Name:______________________________________

Density and Isostatic Equilibrium Lab

Why does the Earth have continental areas and oceanic areas? Rephrasing the question a bit, why does the Earth's surface divide into <u>two distinct regions of elevation</u>: the **continents** (average elevation about one kilometer above sea level), and the **ocean basins** (average depth about 4 kilometers below sea level)?

The answer relates to the fact that Earth's surface is made up of two different types of crust: the **continental crust** and the **oceanic crust**. These two types of crust differ in both their **thickness** and **density**. In this lab, you will see how these two properties control the elevation of continents, mountain ranges, and ocean basins.

PART 1: VOLUME, MASS, & DENSITY

Density is a measure of <u>mass per unit volume</u>. To use water as an example, a <u>gallon</u> (a unit of volume) weighs about 8.33 <u>pounds</u> (a unit of mass). Therefore, the **density** of water is <u>8.33 pounds per gallon</u>. We can use any measurement of mass and/or volume to express density. Water's density is also <u>62.4 pounds per cubic foot</u> (62.4 lbs/ft^3), <u>1.0 kilogram per liter</u> (1.0 kg/L), or <u>1.0 gram per cubic centimeter</u> (1.0 g/cm^3), which is the same thing as 1.0 gram per milliliter (1.0 g/mL).

In this lab exercise, you will use the standard Metric System unit for density, which is **<u>grams per cubic centimeter</u>** (**g/cm^3**). To measure the **density** of an object in **g/cm^3**, you need to measure both its **mass in grams** and its **volume in cubic centimeters**. You will measure the **mass** of objects by simply weighing them on a scale. Measuring volume is a bit more involved. You will measure the **volume** of objects in two ways: by <u>linear dimensions</u> (for rectilinear objects) and by <u>water displacement</u> (for irregularly shaped objects).

PART 1a: Volume from Linear Dimensions

1. Begin with the two rectilinear **metal blocks** in your lab kit. Your job is to determine the density of each one, and from that, identify the type of metal.
   Write the <u>letter</u> printed on each block (A, B, C, or D) in the spaces below. Weigh each block to the nearest gram and record the mass below. Then use a ruler to measure, in centimeters, the length, width and height of each block to the first decimal place (0.1 cm). *Do this carefully; the blocks are small so even a 0.1cm (1.0mm) error may skew your results.*

Block letter _______ mass _______g length _____cm width _____cm height_____ cm

Volume (= length x width x height): ____________ cm^3

Density (= mass / volume): ____________ **g/cm^3** *(round to nearest 0.01)*

Block letter_______ mass _______g length _____cm width _____cm height_____ cm

Volume (= length x width x height): ____________ cm^3

Density (= mass / volume): ____________ **g/cm^3** *(round to nearest 0.01)*

2. This table lists the typical density ranges of several metals. Based on your density measurements, identify the type of metal that makes up each block.

Metal	*Chemical symbo*	*Density* ***g/cm³***
beryllium	Be	1.6 - 1.9
aluminum	Al	2.9 - 3.3
titanium	Ti	4.2 - 4.7
zinc	Zn	8.0 - 8.6
iron	Fe	8.6 - 9.1
copper	Cu	9.6 - 10.2
silver	Ag	10.3 - 10.7
lead	Pb	11.0 - 11.5

Metal block letter _______ is:___________________________________

Metal block letter _______ is:___________________________________

3. Now turn your attention to the two blocks of wood: **ash** (labeled "A") and **redwood** (labeled "R"). Heft them both in your two hands. Which one feels denser (heavier for a given amount)?

4. Weigh each of the wood blocks to the nearest gram and record the mass. Then use a ruler to measure, in centimeters, the length, width and height of each block to the first decimal place (0.1 centimeter).

Ash mass _______g length _____cm width _____cm height_____ cm

Volume (= length x width x height): ____________ cm^3

Density (= mass / volume): ____________ **g/cm^3** *(round to nearest 0.01)*

Redwood mass _______g length _____cm width _____cm height_____ cm

Volume (= length x width x height): _____________ cm^3

Density (= weight / volume): _____________ **g/cm^3** *(round to nearest 0.01)*

3. The density of **water is 1.0 g/cm^3**. Comparing the density of water to the density of ash and of redwood, predict what proportion (percent) of your blocks will stick up out of the water when the pieces of wood are floating. *Note: your percentages should exactly match the densities of the two woods relative to the density of water.*

Ash: _________ % of the block will be underwater, __________ % will stick out of the water.

Redwood: _________ % of the block will be underwater, __________ % will stick out of the water.

4. Take the pieces of redwood and ash and float them in water, observing how high each one floats above the waterline. Question: Do your predictions in question #3 above fit with what you observe?

   Draw a simple side-view sketch of the two blocks across the waterline. Label each block, including their respective percentages of how much of each block is above and below the waterline. *Note: keep this observation in mind for later in the lab when you consider how the Earth's two types of crust float in the mantle.*

____ *water line*

PART 1b: Volume from Fluid Displacement—CYLINDER method

As you have seen, to measure density you need to measure both mass and volume. Measuring volume for a *rectilinear object*, like the blocks of metal or wood, is straightforward: you just measure the linear dimensions. But many natural objects, including rocks, have irregular shapes. To measure the volume of an irregularly shaped object, we can use **Archimedes principle**: the volume of fluid displaced by a submerged object is equal to the object's volume.

You will use the displacement method to measure the volumes of samples **magnetite** and **granite**. Measure water displaced using the plastic graduated cylinders. Each tick mark on the cylinders represents **5 cm^3** (= 5 mL) of volume. It is important to read the water level to the nearest **1 cm^3** (nearest 1 mL), which means estimating as best you can between each tick mark. *Do this as accurately as you can; this is the largest source of error in this part of the lab.*

5. Heft the pieces of granite and magnetite in your two hands. Question: Which one feels denser (heavier for a given amount)?

6. **Determine the density of magnetite and of granite**. Follow steps below to complete the data tables on the next page for the three samples of magnetite and the three samples of granite.

   a. Fill the plastic cylinder to between the 300 and 350 mL level. Tap the cylinder to get out air bubbles.
   b. Weigh the first sample and record its mass in **grams** in the row for "Sample 1" in the data table.
   c. Read the water level to the nearest 1 cm^3 (nearest 1 mL) and record it in the table under "start level" for "Sample 1".
   d. Tilt the cylinder to ~ 45 degree angle and gently slide the sample in so that it slips into the water without splashing. Gently tap the cylinder to get out air bubbles.
   e. Read the water level to the nearest 1 cm^3 and record it in the table under "end level" for "Sample 1."
   f. Calculate the **volume** of the sample (in cm^3) by subtracting the start level from the end level.
   g. Calculate the **density** of the sample (g/cm^3) by dividing the mass (in g) by the volume (in cm^3).
   h. Without removing the water or rocks from the cylinder, repeat Steps b. – g. for the rest of the samples. *Note: the "start level" for each successive sample will be the same as the "end level" of the previous sample.*
   i. Calculate the average density of the three samples of magnetite and of the three samples of granite. By taking the average of three separate density measurements, you will hopefully cancel out some measurement errors and obtain a more accurate value for the density.

MAGNETITE density (from cylinder method)

Sample number	Mass (g)	Start level (cm^3)	End level (cm^3)	Volume (cm^3)	Density (g/cm^3)
Sample 1					
Sample 2					
Sample 3					

Average density of **magnetite** samples = mass/volume = ______________ **g/cm^3**

GRANITE density (from cylinder method)

Sample number	Mass (g)	Start level (cm^3)	End level (cm^3)	Volume (cm^3)	Density (g/cm^3)
Sample 1					
Sample 2					
Sample 3					

Average density of **granite** samples = mass/volume = _______________ **g/cm^3**

PART 1c: Volume from Fluid Displacement—BEAKER method

In this part of the exercise, we'll again use Archimedes principle but in a different way. We'll take advantage of the fact that the density of fresh water at room temperature is almost exactly 1.0 g/cm^3. Therefore the weight of water in **g** displaced by a submerged rock sample is equal to the volume of water displaced in **cm^3**, which is equal to the volume of the sample.

Follow the steps below to complete the data table on the next page for the three samples of magnetite and the three samples of granite.

a. Empty the graduated cylinder and dry the granite and magnetite samples with a paper towel.
b. Weigh the first sample and write its mass in **grams** in the "Sample 1" row of the data table.
c. Fill a 250 mL beaker about three-quarters full of tap water. Put the beaker on the scale and record the mass in **grams** in the data table, in the column labeled "Beaker mass without sample."
d. Put the sample in the sling and immerse it in the beaker. Hold the sample so that it doesn't touch the sides of the bottom, but be sure that it is fully immersed.
e. Notice that the displacement of water in the beaker caused an increase in mass. Record this new mass in the data table in the column "Beaker mass with submerged sample."
f. Subtract the higher mass from the lower mass and write the value in the "Sample volume" column. Because the density of water is 1.0 g/cm^3, the mass of the displaced water in **g** is equal to the volume of displaced water in **cm^3**, which equals the volume of the rock sample in **cm^3**.
g. Calculate the **density** of the sample by dividing the sample mass (in **g**) by the volume (in **cm^3**).
h. Repeat steps b. through g. for the remaining samples.
i. Calculate the average density of the three samples of magnetite and of the three samples of granite.

MAGNETITE density (from beaker method)

Sample number	Mass (g)	Beaker mass without sample (g)	Beaker mass w/ submerged sample (g)	Sample volume (cm^3) equals mass difference in g	Density (g/cm^3)
Sample 1					
Sample 2					
Sample 3					

Average density of **magnetite** samples = mass/volume = ______________ **g/cm^3**

GRANITE density (from beaker method)

Sample number	Mass (g)	Beaker mass without sample (g)	Beaker mass w/ submerged sample (g)	Sample volume (cm^3) equals mass difference in g	Density (g/cm^3)
Sample 1					
Sample 2					
Sample 3					

Average density of **granite** samples = mass/volume = _______________ **g/cm^3**

Questions:

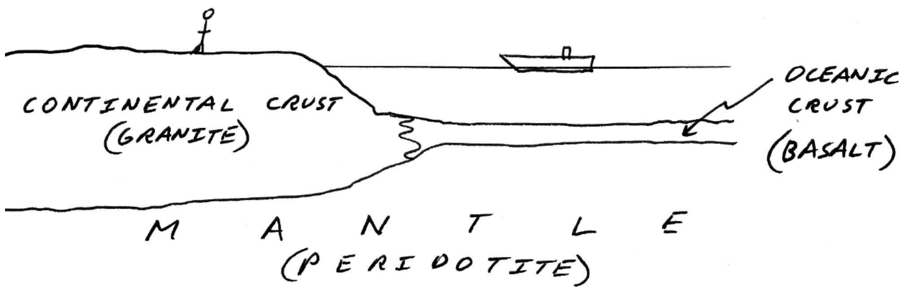
1. Compare your average density results from **Part 1b (cylinder method**) with those from **Part 1c (beaker method**). Did you obtain similar results? Did one or the other method give you results that were more consistent sample to sample?

2. An important principle of good scientific work is **repeatability**. We are generally more confident of the results of a scientific measurement when we obtain similar results using multiple measurements, and when we obtain similar results using different methods of measurement. How does this relate to what you did above?

PART 2: ISOSTATIC EQUILIBRIUM OF THE EARTH'S CRUST

In this part of the exercise, we will see how differences in the **density** and **thickness** of rock control the elevations of the Earth's crust. We'll also see how the crust adjusts when loads of weight are added or taken away.

The earth is made up of two kinds of crust: **continental crust** and **oceanic crust**. Continental crust is mostly **granite** and rocks of similar density. Oceanic crust is mostly the rock **basalt**, and makes up the floors of the ocean basins. Both types of crust lie on the Earth's **mantle**, which is mostly the rock **peridotite**. The illustration below shows that the continental crust and the oceanic crust have different thicknesses. **Continental crust** averages about **35 kilometers** (22 miles) **thick** (more underneath mountains), while **oceanic crust** averages about **8 kilometers** (5 miles) **thick**.



The two types of crust, and the underlying mantle, also differ in their **density**. Most Earth rocks range in density from about 2.6 to about 3.3 g/cm^3 (although there are plenty of exceptions, like magnetite—as you just saw). Even small differences in density can have important effects.

Density of the **continental crust**
(*put in the **average value for granite** from the previous part of the lab*): ________ g/cm^3

Density of the **oceanic crust** (**basalt**): **3.0** g/cm^3

Density of the upper **mantle** (**peridotite**): **3.3** g/cm^3

The geologist Clarence Dutton proposed decades ago that **the Earth's two types of crust "float" buoyantly on the mantle**, much in the way that an iceberg or a block of wood floats buoyantly in water. He called this condition **isostasy** (Greek for "equal standing"). When the crust floats in a balanced, stable manner in the mantle beneath, we have a condition called **isostatic equilibrium.**

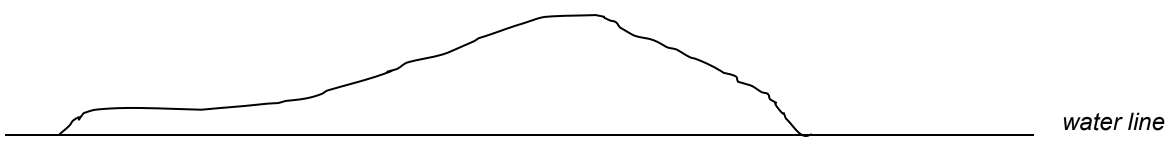
1. Imagine a <u>thick</u> block of wood and a <u>thin</u> block of wood, both with a density of **0.5 g/cm^3** floating in water next to each other. Draw <u>accurately</u> a side-view sketch showing how you think these two blocks would look floating next to each other. *Note: "accurately" here means that you need to consider the density of the wood relative to water, and draw the correct percentage of the blocks above and below the waterline.* Label the blocks and write the percentage of how much of each block you predict would be above versus below the waterline.

____ *water line*

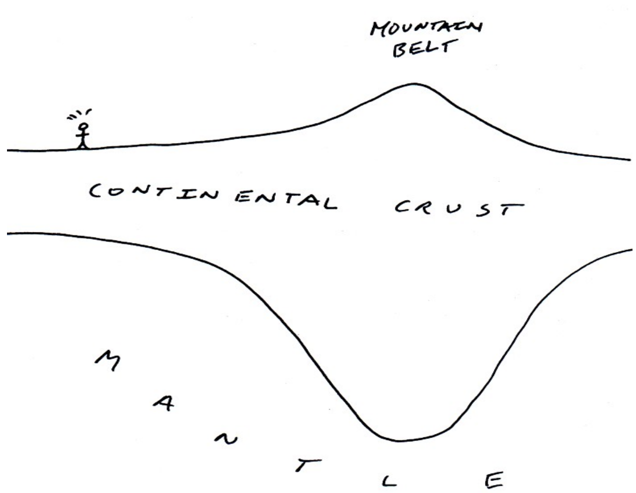
2. Following up on question #1 above, take the pieces of thick redwood and thin redwood and float them in water. Question: Do your predictions in #1 above fit with what you see?

3. The sketch below shows two icebergs above the ocean surface. Notice that the bergs have different heights. Glacial ice has a density of about **0.85 g/cm^3**. Draw accurately how each iceberg would appear below the water. *Note: "accurately" means that you need to consider the **density** of ice relative to water and the **thickness** that each berg would have above and below the waterline.*

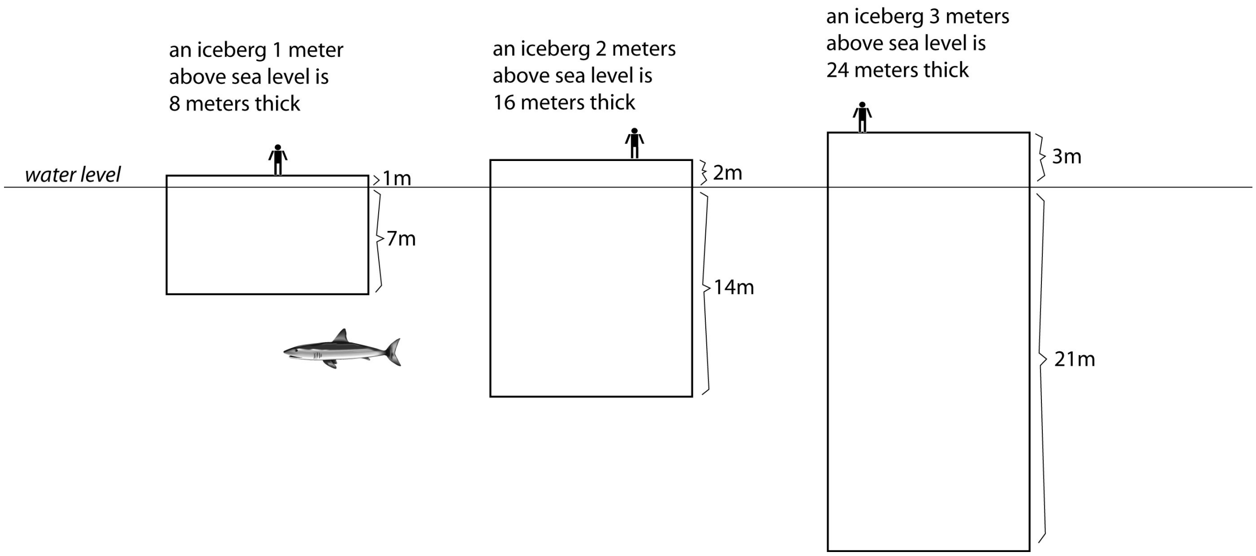
4. This sketch below shows a single iceberg above the ocean surface. Notice that one side of the bergs sticks up much higher than the other side. Draw accurately how this iceberg would appear below the water, keeping in mind your reasoning from step 3 above.



5. This sketch shows how the continental crust is much thicker underneath mountain belts than it is in low-lying areas of the continents. Thinking about your answers above, explain why. *Hint: the Earth's continental crust floats in the mantle much like icebergs float in water, so relate your answer to what you wrote in #3 and #4 above.*



6. The “iceberg analogy” for the isostatic equilibrium of the continental crust turns out to be quite useful because the relative density of icebergs versus seawater is close to the relative density of continental crust versus mantle. Glacial ice is about 15% less dense than seawater; likewise continental crust is about 15% less dense than the mantle. This leads to a simple rule that we can call the **<u>1-to-8 rule</u>: for every 1 unit of extra elevation for an iceberg or a mountain belt, there need to be 8 units of additional thickness.** These iceberg examples illustrate the idea:



For the following questions, apply the **1-to-8 rule**, assuming continental crust in isostatic equilibrium.

a. Continental crust at **sea level** averages about <u>35 kilometers thick</u>. (1 km = 0.6 miles.) Therefore, in general, how thick must the crust be to support a:

1-kilometer high mountain belt? _______________ km

2-kilometer high mountain belt? _______________ km

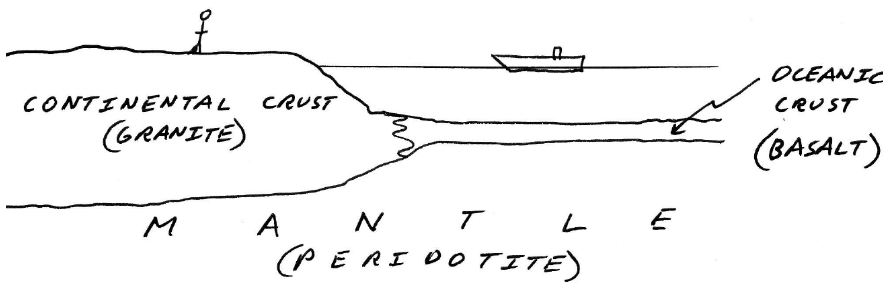
5-kilometer high mountain belt? _______________ km

b. The average elevation of the **Tibetan Plateau** (where the Himalayas, including Mount Everest, occur) is about <u>5 kilometers</u> (3 miles) <u>above sea level</u>. Seismic imaging shows that the continental crust below the Tibetan Plateau ranges from <u>70 to 80 kilometers thick</u> in many areas. Explain the connection.

c. Visualize erosion reducing the elevation of a mountain belt over millions of years. Assume the mountain belt started at an elevation of **3** kilometers above sea level. How much vertical thickness of rock must erosion remove to reduce the mountain belt to an elevation of **1** kilometer above sea level?

7. Think about what you saw in the first part of the lab, with the blocks of **ash** and **redwood** floating. What effect did the difference in density between them have on how high each block floated in the water? How do you think this relates to how high **granite** (continental crust) versus **basalt** (oceanic crust) will float in the mantle? Look back at the numbers you wrote for the densities of these rocks two pages back.

8. Thinking about all of your answers above, explain why the continental crust stands mostly above sea level while the oceanic crust lies on average more than two miles below sea level. Your explanation should take into account differences in ***both*** the thickness and the density of the continental crust versus the oceanic crust.



PART 3: ISOSTATIC ADJUSTMENT

When the Earth's crust floats in a balanced, stable manner in the mantle, we have a condition called **isostatic equilibrium.** When this stability is changed by the addition or subtraction of weight, the crust adjusts by sinking down or rising up—a process called **isostatic adjustment**. Over human scales of time, this process is very slow, but over geologic time it can add up to a lot of change.

1. Picture an iceberg floating in the ocean. A bunch of polar bears jump onto the iceberg. How does the iceberg adjust? The polar bears jump off. How does the iceberg adjust?

2. During the Pleistocene geologic period, large **ice sheets** formed repeatedly over parts of Canada and the northern US. The most recent ice sheet reached its maximum size about 21,000 years ago, and the ice accumulated nearly two miles thick in some places. How do you think the North American continent adjusted to this massive weight?

3. The large ice sheets that once covered much of North America have now mostly melted away. How do you think the North American continent has adjusted?

4. That process of adjustment referred to in #3 above is still going on. Looking at a map of North America, predict where the ice sheet 21,000 years ago was <u>thickest</u>. Explain your reasoning. *(Hint: the thicker the ice, the more the continent would have been pushed down—maybe even down so low that a certain portion of the continent is still below sea level today!)*

5. Antarctica is the *highest* continent, as measured by the average elevation of the surface of its ice sheet. But it is also the *lowest* continent, as measured by where the rock (continental crust) begins below all of that ice—ice that averages more than one mile thick! Explain the connection and how this relates to what has happened in North America.

6. The Hawaiian Islands are volcanoes that have built upward from lava eruptions on the Pacific Ocean floor. The big island of Hawaii is actually the Earth's tallest mountain if you measure it from its base. Interestingly, the sea floor all around Hawaii is actually *deeper* than average for that region of the Pacific Ocean, as shown in the simple sketch below. Notice on the sketch how the oceanic crust *bends down* underneath this huge volcano. Explain why this happens, and how it is similar to what happens with big ice sheets on the continents.