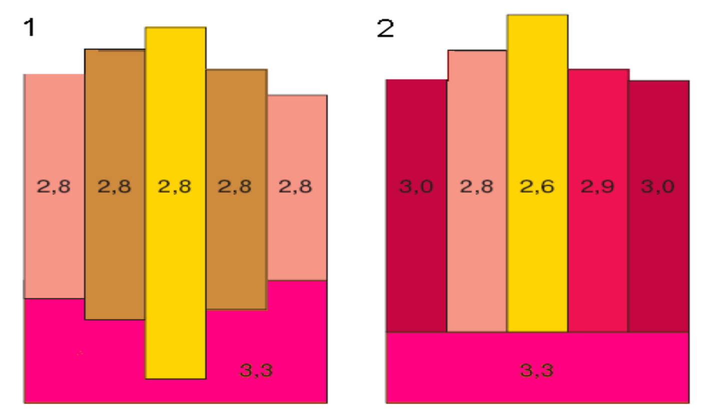
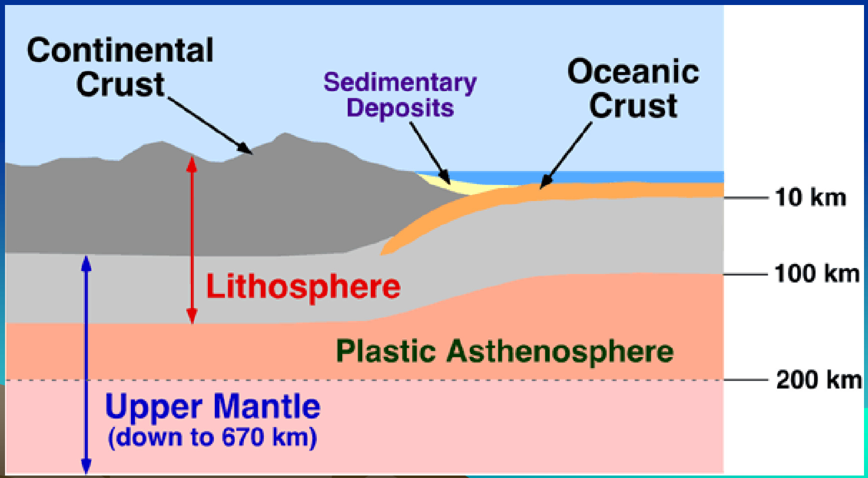
Isostasy Lab

Understanding the Nature and Dynamics of Crust Floating in Mantle



Crust –Mantle Dynamics



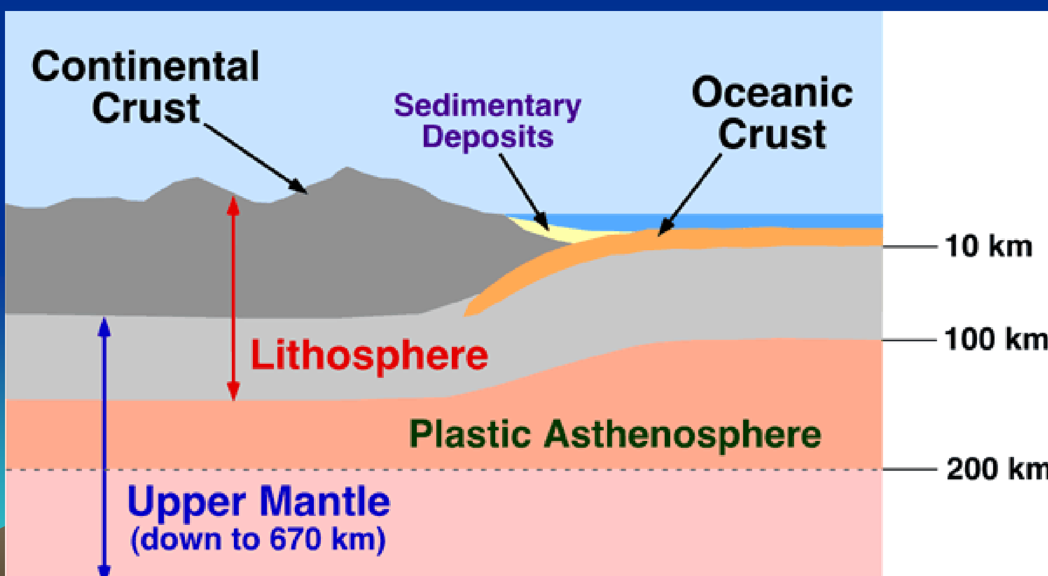
Introductory Geology Lab

Ray Rector - Instructor

Isostasy Laboratory

Topics of Inquiry

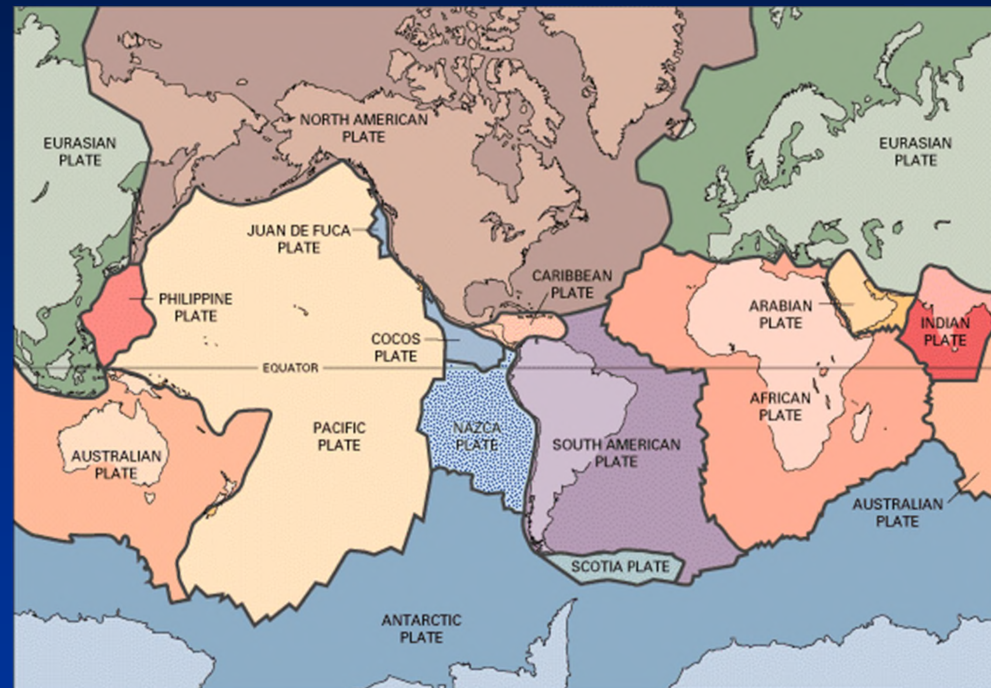
1) Concepts of Density and Buoyancy
2) Layered Physiology of the Earth
3) Isostatic Dynamics – Equilibrium vs. Adjustment
4) Modeling Isostasy in Lab



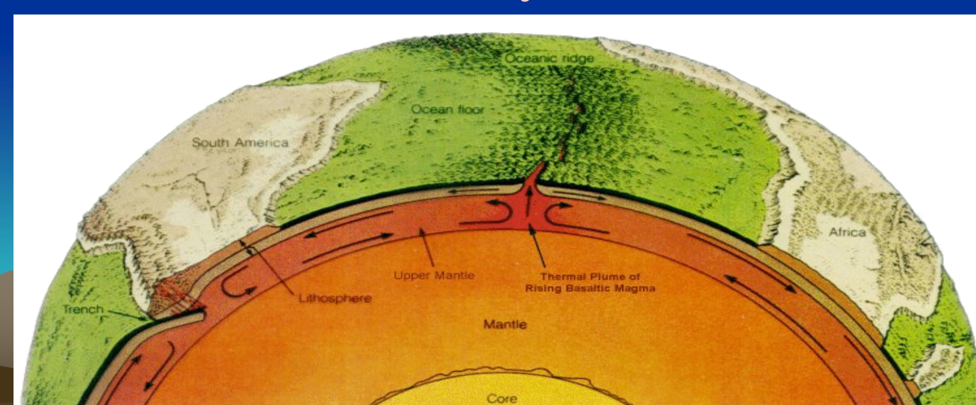
THE MOBILE TECTONIC PLATES

Key Features:

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



Earth's Lithospheric Plates



Inquiry of Lava Lamp Motion

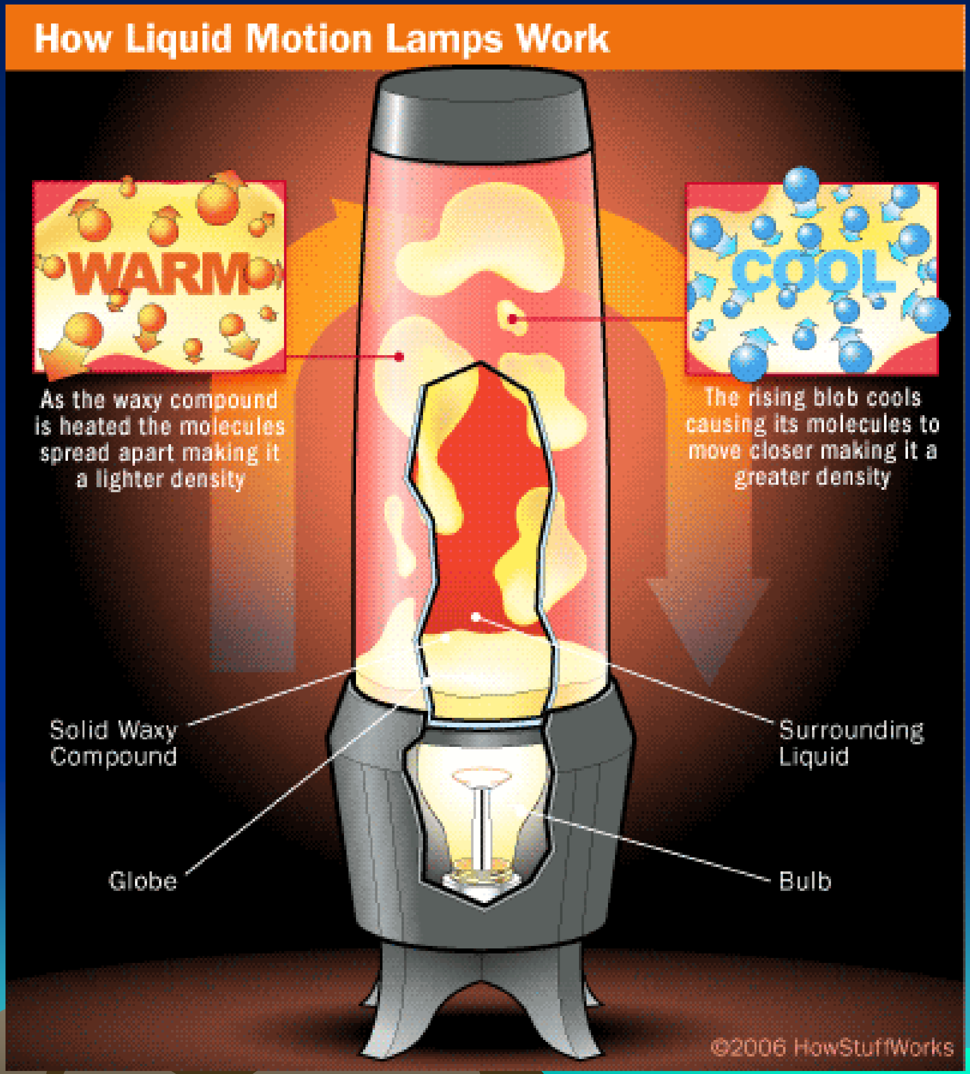
Density and the Convection Process

✓ 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.

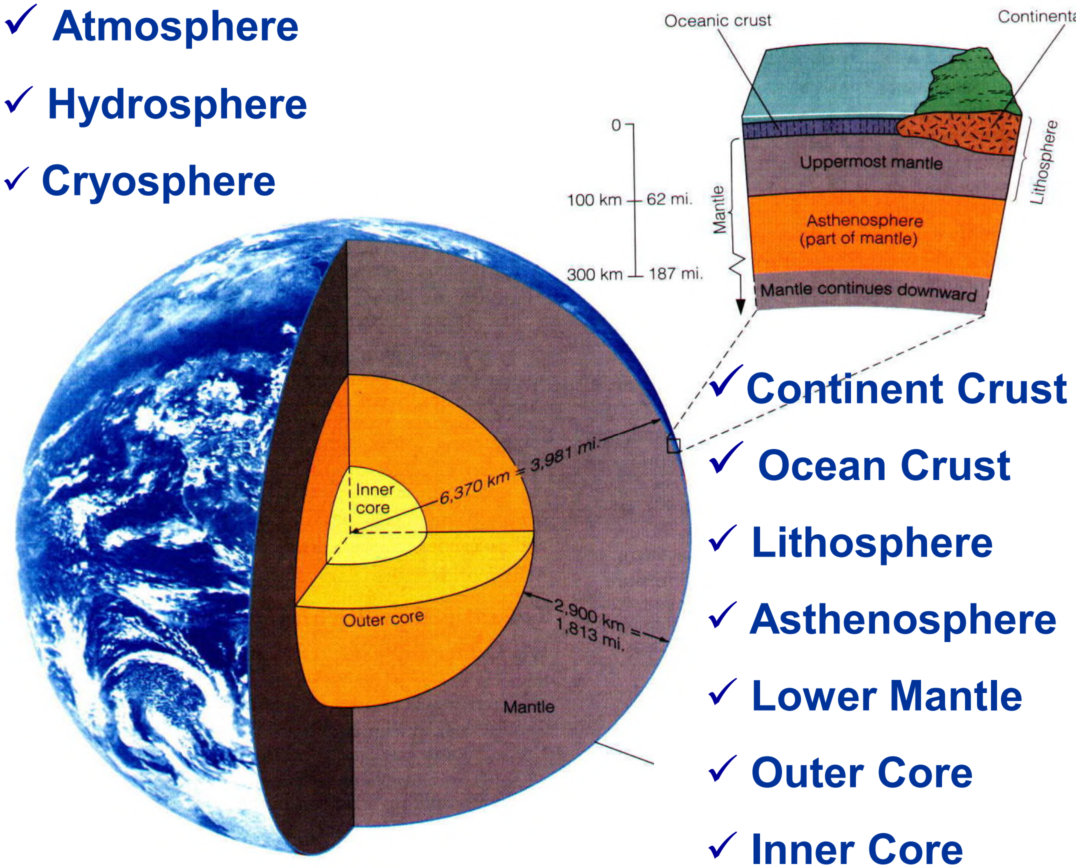
Earth’s Layered Structure

1) Ten Different Density Layers

2) Each Layer Has Unique Physical and Chemical Properties

3) All Layers Arranged According to Density

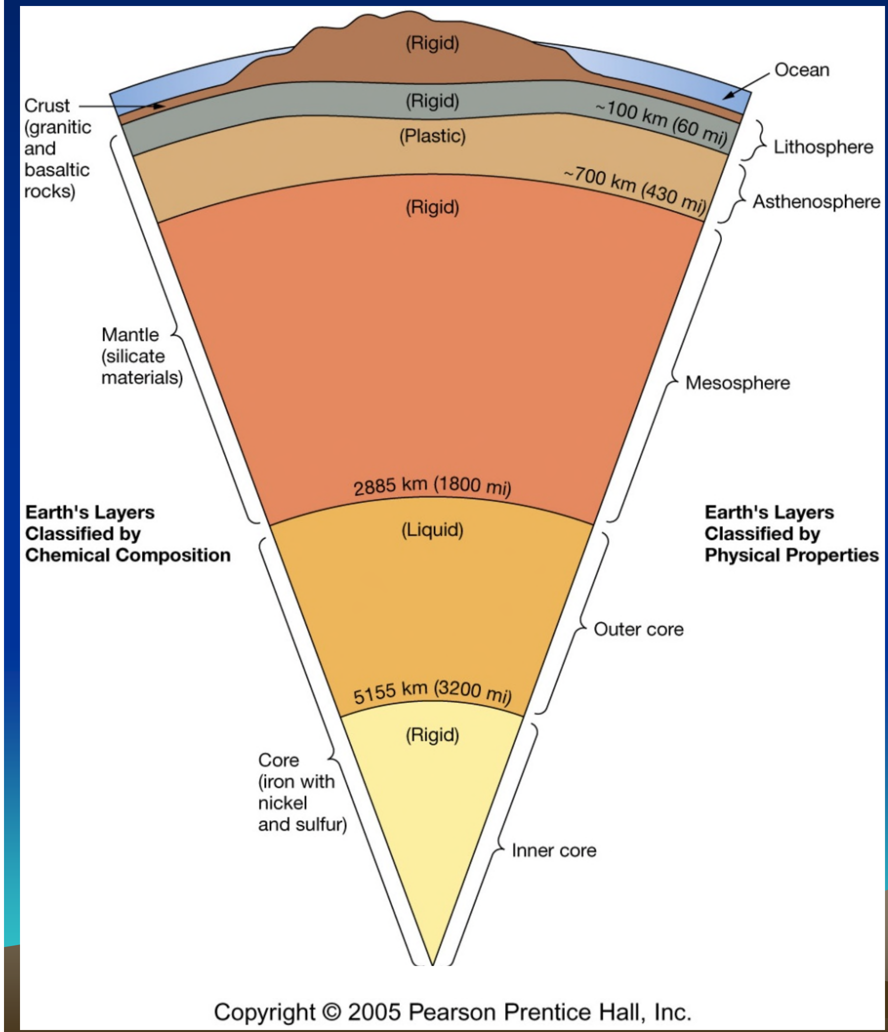
- ✓ Atmosphere
- ✓ Hydrosphere
- ✓ Cryosphere

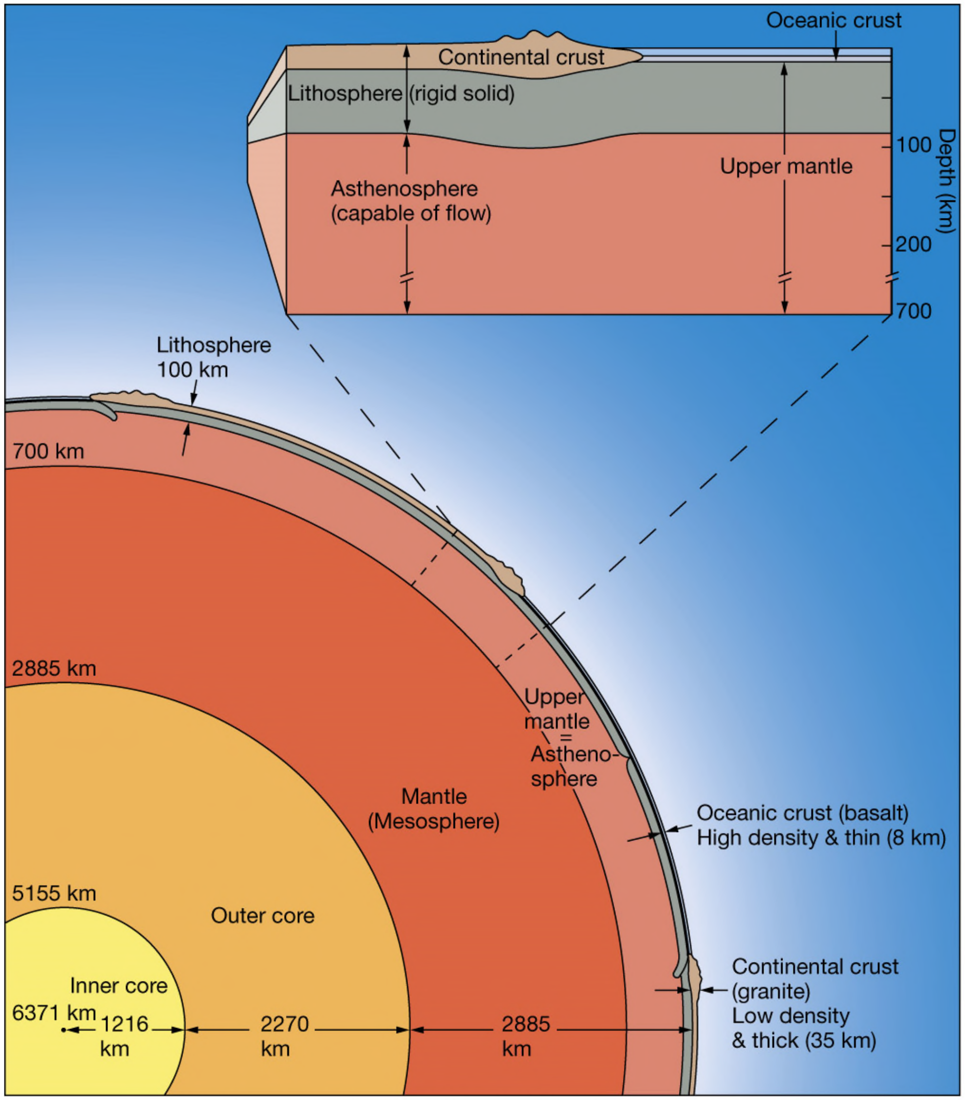


- ✓ Continent Crust
- ✓ Ocean Crust
- ✓ Lithosphere
- ✓ Asthenosphere
- ✓ Lower Mantle
- ✓ Outer Core
- ✓ Inner Core

Earth's Layered Interior

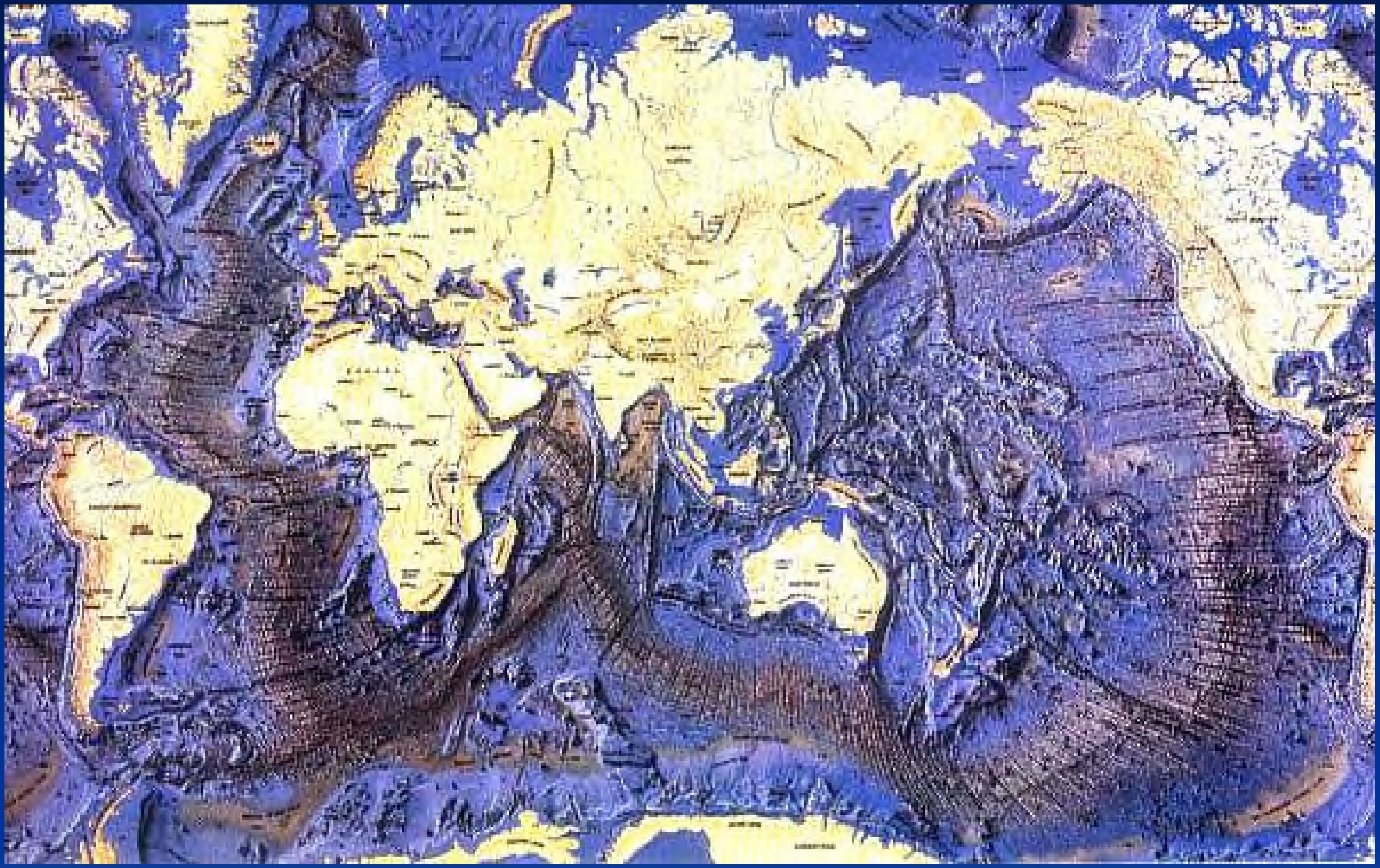
Chemical and Physical Nature of Earth's Interior





Density Layering of Earth's Interior

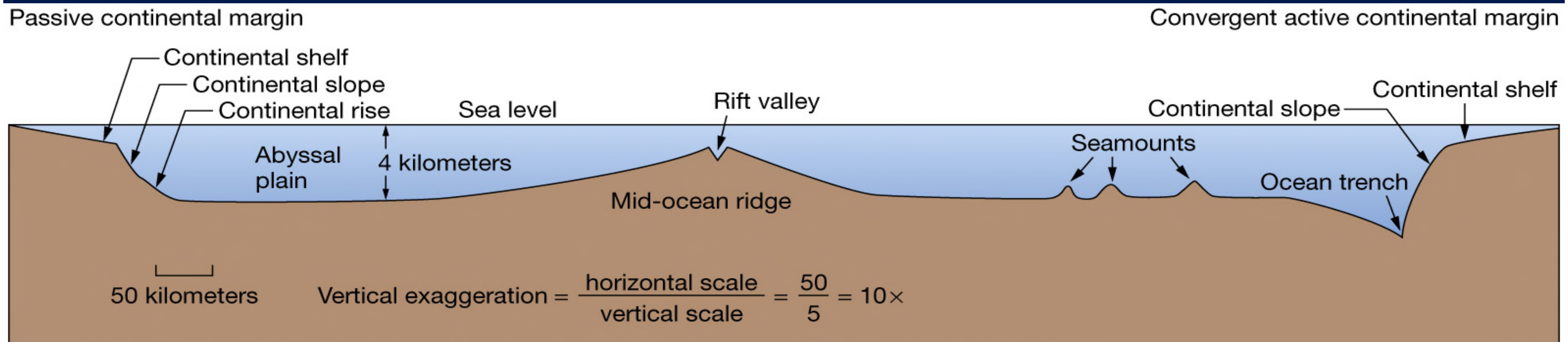
Topography of Earth’s Surface



Earth’s solid surface consists of two distinct topographic provinces:

1) High-standing continents and 2) Low-standing ocean basins

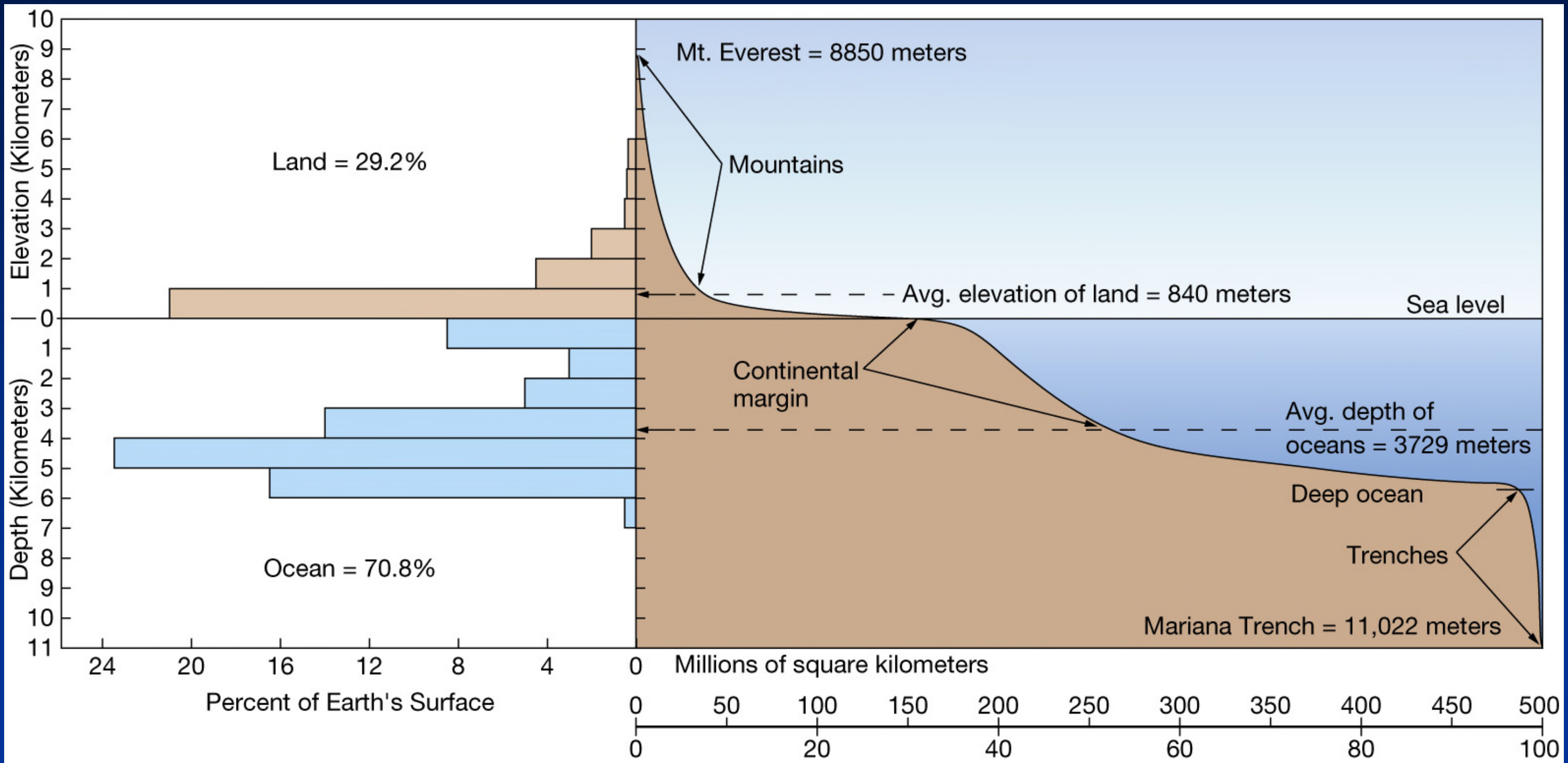
Cross-Section Profile of an Ocean Basin



Large-Scale Ocean Bottom Features

- ✓ Continental platform, shelf, slope, and rise
- ✓ Abyssal plains and hills
- ✓ Mid-ocean ridges, rises, and rift valleys
- ✓ Oceanic fracture zones
- ✓ Oceanic islands, seamounts, and guyots
- ✓ Ocean trenches

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

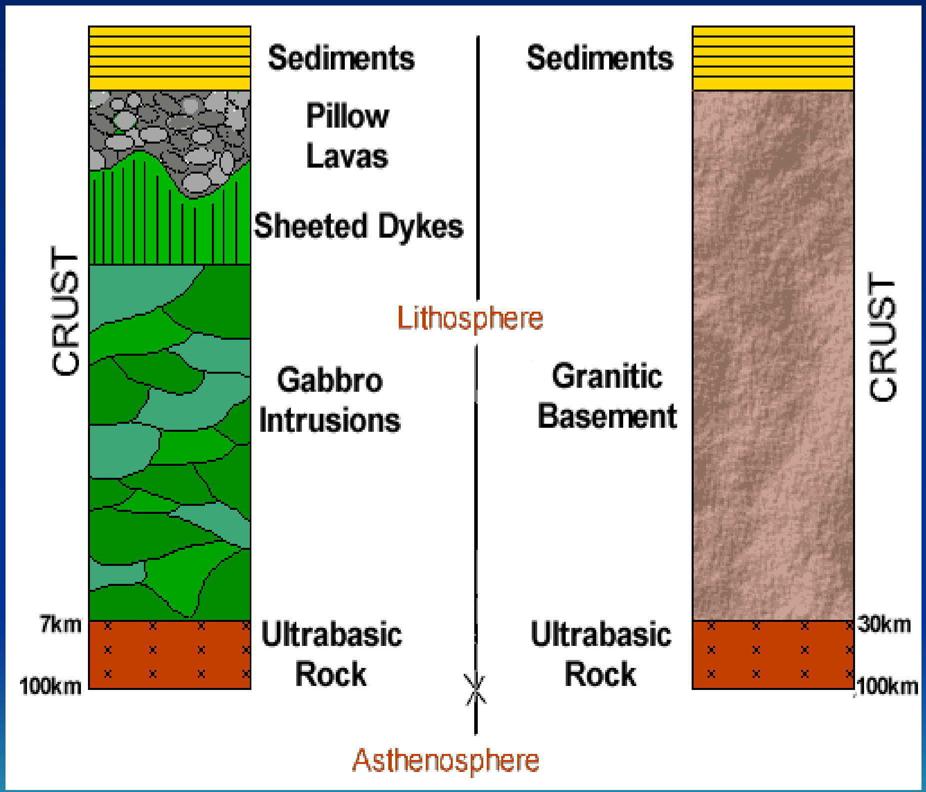
1) **Two Different Types of Crust**
- ✓ Continental = Granitic
- ✓ Oceanic = Gabbroic

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 | **Continental Crust**

Gabbroic Rock | **Granitic Rock**



Concept of Buoyancy

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

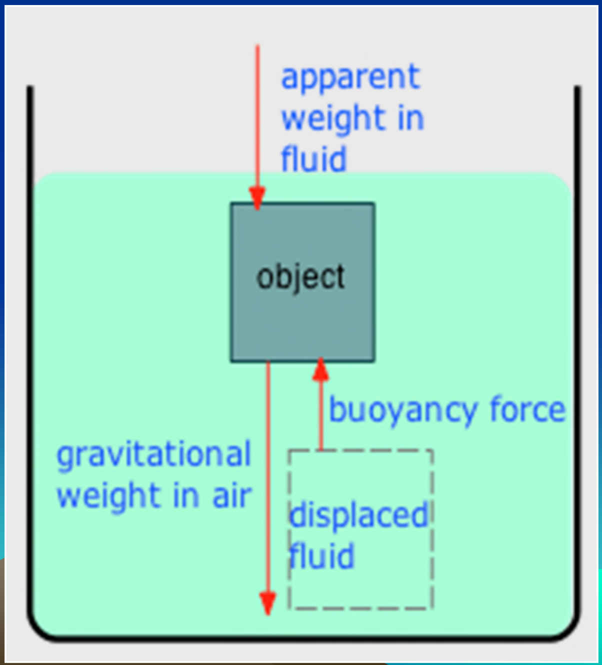
2) Buoyancy is the fluid pressure exerted on an immersed object equal to the weight of fluid being displaced by the object.

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 “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



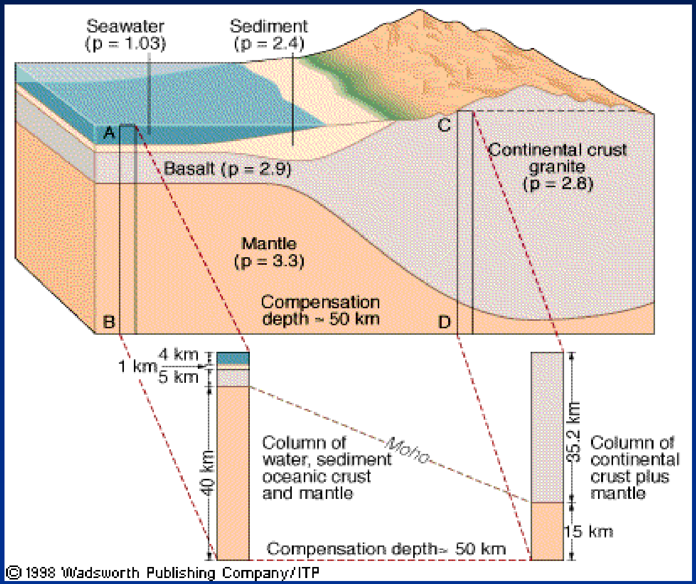
Example of Buoyancy: Boat on a Lake

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

The Concept of Isostasy

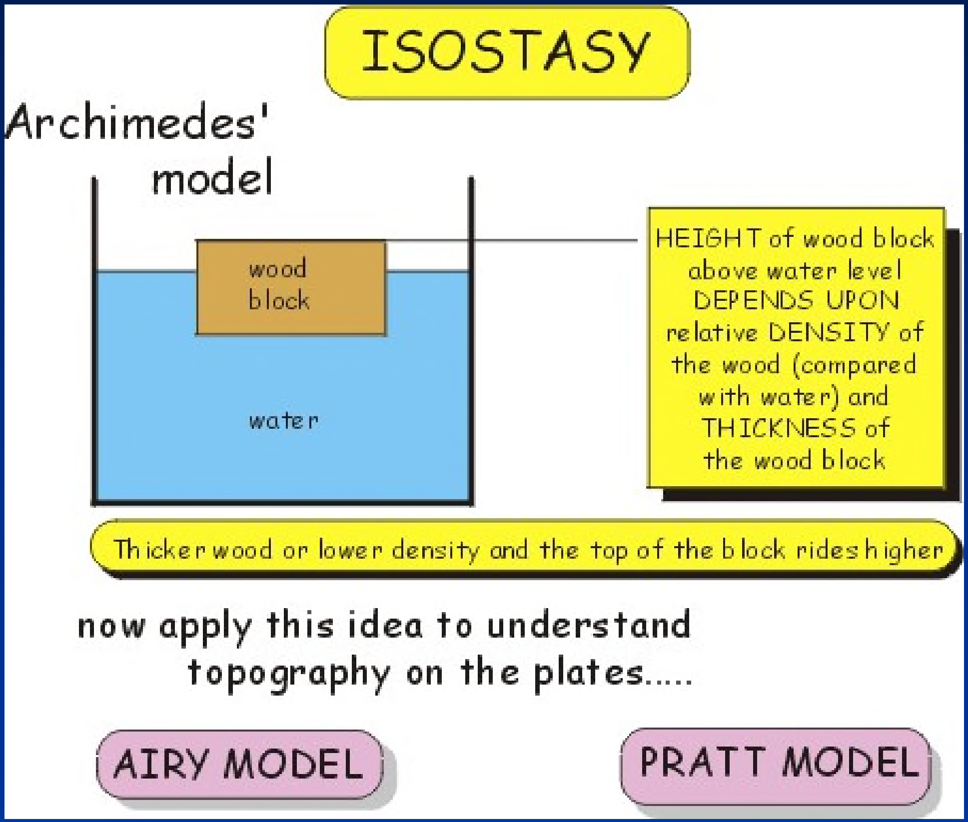
Defined: state of gravitational equilibrium between the earth's *rigid* lithosphere and *fluid* asthenosphere, such that the tectonic plates "float" in and on the underlying mantle at height and depth positions controlled by plate thickness and density.

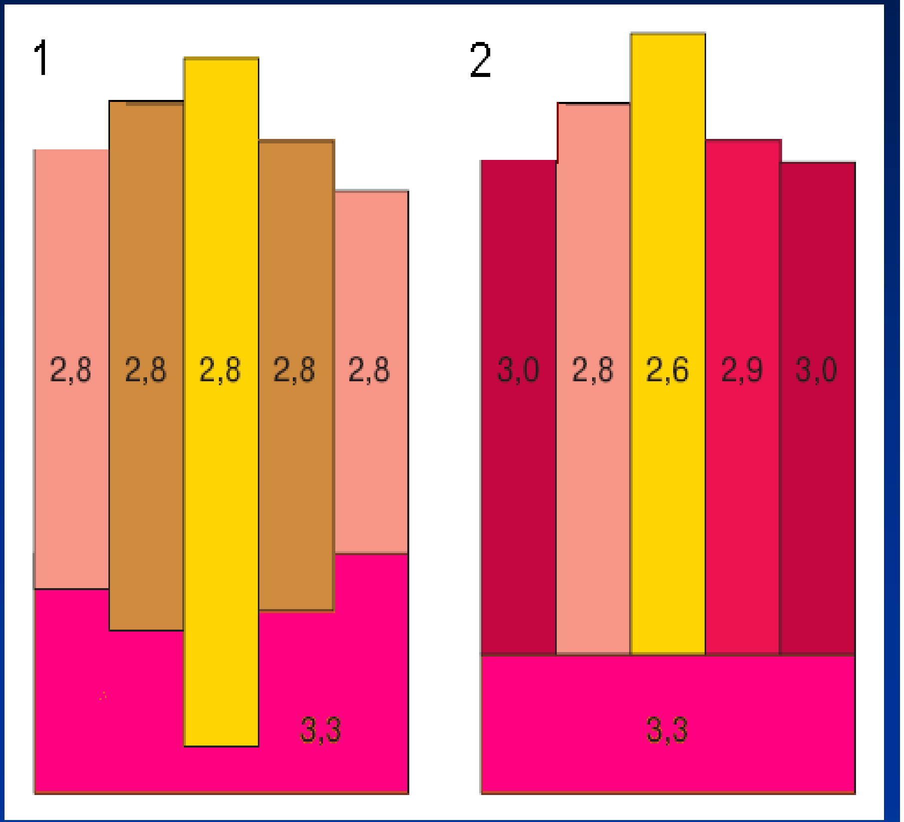
- The term "isostasy" is from Greek "iso" = equal; "stasis" = equal standing.



- 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

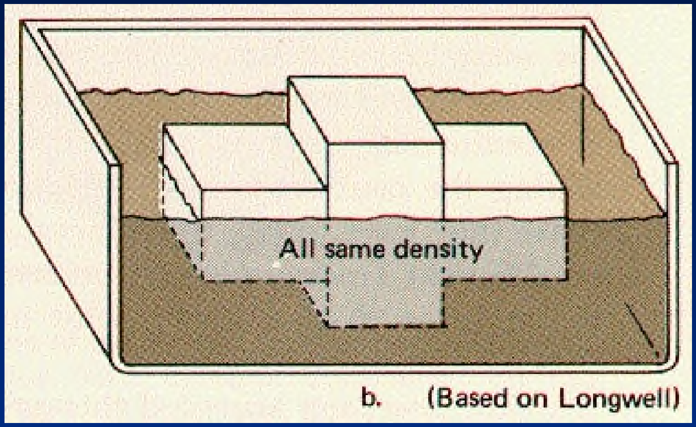
Isostasy and Isostatic Equilibrium

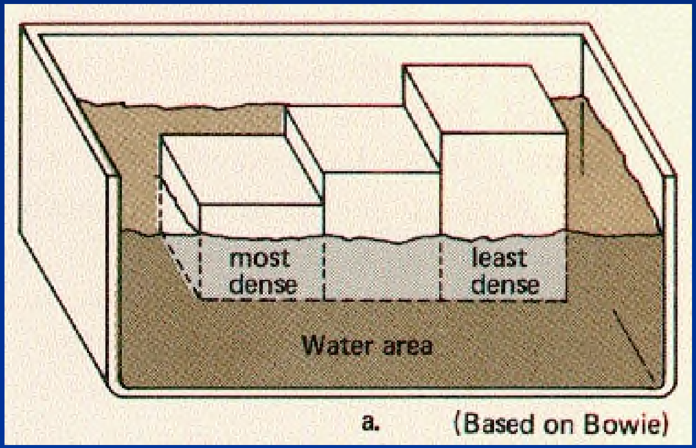


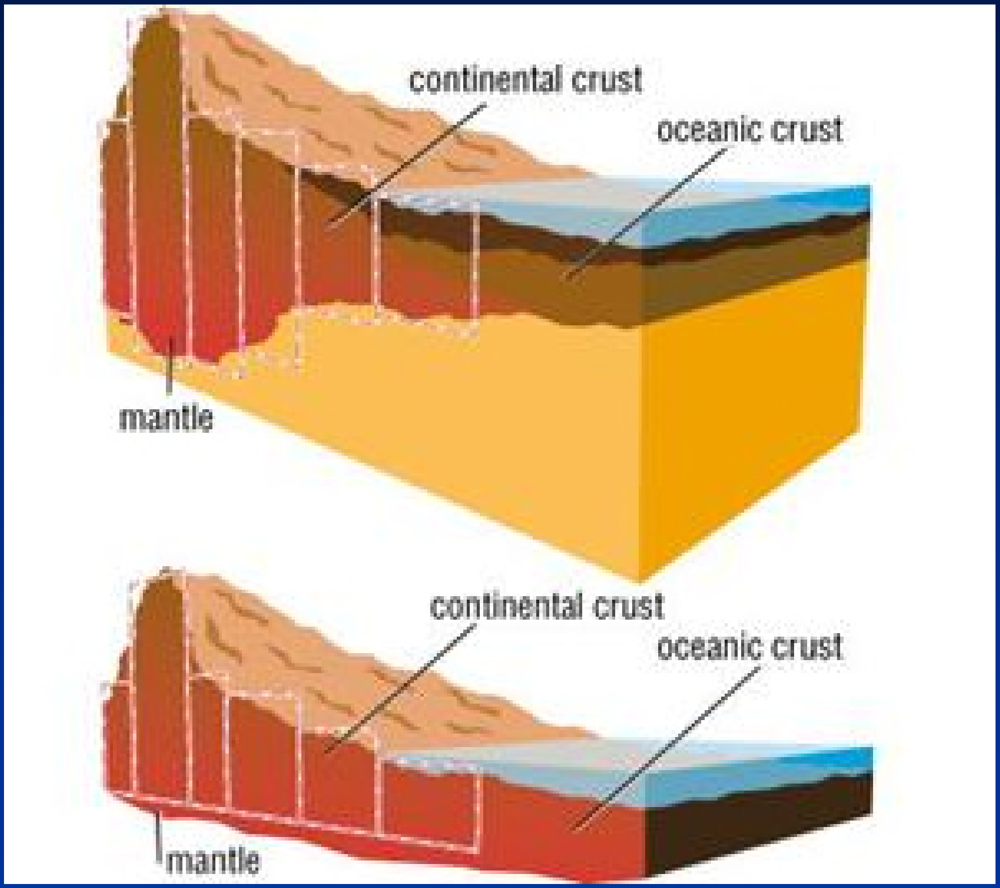


Two Different Models to Explain the Difference in Height (Topography) of the Earth's Crust

The Isostasy Equilibrium Hypotheses





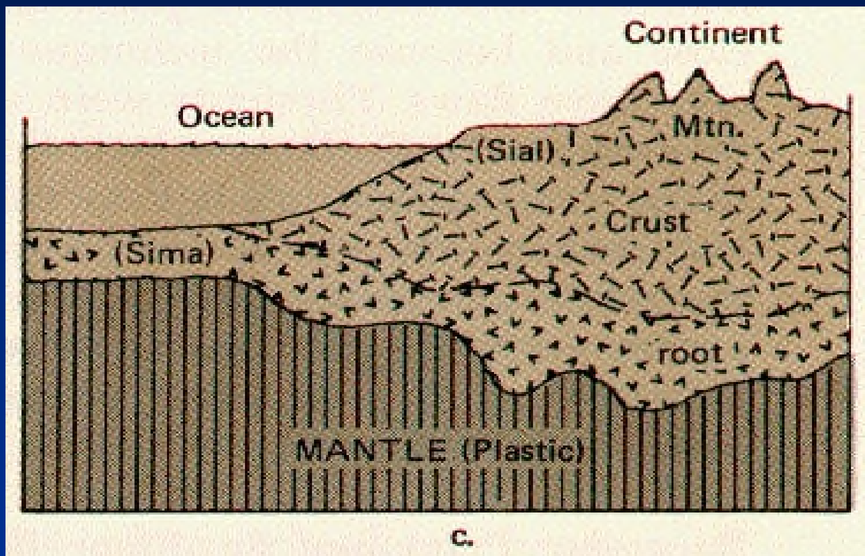


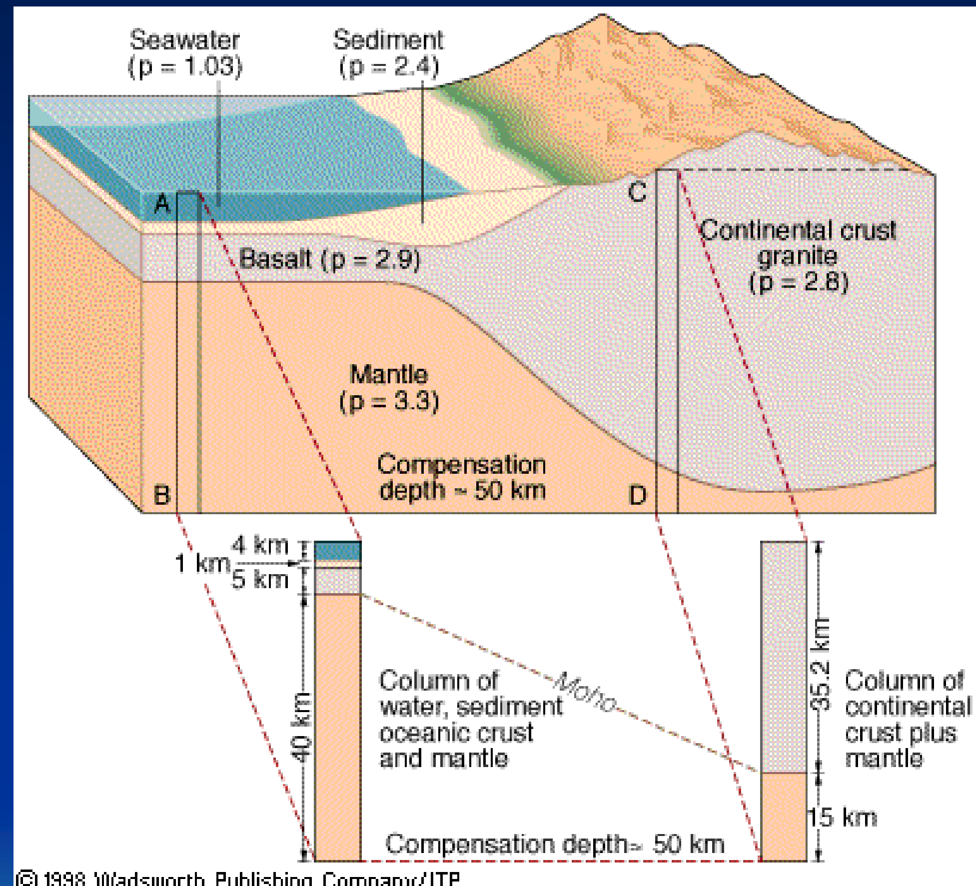
Model 1 (top): Different height blocks of crust all with similar densities

Model 2 (bottom): Different height blocks of crust with different densities: the thinnest with highest density and thickest with lowest density

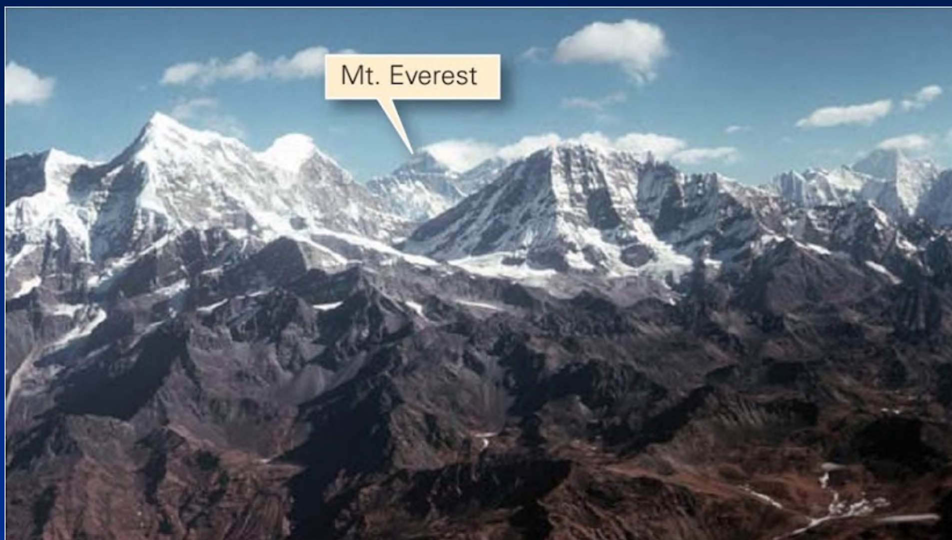
Tested: Earth's actual crustal character turns out to be a combination of both models

The Isostatic Equilibrium

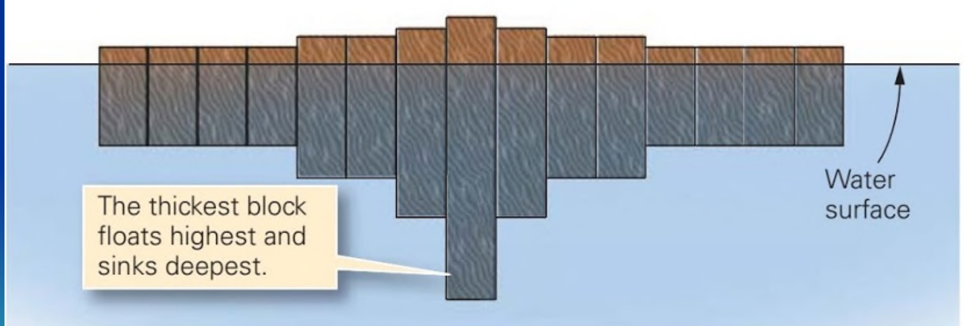




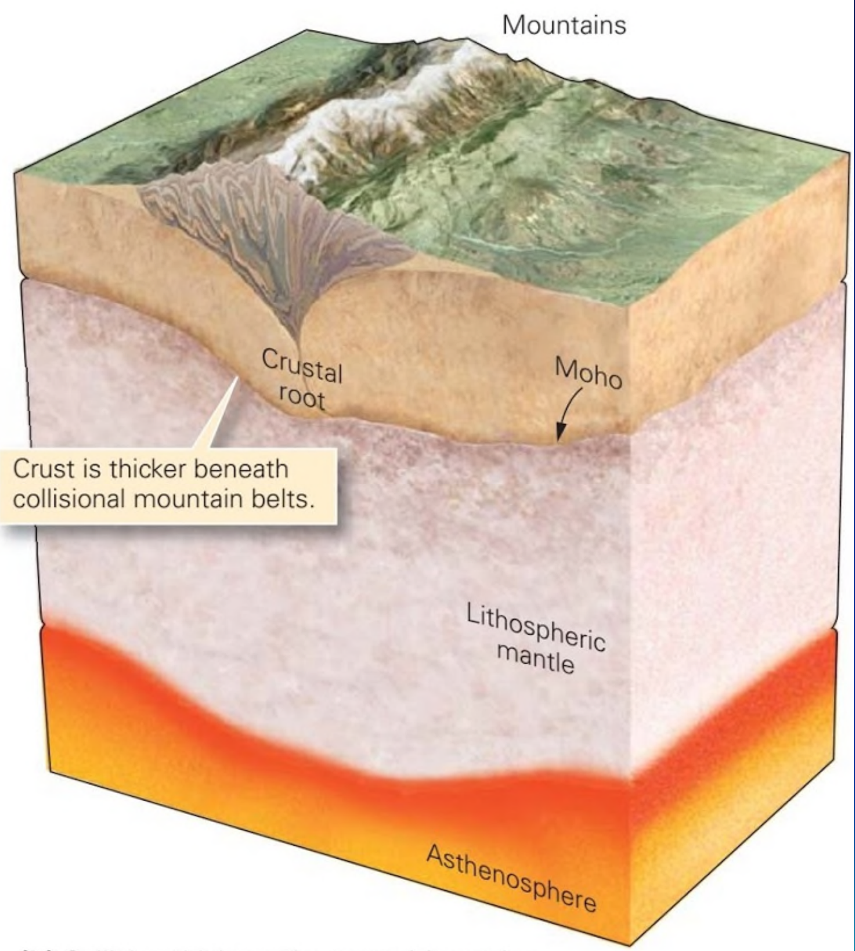
Crustal Thickness and Isostasy



(a) The Himalayas are the world's highest mountain range. The crust beneath them is almost twice the normal thickness.



(c) Because of isostasy, blocks of wood floating in water sink to a depth such that the mass of the water displaced is the same as the mass of the block.

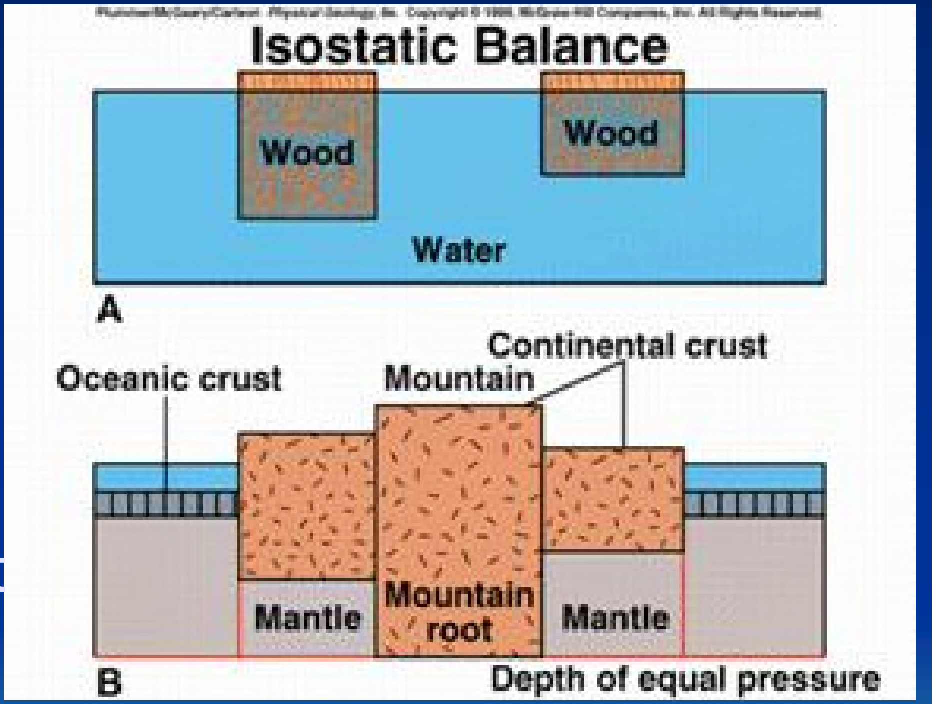


(b) Collision thickens the crust. Mountains form where the low-density crust is thicker.

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

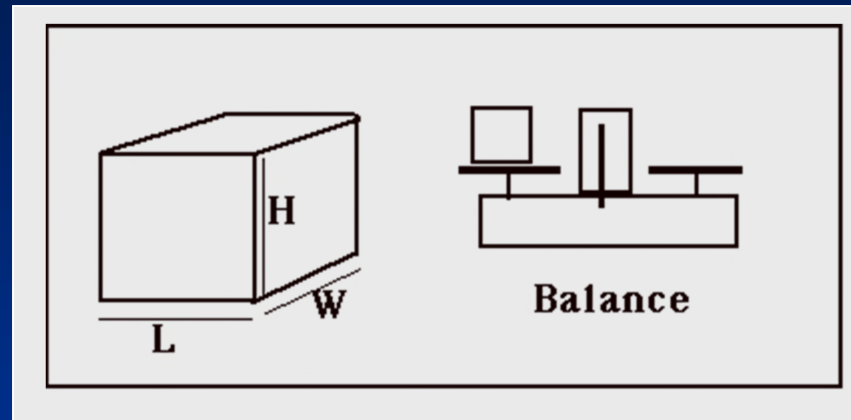
Wood Block Densities:

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

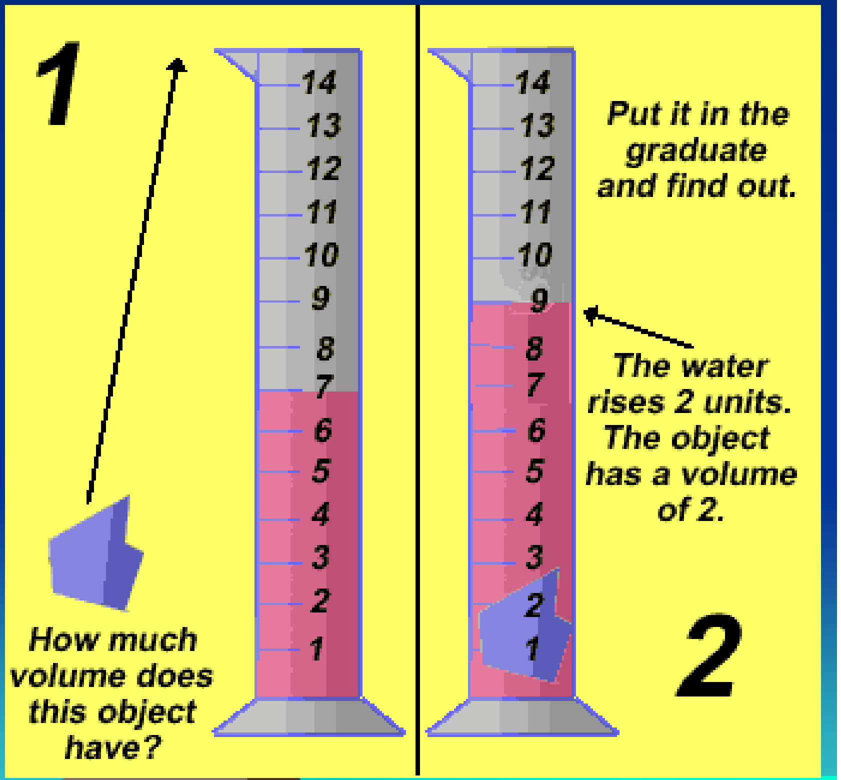
    ✓ Displacement method

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

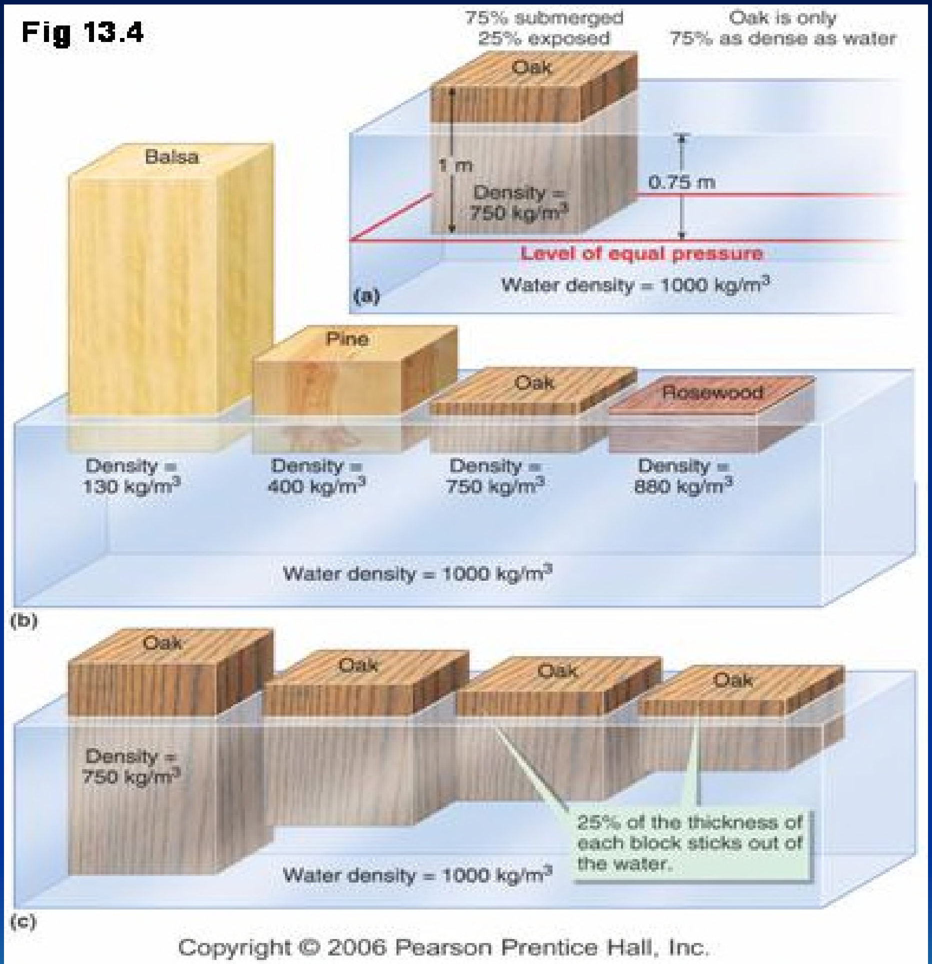
Density/Thickness – Buoyancy Relationship

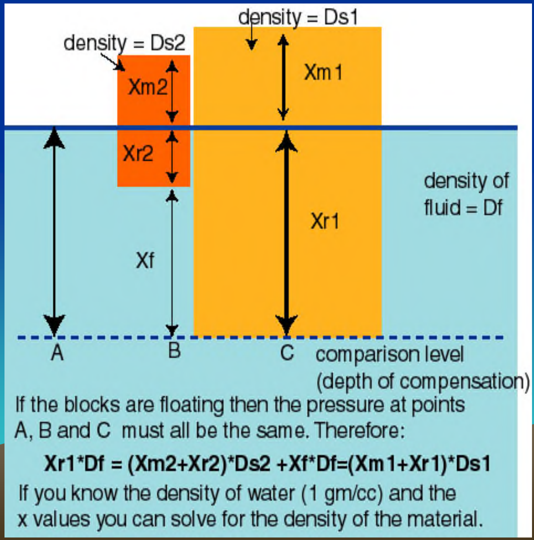
Wood Block Behavior in Water:

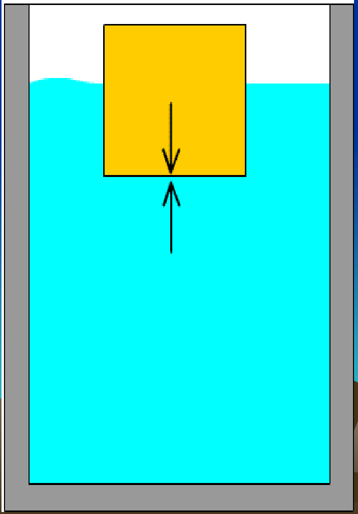
1) Density of wood in relation to water density determines level of buoyancy: (percentages in/out of water)

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

3) Measure thick redwood block

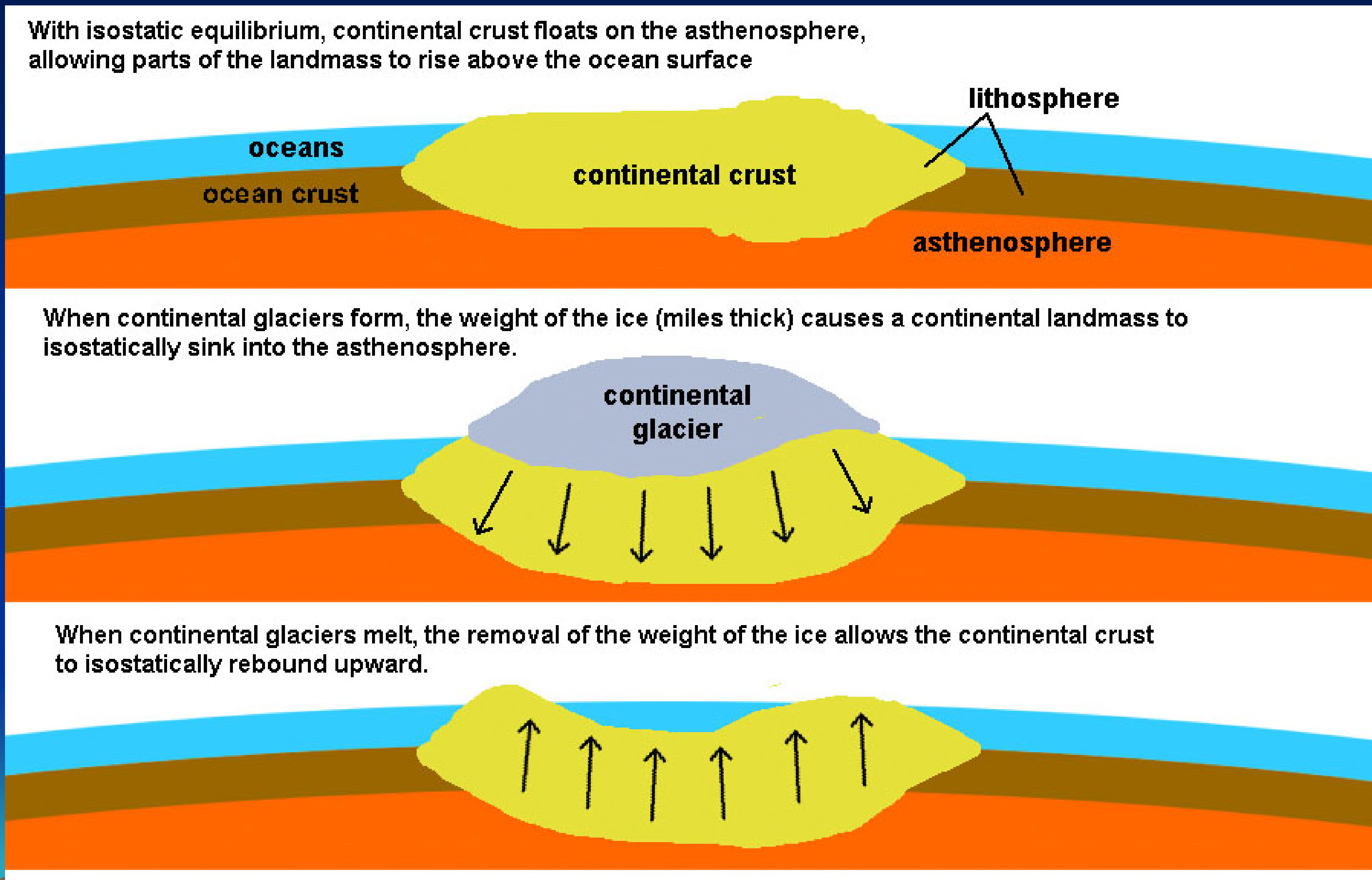






$$\text{Denisty} = \frac{\text{mass}}{\text{volume}} \quad \text{or} \quad D = \frac{m}{v}$$

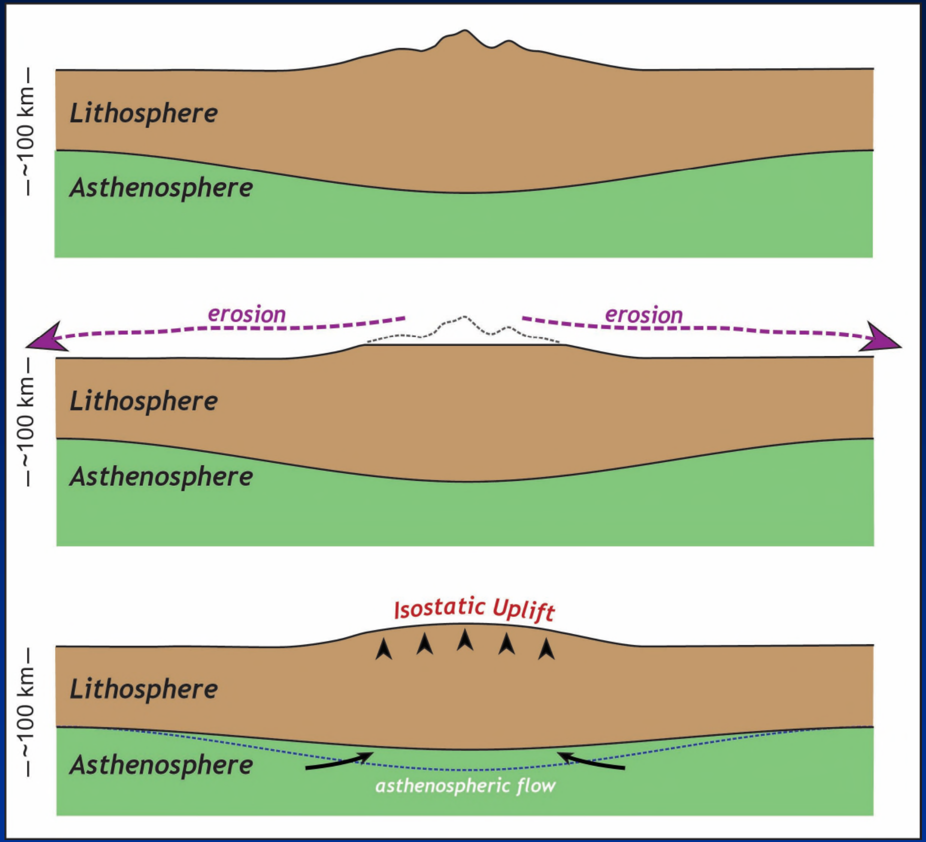
Isostatic Disequilibrium and Adjustment

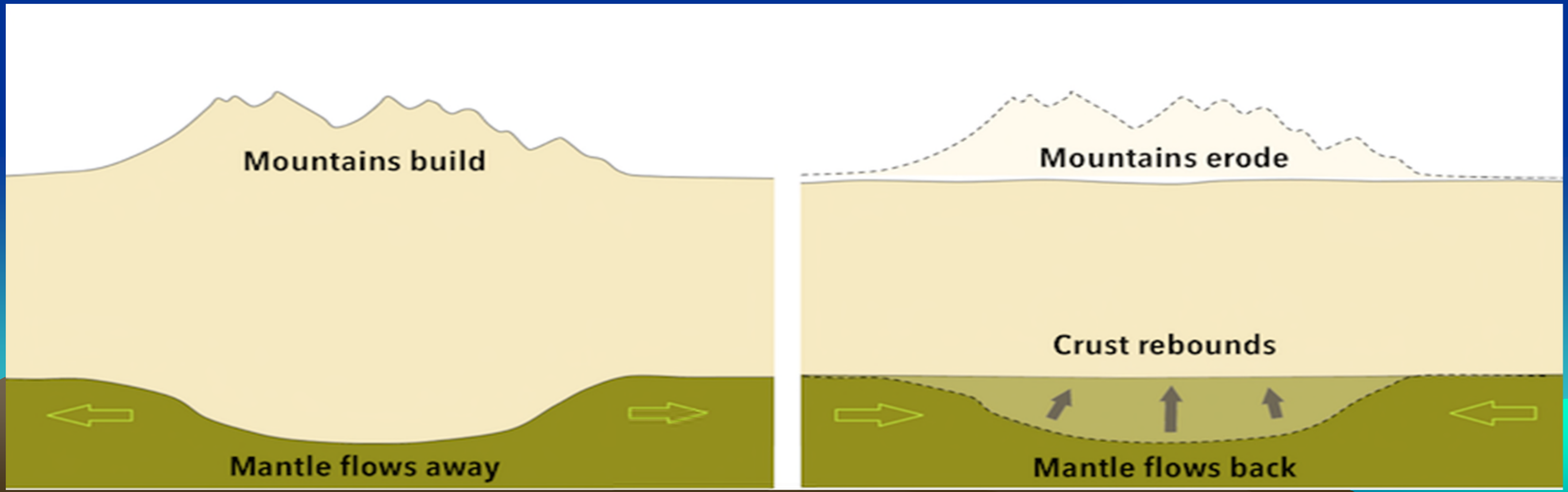


Isostatic Adjustment During and After Mountain Building

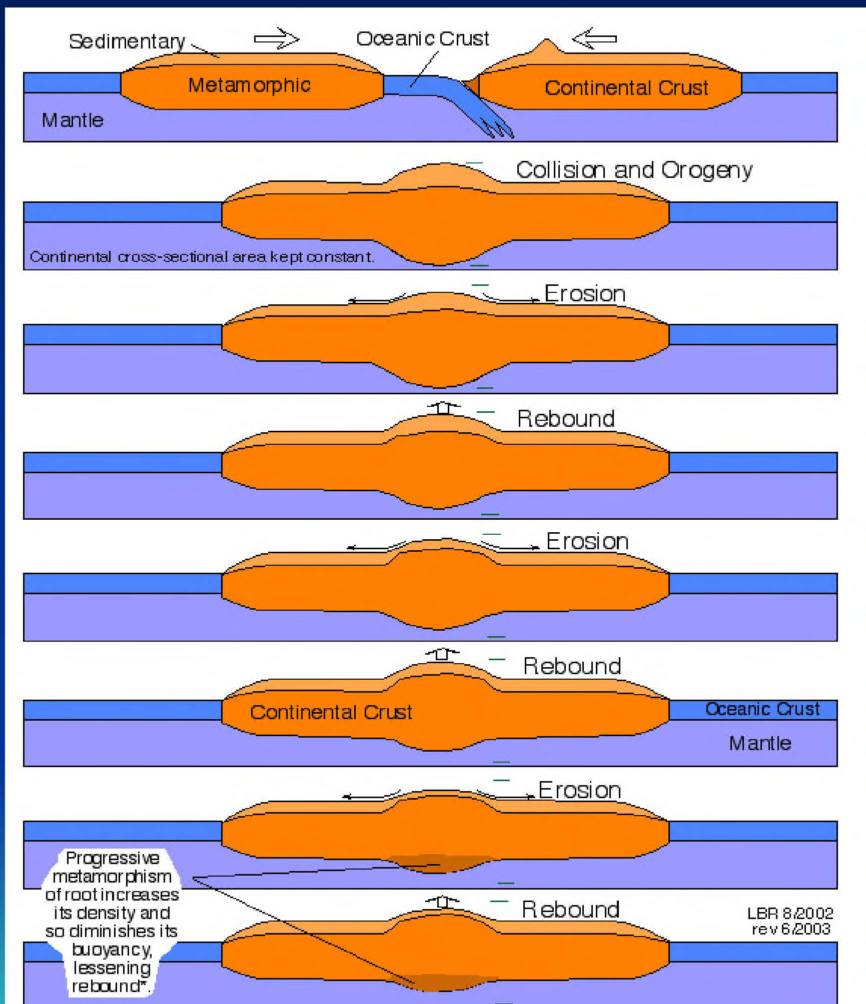
Buildup of a young mountain range causes downward movement of crust/lithosphere into underlying fluid asthenospheric mantle

Subsequent erosion of the tops of a mountain range causes uplift of thinning crust/lithosphere with inflow of underlying asthenospheric mantle beneath mountain

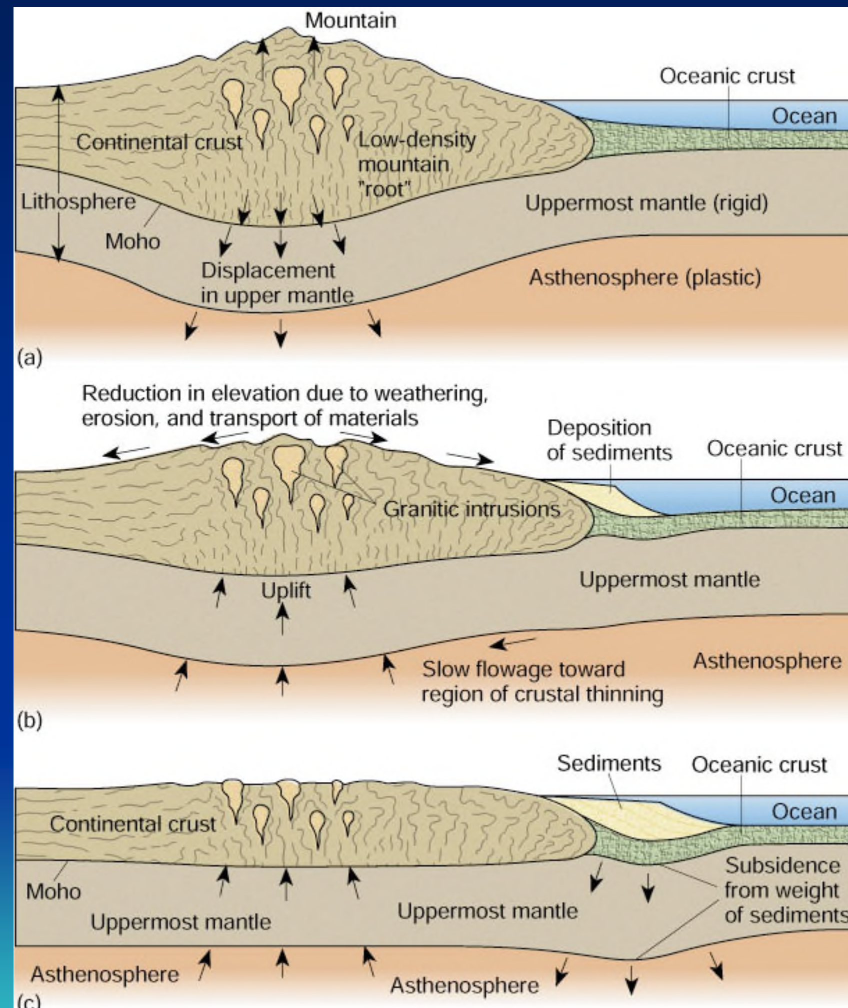




Isostatic Adjustment – Mountain-Building and Erosion



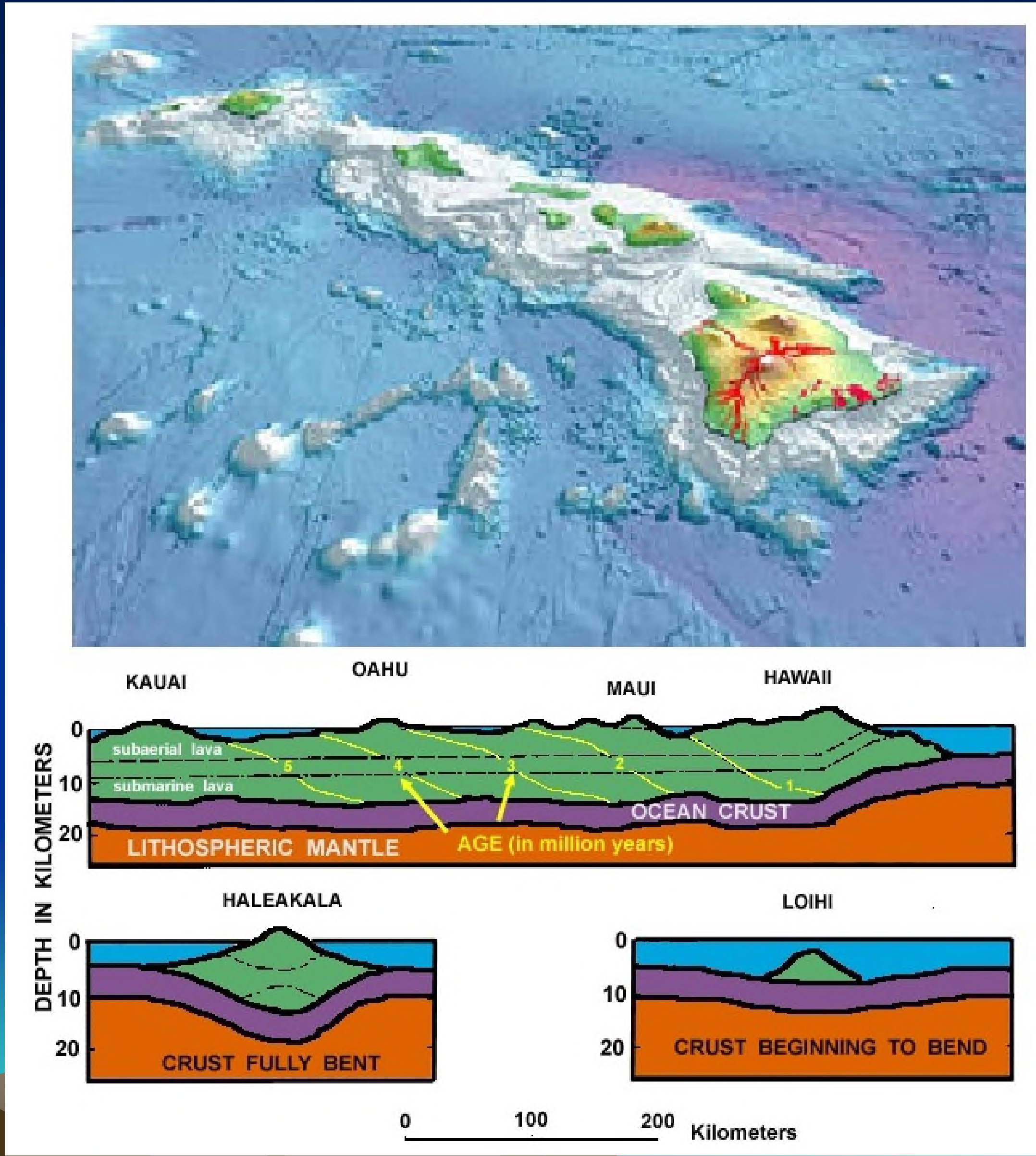
* Karen M. Fischer, 2002, Waning buoyancy in the crustal roots of old mountains: *Nature*, v. 417, p. 933-936.



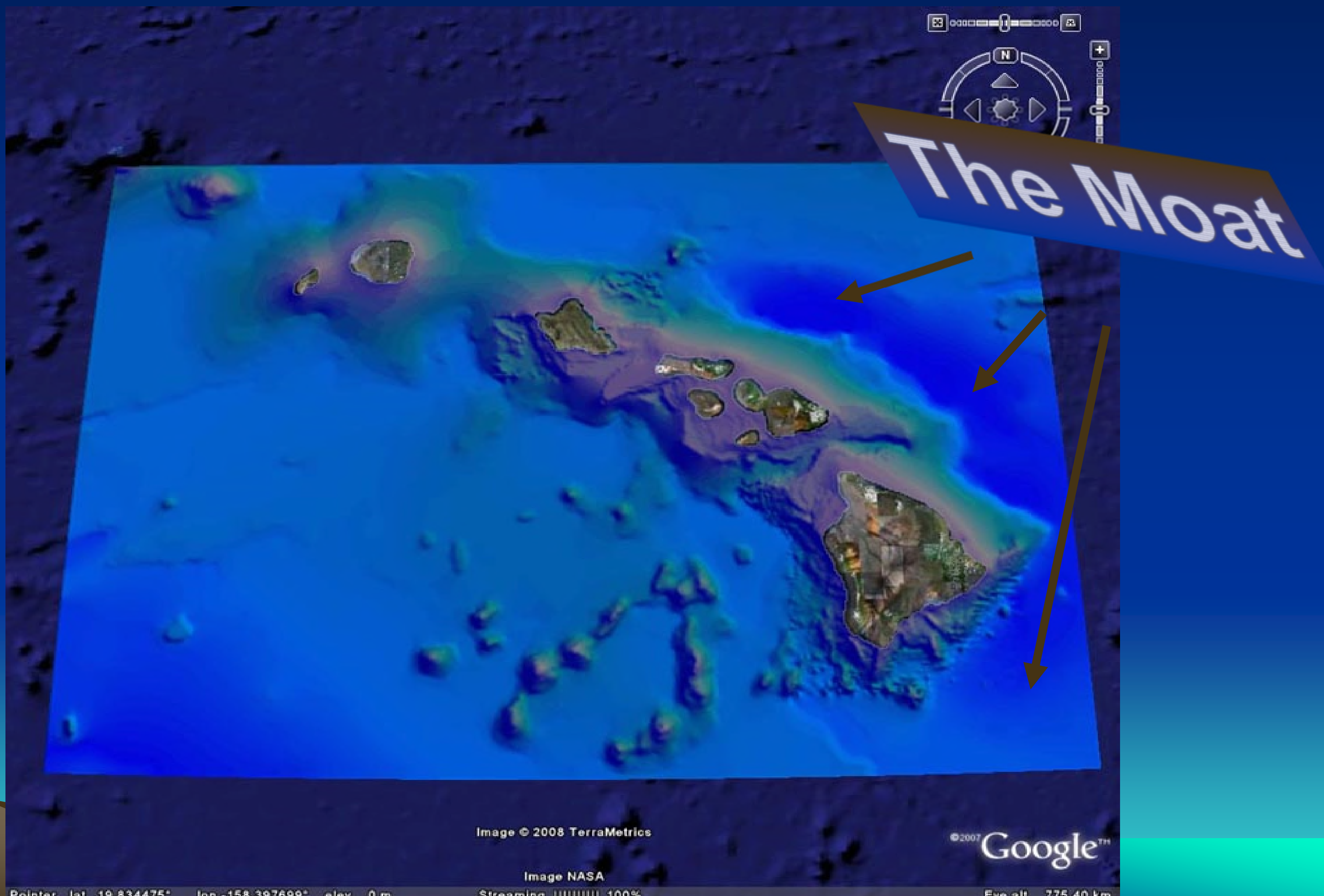
Isostatic Loading and Rebound – *Orogeny and Erosion*

Hawaiian Isostasy

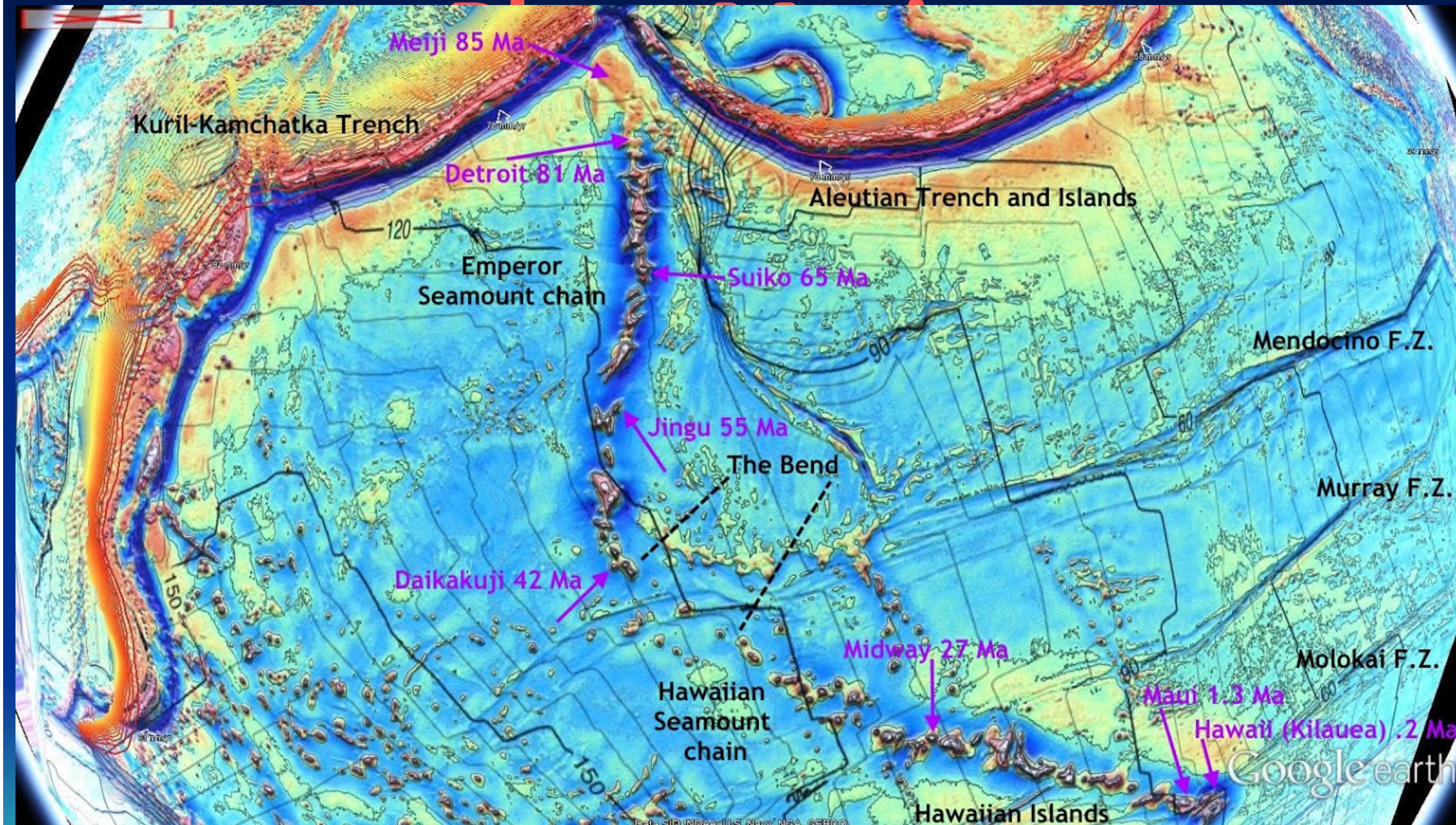
- ✓ Buildup of the basaltic Hawaiian volcanic islands cause downward flexure of underlying oceanic seafloor into fluid mantle
- ✓ Cessation of volcanism and onset of heavy erosion cause islands to uplift with associated upward flexure of underlying seafloor



Evidence of Isostatic Adjustment Around Hawaiian Island – The "Moat"

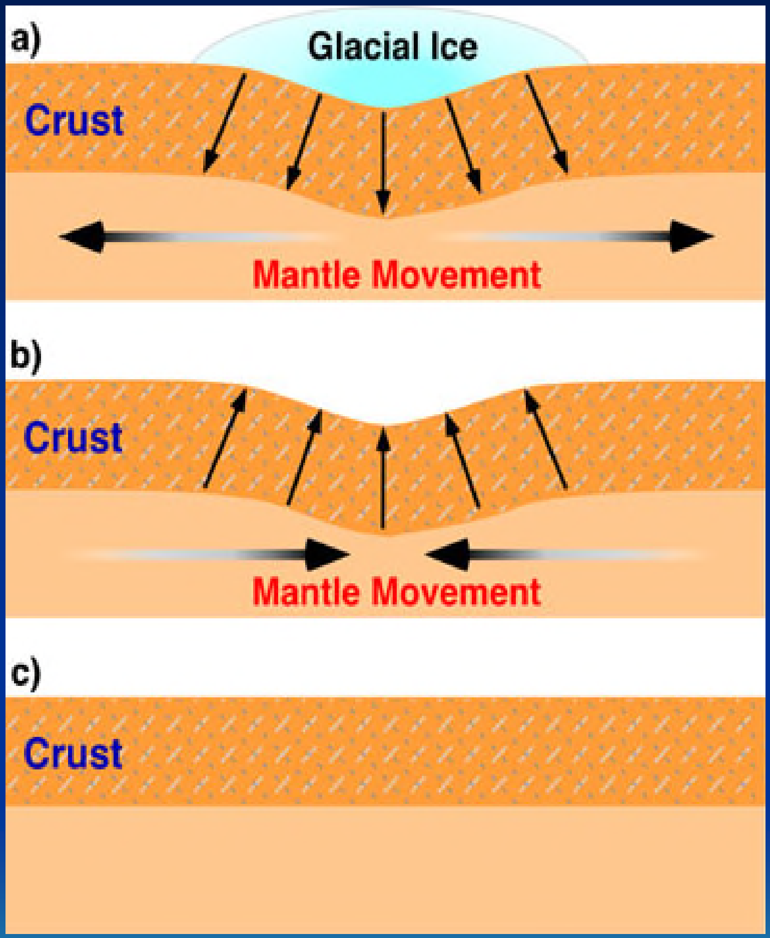


Hawaiian Hot Spot and Pacific

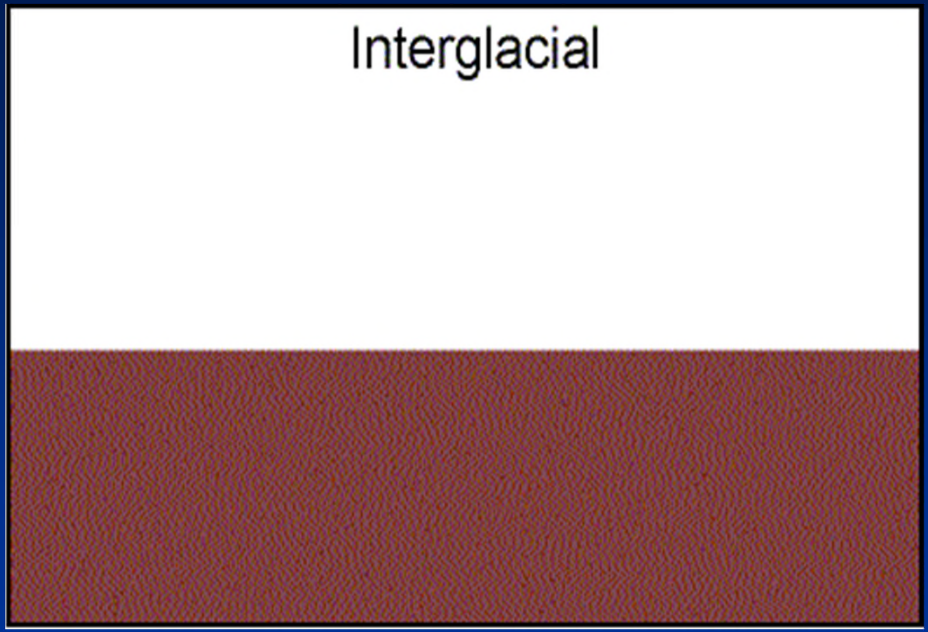


- ✓ Hot Spot trace includes Hawaiian Island Na Emperor Seamount chains
- ✓ Major bend in the hot spot trace between Hawaiian and Emperor segments

Isostatic Adjustment – Ice Caps



Glacial Adjustment



Isostatic Response to Changing Ice Thickness

North American Pleistocene Ice Cap

- ✓ Ice Cap Maximum: 18,000 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

North American Pleistocene Ice Cap

Ice Cap Maximum: 20,000 ya

Ice Cap Retreat: Today

✓ Land around Hudson Bay 150 meters higher (above sea level), compared to 6000 years ago. Global sea level also rose 13 meters.

✓ To establish an accurate rate of uplift, you need to add rise in sea level to uplift amount to get true amount of uplift.