

Planetary Geology (Chapter 9)

Part of Chapter 9:
Geology of Mercury, Venus,
Earth, Moon, and Mars

Based on part of Chapter 9

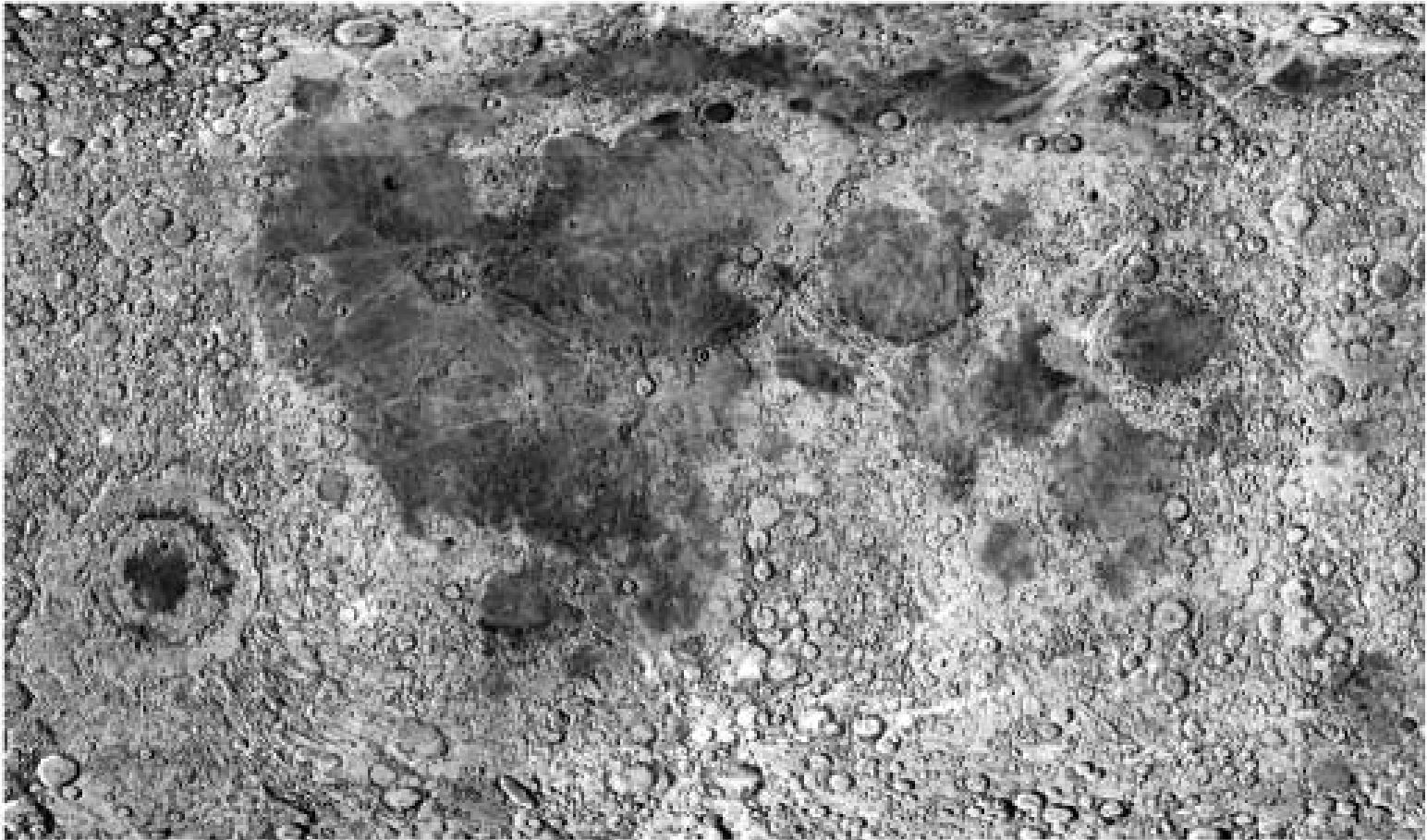
- No subsequent chapters depend on the material in this lecture
- Chapter 7 on “Our Planetary System” will be useful for understanding this chapter. So will the lecture on the first part of this Chapter.

Goals for Learning

- What geological processes shaped Mercury and the Moon?
- What are the main geological features of Mars and has water even flowed on Mars?
- What is the geology of Venus like? How does it compare to Earth's?
- What is plate tectonics?

Moon

What created so many impact craters on the Moon?



What has obliterated impact craters from the dark regions of the Moon?

Fake image of Moon 4 billion years ago



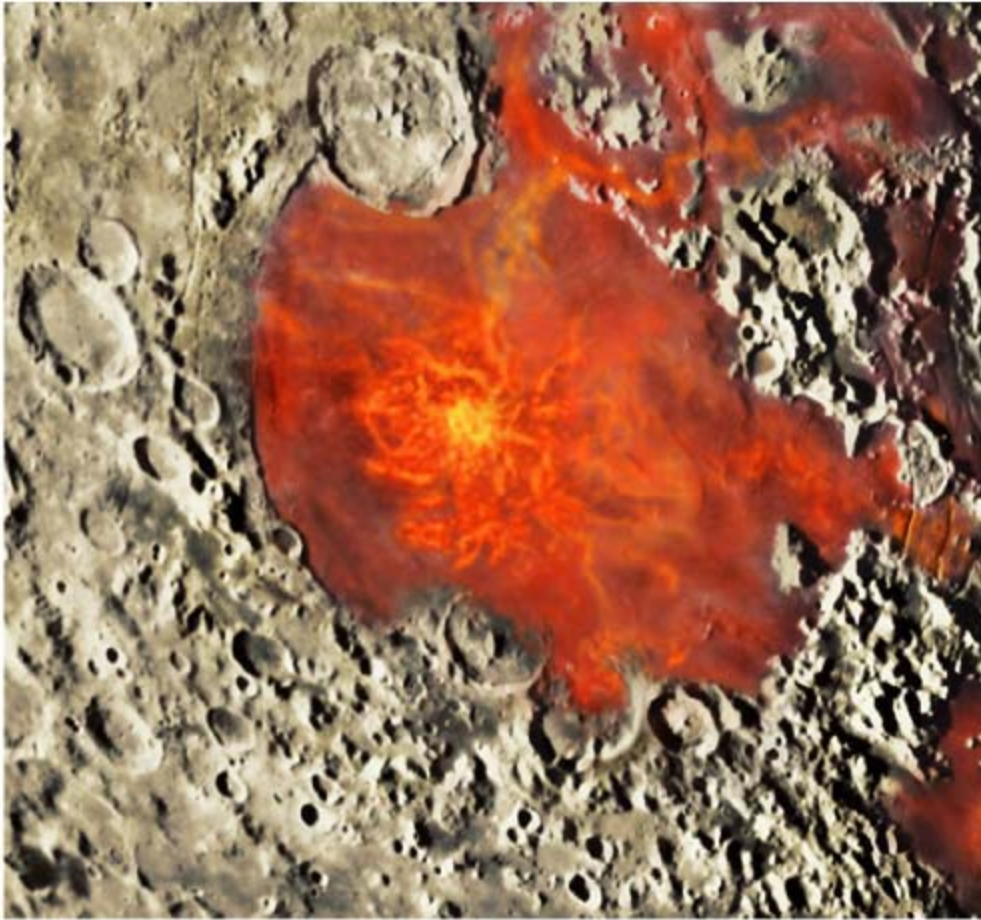
Moon forms, starts to get hit by asteroids
Heavy bombardment in final stages of solar system formation

Interior, which was heated by accretion/differentiation, cools quickly
Probably some volcanism and tectonism early for a short period

Impact cratering continues after they stop, covering the entire surface

Large impacts like this one would have cracked the thick lithosphere

Fake image of Moon 3.5 billion years ago

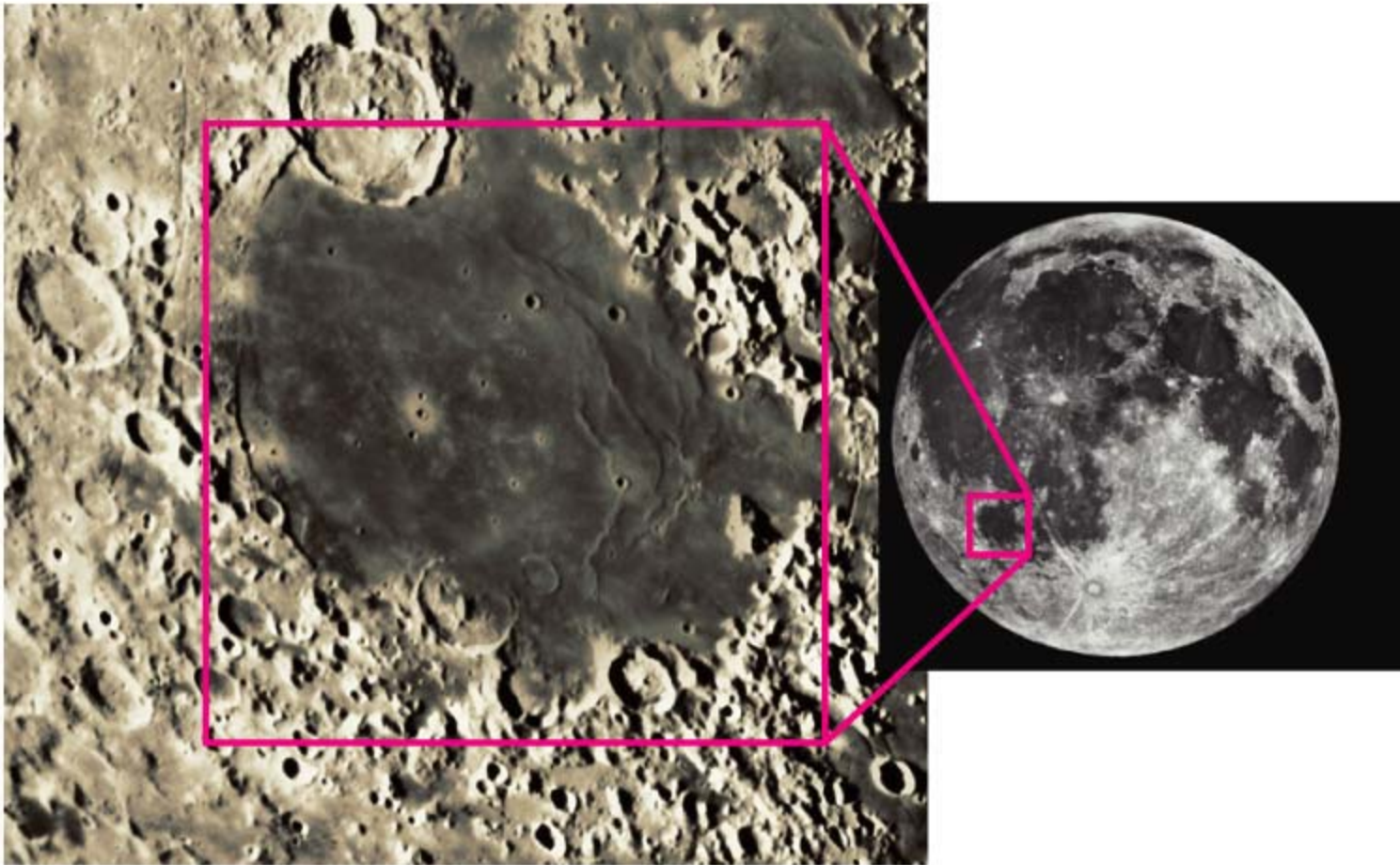


A few hundred million years later, radioactive decay has generated lots of heat inside the Moon

This melts a lot of magma, which flows up through the cracks in the lithosphere and fills up some of the large impact craters

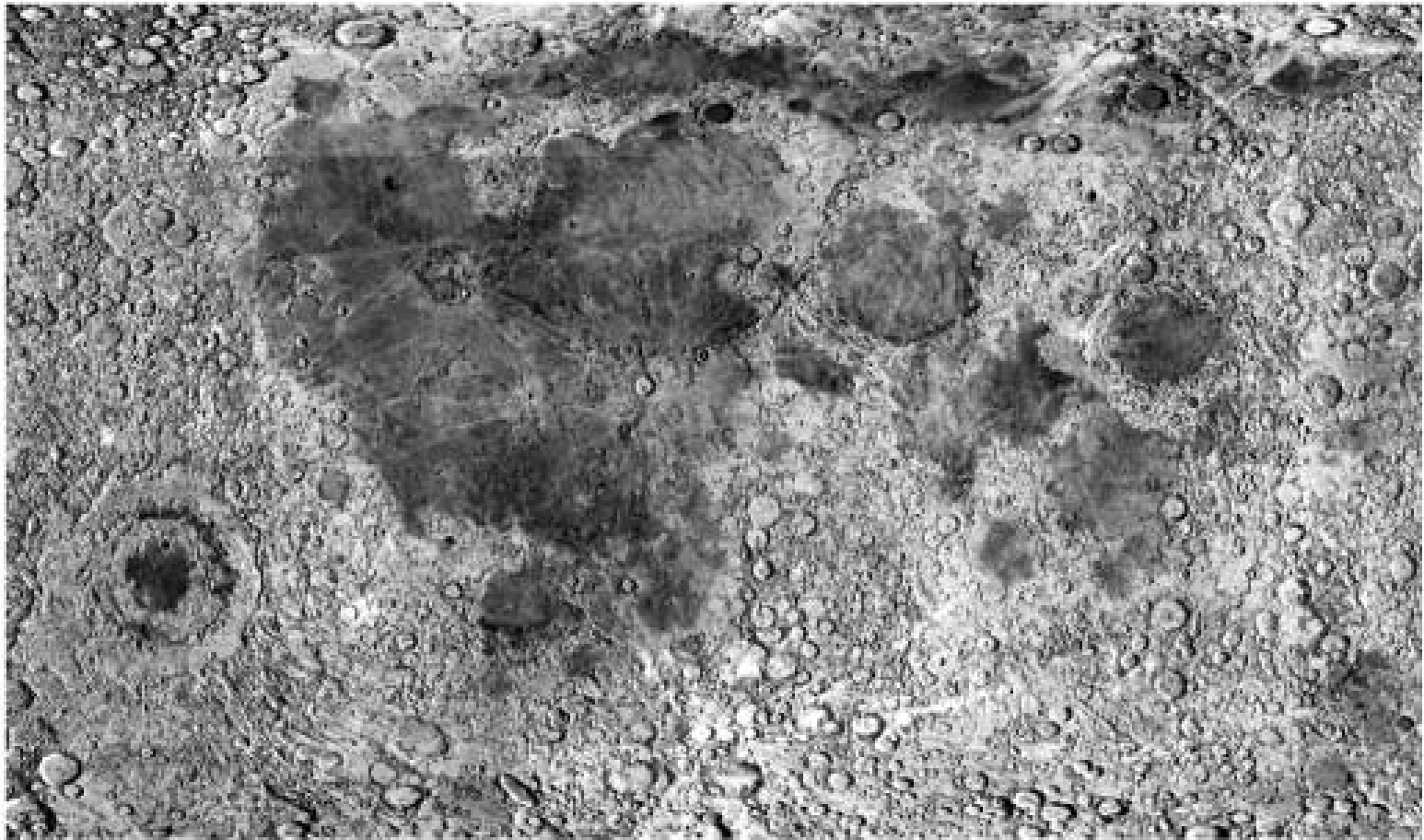
Magma was very thin and runny, because it formed flat volcanic plains

Real image of Moon today



These flat, dark regions are called lunar maria
Light, cratered regions are called lunar highlands

Dark colour due to the chemical composition of the lava
As lava lake solidified and cooled, a few small tectonic wrinkles formed



Far side



Near side



Far side

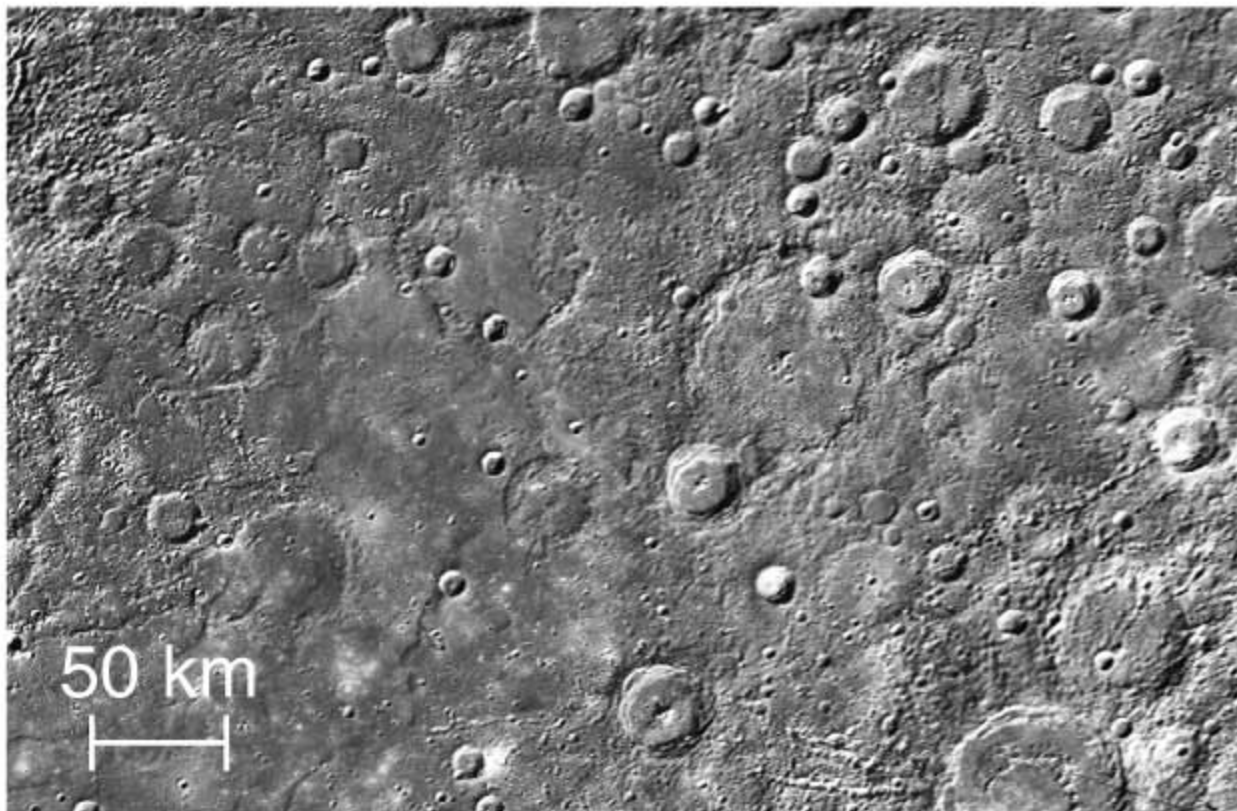
Magma upwelling and the dark maria are concentrated on the near side
The near side is lower than the far side, so magma didn't have as far to rise up

The Moon Today

- Volcanism stopped 3 billion years ago, tectonism shortly afterwards
- No erosion
- Slow sandblasting by small asteroids (micrometeorites) continues today

Mercury

- Lots of craters with smooth plains between the heavily cratered regions
 - Probably just like the Moon



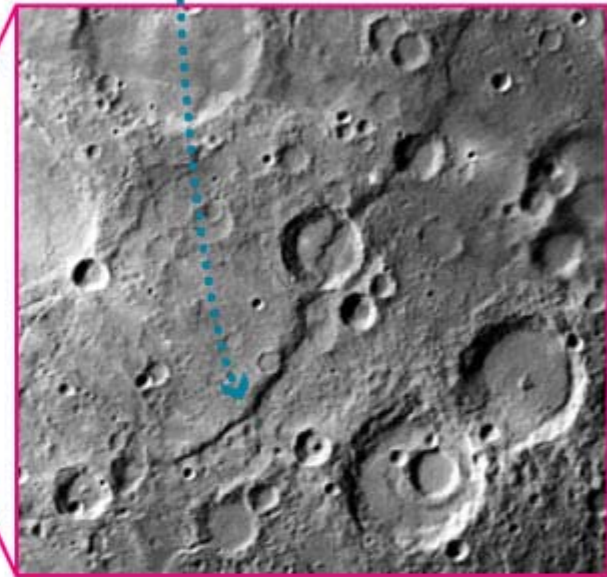
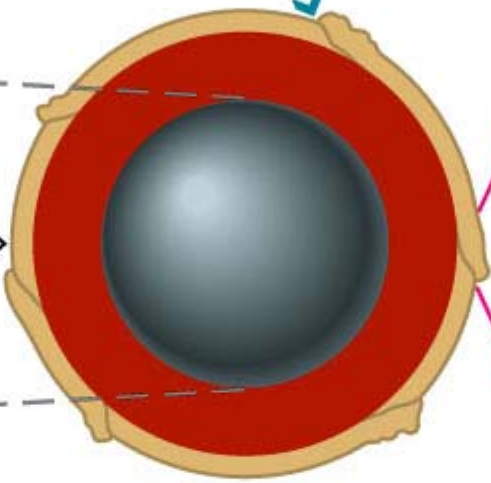
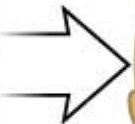
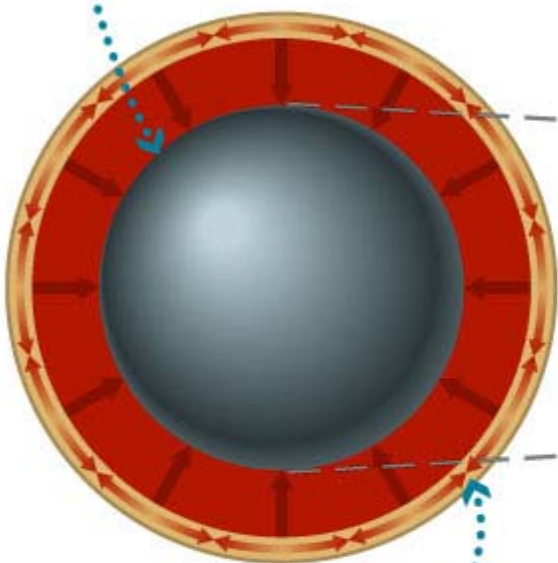
Mercury

- Long (100s of km), tall (3 km) cliffs
 - Lots of tectonic compression
 - Where is the corresponding tectonic stretching?
- Mercury is larger than the Moon (more heat from accretion) and has more iron (more heat from differentiation), so Mercury had a LOT of internal heat when formed
- Iron core was “puffed up” or “inflated” by the heat
- As temperature dropped, core shrank by 20 km
- Mantle and lithosphere shrink with the core
- The surface contracts without needing any balancing extension and large cliffs form

Mercury's core and mantle shrank . . .

Some portions of the crust were forced to slide under others.

Today we see long, steep cliffs created by this crustal movement.



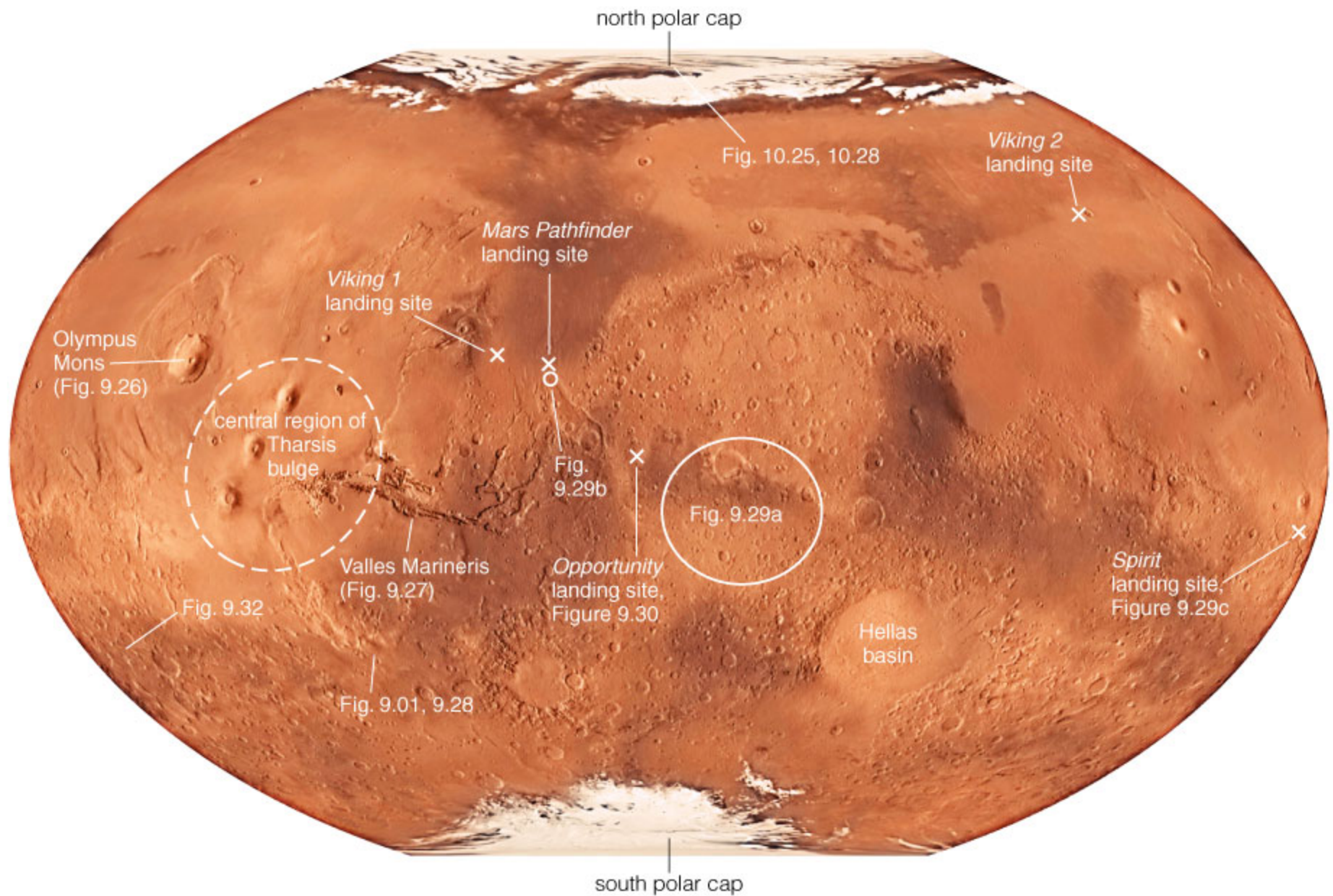
. . . causing Mercury's crust to contract.

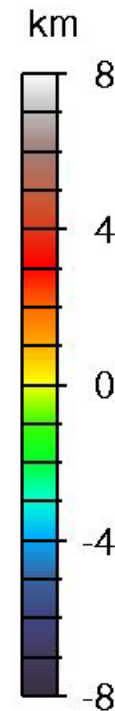
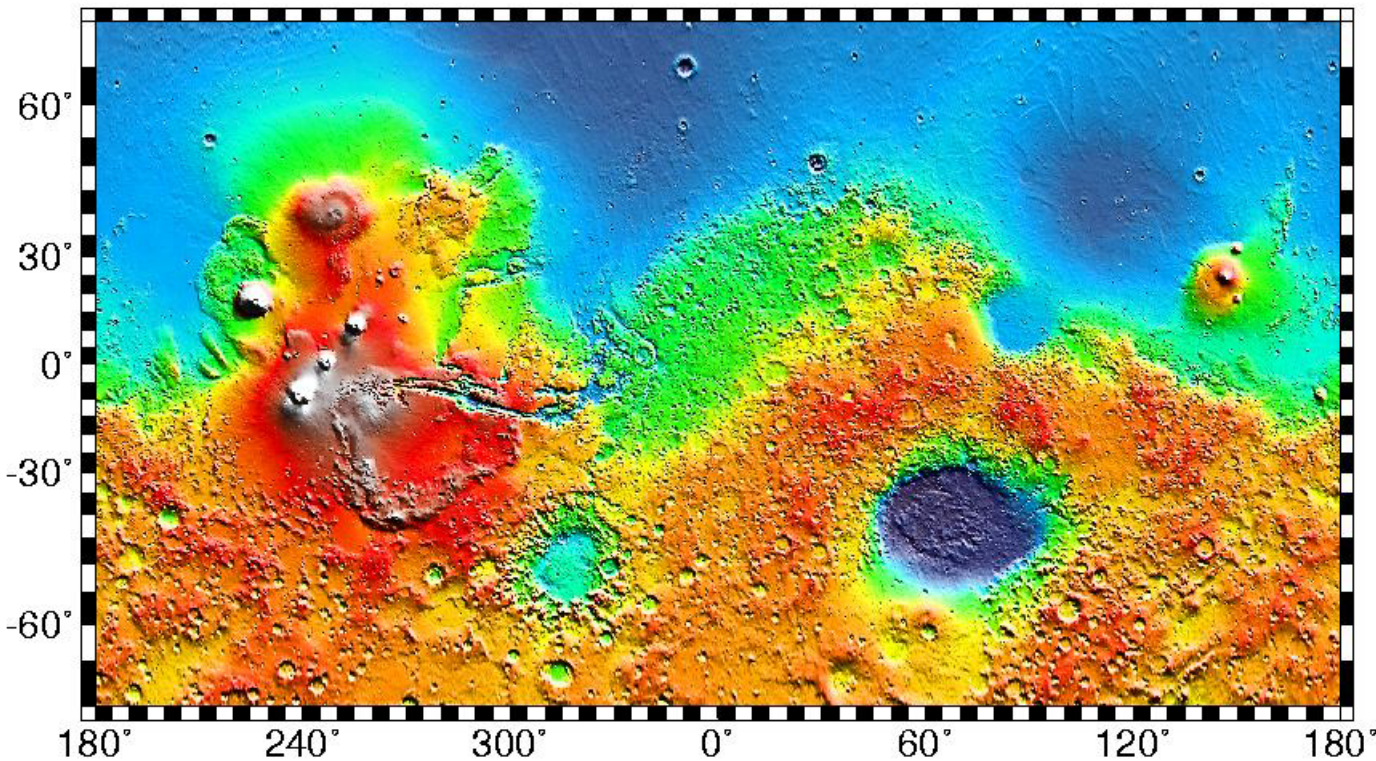
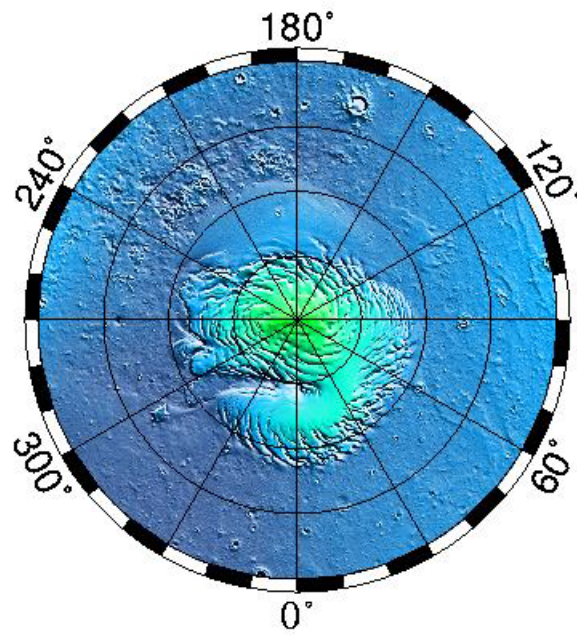
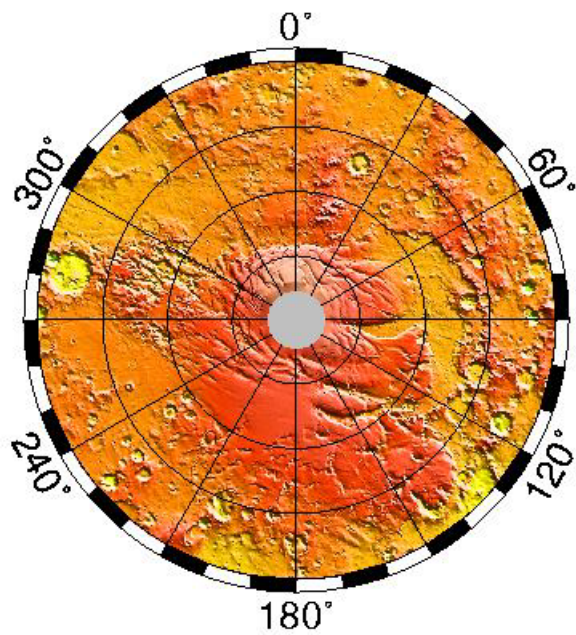
Shrinkage not to scale!

Mars

- Much bigger than Mercury or the Moon
- Much smaller than Venus or Earth
 - Intermediate geological activity
- Has experienced impact cratering, volcanism, tectonism, and erosion

- Water once flowed on Mars in the past





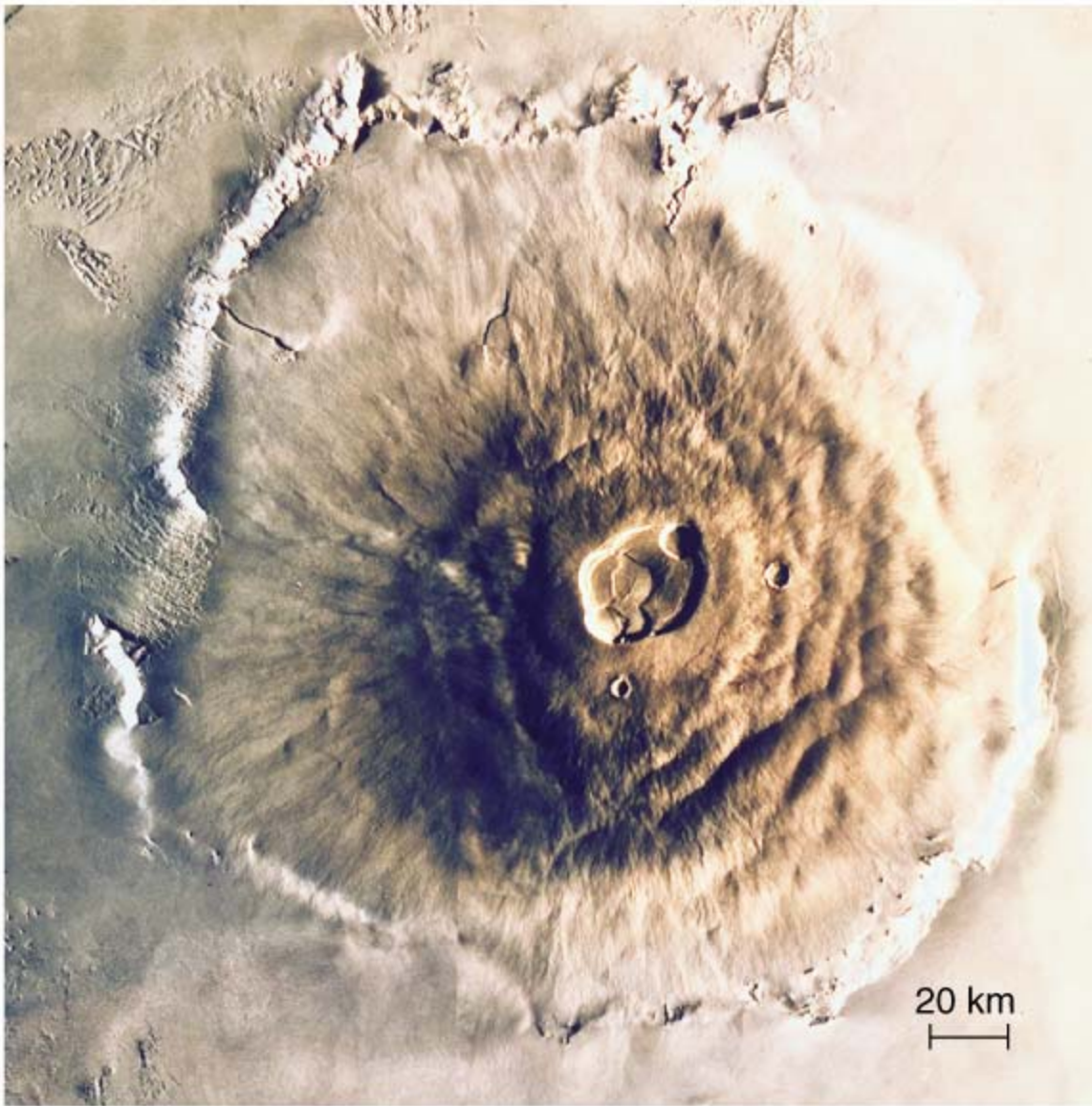
Few impact craters in northern hemisphere

Many impact craters in southern hemisphere

Some very large impact craters

Volcanic resurfacing of the northern plains?

Why is there a difference in height?



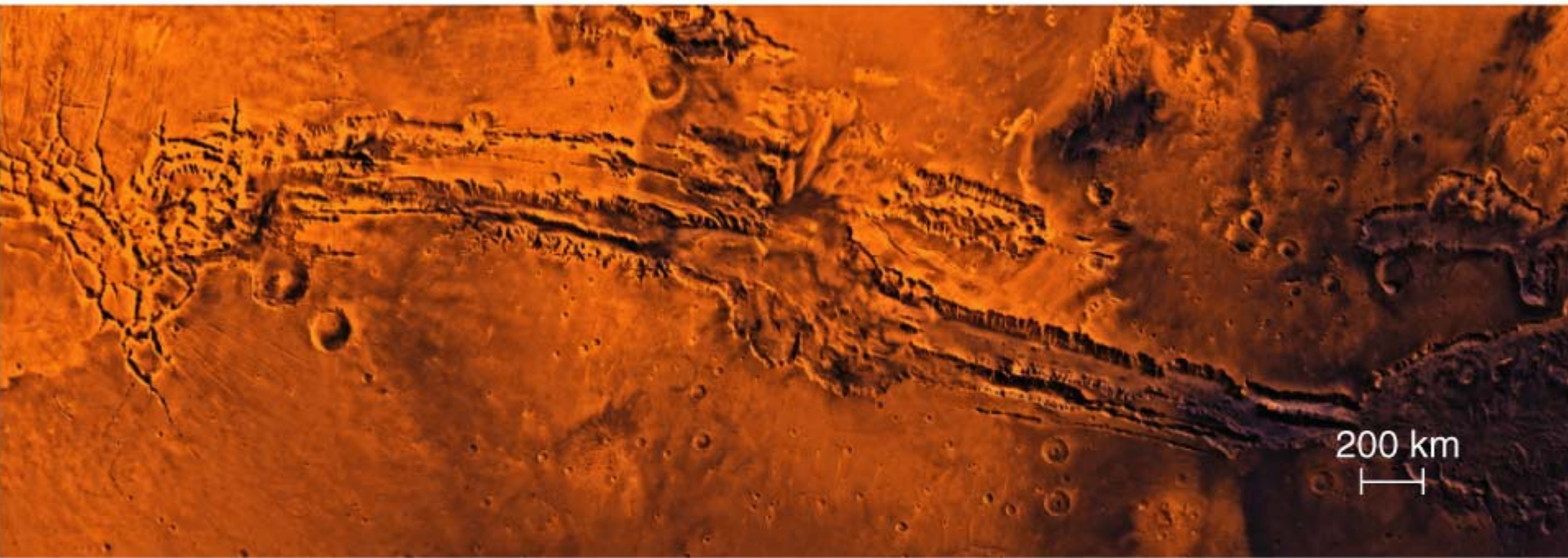
Largest volcano in the solar system

Olympus Mons, 26 km above average surface level

Most volcanism was concentrated in one area (Tharsis Bulge) – why?

It is possible that Mars is still volcanically active today

Mars experienced lots of volcanism early in its history and a lot less in the recent past

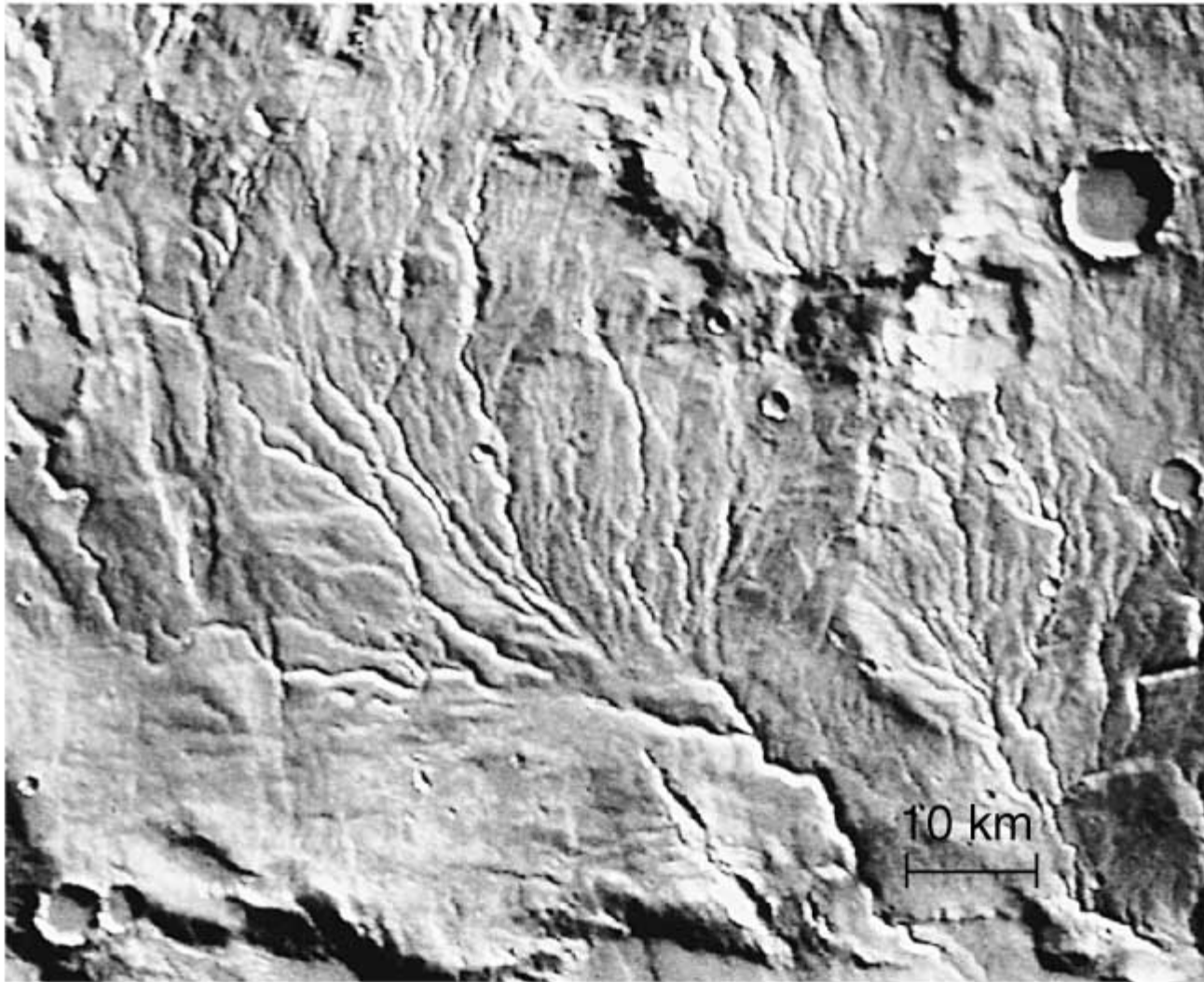


Valles Marineris – as long as the distance from Boston to Los Angeles
Four times deeper than the Grand Canyon

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Tectonism – Lots of cracks and stretching associated with the Tharsis Bulge

Mars doesn't have a global-scale network of tectonic features like Earth does
Did Mars ever experience plate tectonics?



Erosion on Mars

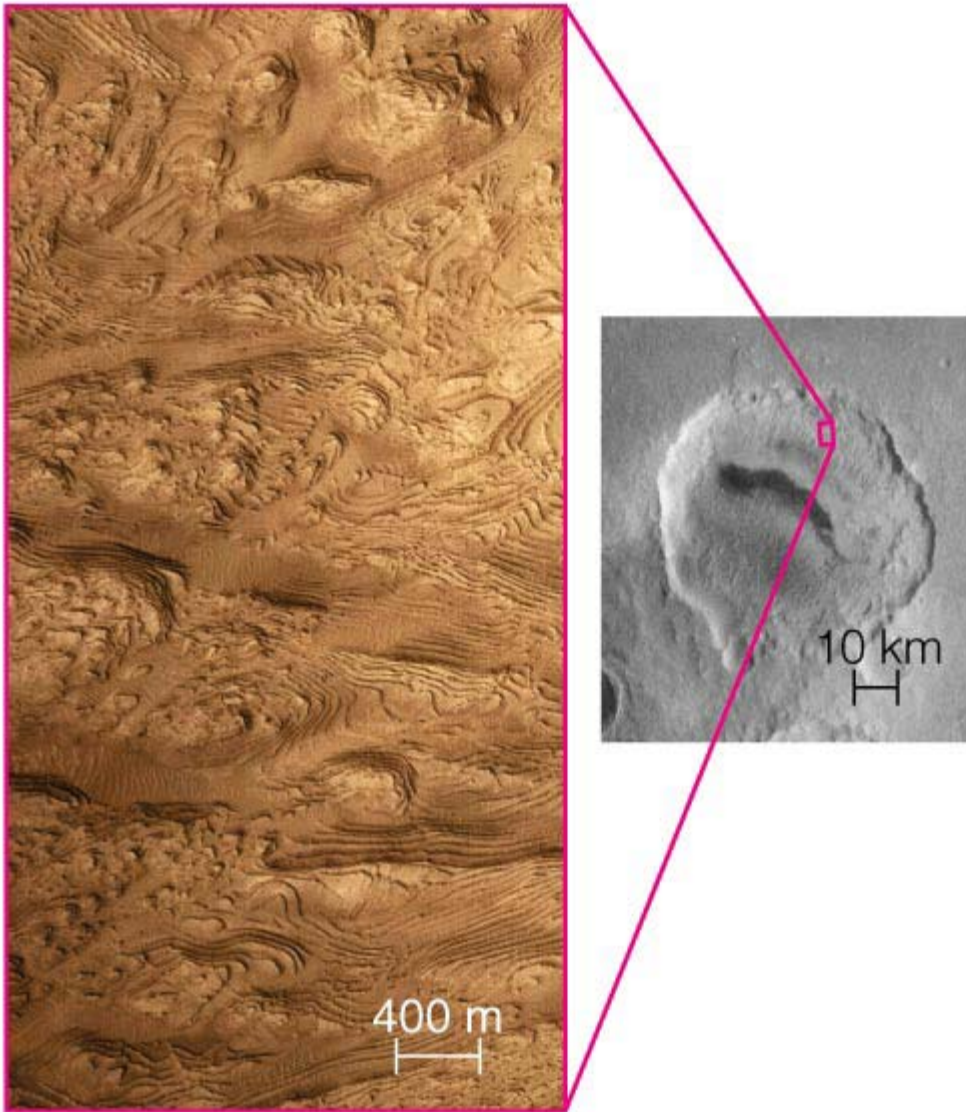
Valley network

Smaller tributaries
merge into the
larger channel
on the lower
right

Dried-up
riverbeds?

Extensive layering

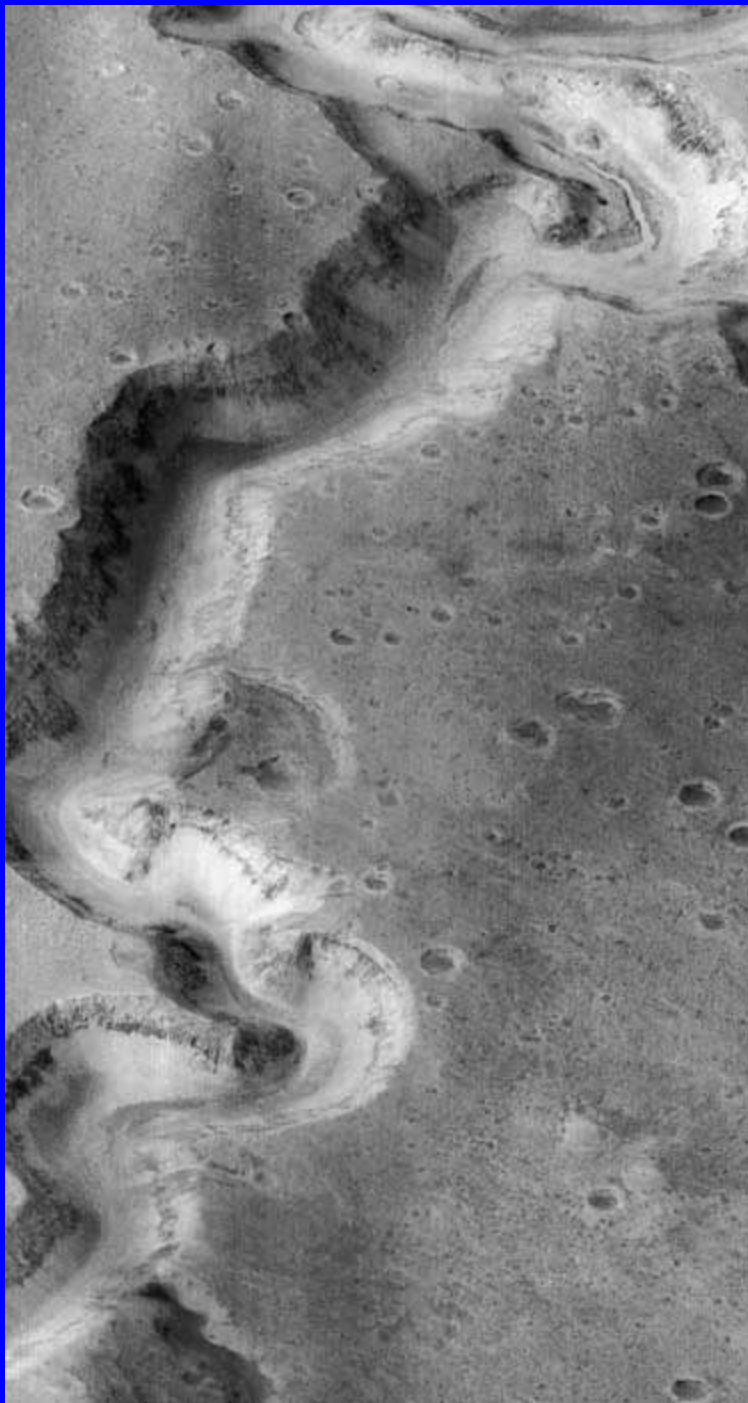
Look like layers of sedimentary rock laid down at a time when the crater was filled with water



Streamlined islands

The flow of a fluid (water?)
has shaped these islands





A river channel within a wider valley

Wet Mars Today?

- Ice at the poles
- Water vapour in the atmosphere
- Buried ice beneath the ground

- Need warmer temperature and greater atmospheric pressures for liquid water to be stable on the surface today
- But there is some evidence for small, occasional amounts of liquid water today



Gullies

Look just like any eroded slope on Earth

Does ice accumulate at the top of these gullies in winter, then melt in spring?

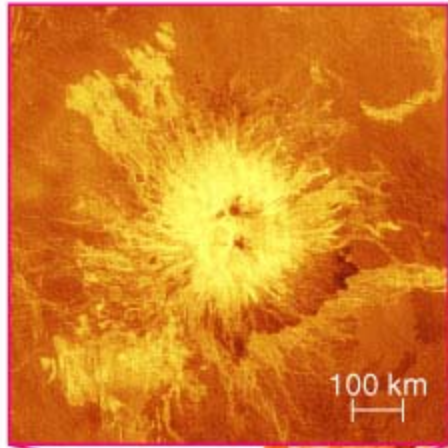
Small-scale means that they must be geologically recent

Much remains to be discovered...

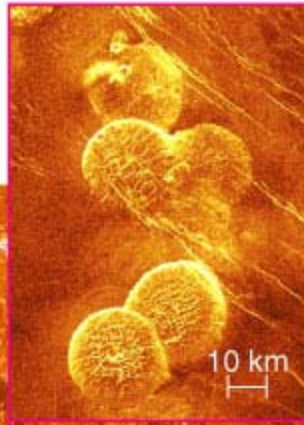
Venus

- Same size as Earth, but very different
- Earth's evil twin?
- Visible light can't penetrate its thick clouds, but radar can
- Volcanism and tectonism are common
- Impact cratering is relatively rare
 - No small craters due to thick atmosphere
- Erosion is rare
 - Too hot for rain or snow
 - Slow rotation means that surface winds are slow

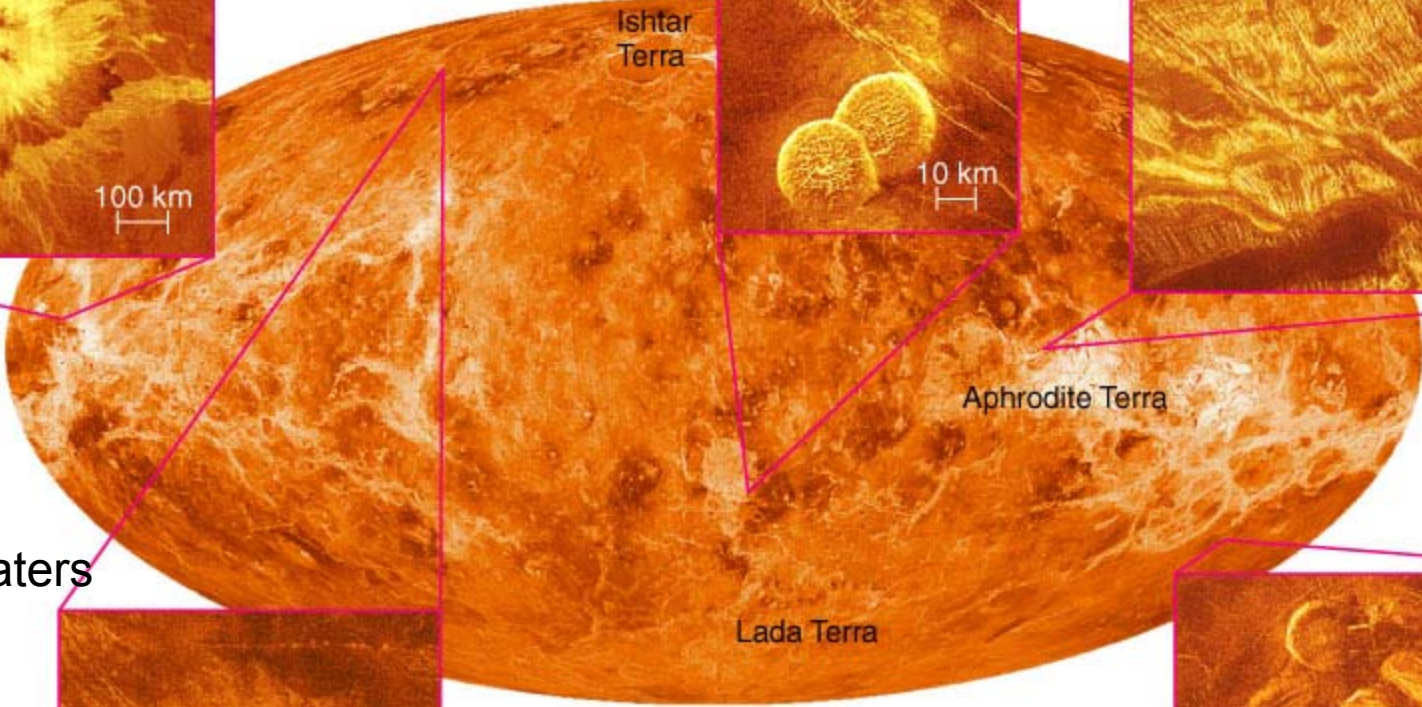
Shield volcanoes



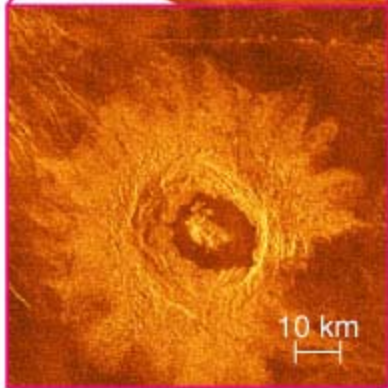
Steep stratovolcanoes Thick lava



Tectonic forces have fractured and twisted the crust

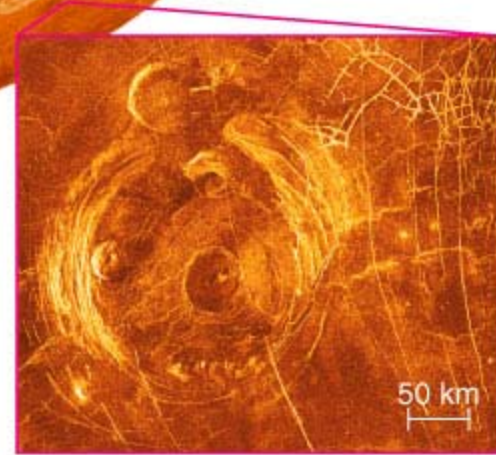


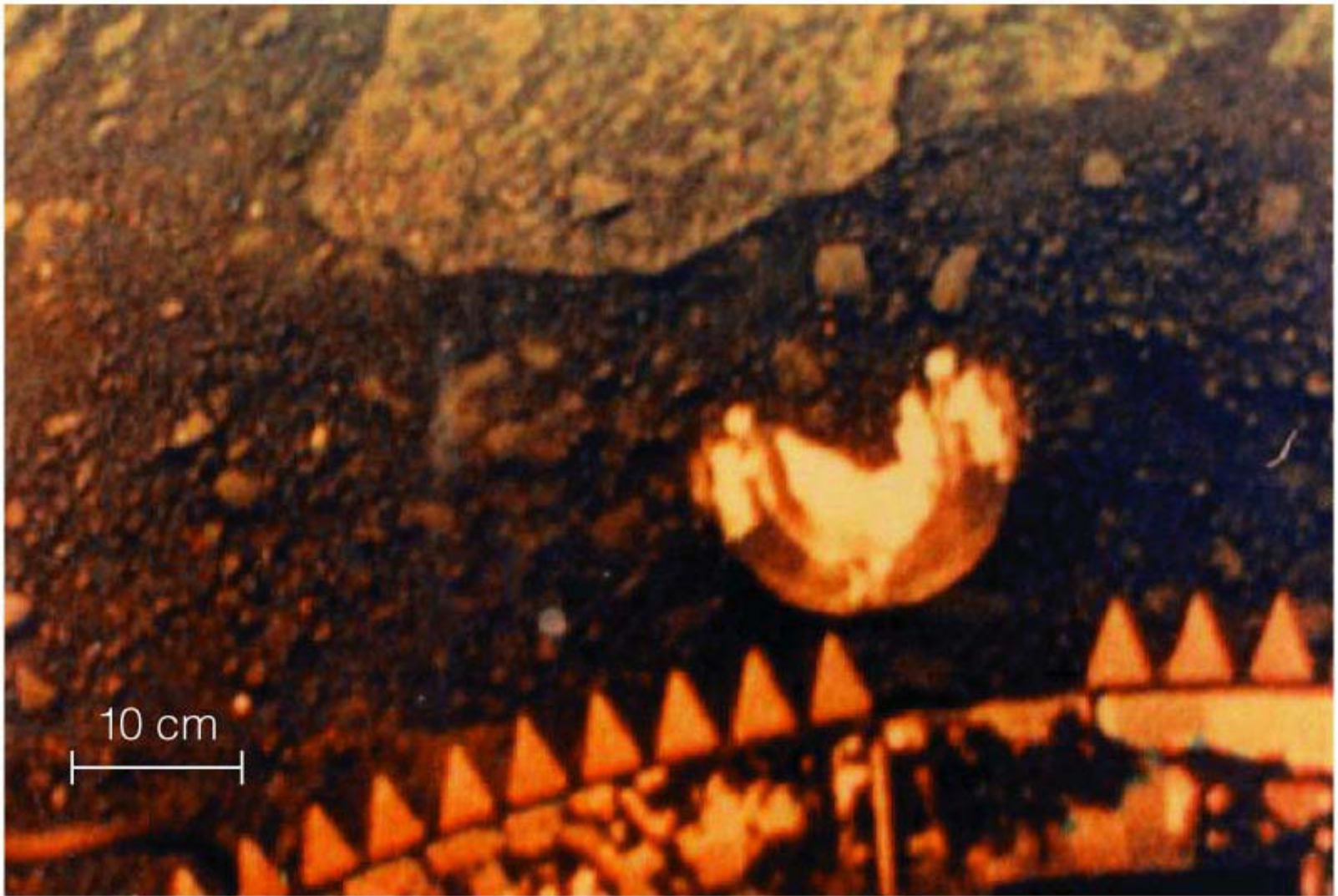
Impact craters Rare and uniformly distributed



750 My old surface

Round corona made by a mantle plume Dotted with small volcanoes and surrounded by marks of tectonic forces





The surface of Venus – lots of flat, volcanic rocks

Venus Global Resurfacing

- Crater counting suggests that the entire surface of Venus was wiped clean about 750 million years ago
- On Earth, different regions have different ages
- Maybe massive volcanic flows, maybe tectonic activity
- Did Venus ever have plate tectonics?
- Volcanism is probably still active on Venus

Impact cratering important or irrelevant for...

- Moon
- Mercury
- Mars
- Venus

Volcanism important or irrelevant for...

- Moon
- Mercury
- Mars
- Venus

Tectonism important or irrelevant for...

- Moon
- Mercury
- Mars
- Venus

Erosion important or irrelevant for...

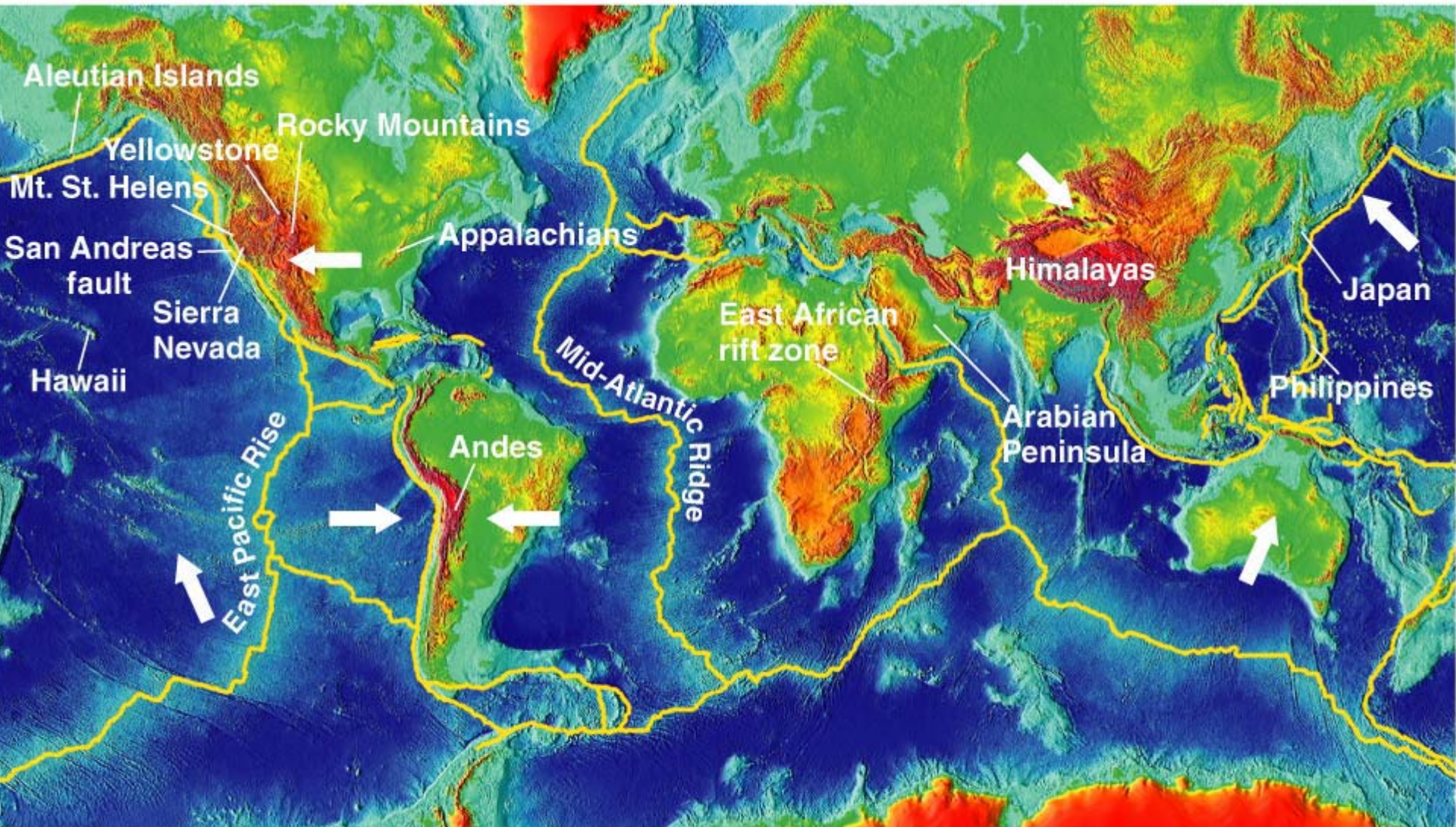
- Moon
- Mercury
- Mars
- Venus

Earth's Unique Geology

- Still geologically active
- Lots of erosion/volcanism/tectonism explain why impact craters are rare
- Thick atmosphere, rapid rotation, and existence of vapour/liquid/solid water explain powerful erosion
- Earth has a unique form of tectonic activity called plate tectonics
 - This is immensely important for geology, climate, and biology

Understand Plate Tectonics!

- Plate tectonics is to geology what
 - DNA or evolution is to biology
 - Quantum theory is to physics
 - The atom is to chemistry
- The development of plate tectonics in the 1960s revolutionized geology and geophysics



Earth's lithosphere is fractured into a small number of large plates
 These move relative to each other in response to mantle convection

Plates can slide past other plates
 Plates can slide over other plates

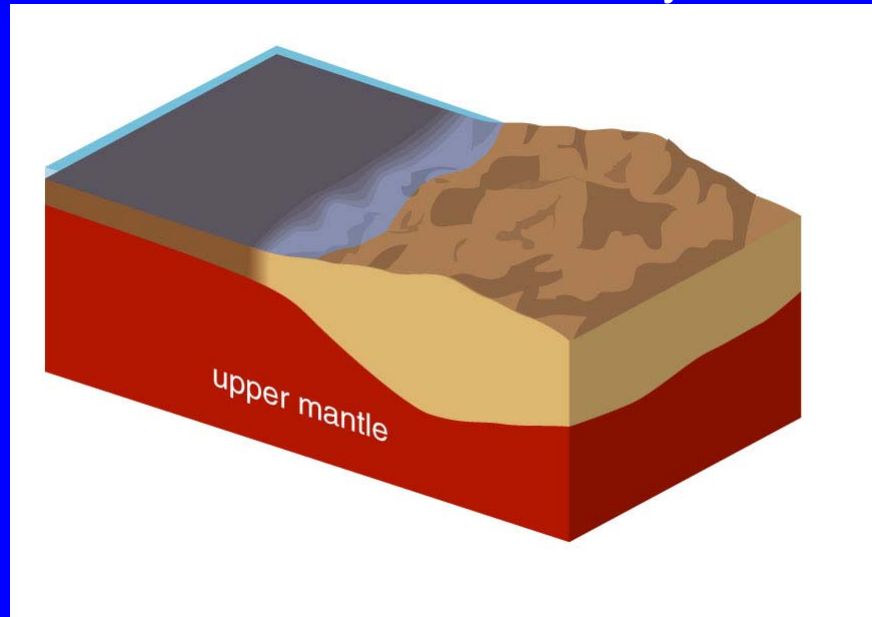
Evidence for Plate Tectonics



- Volcanoes are concentrated on long, narrow bands – plate boundaries
- Eruption of lava at mid-ocean ridges, which pushes apart the existing seafloor
- Similar rock types, fossils, and shorelines in South America and Africa

Seafloor Crust and Continental Crust

Young, thin (5-10 km), high density seafloor crust (often basalt rock)
Basalt is a runny lava, flows out easily from mid-ocean ridges
Seafloor crustal rocks are <200 million years old



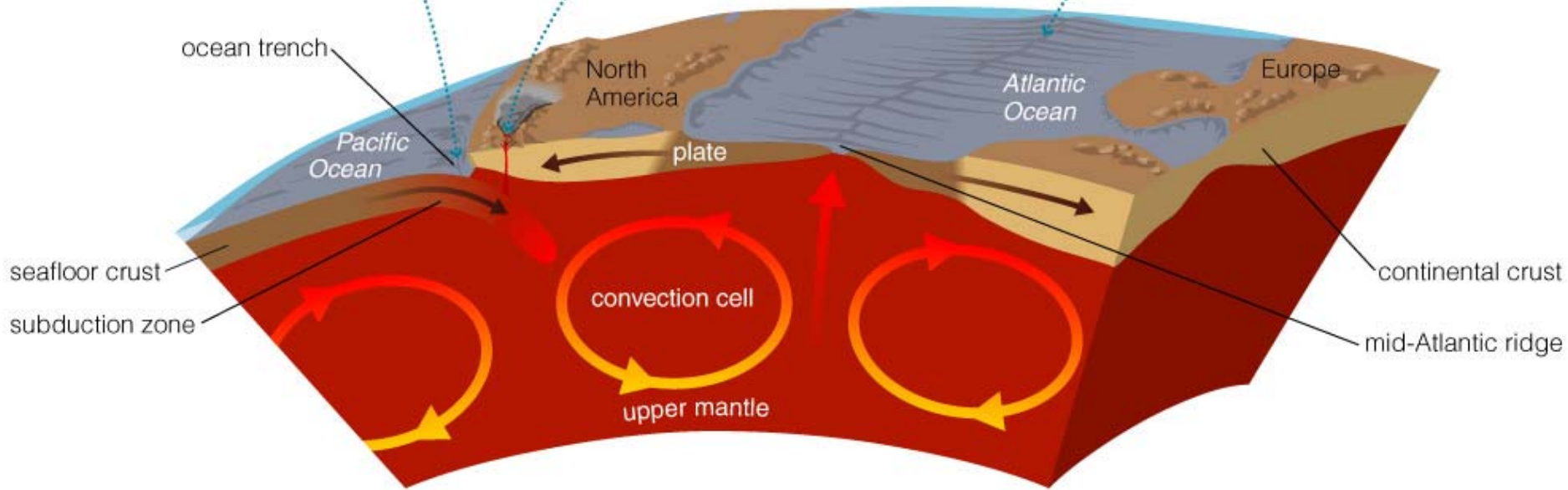
Old, thick (20-70 km), low density continental crust (often granite rock)
Continental crustal rocks have a wide range of ages, some 4 billion years old

New seafloor crust is continually formed at sites of seafloor spreading
Continents have gradually built up over time

Subduction occurs at ocean trenches, where dense seafloor crust pushes under less dense continental crust, thereby returning seafloor crust to the mantle.

The subducting seafloor crust may partially melt, with low-density material melting first and erupting from volcanoes as new continental crust.

New seafloor crust is created by eruptions at mid-ocean ridges, where plates spread apart.

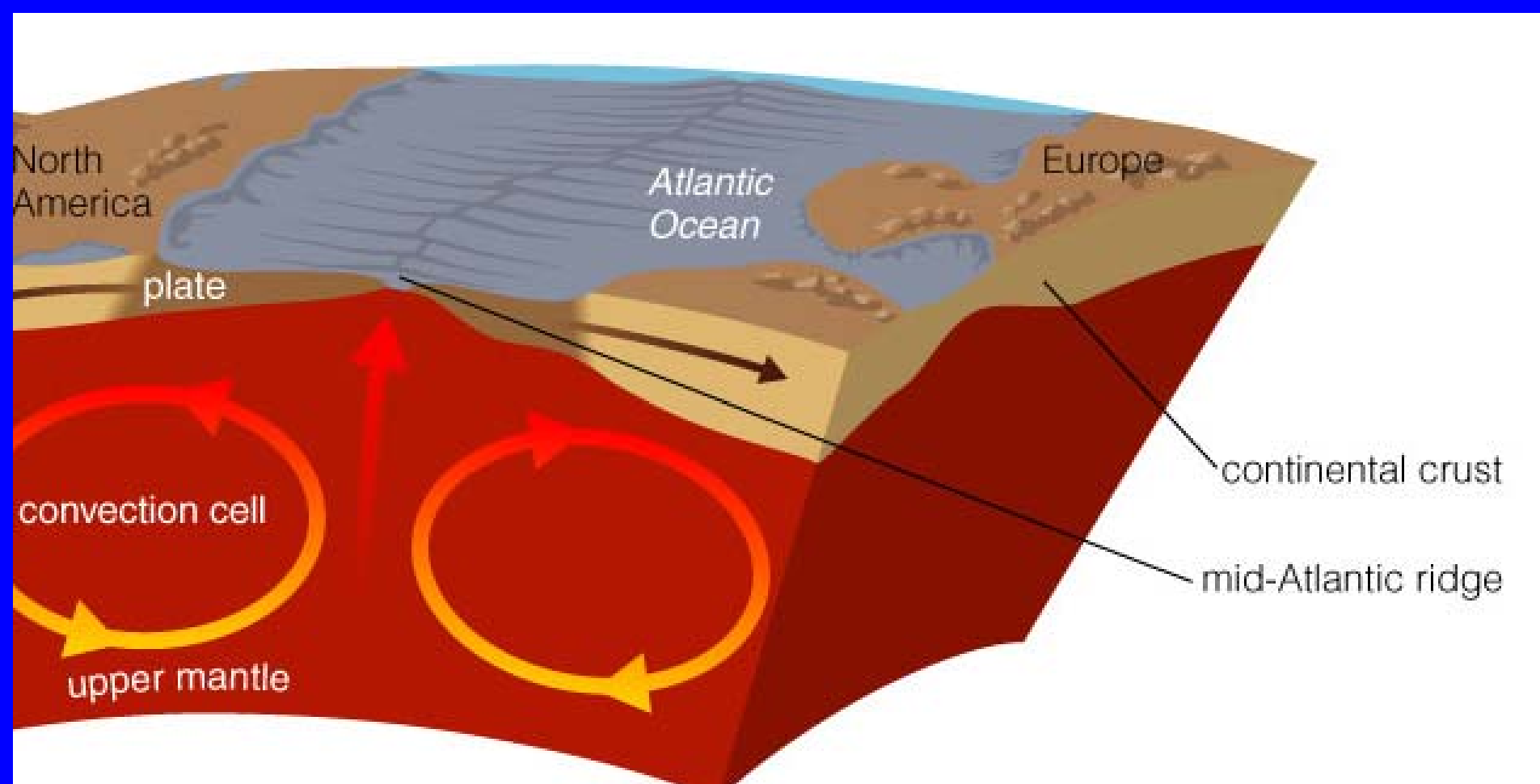


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New seafloor crust is created at mid-ocean ridges where plates spread apart

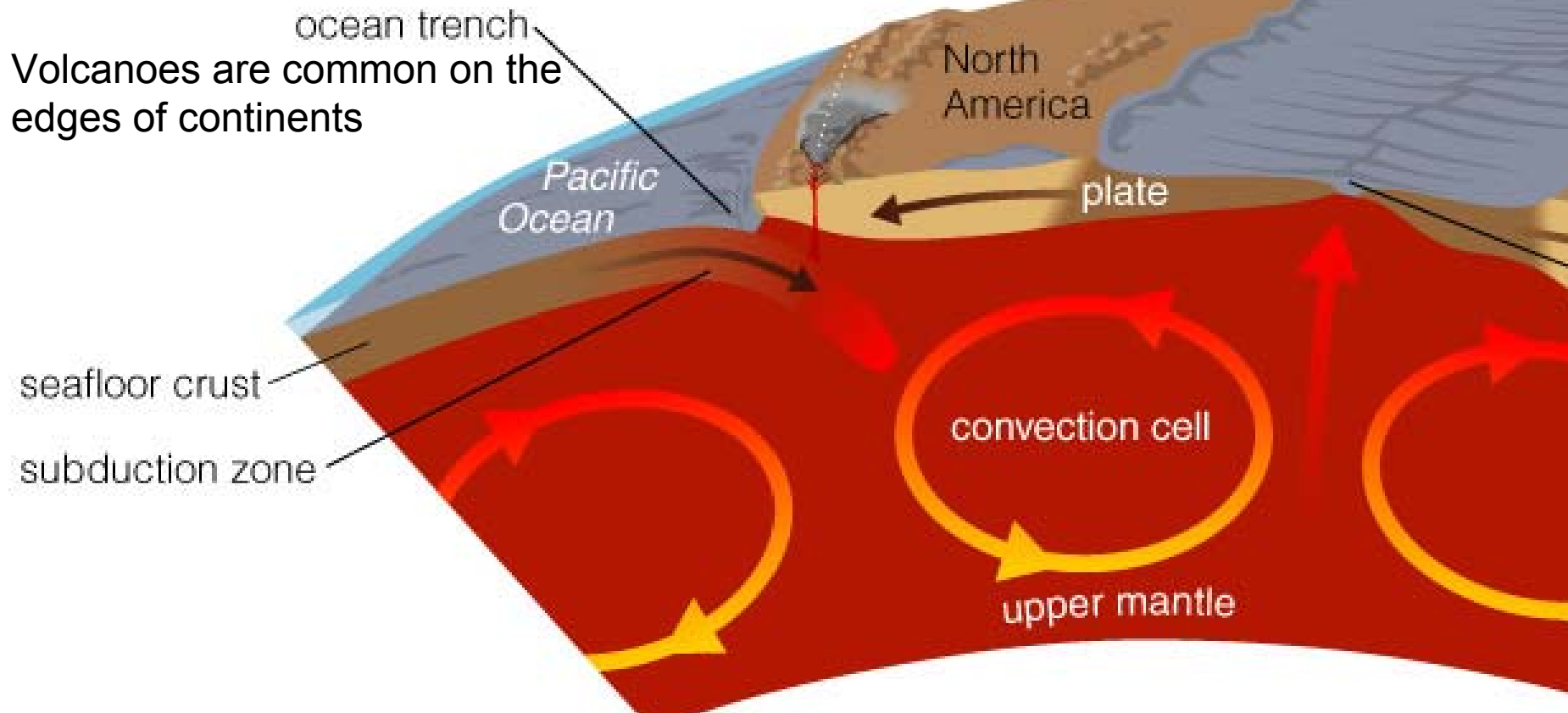
Seafloor crust is destroyed at subduction zones (ocean trenches) where dense seafloor crust pushes under less dense continental crust, thereby returning seafloor crust to the mantle

Plates also slip sideways past each other (discussed later)



2 km² of new seafloor crust is created each year at mid-ocean ridges, consistent with the <200 million year age of seafloor crust. This pushes the far edges of seafloor crust outwards from the mid-ocean ridge at speeds of a few cm per year

Seafloor crust is pushed along by the formation of new seafloor crust



When a dense plate of sea floor crust meets a less dense plate of continental crust, it slides beneath the continental crust

The sea floor crust heats up as it descends and partially melts when it reaches a certain depth. This molten rock can rise upwards, erupting as lava from stratovolcanoes. The lowest density materials in the sea floor crust are the ones that melt, so the lava (which slowly makes the continental crust) is less dense than the sea floor crust

Sea floor crust is pulled along by the descent of old sea floor crust (gravity)

Describe some differences
between seafloor crust and
continental crust

How does plate tectonics explain
each of those differences?

Crustal Recycling

- Earth has two types of crustal rock (basic mantle stuff, basalt, and more processed stuff, granite), whereas the other terrestrial worlds just have basalt
- Earth has stratovolcanoes, made from thick lava that will solidify into granite
- Very efficient at removing heat from interior

Building Up Continents

- Continental crust accumulates and is rarely destroyed. Earth had smaller continents billions of years ago.
- Piling up of continental crust from volcanoes near subduction zones is complicated by
 - tectonic forces that create mountains and valleys
 - erosion that creates sediment, which eventually solidifies into sedimentary rocks

volcanic and tectonic mountains
made over subduction zones

sediments deposited in ancient
seas, later turned to rock

ancient continental
crust, heavily eroded



former Pacific islands
scraped onto continent
during subduction

deep sedimentary layers
formed by erosion of
continent

mountains formed by
repeated collisions with
other continents

low density, didn't subduct

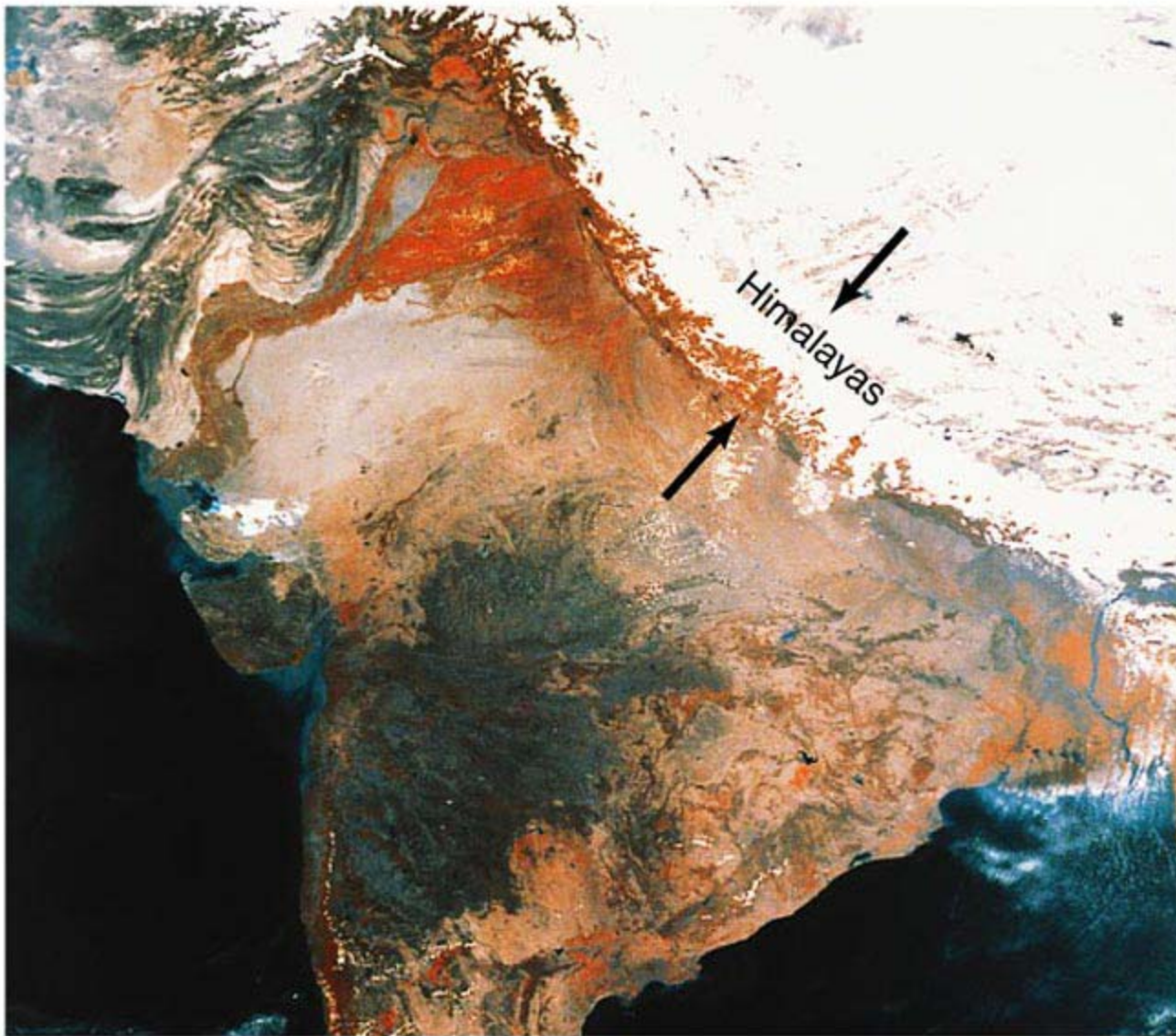
Aleutians -> Japan -> continent

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Sierra Nevada
and Appalachian
mountains used
to be much taller,
Great Plains used
to be shallow seas

Sediment was
eroded from the
mountains into
the shallow seas

The seas filled up
and the sediment
turned into rock



Himalayas are the tallest place on Earth

Not just the mountain peaks, but the whole area is at a very high elevation, thousands of metres

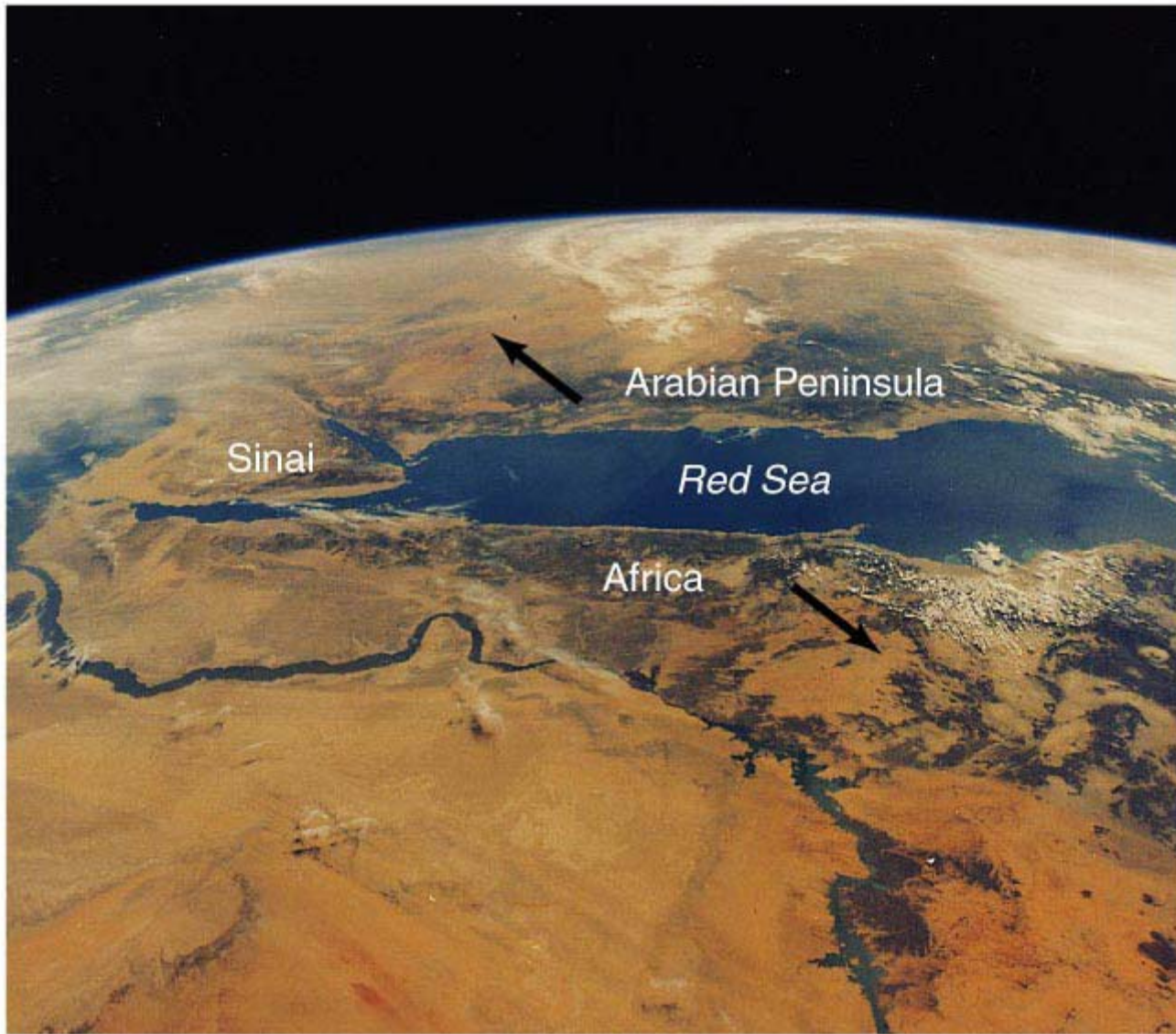
Indian subcontinent crashed into Asia and continues to move north

The Himalayas are still rising

Types of Plate Interactions

- Seafloor crust pulling apart
- Seafloor and continental crust colliding
- Continental and continental crust colliding

- Continental crust pulling apart
- Plates moving sideways past each other
- Plus some others we will ignore today



Continental plates pull apart, the crust thins, and deep rift valleys form

Here the rift valley between Africa and Arabia is filled with water – the Red Sea

The rift extends into Africa:
the East African Great Rift Valley

Ethiopia, Kenya,
Tanzania

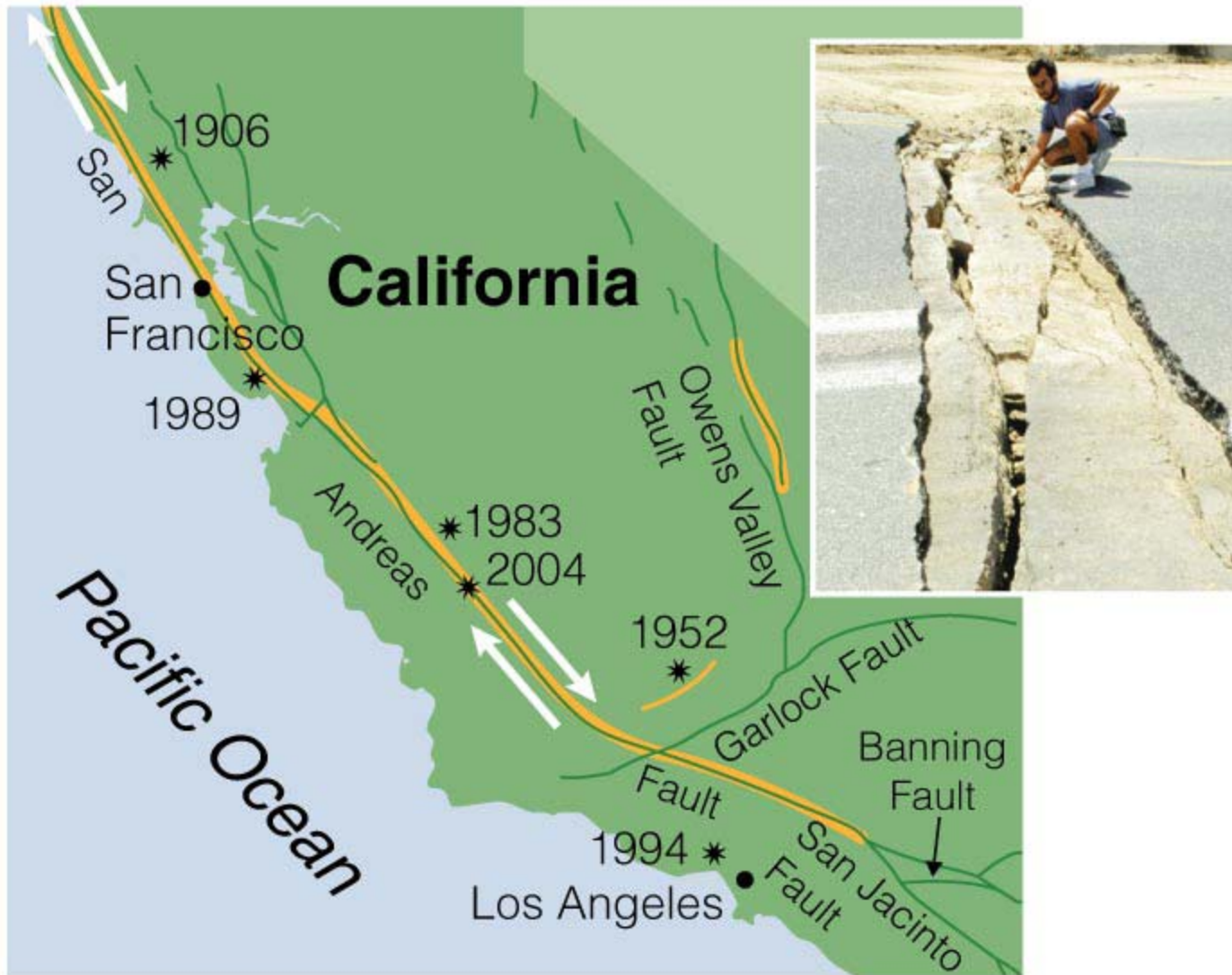


Plate boundaries where plates slip sideways past each other are called "faults"

San Andreas Fault

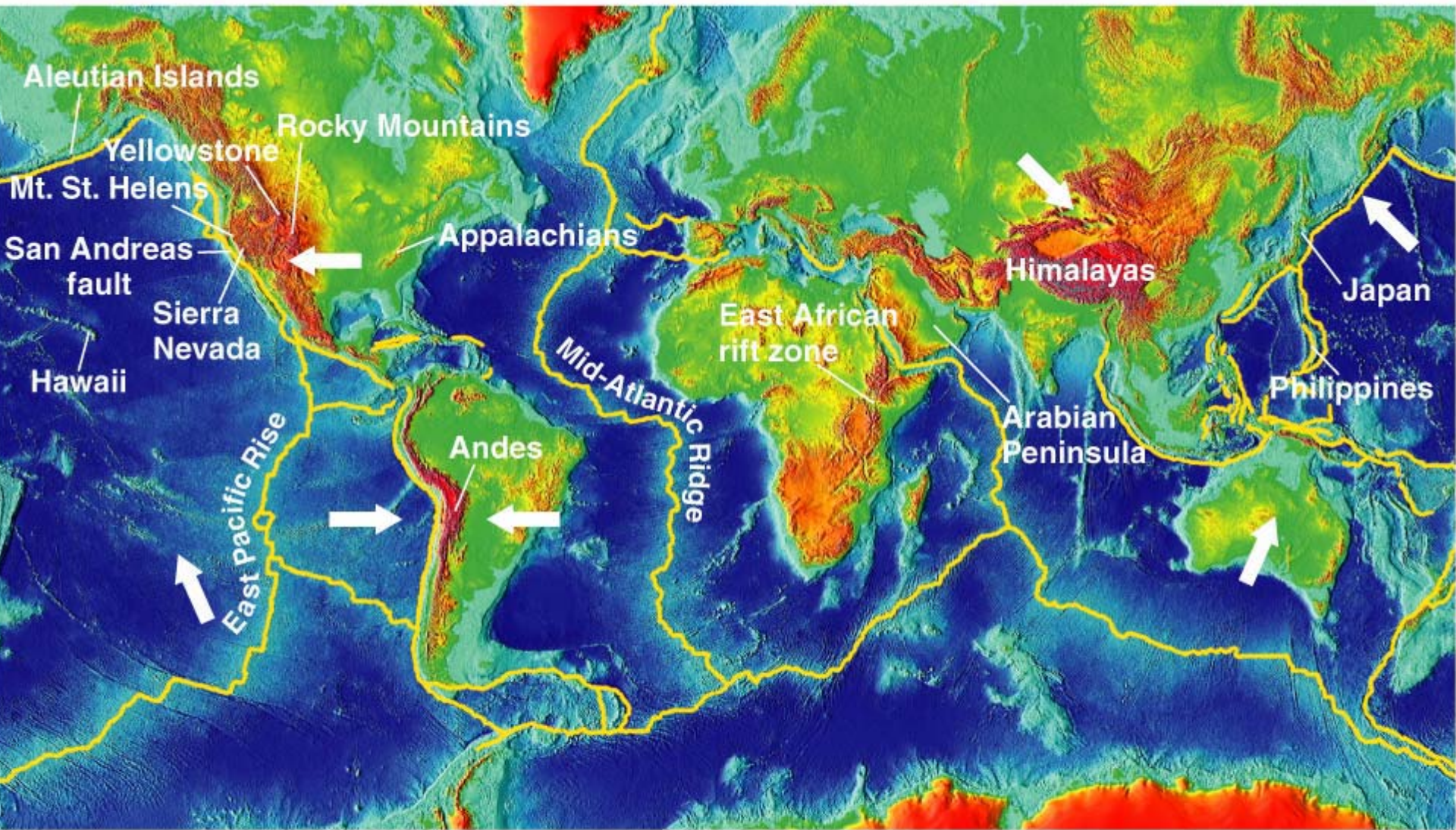
Plate edges do not slide smoothly at a few cm per year

Instead, stay still for a long time, then move a few metres in seconds

Earthquake

Where on Earth can you find plate boundaries?

- Japan?
- Africa?
- South America?
- West coast of USA?
- Europe?
- Antarctica?
- In the oceans?





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City of Bam, Iran
Major earthquake in 2004 killed 40000 people



Midway: island eroded down to sea level

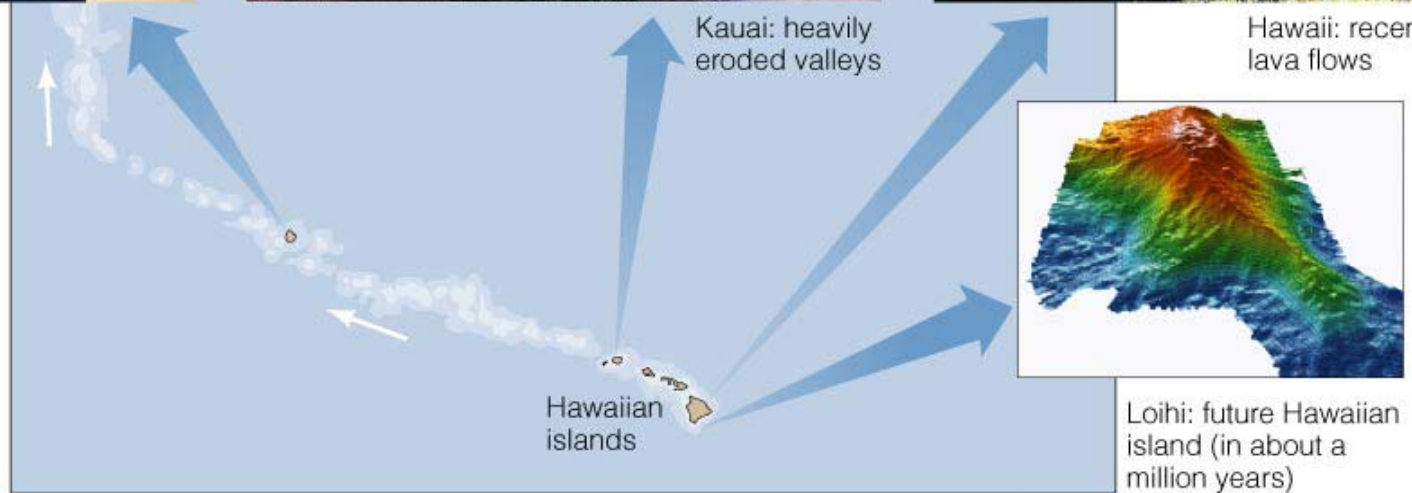


Kauai: heavily eroded valleys



Hawaii: recent lava flows

Hot Spots



Not all volcanoes occur at plate boundaries

A plume of hot mantle material may rise upwards in the centre of a plate, causing a “hot spot”

Magma from the hot plume steadily erupts onto the surface above the hot spot

As the plate above moves, the position of the hot spot appears to shift

Continents have moved
Antarctica was not always cold

200 million
years ago

120 million
years ago

present

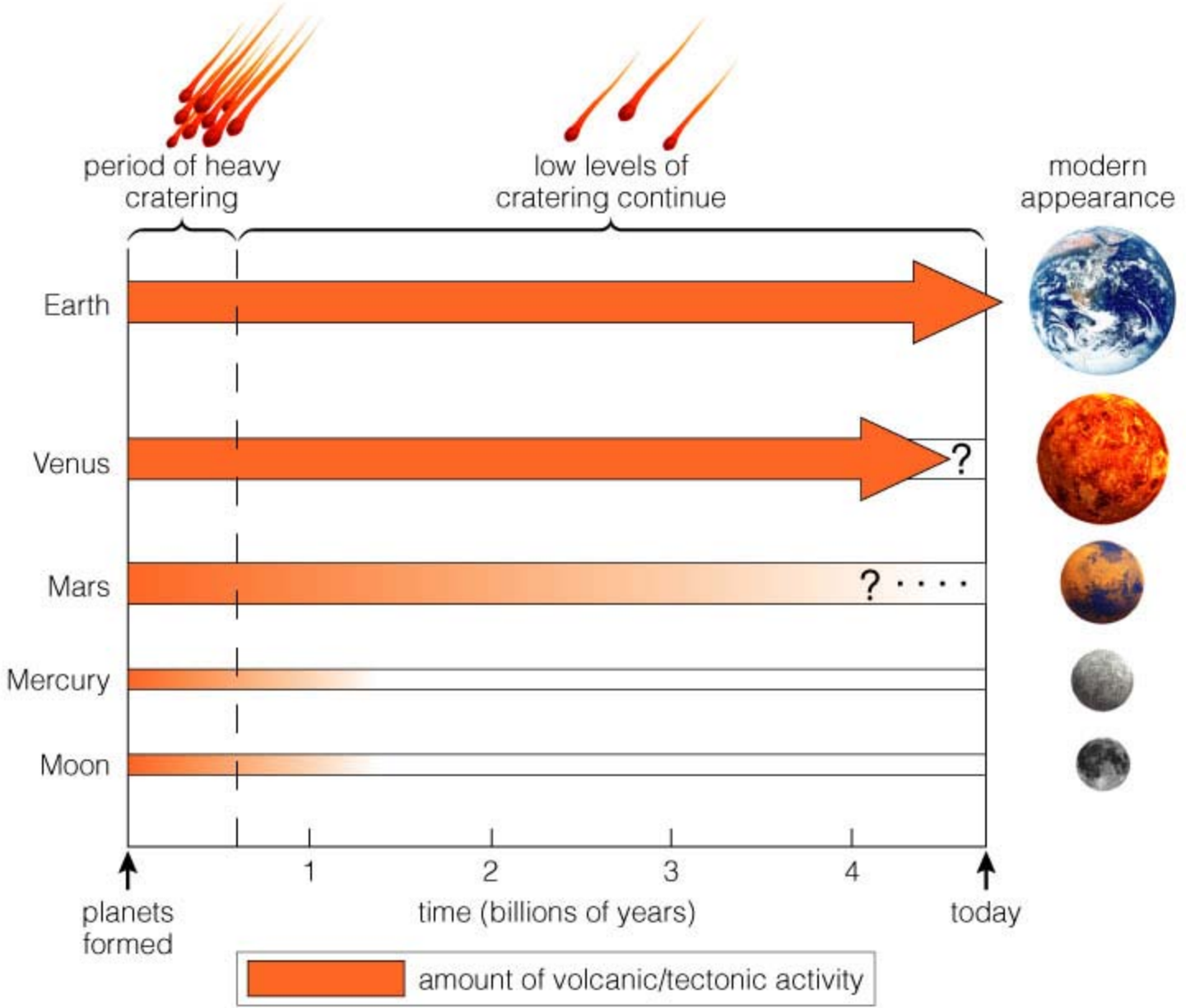
150 million
years from now

2 cm per year
2000 km per million years

Mapping the past (or future) size and location of the continents is difficult
You never see maps like this for 1 billion years ago

Plate Tectonics

- Creates different types of crust
- Recycles water between the surface and the mantle
- Immensely important for the geology of the Earth and why Earth's geology is different
- Implications for climate and biology too



All planets experienced heavy impact cratering in the early solar system

Volcanism and tectonism can erase those craters

Planetary size is the most important factor affecting the geology of a planet over the 4.5 billion year existence of the solar system

Goals for Learning

- What geological processes shaped Mercury and the Moon?
- What are the main geological features of Mars and has water even flowed on Mars?
- What is the geology of Venus like? How does it compare to Earth's?
- What is plate tectonics?

Goals for Learning

- What geological processes shaped Mercury and the Moon?
 - Heavy impact cratering early in their history, followed by the formation of some volcanic plains
 - Mercury has experienced significant tectonic activity, leading to compression, due to interior cooling, whereas the Moon has not
 - No erosion

Goals for Learning

- What are the main geological features of Mars and has water even flowed on Mars?
 - Heavily cratered southern hemisphere, large volcanoes, polar caps, tectonic rift valley
 - Valley networks, streamlined islands, and channels suggest that water once flowed on Mars
 - Mars may still be volcanically active and there is some evidence for liquid water appearing on its surface today

Goals for Learning

- What is the geology of Venus like? How does it compare to Earth's?
 - Few impact craters, little erosion
 - Lots of volcanic plains and volcanoes
 - Lots of tectonic features
 - Entire surface appears same age, 750 million years, unlike the diversity of ages for different regions on Earth's surface

Goals for Learning

- What is plate tectonics?
 - Continual recycling of old crust down into the mantle
 - Formation of new seafloor crust at mid-ocean ridges
 - Formation of new continental crust above subduction zones
 - Leads to two different types of crustal rock

- http://nssdc.gsfc.nasa.gov/planetary/image/mgs_mars_topo.jpg
- http://www.msss.com/mars_images/moc/ec02/athabasca/athabasca_25.jpg
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