

Introduction to Environmental Science and Engineering

(ENV – 167)

Anders Meibom

Welcome

Lectures in:

SG 0213 from 1:15 – 3 pm on Mondays

INM 200 from 2:15 – 4 pm on Wednesdays.

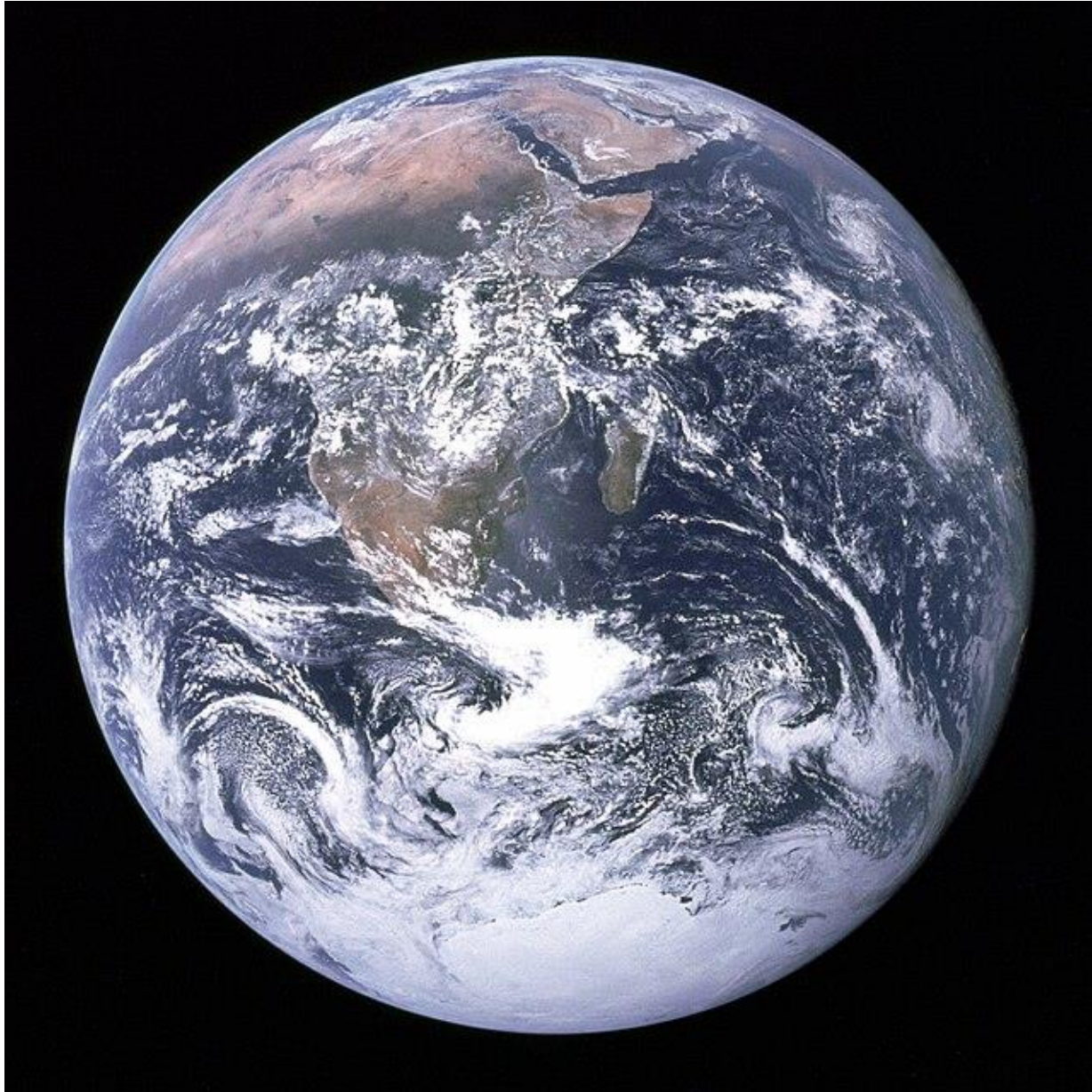
Please be on time.

Our program

Week	day	Topic	Teacher
Sep.08	Monday	Introduction	Anders Meibom
Sep.10	Wednesday	Oceans, mountains and poles	Hendrik Huwald
Sep.15	Monday		Hannes Peter
Sep.17	Wednesday		J�rome Chappellaz
Sep.22	Monday	No class	
Sep.24	Wednesday		Anders Meibom
Sep.29	Monday		Visit to SKIL and SPOT
Oct.01	Wednesday	Soils, microbes and plants	Ianina Altshuler
Oct.06	Monday		Wenyu Gu
Oct.08	Wednesday		Priya Ramakrishna
Oct.13	Monday		Christoph Bachofen
Oct.15	Wednesday		Exam 1
Oct.20		No class	
Oct.22		No class	
Oct.27	Monday	Water	Paolo Perona
Oct.29	Wednesday		Florian Breider
Nov.03	Monday		Tamar Kohn
Nov.05	Wednesday		Visit to water purification plant
Nov.10	Monday	Atmospheric processes and climate, from the poles to the eastern mediterranean	Julia Schmale
Nov.12	Wednesday		Athanasios Nenes
Nov.17	Monday		Satoshi Takahama
Nov.19	Wednesday		
Nov.24	Monday	Environmental sensing, mapping, robotics, environmental health, data science	Mirko Kovac
Nov.26	Wednesday		Stephane Joost
Dec.01	Monday		Stephane Joost - Exercise
Dec.03	Wednesday		Devis Tuia
Dec.08	Monday	Energy, resources and ecosystem resoration	Beate Jessel
Dec.10	Wednesday		Michael Lehning
Dec.15	Monday		J�rome Chenal
Dec.17	Wednesday		Exam 2

Now – let's introduce the star of the show

The Earth



The Earth

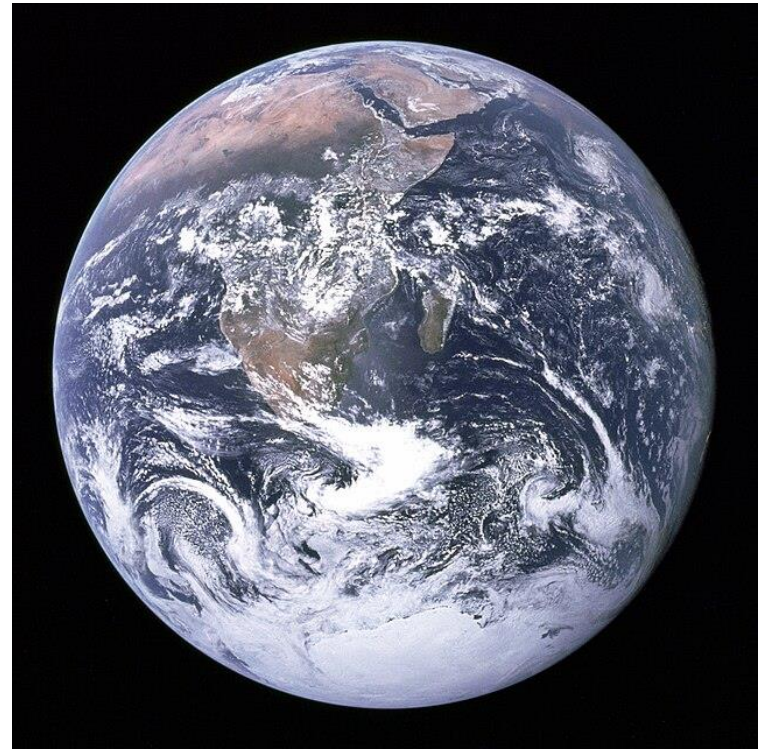
A planet with an average radius of 6371 km.

How did it form?

Internal structure and composition.

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

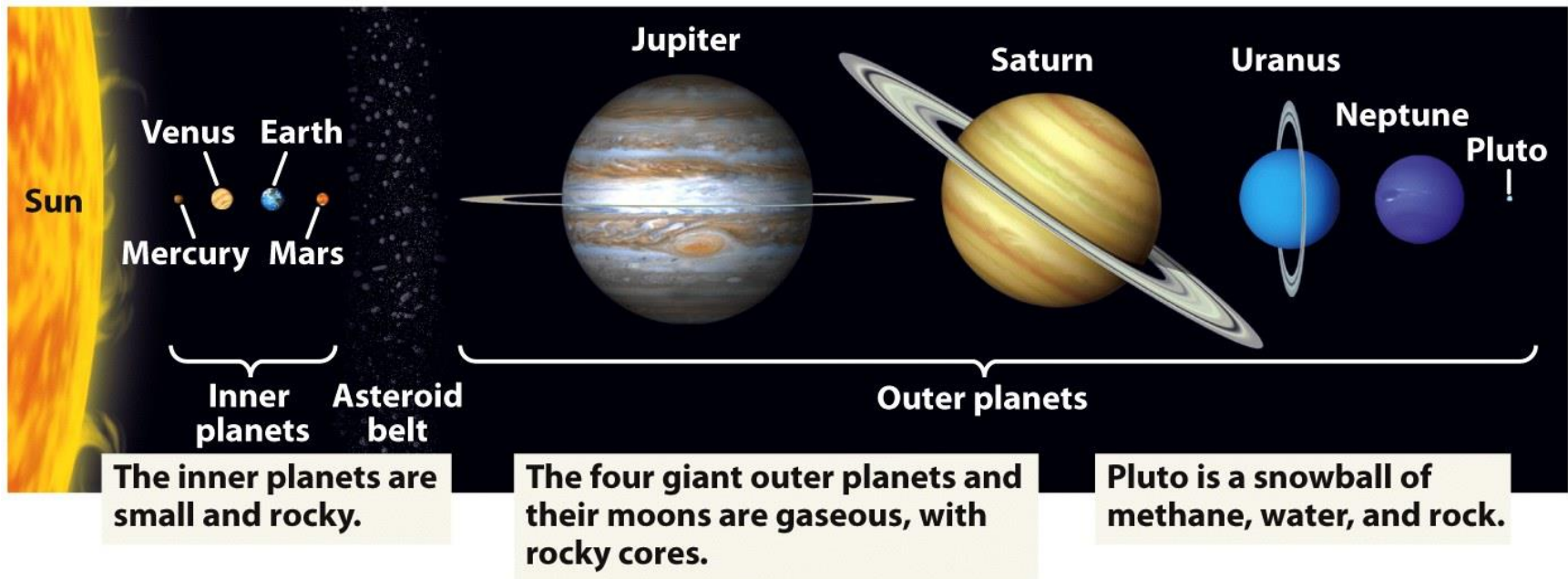
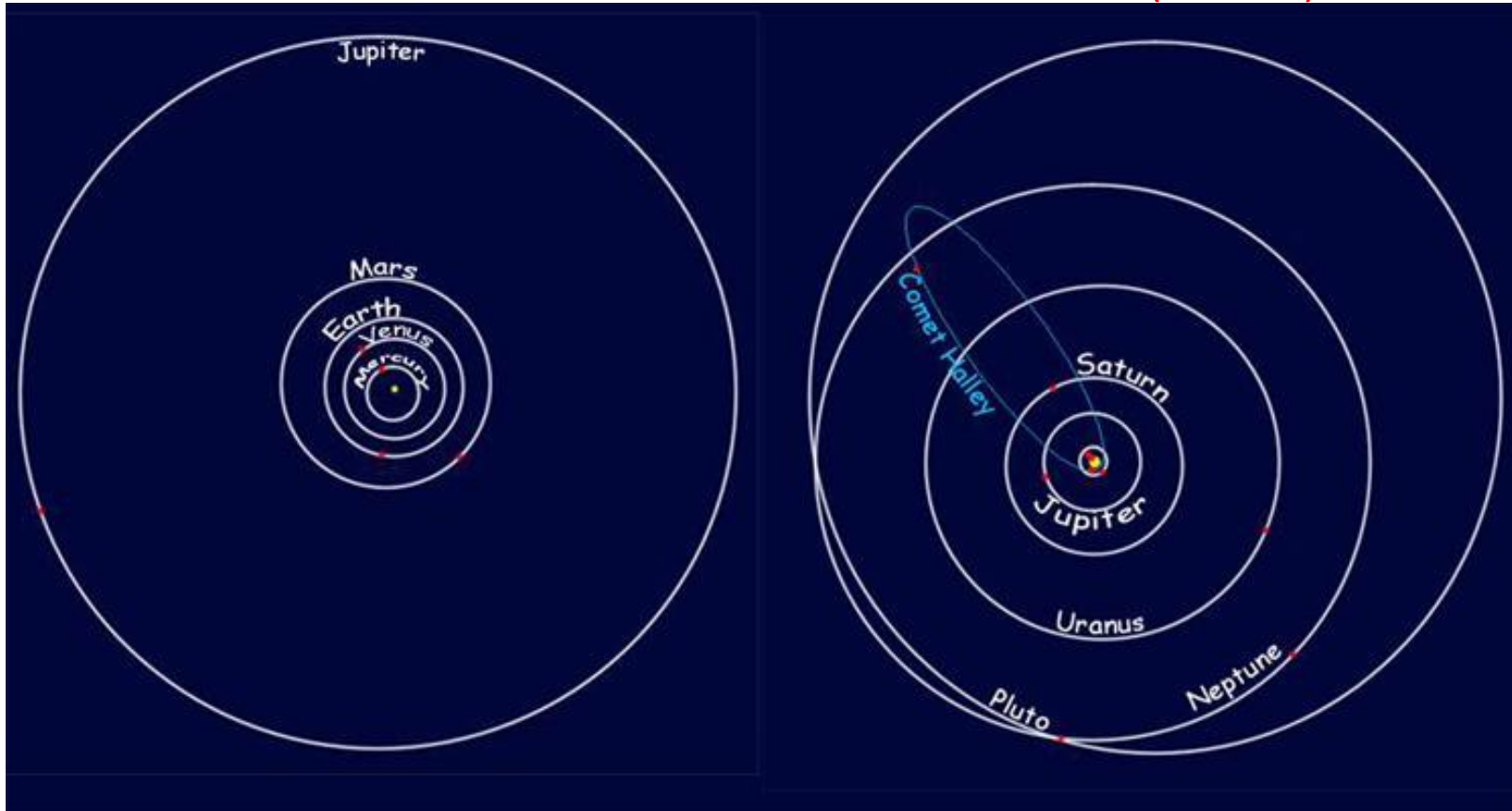


Figure 9.3
Understanding Earth, Sixth Edition
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The Solar System

Distance from Earth to the Sun: 150 million kms (= 1 A.U.)



How did the Solar System form?

Solar System formation

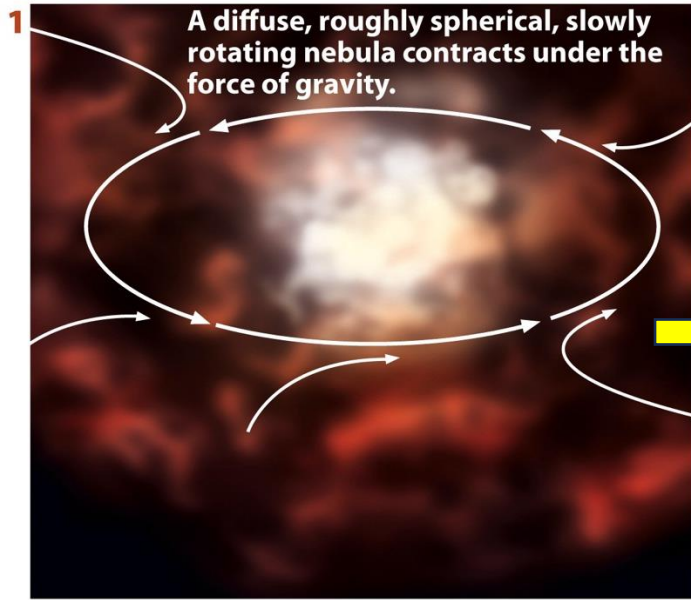


Figure 9.2 part 1
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200 000 AU

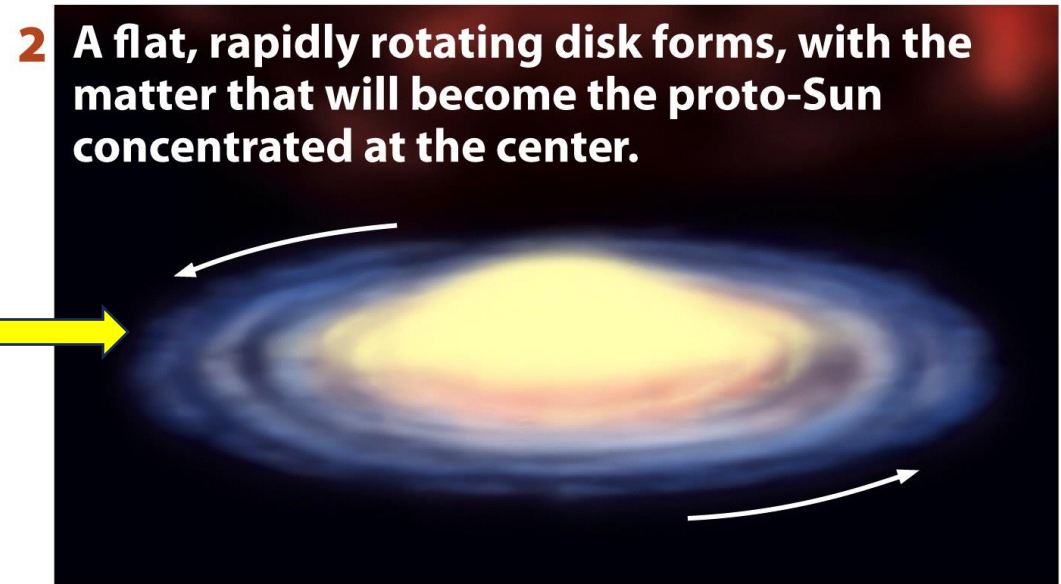


Figure 9.2 part 2
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500 AU

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

Solar System formation

3 The enveloping disk of gas and dust accretes into kilometer-sized chunks called planetesimals.

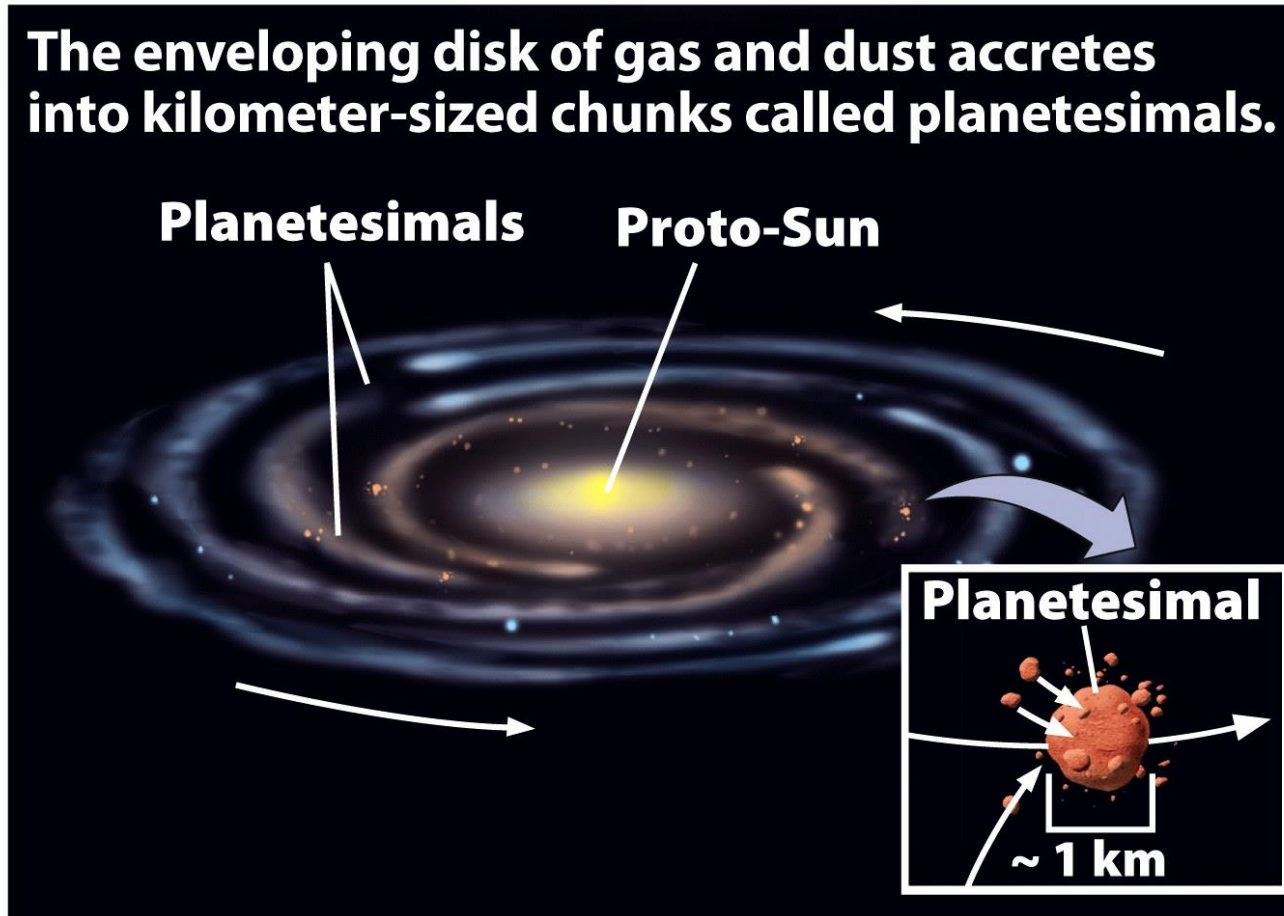


Figure 9.2 part 3
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Solar System formation

- 4** The terrestrial planets build up through collisions of planetesimals. The giant outer planets form mostly from gases.

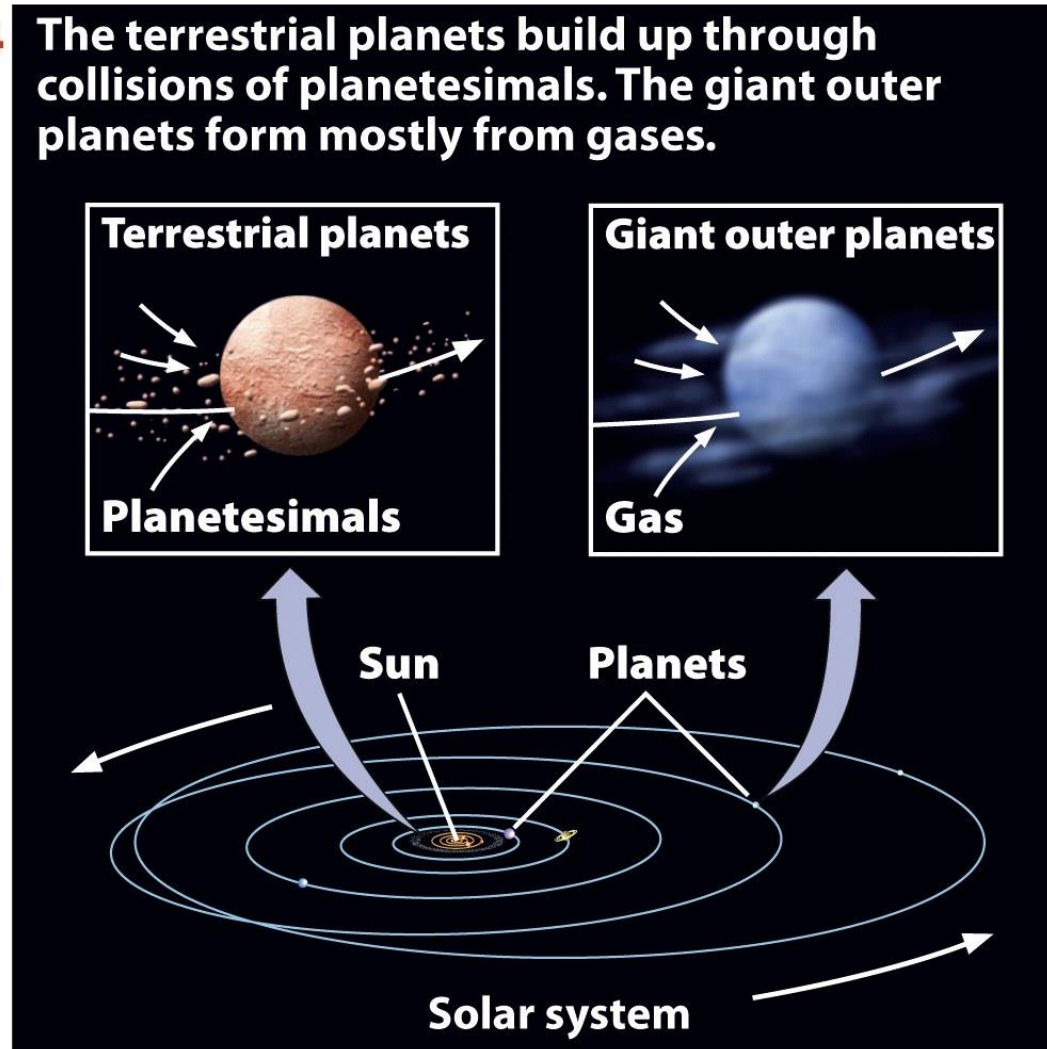
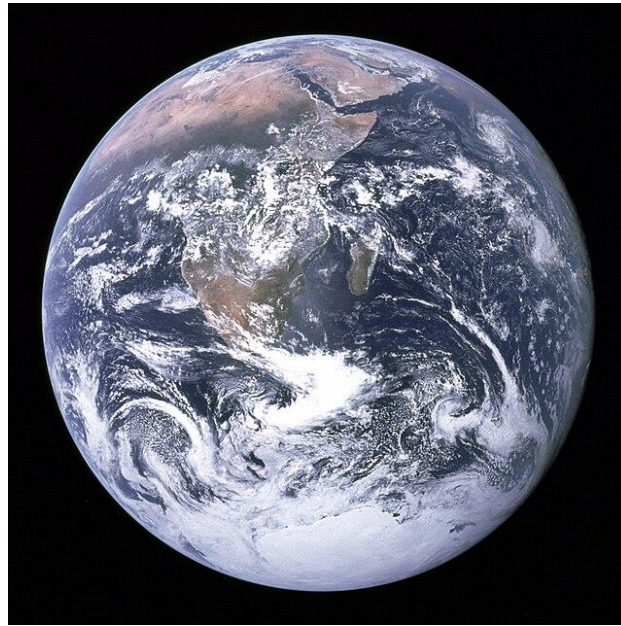


Figure 9.2 part 4
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The Earth:



How did it form? ✓

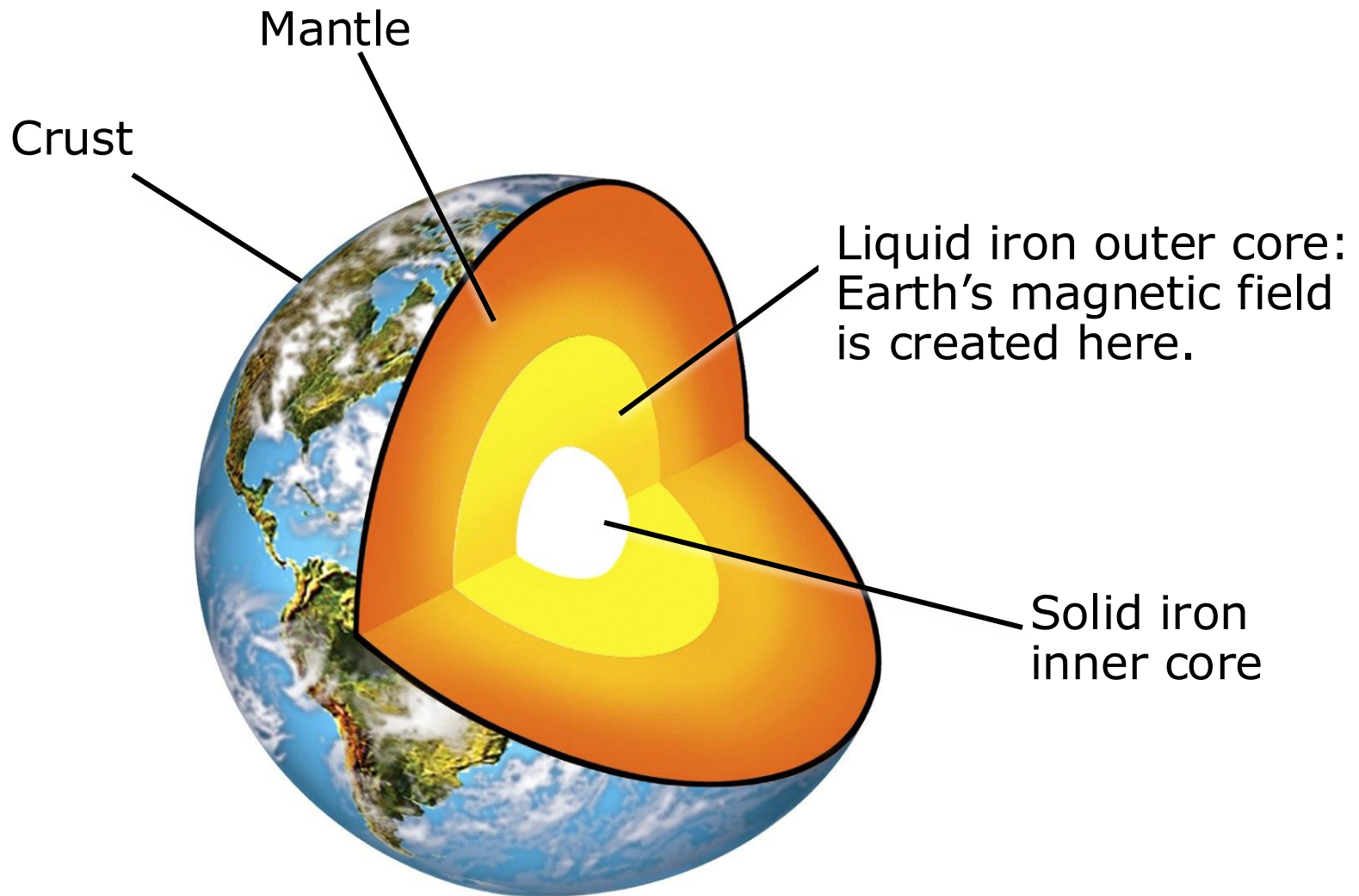
Internal structure and composition.

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

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.

Depending 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.

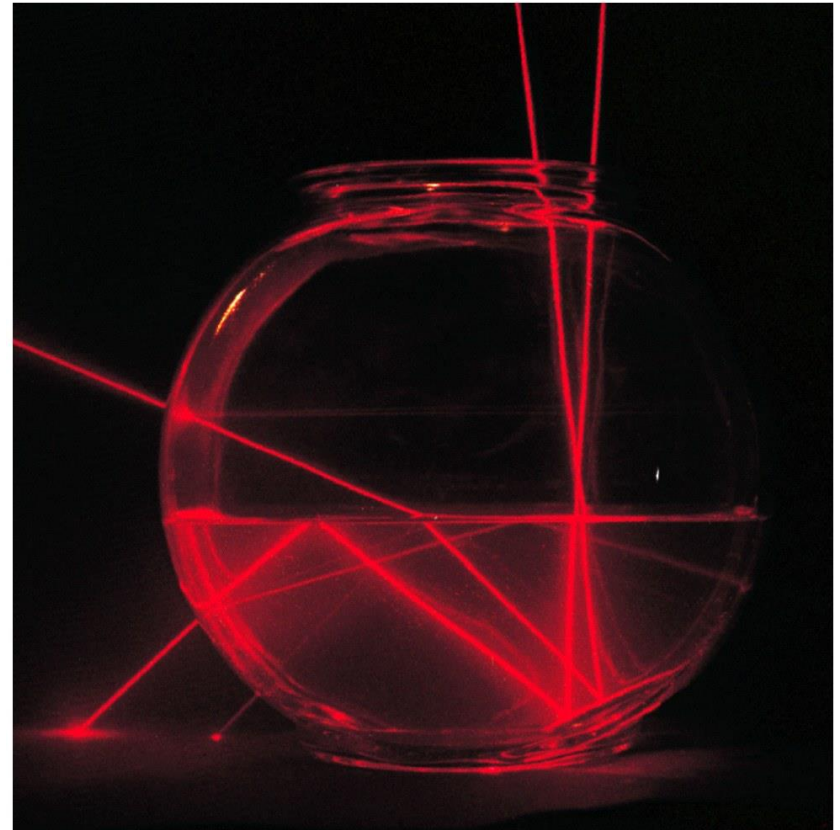
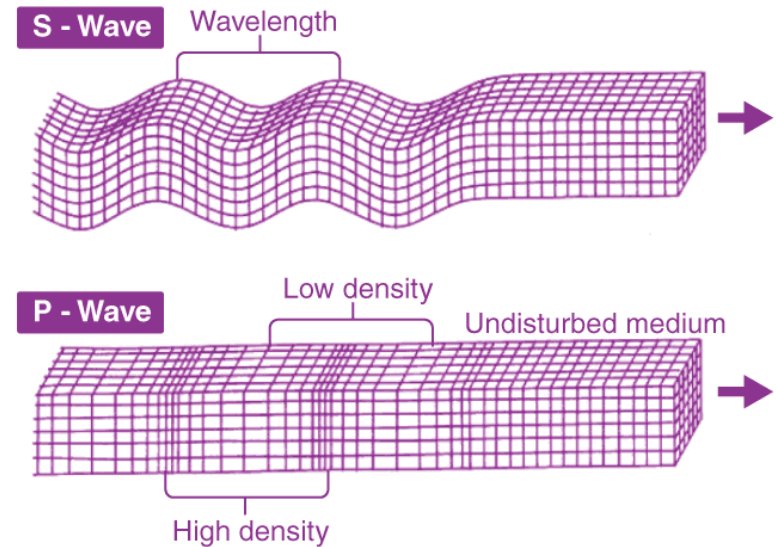


Figure 14.1
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The Earth's internal structure and composition

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...

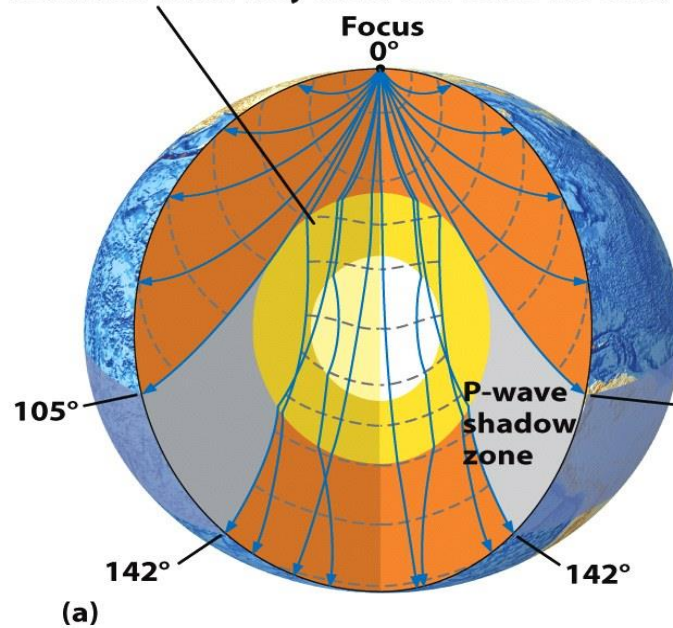
*S waves **travel slower and cannot propagate in a fluid medium** like air, water or...the Earth's liquid outer core.*

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

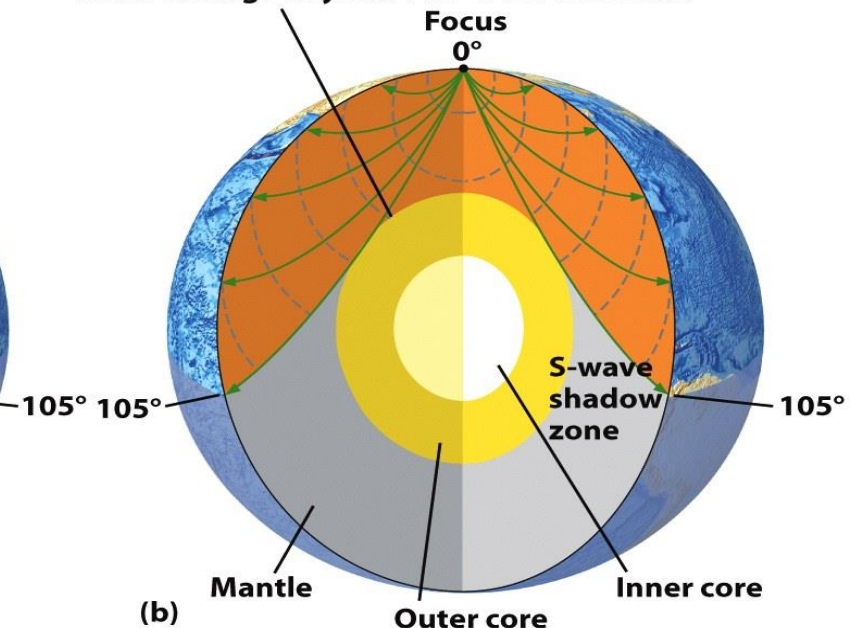
The Earth's internal structure and composition

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

P waves cannot reach the surface within the shadow zone because of the way they are refracted when they enter and leave the core.



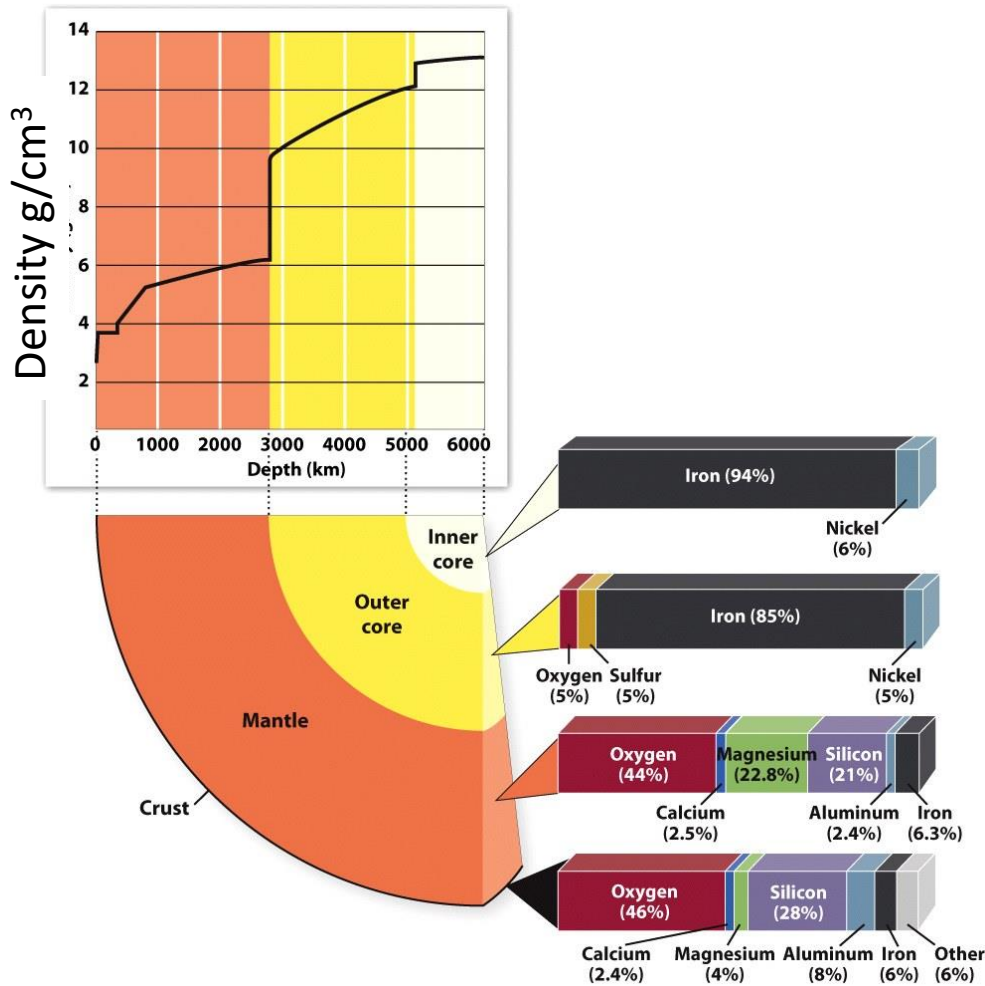
Although S waves reach the core, they cannot travel through its liquid outer region, and therefore never emerge beyond 105° from the focus.



Key
blue: P waves
green: S waves

Figure 14.2
Understanding Earth, Sixth Edition
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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?

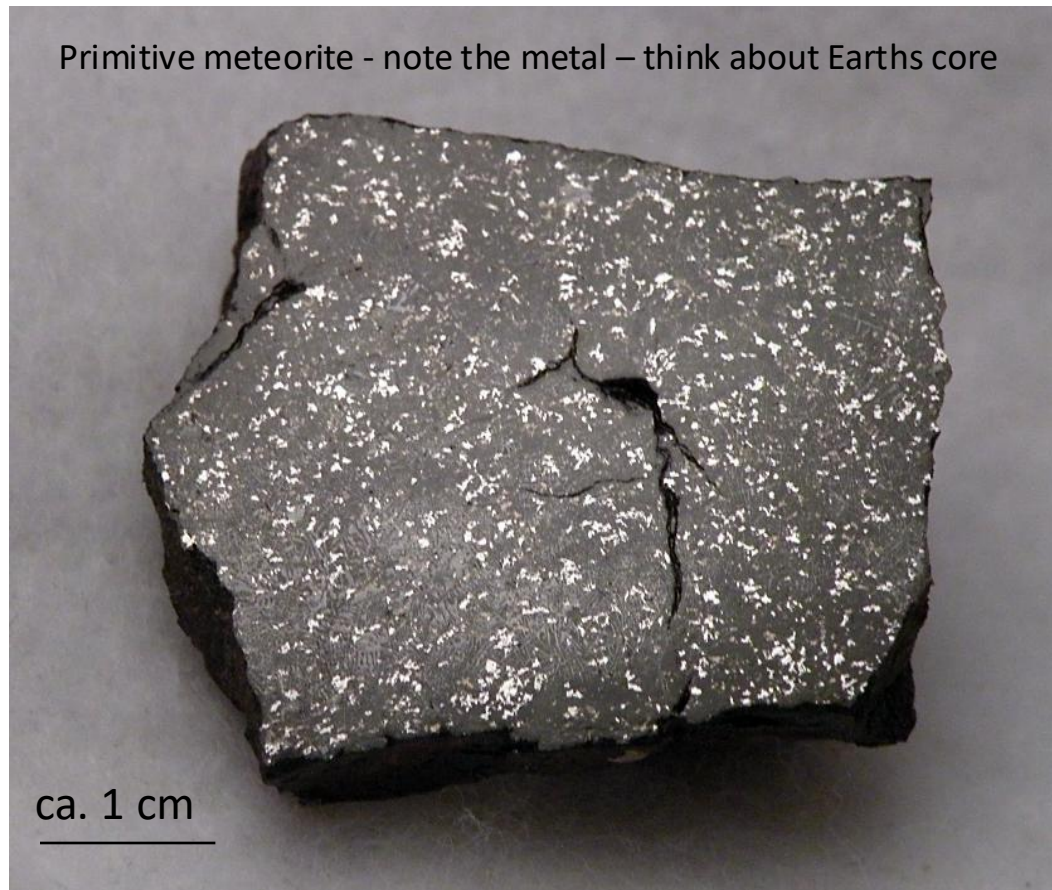
Because of the material from which it formed (look at meteorites) and because Earth got really warm during its formation, partially melted ... and *differentiated*.

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

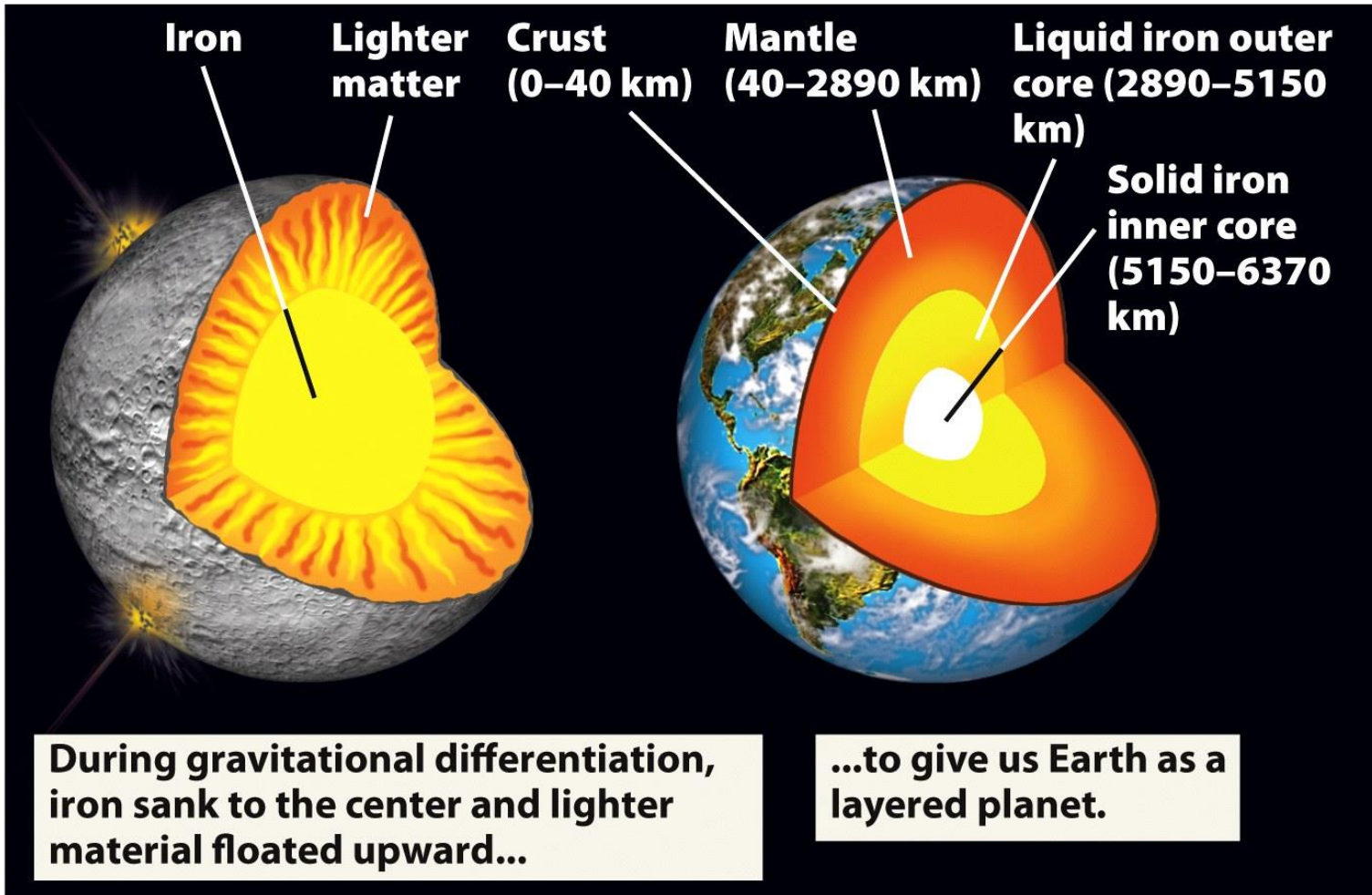


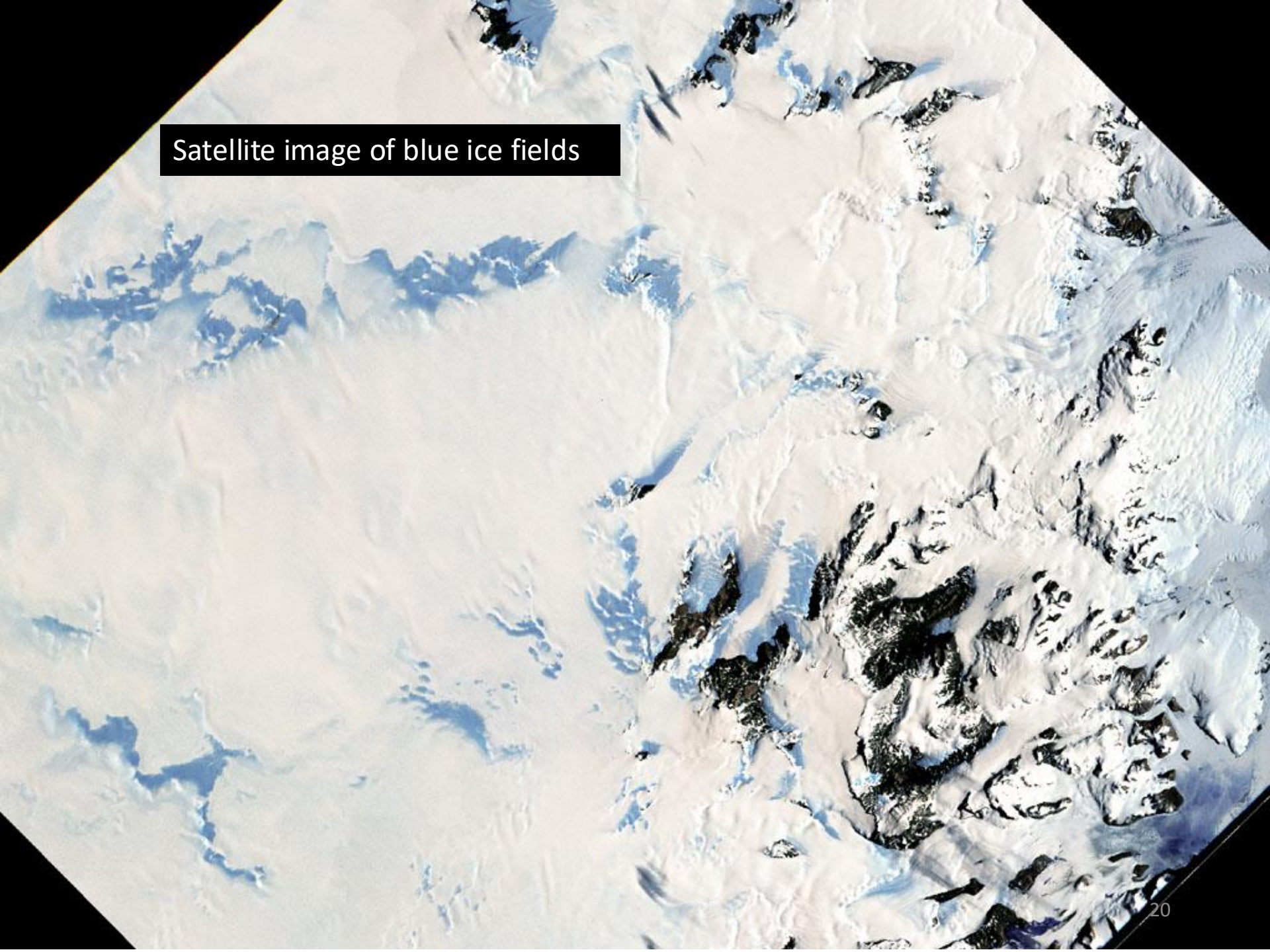
Figure 9.5
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Here is where I went when I was a student - to look for meteorites:

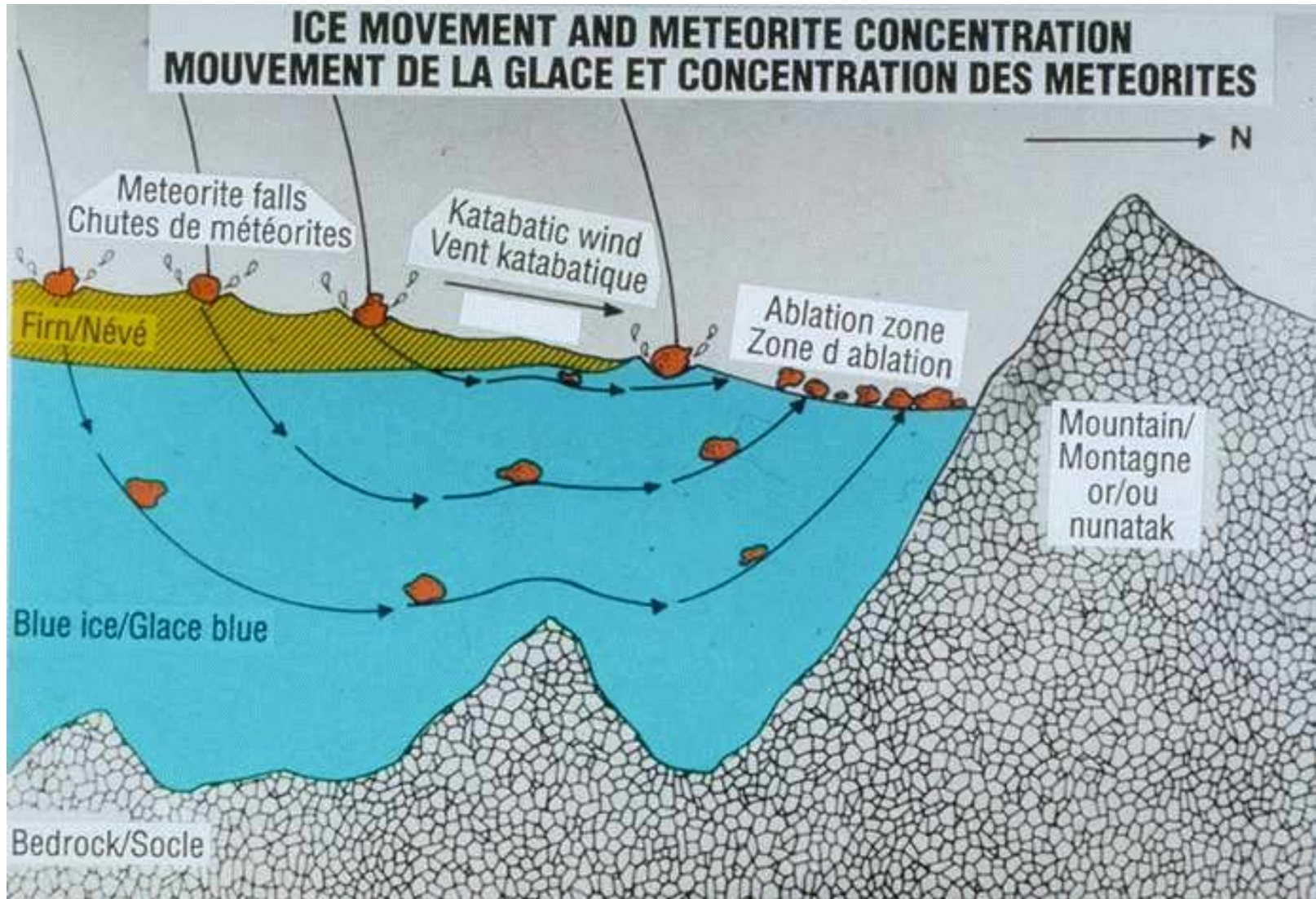
Satellite photo of Antarctica.



Satellite image of blue ice fields



Why are the meteorites there on the blue ice?















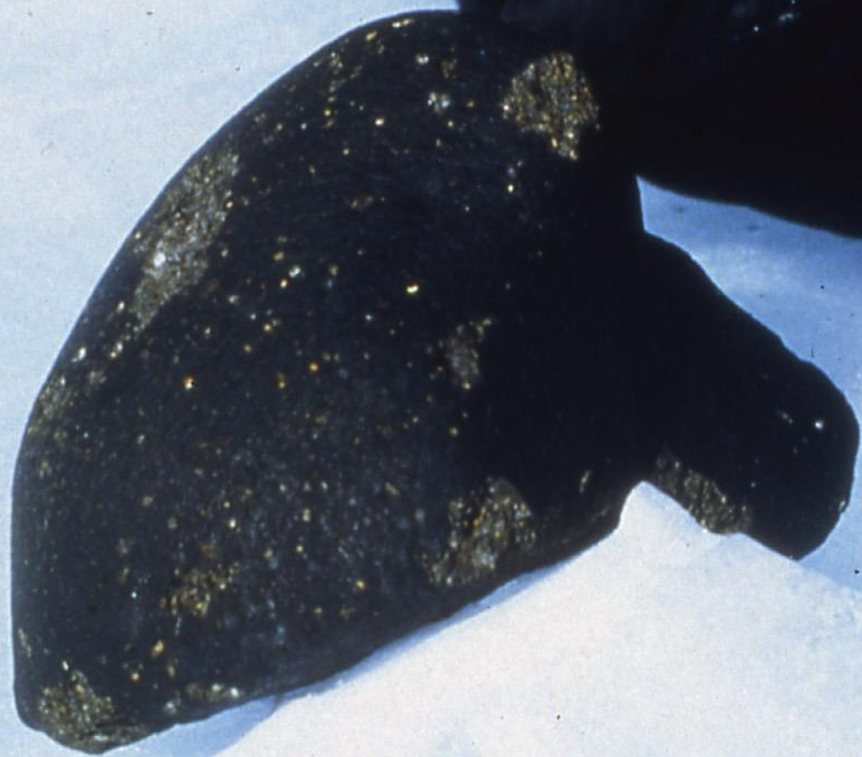
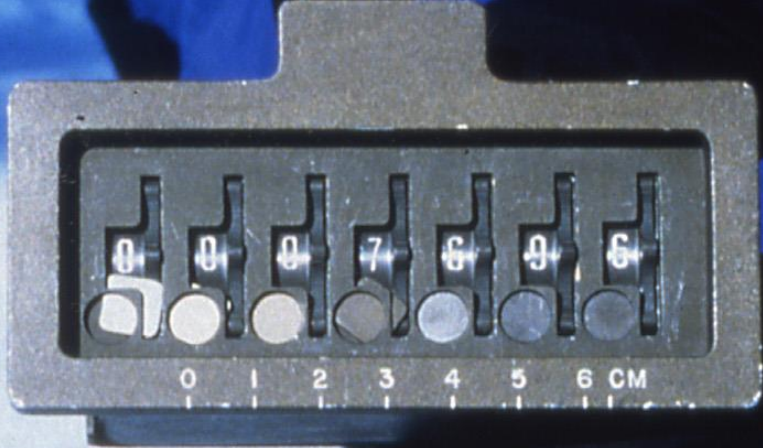






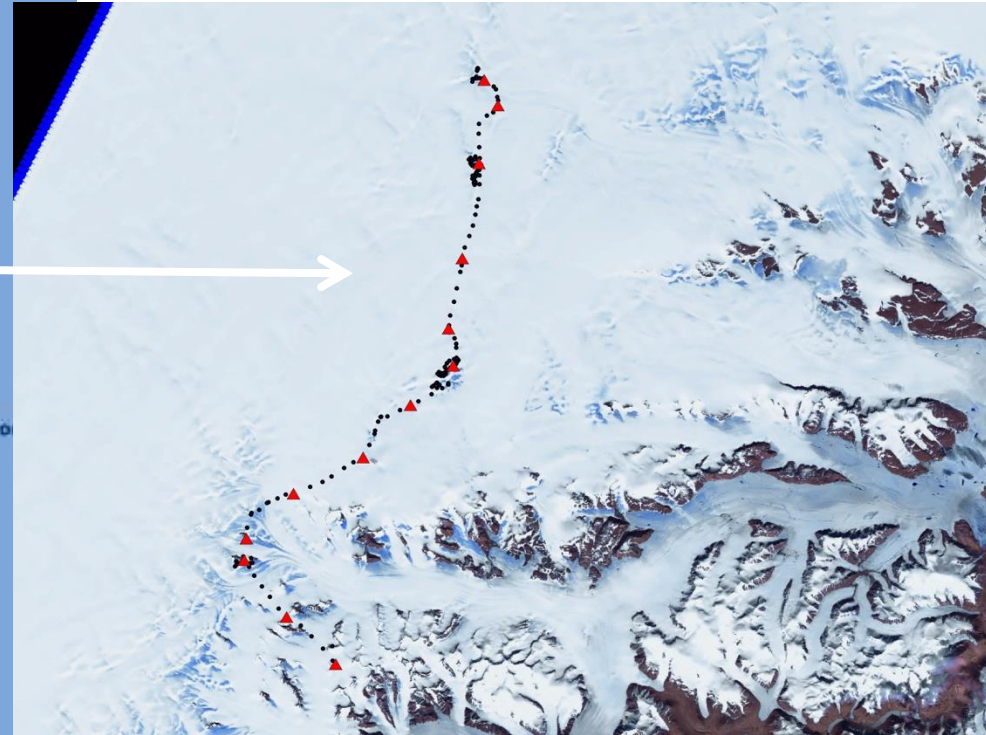








Greenland





OY-HIB





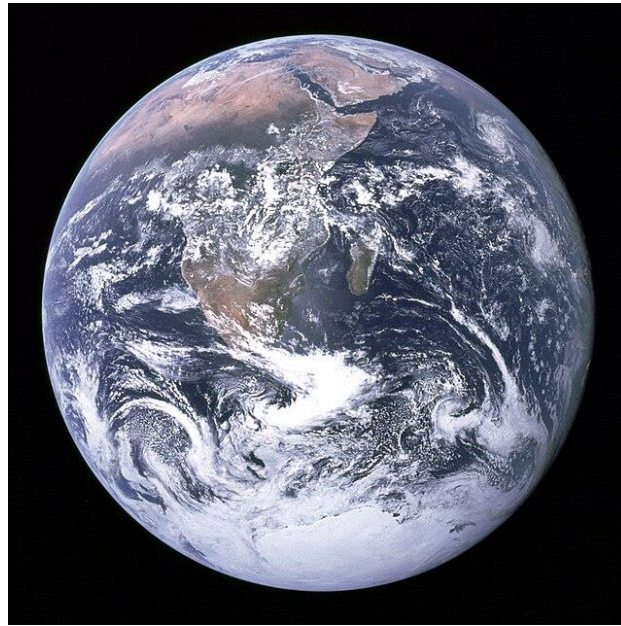


We found nothing ... except.....

A dead musk-ox...



The Earth:



How did it form? ✓

Internal structure and composition. ✓

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.

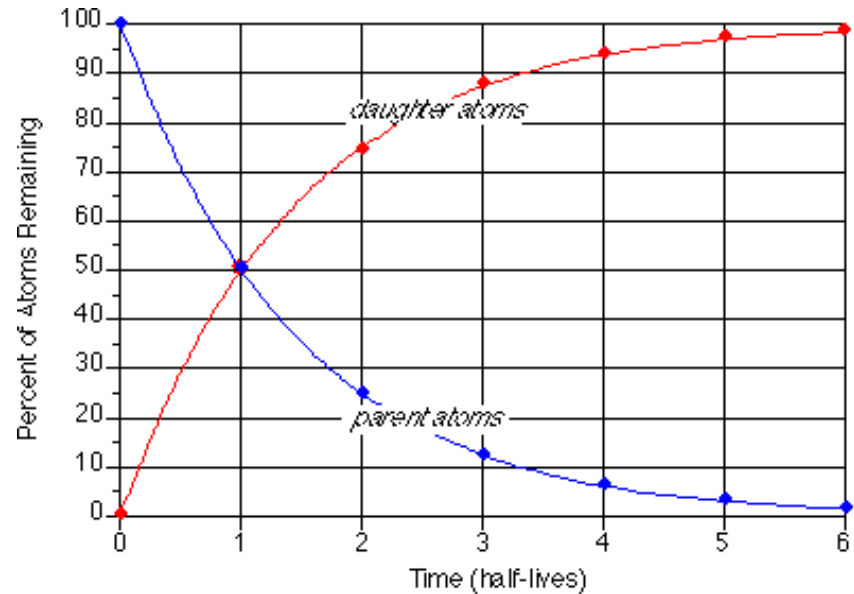
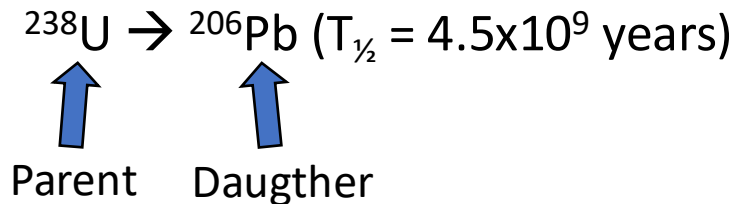
Our only source of material from when the Earth formed are primitive meteorites. These meteorites formed at the same time and were not 'destroyed' by the same processes because they were never part of a big planet, just a small (km sized) asteroid... so they have preserved their original composition.

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).



If you have a rock or a mineral that, when it formed contained some ${}^{238}\text{U}$ and no ${}^{206}\text{Pb}$, 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. 4.4×10^9 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.

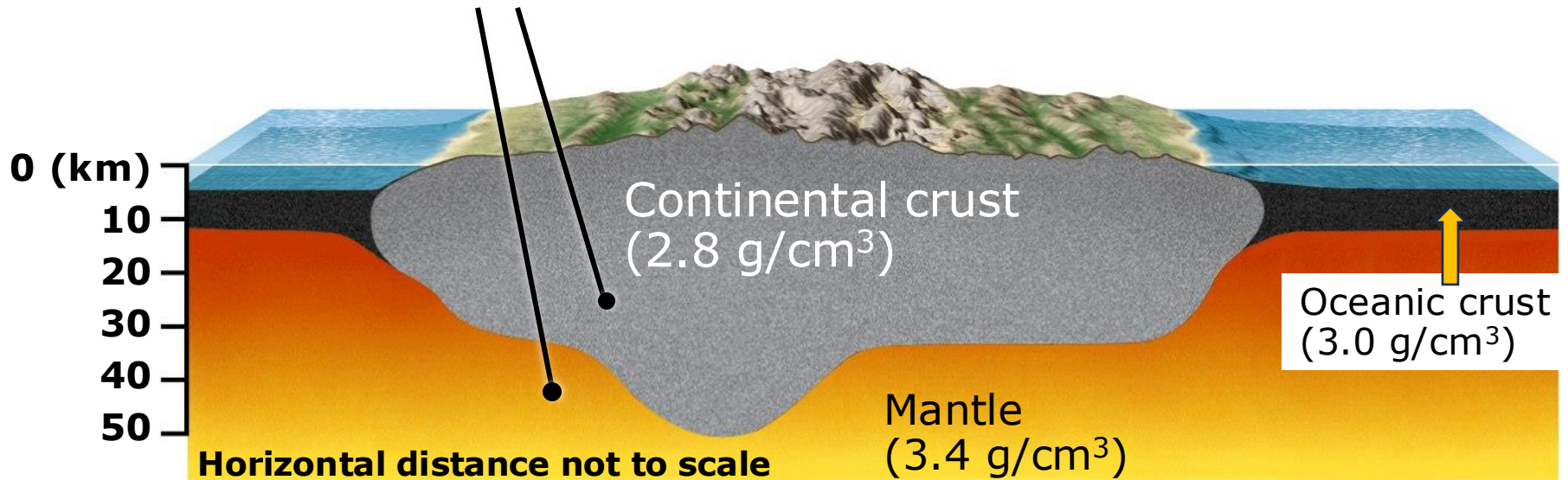
But the continental crust is the lightest and therefore floats higher, which is why the continents stick out of the global ocean...

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.

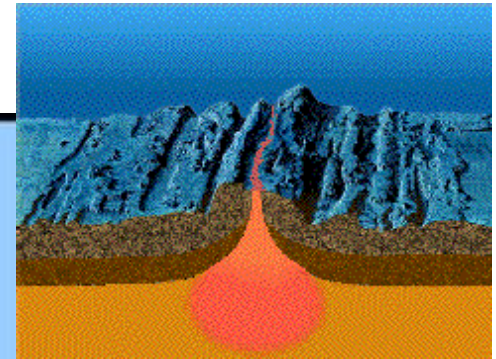
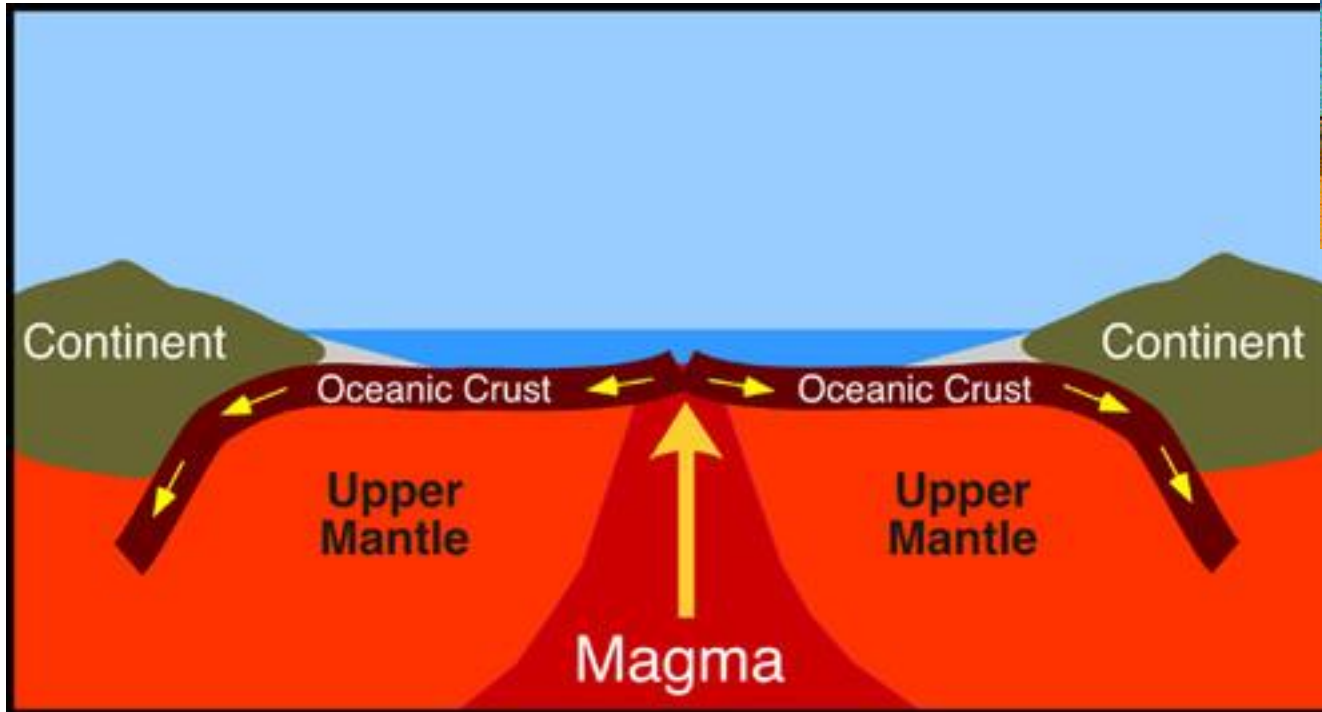
Oceanic crust is created and destroyed all the time – and is much younger...

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 continuously (keeping the surface area constant). The continents are being pushed around... creating continental drift.

This creates earthquakes, volcanoes and mountain chains!



Spreading rates are 1-10 cm / year

How old is the surface of the Earth?

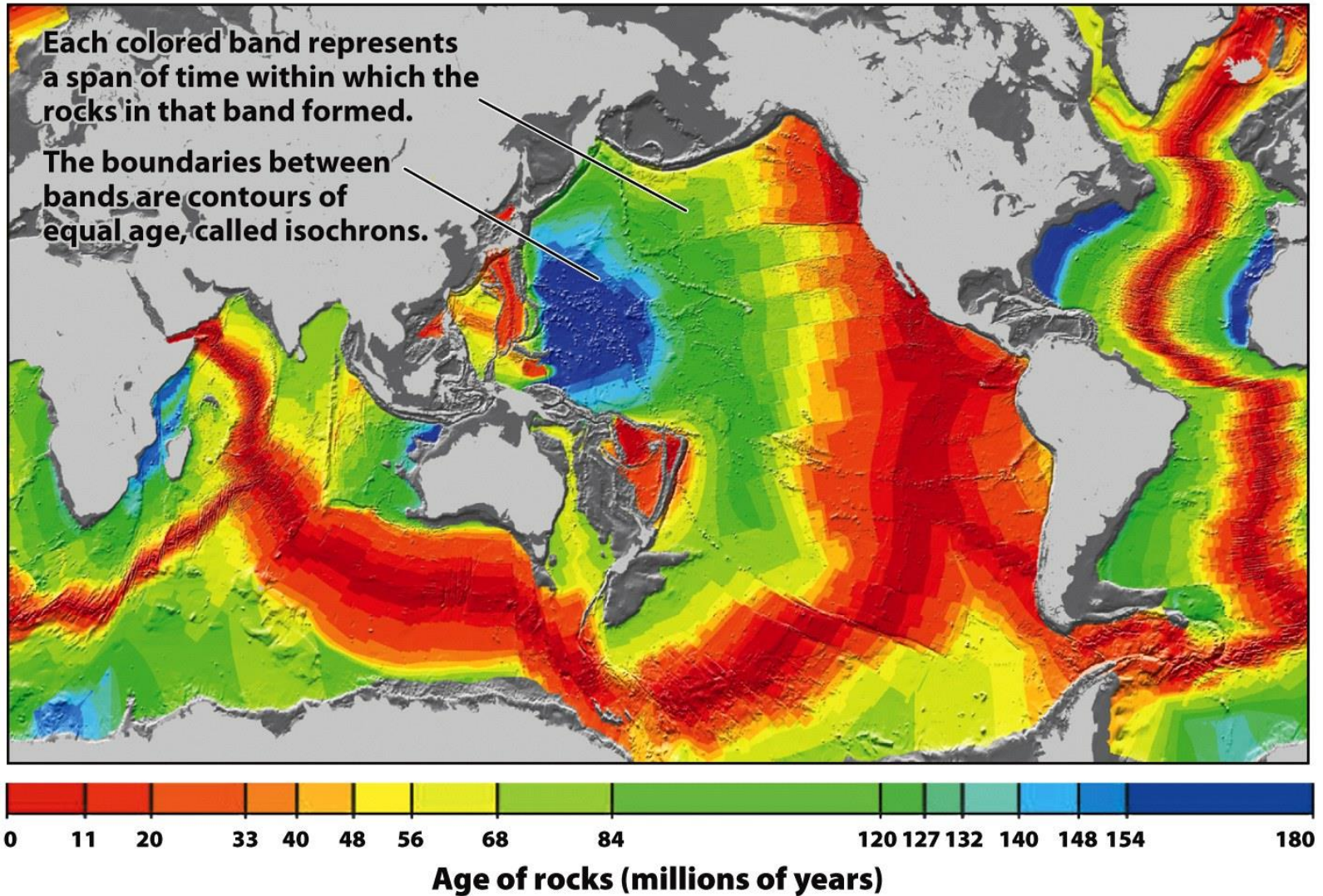


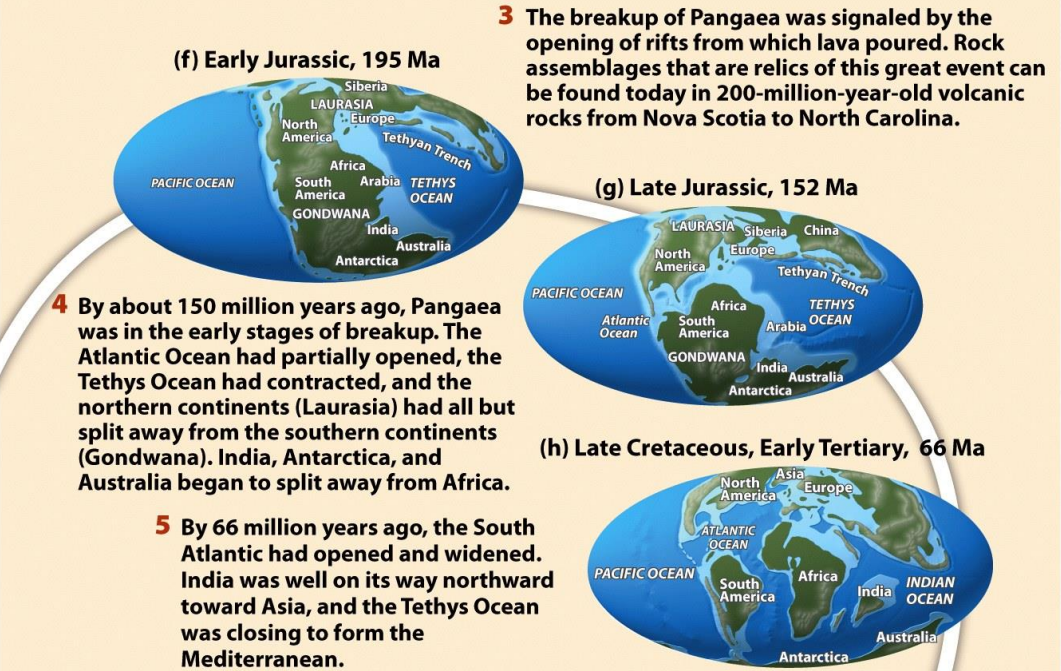
Figure 2.15
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Magma rose from the mantle, creating new oceanic spreading centers that pushed old continental plates apart.

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...

BREAKUP OF PANGAEA



THE PRESENT-DAY AND FUTURE WORLD

6 The modern world has been produced over the past 65 million years. India collided with Asia, ending its trip across the ocean, and is still pushing northward into Asia. Australia has separated from Antarctica.

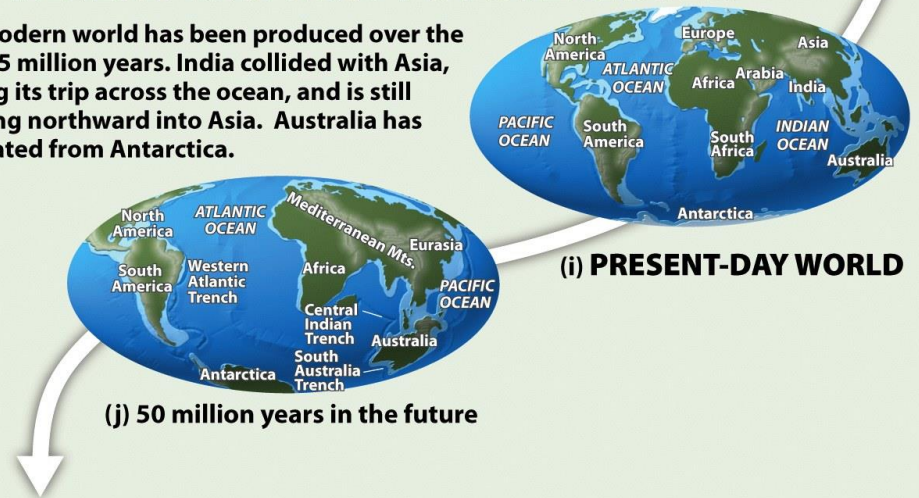
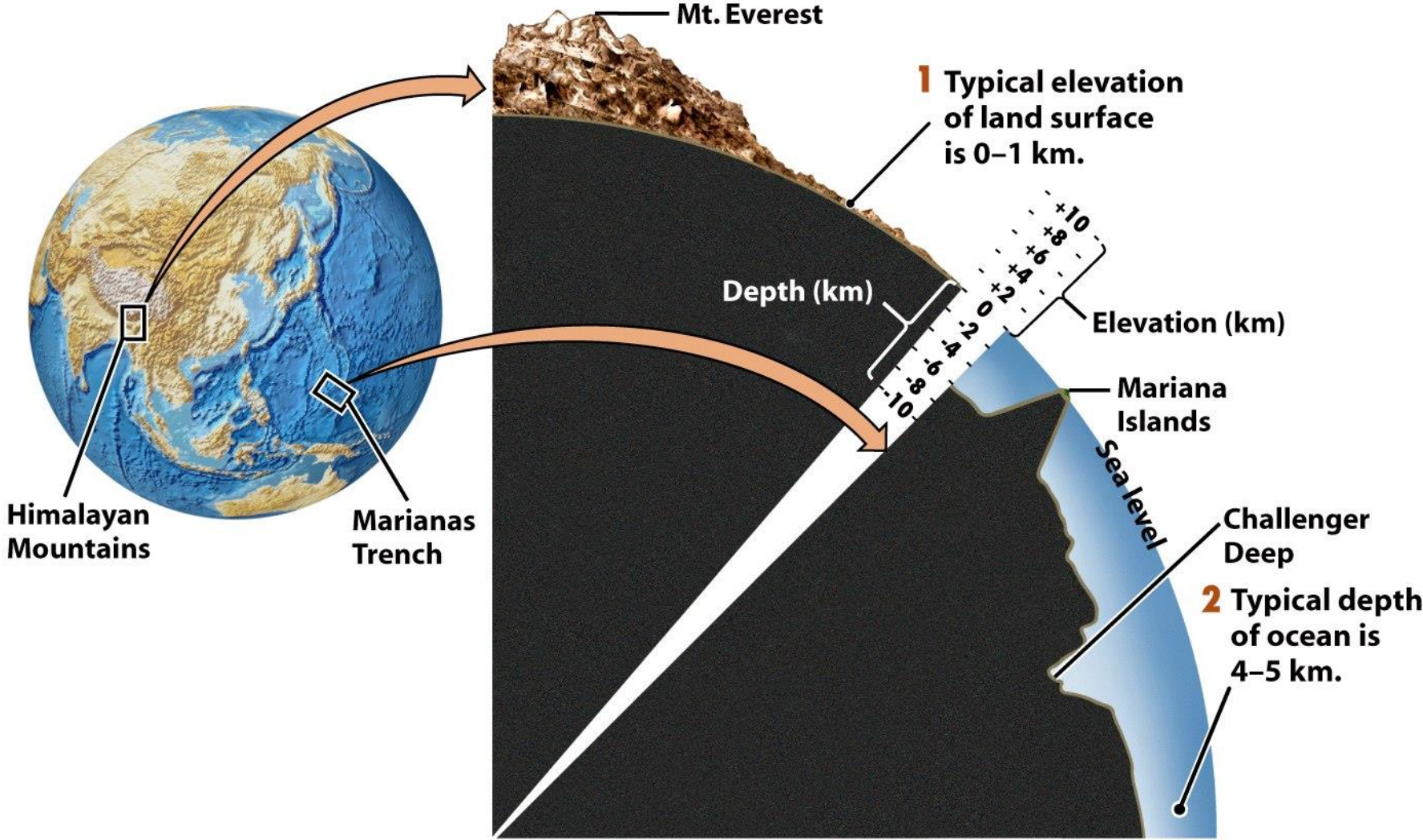
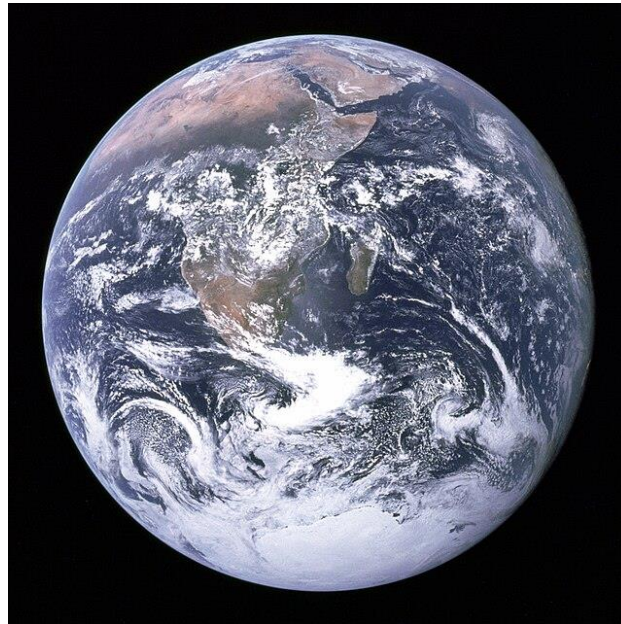


Plate tectonics create topography:



The Earth:



How did it form? ✓

What is it composed of? ✓

How old is it?

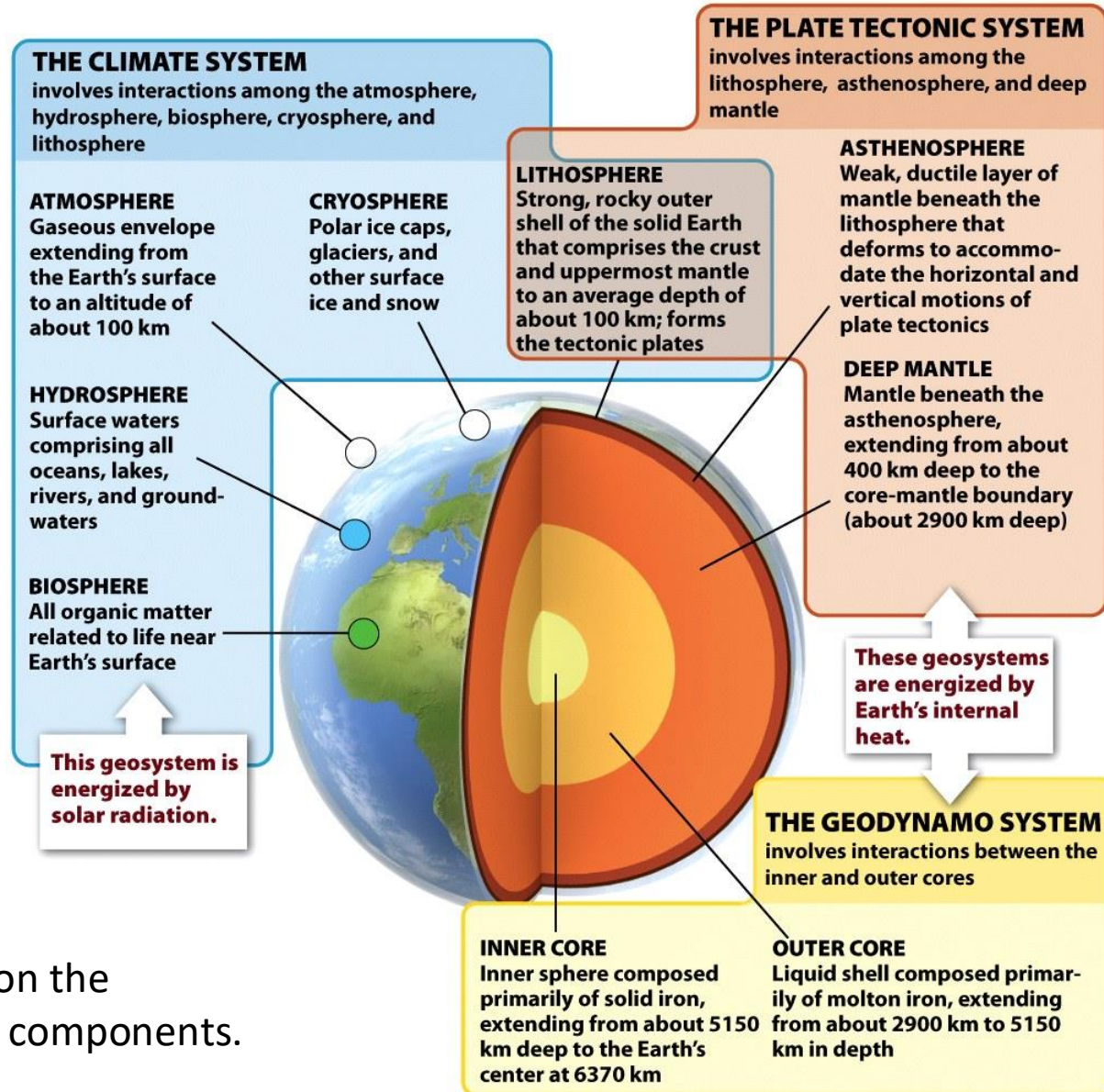
How does it work? ✓

↳ 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.

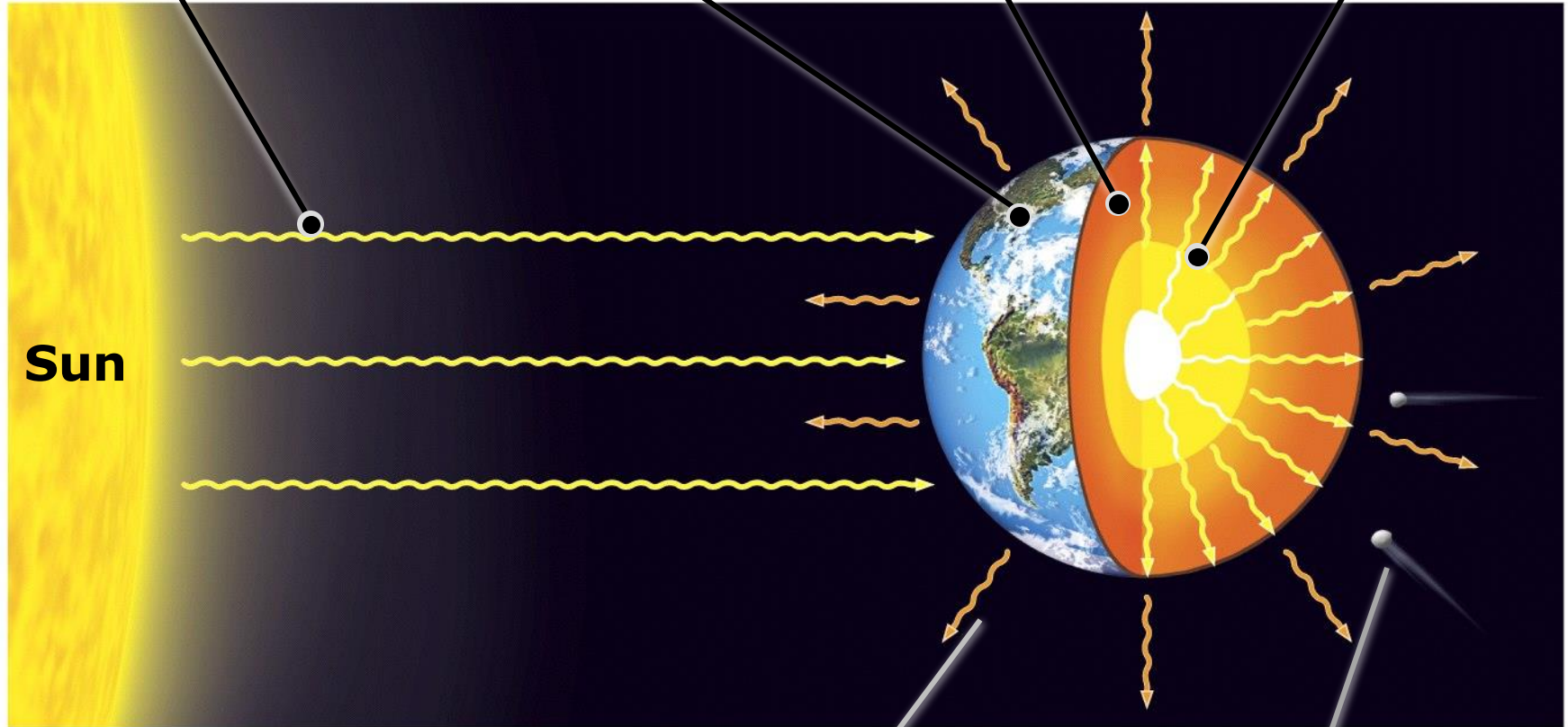
The Earth is an open system:

The Sun drives Earth's external engine

Solar energy is responsible for our climate and weather

Earth's internal engine is powered by trapped heat from its formation...

...and radioactivity in its interior.



Heat radiating from Earth balances solar input and heat from interior (which is minor).

Meteors move mass from the interplanetary space to Earth (this is also minor).

The Atmosphere:

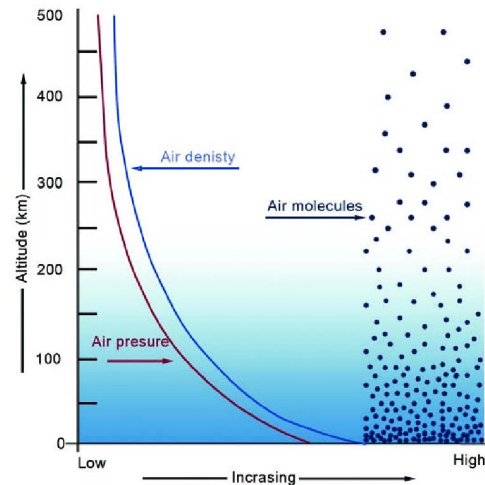
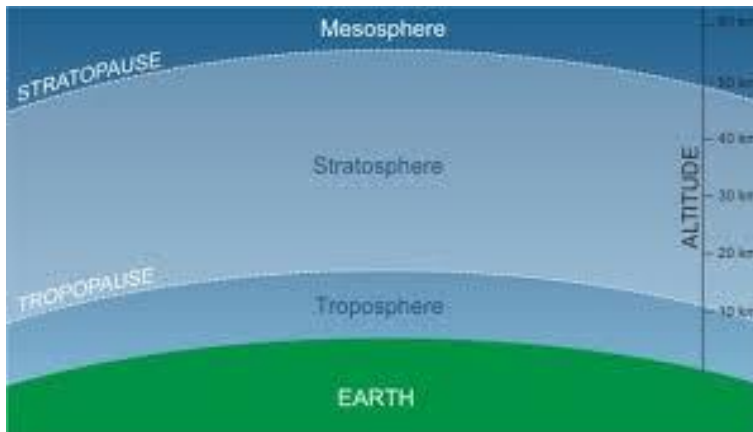
Composition (mole fraction):

78 % N₂

21 % O₂

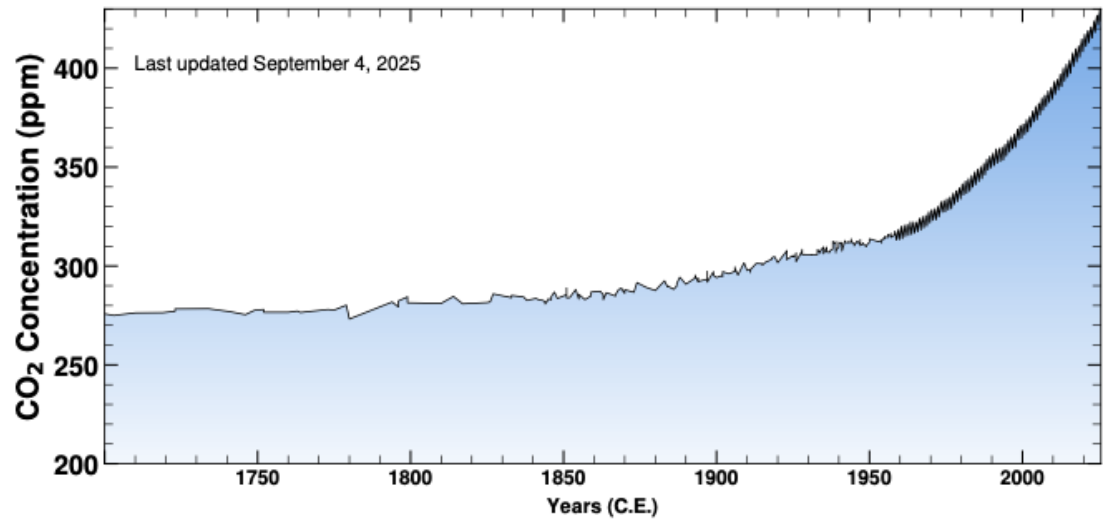
The last 1 % :

Ar, CO₂, water vapor,
methane (CH₄), ozone (O₃⁺),
other trace gasses.

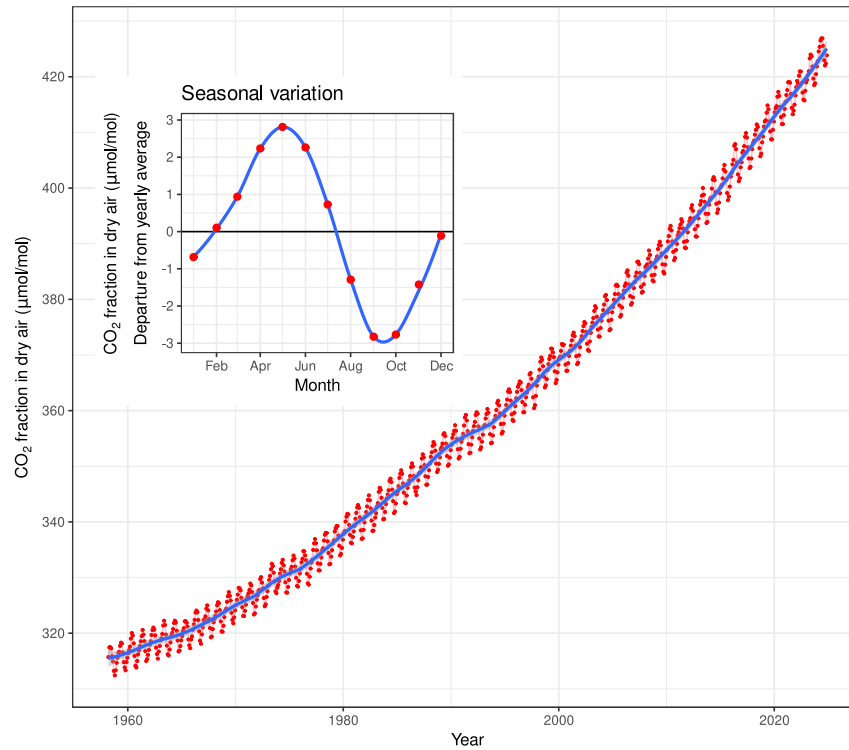


← 75 % of its mass is in the troposphere

The Keeling curve

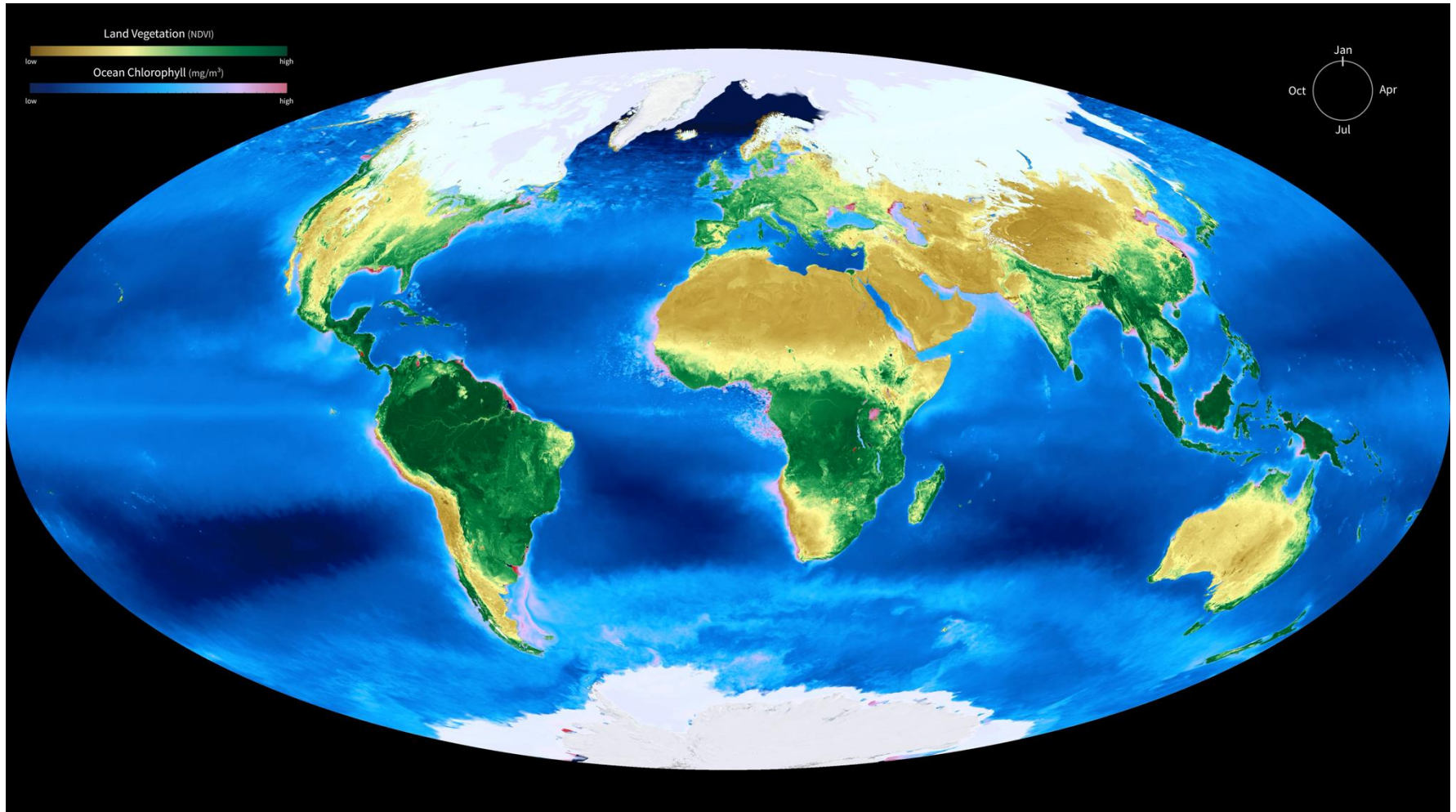


Monthly mean CO₂ concentration
Mauna Loa 1958-2024



Data : Dr. Pieter Tans, NOAA/ESRL (<https://gml.noaa.gov/ccgg/trends/>) and Dr. Ralph Keeling, Scripps Institution of Oceanography (<https://scrippsco2.ucsd.edu/>), Accessed 2024-12-24 <https://www.wiki/4ZWn>

Earth's biosphere – seasonal changes...



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

Overview of Geologic Time

