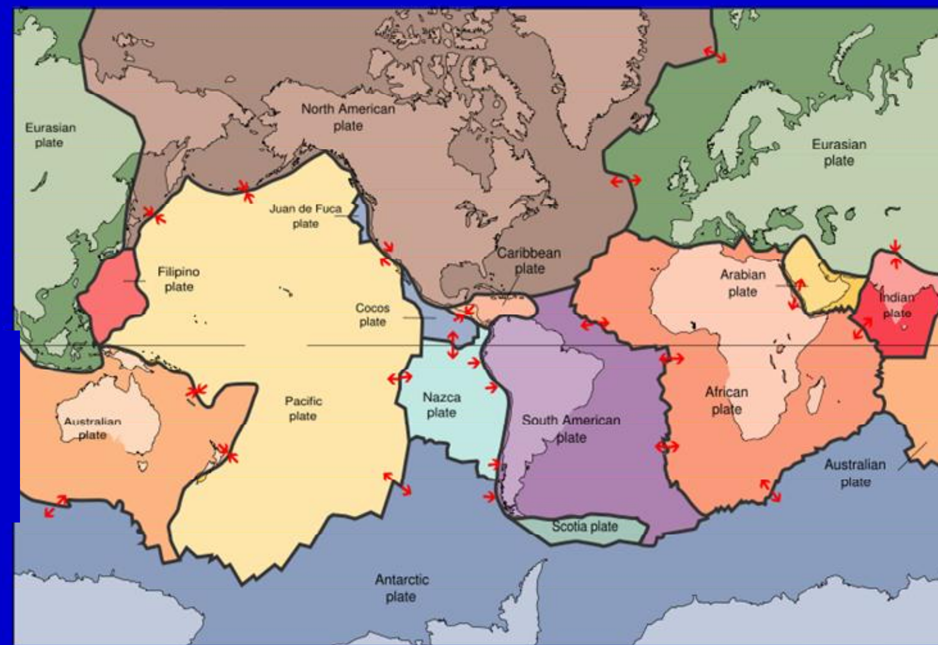
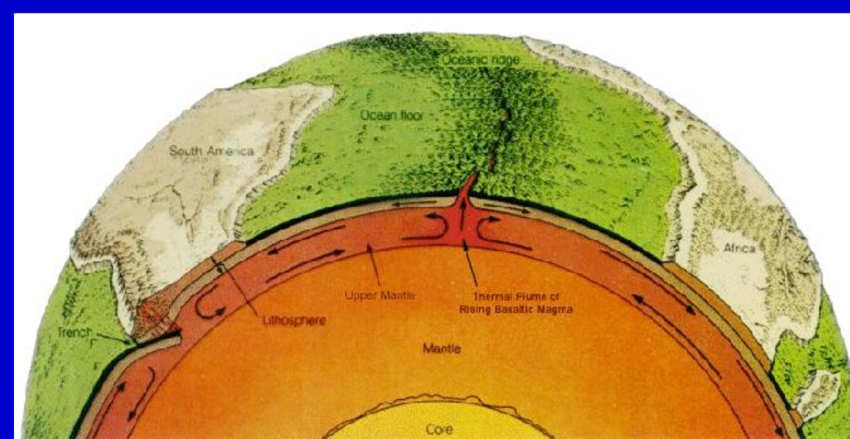
PLATE TECTONICS - Part I

Geology's Modern Paradigm

Background and Overview





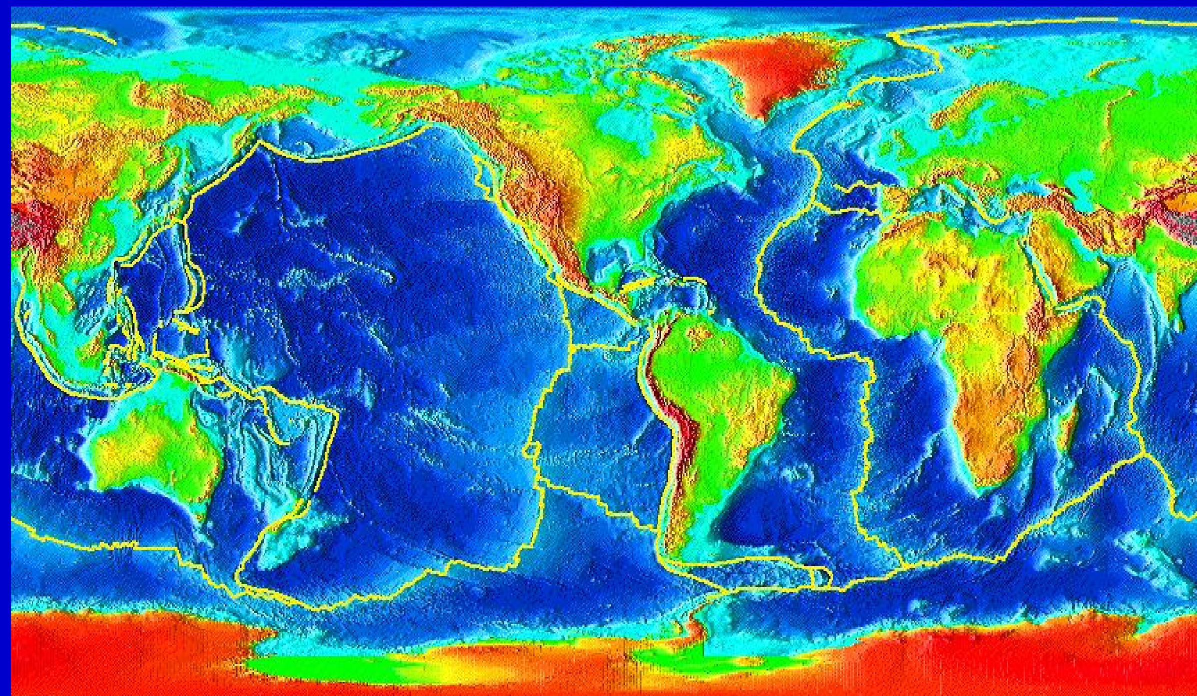
Physical Geology – GEOL100

Ray Rector - Instructor

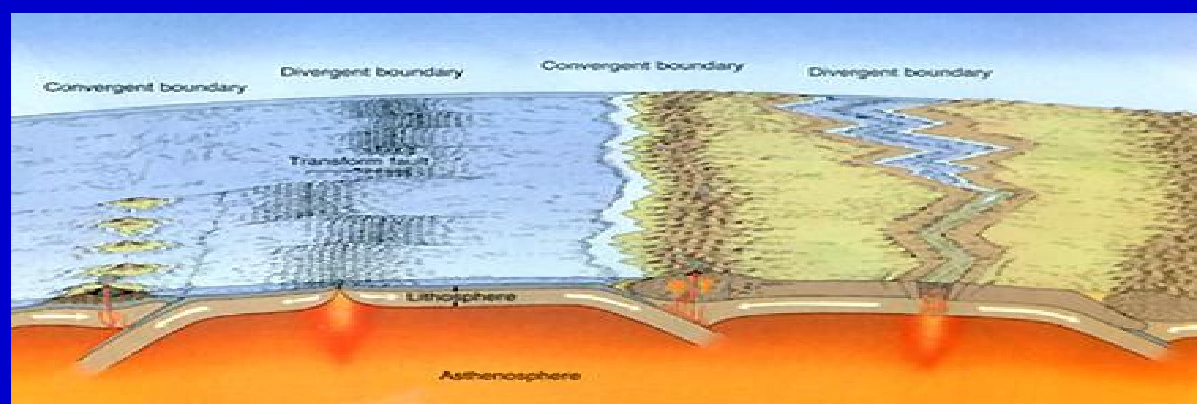
Topics in Plate Tectonics

Topics

- ✓ Age of the Earth
- ✓ Earth Physiology
- ✓ Isostasy
- ✓ Continental Drift
- ✓ Plate Tectonics Theory
- ✓ Seafloor Spreading
- ✓ Subduction
- ✓ Driving Mechanisms



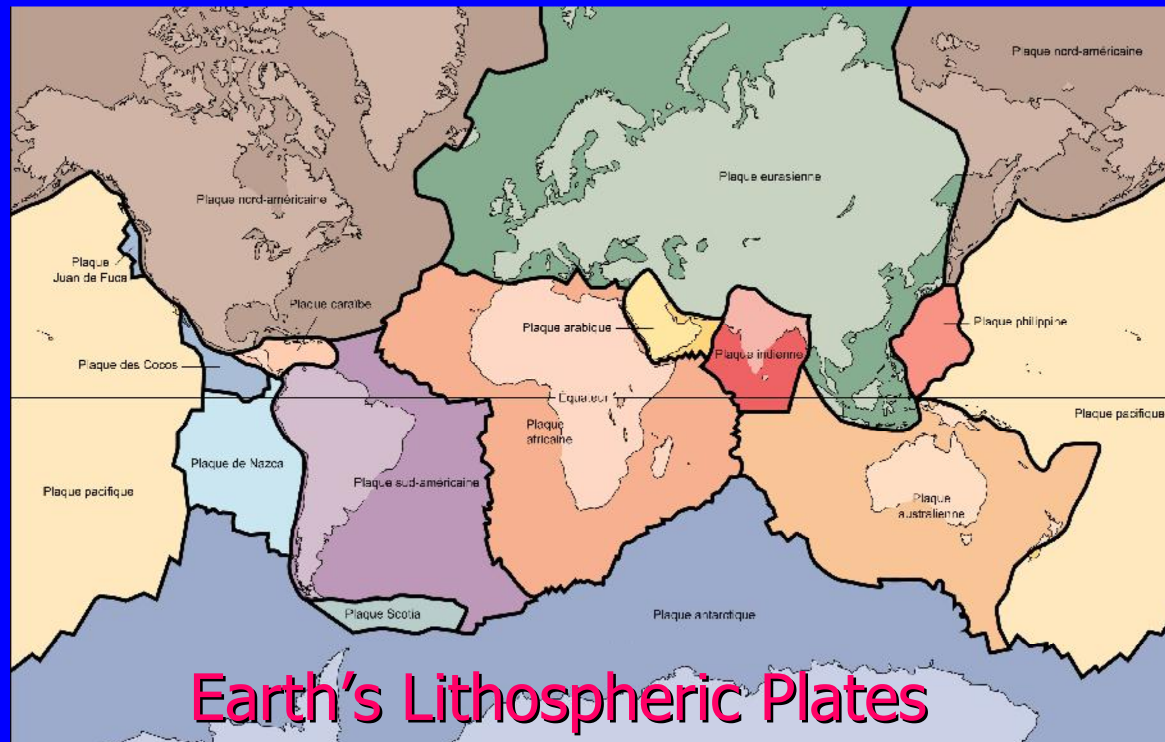
Crustal Plate Boundaries



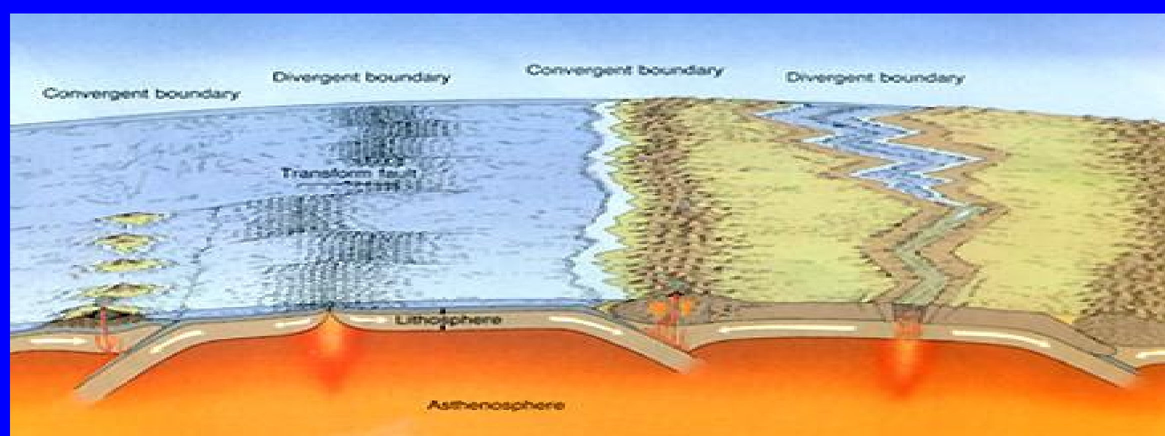
INTRO TO PLATE TECTONICS

Key Features:

- ✓ 14 Lithosphere Plates
- ✓ 6 Major, 8 Minor
- ✓ 100-300 km thick
- ✓ Strong and rigid
- ✓ Plates float on partially molten asthenosphere
- ✓ Plates are mobile
- ✓ Cm's/yr motion rates
- ✓ **Seafloor Spreading creates new oceanic plates**
- ✓ **Subduction destroys older oceanic plates**



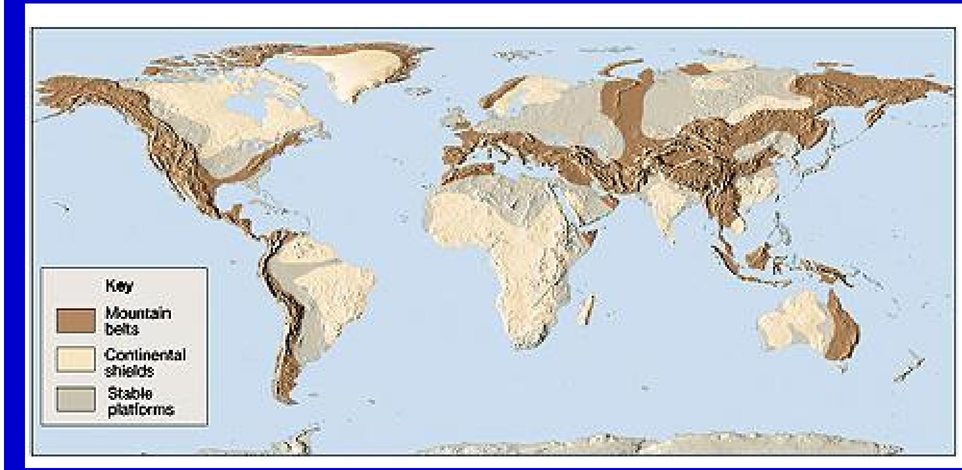
Earth's Lithospheric Plates



Dynamics of a Restless Planet

Earth Exhibits a Long History of Mountain Building Events

- ✓ Activity stretching over billions of years of time
- ✓Numerous belt-like regions of exposed crustal rocks show intense deformation



Present-day Mountain Belt of Folded and Faulted Crust

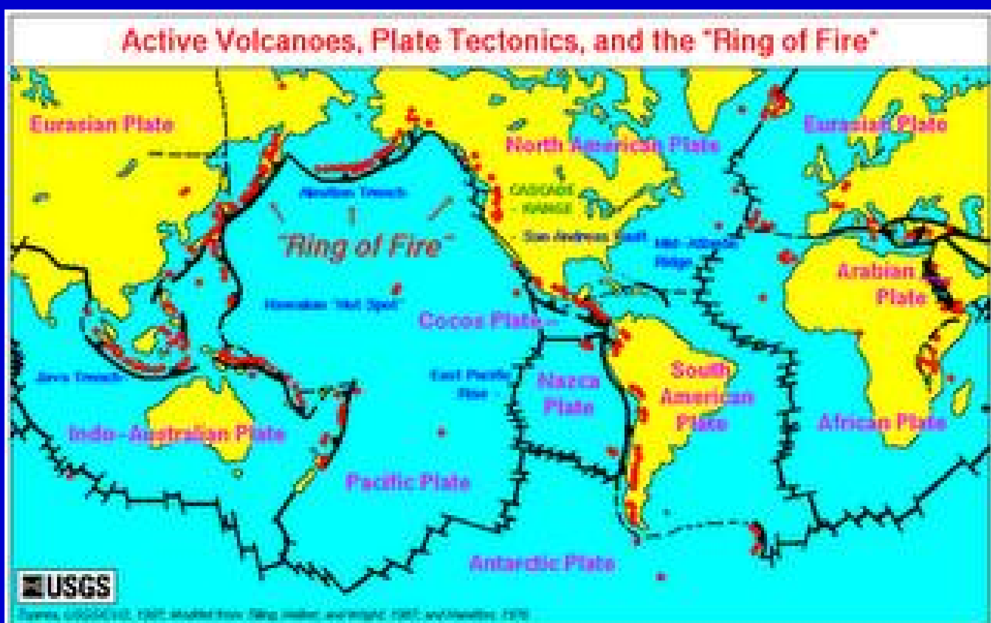
Dynamics of a Restless Planet

Earth's Surface Exhibits a Long History of Volcanic Activity

✓ Billions of years of volcanic activity

✓ Widespread evidence of regional-scale volcanism occur in belt-like exposures

✓ Volcanism found in both continental and oceanic settings



Mt St Helens Eruptions

Dynamics of a Restless Planet

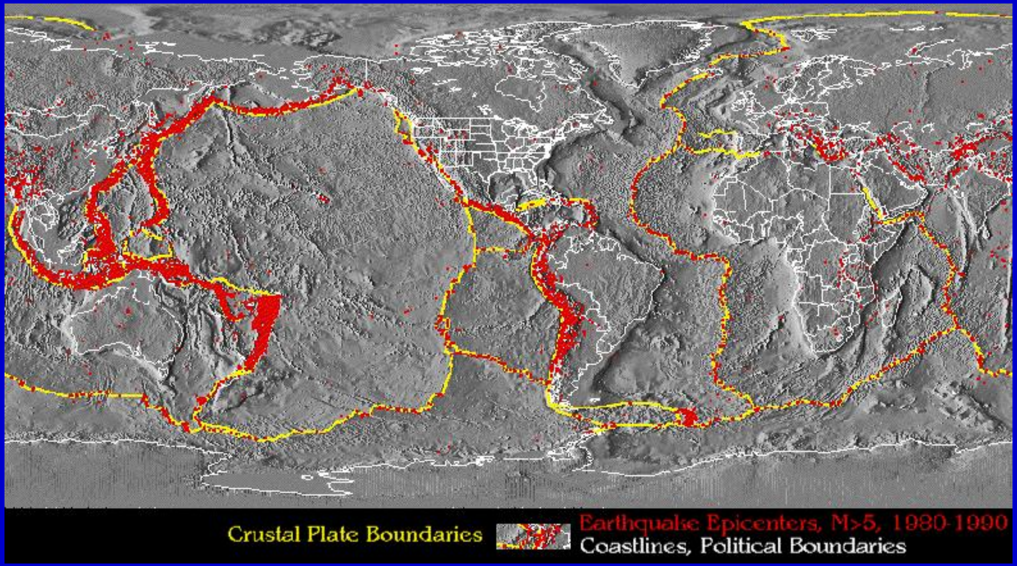
Earth's Surface Exhibits Extensive Faulting Activity

✓ Evidence of faulting stretching over billions of years of time

✓ Worldwide occurrence of local and regional-scale faulting occur along belt-like regions

✓ Faulting and associated quakes found in both continental and oceanic settings

The Great San Francisco Earthquake of 1906



Earth's Age

How Old Is the Earth?

How Can We Determine the Age of Earth?

How Can We Date Earth's Geologic Events?

Scientific Means of Dating Earth

Two Primary Means of Dating Rocks:

1) **Relative Dating**

- ✓ Determines the temporal order of rock forming events
- ✓ Does not give numeric ages
- ✓ Use of stratigraphic principles and fossils

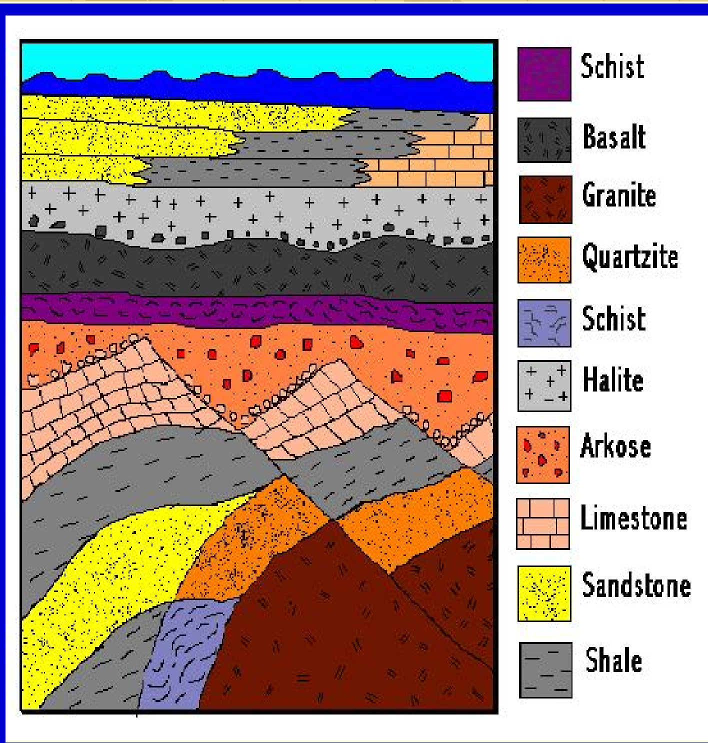
2) **Absolute Dating**

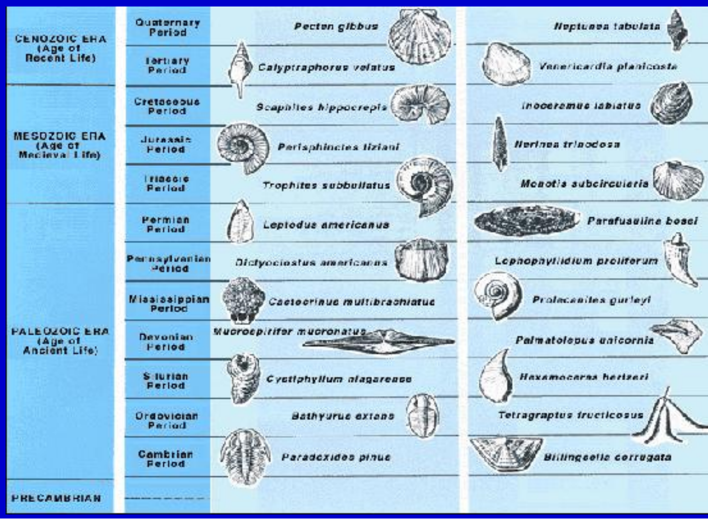
- ✓ Determines the numeric age of rock forming events
- ✓ Only appropriate for ages of igneous rocks and minerals
- ✓ Primary method is the ***radiometric technique***
- ✓ Used in conjunction with stratigraphic principles and fossils

Relative Dating and Stratigraphy

Relative Dating Principles

1) **Superposition**
   - ✓ Oldest on bottom
   - ✓ Youngest on top
2) **Cross-cutting**
   - ✓ Cross-cutting structure is younger than the structure that is being cross-cut
3) **Inclusion**
   - ✓ Inclusion is older than rock that surrounds it
4) **Fossil Succession**
   - ✓ Rocks containing a specific fossil species indicates a specific age

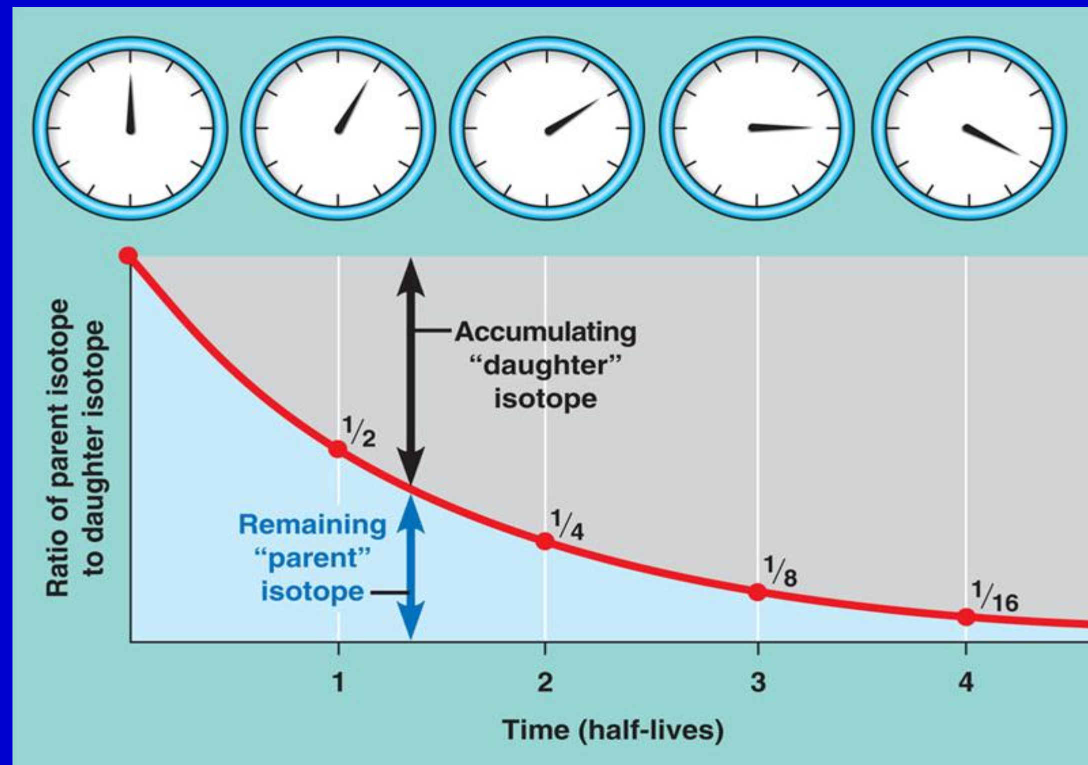


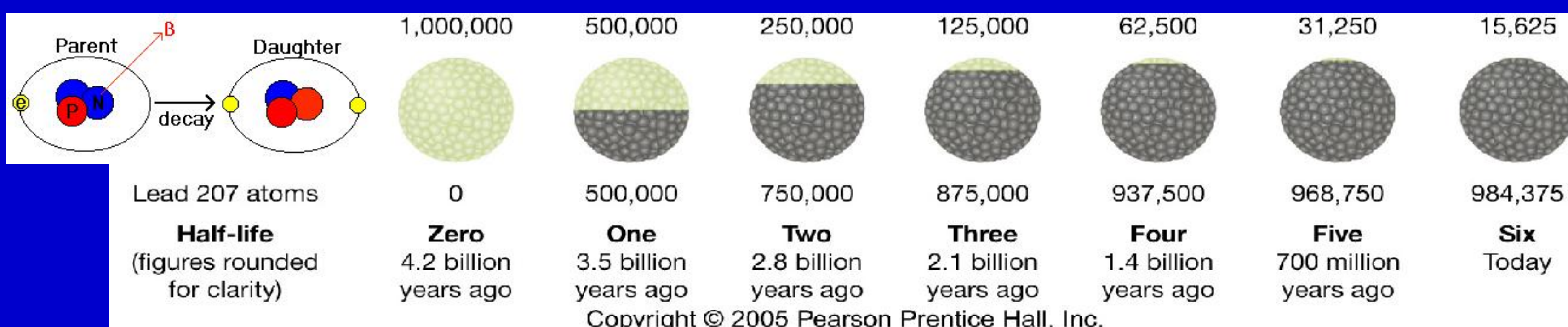


Principles of Radiometric Decay

The Principles

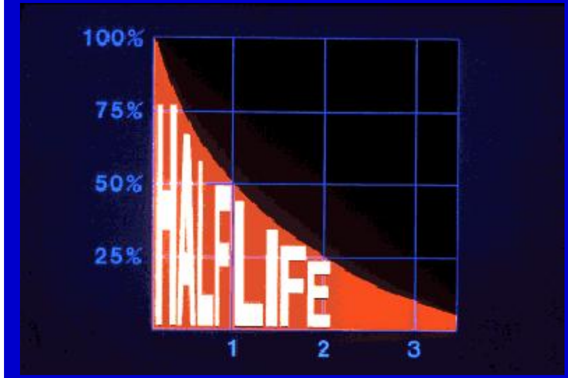
- ✓ Spontaneous decay of unstable parent element into a its unique stable daughter element
- ✓ The half-life of each parent-daughter pair is a constant
- ✓ Age of an igneous rock is determined by measuring the ratio of rock's parent-daughter material





Radiometric Half-Lives

Radioactive Parent/Daughter Pairs and Associated Half-Lives



Parent Isotope	Stable Daughter Product	Currently Accepted Half-Life Values
Uranium-238	Lead-206	4.5 billion years
Uranium-235	Lead-207	704 million years
Thorium-232	Lead-208	14.0 billion years
Rubidium-87	Strontium-87	48.8 billion years
Potassium-40	Argon-40	1.25 billion years
Samarium-147	Neodymium-143	106 billion years

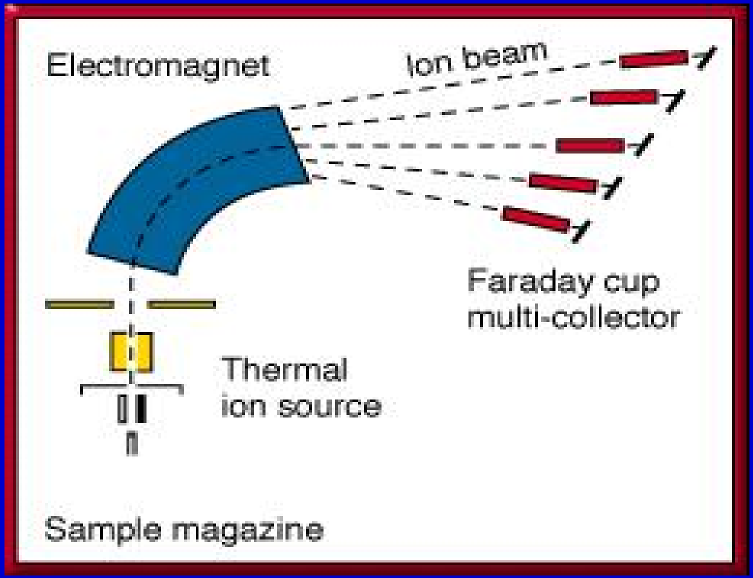
Radiometric Dating Method

Analysis of Parent/Daughter Isotopic Compositions in Rocks

✓Parent and daughter elements are isolated and refined from host mineral using conventional wet chemistry methods.

✓Geochronologists determine the isotopic abundances of each paired parent and daughter element using a mass spectrometer.

✓ Isotopic abundance data are then used to determine rock age using the decay formula.



Radiometric Dating Method

Radioactive Decay of Parent Isotope into a Daughter Isotope

The mathematical expression that relates radioactive decay to geologic time is called the ***age equation***:

$$t = \frac{1}{\lambda} \ln \left(1 + \frac{D}{P}\right)$$

where t is the age of the rock or mineral specimen,
D is the number of atoms of a daughter product today,
P is the number of atoms of the parent isotope today,
ln is the natural lograithm (logarithm to base e), and
λ is the appropriate decay constant.

(The decay constant for each parent isotope is related to its half-life, $t^{1/2}$ by the following expression: $t^{1/2} = \frac{\ln 2}{\lambda}$

Earth's Age - *Radiometric Dating of Rocks*

Earth's Oldest Rocks

Description	Technique	Age (in billions of years)
Acosta Gneiss (NW Territories, Canada)	207Pb-206Pb isochron	4.031 ± 0.003

Oldest Moon Rocks

Mission	Technique	Age (in billions of years)
Apollo 17	Rb-Sr isochron	4.60 +- 0.1

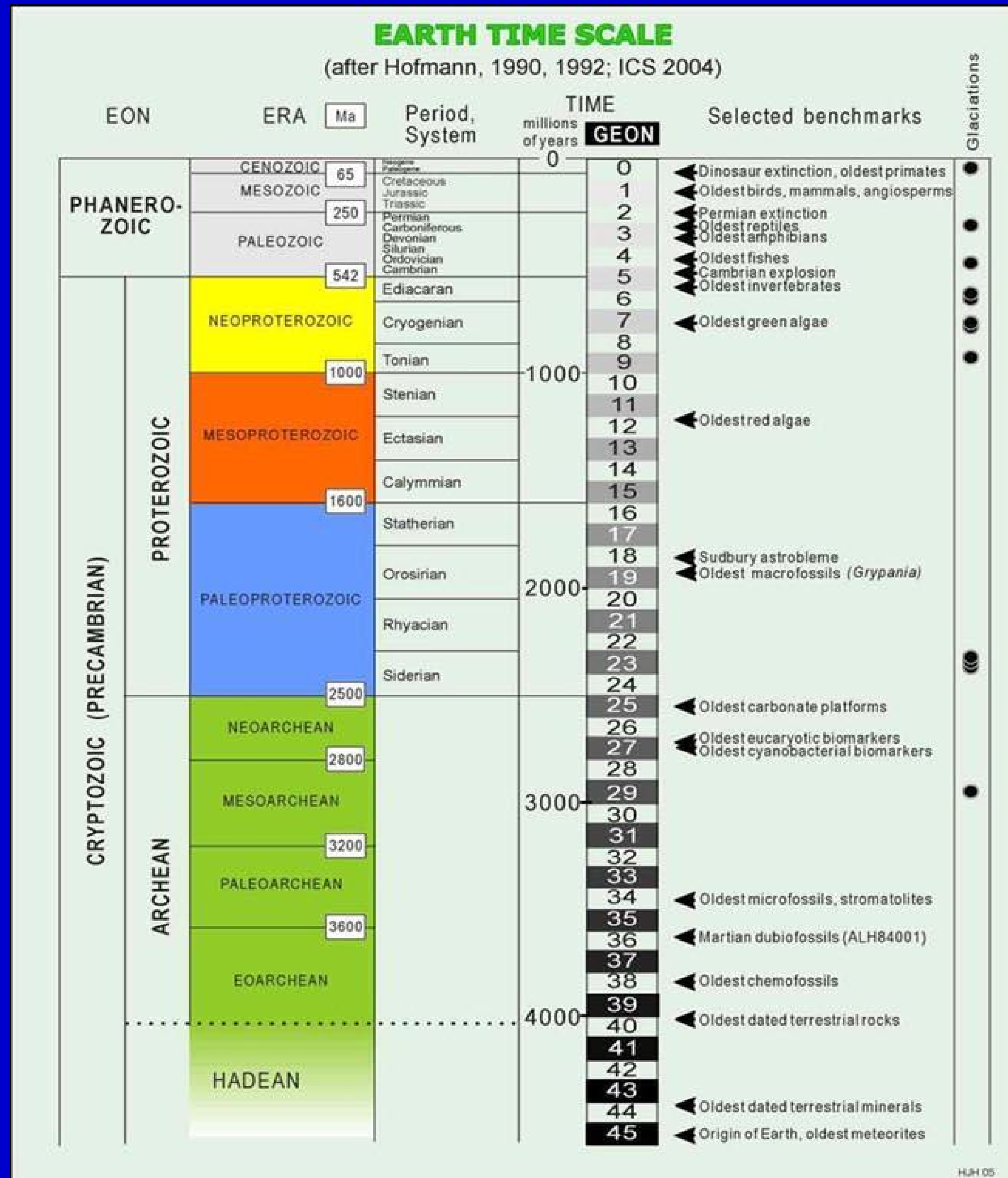
Oldest Meteorites

Description	Technique	Age (in billions of years)
Norton County (achondrite)	Mineral isochron	4.70 +- 0.1

Earth's Geological Timescale

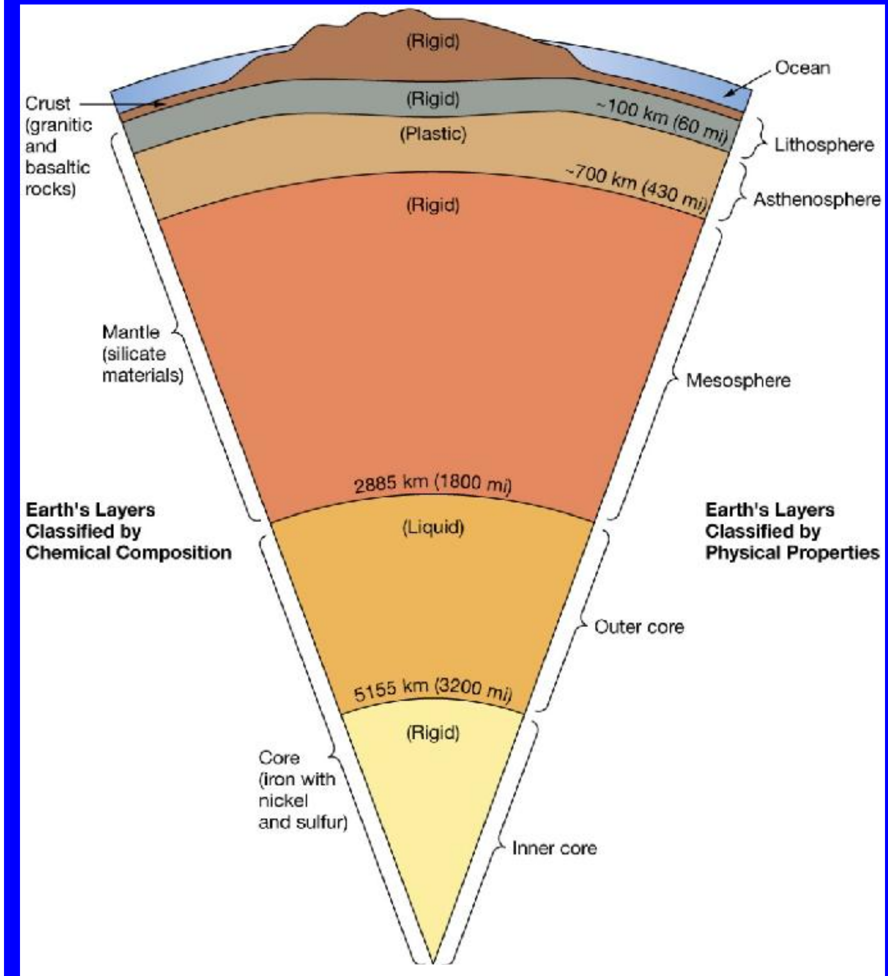
Key Ideas:

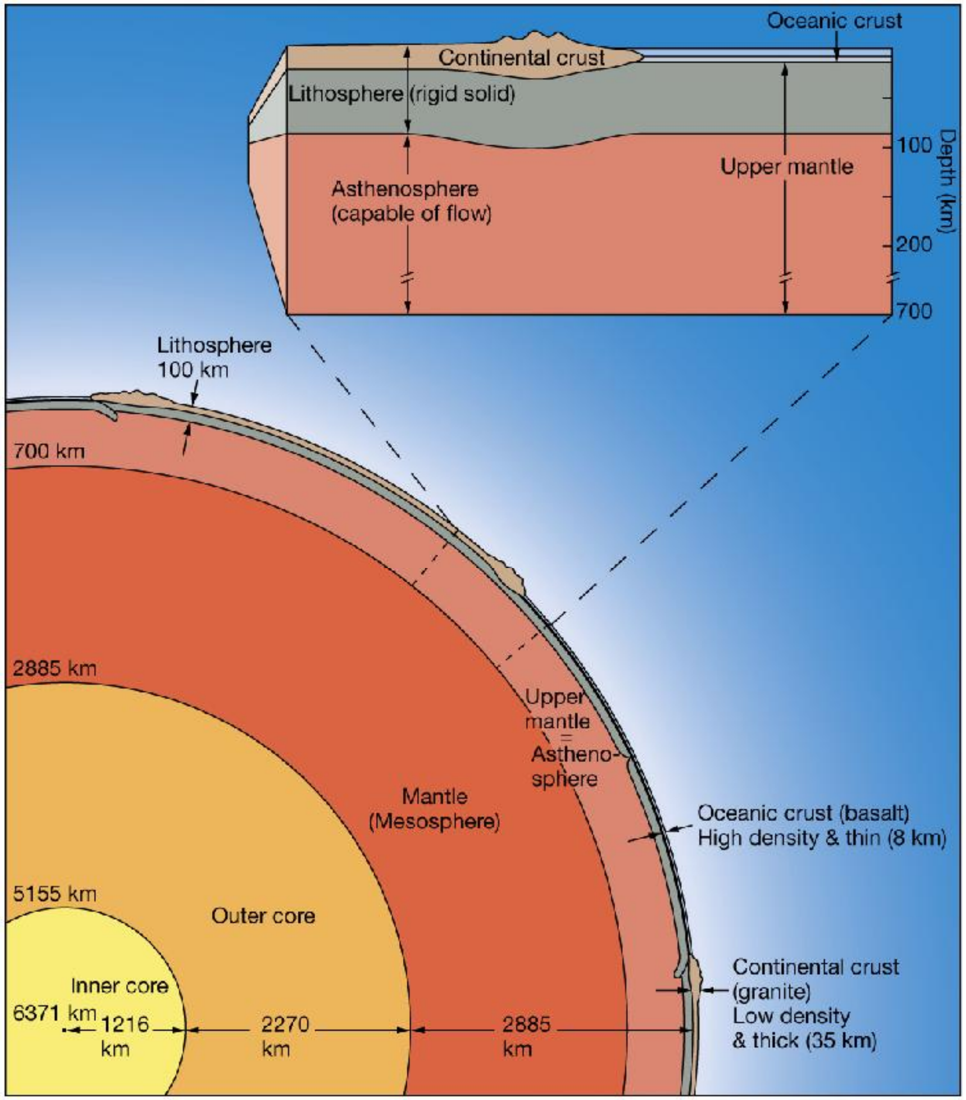
1) Originally based on relative dating and the use of age-specific fossils
2) Each period defined by unique assemblages of organisms
3) Periods separated by mass extinction events
4) Numeric ages derived from radiometric analysis of igneous rocks found within the stratigraphic record



Earth's Anatomy 101

Chemical and Physical Nature of Earth's Interior

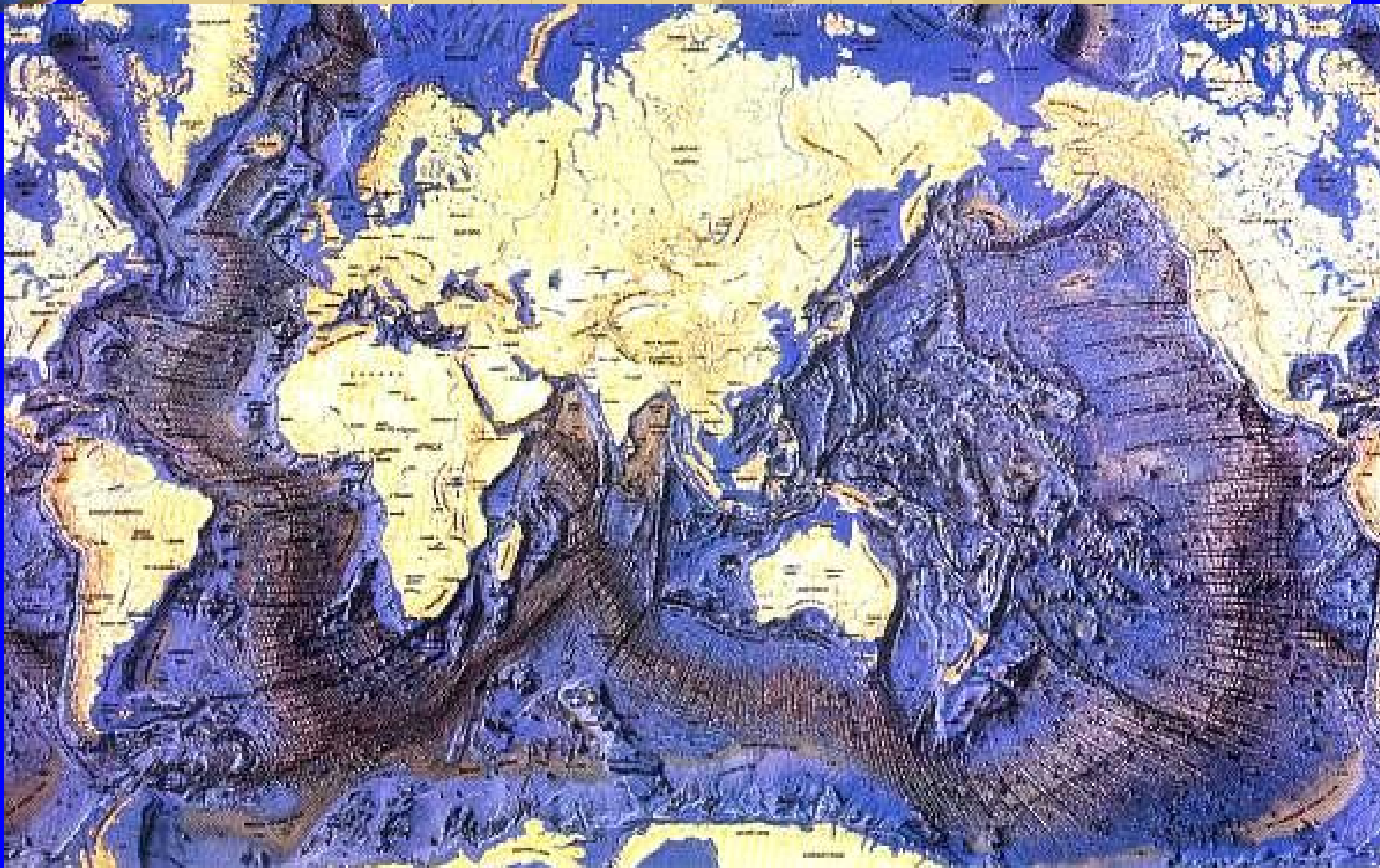




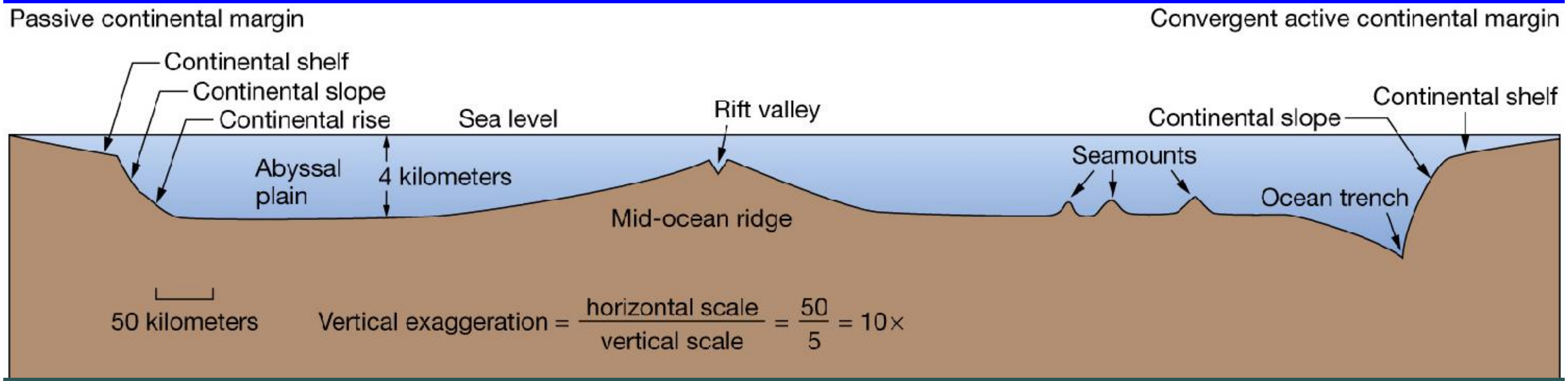
Density Layering of Earth's Interior

Earth's Continents and Ocean Basins

Topography of Earth's Ocean Floors



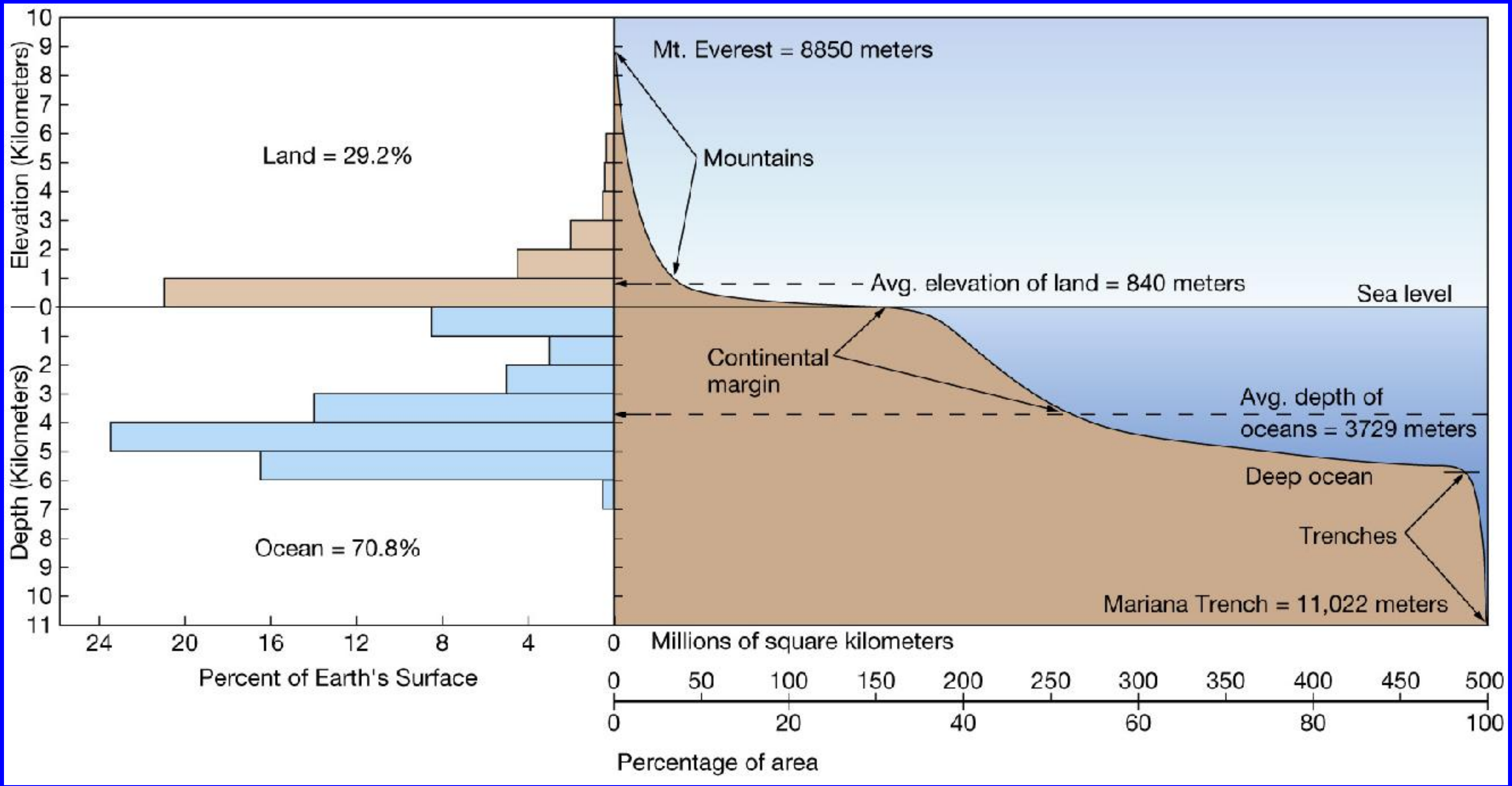
Cross-Section Profile of an Ocean Basin



Large-Scale Ocean Bottom Features

- ✓ Continental shelf, slope, and rise
- ✓ Abyssal plains and hills
- ✓ Mid-ocean ridge and rift valley
- ✓ Oceanic islands, seamounts, and guyots
- ✓ Ocean trench

Elevation Relief Profile of Earth's Crust



1. Sea level
2. Continental shelf
3. Continental slope
4. The deep ocean floor
5. Mean depth of ocean 3700m
6. Mean altitude of land 840m
7. Mt. Everest 8848m
8. Mariana Trench 11022m

Earth's Continents and Ocean Basins

1) Two Different Types of Crust

- ✓ Continental - Granitic
- ✓ Oceanic - Gabbroic

2) Continental Crust

- ✓ Lighter (2.7 g/ml)
- ✓ Thicker (30 km)
- ✓ High Standing (1 km elev.)

3) Oceanic Crust

- ✓ Denser (2.9 g/ml)
- ✓ Thinner (7 km)
- ✓ Low Standing (- 4 km elev.)

Two Primary Types of Earth Crust

1) **Two Different Types of Crust**

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- ✓ Oceanic = Gabbroic

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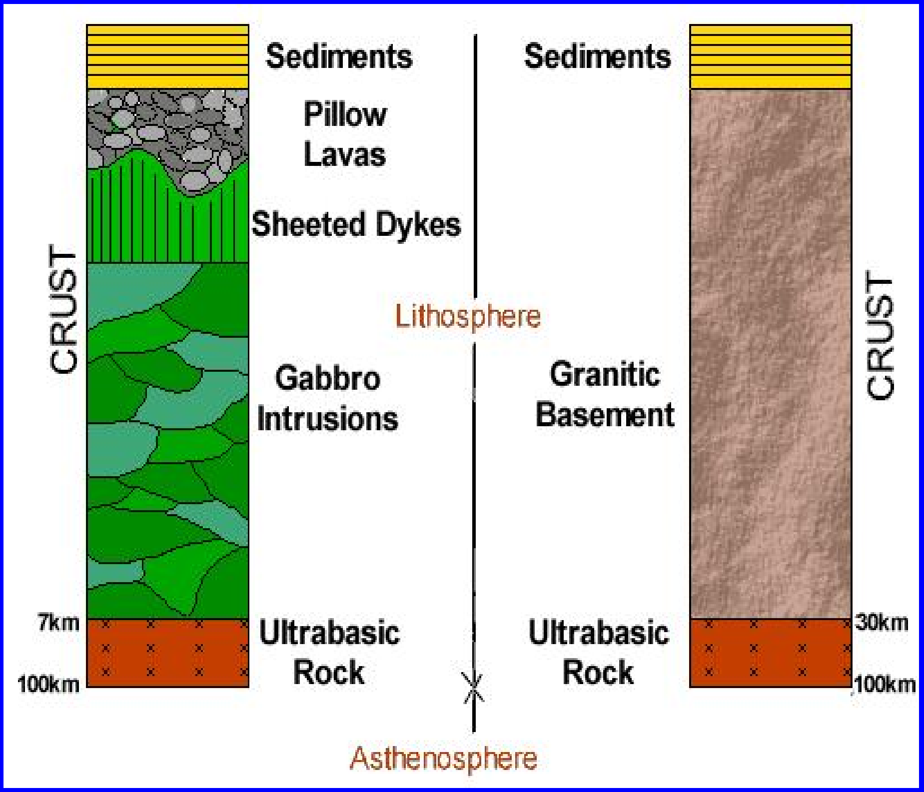
Oceanic Crust | **Continental Crust**

Gabbroic Rock | **Granitic Rock**



Concept of Buoyancy

1) Buoyancy is an important force on objects immersed in a fluid.

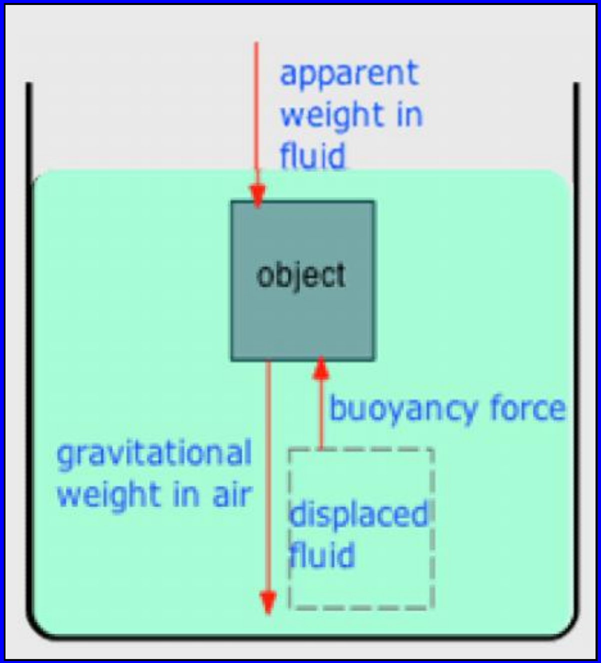
2) Buoyancy is the fluid pressure exerted on an immersed object equal to the weight of fluid being displaced by the object.

3) The concept is also known as Archimedes's principle

- Principle applies to objects in the air and on, or in, the water.
- Principle also applies to the crust "floating" on the mantle, which is specially termed "isostacy".

4) Density is a controlling factor in the effects of buoyancy between an object and its surrounding immersing fluid

- The greater the difference in density between the object and the fluid, the greater the buoyancy force = sits high
- The lesser the difference in density between the object and the fluid, the lesser the buoyancy force = sits low

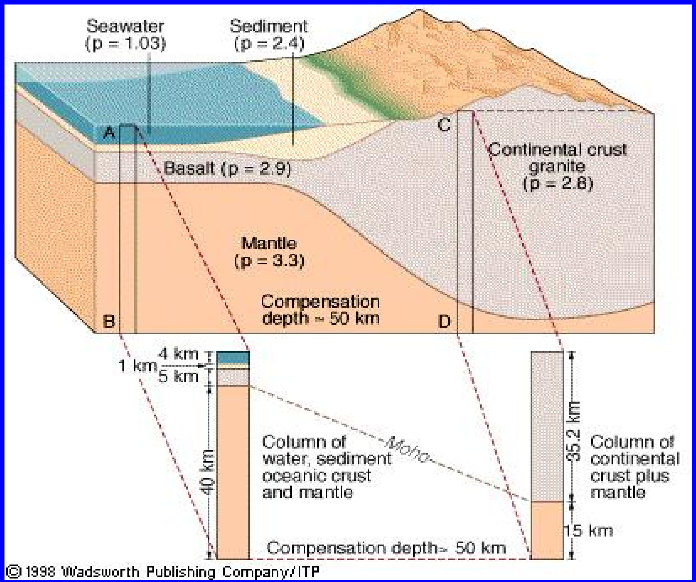


Example of Buoyancy: Boat on a Lake

What is the density of the boat with cat in relation to the lake water?

The Concept of Isostasy

Defined: state of gravitational equilibrium between the earth's *rigid* lithosphere and *fluid* asthenosphere, such that the tectonic plates "float" in and on the underlying mantle at height and depth positions controlled by plate thickness and density.



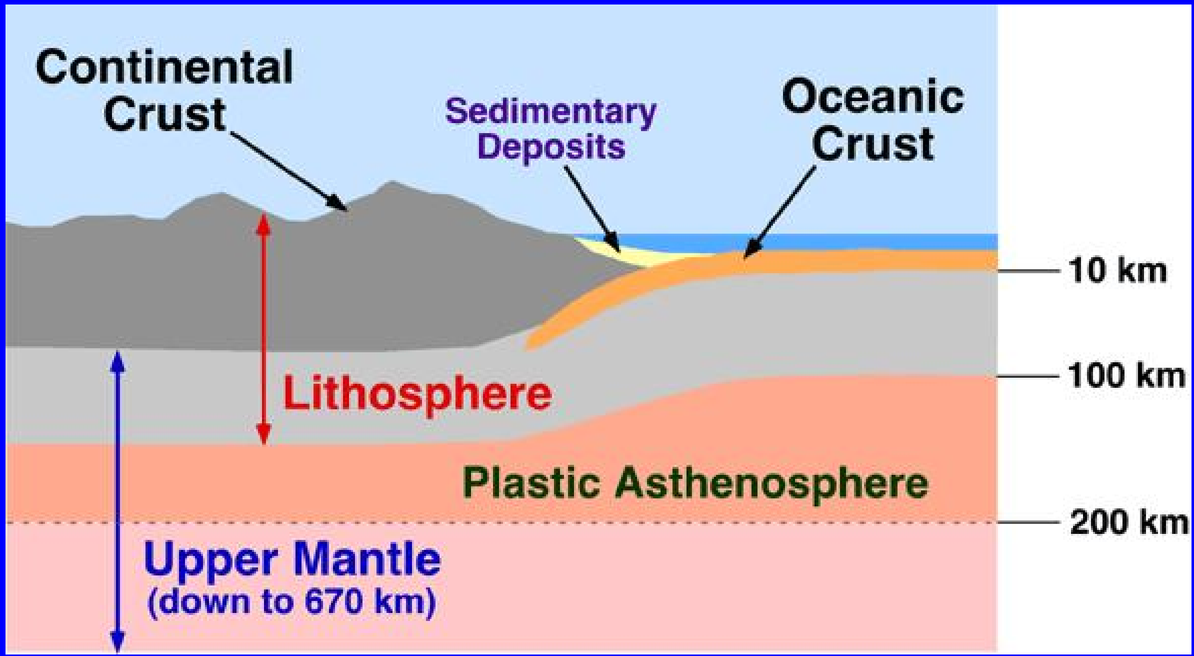
- ➢ The term “isostasy” is from Greek “iso” = equal; “stasis” = equal standing.
- ➢ Earth’s strong rigid plates exert a downward-directed load on the mobile, underlying weaker, plastic-like asthenosphere – pushing down into the mantle.
- ➢ The asthenosphere exerts an upward pressure on the overlying plate equal to the weight of the displaced mantle – *isostatic equilibrium* is established.
- ➢ Mantle will flow laterally to accommodate changing crustal loads over time – this is called *isostatic adjustment*
- ➢ Plate tectonics, erosion and changing ice cap cause isostatic disequilibrium

Crust Floating in Mantle

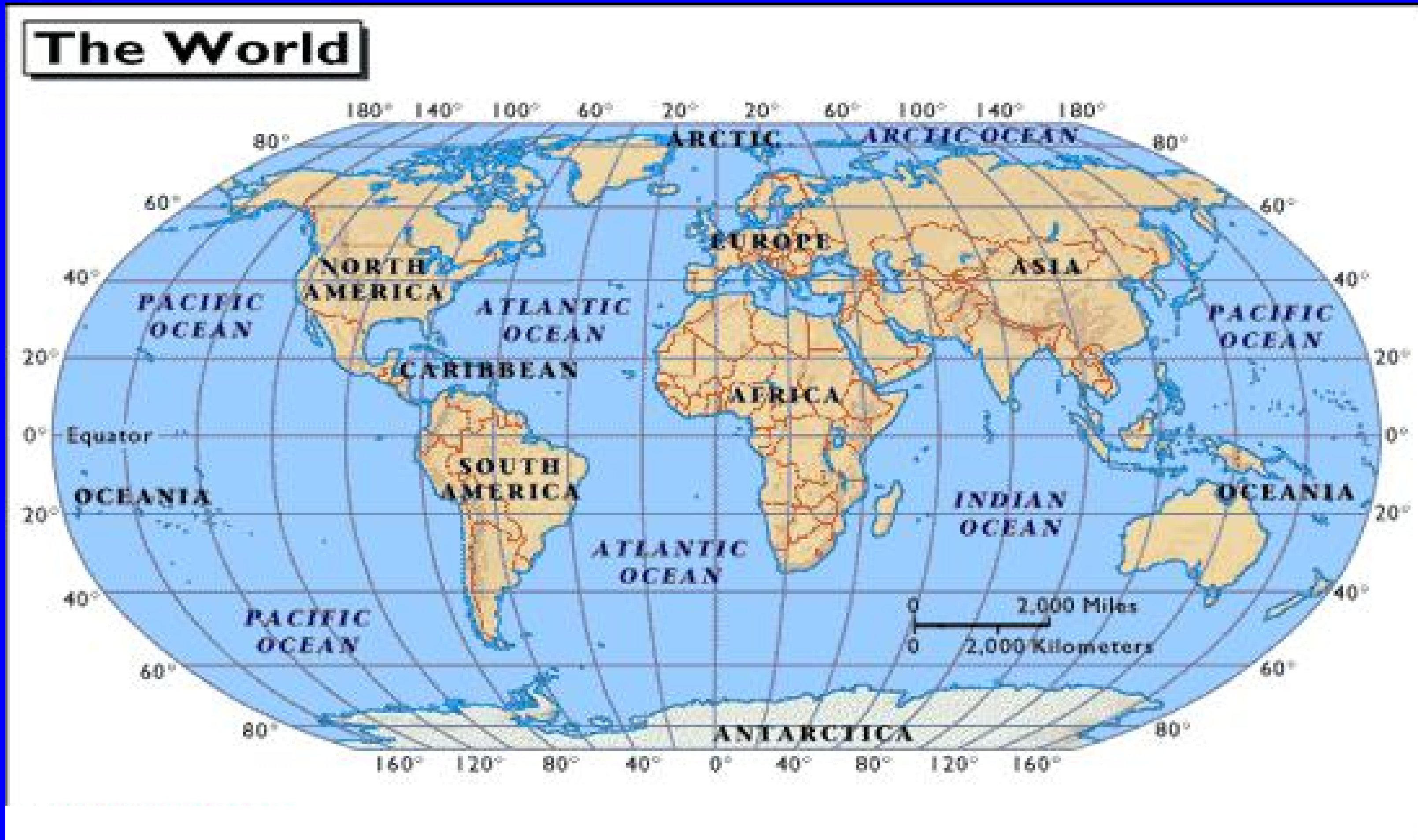
1) Isostatic Equilibrium Between Crust and Mantle; Lithosphere and Asthenosphere

2) Isostatic Adjustments Made Over Geologic Time When A Layer's Density and/ or Thickness Changes

4) Isostatic Adjustments Produce Vertical Movement of Crust – Uplift or Subsidence



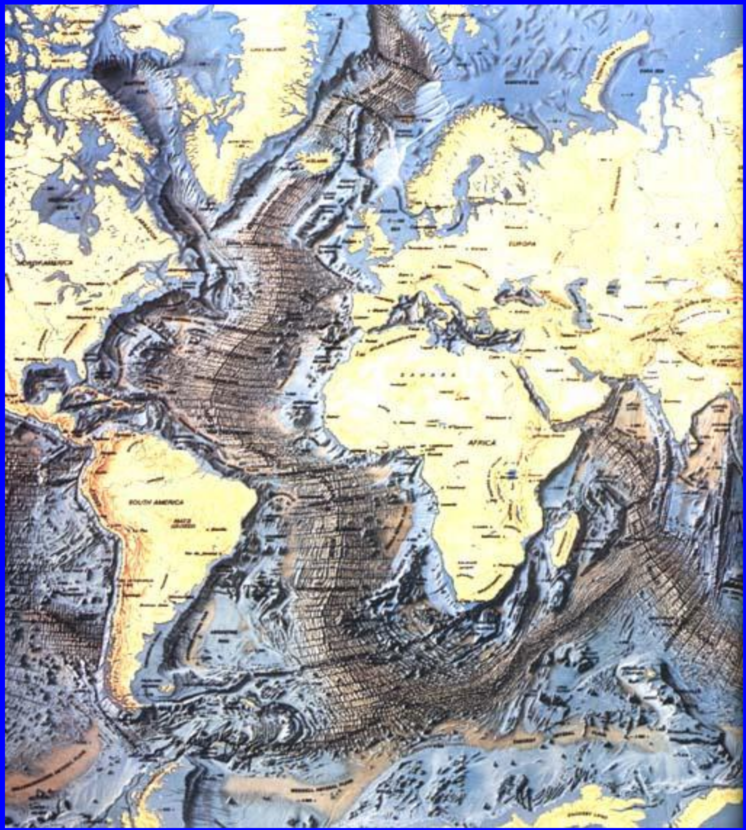
Earth's Continents and Ocean Basins



Key Points: 1) Up until 50 years ago, all physiology maps of earth showed ocean basins as blue = lack of sea bottom data. 2) Continental land masses were well-mapped much earlier on.

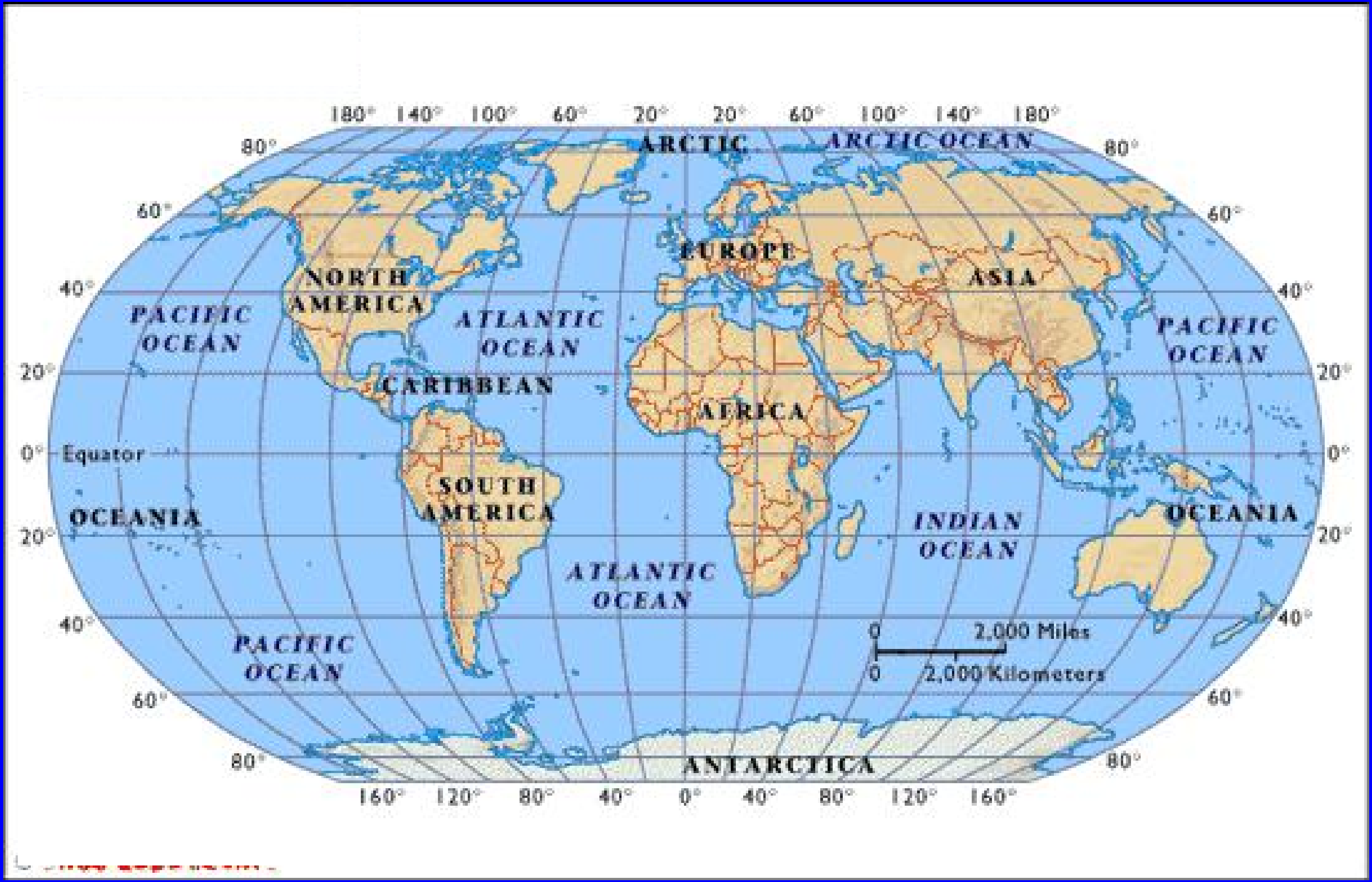
OCEANOGRAPHY AND SEAFLOORS

- Technologic Innovations Light Up the Ocean Bottoms
  - ✓ Sonar and Radar Mapping
  - ✓ Piston coring and Drilling
  - ✓ Magnetometer surveys
  - ✓ Radiometric and fossil dating
  - ✓ Submersible investigations
  - ✓ Subsurface seismic surveys
  - ✓ Computer-assisted research
- Detailed Seafloor Image Emerges
  - ✓ Ridges, fracture zones, trenches
- Radical New Ideas Take Hold
  - ✓ Seafloor Spreading and Subduction
  - ✓ The Plate Tectonic Theory



The Seafloor Illuminated!

Earth's Continents and Ocean Basins



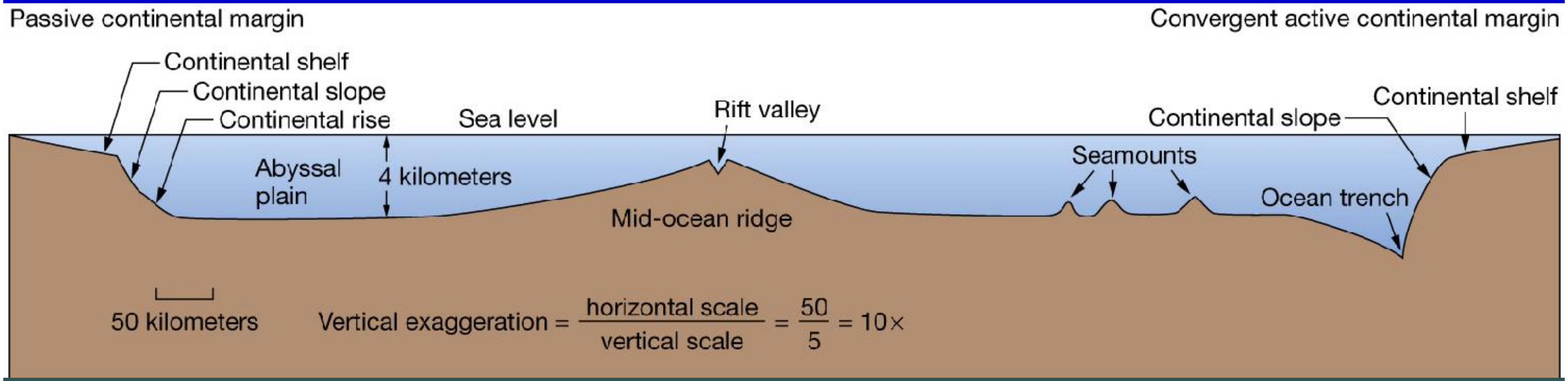
Typical Old-school World Map: Ocean Basins Colored Blue

100 Years ago: Unknown What Lied Under the Blue

Topography of Earth's Surface

An Earth with No Ocean!

Cross-Section Profile of an Ocean Basin



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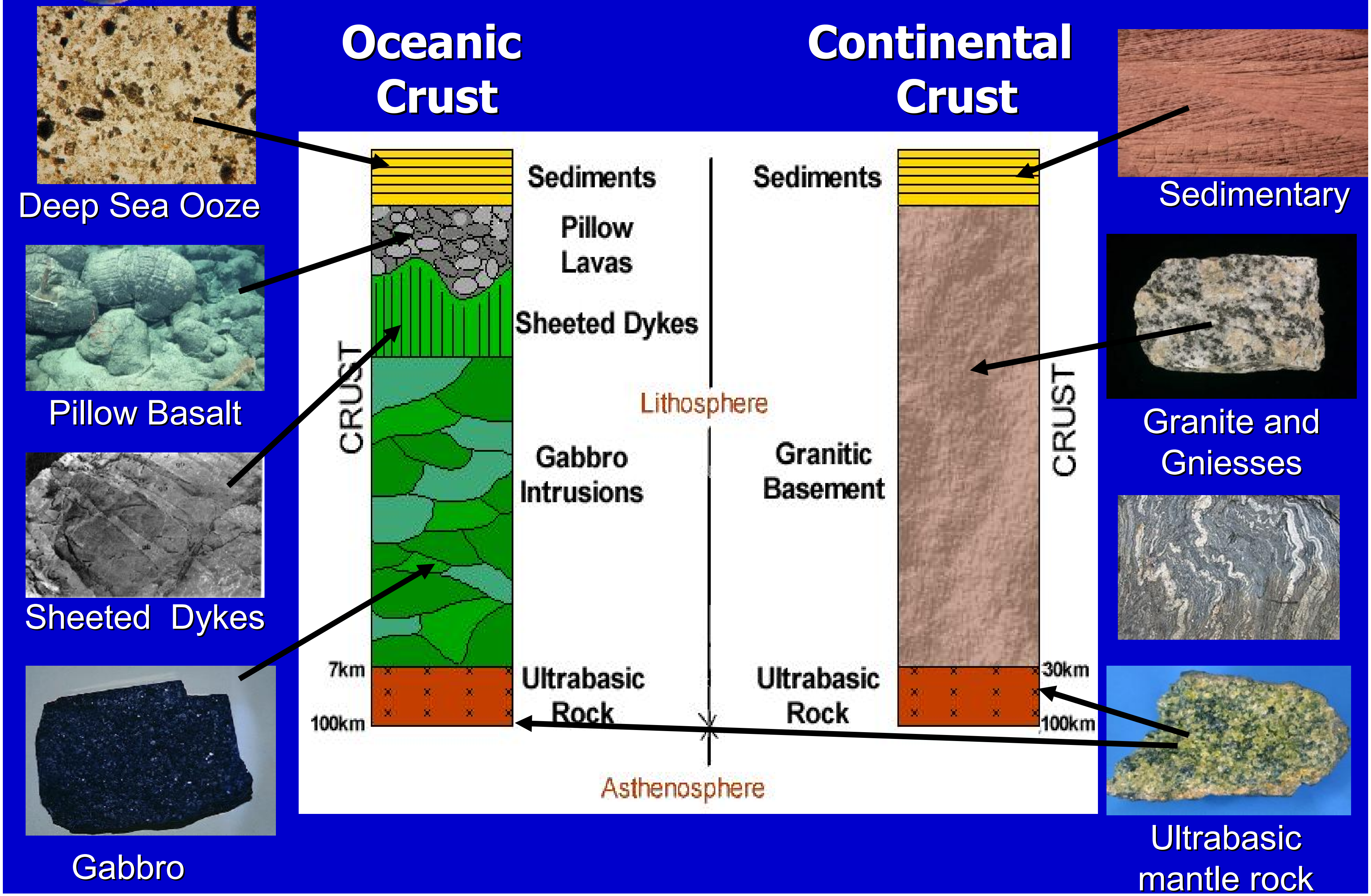
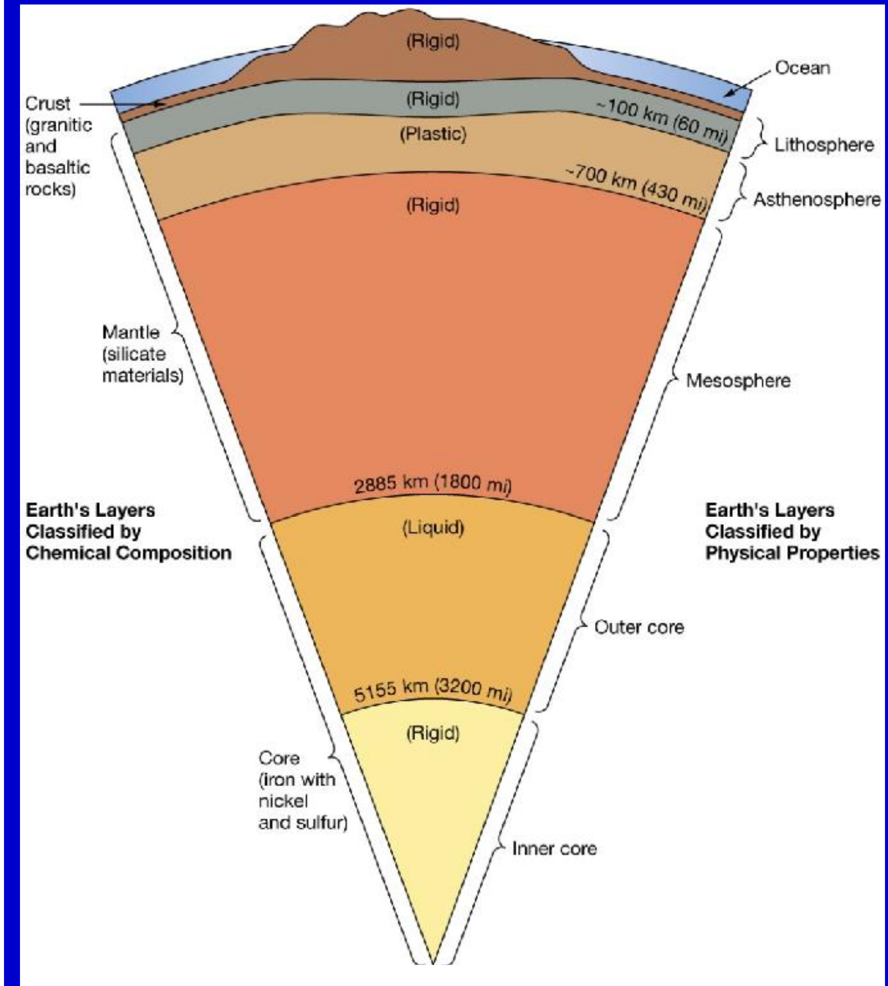
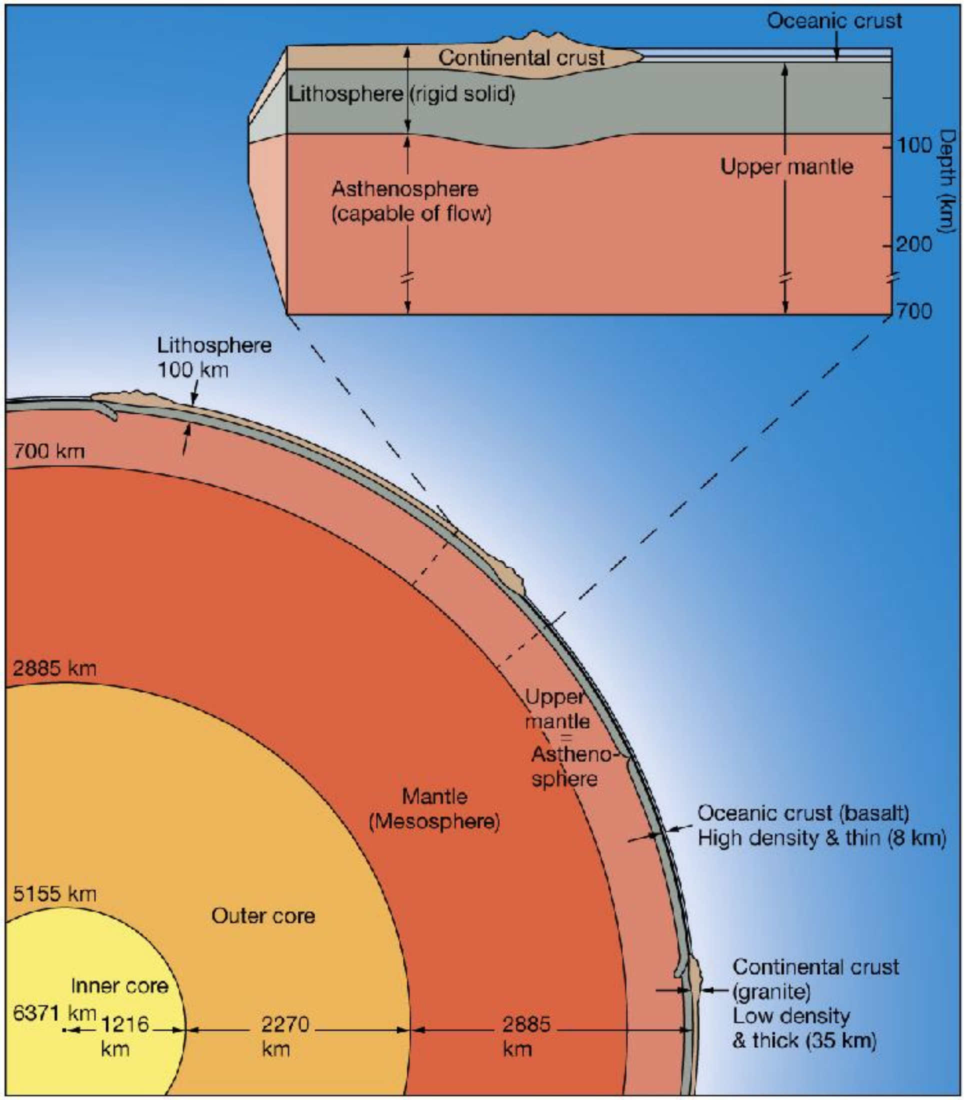
Two Primary Types of Earth Crust



Earth's Layered Interior

Chemical and Physical Nature of Earth's Interior





Density Layering of Earth's Interior

INTRO to PLATE TECTONIC THEORY

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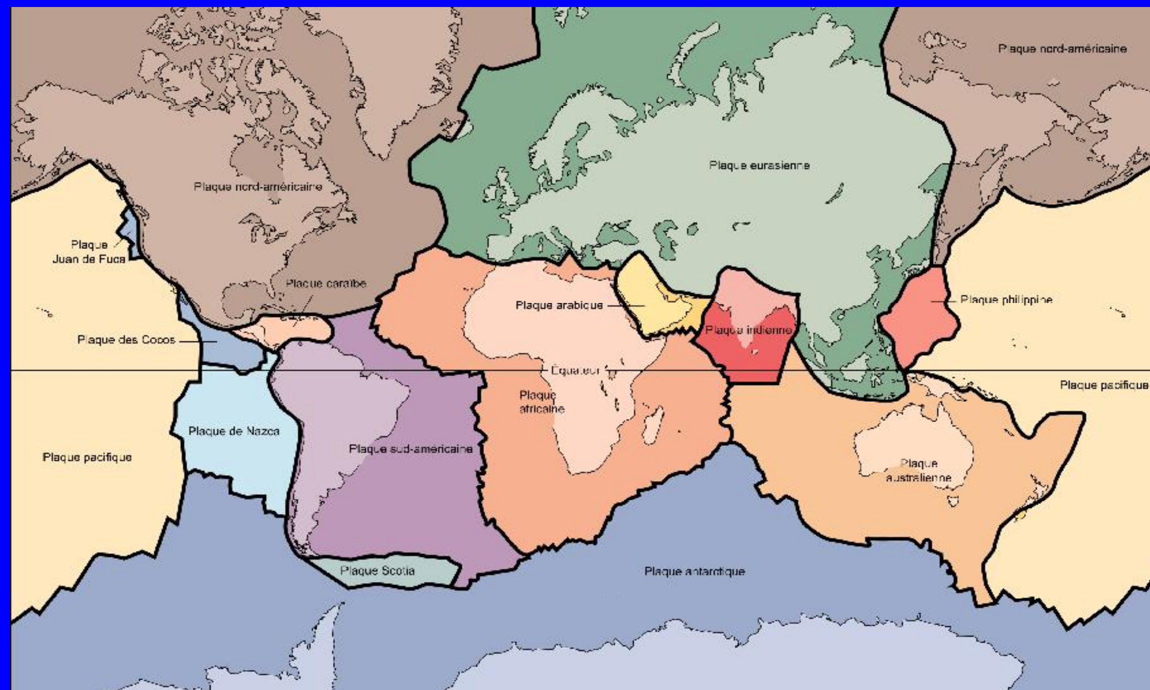
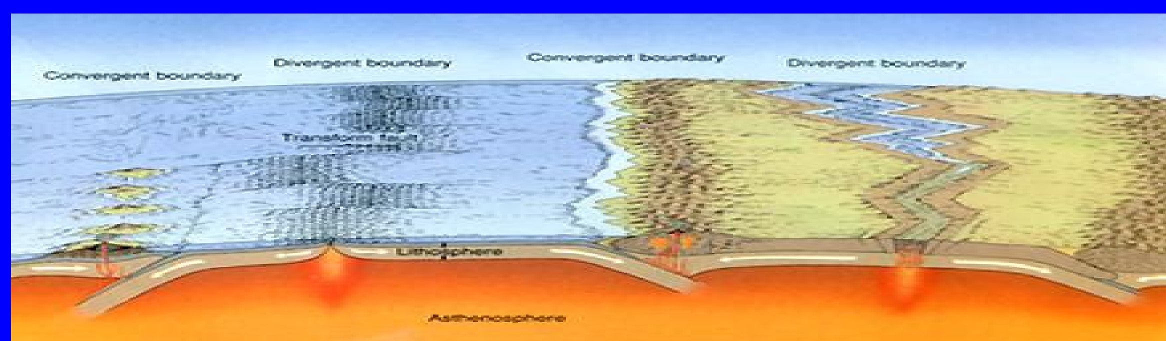
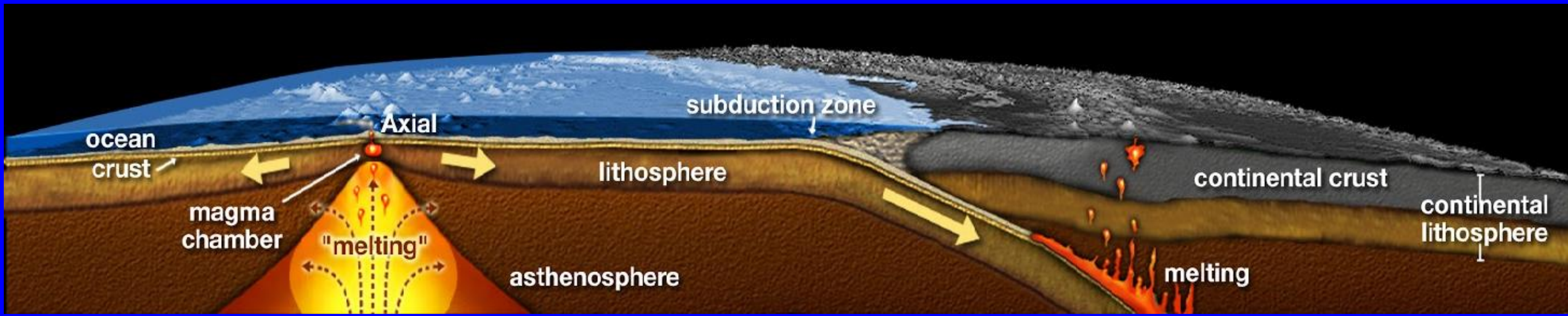


Earth's Lithospheric Plates



Animation of Overview of Plate Tectonics – on YouTube

Two Principle Tectonic Axioms



Seafloor Spreading

Subduction

1) **Seafloor Spreading** = Plate Constructive

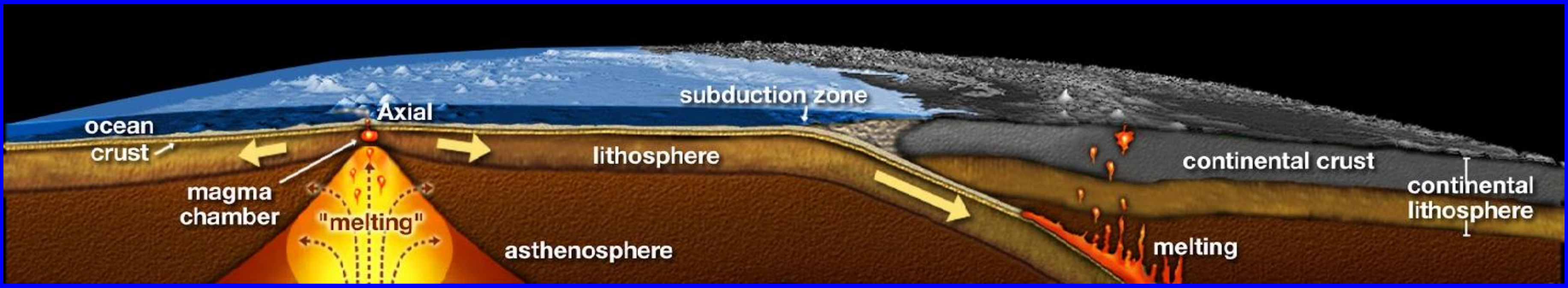
- Coincides with mid-ocean ridges
- Divergent plate boundary
- Tholiietic basaltic volcanism

2) **Subduction** = Plate Destructive

- Coincides with deep sea trenches and volcanic arcs
- Convergent plate boundary
- Explosive Andesitic volcanism

Animation of Overview of Plate Tectonics – on YouTube

Scientific Journey of Discovery/Testing to Tectonic Theory



1) What sorts of observations were made and where? Data collected?

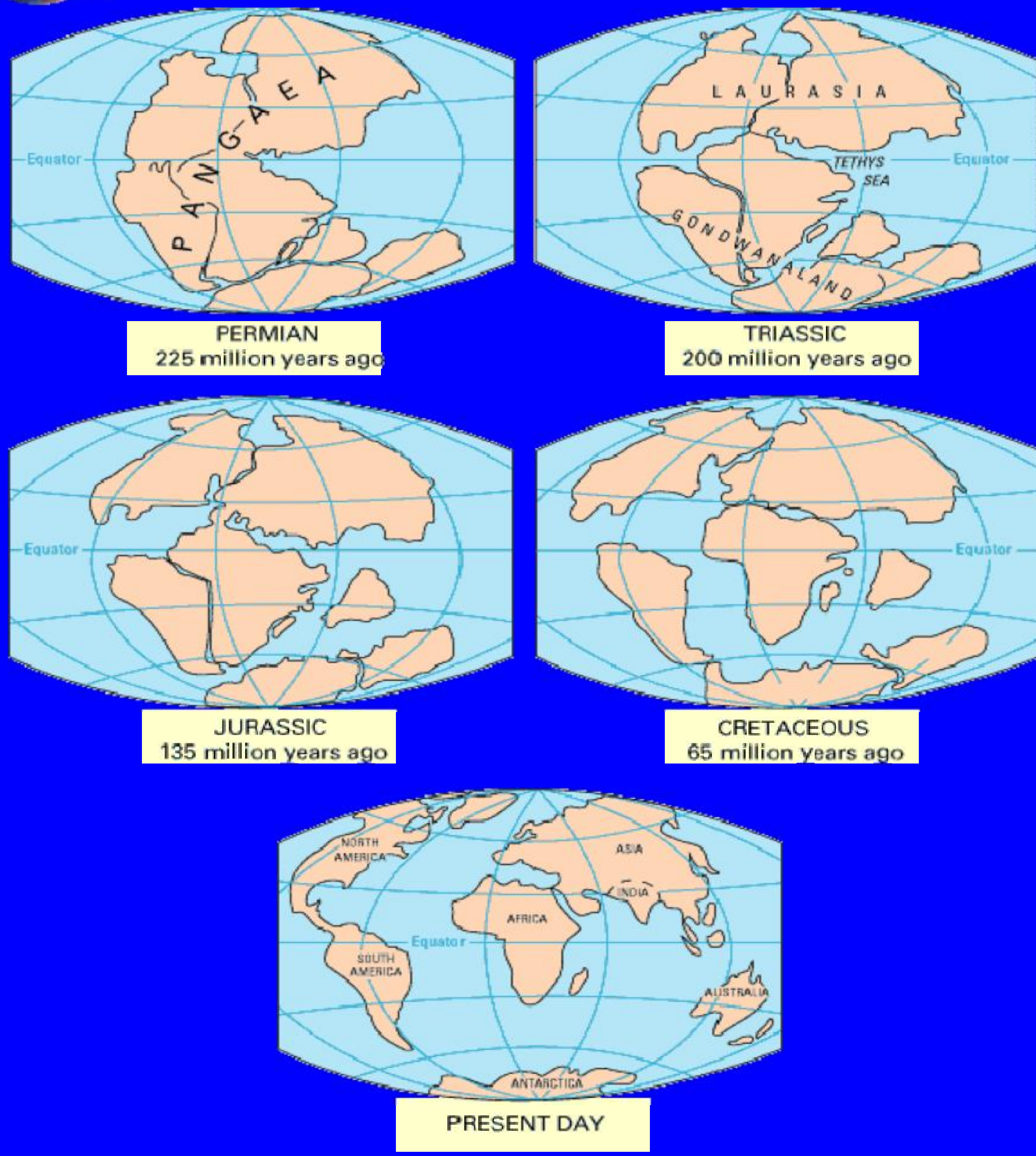
2) What sorts of technologies were developed and used?

3) How were hypotheses tested? Validated hypotheses turned into supporting evidence? Predictions made?

4) How were various established lines of evidence/ideas integrated to form the plate tectonic theory?

5) Road of discovery starts with the continental drift hypothesis starting back in early 1900’s

Continental Drift Hypothesis



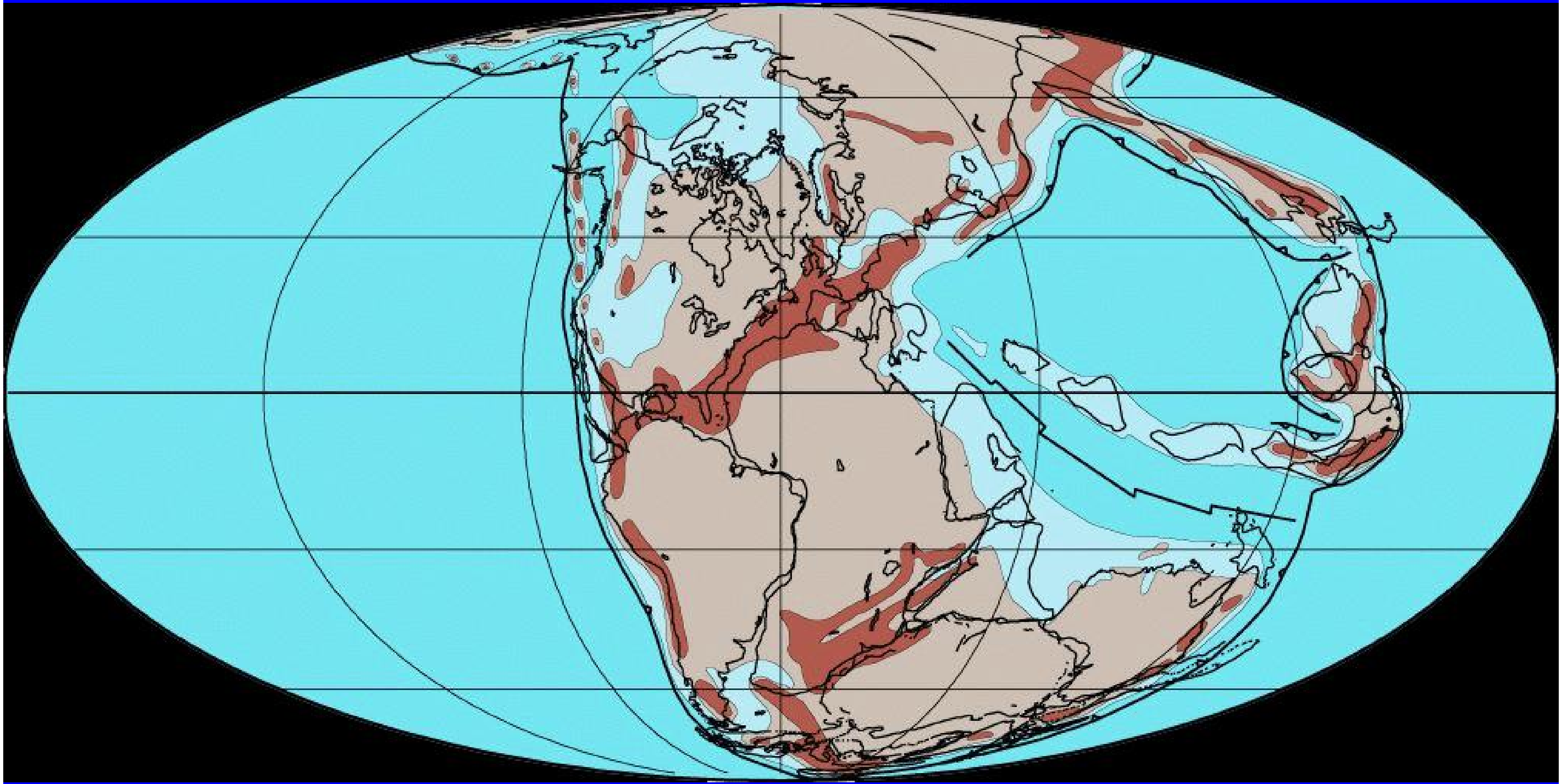
Alfred Wegener
(1880-1930)

Continental Drift Hypothesis

Main Ideas:

1. Alfred Wegener was the primary sponsor of hypothesis
2. Supercontinent “Pangea” existed in the Permian Period
3. Pangea began to break up in the Triassic Period with dispersal, i.e.“drifting”, of the rifted continents
4. Continental masses plowed through ocean crust
5. Strong lines of land-based evidence support the hypothesis
6. Driving mechanism for “continental drift” invalidated
7. Plate tectonics theory replaced continental drift idea

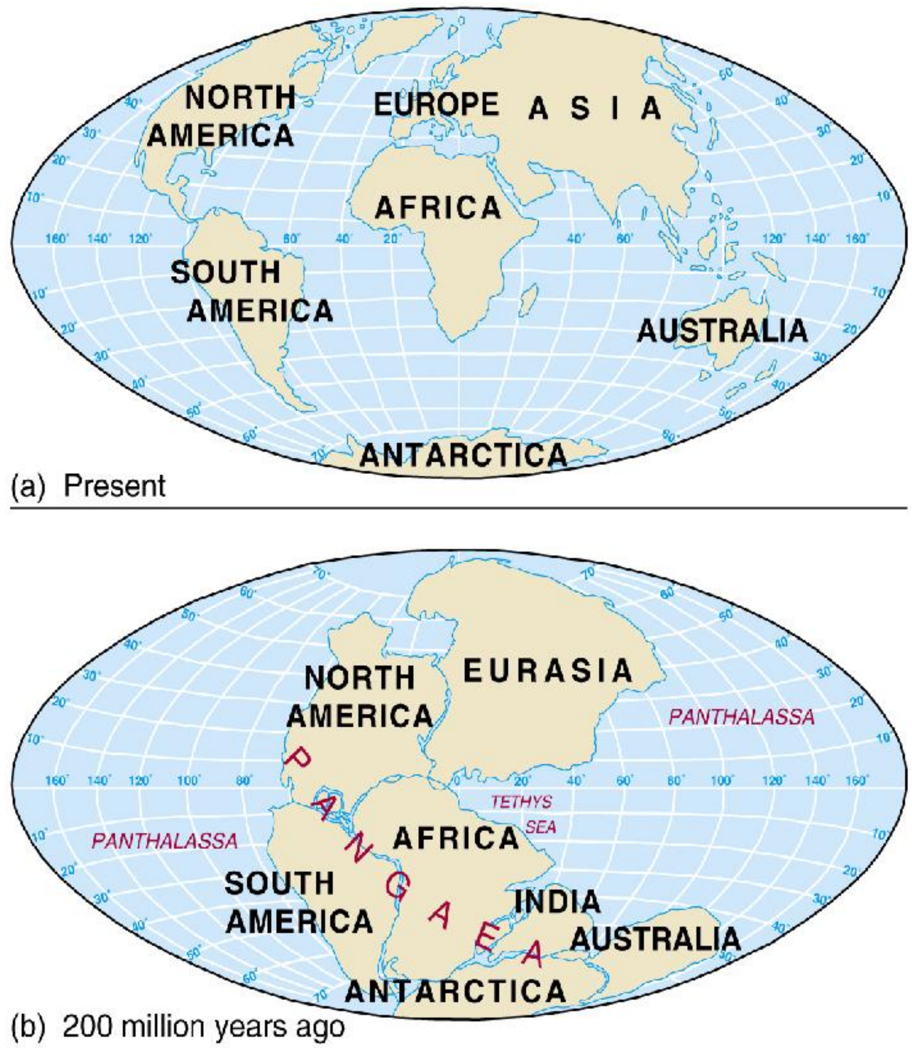
PANGAEA - PANTHALASSA



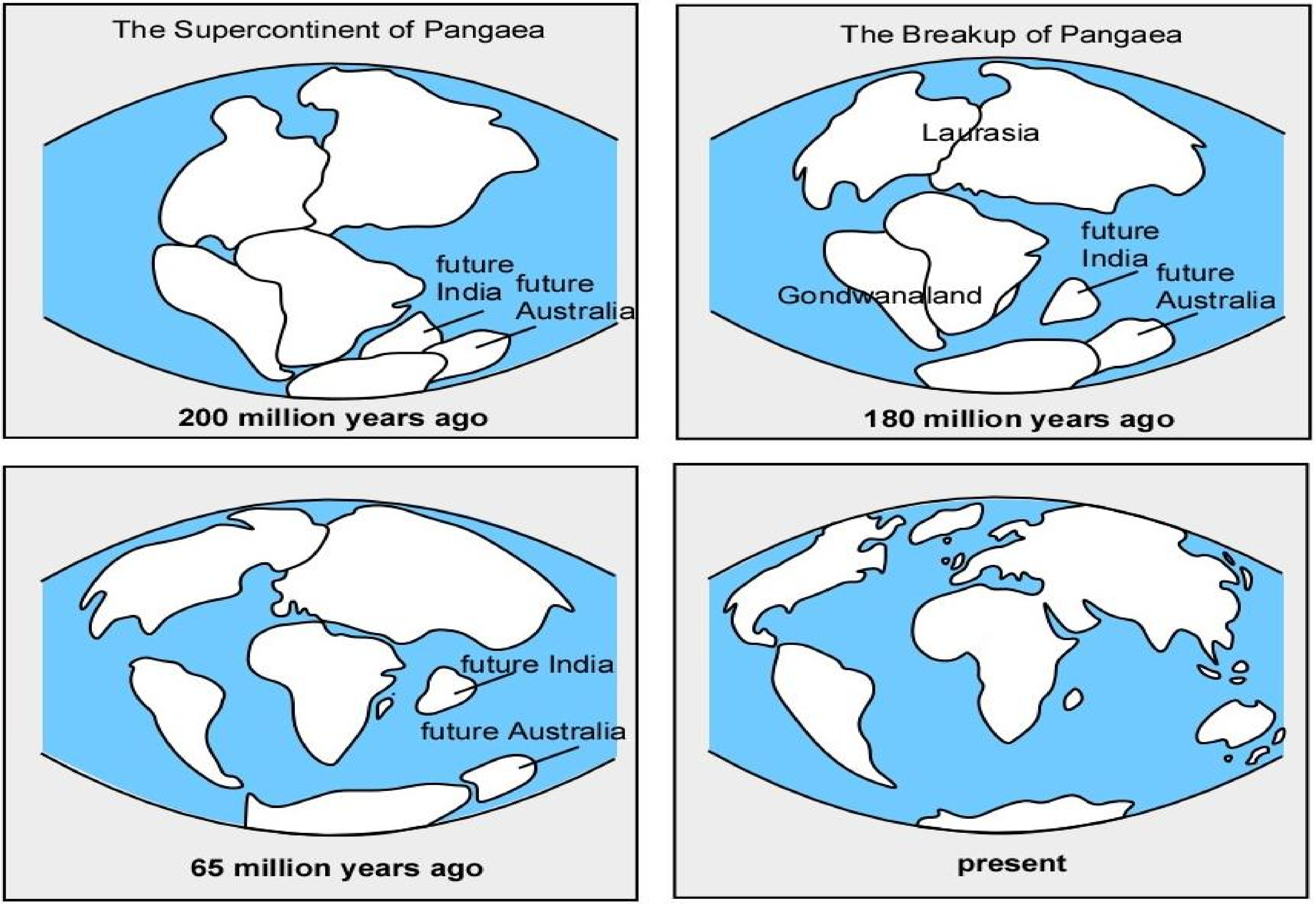
Permian Period - 220 Million Years Ago

Pangaea, Panthalassa, Triassic Breakup, and Continental Drift

- ❖ Animation shows the sequential breakup of the Pangea Supercontinent
- ❖ The progressive breakup of Pangea occurred over the last 200 million years and will continue into the future
- ❖ Opening of Atlantic Ocean basin, collapse of Panthalassa Super-ocean basin, and Continental Drift



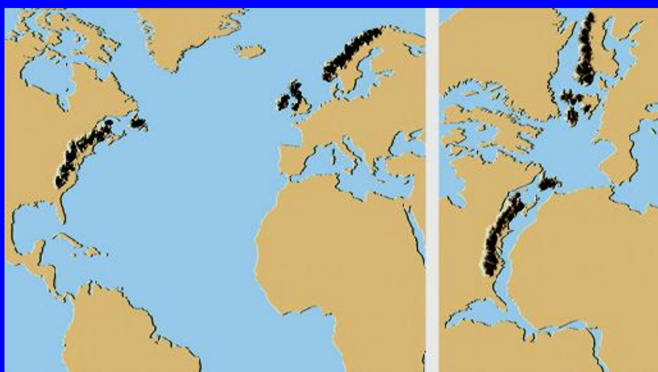
Pangaea and Continental Drift



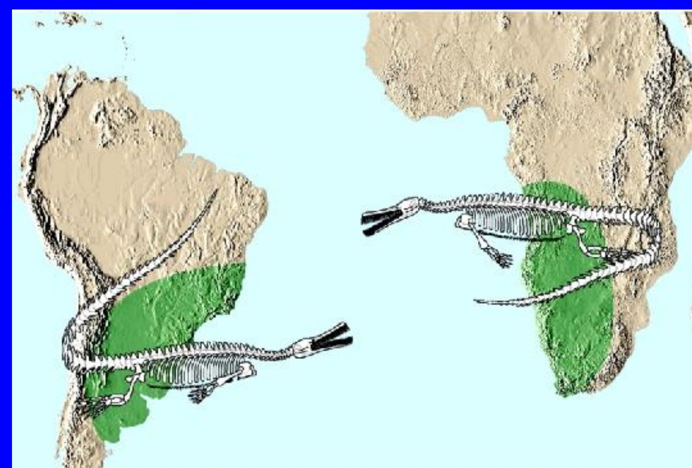
The Continental Drift Hypothesis

Wegener's Lines of Supporting Evidence:

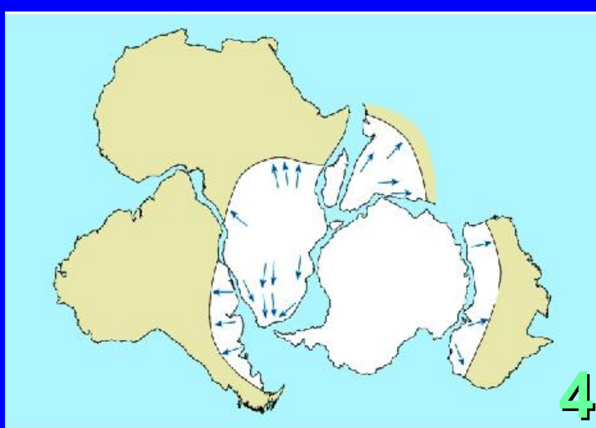
1. Fit of adjoining continental coastlines



2. Truncated mountain and mineral belts

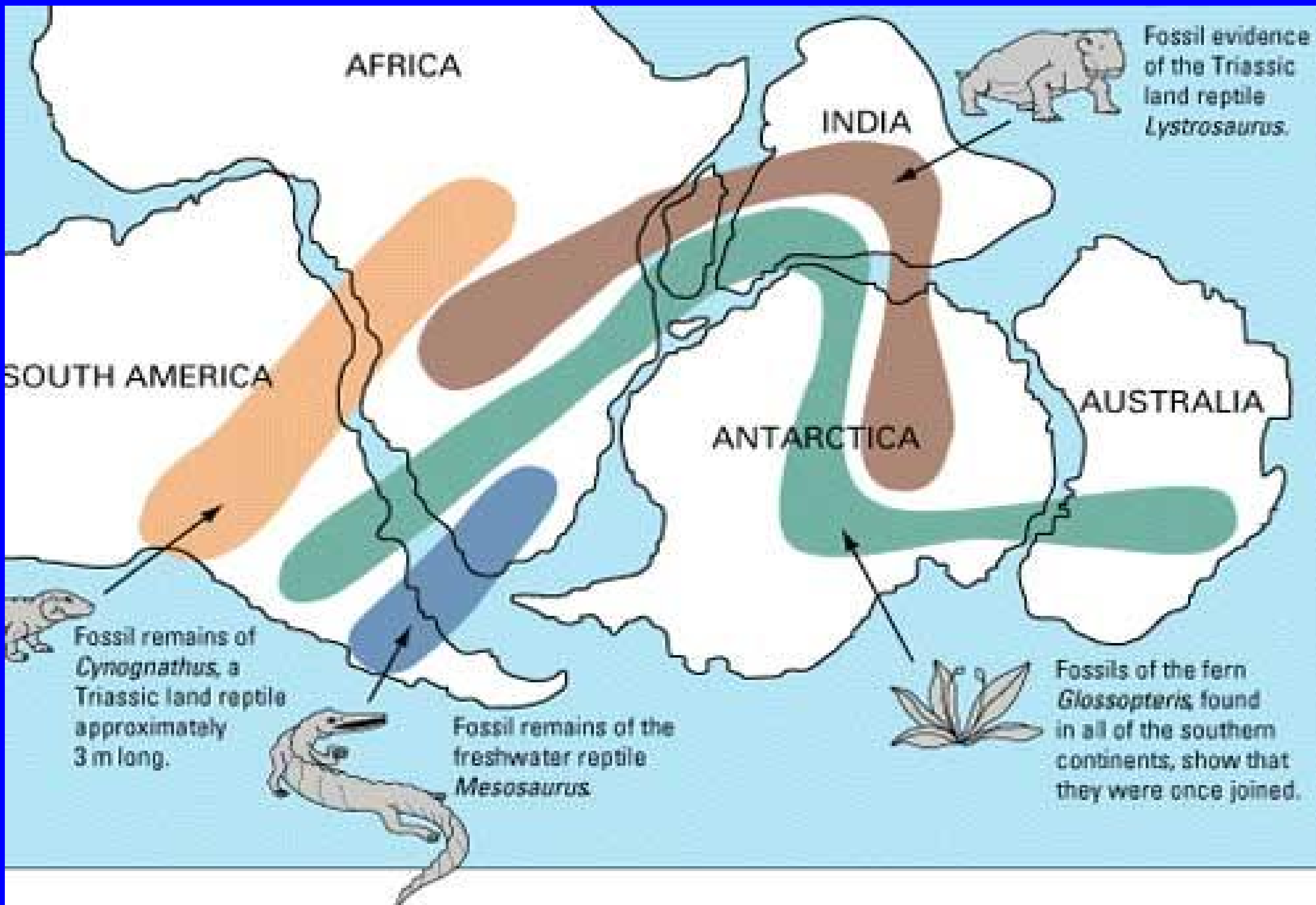


3. Intercontinental fossil affinities



4. Connection of ancient climatic belts

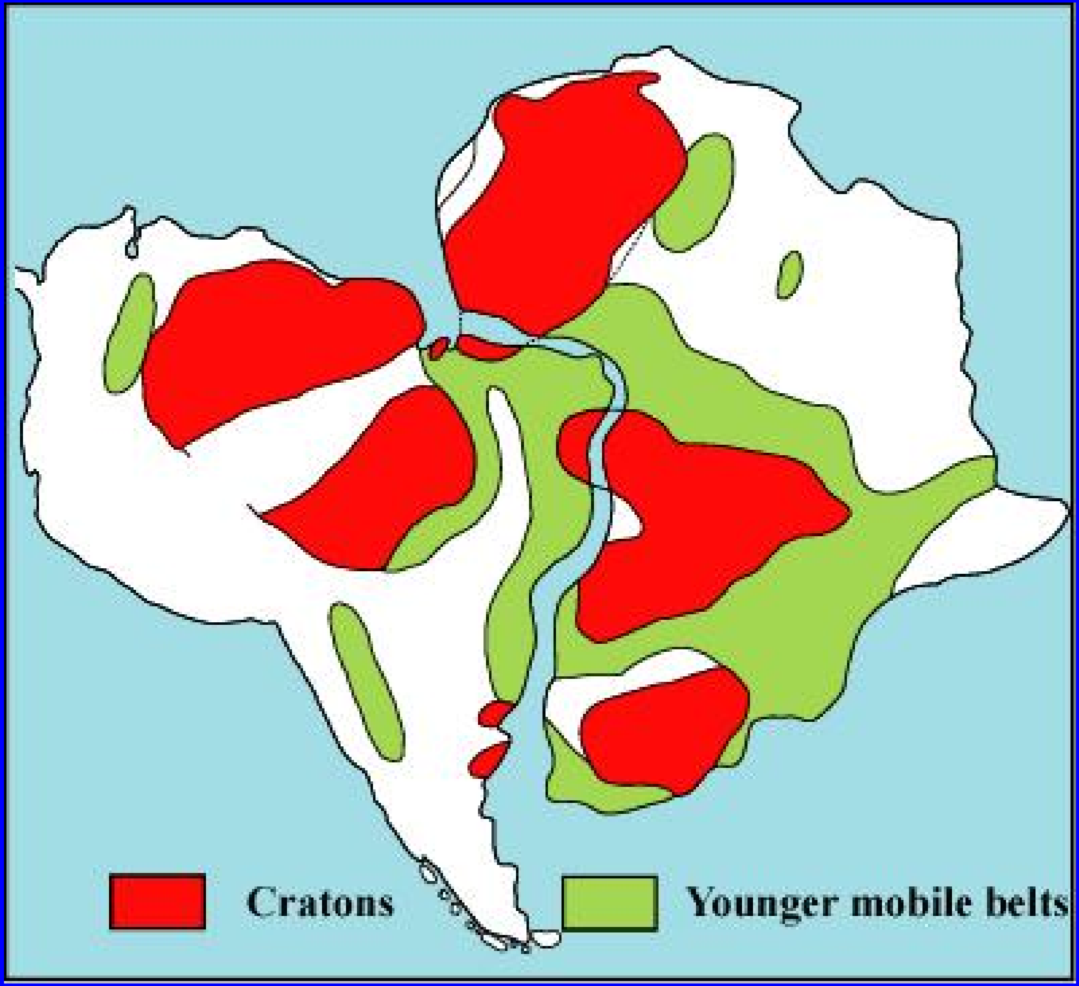
Gonwanaland Fossil Evidence



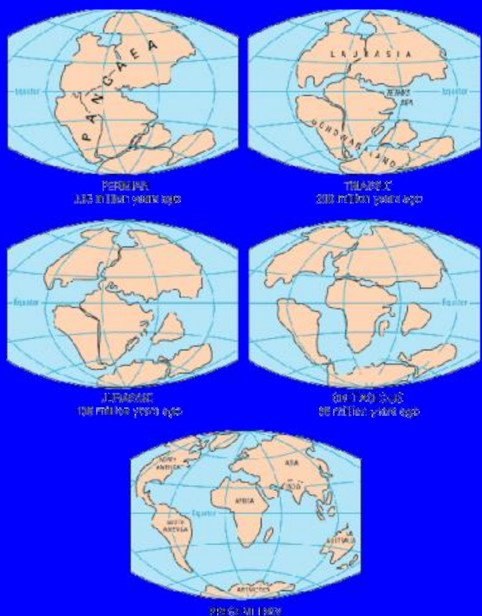
Gonwanaland Rock Evidence

Perfect Fit of Truncated:

1) Mountain Belts
2) Mineral belts
3) Terranes



Continental Drift Hypothesis



Breakup of Pangea
And Continental Drift

Conclusions

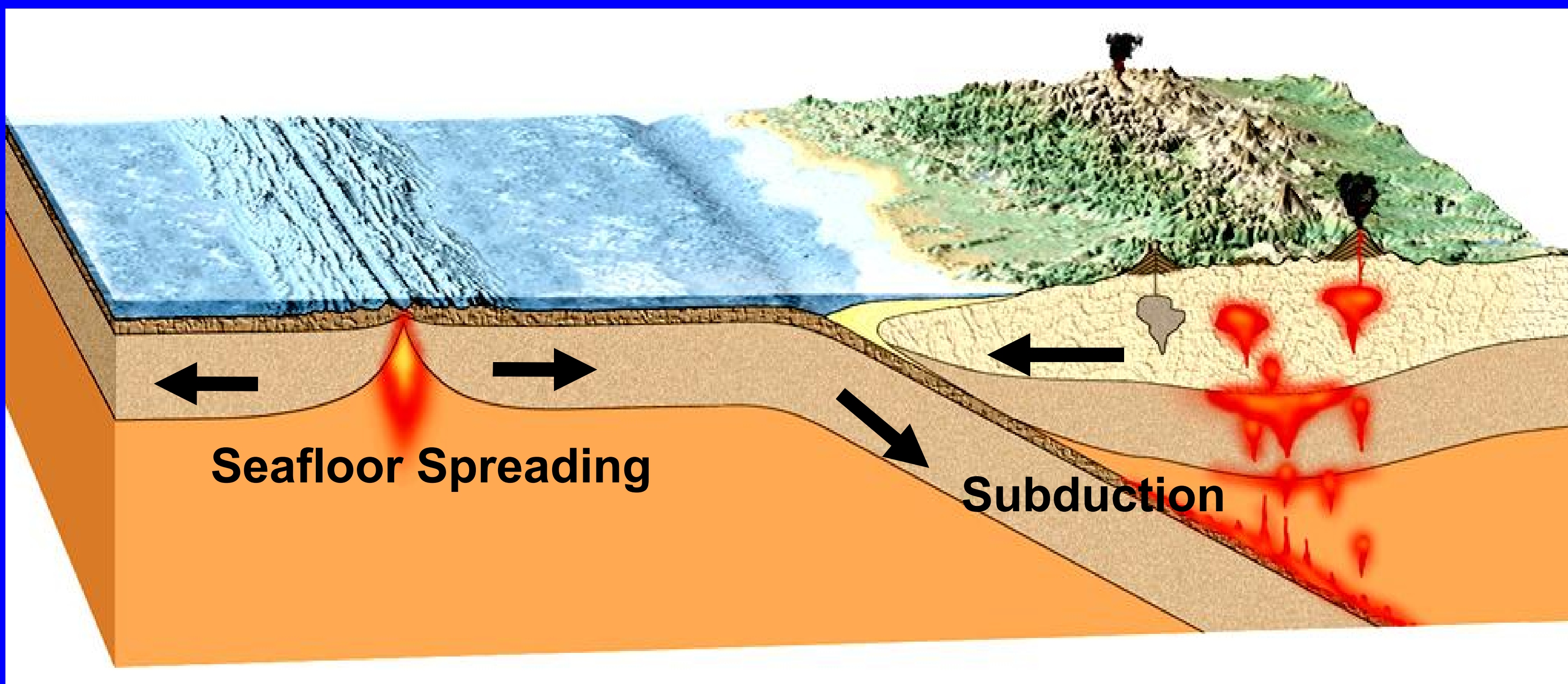
- Good land-based evidence for drift
- No evidence from ocean basins
- Driving mechanism invalidated
- No alternate drift mechanism found
- Hypothesis invalidated and nearly forgotten….until….????.

Wegener

Two Principle Tectonic Processes

1) **Seafloor Spreading** = Plate Constructive

2) **Subduction** = Plate Destructive



Animation of Overview of Plate Tectonics – on YouTube

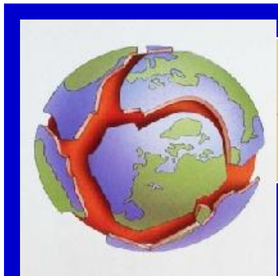
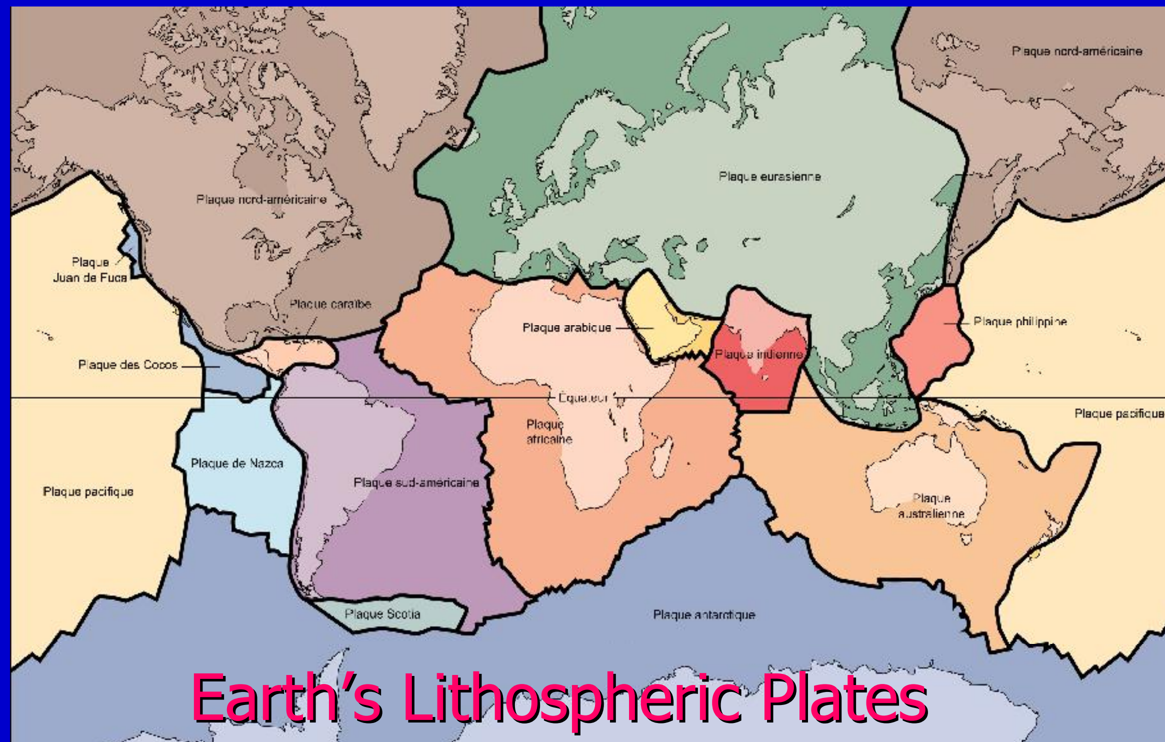


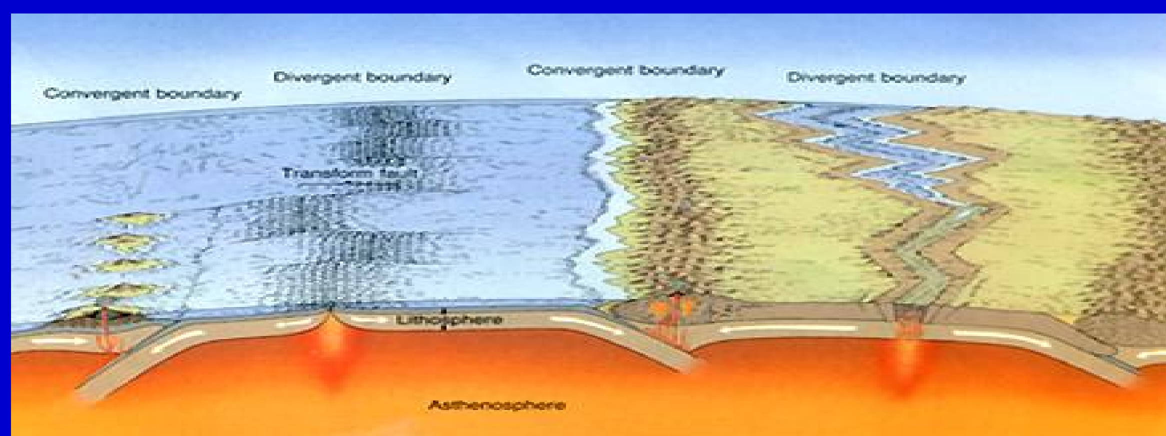
PLATE TECTONIC THEORY

Key Features:

- ✓ 14 Lithosphere Plates
- ✓ 6 Major, 8 Minor
- ✓ 100-300 km thick
- ✓ Strong and rigid
- ✓ Plates float on partially molten asthenosphere
- ✓ Plates are mobile
- ✓ Cm's/yr motion rates
- ✓ **Seafloor Spreading creates new oceanic plates**
- ✓ **Subduction destroys older oceanic plates**



Earth's Lithospheric Plates



Two Principle Tectonic Processes

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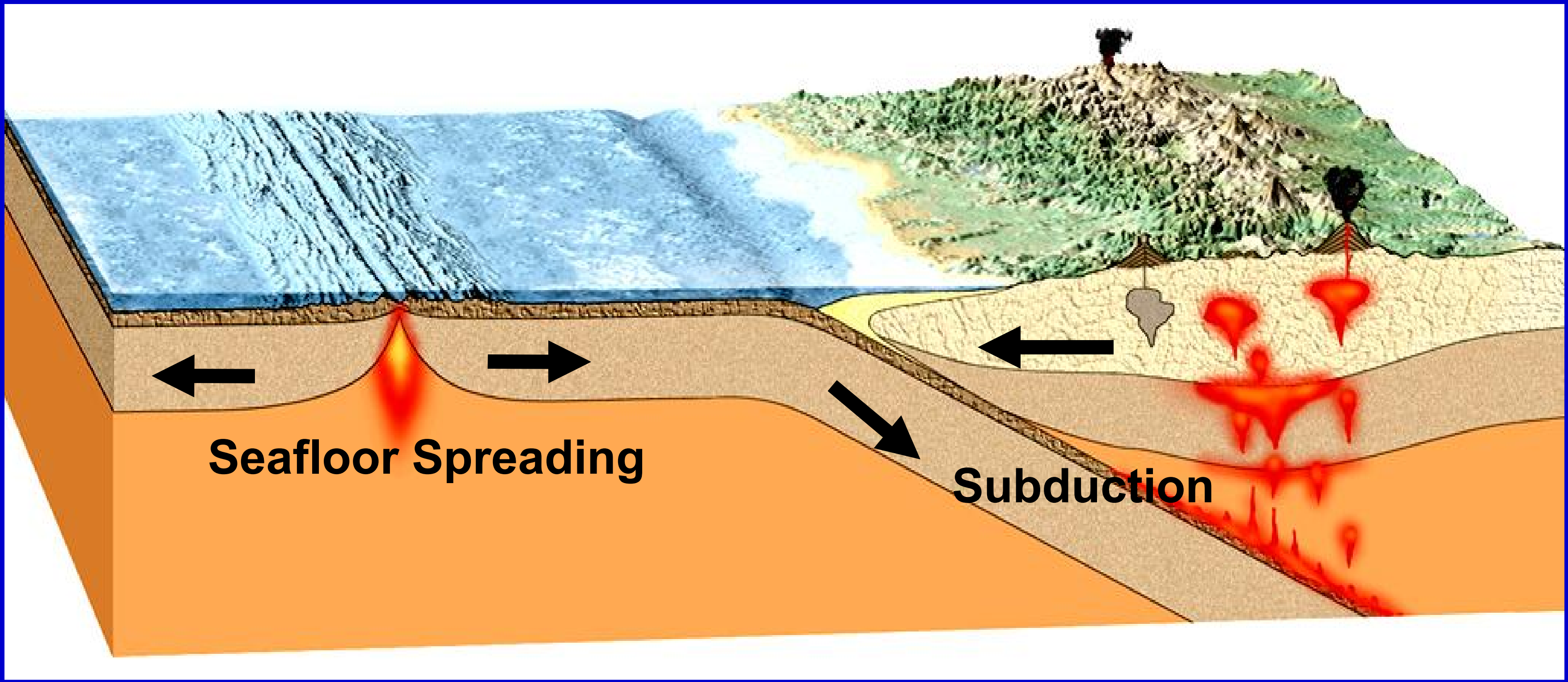
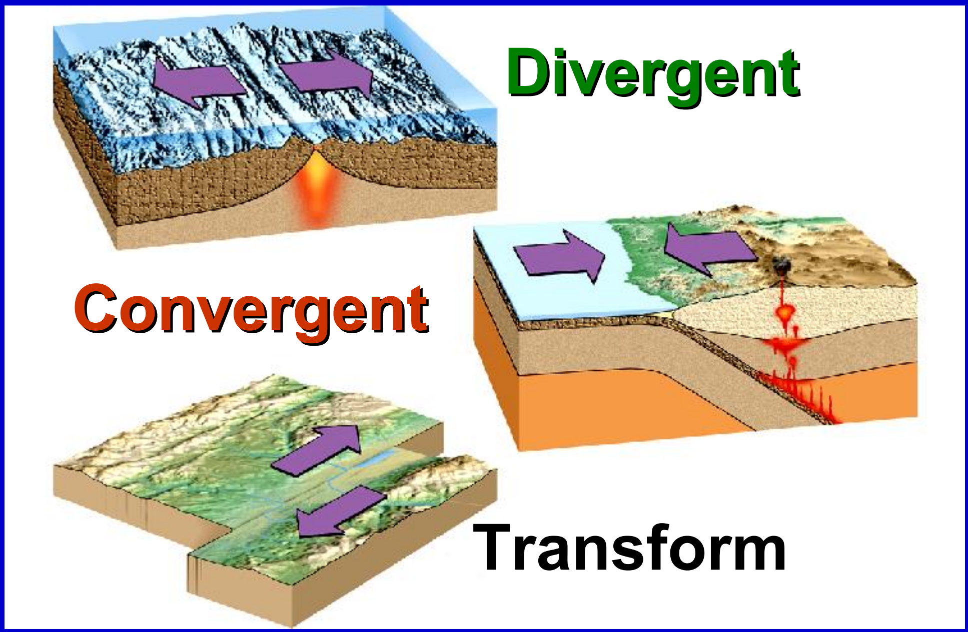
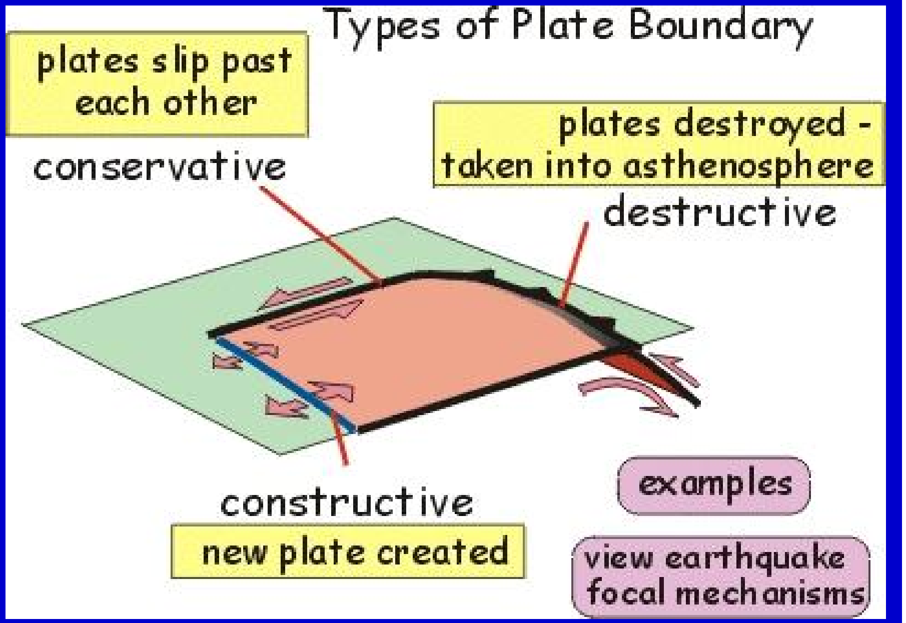


Animation of Overview of Plate Tectonics – on YouTube

Seafloor Spreading and Subduction

3 General Types of Plate Boundaries

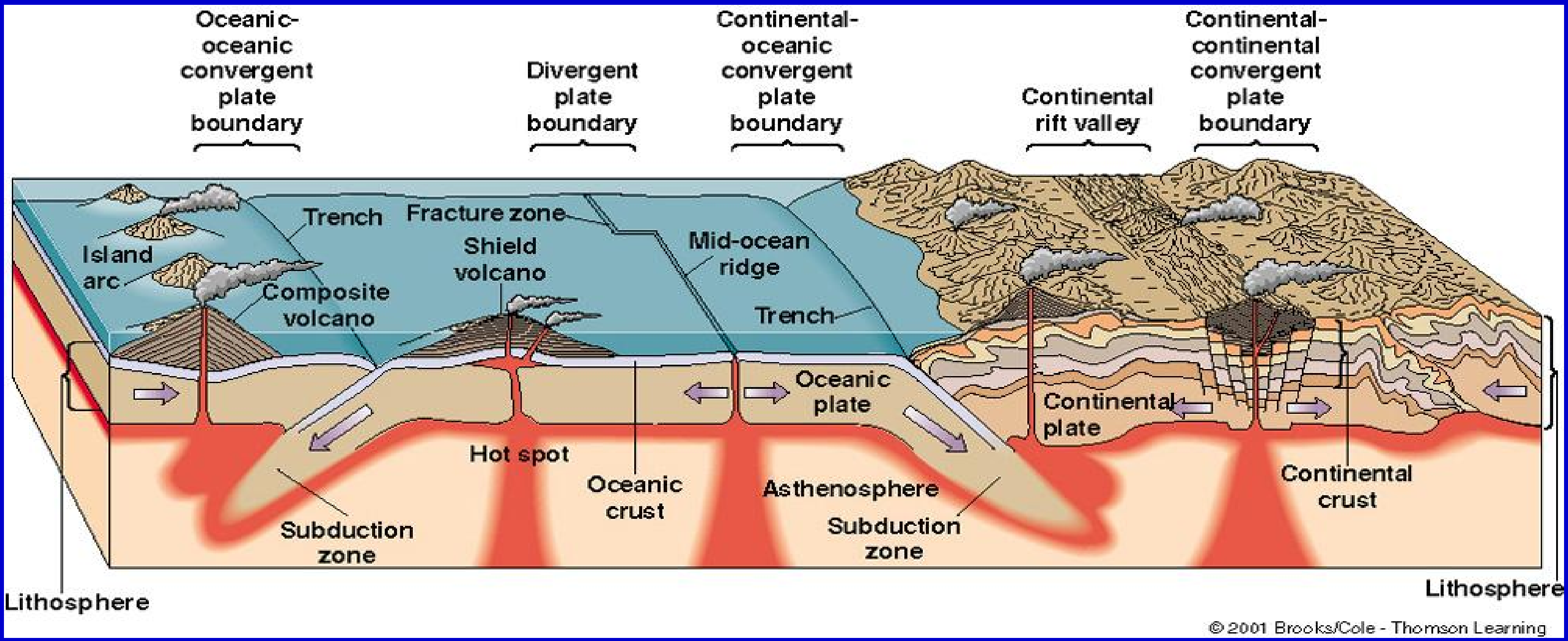




1) **Divergent** = **Constructive: creation of new oceanic plate**
2) **Convergent** = **Destructive: destruction of old oceanic plate**
3) **Transform** = **Conservative: no creation or destruction of plates**

Plate Tectonic Boundaries

- Associated Faulting and Volcanism -



Questions:

1) How many types of plate boundaries do you recognize here?

2) Which type of plate boundaries have little to no volcanism? Why?

3) How does the plate tectonic theory explain inner-plate hot spots?

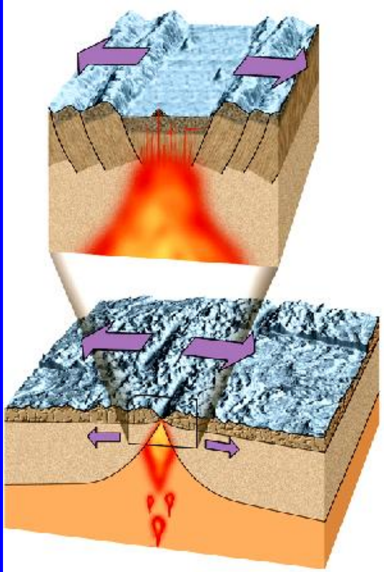
Divergent Plate Boundaries and Seafloor Spreading

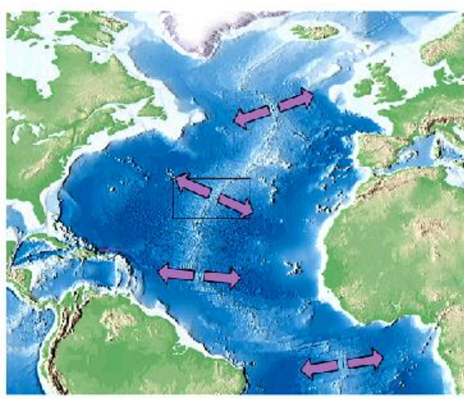
Main Ideas:

1. Seafloor spreading is a double conveyor belt-like process that produces "mirrored" growth of new seafloor between two diverging plates

2. Initiated by continental rifting event

3. Mid-ocean ridges are the most typical geographic expression of active spreading



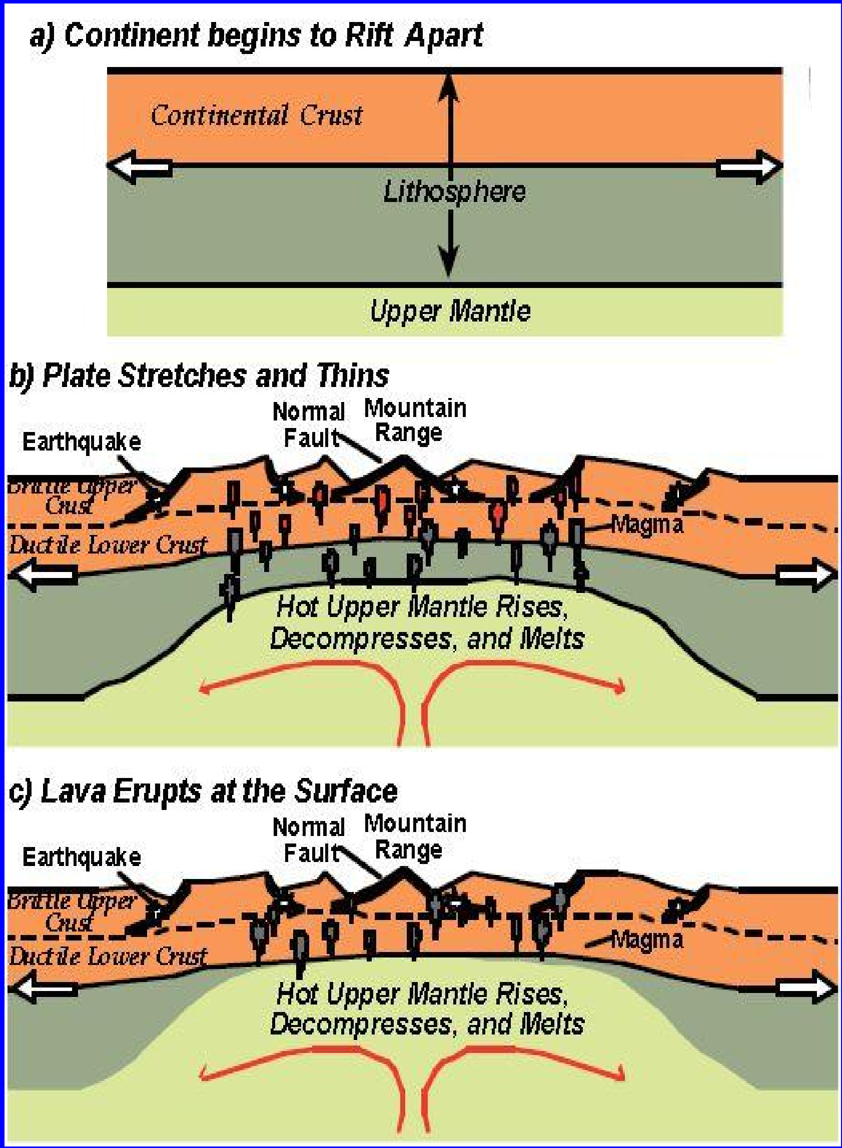


4. Plates "spread" apart to accommodate new additions at the ridge center (rift valley)

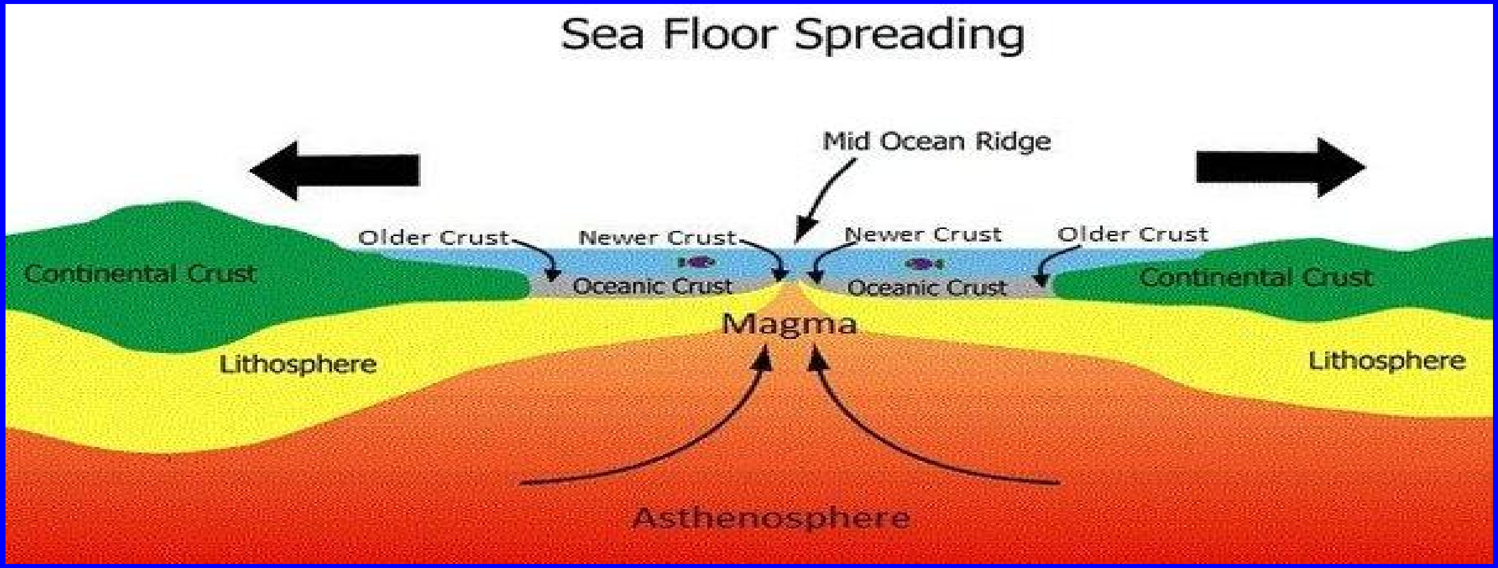
5. Basaltic magmas generated by the decompression melting of upwelling asthenosphere rock beneath the spreading centers

Continental Rifting

- The illustration at right shows the initiation and development of a continent rifting event
- Excessive heat in the underlying asthenosphere causes upward warping and softening of overlying continental lithosphere
- The overlying lithosphere eventually begins to crack and stretch and eventually thin and extend by means of normal and detachment faults (upper crust) and ductile shear zones (lower crust) and ductile shear zones (lower)
- Basaltic lava is generated by decompression of ascending, overheated asthenosphere beneath rift zone.
- If rifting is long-term, then a small ocean basin may develop – transition to seafloor spreading.



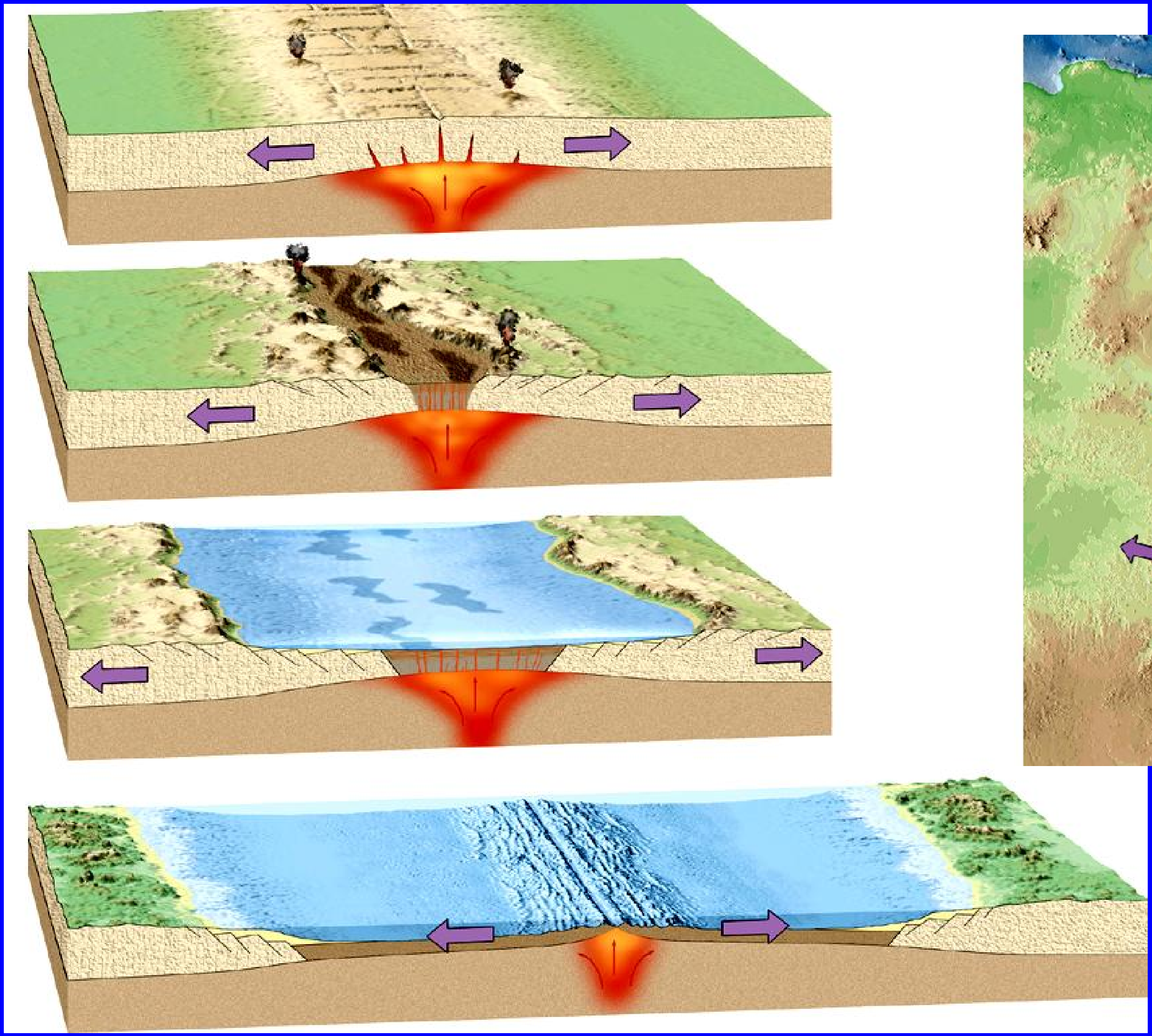
Seafloor Spreading Process

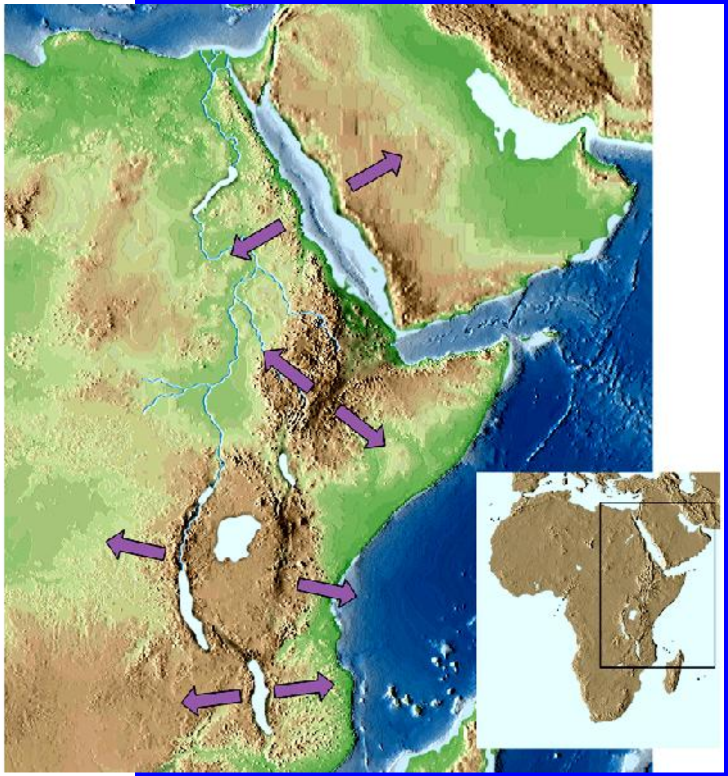


- The illustration above shows the progressive growth of oceanic seafloor at a mid-ocean ridge due to seafloor spreading
- Basaltic magmas arise from decompression melting of hot ascending asthenosphere beneath the mid ocean ridge
- As new oceanic lithosphere is constructed at the mid ocean ridge, older plate material passively moves off and away from both sides of ridge
- Most oceanic lithosphere will eventually get subducted back into the asthenosphere

Continental Rifting & Ocean Basin Development

Progression from Continental Rifting to Seafloor Spreading





East Africa and Arabia

3 Types of Convergent Plate Boundaries

1) Oceanic-Continental

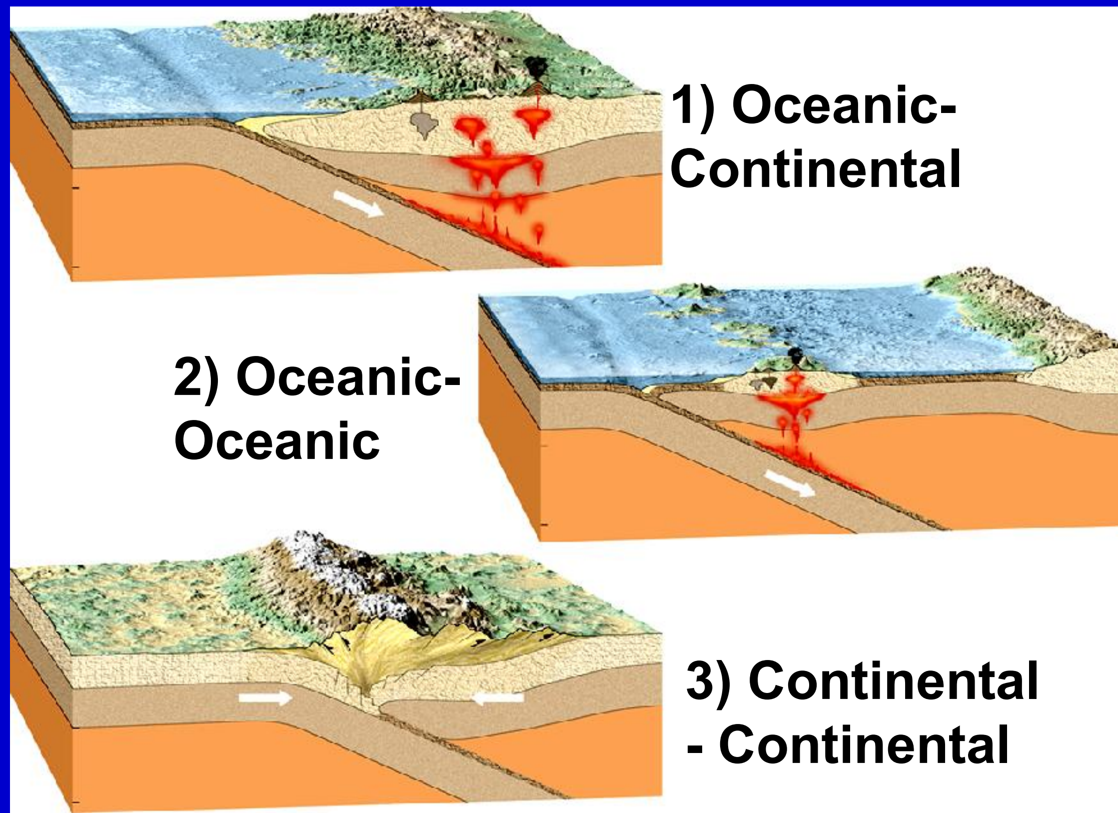
Subduction-related continental margin arc

2) Oceanic-Oceanic

Subduction-related continental margin arc

3) Continental- Continental

Collision boundary of two continents



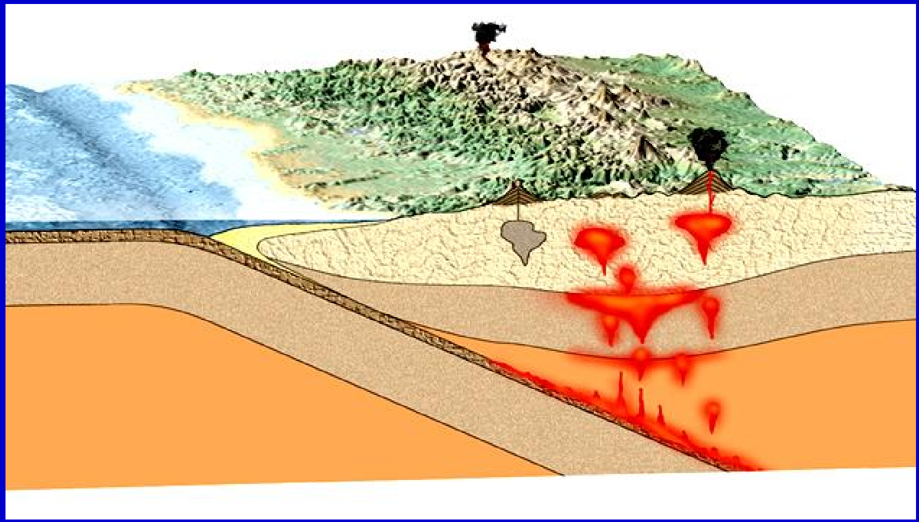
Key Points: Convergent plate boundaries are the sites of 1) formation of new continental crust, 2) intense crustal deformation and 3) recombination of continental masses.

Subduction

Main Ideas:

1) Process of destroying old oceanic lithosphere by sinking down into the mantle at convergent plate boundaries

2) Subduction zones are marked by a paired trench-volcanic arc system



3) Andesite-dominated volcanic arc H_2O magmas are generated by dehydration melting of subducted slab and mantle wedge beneath the volcanic arc

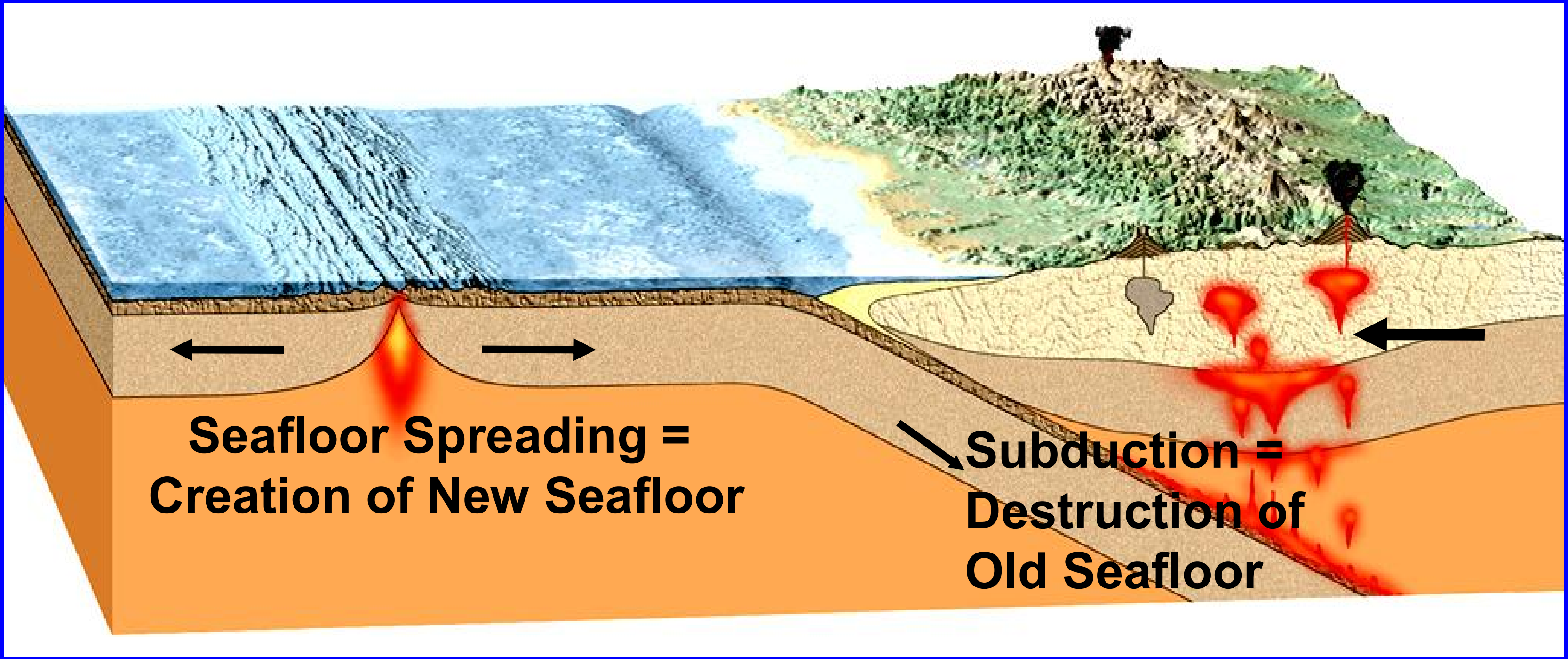
4) Highly explosive arc eruptions due to high silica, H_2O and CO2 content

5) Subduction causes ocean basins to collapse

6) Subduction initiates the accretion of exotic, buoyant, crustal terranes

7) Subduction is the site where new continental crust is being created

Subduction = Seafloor Destruction

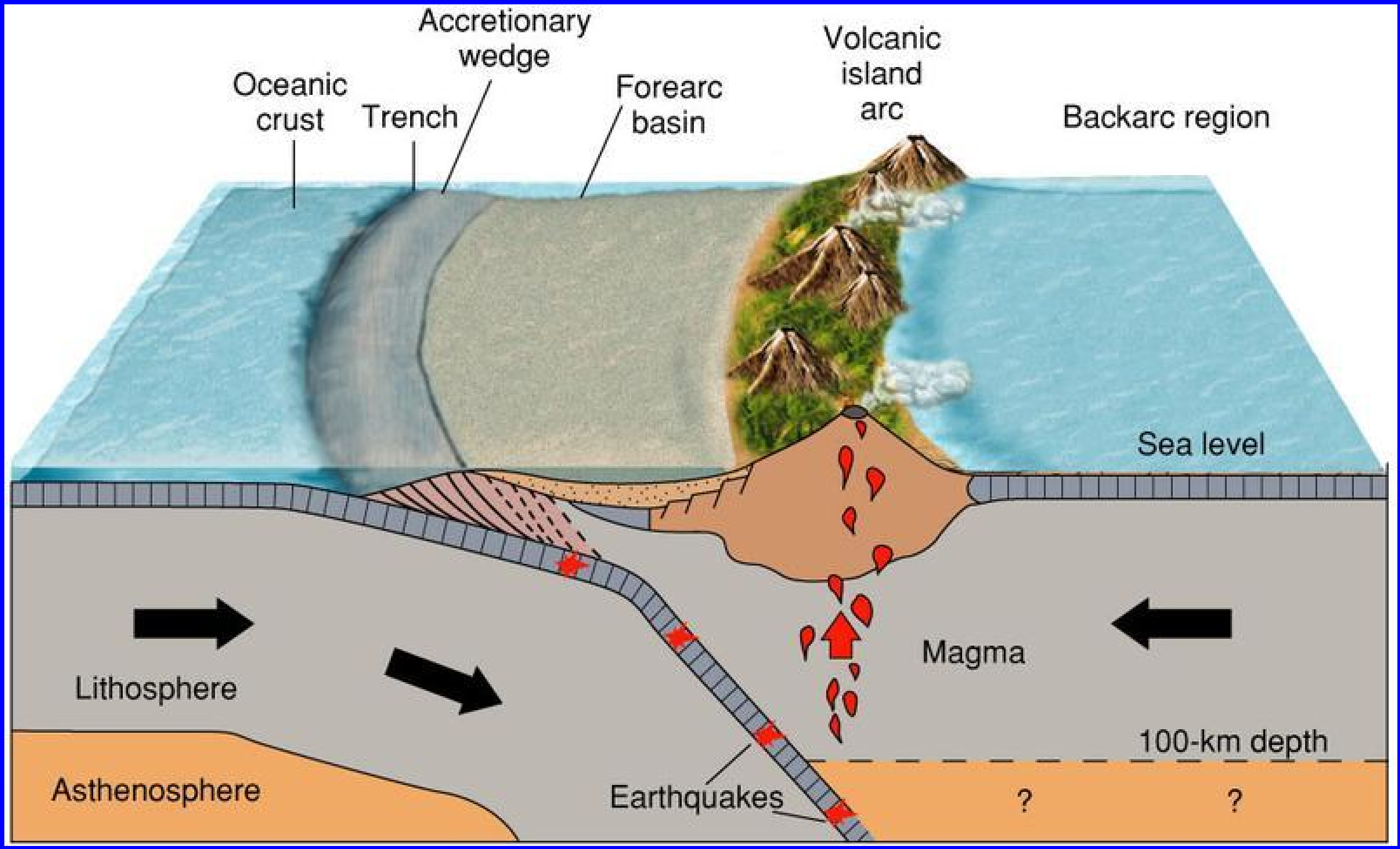


1) Subduction is caused by over-dense oceanic plate sinking back into the asthenosphere under its weight = main driving force of plate tectonics.

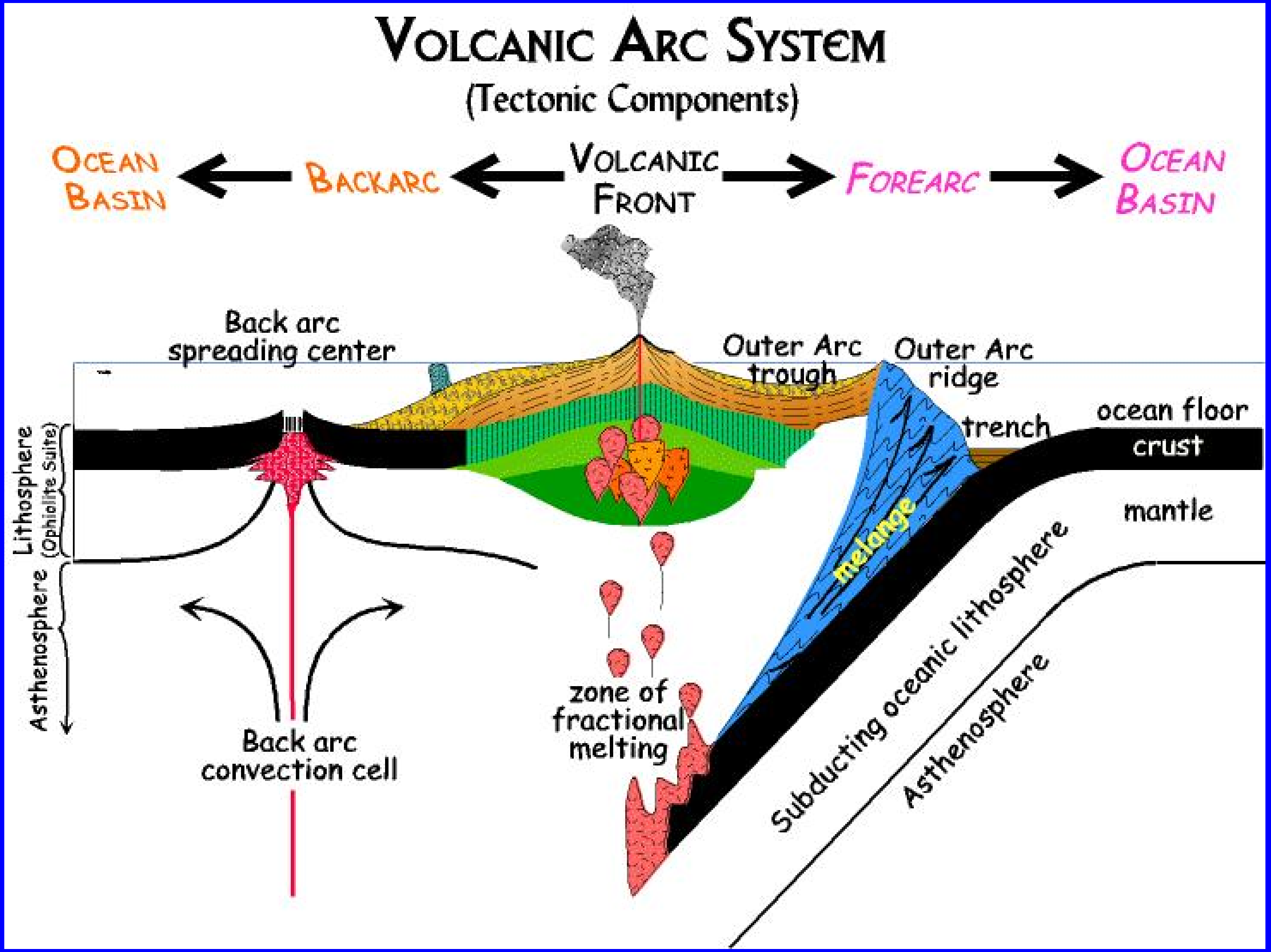
2) Interplate convergent motion at subduction zones leads to the diverging, pull-apart, seafloor spreading plate boundaries = ocean plate mass balance.

3) Seafloor spreading is the crustal mass counter-balancing process to the subduction of older density-unstable seafloor crust sinking back into mantle.

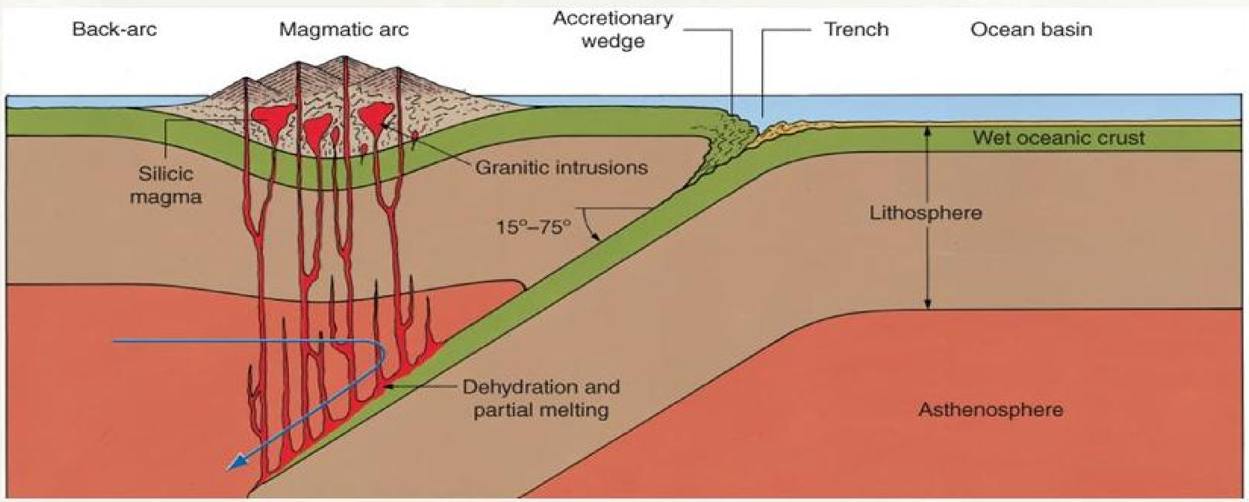
Anatomy of a Volcanic Arc



Anatomy of a Volcanic Arc



Subduction Process



Magma at convergent plate boundaries is generated at depths of about 100 to 150 km.

- Water in slab is released by metamorphism of slab
- Rises and induces melting of overlying mantle
- Water lowers melting points
- Characteristically andesite in composition
- Contains more water than basalt and is more silicic
- Results in more violent volcanism

Illustration above shows the progressive destruction of old oceanic seafloor at a trench due to subduction.

Water-rich basaltic magmas generated from partial melting of asthenosphere above the subducting slab, due to release of ocean water from slab

Subduction-related magmas rise and intrude up through overlying plate creating a volcanic mountain chain or arc

Consequences of subduction are terrane accretion and collapsing ocean basins.

Subduction and Ocean Basin Collapse

Three Stages of Ocean Basin Collapse

1) **Declining = Basin shrinkage**

2) **Terminal = MOR subducted**

3) **Suturing = Continental collision and extinguished subduction**

The ***climax*** of an ocean basin collapse is the formation of a tall, extensive "fold and thrust" mountain chain, much like the Himalayas of today, along with the extinction of the subduction system (loss of active volcanism).

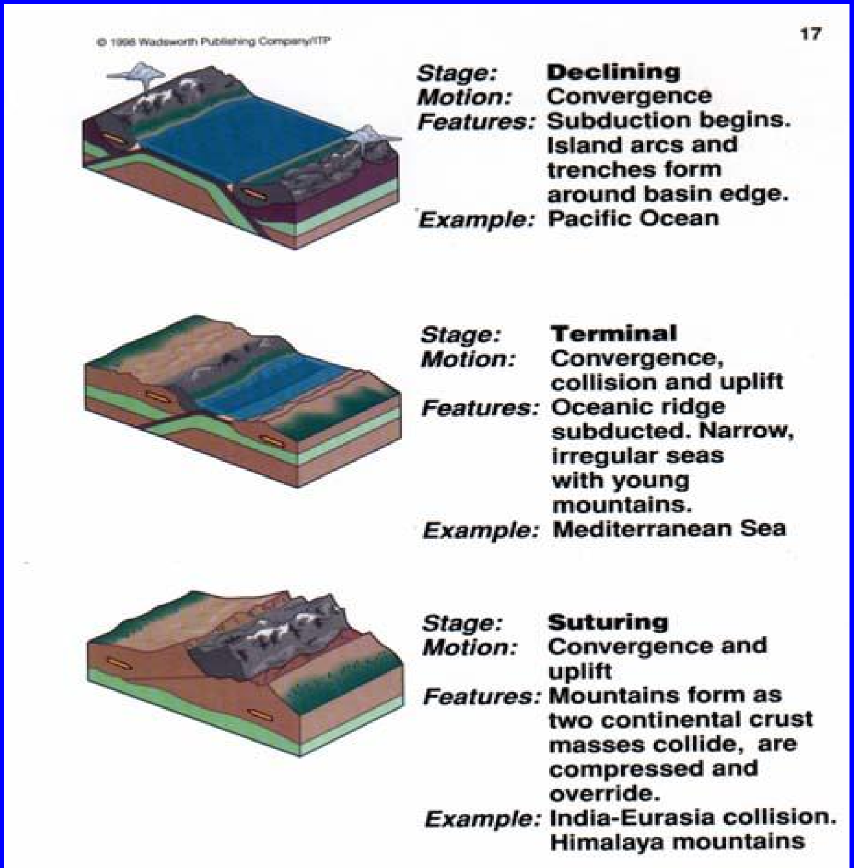
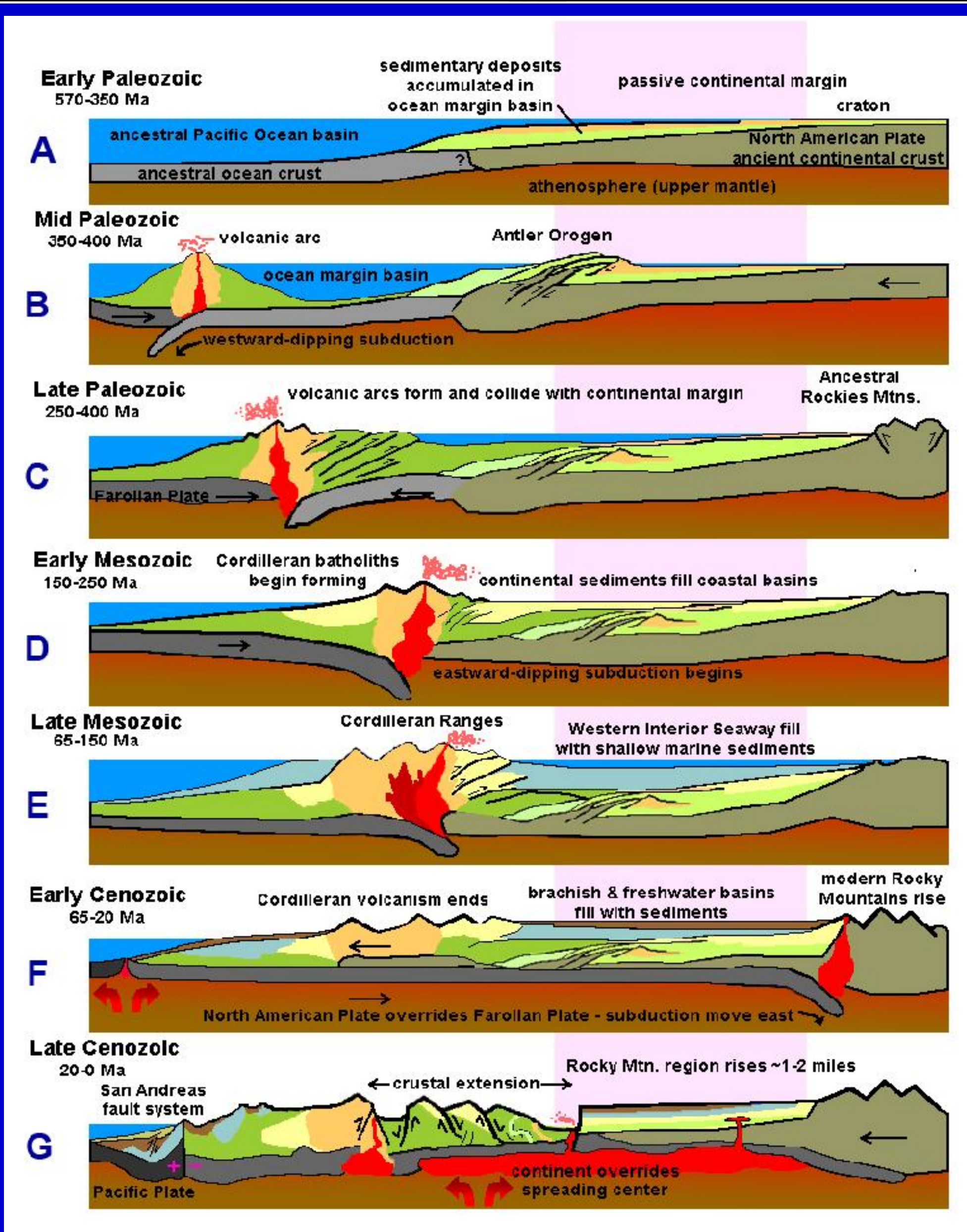


Fig. 3-25 History of an ocean. (Second of two acetates.)

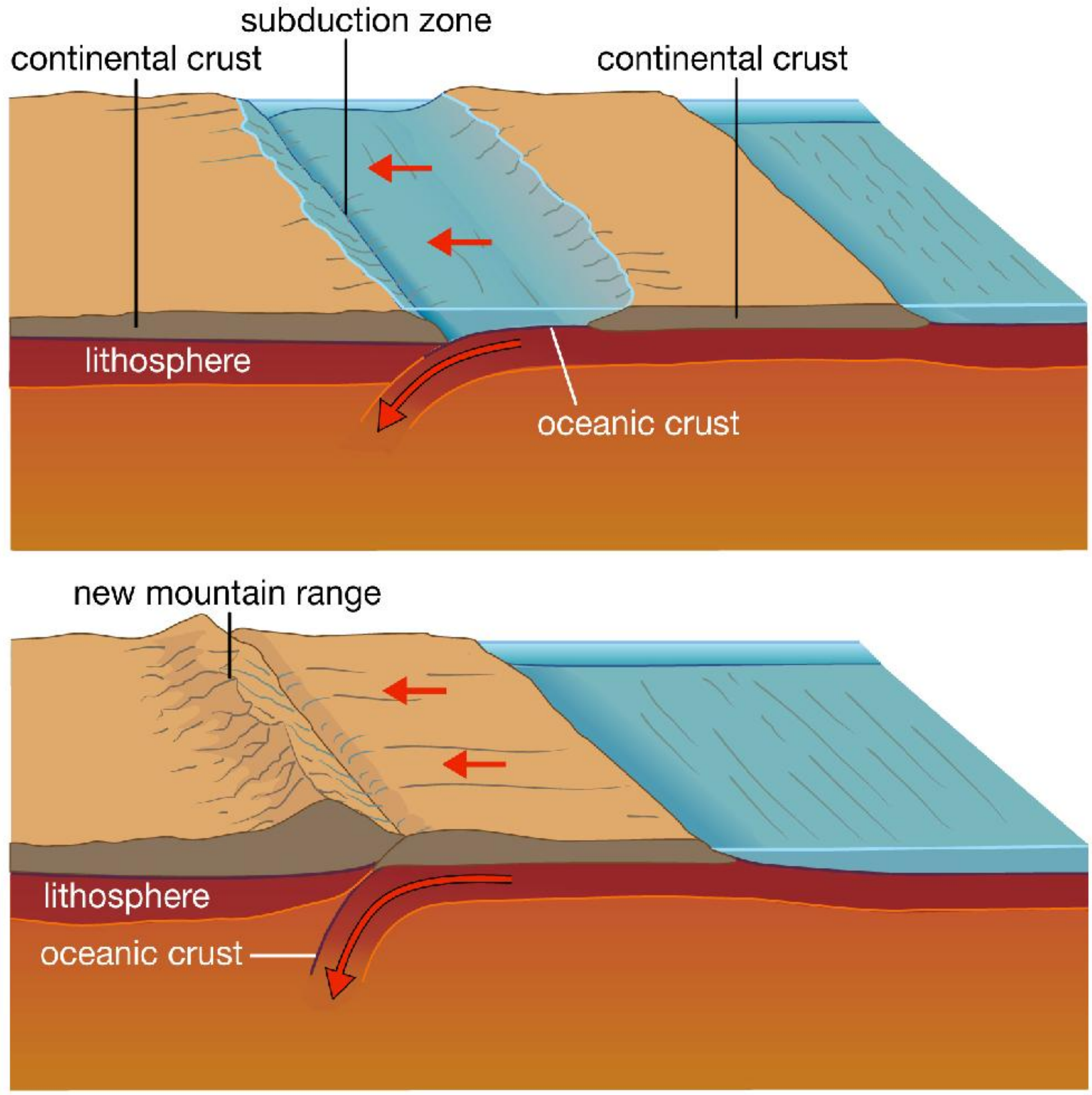
Volcanic Arcs and Terrane Accretion

- **Illustration to the right shows the progressive development of an accreted volcanic arc terrrane at edge of continent due to subduction.**
- **Volcanic island arc is too thick and not dense enough to get subducted, so it gets squeegied against the edge of overlying plate, thereby adding new material to plate.**
- **Ongoing subduction helps weld accreted terrane to plate and transforms island arc into continental margin arc**
- **Subsequent oceanic crustal masses may become accreted against earlier accreted terranes with ongoing subduction**

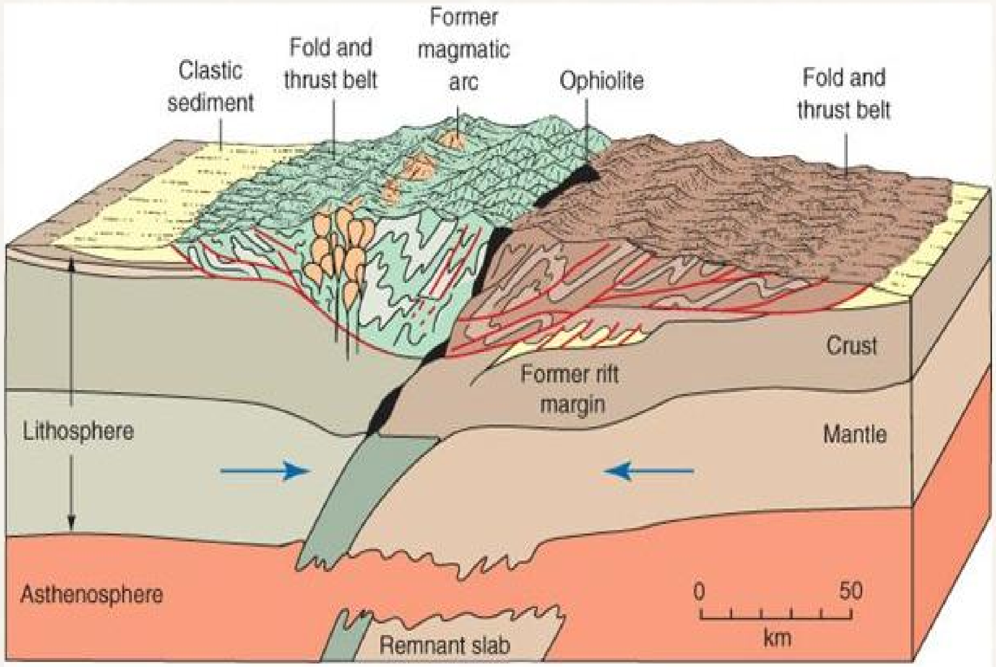


Subduction to Continental Collision

- Illustration to the right shows two continental masses colliding due to subduction and collapse of ocean basin between continents.
- Neither continental mass will subduct, so a massive fold and thrust mountain belt develops between the colliding plates.
- Subduction of remaining oceanic plate eventually ends, and with no more subducting oceanic slab, volcanism also ceases.



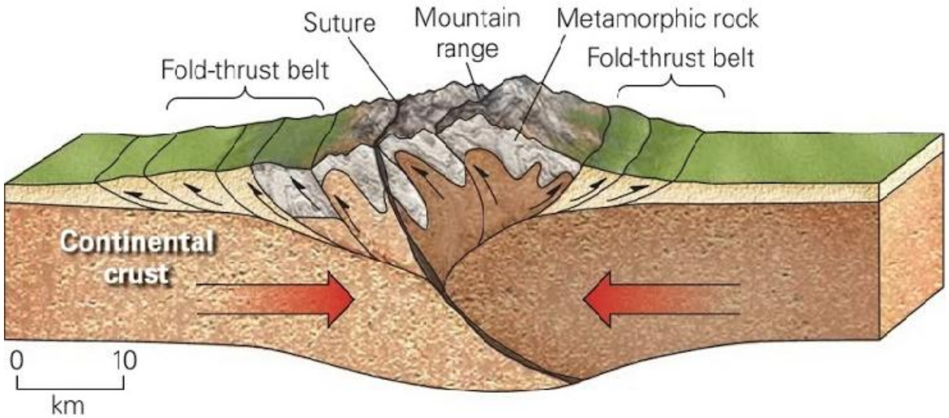
Continental Collision



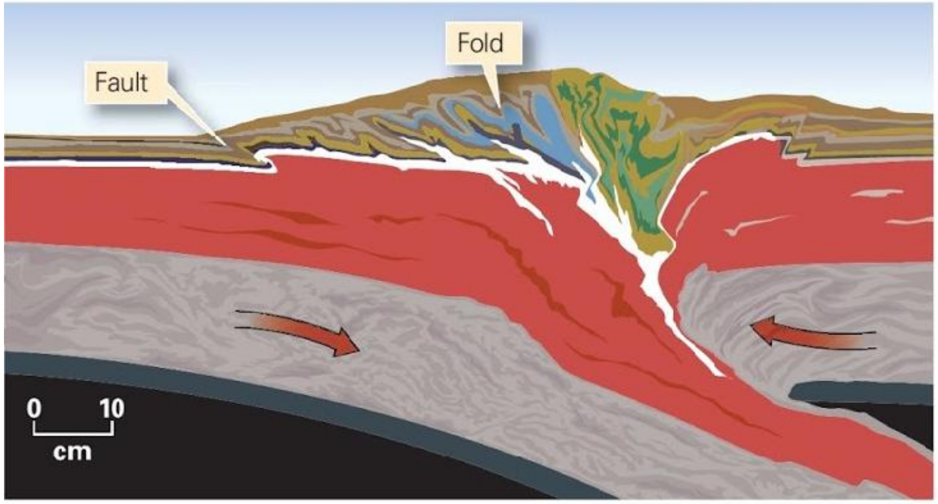
Continent-continent collision is marked by complete subduction of the oceanic crust.

- Continental collision as One continent is thrust beneath the other.
- A high mountain belt forms by folding, thrust-faulting, and doubling of the crustal layers
- Ophiolites are thrust into the suture zone.
- Granite magma and high-grade metamorphic rocks form deep in the mountain belt.

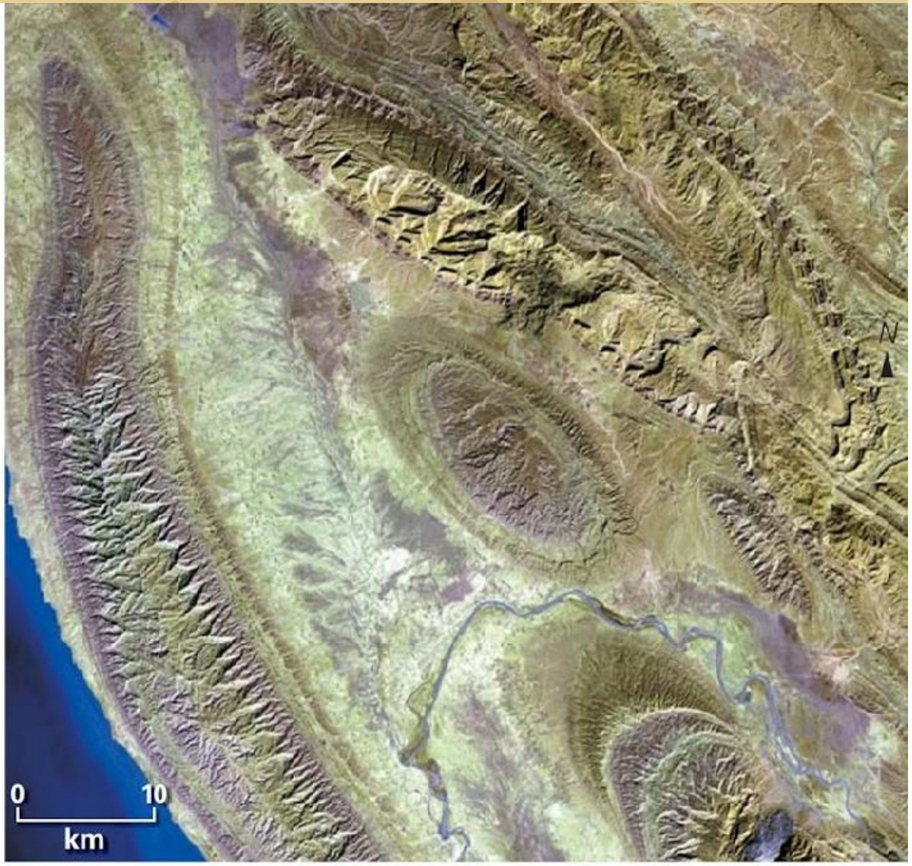
Continental Collision



(a) During collision, continents squeeze together and deform. Thrusting brings metamorphic rock up to shallower levels.

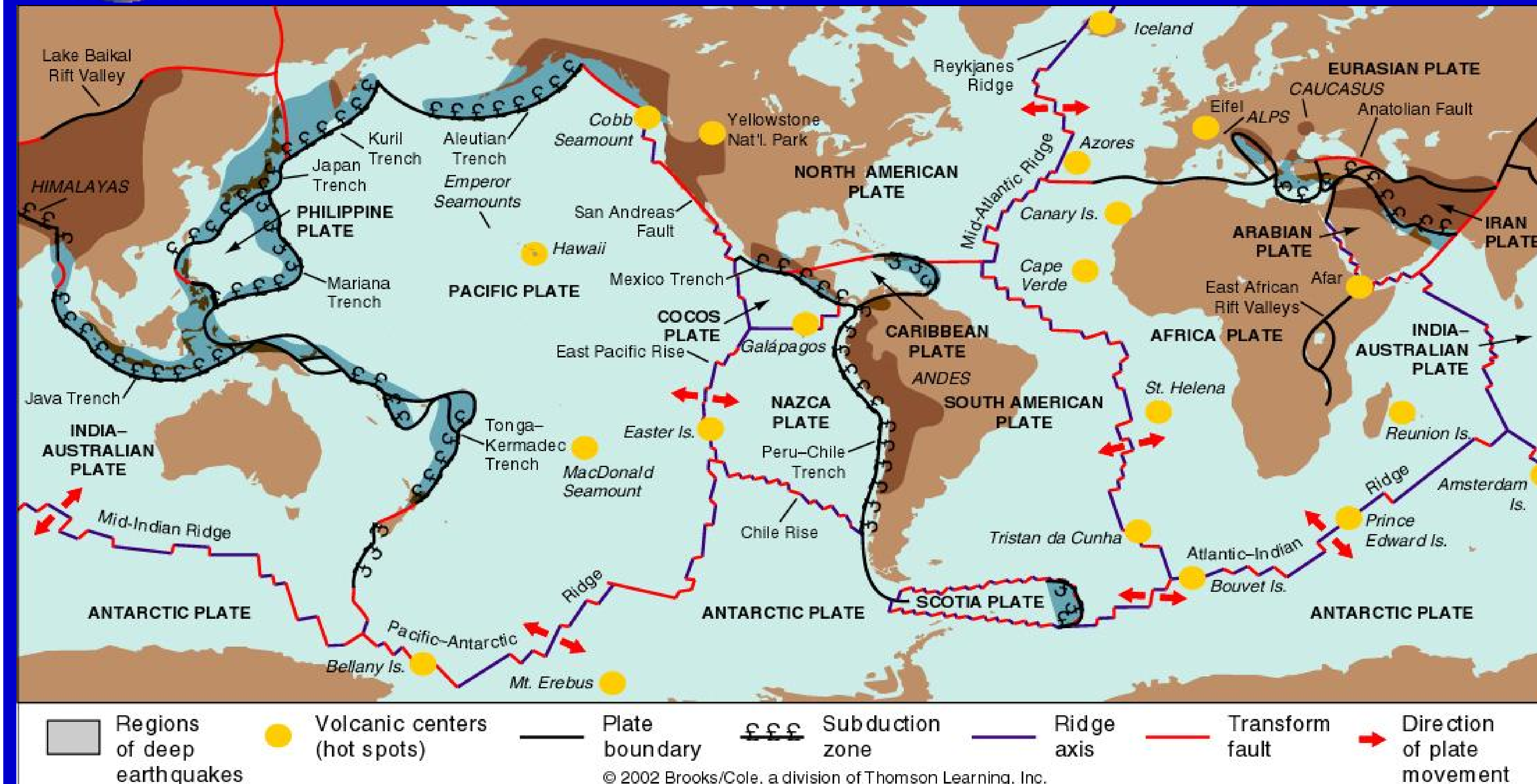


(b) Geologists simulate collision in the laboratory using layers of colored sand. Dragging the left side of the model under the right produces structures and uplift, as shown in this sketch of a model.



(c) In this satellite photo the ridges and valleys of the Zagros Mountains along the coast of Iran represent eroded folds of a collisional orogen. Ridges consist of durable sandstone beds.

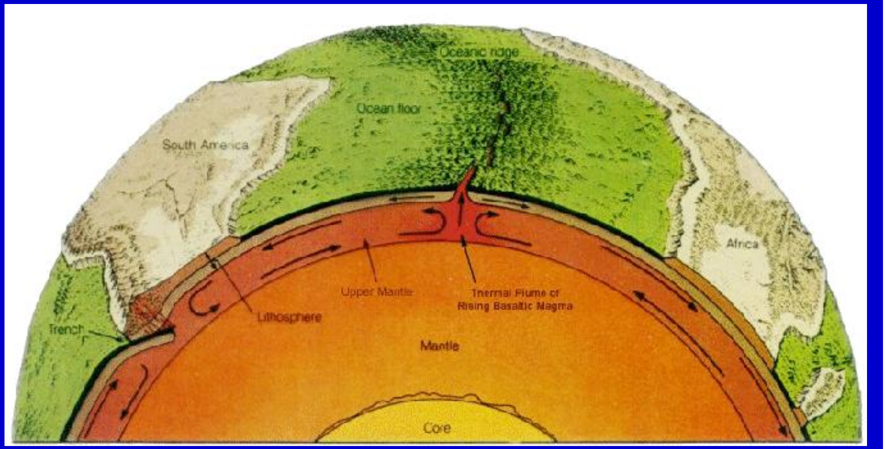
Global Plate Tectonic Map



Key Points: 1) Each plate moves with a unique direction and speed 2) Fastest plates are those with greatest length of subducting edge. 3) Slowest plates have no subducting edges.

Discussion

Subductive Thoughts?



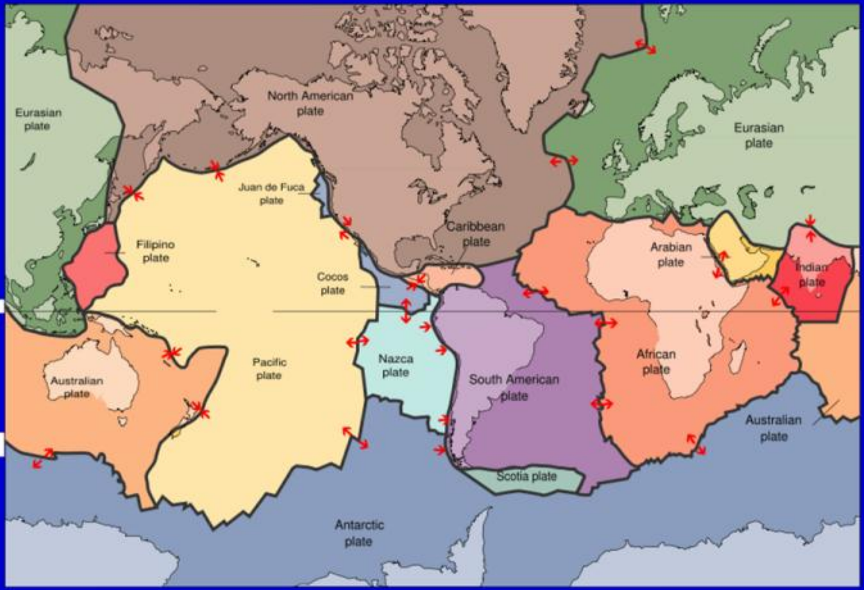
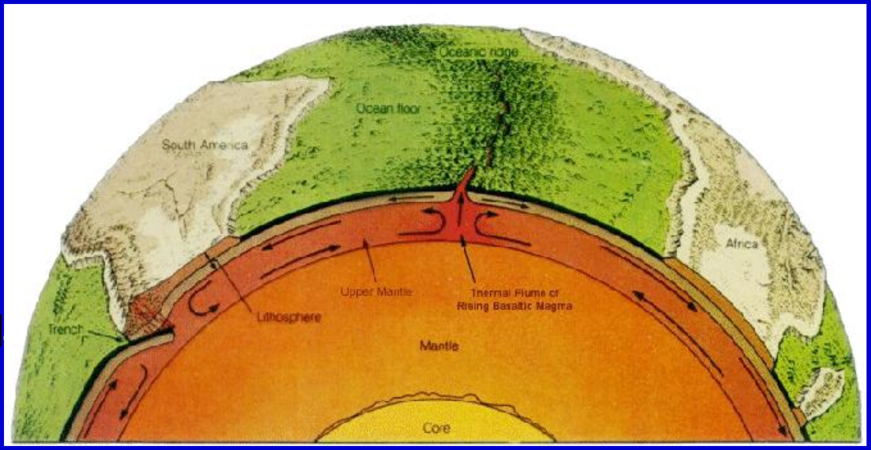


PLATE TECTONICS - Review

Key concepts:

1) Earth's crust and uppermost mantle broken up into **18** mobile, rigid slabs called **lithospheric plates**
2) Lithospheric plates ride independently atop the underlying **partially-molten** mantle called the **asthenosphere**
3) **Three types** of dynamic lithospheric plate boundaries:
   Divergent, Convergent, and Transform
4) Divergent boundaries
   - Continental rifting
   - Seafloor-spreading
   - Creation of new oceanic plate
5) Convergent boundaries
   - Subduction
   - Destruction of older oceanic pl
   - Terrane accretion
   - Continental collision



6) Transform boundaries
   - Strike-slip faulting
7) Plate tectonics driven by **density**, **heat** and **gravity** (**convection**)
8) Plate tectonic theory explains most geologic phenomena

Review of Today's Topics

Topics

- ✓ Age of the Earth
- ✓ Earth Physiology
- ✓ Continental Drift
- ✓ Plate Tectonics Theory
- ✓ Seafloor Spreading
- ✓ Subduction
- ✓ Terrain Accretion