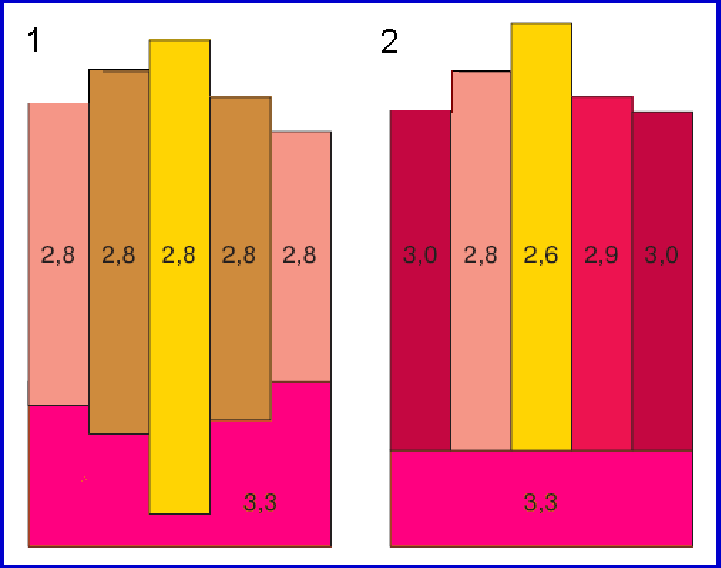
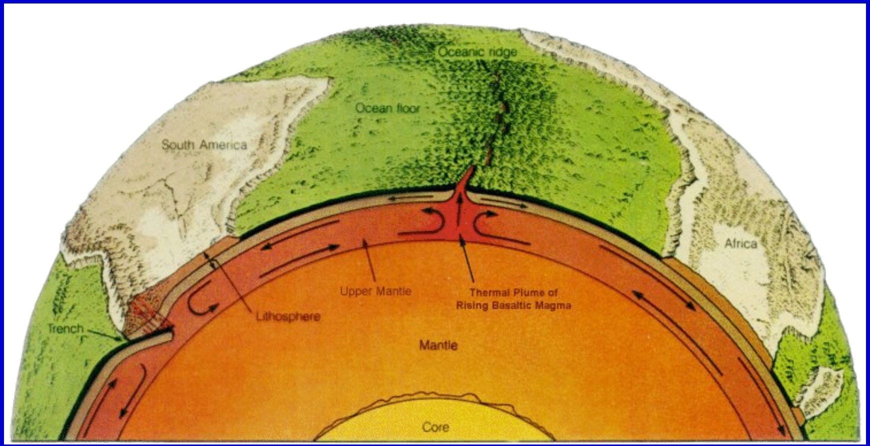
Isostasy Lab

Understanding the Nature of Floating Rock



Crust Mantle Density Relationship



Introductory Oceanography

Ray Rector - Instructor

Isostacy Laboratory

Topics of Inquiry

1) Concepts of Density and Buoyancy
2) The Layered Nature of the Earth
3) Isostatic Dynamics – Equilibrium vs. Adjustment
4) Modeling Isostasy in Lab
5) Applying Isostasy Models to Earth Systems

Inquiry of Lava Lamp Motion

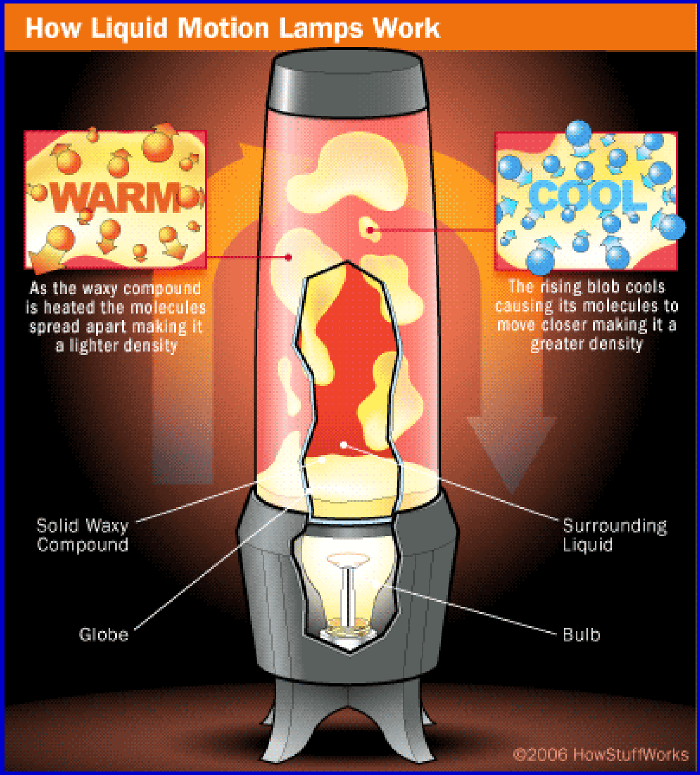
Density, Gravity and the Convection Process

✓ *Differential Heating of a Fluid Under the Influence of Gravity*: Fluid material at bottom of lamp is overheated; material at the top of lamp is under-heated (cooler).

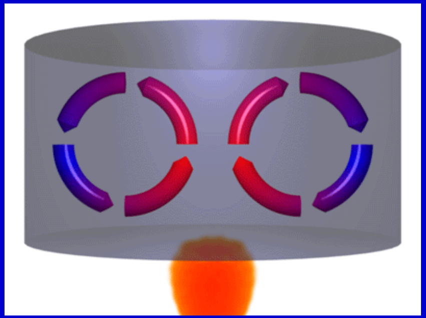
✓ Hotter material is less dense than cooler material

✓ Less dense fluid rises while more dense fluid sinks

✓ Heat and gravity drive the movement in the system



Convection Process



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.

Elements - Mass and Density

Periodic Table of Elements

Key: Atomic # / Symbol / Name / Atomic Mass

C Solid
Hg Liquid
H Gas
Rf Unknown

Metals: Alkali metals | Alkaline earth metals | Lanthanoids | Actinoids | Transition metals | Poor metals
Nonmetals: Other nonmetals | Noble gases

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1 H Hydrogen 1.00794																	2 He Helium 4.002602
2	3 Li Lithium 6.941	4 Be Beryllium 9.012182											5 B Boron 10.811	6 C Carbon 12.0107	7 N Nitrogen 14.0067	8 O Oxygen 15.9994	9 F Fluorine 18.9984032	10 Ne Neon 20.1797
3	11 Na Sodium 22.98976928	12 Mg Magnesium 24.3050											13 Al Aluminium 26.9815386	14 Si Silicon 28.0855	15 P Phosphorus 30.973762	16 S Sulfur 32.065	17 Cl Chlorine 35.453	18 Ar Argon 39.948
4	19 K Potassium 39.0983	20 Ca Calcium 40.078	21 Sc Scandium 44.955912	22 Ti Titanium 47.867	23 V Vanadium 50.9415	24 Cr Chromium 51.9961	25 Mn Manganese 54.938045	26 Fe Iron 55.845	27 Co Cobalt 58.933195	28 Ni Nickel 58.6934	29 Cu Copper 63.546	30 Zn Zinc 65.38	31 Ga Gallium 69.723	32 Ge Germanium 72.64	33 As Arsenic 74.92160	34 Se Selenium 78.96	35 Br Bromine 79.904	36 Kr Krypton 83.798
5	37 Rb Rubidium 85.4678	38 Sr Strontium 87.62	39 Y Yttrium 88.90585	40 Zr Zirconium 91.224	41 Nb Niobium 92.90638	42 Mo Molybdenum 95.96	43 Tc Technetium (97.9072)	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.90550	46 Pd Palladium 106.42	47 Ag Silver 107.8682	48 Cd Cadmium 112.411	49 In Indium 114.818	50 Sn Tin 118.710	51 Sb Antimony 121.760	52 Te Tellurium 127.60	53 I Iodine 126.90447	54 Xe Xenon 131.293
6	55 Cs Caesium 132.9054519	56 Ba Barium 137.327	57–71	72 Hf Hafnium 178.49	73 Ta Tantalum 180.94788	74 W Tungsten 183.84	75 Re Rhenium 186.207	76 Os Osmium 190.23	77 Ir Iridium 192.217	78 Pt Platinum 195.084	79 Au Gold 196.966569	80 Hg Mercury 200.59	81 Tl Thallium 204.3833	82 Pb Lead 207.2	83 Bi Bismuth 208.98040	84 Po Polonium (208.9824)	85 At Astatine (209.9871)	86 Rn Radon (222.0176)
7	87 Fr Francium (223)	88 Ra Radium (226)	89–103	104 Rf Rutherfordium (261)	105 Db Dubnium (262)	106 Sg Seaborgium (266)	107 Bh Bohrium (264)	108 Hs Hassium (277)	109 Mt Meitnerium (268)	110 Ds Darmstadtium (271)	111 Rg Roentgenium (272)	112 Uub Ununbium (285)	113 Uut Ununtrium (284)	114 Uuq Ununquadium (289)	115 Uup Ununpentium (288)	116 Uuh Ununhexium (292)	117 Uus Ununseptium	118 Uuo Ununoctium (294)

For elements with no stable isotopes, the mass number of the isotope with the longest half-life is in parentheses.

57 La Lanthanum 138.90547	58 Ce Cerium 140.116	59 Pr Praseodymium 140.90765	60 Nd Neodymium 144.242	61 Pm Promethium (145)	62 Sm Samarium 150.36	63 Eu Europium 151.964	64 Gd Gadolinium 157.25	65 Tb Terbium 158.92535	66 Dy Dysprosium 162.500	67 Ho Holmium 164.93032	68 Er Erbium 167.259	69 Tm Thulium 168.93421	70 Yb Ytterbium 173.054	71 Lu Lutetium 174.9668
89 Ac Actinium (227)	90 Th Thorium 232.03806	91 Pa Protactinium 231.03588	92 U Uranium 238.02891	93 Np Neptunium (237)	94 Pu Plutonium (244)	95 Am Americium (243)	96 Cm Curium (247)	97 Bk Berkelium (247)	98 Cf Californium (251)	99 Es Einsteinium (252)	100 Fm Fermium (257)	101 Md Mendelevium (258)	102 No Nobelium (259)	103 Lr Lawrencium (262)

Ptable.com

Earth's Layered Structure

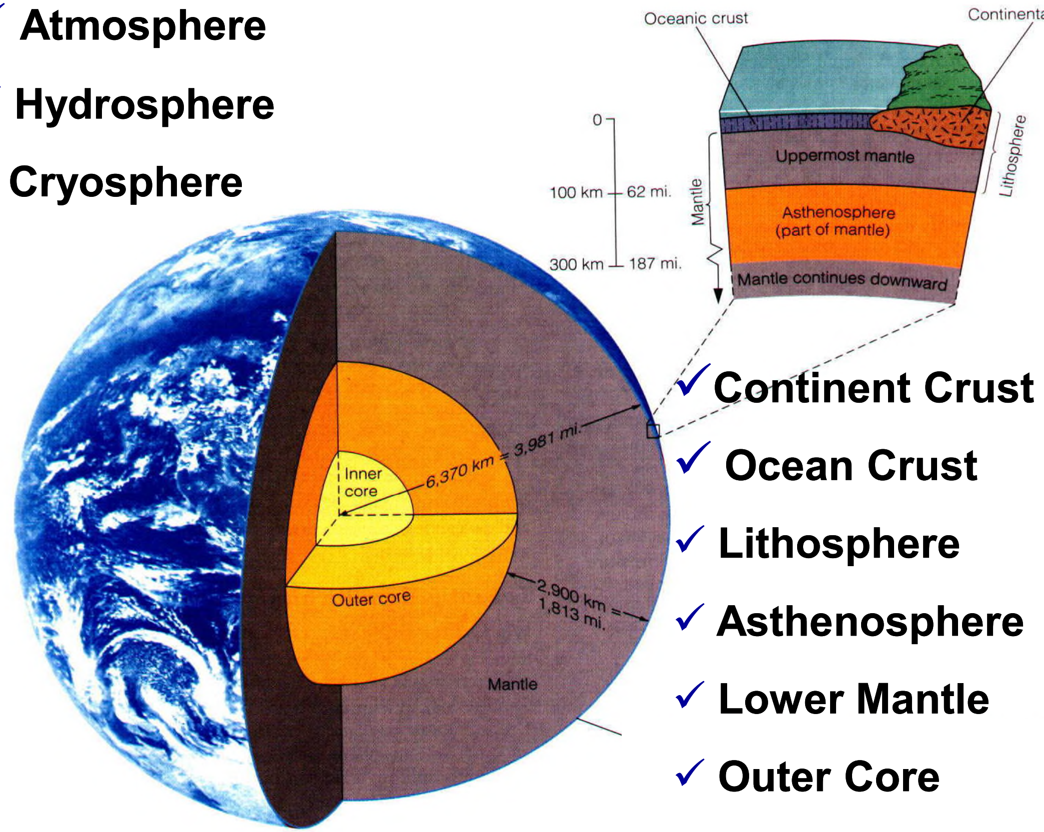
1) The Earth is Vertically Arranged into Ten Density Layers

2) Each Layer has Unique Physical and Chemical Properties

3) Layers are Arranged According to Density Value, as Controlled by Gravity

4) Densest Solid = Core

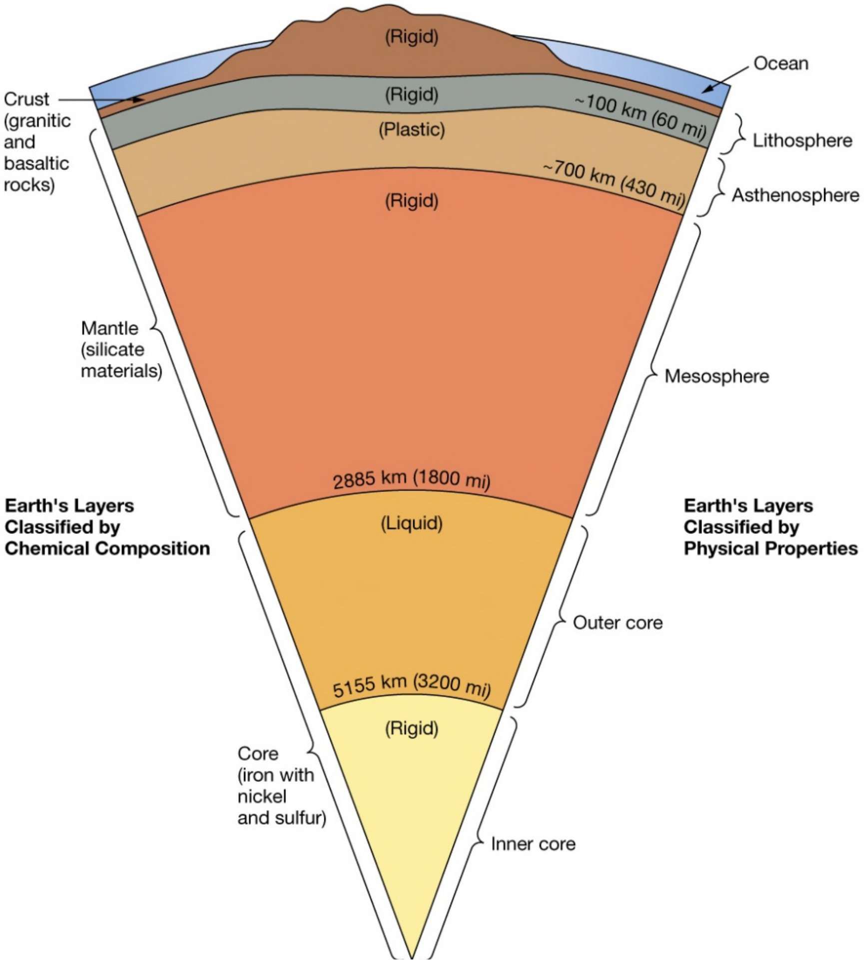
Least Dense Solid = Crust

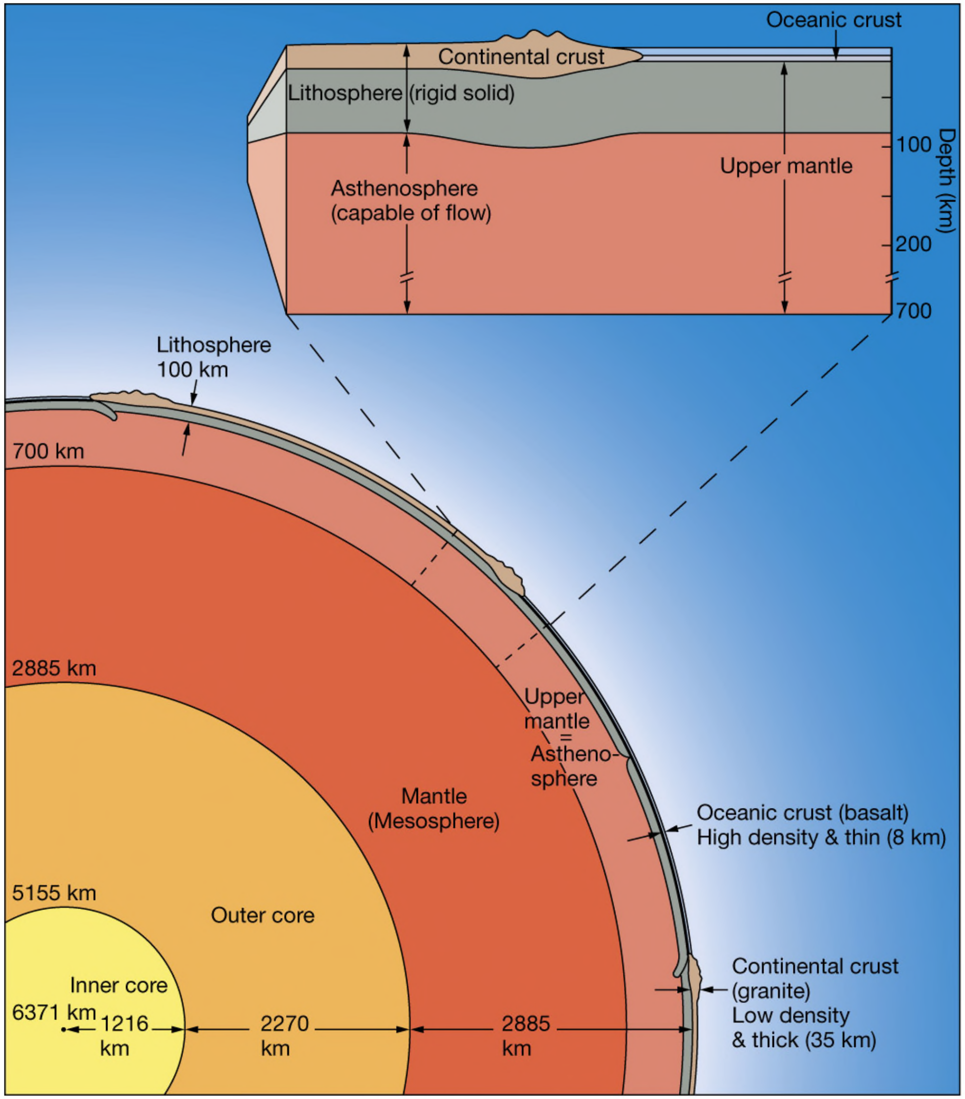


- ✓ Atmosphere
- ✓ Hydrosphere
- ✓ Cryosphere
- ✓ Continent Crust
- ✓ Ocean Crust
- ✓ Lithosphere
- ✓ Asthenosphere
- ✓ Lower Mantle
- ✓ Outer Core
- ✓ Inner Core

Earth's Interior

Chemical and Physical Nature of Earth's Interior

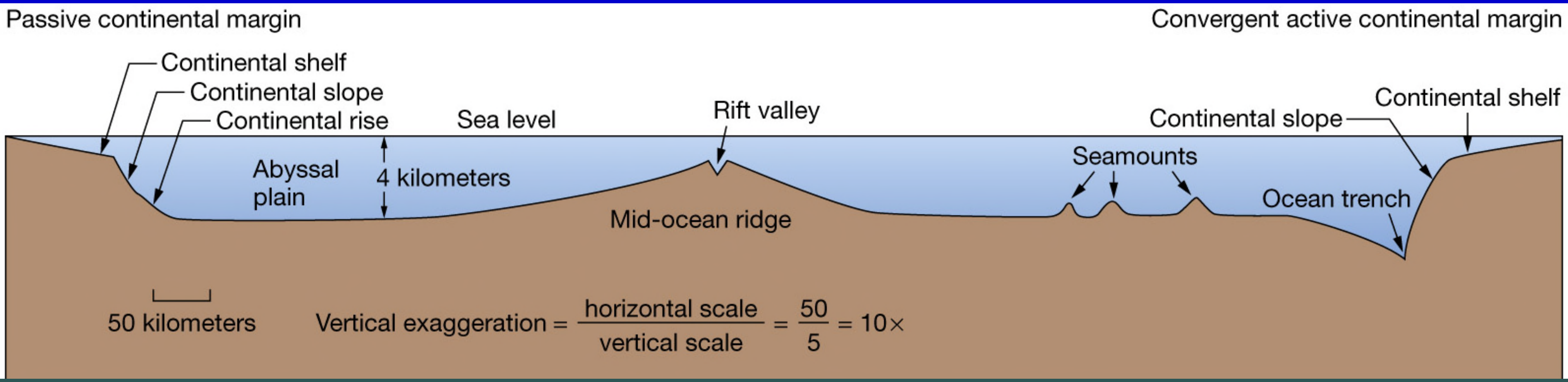




Density Layering of Earth's Interior

Topography of Earth's Ocean Floors

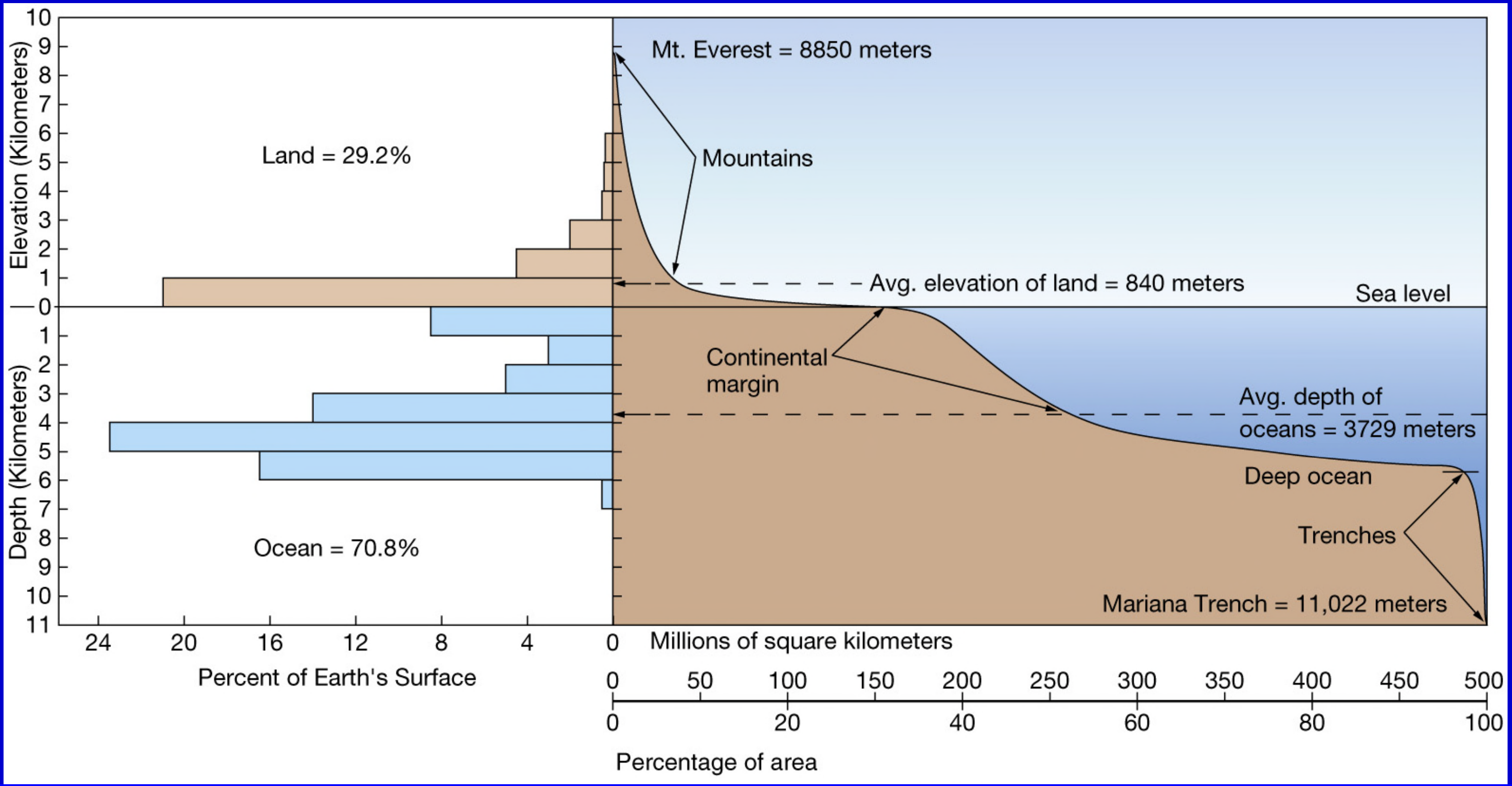
Cross-Section Profile of an Ocean Basin



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**
- ✓ Continental = Granitic
- ✓ Oceanic = Gabbroic

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

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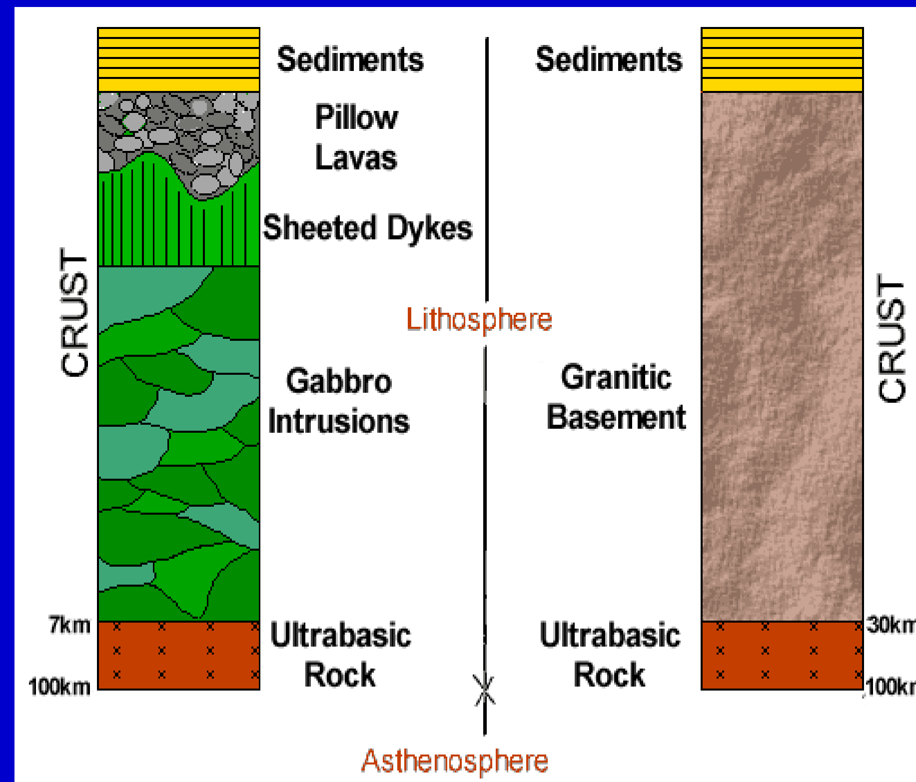
Oceanic Crust
Gabbroic Rock

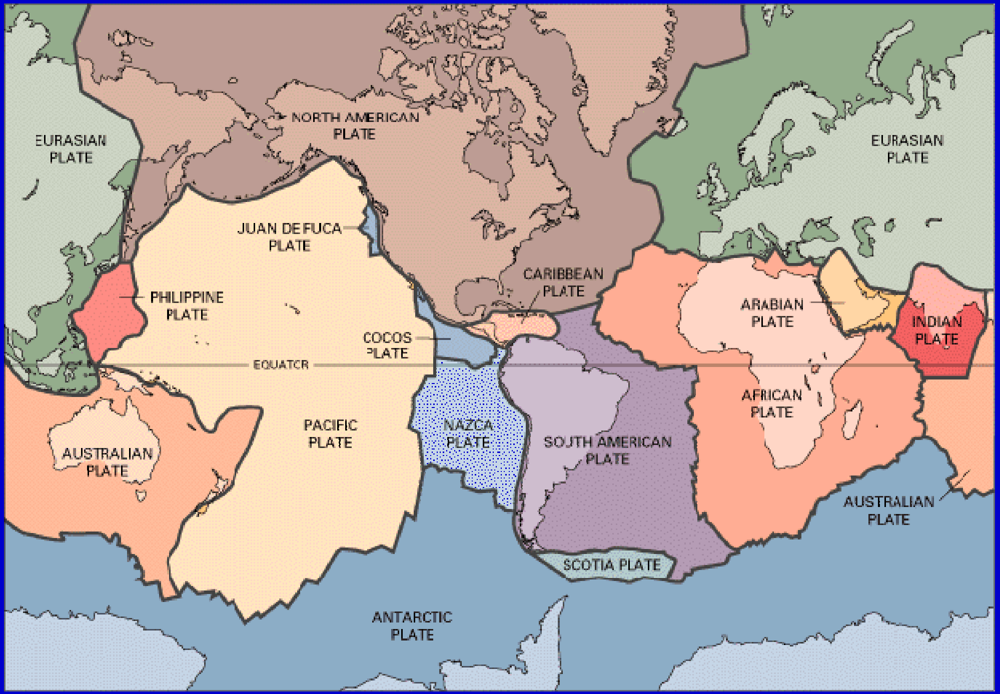
Continental Crust
Granitic Rock



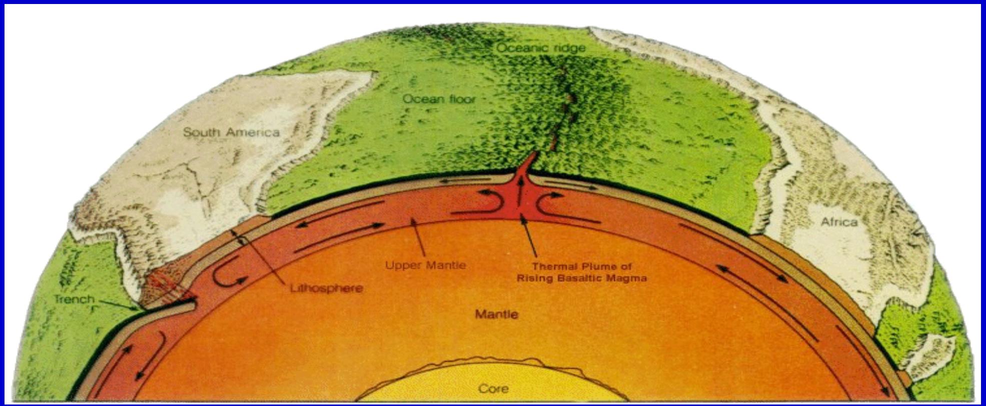
THE TECTONIC PLATES

Key Features:

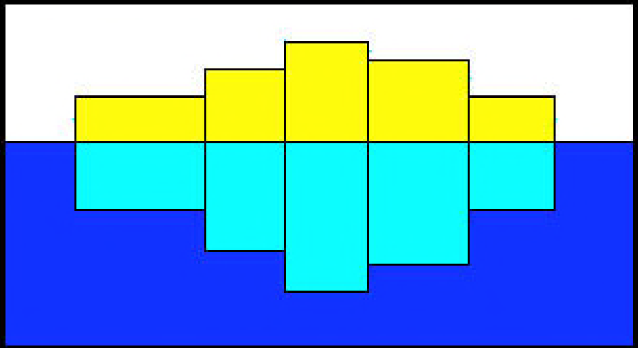
- ✓ 6 Major Plates
- ✓ 8 Minor Plates
- ✓ 100 km thick
- ✓ Strong and rigid
- ✓ Plates float on fluid asthenosphere
- ✓ Plates are mobile
- ✓ Plates move at a rate of centimeters per year



Earth's Lithospheric Plates

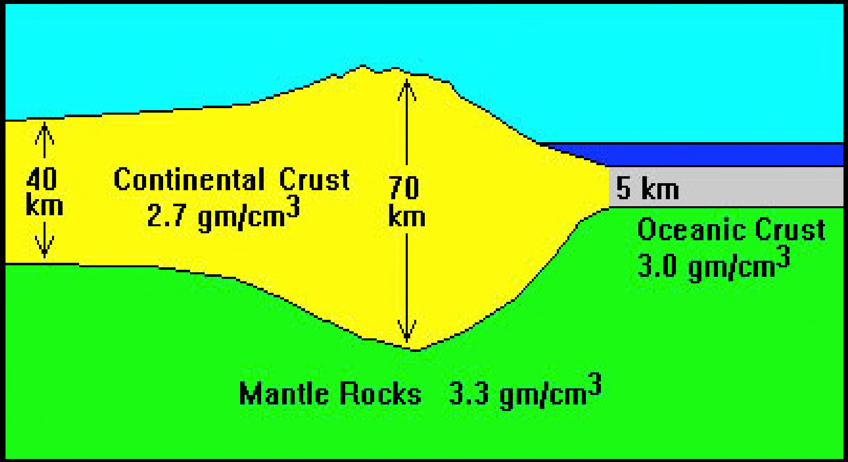


Isostasy



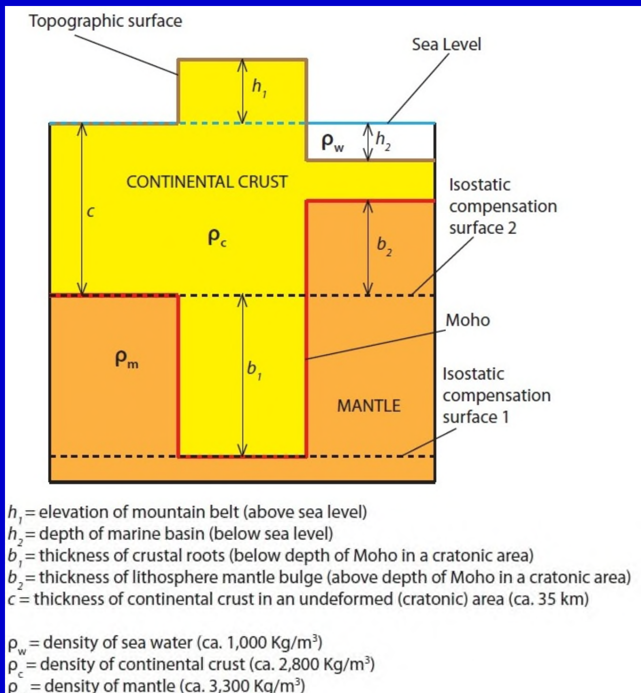
Wooden blocks of different sizes float to different heights (and depths) in equilibrium with the water it floats in.

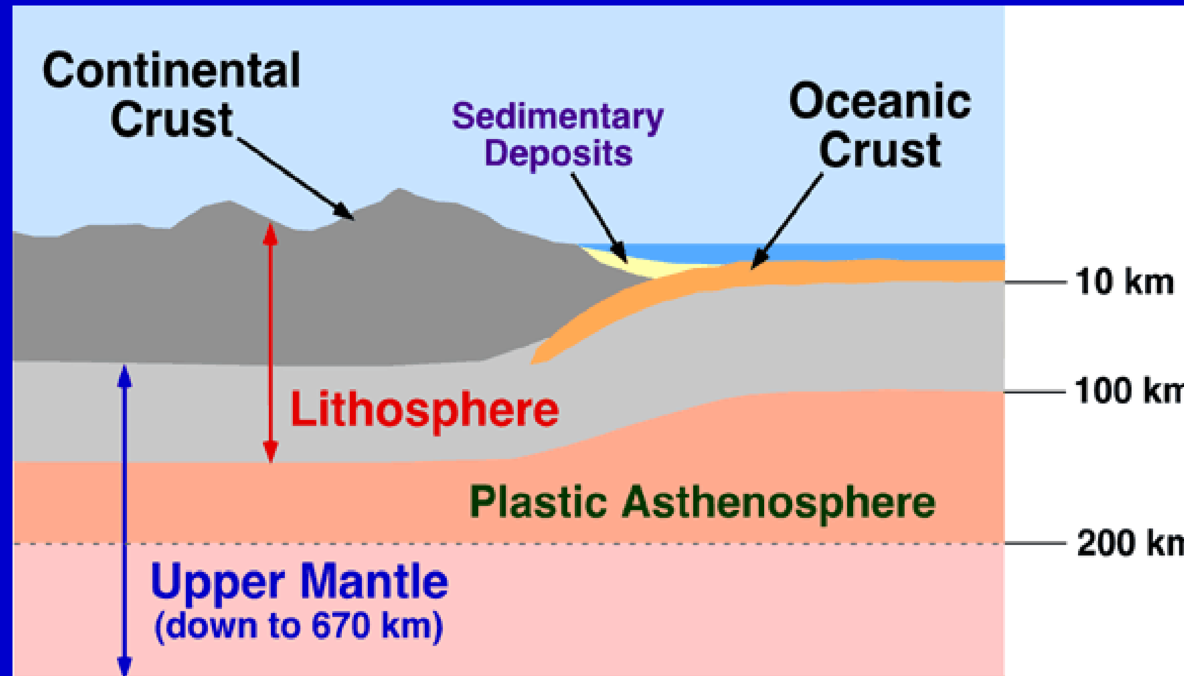
Likewise, continental and oceanic crust are in equilibrium, floating on the asthenosphere in the upper mantle.



The density of rocks in continental crust are less dense than rocks in oceanic crust.

Isostasy: Crust *Floating* in Mantle





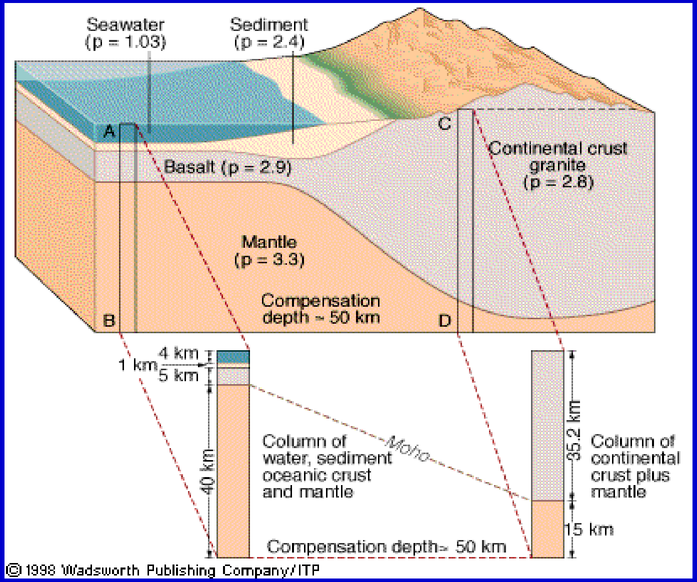
1) Isostatic Equilibrium Between Crust and Mantle; Lithosphere and Asthenosphere

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

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

Concept of Buoyancy

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

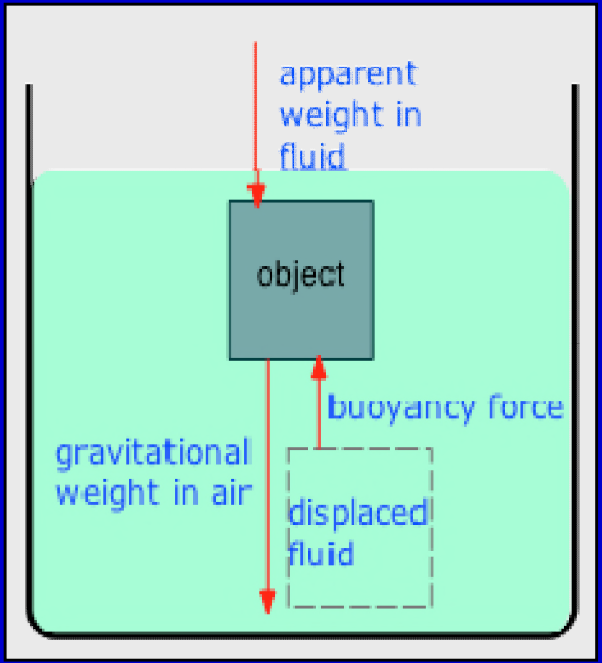
2) Buoyancy is the fluid pressure exerted on an immersed object equal to the weight of fluid being displaced by the object.

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

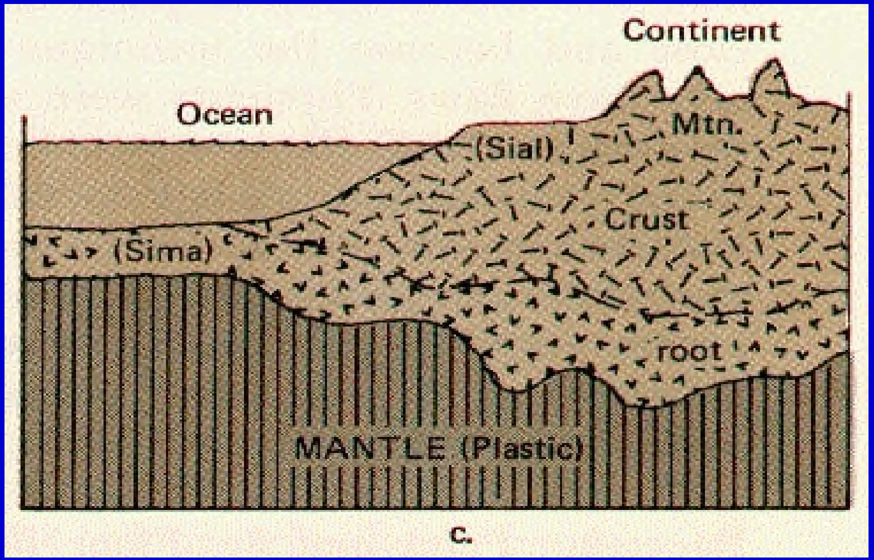
- The greater the difference in density between the object and the fluid, the greater the buoyancy force = sits high
- The lesser the difference in density between the object and the fluid, the lesser the buoyancy force = sits low

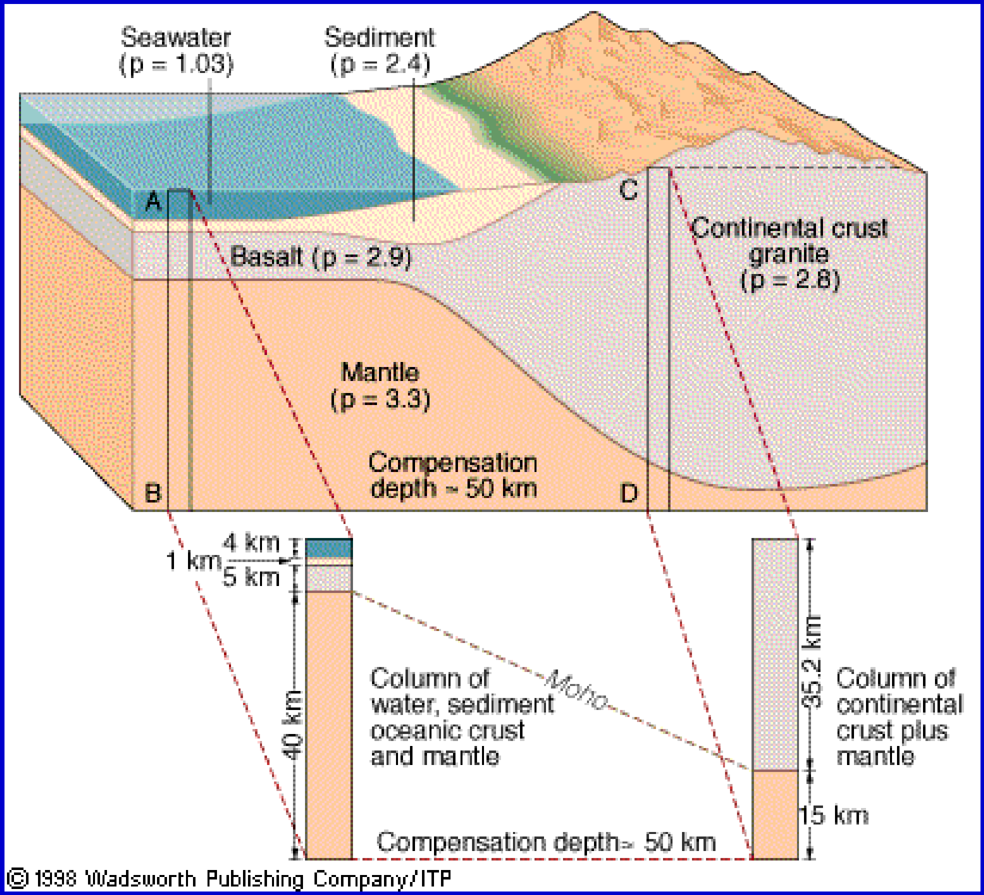


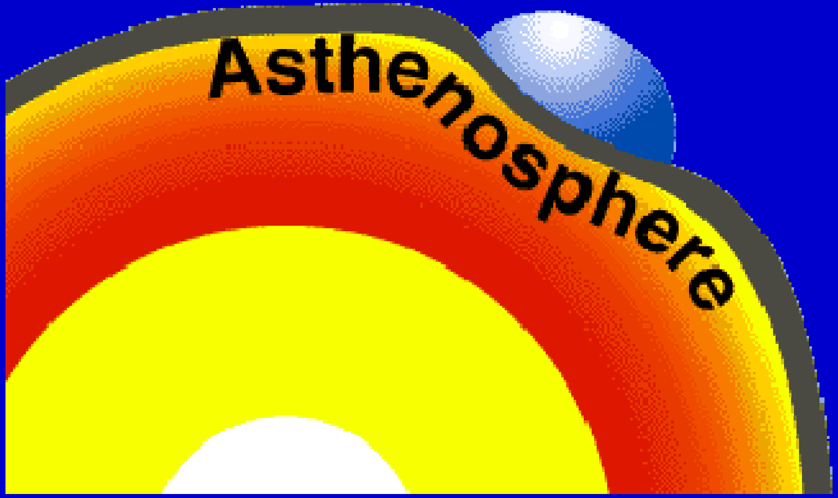
Example of Buoyancy: Boat on a Lake

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

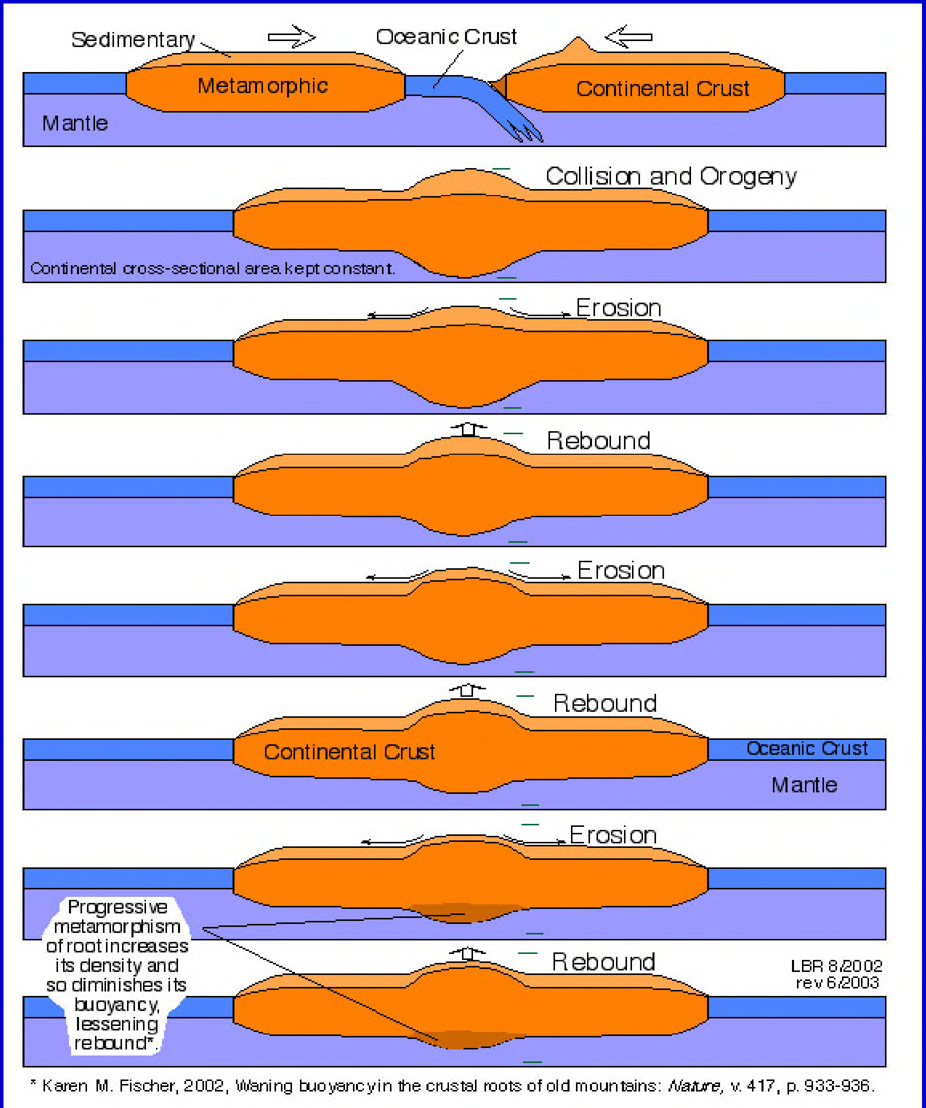
The Isostatic Equilibrium

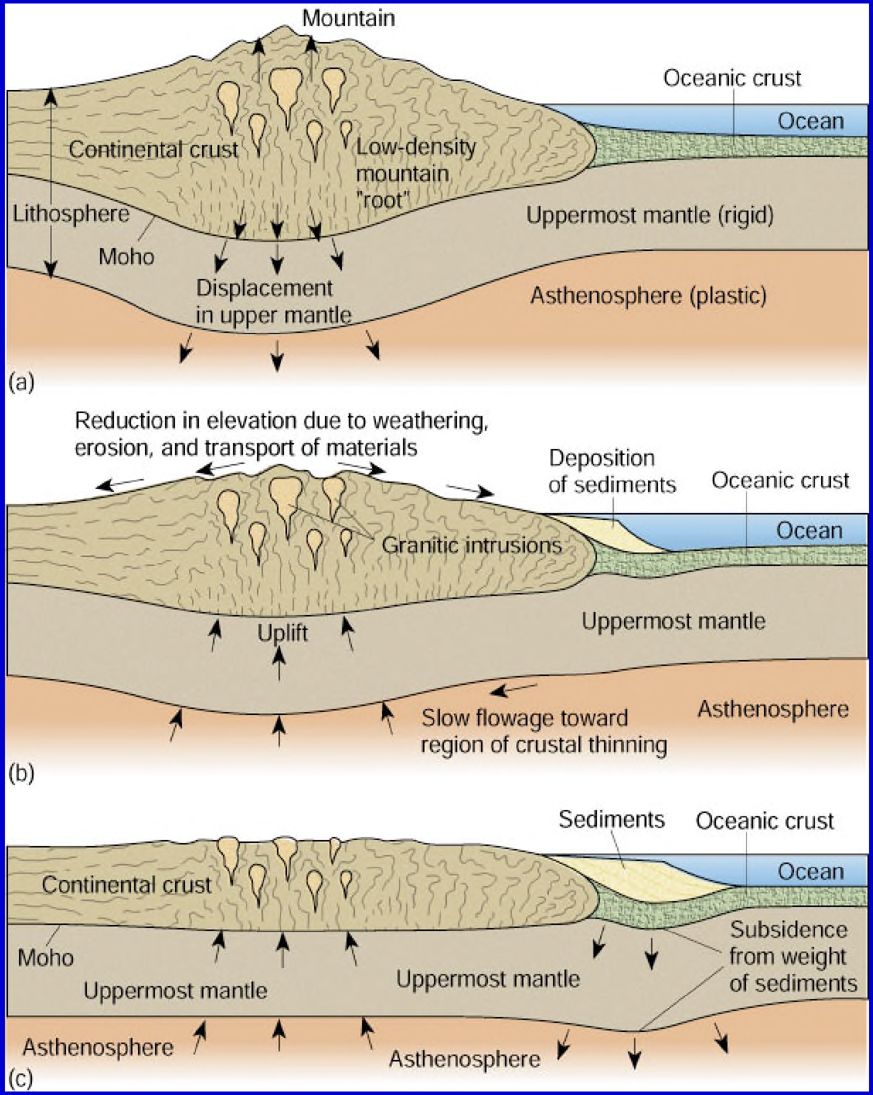






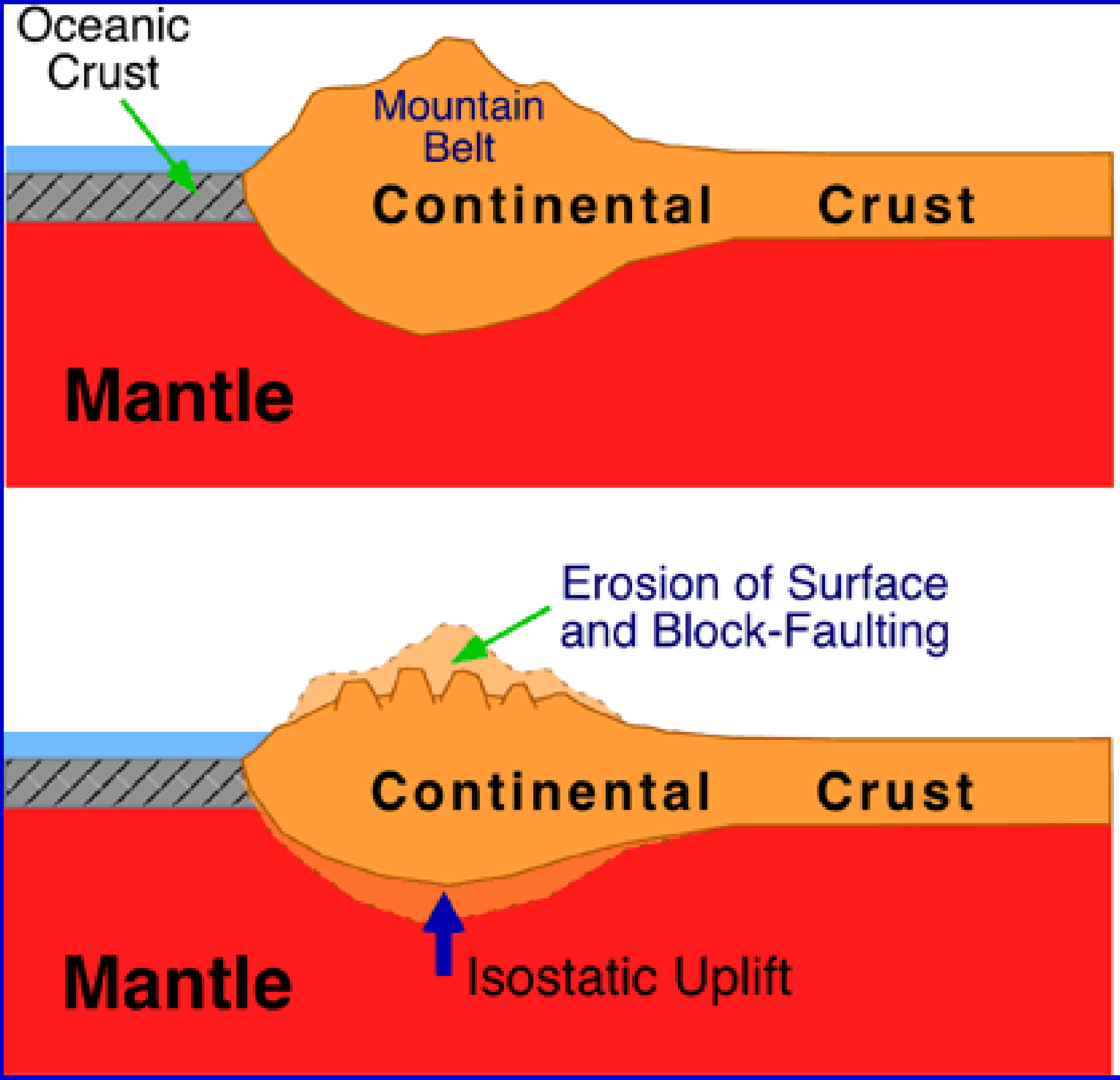
Isostatic Adjustment - Orogeny





Isostatic Loading and Rebound – *Orogeny and Erosion*

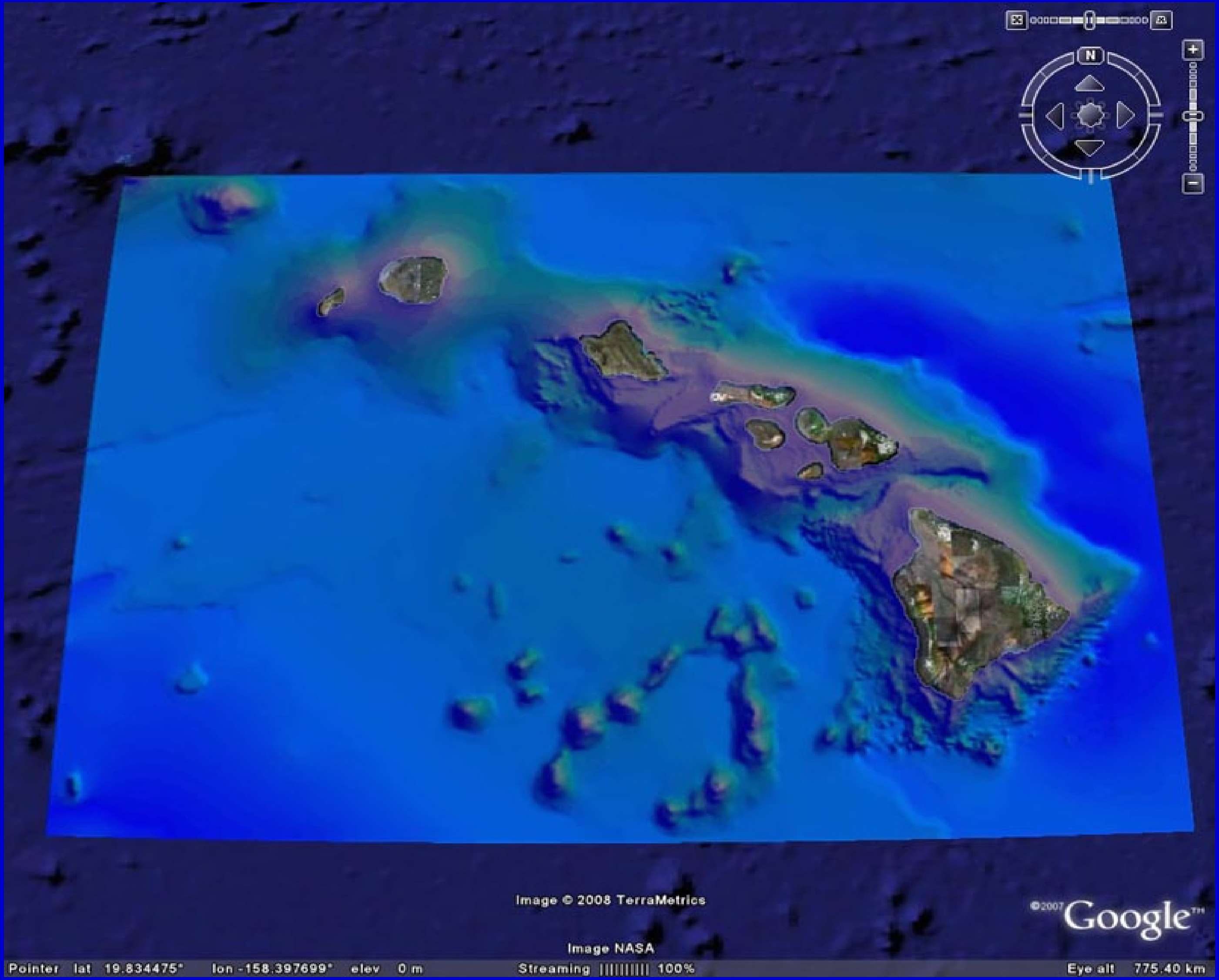
Isostatic Adjustment - Orogeny



A. End of the Orogenic Stage

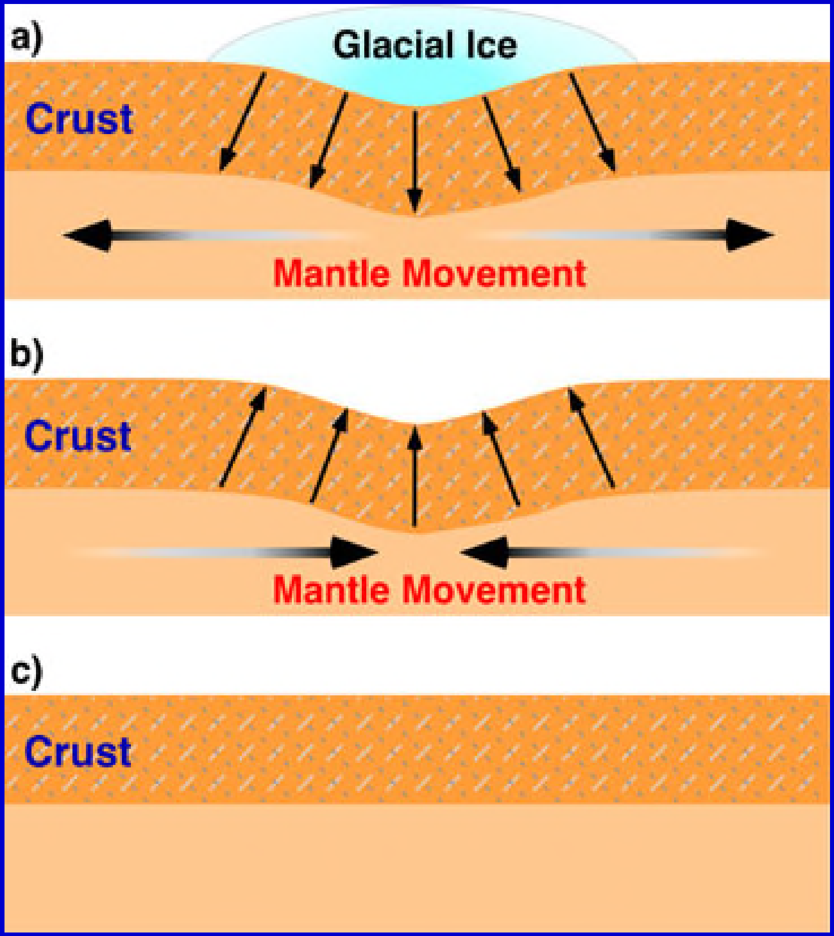
B. Isostatic Uplift and Block-Faulting Stage

Isostatic Adjustment – Volcanism

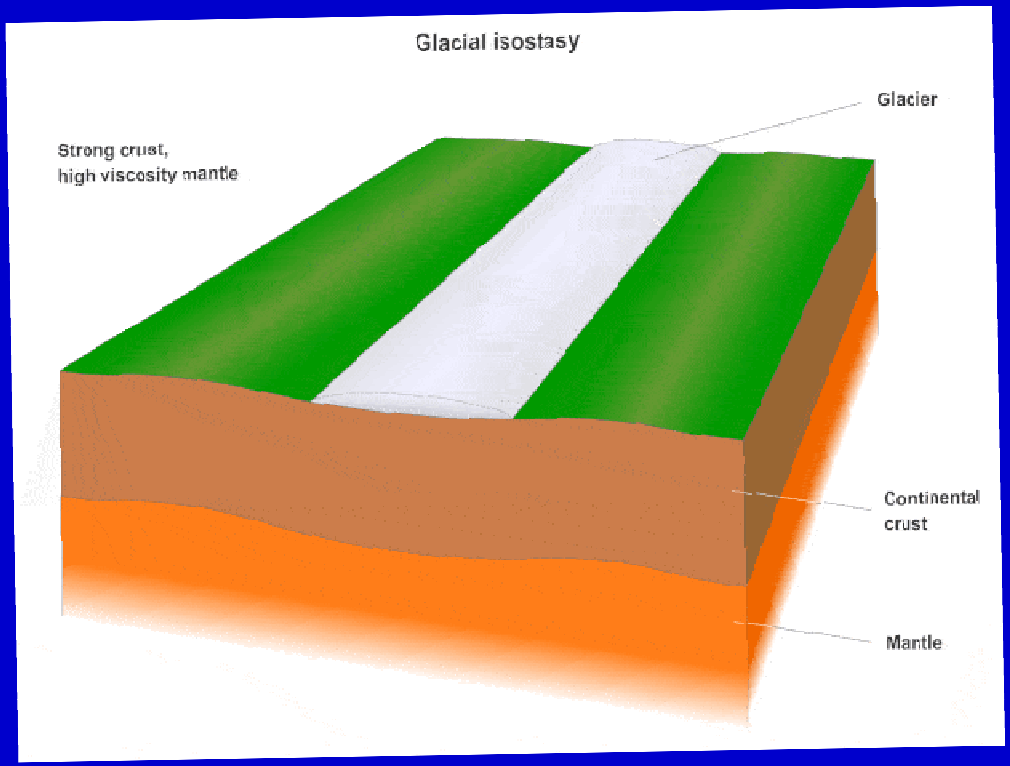


Growth of the Hawaiian Islands – Crustal Depression

Isostatic Adjustment – Ice Caps



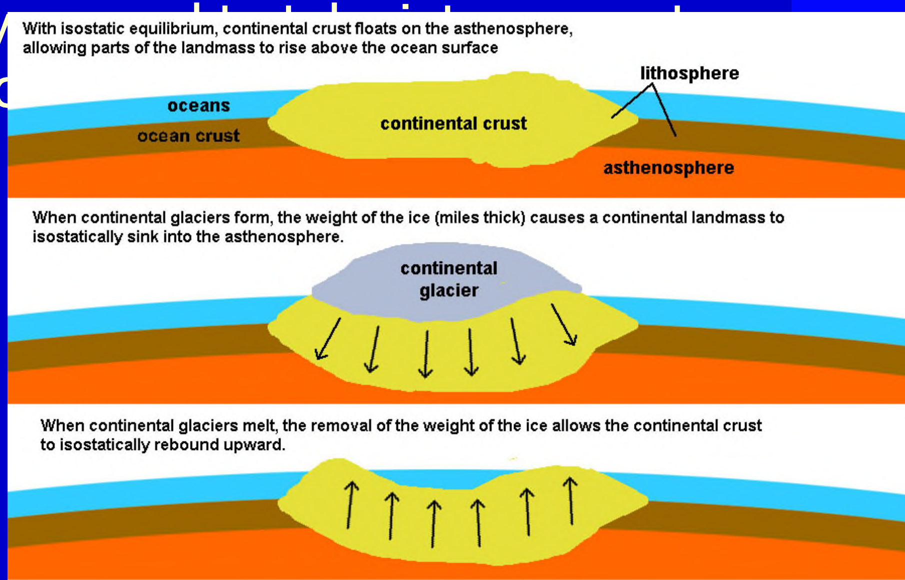
Glacial Adjustment



Isostatic Response to Changing Ice Thickness

North American Pleistocene Ice Cap

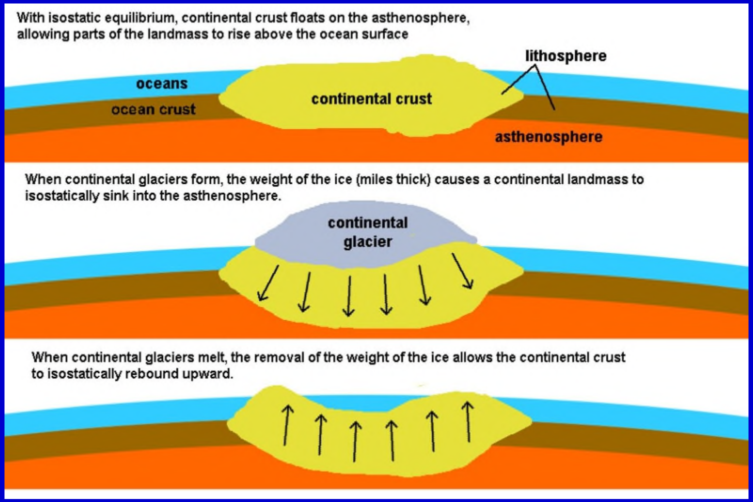
- ✓ Ice Cap Maximum: 20,000 ya
- ✓ Ice Cap Retreat: By 6,000 ya
- ✓ Last 6,000 years:
  - ➢ Sea level rising = 13 meters
  - ➢ Land uplifting = Variable
- ✓ To establish an accurate rate of uplift, y eustatic crust.



20,000 years ago

North American Pleistocene Ice Cap

Ice Cap Maximum: 20,000 ya



Isostatic Adjustment

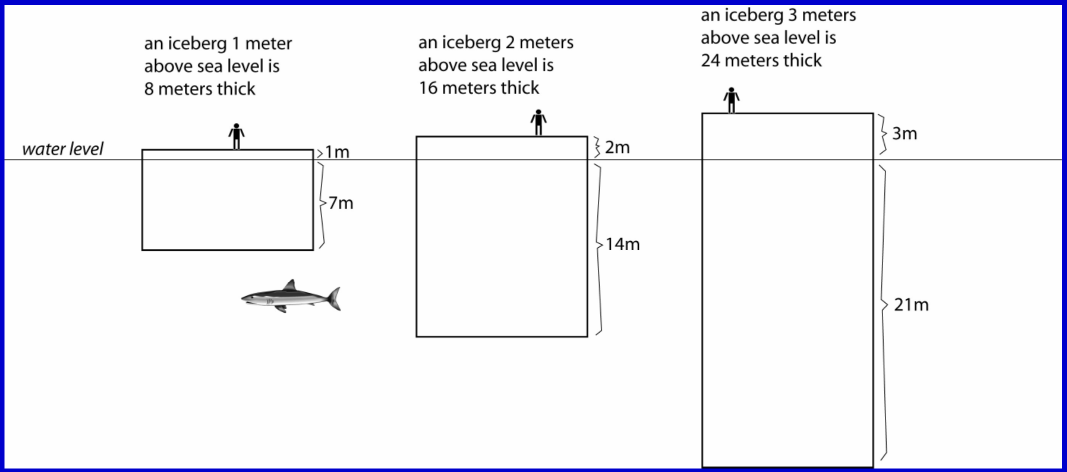
Ice Cap Retreat: Today

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

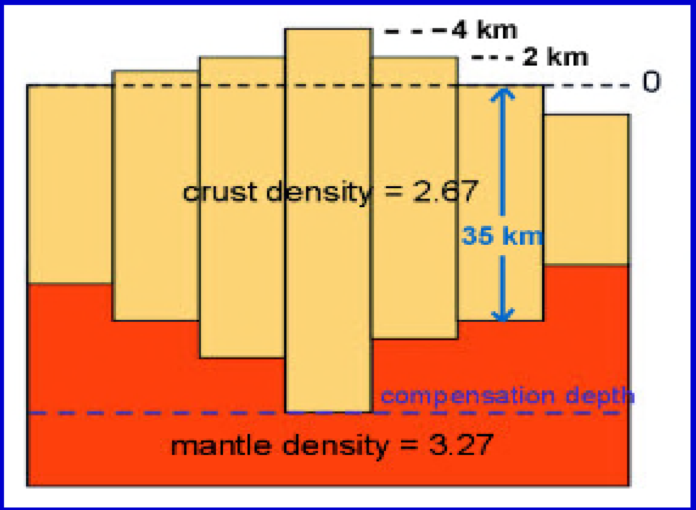
✓ To establish an accurate rate of uplift, you need to add rise in sea level to uplift amount to get true amount of uplift.

Isostatic Equilibrium and Thickness

- *The One to Eight Rule* -



Icebergs of different thicknesses



Crust of different thicknesses

1) For icebergs and continental crust, apply the **1-to-8 rule**, assuming ice or continental crust is in isostatic equilibrium.

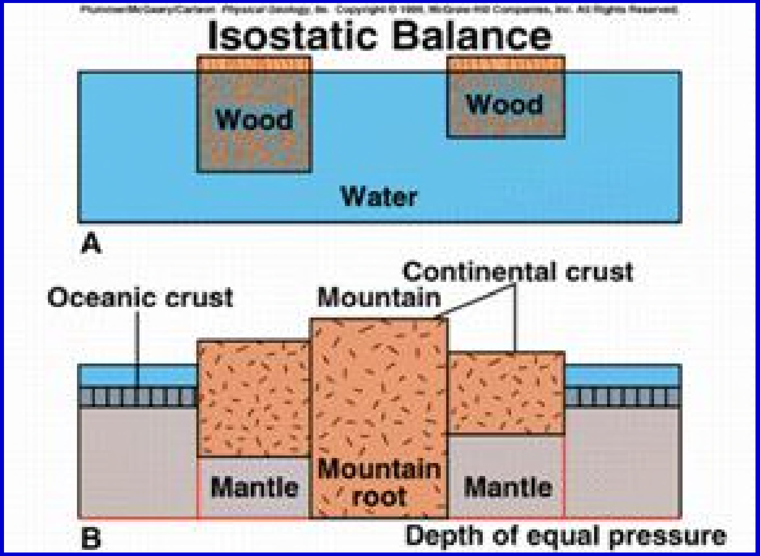
2) Continental crust at **sea level** averages about 35 kilometers thick. (1 km = 0.6 miles.)

3) How thick must the crust be to support a:
1-kilometer high mountain belt? 2-kilometer high mountain belt?
km 5-kilometer high mountain belt?

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



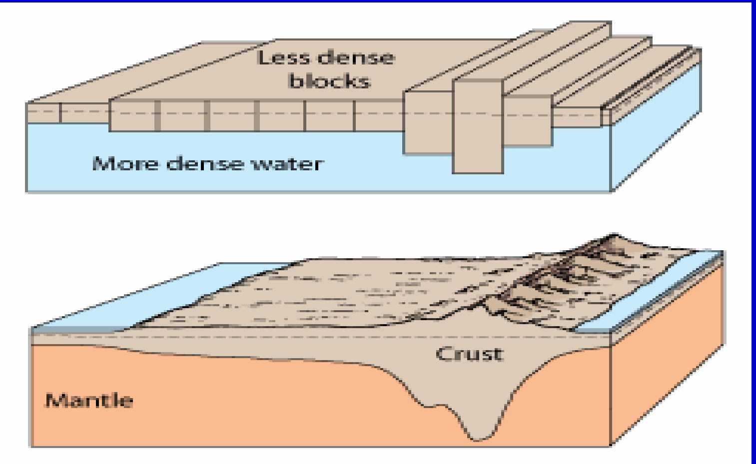
The Lab Model:

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

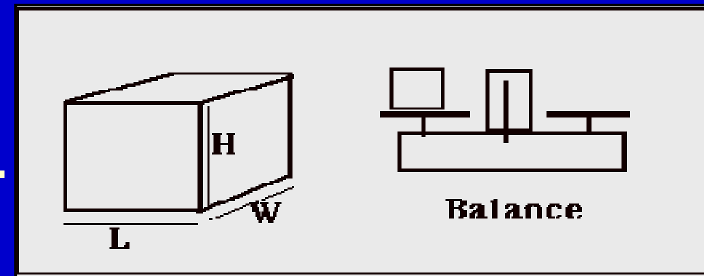
Metal and Wood Block Densities:

1) Determine Mass (grams) with flattop scale.

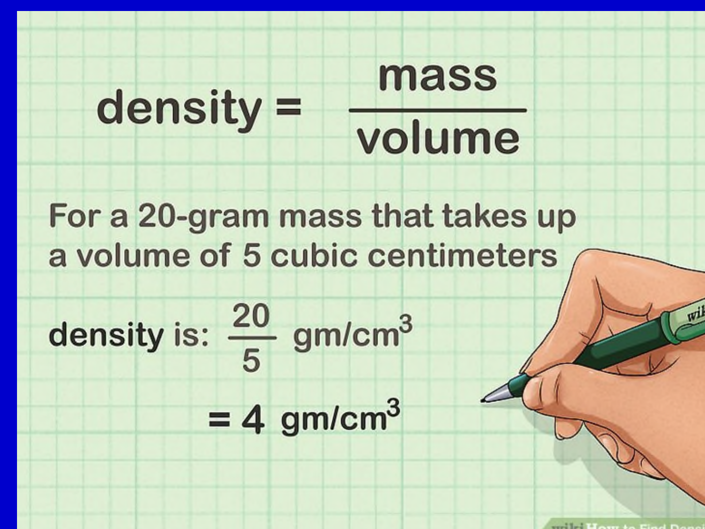
2) Determine Volume (cubic cm) with ruler

- ✓ Length x height x width

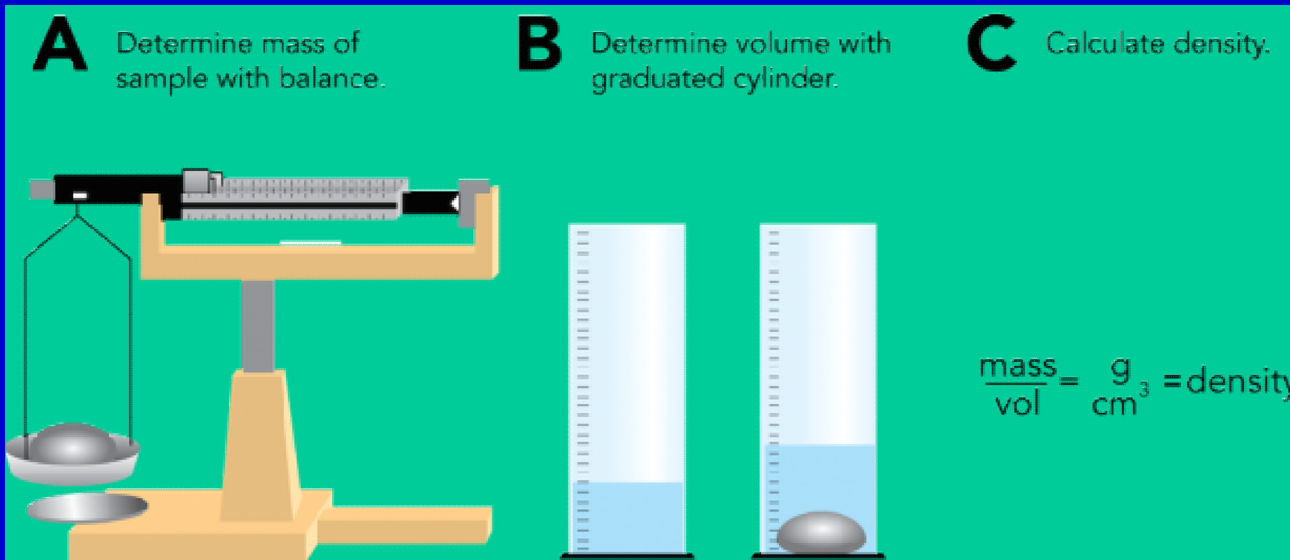
3) Only measure the thick redwood block and oak blocks

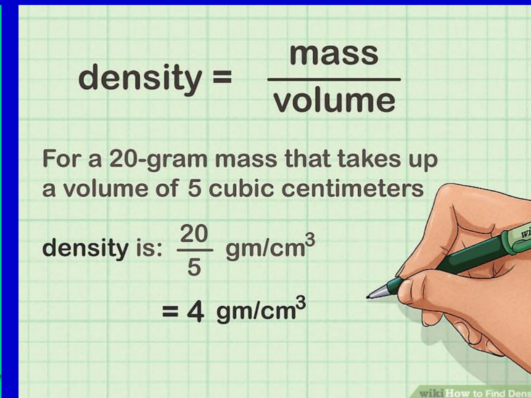


$$\text{Denisty} = \frac{\text{mass}}{\text{volume}} \quad \text{or} \quad D = \frac{m}{v}$$



Determining Rock Sample Density





Rock Densities:

1) Determine Mass (grams) with flattop scale

2) Determine Volume (cubic cm) with graduated cylinder

   - ✓ Displacement method

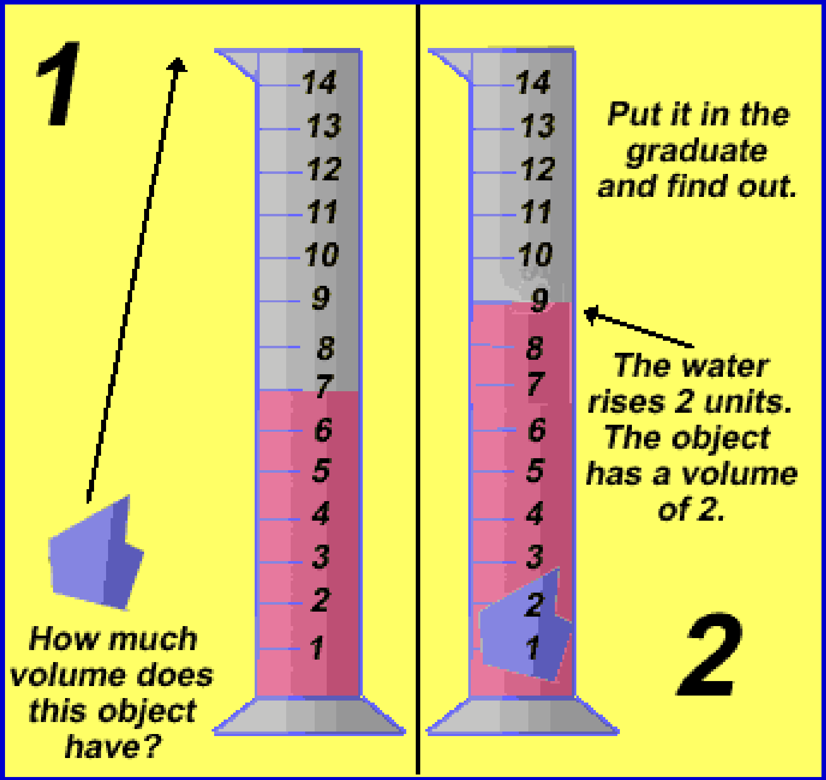
3) Calculate Density by Dividing Mass by Volume

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

Suspended Immersion Method

Step 1 – Weigh dry rock sample

Step 2 – Fill 300 ml beaker with ¾'s full of water and weigh

Step 3 – Place dry rock sample (in mesh bag) into beaker and reweigh

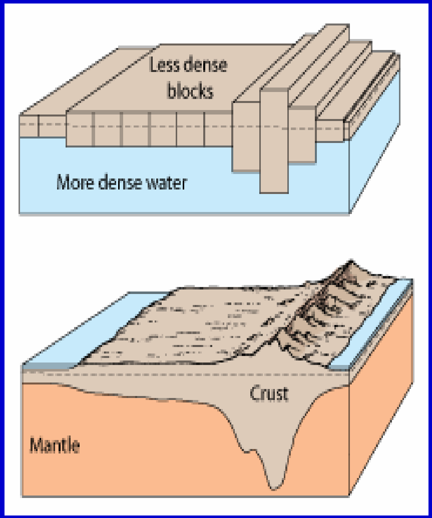
Step 4 – Place bag with rock in beaker of water and reweigh

Step 5 – Calculate difference in weights = equals the sample volume

Step 6 - Calculate the density of the sample by dividing the sample mass (in g) by the volume (in cm^3).

Density/Thickness – Buoyancy Relationship

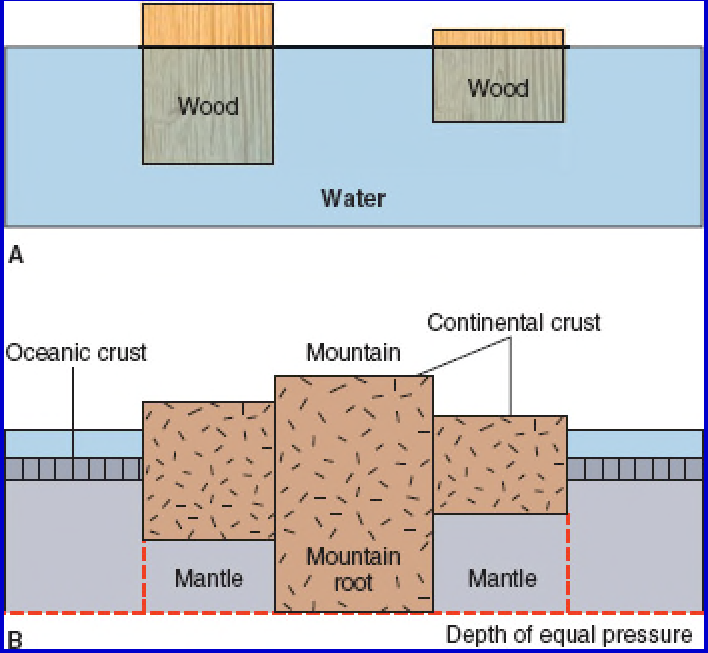
Modelling Wood Block Behavior in Water:



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 of block in and out of water

3) Compare redwood and oak wood blocks floating in water to that of continental and oceanic crust floating the mantle



4) Keep in mind the differences in BOTH ***density*** and ***thickness*** of the two different blocks and the two different types of crust

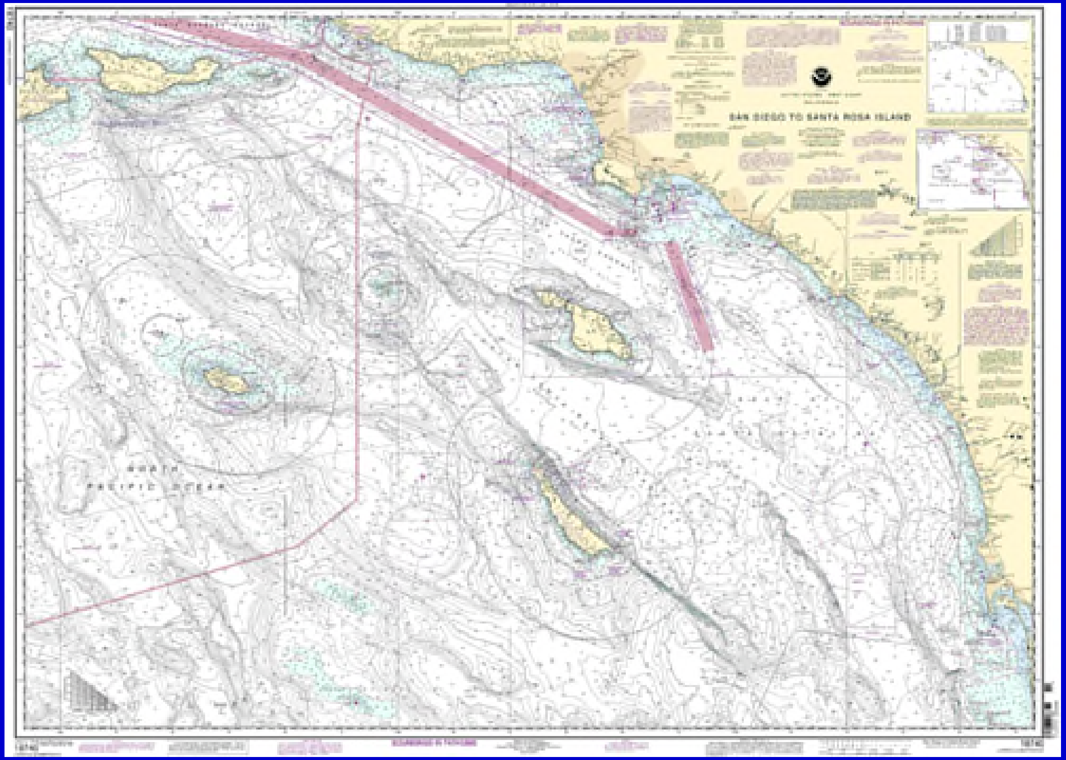
5) Note that high-standing floating objects require a much deeper bottom portion to maintain (hold up) the high-standing portion.

Next Weeks Lab Topic

- Maps and Charts Lab

Preparation:

- ✓ Study PowerPoint
- ✓ Study Worksheet



Make sure to bring your workbook