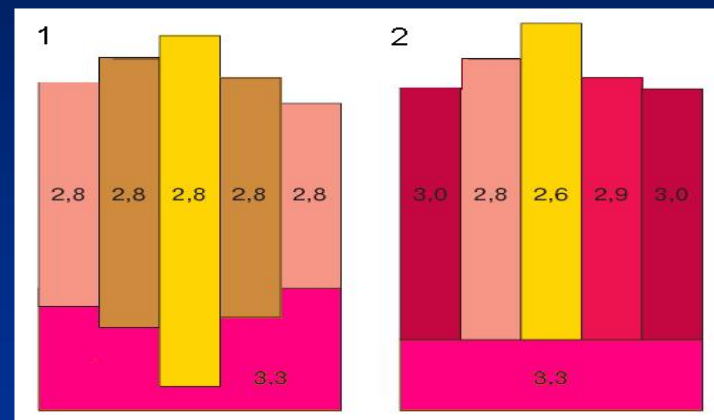
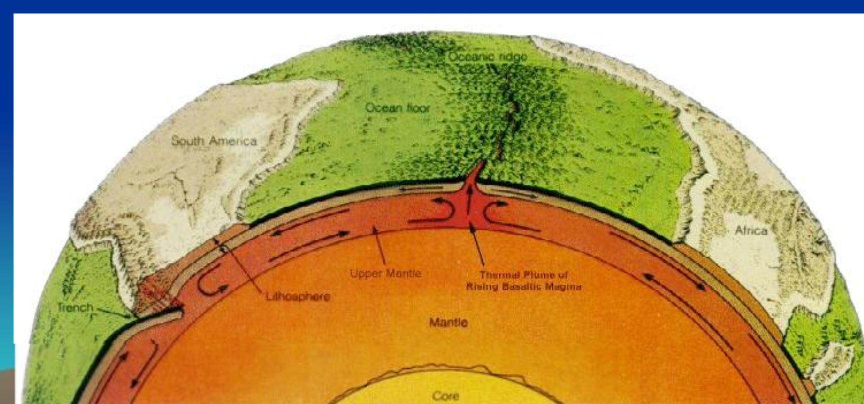
Isostasy and Tectonics Lab

Understanding the Nature of Mobile Floating Lithospheric Plates



Crust –Mantle Dynamics



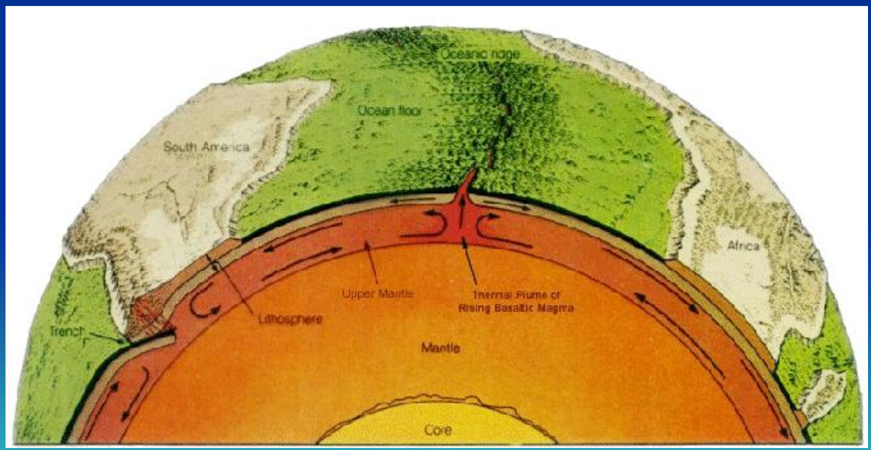
Introductory Geology Lab

Ray Rector - Instructor

Isostasy and Tectonics Laboratory

Topics of Inquiry

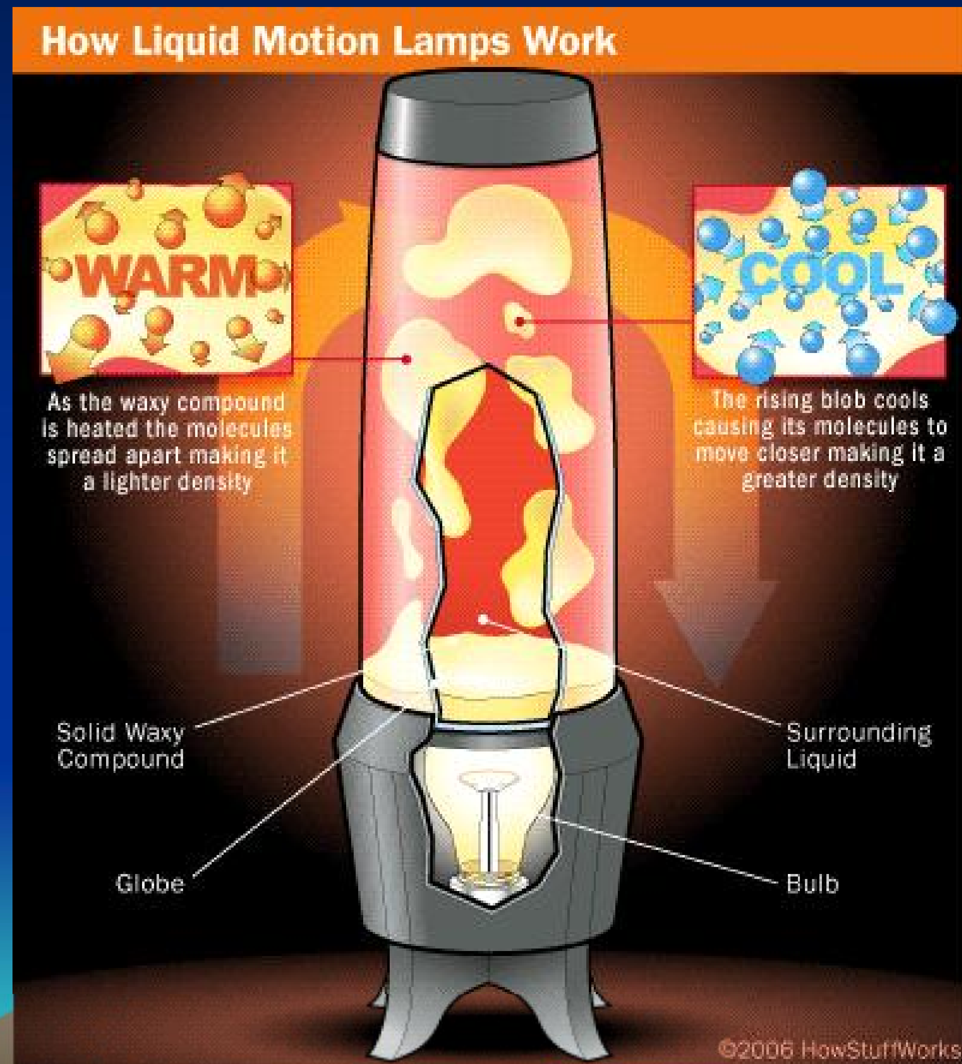
1) Concepts of Density and Buoyancy
2) Layered Physiology of the Earth
3) Isostatic Dynamics – Equilibrium vs. Adjustment
4) Modeling Isostasy in Lab
5) Plate Tectonic Theory
6) PT Processes:
   - ✓ Seafloor Spreading
   - ✓ Subduction
   - ✓ Hot Spots
7) Inter-Plate Dynamics
8) Measuring Plate Motion



Inquiry of Lava Lamp Motion

Density and the Convection Process

- ✓ Fluid material at top of lamp is cooler than material at the bottom.
- ✓ Hotter material is less dense than cooler material
- ✓ Less dense fluid rises while more dense fluid sinks
- ✓ Heat and gravity drive the system



Concept of Density

1) Density is an important intensive property

2) Density is a function of a substance's mass and volume

3) The density of a substance is a measure of how much mass is present in a given unit of volume.

- The more mass a substance has per unit volume, the greater the substance's density.
- The less mass a substance has per unit volume, the lesser the substance's density.

$$\text{Denisty} = \frac{\text{mass}}{\text{volume}} \quad \text{or} \quad D = \frac{m}{v}$$

4) Gravity controls the weight of a given volume of a substance, based on the substance's density

- The more dense the material, the heavier it weighs.
- The less dense the material, the less it weighs.

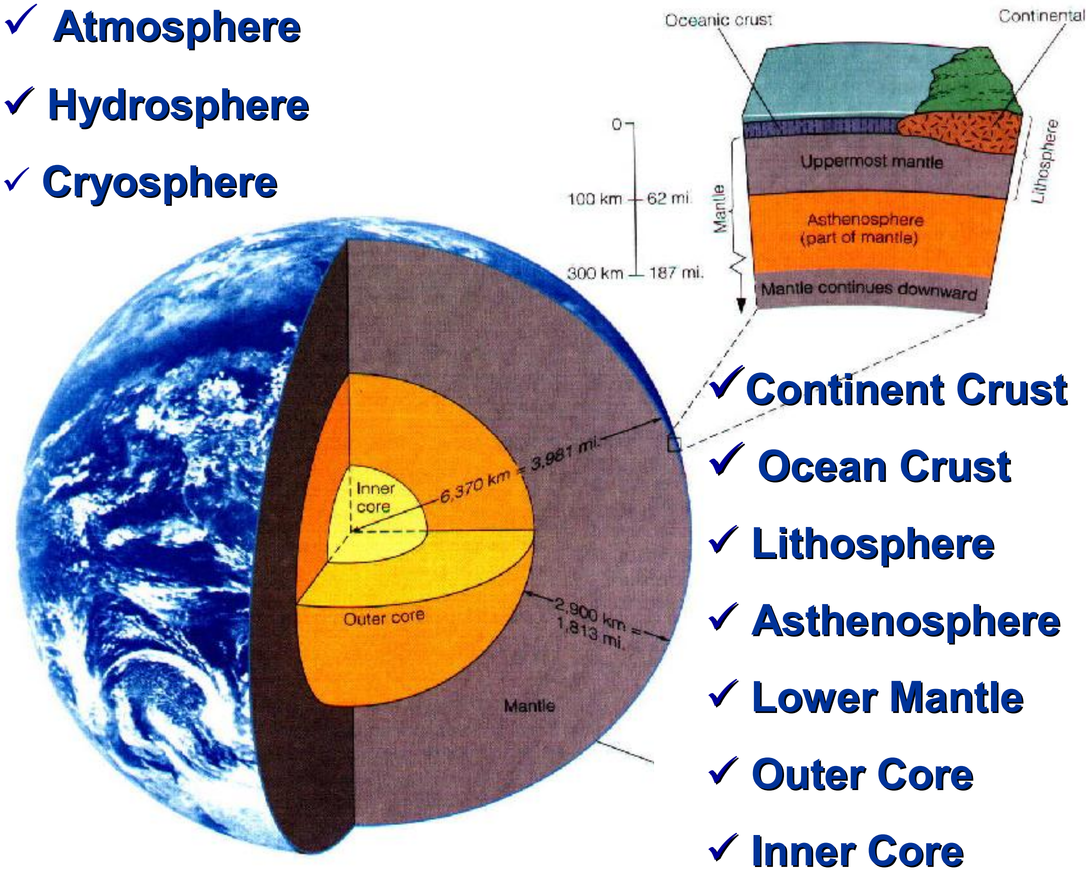
Earth's Layered Structure

1) Ten Different Density Layers

2) Each Layer Has Unique Physical and Chemical Properties

3) All Layers Arranged According to Density

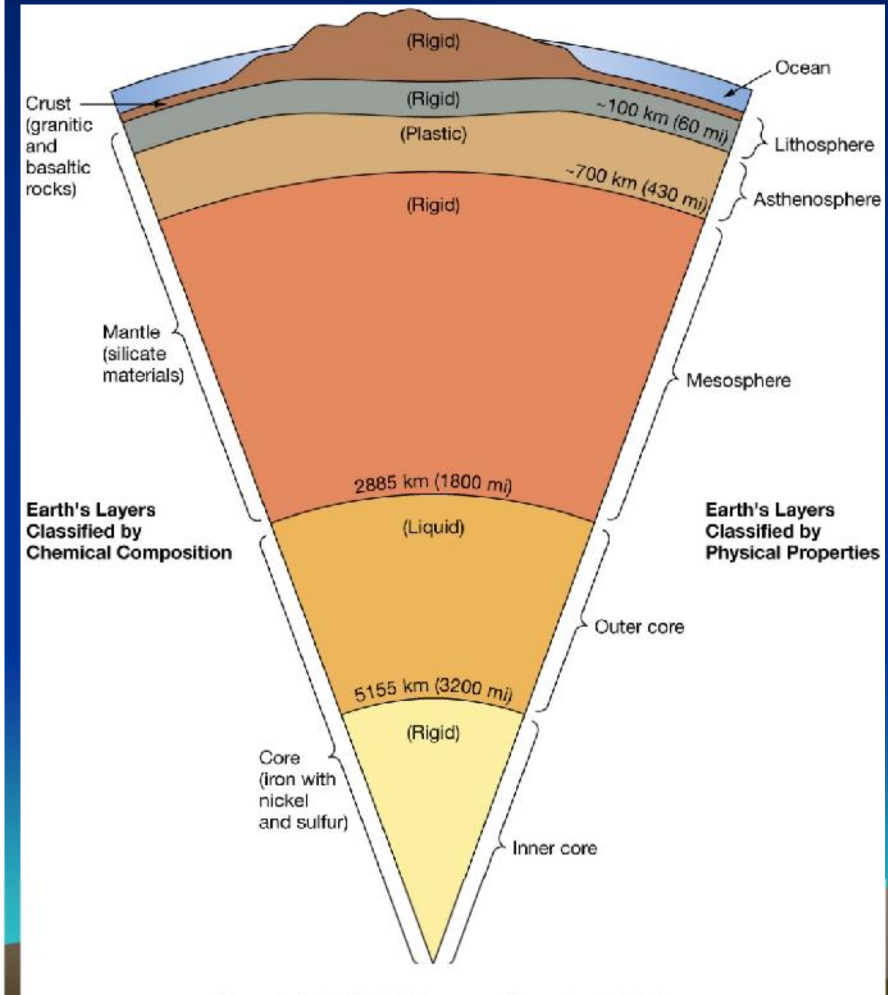
- ✓ Atmosphere
- ✓ Hydrosphere
- ✓ Cryosphere

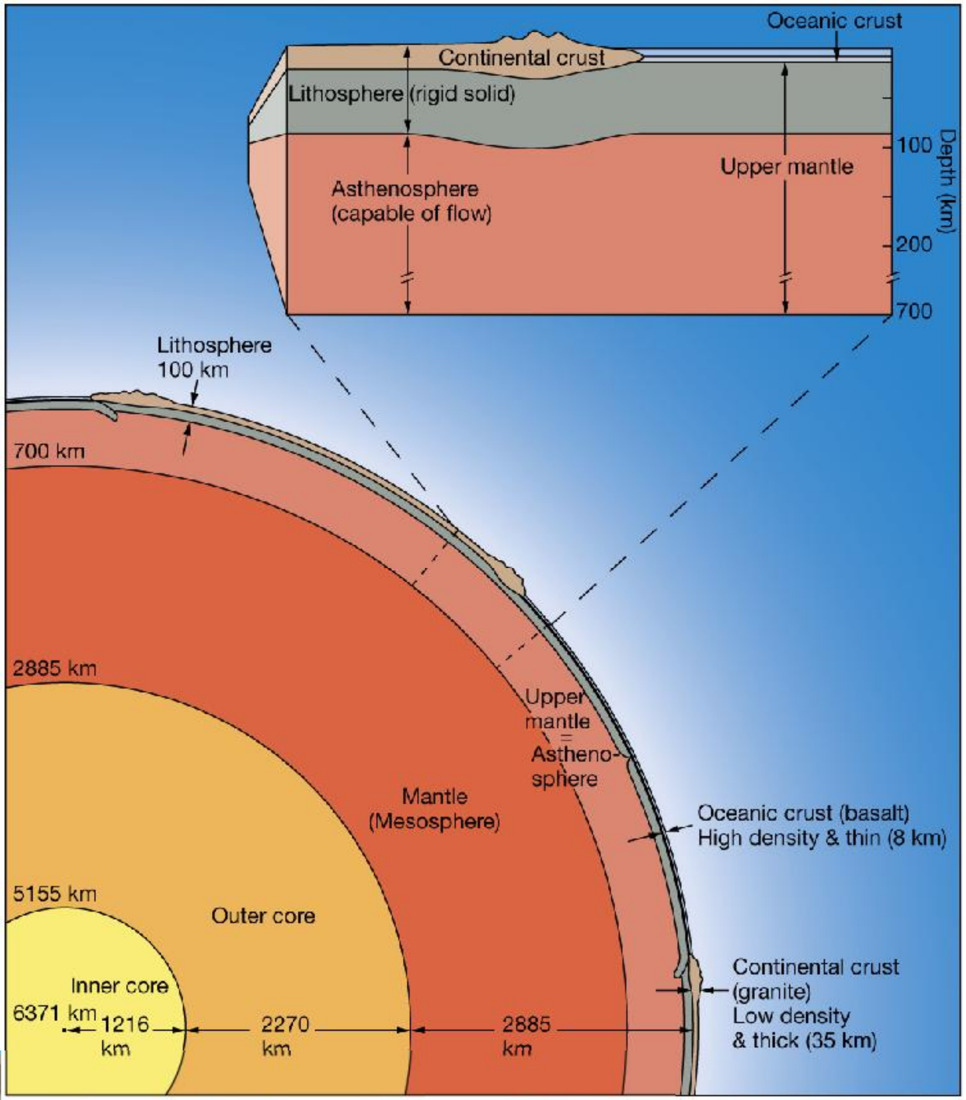


- ✓ Continent Crust
- ✓ Ocean Crust
- ✓ Lithosphere
- ✓ Asthenosphere
- ✓ Lower Mantle
- ✓ Outer Core
- ✓ Inner Core

Earth's Interior

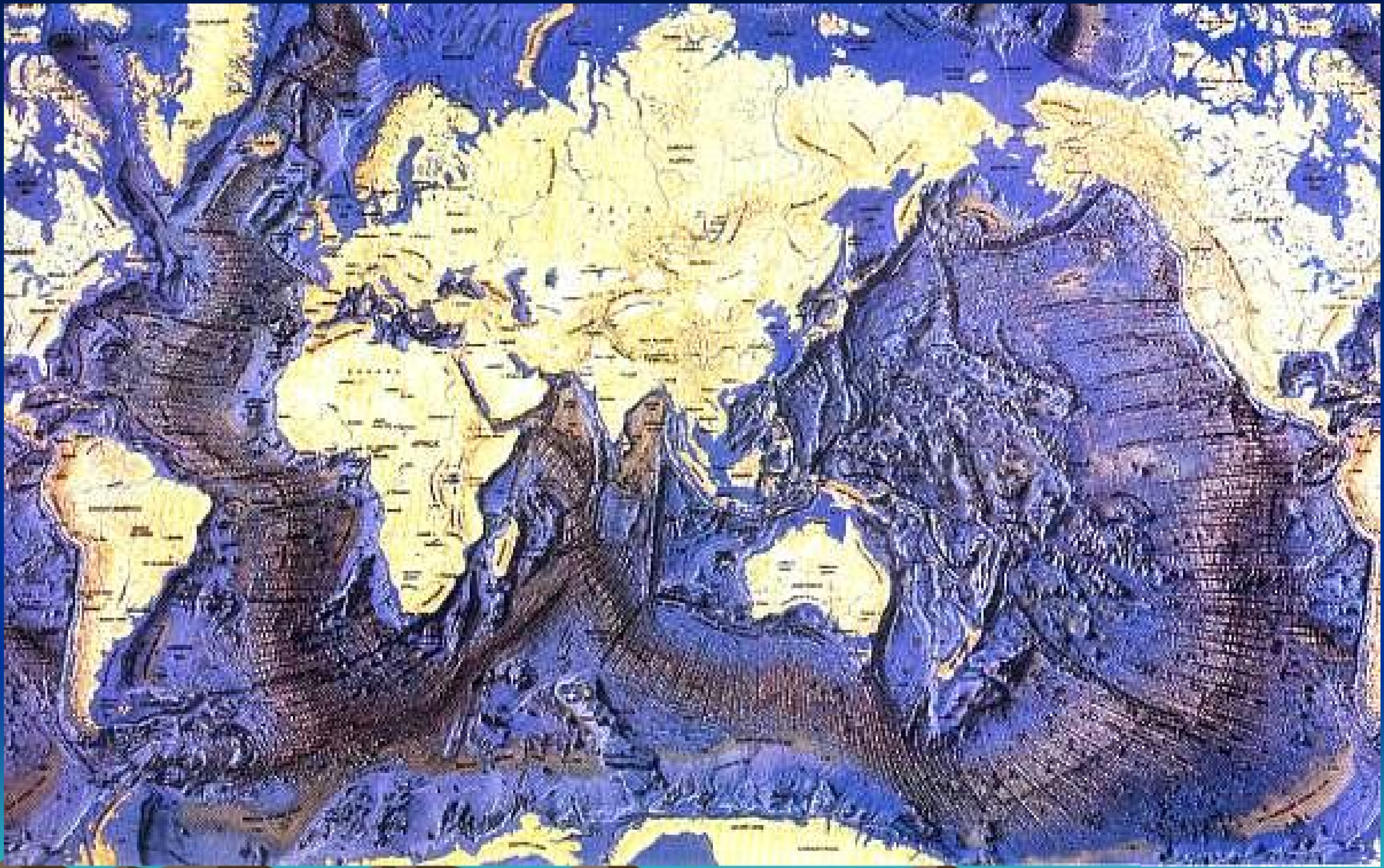
Chemical and Physical Nature of Earth's Interior



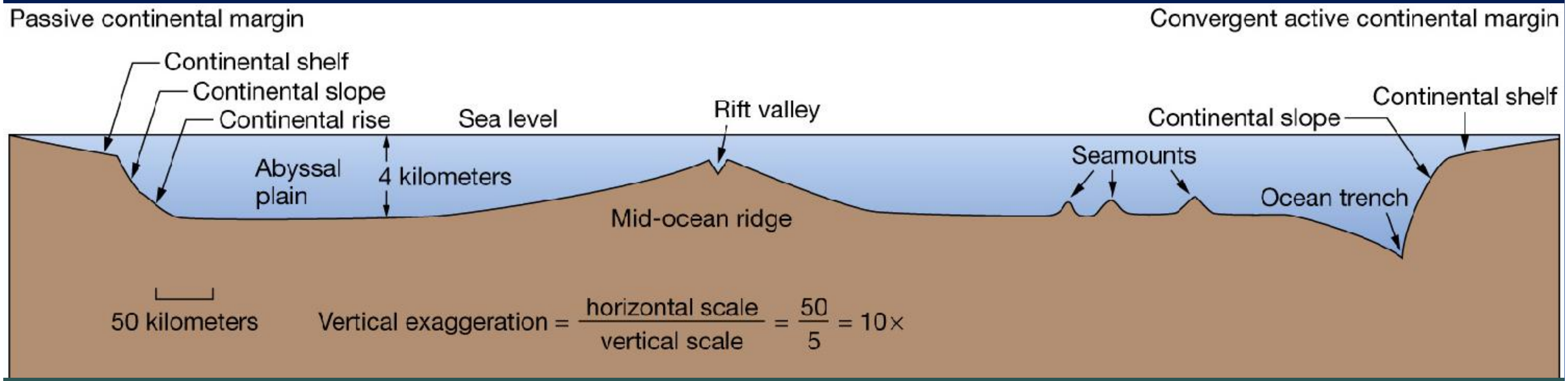


Density Layering of Earth's Interior

Topography of Earth's Surface



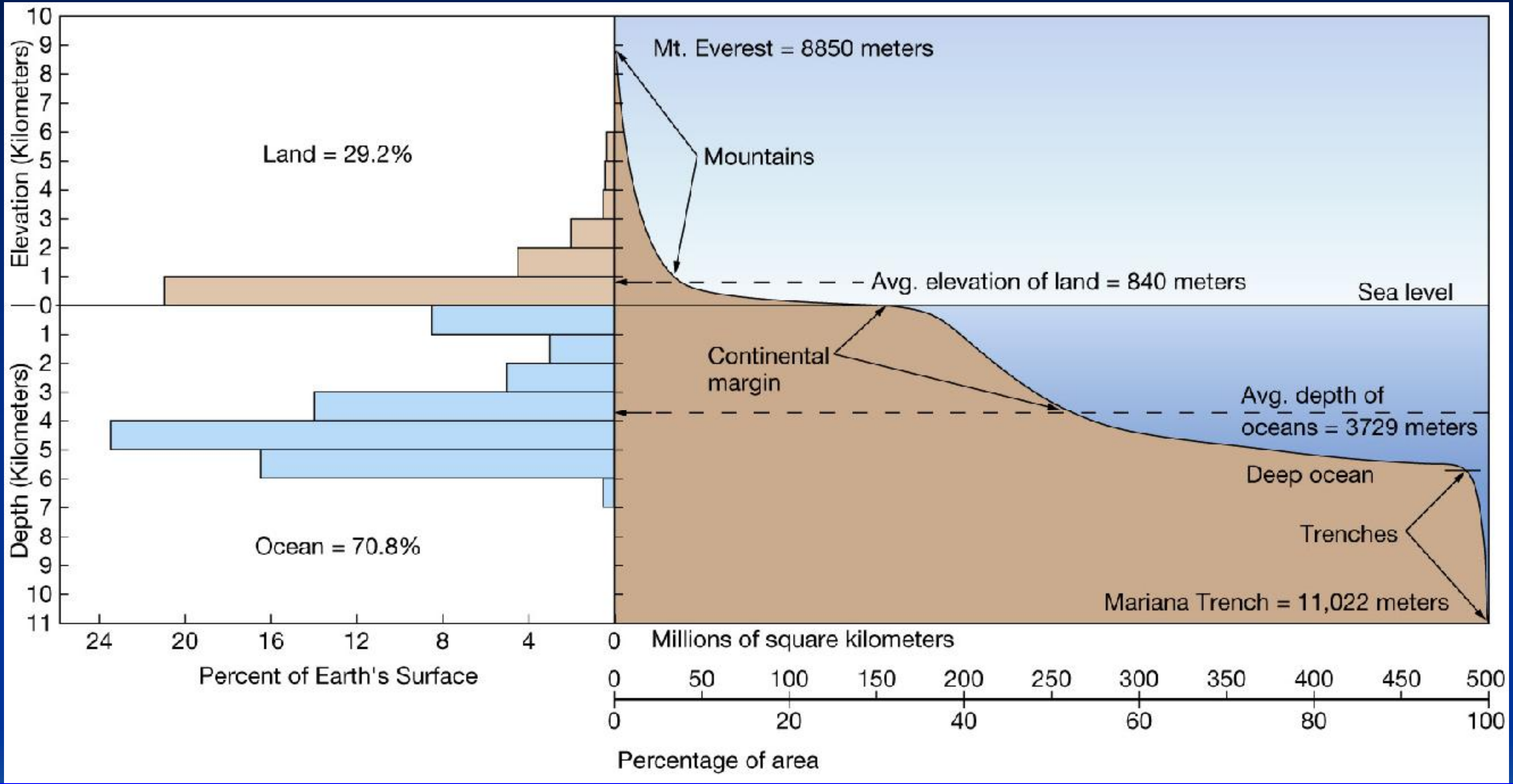
Cross-Section Profile of an Ocean Basin



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

Two Primary Types of Earth Crust

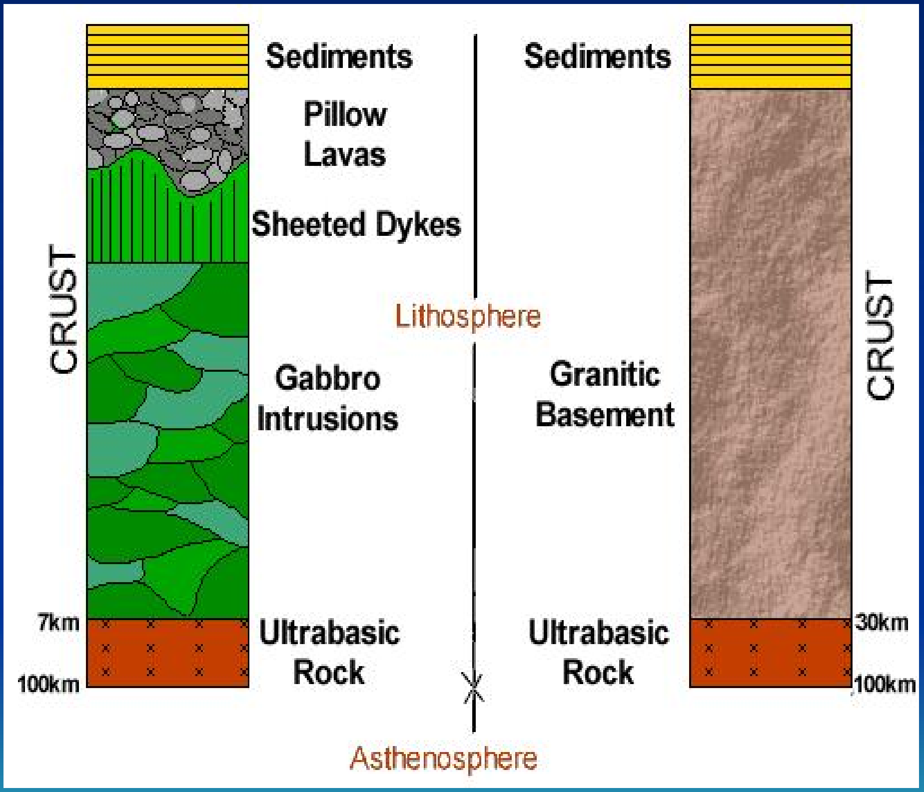
1) **Two Different Types of Crust**
   - ✓ Continental = Granitic
   - ✓ Oceanic = Gabbroic

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

3) Oceanic Crust
   - ✓ Denser (2.9 g/ml)
   - ✓ Thicker (7 km)
   - ✓ Low Standing (- 4 km elev.)

Oceanic Crust
Gabbroic Rock

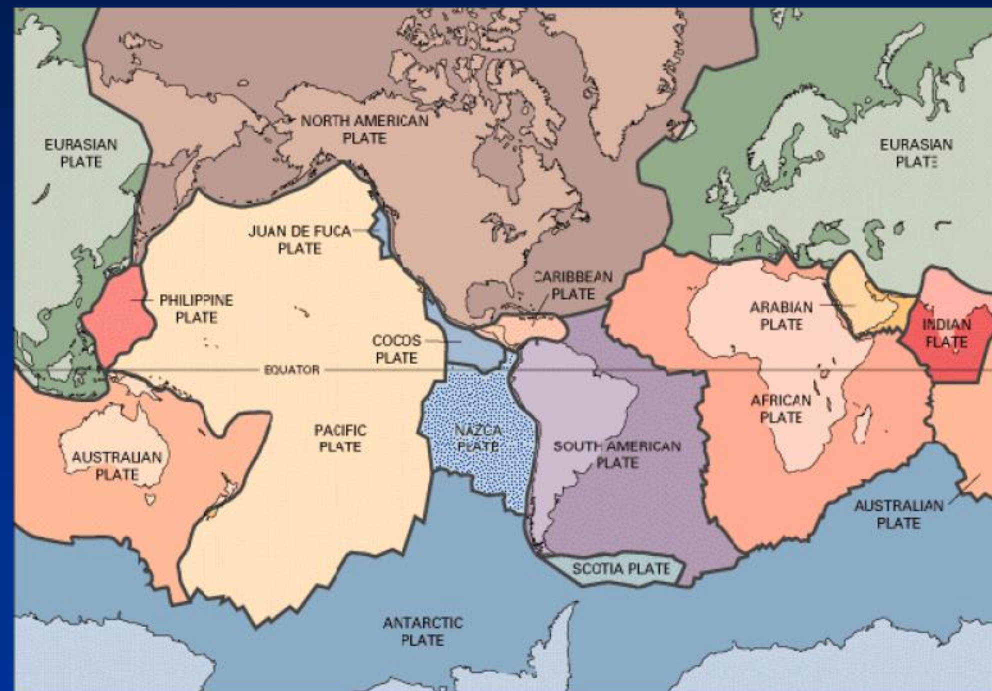
Continental Crust
Granitic Rock



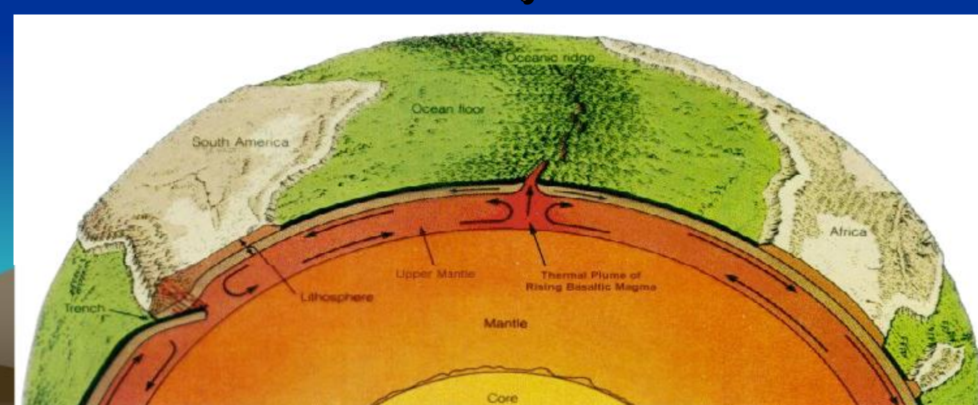
THE TECTONIC PLATES

Key Features:

- ✓ 6 Major Plates
- ✓ 8 Minor Plates
- ✓ 100 km thick
- ✓ Strong and rigid
- ✓ Plates float on fluid asthenosphere
- ✓ Plates are mobile
- ✓ Plates move at a rate of centimeters per year



Earth's Lithospheric Plates



Concept of Buoyancy

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

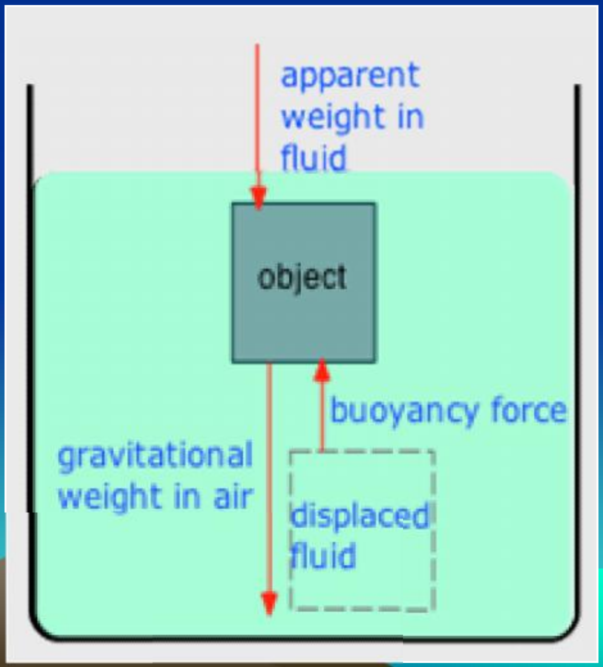
2) Buoyancy is the fluid pressure exerted on an immersed object equal to the weight of fluid being displaced by the object.

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 "isostasy".

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

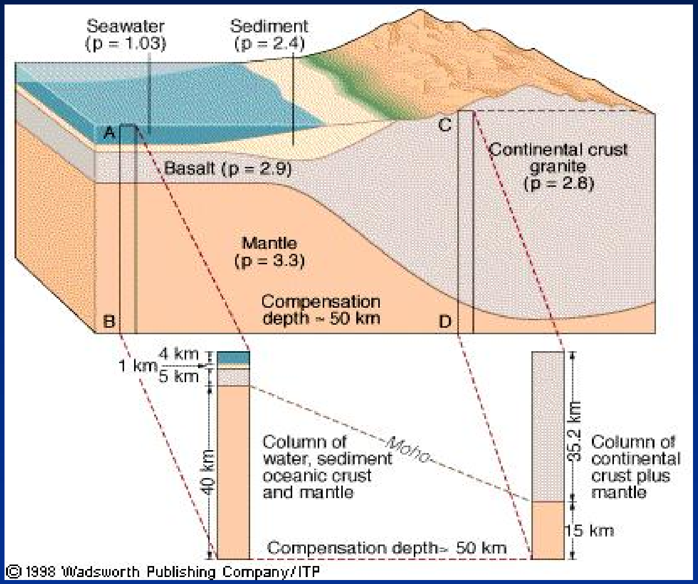


Example of Buoyancy: Boat on a Lake

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.

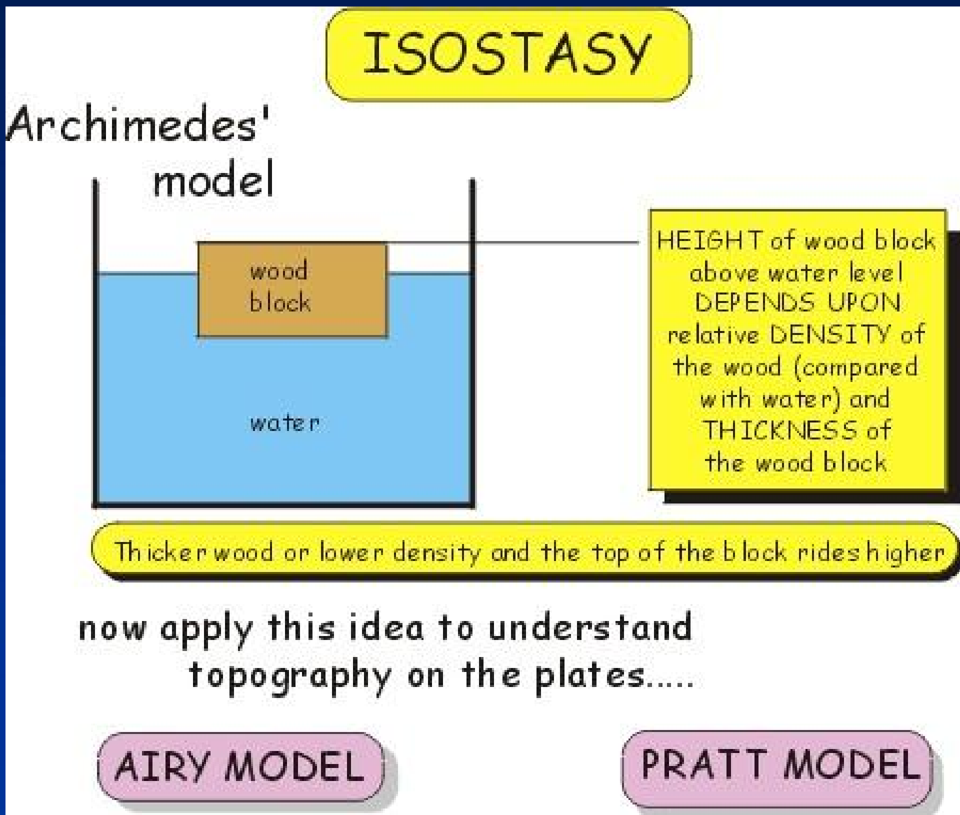
- Earth's strong rigid plates exert a downward-directed load on the mobile, underlying weaker, plastic-like asthenosphere – pushing down into the mantle.

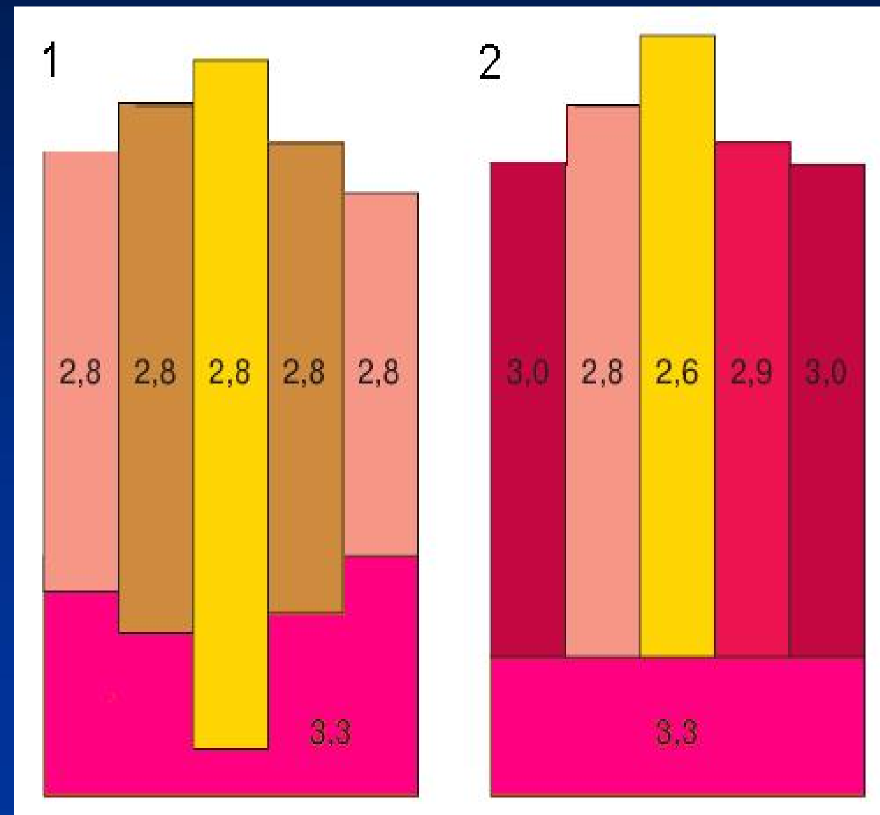
- The asthenosphere exerts an upward pressure on the overlying plate equal to the weight of the displaced mantle – *isostatic equilibrium* is established.

- Mantle will flow laterally to accommodate changing crustal loads over time – this is called *isostatic adjustment*

- Plate tectonics, erosion and changing ice cap upsets isostatic equilibrium

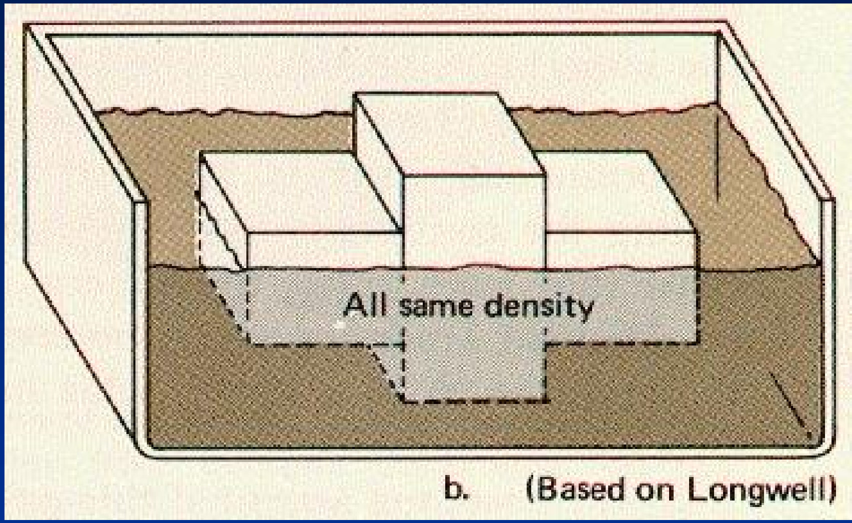
Isostasy and Isostatic Equilibrium

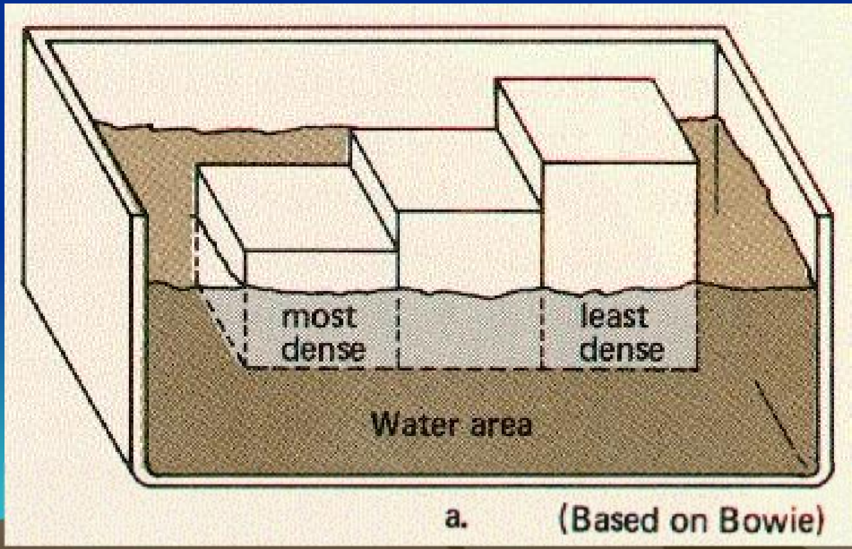


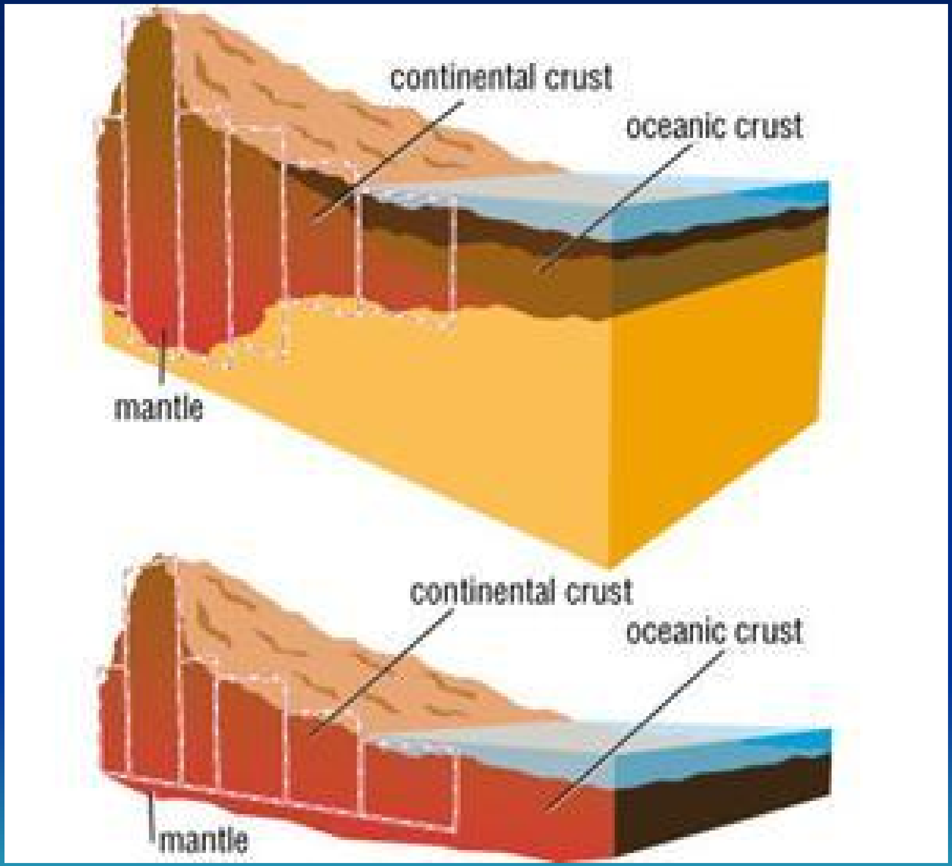


Two Different Models to Explain the Difference in Height (Topography) of the Earth's Crust

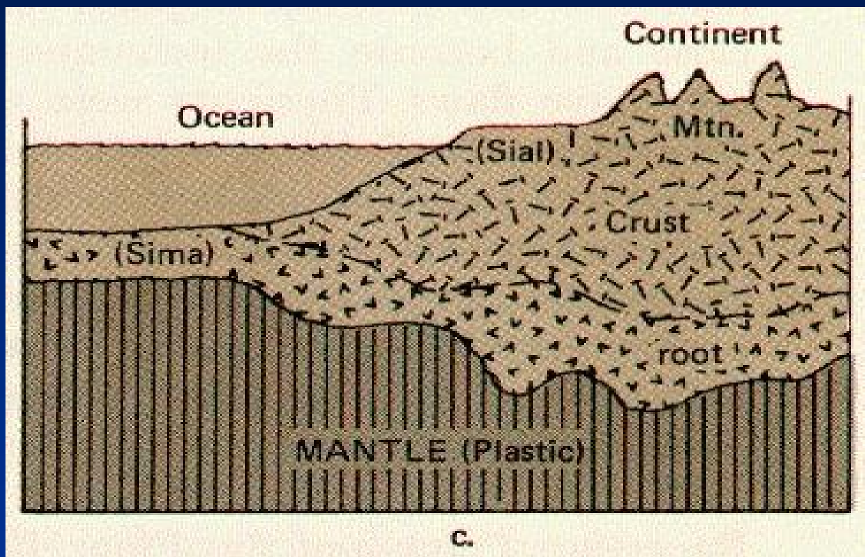
The Isostasy Equilibrium

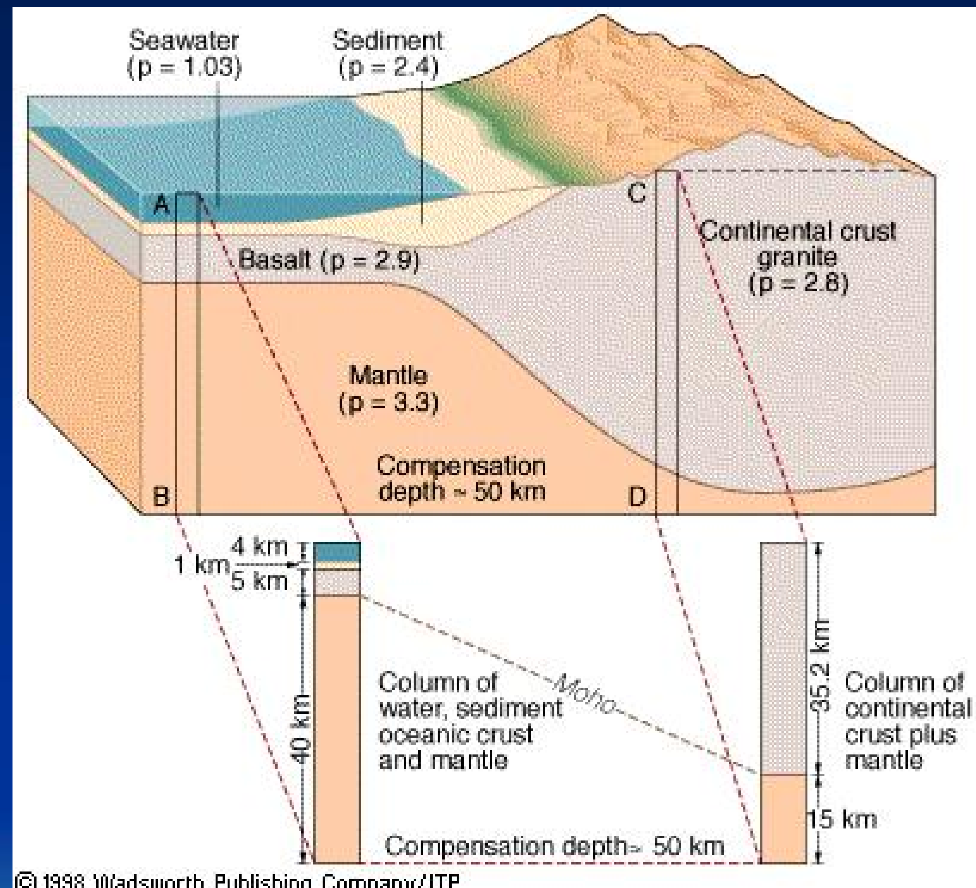


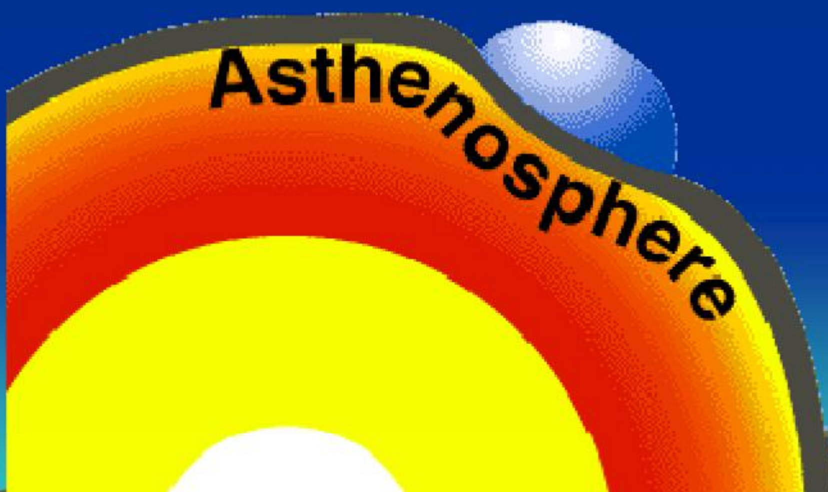




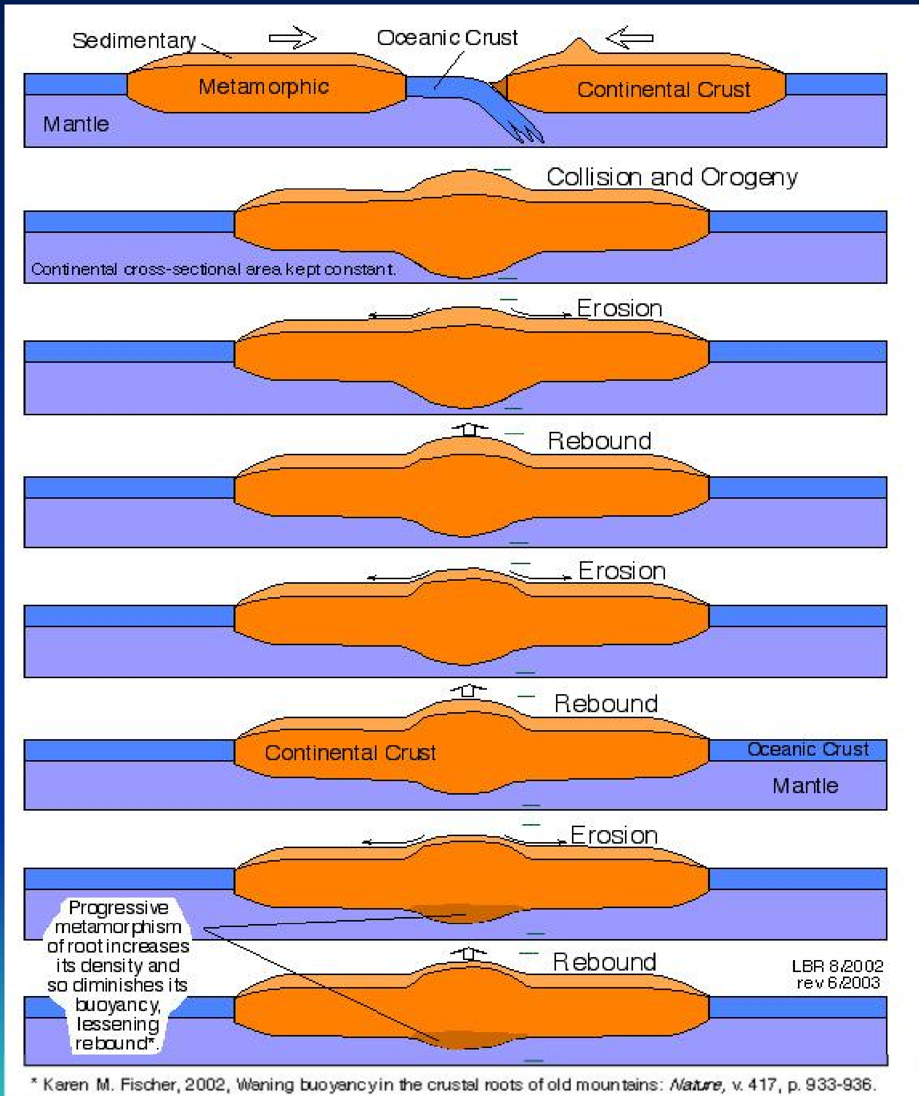
The Isostatic Equilibrium

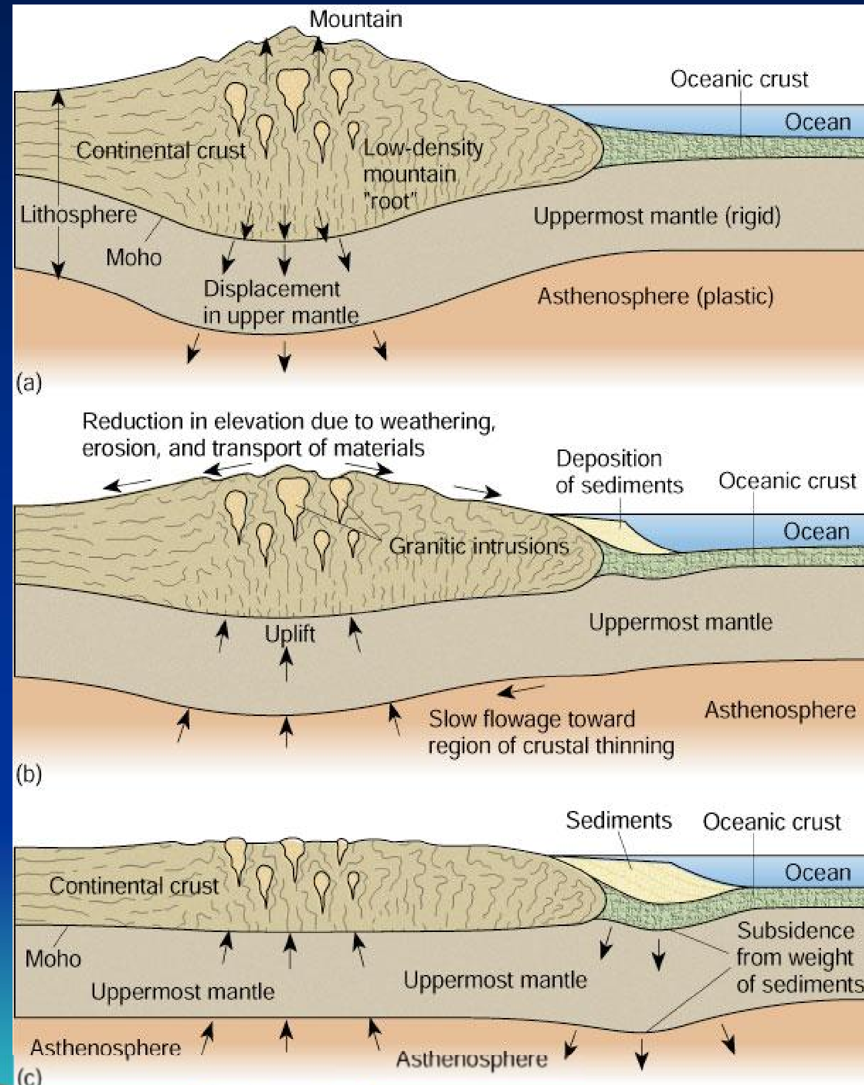






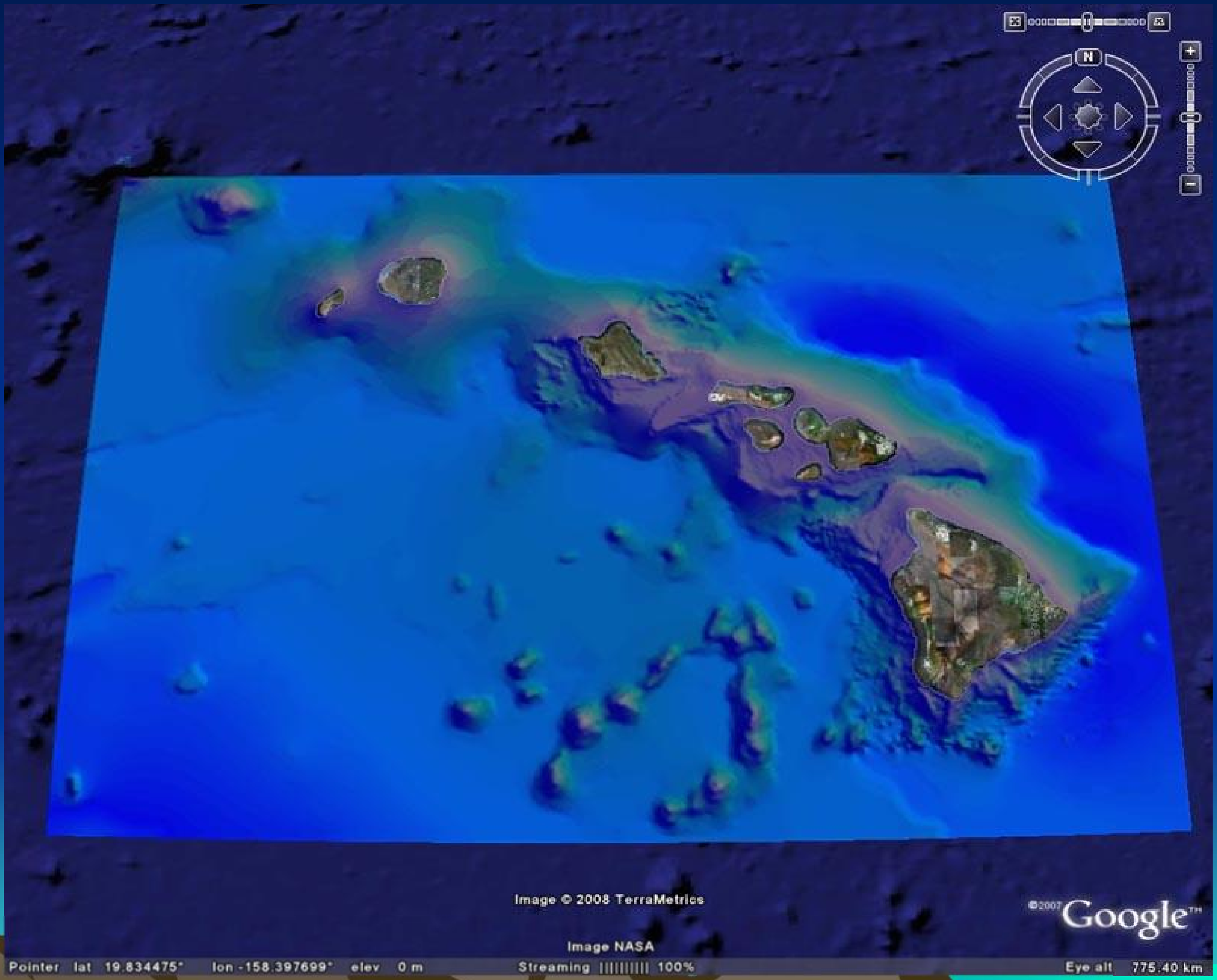
Isostatic Adjustment - Orogeny





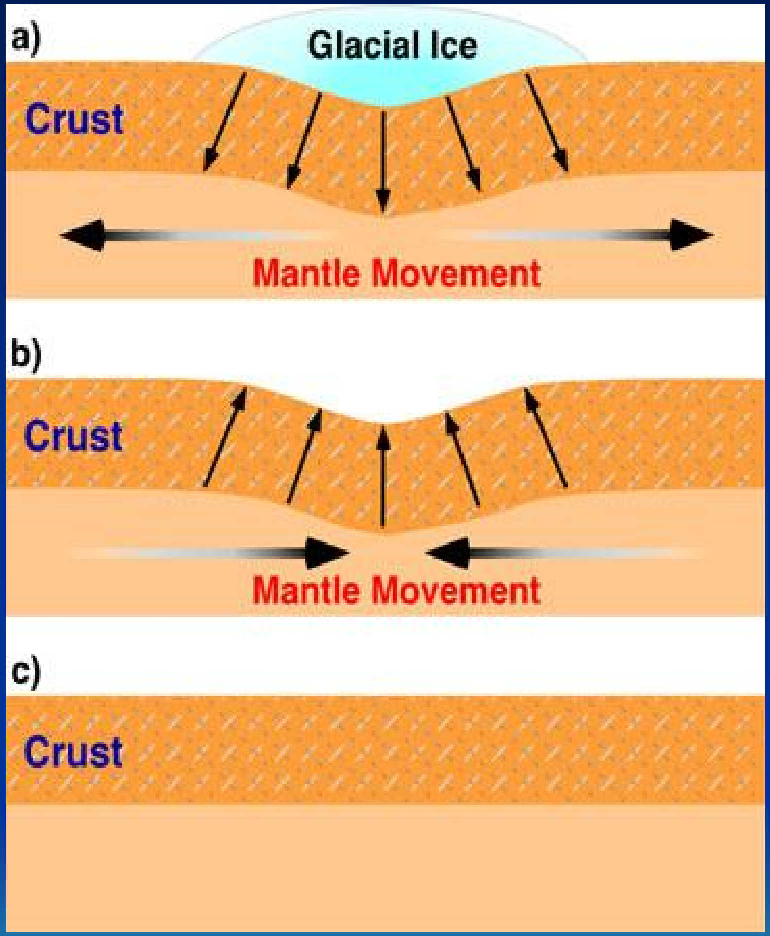
Isostatic Loading and Rebound – *Orogeny and Erosion*

Isostatic Adjustment – Volcanism

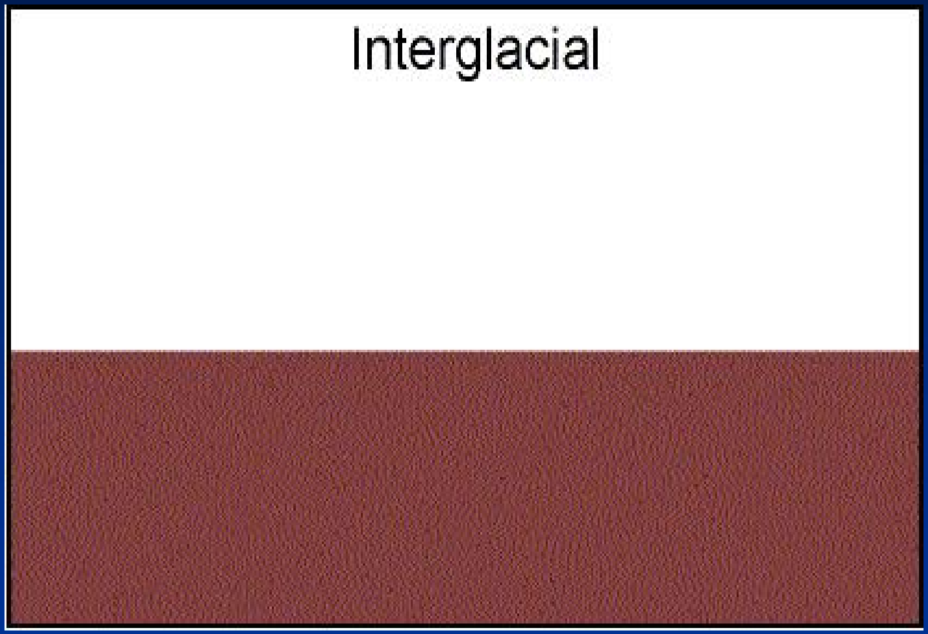


Growth of the Hawaiian Islands – Crustal Depression

Isostatic Adjustment – Ice Caps



Glacial Adjustment



Isostatic Response to Changing Ice Thickness

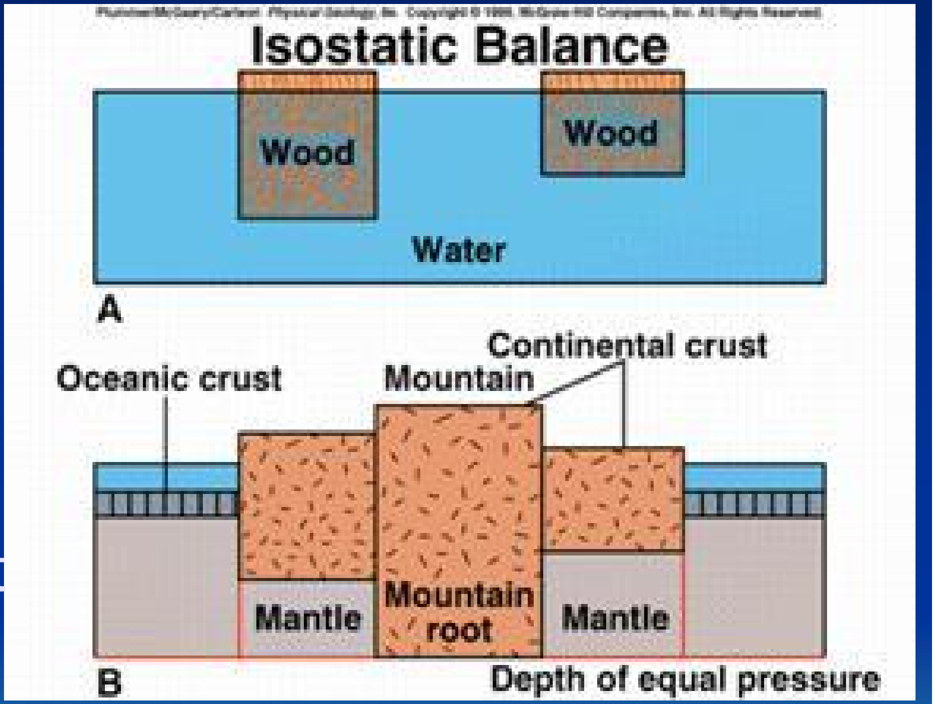
North American Pleistocene Ice Cap

- ✓ Ice Cap Maximum: 20,000 ya
- ✓ Ice Cap Retreat: 6,000 YA
- ✓ Last 6,000 years:
  - ➢ Sea level rising
  - ➢ Land uplifting
- ✓ To establish an accurate rate of uplift, you need to add rise in sea level to uplift amount

Modeling Earth's Isostasy

Using Wood Blocks and Water to Understand the Key Concepts of Isostatic Equilibrium and Adjustment

- ➢ Density of Floating Blocks
- ➢ Thickness of Floating Block
- ➢ Density of Liquid Water



The Lab Model:

1) Hardwood as Ocean Crust

2) Redwood as Continental Crust

- ✓ Thick = Mountains
- ✓ Thin = Low-lying Regions

3) Water as the Underlying Mantle

Determining Material Densities

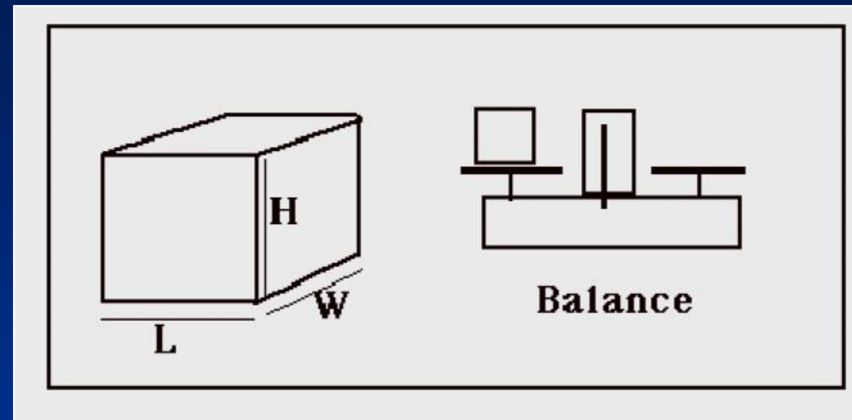
Wood Block Densities:

1) Determine Mass (grams) with flattop scale.

2) Determine Volume (cubic cm) with ruler

- ✓ Length x height x width

3) Measure thick redwood block



$$\text{Denisty} = \frac{\text{mass}}{\text{volume}} \quad \text{or} \quad D = \frac{m}{v}$$

Rock Densities:

1) Determine Mass (grams) with flattop scale

2) Determine Volume (cubic cm) with graduated cylinder

- ✓ Displacement method

The Water Displacement Method

1) Useful for determining the volume of irregular solid objects.

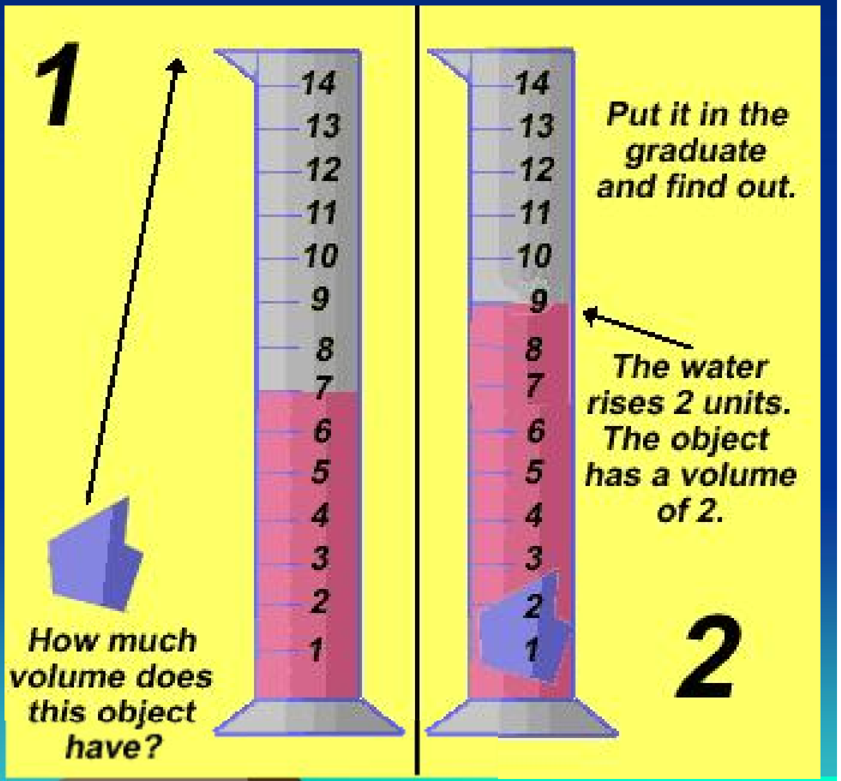
2) You need a graduated cylinder and water.

3) An object's volume will displace an equal volume of water in the graduated cylinder.

The Lab Model:

1) Dark Rock as Ocean Crust

2) Light Rock as Continental Crust



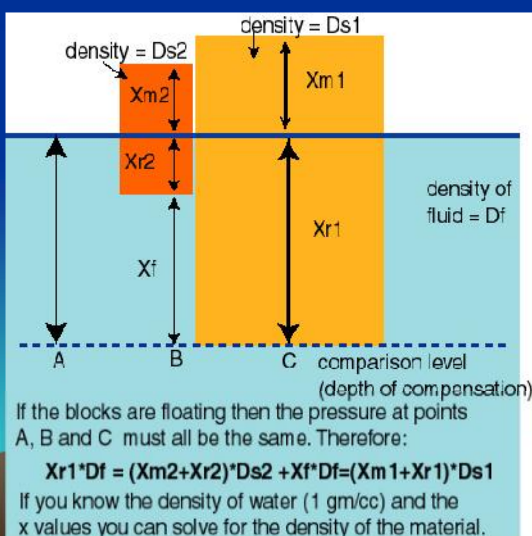
Density/Thickness – Buoyancy Relationship

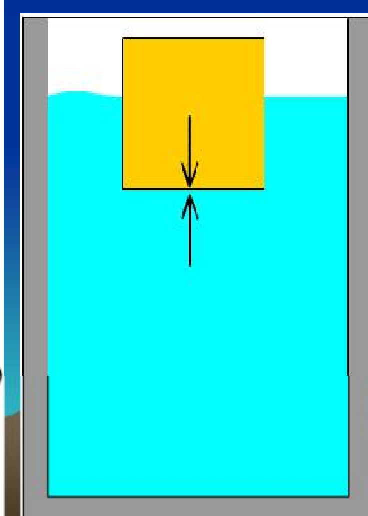
Wood Block Behavior in Water:

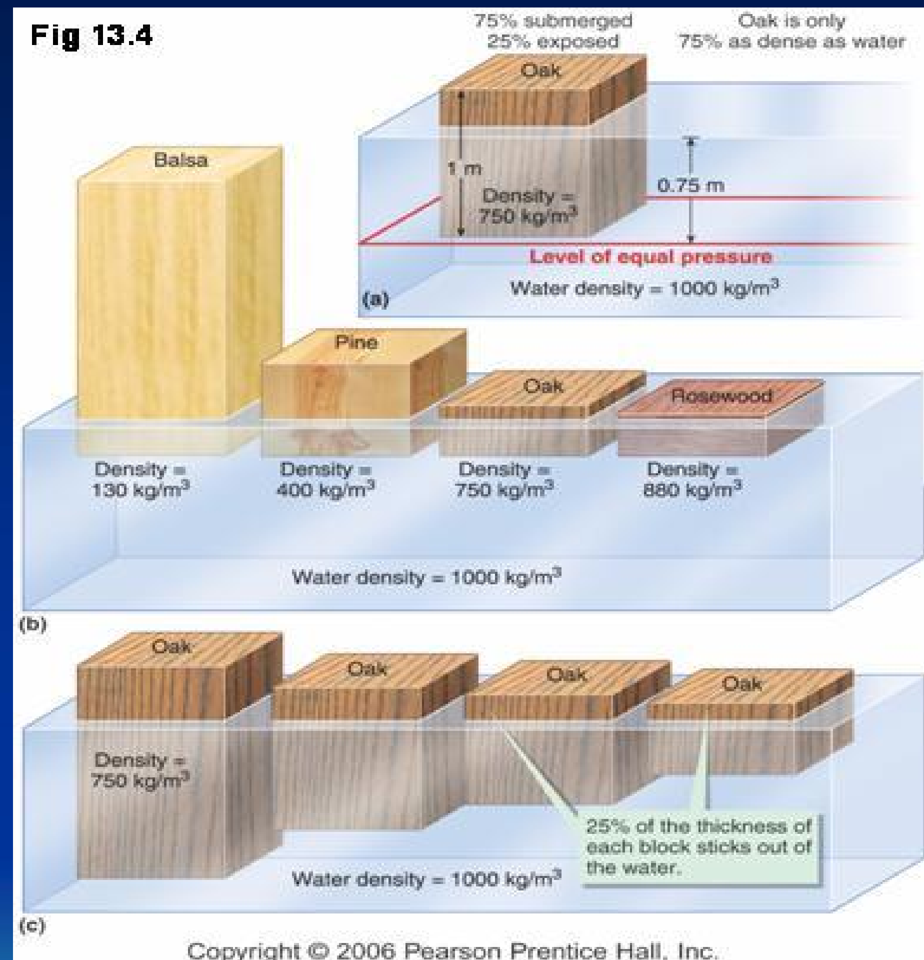
1) Density of wood in relation to water density determines level of buoyancy: (percentages in/out of water)

2) Thickness of block determines absolute height in and out of water

3) Measure thick redwood block







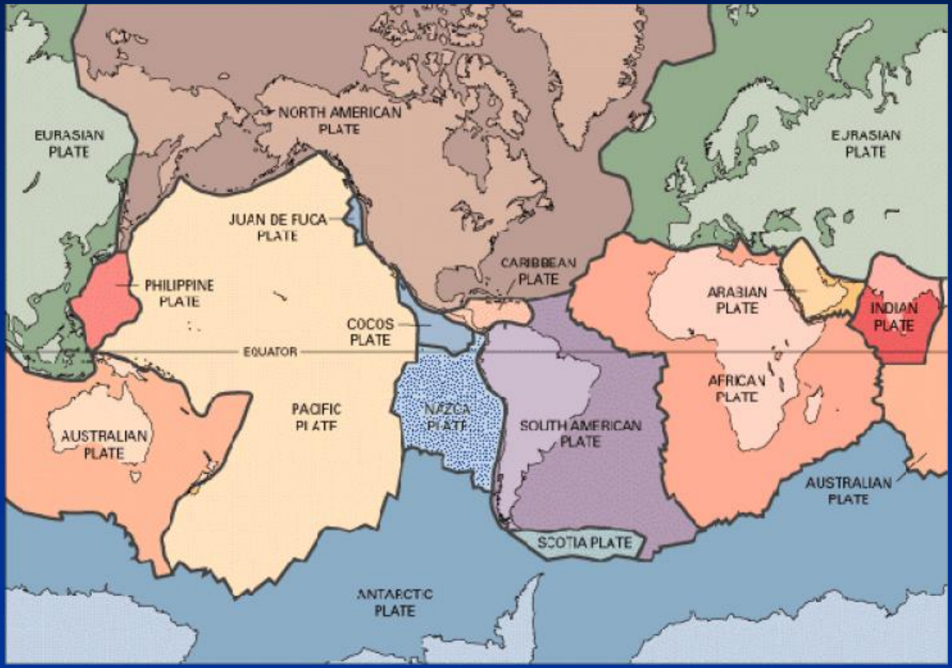
$$\text{Denisty} = \frac{\text{mass}}{\text{volume}} \quad \text{or} \quad D = \frac{m}{v}$$

PLATE TECTONICS THEORY

Key Features:

- ✓ 6 Major Plates
- ✓ 8 Minor Plates
- ✓ 100 km thick
- ✓ Strong and rigid
- ✓ Plates float on top of soft asthenosphere
- ✓ Plates are mobile
- ✓ Plates move at a rate of centimeters per year

Earth's Lithospheric Plates



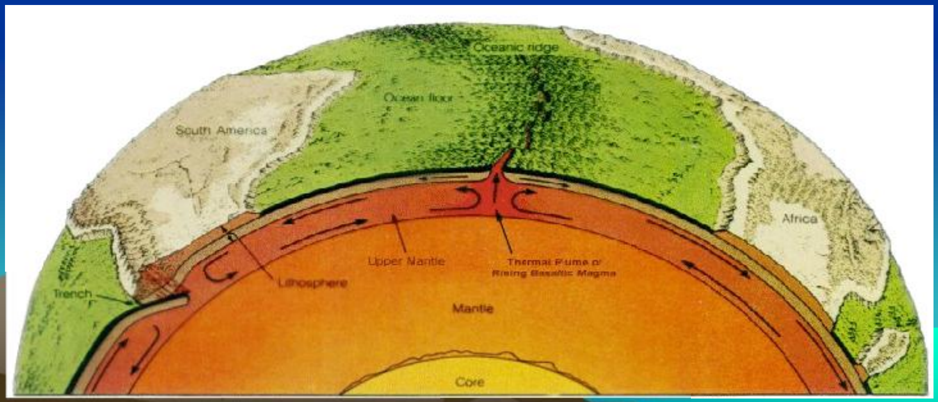
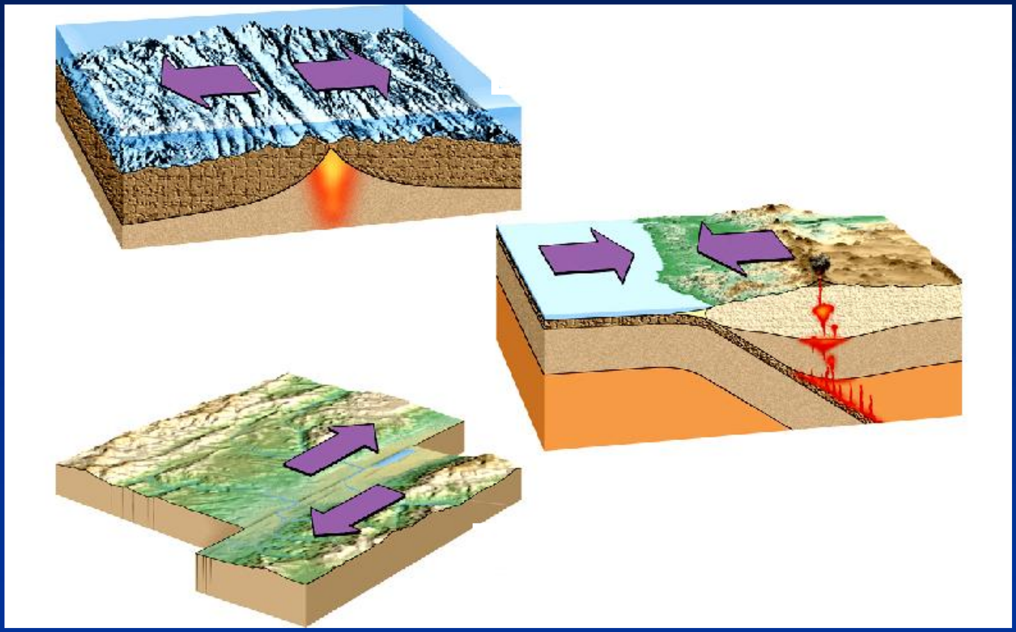
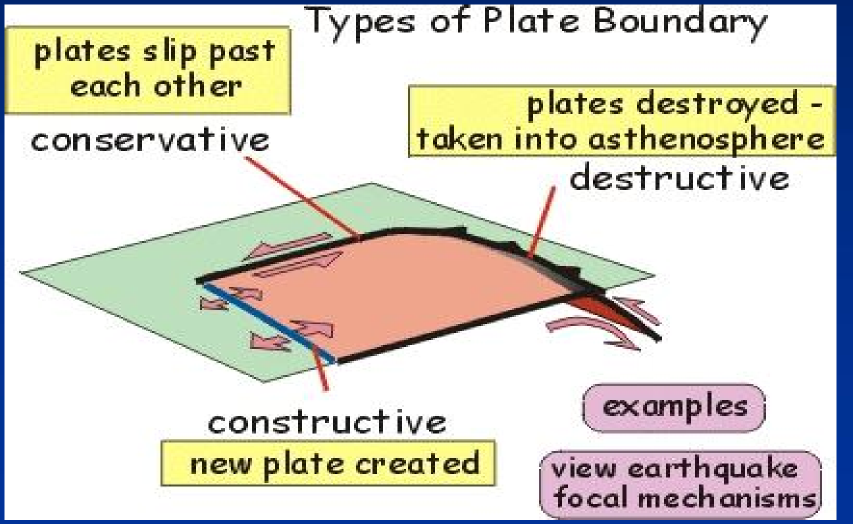


PLATE TECTONICS

Three Principle Types



of Plate Boundaries



1) **Divergent** = Tensional Stress = Constructive Tectonics

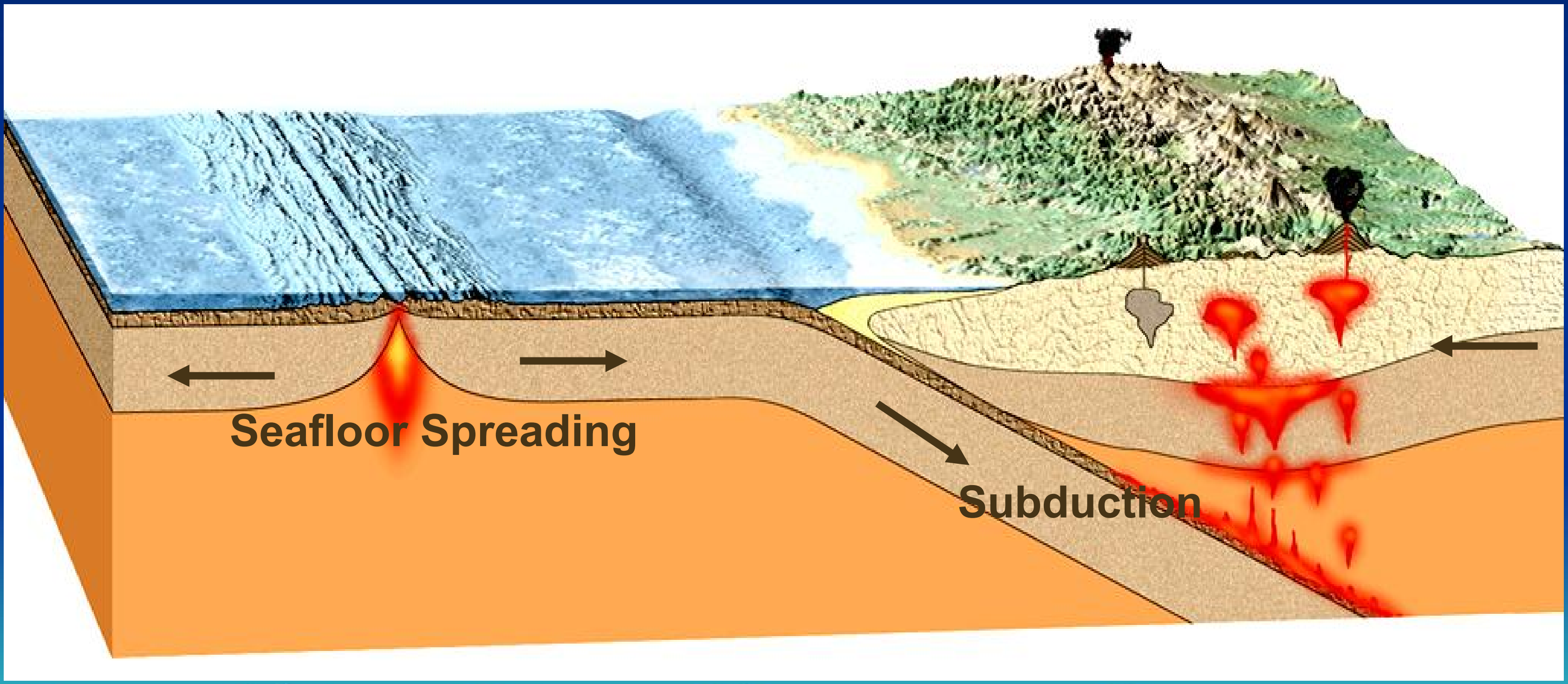
2) **Convergent** = Compressional Stress = Destructive Tectonics

3) **Transform** = Lateral Shear Stress = Conservative Tectonics

PLATE TECTONICS

Two Principle Tectonic Processes

1) **Seafloor Spreading = Constructive**
2) **Subduction = Destructive**



Seafloor Spreading and Subduction Animation

Key Features:

1) The illustration shows both progressive growth and destruction of oceanic lithosphere by seafloor spreading and subduction, respectively.

2) Basaltic magmas are generated at both centers of seafloor spreading and subduction.

3) Magmas at seafloor spreading centers are hot, fluid and dry, and produce relatively non-violent eruptions

4) Magmas at subduction centers are rich in silica and water and produce infrequent, massive, and violent volcanic eruptions

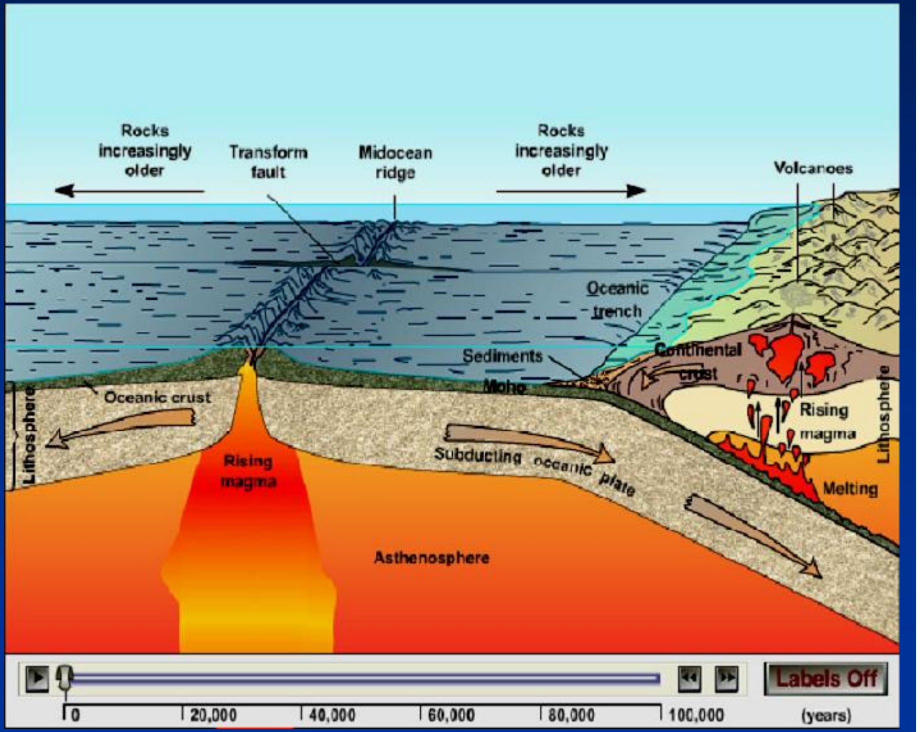


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PLATE TECTONICS

Three Types of Convergent Plate Boundaries

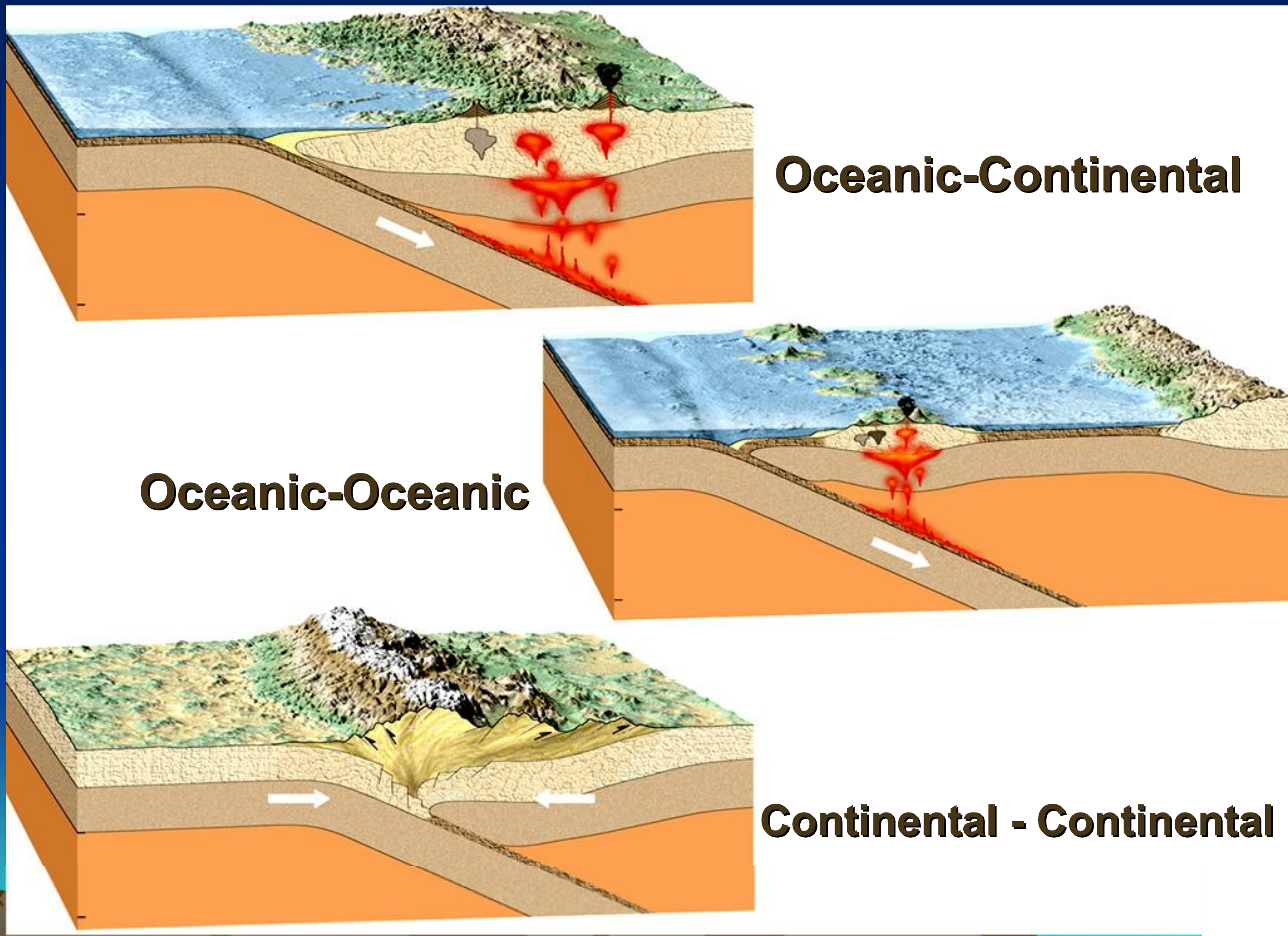
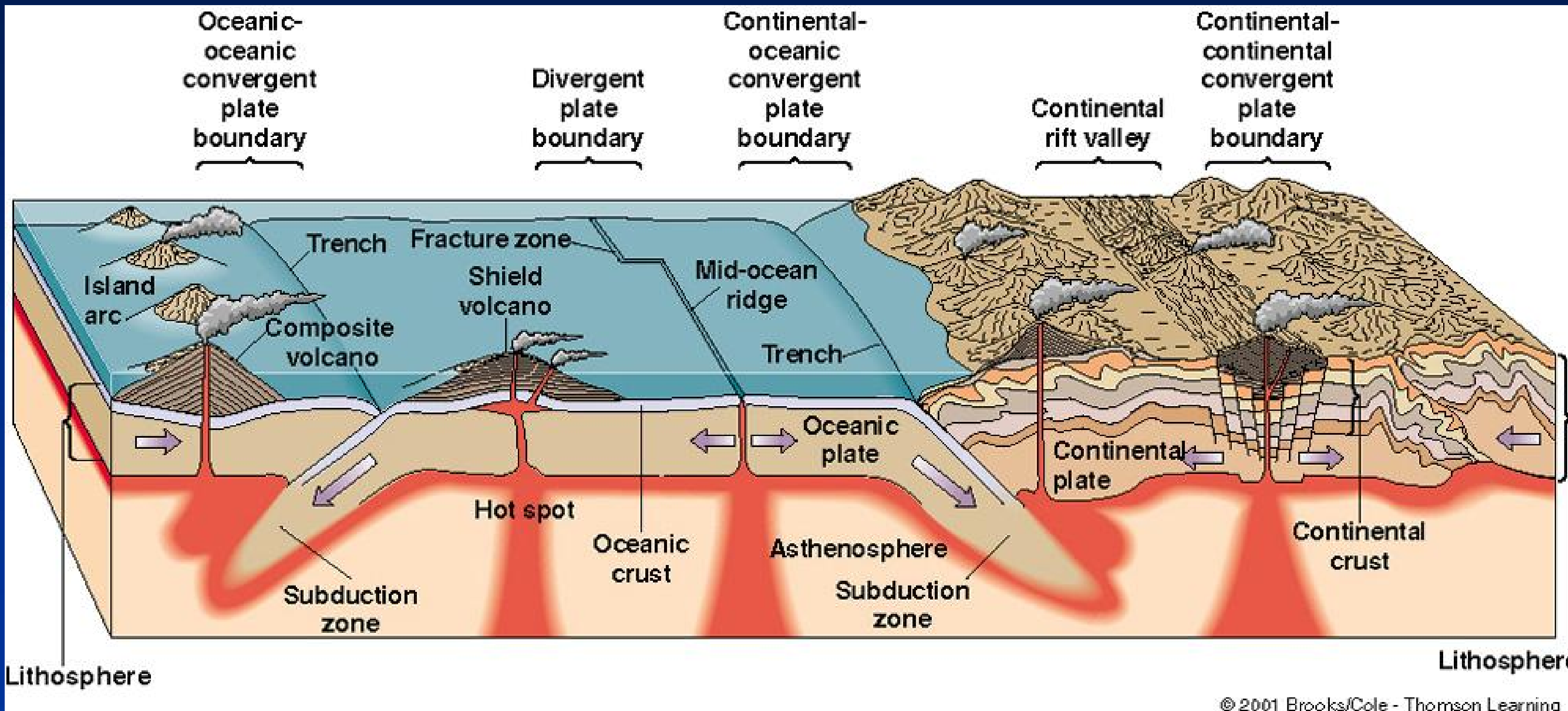


Plate Boundary Configurations



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Four Principle Mechanisms Driving Plates

1) Slab Pull

- Pulling of whole plate by the __sinking of the subducting slab
- Gravity-assist

2) Trench Suction

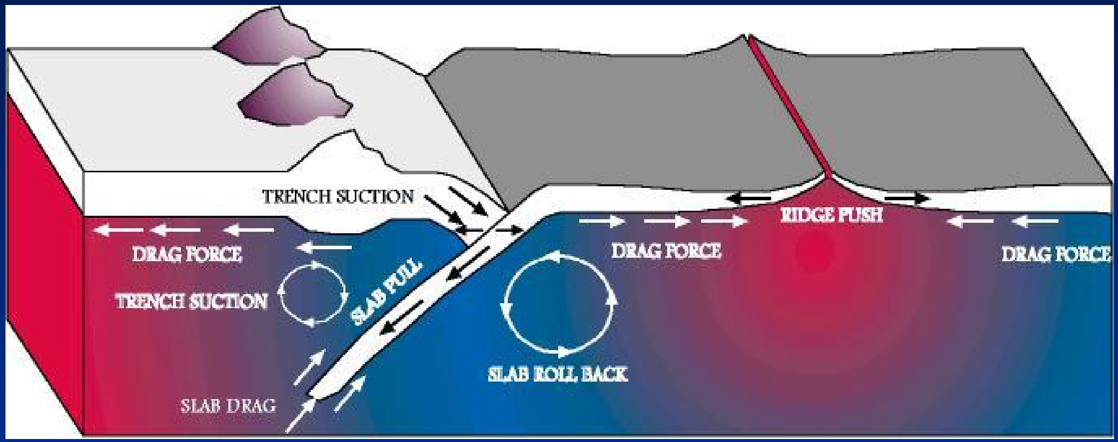
- Sucking of slab downward
- Downward flow of __asthenosphere around slab

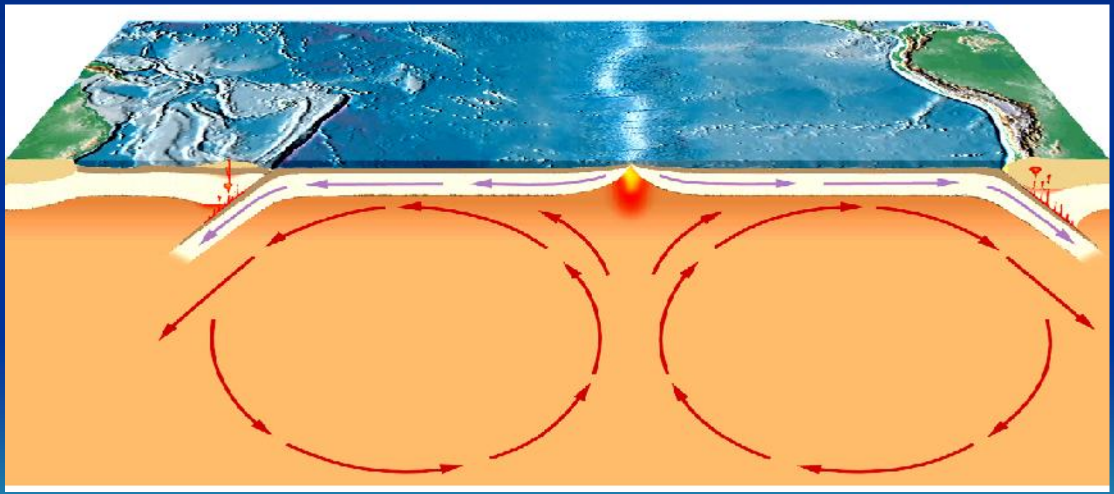
3) Ridge Push

- Pushing of "elevated" ocean ridge lithosphere toward trench
- Gravity-assist

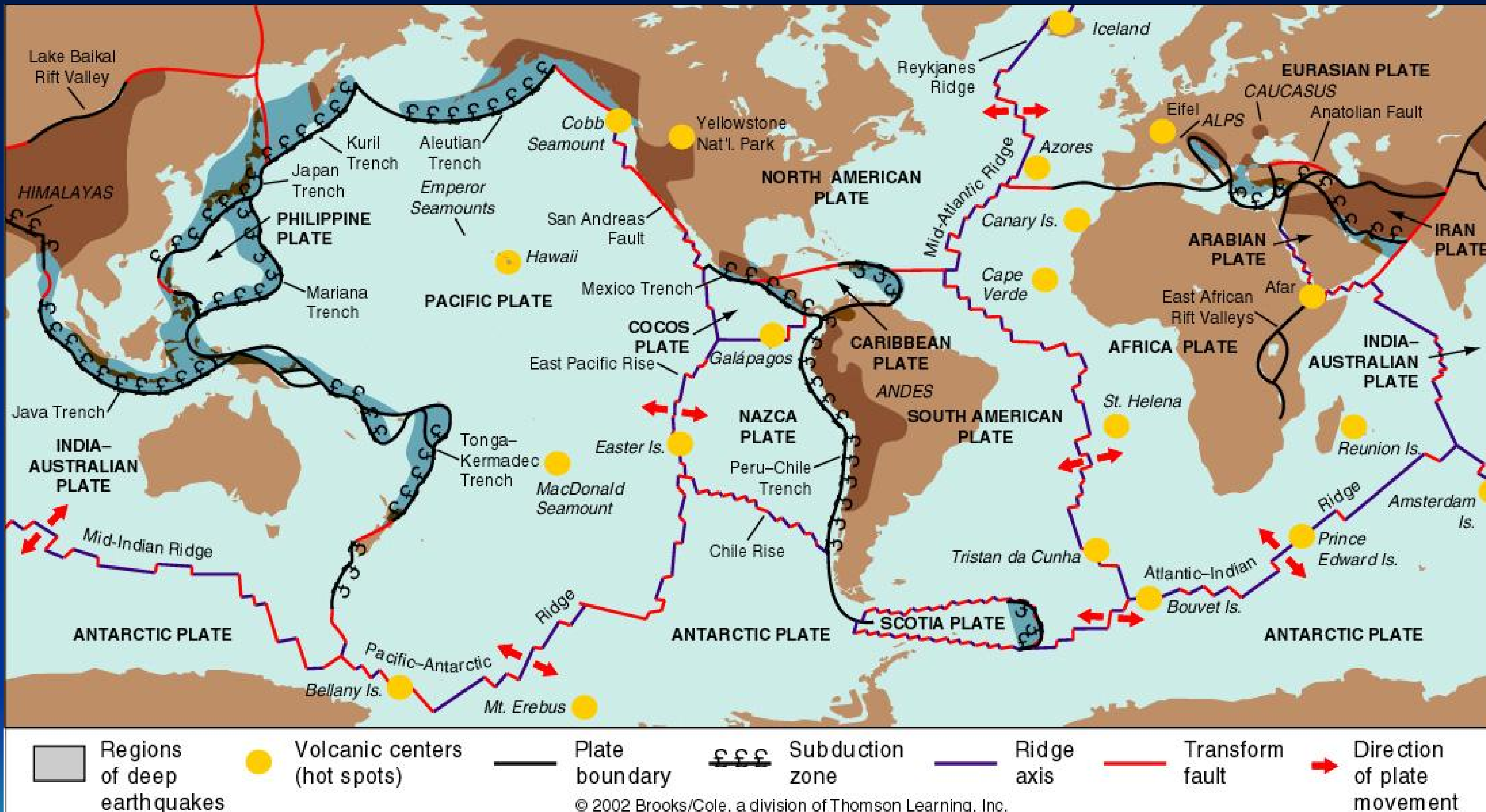
4) Drag Force

- Dragging forces on base of __lithosphere by asthenosphere
- Earth's mantle convection



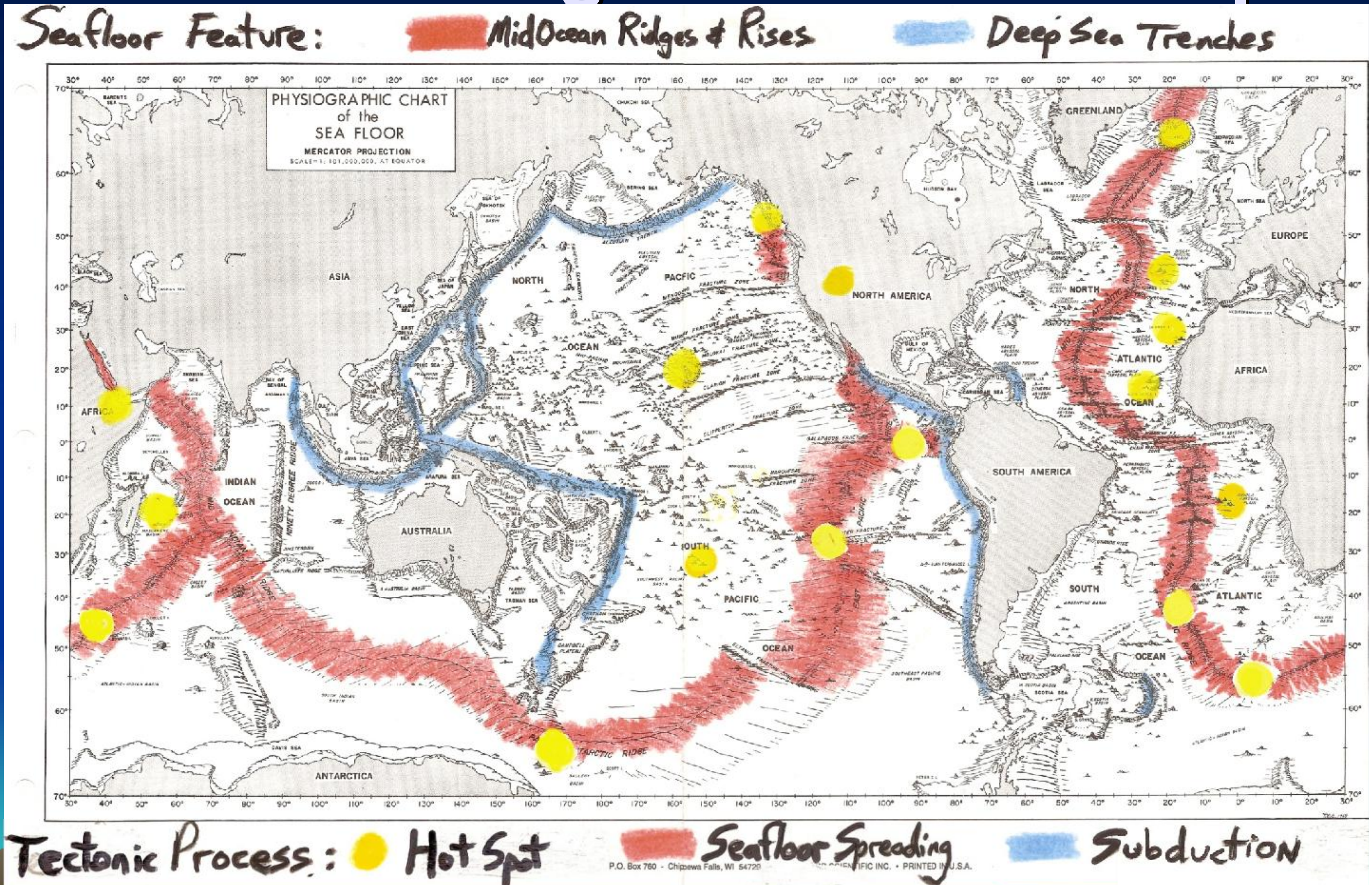


The Mobile Lithospheric Plates

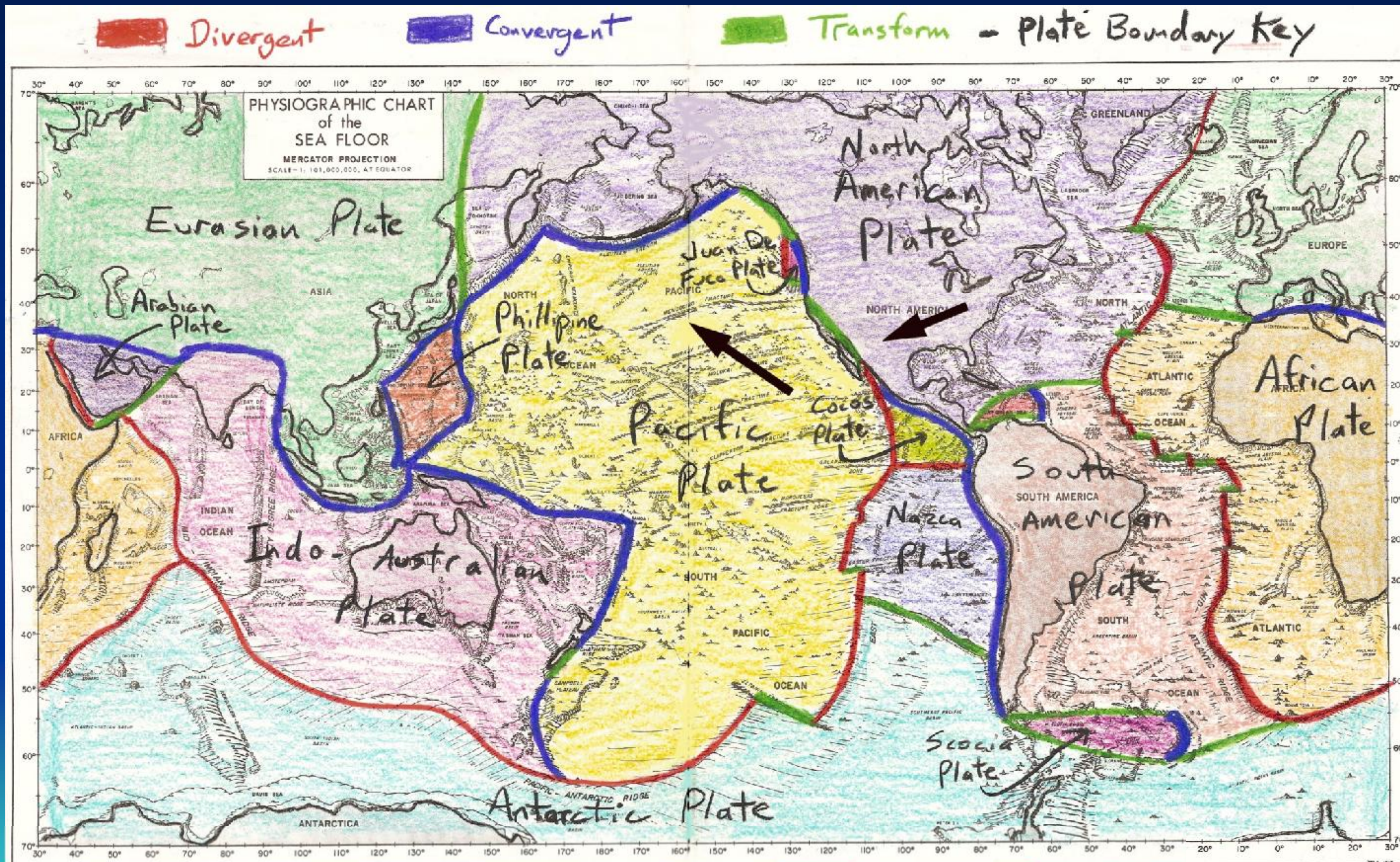


Convergent = Black line/Blue shading **Divergent** = Purple line **Transform** = Red line

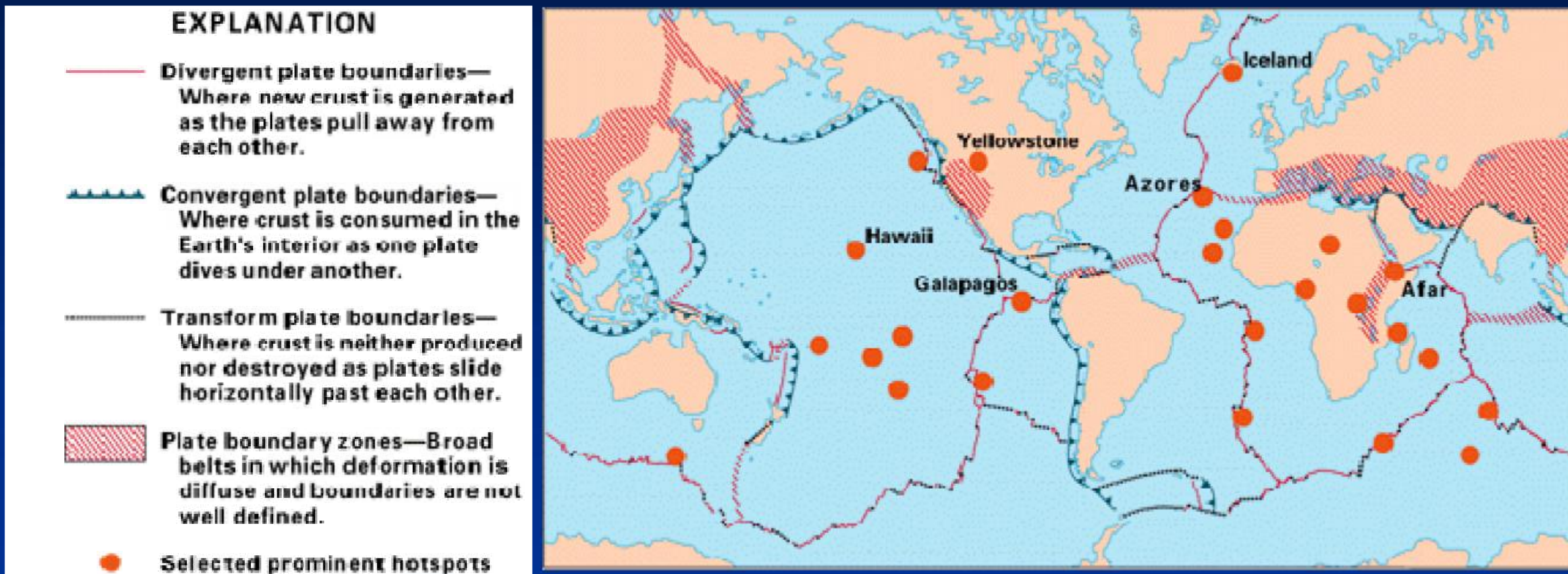
Seafloor Ridge and Trench Map



Global Plate Tectonic Map



Earth's Hot Spots

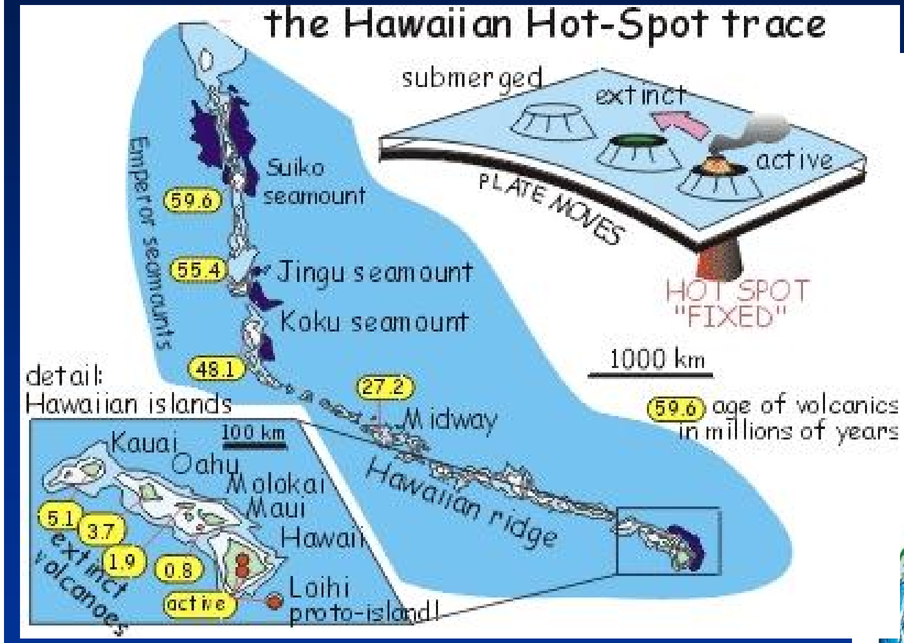


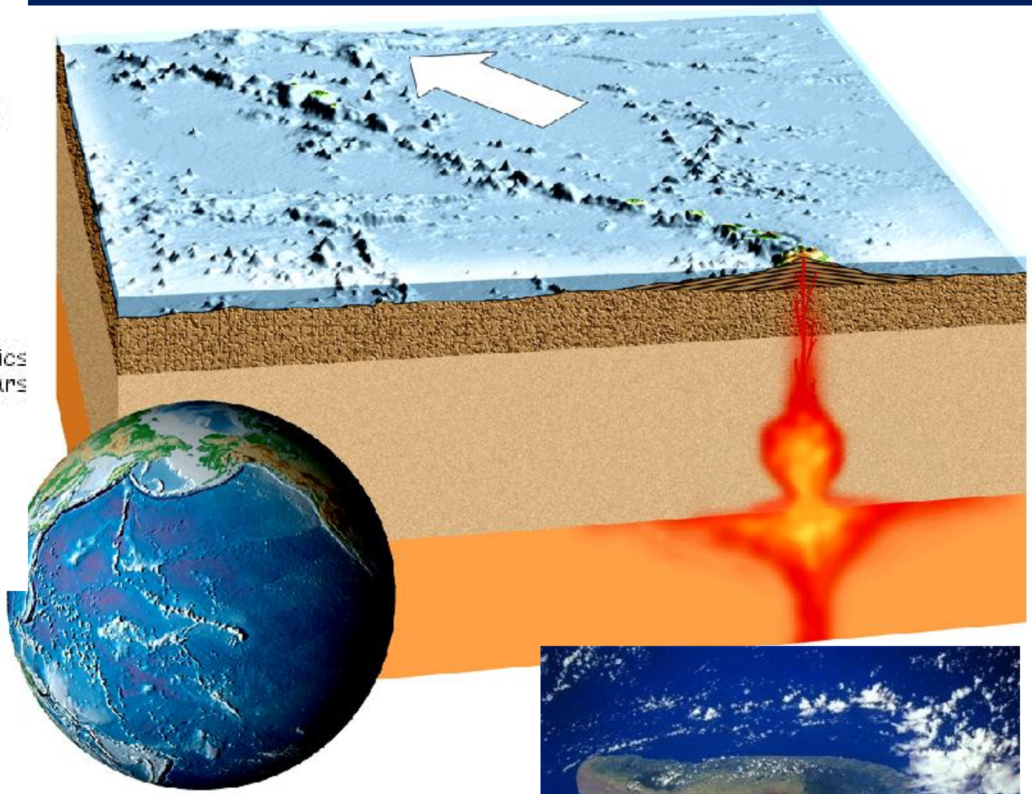
Hawaii

Yellowstone

Iceland

Hawaiian Hot Spot and Pacific Plate Motion



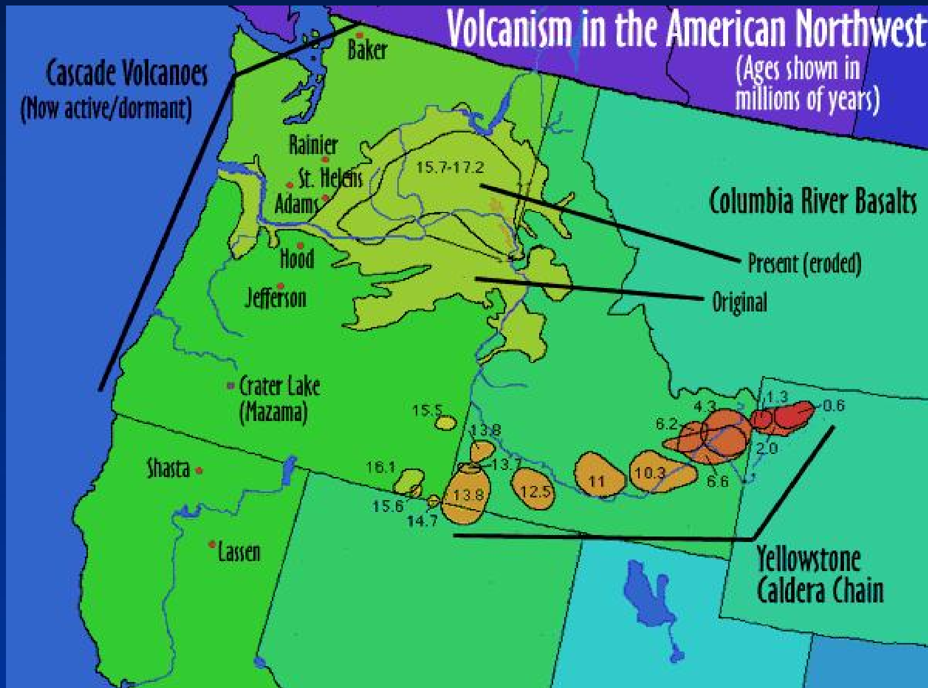


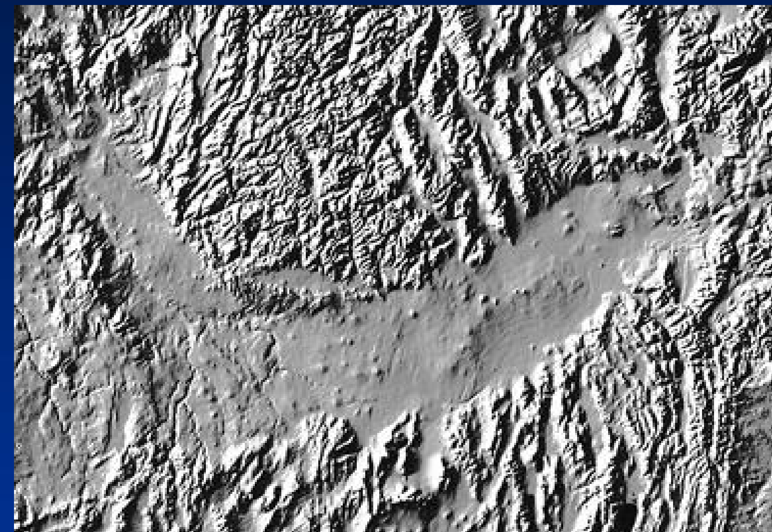
Key Points:

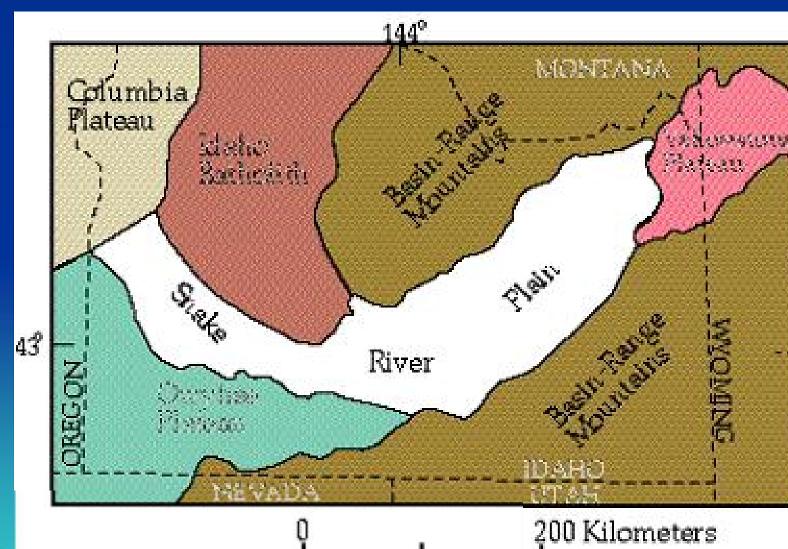
✓ Hot spot plume anchored in mantle = assumed to be ***stationary***

✓ ***Distance and age*** between linear sequence of hot spot- generated volcanic centers indicates the ***direction and rate*** of motion of lithospheric plate

Yellowstone Hot Spot



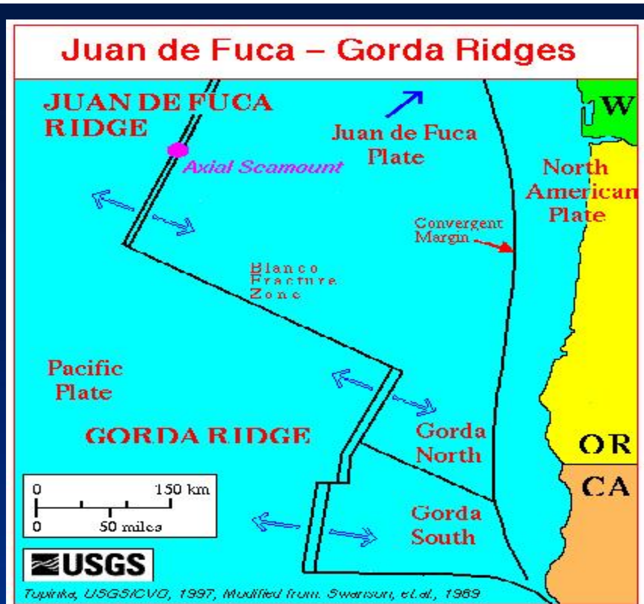


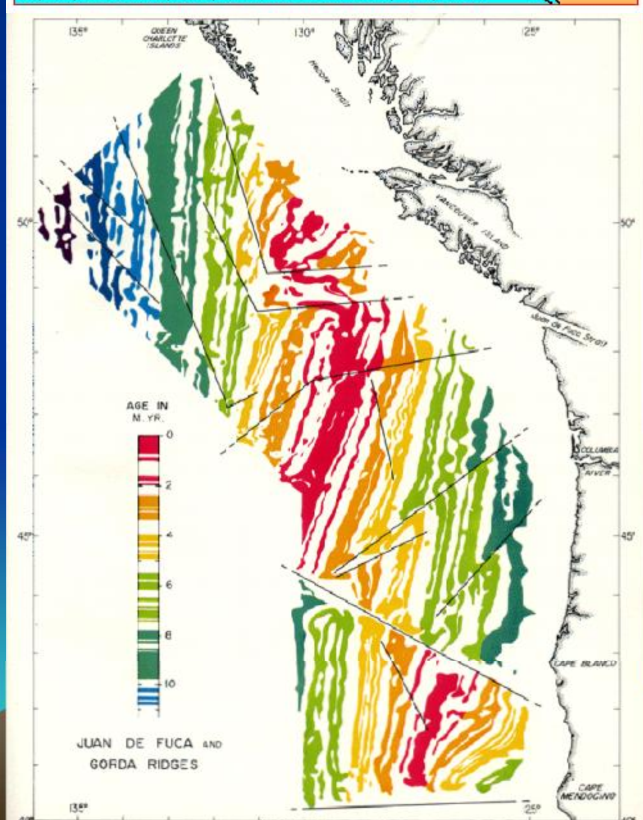


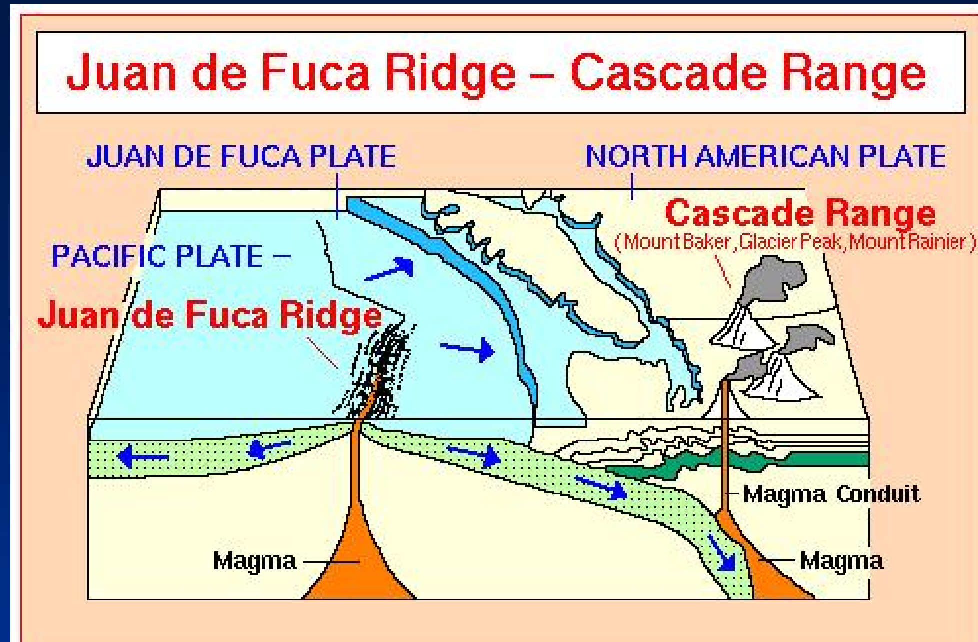
Key Points:

✓Hot spot plume anchored in mantle = assumed to be ***stationary***

✓ ***Distance and age*** between linear sequence of hot spot- generated volcanic centers indicates the ***direction and rate*** of motion of lithospheric plate

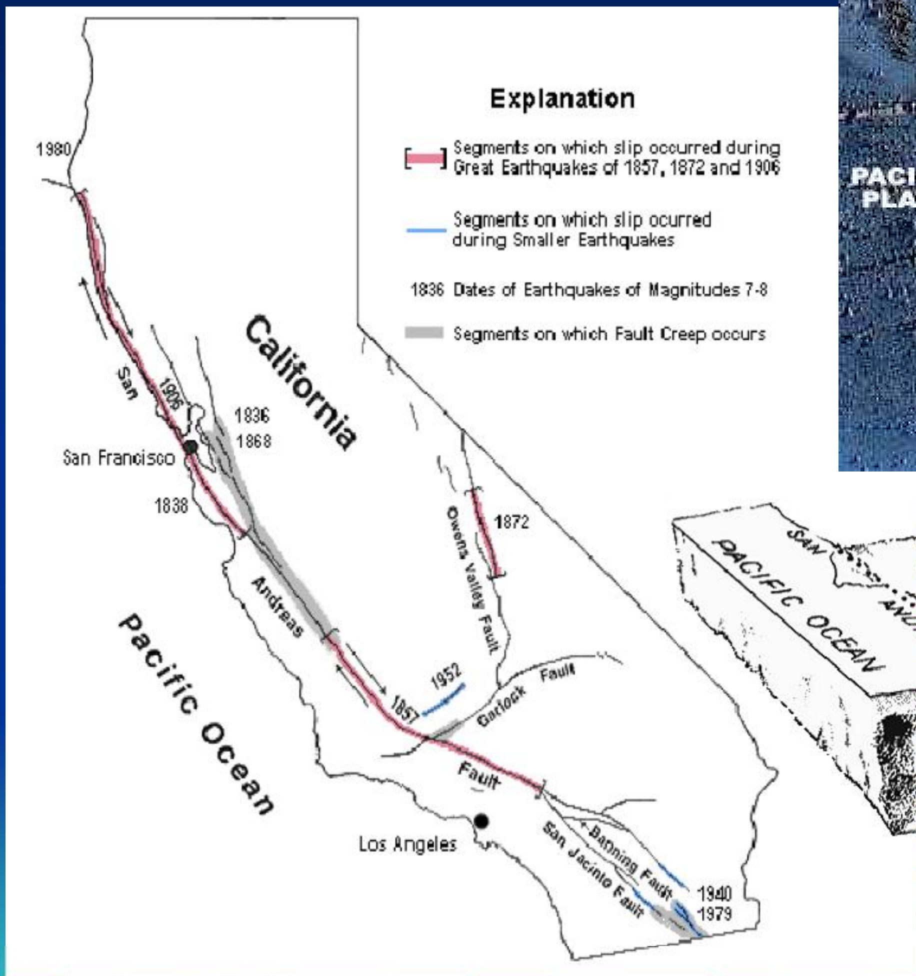


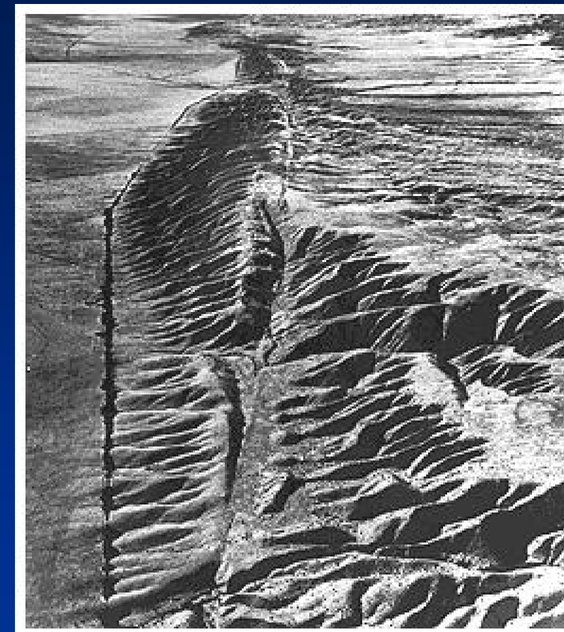


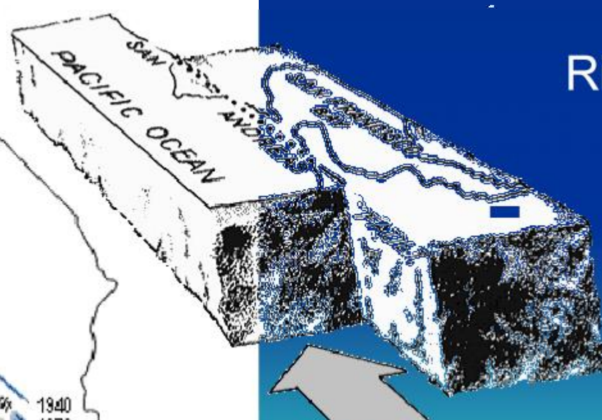


Juan de Fuca Spreading Center and Cascade Subduction System

San Andreas Transform Fault







Right Lateral Strike-slip Offset

Next Weeks Lab Topic

Minerals

– Define
– Formation of Minerals
– Mineral Classification
– Physical Properties
– Identification

Pre-lab Exercises

- Read Mineral Chapter in Lab Textbook
- Complete the Pre-labs