Lecture 9

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The Living Earth

Water covers 71% of the surface of the earth, the blue planet

Guiding Questions

1. Why is Earth the only planet with an oxygen-rich **atmosphere**?
2. What is the **greenhouse effect**? How does it affect the average temperature of the Earth?
3. Is the Earth completely solid **inside**? How can scientists tell?
4. What is **plate tectonics**? How does it shape the surface of Earth?
5. How does our planet's **magnetic field** protect life on Earth?

Basic facts: our planet, the earth, is the largest terrestrial planet. 71% of the Earth's surface is covered by **liquid water**. There is abundant **oxygen** in the Earth's atmosphere to sustain life …

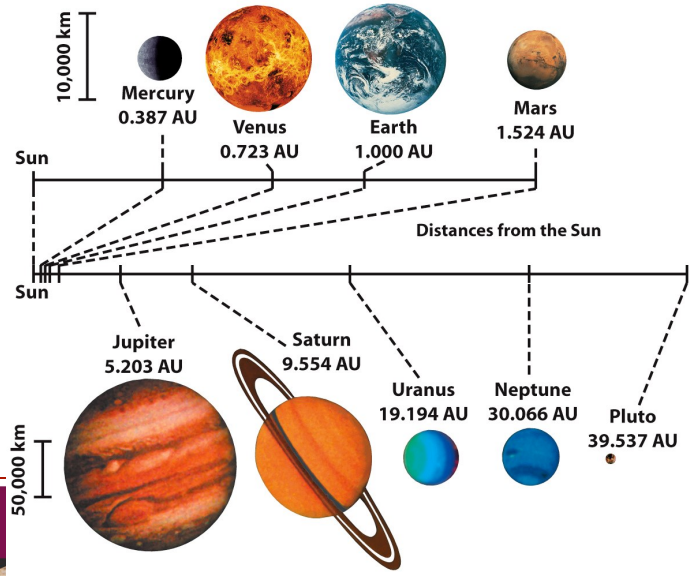
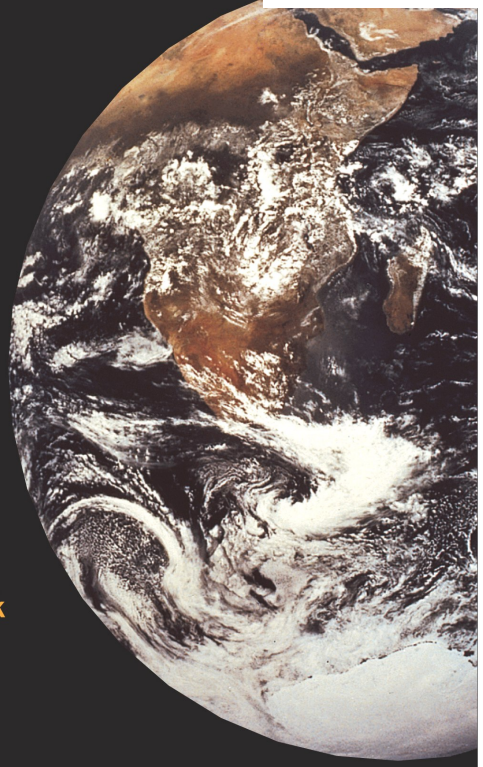


table 9-1	Earth Data
Average distance from the Sun:	1.000 AU = 1.496×10^8 km
Maximum distance from the Sun:	1.017 AU = 1.521×10^8 km
Minimum distance from the Sun:	0.983 AU = 1.471×10^8 km
Eccentricity of orbit:	0.017
Average orbital speed:	29.79 km/s
Orbital period:	365.256 days
Rotation period:	23.9345 hours
Inclination of equator to orbit:	23.45°
Diameter (equatorial):	12,756 km
Mass:	5.974×10^{24} kg
Average density:	5515 kg/m^3
Escape speed:	11.2 km/s
Albedo:	0.39
Surface temperature range:	Maximum: 60°C = 140°F = 333 K Mean: 14°C = 57°F = 287 K Minimum: −90°C = −130°F = 183 K
Atmospheric composition (by number of molecules):	78.08% nitrogen (N_2) 20.95% oxygen (O_2) 0.035% carbon dioxide (CO_2) about 1% water vapor



Q: to have everything right for life, the distance to the Sun is a critical element, and Earth's mass is another – Why?

9.1 Earth's activity, energy, and greenhouse effect

table 9-2 The Earth's Energy Sources

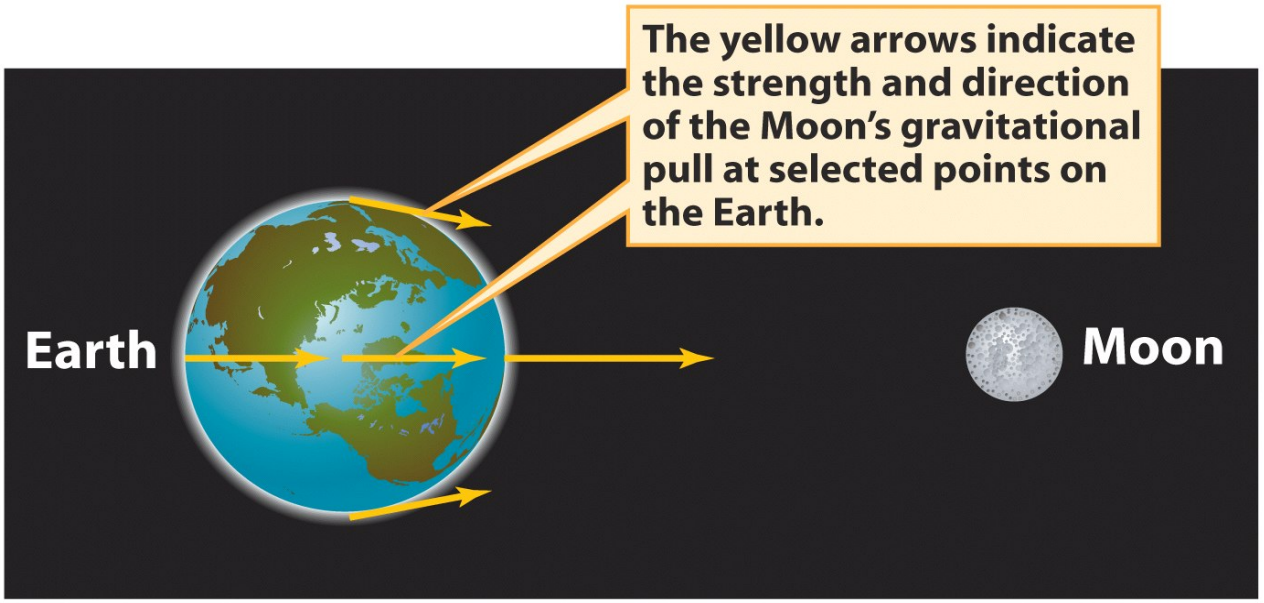
Activity	Energy Sources
Motion of water in oceans, lakes, rivers	Solar energy, tidal forces
Motion of the atmosphere	Solar energy
Reshaping of surface	Earth's internal heat
Life	Solar energy (a few species that live on the ocean floor make use of the Earth's internal heat)

Q: what is the nature of these energy sources?

- The Earth's atmosphere, oceans, and surface are extraordinarily active.
- All activity in the Earth's atmosphere, oceans, and surface is powered by three sources of energy, **solar energy, tidal force,** and **Earth's internal heat.**

The Earth's dynamic oceans are powered by **tidal forces** and **solar energy**.

Gravitational forces between two objects produce tides.
Tidal forces from the Moon and Sun help to power the motion of the oceans.

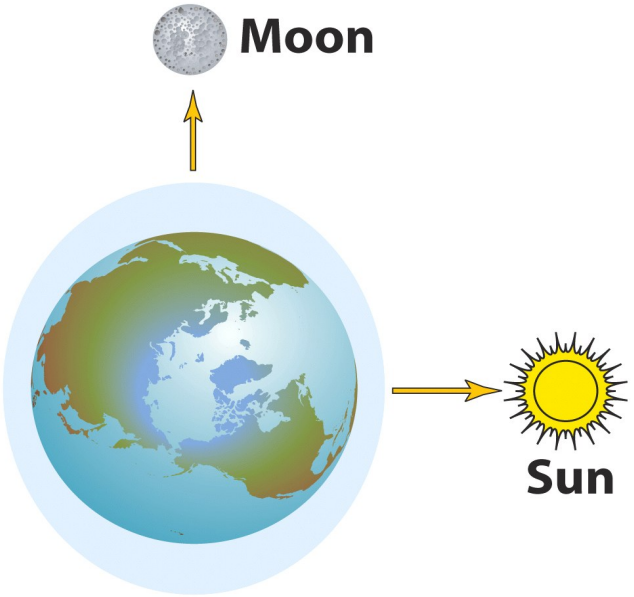


The tidal force on the Earth by the Moon

Ex.1: compare the tidal forces by the moon and the Sun:

tidal force by the Moon is about twice the tidal force by the Sun.

spring tide at full moon or new moon

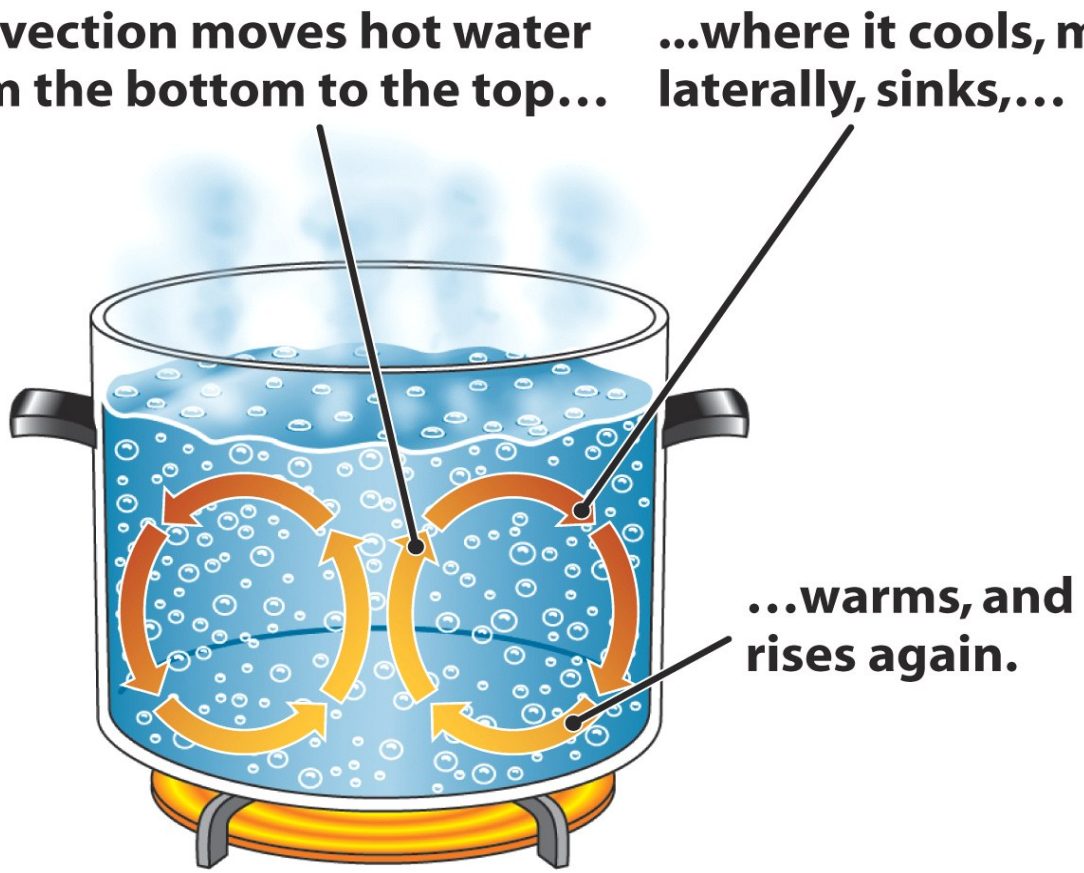


neap tide at first and third quarter moon

The Earth's dynamic atmosphere, powered by solar energy through **convection** and **evaporation**.

thunderstorm clouds over Zaire

Tornado and rainbow in Kansas. Over 1,000 tornadoes, the most violent type of storm known, occur on Earth every year.



Convection in boiling water.

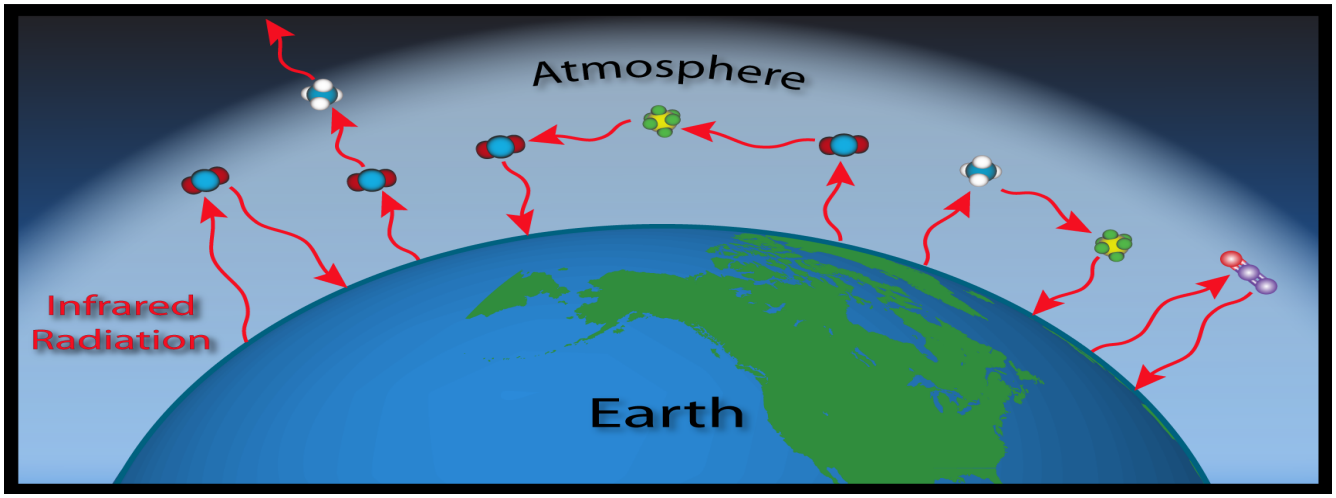
Convection is the motion of heated air/fluid/plasma bubbles. It is an important energy transport mechanism in the Earth's atmosphere and water, as well as the Earth's and stars' interior.

Ex.2: means of energy transport in stars.

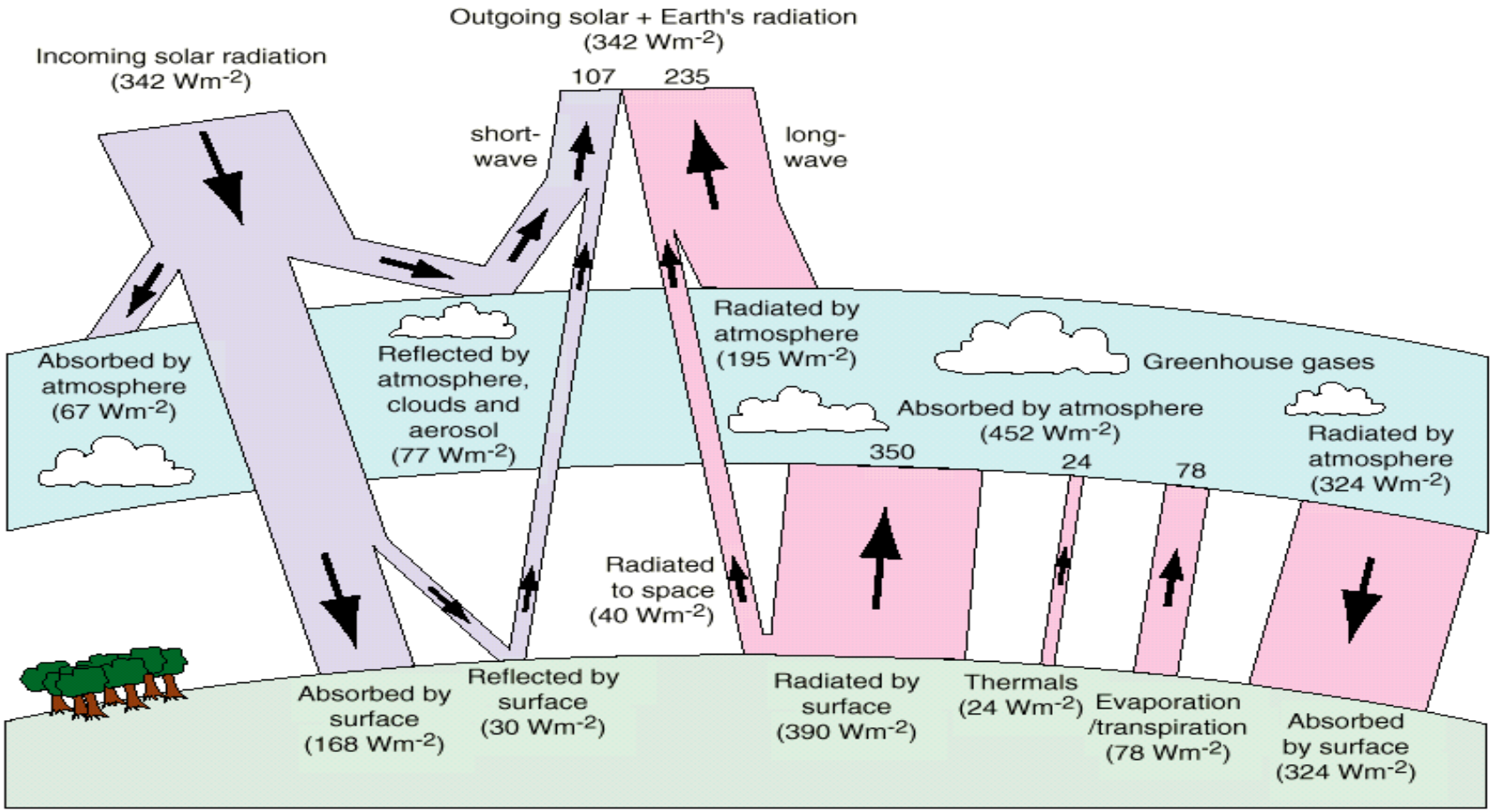
Solar energy is the most important energy source. On average, Earth's incoming and outgoing energy budget should be balanced at a theoretic mean surface temperature.

Q: what's the form of the incoming and outgoing energy?
How to calculate the theoretic mean temperature? (HW)

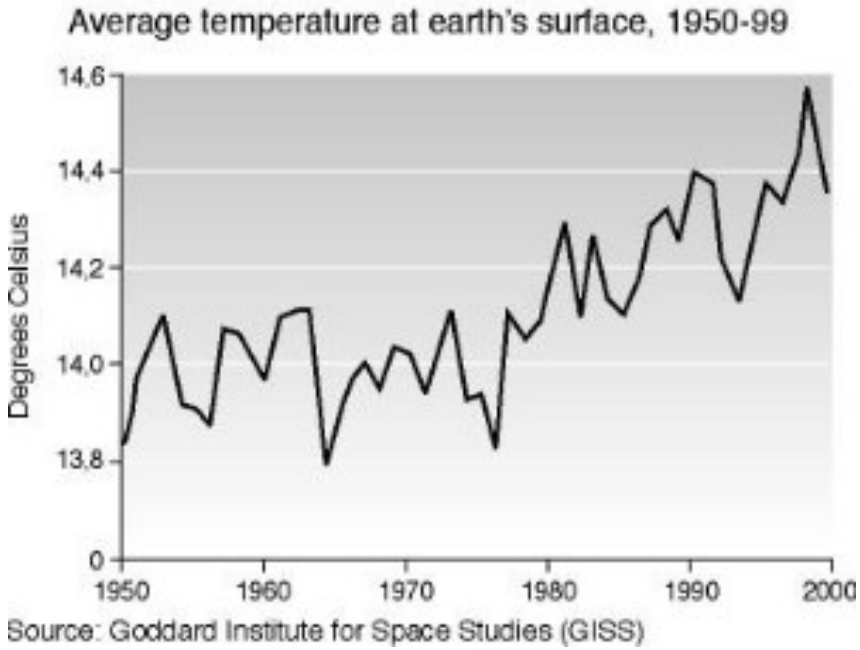
The **greenhouse effect**: some gases - **greenhouse gases** like water vapor and carbon dioxide - in the Earth's atmosphere, trap infrared radiation (out) by the Earth, hence raising the Earth's surface temperature.

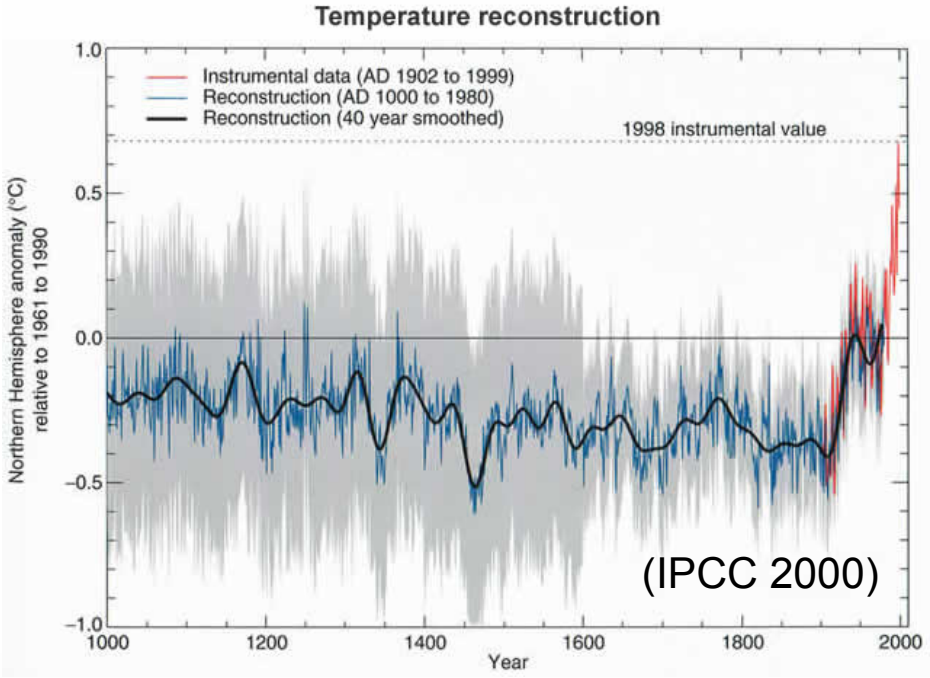


Ex.3: energy budget breakdown



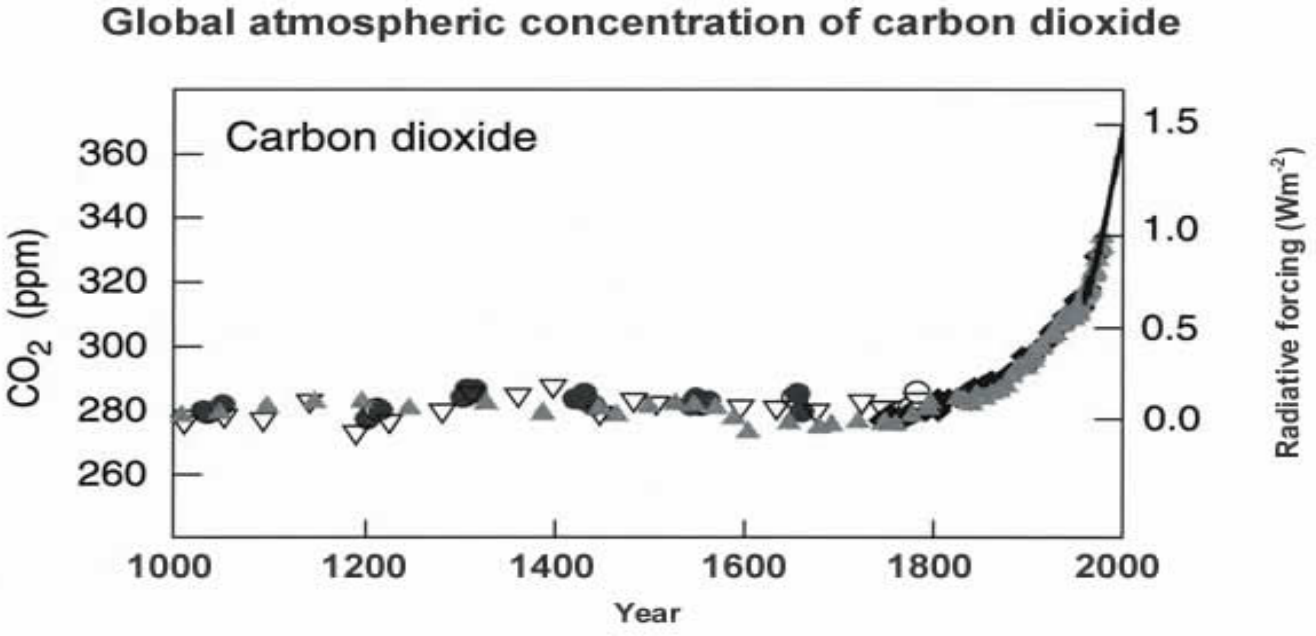
Average temperature at Earth's surface



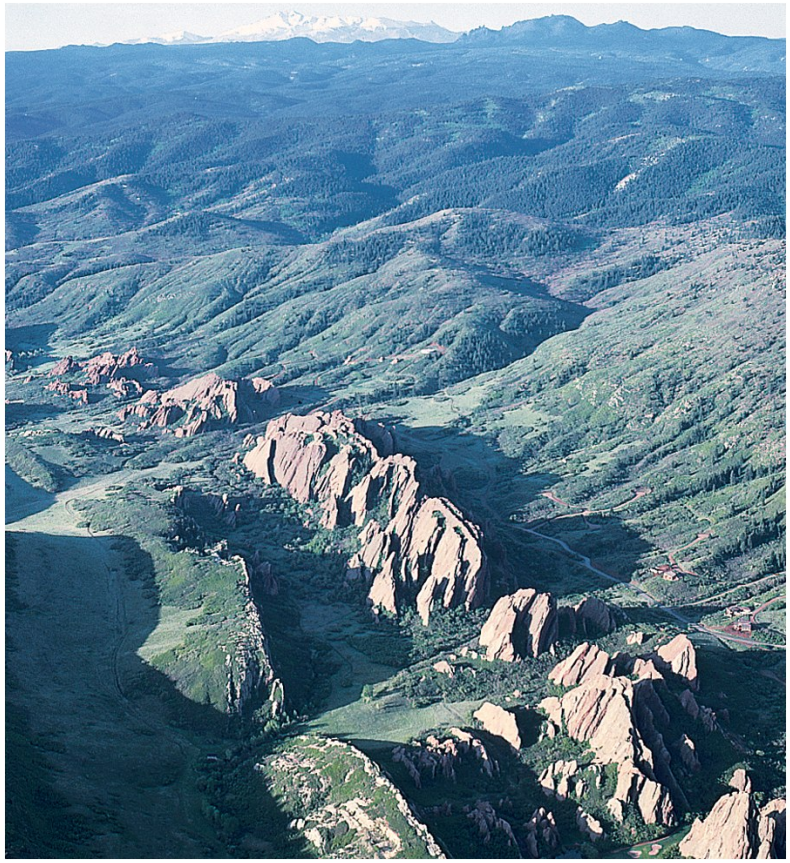


Q: greenhouse effect -- good or bad?

(read more in FK Chap 9-7)



The Earth's dynamic surface, a result of **geological activity** driven by Earth's **internal heat**.



Hogback ridges in the Rocky Mountains of Colorado.

Stone forest, China

9.2 The Earth's atmosphere

table 9-4 Chemical Compositions of Three Planetary Atmospheres

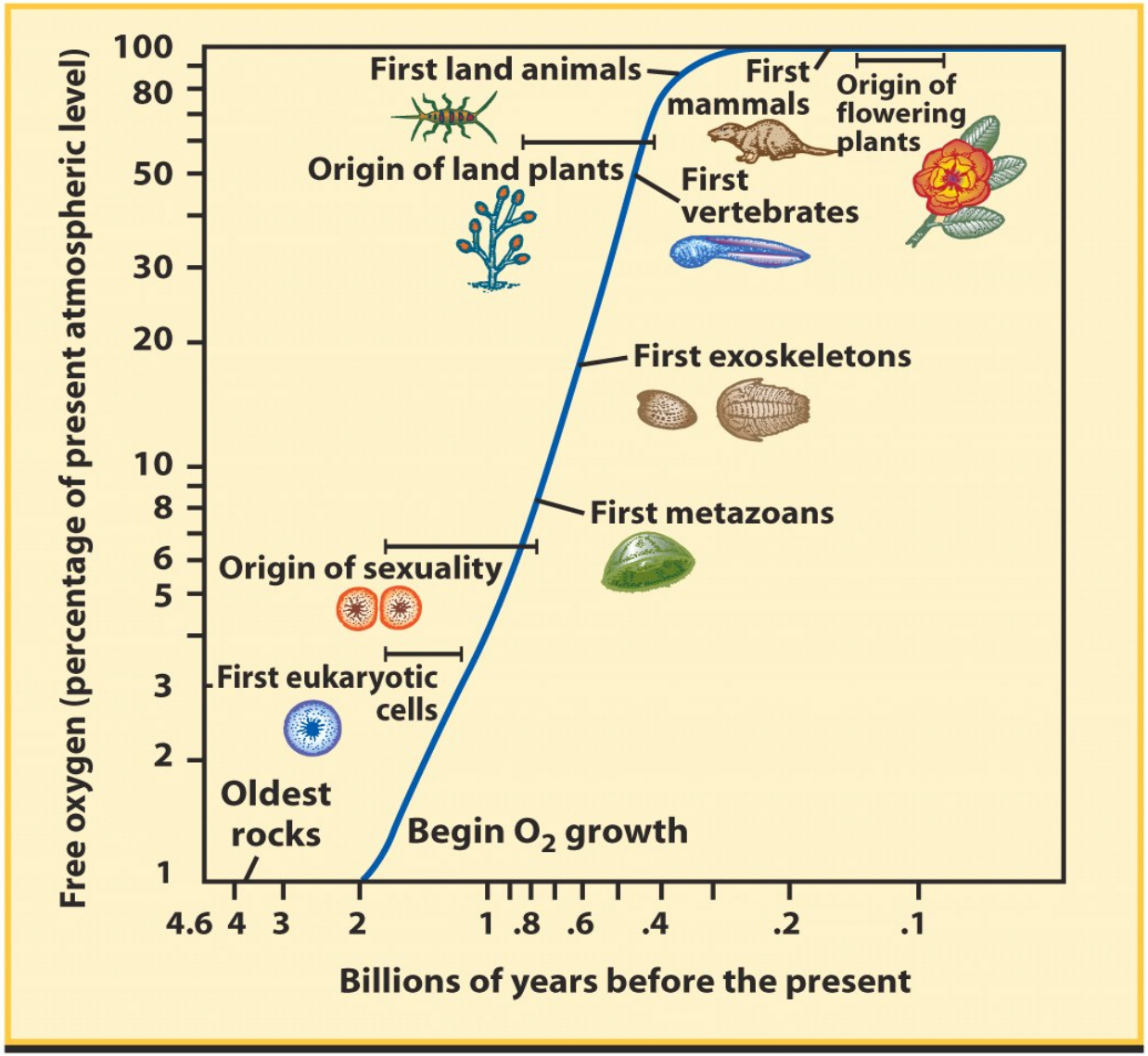
	Venus	Earth	Mars
Nitrogen (N_2)	3.5%	78.08%	2.7%
Oxygen (O_2)	almost zero	20.95%	almost zero
Carbon dioxide (CO_2)	96.5%	0.035%	95.3%
Water vapor (H_2O)	0.003%	about 1%	0.03%
Other gases	almost zero	almost zero	2%

The chemical composition of the Earth's atmosphere is drastically different from that of other two terrestrial planets also possessing an atmosphere.

-- why doesn't mercury have an appreciable atmosphere?
-- how do we know the composition of the atmosphere?
-- what leads to the difference in atmosphere composition if planets all formed from the same nebula?

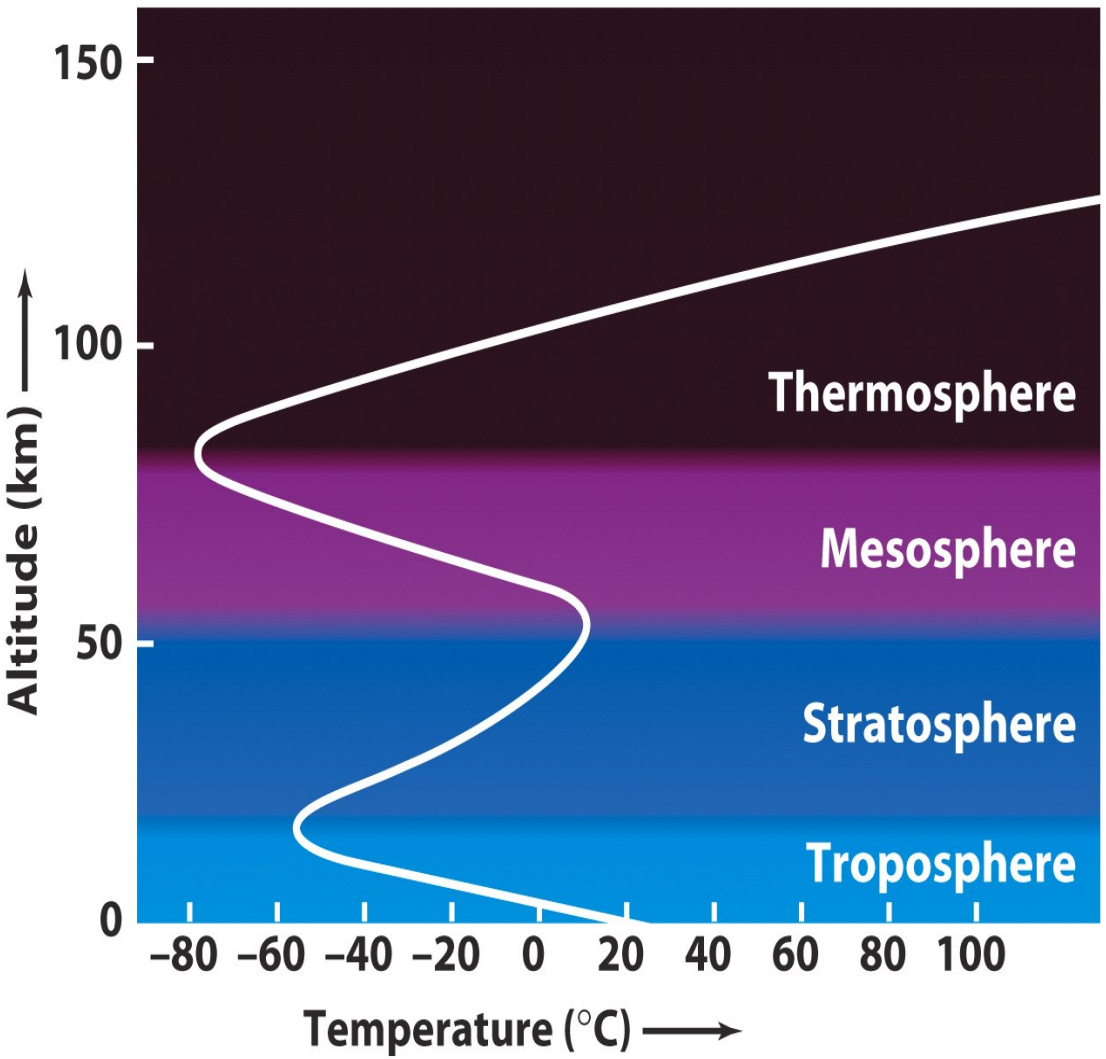
They all started with the same composition, but the evolution took different paths as determined by the distance to the Sun and consequently the temperature (and mass as well).

Why abundant nitrogen and oxygen in the Earth's atmosphere?



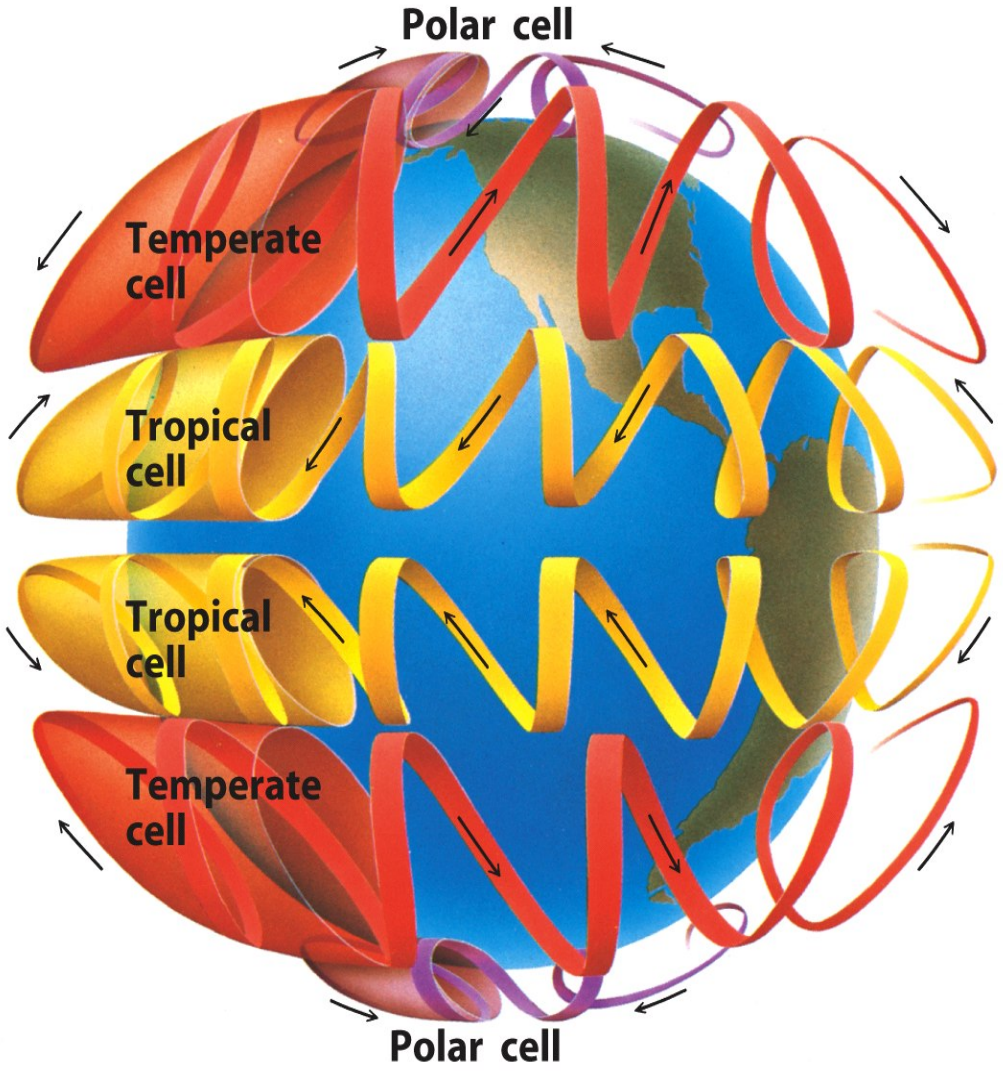
The appearance of **photosynthetic** living organisms led to our present atmospheric composition, about four- fifths nitrogen and one-fifth oxygen.

Stratification of the Earth's atmosphere



- Atmospheric pressure decreases exponentially with height - we often talk about a **scale height** ..
- The atmosphere is layered: **troposphere, stratosphere, mesosphere,** and **thermosphere,** with distinctive temperature profiles.
- Weather is caused by **convection** patterns in the **troposphere.**
- **Ozone** (O_3) molecules in the **stratosphere** absorb ultraviolet light.
- The **thermosphere** is heated because N and O atoms absorb radiation in even shorter wavelength.

Circulation in our atmosphere results from **convection** and the Earth's **rotation.**

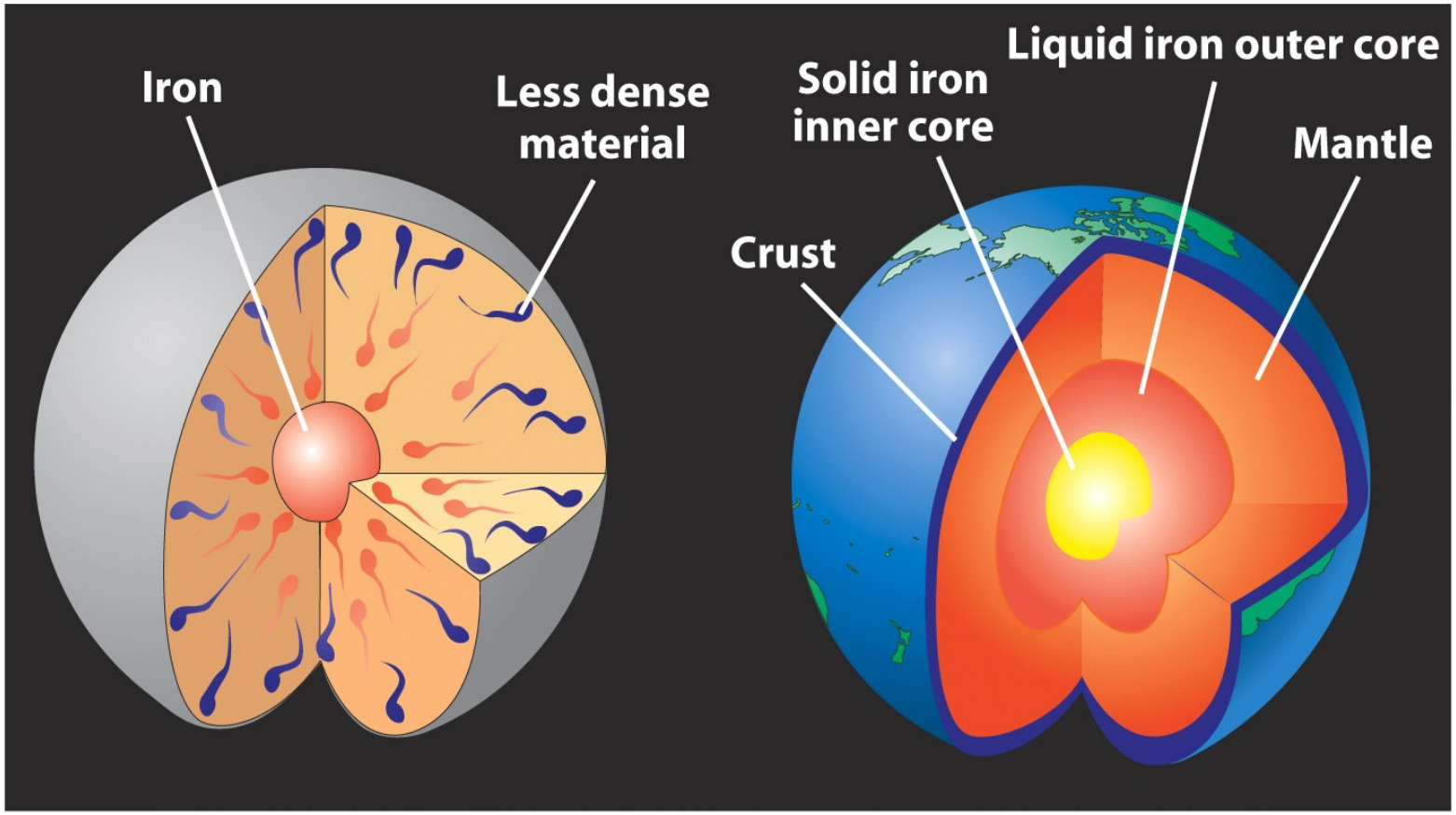


Without the Earth's rotation, there would be two patterns of convection in the troposphere: from bottom to up, and from equator to polar regions.

With the rapid rotation, the circulation in its atmosphere is complex, with three circulation cells in each hemisphere.

9.3 The Earth's internal structure

Studies of earthquakes – seismology - reveal the Earth's **layered** interior structure: inner/outer **core**, **mantle**, and **crust**.

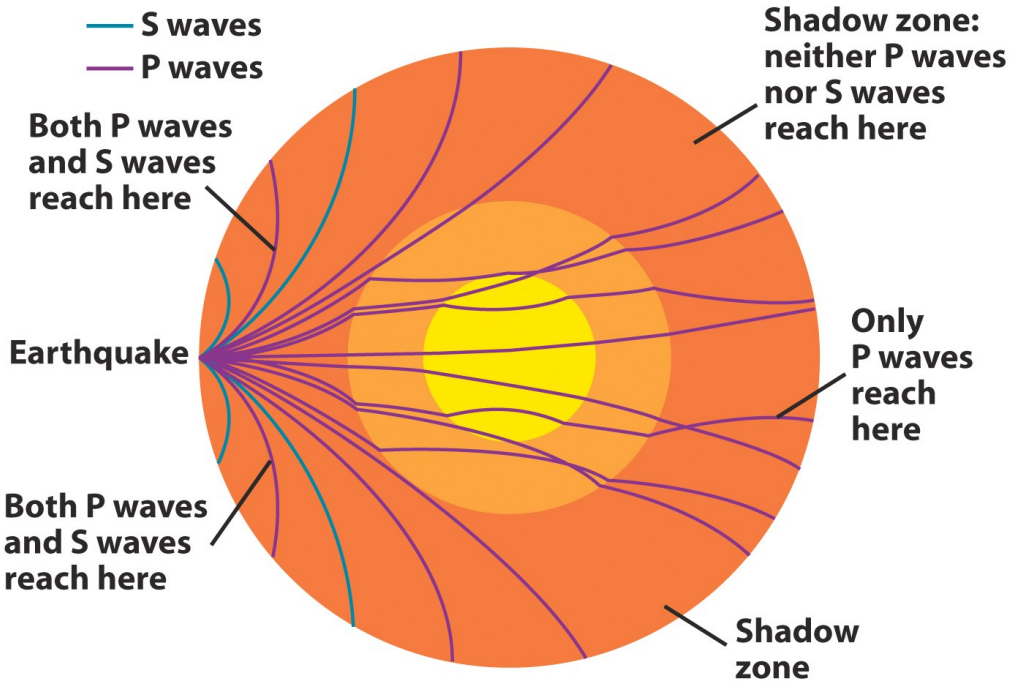


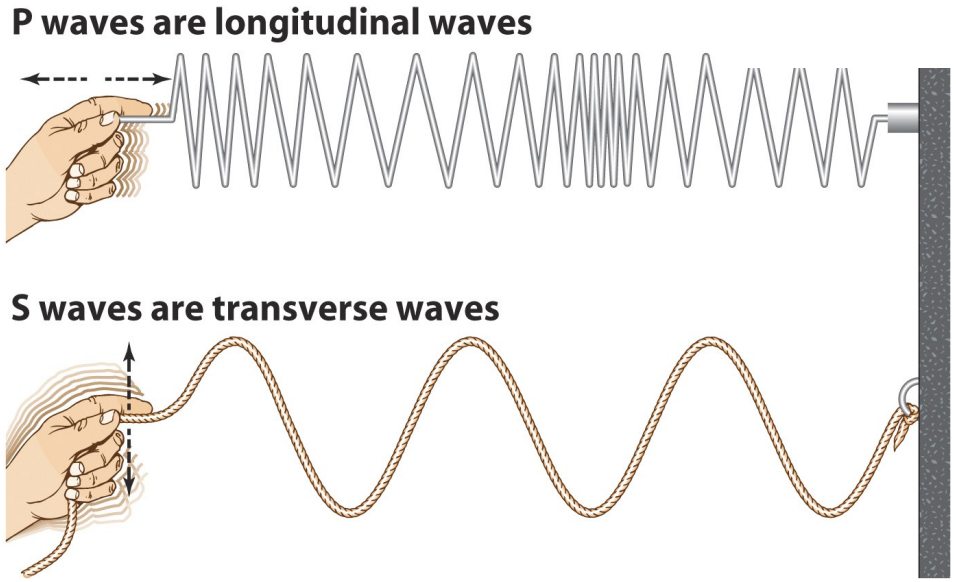
(a) During differentiation, iron sank to the center and less dense material floated upward

(b) As a result of differentiation, the Earth has the layered structure that we see today

How to find internal structure? Study seismic waves!

Earthquakes produce surface waves, P (primary) waves, and S (secondary) waves. Seismologists deduce the Earth's interior structure by studying how longitudinal P waves and transverse S waves travel through the Earth's interior.





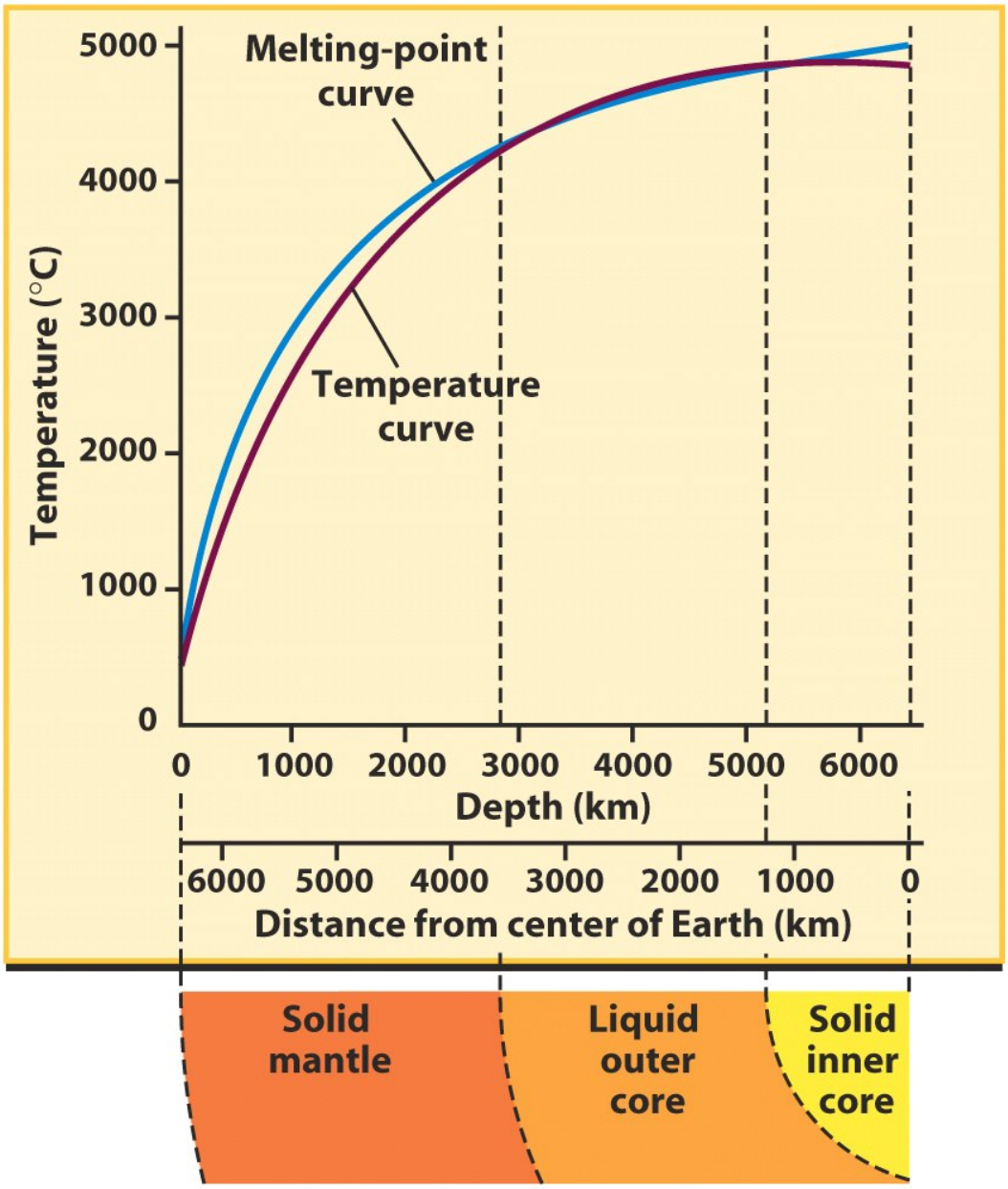
Seismic waves refract as they pass through different parts of the Earth's interior with varying density and composition. The paths of P waves and S waves are different.

Earth's layered structure:

- Solid iron inner core (1300 km)
- Liquid iron outer core (2200 km)
- solid iron rich mantle (2900 km)
- rocky crust (5 to 35 km)
- Both temperature and pressure steadily increase with depth inside the Earth

Q: why solid inner core and liquid outer core?

Region	Depth below surface (km)	Distance from center (km)	Average density (kg/m^3)
Crust (solid)	0–5 (under oceans) 0–35 (under continents)	6343–6378	3500
Mantle (solid)	from bottom of crust to 2900	3500–6343	3500–5500
Outer core (liquid)	2900–5100	1300–3500	10,000–12,000
Inner core (solid)	5100–6400	0–1300	13,000



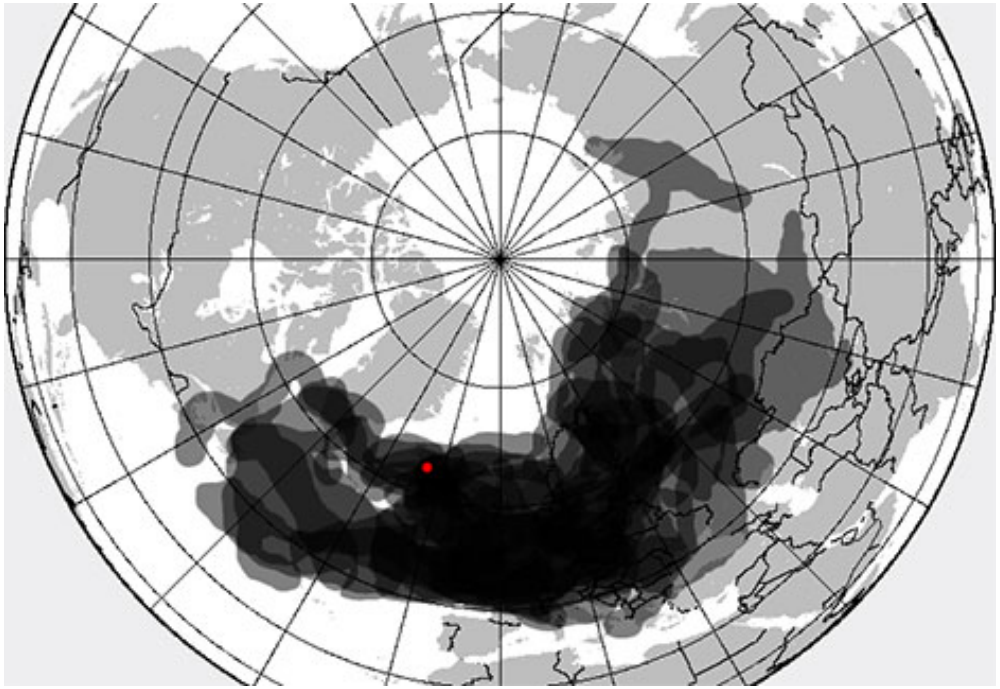
Melting point of a material depends on pressure.

So does the boiling point.

Ex. 4: boiling point of water at sea level and on top of Mount Everest.

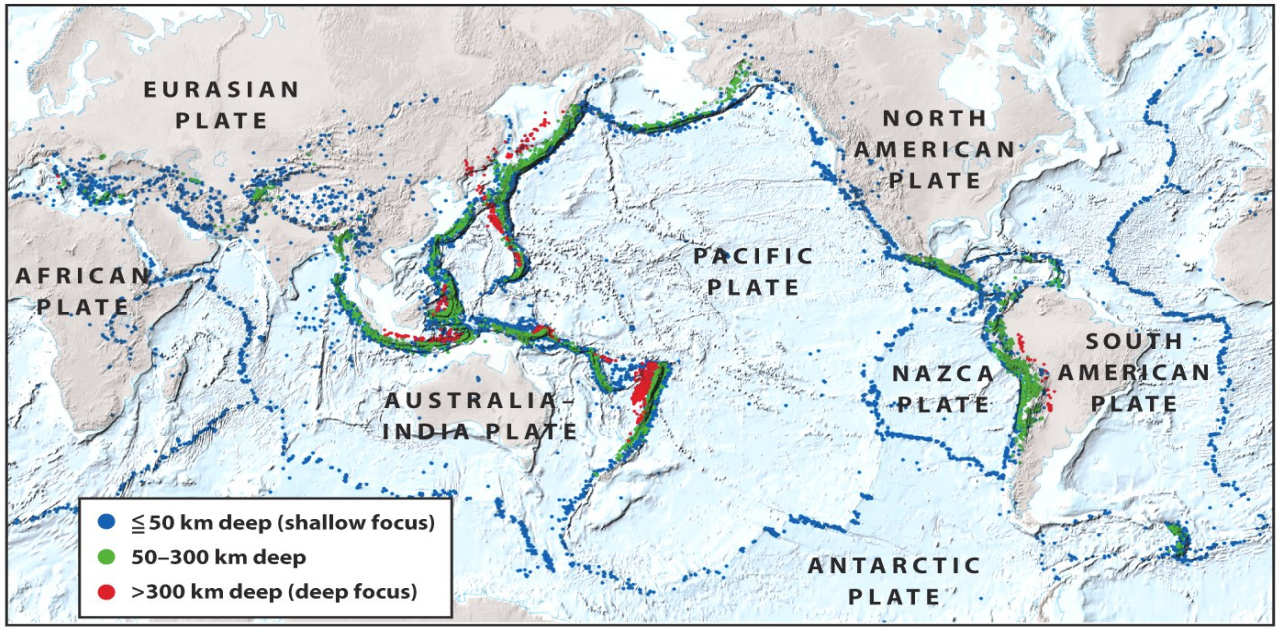
An iceland volcano erupted in 2010 Spring

Q: Why there?



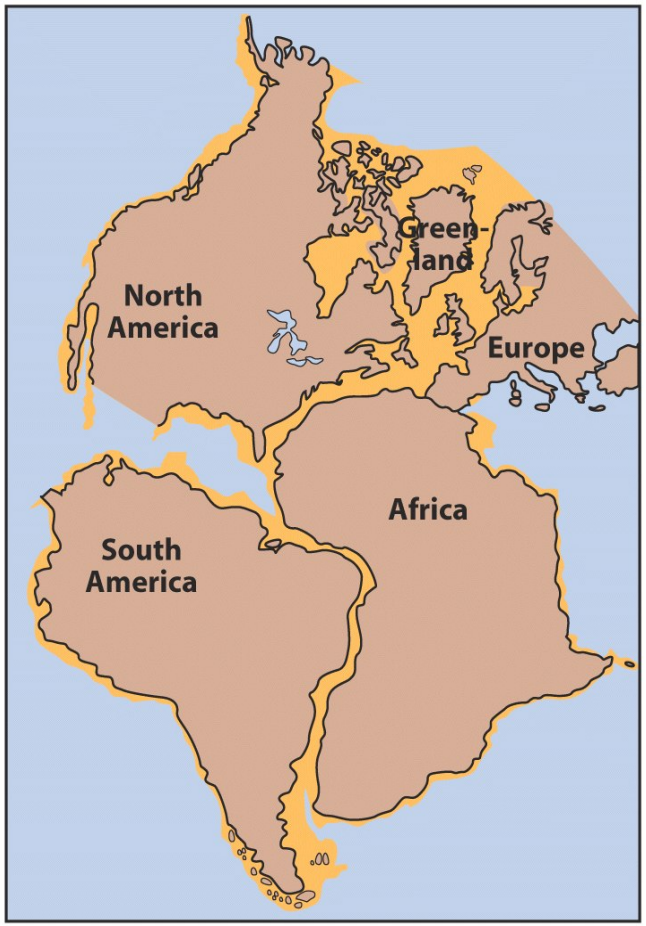
9.4 Plate tectonics

Plate movement produces earthquakes, mountain ranges, and volcanoes that shape the Earth's surface.



- The Earth's crust and a small part of its upper mantle form a rigid layer called the **lithosphere**.
- The lithosphere is divided into huge **plates** that move about over the plastic layer called the **asthenosphere** in the upper mantle

The Earth started as a supercontinent – Pangaea.



Breakup of the Pangaea produced today's 7 continents.

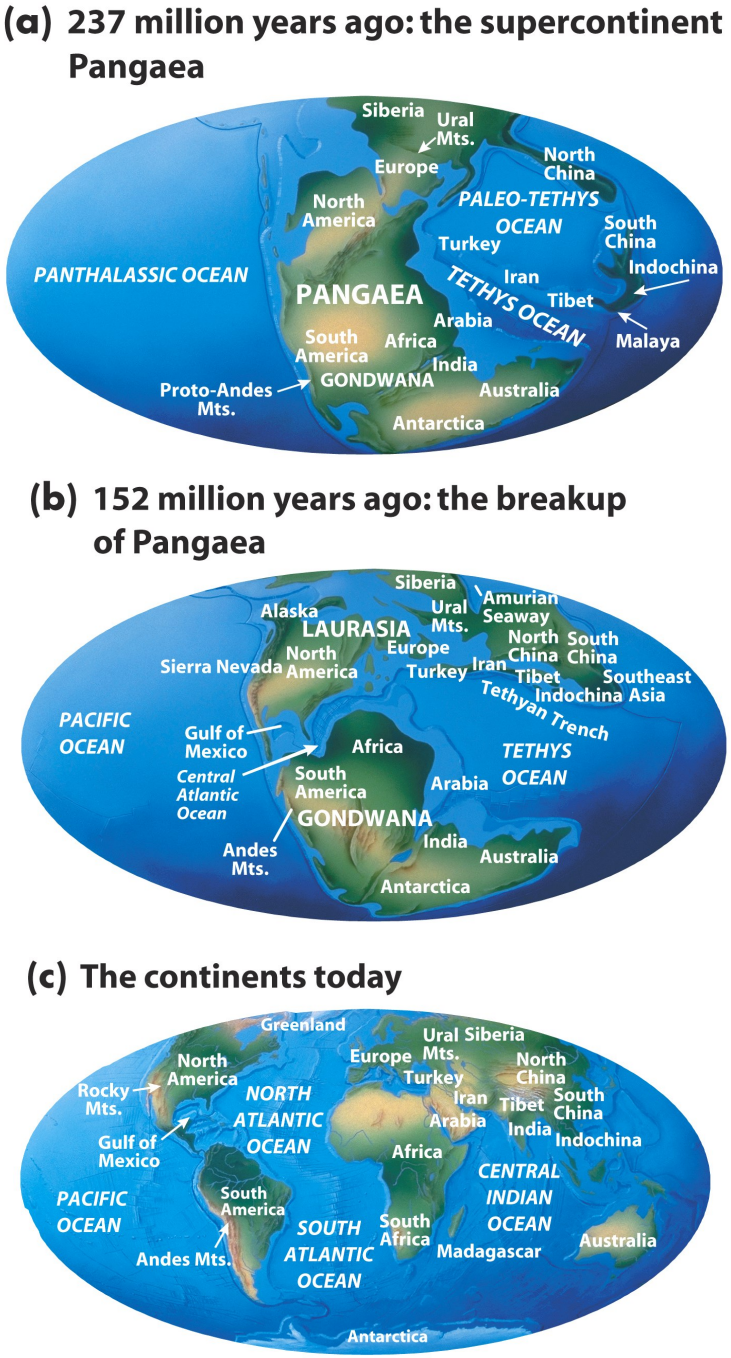
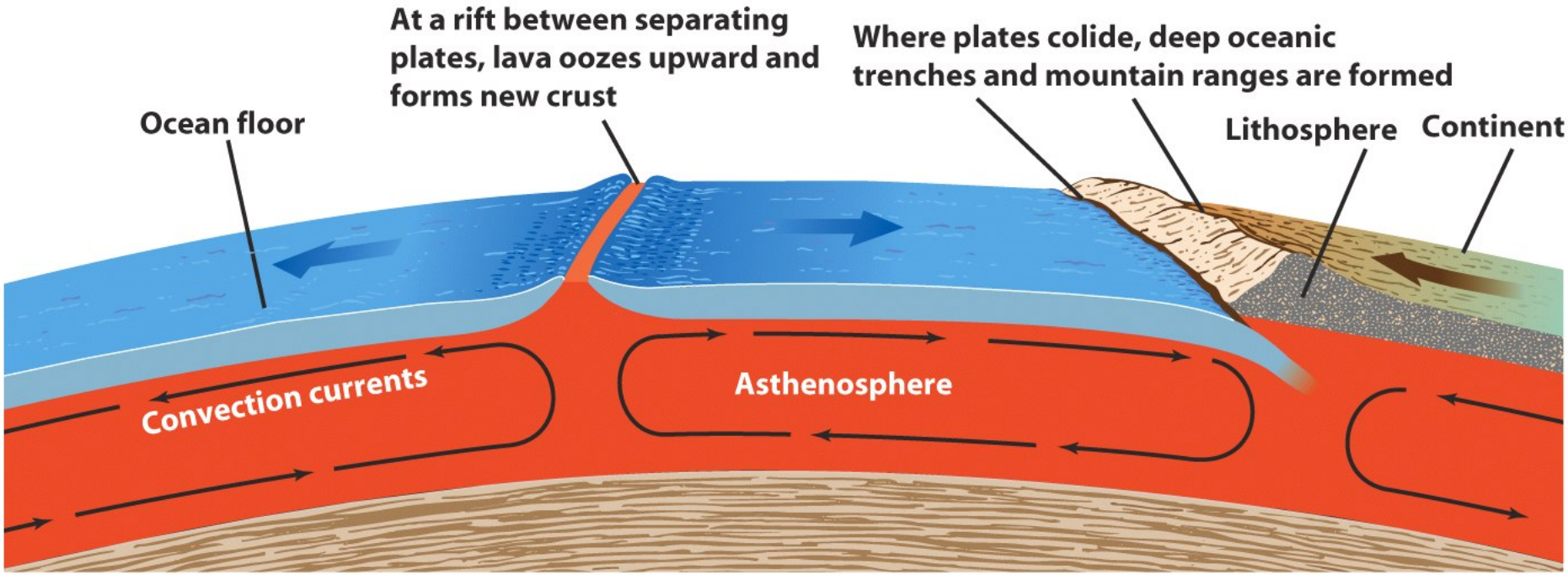
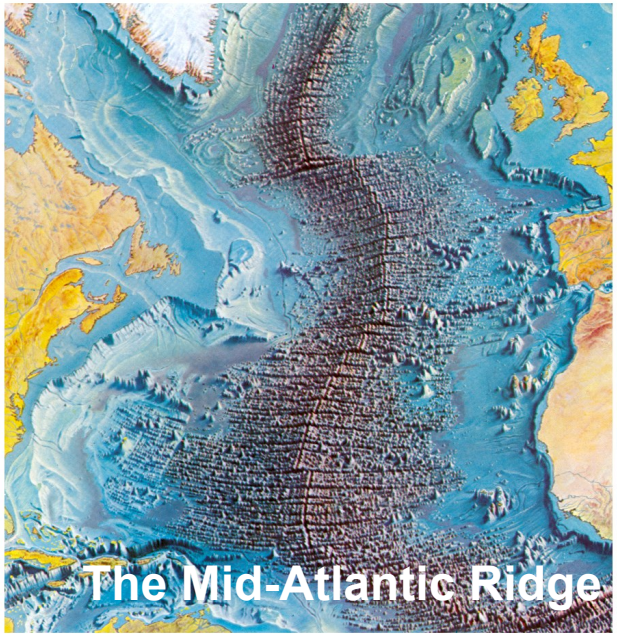


Plate tectonics, or movement of the plates, is driven by convection within the **asthenosphere**

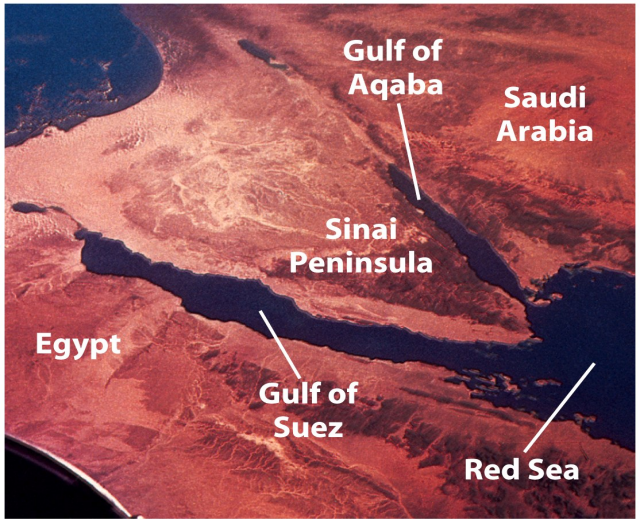
- Molten material wells up at **oceanic rifts**, producing seafloor spreading, and is returned to the asthenosphere in **subduction zones**
- As one end of a plate is subducted back into the asthenosphere, it helps to pull the rest of the plate along



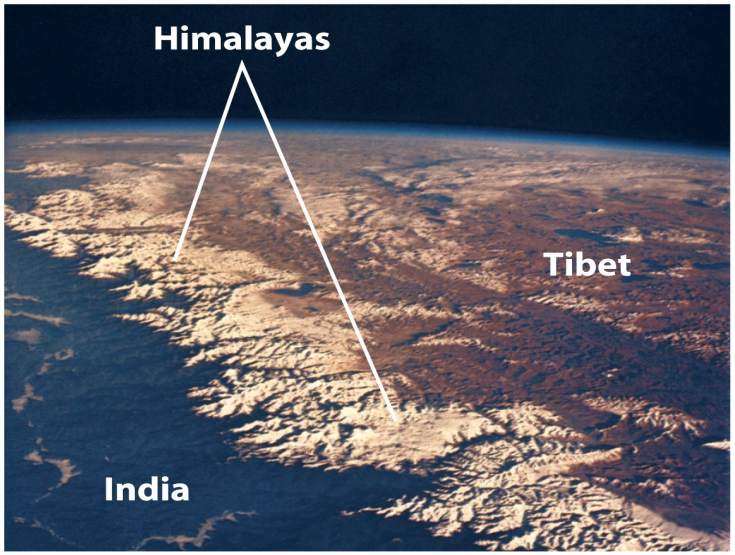


The landscape of our planet Earth is shaped by **plate tectonics**: mountain ranges, volcanoes, the shapes of the continents and oceans.

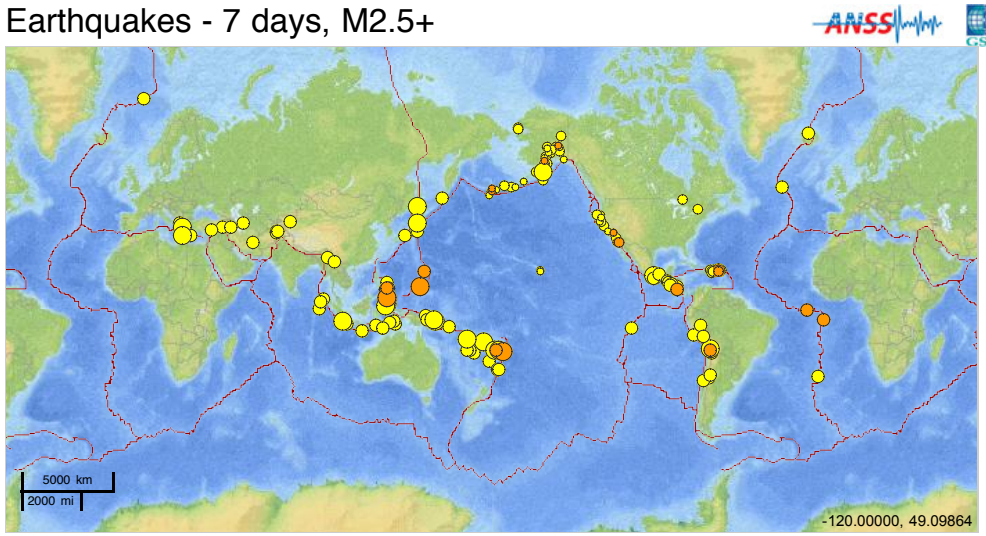
Everest (alt: 8848 m) still grows by 4mm per year.

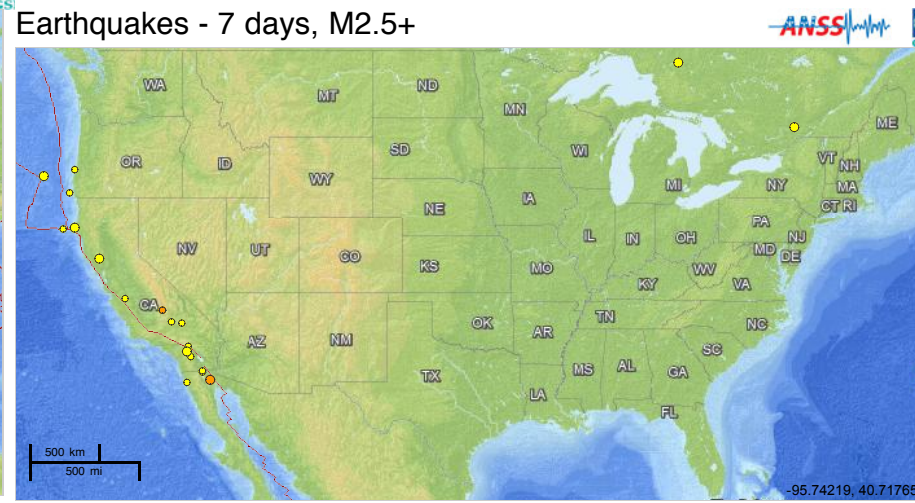


separation and collision of two plates



Earthquakes in the world and USA





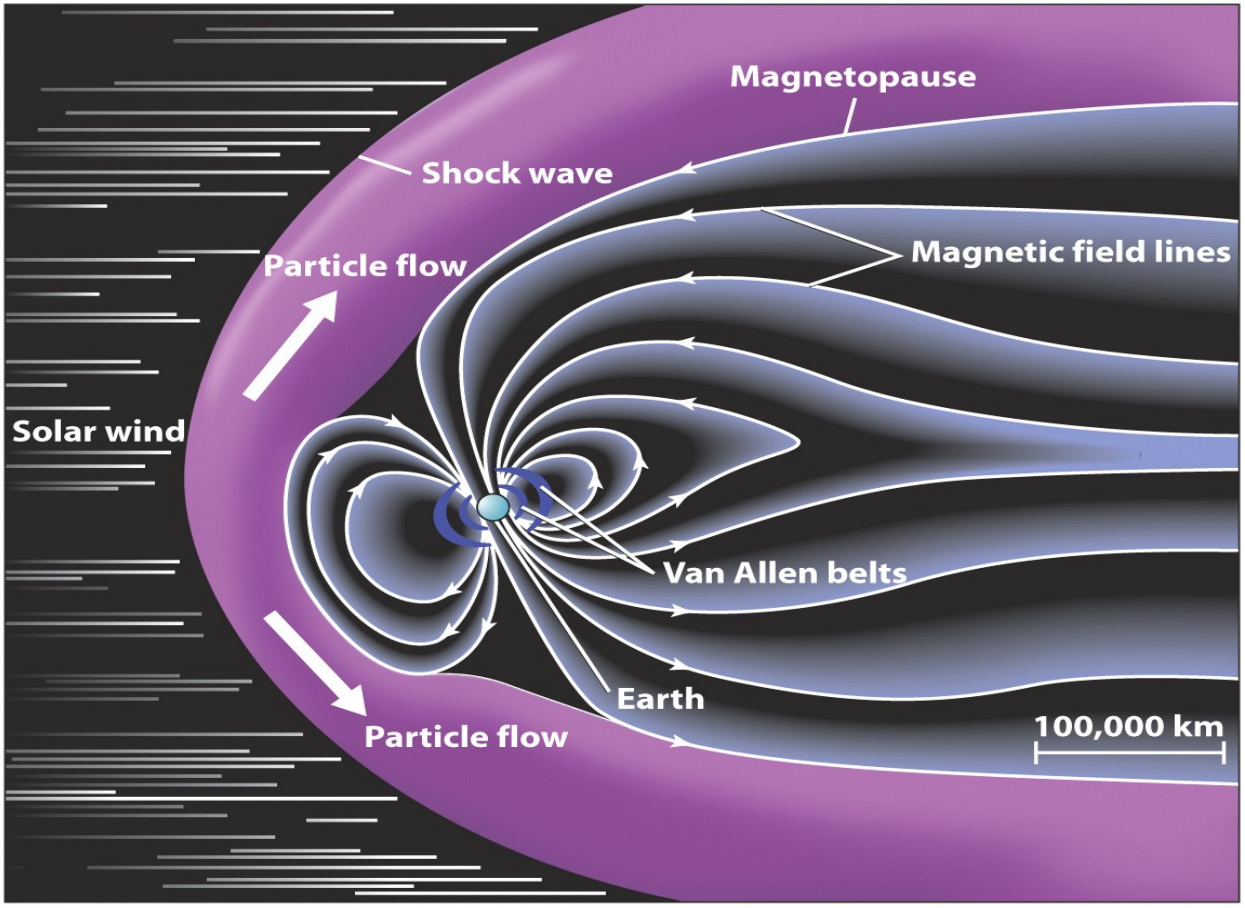
Ex.5: Earthquake report from the USGS earthquake network.

Earthquakes tend to occur at the boundaries of the Earth's crustal plates, where the plates are colliding, separating, or rubbing against each other. The earthquake epicenter zones therefore outline the boundaries of the plates.

Q: what do you think are important factors to produce plate tectonics?

Q: what are the proofs that Earth has a liquid core?

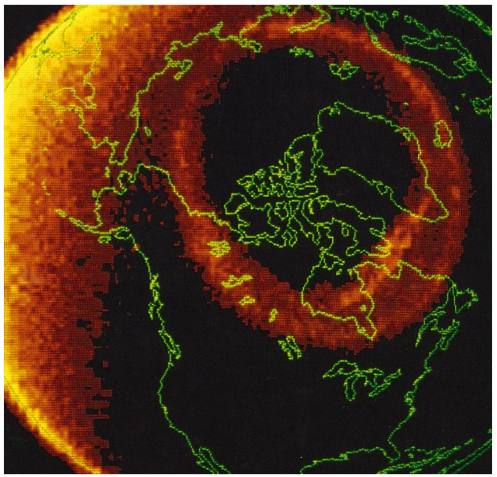
5.5 The Earth's magnetosphere

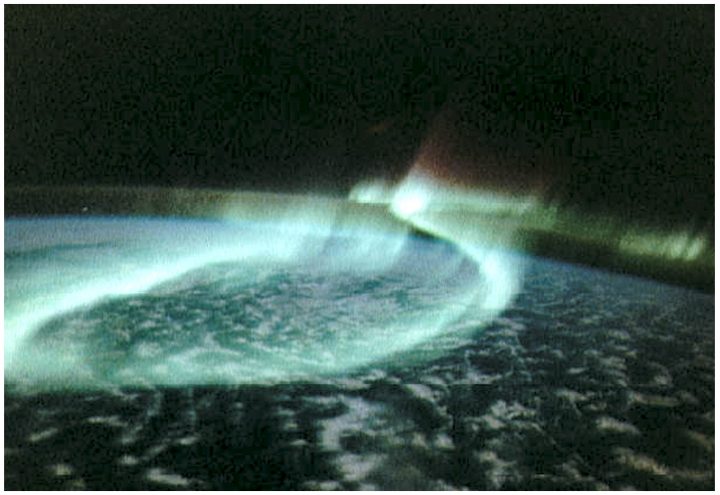


- The Earth's magnetic field is generated by motions of liquid iron, or **dynamo**.
- The Earth's **magnetosphere** deflects charged particles, mostly protons and electrons, brought by **solar wind**.

A bow-shaped **shock wave**, where the supersonic **solar wind** is abruptly slowed to subsonic speeds, marks the outer boundary of the **magnetosphere**.

Some charged particles from the solar wind are trapped in two huge, doughnut-shaped rings called the **Van Allen belts.** An increased flow of charged particles from the Sun can overload the Van Allen belts and cascade toward the Earth, producing **aurorae.** Violent explosions on the Sun, such as a **coronal mass ejection**, can lead to bright auroral display.





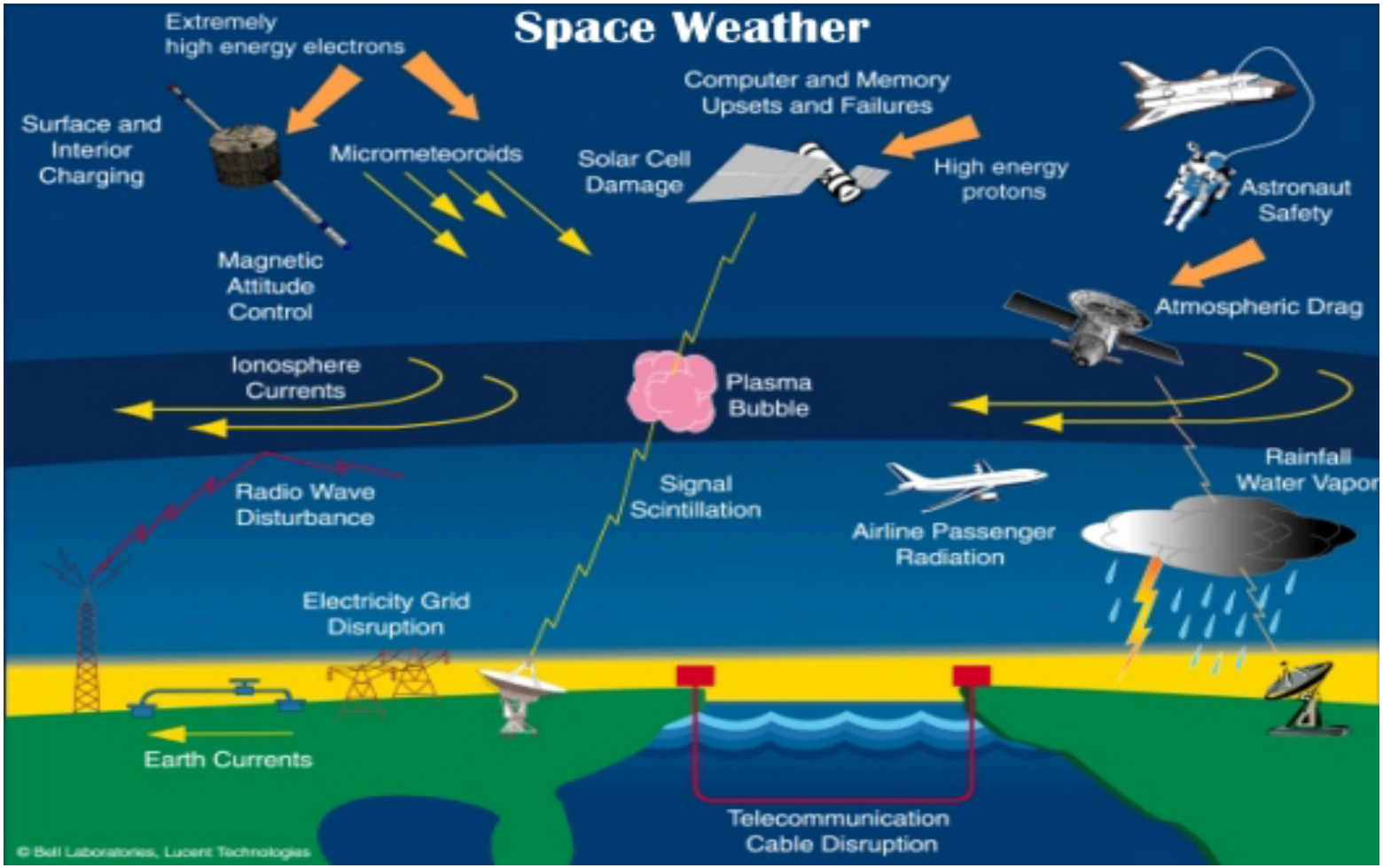
The aurora galleries at spaceweather.com

Charged particles move along magnetic field lines.

Q: If the Earth's magnetosphere were removed, would we see more or less aurorae, and where? What if the solar wind were a flow of high energy neutral particles?

Q: how do Earth's atmosphere and magnetosphere protect life?

Streams of charged particles from the Sun lead to adverse space weather and pose threat to our ambition to explore the outer space and solar system.



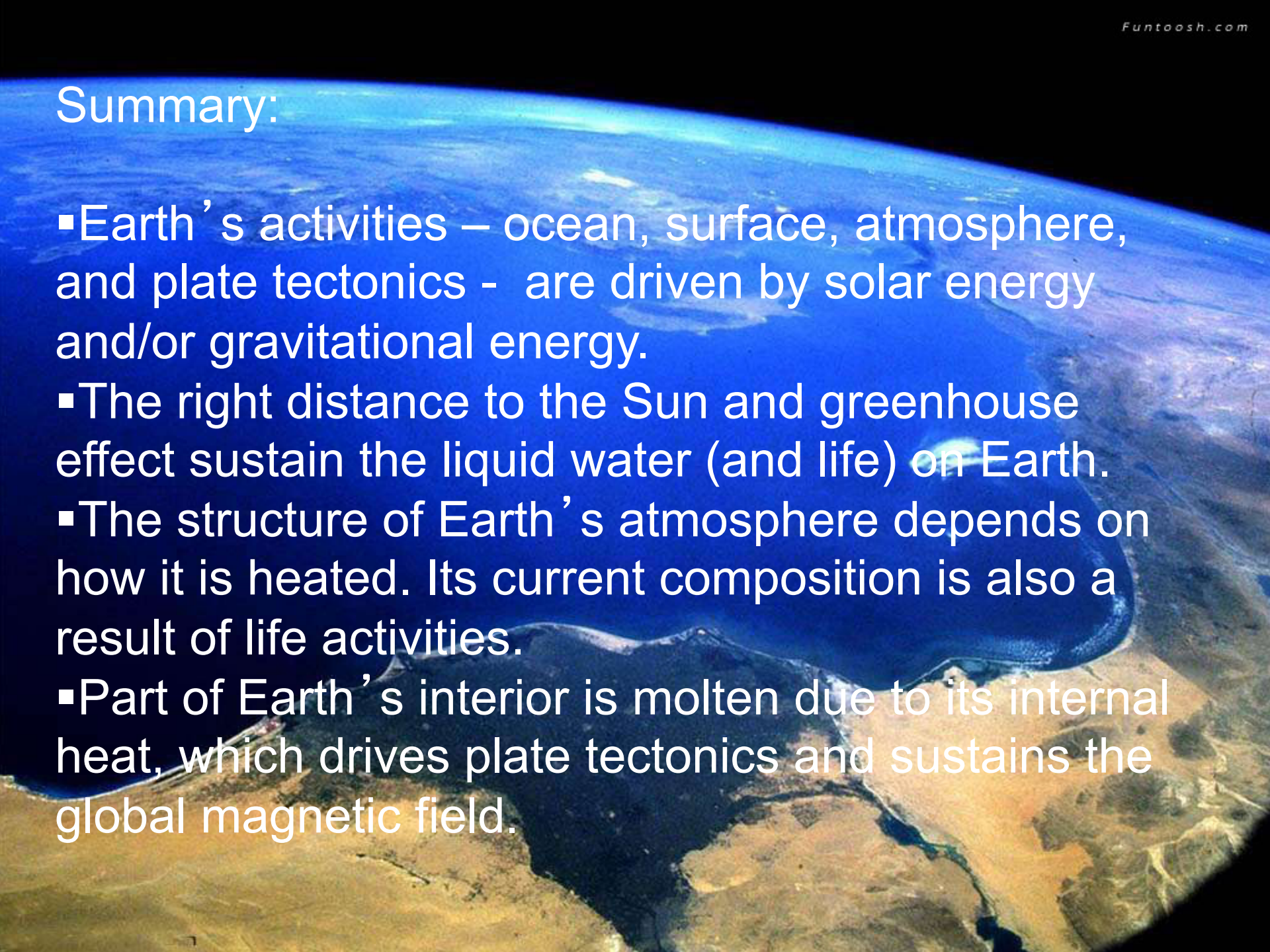
Q: how can we forecast space weather?

Summary:

1.Earth's activities – ocean, surface, atmosphere, and plate tectonics - are driven by solar energy and/or gravitational energy.
2.The right distance to the Sun and greenhouse effect sustain the liquid water (and life) on Earth.
3.The structure of Earth's atmosphere depends on how it is heated. Its current composition is also a result of life activities.
4.Part of Earth's interior is molten due to its internal heat, which drives plate tectonics and sustains the global magnetic field.

Key Words

- albedo
- asthenosphere
- atmosphere
- aurora (*plural* aurorae)
- convection
- coronal mass ejection
- crust (of Earth)
- earthquake
- epicenter
- global warming
- greenhouse effect
- greenhouse gas
- igneous rock
- Inner and outer core (of Earth)
- lava
- lithosphere
- magma
- magnetosphere
- mantle
- melting point
- mesosphere
- metamorphic rock
- northern and southern lights
- oceanic rift
- ozone layer
- P and S waves
- photosynthesis
- plate (lithospheric)
- plate tectonics
- sedimentary rock
- seismic wave
- stratosphere
- subduction zone
- surface wave
- thermosphere
- troposphere
- Van Allen belts



Summary:

- Earth's activities – ocean, surface, atmosphere, and plate tectonics - are driven by solar energy and/or gravitational energy.
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- The structure of Earth's atmosphere depends on how it is heated. Its current composition is also a result of life activities.
- Part of Earth's interior is molten due to its internal heat, which drives plate tectonics and sustains the global magnetic field.