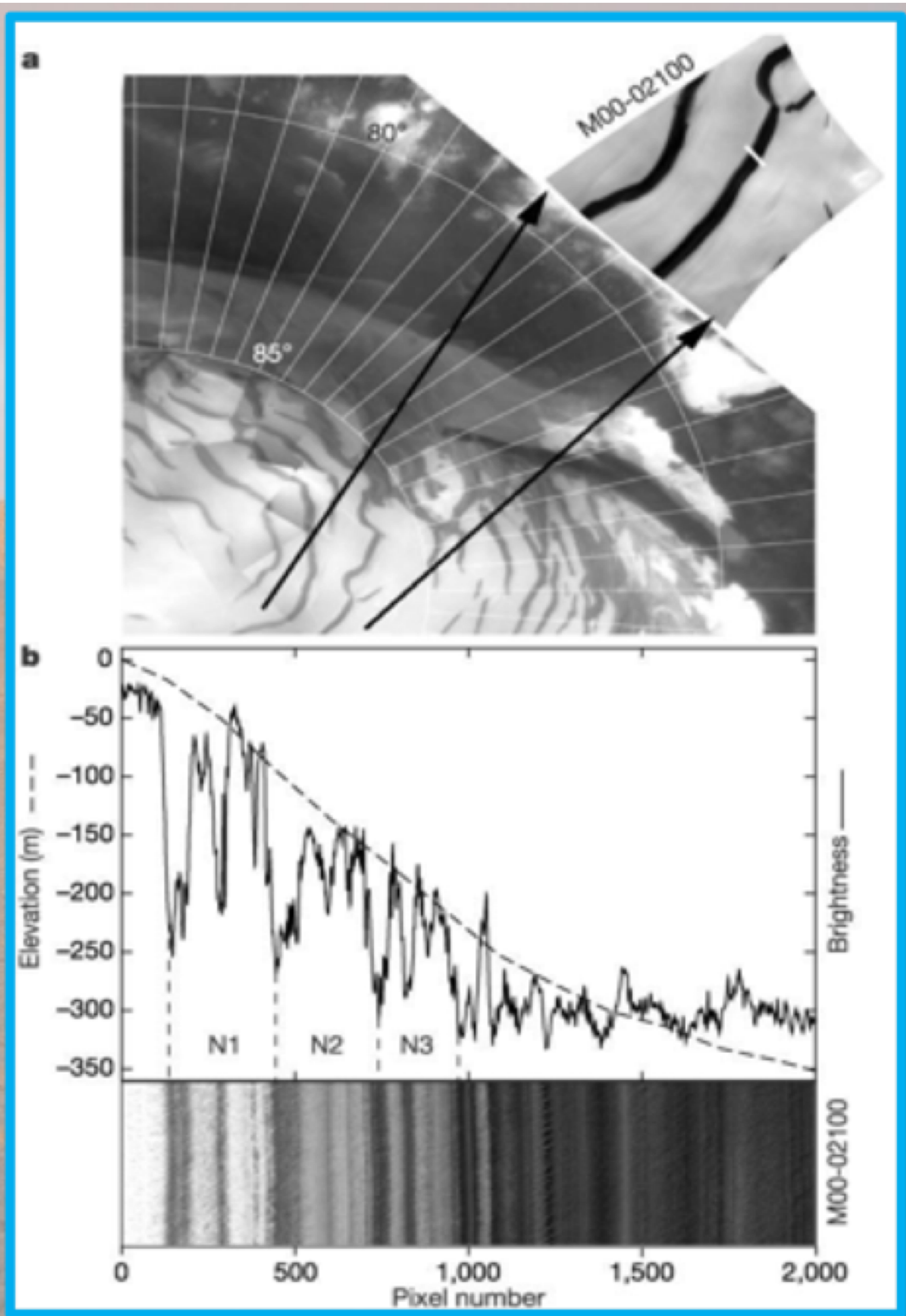
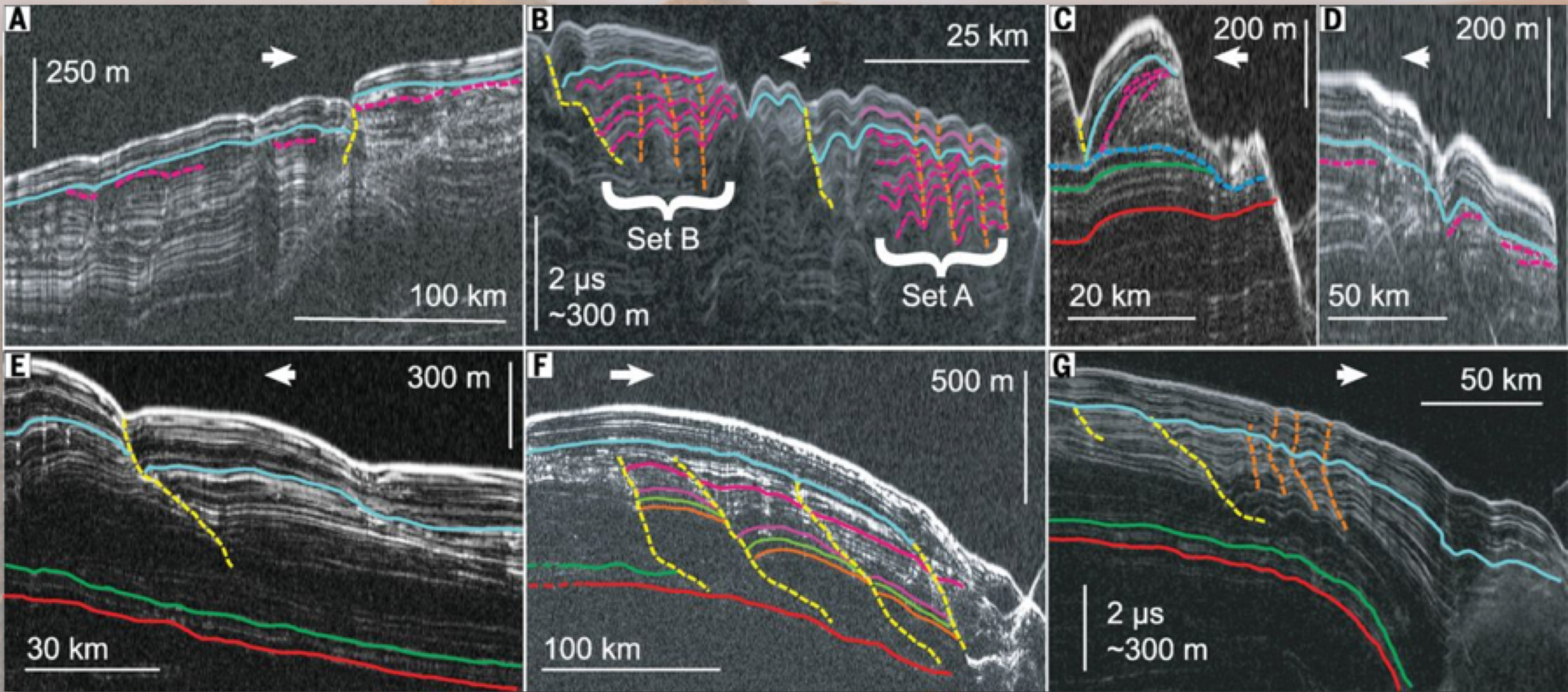


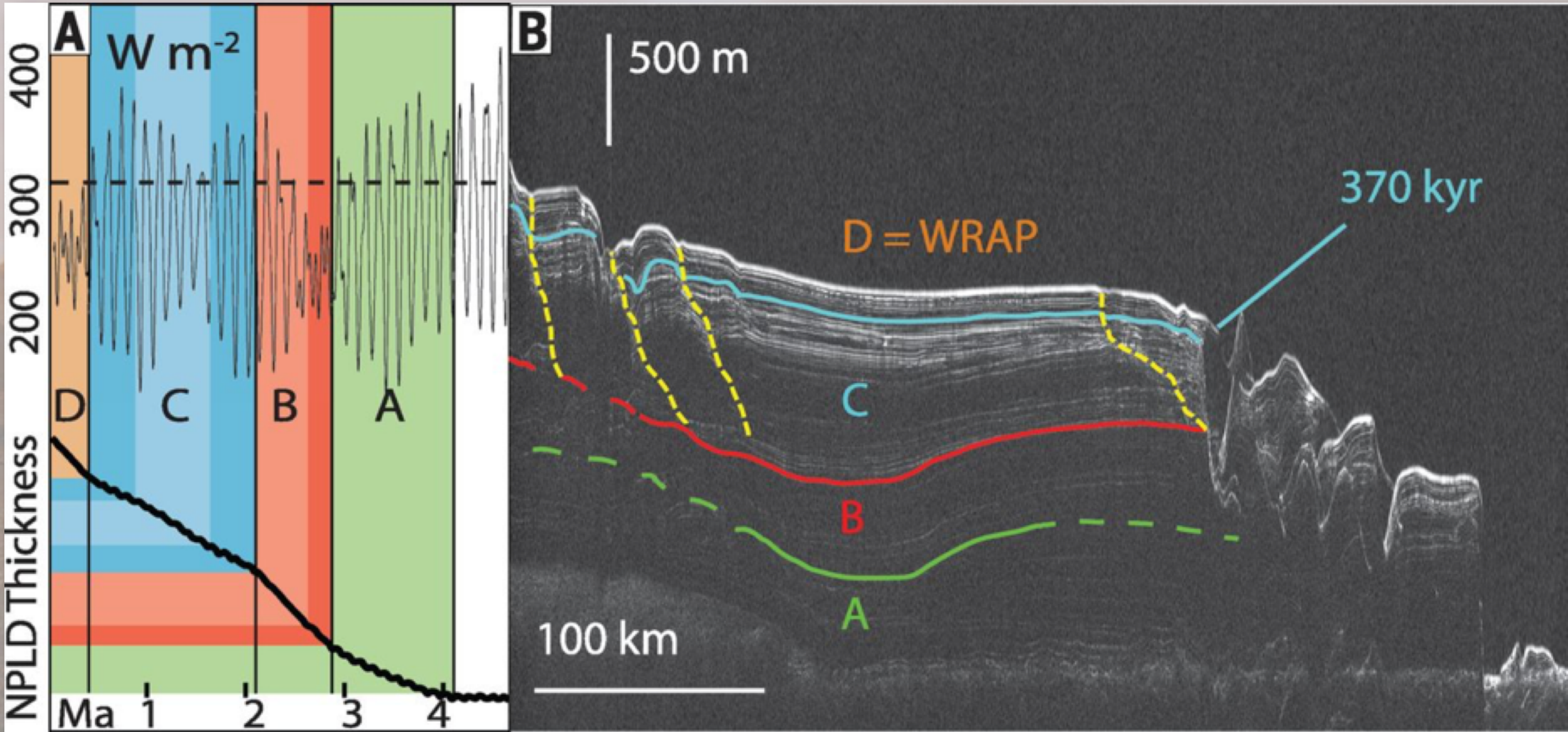
Laskar et al., 2002 – Nature 419

SHARAD radargrams highlighting the widespread, recent accumulation package



Isaac B. Smith et al. Science 2016;352:1075-1078

Polar Caps



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THANK YOU