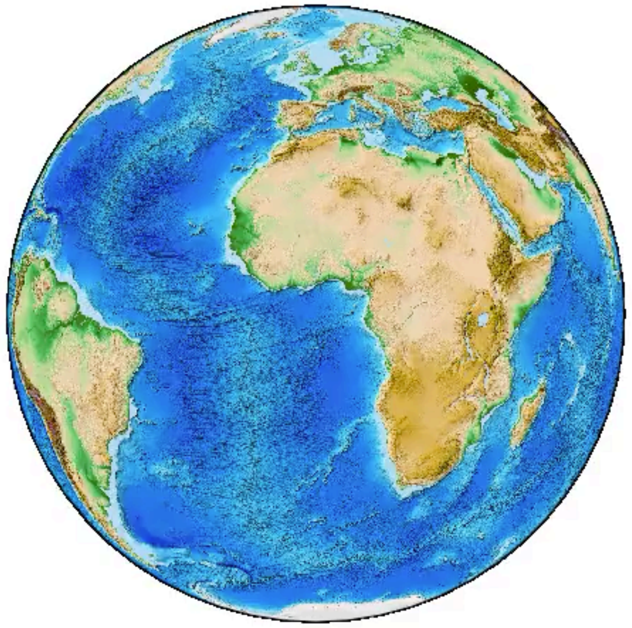
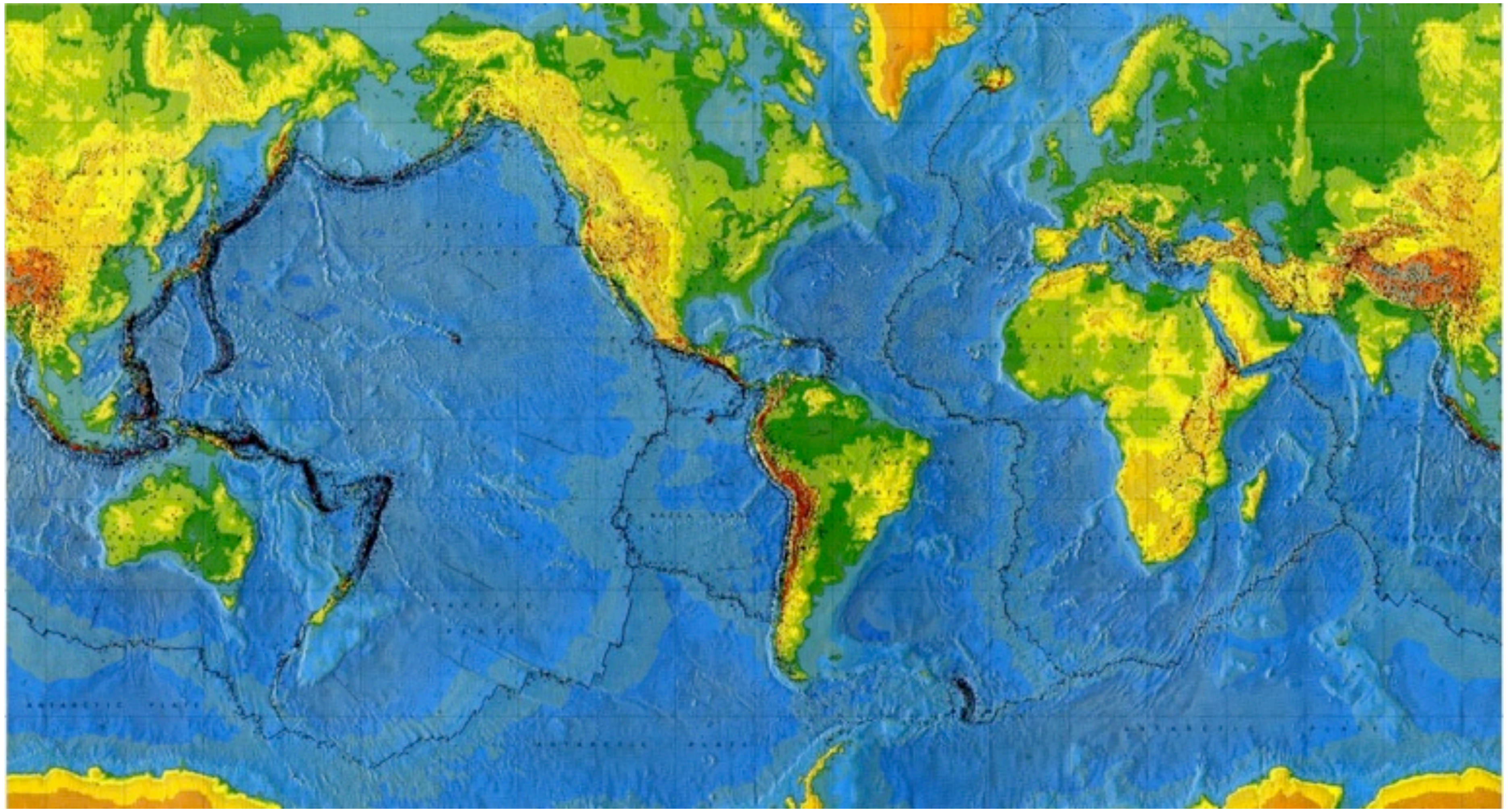
PHYS 3070 Section 2/1:

Introduction



In which we explore the background to the **dynamic Earth** — starting with observations of the Earth as one of the solid planets in the solar system and what we know about it.

What is this course about ?



Understanding interacting dynamic processes so we can answer

- Why are there continents and oceans ?
- Why are the earthquakes where they are ?
- Why are oceans shallow in the middle ?
- Why are some parts of the continents flat, others mountainous ?

What will you have learned by the end ?

You will have a good intuition of the way the physical processes in the interior of the Earth play out in the geology at the surface.

You will be able to explain how the deep Earth behaves as a viscous fluid and why it must flow

You will know how we probe the deep Earth with gravity measurements, seismology, geochemical signals and models

You will have explored the kinematics of plate motions and how geologists reconstruct the paths of continents from plate rotation poles.

You will know why there is a relationship between Earth's interior structure and its rotation, orbit, polar orientation and, therefore, paleoclimate

You will have seen and explored the equations which govern all this behaviour (but you will not be required to solve them from scratch or recall them verbatim in an exam)

What is / is not expected of you ?

This course is about the physical processes in the Earth which produce large scale plate tectonics. It addresses the fact that we can be precise about geology and geological processes.

You are expected to think quantitatively about the Earth as a whole and its long term evolution

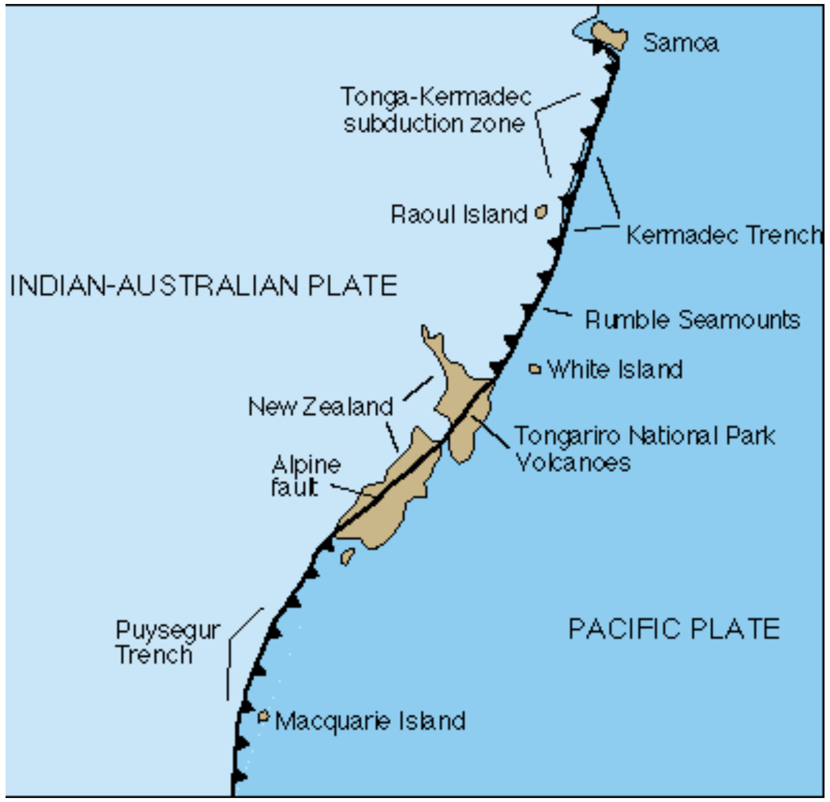
You will need to plot graphs, calculate numbers from equations given to you, and use the results to describe what happens in particular geological settings. You will need to have some proficiency with python but we will do some labs for this.

Mathematics

- You will not have to derive any equations *but you should be able to follow my derivations*
- You will not have to solve any equations *but you may need to check that solutions work*
- You will not have to remember equations but *you should be able to interpret the equations you are shown*

I think it is much more important to understand the underlying meaning of equations than to be able to find over-simple solutions by complicated derivations. Computational solutions are a good way to understand the inherent structure that can emerge in solutions to equations.

Solar system geology

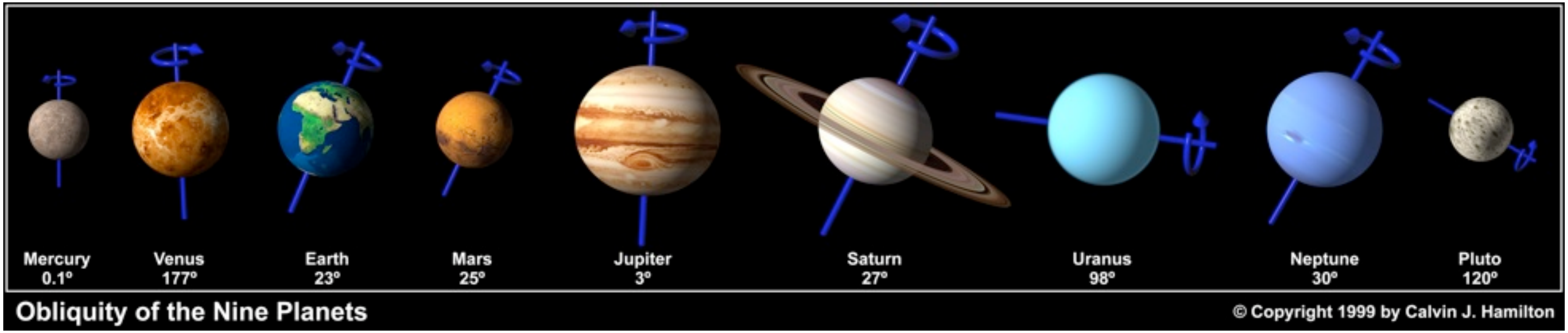


Geologists don't get to choose the experiments they would like to see the Earth perform for them. They compare events from different places (and times) and assume they can generalize processes.

Uniformity of processes from place to place and time to time.

It is harder to take this approach when we think on the scale of the whole Earth.

Solar system geology

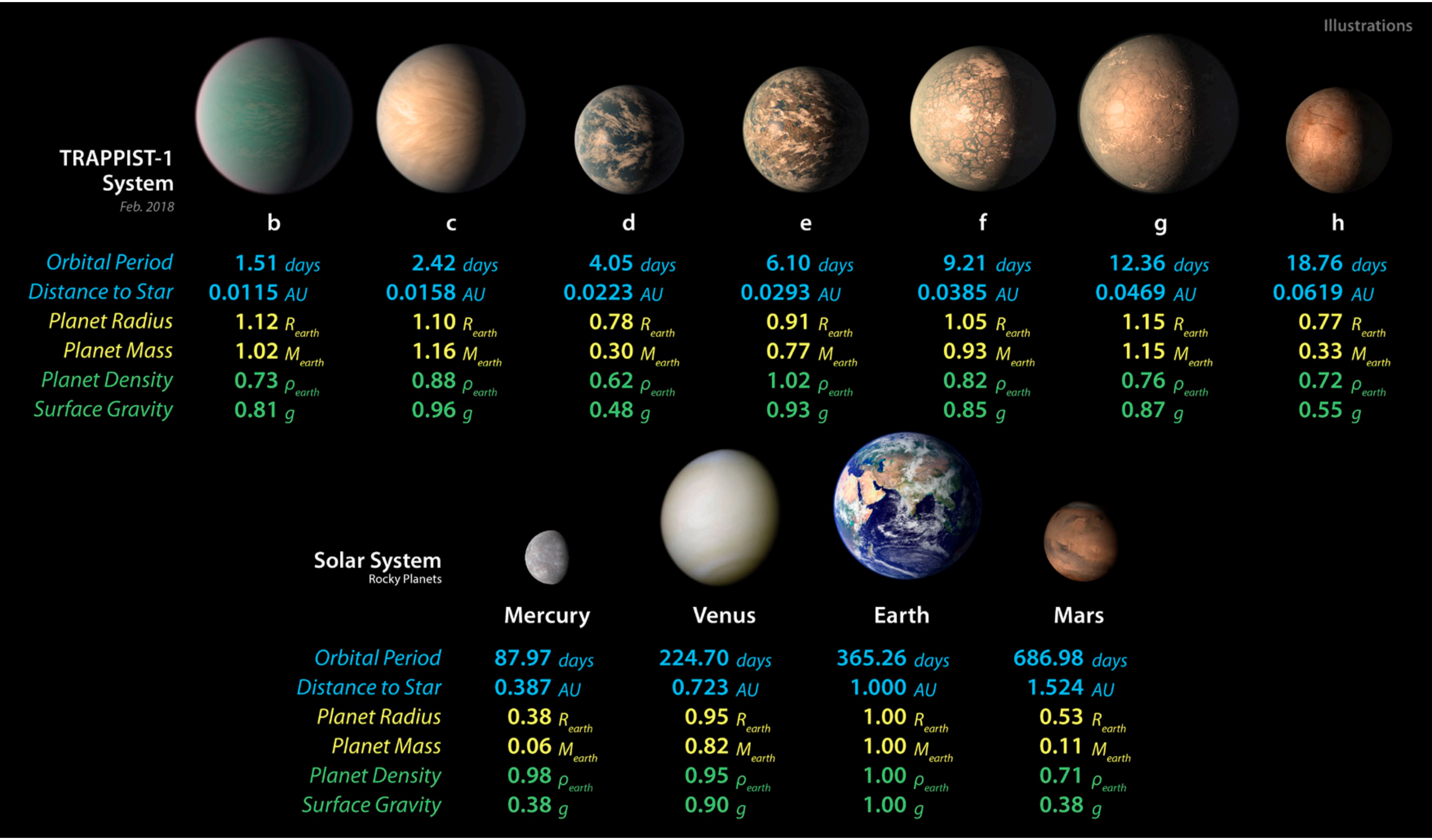


We're going to have to think about the dynamics of

- Earth, Venus, Mars
- Mercury and the Moon
- Rocky and Icy moons of the gas planets
- Asteroids

We want to have enough information to talk about general processes for the whole planet so we need at least one or two more examples to test our theories.

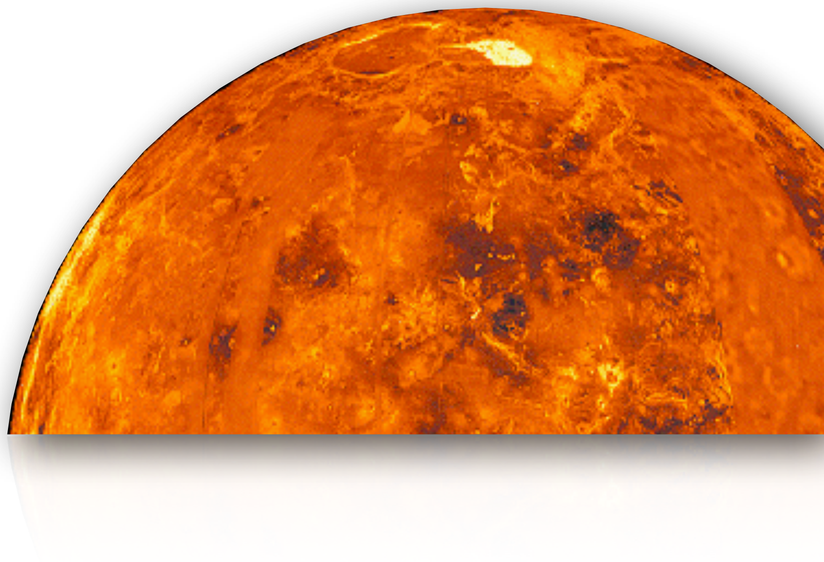
Extra-Solar system geology

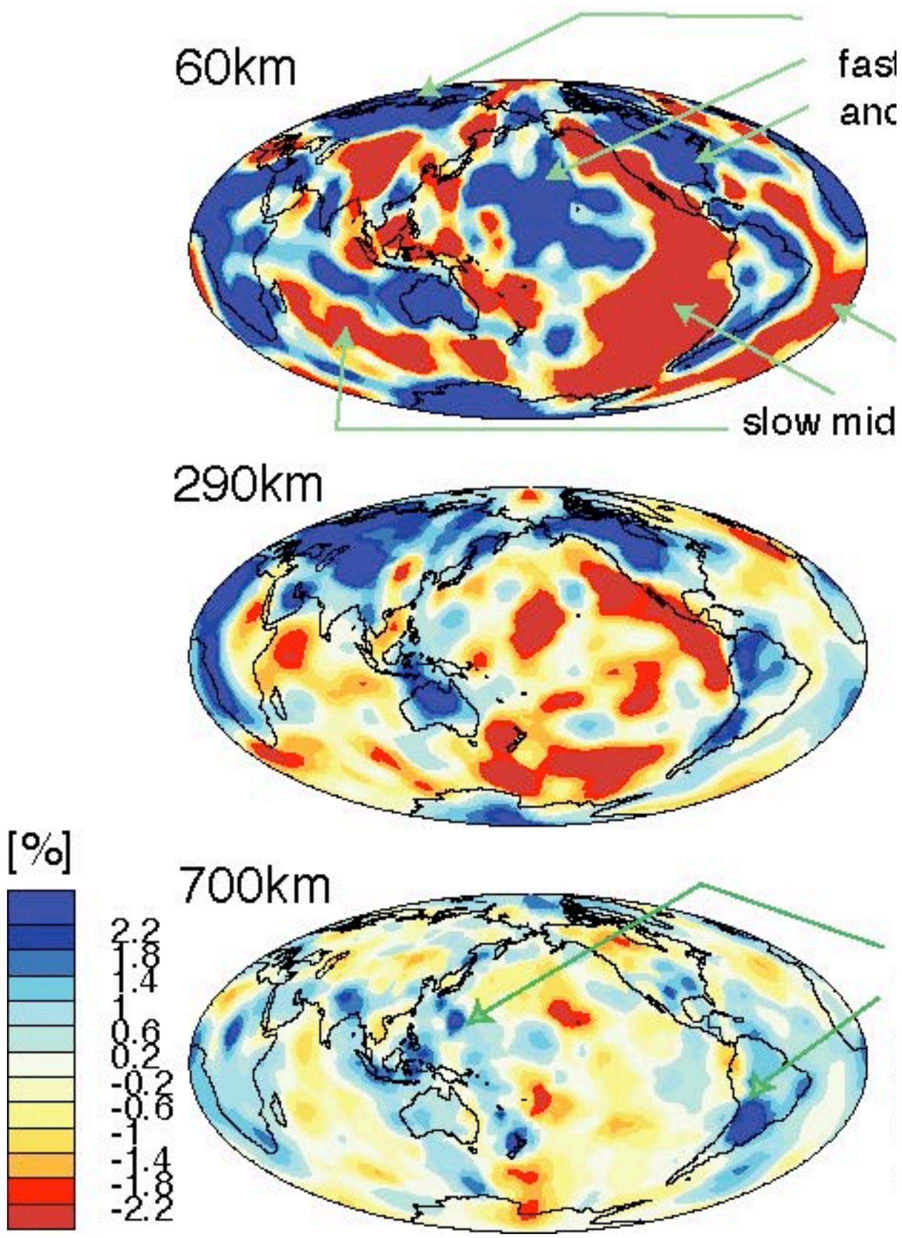


At the moment, our understanding of exoplanets is by extrapolation from our own solar-system.

Dynamics of Other Planets

We mostly have to proceed by analogy with the one planet where we do have reasonable information about the interior.





However, the Earth is not a typical example of a solid planet because it alone has plate tectonics.

Plate tectonics is a critical background concept of the course — we will need to consider why the Earth is unique if we are to understand plate tectonics.

Venus

Major layering

- Metallic core
- solid silicate lower mantle
- solid silicate upper mantle
- crust (highlands + plains)
- atmosphere

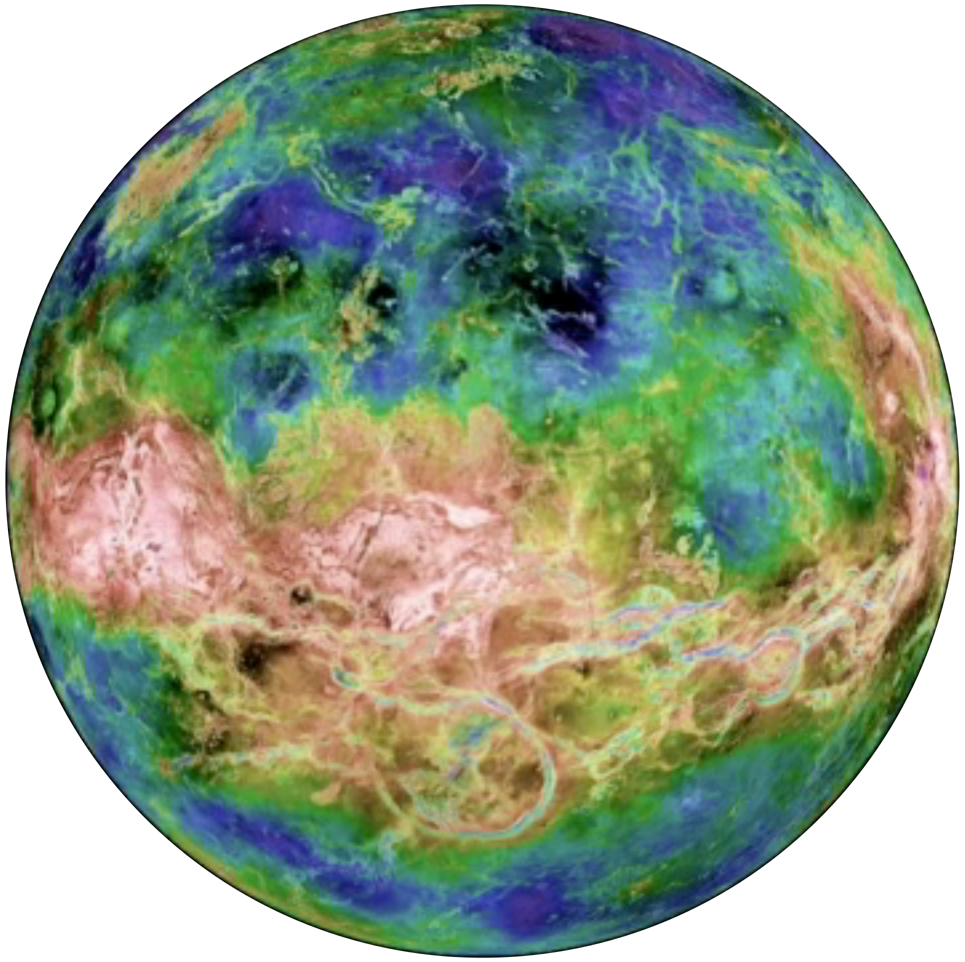
Surface Features

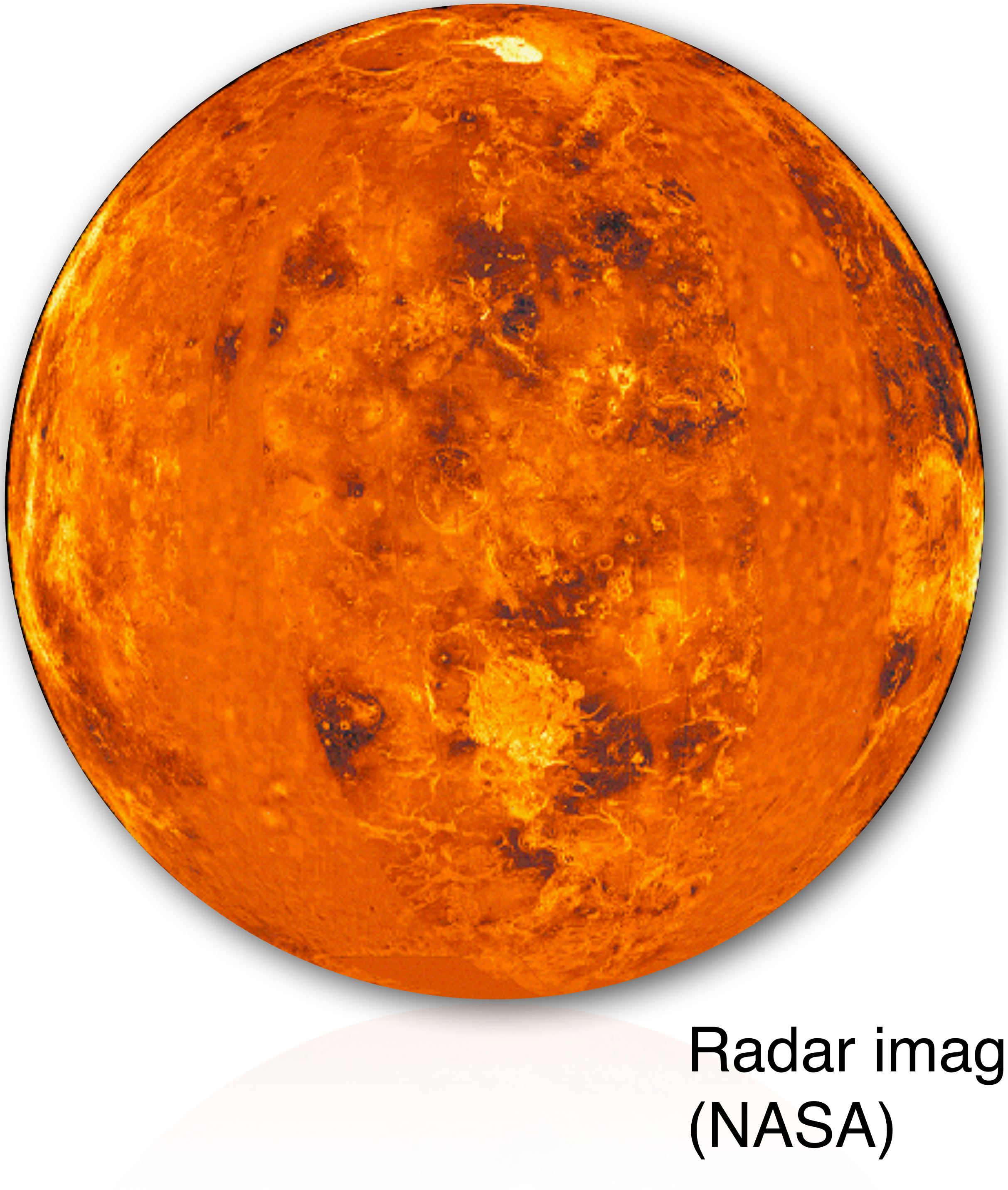
- active volcanoes
- old lithosphere
- large craters (not small)

Oddities

- no magnetic field
- slow, retrograde rotation
- thick atmosphere (prograde)
- high surface T, low erosion

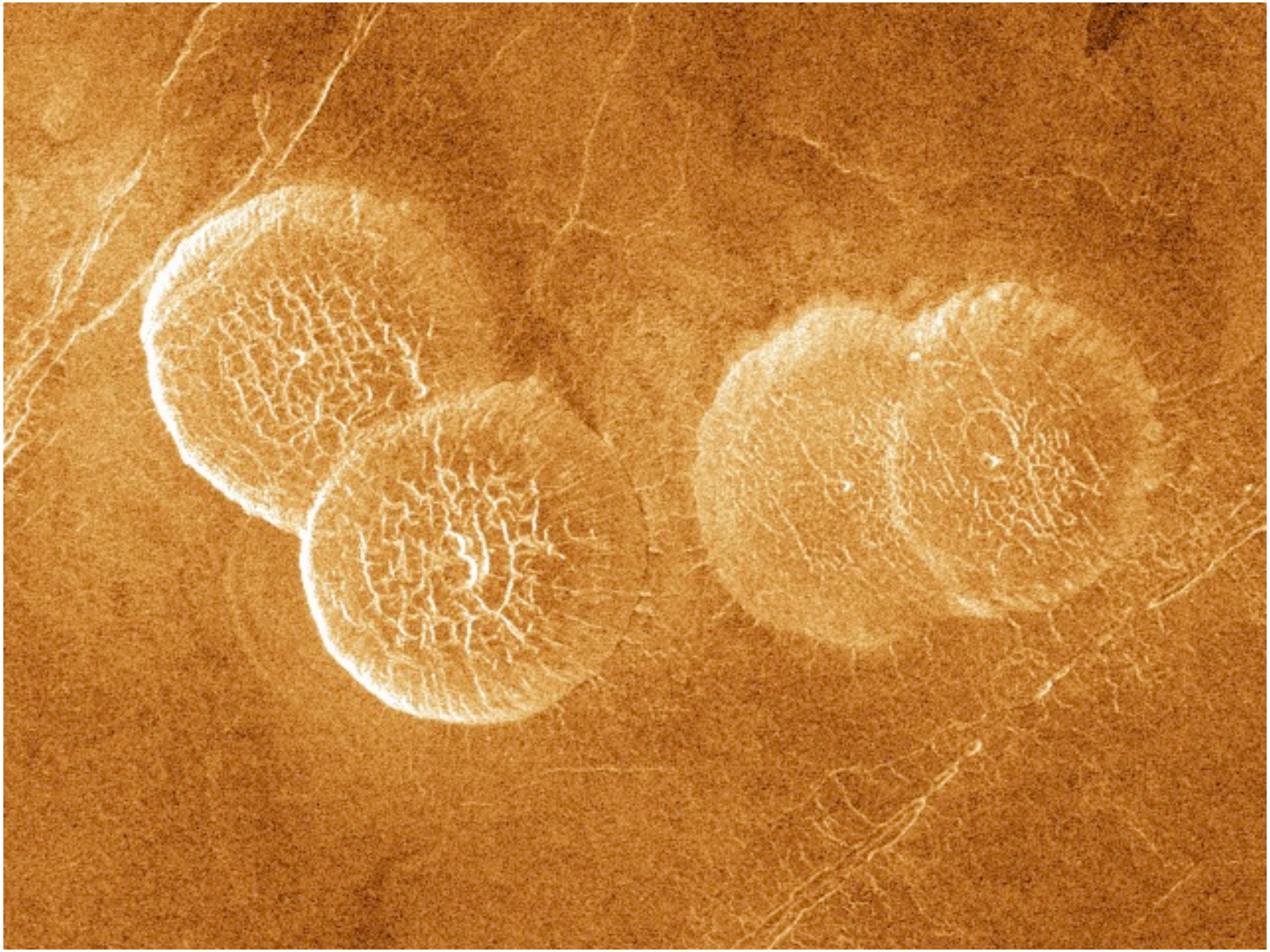
Topography (NASA)





Radar image (NASA)

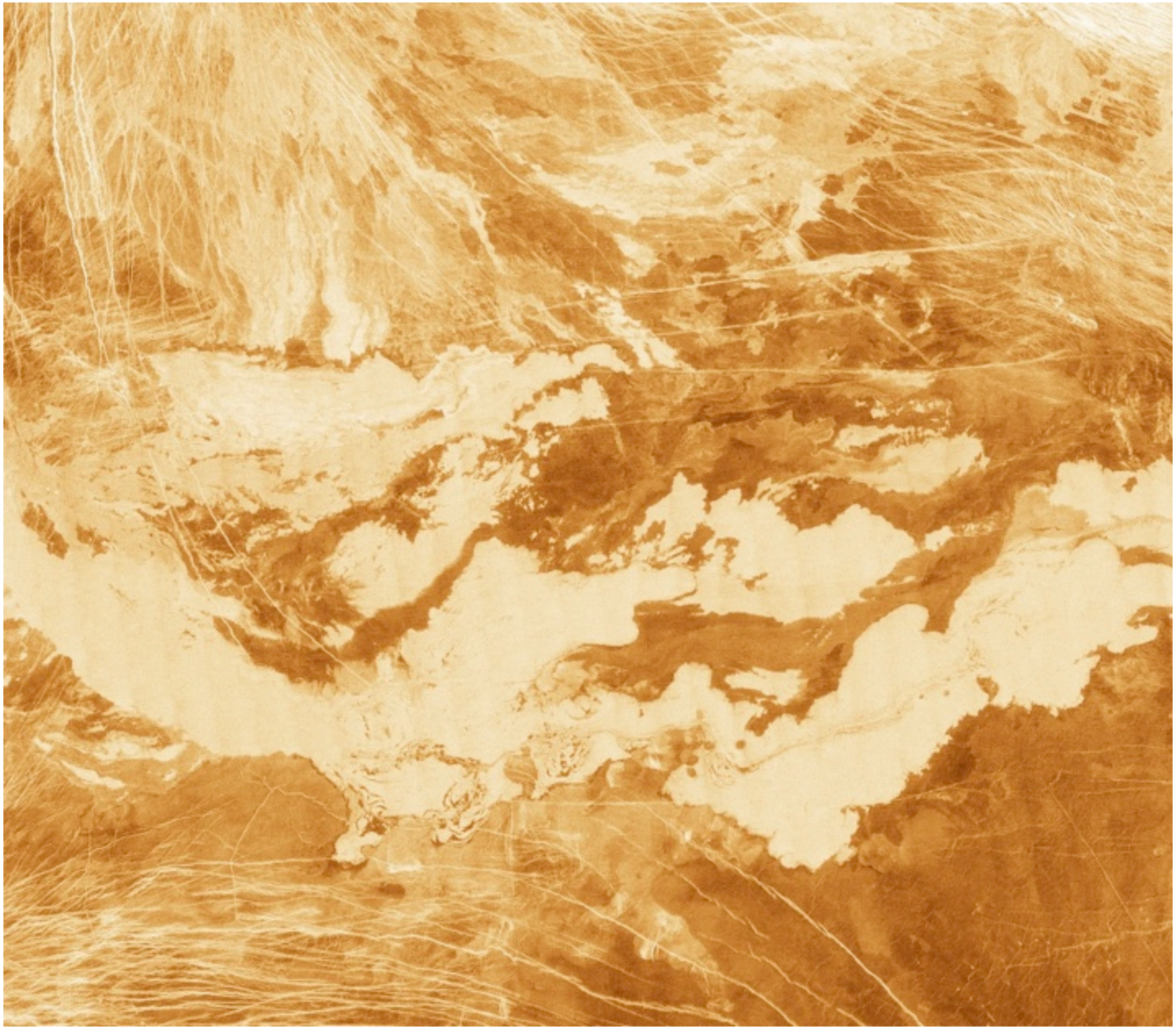
Venus - surface features



Pancake domes

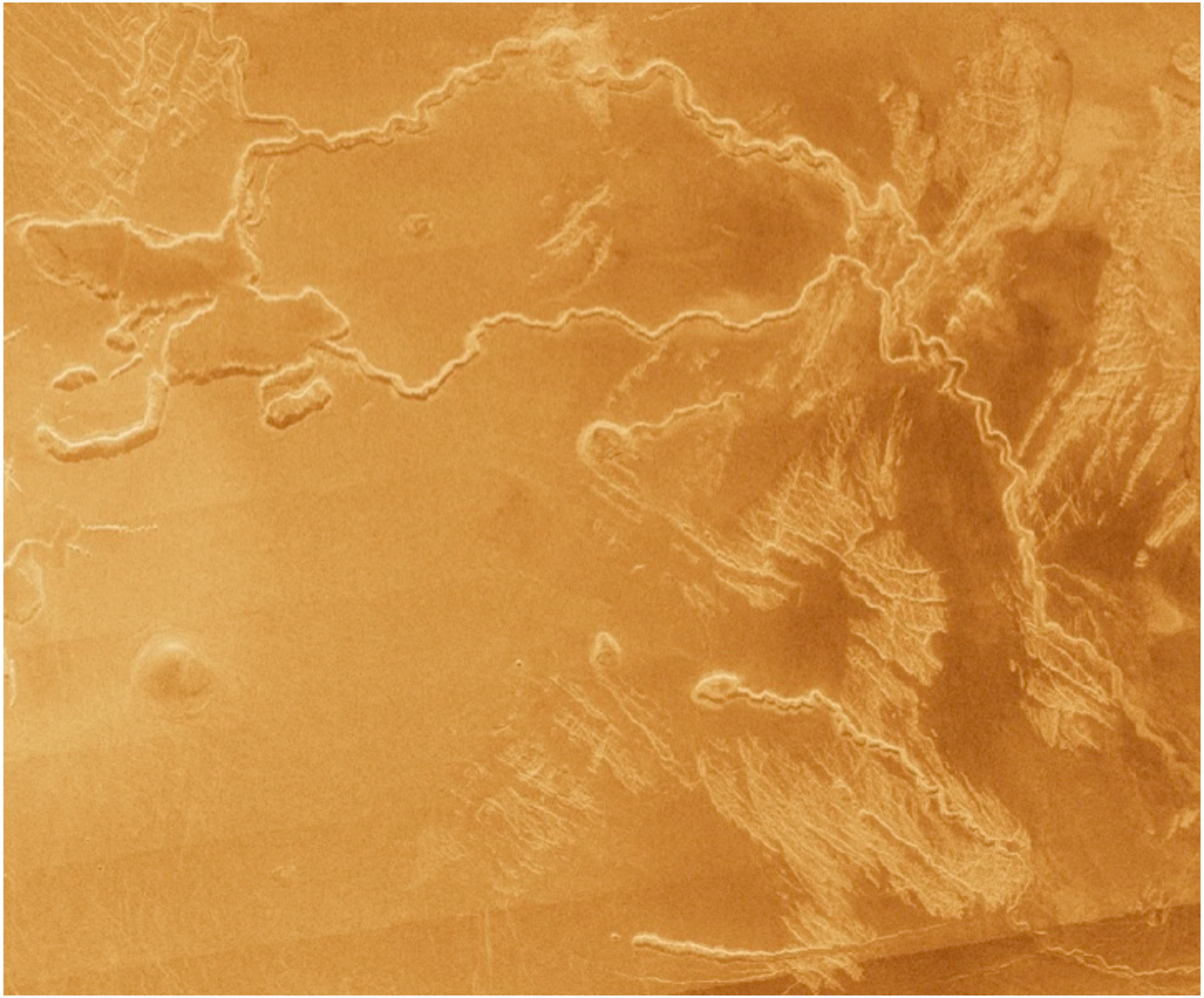
Venus - surface features

Lava flow field



Venus - surface features

Rilles



Mars

Major layering

- solid metallic core
- solid silicate lower mantle
- solid silicate upper mantle
- crust (half thick, half thin)
- very thin atmosphere

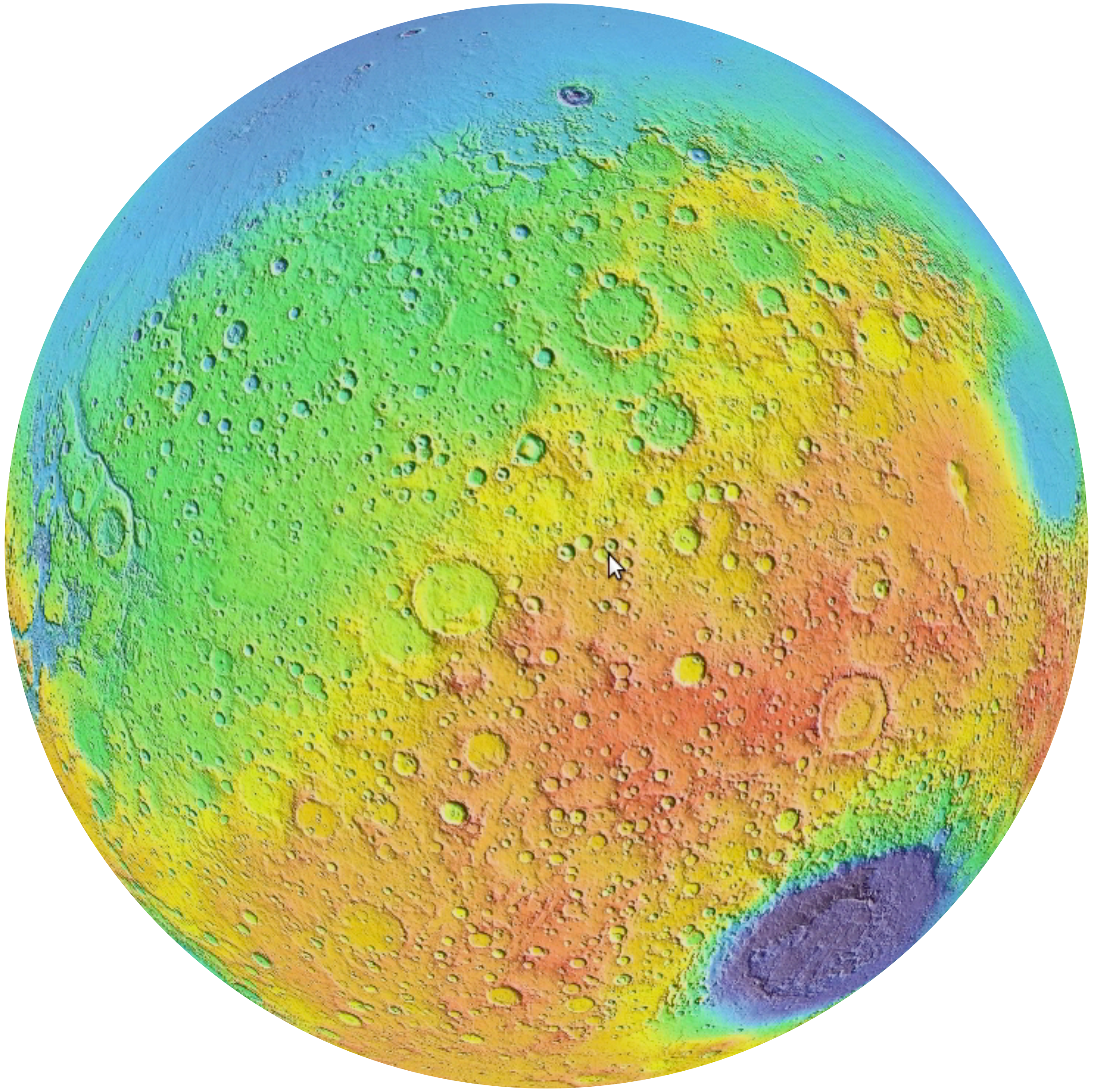
Surface Features

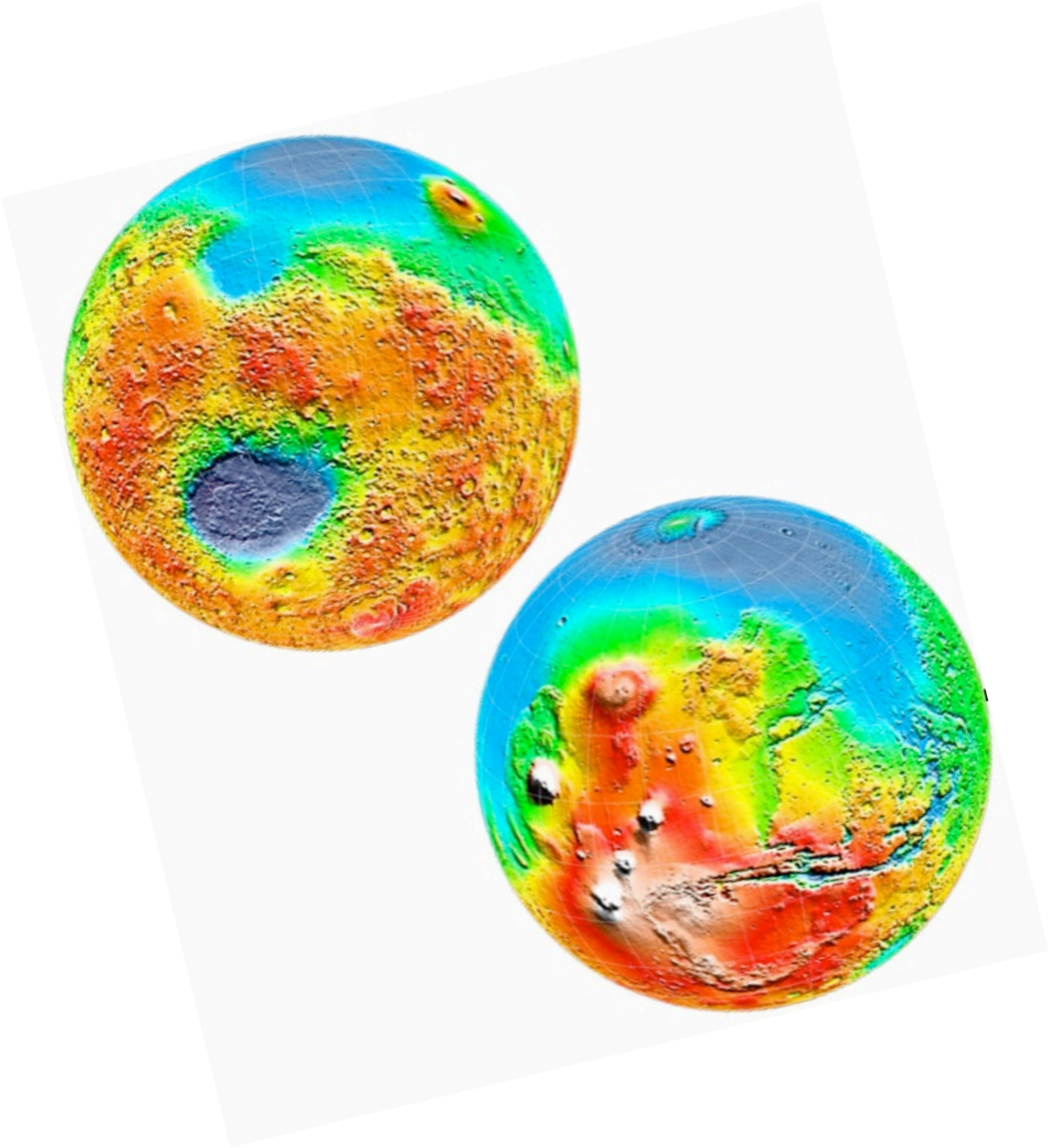
- volcanoes
- craters
- rifting
- crustal thickness variations
- changing ice caps
- erosion (water, wind, CO2)
- sand dunes

Oddities

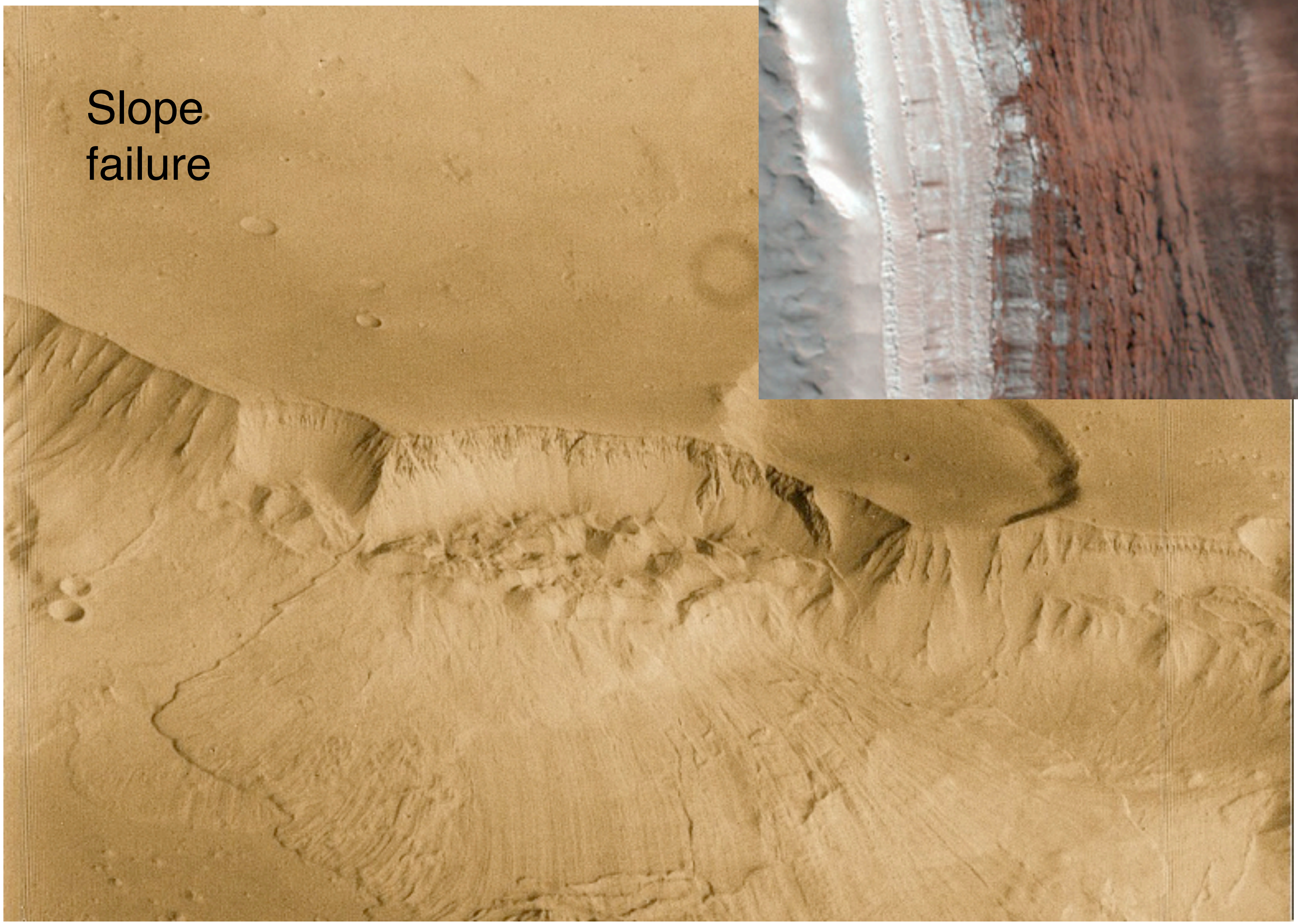
- magnetic stripes (?)
- ancient oceans or surface water (?)

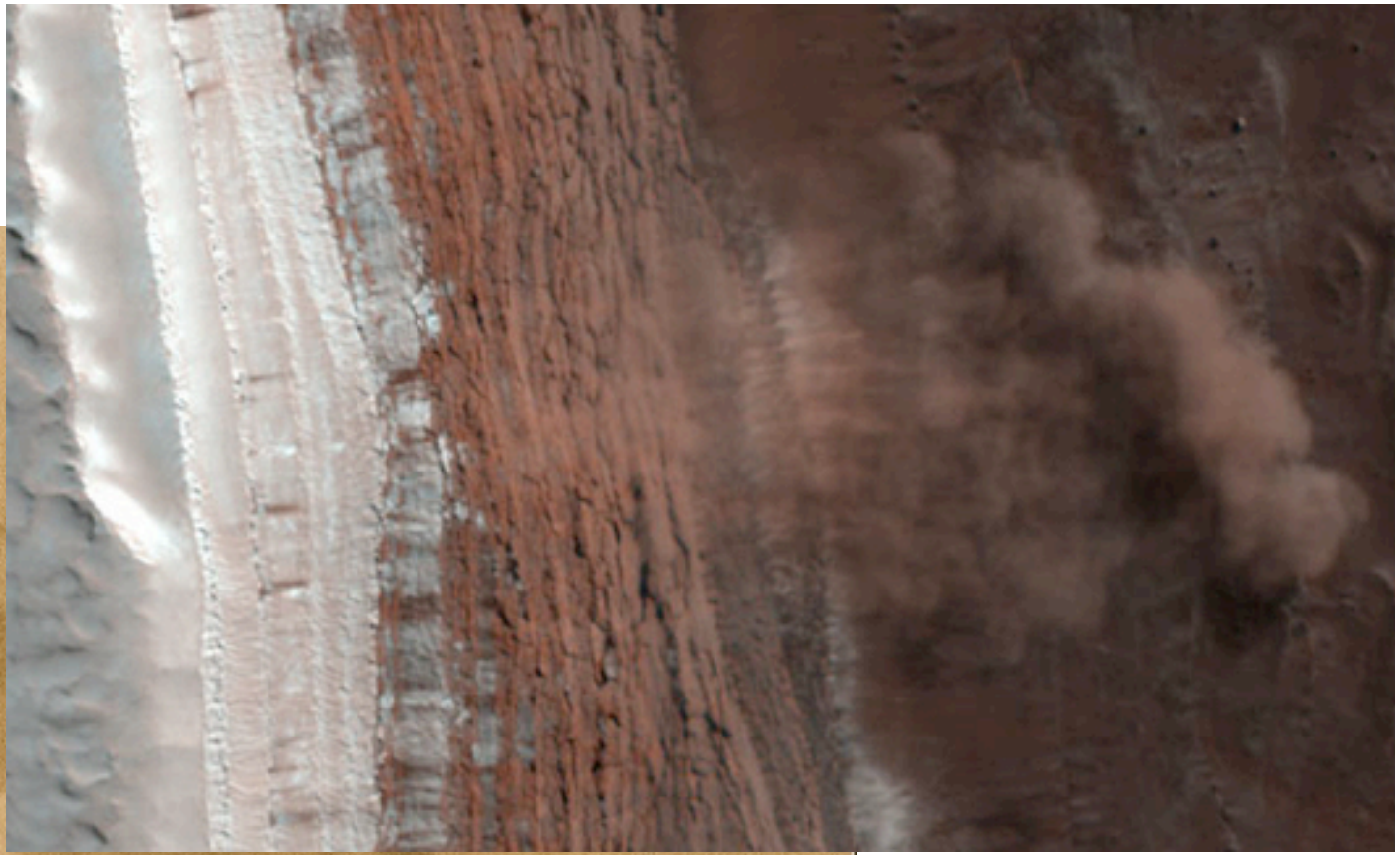
Mars - surface features





Mars - surface features





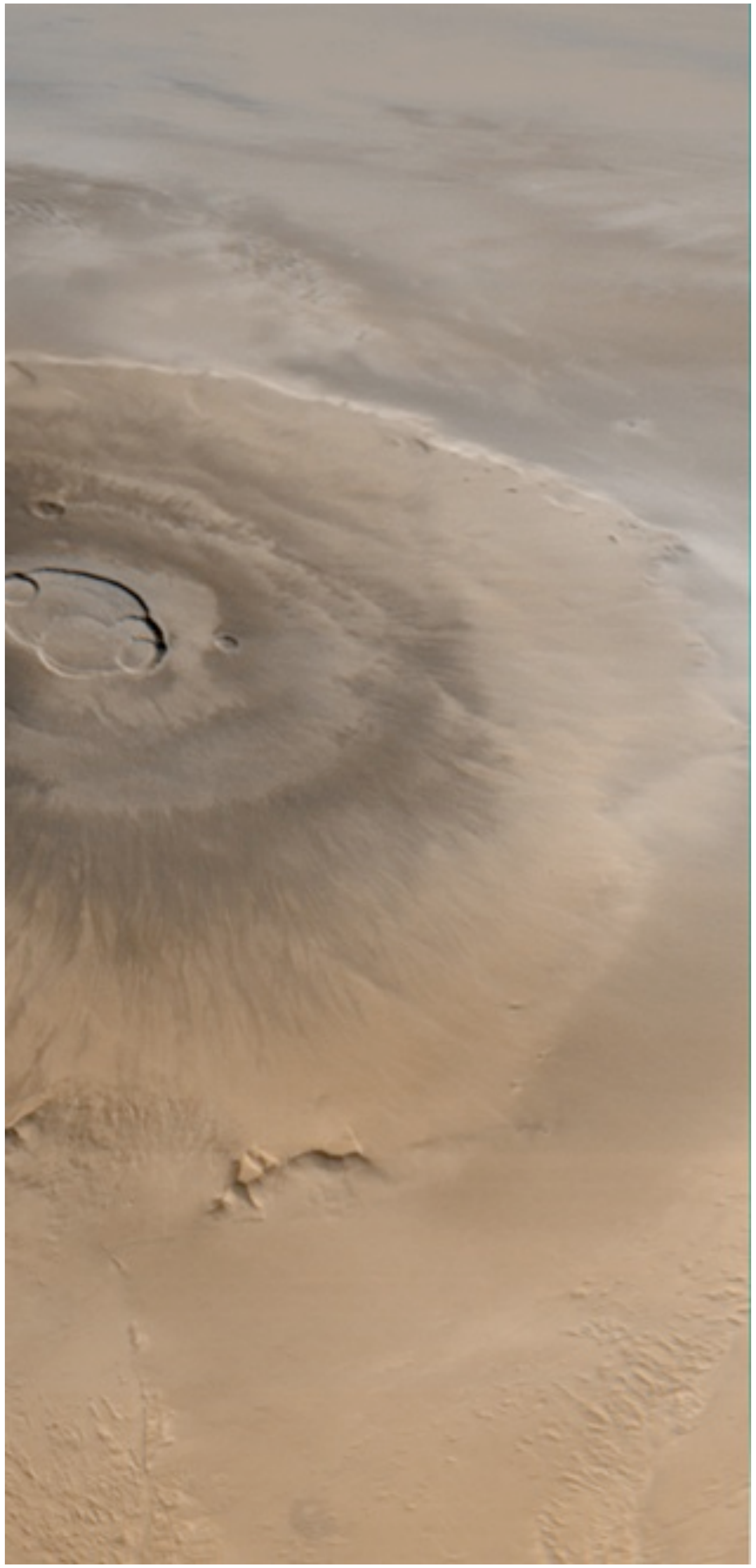
Mars - surface features

Rift valley

Mars - surface features

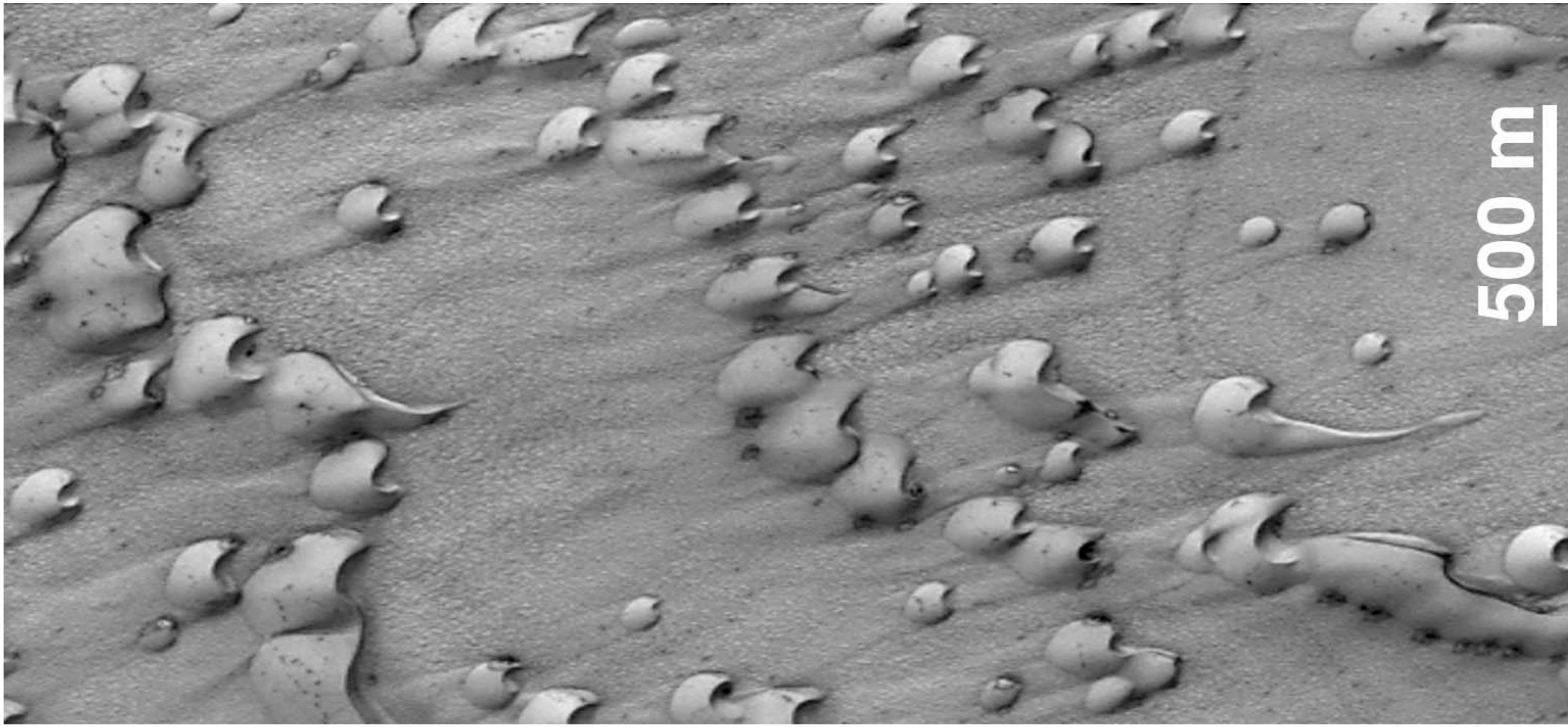
Polar ice caps
CO_2 and H_20

Mars - surface features



Giant volcanoes

Mars - surface features



Sand dunes

Mercury

Major layering

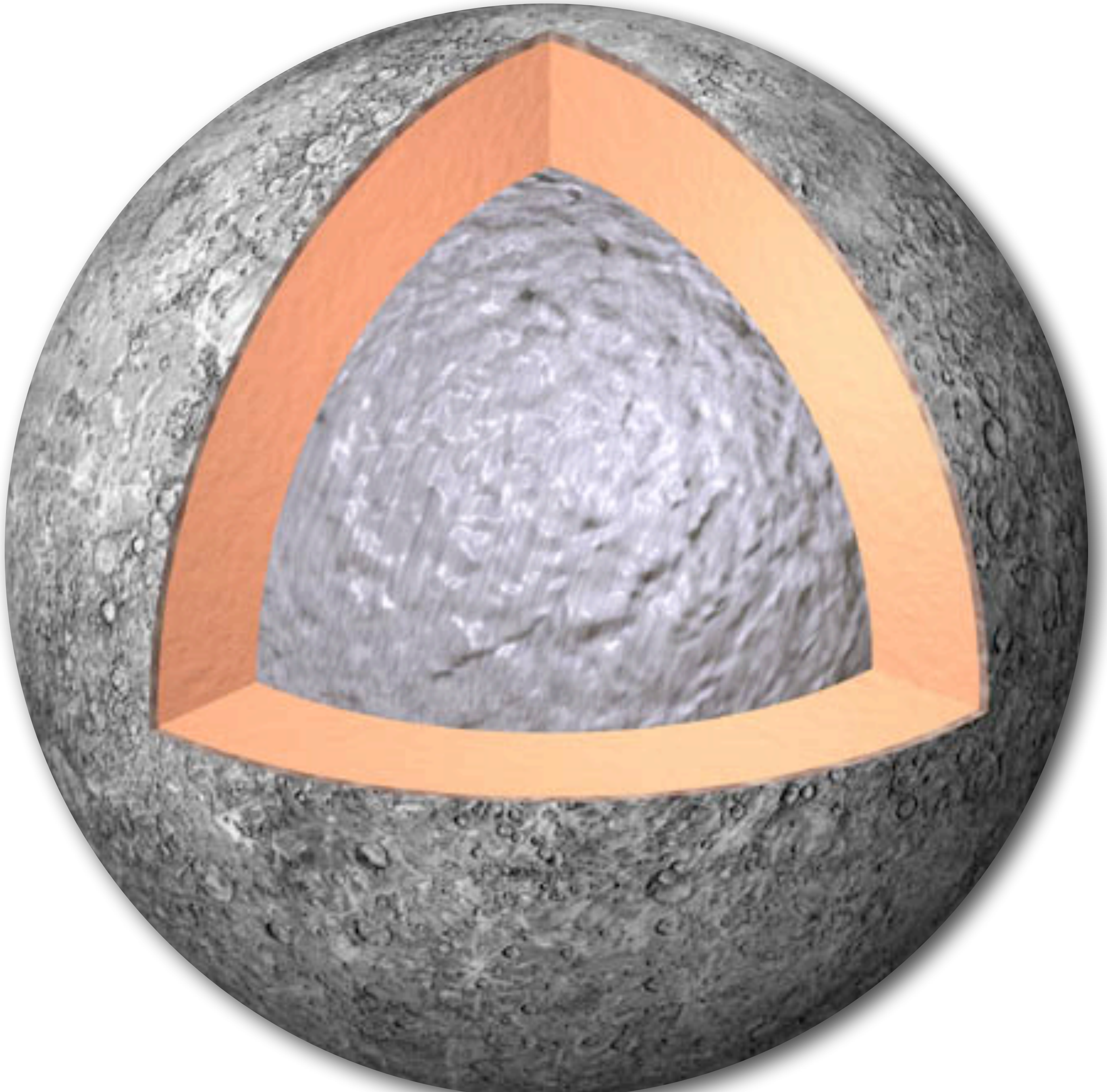
- Huge metallic core (solid ?)
- Solid silicate mantle
- Crust
- No atmosphere

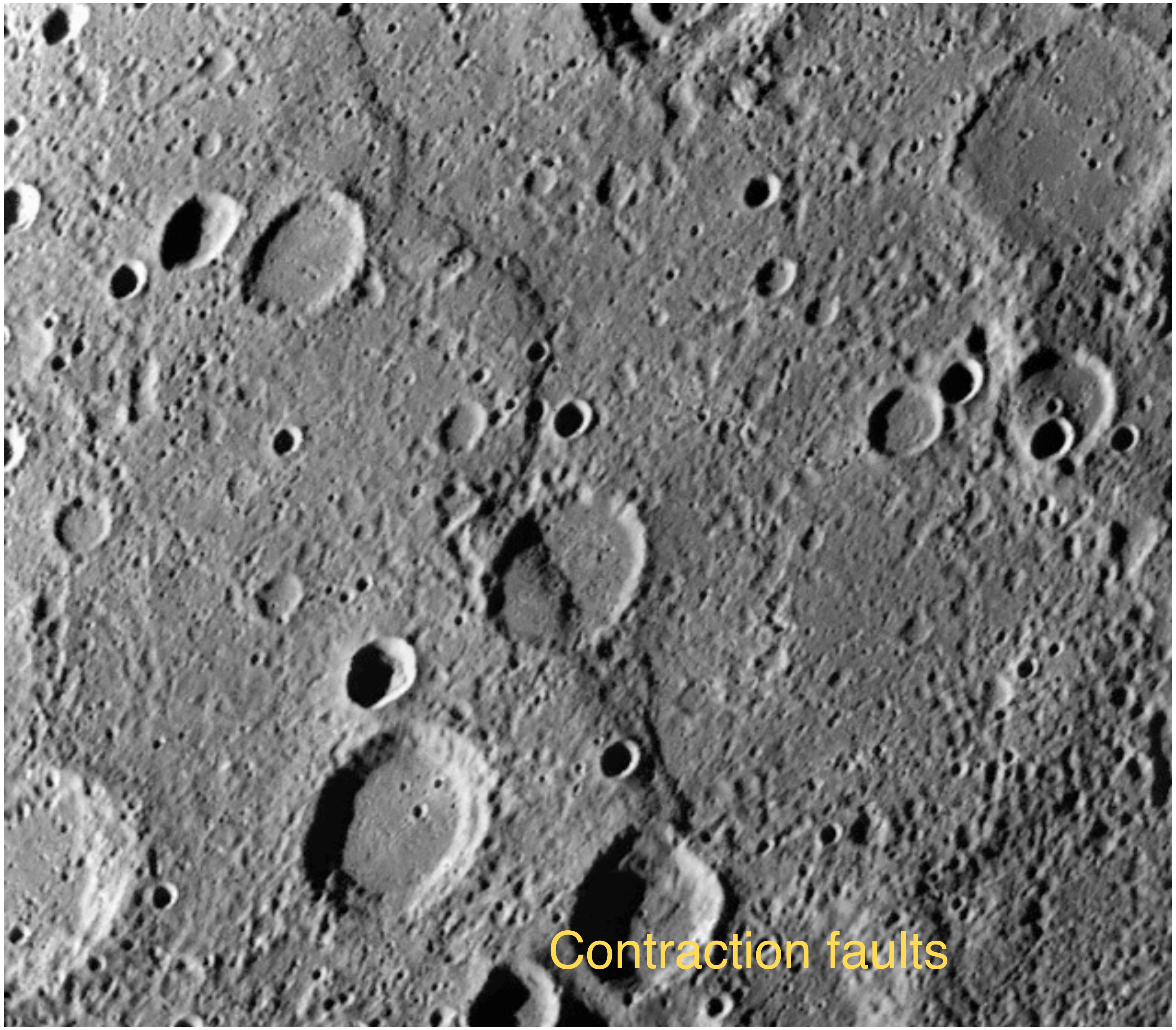
Surface Features

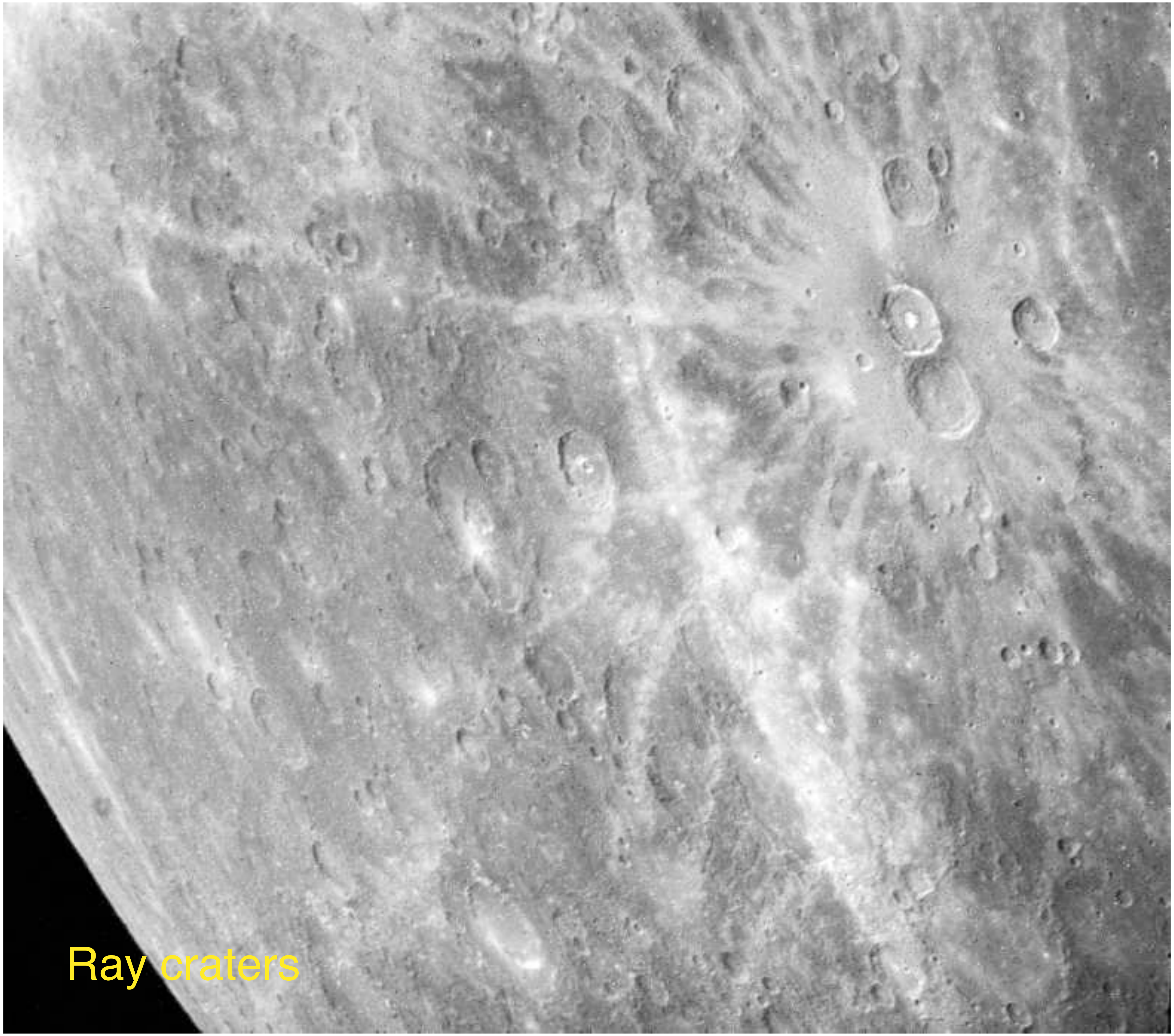
- Craters
- Contraction cracks
- Not active

Oddities

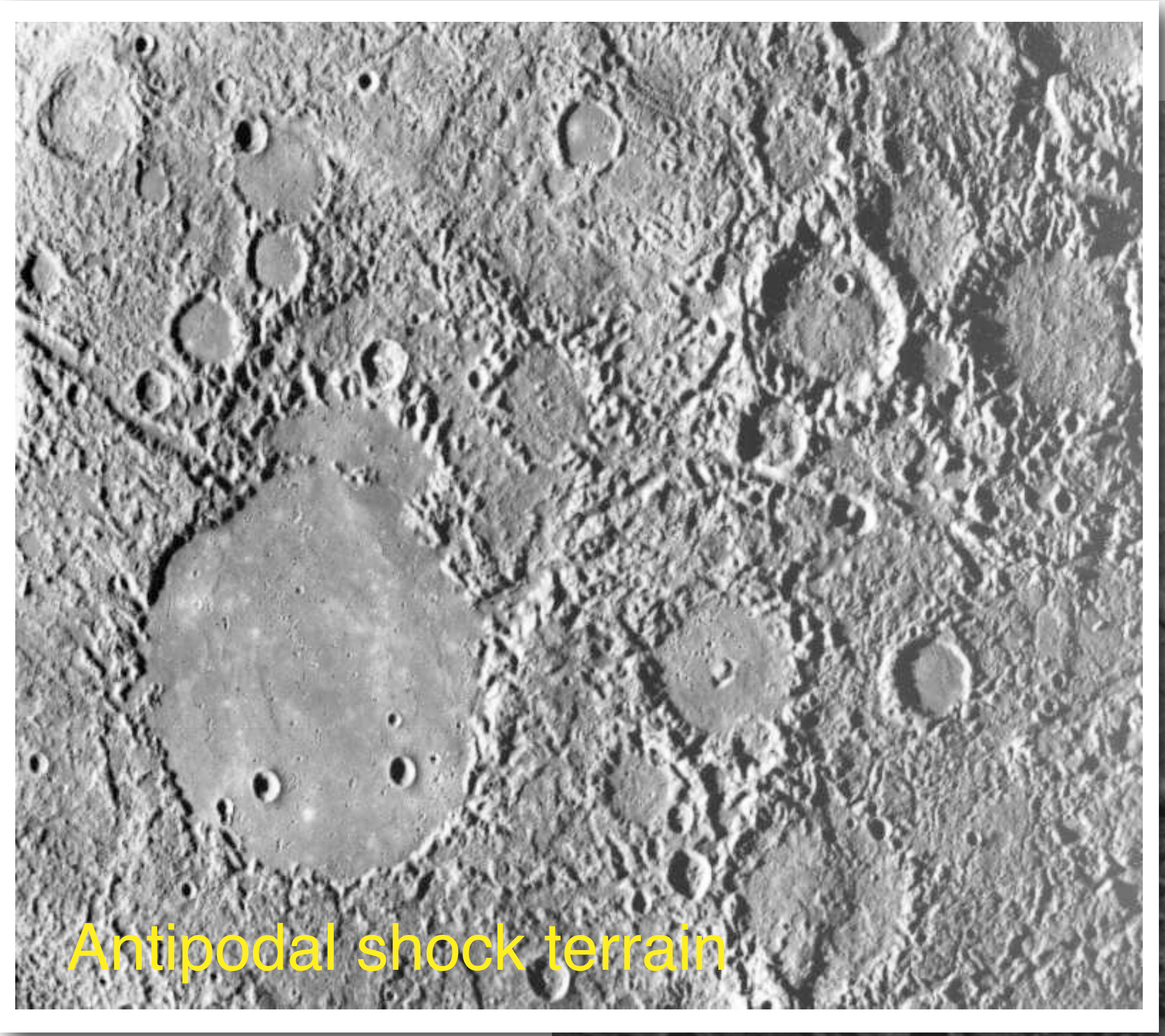
- Significant magnetic field
- Water in polar craters (??)

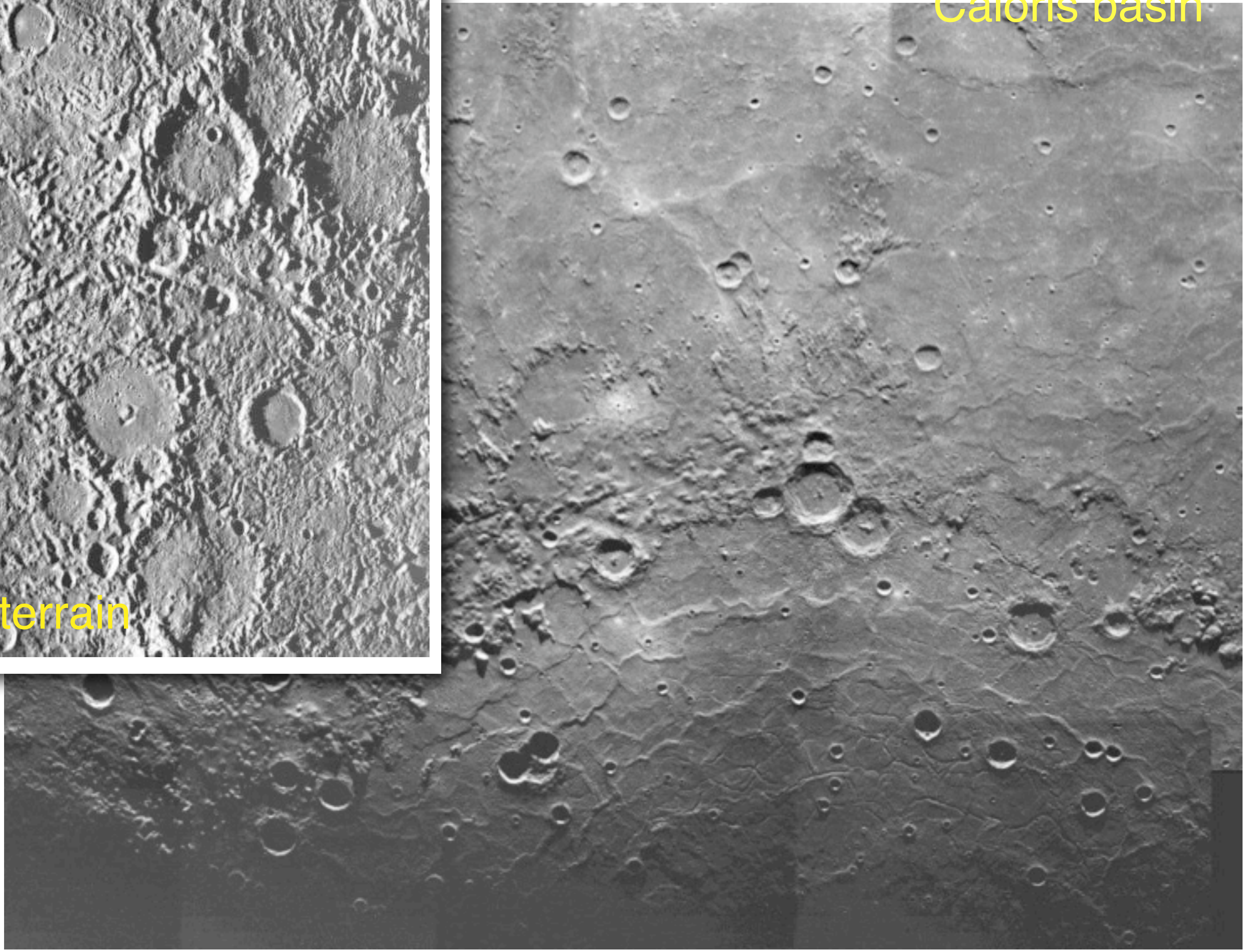



Contraction faults


Ray craters

Mercury - surface features





Moon

Major layering

- small solid core
- solid silicate mantle
- crust > 60km (plains + maria)
- no atmosphere/biosphere

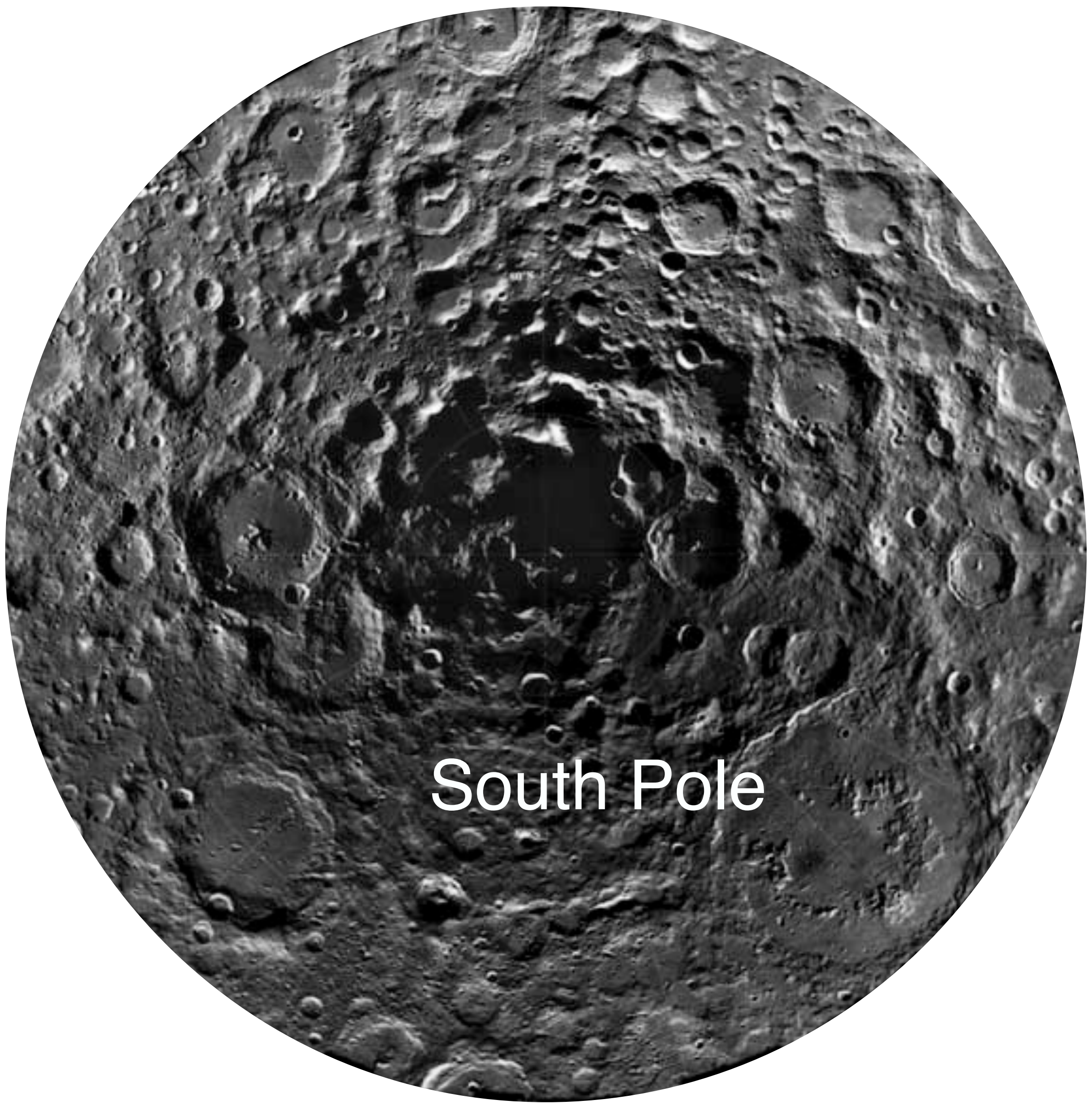
Surface Features

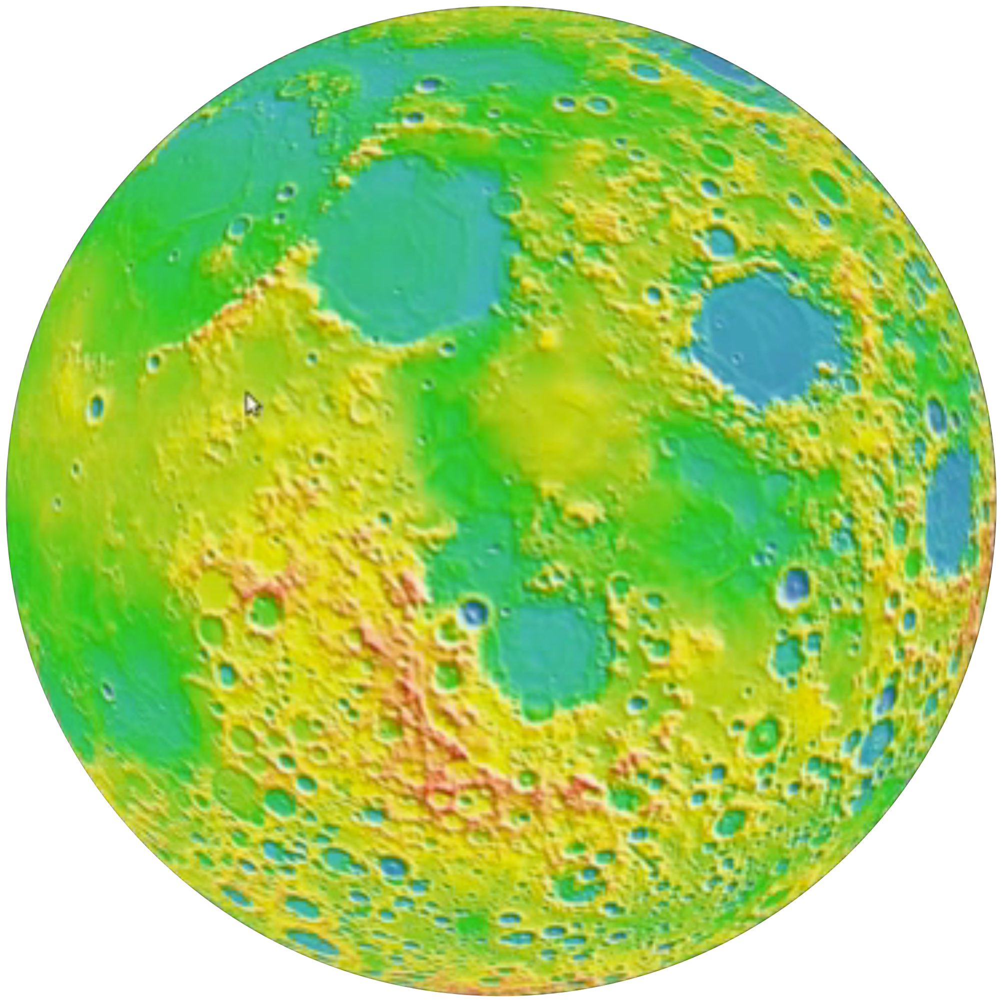
- younger maria (basalt)
- cratered
- regolith
- frozen surface

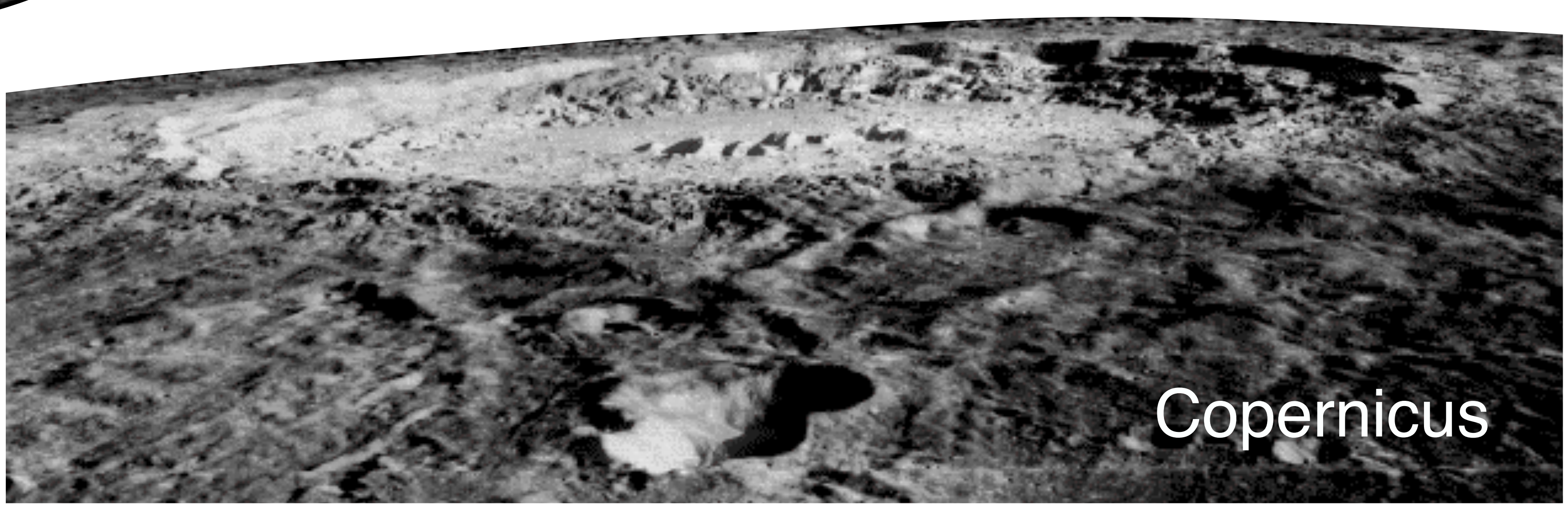
Oddities

- seismic studies (dead)
- maria clustered towards Earth
- crustal thickness greater on farside
- low density
- impact formation ?

Moon - surface features







Io

Major layering

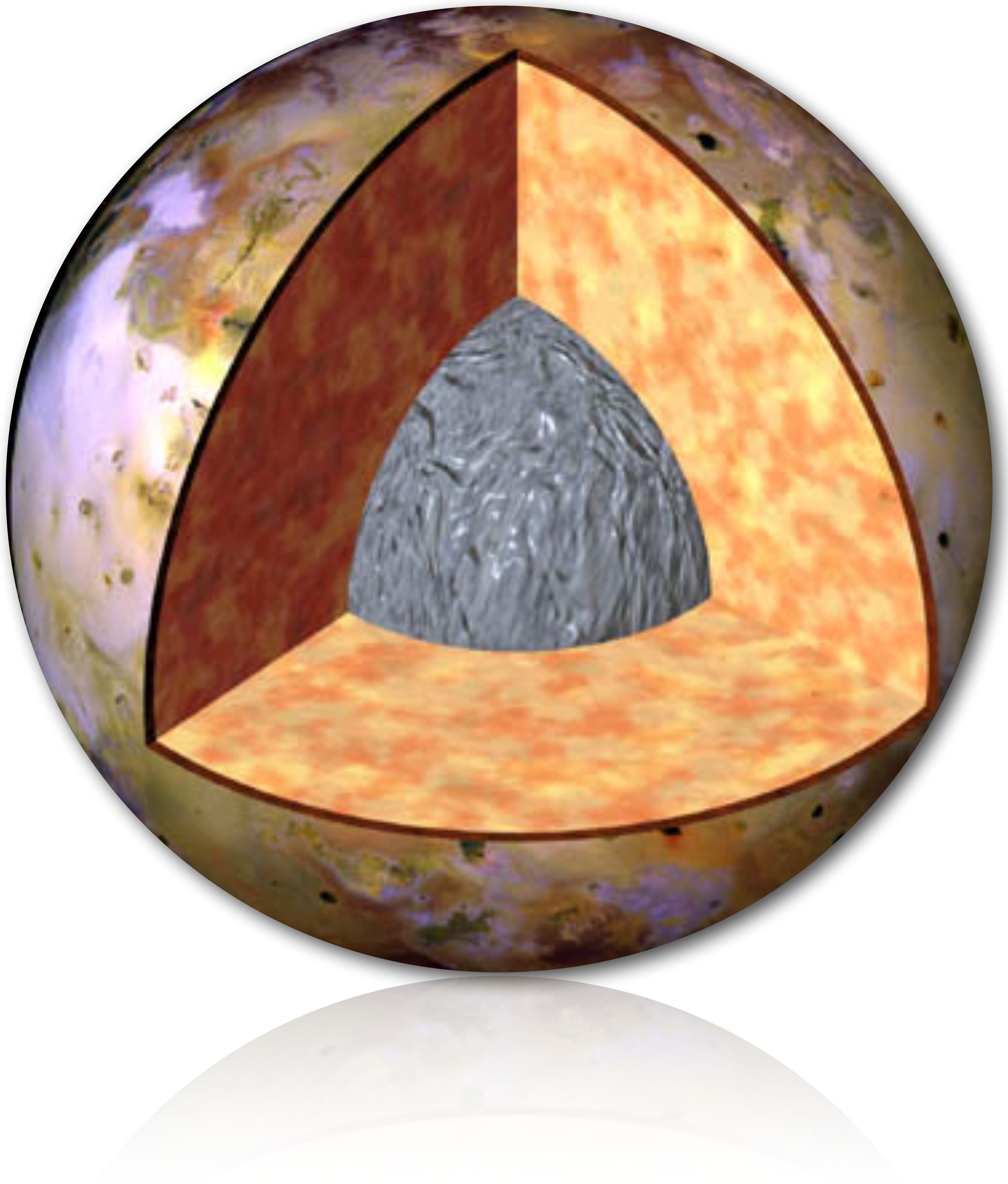
- metallic core
- solid silicate mantle
- crust
- atmosphere

Oddities

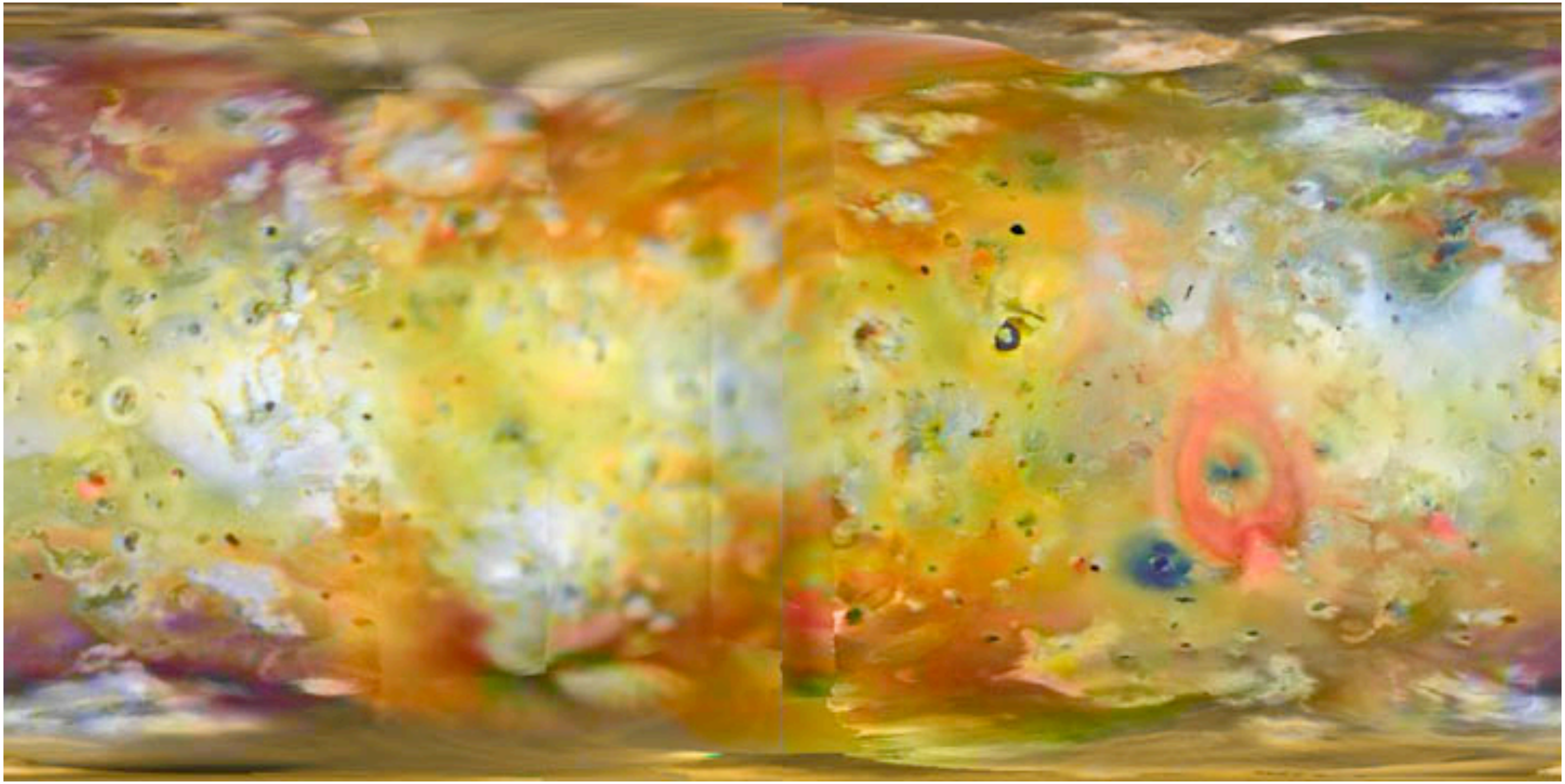
- Tidal heating

Surface Features

- Extremely active volcanism
- Young surface

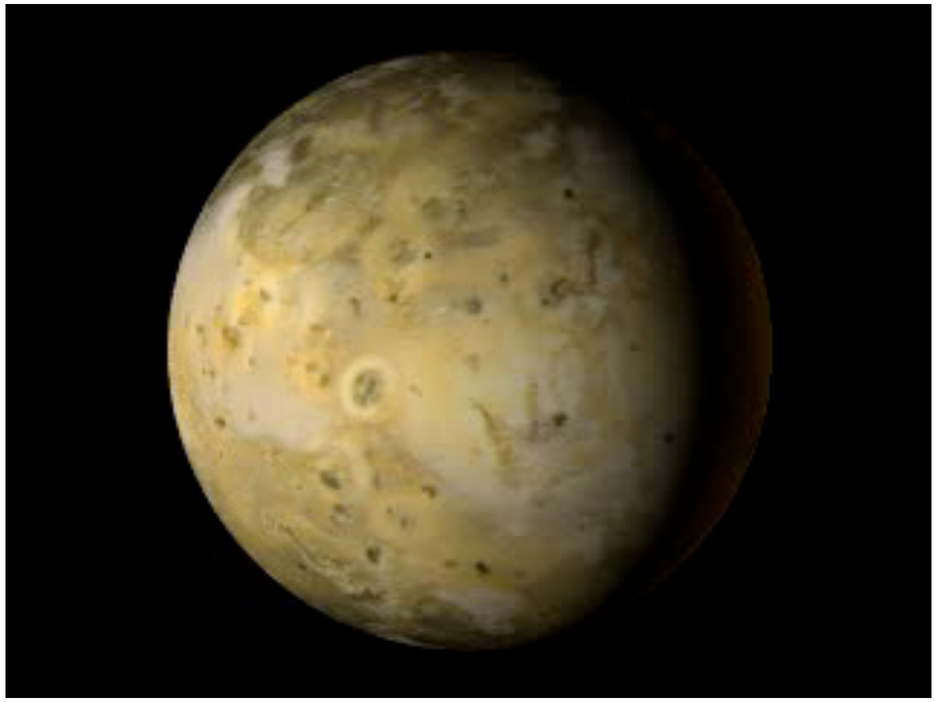


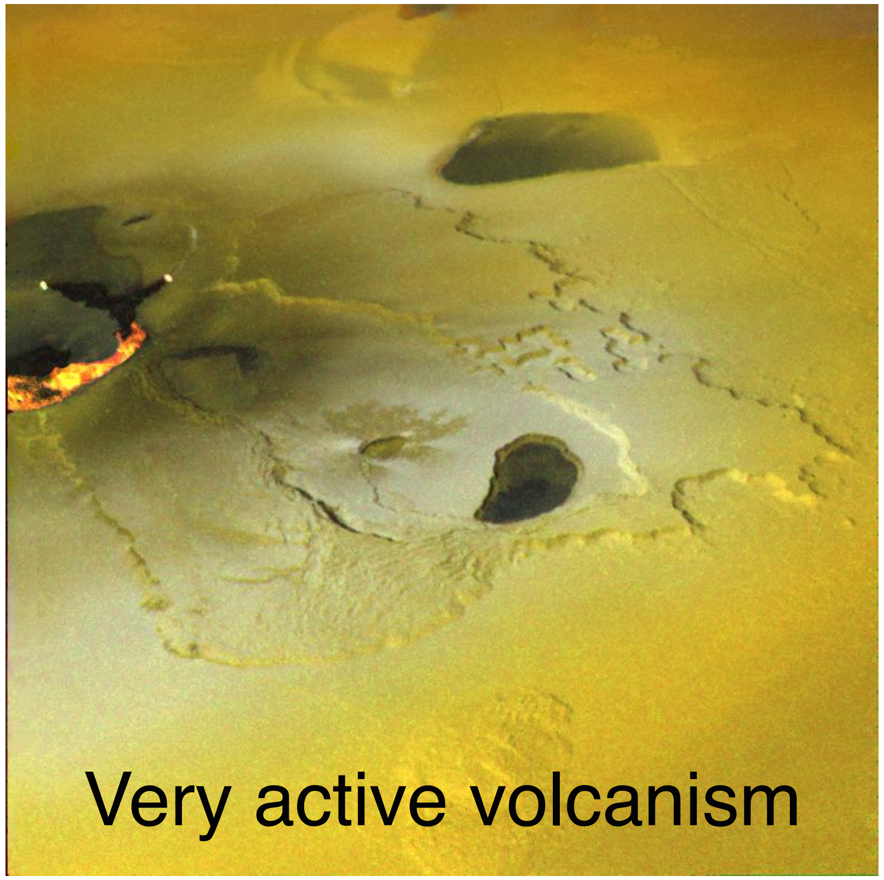
Io - surface features



Stratigraphy — actively changing

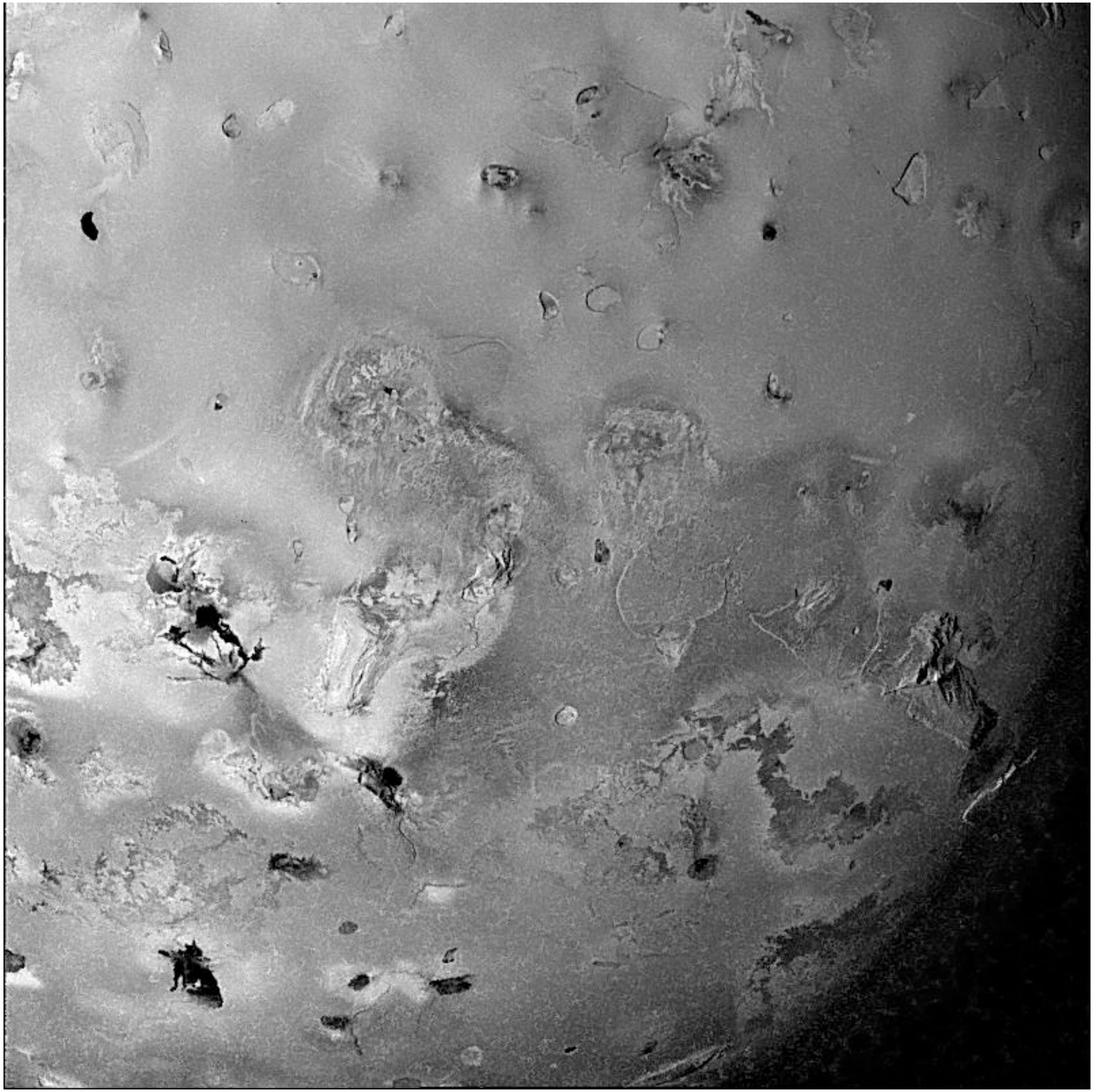
Io - surface features



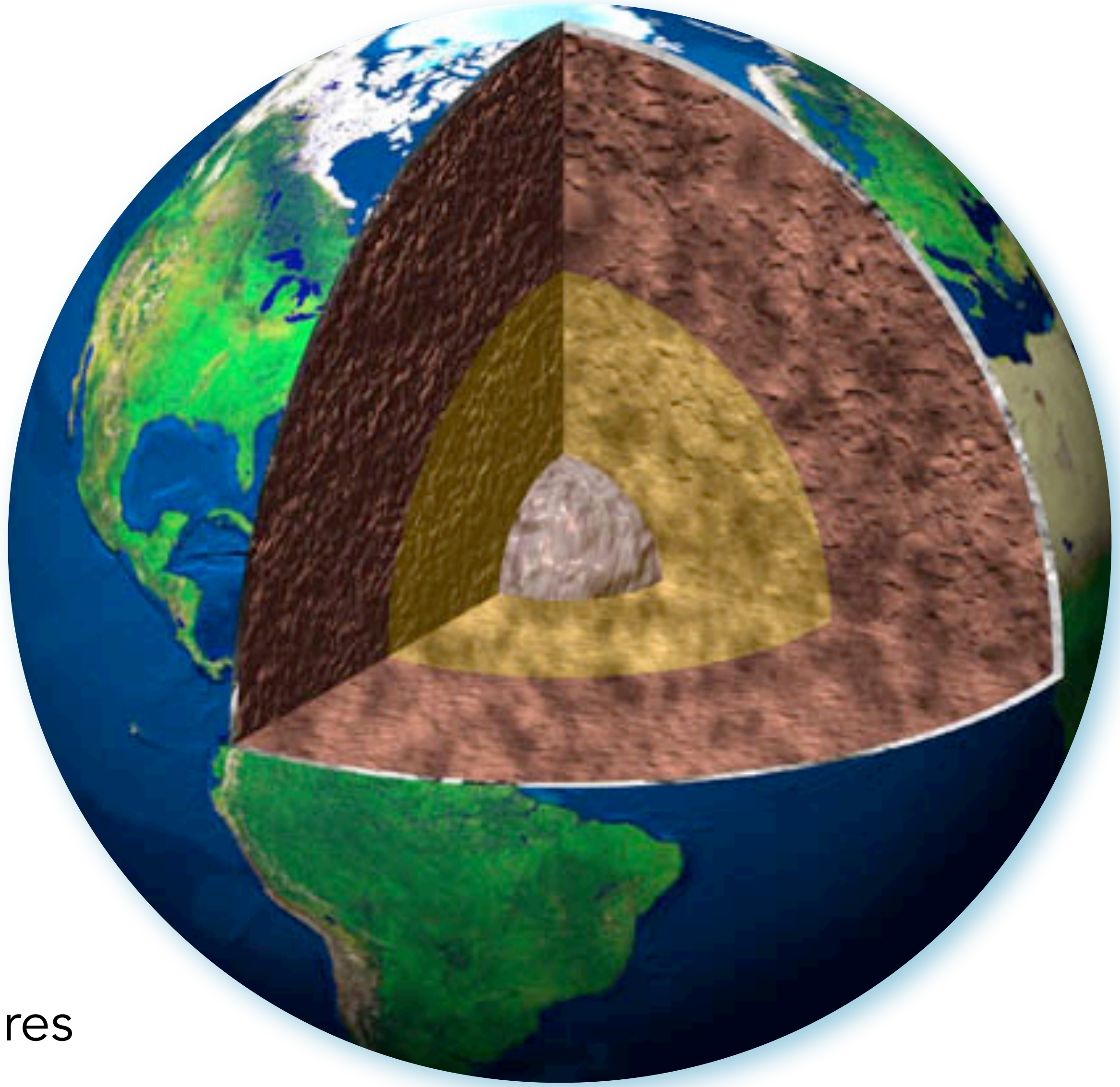


Io - surface features

Mountains
Plateaux
Calderas



Earth



Major layering

- Solid inner core
- Liquid outer core
- Solid silicate lower mantle
- Solid silicate upper mantle
- Crust (oceanic & continental)
- Hydrosphere/atmosphere/biosphere

Rheological domains

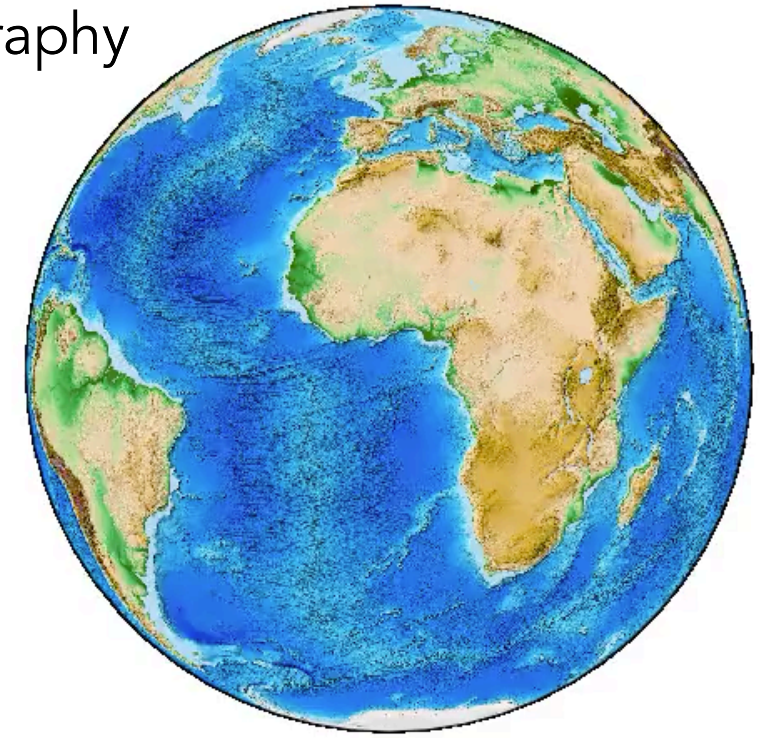
- Lithosphere
- Asthenosphere
- Transition zone
- D″ layer

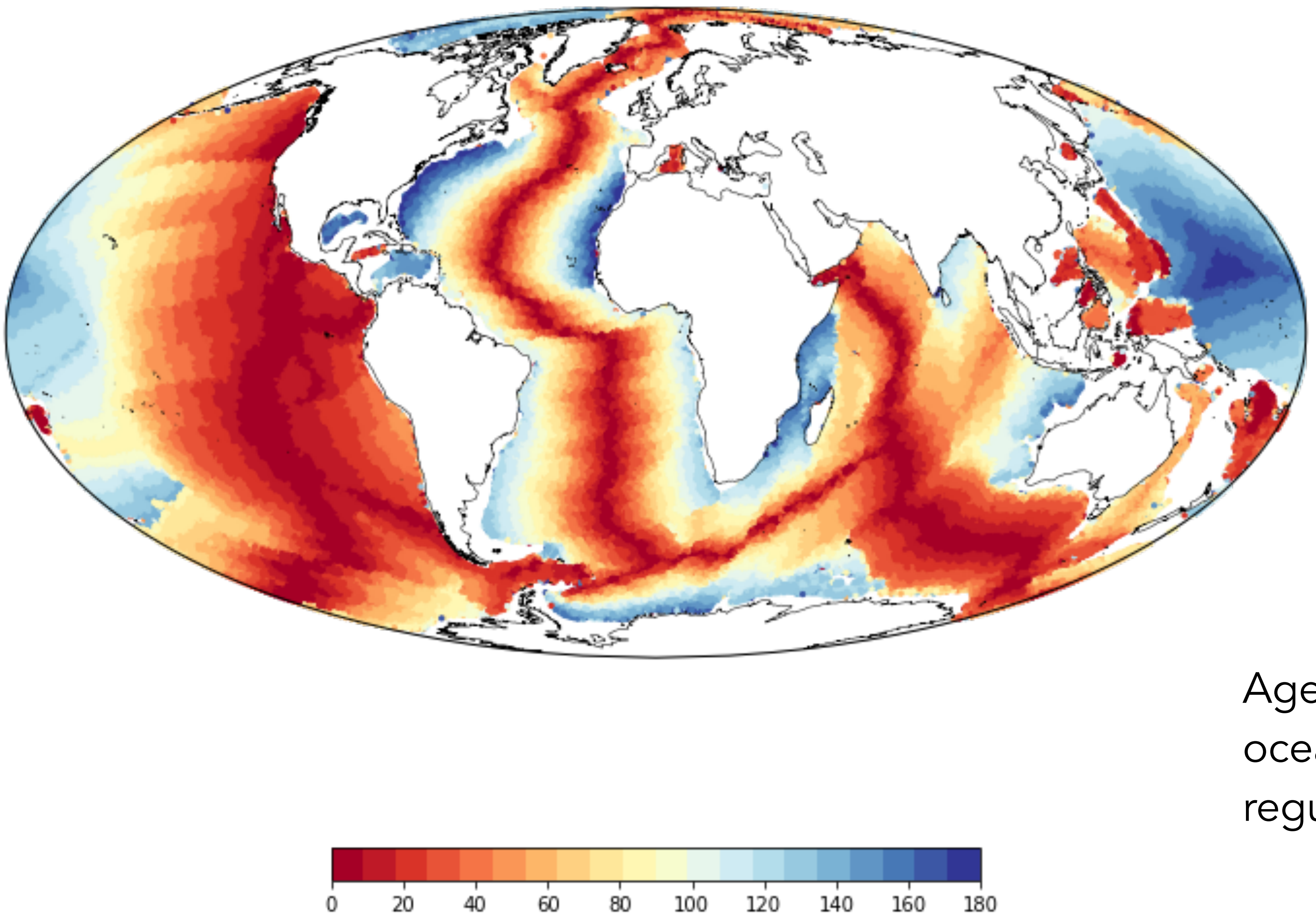
Surface Features

- Young ocean basins
- Continents of all ages
- Erosion, weather
- Active tectonics, volcanism, hotspots
- Isostasy
- Strong surface magnetic field

Earth - surface and more

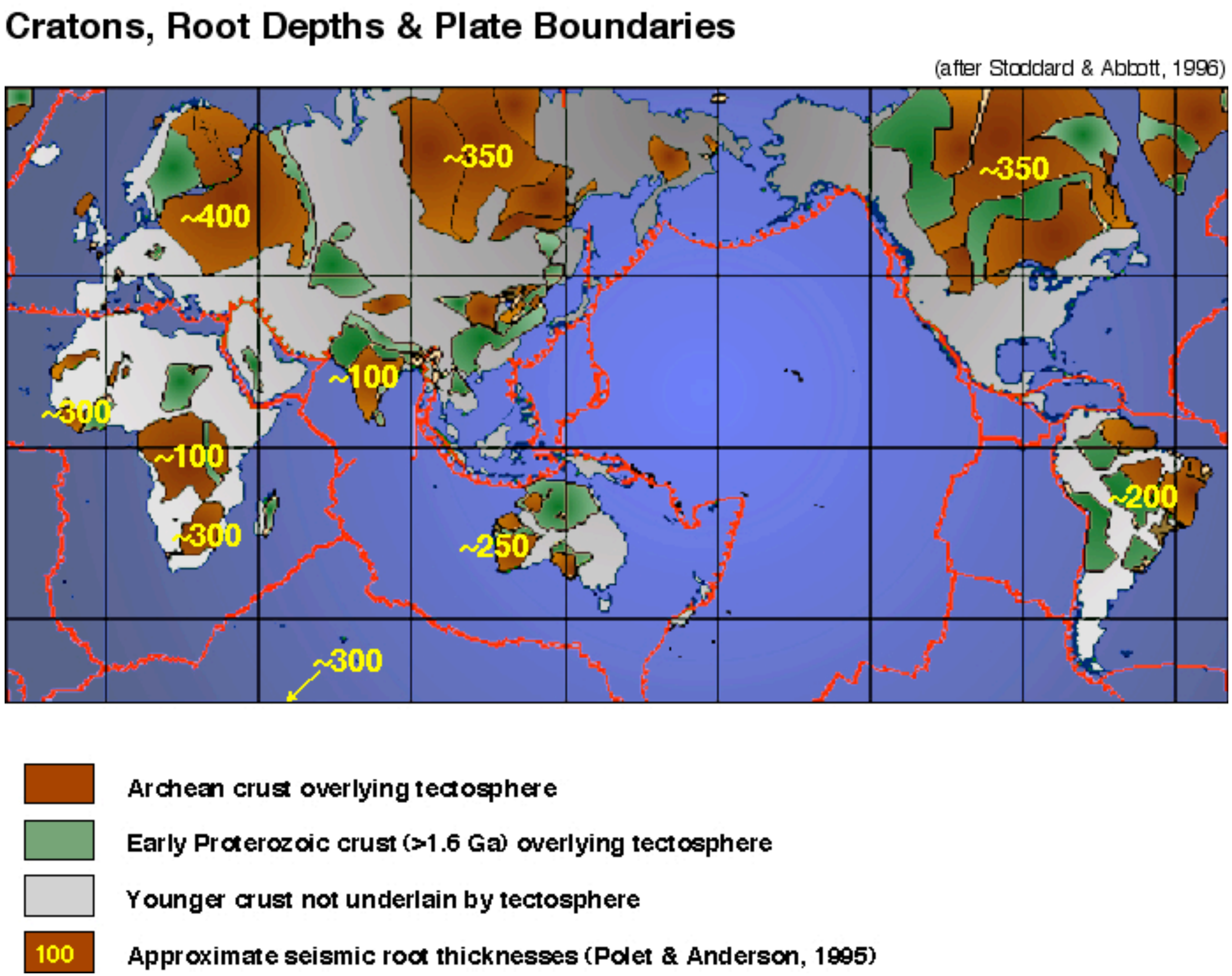
Bimodal topography





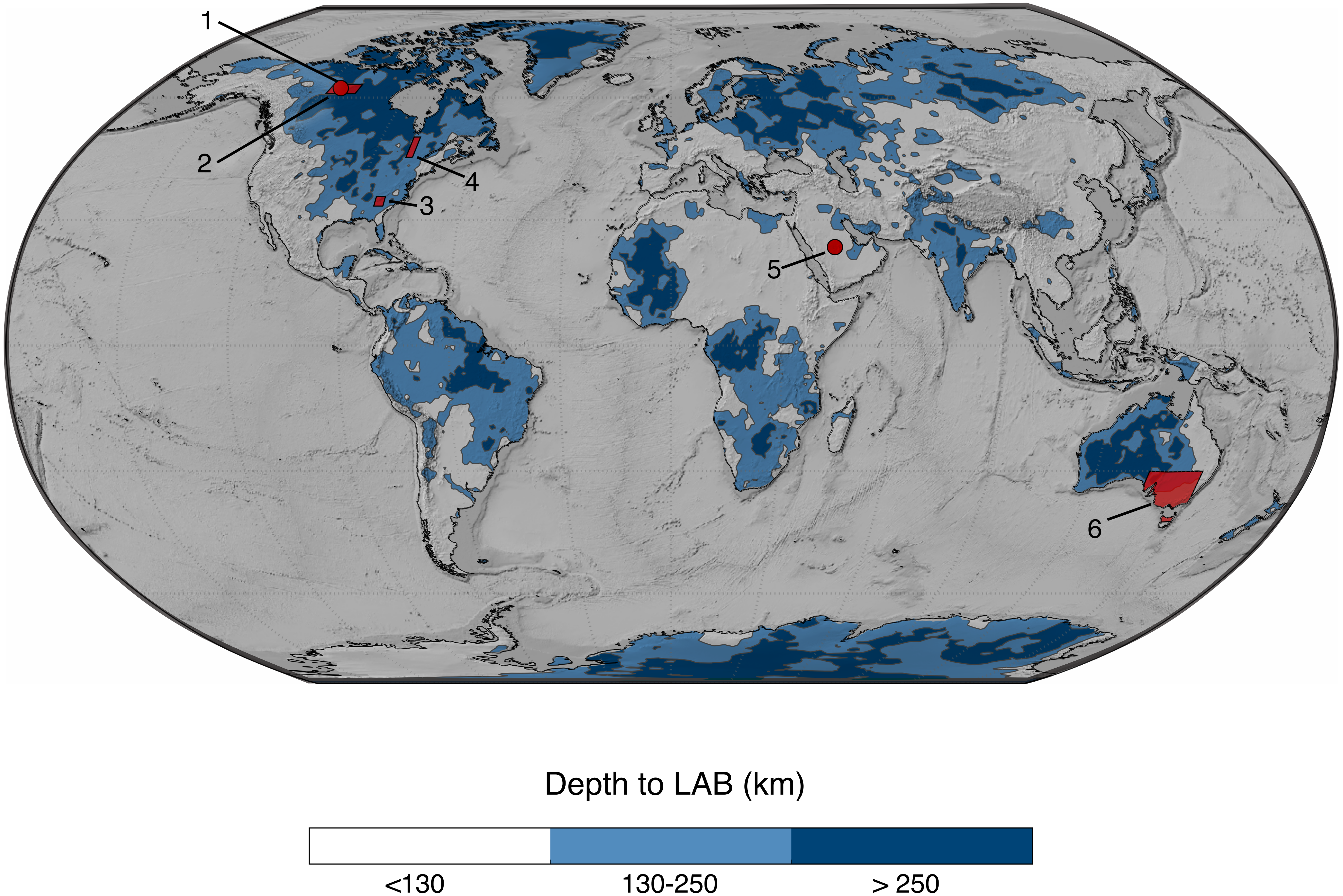
Age distribution in the ocean floor is systematic and regular 0 — ~200Myr.

Earth - surface and more



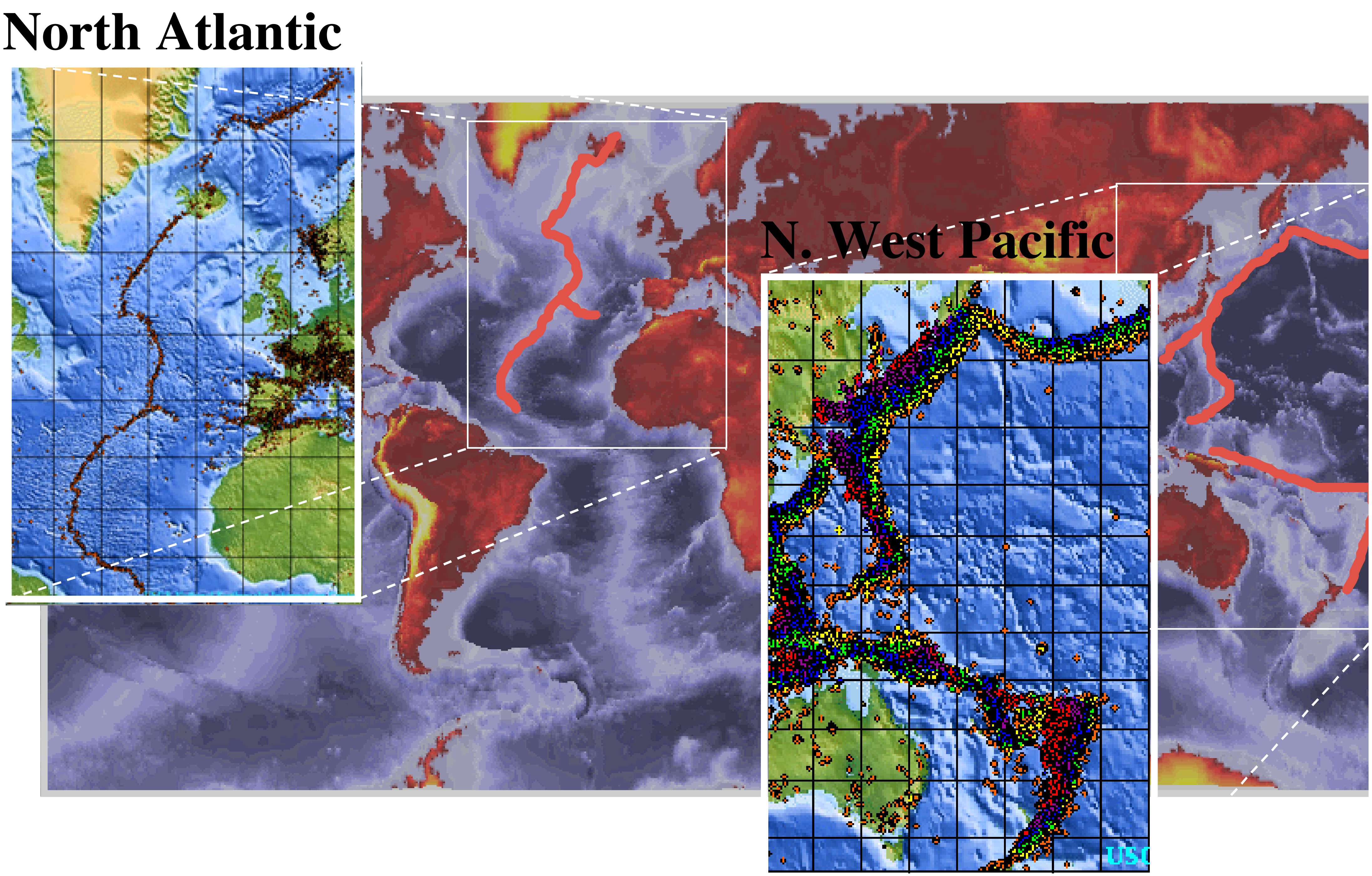
Age distribution in the continents an order of magnitude greater than in oceans

Earth - surface and more



Lithospheric thickness and age systematically related in the oceans and (differently) in the continents

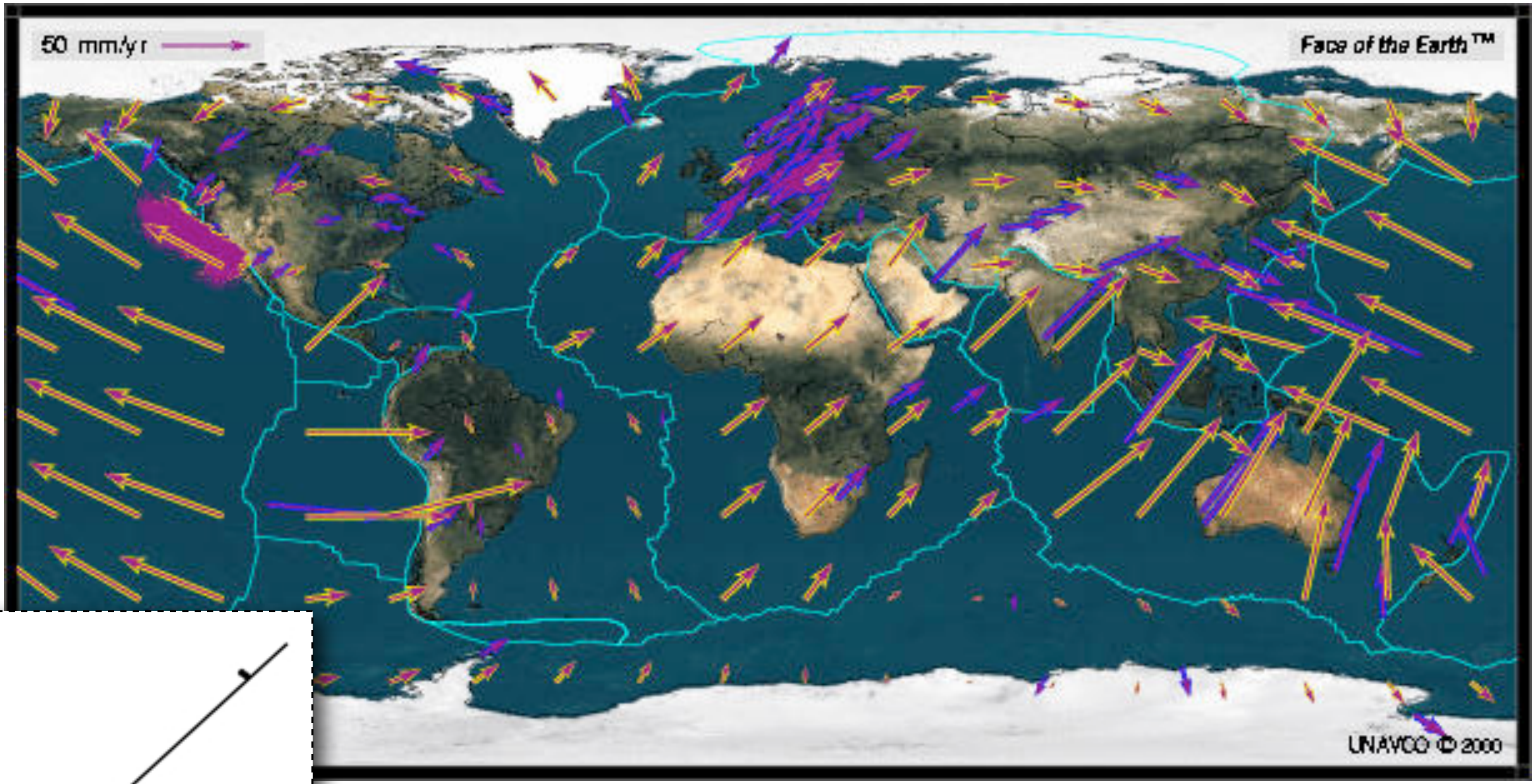
Earth - surface and more



Earthquakes cluster at plate boundaries, and there is also a difference in hypocentre-depth pattern with convergent / divergent boundaries.

Deep earthquakes are very very strongly correlated with convergent oceanic plate boundaries.

Earth - surface and more



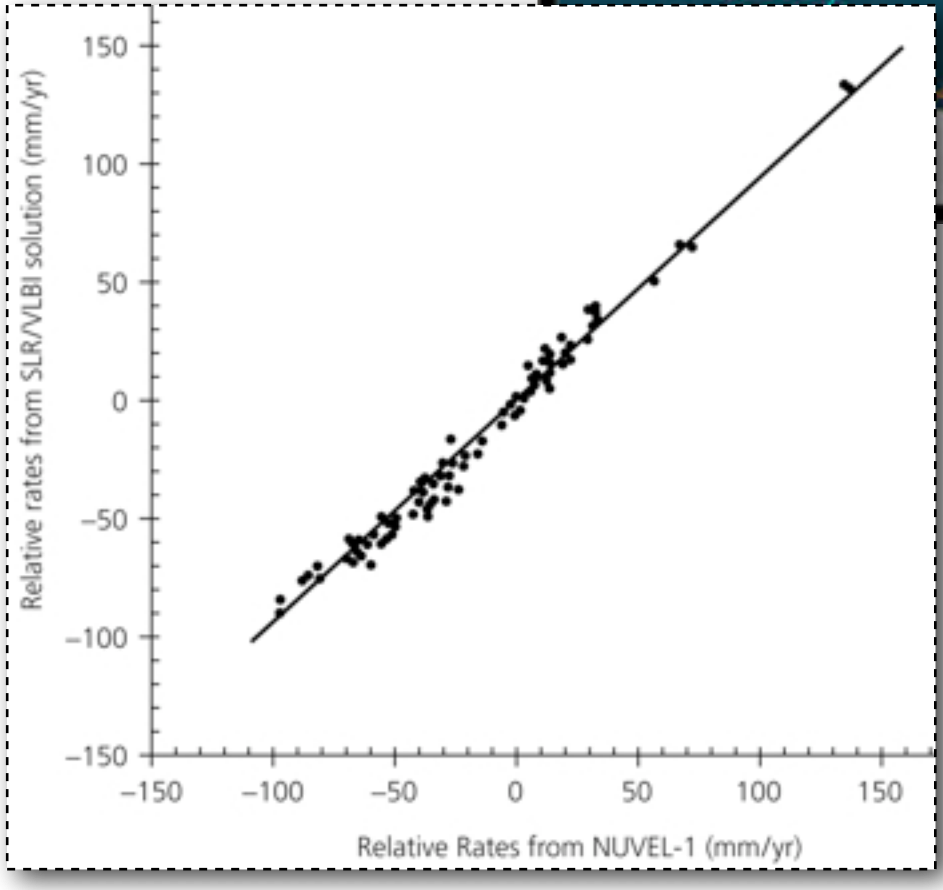
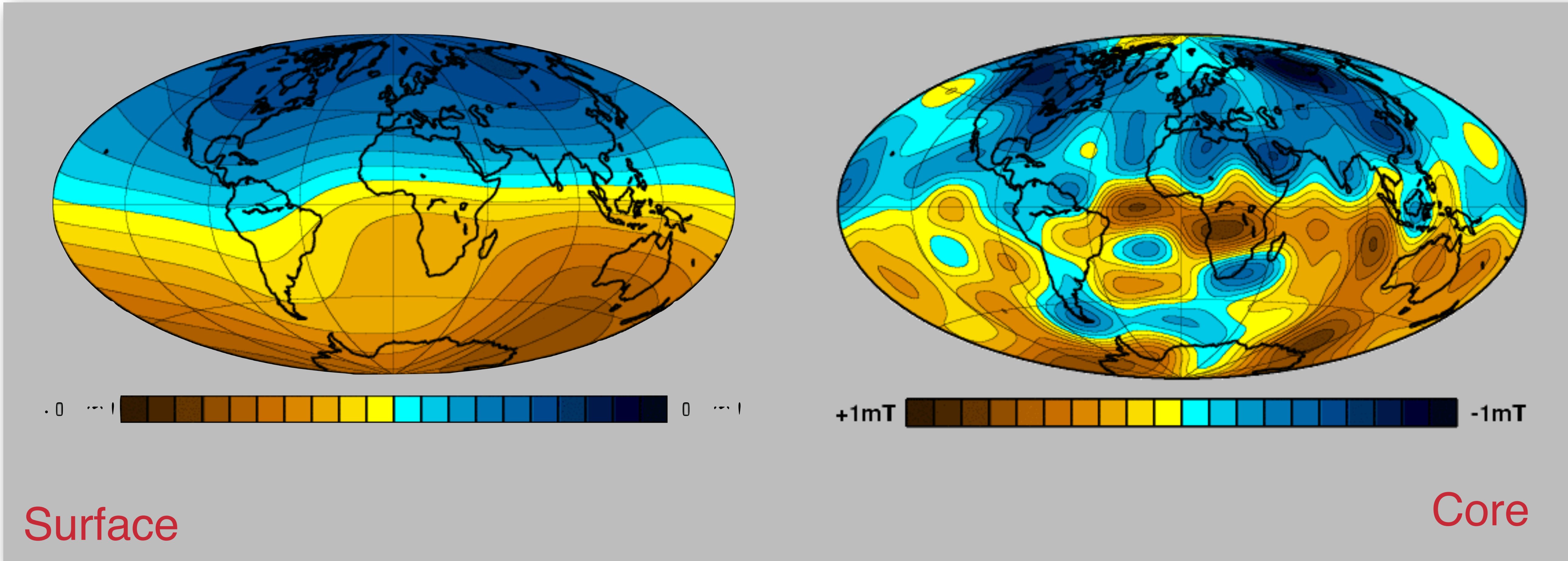


Plate motions over the short term and the long term agree (at the moment)

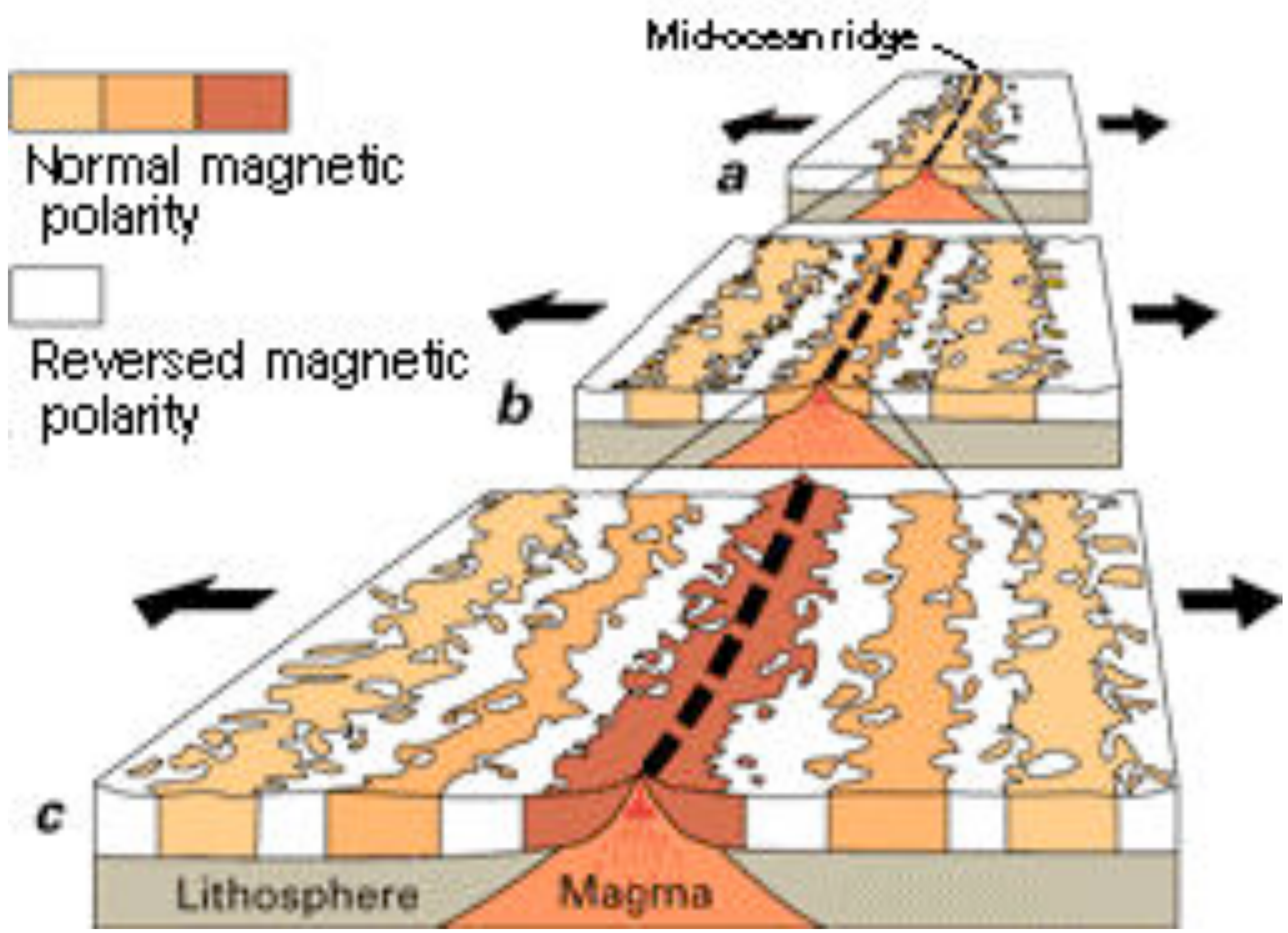
Earth - surface and more

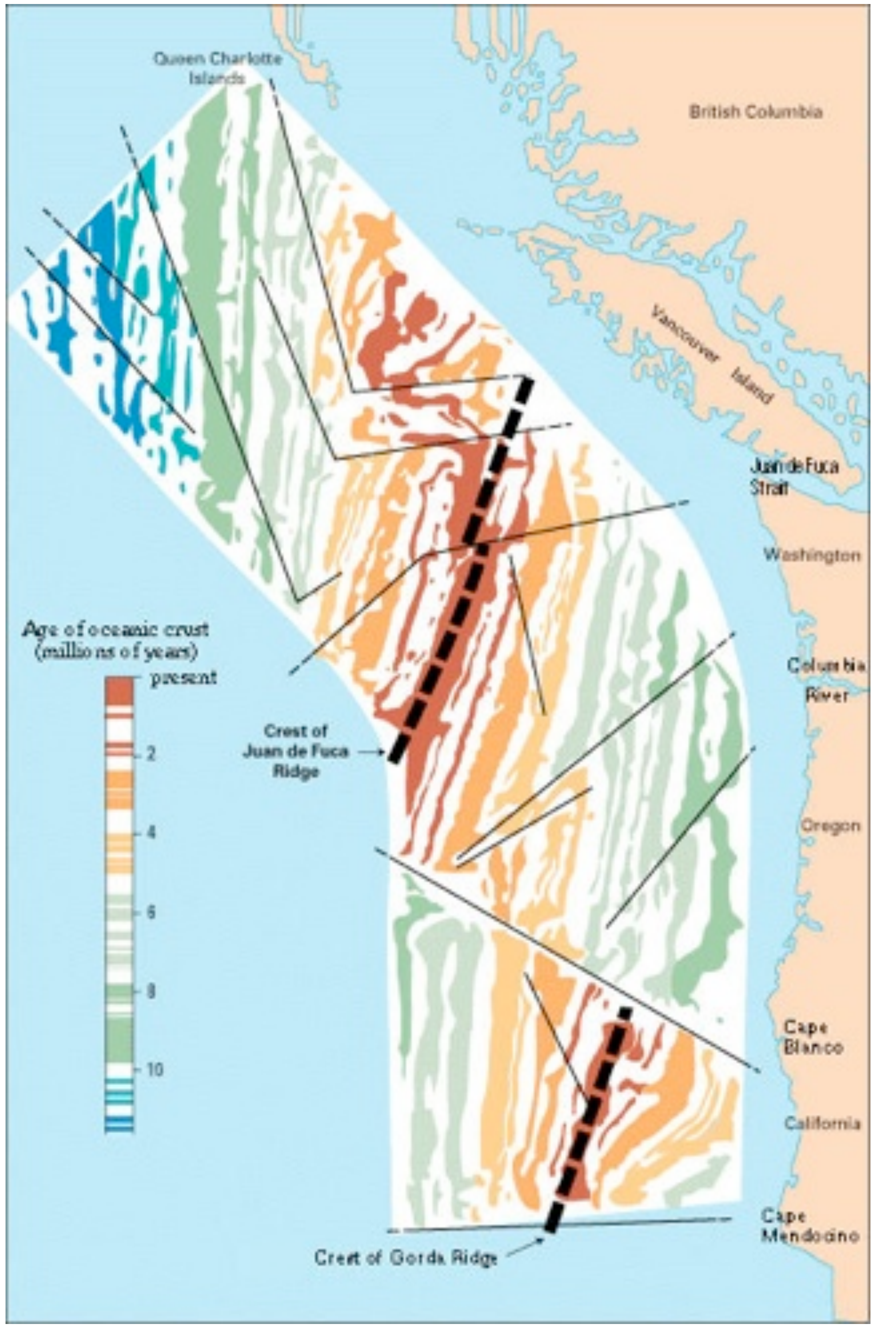


The Earth has a strong, dominantly dipolar, magnetic field which periodically reverses. This allows

- paleo-latitudes to be determined
- ocean floor ages to be determined.

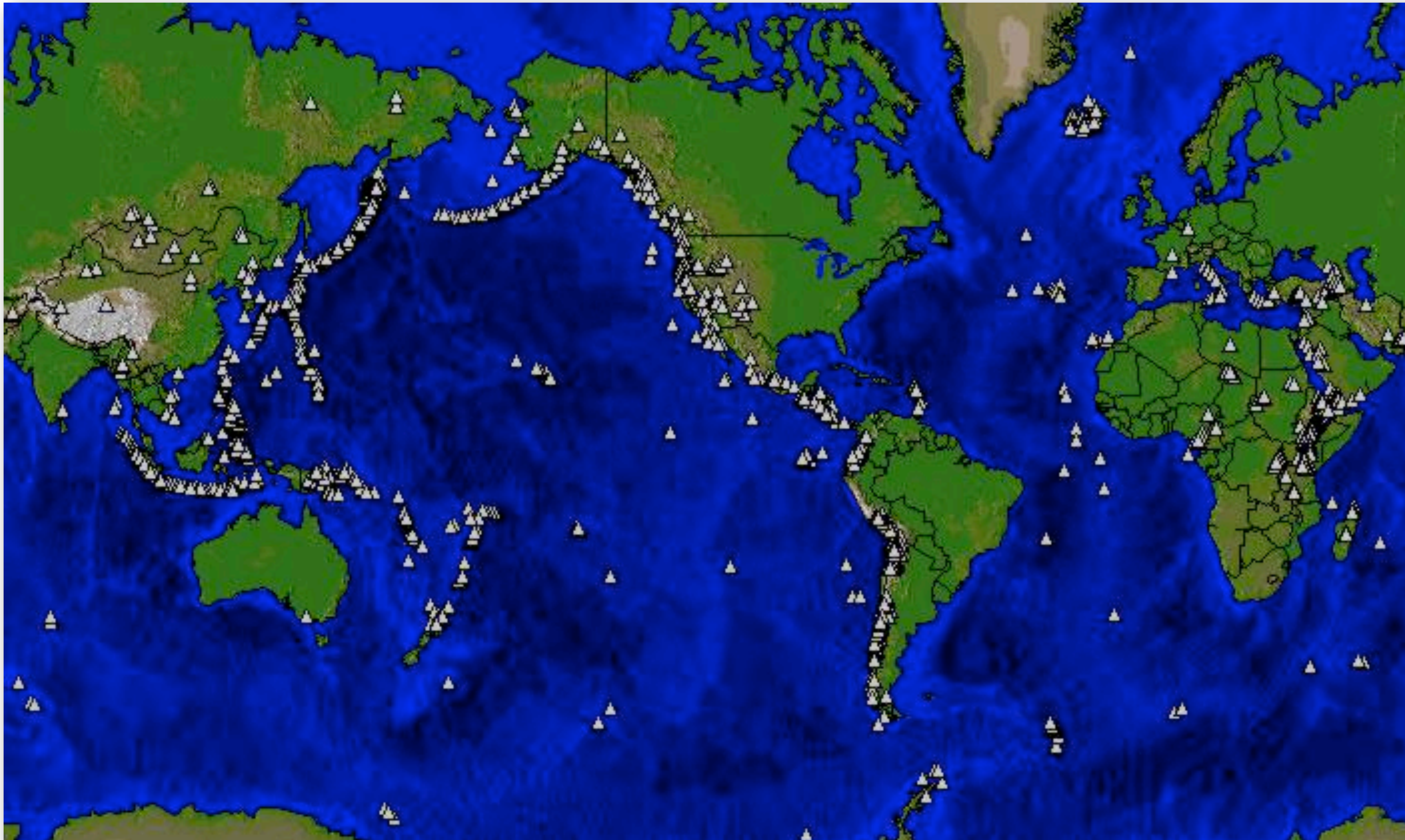
Earth - surface and more





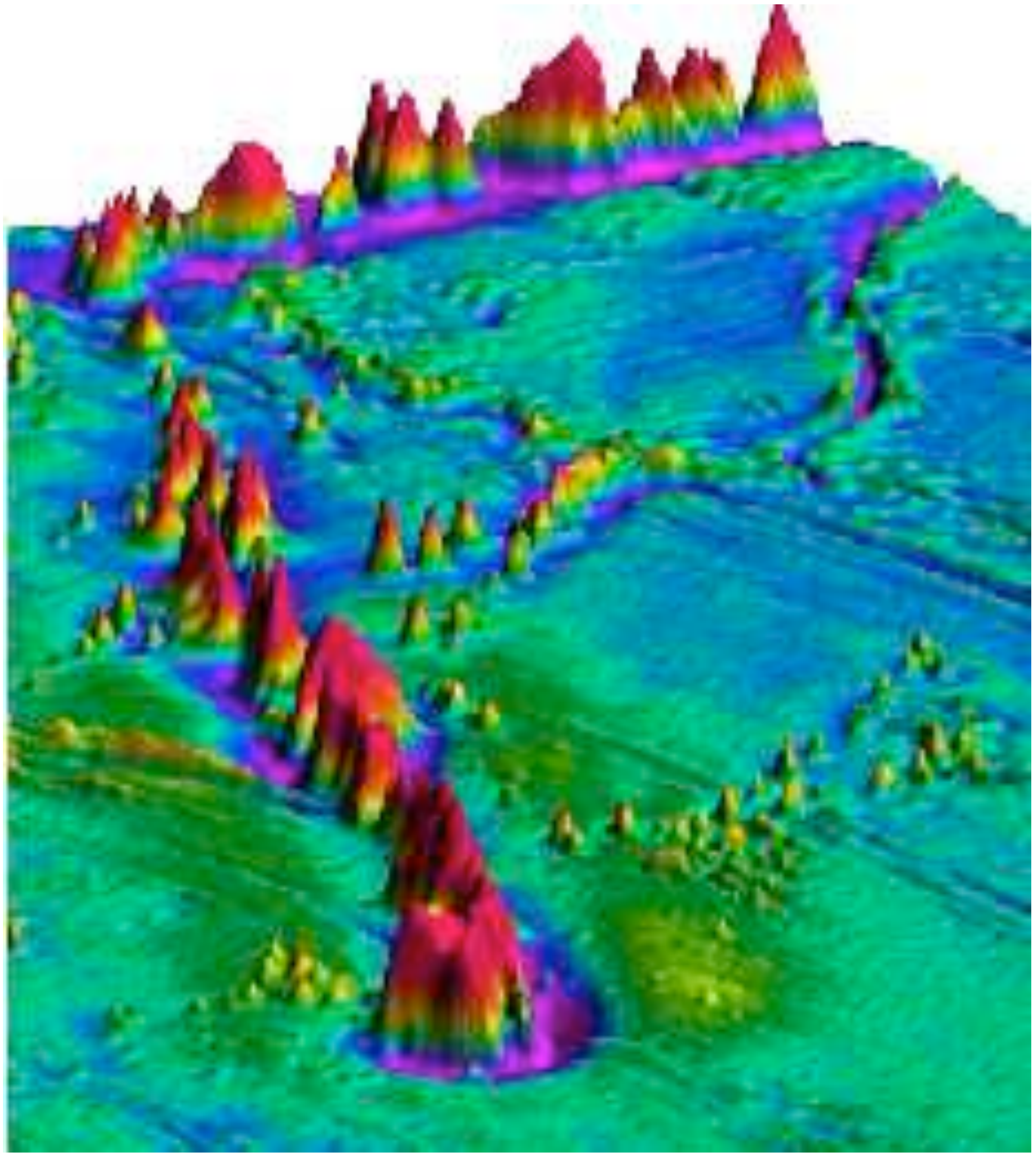
The chaotic fluctuation of the dipole field records a uniquely varying signature into rocks newly formed at mid-ocean ridges. fragments of the signal can then be used to date the ocean floor.

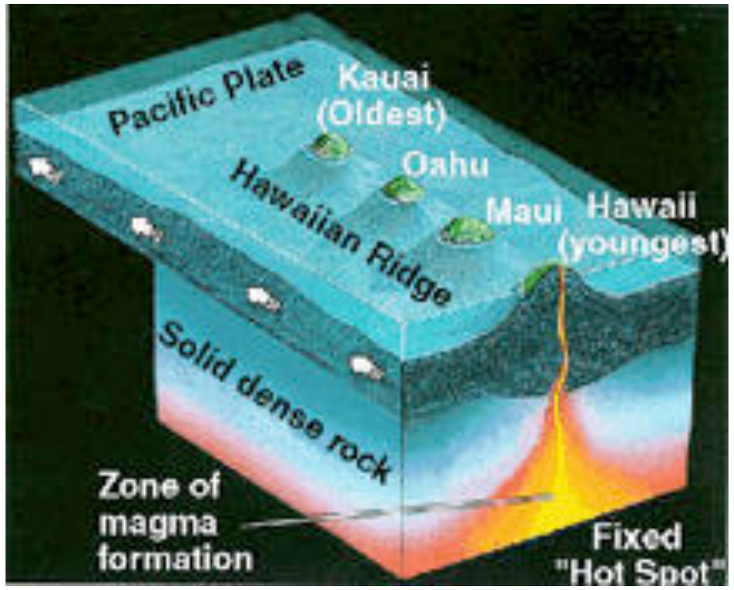
Earth - surface and more

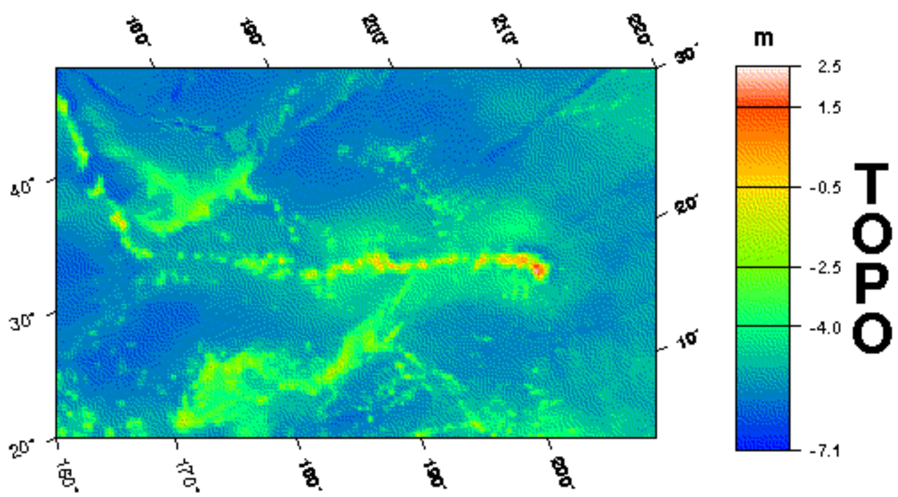


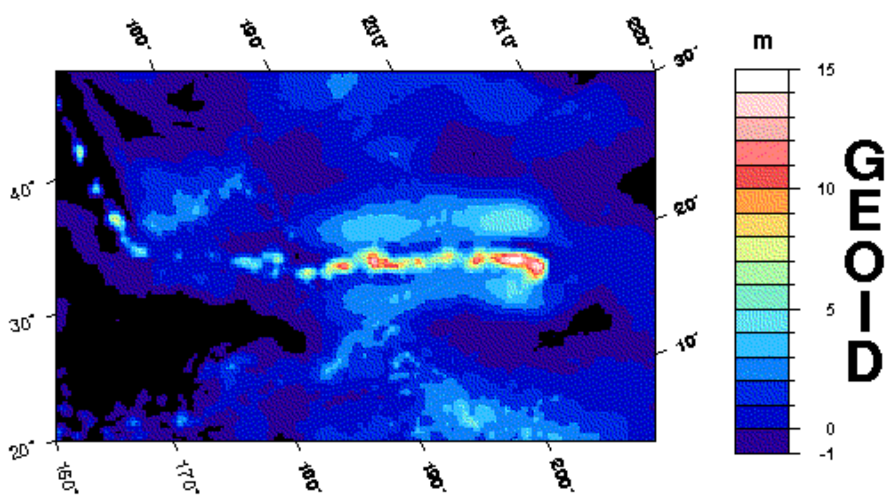
Volcanos are not distributed uniformly over the surface of the Earth but cluster along plate boundaries. There are also volcanic regions in the middles of some plates - at the so-called hotspots.

Earth - surface and more







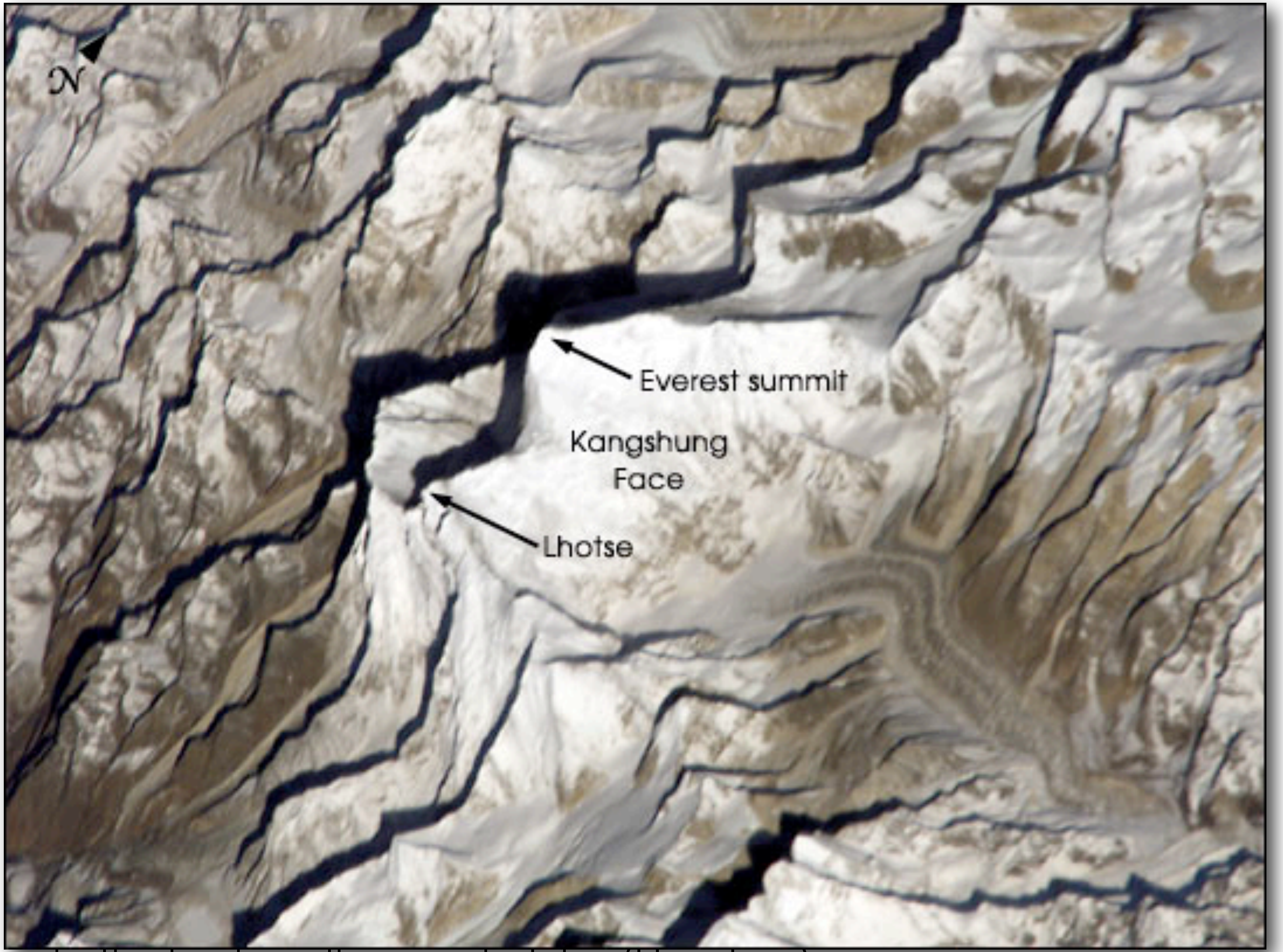


Hotspots — volcanic regions in the middle of plates which overhead

Earth - surface and more

Mountain belts due to collisions of plates (Andes)

Earth - surface and more

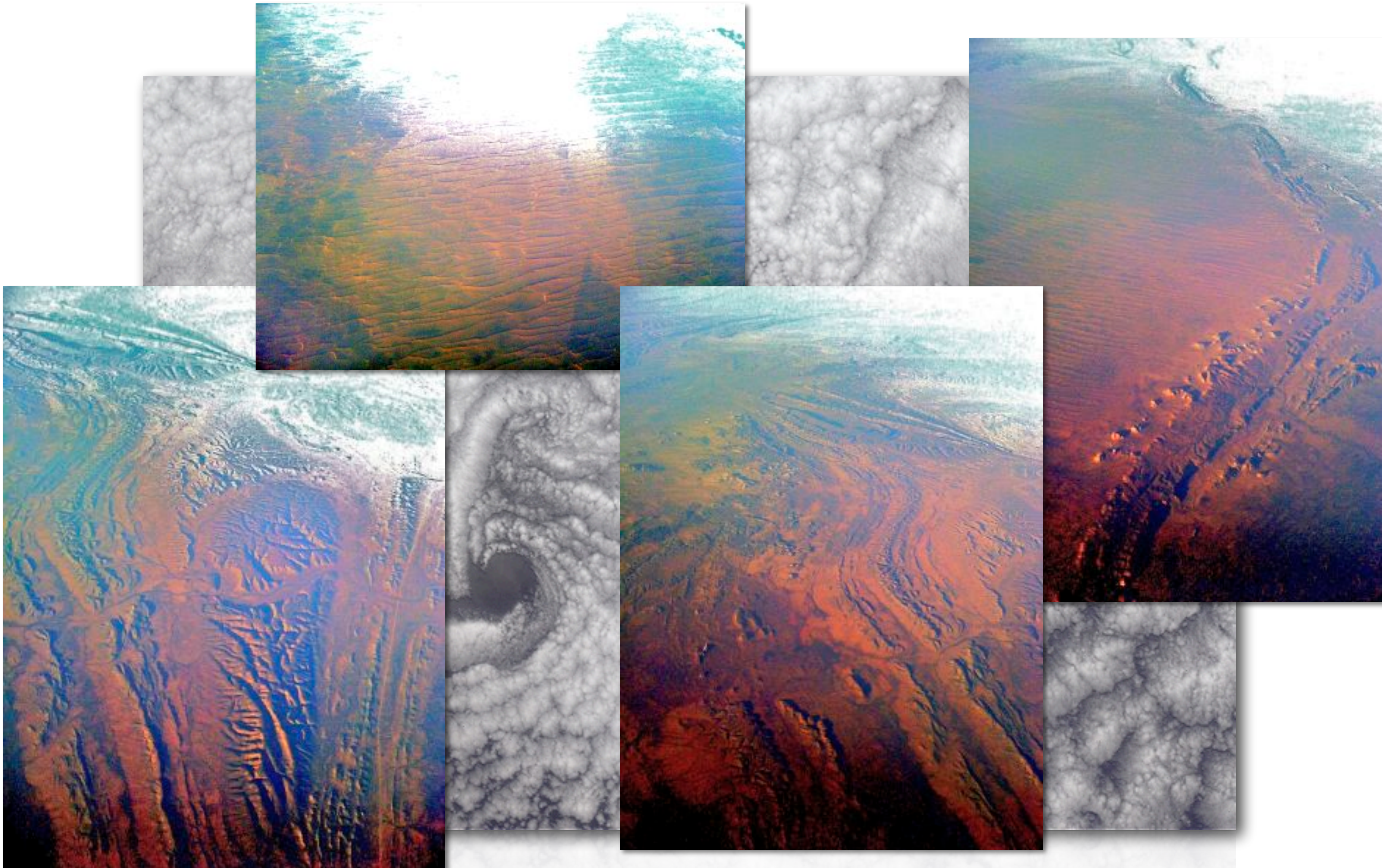


Mountain belts due to collisions of plates (Himalaya)

Earth - surface and more

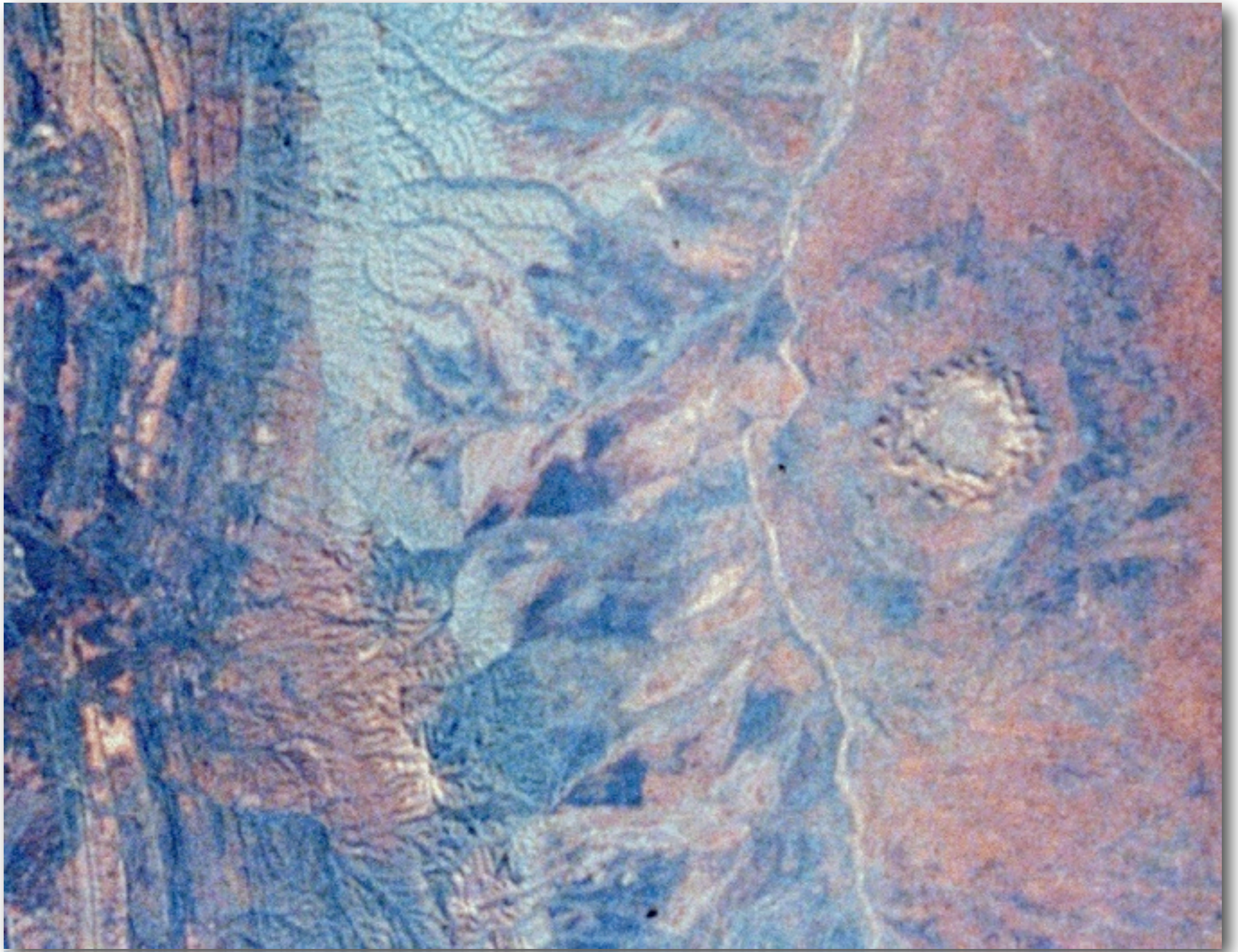
Mountain belts due to collisions of plates (San Gabriel)

Earth - surface and more



Effects of vigorous weather and oceans — erosion, material transport, sedimentation

Earth - surface and more

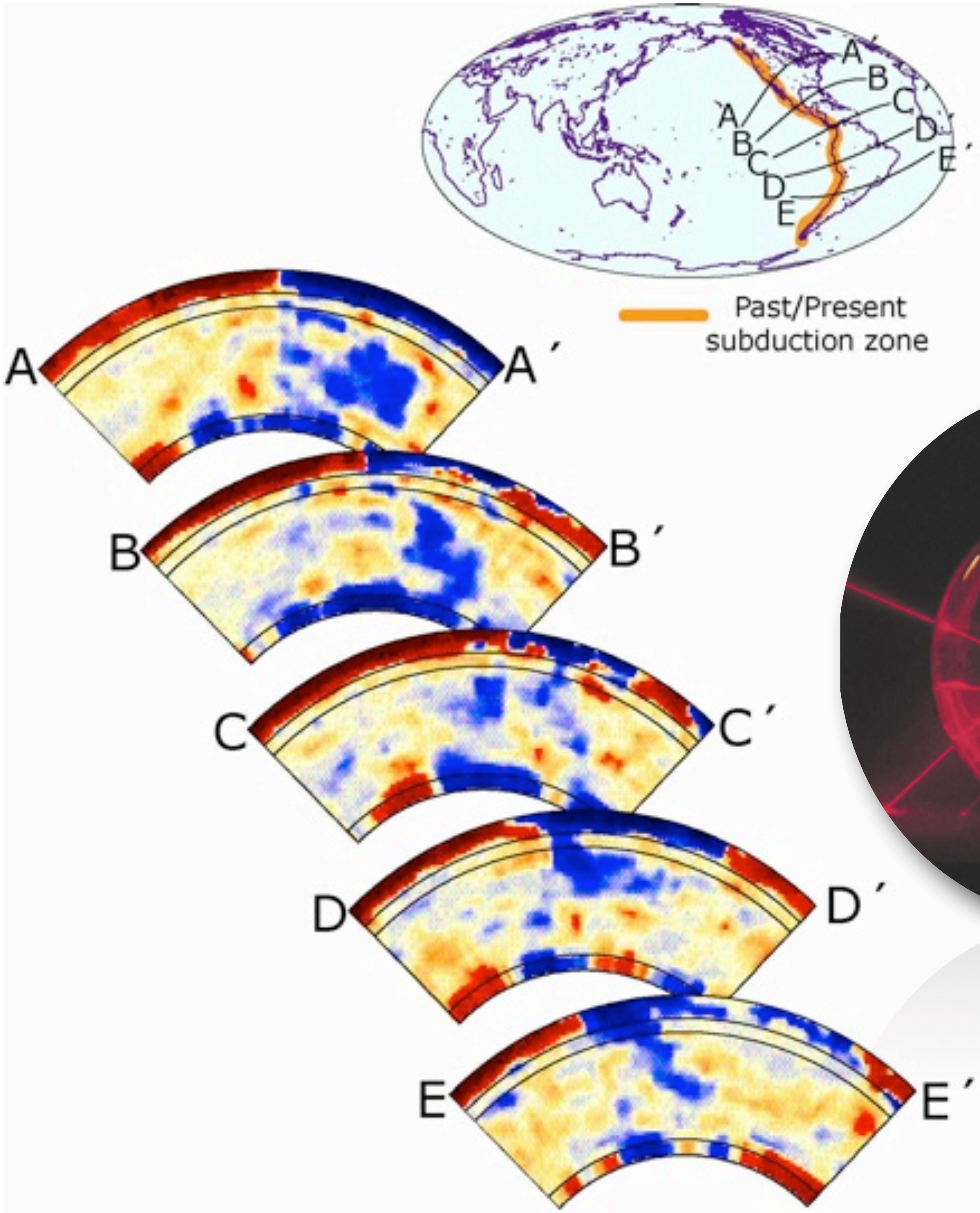


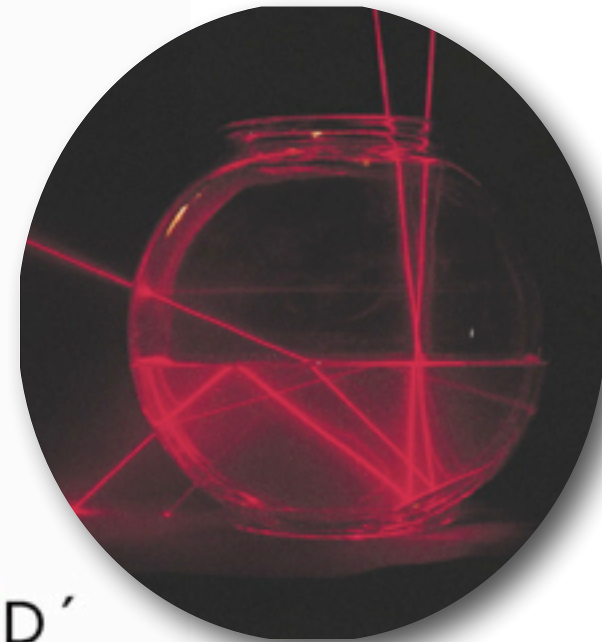
Gosse’s bluff

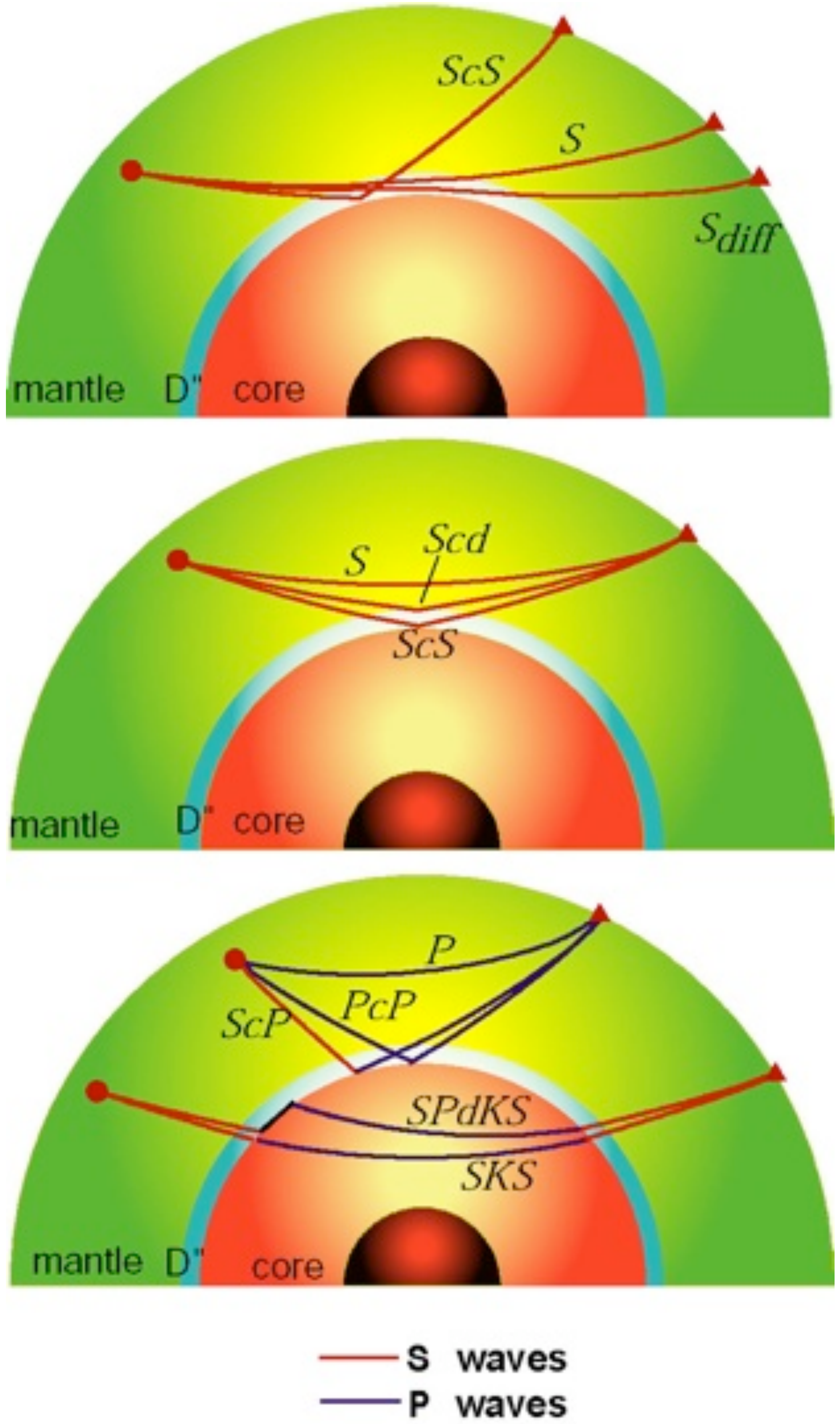
Impact craters are not a particularly obvious or important way to modify the surface at present

The presence of the biosphere and (intelligent) life: important feedback into tectonics and Earth evolution.

Earth - interior

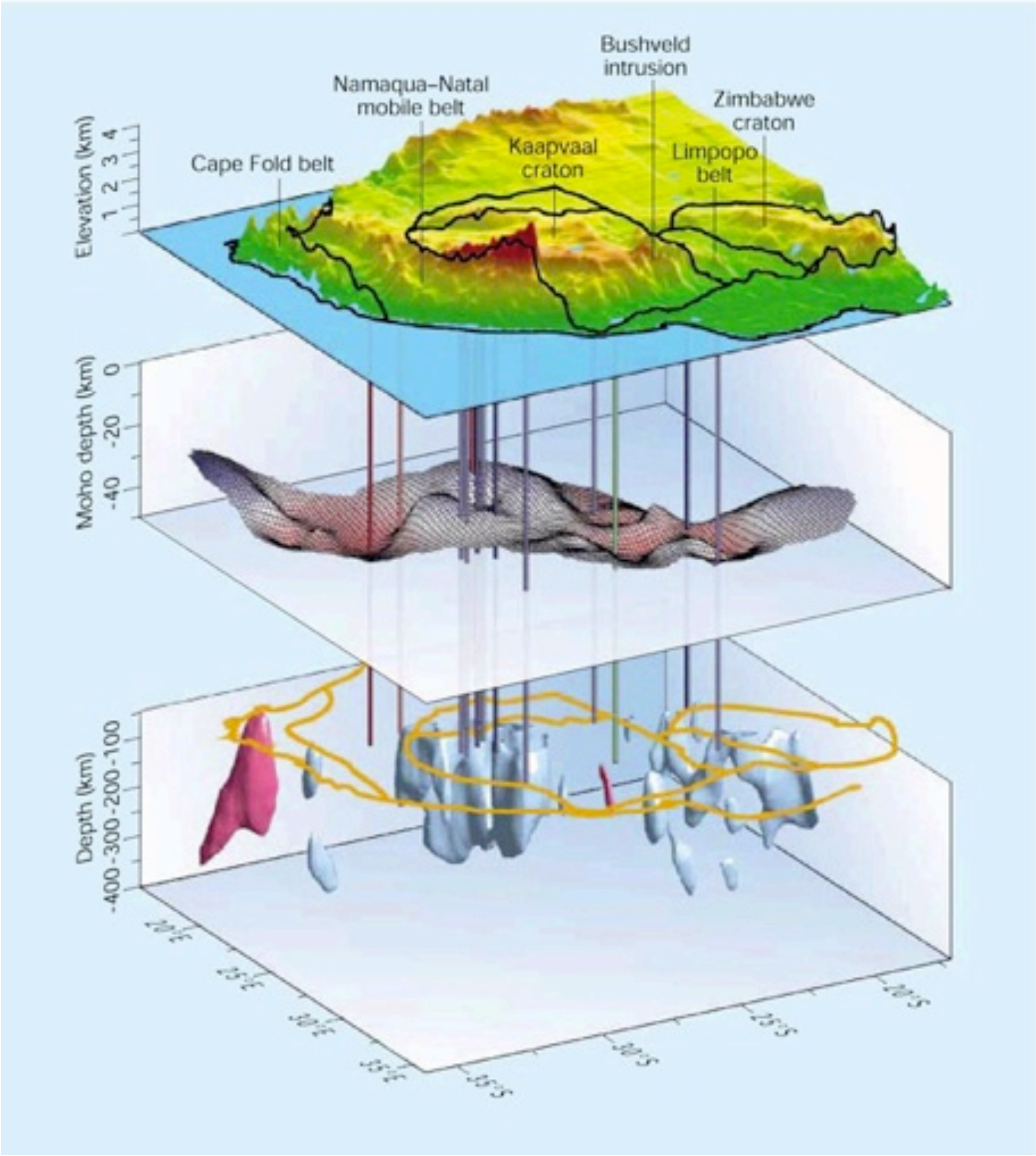






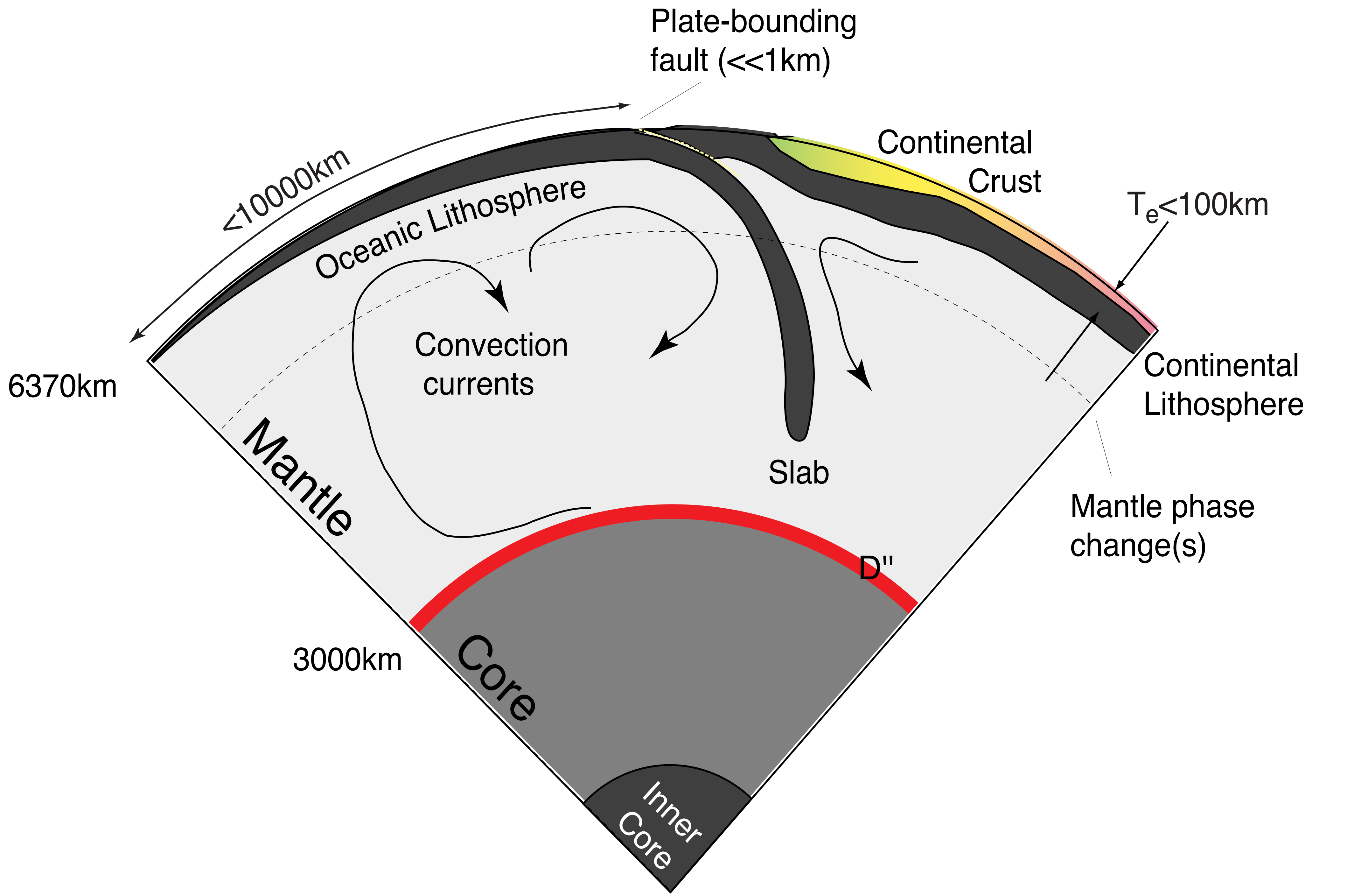
Seismology — elastic waves triggered by earthquakes propagating through the Earth allow us to image the interior in considerable detail (you know more about this now that I do)

Earth - interior



Xenoliths — rocks dredged up from the “deep” interior during volcanic eruptions etc.

Dynamics of planets



We have a reasonable 3D picture of the Earth from the many methods of remote sensing + theoretical models

Dynamics of planets

For other planets we have very good remote sensing for the surfaces such as

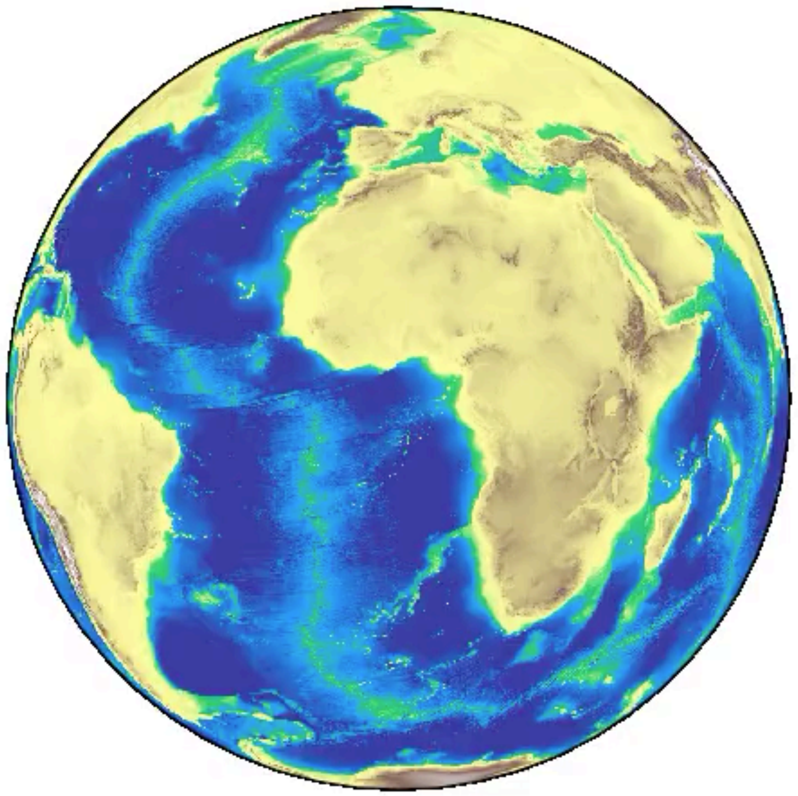
- Composition (e.g. X ray fluorescence)
- Imaging (radar, visible, IR, UV etc)
- Samples
- Altimetry
- Gravity anomalies

but very little information about the interior

- coupling of mass distribution into spins
- volcanic activity and composition

What is the Rayleigh number of the Earth's mantle ?

- Gravity is about 10ms^{-2} throughout
- Density 3000 kg m^{-3}
- Thermal expansivity 10^{-5} K^{-1}
- Temperature drop 1300 K
- Thickness of the mantle is roughly 3000km
- Thermal diffusivity 10^{-7} m^{2}s^{-1}
- Viscosity 10^{23} Pa.s



Is it above the critical value ?

What does that tell us ?

Summary

Convection is a heat engine (i.e. it converts heat energy into mechanical work)

Convection is a balance between heat transported by fluid motion and diffusion. The fluid self-organises to create large scale patterns "out of nowhere"

In tanks of viscous fluids like syrup or honey, convection depends on just the one free parameter which is a combination of fluid properties, geometry and boundary conditions — this is called the Rayleigh number.

If we know the Rayleigh number, we can predict the heat flow and typical velocity of the system

If the Rayleigh number is below a critical value, convection dies away even if it is stirred up to begin with … but if the Rayleigh number is more than (about) ten times this value then convection cannot be suppressed.

The Earth's mantle is super-critical and so it is guaranteed to be convecting.

None of these simple models actually produce plate tectonics but they do still tell us about the heat flow in the Earth.