Introduction to Environmental Science and Engineering

(ENV – 167)

Anders Meibom

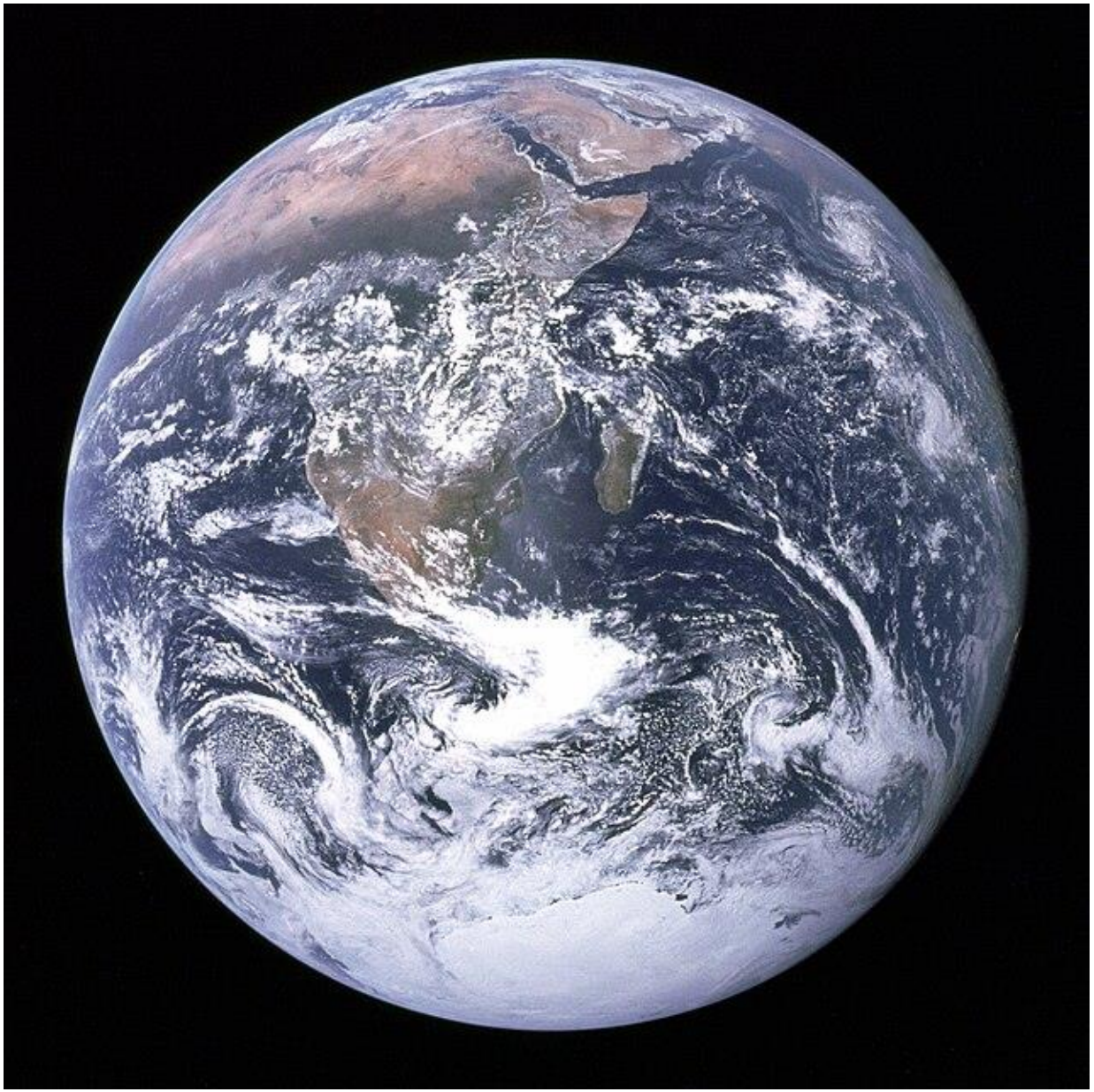
Welcome

Our program

Week	day	Topic	Professor
Sep.09	Monday	Introduction	Anders Meibom
Sep.11	Wednesday	**Oceans, mountains and poles**	Jérome Chappellaz
Sep.16		No class	
Sep.18	Wednesday		Tom Battin
Sep.23	Monday		Anders Meibom
Sep.25	Wednesday		Hendrik Huwald
Sep.30	Monday		**Exercise**
Oct.02	Wednesday	**Environmental sensing, mapping, robotics, environmental health, data science**	Mirko Kovac
Oct.07	Monday		Devis Tuia
Oct.09	Wednesday		Stephane Joost
Oct.14	Monday		**Exercise Joost**
Oct.16	Wednesday		**Exam 1**
Oct.21		No class	
Oct.23		No class	
Oct.28	Monday	**Water we use**	Florian Breider
Oct.30	Wednesday		Tamar Kohn
Nov.04	Monday		Urs von Gunten
Nov.06	Wednesday		**Exercise**
Nov.11	Monday	**Soils, microbes and plants**	Hannes Peter
Nov.13	Wednesday		Ianina Altshuler
Nov.18	Monday		Christoph Bachofen
Nov.20	Wednesday		**Exercise**
Nov.25	Monday	**Atmospheric processes and climate, from the poles to the eastern mediterranean**	Julia Schmale
Nov.27	Wednesday		Athanasios Nenes
Dec.02	Monday		Satoshi Takahama
Dec.04	Wednesday	**Energy, resources and the urban environment**	Michael Lehning
Dec.09	Monday		Beate Jessel
Dec.11	Wednesday		Jérome Chenal
Dec.16	Monday		Lyesse Laloui
Dec.18	Wednesday		**Exam 2**

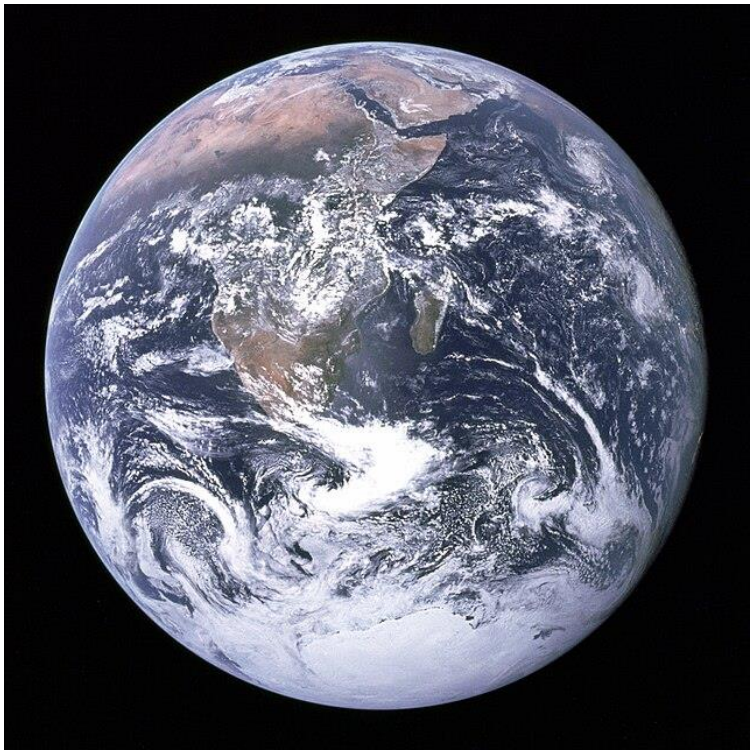
Now – let’s introduce the star of the show …..

The Earth



The Earth

A planet with an average radius of 6371 km.



How did it form?
What is it composed of?
How old is it?
How does it work?

The climate system: atmosphere, hydrosphere, cryosphere and biosphere

… a brief introduction.

A good resource:
Understanding the Earth by Grotzinger and Jordan.
Publisher: Freeman and Company.

The Solar System

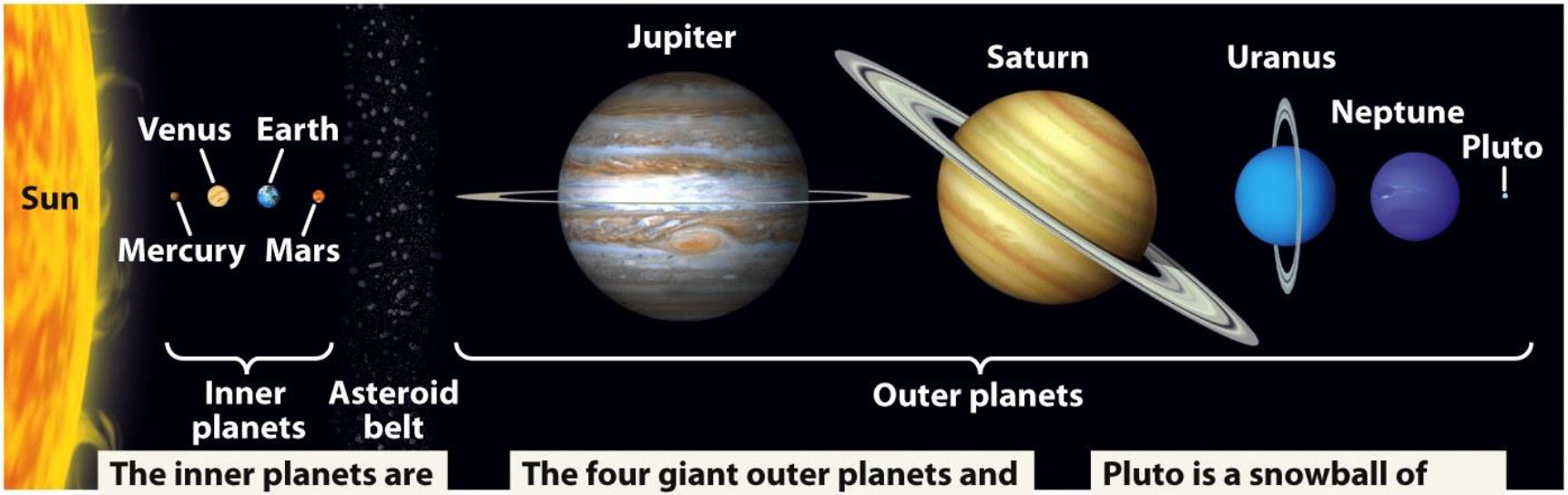
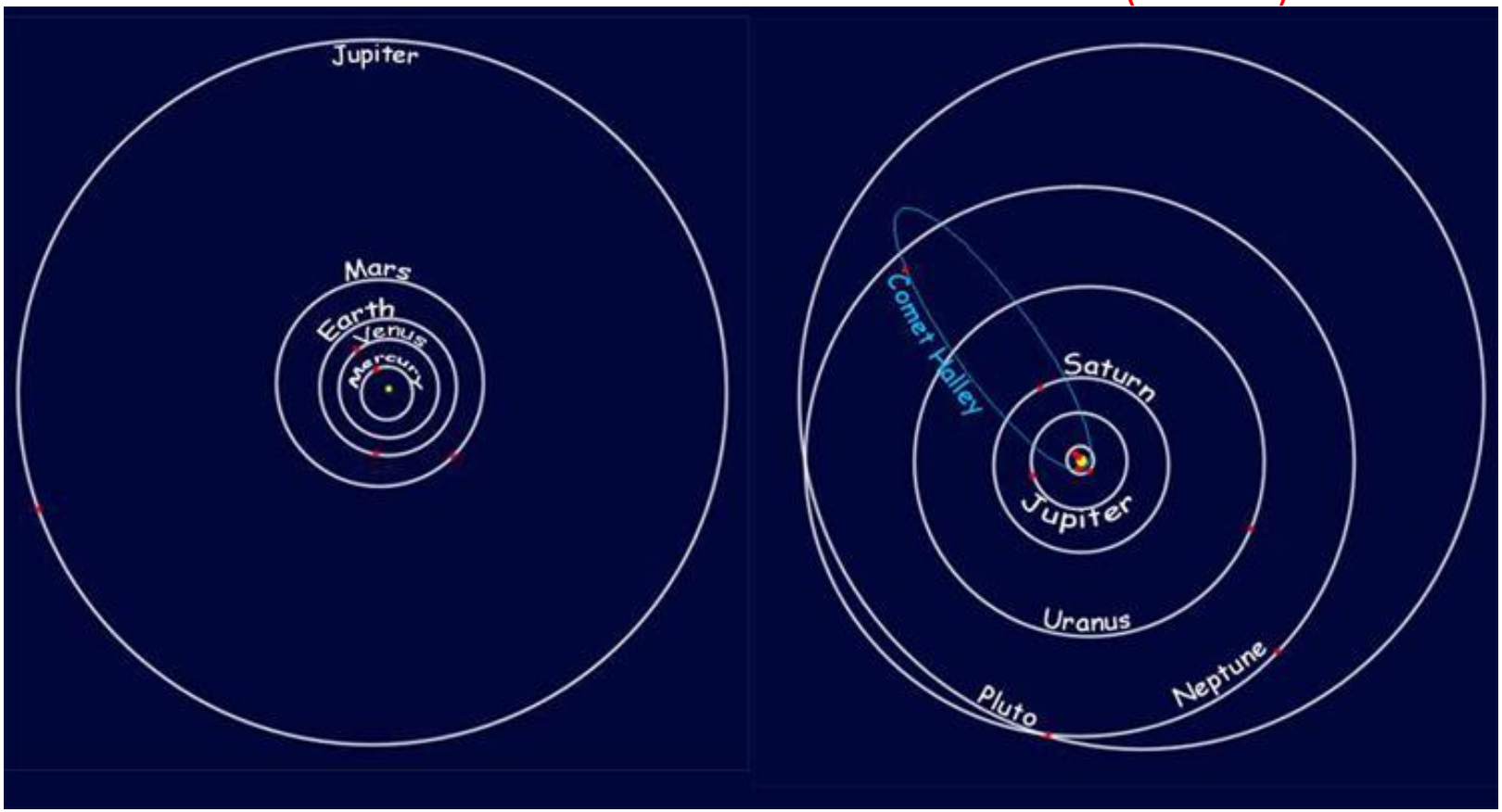


Figure 9.3
***Understanding Earth*, Sixth Edition**

The Solar System

Distance from Earth to the Sun: 1.5 million kms (= 1 A.U.)



How did the Solar System form?

Solar System formation

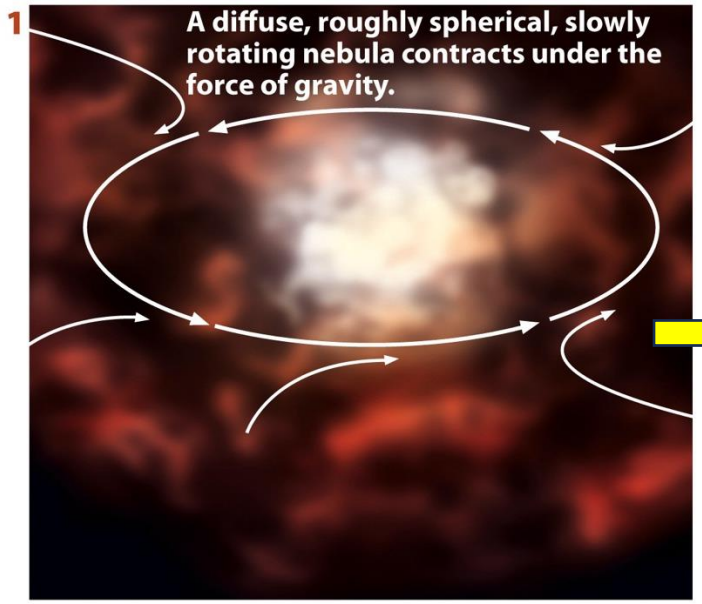


Figure 9.2 part 1
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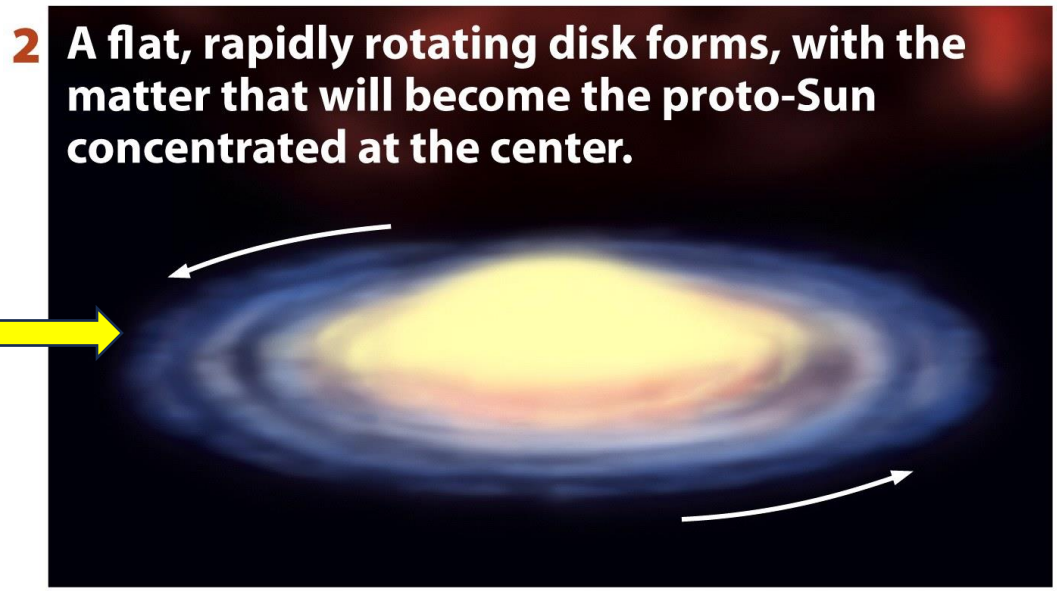

Figure 9.2 part 2
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200 000 AU

500 AU

The planets form in this disk, which is why they all circle the Sun in roughly the same plane: The ecliptic.

Solar System formation

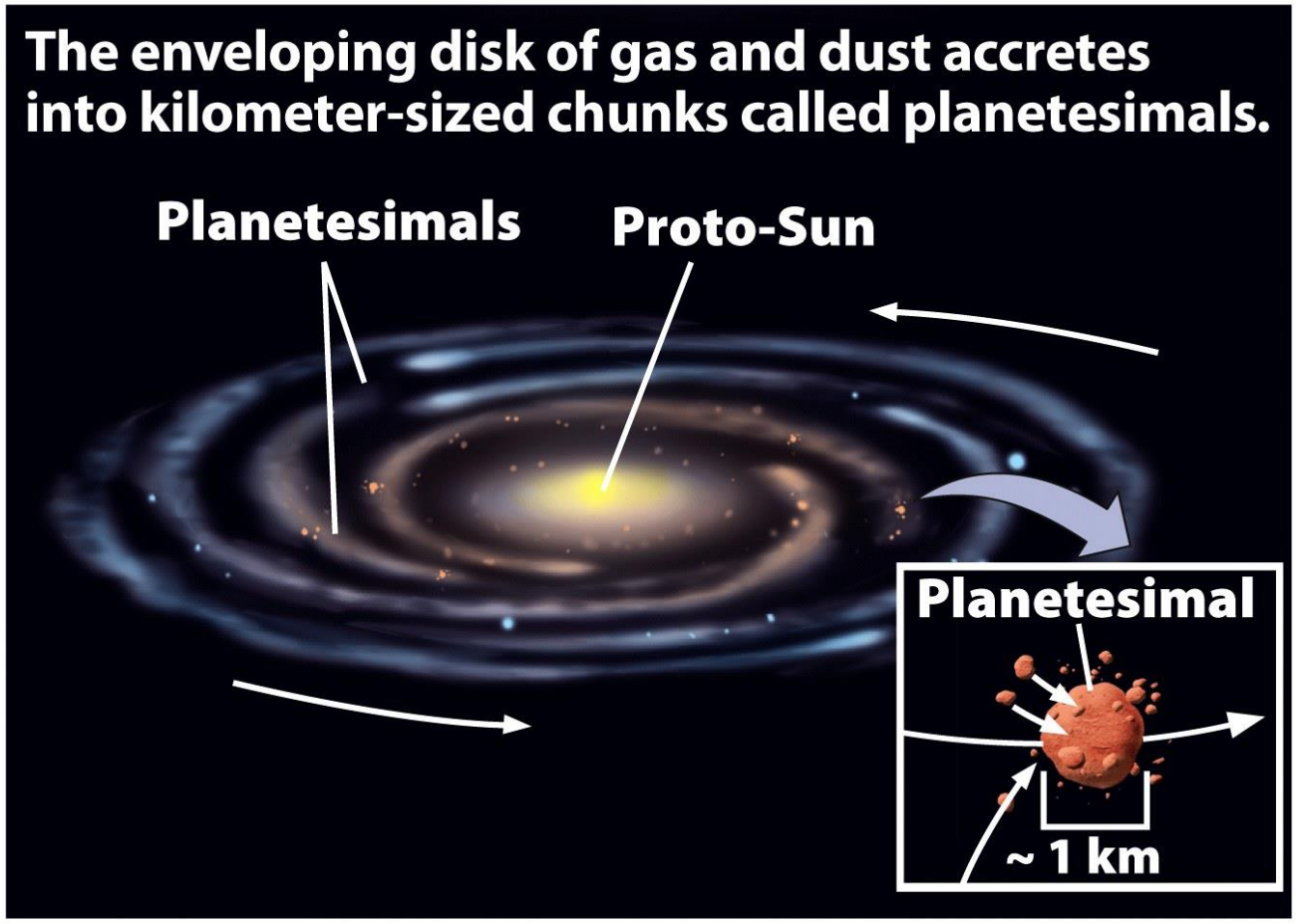

Figure 9.2 part 3
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Solar System formation

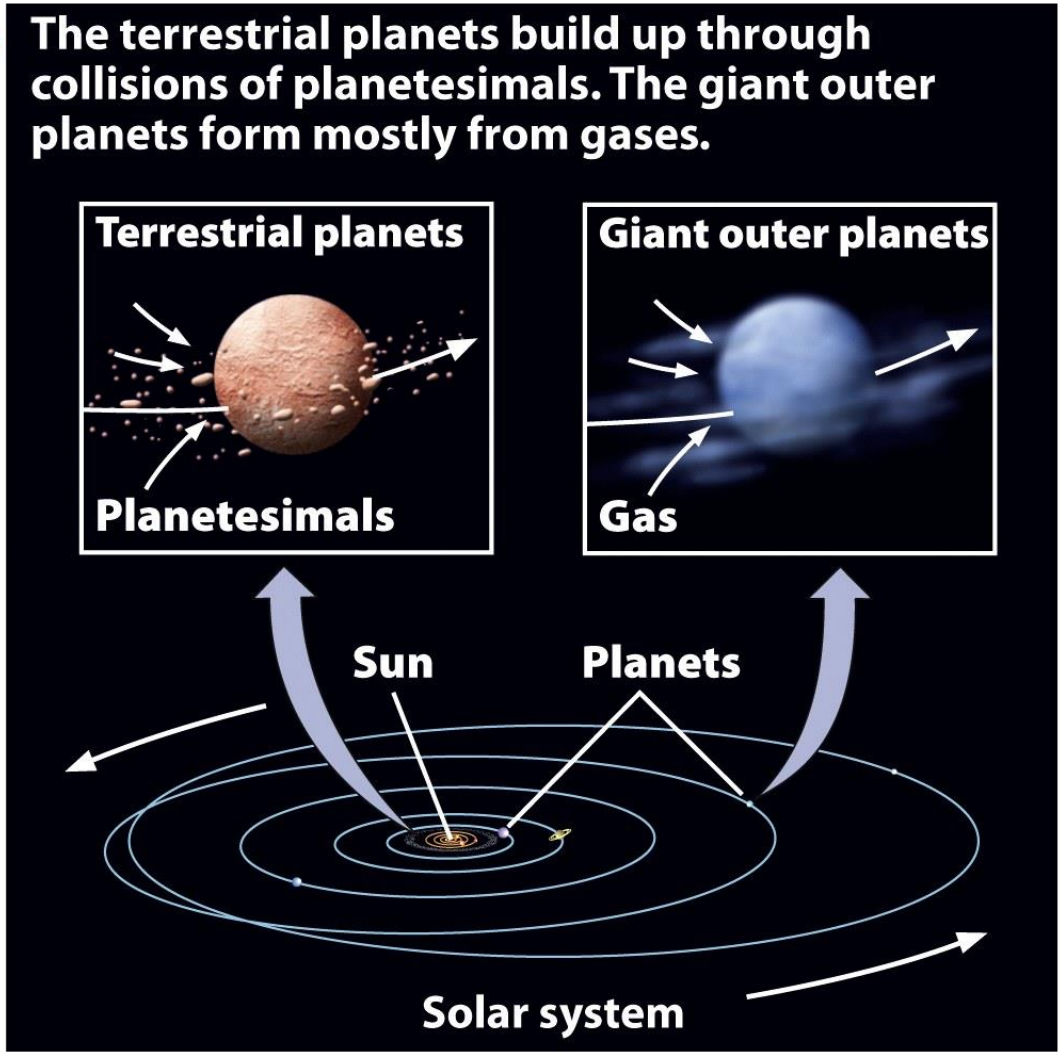

Figure 9.2 part 4
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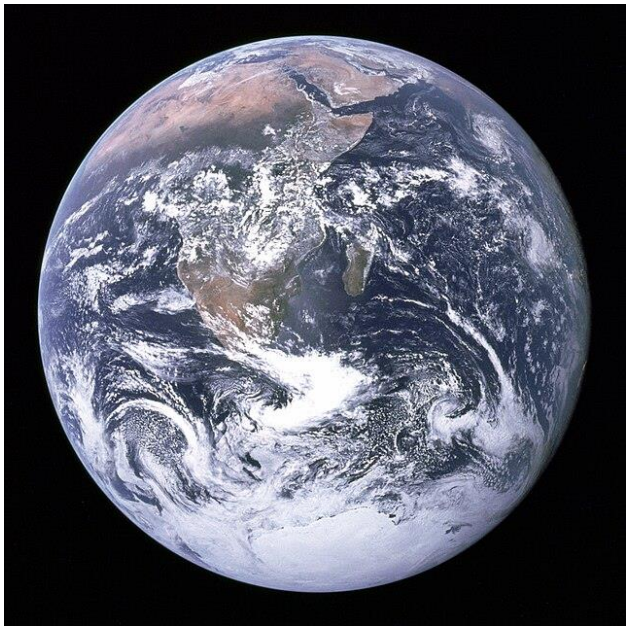
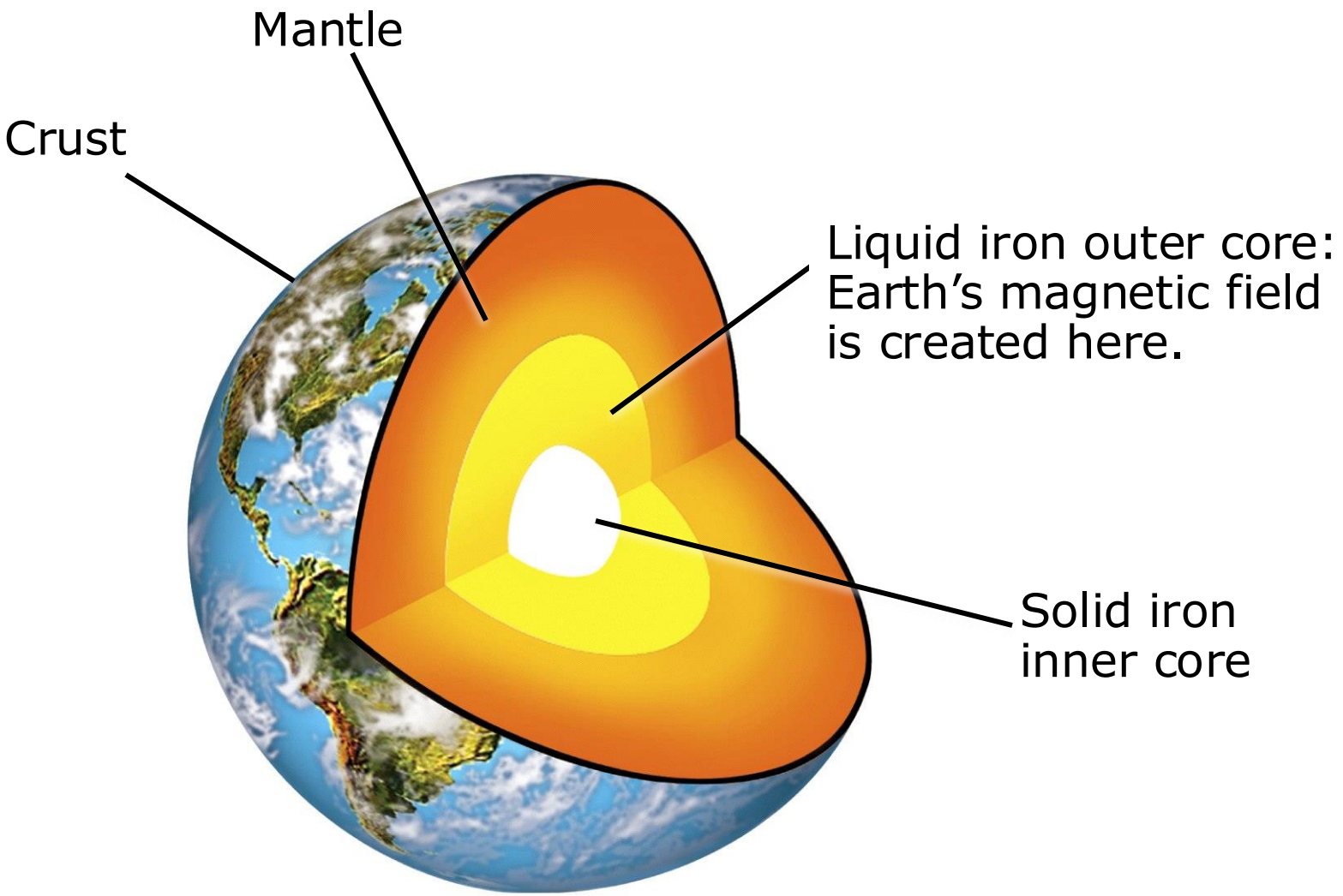
The Earth:



How did it form? ✓
What is it composed of?
How old is it?
How does it work?

The climate system… a brief introduction.

The Earth's internal structure and composition



The Earth's internal structure and composition

Discovery of a Layered Earth

Seismic waves travel through the Earth and are refracted/reflected at interfaces where the density changes, just like light:

Two laser beams travel from air into water and are reflected with a mirror.

Dending on the angle the reflected beams are either reflected back at the water/air interface (and end up on the table), or return to the air.

Seismic waves, which are either compressional (P) waves or shear (S) waves, do something similar inside the Earth.

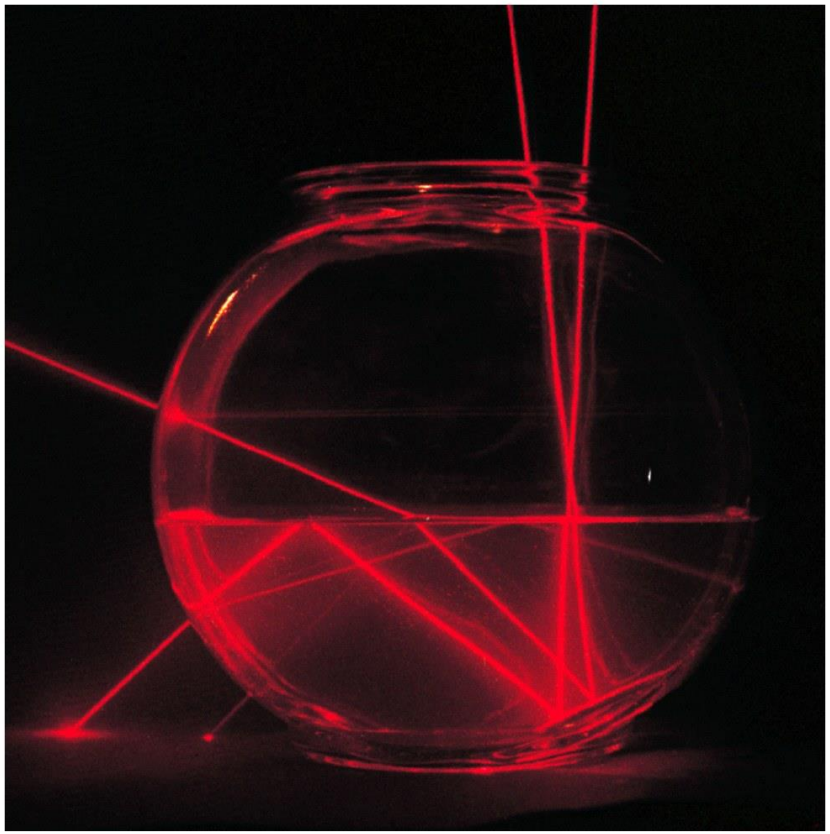


Figure 14.1
Understanding Earth, Sixth Edition

Discovery of a Layered Earth

Seismic waves are either compressional (P) or shear (S) waves.

The speed of wave propagation depends on the density of the medium…

Sound is a P wave propagating at 0.34 km/s in air and at 1.5 km/s in water

P waves in rock (granite) propagates at 6 km/s… !

S waves travel slower and cannot propagate in a fluid medium like air, water or…the Earth's liquid outer core.

So, if we have a strong earthquake… P and S waves take off from the epicenter…

The Earth's internal structure and composition

Discovery of a Layered Earth

Seismic waves travel through the Earth and are refracted/reflected at interfaces where the density changes, arriving (or not) back to the surface at different times, allowing the inner structure to be determined:

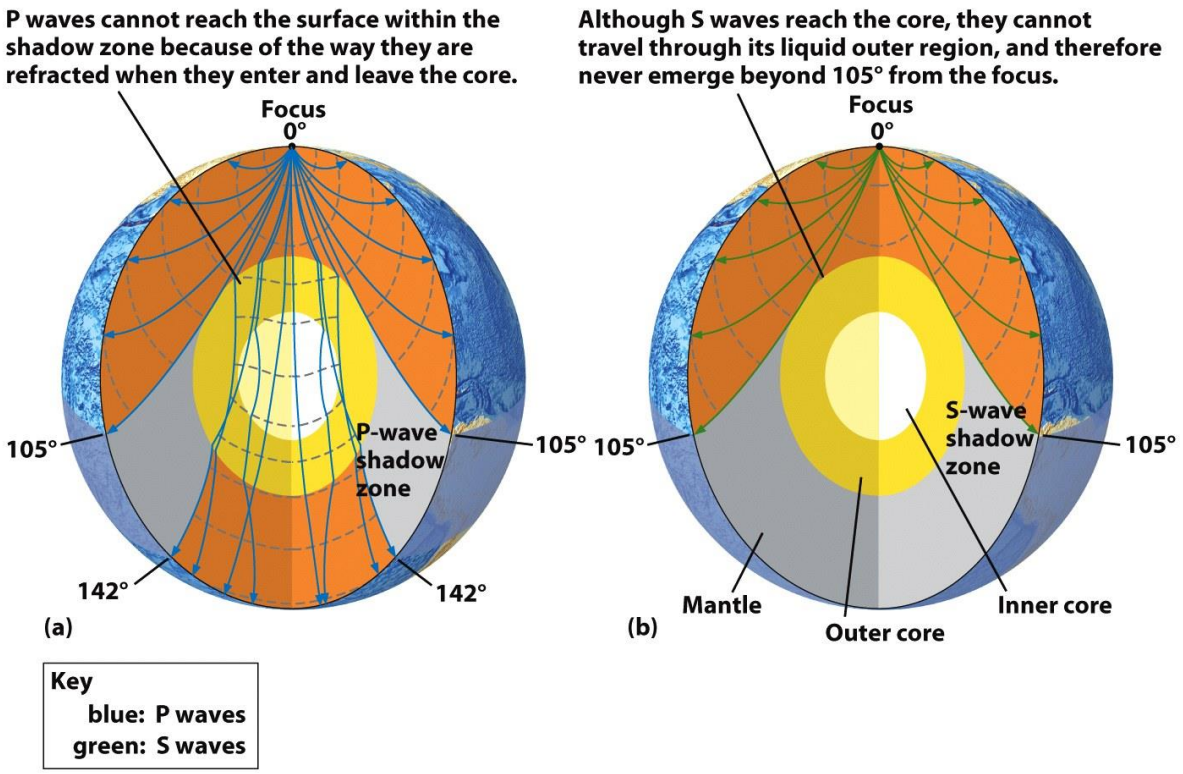
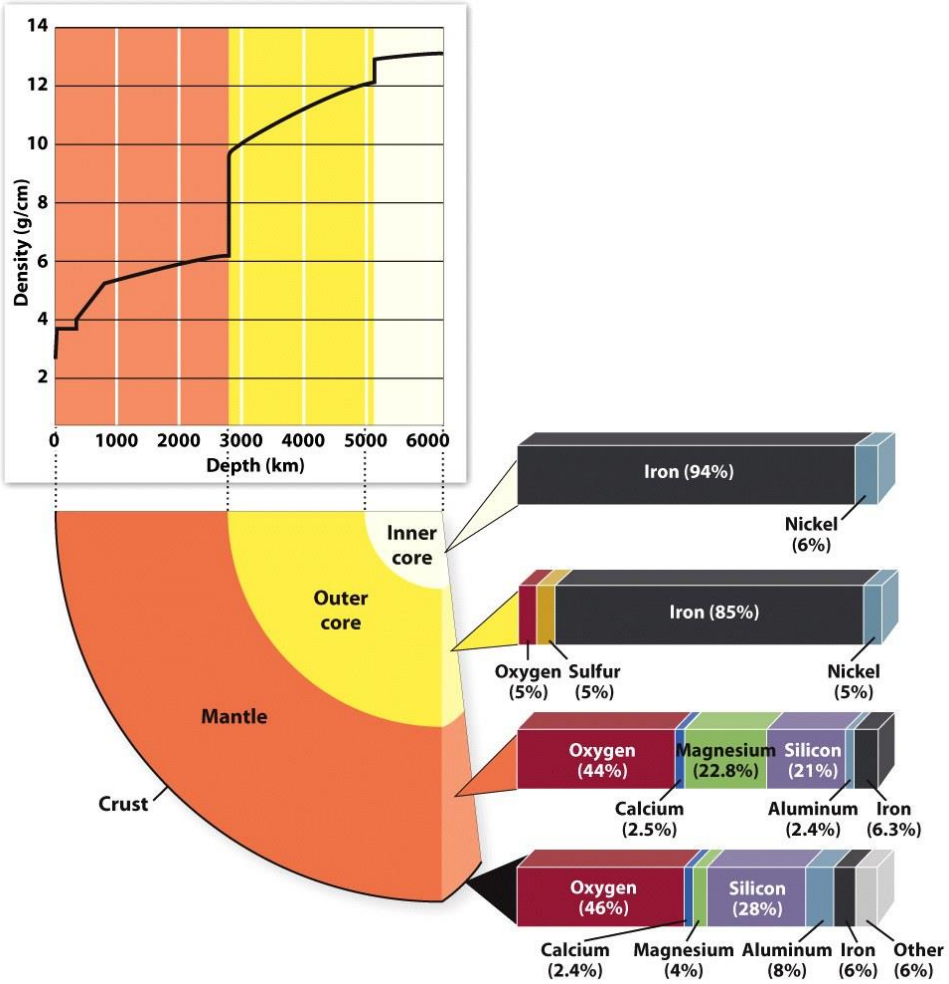


Figure 14.2
Understanding Earth, Sixth Edition

The Earth's internal structure and composition



Abrupt changes in density between Earth's major interior layers are caused by changes in the chemical composition of those layers.

Why is there so much metal (mostly Fe with some Ni) at the center of the Earth?

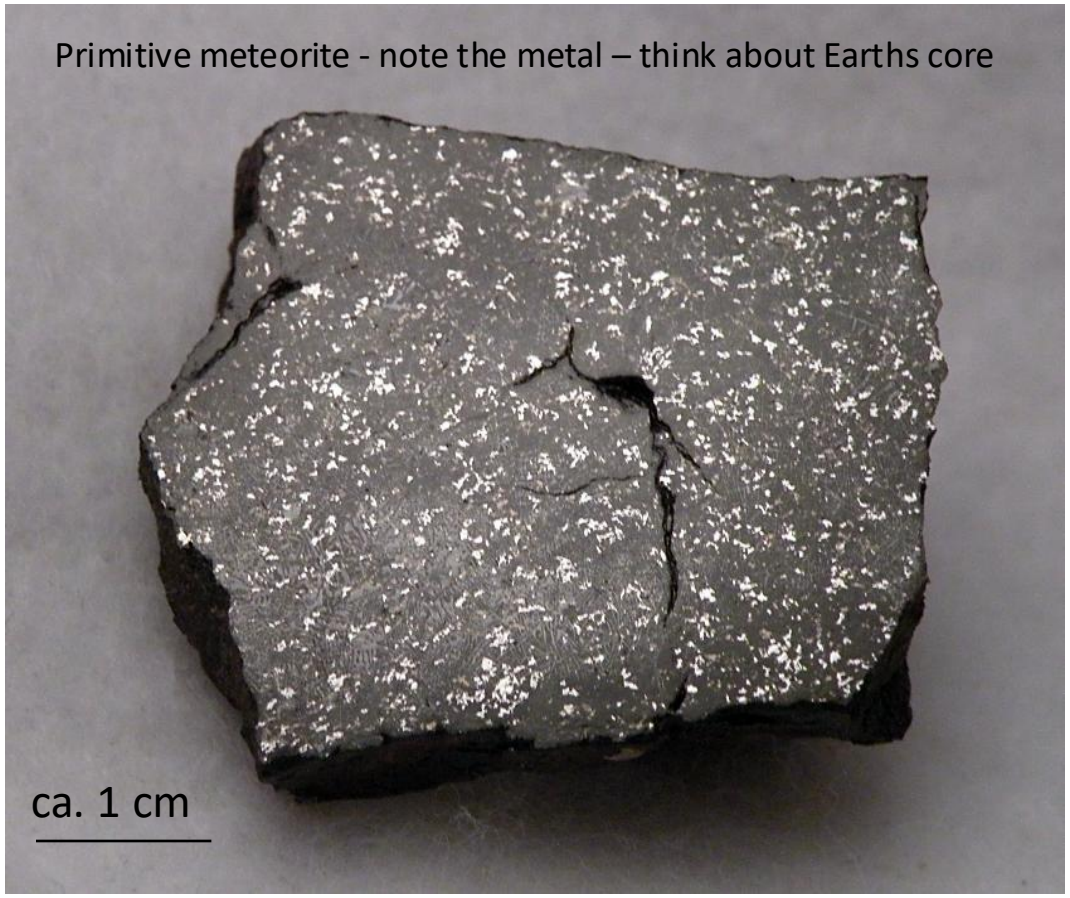
Because of the material from which it formed (look at meteorites) and because Earth got really warm during its formation, partlially melted … and *differentiated.*

The mantle and crust are silicates, i.e., primarily consisting of O and Si.
But the crust silicates are lighter than the mantle silicates.

The Earth's internal structure and composition

Meteorites are fragments from asteroids, i.e., small planets orbiting the Sun between Mars and Jupiter. Their orbits get perturbed (by the gravitational pull from Jupiter) and enter Earth-crossing orbits. They fall on the Earth often.

Some of them are similar to the material Earth was initially made of:



The Earth's internal structure and composition

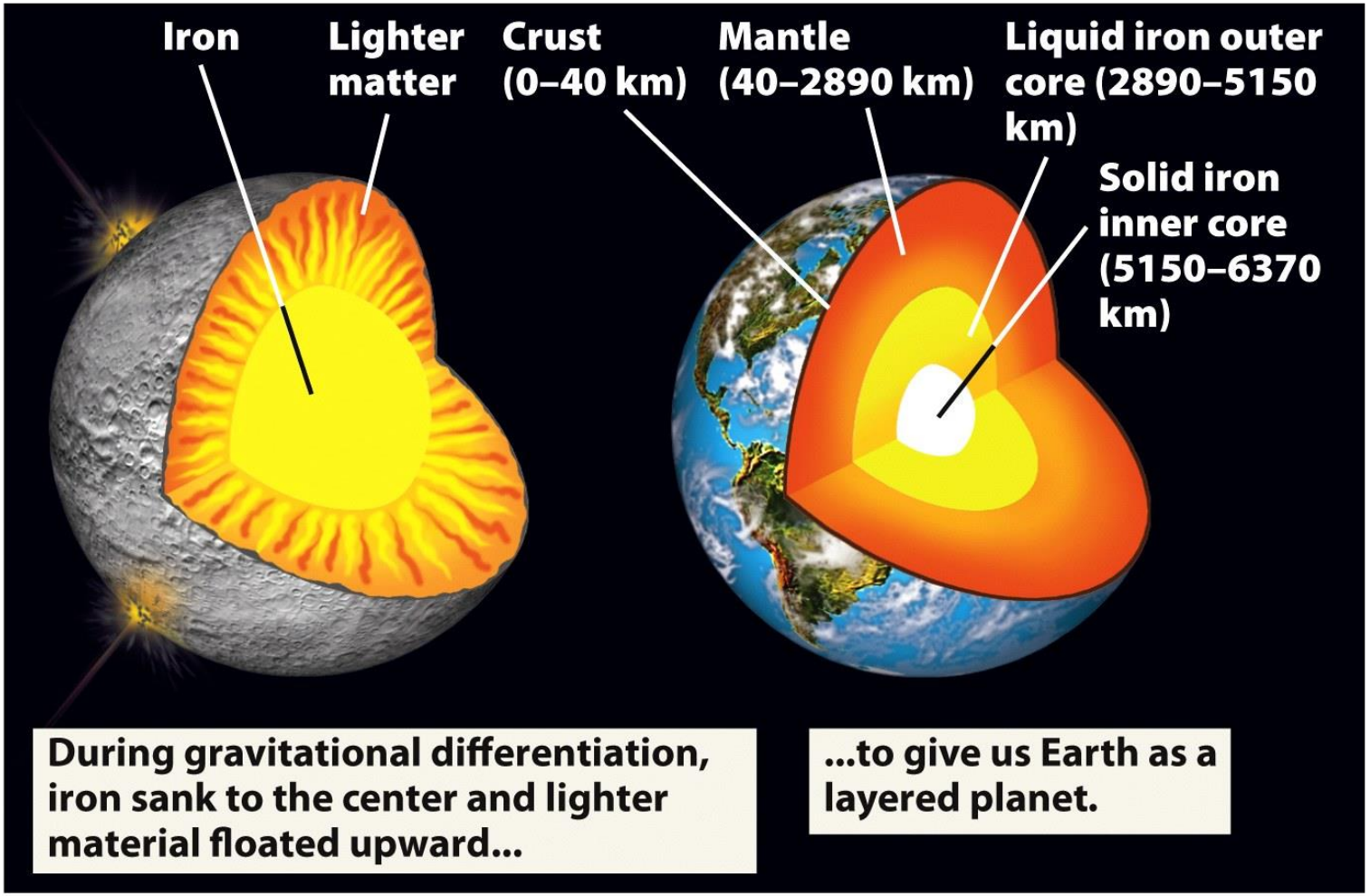
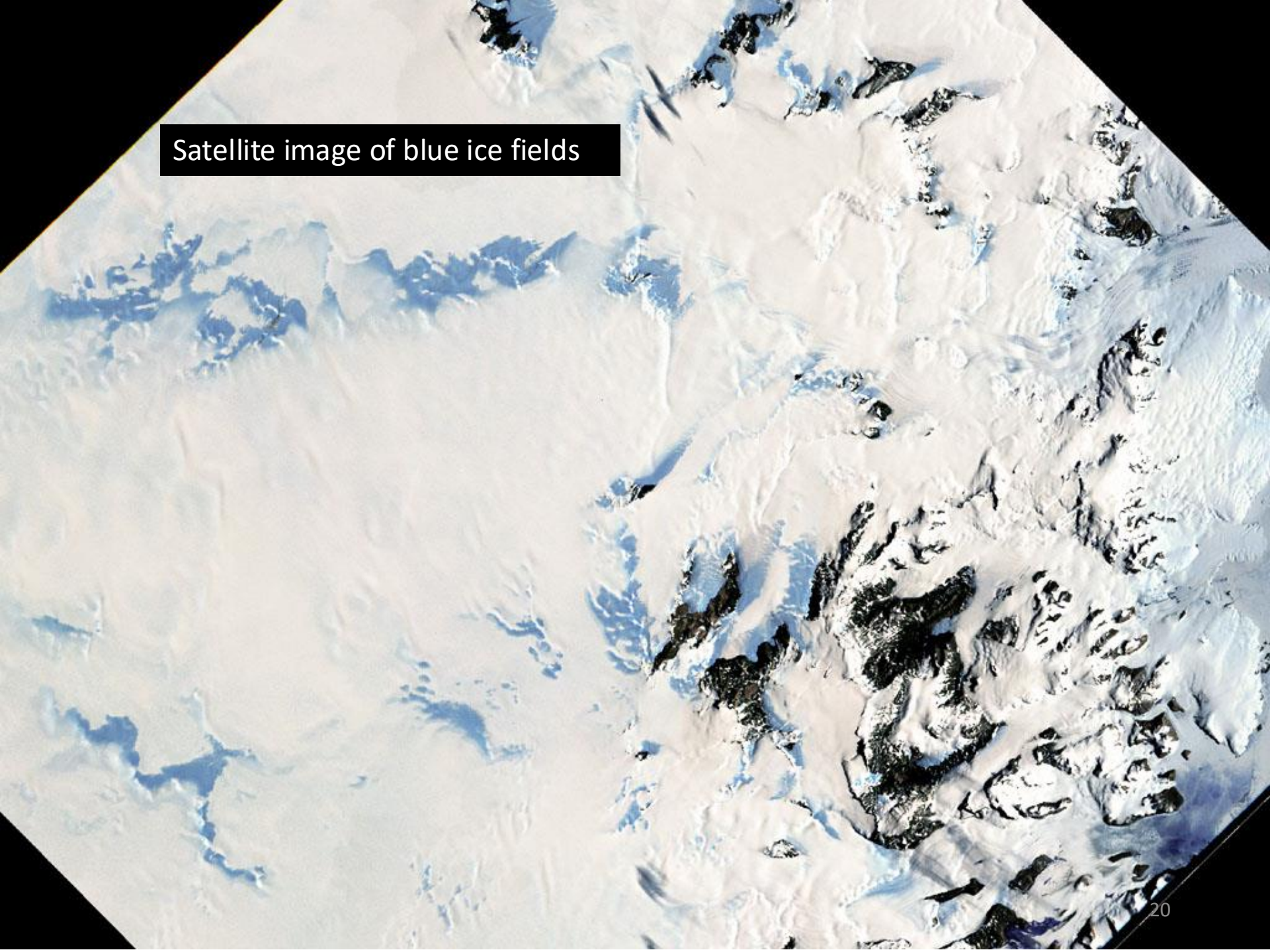


Figure 9.5
***Understanding Earth*, Sixth Edition**

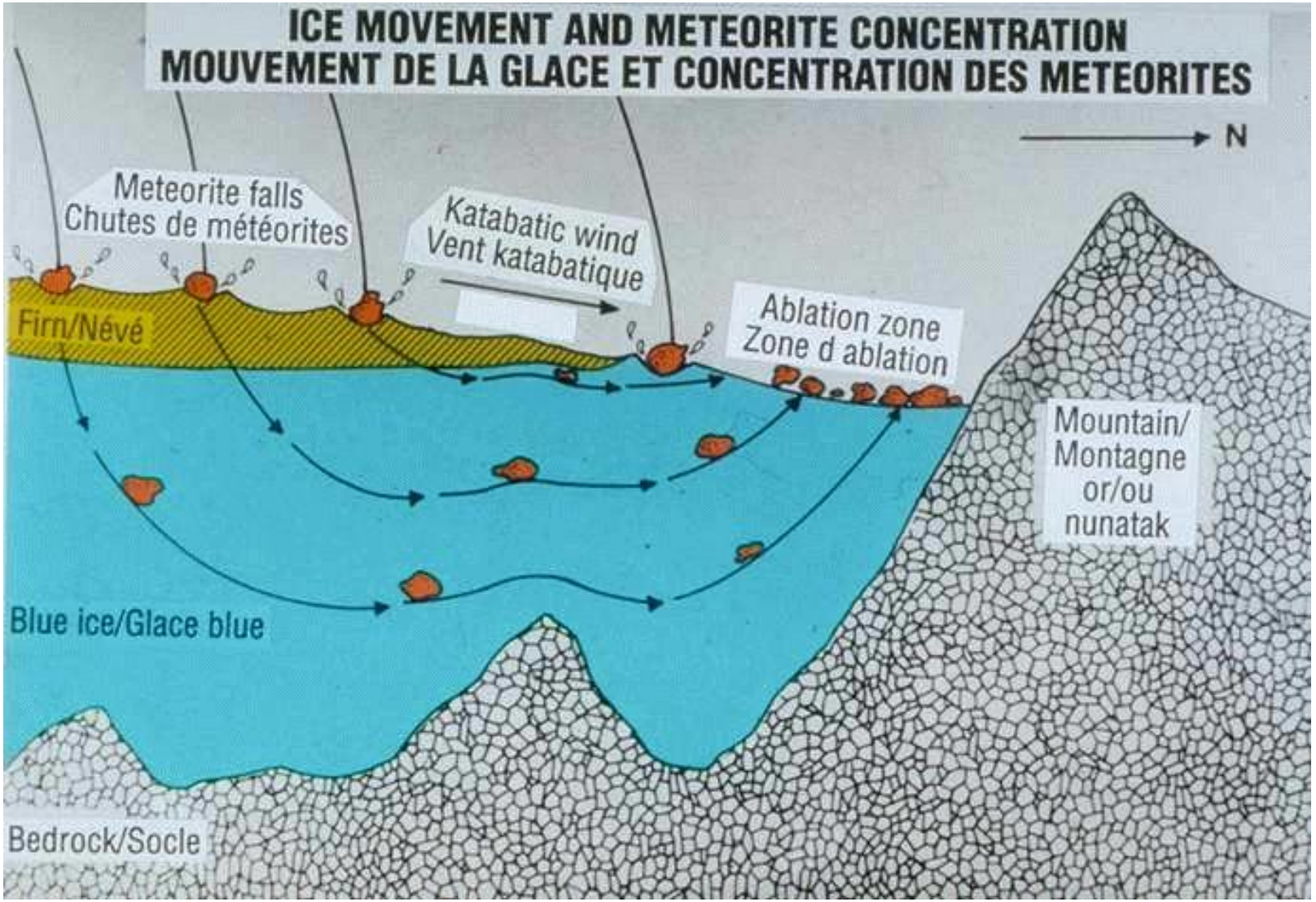
Here is where I went when I was a student - to look for meteorites:

Satellite photo of Antarctica.



Satellite image of blue ice fields

Why are the meteorites there on the blue ice?




0 0 0 7 6 9 6
0 1 2 3 4 5 6 CM

Greenland


Kap Morris Jesup
Qaanaaq
Upernavik
Uummannaq
Ittoqqorto
Qeqertarsuaq
Ilulissat
Qasigiannguit
Aasiaat
Kangaatsiaq
Sisimiut
Kangerlussuaq
Maniitsoq
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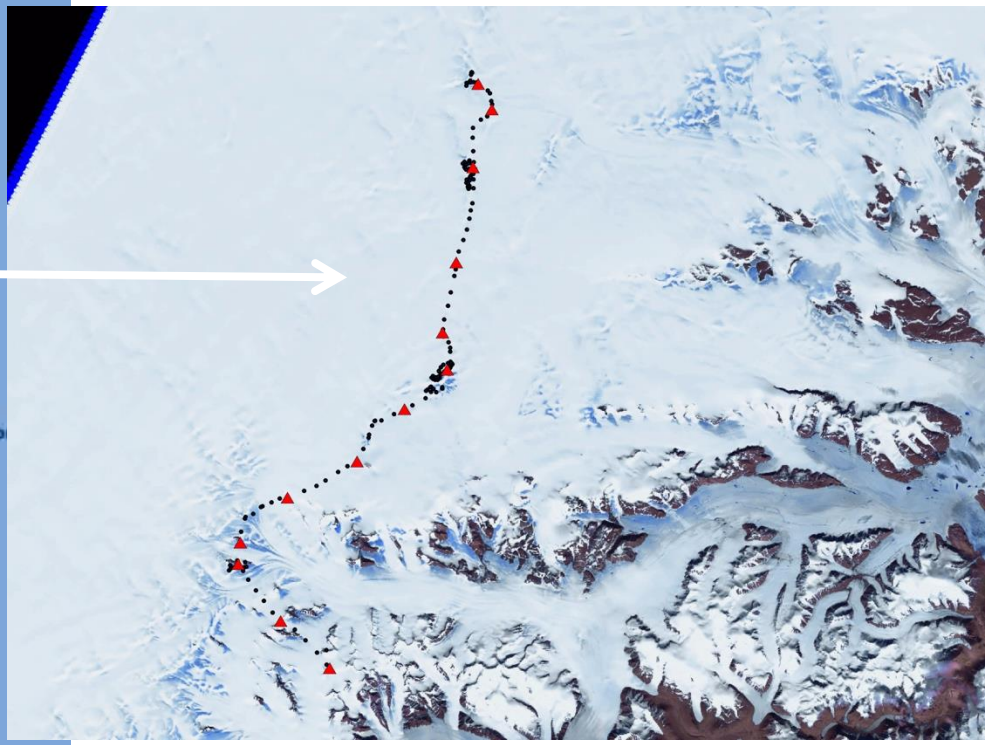
Qaqortoq
Nanortalik
Kap Farvel

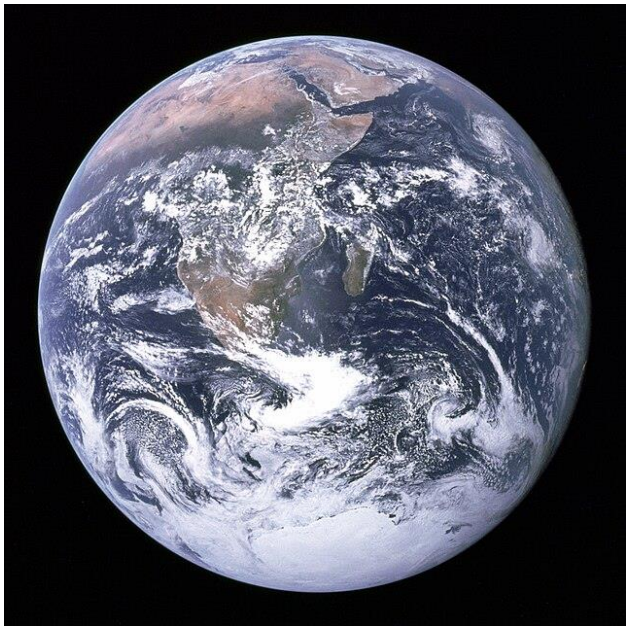



OY-HIB


We found nothing … except…..

A dead musk-ox…

The Earth:



How did it form? ✓
What is it composed of? ✓
How old is it?
How does it work?
→ Plate tectonics

The climate system… a brief introduction.

How old is the Earth?

All the terrestrial rocks (i.e., the crust) that we have access to are 'destroyed' by melting (volcanism), erosion, recycling, deformation … all the processes that take place all the time in the mantle, in the crust and on the surface.

Our only source of material from when the Earth formed are primitive meteorites. These meteorites formed at the same time and were not 'destroyed' by the same processes because they were never part of a big planet, just a small (km sized) asteroid… so they have preserved their original composition.

We have these meteorites, e.g., from Antarctica as you saw, but how can we date them?

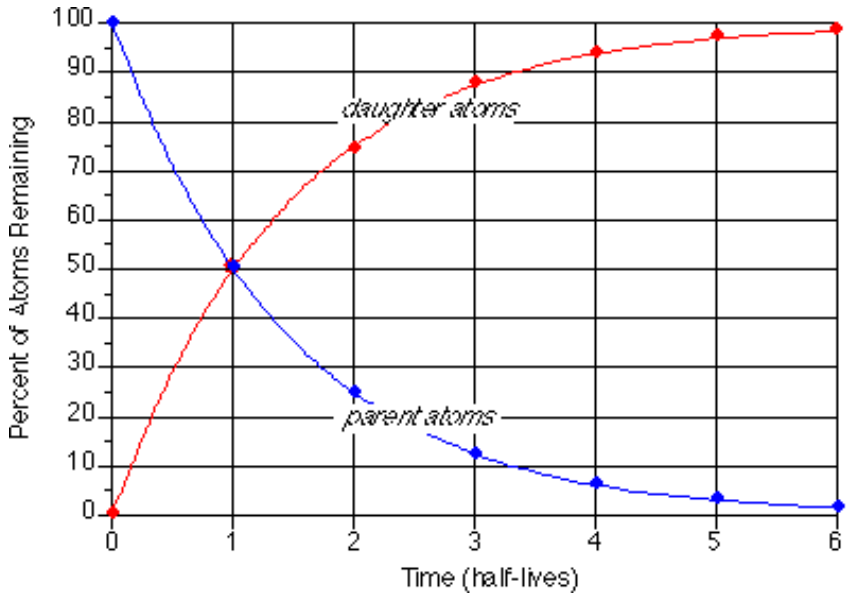
Answer: Radioactive elements… notably uranium (U) that decays to lead (Pb).

How old is the Earth?

Radioactive elements…
e.g., uranium (U).

$^{238}U \rightarrow {}^{206}Pb$ ($T_{½}$ = 4.5x10^9 years)

Parent Daugther



If you have a rock or a mineral that, when it formed contained some ^{238}U and no ^{206}Pb, and you can measure (by mass spectrometry) the concentration of both isotopes, then, knowing the half-life of the parent, you can calculate the age of the rock or mineral.

The oldest components we can find in meteorites dated this way give an age of **4.56 billion years** (10^9). The meteorites formed in the same process as the Earth when the Solar System formed, as we discussed, so this is taken as the age of the Earth and the Solar System in general.

This is consistent with the age of the oldest rocks in the crust, which are ca. 4.4x10^9 years old. But most crustal rocks are *much* younger – why? **Plate tectonics….**

How old is the surface of the Earth?

So, the Earth formed 4.56 billion years ago… but why is any terrestrial rock we can find so much younger … the answer is that everything in the Earth's mantle and crust is part of the plate tectonic cycle…

First of all – there are two types of crust covering the Earth:
Continental crust and **oceanic** crust.

Both types of crusts are silicates, but they have lower density than the mantle underneath and therefore float on the mantle.

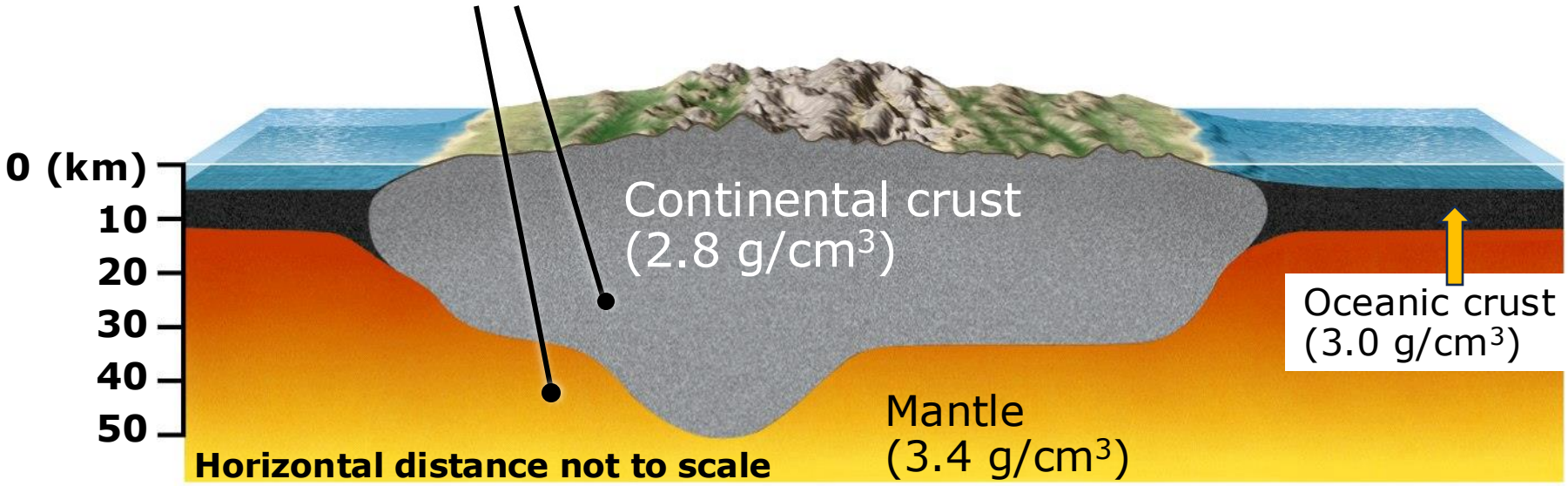
But the continental crust is the lightest and therefore floats higher, which is why the continents stick out of the global ocean…

The ocean covers the oceanic crust with an average depth of 4-5 km.

And the ocean covers about 70 % of the surface of the Earth.

How old is the surface of the Earth?

Less dense continental crust floats on denser mantle



The continents generally formed early in the evolution of the Earth and are so light that they cannot sink back into the mantle. Their rocks are typically billions of years old.

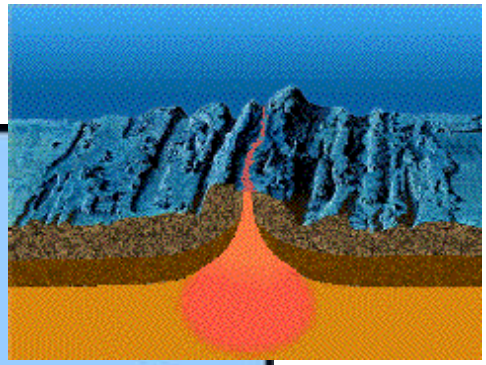
In contrast, the oceanic crust, which is created all the time, also sinks back into the mantle. This is called subduction.

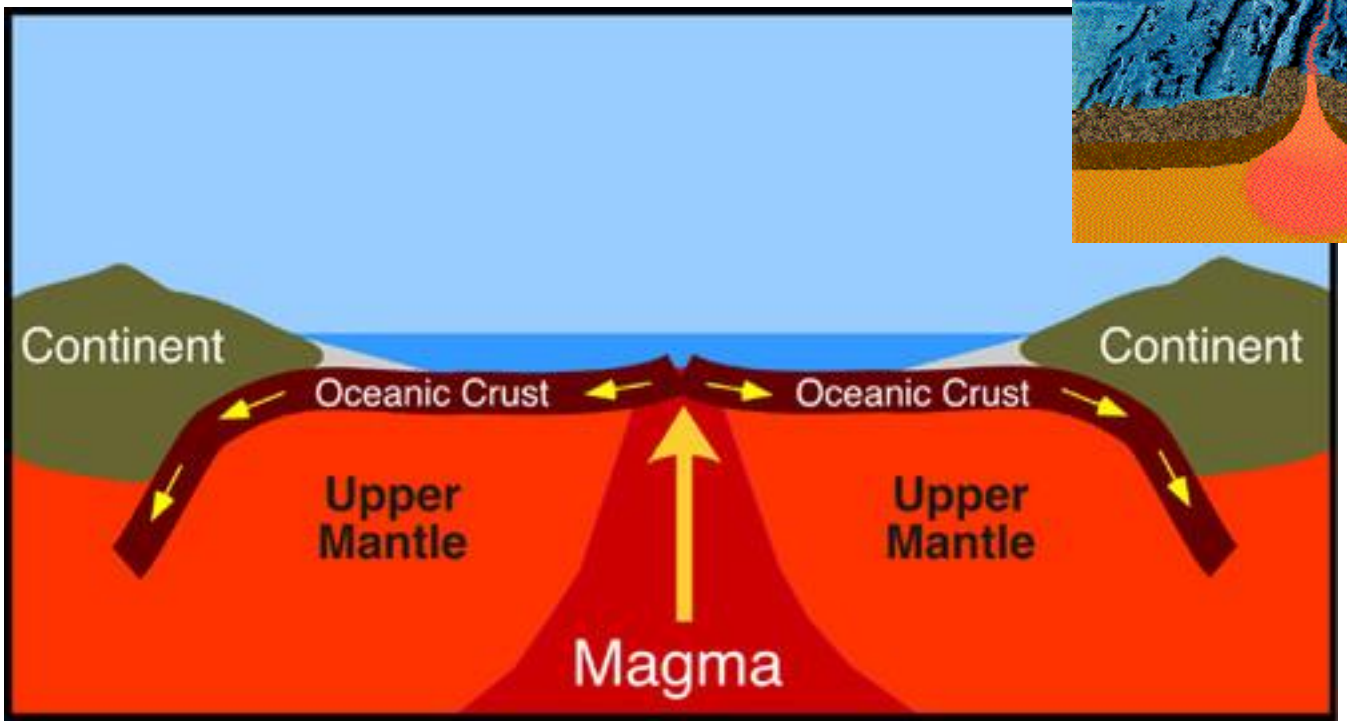
So continents stay on the surface and are old.
Oceanic crust is created and destroyed all the time – and is much younger…

How old is the surface of the Earth?

Here is the principle of the plate tectonic cycle.
Oceanic crust is formed by magma rising from the mantle at mid-ocean ridges and subducts under the lighter oceans. This takes place continously (keeping the surface area constant). The continents are being pushed around… creating continental drift.

This creates earthquakes, volcanoes and mountain chains!





How old is the surface of the Earth?

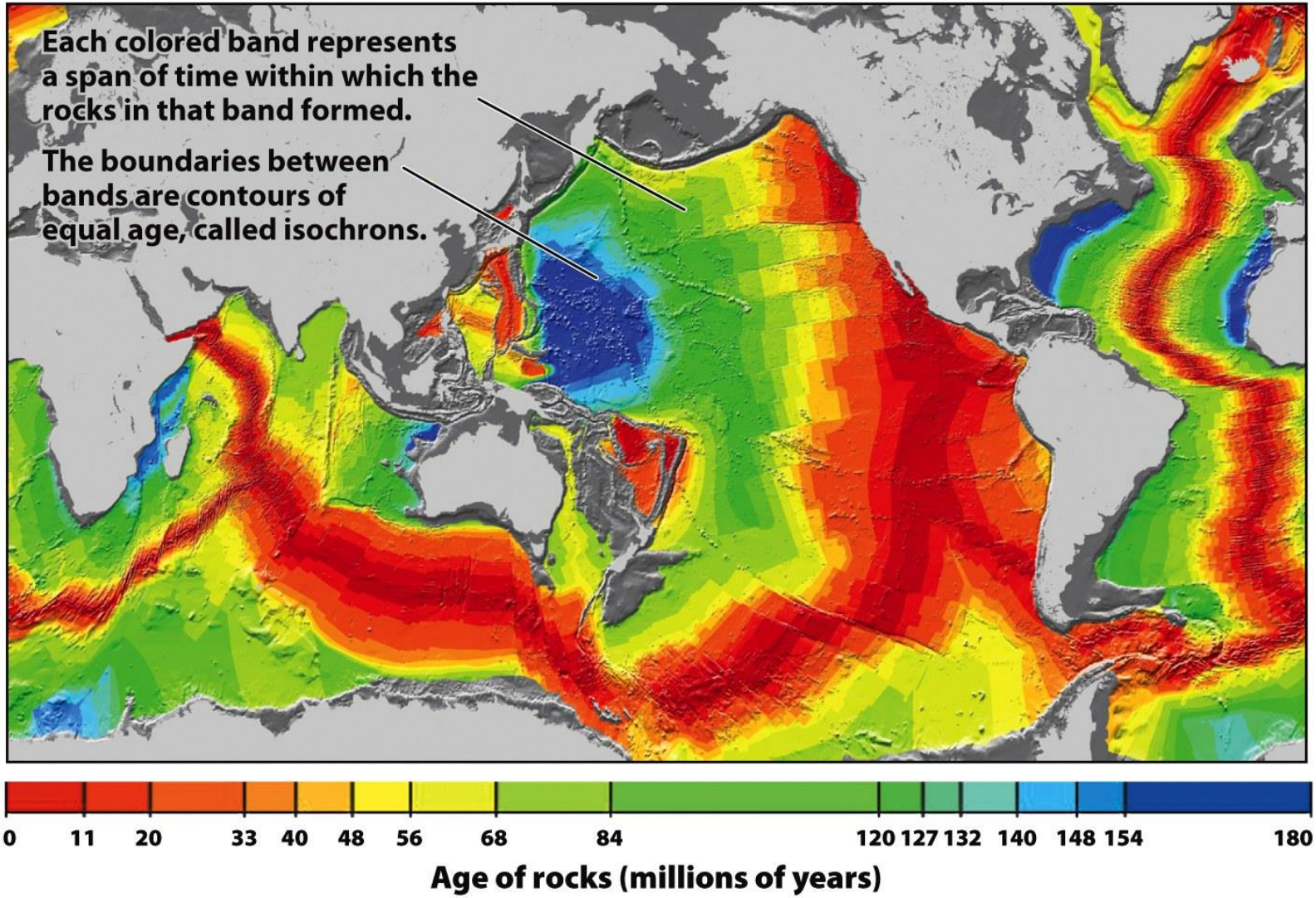


Figure 2.15
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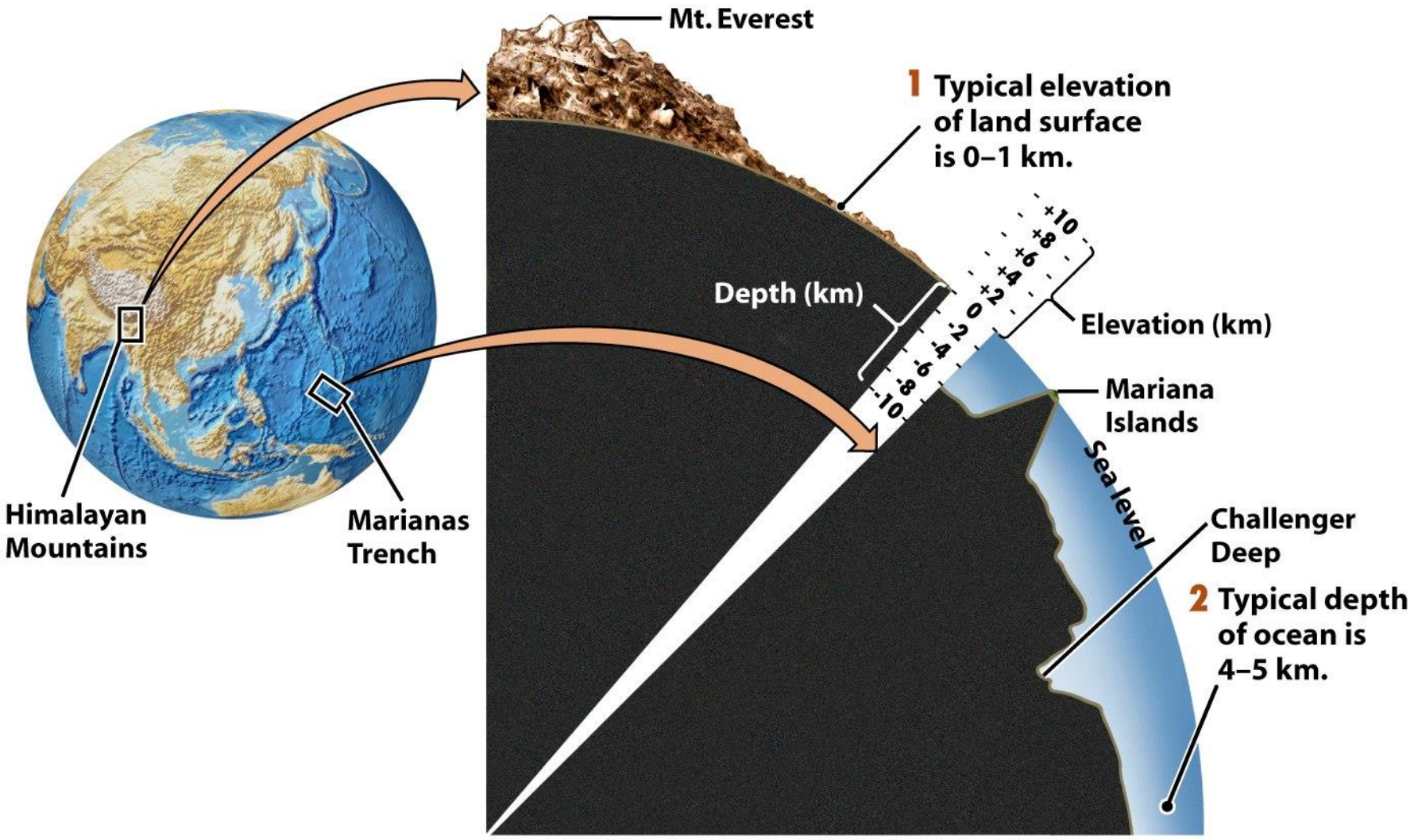
Mt. Everest
1 Typical elevation of land surface is 0–1 km.
Depth (km)
+10
+8
+6
+4
+2
0
-2
-4
-6
-8
-10
Elevation (km)
Mariana Islands
Sea level
Challenger Deep
2 Typical depth of ocean is 4–5 km.
Himalayan Mountains
Marianas Trench

Magma rose from the mantle, creating new oceanic spreading centers that pushed old continental plates apart.

This will of course continue into the future, e.g., pushing Europe/African and the Americas further apart.

You can search for movies showing the reconstructed plate motions on e.g. Youtube…

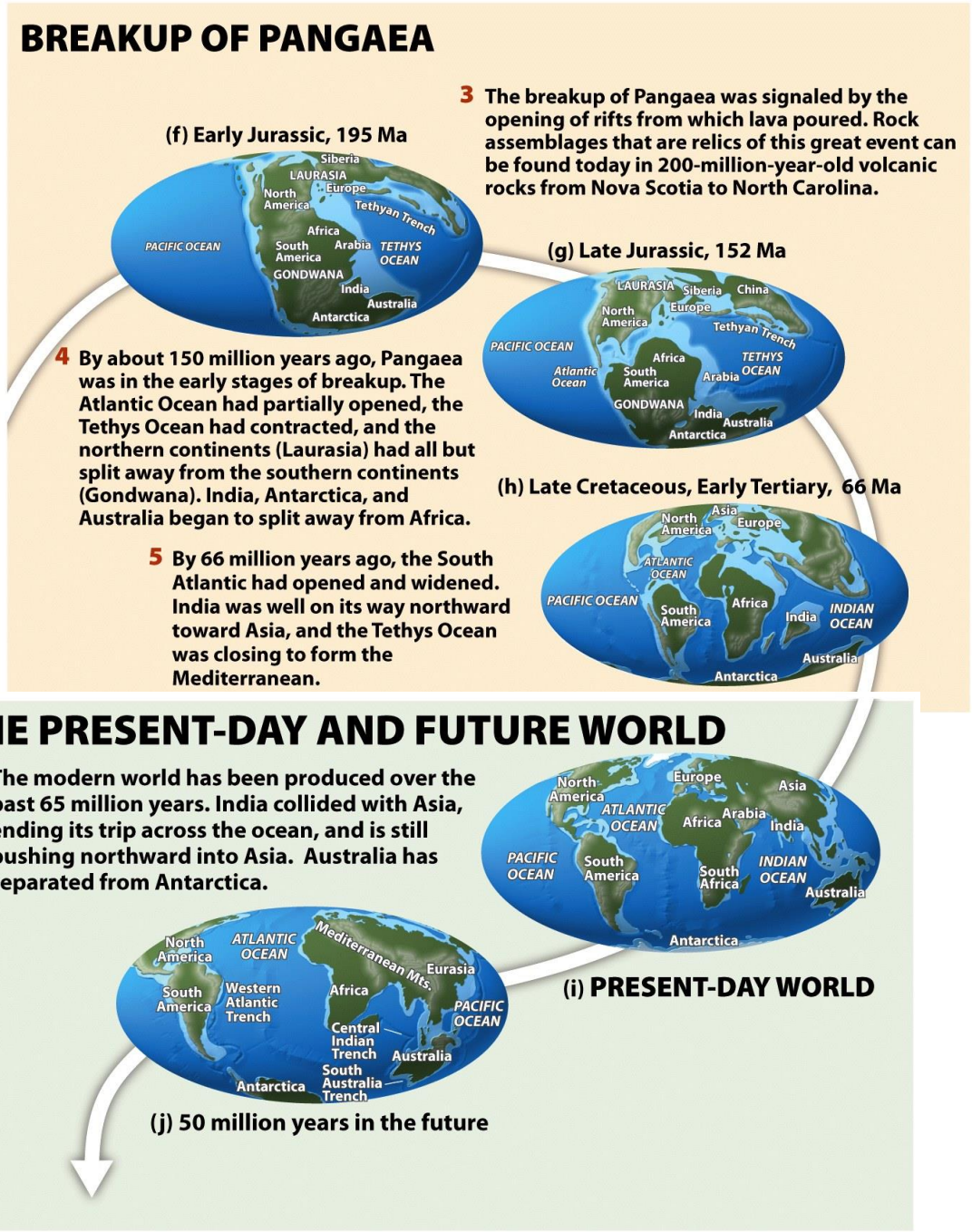

Figure 2.16 part 3
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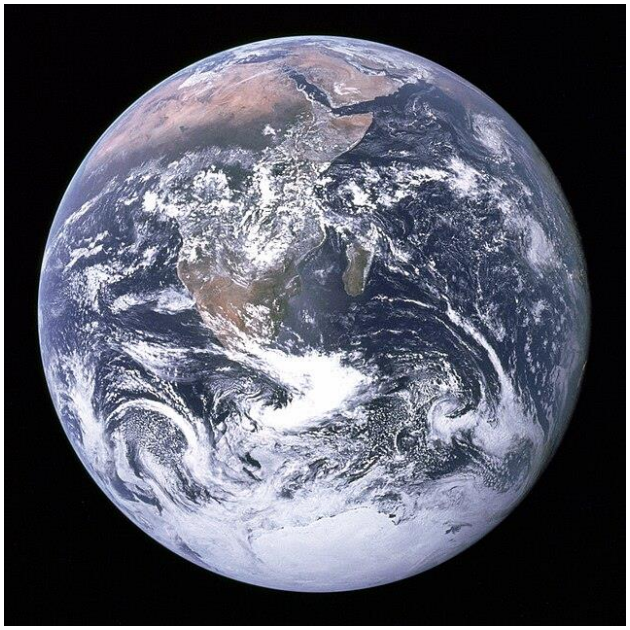
The Earth:

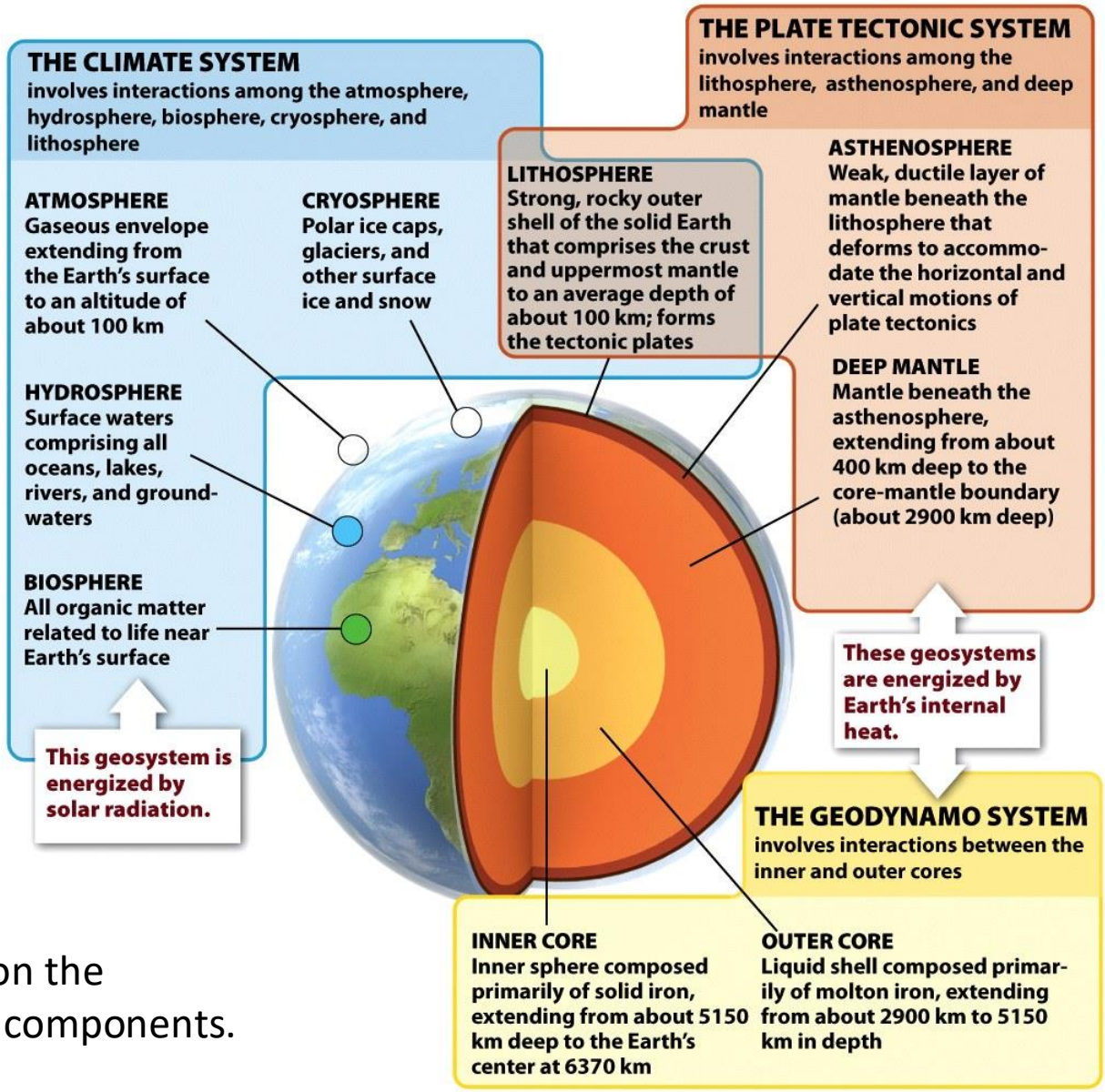


How did it form? ✓
What is it composed of? ✓
How old is it?
How does it work? ✓

→ Plate tectonics

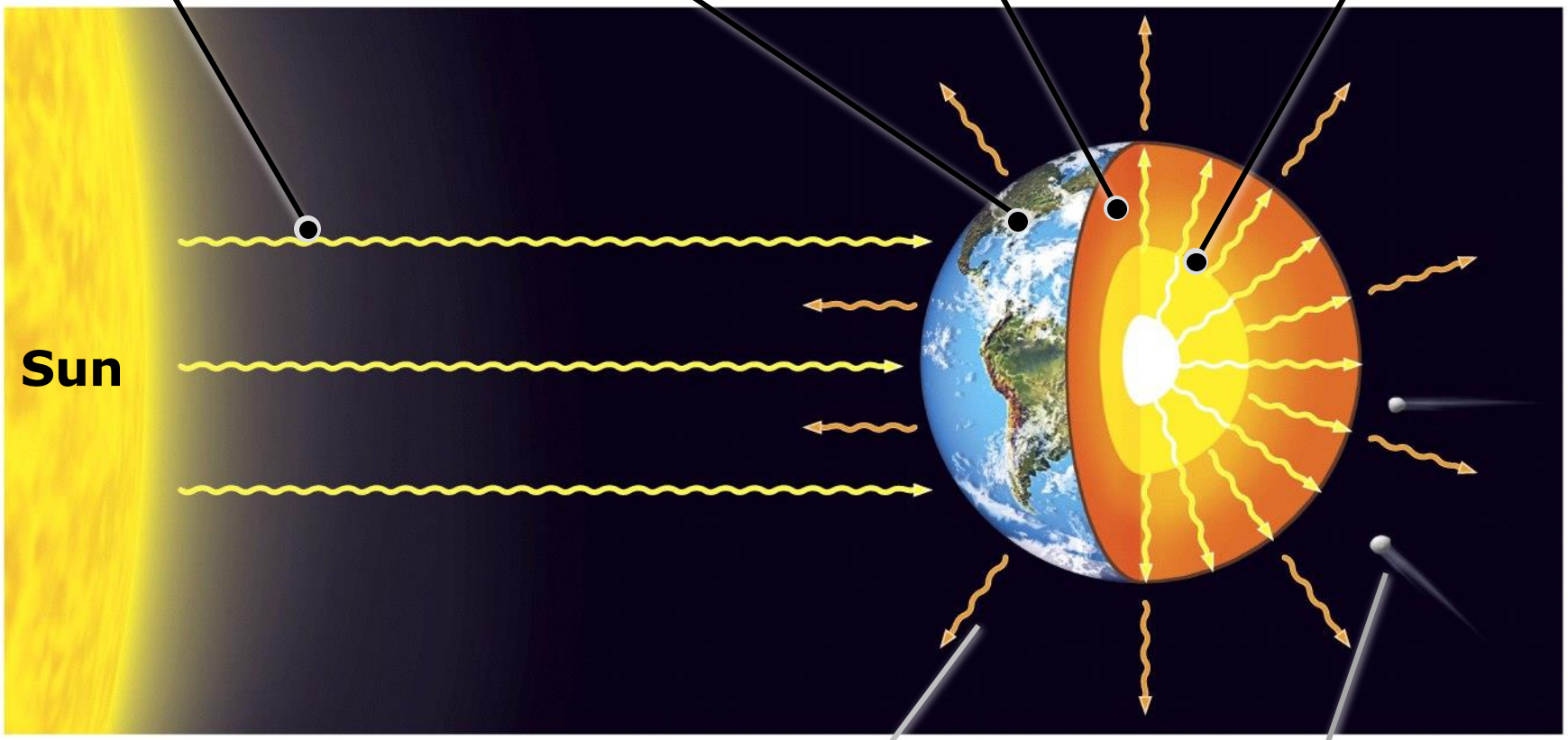
The climate system… a brief introduction.

Earth system:
Interactions of the climate, plate tectonic and geodynamo systems.



This course will focus on the climate system and its components.

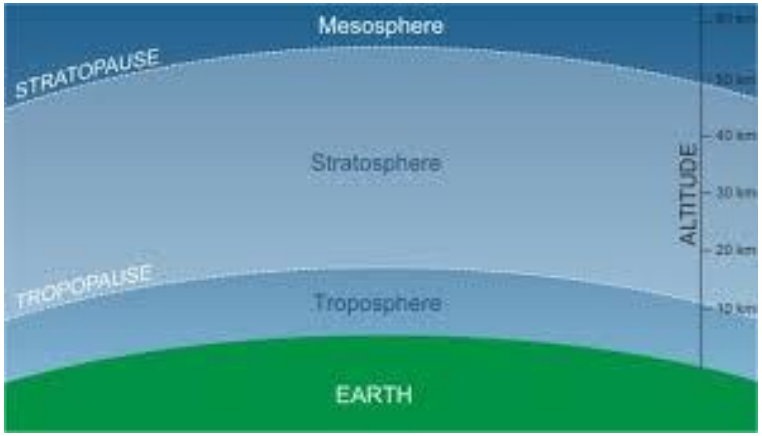
The Earth is an open system:

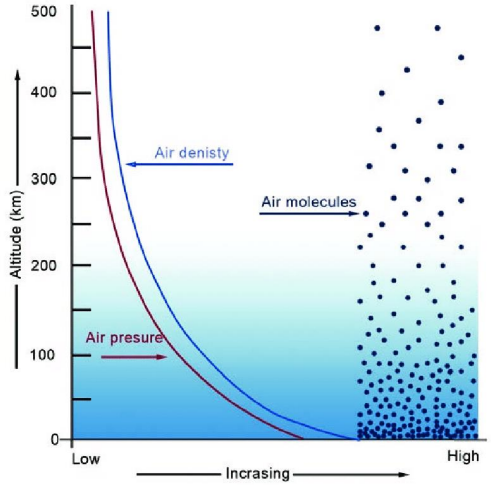


The Atmosphere:

Composition (mole fraction):
78 % N_2
21 % O_2

The last 1 % :
Ar, CO_2, water vapor,
methane (CH_4), ozone (O_3^+),
other trace gasses.

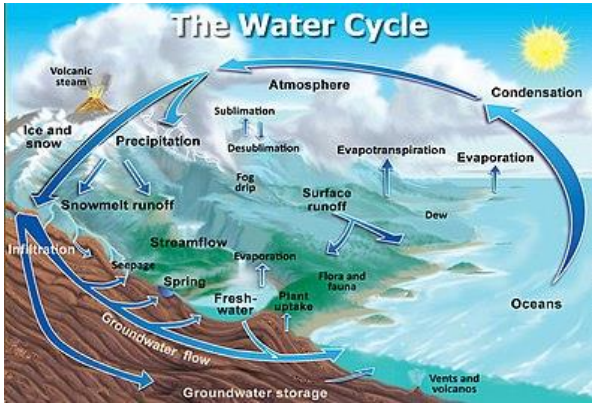




75 % of its mass is in the troposhere

The Hydrosphere:

All the waters on the earth's surface, such as lakes, rivers and oceans, and sometimes including clouds/precipitation.



Ocean currents:

Surface currents:

Thermohaline circulation – moves heat!

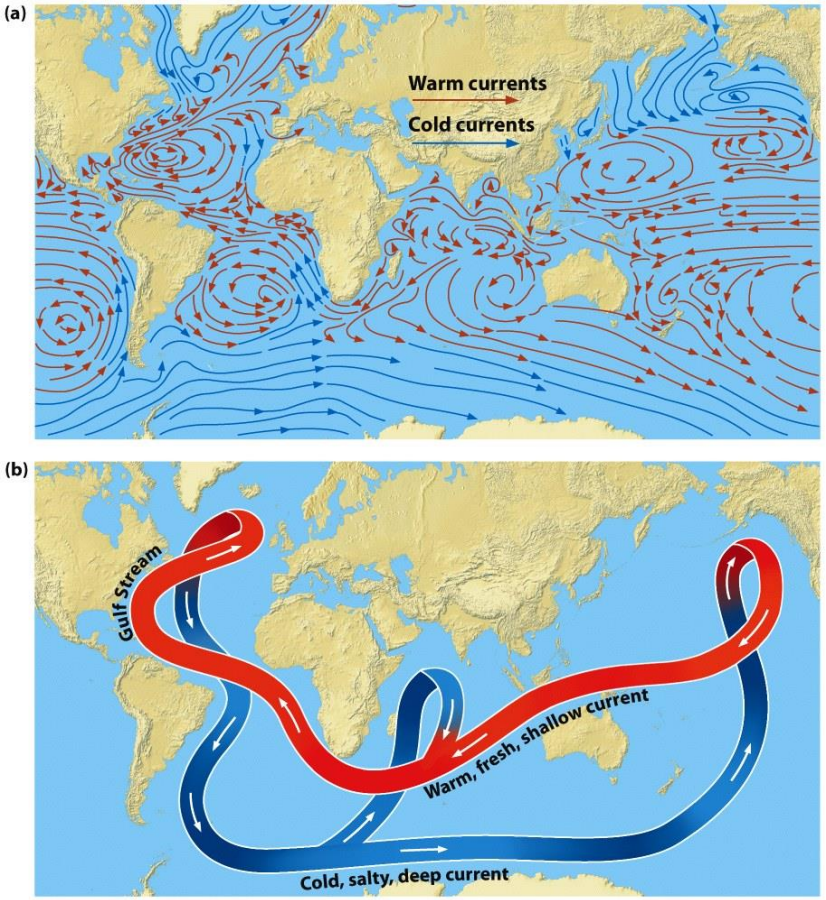


Figure 15.3
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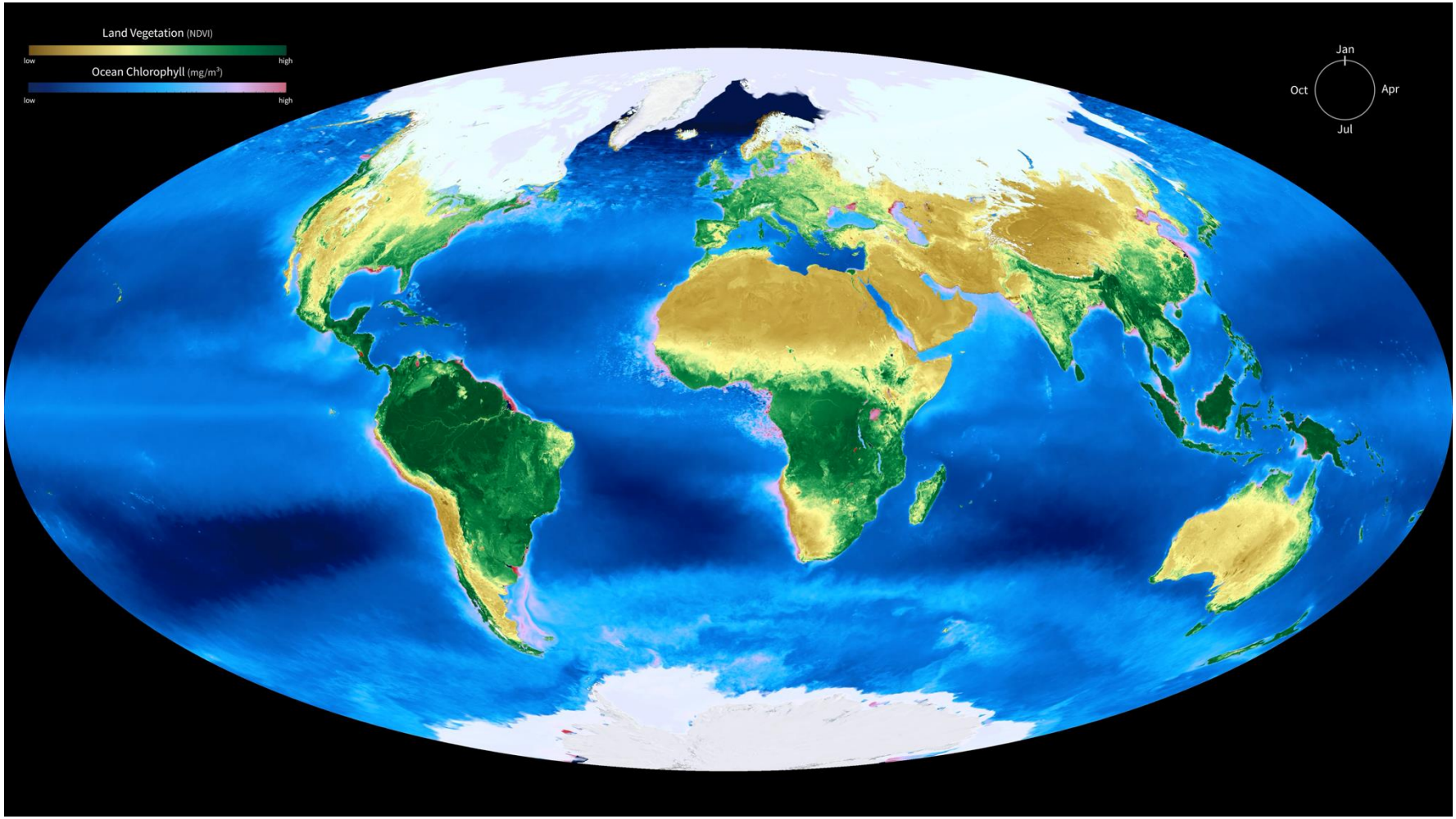
Earth’s biosphere – seasonal changes…



You can find the movie here: https://svs.gsfc.nasa.gov/11861/

Overview of Geologic Time