Announcements

- **Late HW3s due now**
  - 50% late credit

- **Thursday office hours?**
  - No one was concerned
  - We'll drop this slot – email me for a time to meet instead

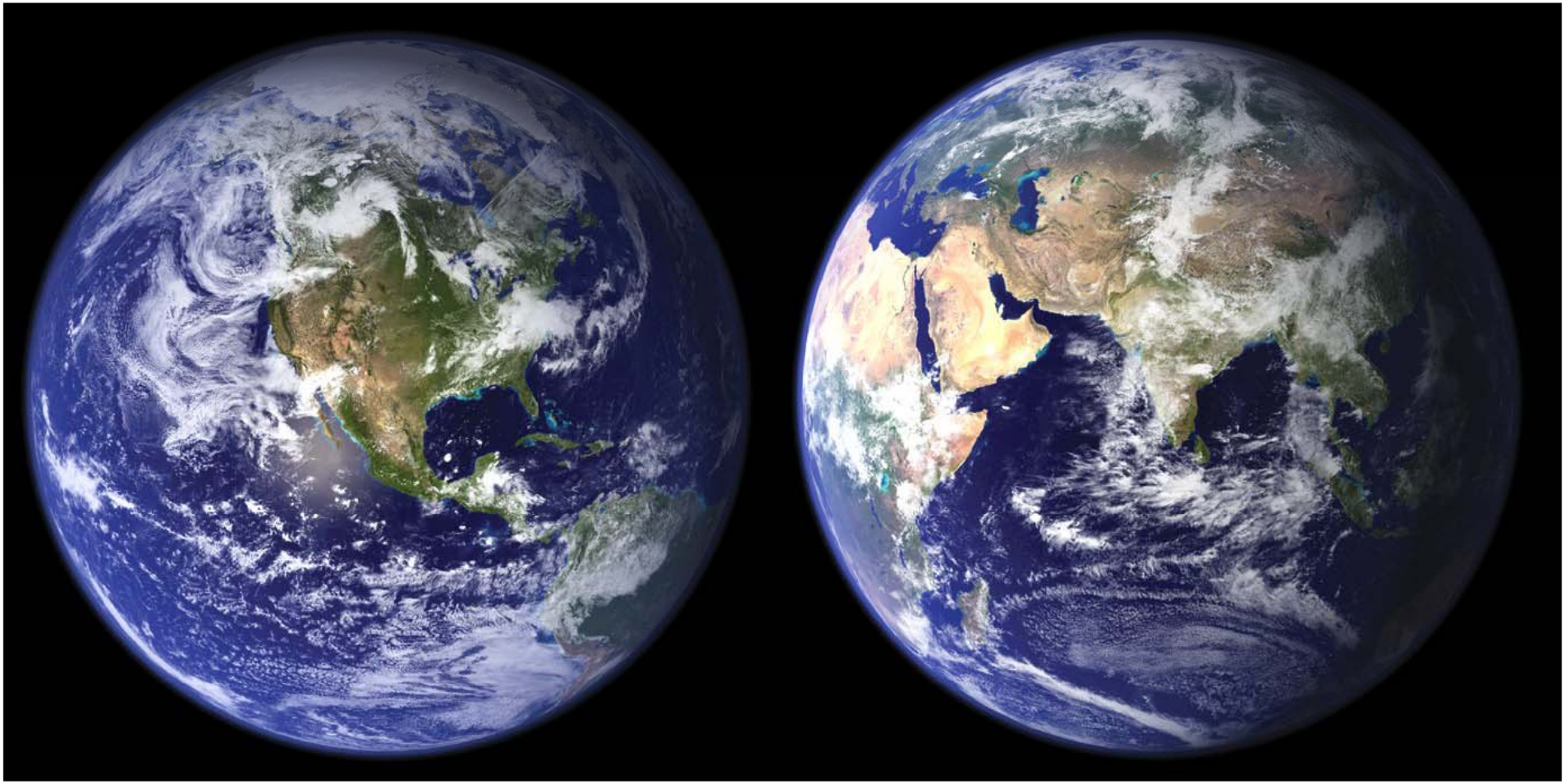
- **Drop day is today**

- **Calculate your expected grade…**
  - Add HW1 and HW2 percentages together, multiply by 0.15
  - Add the two in-class activity marks (out of 5) together, multiply by 2
  - Take your mid-term score (out of 45), multiply by 1.111
  - Add these three things together…. And compare to grade table

90-100%	A
75-89%	B
60-74%	C
50-59%	D
0-49%	E

  - This is a <u>REALLY</u> rough guess, you can easily move up/down a grade

Earth



PTYS/ASTR 206 – The Golden Age of Planetary Exploration

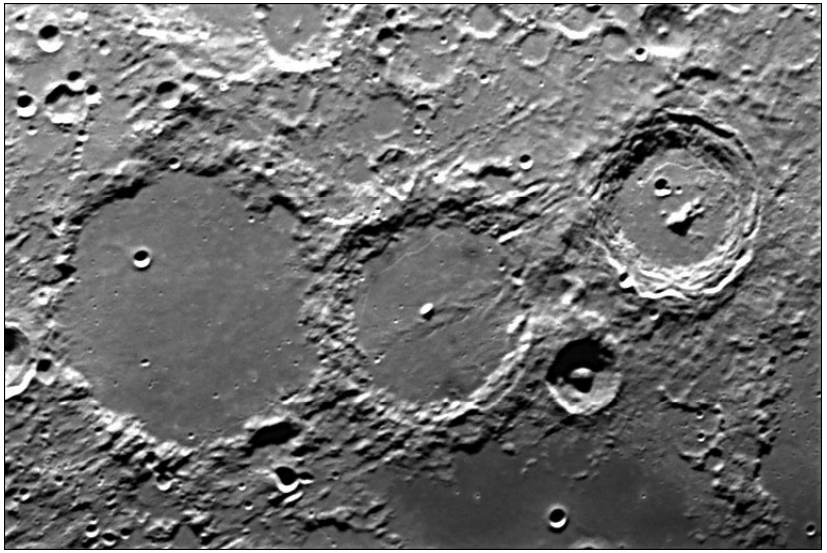
Shane Byrne – shane@lpl.arizona.edu

In this lecture…

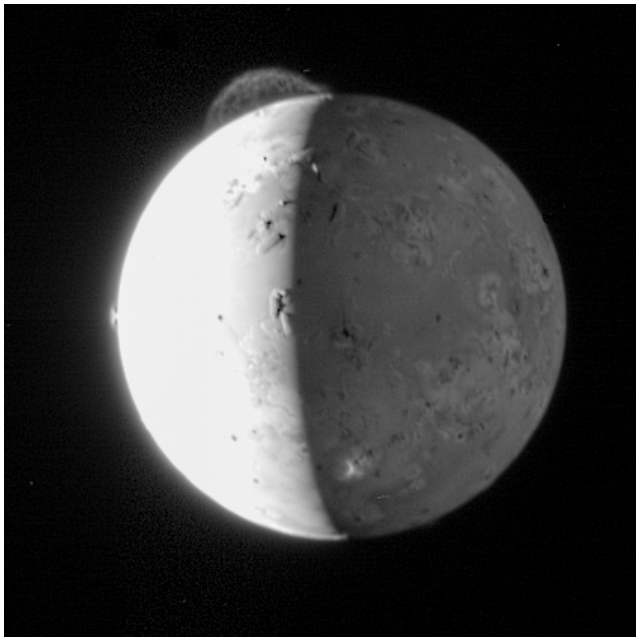
- **Introduction to the Earth**
  - Recap on Interior
- **Two types of crust**
  - Oceanic crust
  - Continental crust
- **Plate Tectonics**
  - Current plates
  - Evidence for plate tectonics
- **Plate motion**
  - Spreading centers and subduction
  - History of plate motions
- **Early Earth**
  - Building continents
  - Early atmosphere
  - Forming the oceans
- **Life**
  - When it formed
  - Rise of Oxygen

Figure 9-4
Universe, Eighth Edition

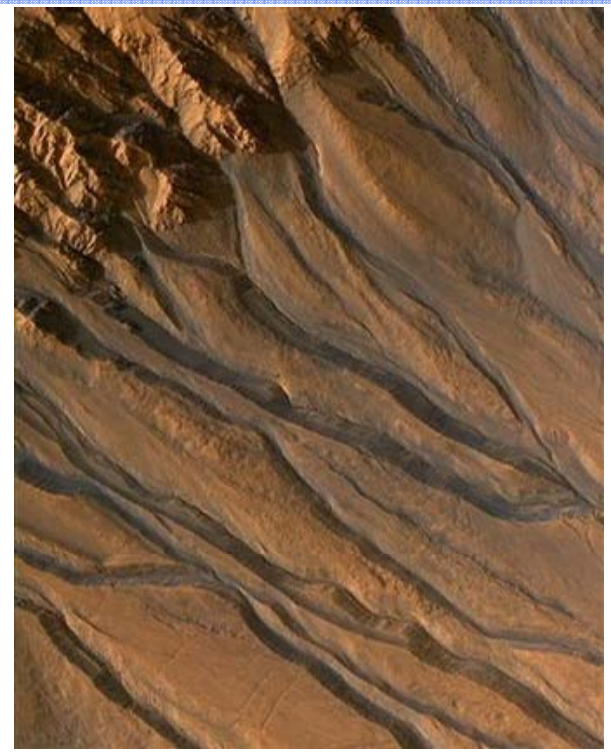
- **What's unique about the Earth?**
  - **Impact craters? – No**



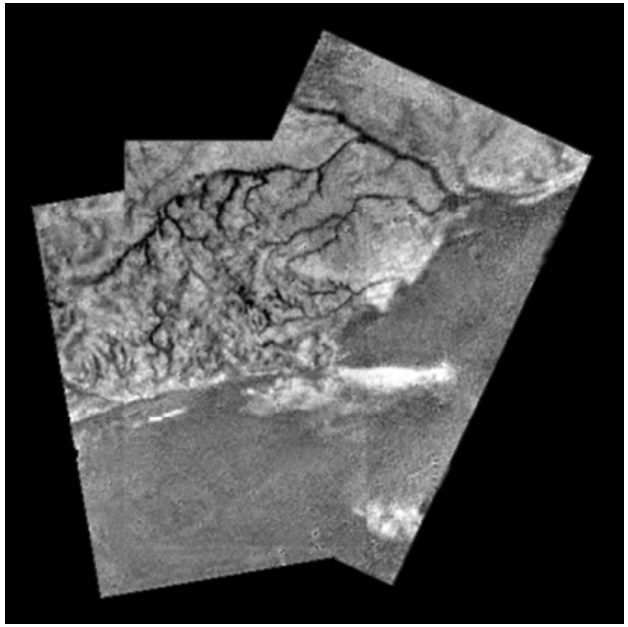
  - **Volcanoes? – No**



- **What's unique about the Earth?**
  - **Fluvial erosion? – No**

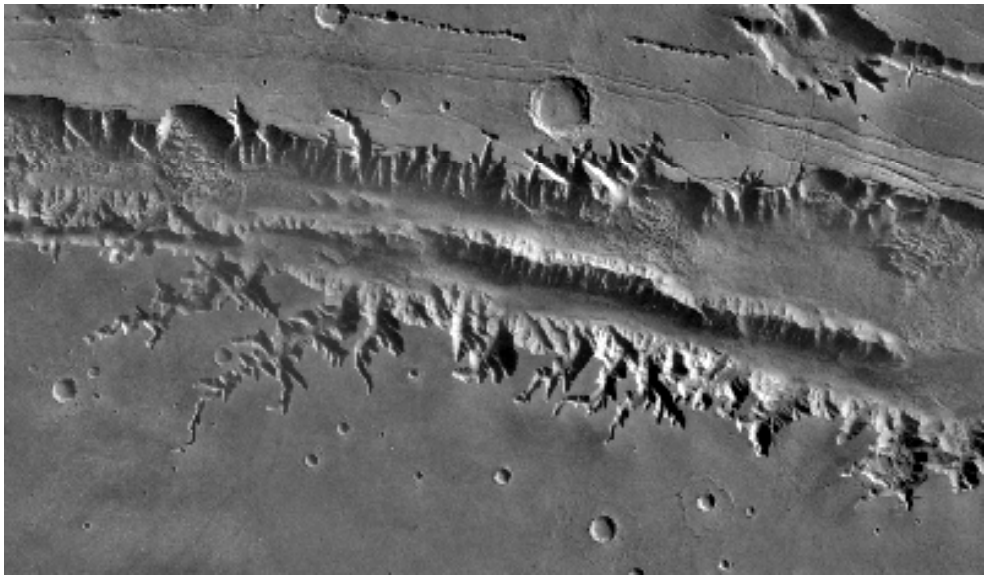


  - **Rivers? – No**

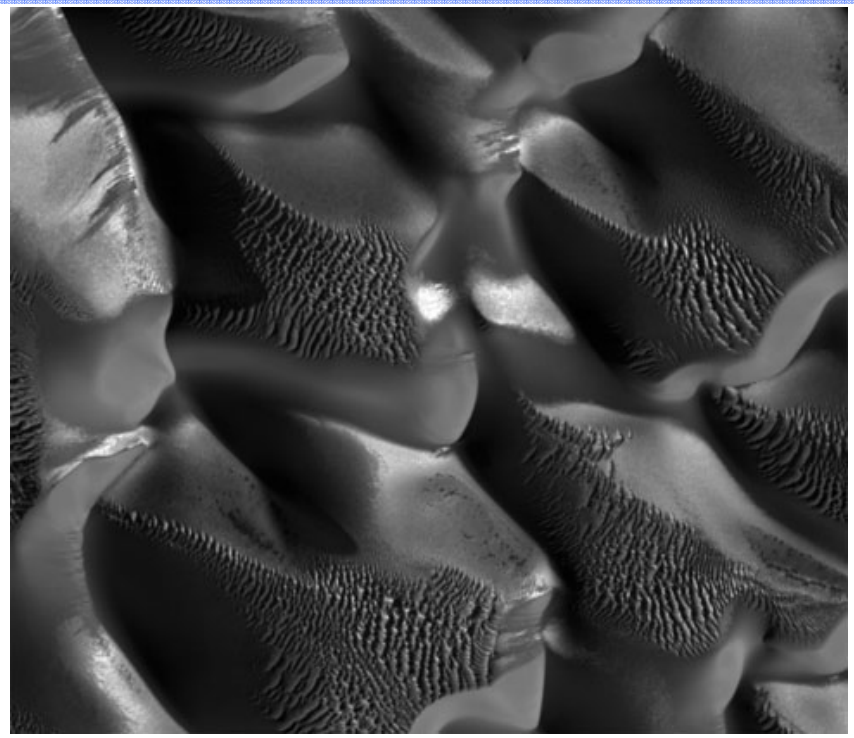


- **What's unique about the Earth?**
  - **Glaciers? – No**

  - **Tectonics? – No**



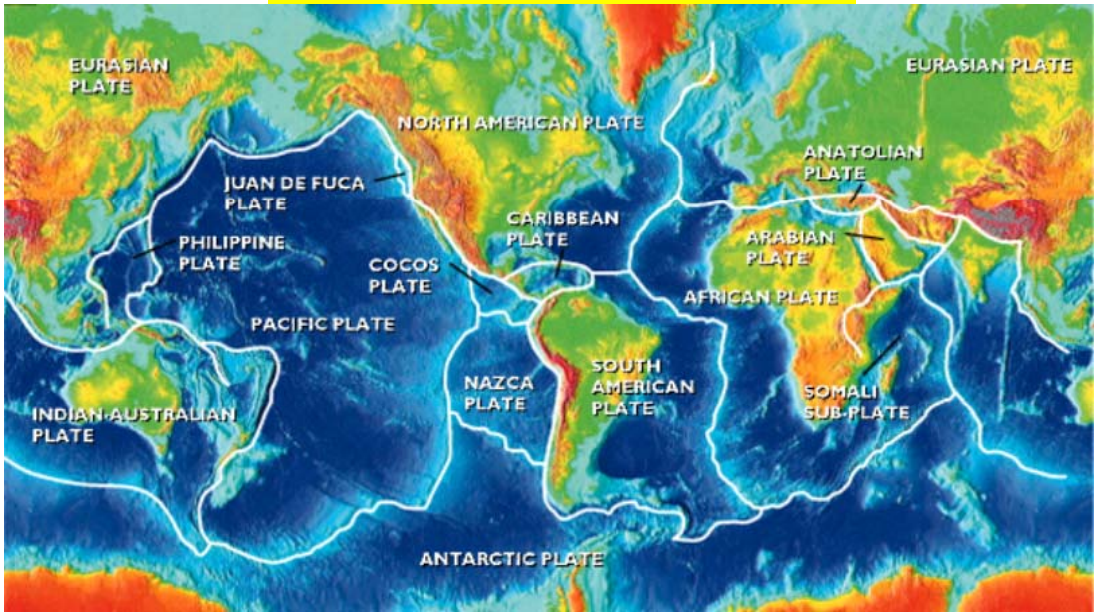
- **What's unique about the Earth?**
  - **Wind action? – No**



  - **So what is unique about the Earth?**

- What's unique about the Earth?
- Two main things to talk about in this lecture…

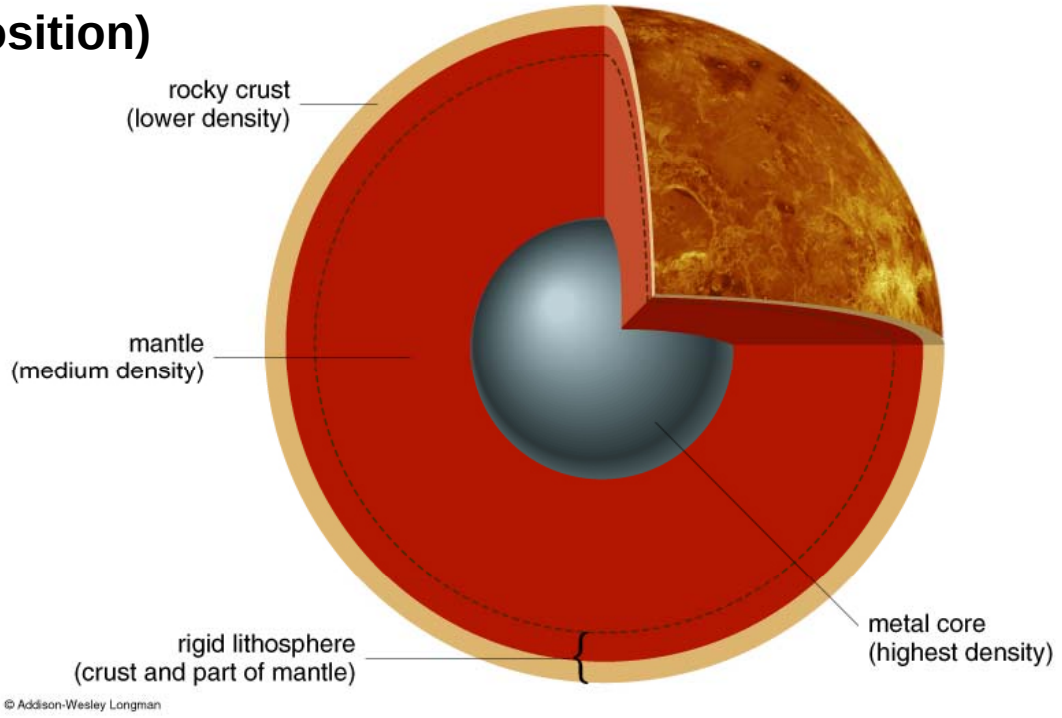
Plate Tectonics



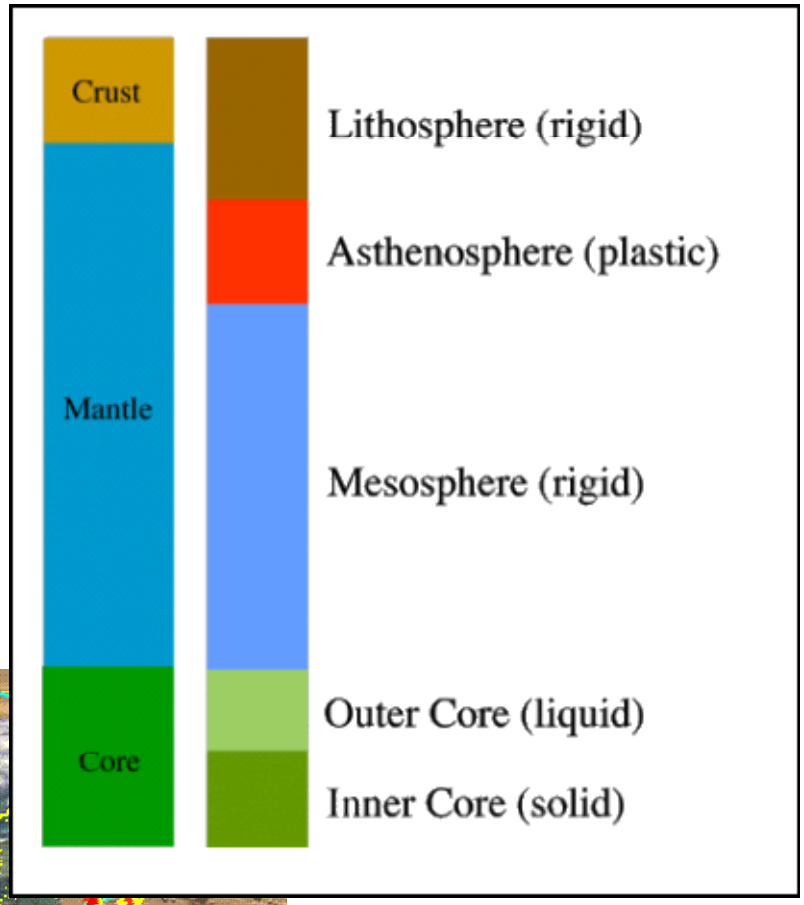
Life

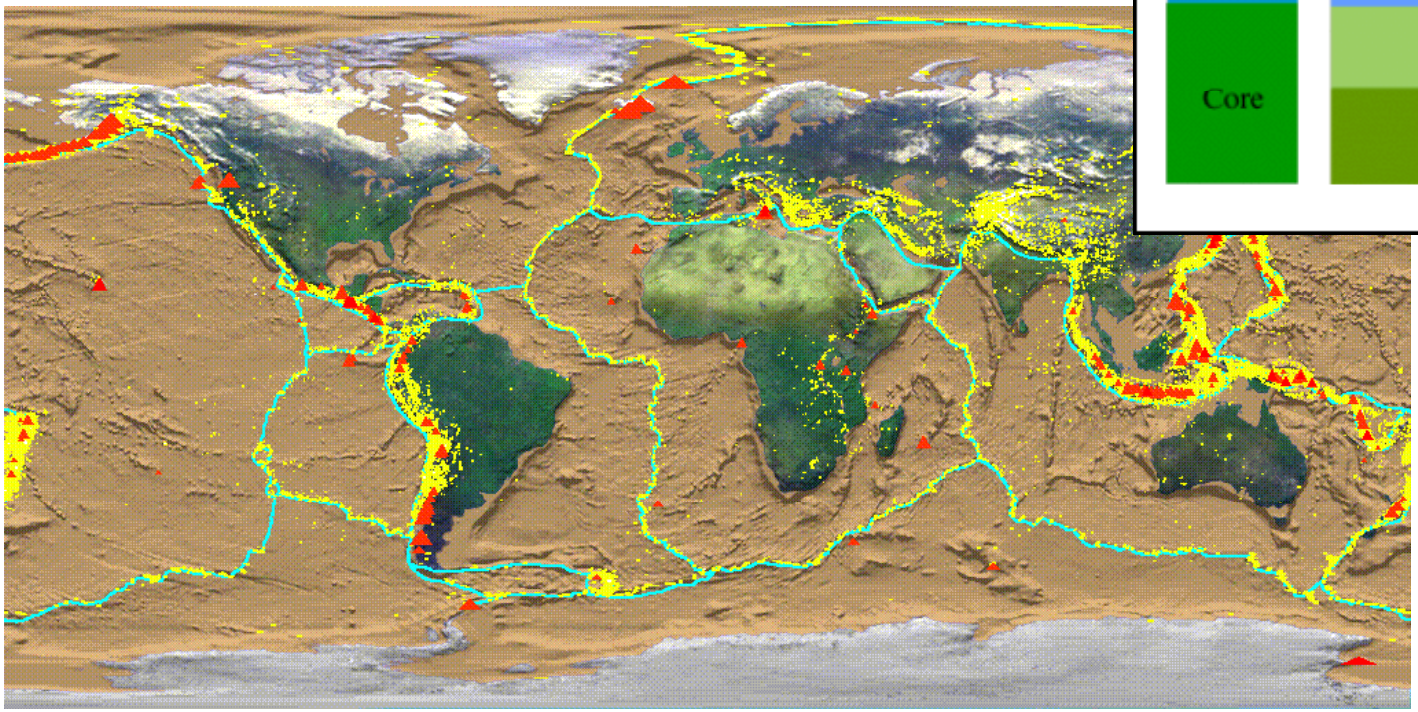
Recap interior…

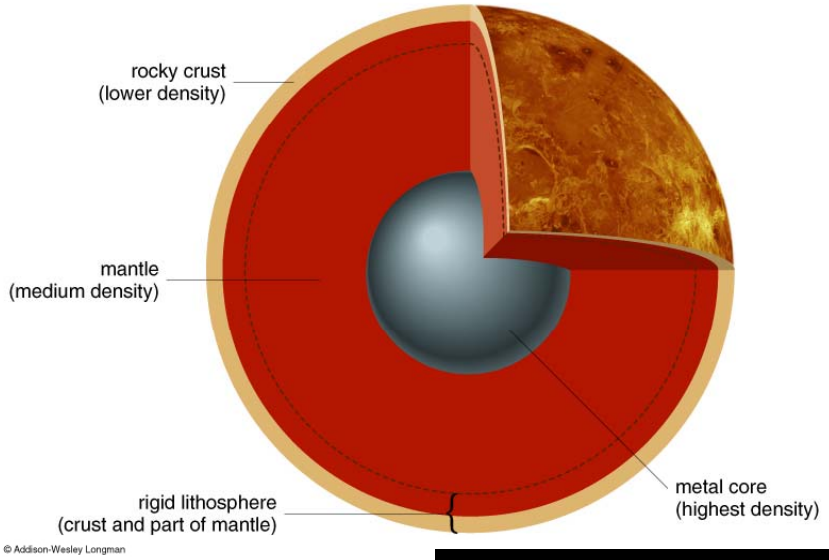
- Rocky planets have several parts
  - Core – Iron/Nickel
  - Mantle – Rocky
  - Crust – Rocky (different composition)
- Strong rocks near surface
  - Colder rocks = stronger rocks
  - Lithosphere
  - Rocks are brittle
- Weak rocks deeper
  - Hotter rocks = weaker rocks
  - Asthenosphere
  - Rocks flow
- Core
  - Solid in center – inner core
  - Surrounded by liquid iron – outer core



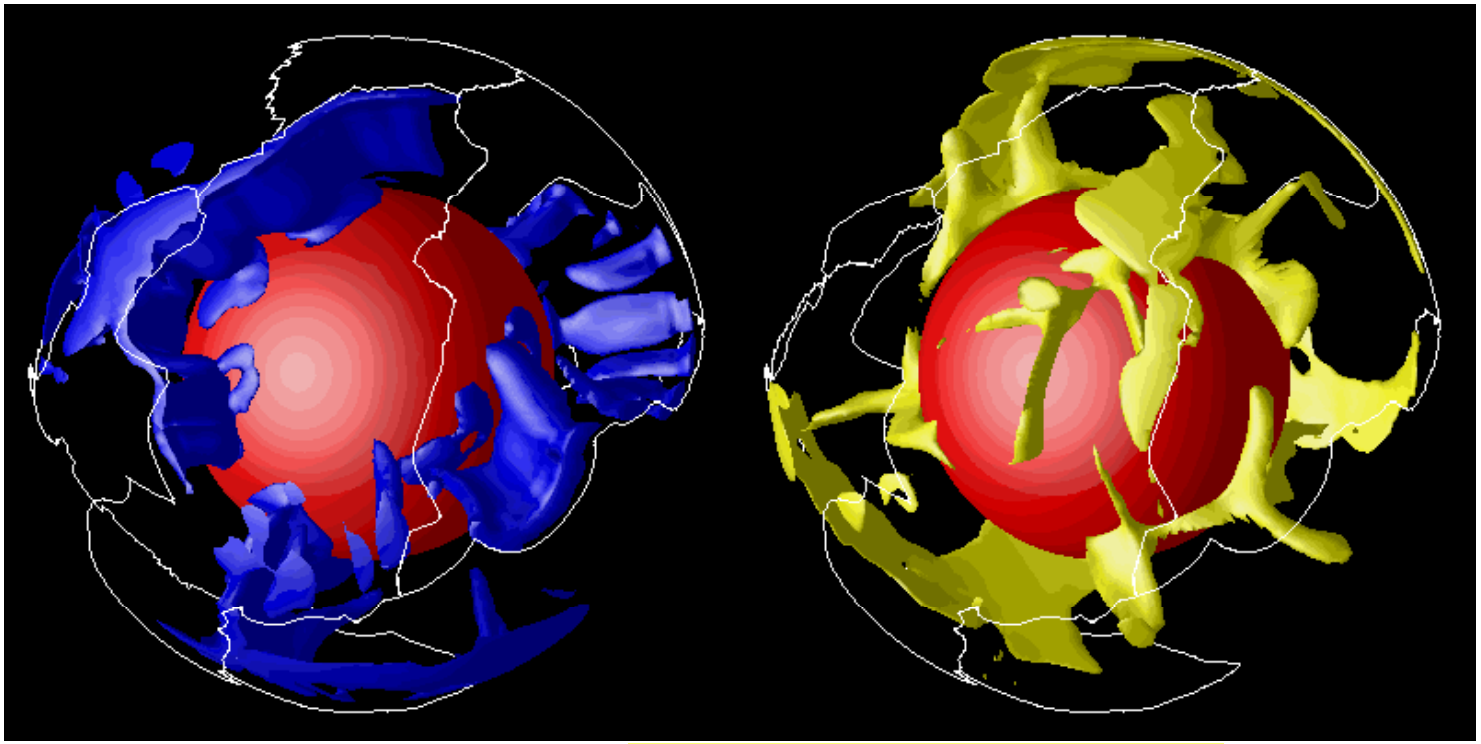
- **Compositional vs mechanical terms**
  - **Crust, mantle, core are <u>compositionally</u> different**
  - **Lithosphere, Asthenosphere, Mesosphere, Outer Core and Inner Core are <u>mechanically</u> different**
  - **Lithosphere is divided into plates…**







- **Hotter interior temperatures cause convection in the mantle**



Shijie Zhong, U. Colorado

- **Convection causes melting**
  - Melting point depends on pressure
  - Material rises to lower pressure zone
  - Previously solid, but can now partly melt
- **Partly molten zone**
  - Called ‘asthenosphere’
  - Able to flow

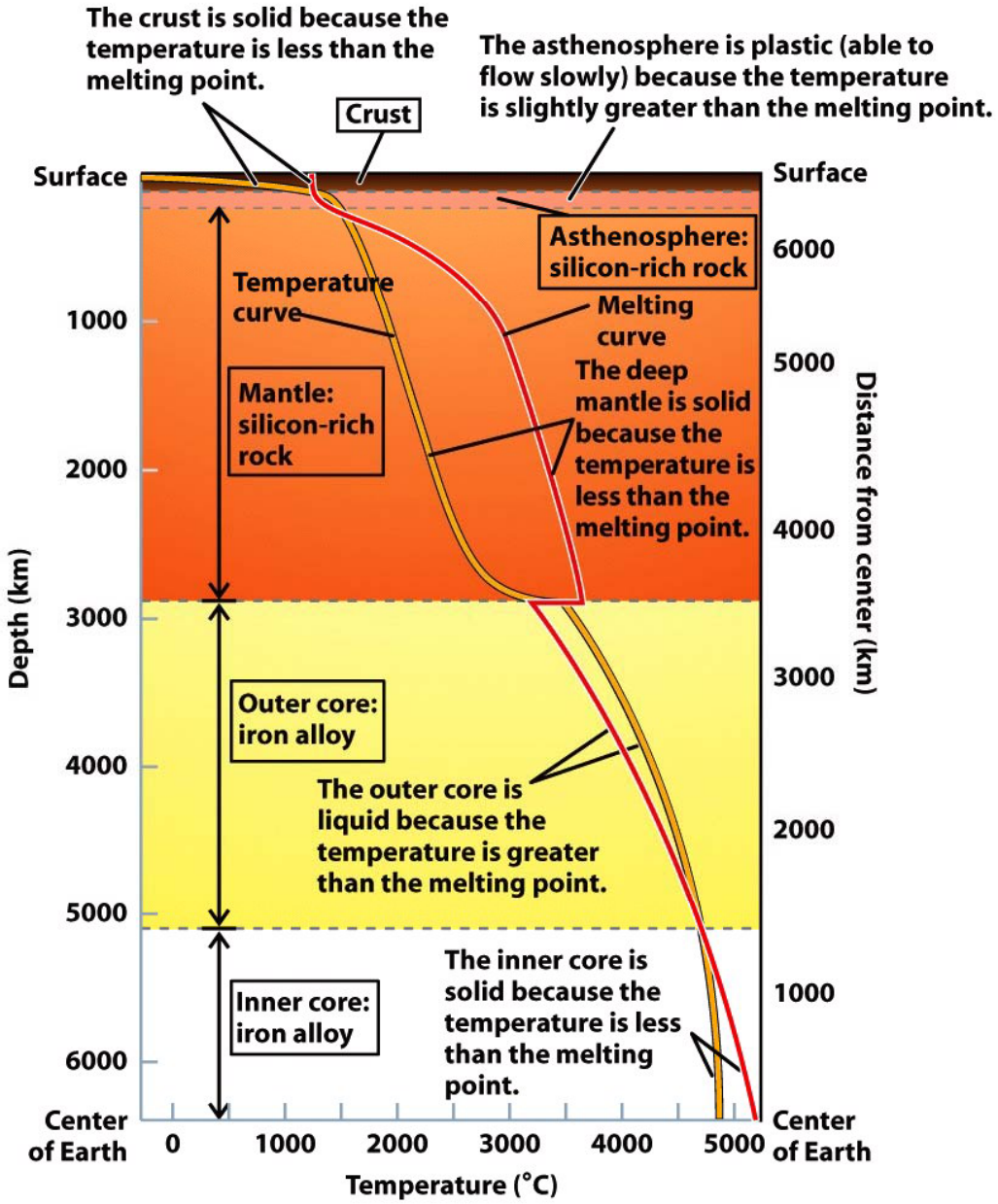
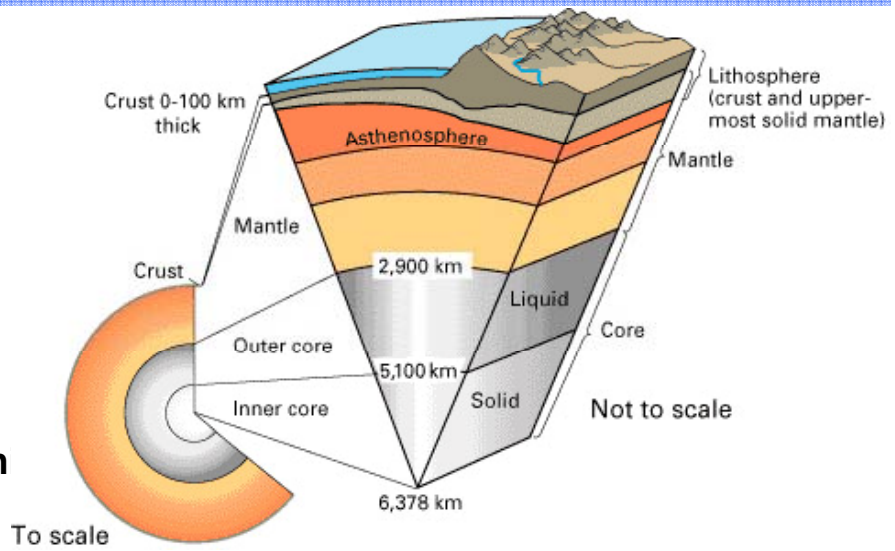
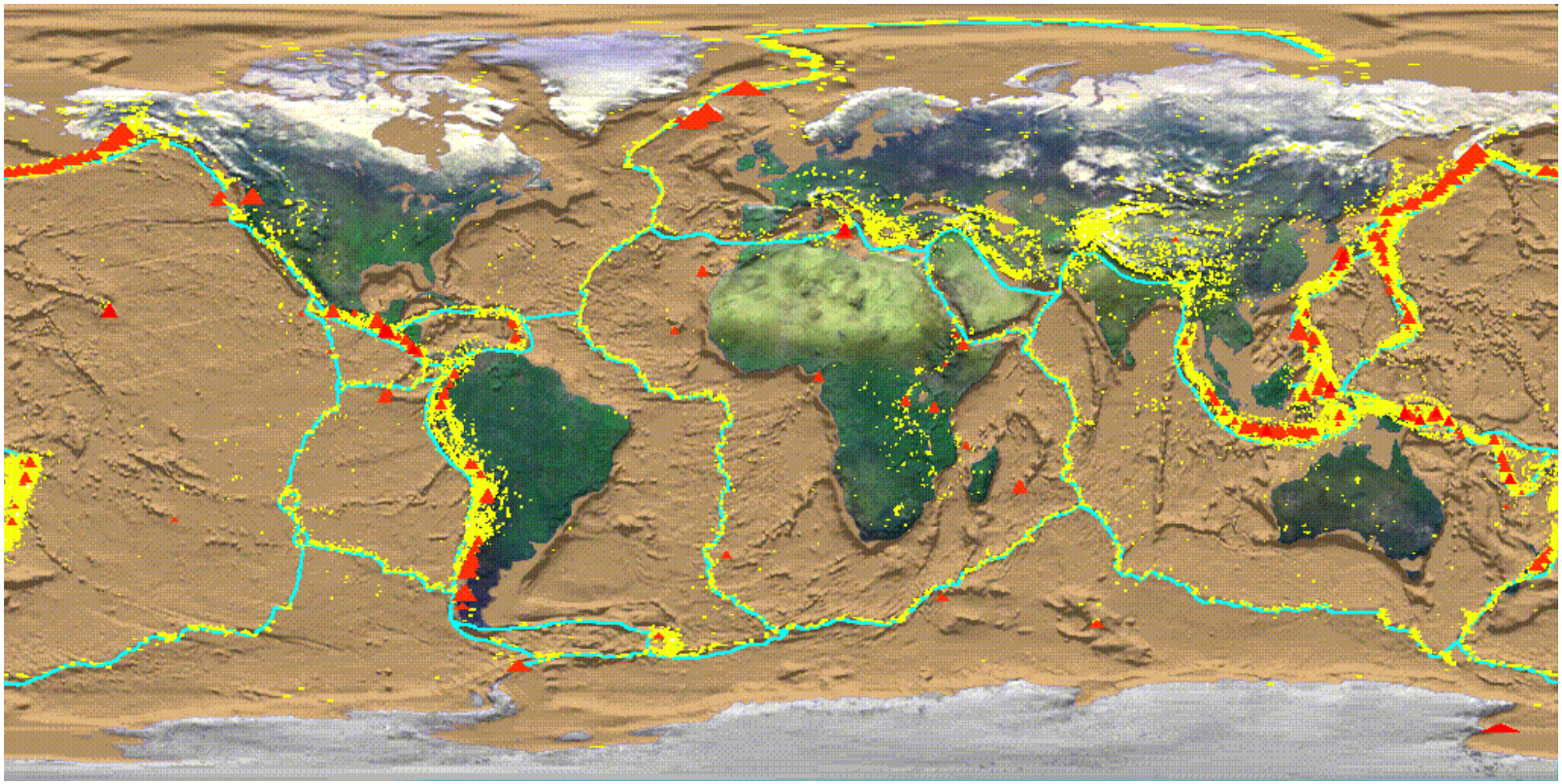


Figure 9-10
Universe, Eighth Edition

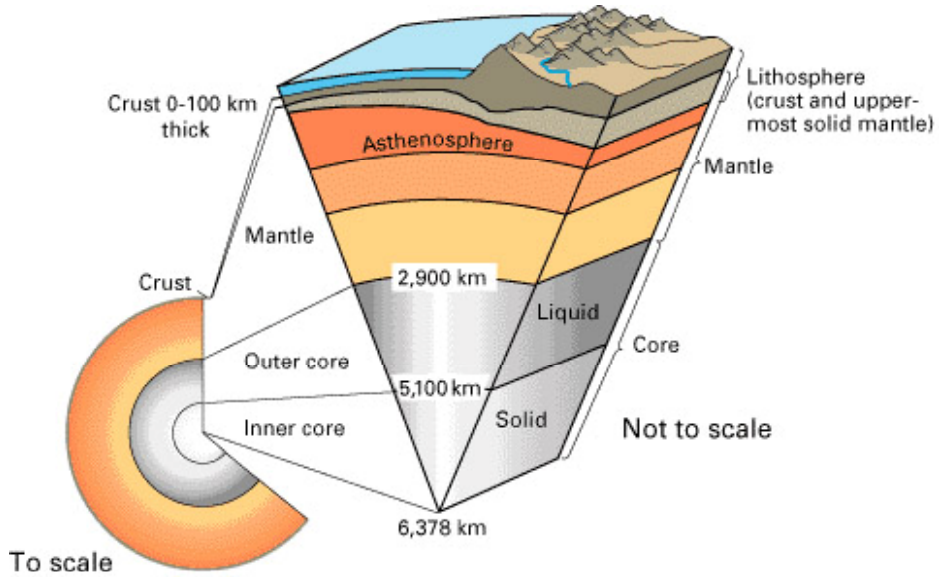
- **Lithosphere**
  - **Brittle upper layer**
  - **Can move around on plastic asthenosphere**
  - **Divided into many plates**
    - **1000-10000 km across**
    - **Most plates contain both continental and ocean crust**





Two types of crust

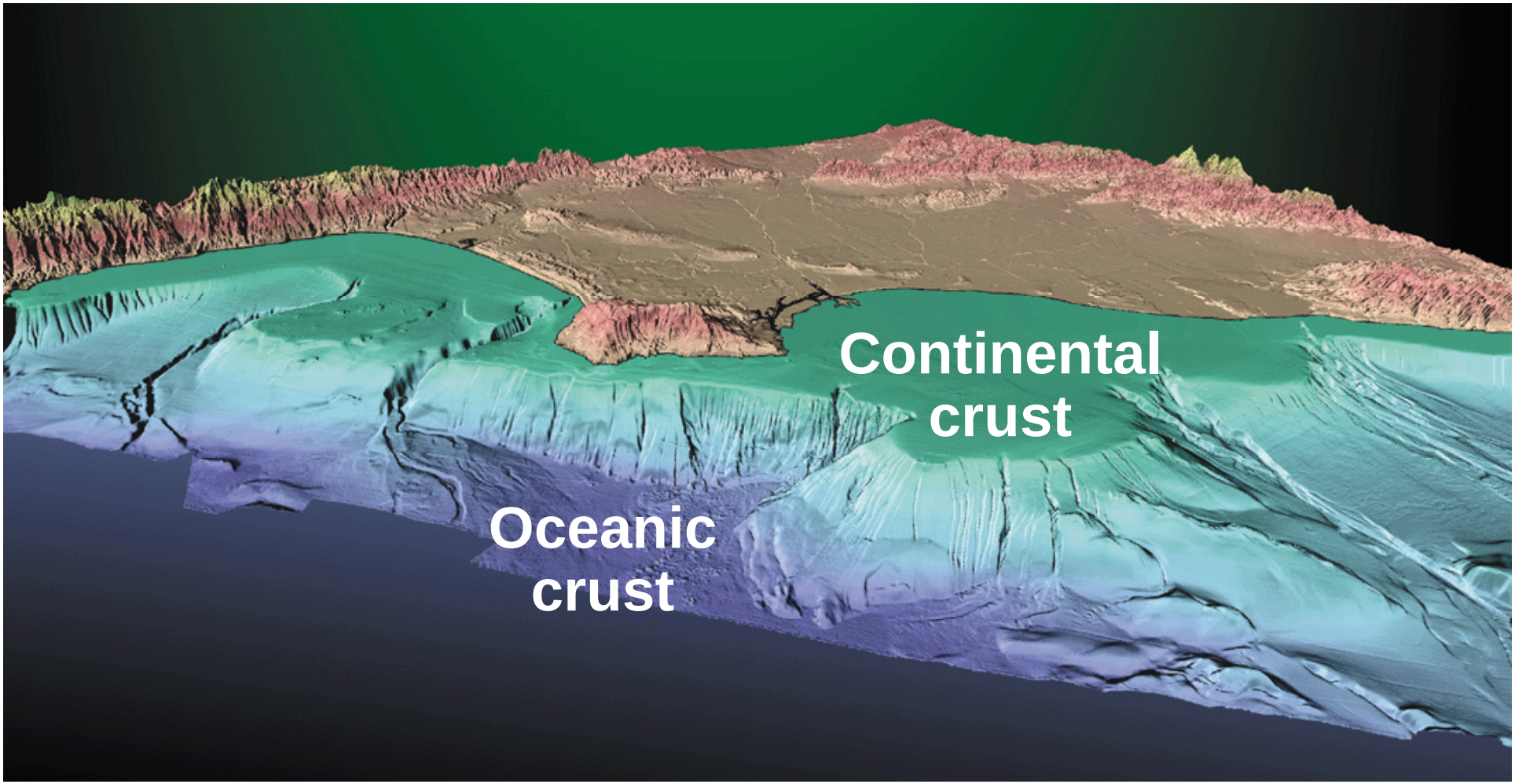
- Crust is a compositional distinction
- Most rock is in the mantle
  - Mixture of two main minerals
    - Olivine and Pyroxene



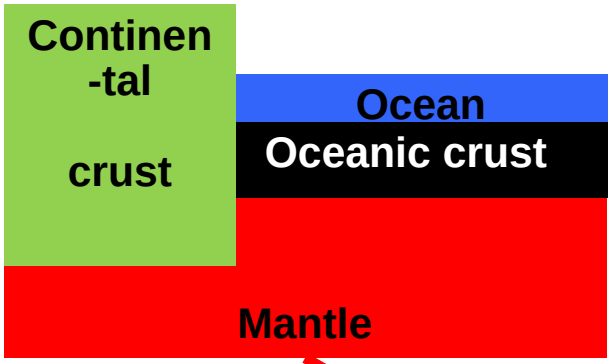
- Earth has two types of crust
  - Oceanic crust – low-lying
  - Continental crust – high-standing
  - Oceans cover oceanic crust and some of the continental crust

- How do we manufacture this crust?
  - Through volcanic activity

- Oceans cover oceanic crust and some of the continental crust
  - Not always the case
  - More continental crust exposed during the last ice age when sea levels dropped



- **Oceanic and continental crust compared**



	Oceanic	Continental
Density	3000 kg m^{-3}	2700 kg m^{-3}
Thickness	5km	20-100km
Composition	Basalt	Granite
Age	<0.1 billion years	> 1 billion years

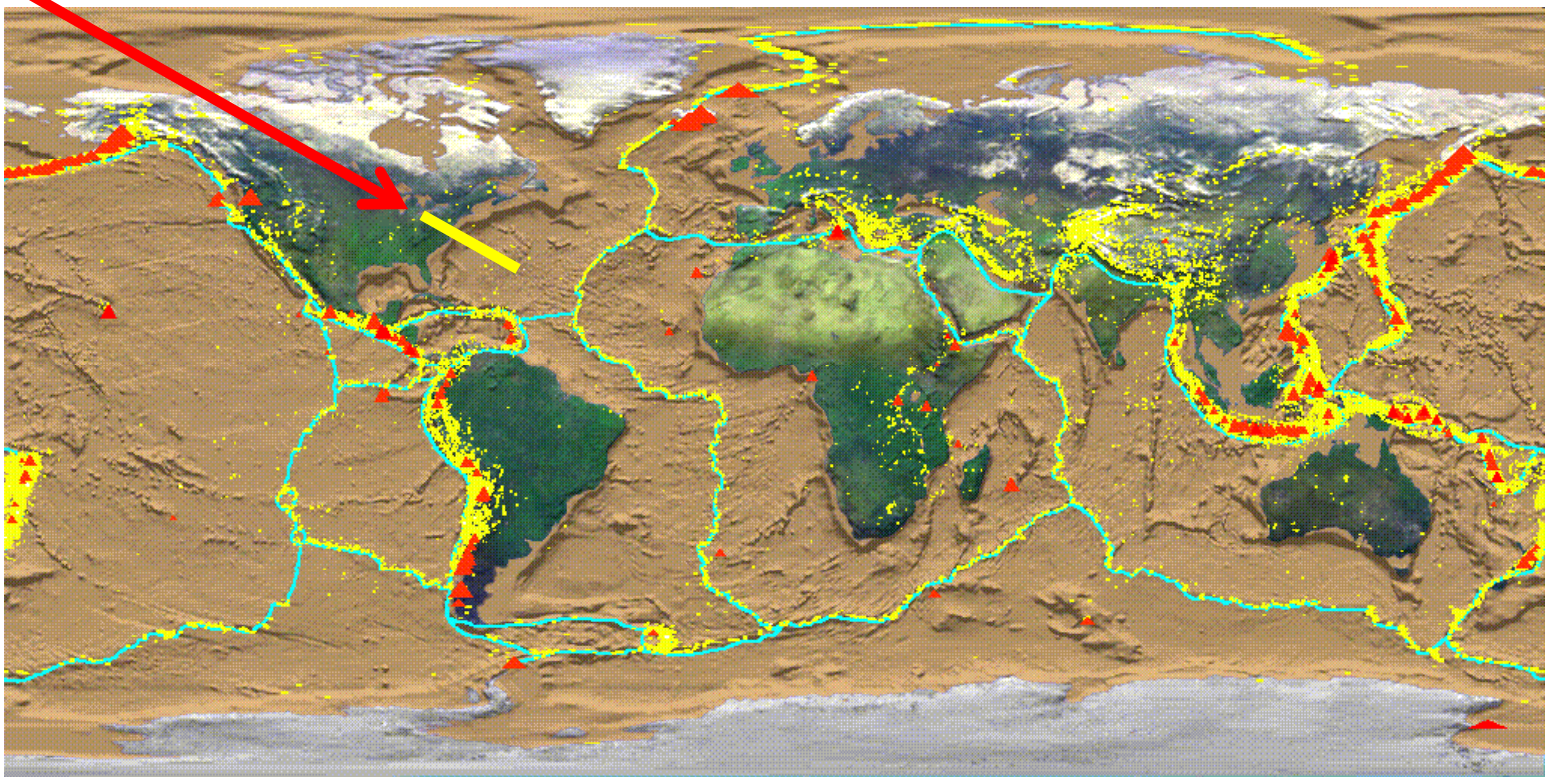
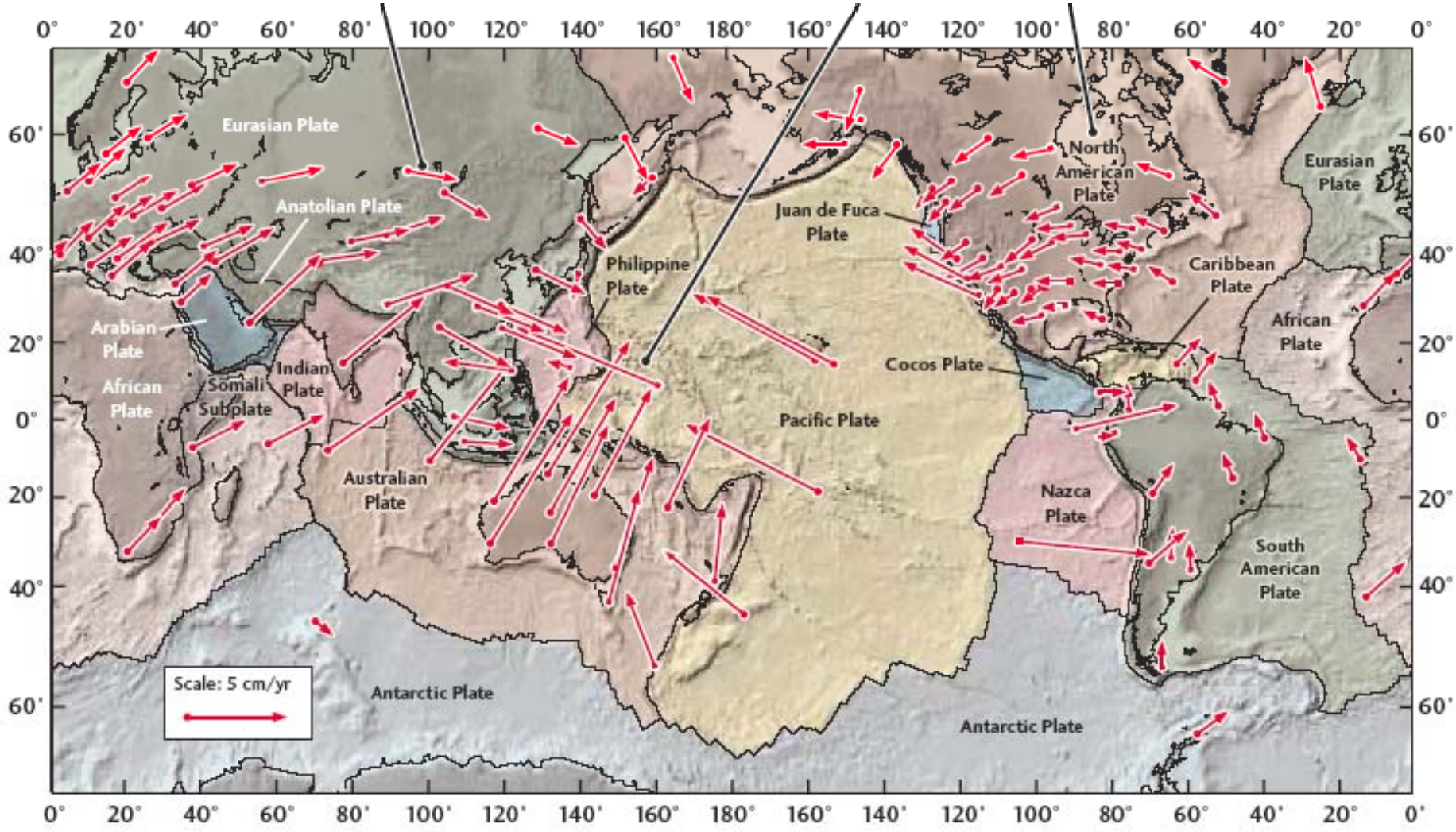
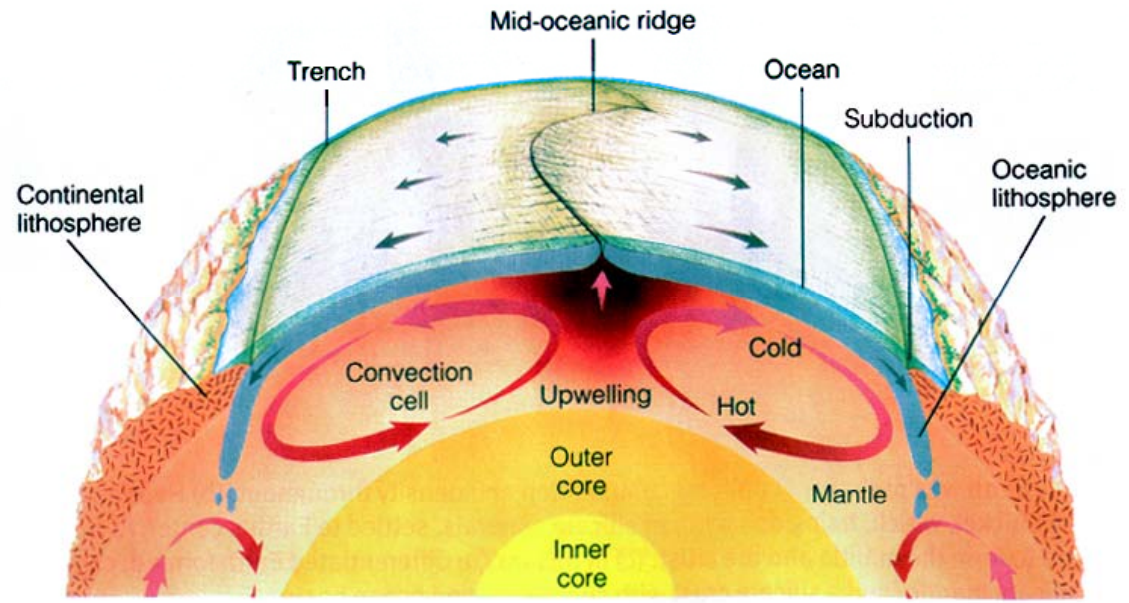


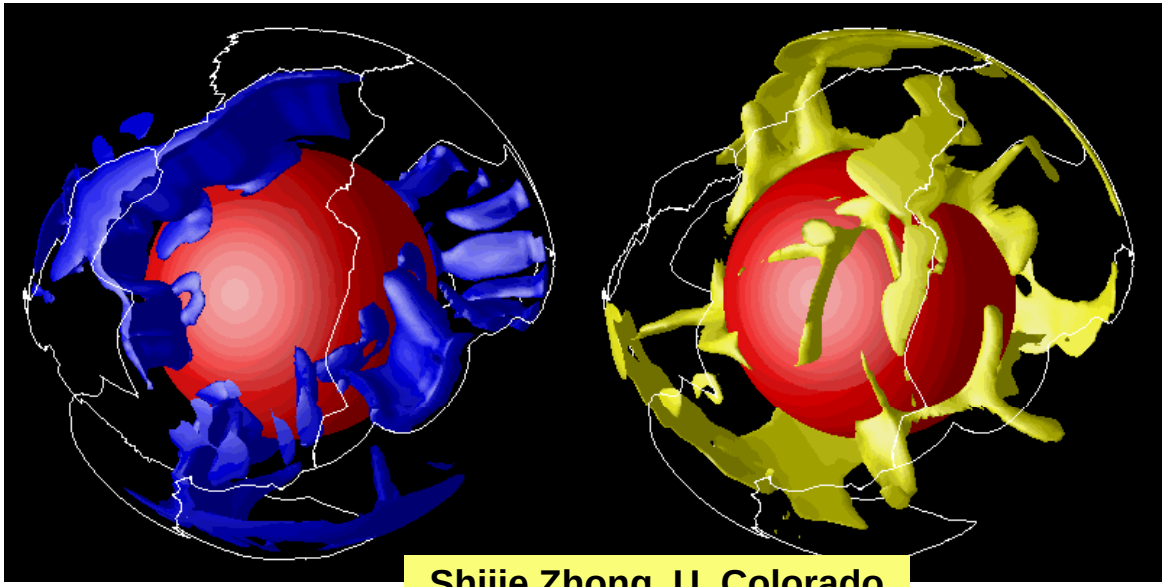
Plate Tectonics

- **These large plates are constantly moving**
  - **Most plate move at centimeters/year – like growing fingernails…**
  - **Measured with GPS and Very Long Baseline Interferometery**



- **Plates move around from…**
  - **Convection currents**
  - **Pull of sinking slabs**
  - **Still not totally understood**





Shijie Zhong, U. Colorado

- **Old evidence for plate tectonics…**
  - **Similar fossils in locations that are widely separated today**
  - **Continental shapes fit together like a jigsaw**
  - **Matching rock types**
  - **Plate tectonics was already a theory before modern instruments confirmed it**

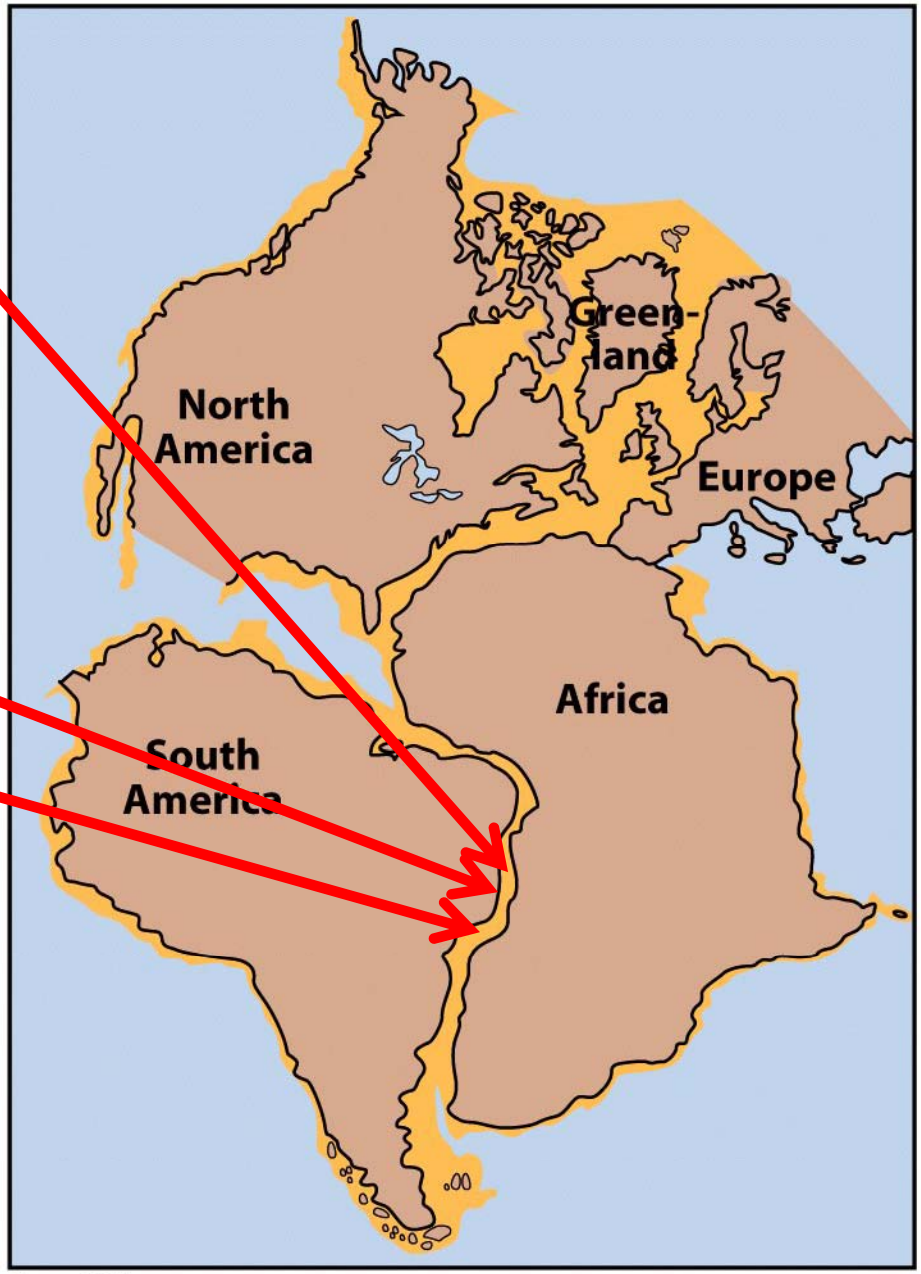
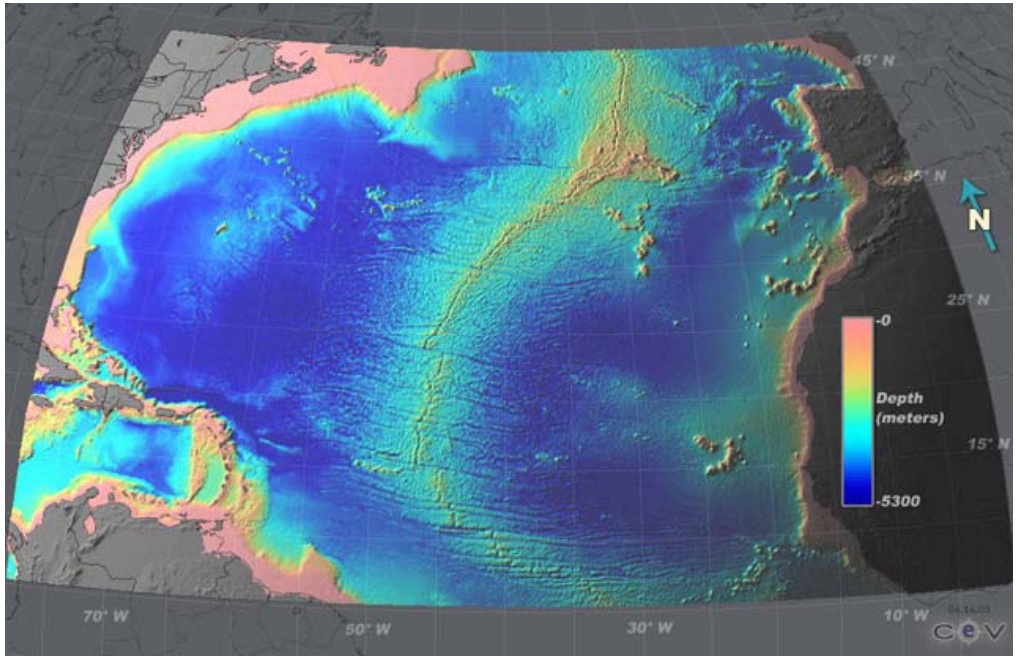
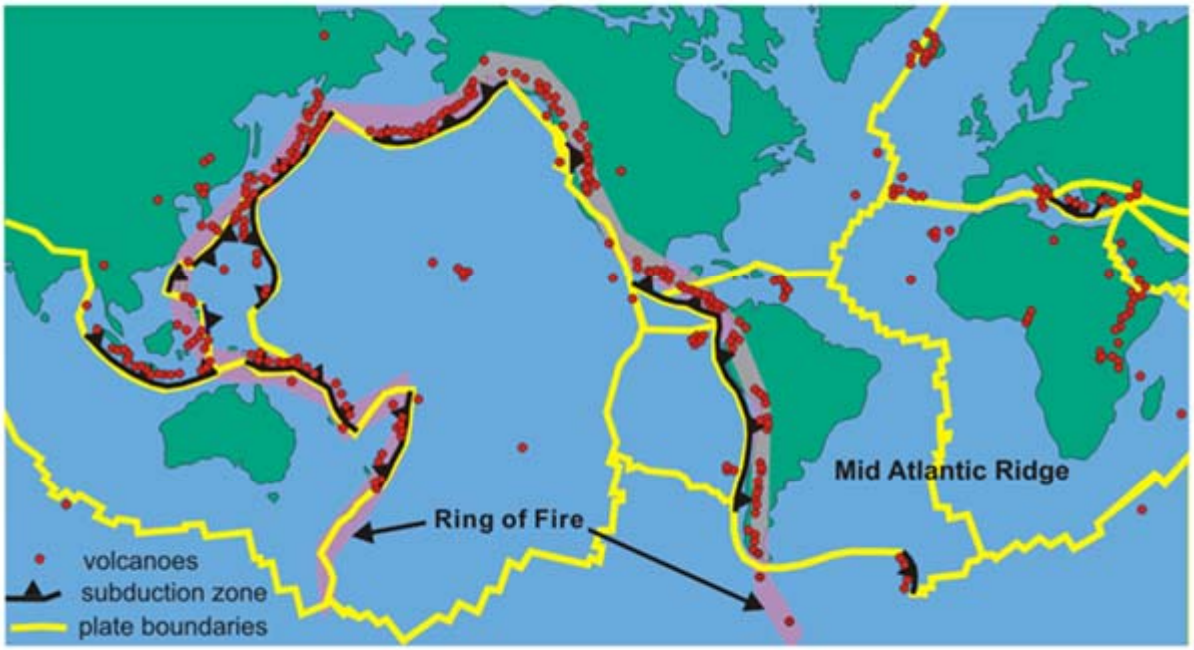


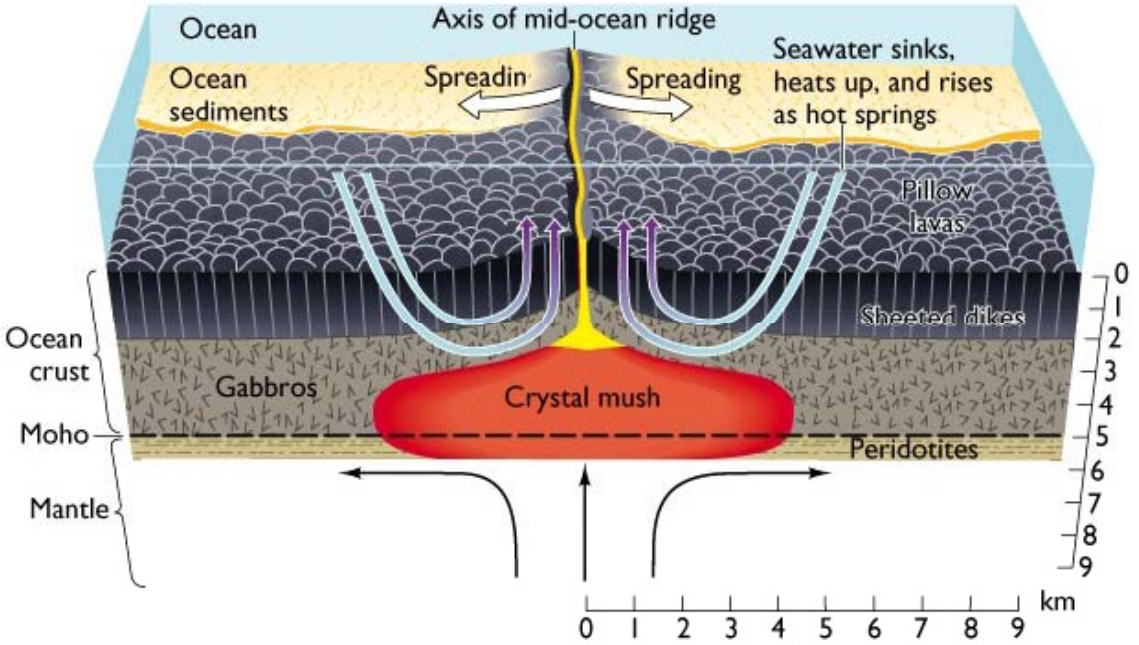
Figure 9-11
Universe, Eighth Edition

- **More-recent evidence for plate tectonics…**
  - **Seafloor surveys revealed mid-ocean spreading ridges**
  - **Magnetic reversals across ridges**
  - **Locations of earthquakes and volcanoes**
    - **Pacific ring of fire**

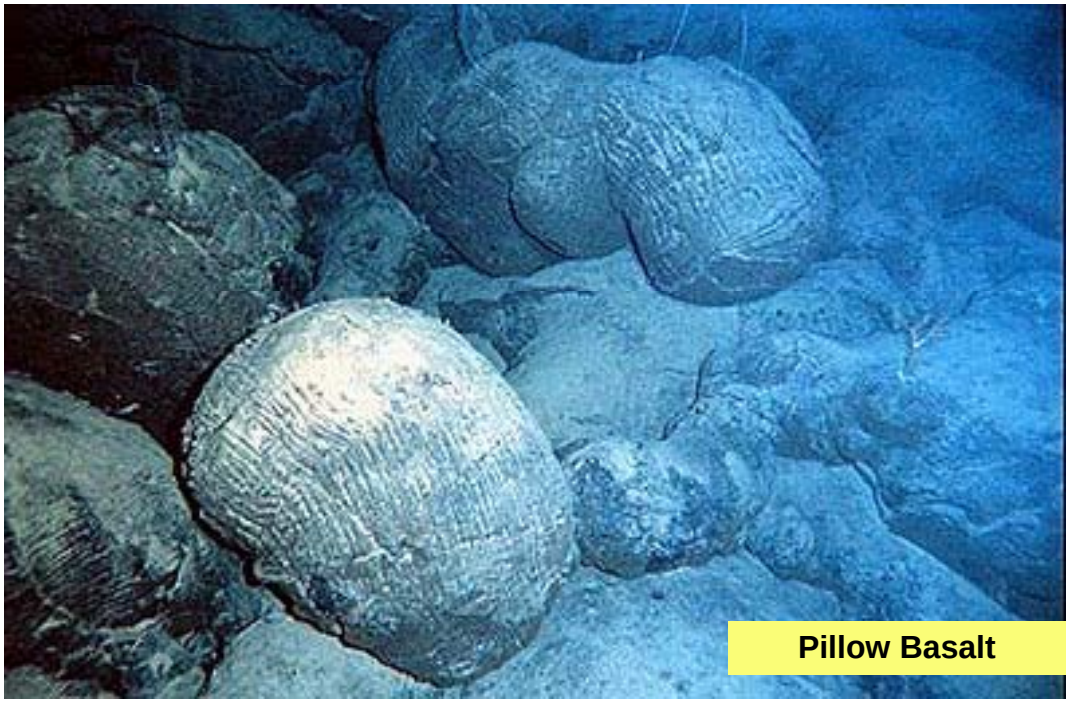




- **When plates separate…**
  - **New oceanic crust**
  - **Partial melting of mantle material**

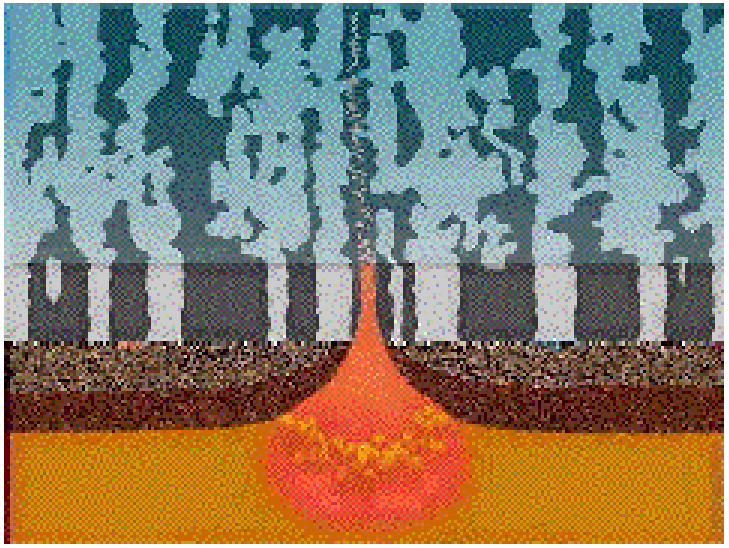


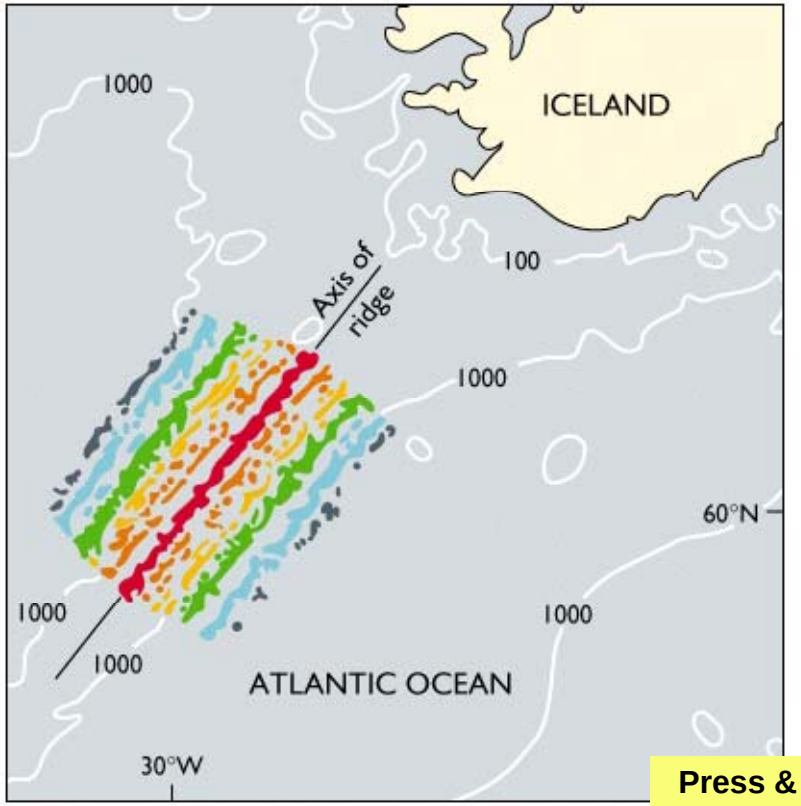
- **Characteristic stratigraphic sequence:**
  - **Gabbro**
    - **(large grained basalt)**
  - **Sheeted dikes**
    - **Each sheet was the wall of the inner ridge**
  - **Pillow basalts**
    - **Blobs of basalt that are quickly quenched**
  - **Ocean sediments**
    - **Fine-grained muds**

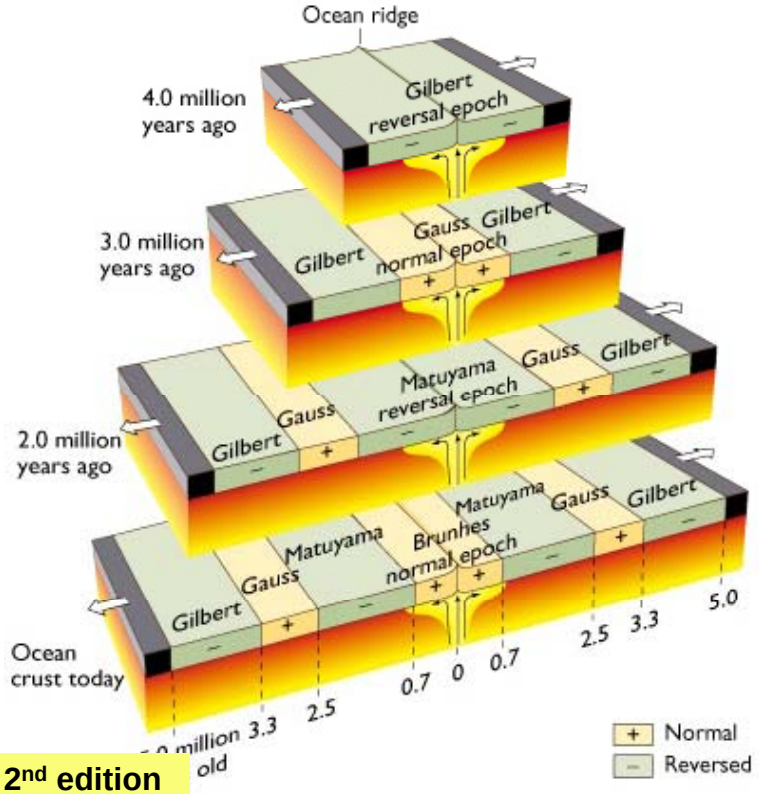


Pillow Basalt

- **Magnetic reversals match across spreading ridges**
  - **Earth's magnetic field switches north and south pole every so often**
  - **New rock gets magnetized before it cools**
  - **Magnetic record is preserved**
  - **Same pattern on each side of the spreading ridge**

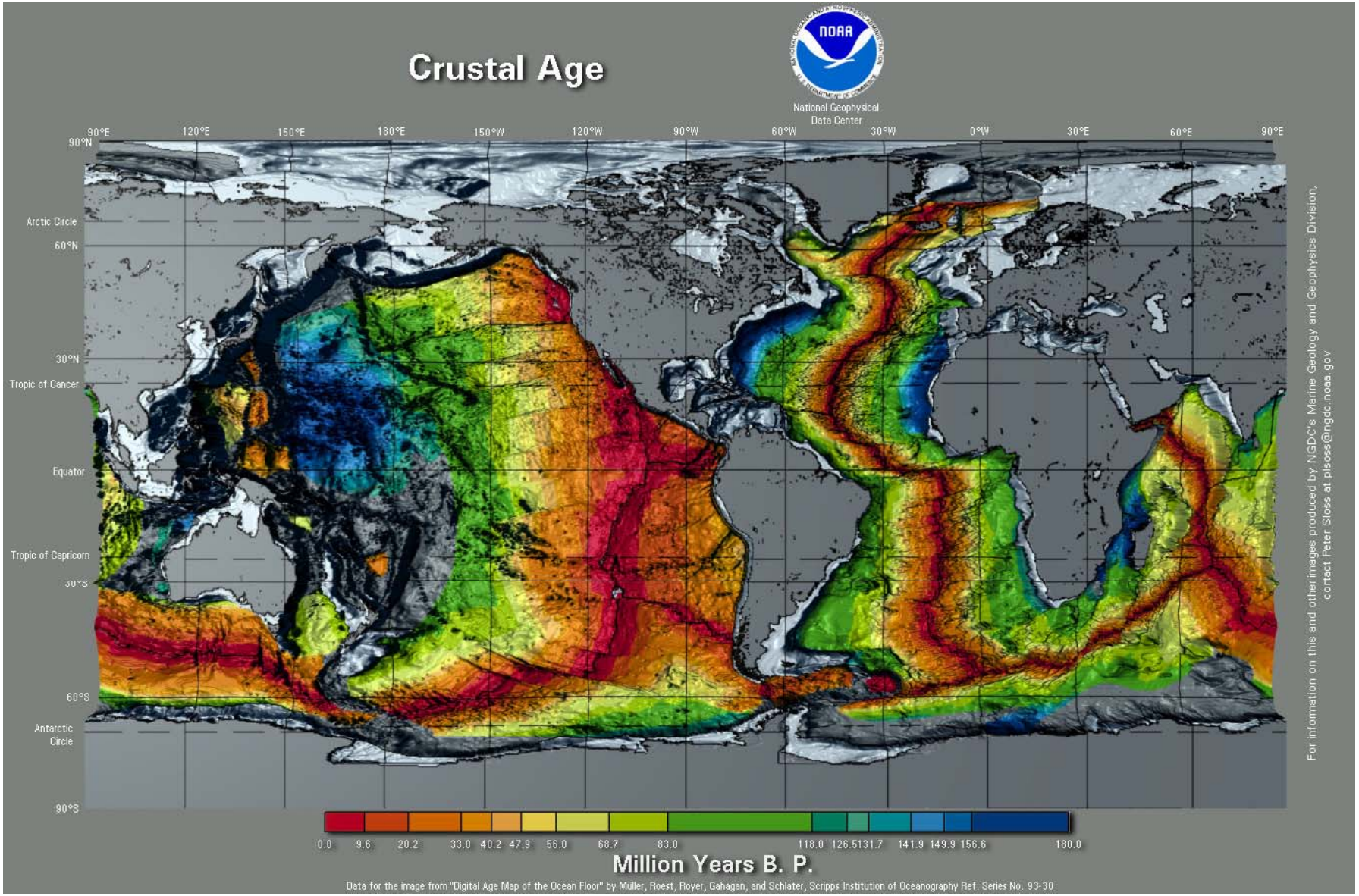




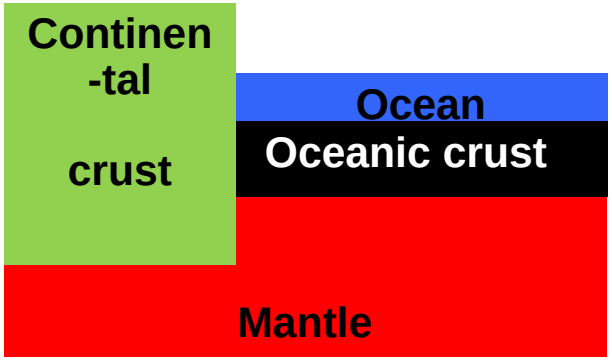


Press & Siever, 2nd edition

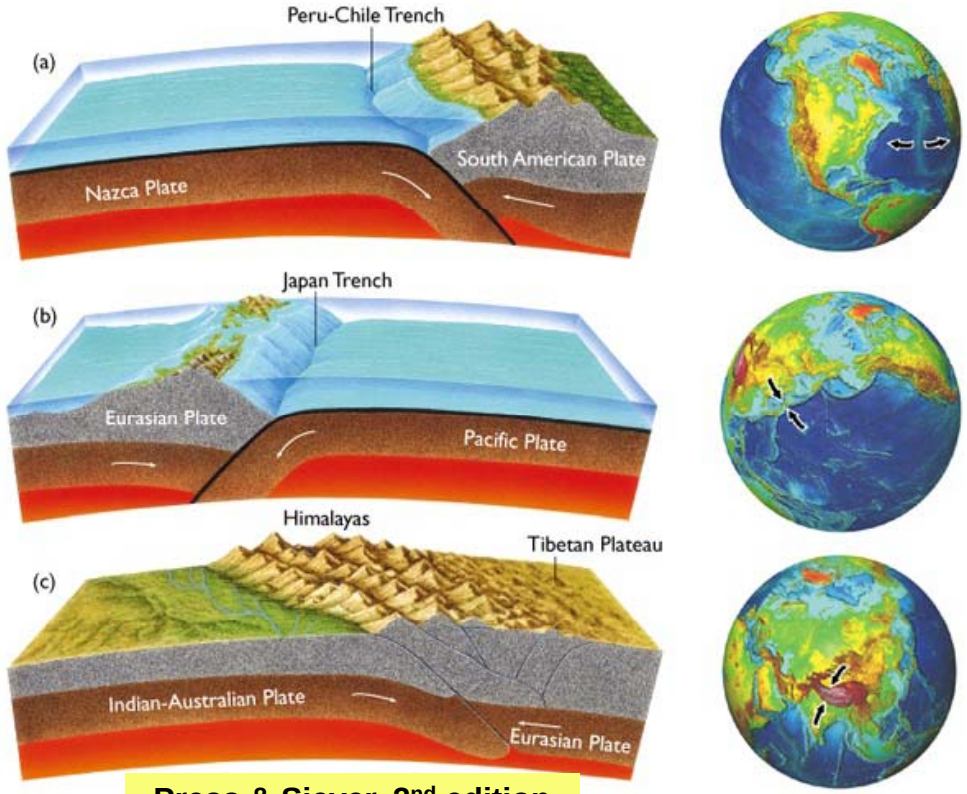
- **Crust moves away from spreading centers**
  - **Crust near the spreading centers is still young**



- **What happens when plates collide?**
  - **All depends on density**
  - **Oceanic crust has a higher density than the continents**

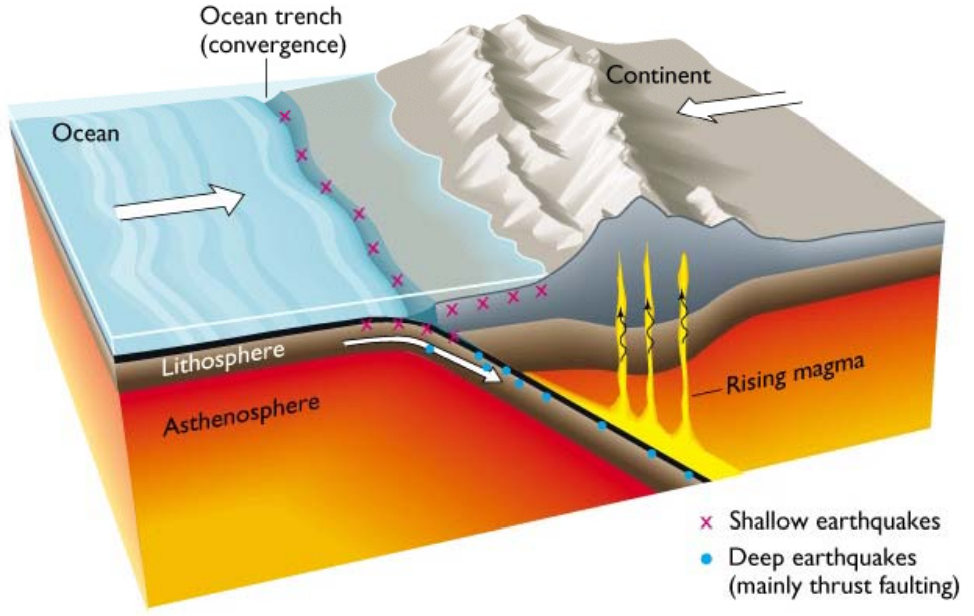


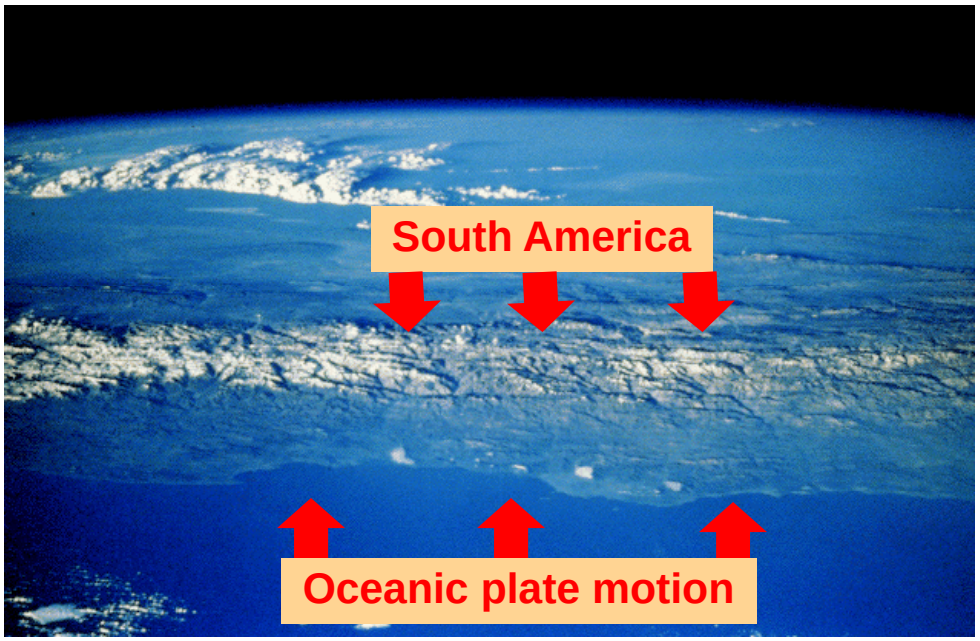
- **Three possible collisions**
  - **Ocean-continent**
  - **South America and the Nazca plate**
  - **Ocean-ocean**
  - **West pacific region**
  - **Continent-continent**
  - **India collides with Eurasia**



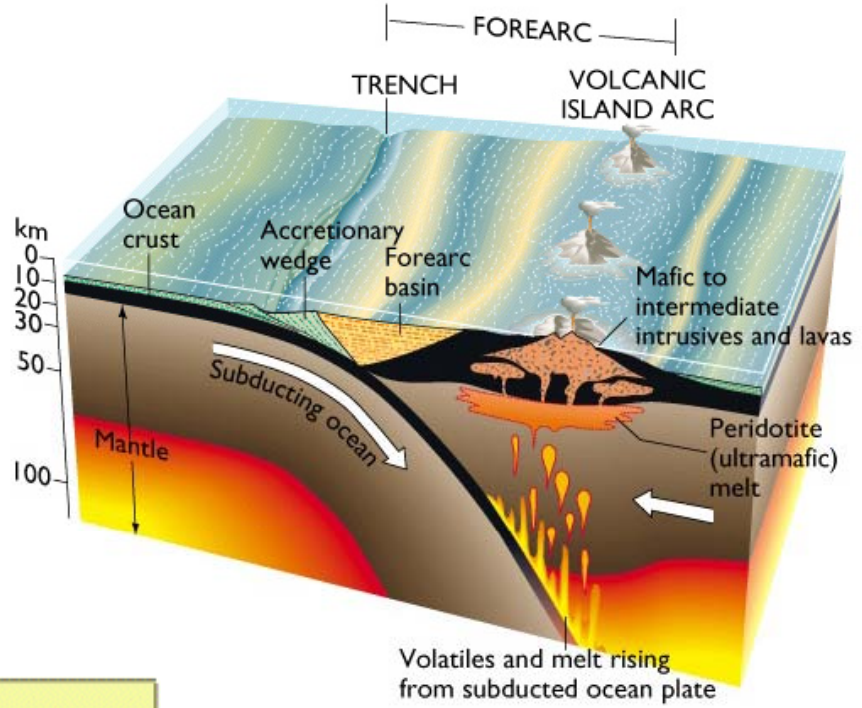
Press & Siever, 2nd edition

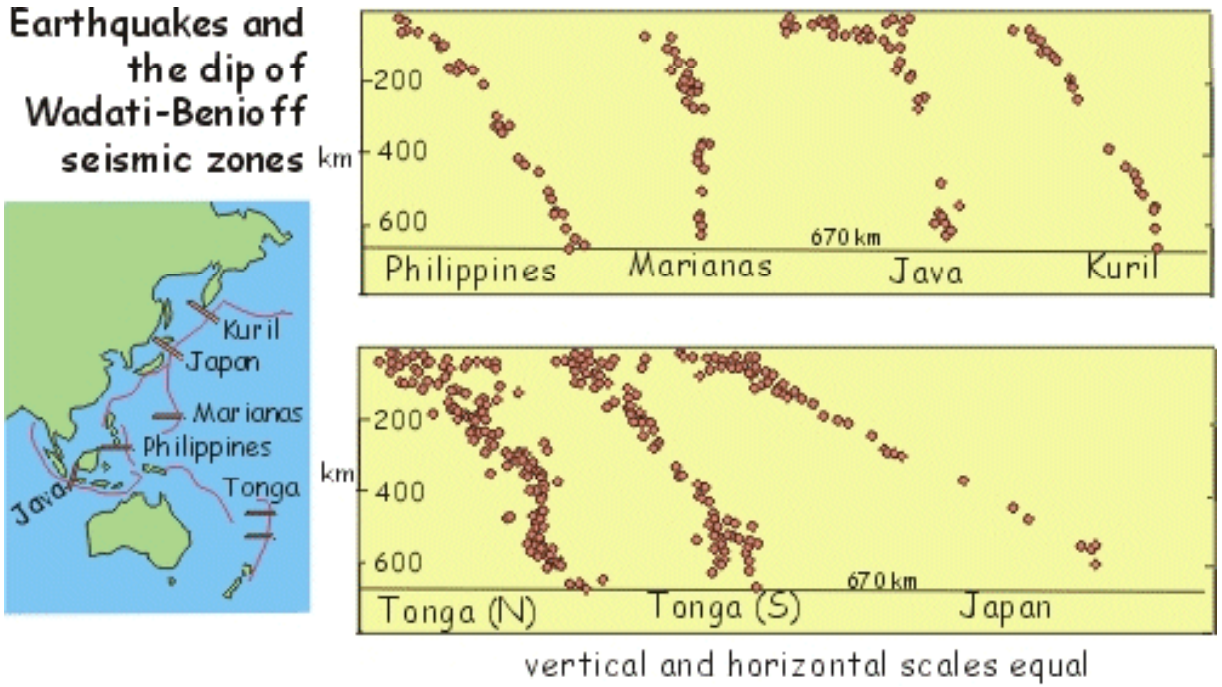
- **A continent-ocean plate collision**
  - **West of South-America**
  - **Ocean plate is denser**
  - **Continent ends up on top**
  - **Ocean plate 'subducts'**
  - **Ocean-plate drags down water which lowers the melting point of rocks**
  - **Lots of volcanoes**
  - **…but these volcanoes spew out reprocessed oceanic crust (not mantle material)**
  - **They make continental rocks**





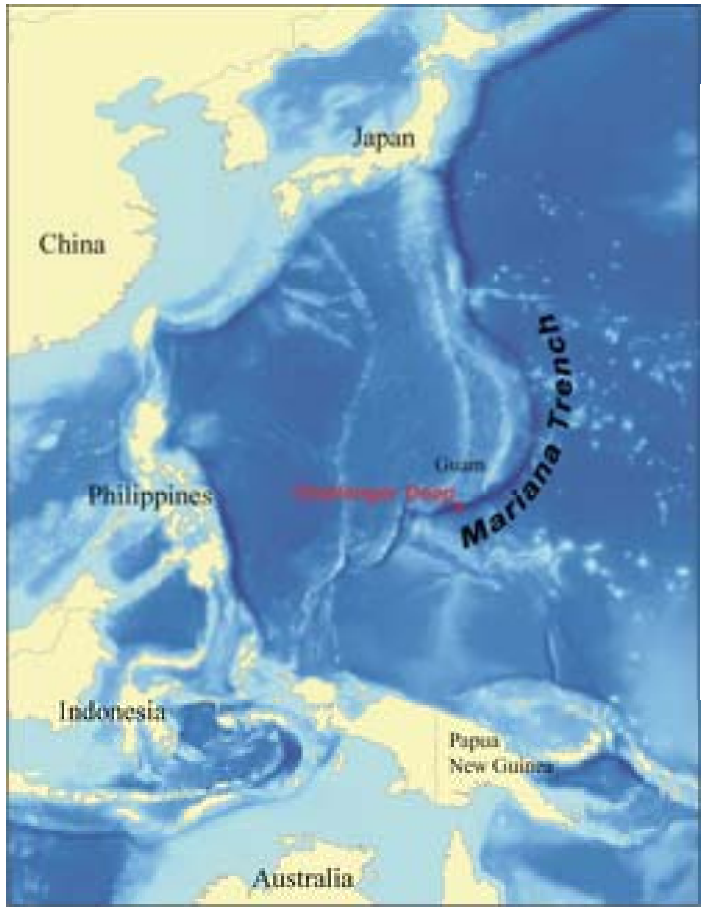
- **Ocean-ocean collision**
  - **Older ocean plates are colder**
  - **Colder=denser**
  - **The younger plate end up on top**
  - **Again – water dragged down**
  - **Causes volcanism**
  - **Makes island arcs – continental rocks**

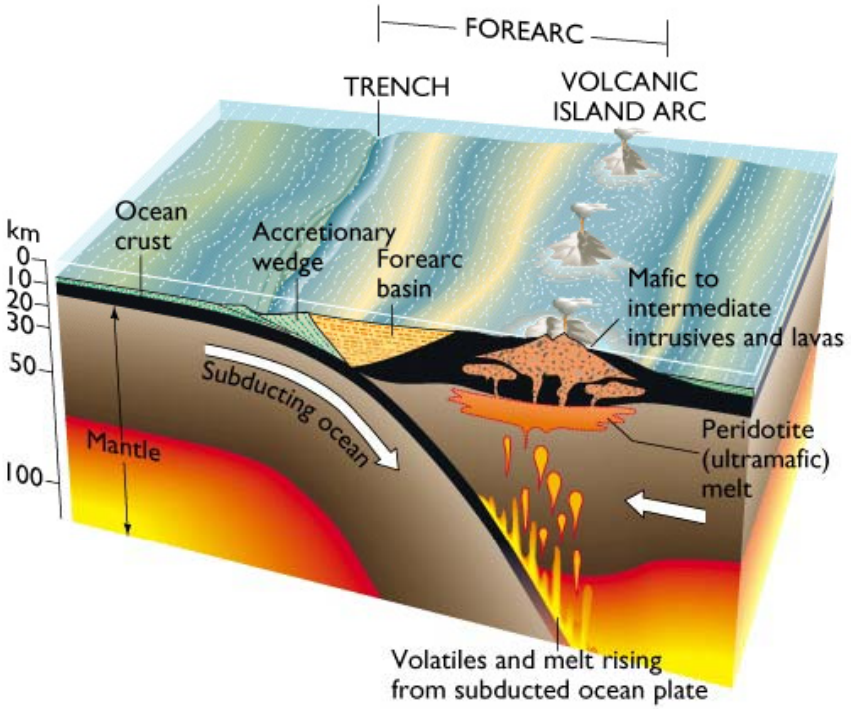




We can 'see' these slabs diving into the mantle.

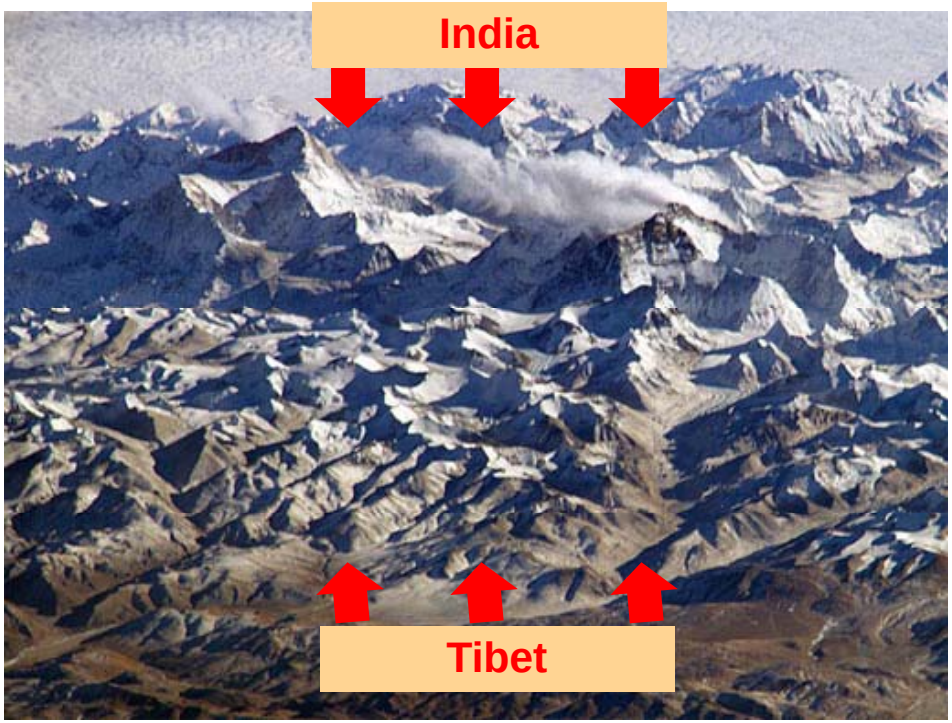
- **Famous Mariana trench**
  - **Almost 11km below seas level**
  - **Pressure > surface of Venus**
  - **You could fit Mt. Everest in there and still have a few km to spare!**

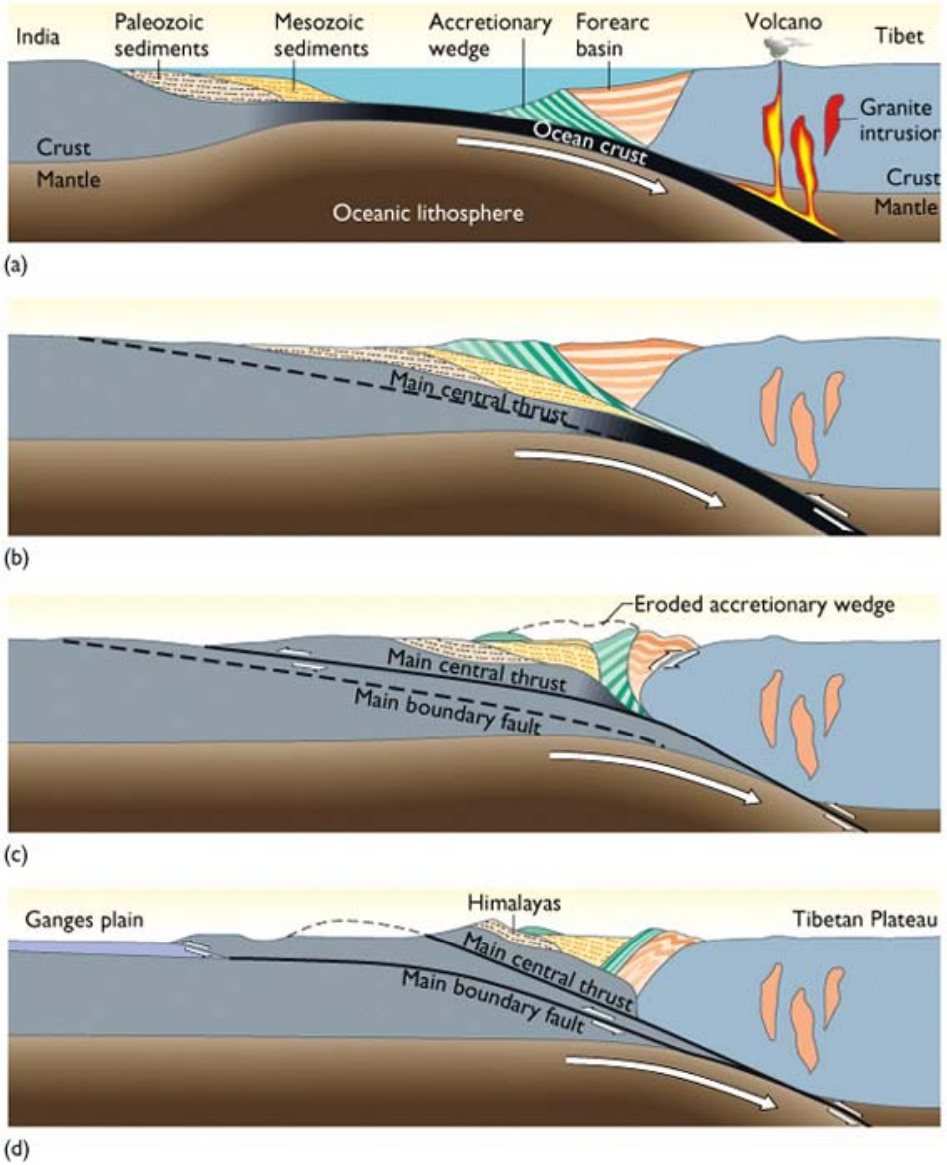




- **New continental crust is created**
- **Continental crust doesn't subduct**
- **Area of continents growing with time**

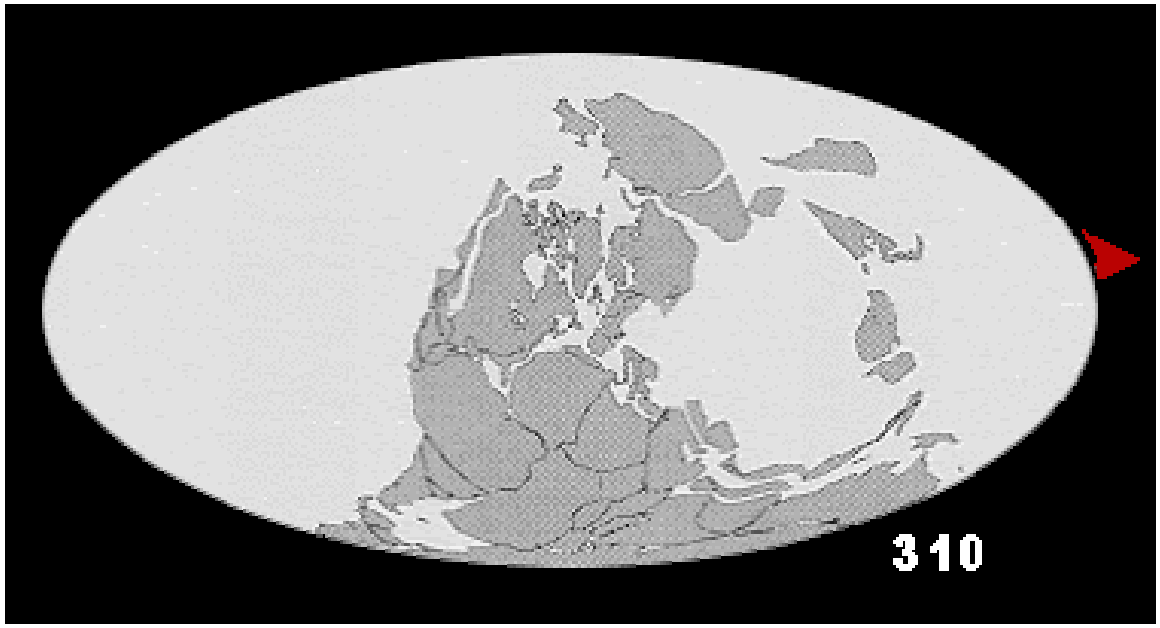
- **Continent-continent collision**
  - **Usually preceded by a continent-ocean collision**
  - **Both plates are low density**
  - **Neither one can sink**
  - **Compression builds mountains**
  - **Not much volcanism**
  - **Mostly old ocean sediments**





Press & Siever, 2nd edition

- **Past plate motions**
  - **From UC Berkeley**
  - **Former super-continent broke up 150Myr ago**
    - **Pangaea**



237 million years ago: the supercontinent Pangaea

Figure 9-12a
Universe, Eighth Edition
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152 million years ago: the breakup of Pangaea

Figure 9-12b
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The continents today

Figure 9-12c
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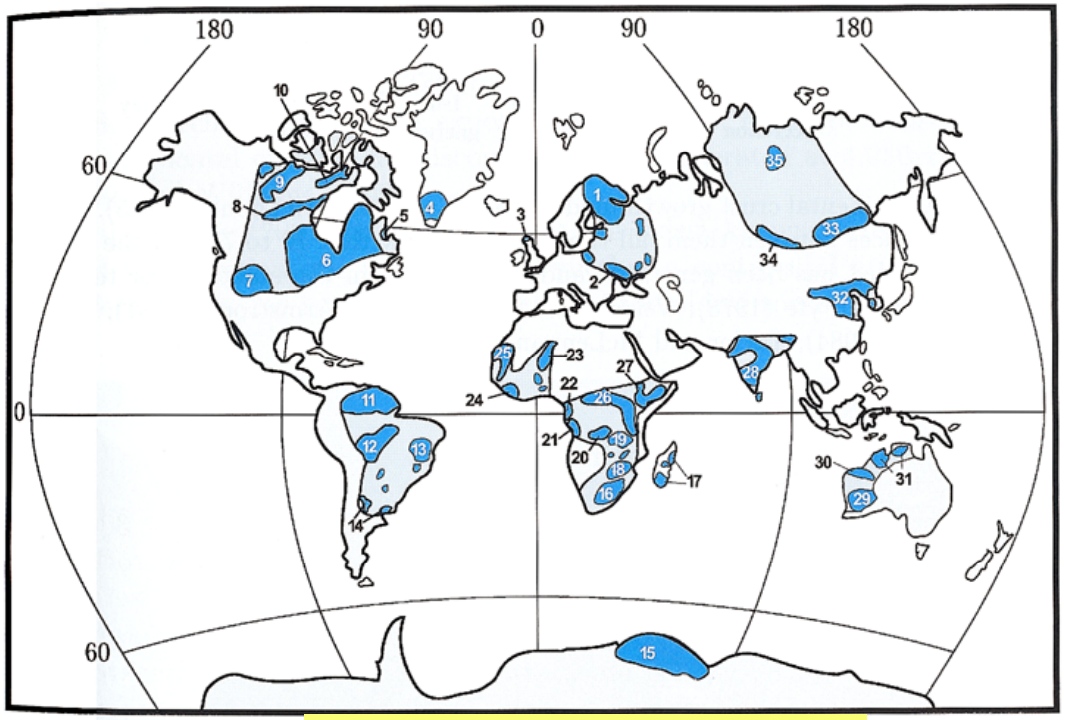
Early Earth

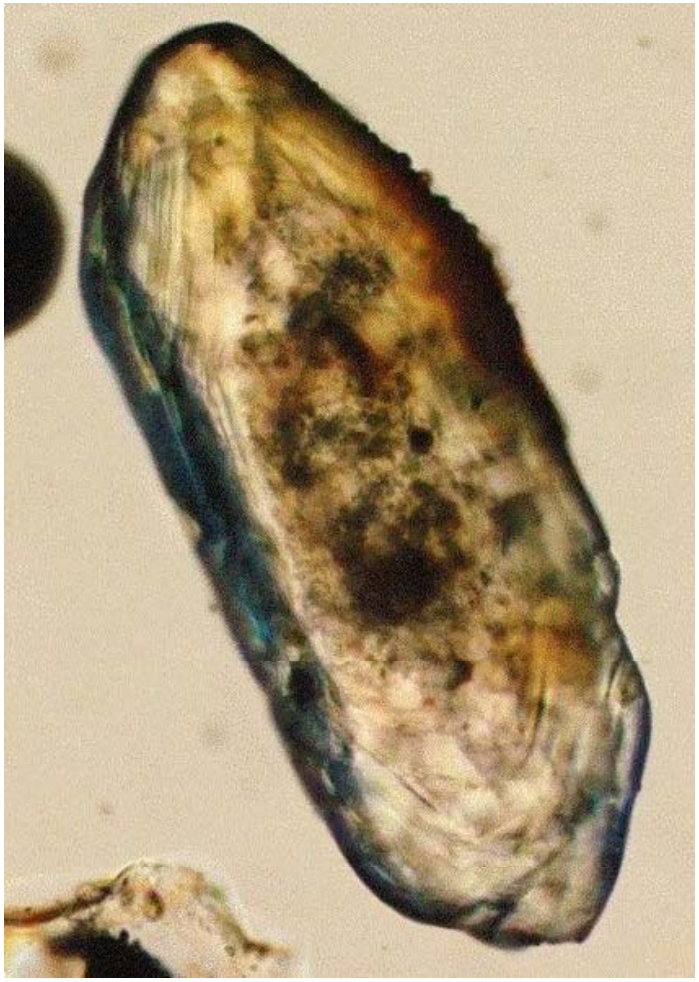
- **Hadean period**
  - Formation of the Earth to ~4 Ga
  - No preserved rocks
  - Oldest rocks are 4.03 Ga Acasta Gneisses
  - Mysterious until recently

- **Old Paradigm**
  - 'hellish' heat
  - No continental crust
  - Constant surface melting from impacts
  - Massive steam and CO_2 atmosphere
  - Generally unhappy place…



Surviving crust > 2.5 Ga

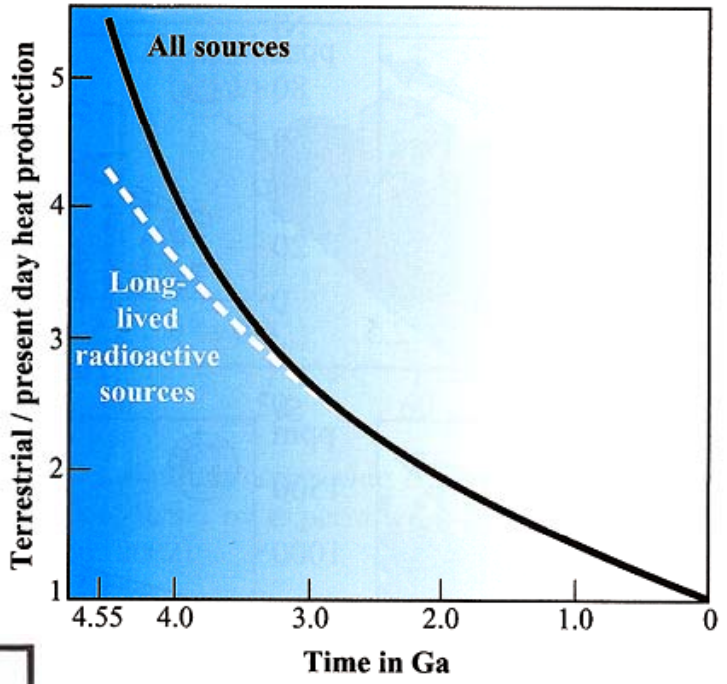
- **New work on analysis of Zircon crystals**
  - **Virtually indestructible**
  - **Survive long after the original rock is eroded away**
  - **Dated back to 4.4 Gyr ago**
    - **Earth formed 4.5Gyr ago**

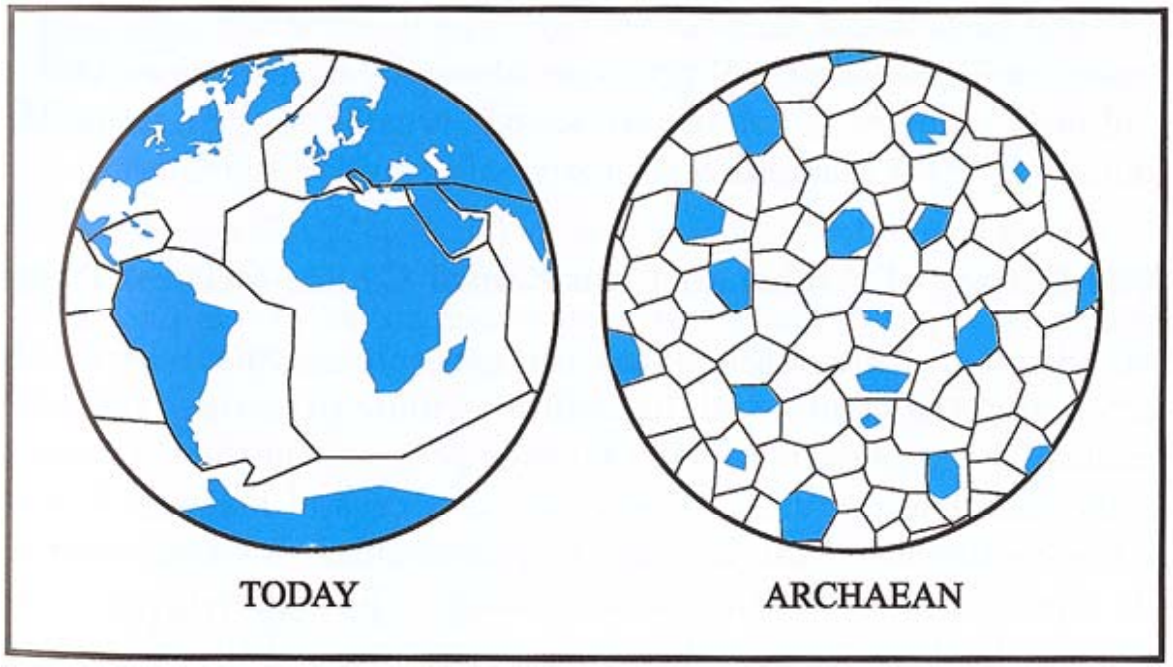


- **Results**
  - **Formed with continental rocks**
    - **i.e. plate tectonics was operating**
  - **Formed in the presence of water**
    - **i.e. oceans already existed**

- **Plate tectonics swaps hot mantle material for cold crustal material**
  - **Important way for Earth to lose heat**

- **More heat to lose in the early Earth so plate tectonics was probably more active**
  - **Many smaller plates**





- **Starting with only oceanic crust we can manufacture continental crust as ocean arc islands**

- **These continental fragments get shuffled around**
  - **Eventually they stick together to form the first continents**

- **This is still a <u>VERY</u> preliminary version of the story**

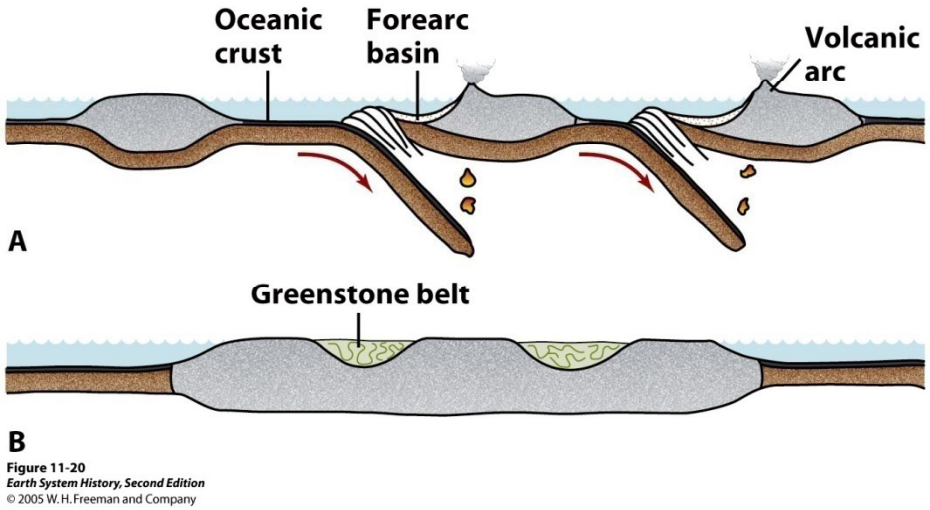
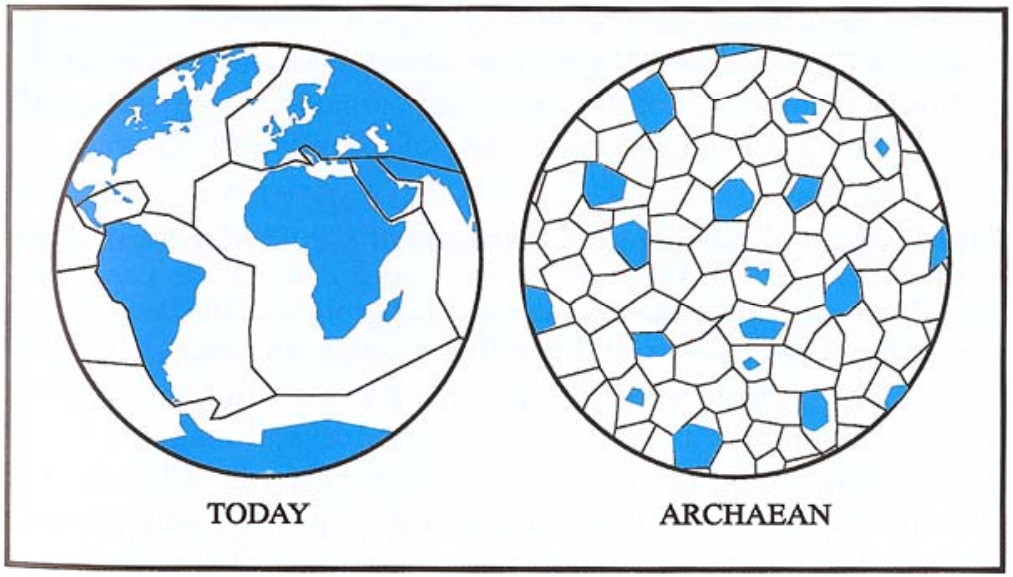
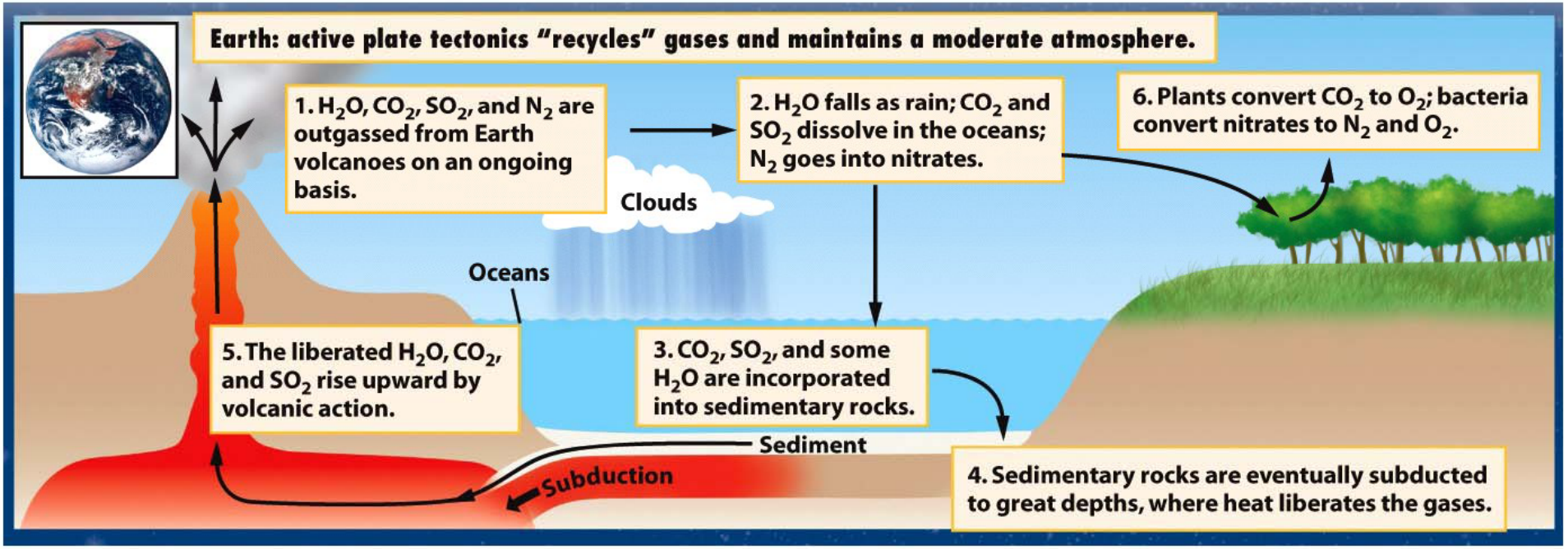


Figure 11-20
Earth System History, Second Edition



Early Atmospheres

- First atmosphere probably hydrogen and helium mix left over from Earth's formation
  - Lost quickly
  - Definitely lost at moon-forming impact
- Second atmosphere - product of volcanoes
  - CO_2 and water were produced (along with some other stuff)
  - Water stays as stream until Earth cools
  - After cooling, water condenses into liquid
  - Liquid can dissolve CO_2
  - Greenhouse effect collapses and Earth escapes the fate of Venus



Earth, Venus, Mars

All start with CO_2 and water in their atmosphere

Mars, Earth

CO_2 and water goes into rocks

Earth

Rocks recycled by plate tectonics

Rock cycle

Mars

No plate tectonics–CO_2 stuck in rocks

Runaway icehouse

Venus

Water not stable as liquid

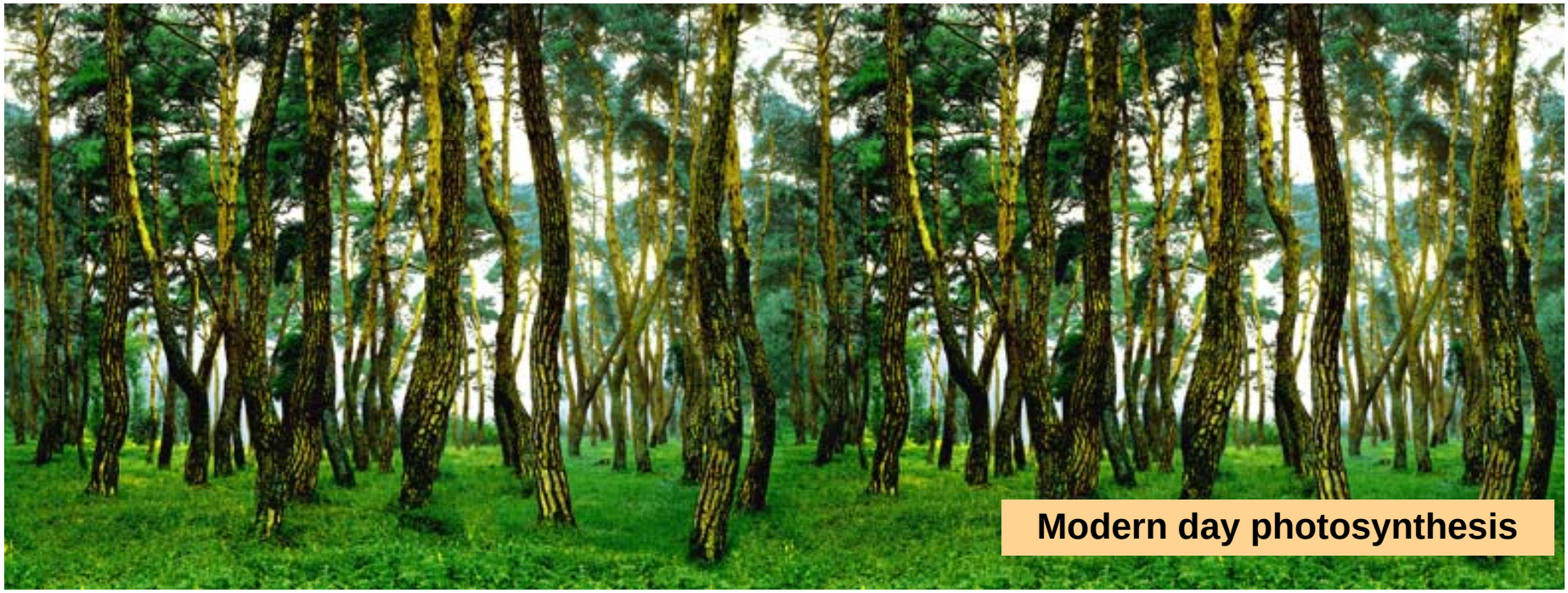
Venus

CO_2 stays in atmosphere

Runaway greenhouse

- **Atmospheric change**
  - **Atmospheric CO_2 levels steadily decline**
  - **CO_2 get incorporated into rocks**
  - **Plate tectonics recycles these rocks slowly**
    - **Earth escapes the fate of Mars**
  - **Current CO_2 levels ~0.001 bars**
  - **UV breakup of water molecules can release oxygen**
    - **Generates only small amounts**
  - **Volcanoes also produce nitrogen**
  - **Nothing to remove this yet – so it builds up in the atmosphere**
    - **Currently 0.78 bars**

- **Something else happened… something unexpected?**
  - **Life started using photosynthesis to manufacture energy**



  - **Photosynthesis uses water, CO_2 and sunlight**
  - **…but, it has an interesting waste-product – Oxygen!**

- Rocks older than 2 Gyr are not oxidized
- Younger rocks are oxidized
- Substantial amounts of Oxygen appeared in the atmosphere about 2 Gyr ago.
- When oxygen became common a new life form developed that used respiration to produce energy
  - And eventually turned into you and me…
- Nitrogen and Oxygen levels now regulated by life

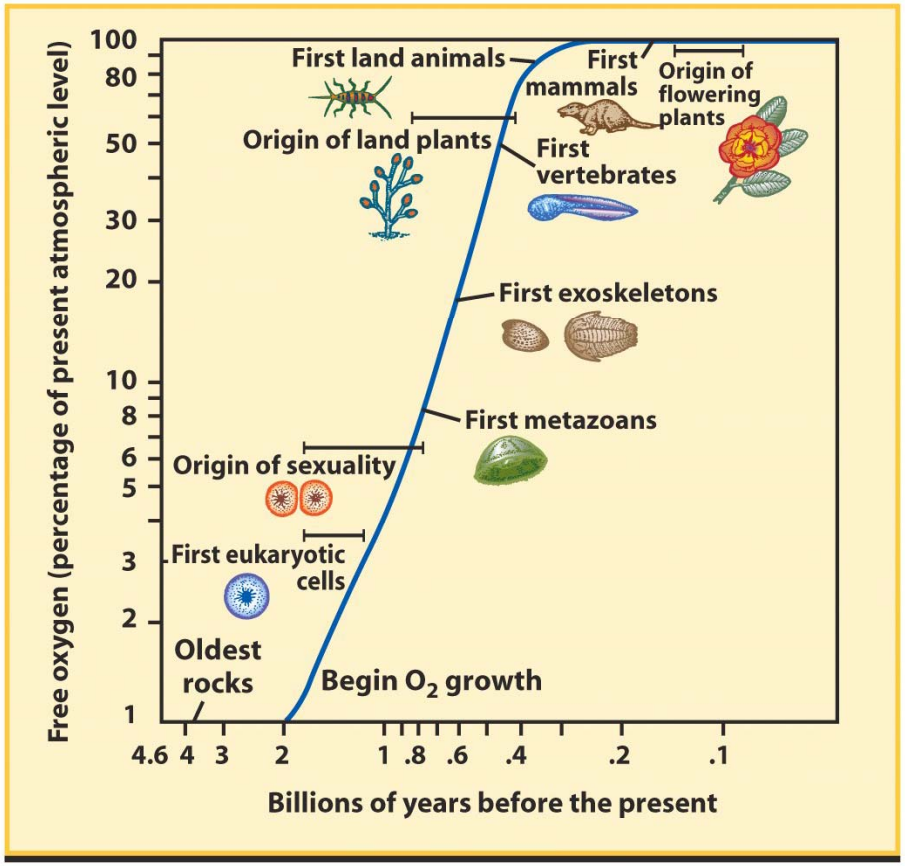
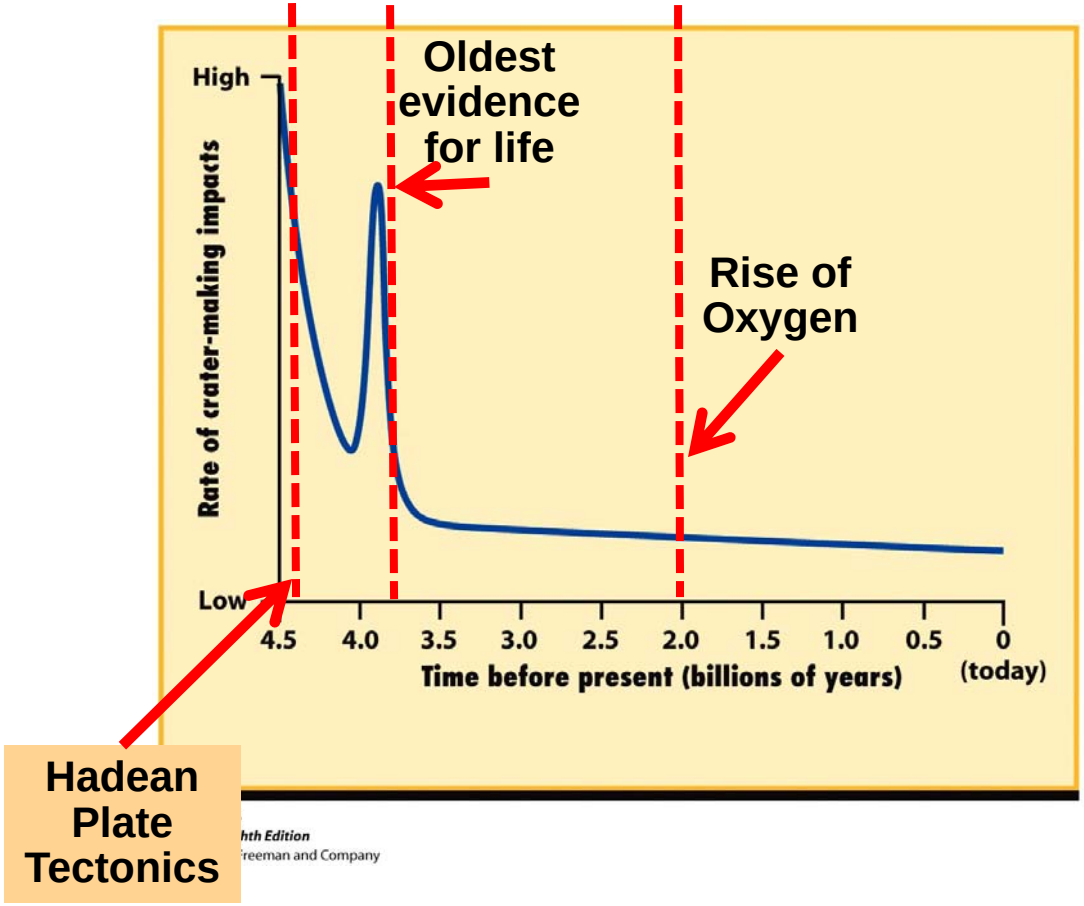


Table 9-4 Chemical Compositions of Three Planetary Atmospheres

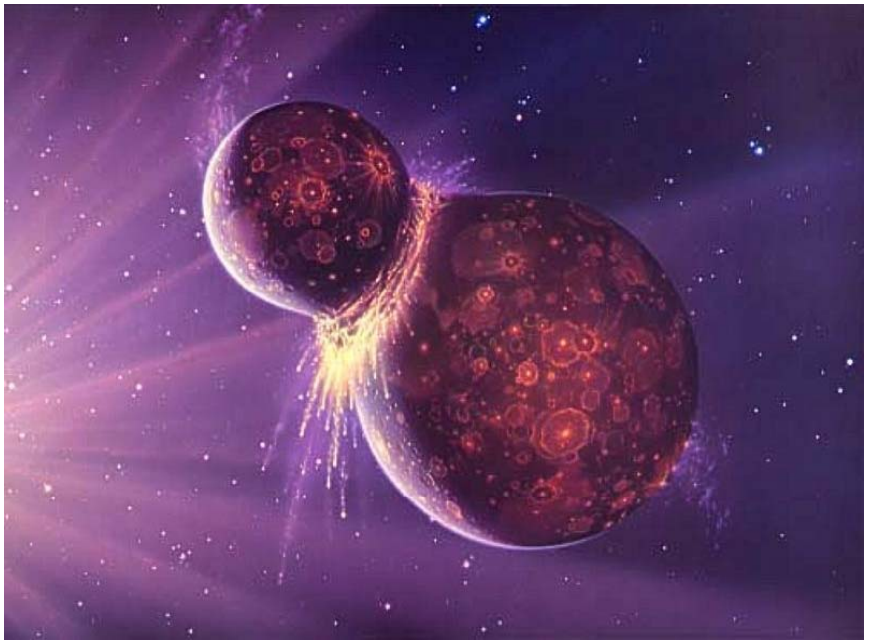
	Venus	Earth	Mars
Nitrogen (N_2)	3.5%	78.08%	2.7%
Oxygen (O_2)	almost zero	20.95%	almost zero
Carbon dioxide (CO_2)	96.5%	0.035%	95.3%
Water vapor (H_2O)	0.003%	about 1%	0.03%
Other gases	almost zero	almost zero	2%

- **Origin of life?**
  - Hadean is generally inhospitable to life
  - Giant impacts vaporize oceans – takes thousands of years to recover liquid water
  - Earliest evidence for life is 3.8 Gyr ago – carbon isotopes
  - Earliest fossils from 3.5 Gyr ago

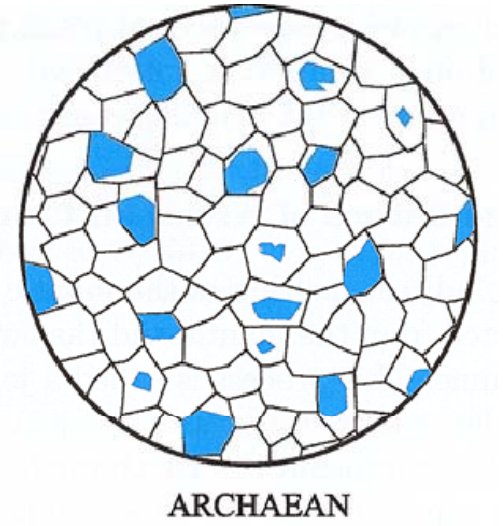


- **Late heavy bombardment**
  - Life sterilized by late heavy bombardment?
  - Independent origin of life before this period?

History of the Earth – in two slides



- The first 200 million yr
  - out of ~4500 million yr
- Planet forms and differentiates
  - Iron core & Rocky mantle
- Escape of initial H and He atmosphere
- Giant impact creates a large moon
- Oceanic crust produced



- Volcanoes produce secondary atmosphere of water and CO_2
- Continental fragments produced from reprocessing of oceanic crust
- Earth cools water forms oceans
  - CO_2 starts to dissolve
  - Venus-style greenhouse avoided
  - Plate tectonics and liquid water established by 4.4 Gyr ago

History of the Earth – in two slides

- CO_2 removed over the next billion years (4400 – 3400 Myr ago)
  - By rainfall and rock weathering
- Late heavy bombardment (roughly 4000-3800 Myr ago)
  - Life sterilized
  - Oceans vaporized
- Oldest evidence for life at 3800 Myr ago
  - Photosynthesis produces oxygen
  - Respiration appears 2000 Myr ago
  - Several mass-extinctions since then
- Plate tectonics continues
  - Continents get larger slowly
  - Super-continents come and go

In this lecture…

- Introduction to the Earth - uniquiness
- Two types of crust
  - Oceanic and Continental crust
- Plate Tectonics and Motion
  - Spreading centers and subduction
  - History of plate motions
- Early Earth
  - Building continents
  - Early atmosphere
  - Forming the oceans
- Life
  - When it formed
  - Rise of Oxygen

Next: Asteroids and Meteorites

- Reading
  - Chapter 9 to revise this lecture
  - Chapter 15 (section 1-6) for the next lecture