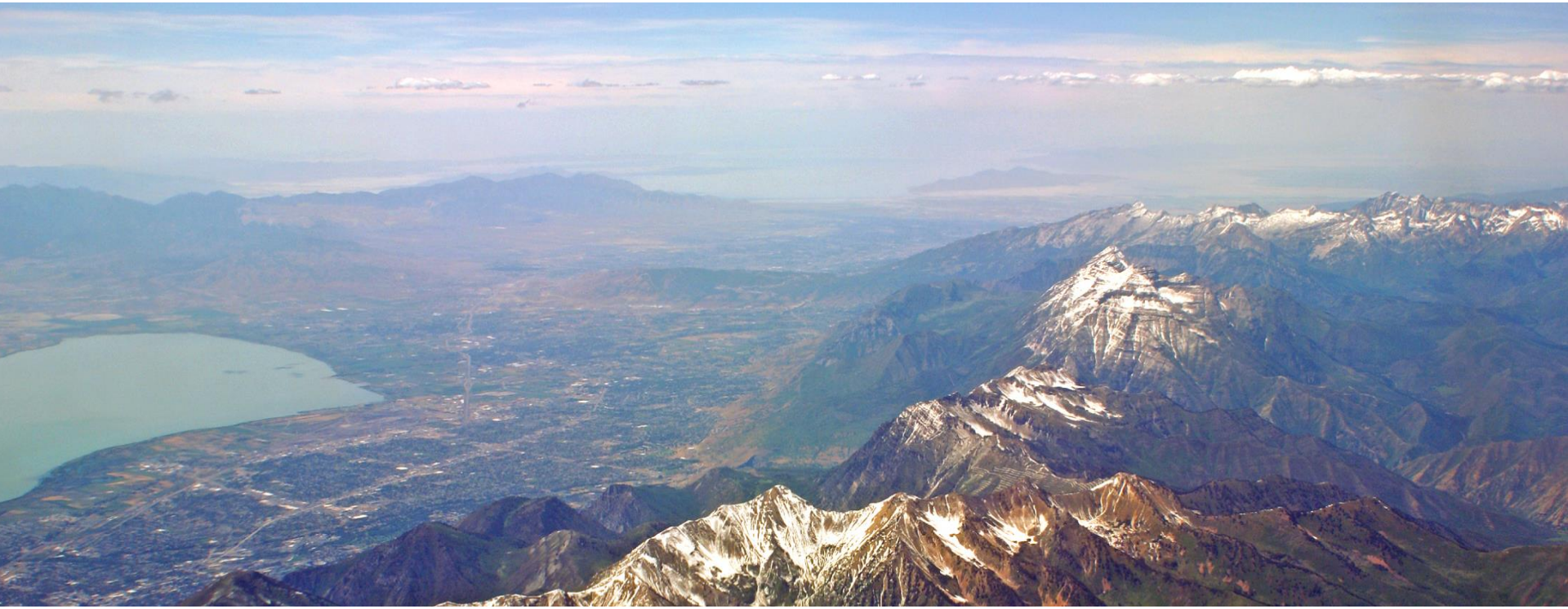

Lecture 2A

Structure and composition of the Earth
Plate tectonics

Dr Tom Raimondo

UniSA

See Marshak pg. 42–53; 78–100

Figures taken from Earth: Portrait of a Planet, WW Norton & Co.

Sweet weekly homework

Every week, there are regular tasks that must be completed. There are clear expectations about the amount of time you should spend studying this course.

	Contact time per week	Non-contact time per week
Lectures	2 hours	1–2 hours pre-reading and revision
Practicals	2 hours	1 hour pre-reading
Weekly quizzes	-	30 mins to 1 hour
eModules	-	30 mins to 1 hour
Textbook online resources	-	30 mins to 1 hour
Total	**4 hours**	**4–5 hours**

Why do I need to know all this stuff?

- Knowing the **structure and composition** of the Earth forms the basis for all geological concepts
- We need to have a understanding of how the Earth behaves as a whole, and what its properties are, before we can consider more specific Earth systems and cycles
- **Plate tectonics** is the fundamental geological theory for how the Earth works and how we can predict its behaviour
- We need to understand this theory to be able to understand and interpret a range of **geological phenomena** (e.g. earthquakes, volcanoes, tsunamis, landslides, etc.)

Lecture outline

Part 1: Structure and composition of the Earth

- Layers of the Earth: crust, mantle and core
- Lithosphere and asthenosphere

Part 2: Plate tectonics

- What is a tectonic plate?
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- Other plate features
- Key features of plate tectonics

Internal structure of the Earth

What does the interior of the Earth look like?

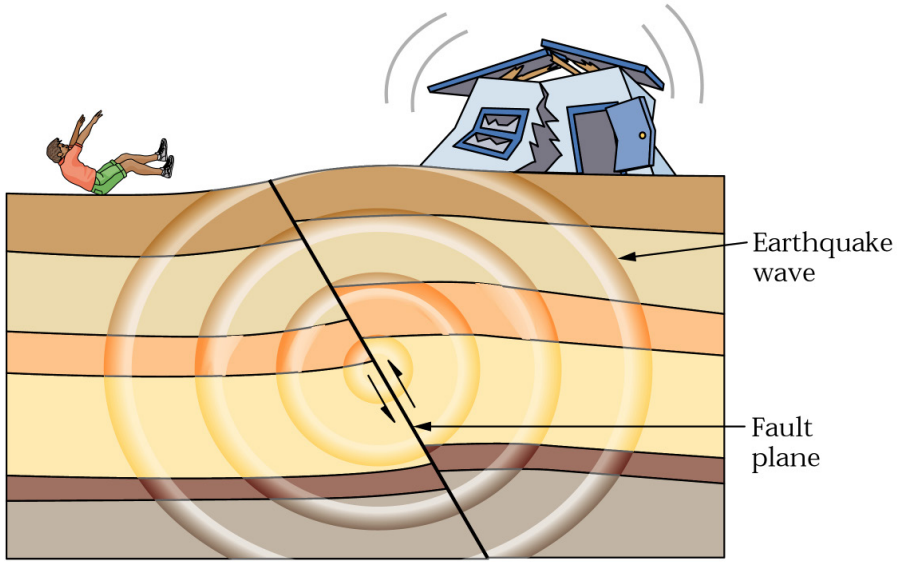
What is it made of?

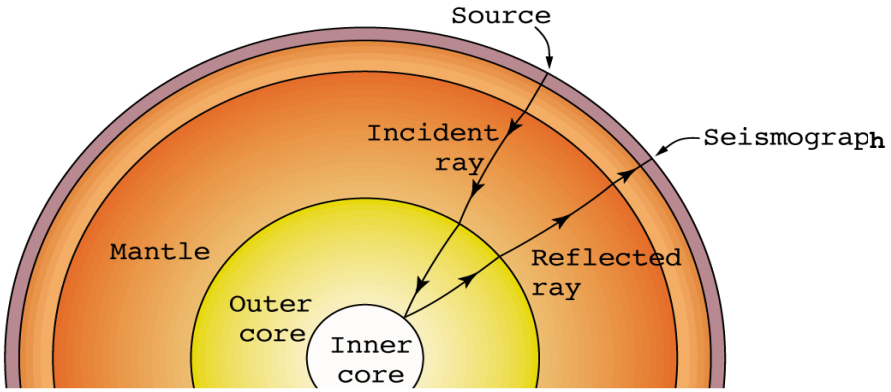
How do we know?

Investigating the Earth's interior

Detailed understanding of Earth's interior structure comes from **seismology** (the study of earthquakes)

- Earthquakes generate energy waves that pass through the Earth's interior
- Waves travel at varying velocities depending on the density of their host material
- By detecting at what depths wave speeds change, seismologists can identify **major subsurface boundaries**



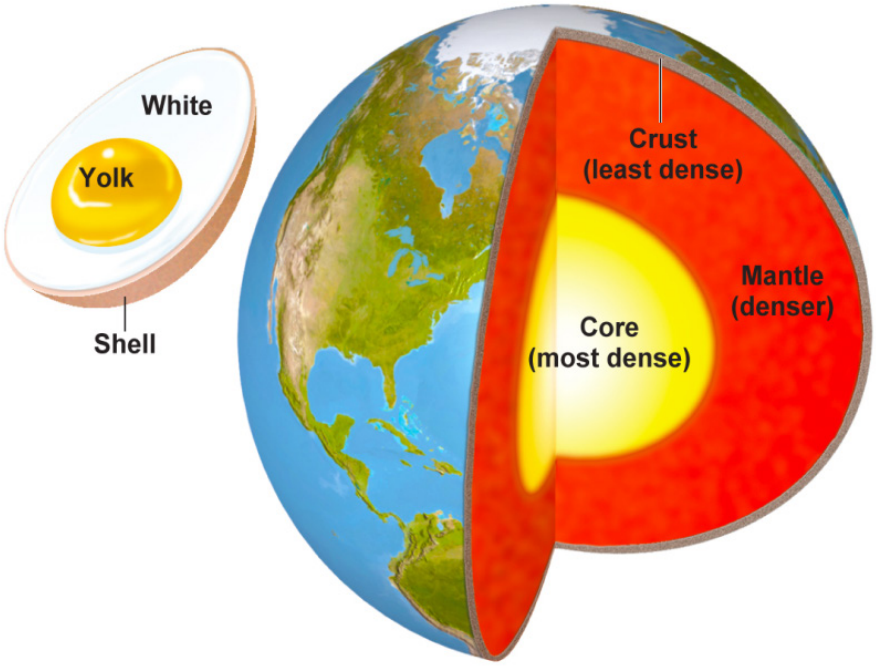


But what are the density differences caused by?

A layered Earth

The density differences are caused by different Earth **layers**

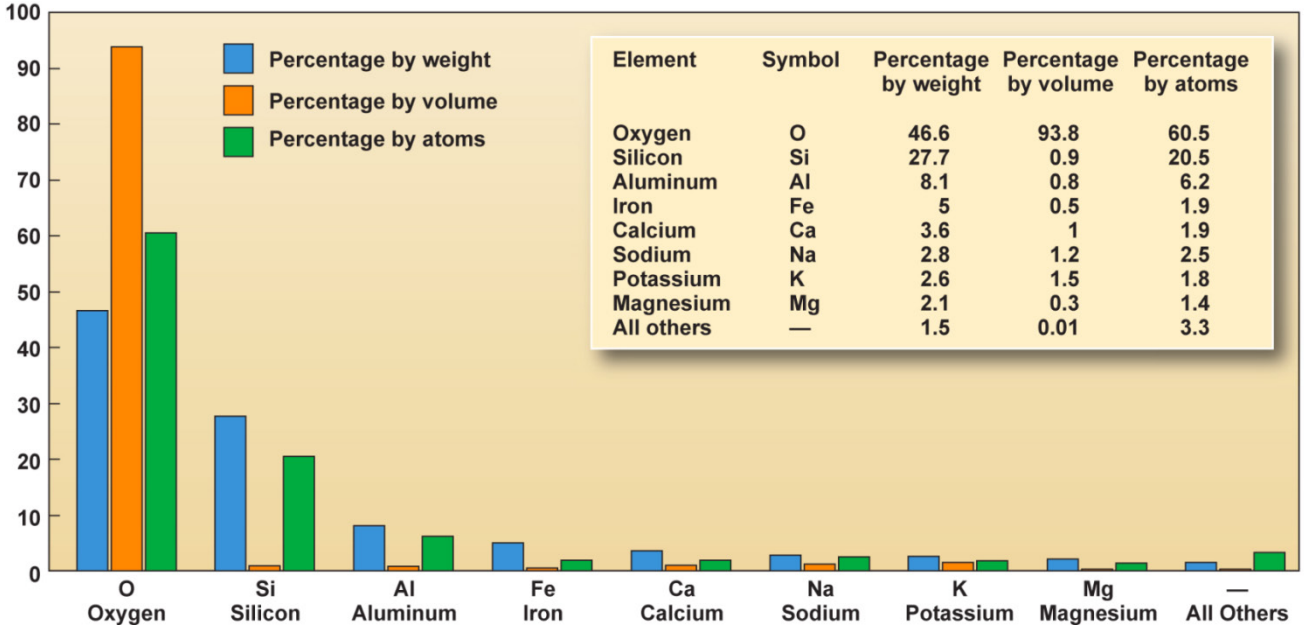
- Thin, low-density outer layer: the **crust**
- Thicker, more dense middle layer: the **mantle**
- Very dense innermost layer: the **core**



What are the layers made of?

The crust

- Thin, rigid shell that encompasses the Earth's surface
- 98.5% of crust comprised of just **eight elements**
- Mainly silicon (Si), oxygen (O) and aluminium (Al) – silicate (SiO_4) and aluminosilicate (Al_2SiO_5) minerals dominate crustal rocks
- Also contains significant amounts of iron (Fe), calcium (Ca), sodium (Na), potassium (K) and magnesium (Mg)

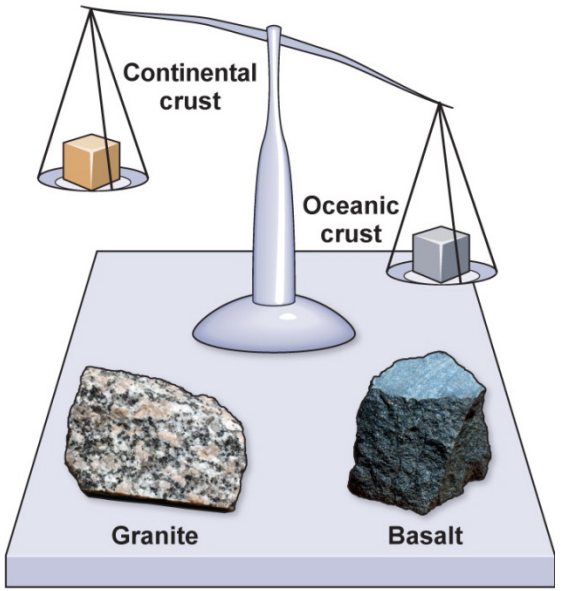


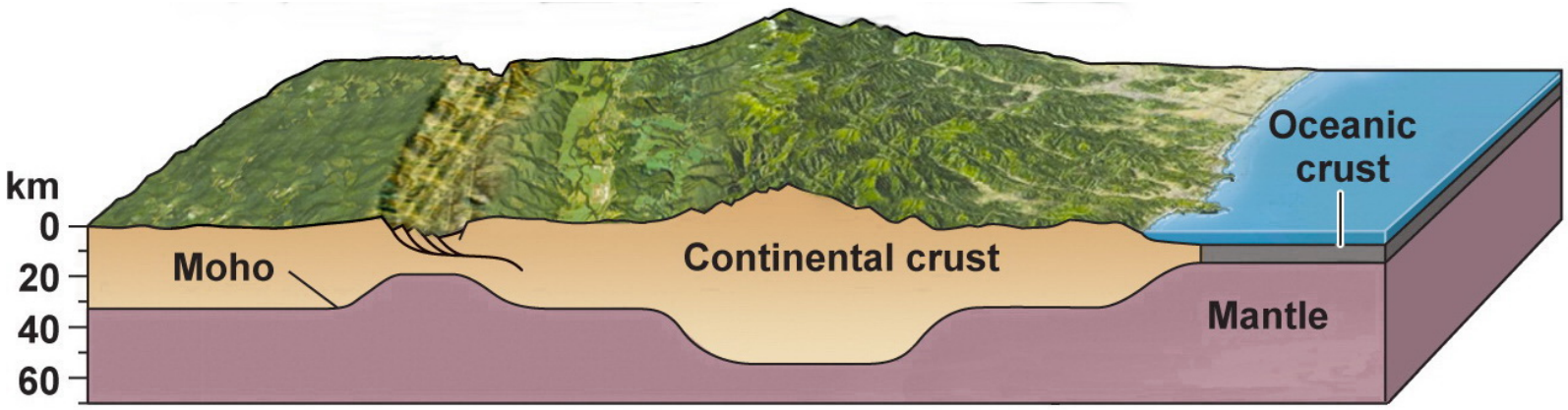
Element	Symbol	Percentage by weight	Percentage by volume	Percentage by atoms
Oxygen	O	46.6	93.8	60.5
Silicon	Si	27.7	0.9	20.5
Aluminum	Al	8.1	0.8	6.2
Iron	Fe	5	0.5	1.9
Calcium	Ca	3.6	1	1.9
Sodium	Na	2.8	1.2	2.5
Potassium	K	2.6	1.5	1.8
Magnesium	Mg	2.1	0.3	1.4
All others	—	1.5	0.01	3.3

The crust

Two types of crust: **continental** and **oceanic**

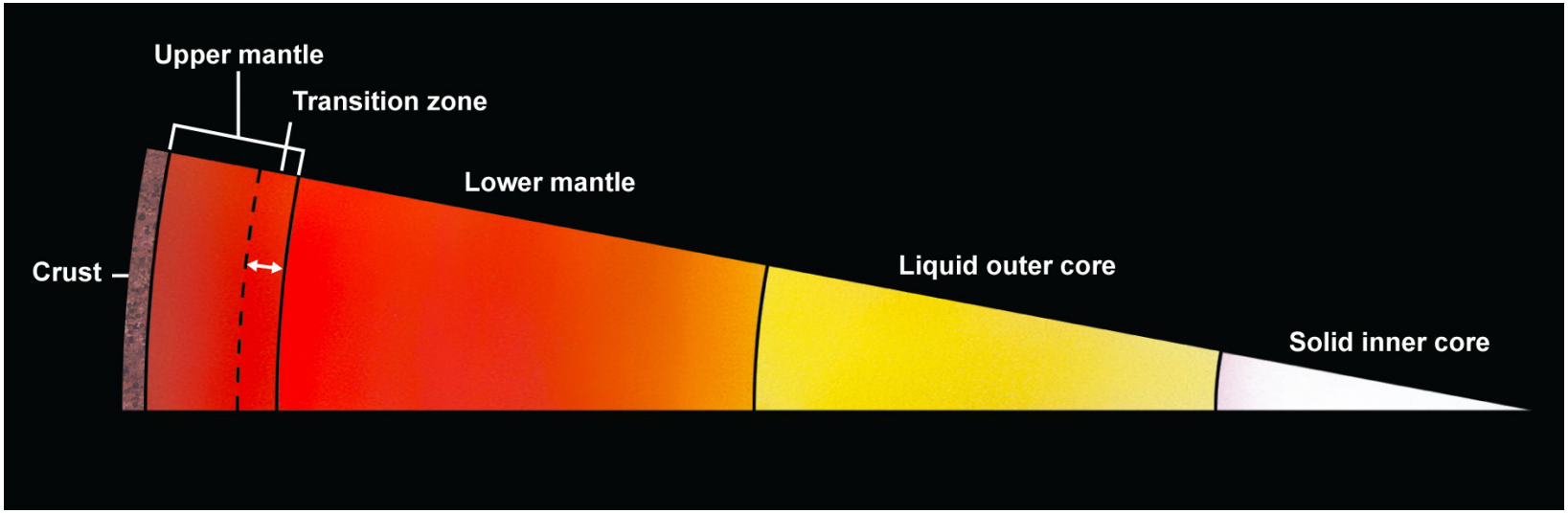
- Continental crust underlies the continents
  - Average density of ~2.7 g/cm^3
  - Average thickness 35–40 km
  - Felsic (granitic) to intermediate in composition
- Oceanic crust underlies the oceans
  - Average density of ~3.0 g/cm^3
  - Average thickness 7–10 km
  - Mafic (basaltic and gabbroic) in composition
- Crust–mantle boundary is termed the '**Moho**'





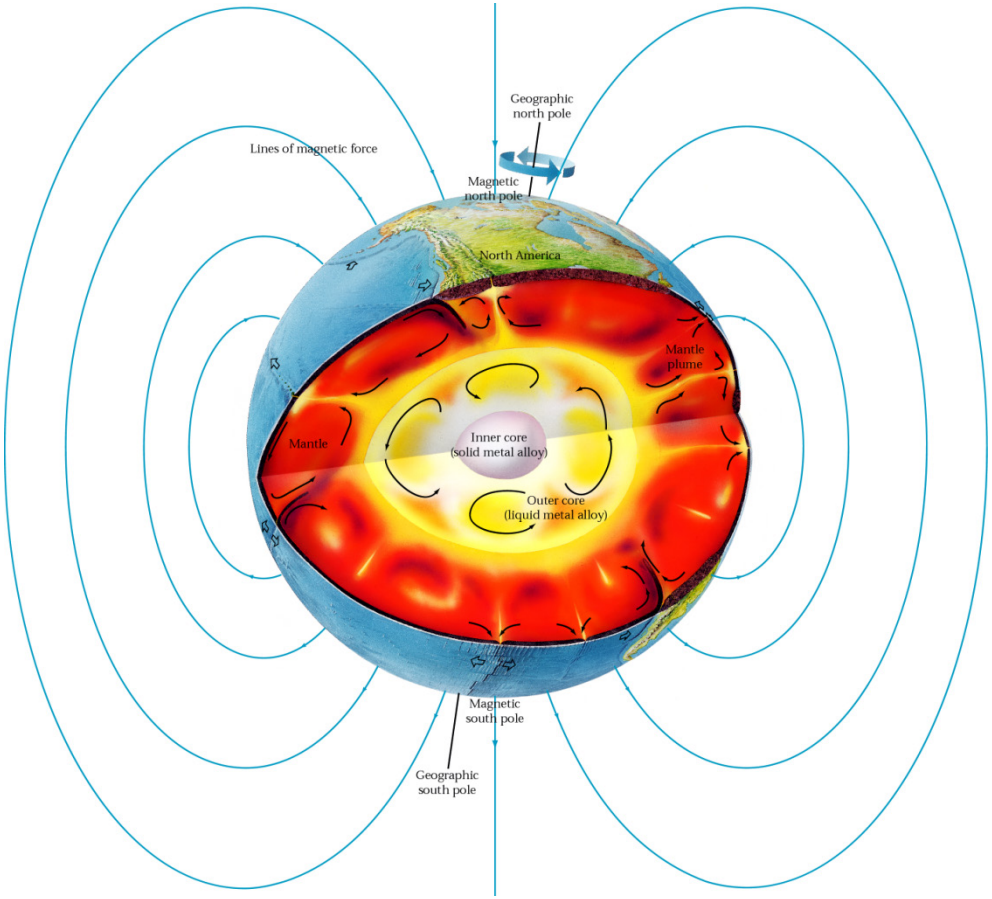
The mantle

- Solid rock, comprised entirely of ultramafic peridotite (82% of Earth's volume)
- Density increases from ~3.5 g/cm^3 at top to ~5.5 g/cm^3 at base
- Below ~100 km depth, mantle is hot enough to flow very slowly (~15 cm/year)
- This is known as **convection**: hot material rises, cool material sinks
- 2885 km thick in total, but split into two separate sublayers:
  - Upper mantle (0–660 km depth)
  - Lower mantle (660–2900 km depth)
    - Also includes the **transition zone** between 400–660 km depth



The core

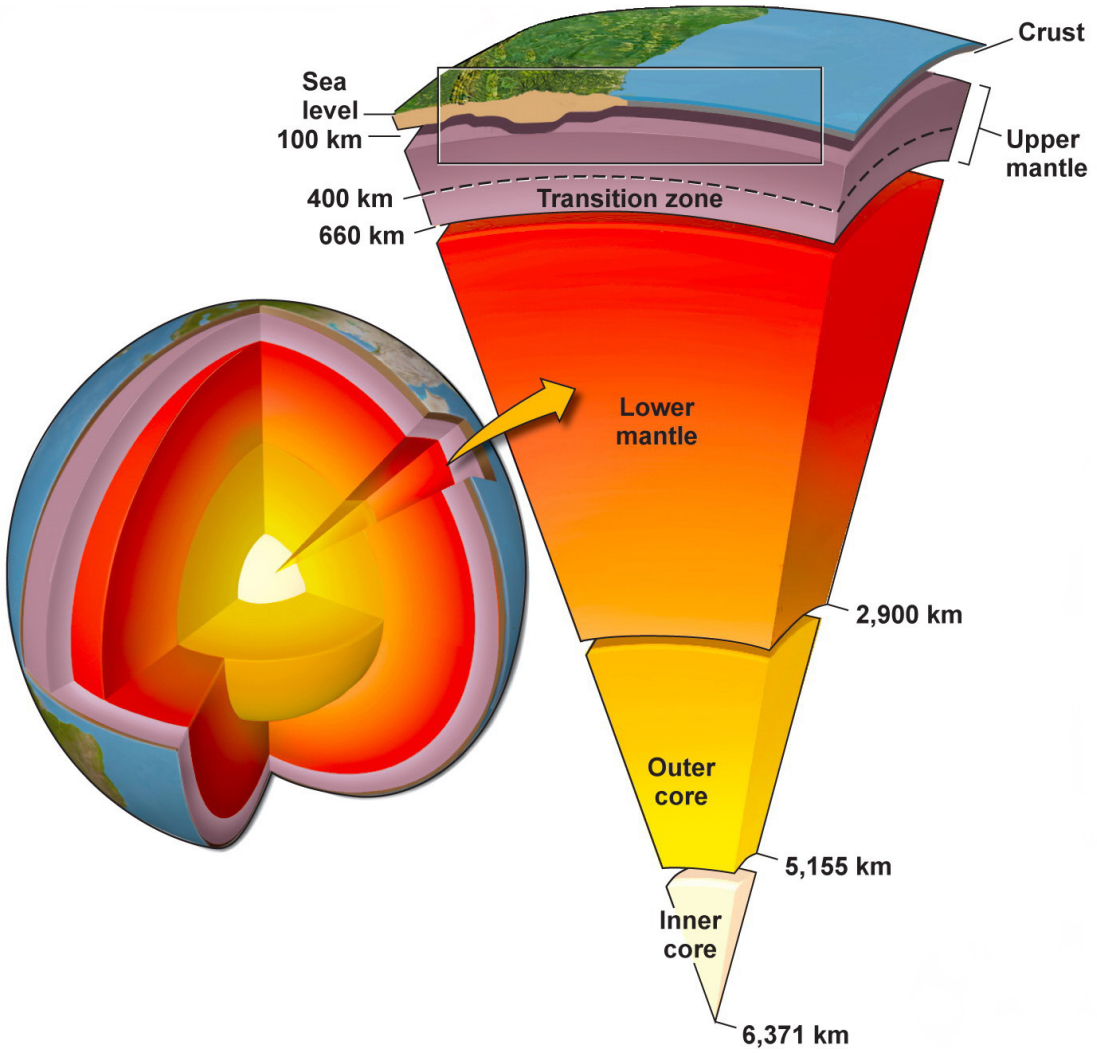
- A metal alloy containing mainly iron (Fe) and Nickel (Ni)
- Also rich in heavy metals such as platinum (Pt) and gold (Au)
- Inner core is **solid**
  - Density is 13 g/cm^3
  - 1220 km thick
- Outer core is **liquid**
  - Density is 10–12 g/cm^3
  - 2255 km thick
- Initially mostly liquid, but has cooled over time and partially solidified
- Flow in the outer core generates the Earth's magnetic field



Summary of Earth's layers

Earth has a **layered interior** subdivided on the basis of seismic wave velocities

- **Crust**
  - Continental
  - Oceanic
- **Mantle**
  - Upper
  - Transitional
  - Lower
- **Core**
  - Outer—liquid
  - Inner—solid



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Part 1: Structure and composition of the Earth

- Layers of the Earth: crust, mantle and core
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Part 2: Plate tectonics

- What is a tectonic plate?
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- Other plate features
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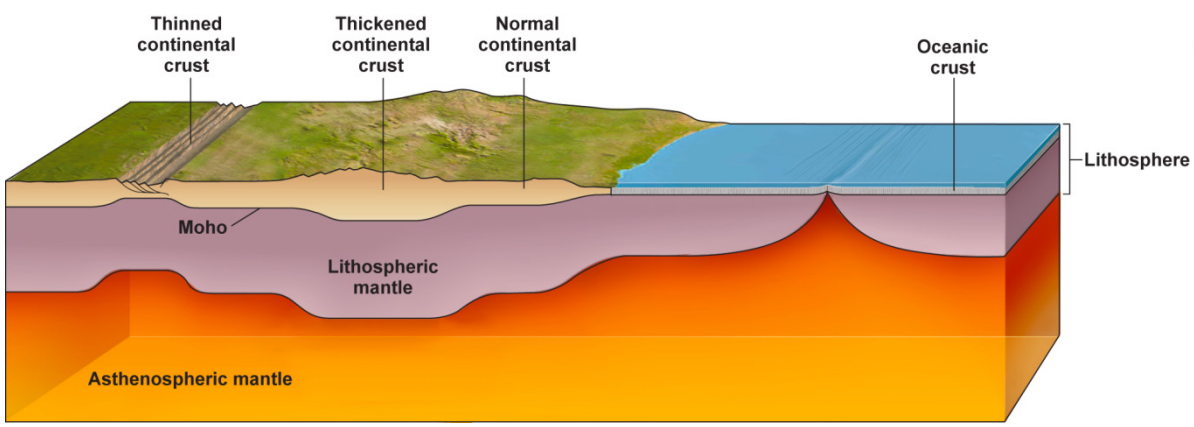
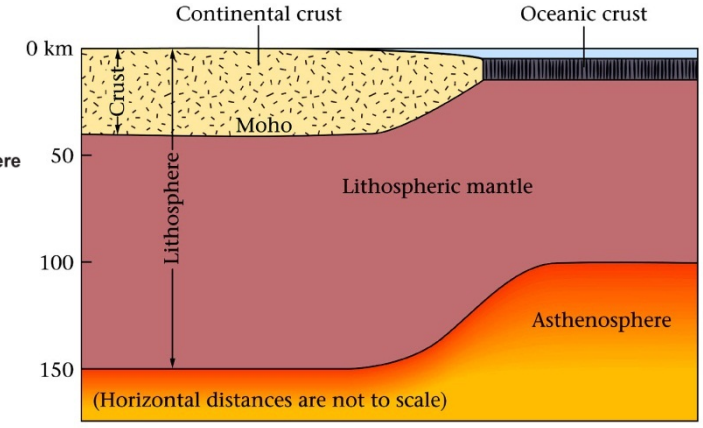
Other classifications of Earth's internal structure

- Rather than layers of different seismic velocities or composition, can also classify the Earth's interior based on **rock strength**
- Strength indicates the ability of materials to 'flow' – i.e. rigid vs. plastic
- **Lithosphere**: uppermost 100–150 km of Earth = crust + upper mantle; rigid, non-flowing
- **Asthenosphere**: upper mantle below the lithosphere; flows like a soft solid (e.g. wax), not a liquid; shallow under oceans, deeper under continents

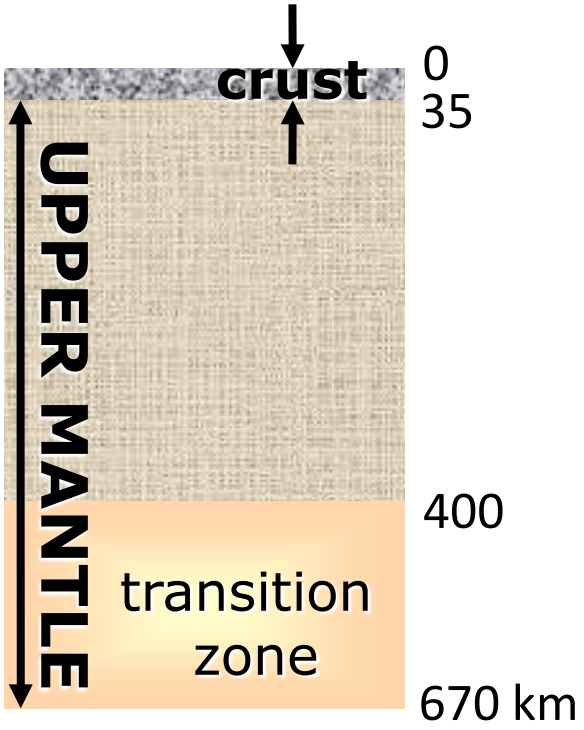




Other classifications of Earth's internal structure

- Two ways to classify the Earth's layers from 0–670 km depth

1. Compositionally



2. Mechanically

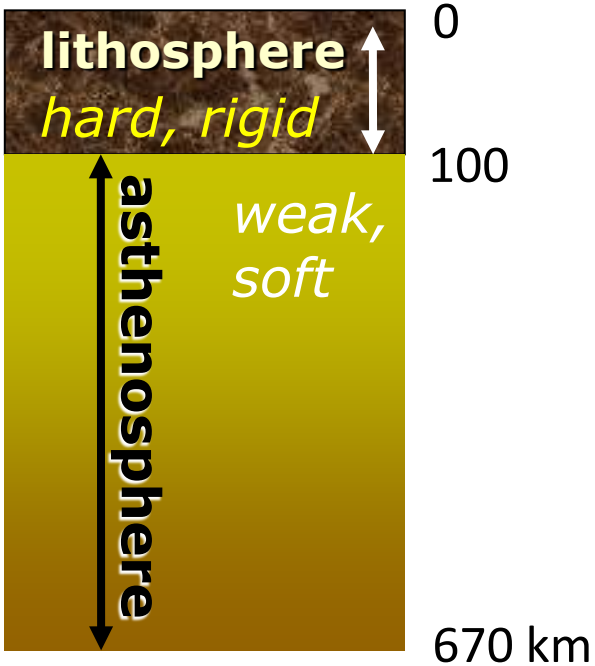


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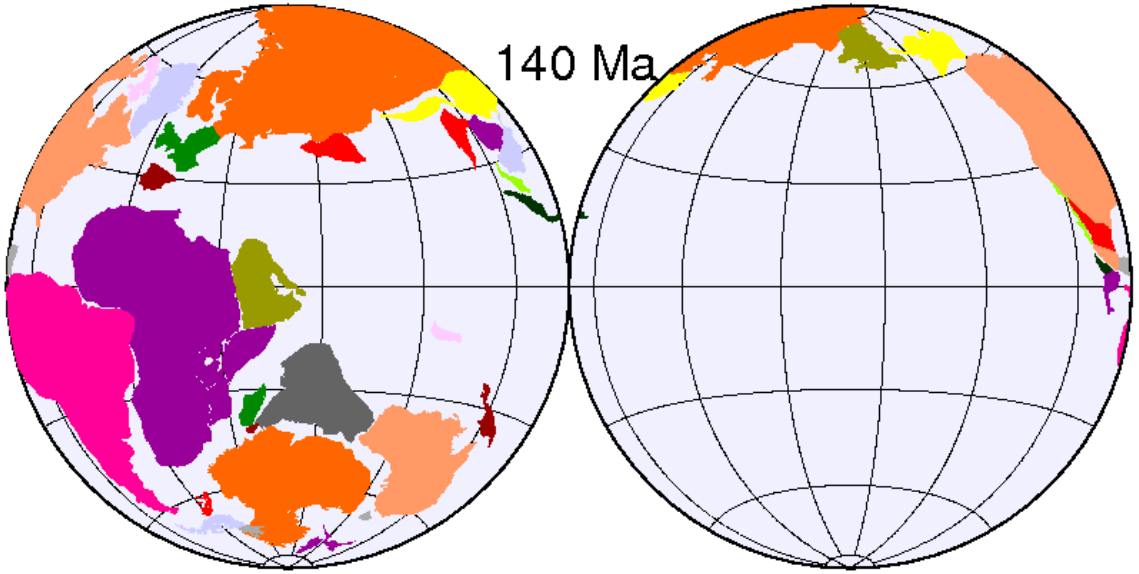
Plate tectonics vs. continental drift

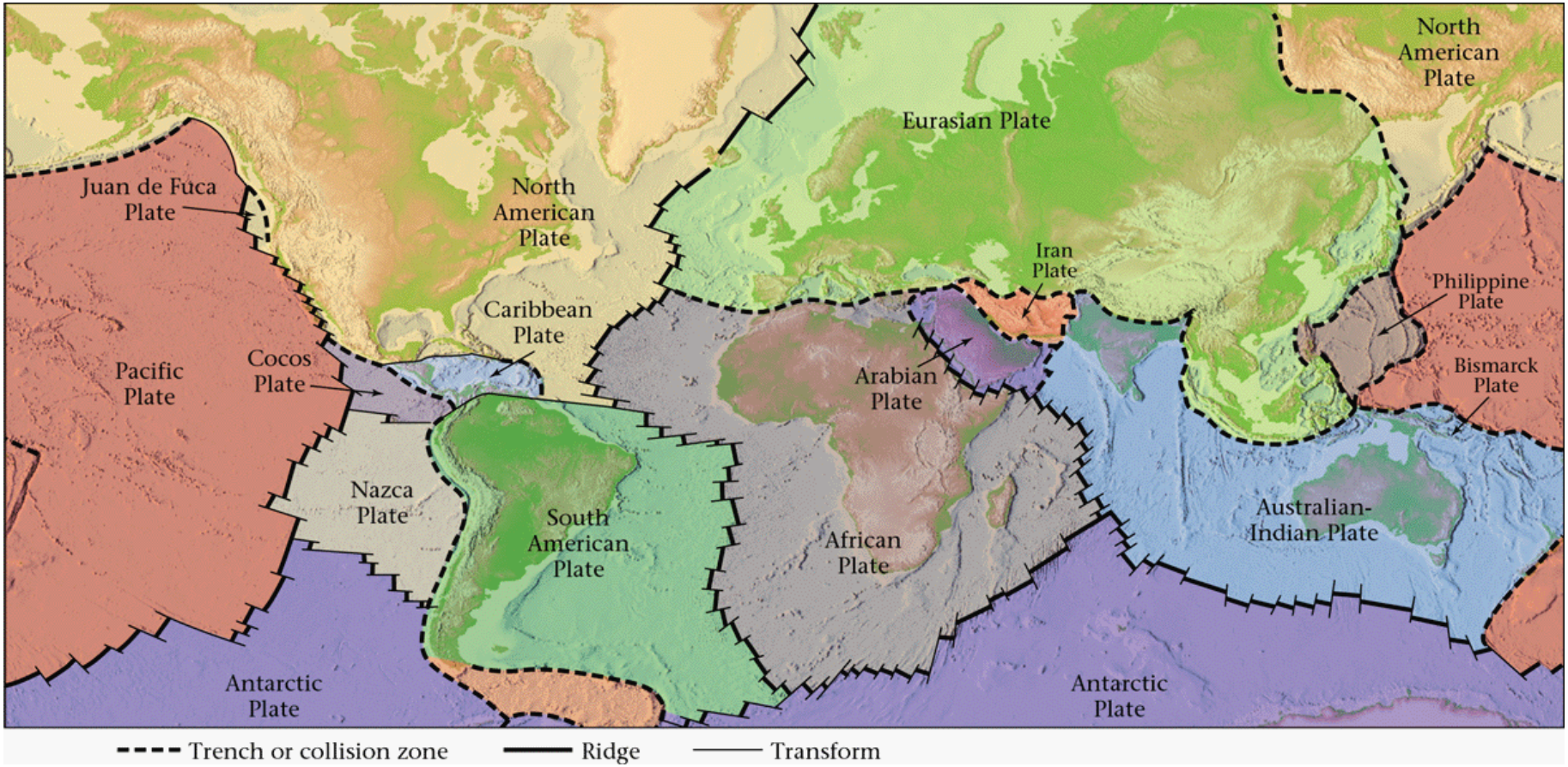
Who has heard of continental drift?



http://www.tectonics.caltech.edu/movies/outreach/plates_anim.mov

What is the difference between continental drift and plate tectonics?

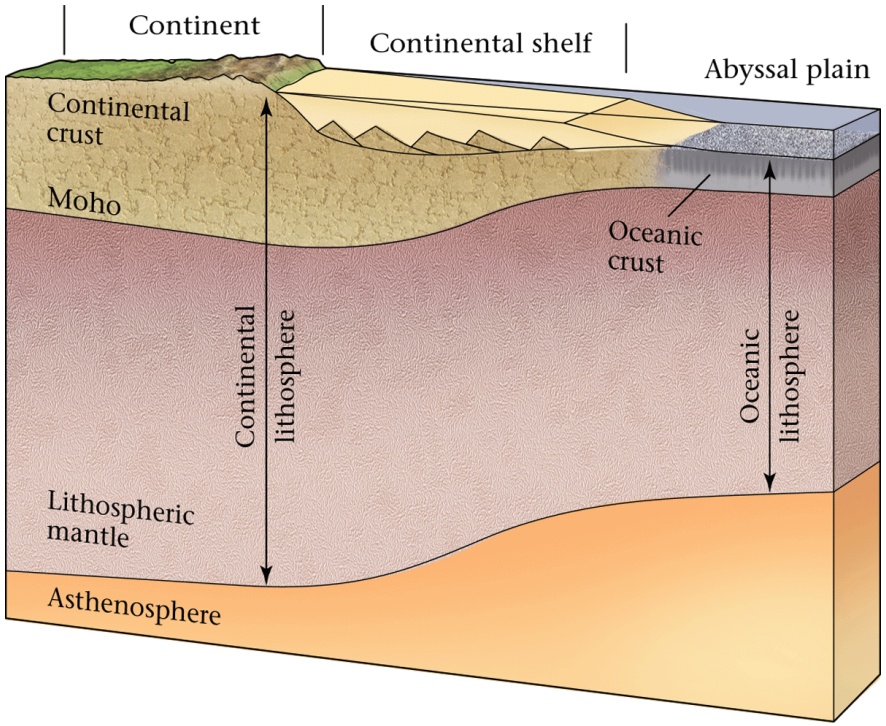
The plate tectonics paradigm



How do we define a tectonic plate?

What is a tectonic plate?

- Fragments of the **lithosphere** (sometimes called **lithospheric plates**)
- Rigid, non-flowable layer
- Includes the crust and the uppermost part of the mantle (**lithospheric mantle**)
- In general, they are ~100 km thick for oceanic lithosphere; ~150 km thick for continental lithosphere
- 'Floats' above the **asthenosphere** (softer, flowable part of the mantle) due to higher buoyancy



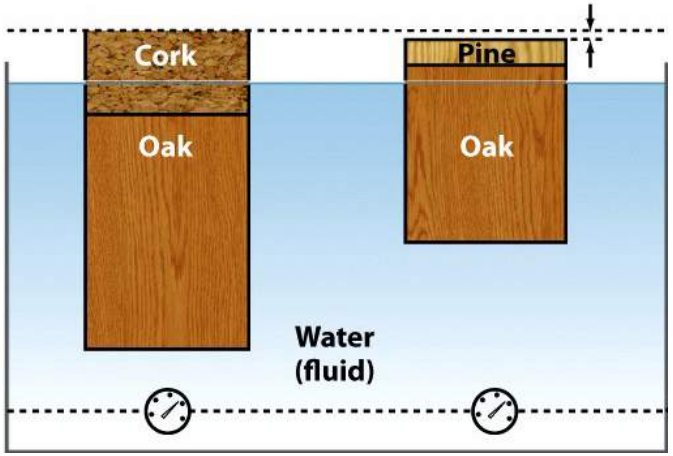
Two types of lithosphere

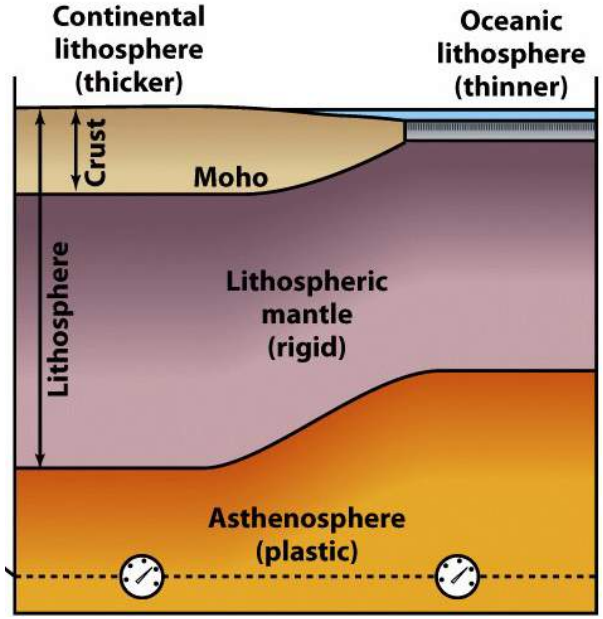
Continental: ~150 km thick in total

- Contains 35–40 km thick zone of granitic crust
- This crust is lighter (less dense)
- Also more buoyant – floats higher, hence continents are emergent

Oceanic: ~7–100 km thick in total

- Contains 7–10 km thick zone basaltic crust
- This crust is heavier (more dense)
- Also less buoyant – sinks lower, hence oceans are filled with water





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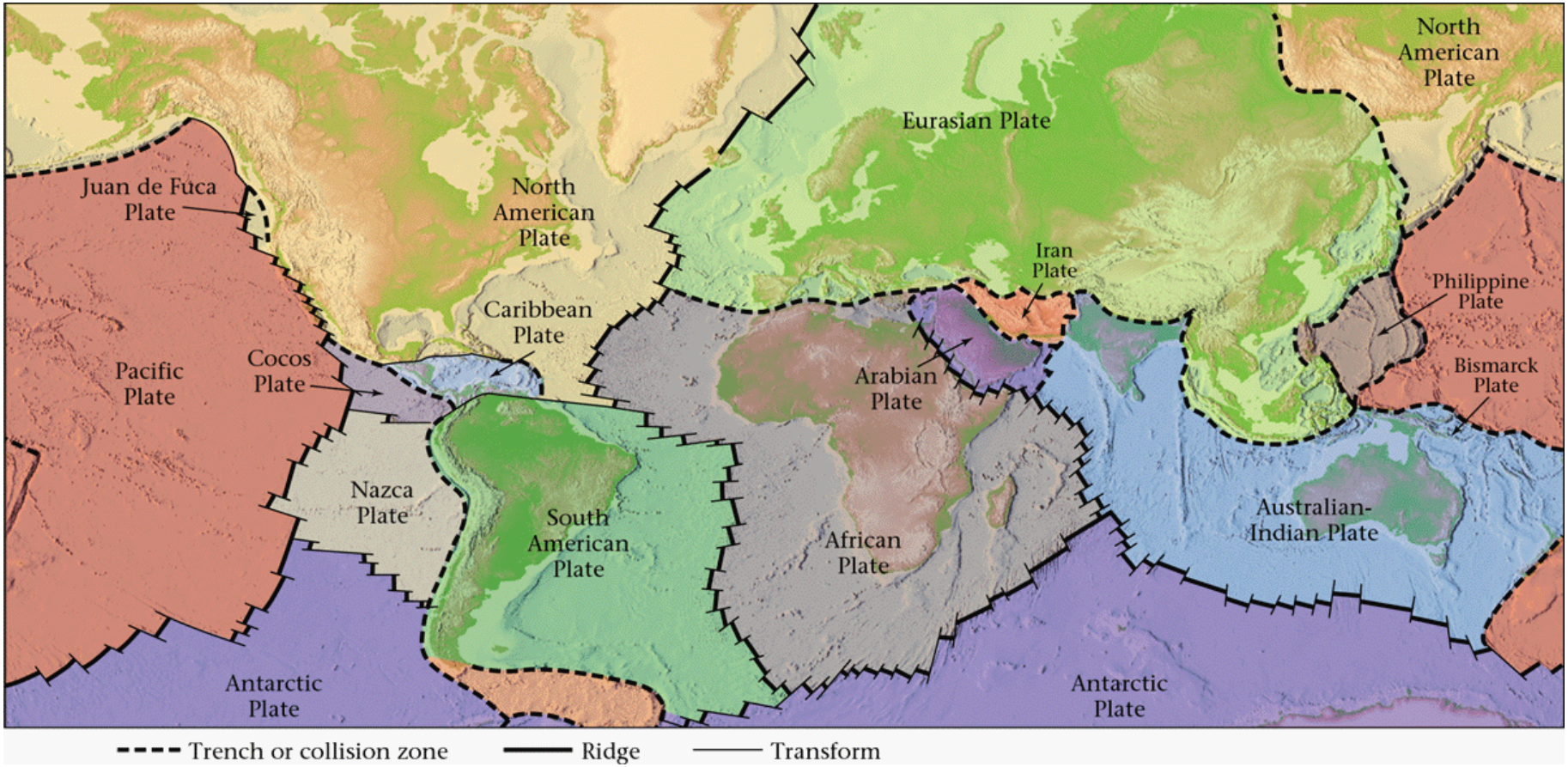
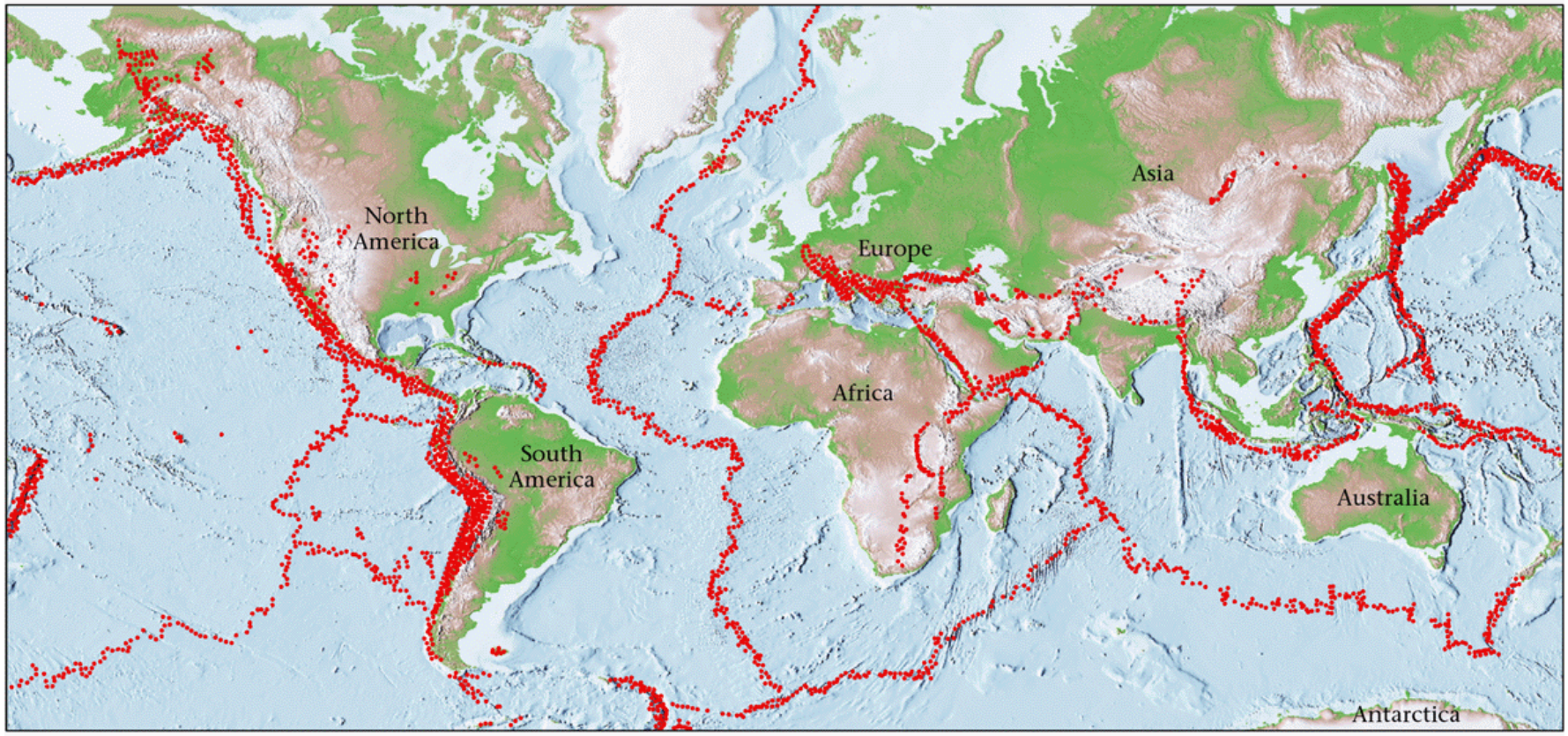
The plate tectonics paradigm



How do we know where the plate boundaries are?

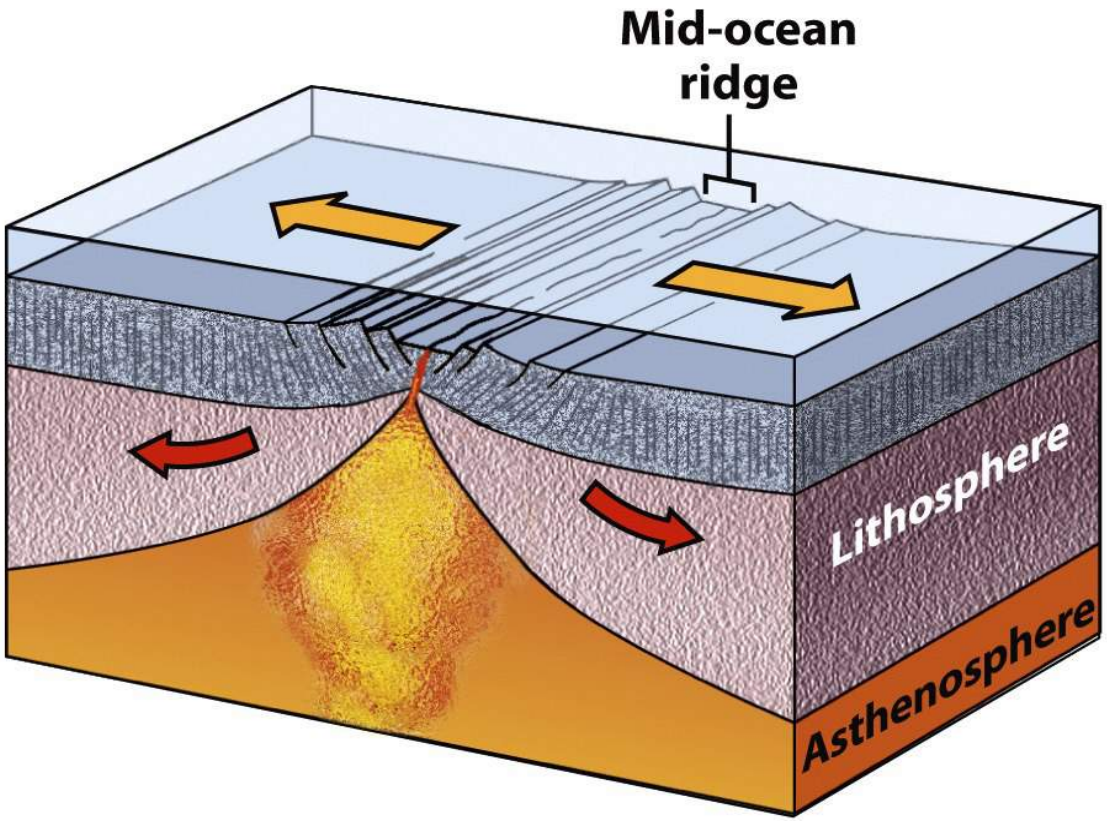
Identifying plate boundaries

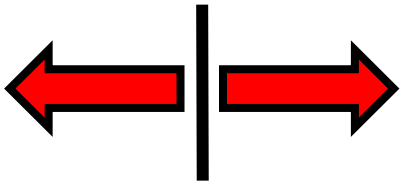
- The lithosphere is fragmented into ~20 tectonic plates
- Plates move continuously at 1–15 cm/yr and interact at their margins
- Earthquakes are concentrated at locations where plates meet



3 types of plate boundaries

1. Divergent: tectonic plates move apart

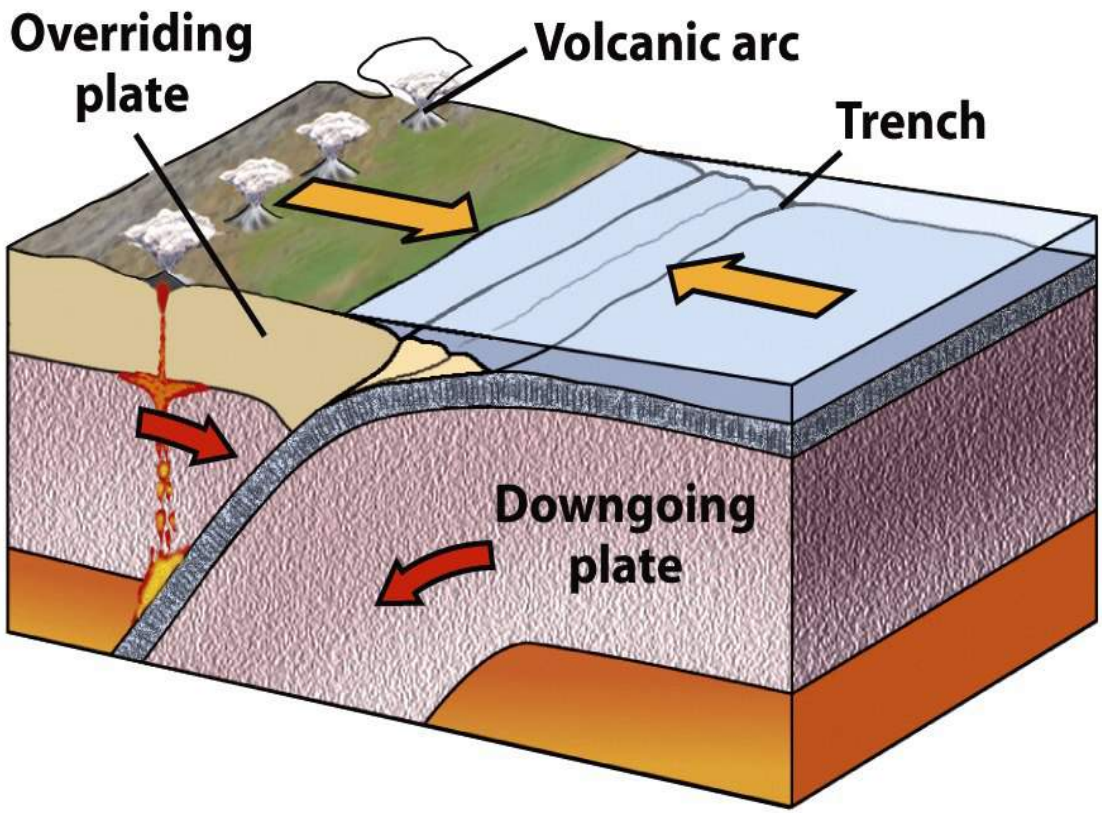


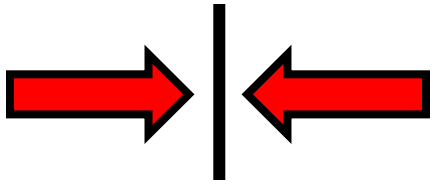


Divergent boundary
also called
Spreading boundary
Mid-ocean ridge
Ridge

3 types of plate boundaries

2. Convergent: tectonic plates move together

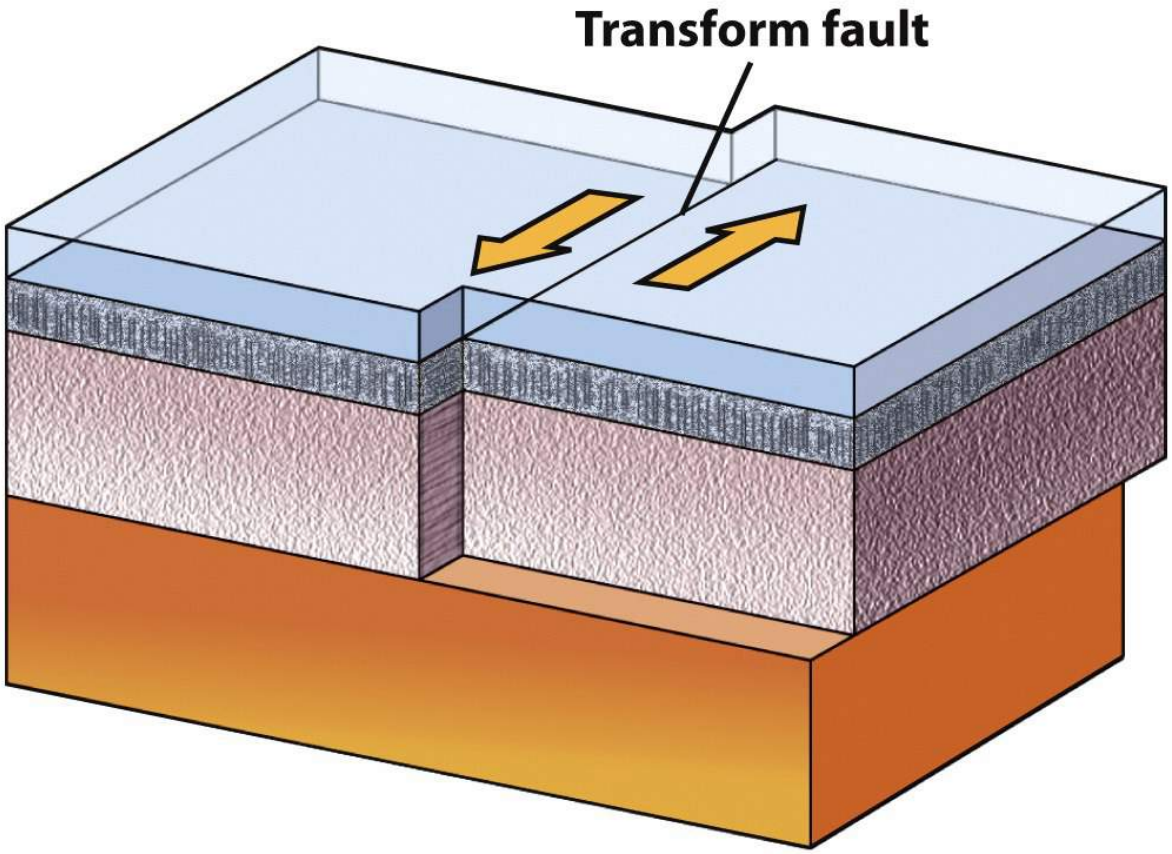




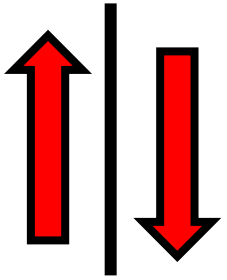
Convergent boundary
also called
Convergent margin
Subduction zone
Consuming boundary
Trench

3 types of plate boundaries

3. Transform: tectonic plates slide sideways past each other



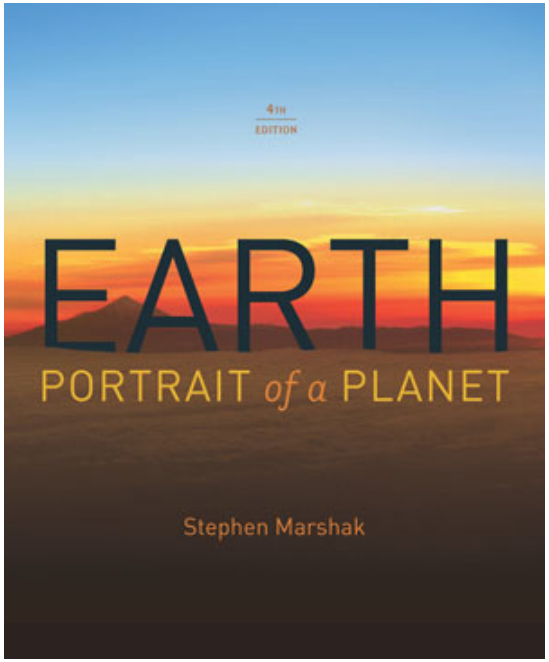
Transform boundary
also called
Transform fault
Transform



3 types of plate boundaries

Textbook supplement – check it out:

http://wwnorton.com/college/geo/earth4/



- Use a study plan to map your progress
- Study with interactive flash cards
- Take quizzes and test your knowledge
- Use animations to help your understanding
- Learn from Science and Society features
- Links to Google Earth and eBook sections
- Links to Geology in the News

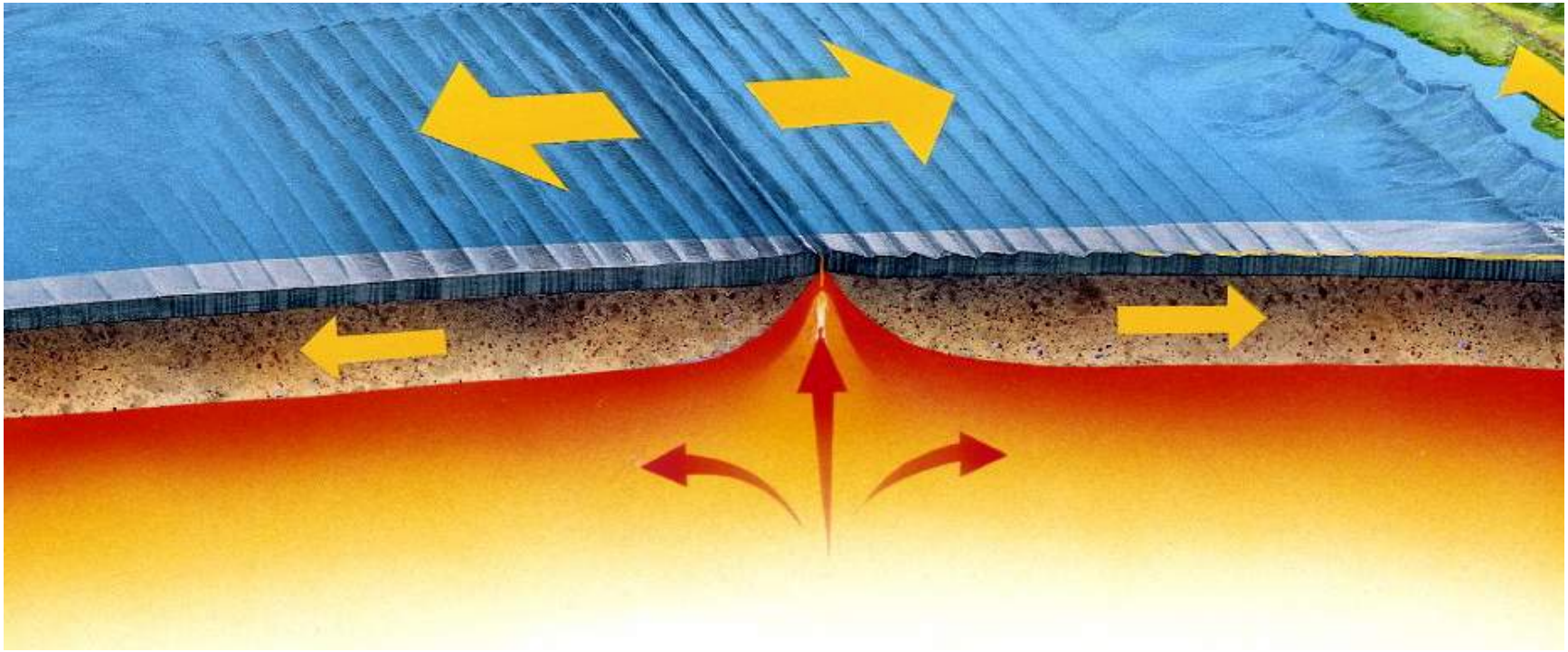
…All good resources for learning the course material and for exam prep!

Plate boundary animations:

http://www.wwnorton.com/college/geo/animations/basic_plate_boundaries.htm

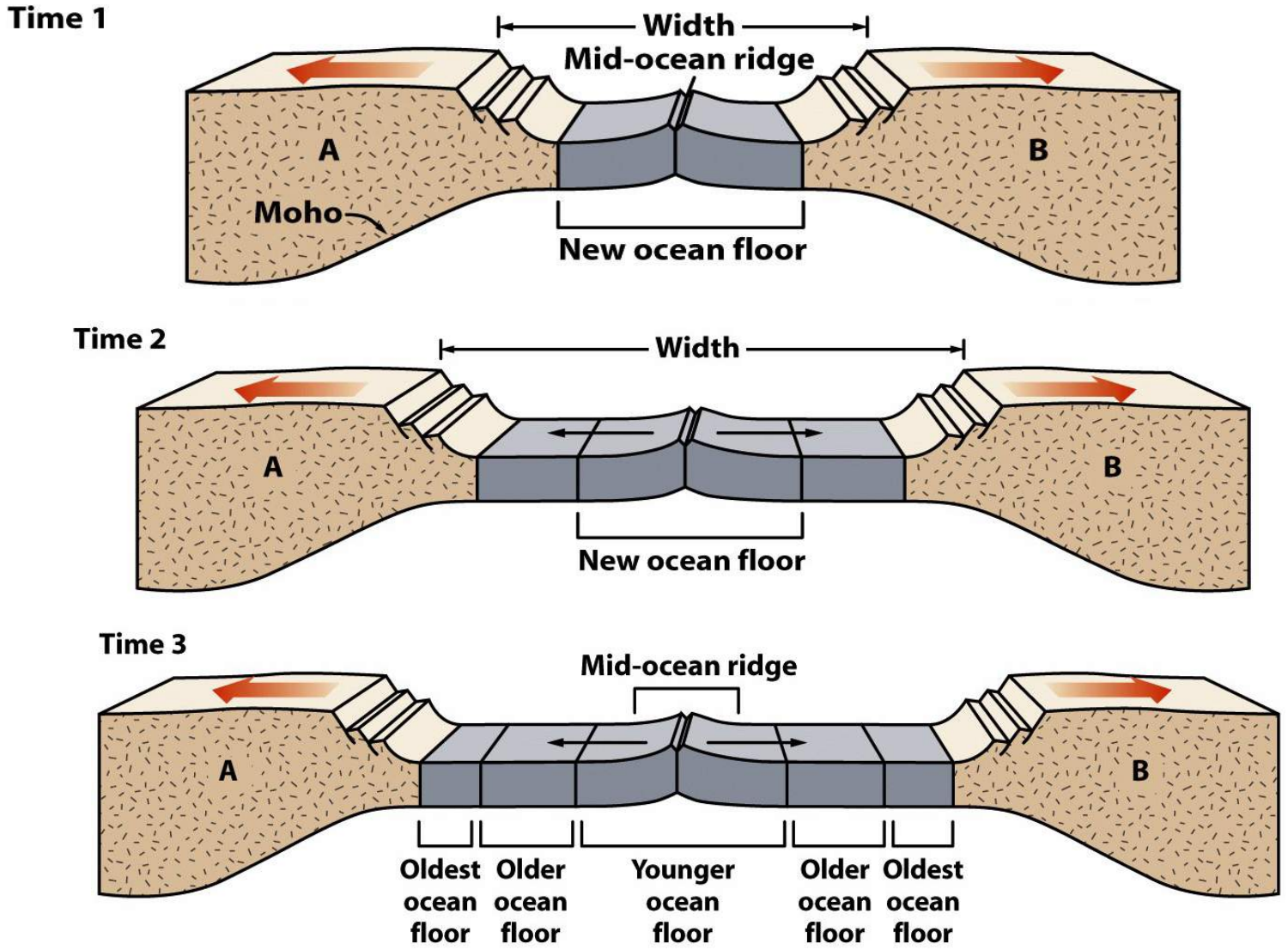
Divergent plate boundaries

- Sea-floor spreading causes plates to move apart
- Magma wells up to fill the gap
- Magma cools, adding material to each plate

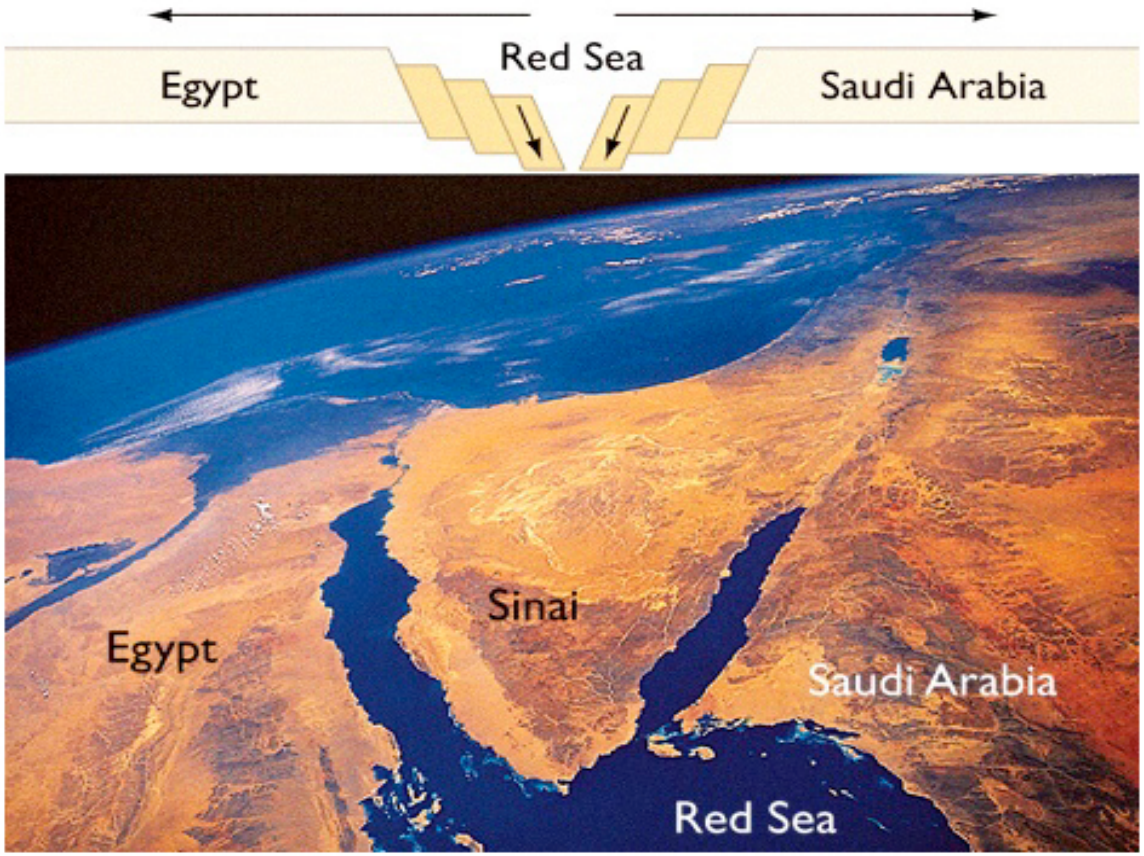


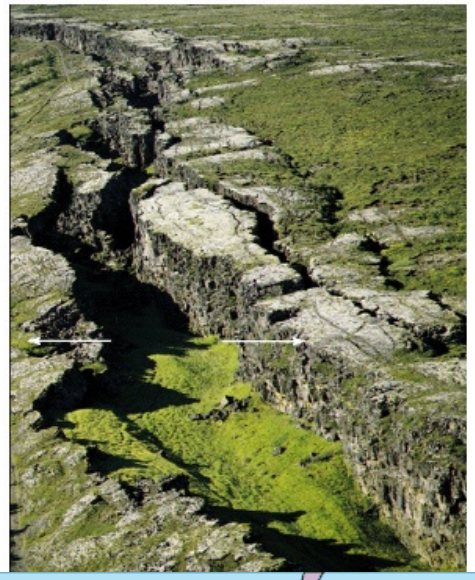
http://www.wwnorton.com/college/geo/animations/formation_of_ocean_crust.htm

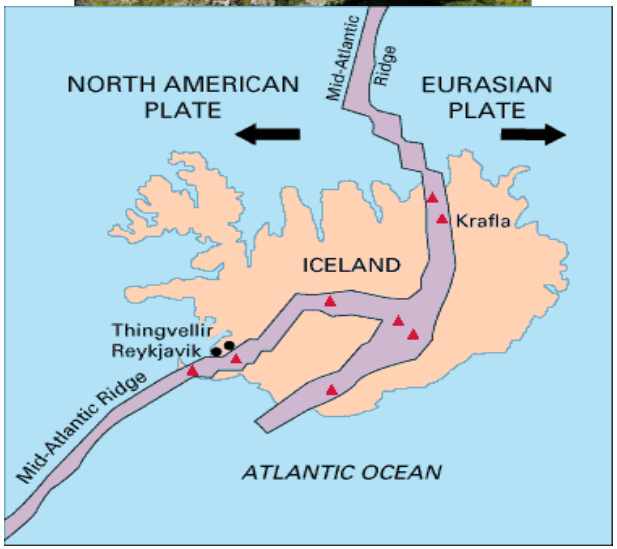
Divergent plate boundaries



Divergent plate boundaries



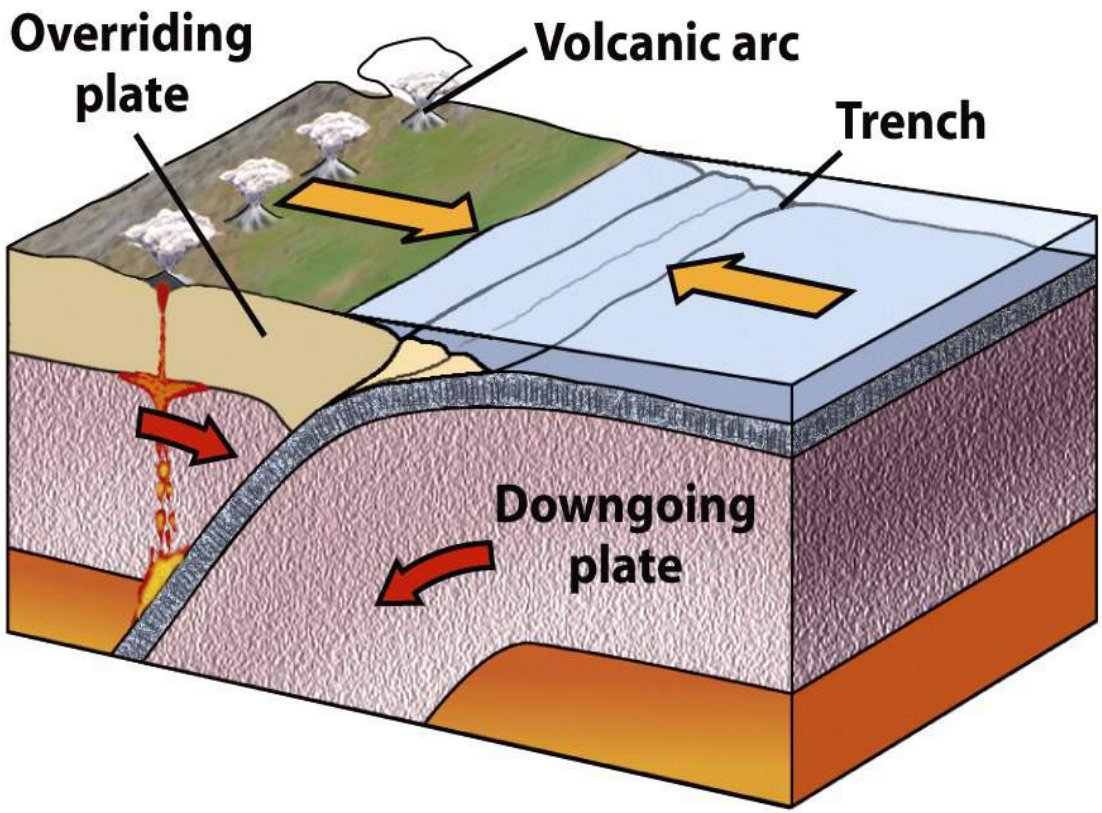


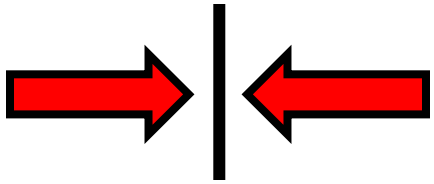


http://www.wwnorton.com/college/geo/animations/the_process_of_rifting.htm

3 types of plate boundaries

2. Convergent: tectonic plates move together

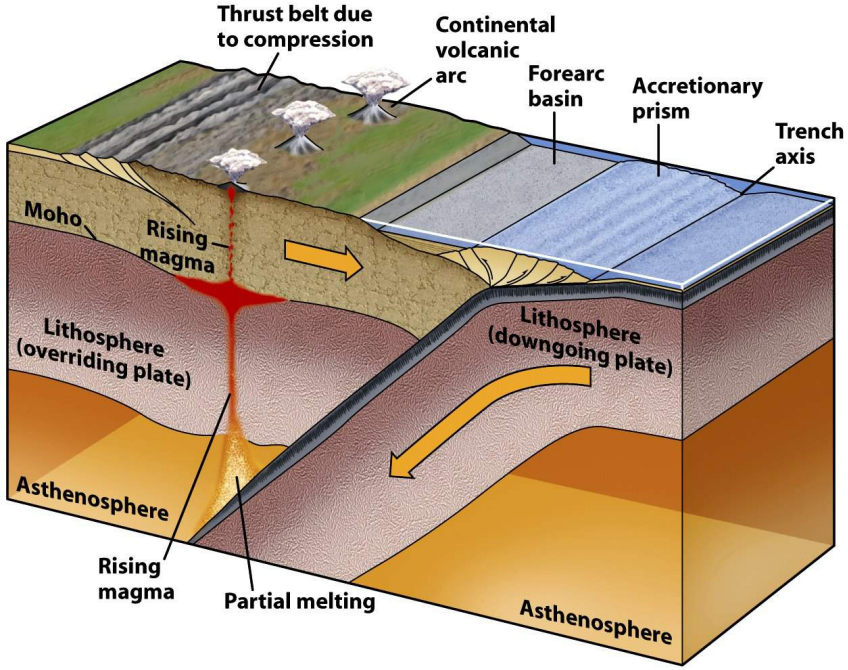




Convergent boundary
also called
Convergent margin
Subduction zone
Consuming boundary
Trench

Convergent plate boundaries

- Lithospheric plates move toward one another
- One plate is driven back into the mantle because of lower buoyancy – this process is known as **subduction**
- Subduction recycles oceanic lithosphere
- Subduction is balanced by sea-floor spreading, hence the Earth maintains a constant circumference

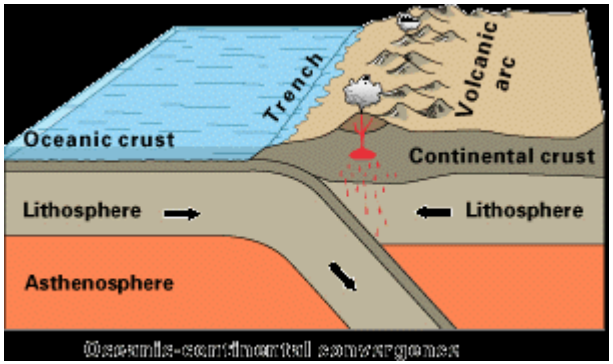


http://www.wwnorton.com/college/geo/animations/the_process_of_subduction.htm

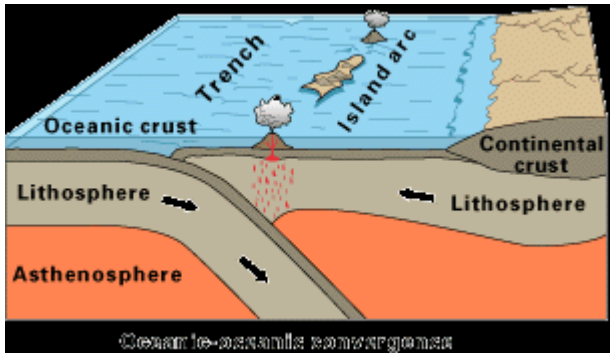
Convergent plate boundaries

Subduction zones – 3 types:

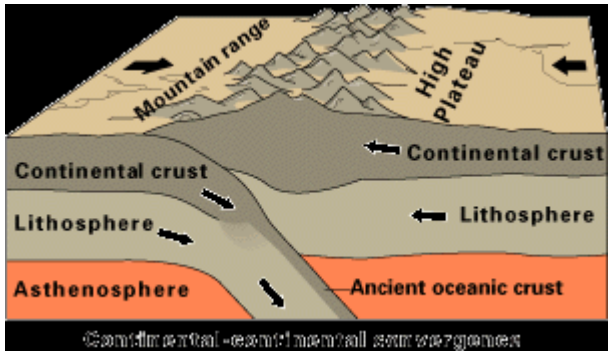
1. **Ocean–continent**
   Accretionary wedges/prisms
   and trenches
   e.g. west coast of South America



2. **Ocean–ocean**
   Volcanic island arcs
   e.g. Tonga, Mariana arcs

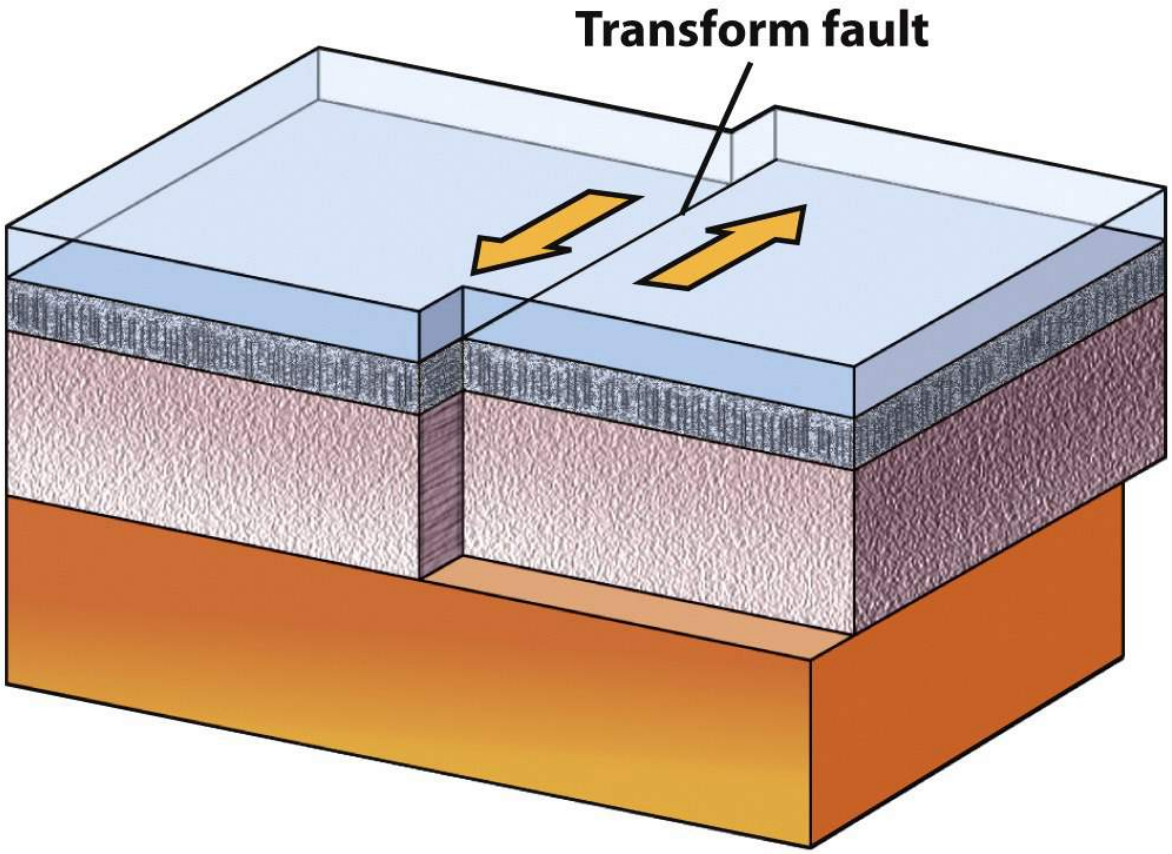


3. **Continent–continent** (#1 can lead to #3)
   Crustal shortening and thickening
   (mountain building)
   e.g. Himalayas

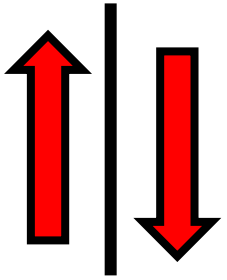


3 types of plate boundaries

3. Transform: tectonic plates slide sideways past each other

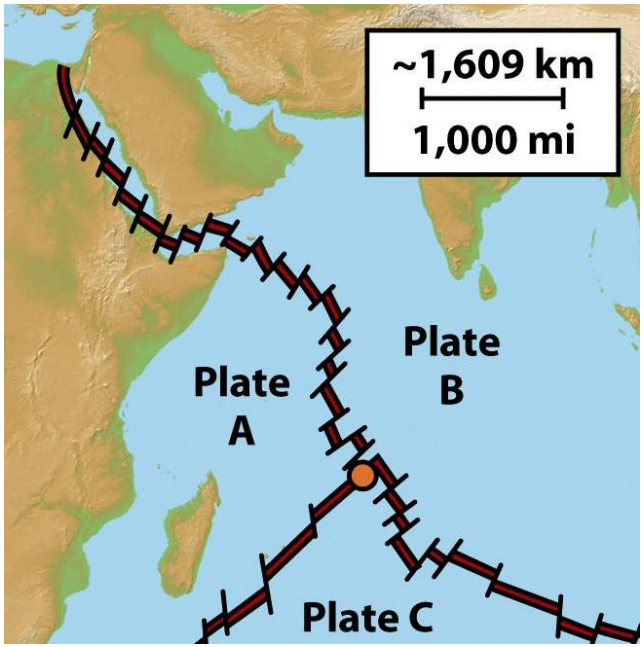


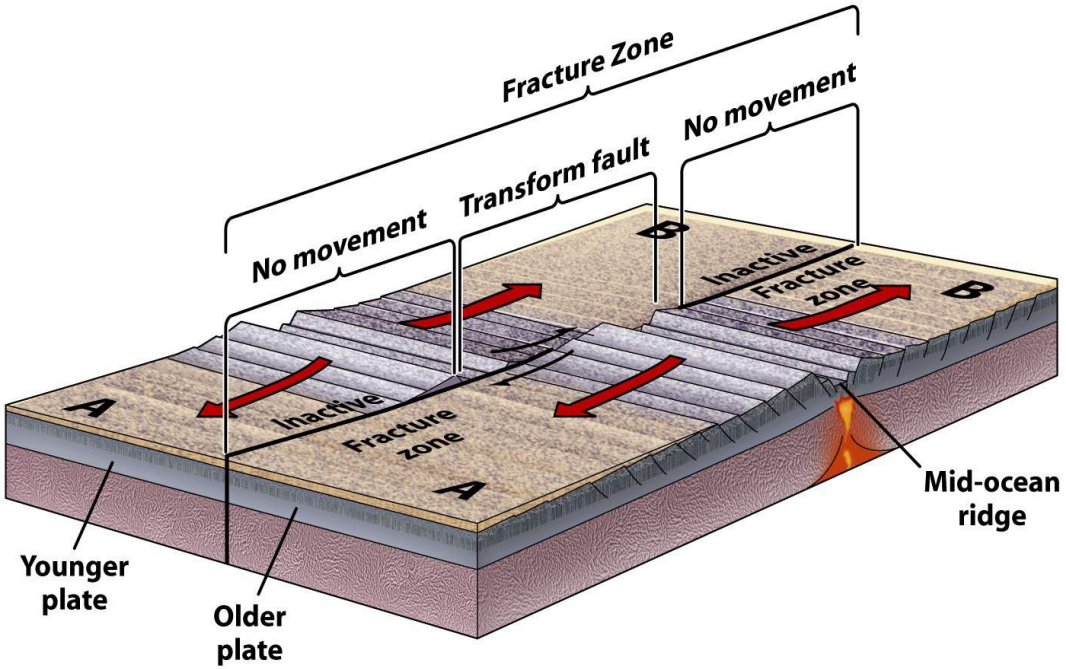
Transform boundary
also called
Transform fault
Transform



Transform plate boundaries

- Lithosphere slides past; not created or destroyed
- Many transforms offset spreading ridge segments in oceanic crust
- Some transforms cut through continental crust
- Characterized by seismic activity (earthquakes) and an absence of volcanism (no upwelling molten rock)



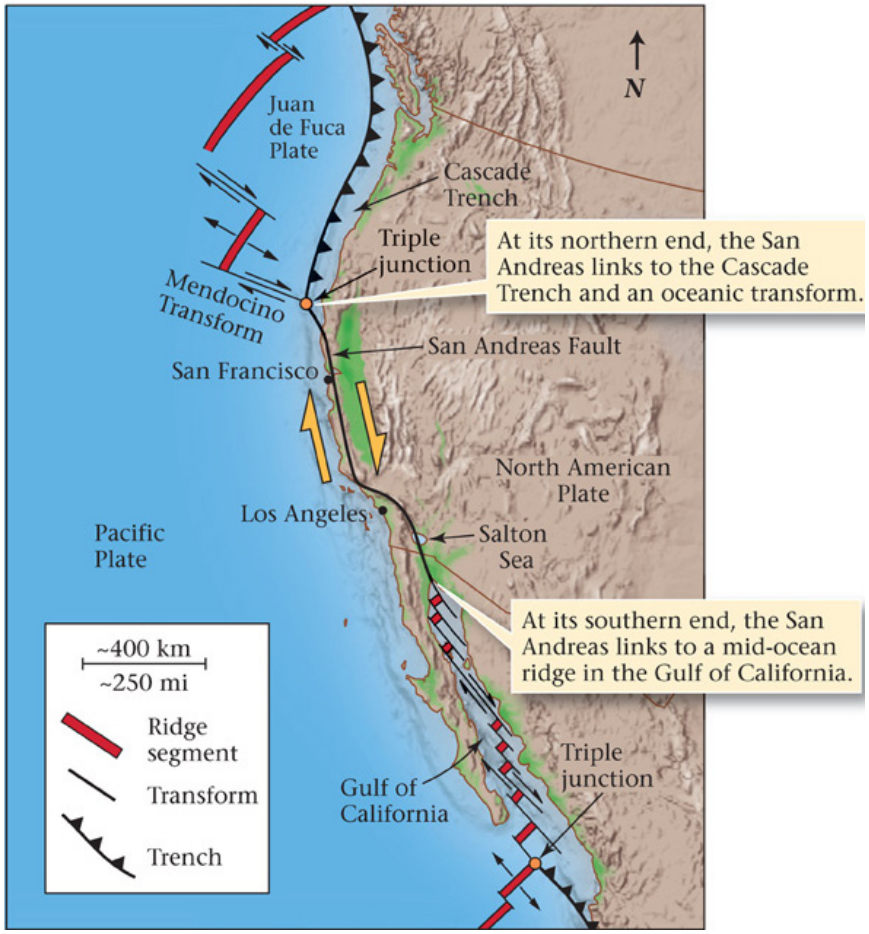


http://www.wwnorton.com/college/geo/animations/transform_faulting.htm

Transform plate boundaries

A transform fault cutting continental crust: the San Andreas Fault

Links subduction trench with spreading ridge segment



Lecture outline

Part 1: Structure and composition of the Earth

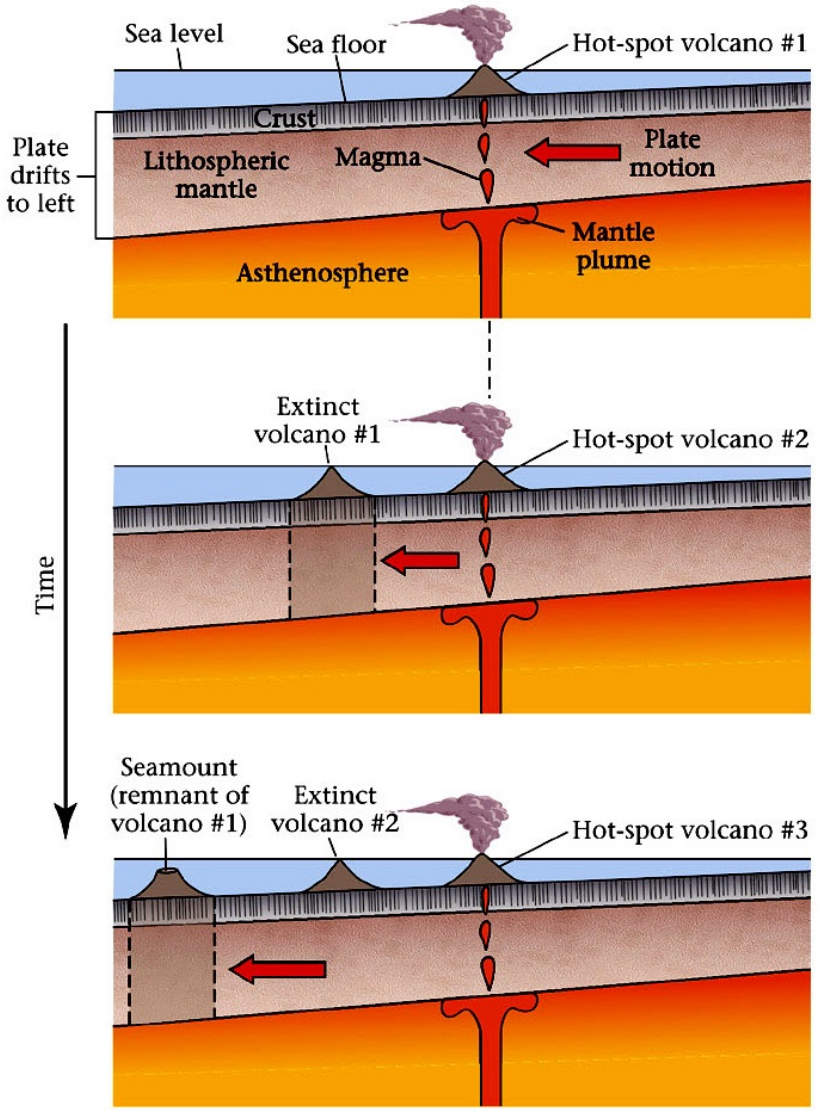
- Layers of the Earth: crust, mantle and core
- Lithosphere and asthenosphere

Part 2: Plate tectonics

- What is a tectonic plate?
- Types of plate boundaries
- Other plate features
- Key features of plate tectonics

Other plate features: hot spots

- **Hot spots** are volcanic plumes independent of tectonic plates
- Mafic magmas derived from the lower mantle
- Imprint a series of volcanoes on the overriding plate
- Extinct volcanoes create **seamounts**
- Seamounts age away from originating hot spot
- Age increase marks the direction of overriding plate motion

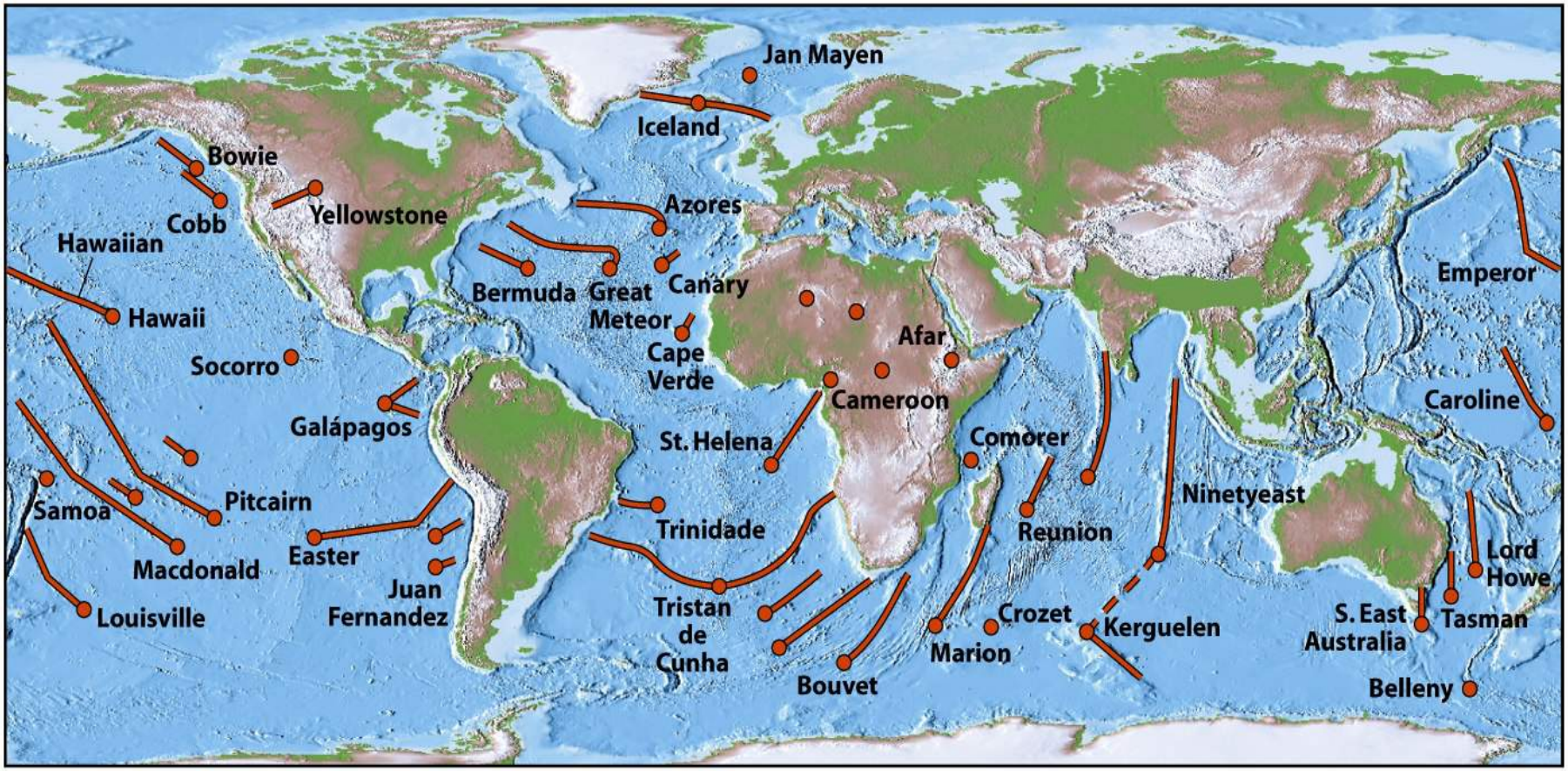


Other plate features: hot spots

Hot spot animation:

http://www.wwnorton.com/college/geo/animations/hot_spot_volcanoes.htm

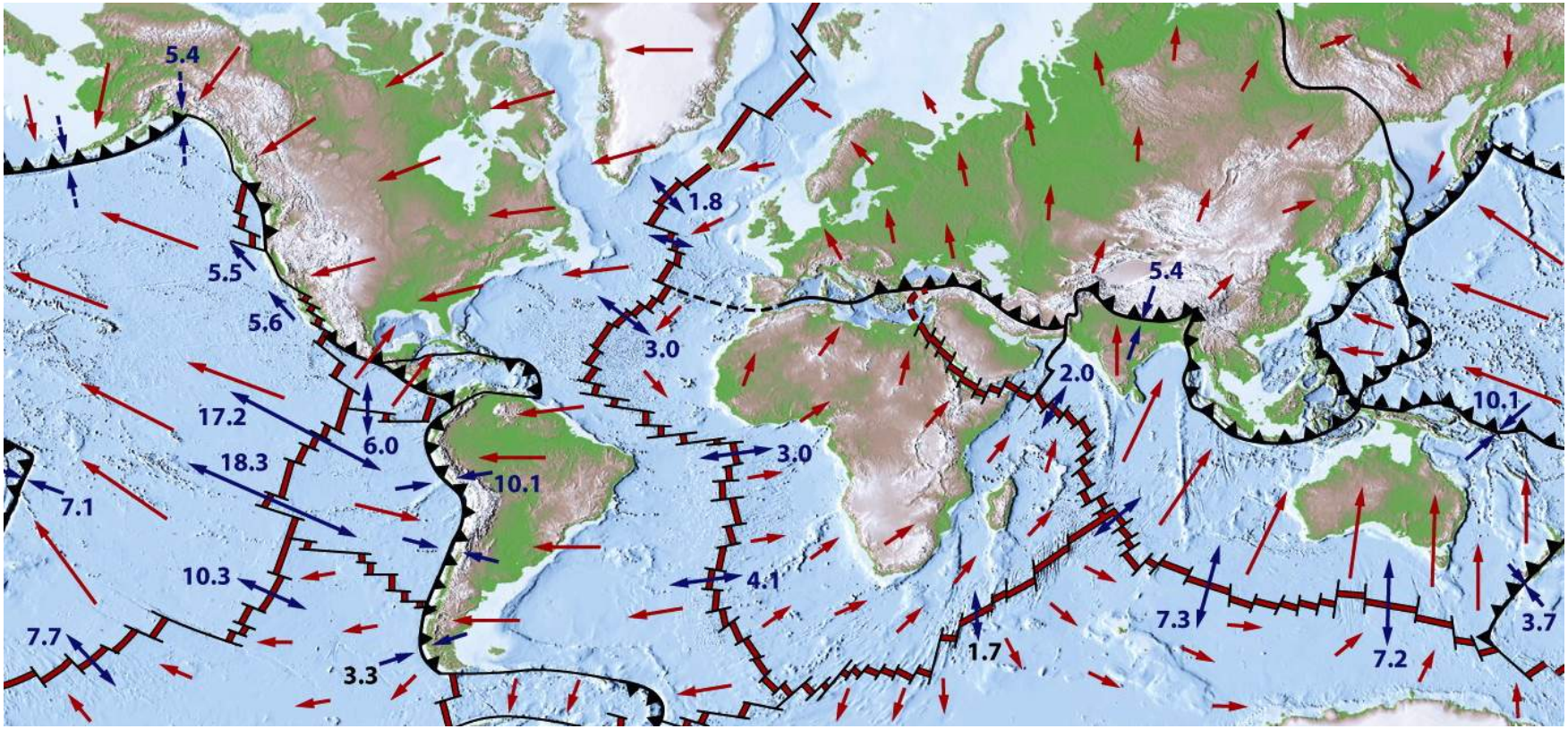
Other plate features: hot spots



How do we know the plates are moving?

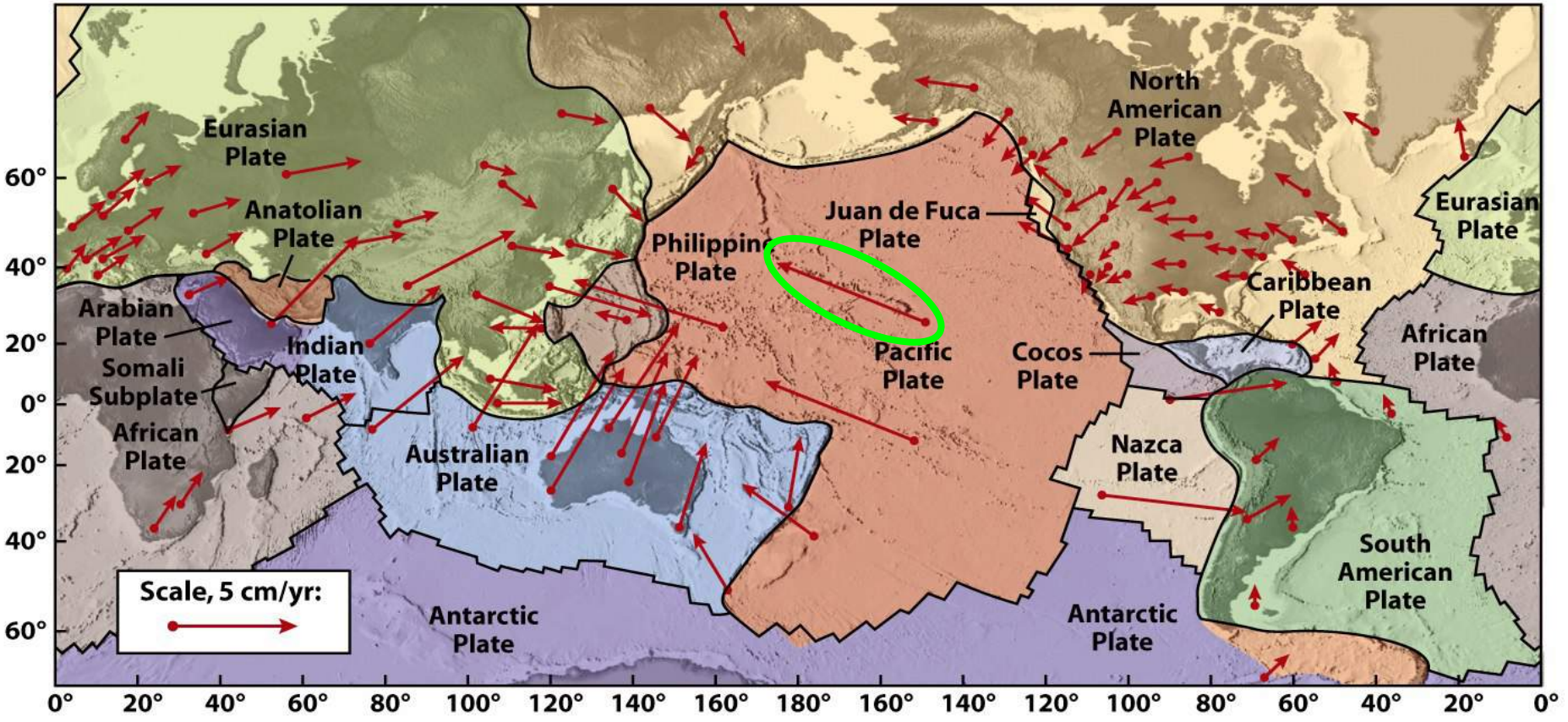
Absolute plate velocities may be mapped by plotting plate motion relative to a fixed spot in the mantle:

- Measuring volcano ages/distance along a hot spot track
- Measuring the amount sea floor spreading from a MOR axis relative to its age



How do we know the plates are moving?

- Plate vectors are determined using GPS measurements
- Permanent GPS stations positioned across the continents; few on oceans
- More accurate and precise than alternative methods



Lecture outline

Part 1: Structure and composition of the Earth

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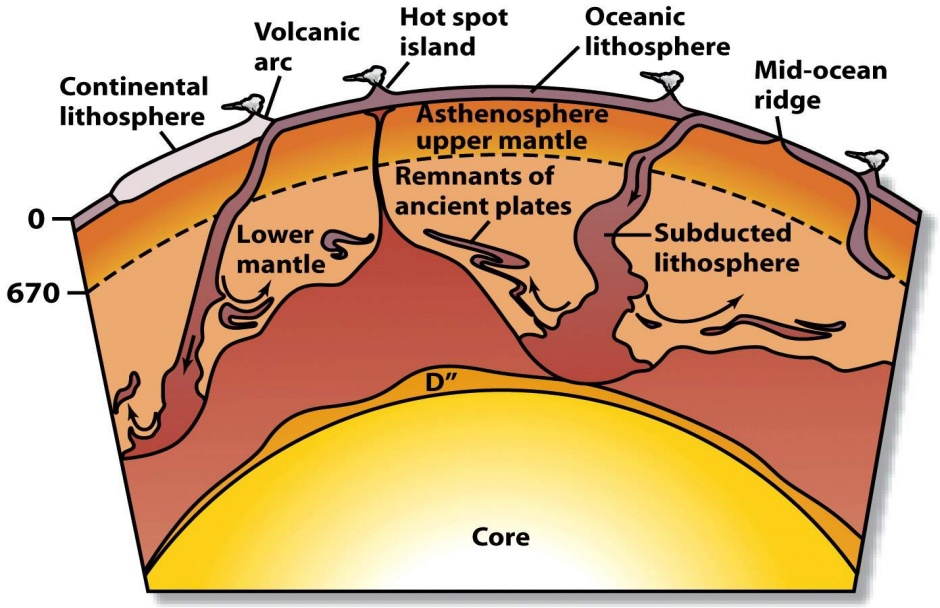
Key features of plate tectonics

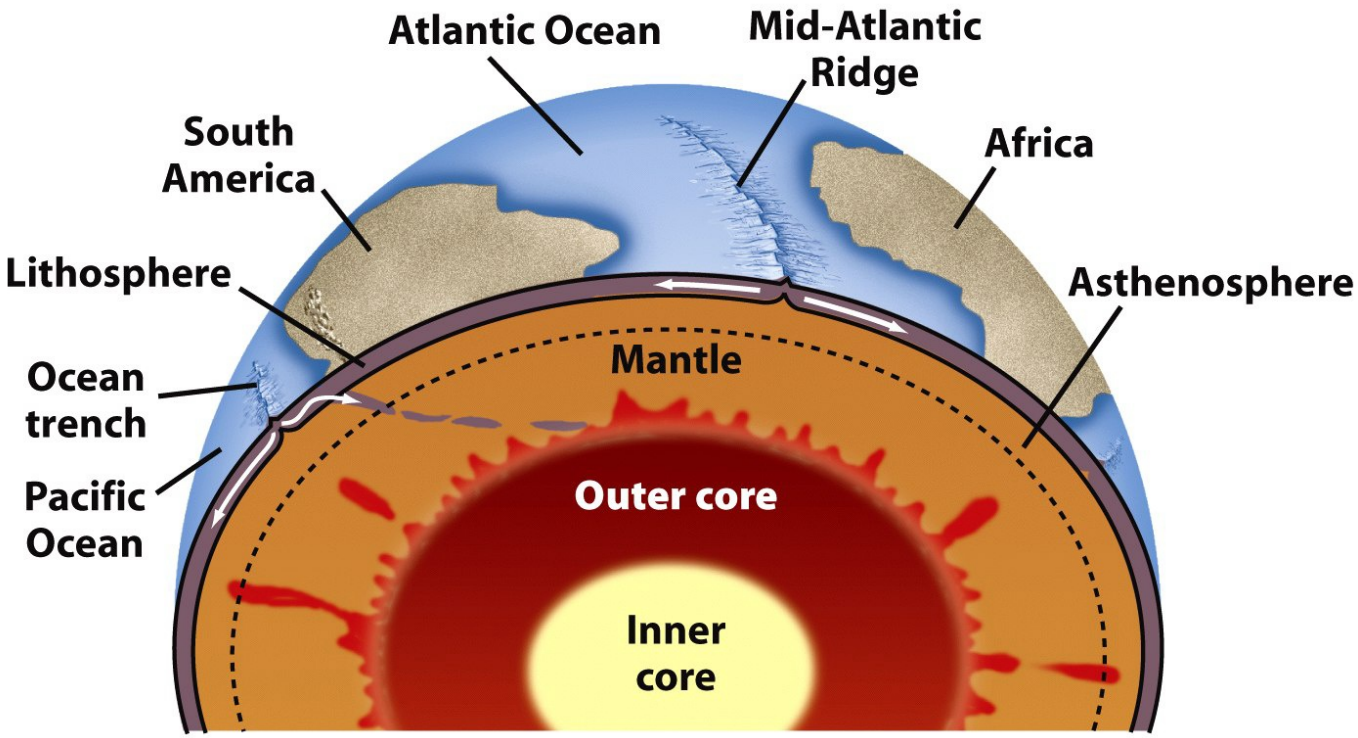
- The Earth's crust is constantly being created and destroyed (or recycled)
- Oceanic crust, formed at **divergent boundaries**, is mafic and dense
- Because it is dense it has low topography
- As oceanic crust ages and cools, its great density relative to continental crust results in subduction as plates **converge**
- As a result, old oceanic crust cannot persist, but continental crust is buoyant and can survive
- **Transform plate margins** are parallel to the current motion of the plates



Key features of plate tectonics

Plate tectonics is the key to understanding the Earth System

- Mantle material is transferred to the surface and back down again
- The interior and surface of Earth are in constant motion
- Plate tectonics explains earthquakes, volcanoes and continental drift



Key features of plate tectonics

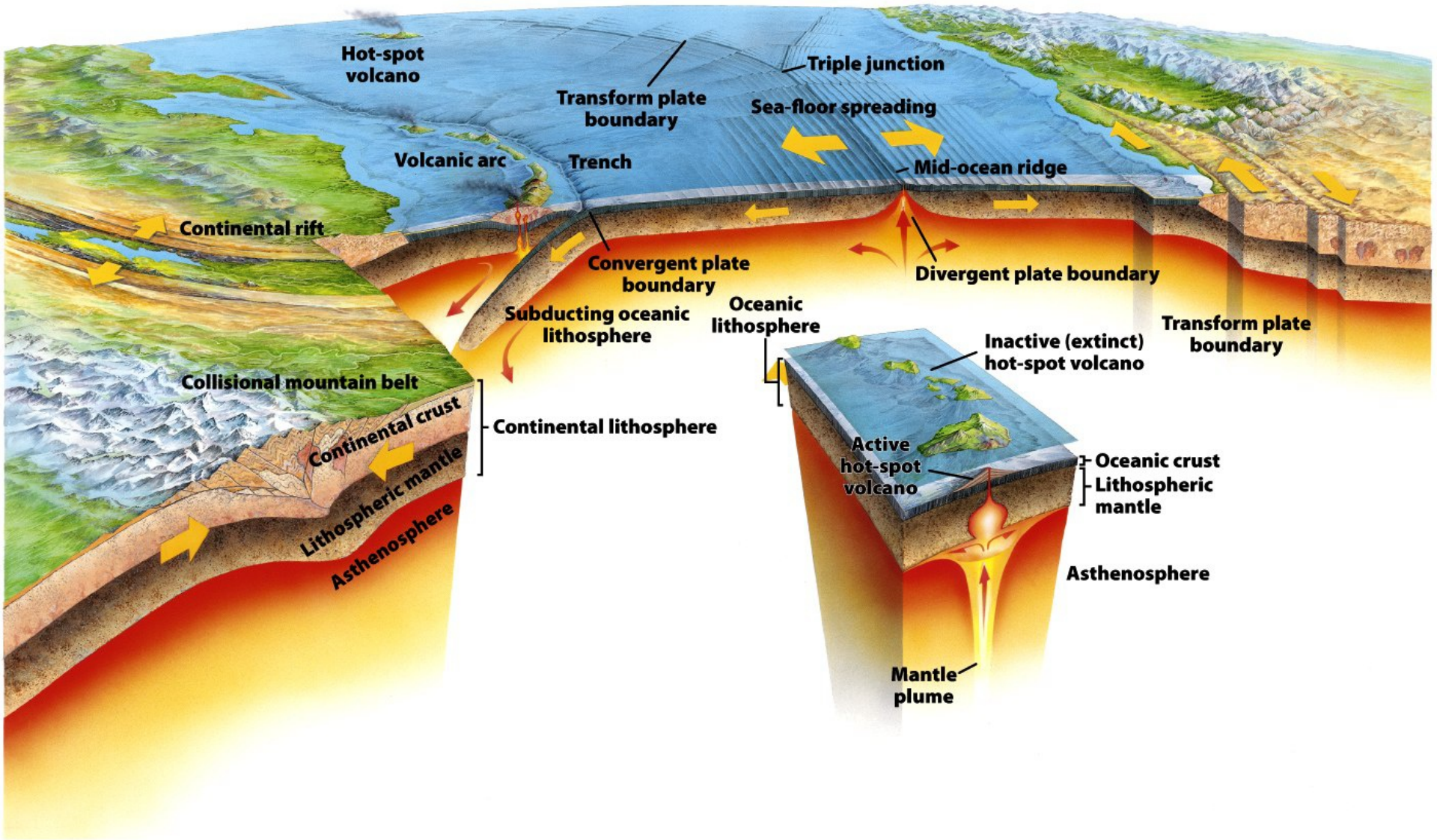


Plate boundaries in the modern Earth

See For Yourself C: investigating plate boundaries using Google Earth

pg. S-6 (Appendix at back of Marshak text)

http://www.wwnorton.com/college/geo/earth4/google-earth.aspx

- Download 'SeeForYourselfSites.kmz' – location file for Google Earth
- Read introduction on pg. S-1 of Marshak
- See also GeoTours textbook supplement – download 'GeoTours.kmz' file to accompany it