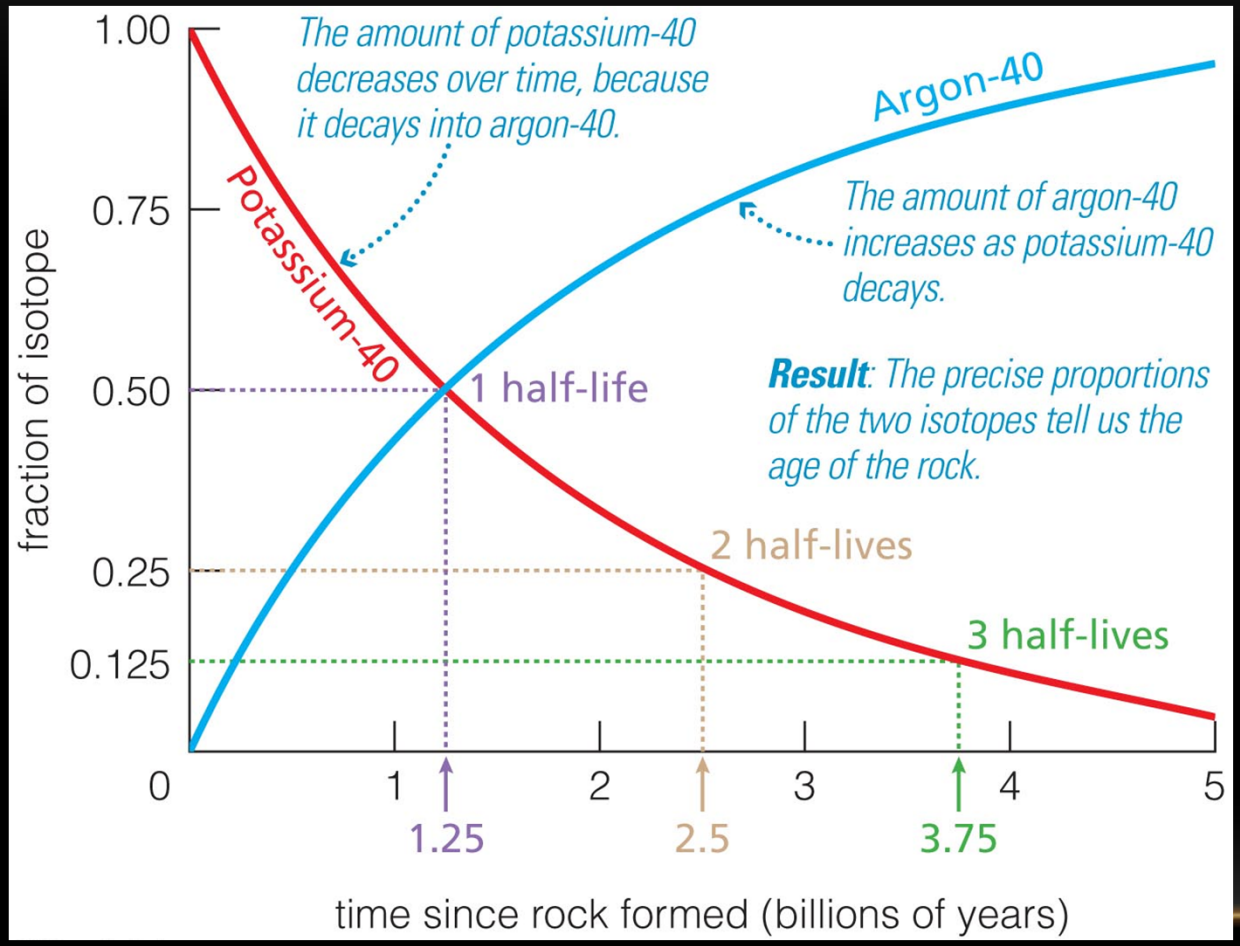
AGE OF SOLAR SYSTEM

- I keep saying “solar system is 4.5 billion years old”. How can we know that?
- While we can’t date a planet directly, we can date the rocks which make it up
  - And if the planet formed by an accretion melting-fest, that’s when the oldest rocks were formed: so not a bad way to measure it

RADIOACTIVE DECAY



- Some isotopes decay into other elements
- A "half-life" is the time it takes for ½ the original element to decay away
  - Measured in the lab for many isotopes

Fig.6.26

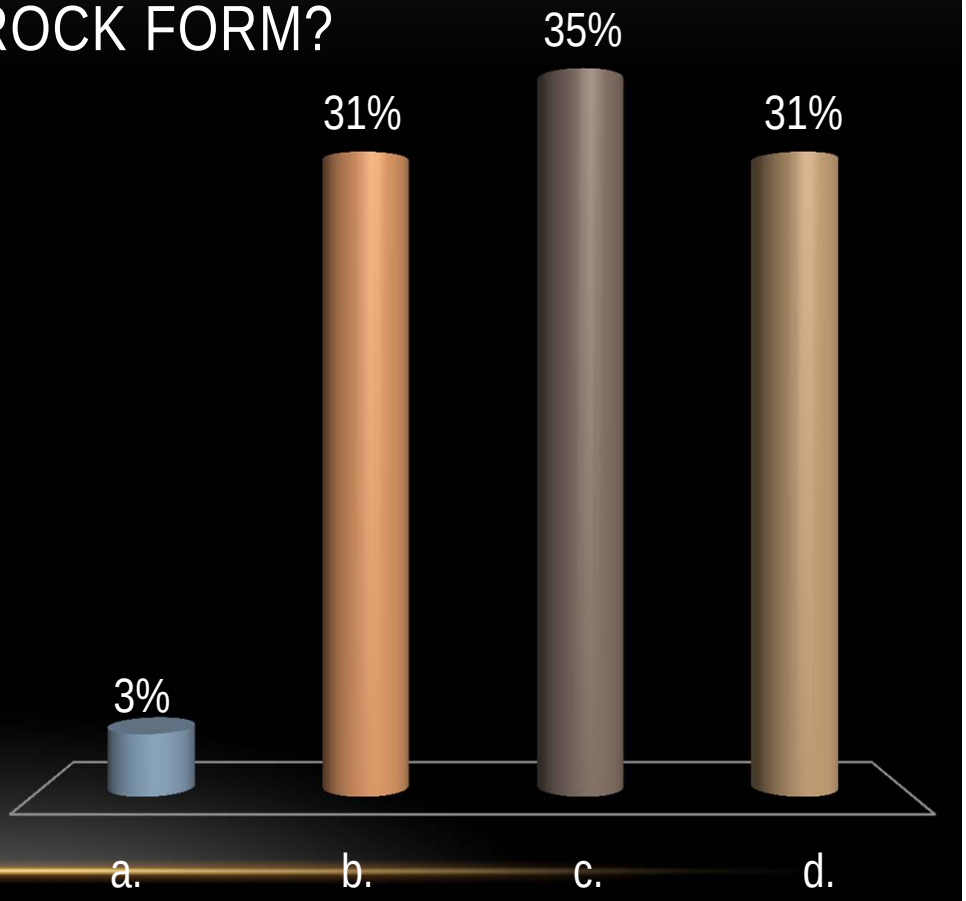
SUPPOSE YOU FIND A ROCK ORIGINALLY MADE OF POTASSIUM-40, HALF OF WHICH DECAYS INTO ARGON-40 EVERY 1.25 BILLION YEARS. YOU OPEN THE ROCK AND FIND 15 ATOMS OF ARGON-40 FOR EVERY ATOM OF POTASSIUM-40. HOW LONG AGO DID THE ROCK FORM?

a. 1.25 billion years ago

b. 2.5 billion years ago

c. 3.75 billion years ago

✓ d. 5 billion years ago



WHY?

- After one half life, half the ^{40}K turns into ^{40}Ar
  - One-to-one, stuff is now half-and-half
- After two half-lives, half of what's left changes
  - Now 3-to-1 ratio: ¼ left, ¾ new stuff
- After three half-lives, half of what's left changes
  - 1/8 original stuff left, 7/8ths new stuff: that's 7-1
- After four half-lives, half of what's left changes
  - $1/16^{th}$ ^{40}K left, 15/16ths is now ^{40}Ar: that's 15-1
- How long was that? 4 times 1.25 by = 5 billion years

MANY SUCH HANDLES

- This particular ratio might have some questions:
  - (ie, *How well is the ^{40}Ar trapped vs how much escapes*?)
- But there are many such different sets of isotopes, all with different problems to worry about
  - And in the end, they all should more or less agree before we're confident in some rock's age

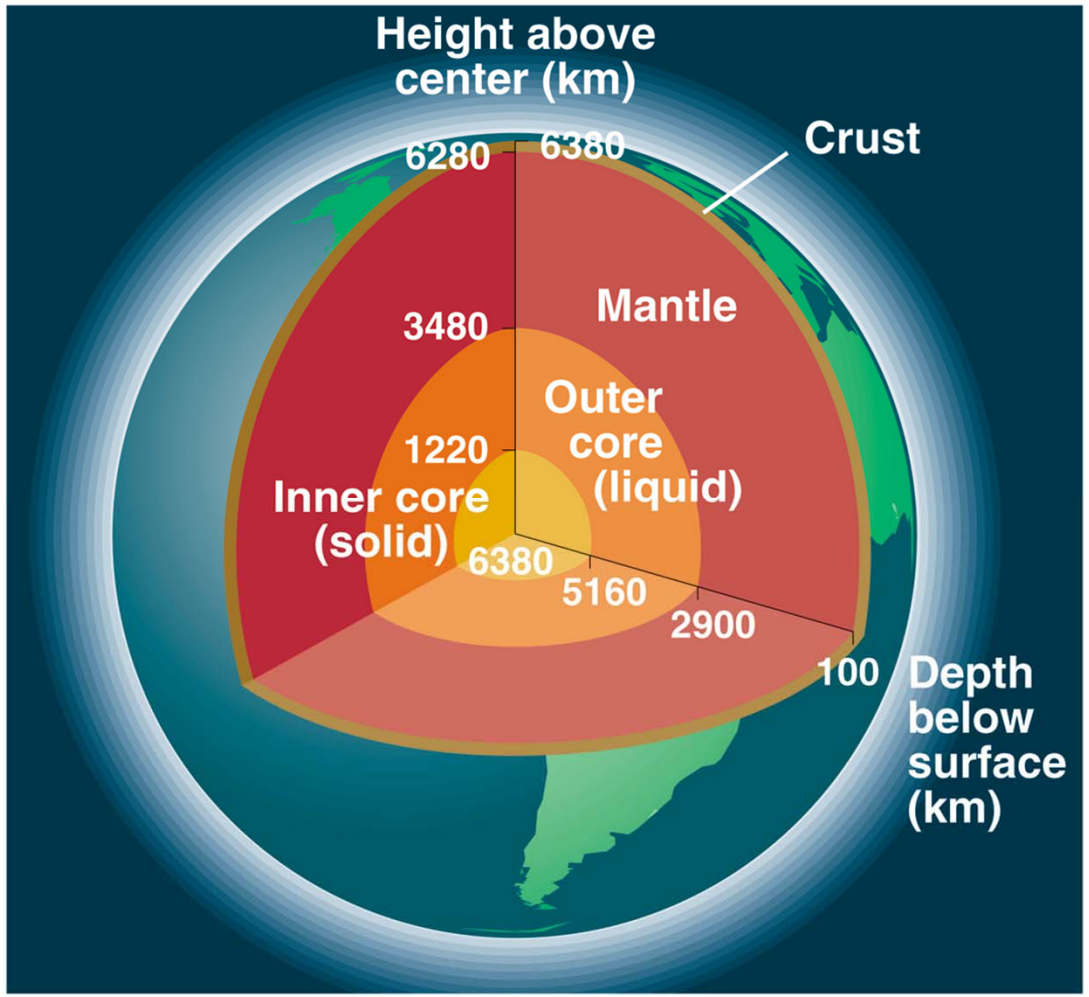
SOLAR SYSTEM AGE?

- A random rock you find on Earth is much younger than the planet
  - Plate tectonics, volcanoes…
- But meteorites are leftover debris from Solar Nebula
  - and clock in at 4.55 by old
  - Moon rocks: 4.4by
  - Planets probably formed about 4.5by ago

THE EARTH

- We now embark on a tour of the Solar System, starting here at home
- This ½ a chapter is Geology 101 in ½ hour
  - Our goal – have something to compare and contrast to rest of Solar System
- Size of Earth – remember Eratosthenes' well
  - 12,756 km at equator (slightly *oblate* due to spin)
- Mass is 5.97×10^{24} kg
  - Measured using Kepler's 3rd law as modified by Newton, as applied to the orbits of the Moon and satellites

COMPOSITION?



- That mass and diameter works out to an avg. density of 5.5 g/cm^3
  - Water is 1.0
  - Rock is ~3.0
  - Iron is 7.8
- So we must have a bunch of heavy stuff down there
- More details discovered by watching earthquake waves rattle around in Earth

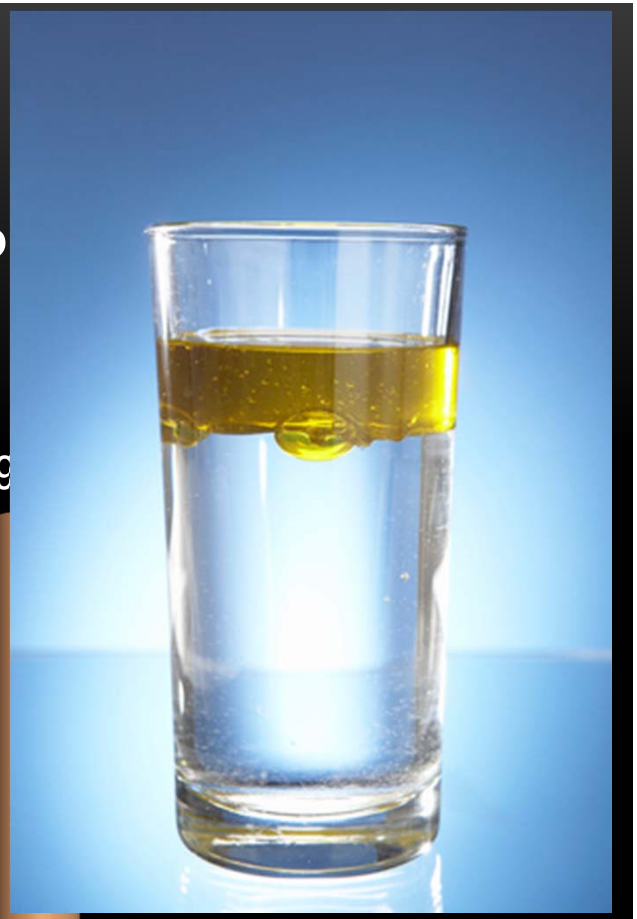
WHY DO OIL AND WATER SEPARATE?

a. Water molecules repel oil molecules electrically.

✓ b. Water is denser than oil, so oil floats on water.

c. Oil is more slippery than water, so it slides to the surface of the water.

d. Oil molecules are bigger than the spaces between water molecules.



THINGS TO NOTICE

- Earth is layered, or *chemically differentiated*
  - Heavier, more dense stuff sunk to the bottom
- Solid crust ~100km deep is all we can get directly (2.5-3.0 g/ cm^3)
  - This floats about on the gooey mantle (3-9 g/cm^3)
  - The core is liquid then solid iron and nickel (9-13 g/ cm^3)
  - Even rock and metal get more dense if under tremendous pressure

WHAT'S GOING ON?

- Why is it liquid down there?
  - It's Really Hot, molten iron/lava
- Why is it Really Hot?
  - Early on, lots of gravitational potential energy coming from planetesimals falling down
  - Now, still warm from formation of Earth
    - Space is a really good vacuum = thermos!
  - Plus, a whole Earth full of trace amounts of Uranium etc. creates a lot of heat

WHY A SPHERE?

Fig.7.3:
Silly Putty!

- Rock stretches when pulled slowly but breaks when pulled rapidly.
  - Doesn't need to be molten (although that's easier)
- The gravity of a large world pulls slowly on its rocky content, shaping the world into a sphere.

CONVECTION

- Hot rock rises, cool rock falls
  - Same as water in your pasta pot
- One convection cycle takes 100 million years on Earth

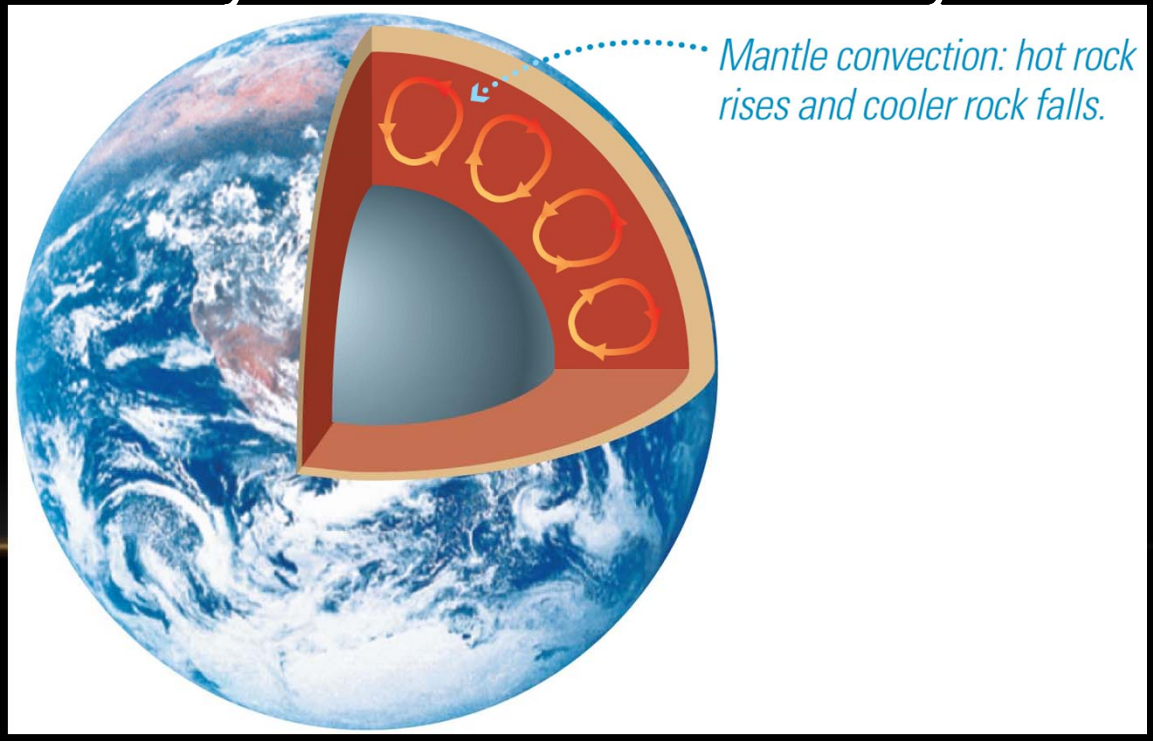
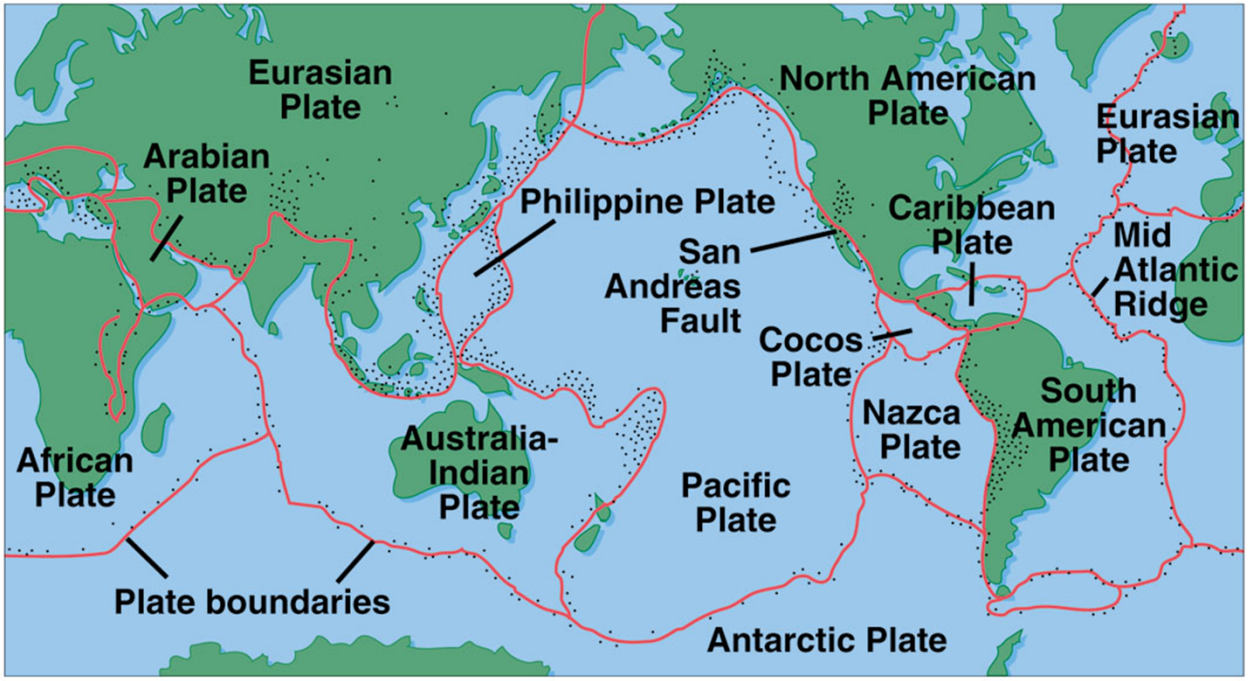


Fig.7.4

PLATE TECTONICS

- The crust is chunks (“plates”) and floats on mantle
- The plates move about, where they join there is lots of tectonic activity
  - Earthquakes
  - Volcanoes



TECTONIC ACTION AT BOUNDARIES

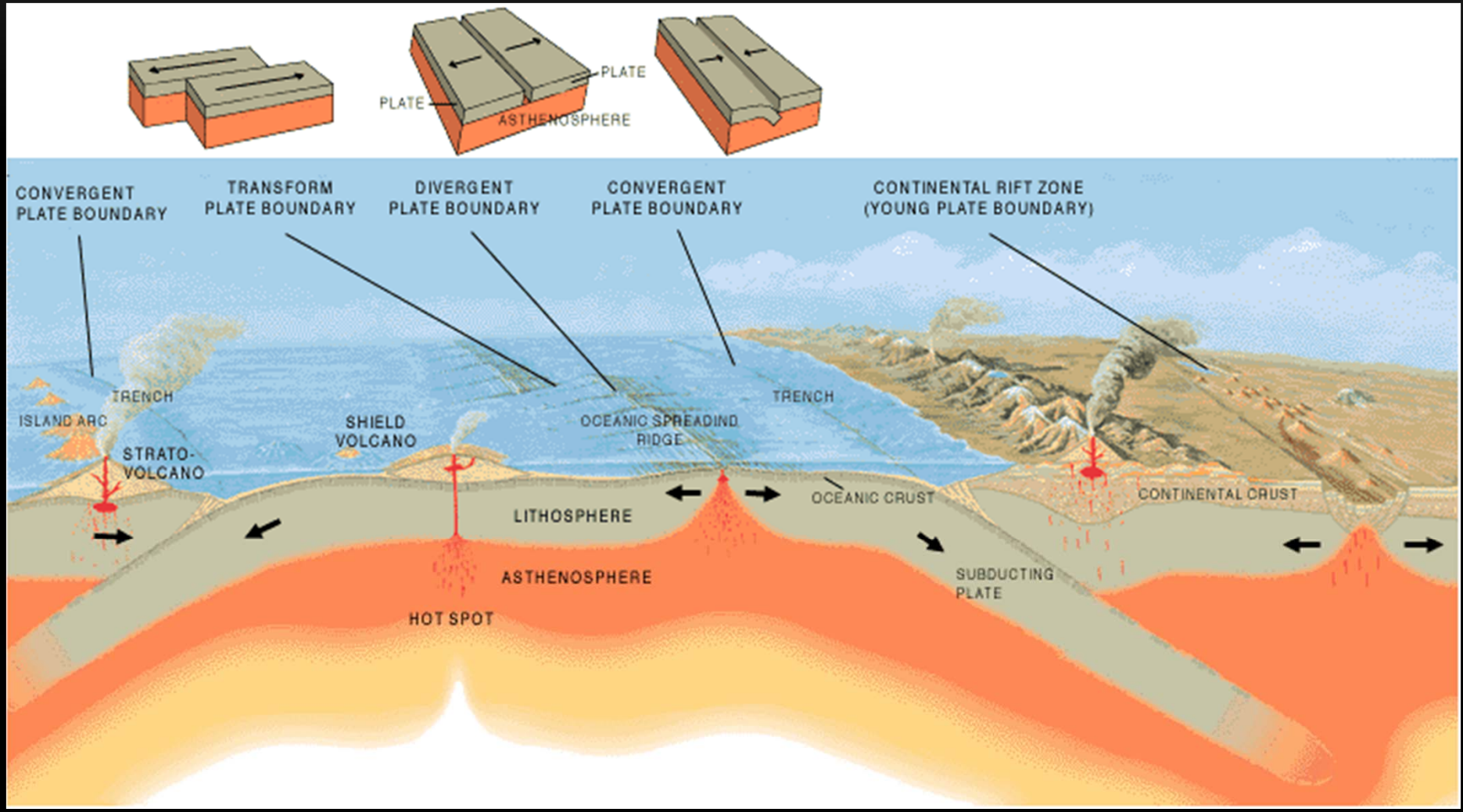


Diagram from USGS

IN REWIND…

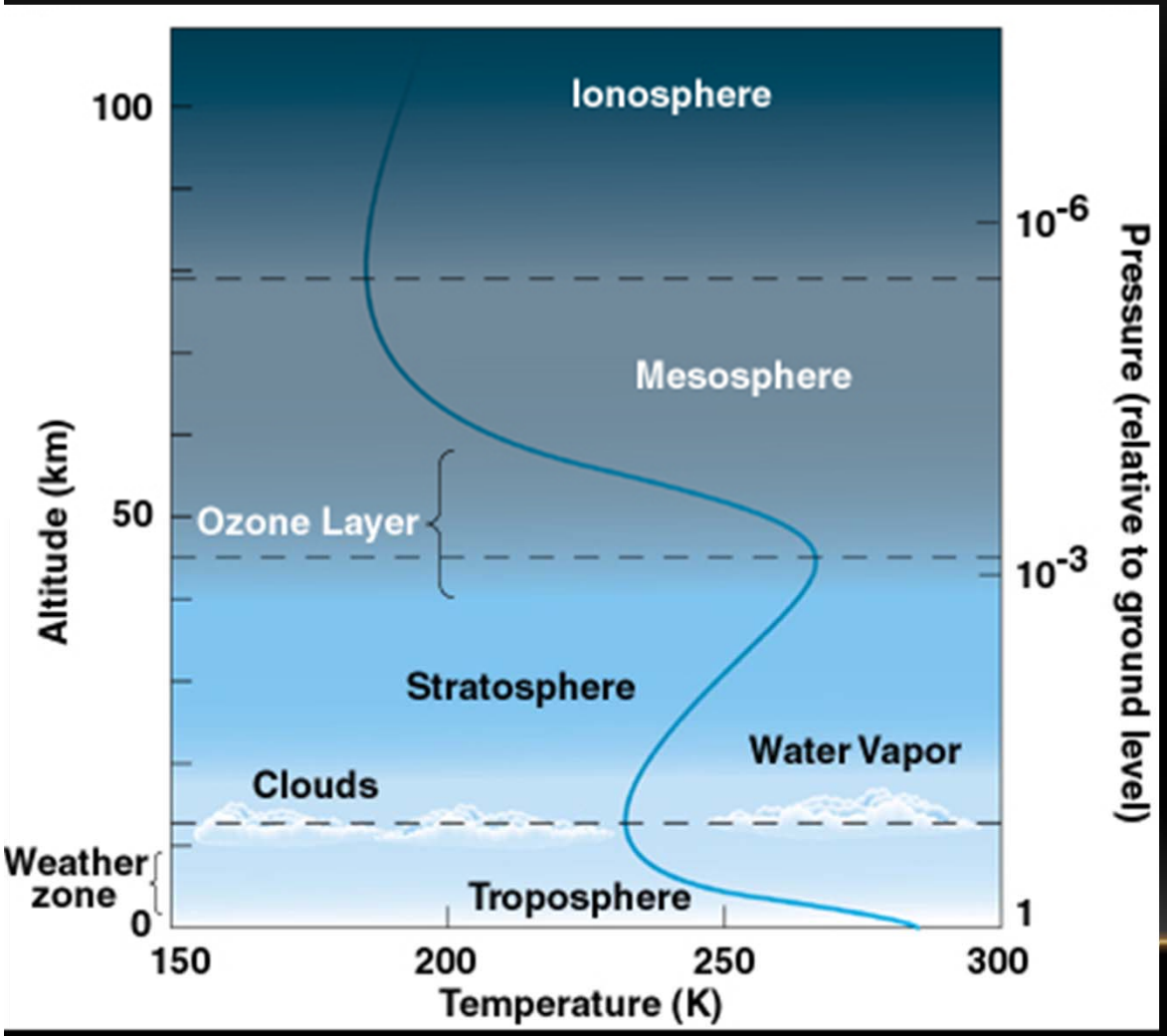
- Run the several inches/year motions of the continental plates back in time
  - (a) is now
  - (b) is ~200 million years ago
- So the maps of the early dinosaurs looked a lot different

PLAY

EARTH'S MAJOR FEATURES

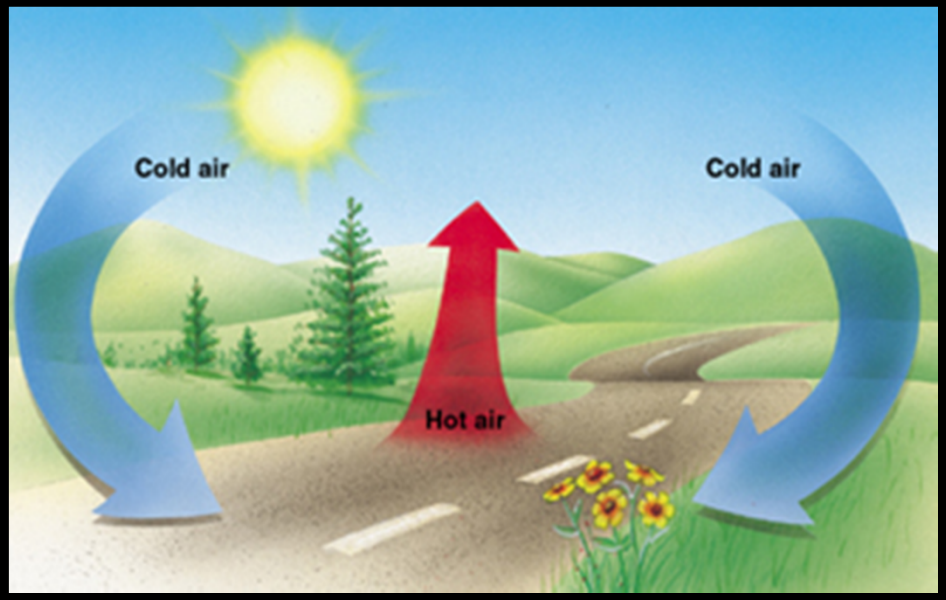
- 3rd rock from the Sun
- Hot, active interior
- Largest satellite compared to size (the Moon or Luna)
- Takes ~365.25 days to revolve around Sun
- Rotates on axis once every ~23h 56m
- Has a layer of crusty scum on surface…

HEY, THAT'S US!



- There is also a thin layer of atmosphere on this rock
  - Plus a lot of liquid water – unique!
- Air is ~80% nitrogen, ~20% oxygen
  - Small amounts of CO_2, H_2O

TROPOSPHERE?



- The area of the atmosphere where *convection* occurs
- Convection –
  - Hot air less dense, rises, cools
  - Cold air denser, sinks, gets warmed by the ground

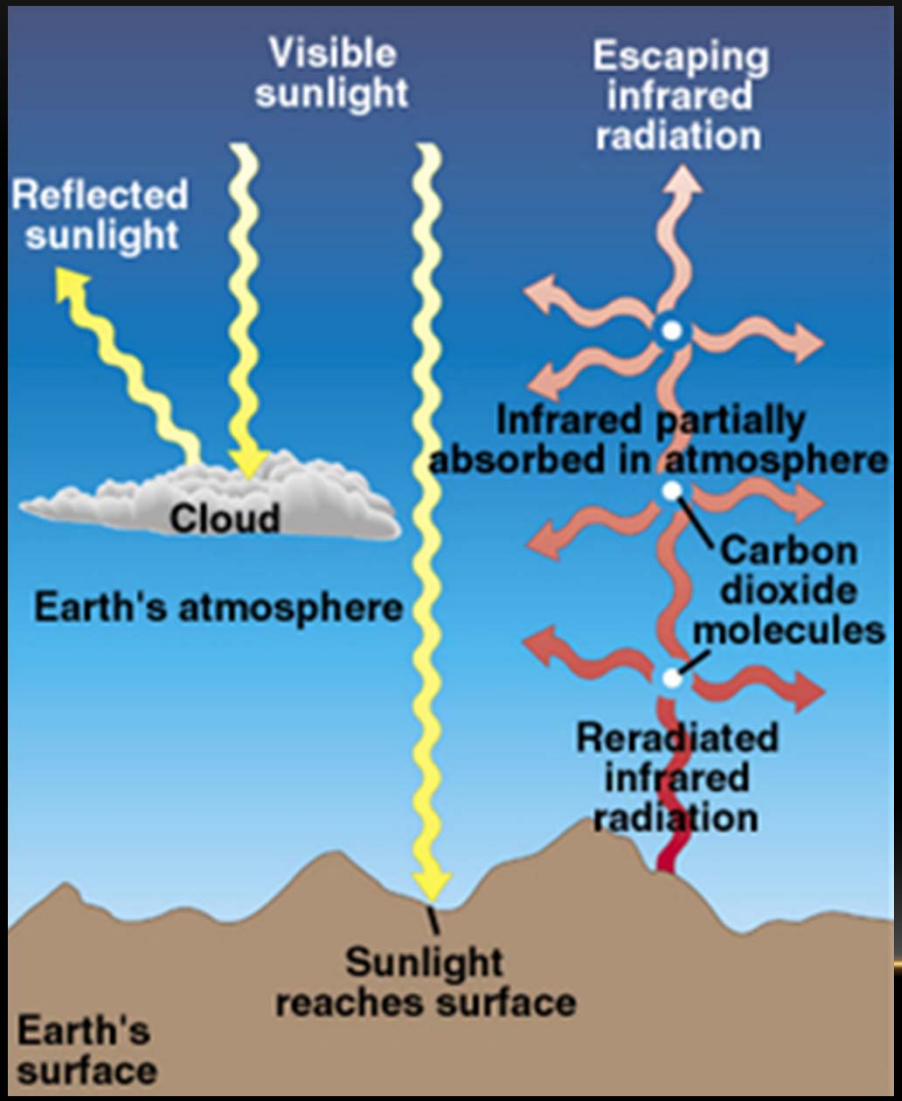
JUST RIGHT

- Temperature:
  - Earth is not too hot to boil all the water
  - Not too cold to freeze it all
- Atmospheric density
  - Has a thick enough atmosphere to keep us warm and keep radiation from space out
  - Not so thick to cook us
- Water, oxygen easy to use in biology

HOW DOES IT KEEP US WARM?

- We see this happen in the weather
- Clear nights –
  - No clouds, heat escapes to space
  - Gets cold!
- Cloudy nights –
  - Clouds act like blankets
  - Doesn’t get so cold

WHY? GREENHOUSE EFFECT



- Sunlight goes through air well, warms Earth
- Warm Earth radiates in the IR
  - But IR absorbed by CO_2, H_2O
  - Heat stays here!
- Earth a lot warmer than it would be without an atmosphere – 30°C or so, the difference between “nice” and “frozen”
  - But we don’t want too many blankets

PLAY

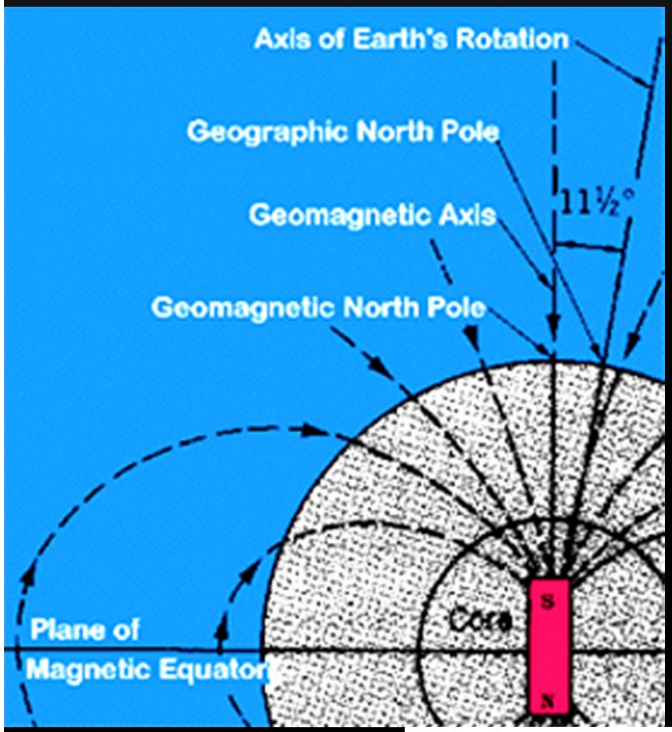
GREENHOUSE EFFECT

- Add more “greenhouse gases”
  - Carbon Dioxide, Methane, Water
- … and it gets warmer
  - Book (and HW) have good data to look at and explore
  - Similar things have happened in the distant past on earth, without our help
- Pretty much all the science out there says that this time it’s our doing

GLOBAL WARMING AND POLITICS

- Things should work like:
  - What's happening and why? (job of Science and Scientists)
  - What to do about it (creating Policy by Politicians)
- Unfortunately, this well established bit of science has gotten hijacked by a political argument *(much like Evolution in a Biology class)*
  - Politicians who don't like what the science is saying shouldn't try to dupe people into "not believing" the science. Unfortunately, that's what has happened.
  - There's no "belief" involved in science. Does the data fit the observations? How well?

MAGNETIC FIELD



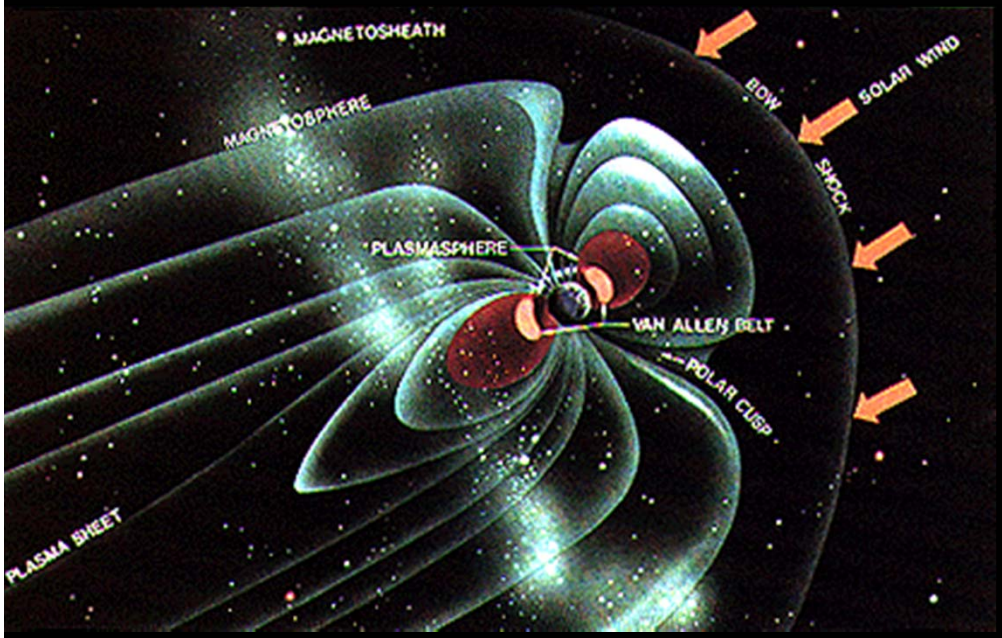
Diagrams from NASA GSFC & National Geophysical Data Center

- All that liquid iron down there generates a magnetic field around the Earth
  - "dynamo model"
- North pole is actually a magnetic South Pole
  - It attracts magnetic North poles, like on your compass
  - Tilted from axis of rotation, and this tilt wanders around over the decades

IT FLOPS ABOUT!

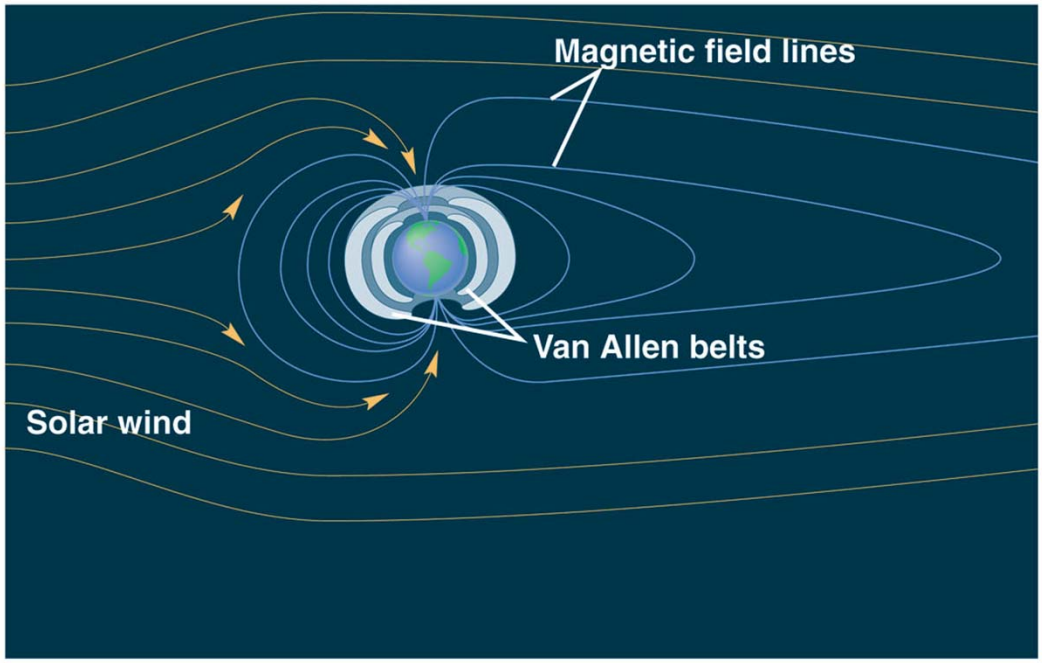
- Looking at layers of old magnetic rocks
  - In the past, the field regularly reverses!
  - Most recently 30,000 years ago
  - >300 times in last 170 million years
- Has to do with the dynamo action of the core
  - Not well understood
  - But the Sun’s magnetic field does this every 11 years, so it’s not unprecedented

MAGNETOSPHERE

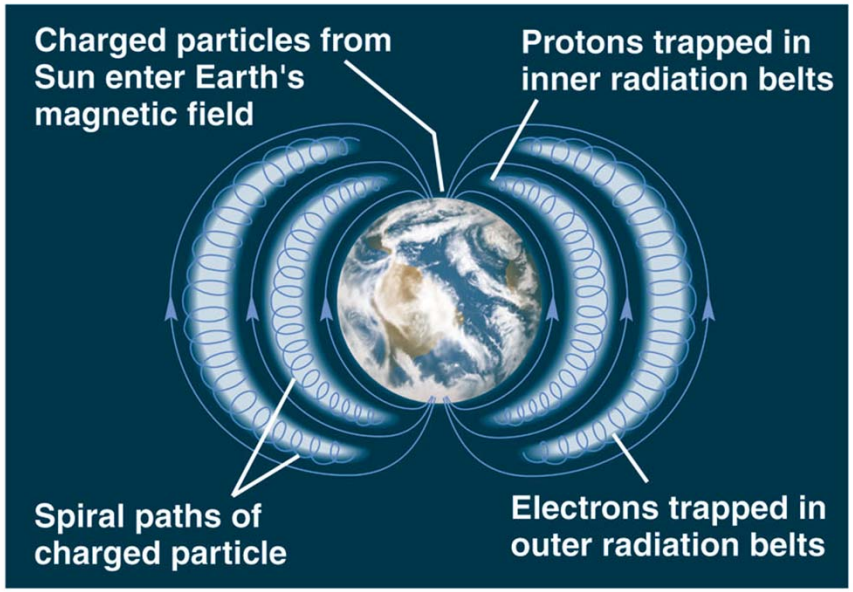


- Solar Wind of charged particles pushes on Earth's magnetic field
- Charged particles tend to follow field lines
- … right down to the Earth's poles

Diagram from NASA MSFC



(a)

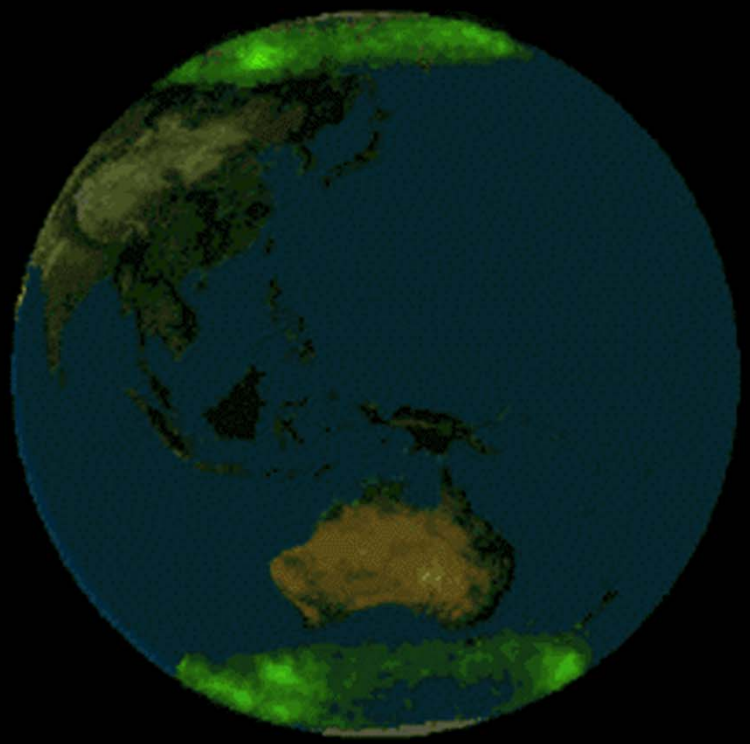


(b)

VAN ALLEN BELTS

- Solar wind charged particles follow the field lines
- Charged particles spiral in magnetic fields
- These traffic jams are called the “Van Allen Radiation Belts”

AURORA



Picture by POLAR spacecraft, October, 2001

- When the particles hit the atmosphere near the poles, they excite the air atoms
  - Glowing Gas!
- Aurora Borealis
  - In the North
- Aurora Australis
  - In the South

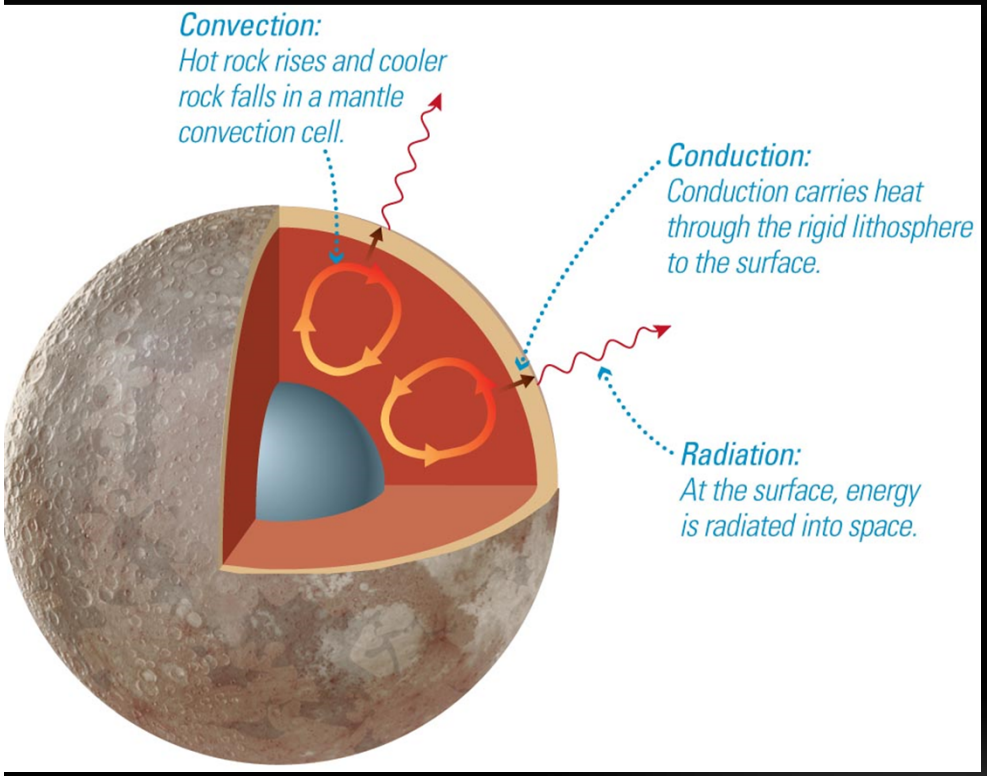
MORE AURORA

Picture by Duane Clausen
Jan 15, 2002

AND ANOTHER…

Picture by
Jan Curtis

PLANETARY COOLING

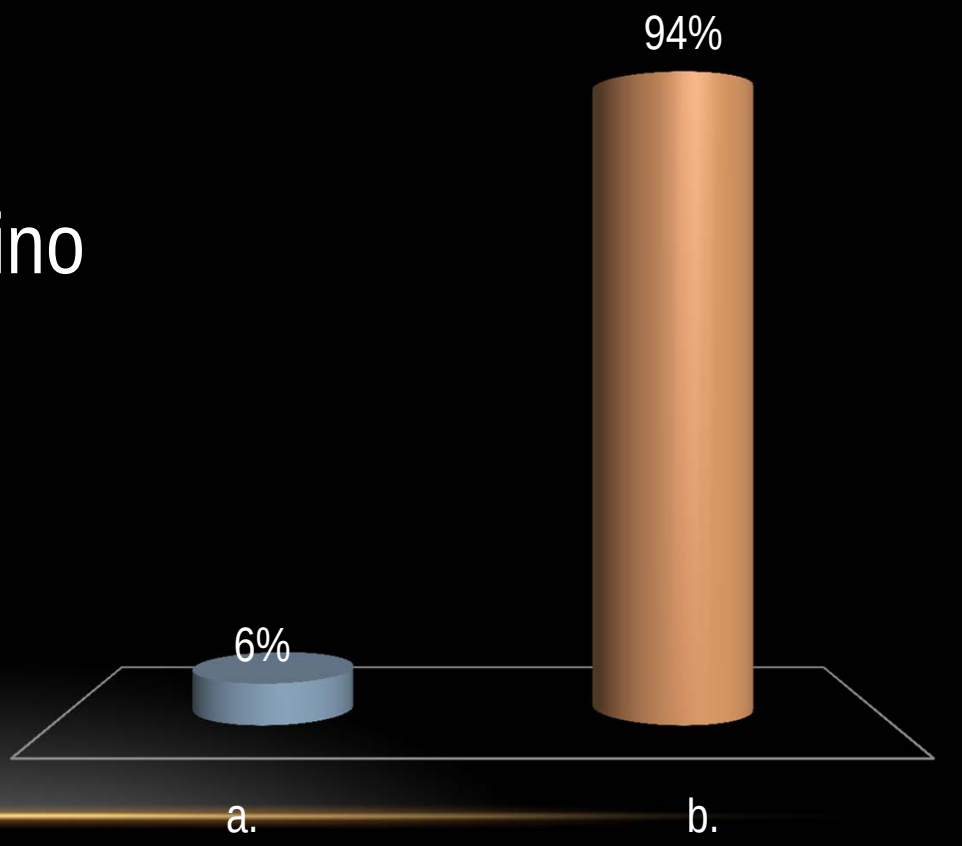


- **Convection** transports heat as hot material rises and cool material falls.
- **Conduction** transfers heat from hot material to cool material.
- **Radiation** sends energy into space.

WHAT COOLS OFF FASTER?

a. A grande-size cup of Starbucks coffee

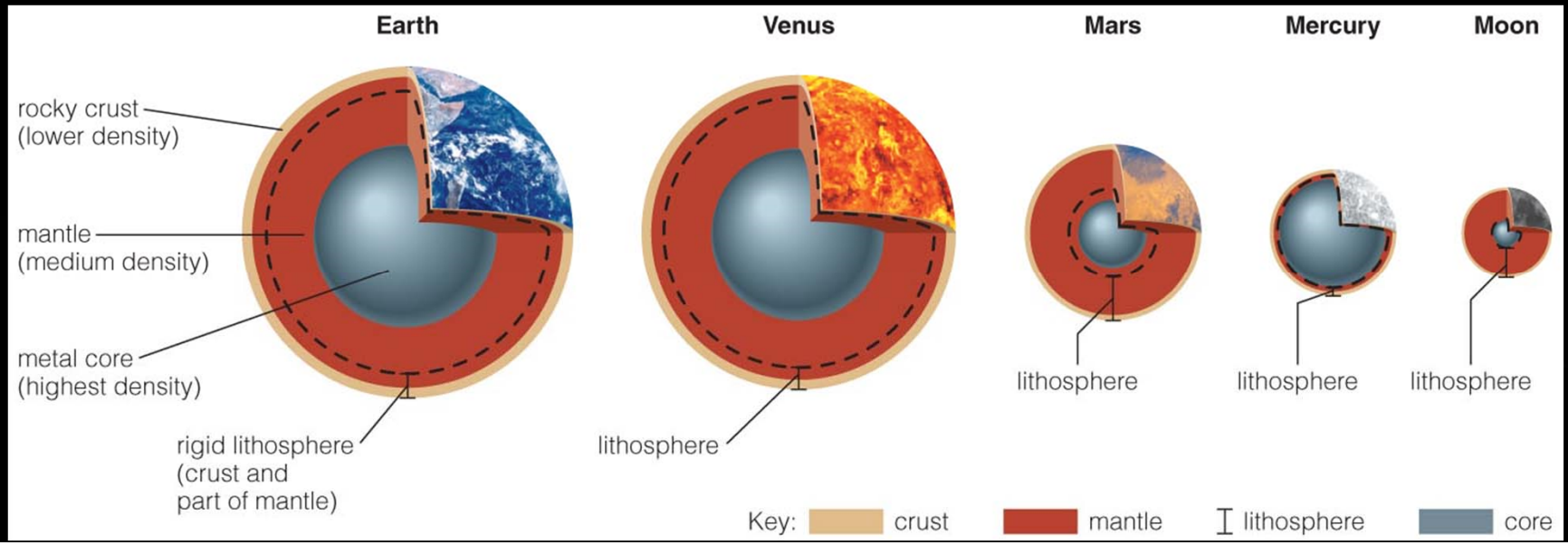
b. A teaspoon of cappuccino in the same cup



SMALLER THINGS COOL FASTER

- Have less heat to give, and have a larger surface area to volume ratio
- Moon and Mercury are all cooled off and solid
- Mars mostly there

Fig.7.2



THE MOON

Picture by T.A. Rector, &
I.P. Dell'Antonio, NOAO

- About ¼ the diameter of the Earth
  - 3475 km
- Only 1.2% the mass of the Earth
  - So avg. density is only 3.34 g/cm^3
- Dark surface (asphalt-like)
- No atmosphere