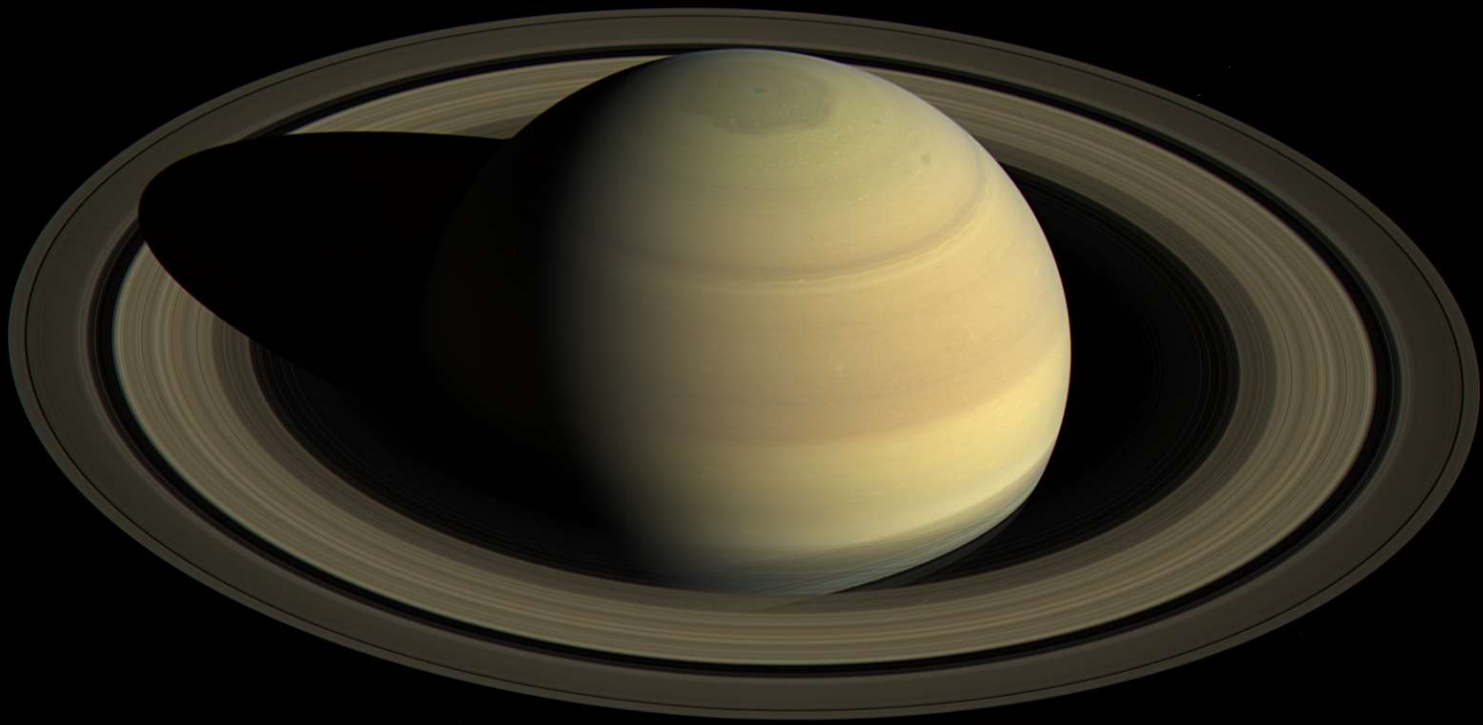
AST 2002
Introduction to Astronomy



A Few Quick Things…

E-mailing me: Must have AST2002 in the subject

Mary Hinkle, Graduate Teaching Assistant:
Office Hours: Mon 1:30-3:00pm. PSB 316

My office hours: Mon 3:00-4:00pm. PSB 308
Tue 3-4 pm. PSB 308

First Mid-term was last week… Friday 9th February.

Next Knights Under the Stars Event – Thur 22nd Feb 7-8:30pm

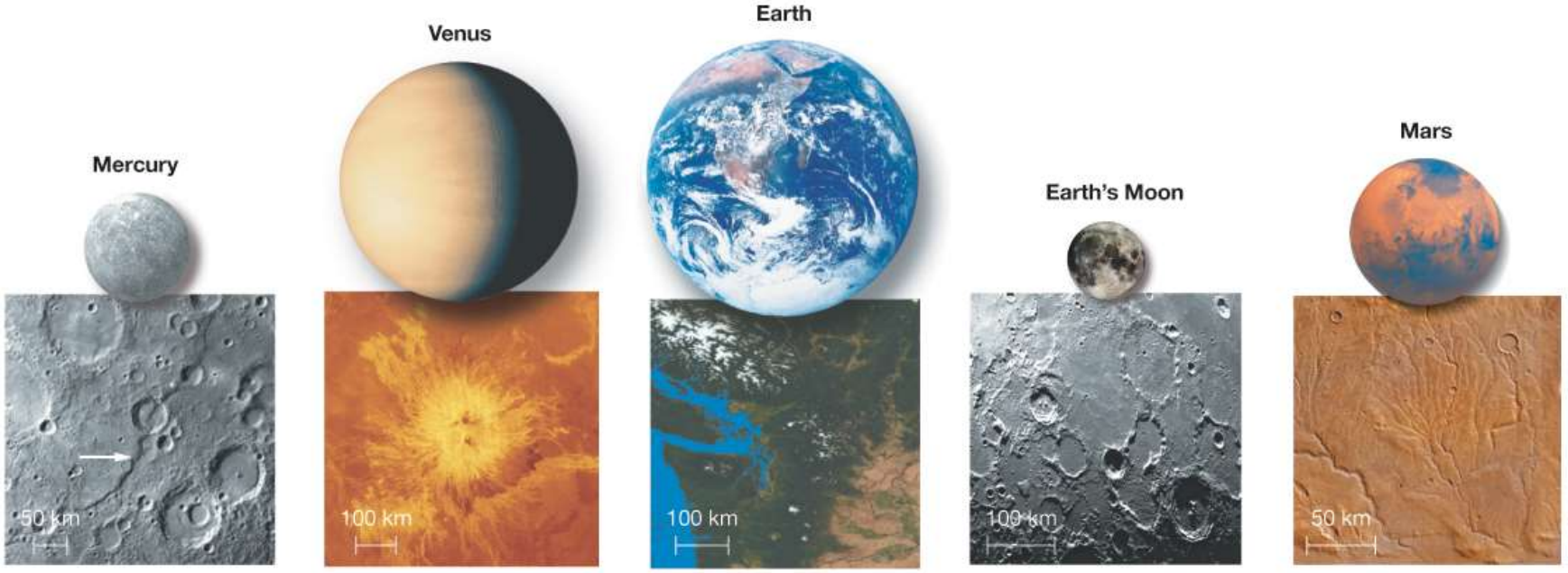
Summary of Last Time

Part III – Learning from other Worlds

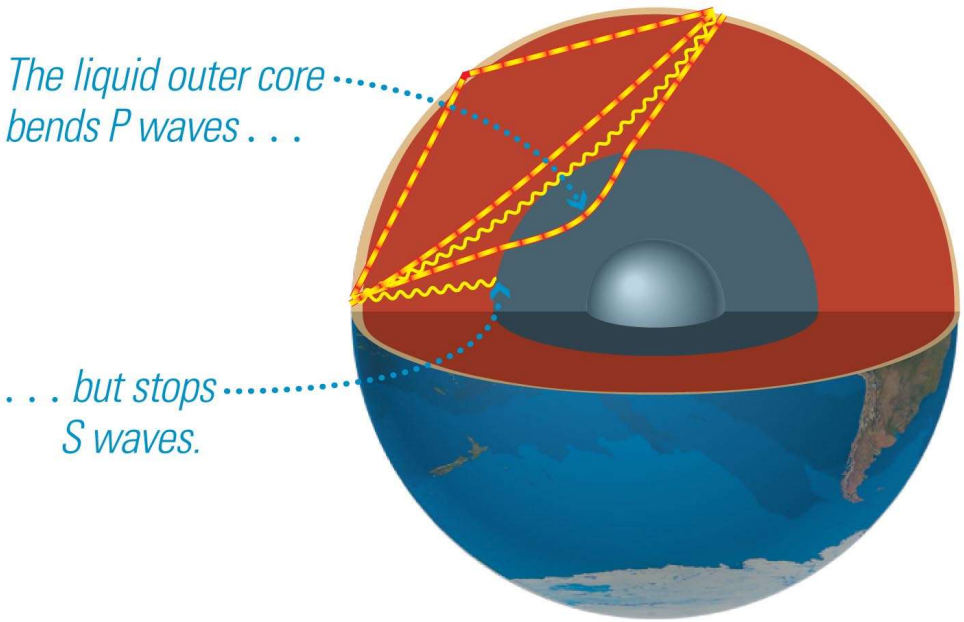
- **Chapter 6:** Formation of the Solar System
- **Chapter 7:** Earth and the Terrestrial Worlds
- Earth as a Planet
  - Why is Earth geologically active?
  - What processes shape Earth's surface
  - How does Earth's atmosphere affect the planet?
- The Moon and Mercury: Geologically Dead
  - Was there ever geological activity on the Moon or Mercury?
- Mars: A Victim of Planetary Freeze-Drying
  - What geological features tell us that water once flowed on Mars
  - Why did Mars change?

Comparative Planetology

Why have the surfaces of planets turned out so differently, even though they formed at the same time from the same materials? *What processes are shaping these surfaces?*



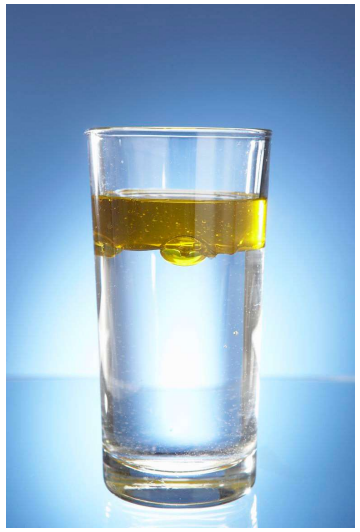
How do we know what's inside a planet?



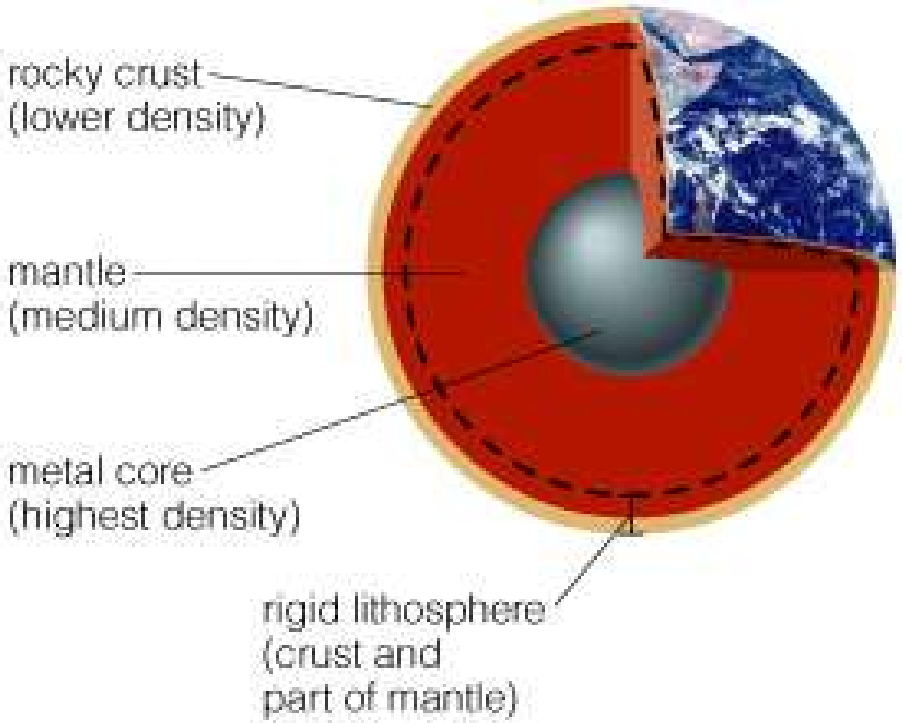
P waves go through Earth's core, but S waves do not.

We conclude that Earth's core must have a liquid outer layer.

Also, bear in mind that this also means that most of the REST of the Earth is SOLID (*not molten magma!)*



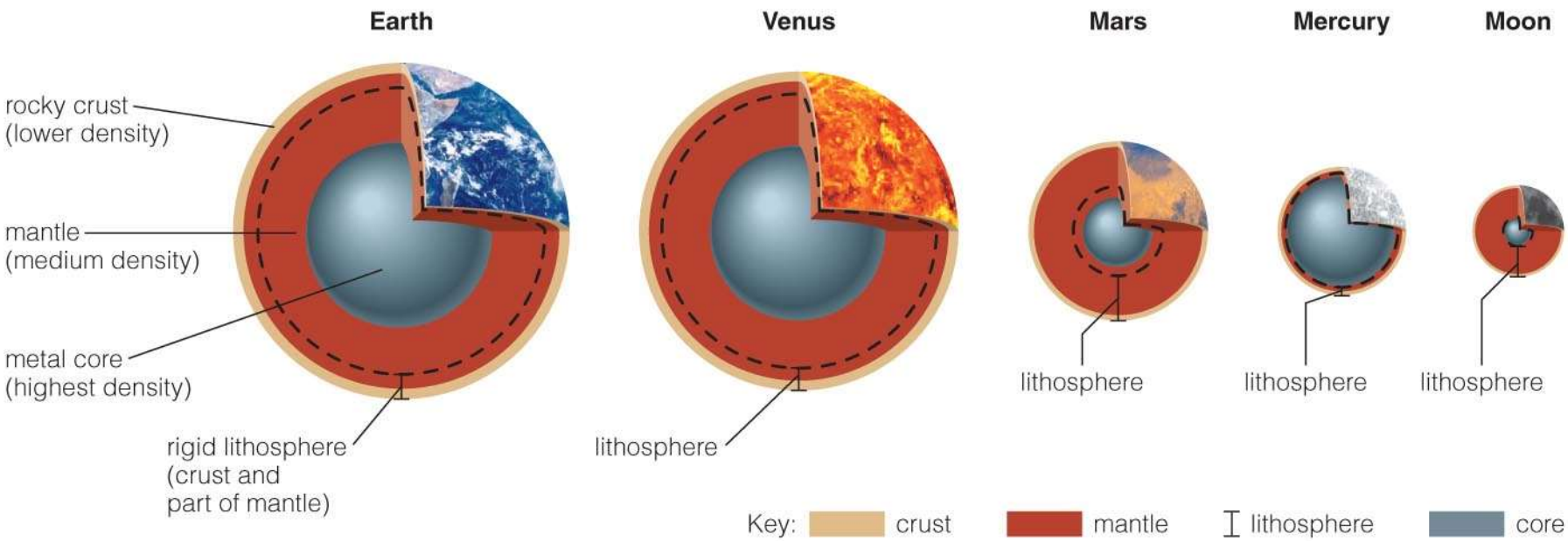
Differentiation



- Gravity pulls high-density material to center
- Lower-density material rises to surface
- Material ends up separated by density
- Iron-Nickel sinks to the core…
- *This process generates more heat…*

Gravitational potential energy → Kinetic energy

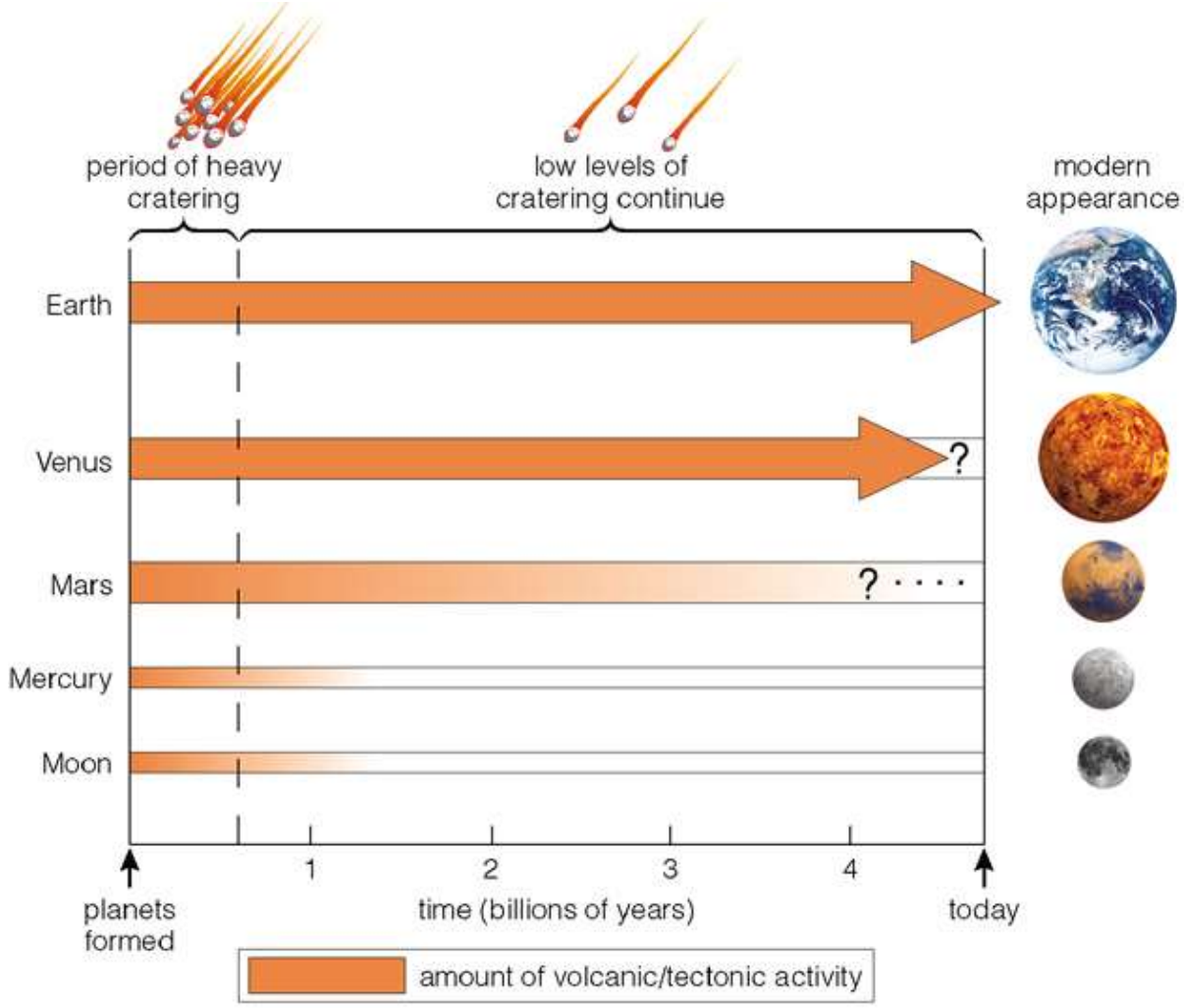
Terrestrial Planet Interiors



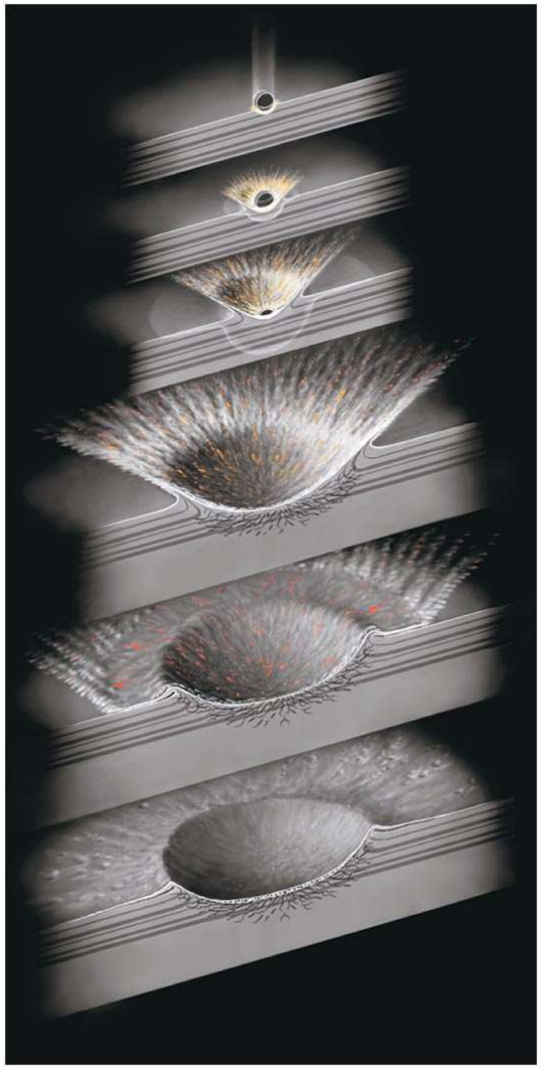
Applying what we have learned about Earth's interior to other planets tells us what their interiors are probably like. *Comparative Planetology*

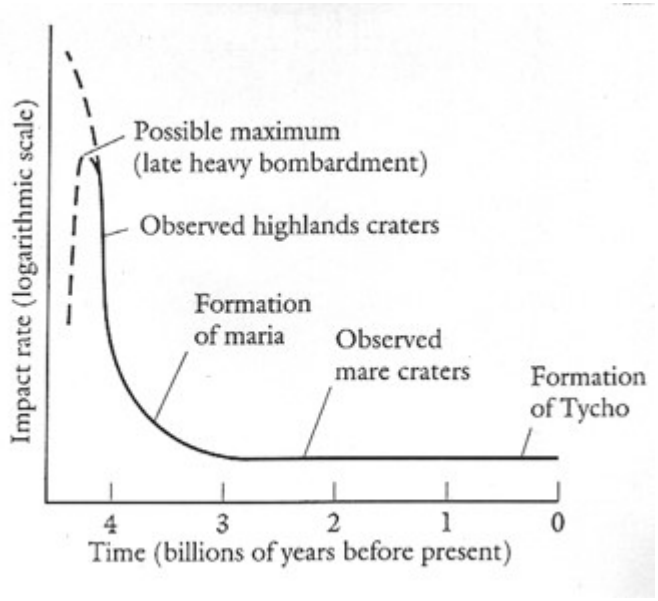
What Causes Geological Activity?

- HEAT drives activity
- Smaller worlds cool off faster and harden earlier
- The Moon and Mercury are now geologically "dead"



Impact Cratering





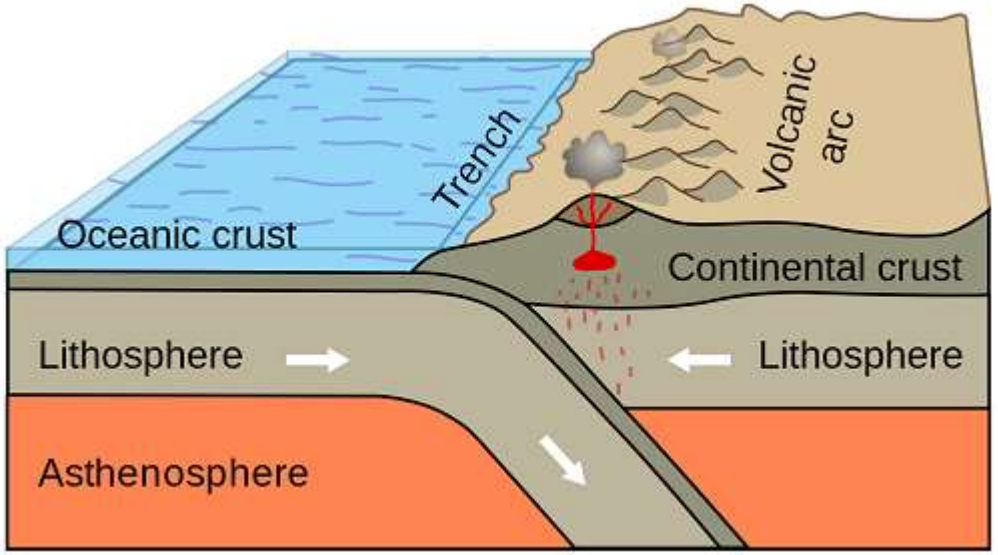
- Most cratering happened soon after the solar system formed.
  - Late heavy bombardment??
- Craters are about 10 times wider than the objects that made them, and 1-2 times deeper.
- Small craters greatly outnumber large ones.
- Can inform you of the age of an objects surface
  - No cratering? must be a fresh surface!

Volcanism

Volcanism happens when molten rock (usually from submerged lithosphere) finds a path to the surface

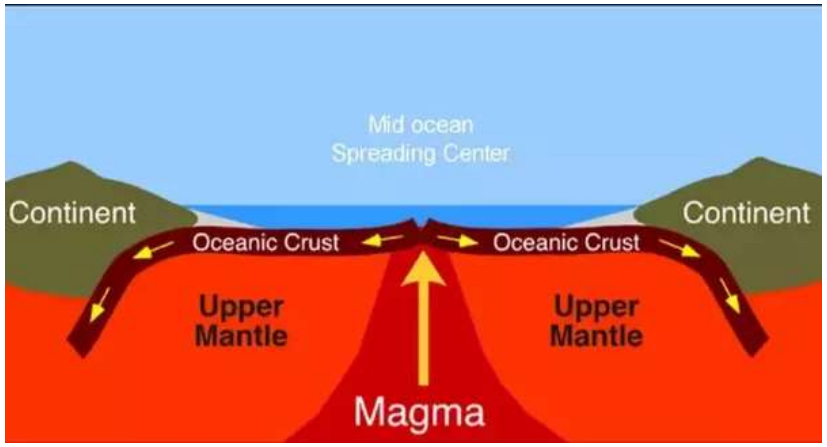
Molten rock is called lava after it reaches the surface

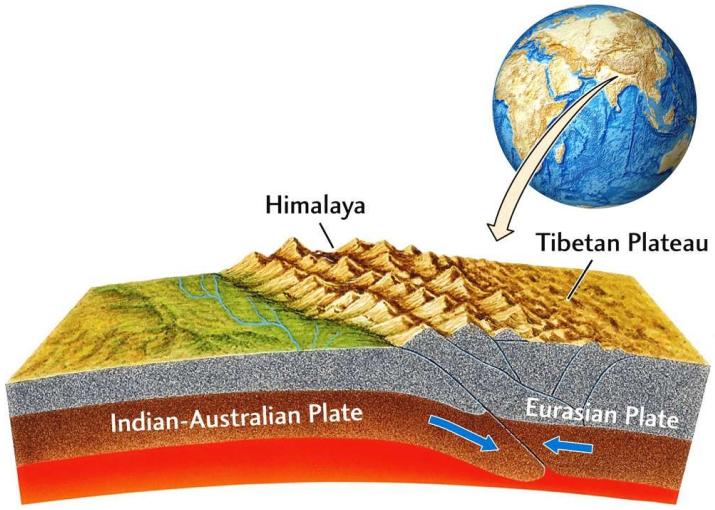
The melting point of a rock is affected by pressure, so rocks can melt more easily at the surface

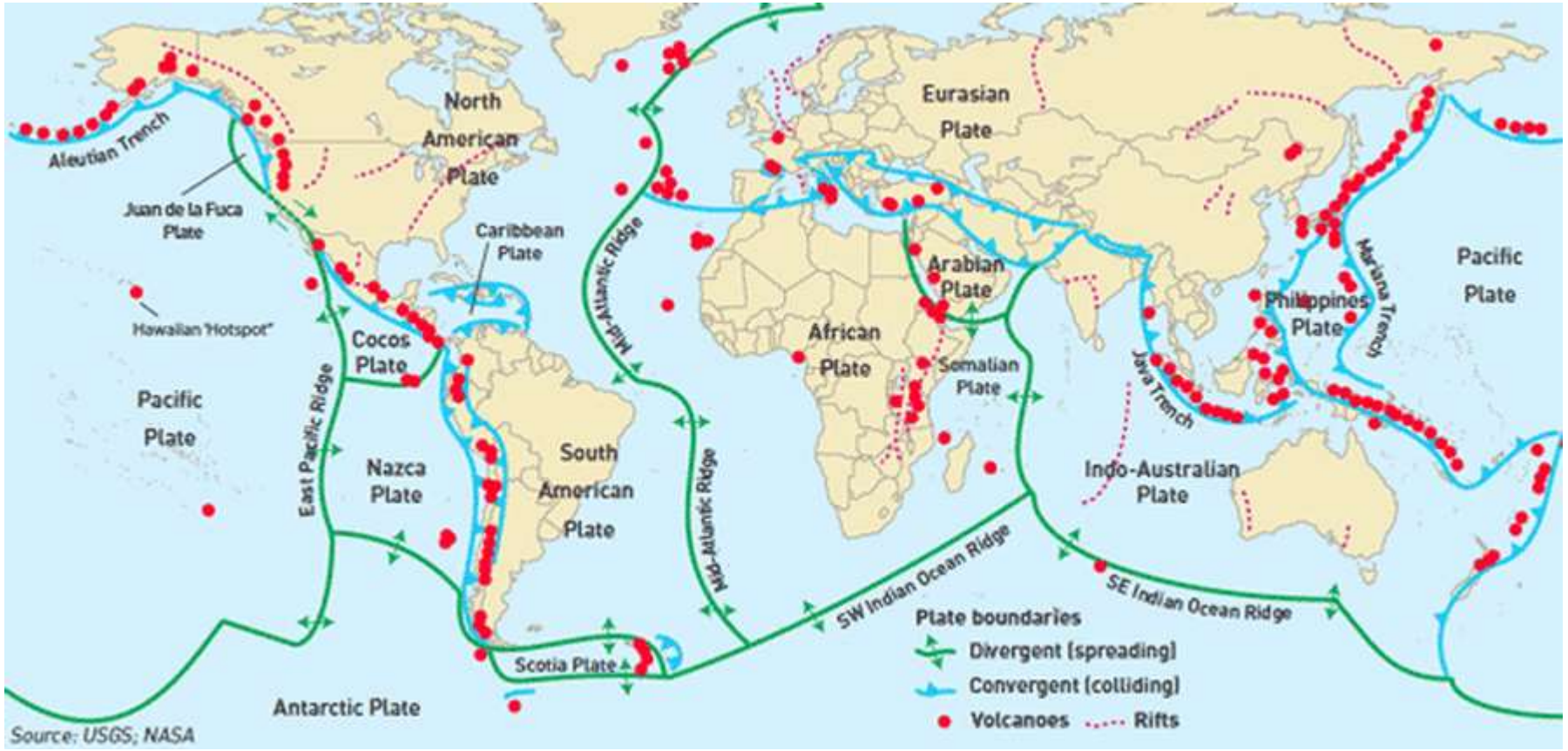


Outgassing

- Volcanism also releases gases from Earth's interior into the atmosphere.
- N_2, along with CO_2 and H_2O are released, originally bought to the earth from planetesimals.
- N_2 is 77% of our atmosphere today.

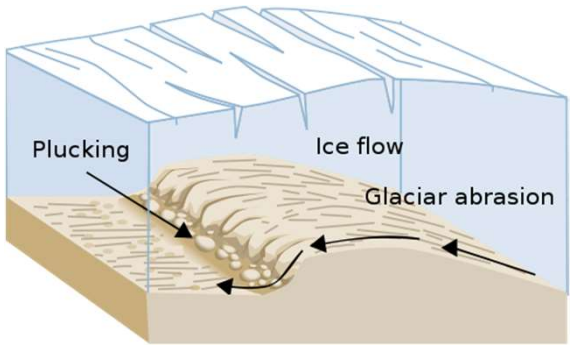

Mid ocean
Spreading Center
Continent
Continent
Oceanic Crust
Oceanic Crust
Upper
Mantle
Upper
Mantle
Magma


Himalaya
Tibetan Plateau
Indian-Australian Plate
Eurasian Plate


Aleutian Trench
North
American
Plate
Juan de la Fuca
Plate
Caribbean
Plate
Hawaiian "Hotspot"
Cocos
Plate
Pacific
Plate
East Pacific Ridge
Nazca
Plate
South
American
Plate
Mid-Atlantic Ridge
Mid-Atlantic Ridge
Eurasian
Plate
Arabian
Plate
African
Plate
Somalian
Plate
Java Trench
Philippines
Plate
Mariana Trench
Pacific
Plate
Indo-Australian
Plate
SW Indian Ocean Ridge
SE Indian Ocean Ridge
Scotia Plate
Antarctic Plate
Plate boundaries
Divergent (spreading)
Convergent (colliding)
Volcanoes
Rifts
Source: USGS; NASA

Erosion

- Erosion is a blanket term for weather-driven processes that break down or transport rock.
- Rivers, glaciers, wind, deposition (e.g., deltas)



iClicker Question

Question: The geological age of a planet's surface can be determined from the relative amount of…

A. Volcanic features
B. Erosion features
C. Impact craters
D. Tectonic features

iClicker Question

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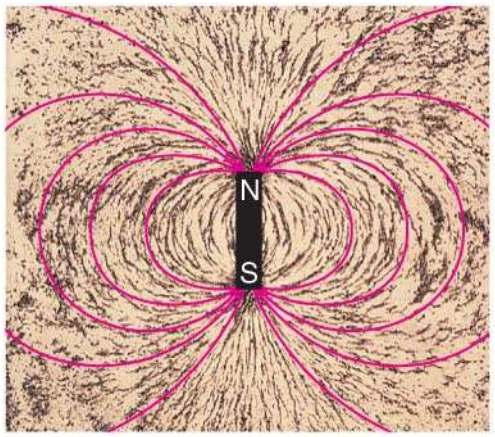
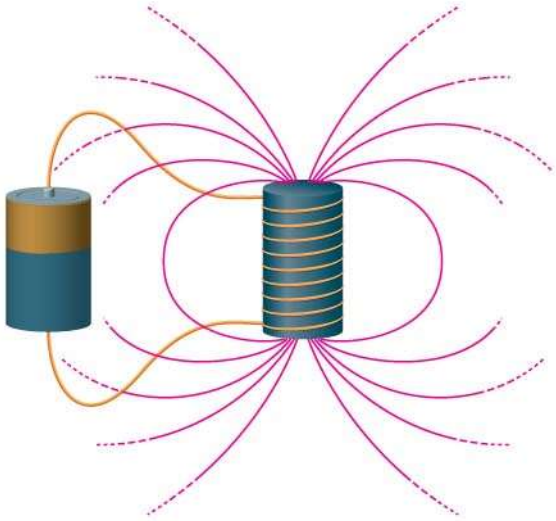
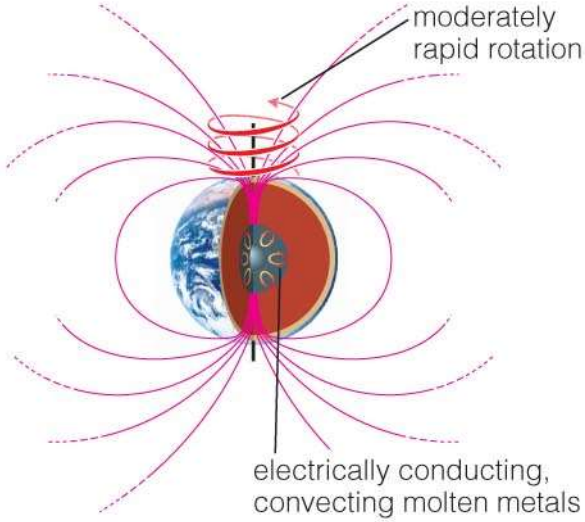
Planetary Magnetic Fields



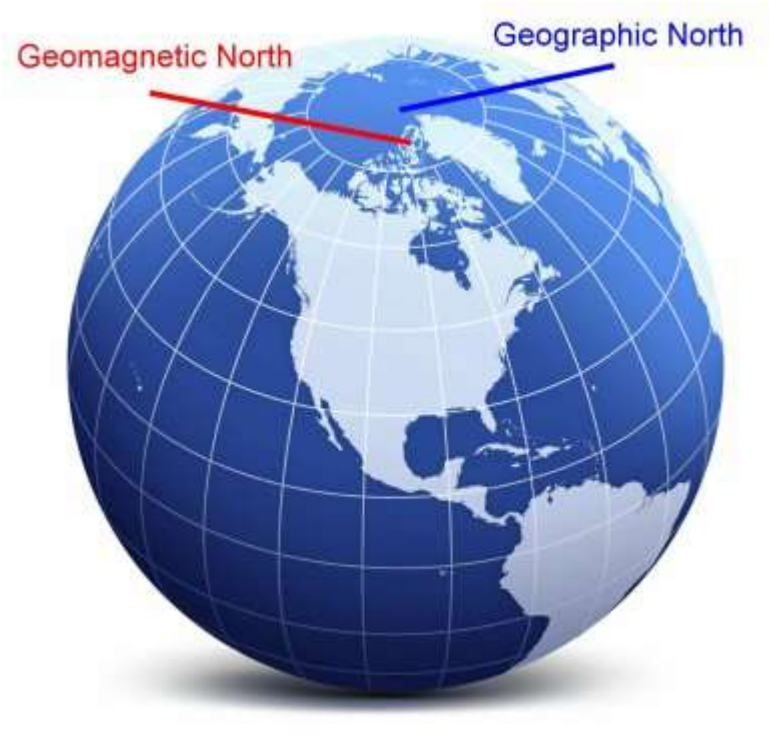


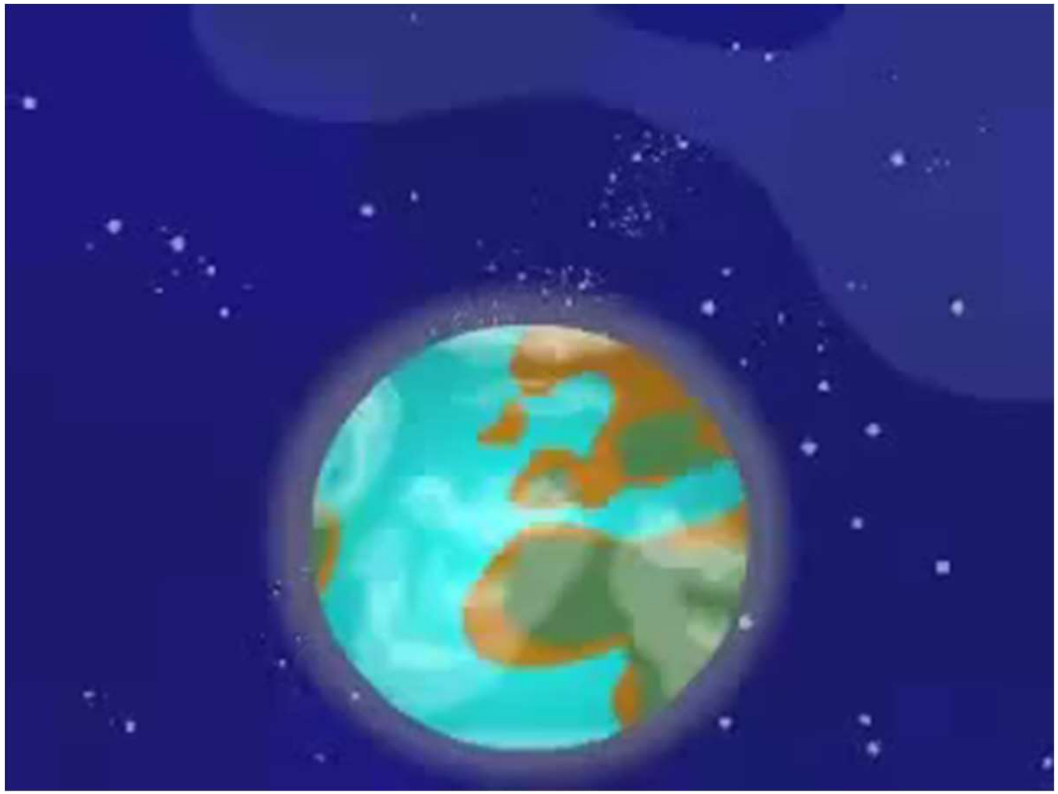


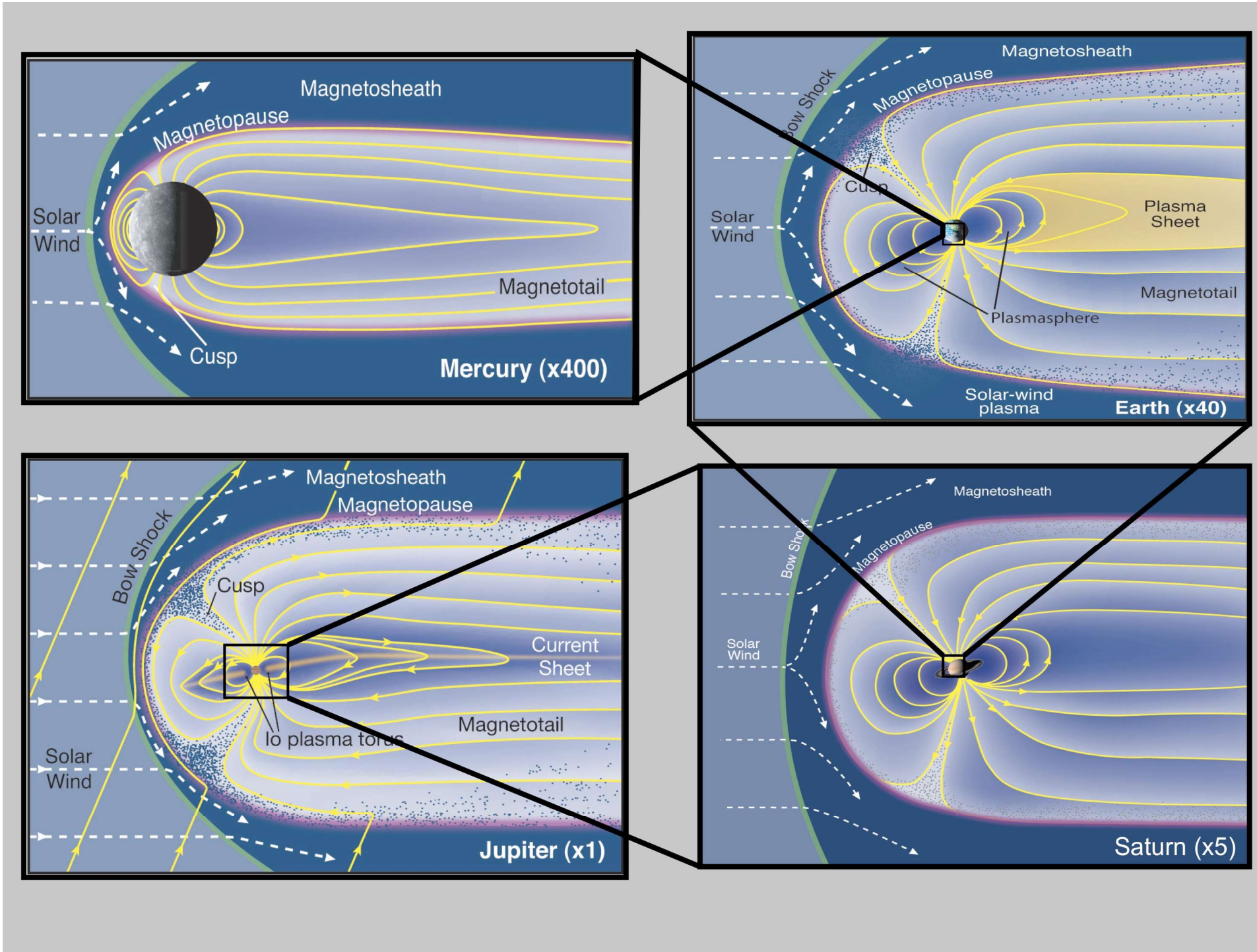
- Moving charged particles create magnetic fields.
- A planet's interior can create magnetic fields if:
  - its core is electrically conducting (iron-nickel works well)
  - Its core is convecting (liquids work well)
  - Rotating (IMPORTANT: No Rotation = No magnetic field)

Earth's Magnetic Dynamo

https://www.youtube.com/watch?v=8_P4WpxUYq4

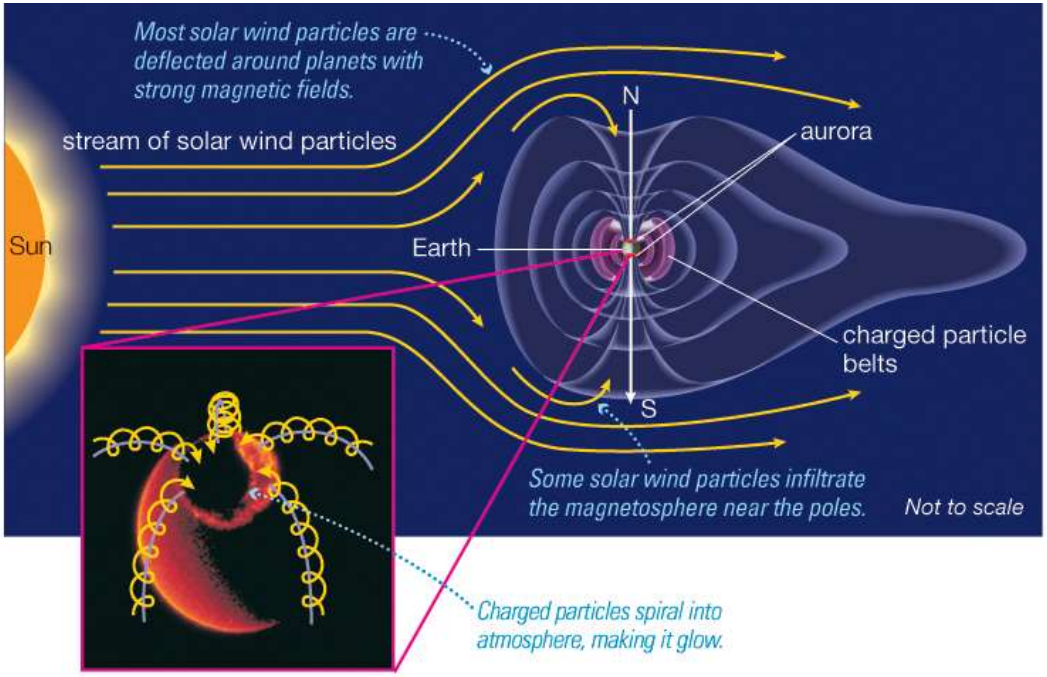





Magnetosheath
Magnetopause
Solar
Wind
Magnetotail
Cusp
Mercury (x400)
Bow Shock
Plasma
Sheet
Plasmasphere
Solar-wind
plasma
Earth (x40)
Current
Sheet
Io plasma torus
Jupiter (x1)
Saturn (x5)

Earth's Magnetosphere

- The majority of solar wind particles are deflected by Earth's magnetosphere
- The charged particles can enter at the poles, generating the aurorae.



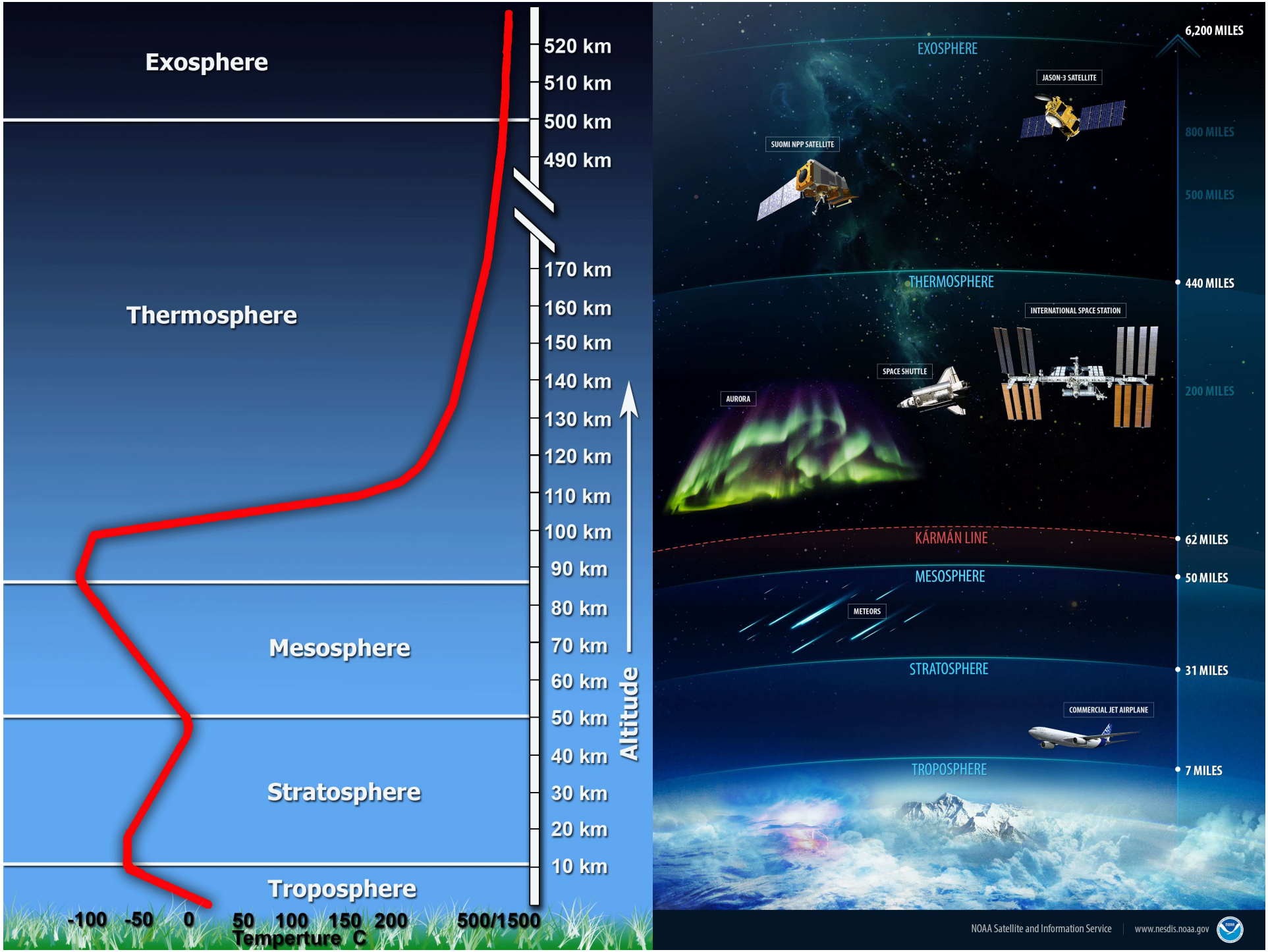
a This diagram shows how Earth's magnetosphere deflects solar wind particles. Some particles accumulate in charged particle belts encircling our planet. The inset is an ultraviolet image of a ring of auroras around the North Pole; the bright crescent at its left is part of the day side of Earth.

b This photograph shows the aurora near Yellowknife, Northwest Territories, Canada. In a video, you would see these lights dancing about in the sky.

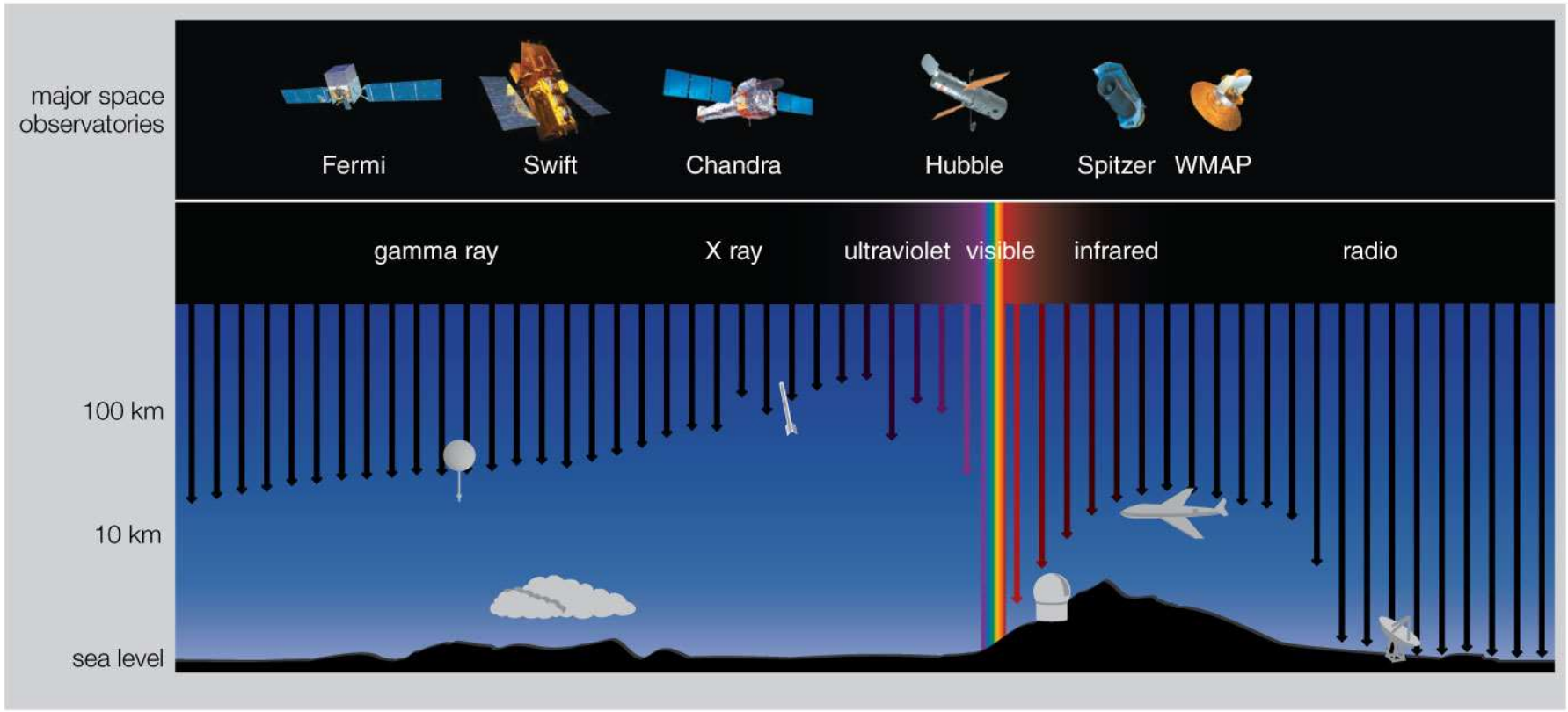
Earth's Atmosphere

How does this change our planet?

- Protects us from radiation & meteoroids
- Makes the sky blue
- Erodes our surface
- Keeps us warm (Greenhouse effect)


Exosphere
Thermosphere
Mesosphere
Stratosphere
Troposphere
520 km
510 km
500 km
490 km
170 km
160 km
150 km
140 km
130 km
120 km
110 km
100 km
90 km
80 km
70 km
60 km
50 km
40 km
30 km
20 km
10 km
Altitude
-100 -50 0 50 100 150 200 500/1500
Temperture C
6,200 MILES
EXOSPHERE
JASON-3 SATELLITE
SUOMI NPP SATELLITE
800 MILES
500 MILES
THERMOSPHERE
440 MILES
INTERNATIONAL SPACE STATION
SPACE SHUTTLE
AURORA
200 MILES
KÁRMÁN LINE
62 MILES
MESOSPHERE
50 MILES
METEORS
STRATOSPHERE
31 MILES
COMMERCIAL JET AIRPLANE
TROPOSPHERE
7 MILES
NOAA Satellite and Information Service
www.nesdis.noaa.gov

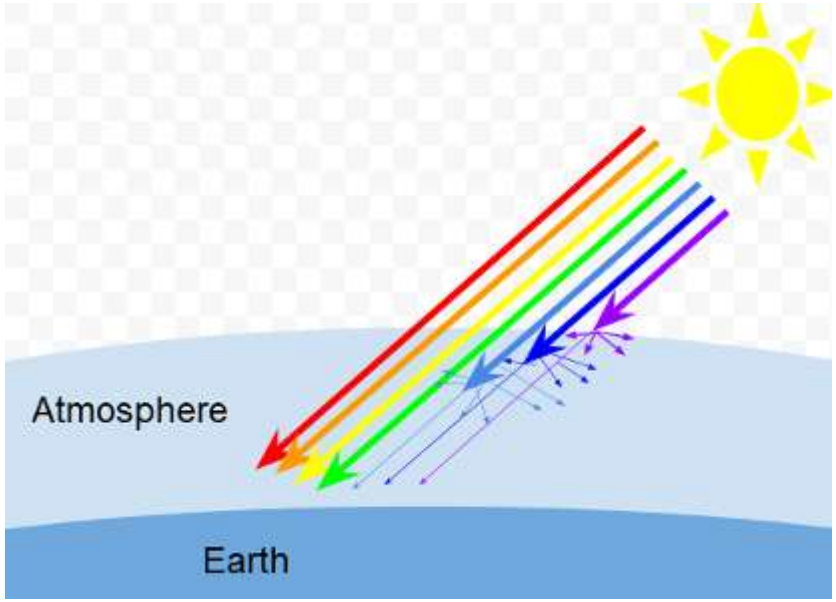
Protection from Radiation

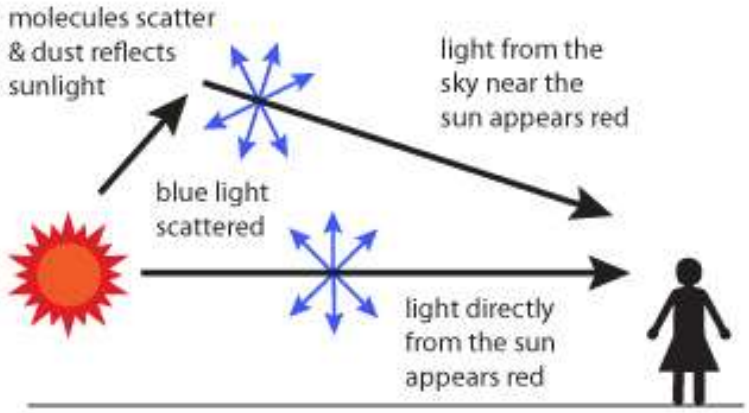


- Earth's atmosphere absorbs light at most wavelengths
  - Ozone (O_3) absorbs UV. Most X-rays don't make it to the ground
- Most meteoroids usually burn up in the mesosphere

Why is the Sky Blue? And Sunsets Red?

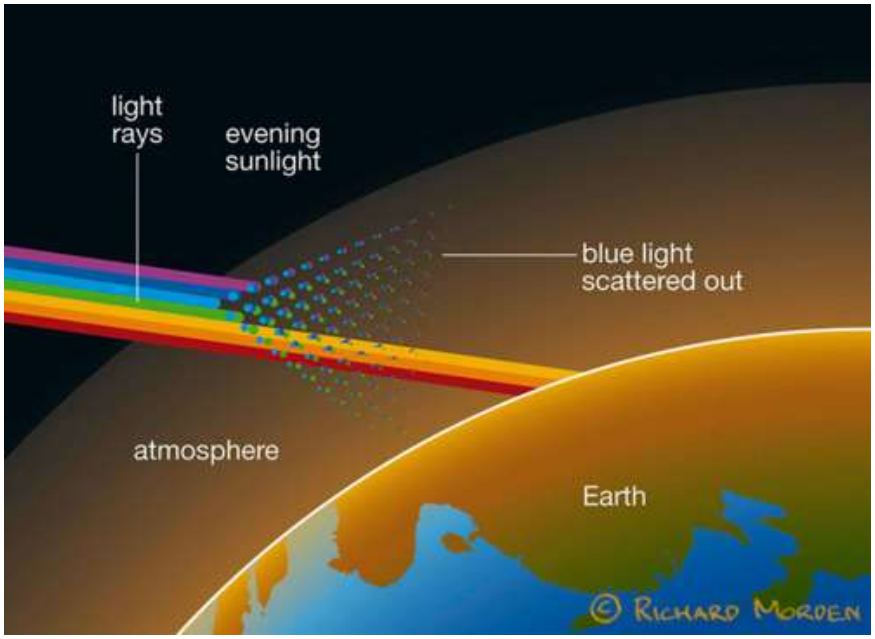
Blue particles are scattered more effectively so appear to be coming from every direction

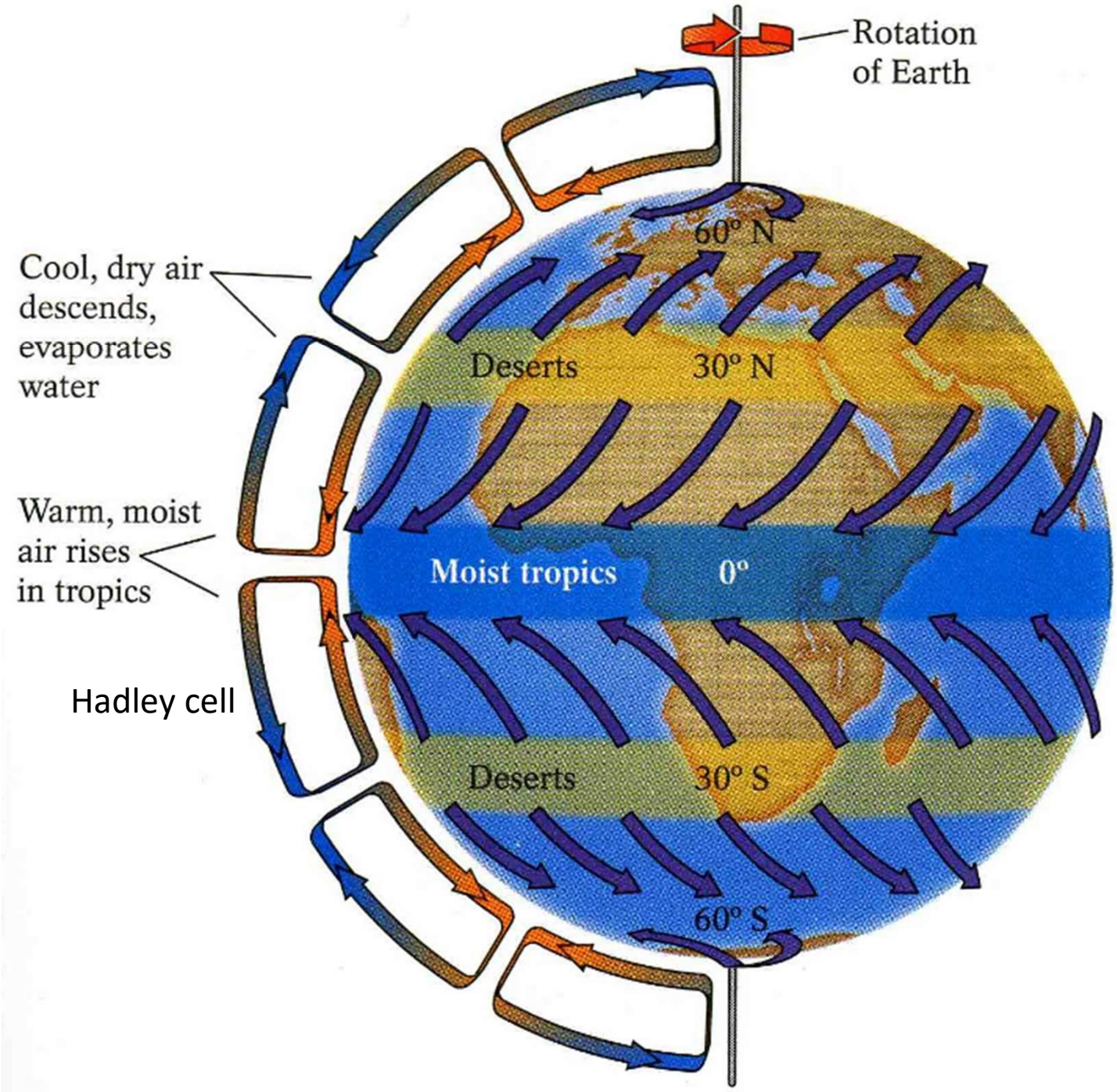




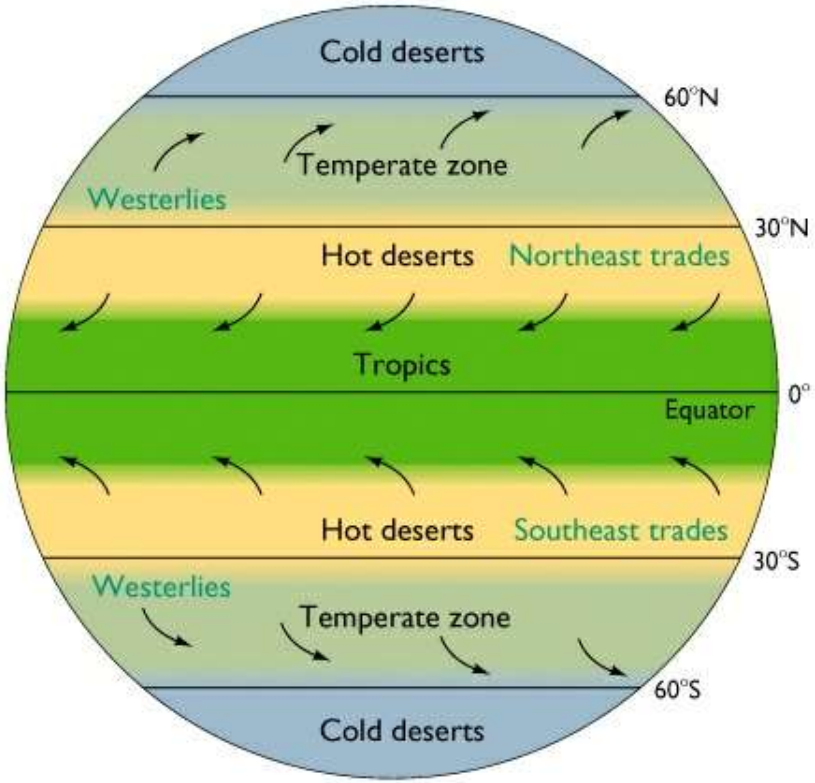
At Sunset, the suns rays have to travel through more atmosphere so more of the blue light never reaches you.

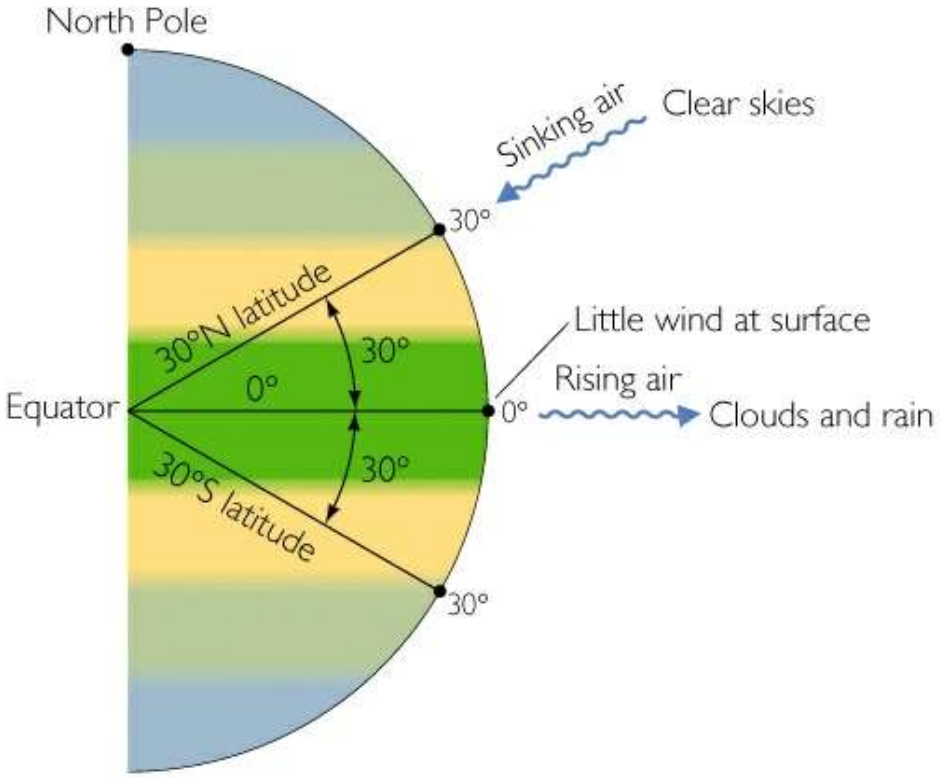
In addition, dust particles (smog) scatters red particles




Rotation of Earth
60° N
Cool, dry air descends, evaporates water
Deserts
30° N
Warm, moist air rises in tropics
Moist tropics
0°
Hadley cell
Deserts
30° S
60° S

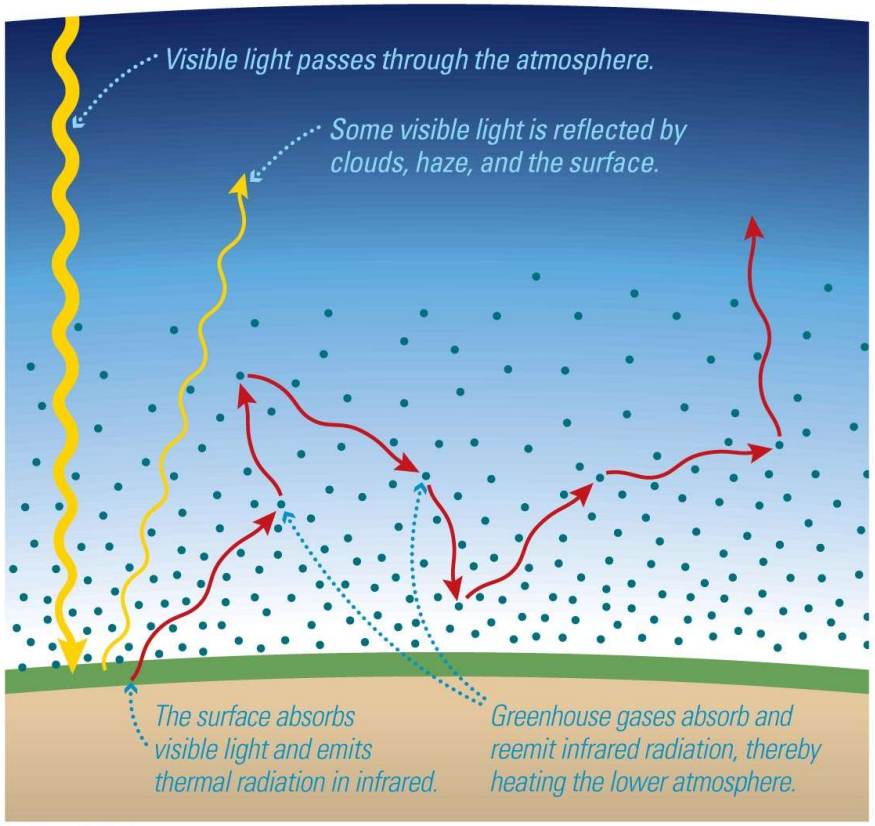
Why are the Deserts where they are?





- This sort of rising and falling circulation is called a *Hadley Cell*
- A non-rotating planet (Venus) would have one Hadley Cell per hemisphere
- On rotating planets the 'Coriolis Force' breaks up the Hadley circulation into three cells, each occupying approximately 30° in latitude.

What is the Greenhouse Effect?



Light from the Sun heats the Earth Surface

- ~50% heating caused by visible light

The Earth, at ~300 K emits light in the infrared region

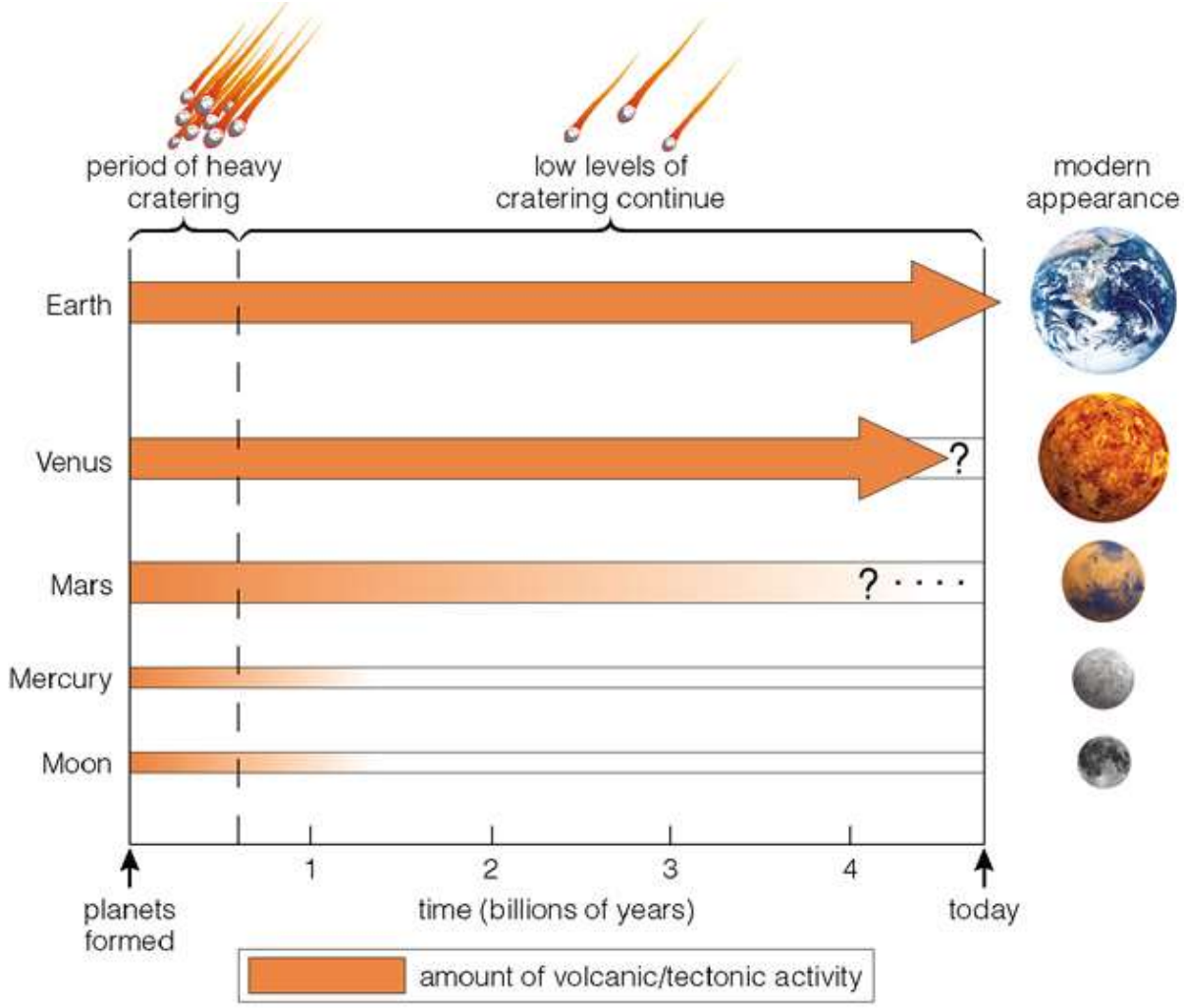
- Molecules that absorb infrared light in the atmosphere re-irradiate it in random directions.
- As a result, that infrared light can't escape

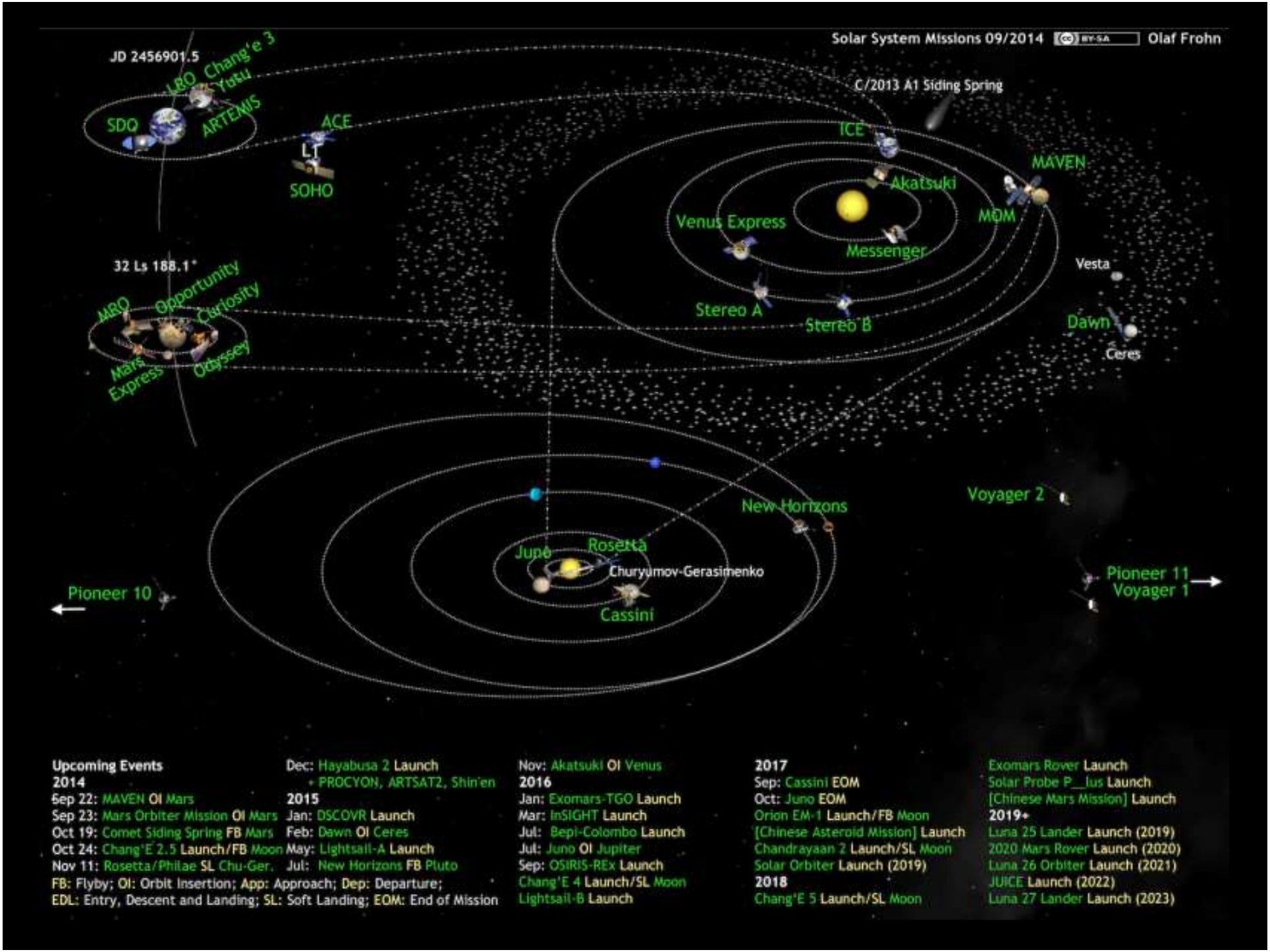
What are Greenhouse gases?

- Any gas that absorbs infrared
- Greenhouse gas: molecules with two different types of elements (CO_2, H_2O, CH_4)
- Not a greenhouse gas: molecules with one or two atoms of the same element (O_2, N_2)

What Causes Geological Activity?

- HEAT drives activity
- Smaller worlds cool off faster and harden earlier
- The Moon and Mercury are now geologically "dead"





Upcoming Events

2014
Sep 22: MAVEN OI Mars
Sep 23: Mars Orbiter Mission OI Mars
Oct 19: Comet Siding Spring FB Mars
Oct 24: Chang'E 2.5 Launch/FB Moon
Nov 11: Rosetta/Philae SL Chu-Ger.
FB: Flyby; OI: Orbit Insertion; App: Approach; Dep: Departure;
EDL: Entry, Descent and Landing; SL: Soft Landing; EOM: End of Mission

Dec: Hayabusa 2 Launch
+ PROCYON, ARTSAT2, Shin'en

2015
Jan: DSCOVR Launch
Feb: Dawn OI Ceres
May: Lightsail-A Launch
Jul: New Horizons FB Pluto

Nov: Akatsuki OI Venus

2016
Jan: Exomars-TGO Launch
Mar: InSIGHT Launch
Jul: Bepi-Colombo Launch
Jul: Juno OI Jupiter
Sep: OSIRIS-REx Launch
Chang'E 4 Launch/SL Moon
Lightsail-B Launch

2017
Sep: Cassini EOM
Oct: Juno EOM
Orion EM-1 Launch/FB Moon
[Chinese Asteroid Mission] Launch
Chandrayaan 2 Launch/SL Moon
Solar Orbiter Launch (2019)

2018
Chang'E 5 Launch/SL Moon

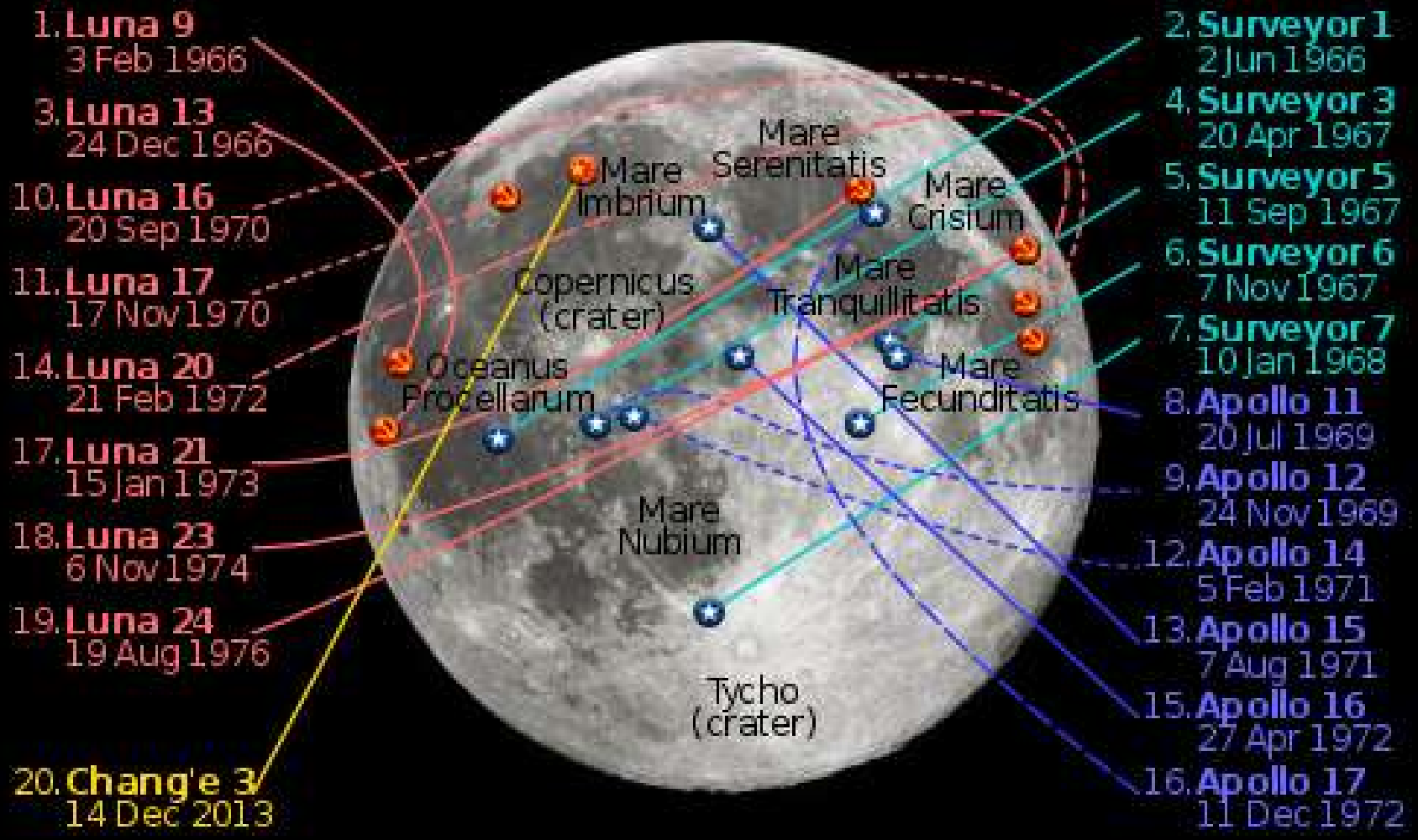
Exomars Rover Launch
Solar Probe P__lus Launch
[Chinese Mars Mission] Launch

2019+
Luna 25 Lander Launch (2019)
2020 Mars Rover Launch (2020)
Luna 26 Orbiter Launch (2021)
JUICE Launch (2022)
Luna 27 Lander Launch (2023)

MISSIONS TO PLANETS

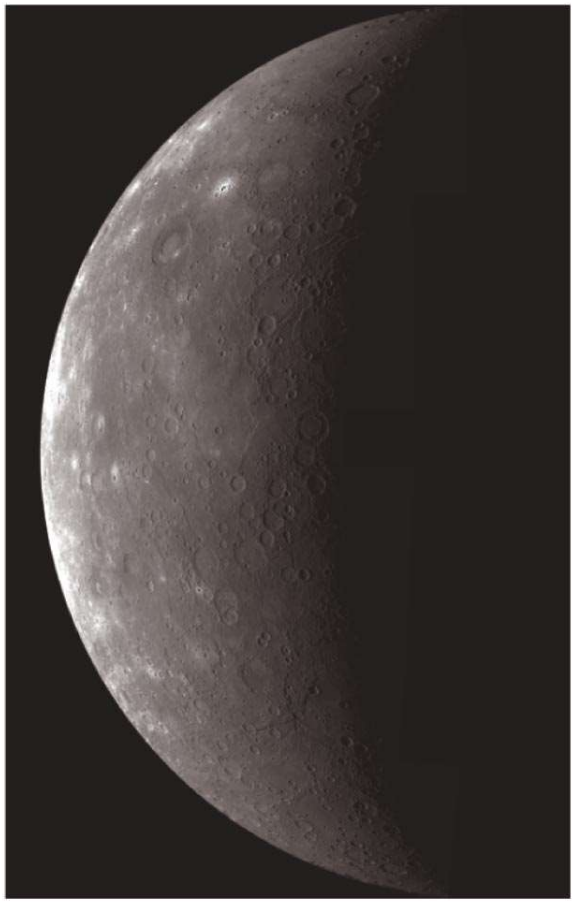
PLANET	MISSIONS
Mercury	Mariner 10, Messenger (NASA), Bepicolombo (ESA)
Venus	Mariner 2/Mariner 5(NASA); Venera 2 To 15 ,Vega 1 (USSR);Magellan (NASA).
Earth -Moon	Pioneer , Luna 1 to 14 (USSR),Ranger; Zond 3 to 7 (USSR), Lunar Orbiter ,Surveyor ,Apollo 1 to 18 (NASA); Luna Ye-8 series (USSR);Clementine ,Lunar Prospector,Smart-1,Selene (NASA); Chang'e 1 (China); Chandrayaan 1 (India).
Mars	Mariner 2 to 4(NASA);Mars probes(USSR);Viking (NASA); Mars Orbiter Mission (India).
Jupiter	Pioneer 10, Pioneer 11 ,Voyager 1, Voyager 2,Galileo (NASA);
Saturn	Pioneer ,Voyager ,Cassini ,Huygens (ESA);
Uranus	Voyager 2 (NASA);
Neptune	Voyager 2 (NASA);

Moon Landing Sites

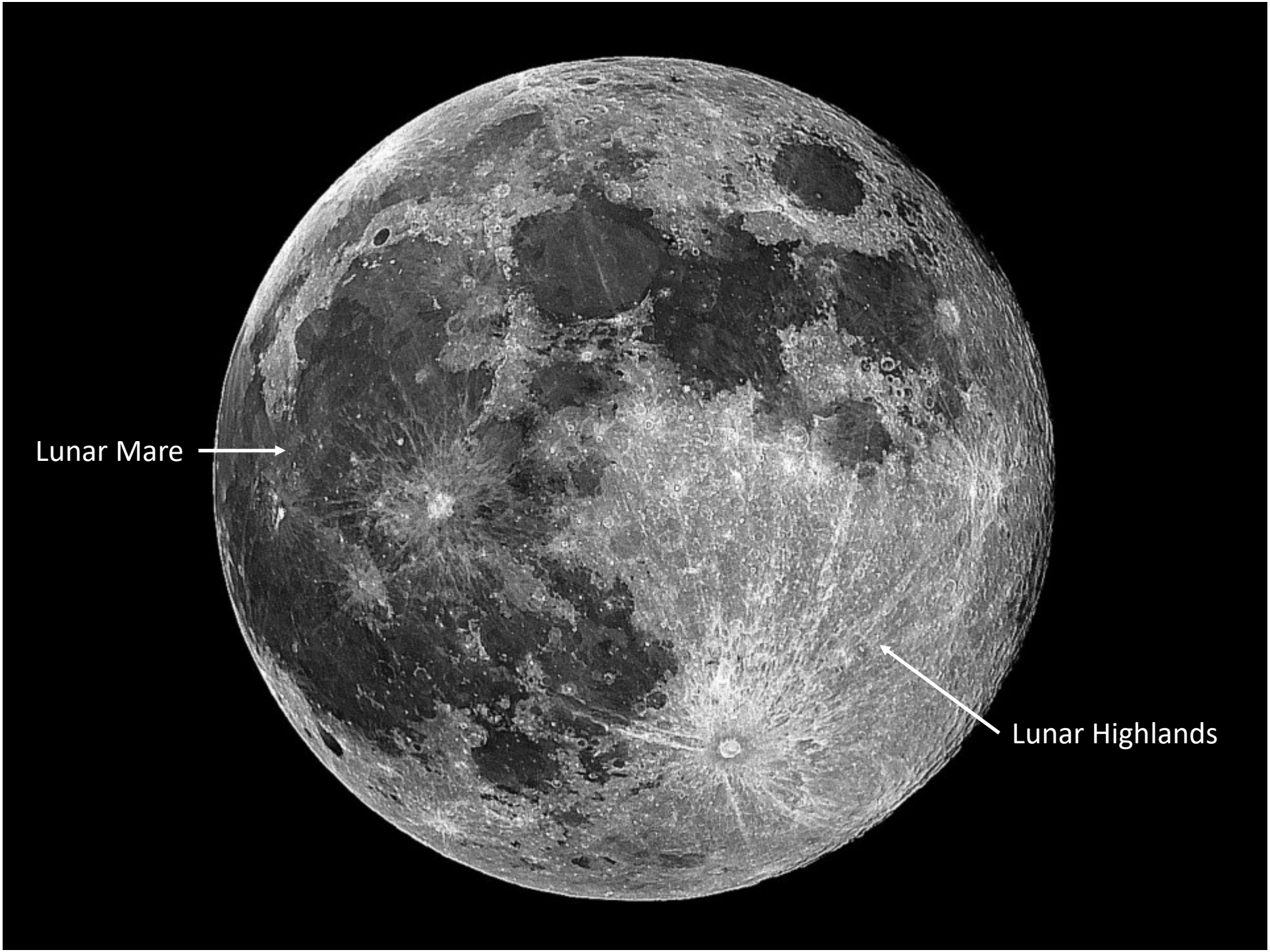


Was there ever geological activity on the Moon or Mercury?

Moon



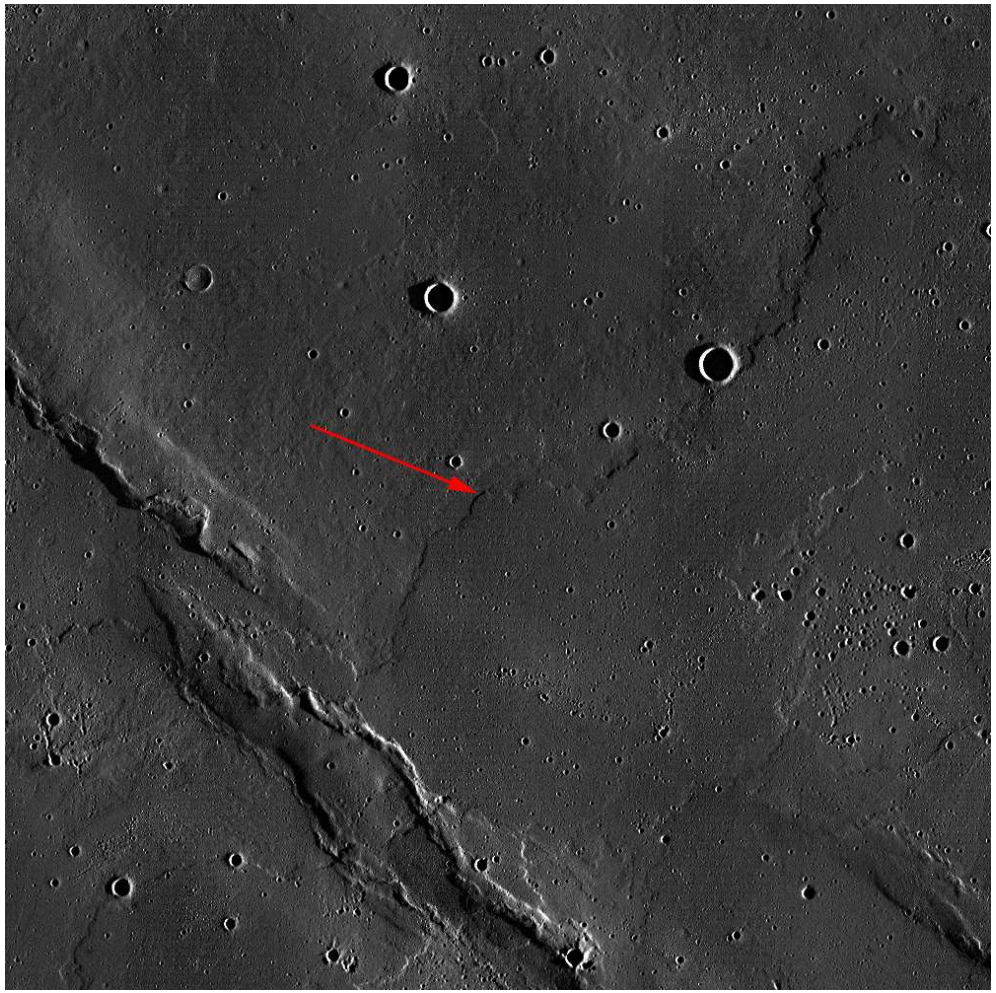
Mercury


Lunar Mare
Lunar Highlands

How did the Lunar Mare Form?

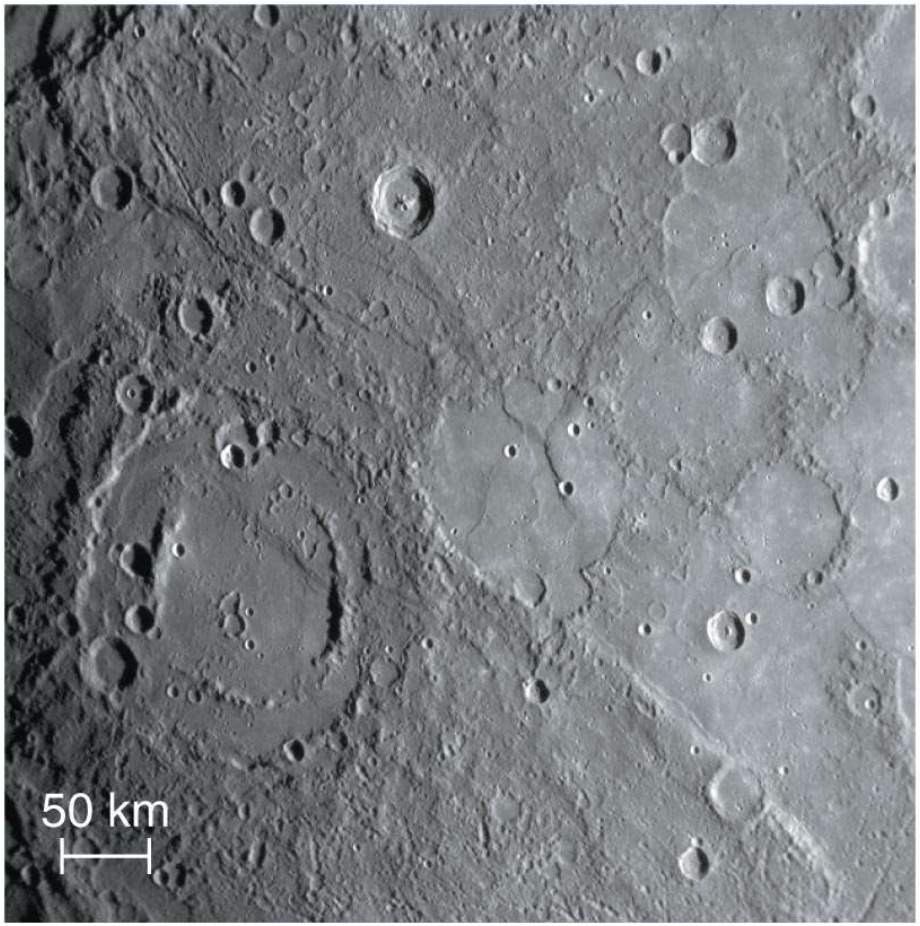
- Large impact occurred during ‘Late Heavy Bombardment’
  - Sufficient to crack the lithosphere
- Radioactive decay peaked around 3-4 billion years ago…
  - Some volcanic activity 3 billion years ago must have flooded lunar craters, creating *lunar maria*.
- The Moon is now geologically dead.

Evidence of Lunar Volcanism



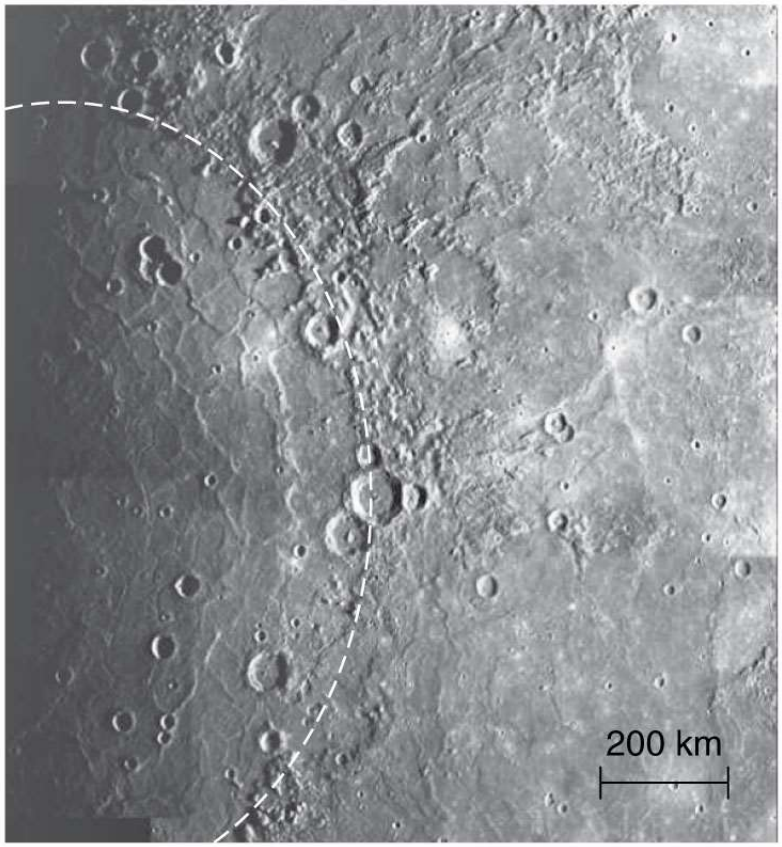
- Lava flows on the surface, so these regions are very flat
- Mare has relatively few craters → lava covered them
- Edges of flow can be seen in certain regions
- Mercury has similar features…

Cratering of Mercury

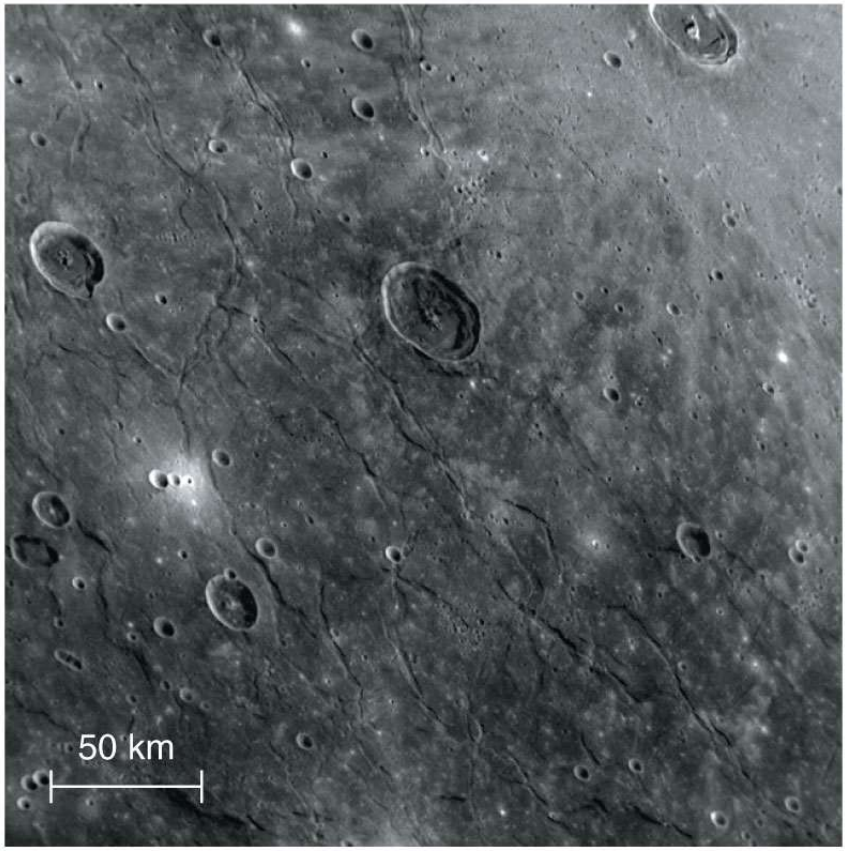


- Mercury has a mixture of heavily cratered and smooth regions like the Moon.
- The smooth regions are likely ancient lava flows.

Cratering of Mercury

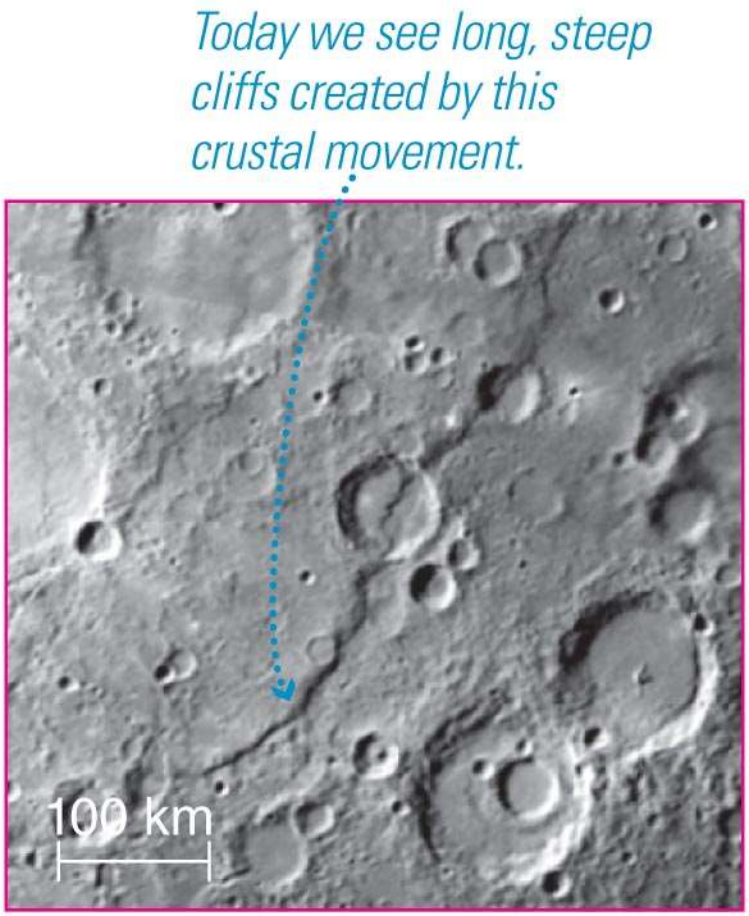


The Caloris Basin is the largest impact crater on Mercury.

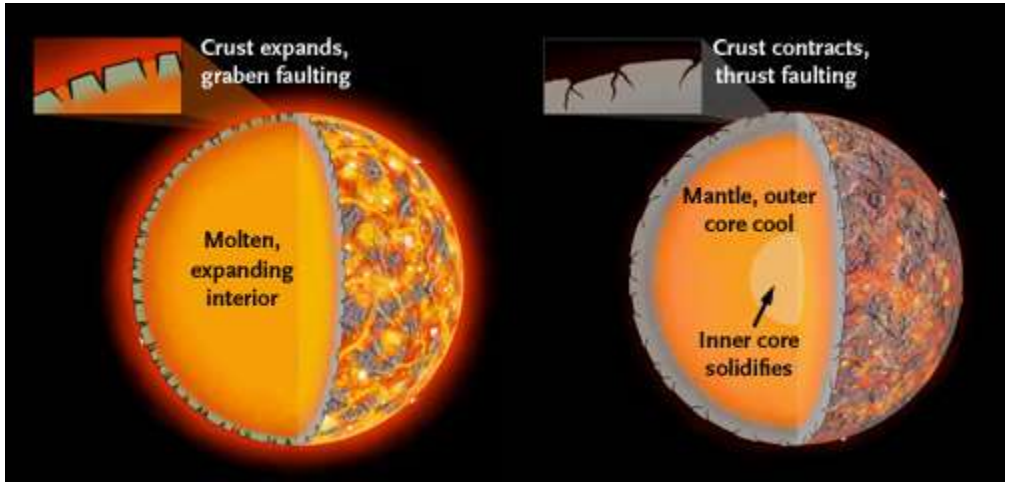


Region opposite the Caloris Basin is jumbled from seismic energy of impact.

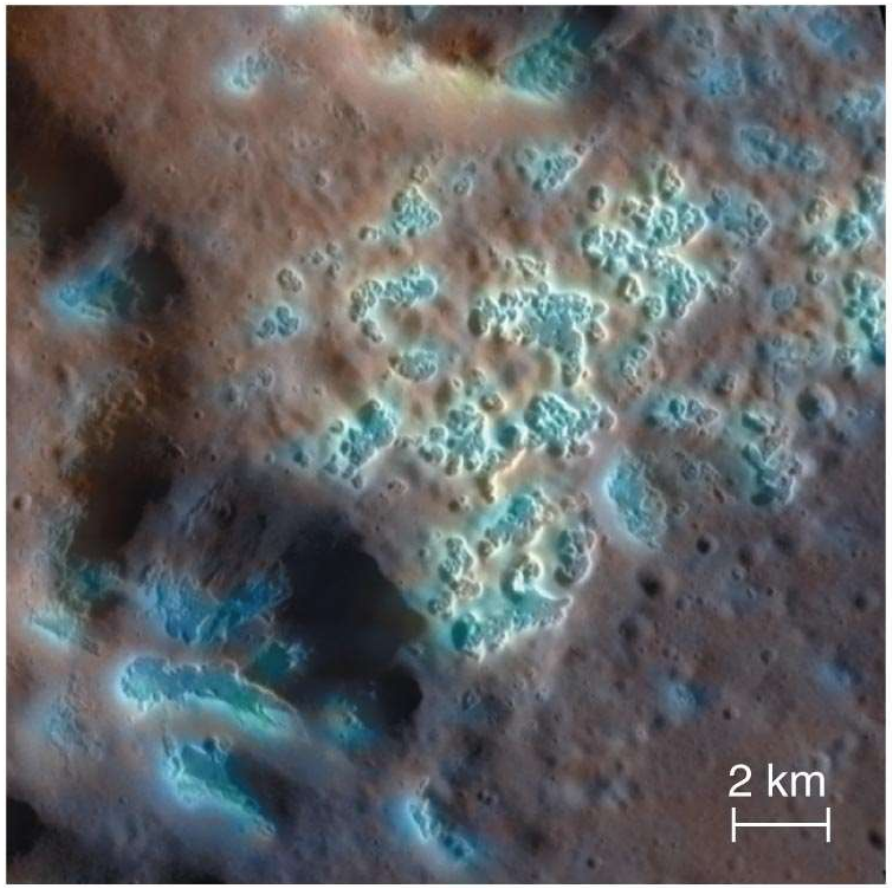
Tectonics on Mercury



- Long cliffs indicate that Mercury shrank early in its history.



Recent Geology on Mercury



- Lighter areas (color enhanced) are thought to be "hollows" formed as easily vaporized minerals escape.

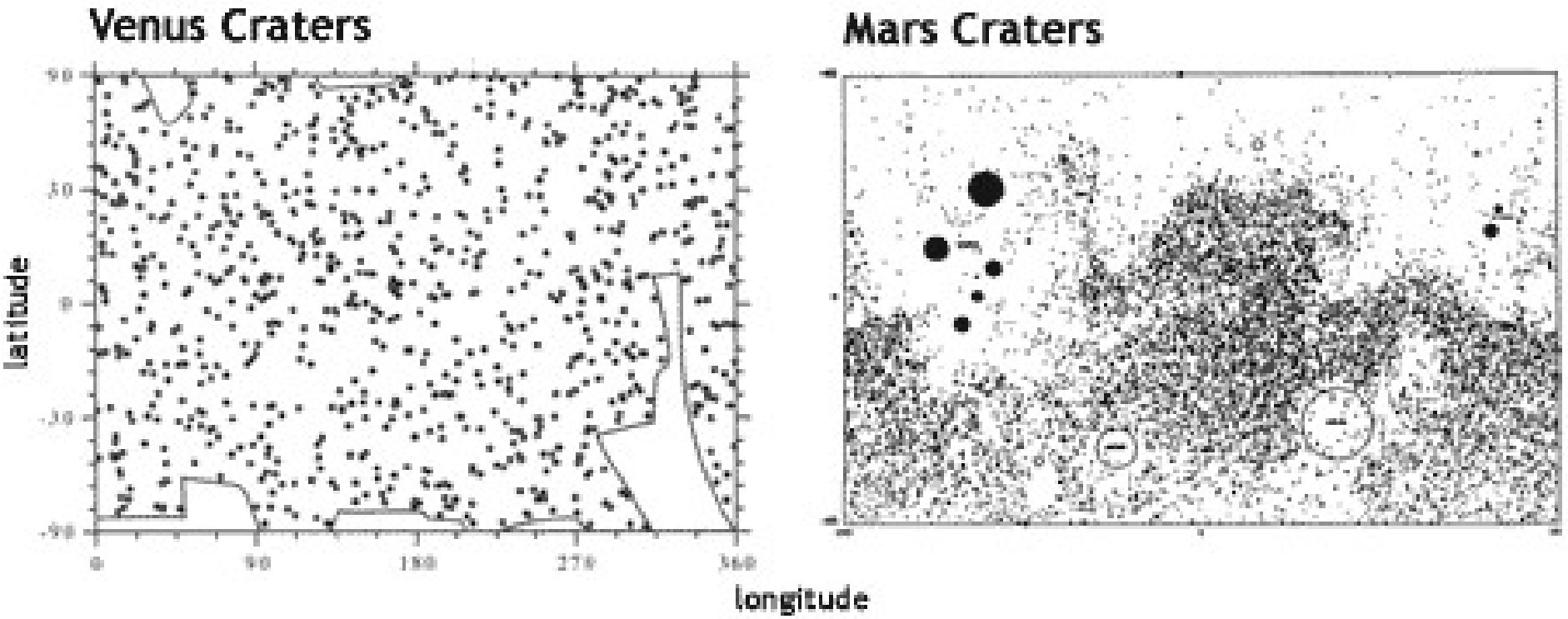
What have we learned?

- Was there ever geological activity on the Moon or Mercury?
  - Early cratering on the Moon and Mercury is still present, indicating that activity ceased long ago.
  - Lunar maria resulted from early volcanism.
  - Tectonic features on Mercury indicate early shrinkage.

7.3 Mars: A Victim of Planetary Freeze-Drying

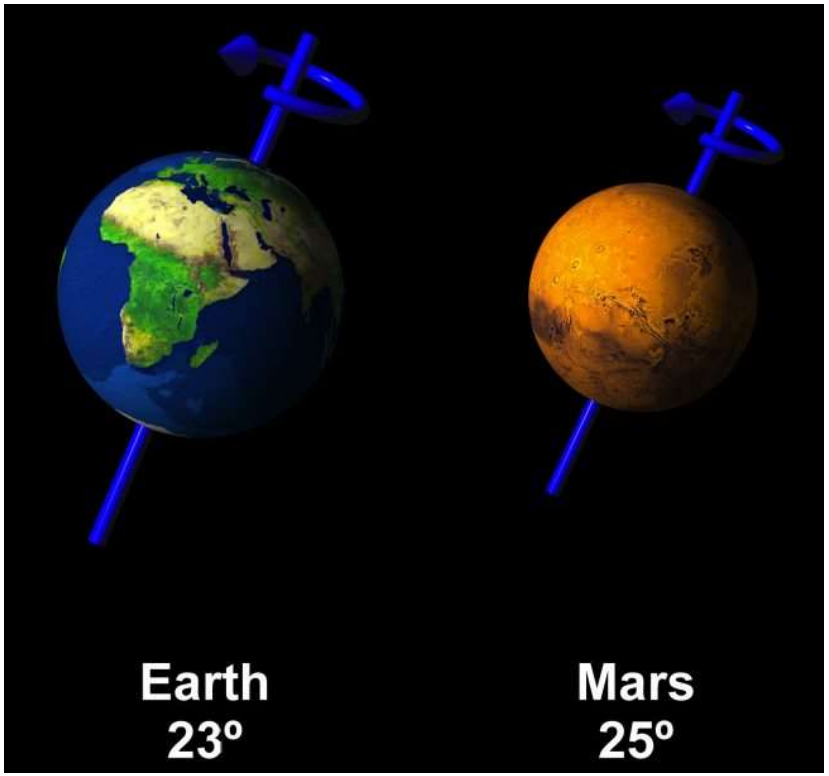
Our goals for learning:

- What geological features tell us that water once flowed on Mars?
- Why did Mars change?

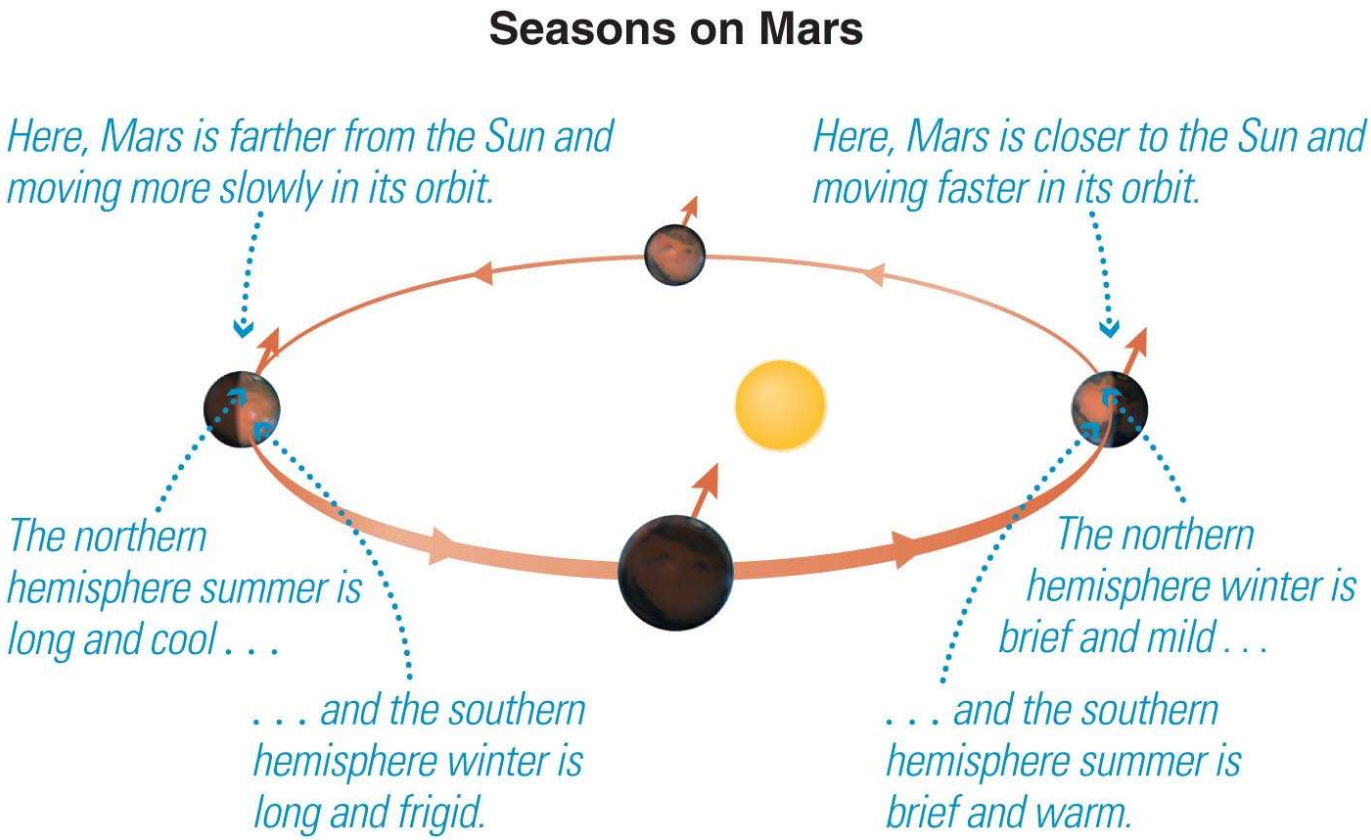


Mars versus Earth

- 50% Earth's radius, 10% Earth's mass
- 1.5 AU from the Sun
- Axis tilt about the same as Earth
- Similar rotation period
- Thin CO_2 atmosphere: little greenhouse
- Main difference: Mars is SMALLER

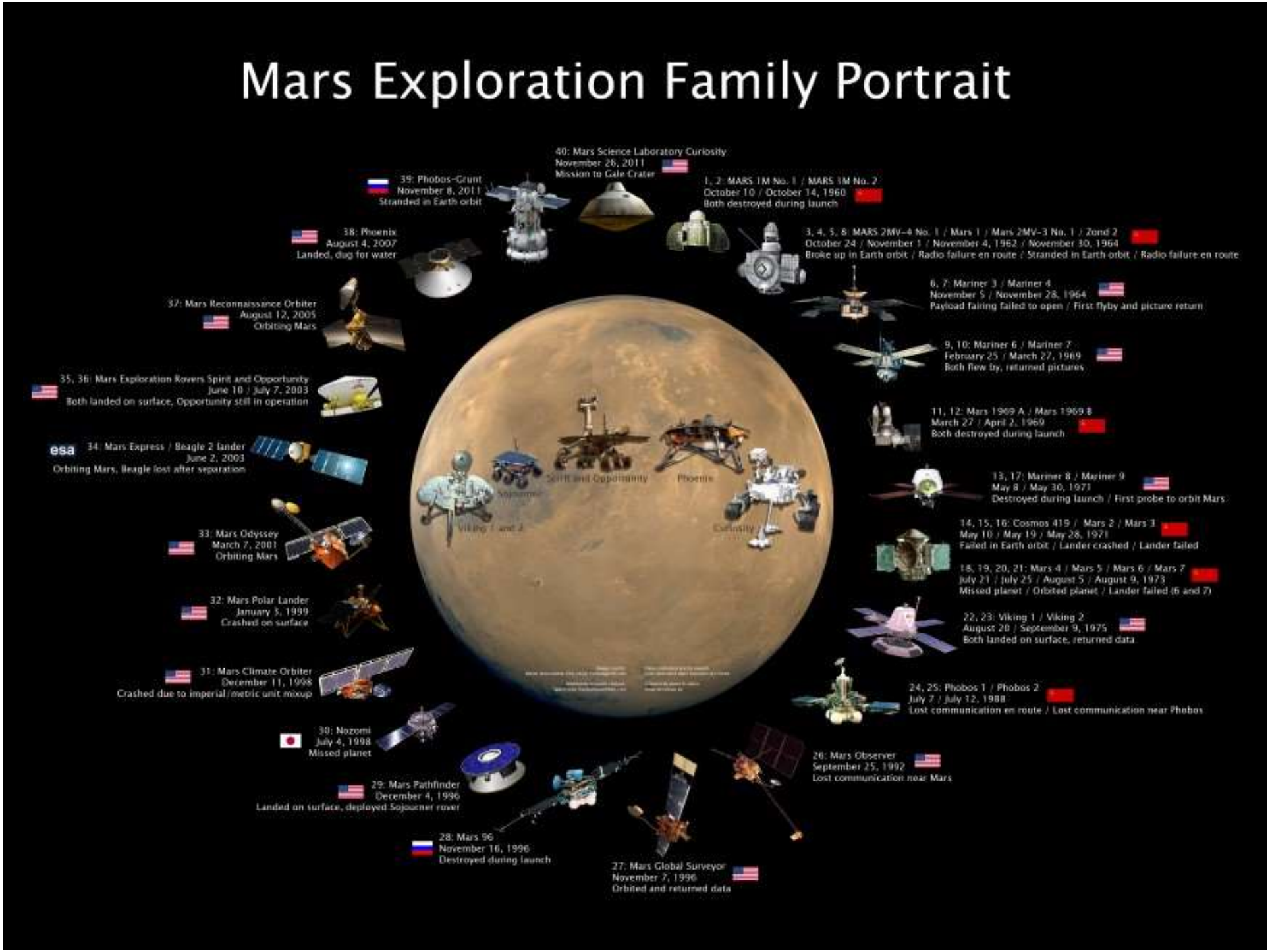


Seasons on Mars



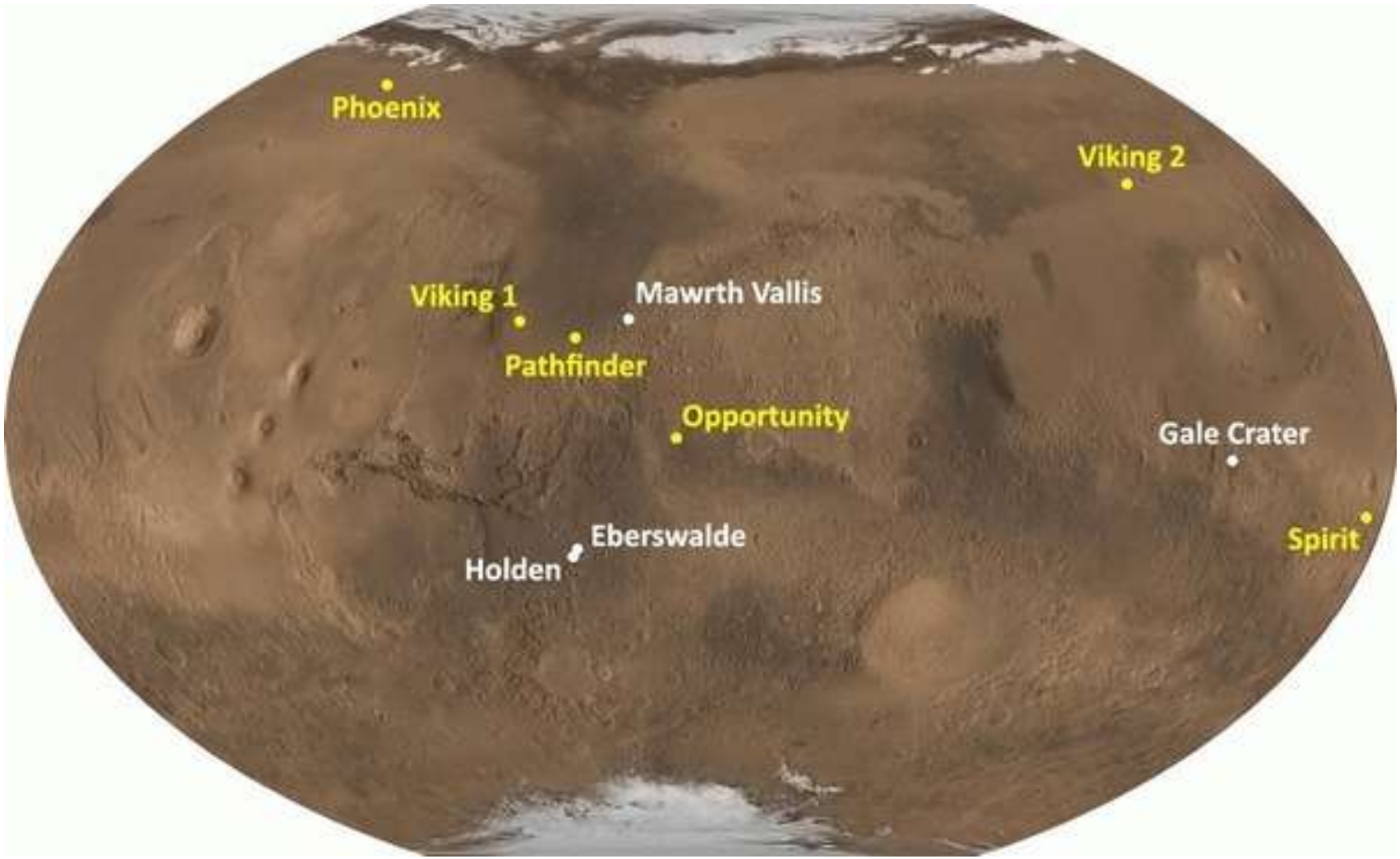
- Seasons on Mars are more extreme because of its elliptical orbit.

Mars Exploration Family Portrait

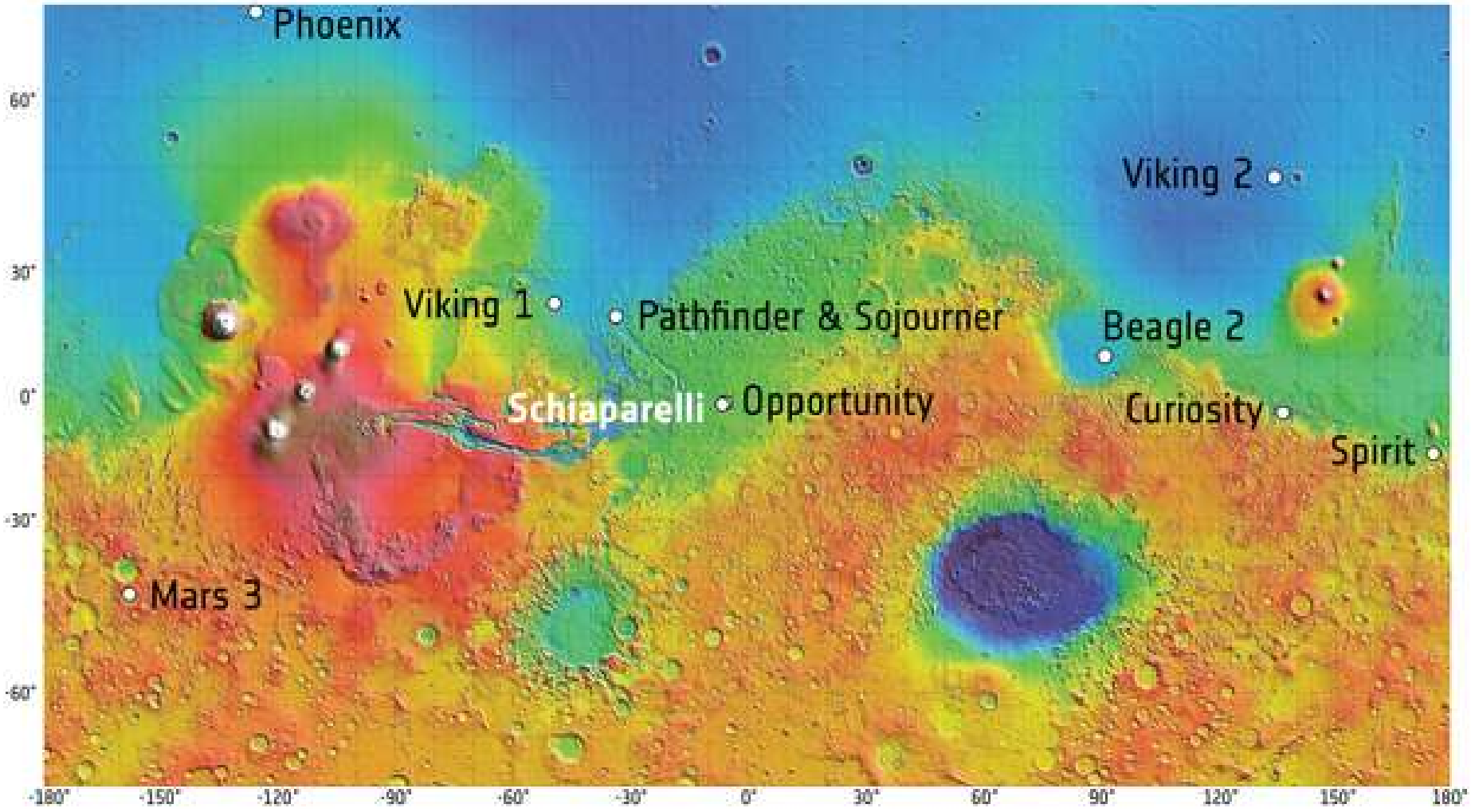


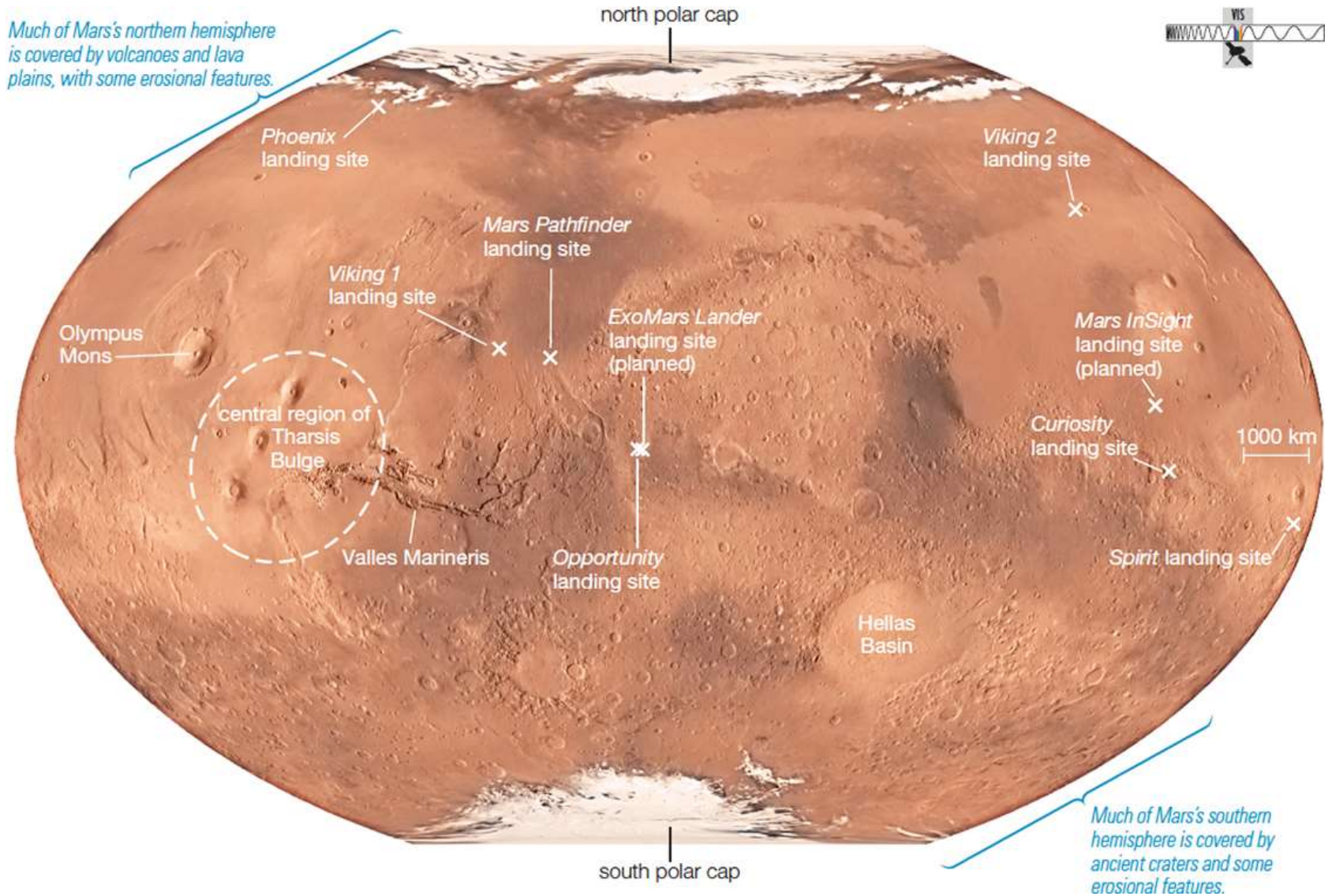
Recent Mars Missions

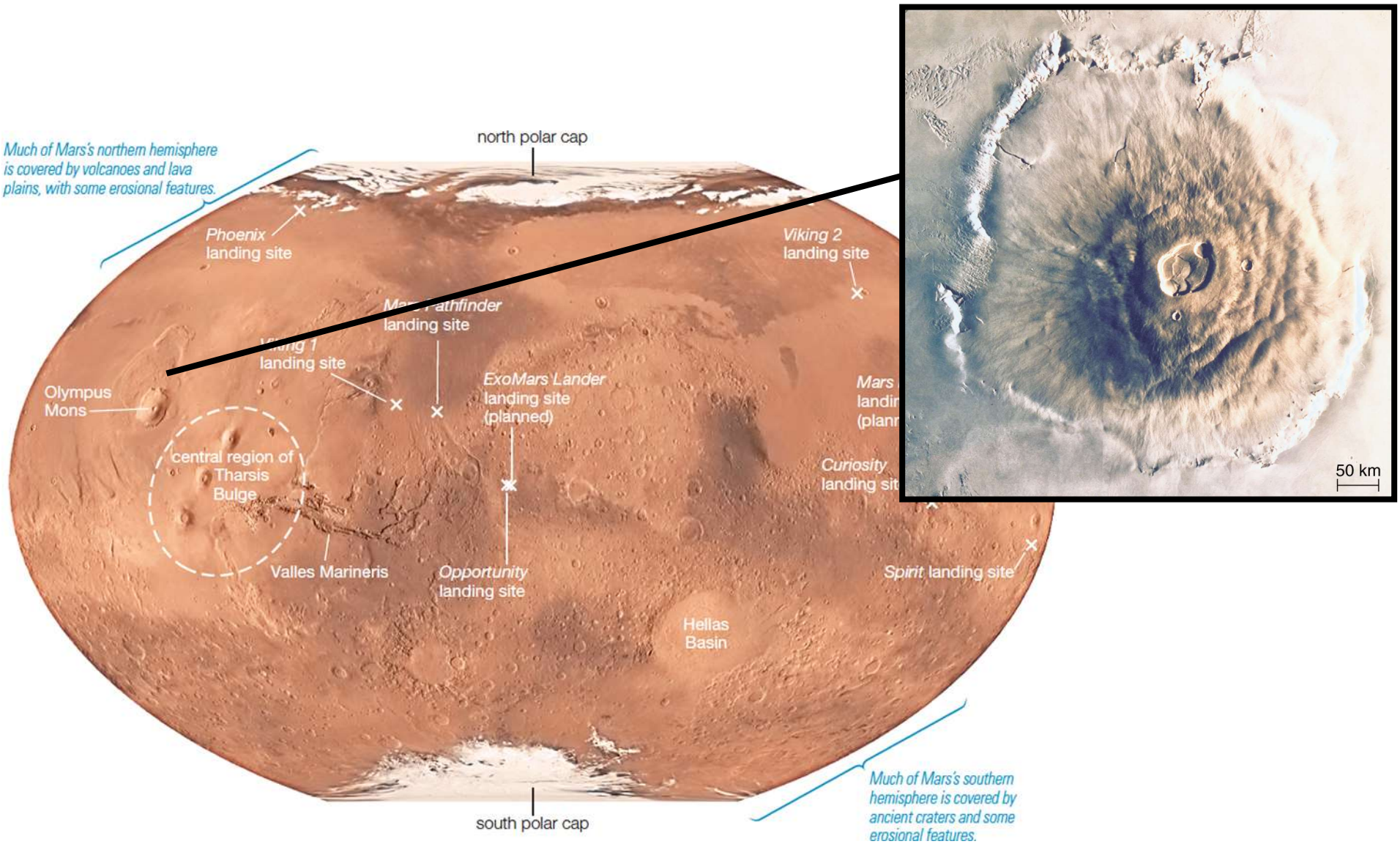
Where are they Now?



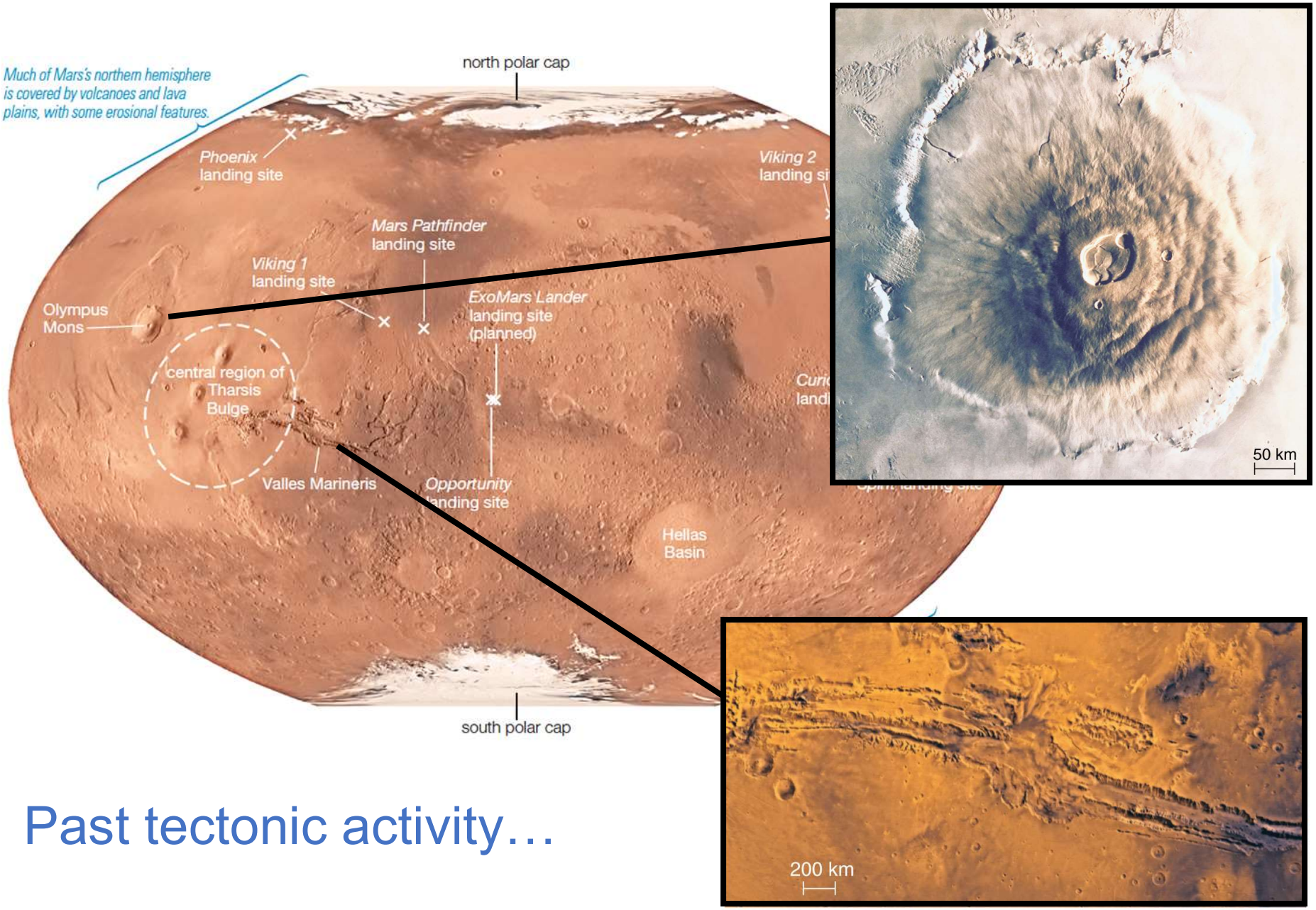
Relief Map Locations of Landers



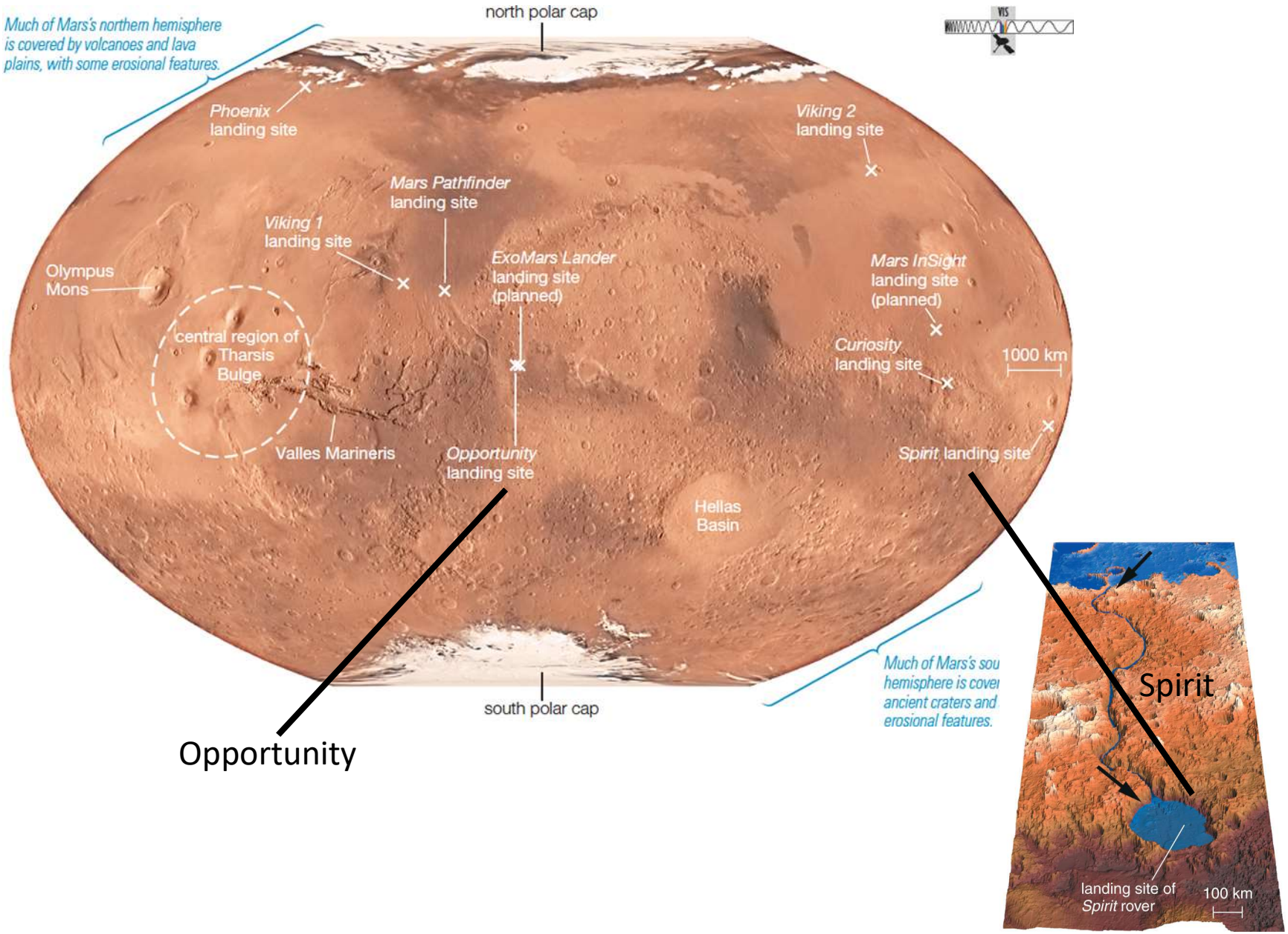

Much of Mars's northern hemisphere is covered by volcanoes and lava plains, with some erosional features.
north polar cap
VIS
Phoenix landing site
Viking 2 landing site
Mars Pathfinder landing site
Viking 1 landing site
ExoMars Lander landing site (planned)
Mars InSight landing site (planned)
Olympus Mons
central region of Tharsis Bulge
Curiosity landing site
1000 km
Valles Marineris
Opportunity landing site
Spirit landing site
Hellas Basin
south polar cap
Much of Mars's southern hemisphere is covered by ancient craters and some erosional features.



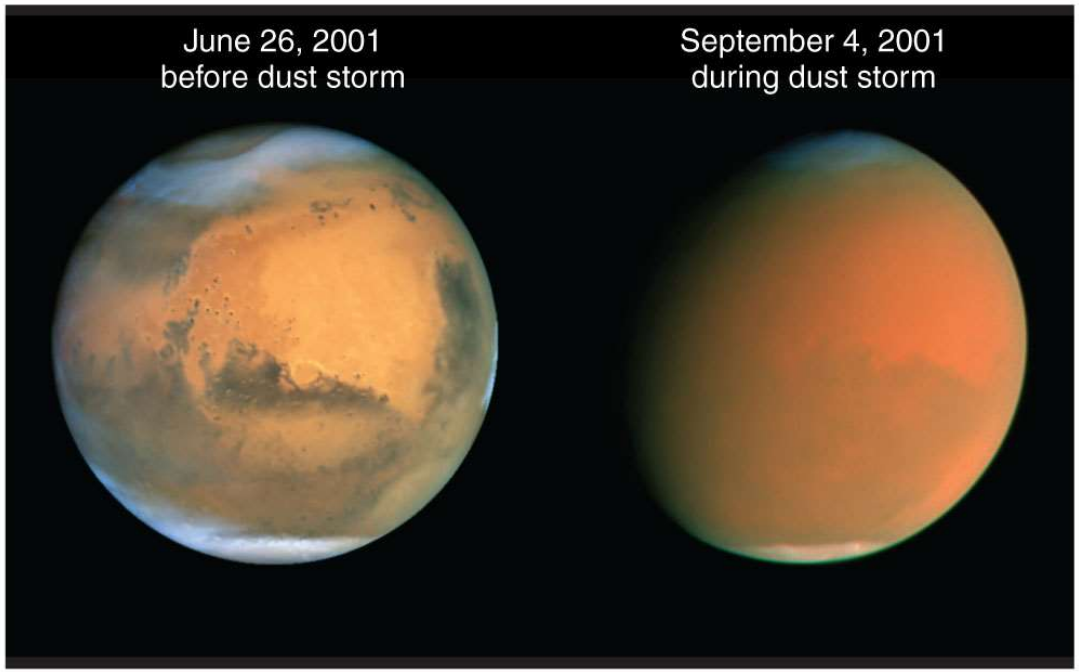
Volcanoes…as recent as 180 million years ago…



Past tectonic activity…

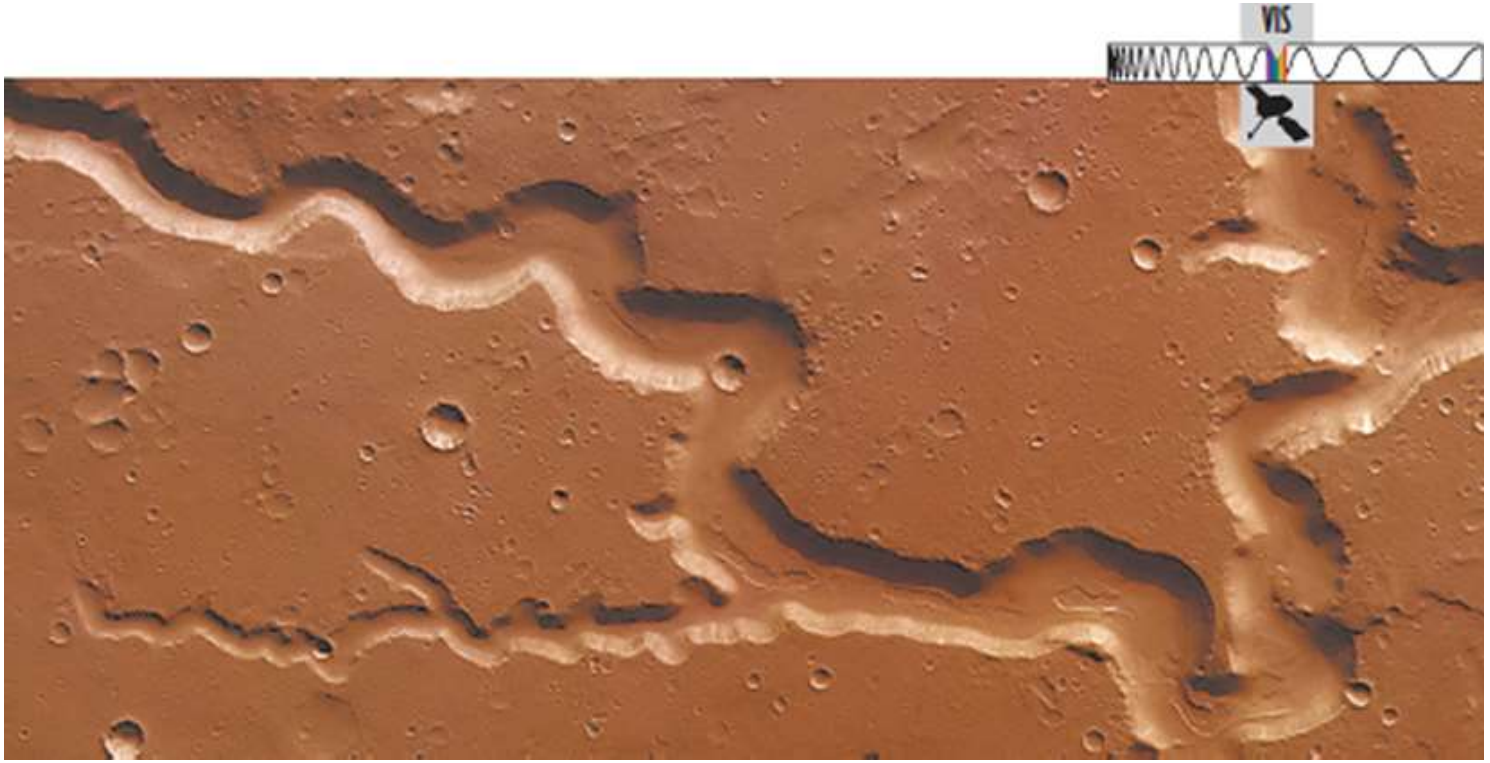

north polar cap
Much of Mars's northern hemisphere is covered by volcanoes and lava plains, with some erosional features.
Phoenix landing site
Viking 2 landing site
Mars Pathfinder landing site
Viking 1 landing site
ExoMars Lander landing site (planned)
Mars InSight landing site (planned)
Olympus Mons
central region of Tharsis Bulge
Curiosity landing site
1000 km
Valles Marineris
Opportunity landing site
Spirit landing site
Hellas Basin
Much of Mars's sou hemisphere is cover ancient craters and erosional features.
south polar cap
Opportunity
Spirit
landing site of Spirit rover
100 km

Evidence of Storms on Mars



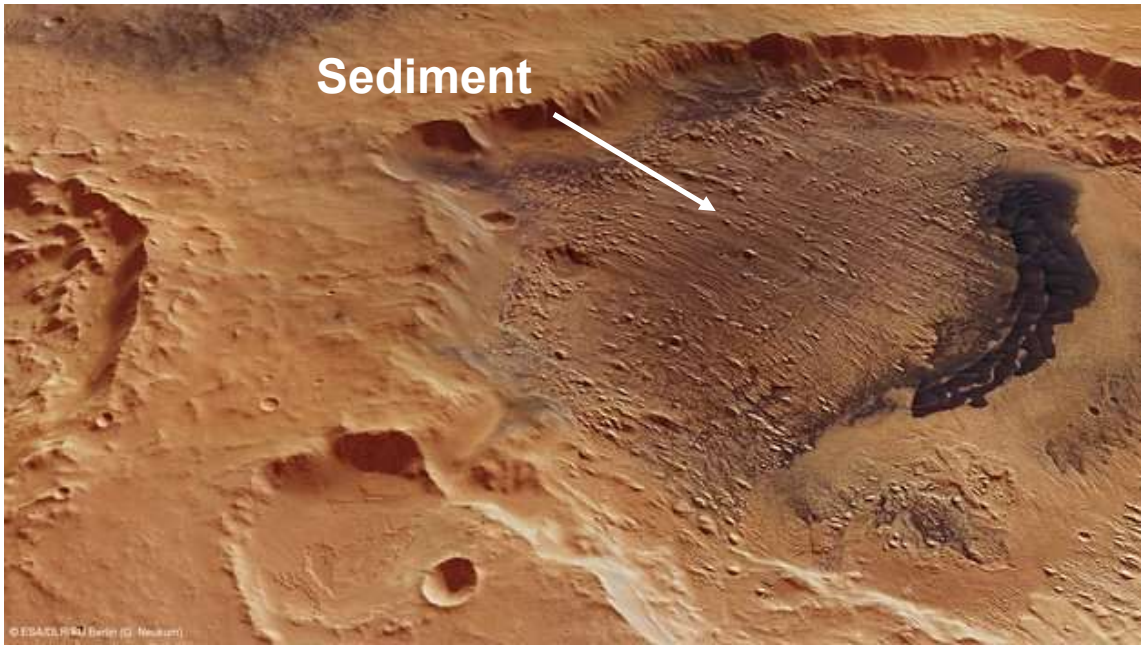
- Seasonal winds on Mars can drive huge dust storms.
- Locally, twisters are common
  - These clean solar panels from Rovers
  - Helps Spirit keep going!

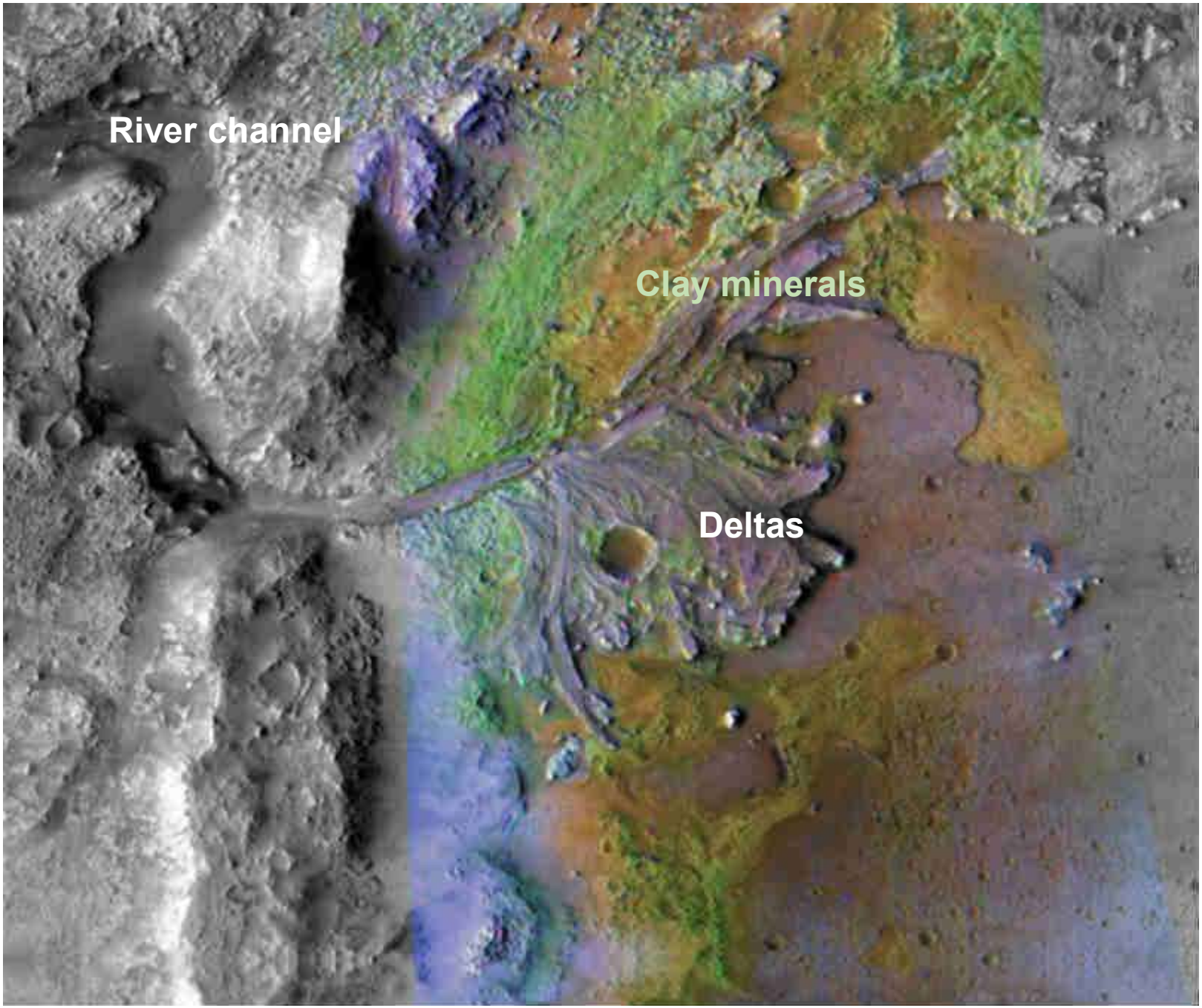
What geological features tell us that water once flowed on Mars?



The surface of Mars appears to have ancient riverbeds.

More evidence of Ancient Rivers


Sediment


River channel
Clay minerals
Deltas

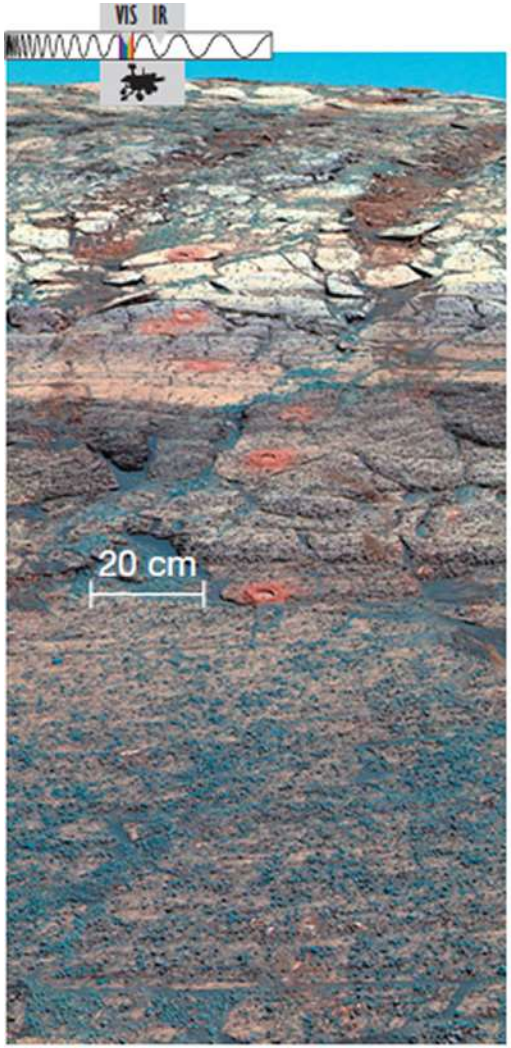
Evidence of Streambeds

Mars

Earth

Clumps of rounded pebbles discovered by the *Curiosity* rover compared with similar formations in Earth streambeds

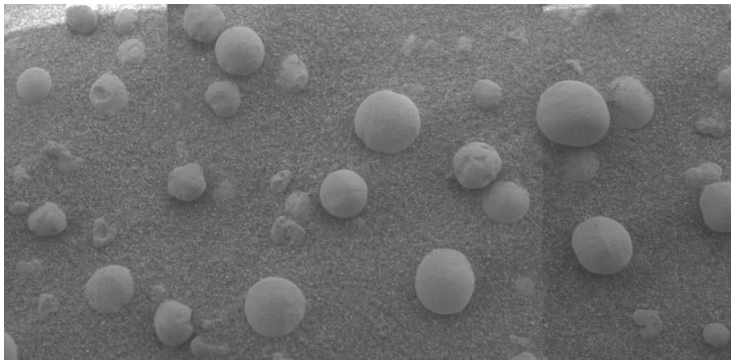
Evidence of “hematite” Blueberries



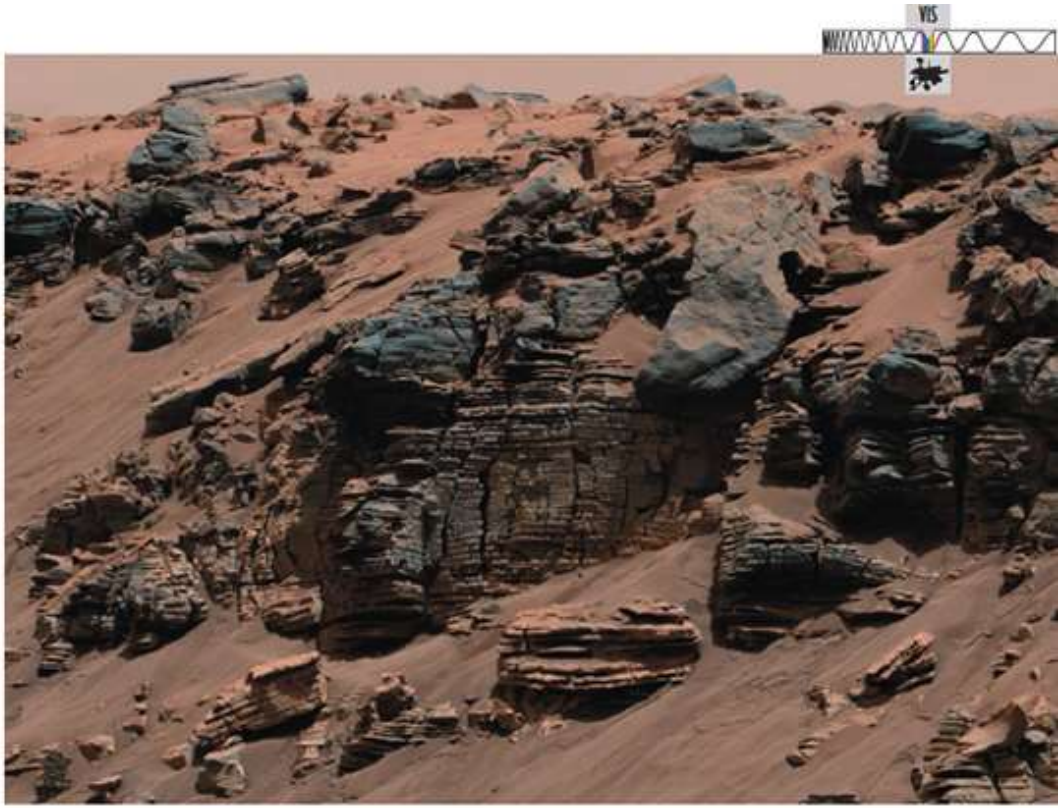
Mars (Endurance Crater)

Earth (northern Arizona)

- 2004 *Opportunity* rover provided strong evidence for abundant liquid water on Mars in the distant past.
- The mineral hematite, typically formed in a salty water environment.



Evidence of Sedimentary Rock Layering



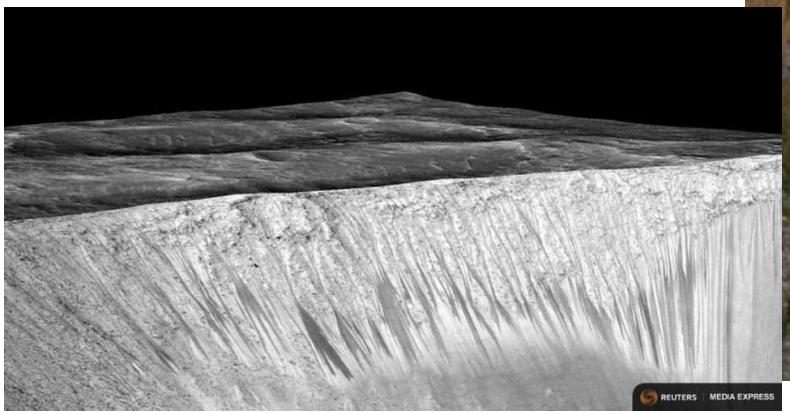
b The even layers of the foreground rocks in this image from *Curiosity* are characteristic of sediment deposited over time in the delta of a river that emptied into a lake.

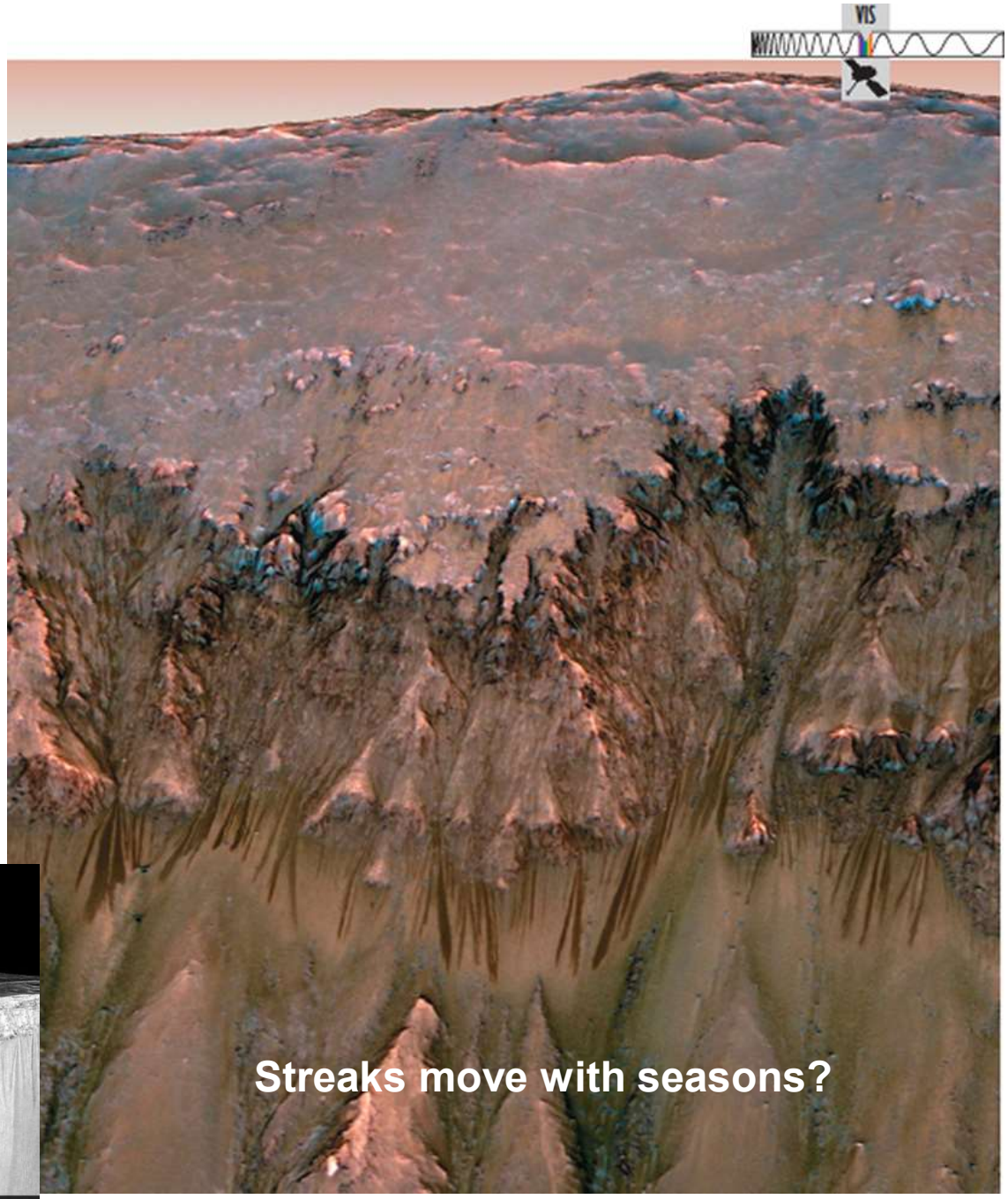
Curiosity also found these layered rocks, characteristic of sedimentation by water.

Evidence of Flowing Water ???

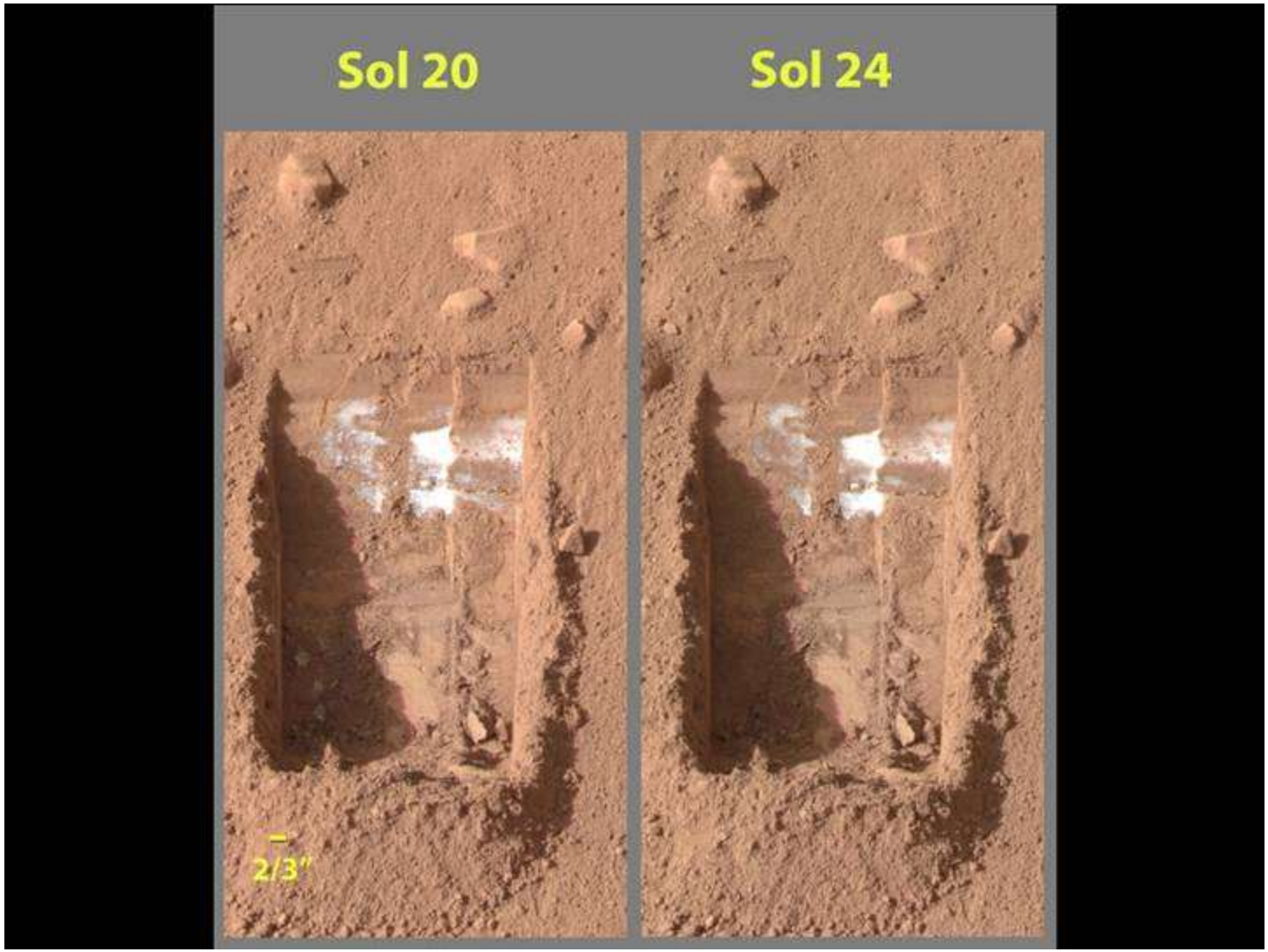
Recent evidence does suggest small-scale flow of salty water at or near the surface—here seen as seasonally changing dark streaks.

Recurring Slope Lineae (RSL)

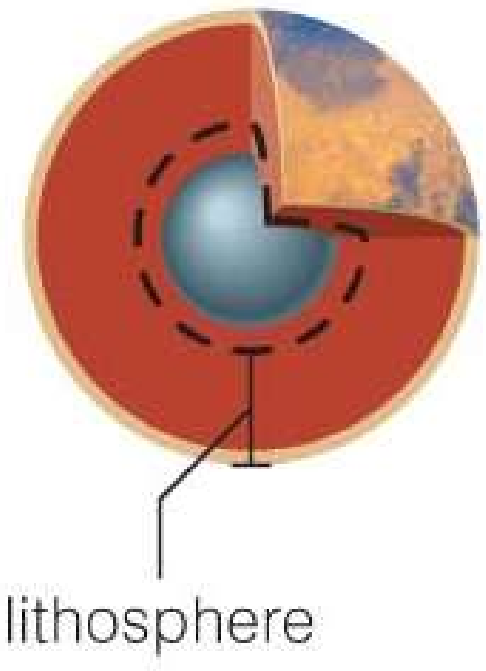




Evidence of Subsurface Water



Why did Mars change?



End of Todays Lecture