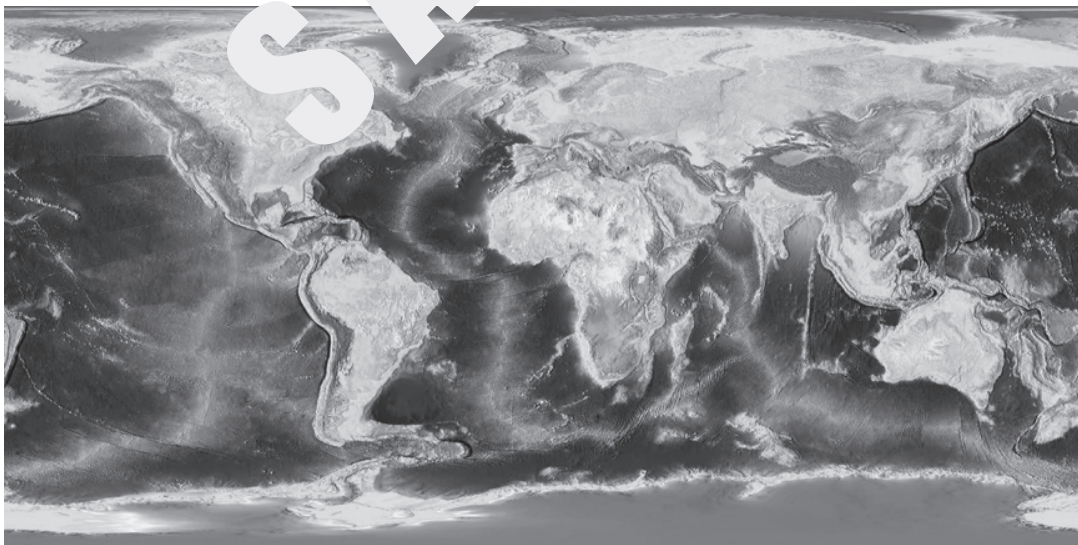


CYCLE 2

*How do we observe
and measure things in
the Earth system?*



CYCLE 2

How do we observe and measure things in the Earth system?*

OVERVIEW

In this unit we will explore how Earth can be observed and measured at a variety of scales from atomic to global. These observations and measurements, repeated over time, lead us to see that the Earth is a dynamic, changing planet.

During the following activities you will have practice making some of the most basic measurements that Earth scientists make: measuring or calculating length, area, volume, mass, and density.

By the end of the cycle, you will begin to see why density is such a critical concept for understanding how energy is transferred in Earth (we will learn more about it in Cycle 4). In particular, the density and thickness of Earth's various materials can be used to explain why continents have high elevations and Earth's ocean floor has low elevations.

ACTIVITY 1 *Physical Scales of Observation*

PURPOSE

To begin our investigations of the flow of energy and matter in Earth systems, we must first become familiar with how we make observations and inferences about Earth, and how we can understand how the Earth changes over time.

Q. How small and how big are our observations of Earth?

INITIAL IDEAS

On your own, use the 3-D glasses to look at the 3-D bathymetric/topographic map provided to your group using 3-D glasses. Write down three observations, each at a different scale (small section of the map, medium section of the map, large section of the map) that tell you something about the Earth's surface (both below and above sea level).

What do you observe about the average elevation of the ocean basins compared to the average elevation of the continents? Why do you think they are different?

*This cycle has been in part adapted from the Amencal Geological Institute/National Association of Geology Teachers *Laboratory Manual in Physical Geology* edited by Richard M. Busch.



Share your observations with your group. Then, with your group, use a white-board to describe a few of your *observations* at the three different scales. Be prepared to discuss these observations with the class.

OPTIONAL: share your *inferences* about why those features are present.

COLLECTING AND INTERPRETING EVIDENCE

STEP 1

As a class, view the video “Powers of Ten.” Can your group find some natural divisions of scale in how we observe nature?

STEP 2

We can observe Earth at different scales, from global (thousands of kilometers, 10^3m) to atomic scale (nanometers, 10^{-9}m). Each of these scales of observation can tell us different things. When we ask questions about Earth, we must figure out what the appropriate scale of observation should be. Review Table 2-1 for the physical scale of observation used by Earth Scientists.

TABLE 2-1 PHYSICAL SCALES OF OBSERVATION USED BY EARTH SCIENTISTS

SCALE OF OBSERVATION	USED TO STUDY THINGS	MEASURED IN....	EXAMPLE
Global	Earth as a whole	Thousands of kilometers (km) or miles	Earth
Regional	Portions of oceans, continents, countries, provinces, states, islands	Kilometers (km) or miles	Lake Michigan
Local (outcrop or field site)	Specific locations that can be “pin-pointed” on a map	Meters (m) or feet	Road cut on I-5
Hand sample (field/lab sample)	Sample of a mineral, a rock, air, water, or an organism that can be held in your hand	Centimeters (cm), millimeters (mm), inches	Rock in your garden
Microscopic	Features of a hand sample that can only be seen with a hand lens (magnifier) or microscope	Fractions of millimeters, micrometers (μm)	Mineral under a microscope
Atomic (or molecular)	Arrangements of the atoms or molecules in a substance	Nanometers (nm), angstroms (Å)	Sodium atom

Review your ideas from Cycle 1 about the difference between an observation and an inference. Now, look at the images that are being projected in front of the room (Earth from space, satellite image of Mt. Etna, Grand Canyon, rock). For each image, work with your group and fill in Table 2-2. For the physical scale of observation, you can refer to Table 2-1.

TABLE 2-2 IMAGES OF EARTH

IMAGE	What physical scales of observation are represented? (Refer to Table 2-1)	If you could view Earth 10,000 years from now, from this same location and scale, what features would be the same? What would be different?
Image of Earth from space		Same: Different:
Satellite image of Mt. Etna		Same: Different:
Grand Canyon photograph		Same: Different:
Granite, basalt, peridotite		Same: Different:

In Table 2-2, does the third column consist of observations or inferences? Explain your reasoning.

STEP 2 - SCIENTISTS' IDEAS

Process of Change and Scales of Understanding

PROCESSES AND CYCLES OF CHANGE

Earth is characterized by energy flow and processes of change at every spatial scale and time scale of observation. Earth's surface is energized by geothermal energy (from within the planet) and solar energy (from outside the planet). The energy flows from *sources* to *sinks* (materials that store or convert energy) and drives processes of change like the examples in the Table below.

Note that many of the processes have opposites depending on the flow of energy to or from a material: melting or freezing, evaporation and condensation, dissolution and chemical precipitation. Such effects cause chemical materials to be endlessly recycled and recycled between two or more phases. An example of one of these cycles is the hydrologic cycle.

RELATING SCALES OF UNDERSTANDING

Geologists seek to understand complex relationships of things on Earth relative to human lifetimes and the geologic time scale. To think like a geologist, you must consider many materials and processes over a broad range of time scales and spatial scales of observation. One way to simplify this thinking process is to develop different levels of understanding, from the most general to the most specific. The most general way of thinking about Earth is to think of it as a single planet (global scale). A more specific and complex way to think about Earth is to think about individual locations, samples, or even atoms. Of course, materials and processes observed at one scale might not be visible at another scale.

At the global scale of observation, geologists conceptualize Earth as a dynamic planetary system comprised of interacting spheres (subsystems). They are lithosphere (rock), hydrosphere (water), atmosphere (air), cryosphere (ice), and biosphere (life).

Observation of materials and processes at more specific scales of observation provides more specific data and levels of understanding. Any comprehensive study of geology involves data collected from several space and time scales, each one linked to the other at some level.

TABLE 2-3 COMMON PROCESSES OF CHANGE

PROCESS	KIND OF CHANGE	EXAMPLES OF THIS PROCESS IN EARTH SYSTEMS
Melting	Solid phase changes to liquid phase	Water ice turns to water.
Freezing	Liquid phase changes to solid phase	Molten rock freezes to glass.
Crystallization	Atoms, ions, or molecules arrange them-selves into a regular repeating 3-dimensional pattern. The formation of a crystal	Water vapor freezes into snowflakes. Liquid magma cools into a solid mass of crystals.
Evaporation	Liquid phase changes to gas (vapor) phase	Water turns to water vapor or steam (hot water vapor).
Condensation	Gas (vapor) phase changes to liquid phase	Water vapor turns to water droplets.
Dissolution	A substance becomes evenly dispersed into a liquid (or gas). The dispersed substance is called a solute, and the liquid (or gas) that causes the dissolution is called a solvent	Table salt (solute) dissolves in water (solvent).
Reaction	Any change that results in formation of a new chemical substance (by combining two or more different substances)	Sulfur dioxide (gas) combines with water vapor in the atmosphere to form sulfuric acid, one of the acids in rain.
Decomposition	An irreversible reaction. The constituent elements in a chemical compound are irreversibly split apart from one another to form new compounds	Feldspar mineral crystals decompose to clay minerals and metal oxides (rust).
Dissociation	A reversible reaction. Some of the elements in a chemical compound are temporarily split up, but can combine again under the right conditions to form back into the starting compound	The mineral gypsum dissociates into water and calcium sulfate, which can recombine to form gypsum again.
Chemical Precipitation	A solid that forms when a liquid solution evaporates or reacts with another solution	Salt forms as ocean water evaporates. Table salt forms when hydrochloric acid and sodium hydroxide solutions are mixed
Weathering	Materials are fragmented, worn, or chemically decomposed	Rocks break apart, get worn into pebbles or sand, dissolve, rust, or decompose to mud
Transportation	Materials are pushed, bounced, or carried by water, wind, ice, or organisms	Sand and soil are blown away. Streams push, bounce, and carry materials downstream



Refer to Table 2-2, Grand Canyon photograph. In your group, discuss the processes of change that would need to occur at the Grand Canyon to cause the different features you listed in Table 2-2 10,000 years from now. You can use the Common Processes of Change table in your Scientists' Ideas as a reference for this. Be prepared to discuss these processes with the class.

SAMPLE

ACTIVITY 1: HOMEWORK

Name _____ Date _____

Group _____

PURPOSE

You have already seen how your observations can lead you to make inferences based on photographs. Now it is your turn to go out into the real world and make observations of your own.

COLLECTING AND INTERPRETING DATA

YOU WILL NEED

- a digital camera or a sketch pad and pencil

STEP 1

Got outside and take a picture of a geologic process in action (geological process as in Table 2-3). If you don't have access to a digital camera, you can sketch it. Be sure to include your photo or sketch when you turn this in.

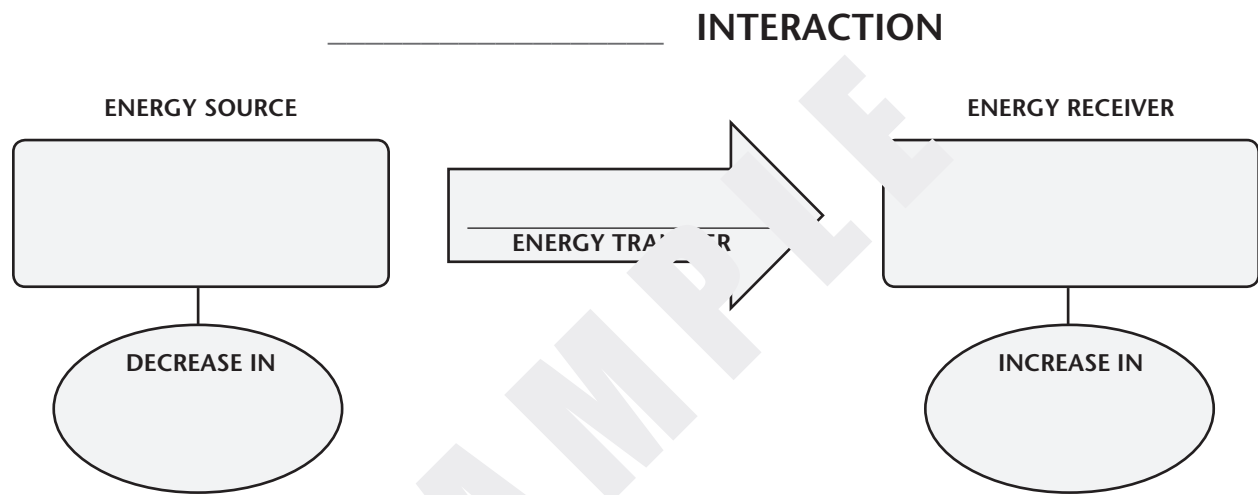
What did you observe?

What physical scale of observation is represented in your photo or sketch? (Refer to Table 2-1)

If you could view this same scene from the same location in 10 years, what would be the same? What would be different? How about in 1,000 years? 100,000 years? 10 million years?

List each process of change from Table 2-3 that you can infer in your photo or sketch, and say why you inferred it.

Now, see if you can come up with an appropriate energy diagram for the process you observed. Depending on your process, this could be very complicated. You won't be graded on your accuracy, just on your effort.



Explain your reasoning.

ACTIVITY 2 *Measurement*

PURPOSE

Making accurate measurements is a critical part of the process of doing science. Measurements are the “observations” of Earth Scientists. Without accurate measurements, how could we recognize and decipher patterns and make inferences? In the following activity, you will review some measurements that you have been using since you were in elementary school, and then expand your understanding of those measurements to include density.

Q. What are some of the various ways that we measure things?

INITIAL IDEAS

YOUR GROUP WILL NEED

- 2 cubes
- 2 graduated cylinders
- lump of modeling clay
- beaker of water

1. Inspect (pick up and feel) the two cubes that are set up at your table (you might need to share with another group). Fill two graduated cylinders to the same water level, about 3/4 full.

Predict how the water levels in the graduated cylinders will compare after a cube is placed in each. Assume both cubes will sink. Explain your reasoning for your prediction. Don't actually put the cubes in the water, this is only a prediction at this point.

2. Inspect the lump of modeling clay at your table. Predict whether the clay will sink or float when it is placed in a beaker of water. Explain your reasoning.

3. Next, predict what will happen to the clay if a smaller piece of clay is broken off the larger lump and placed into the water. Explain your reasoning.

Go ahead and test your predictions.



On your group whiteboard, discuss and record your group's predictions for questions 1 and 2 above and be prepared to explain your reasoning.

SAMPLE

COLLECTING AND INTERPRETING EVIDENCE

EXPERIMENT 1 *Properties of Materials*

YOUR GROUP WILL NEED

(You may need to work in groups of six for this)

- 1 set of six or seven balls
- metric ruler
- two graduated cylinders (250 mL and 500 mL)
- two gram balances (0.1 g accuracy and 1 g accuracy)
- small lump of modeling clay
- calculator
- few pieces of steel wool
- small piece of rock

STEP 1

Obtain a set of balls from the supply table. First, sort the balls by heaviness (heft). Sketch your results:

Second, sort the balls by how much space they take up. Sketch the results:

Did you end up with the same organization of balls with the two different ways of sorting? Why or why not?



Discuss your results with your group.

STEP 2

MASS

In Step 1, you sorted balls by their heaviness or heft. We call this property an object's **mass**. You can use a gram balance to measure the mass of materials (by determining their weight under the pull of Earth's gravity). The gram (g) is the basic unit of measurement of mass in the metric system, but instruments used to measure grams vary from triple beam balances to spring scales to digital balances.

For the purposes of this class, we will interchange mass with weight. Strictly speaking, this is not correct, because an object's weight will depend on the pull of gravity, whereas its mass does not. But for this quarter, we can stay rooted firmly on Earth and use an object's weight as a representation of its mass.

Measure and record the mass (weight) of the two cubes that you looked at in #1 of the initial ideas.

VOLUME

In Step 1, you also sorted the balls by the amount of space they took up. We call this property the object's **volume**. We measure volume in cubic centimeter (cm^3).

You can measure an object's volume with a ruler (length $\times$ width $\times$ height) if it has regular dimensions, or with a graduated cylinder filled with water if it sinks and has irregular dimensions. One milliliter (mL) of water is equal to 1 cm^3 , so you can easily convert between them.

Measure and record the volume of the two cubes that you used in your initial ideas. Show your work. Use both methods described above.

Now measure the volume of a small piece of rock (use one of the three varieties on the supply table). Brainstorm the best way to do this with your group, and then record below the method you came up with. Go ahead and measure the volume, and please be sure to include units.

On your own, how would you describe the difference between the two cubes in the initial ideas? Be as specific as you can.

STEP 3

Take a piece of steel wool and put it in water. Does the steel wool sink or float?

Now, take that same steel wool and squish it in your fingers as much as you can without removing any (or hardly any) material from it. What property has changed? What property has stayed (roughly) the same?

Put the squished steel wool back in the water. Does it sink or float? If it sinks, why does it sink?

DENSITY

We call the inter-relationship of an object's mass and its volume its **density**. Every material has a mass that can be weighed and a volume of space that it occupies. However, the relationship between a material's mass and volume tends to vary from one kind of material to another. For example, a bucket of rocks has a much greater mass than an equal-sized bucket of air. Therefore, a useful way to describe an object is to determine its mass per unit of volume, called density. Per refers to division, as in miles per hour (distance divided by time). So density is the measure of an object's mass divided by its volume (density = mass/volume). Scientists and mathematicians use the Greek character rho (ρ) to represent density. Also, as the gram (g) is the basic metric unit of mass, and the cubic centimeter is the basic unit of metric volume (cm^3), so density (ρ) is usually expressed in grams per cubic centimeter (g/cm^3).

Now let's go back to the modeling clay that you used in your initial ideas. When you break off a piece and put it in water, does it sink or float? What about the smaller piece, does it sink or float?

Do you predict that you could ever get the clay to float by breaking off a smaller and smaller piece? Why or why not?

Now go back and determine the density of each of the two cubes from your initial ideas. Is the density of each cube the same or different? How do you know?

STEP 4

Explain how you could use a graduated cylinder and a gram balance to determine the density of water (ρ_{water}) in g/cm^3 .

Now use your procedures to calculate the density of water as precisely as you can. Show your data and conclusions.

SUMMARIZING QUESTIONS

1. If you have two objects of the same volume, but one weighs more than the other, which has a greater density? What is your evidence?

2. If you have two objects of the same weight, but one is larger (greater volume) than the other, which one has a greater density? What is your evidence?

3. a. Look at one of your cubes from the initial investigation. If you cut it in half and take one half away, has the mass changed? If so, by how much?

- b. Has the volume changed? If so, by how much?

- c. Has the density changed? How do you know?

- d. Would the density change if you cut it into quarters? Eighths? Sixteenths? Why or why not?

4. What happens to the volume of the clay when you reduce the mass (or vice versa)?

5. In your own words, how would you describe density (don't just say mass divided by volume!)?



In your group, discuss your answers to these questions. Summarize and illustrate your answers on a whiteboard and be prepared to discuss them with the rest of the class.

ACTIVITY 3

Density, Gravity and Motionless Floating (Isostasy)

PURPOSE

In this activity we will get our first look at why understanding density is so important for understanding Earth processes. Floating wood blocks in water may seem like an odd place to start, but it is our best analogy for understanding processes such as how icebergs float in water and how the Earth's crust "floats" on its solid (but flowing) mantle.

Q. How can we relate the density of an object to how high it floats in a fluid?

INITIAL IDEAS

You have probably heard or seen pictures of icebergs floating in the ocean. On your own, why do you think icebergs float? Be sure to include density in your answer.

You've also probably heard the expression the "tip of the iceberg." Why do you think that more of an iceberg sits below the surface of the ocean (the water line) than above it?



CHECK WITH YOUR INSTRUCTOR: In your group, discuss your answers to the questions above. Modify your previous answer if you need to in the space below. Share your group's answer with the class.

EXPERIMENT 1

How does the density of an object affect how high it will float in a fluid?

COLLECTING AND INTERPRETING EVIDENCE

YOUR GROUP WILL NEED

- 1 labeled Wood block (about 8 cm x 10 cm x 4 cm)
- small bucket to float wood block
- water
- gram balance
- ruler
- calculator
- grease pencil
- graph paper or Excel

STEP 1

Obtain one (or two) of the wood blocks provided at the supply.

1. Measure the height, length, and width of your block (in centimeters), then calculate the block volume:

Height ____ cm x Width ____ cm x Length ____ cm = Volume ____ cm³

2. Weigh the wood block (in grams) and calculate the block density:

Mass ____ g

Volume ____ cm³
Density ____ g/cm³

There is a lot of confusion about how much stuff and how big the stuff is when we use the scientific term density. An example of this problem is shown in this question:

“Sara reports that she has a second block of this same kind of wood that was three times as large as the one you had. What does she mean? Does this mean three times the volume? Or three times the mass? Or does it mean: Each side is three times as long?”

YOU CANNOT TELL! That is the problem with just referring to big or large or small. When talking about density, we are talking about a fixed or constant ratio of the mass of a chunk of stuff to the volume of that particular chunk of stuff: M:V is always the same ratio.

Using the density of your block of wood, figure out the mass of a chunk of your wood if you had 3 times the volume of your chunk. Take notes on your reasoning. Make sure everyone in your group gets the same answer and you all agree on the reasoning.

Mass = _____

Using the density of your wood, figure out (as a group) the volume of a chunk of your wood if you had 5 times the mass as your piece in the lab. Take notes on your reasoning.

Volume = _____

3. Return to Activity 2 for the results you obtained for the density of water: _____ g/cm³

Compare the density of your block to water by expressing your block density as a percentage of water:

Block density _____ g/cm³

x 100 = _____ **Block % of water**

Water density _____ g/cm³

Note: We multiply this fraction by 100 to convert the result into a percentage.

Record all of the above data for your specific block in Table 2-4.

STEP 2

Before proceeding, make a prediction of the percentage of the wood block that will be submerged when it is placed in water. What information did you use to make this prediction?

Float the wood block in a bucket of water, then use the grease pencil to mark the water line on the side of the block. Measure the height of the wood block that was submerged in the water, then calculate the percentage of the wood block that was submerged

Height submerged ____ cm
 _____ x 100 = ____ % submerged
 Total height of block ____ cm



Fill in your data in Table 2-4 below for your block.

TABLE 2-4

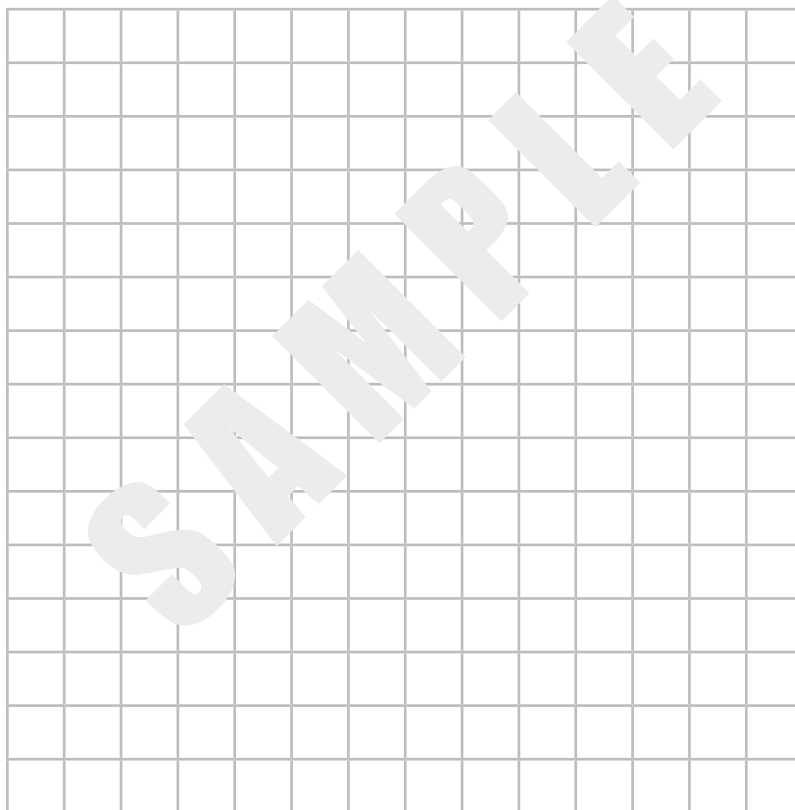
	Height (cm)	Width (cm)	Length (cm)	Density (g/cm ³)	Mass (g)	Density (g/cm ³)	Density as % of Water	Height Submerged (cm)	% Submerged
Block 1									
Block 2									
Block 3									
Block 4									
Block 5									
Block 6									
Block 7									
Block 8									

Your instructor will provide a table in the front of the room like the one above. Fill in your group's data on that table, then fill in your classmates' data on the table above.

Finding Patterns in this numerical data

Using the graph paper and scale below, plot the % submerged versus the density as a % of water. Scientists avoid looking at any single measurement, understanding that all measurements are the best estimate at the moment of the quantity represented. There is often variability due to lots of things, not the least of which can be attributed to how difficult it is to make those measurements in the first place. One of the more powerful strategies to reveal patterns and to help de-emphasize this variability in individual data, is to graph pairs of related quantities and look for “trends”. Typical “trends” can be represented by lines and curves, not by connect the dots on the graph.

Plot the % submerged on the horizontal axis and the density as a % of water on the vertical axis



Describe the **general** trend that you observe between how dense the block of wood is compared to how deeply it sinks into the fluid it is floating in.

Use one stroke of your pen to draw a single straight line that you think best represents the “trend” in your class data. Do you think this line should go through the (0,0) point? What would that mean?



In your group, discuss the answers to the following questions, and be prepared to discuss your answers with the rest of the class.

Based on the above data, describe the relationship between the density of a block (as a percentage of water), and the percentage of that block that is submerged in water.

If you submerged these same blocks in a liquid that is twice as dense as water (i.e. 2 g/cm^3). How would that change the percentage of the block that would be submerged?

If each of these blocks were half as thick, and then were floated in a bucket of water, how would that change the block submerged height? How would that change the percentage of the block that would be submerged?

If each of these blocks were half as thick, and then were floated in a bucket of water, how would that change the block's submerged height? How would that change the percentage of the block that would be submerged?

SCIENTISTS' IDEAS

Density, Gravity and Isostasy

Isostasy is just a fancy word for motionless, balanced floating. As you found in your equation, the height of this floating depends upon the densities of the materials involved.

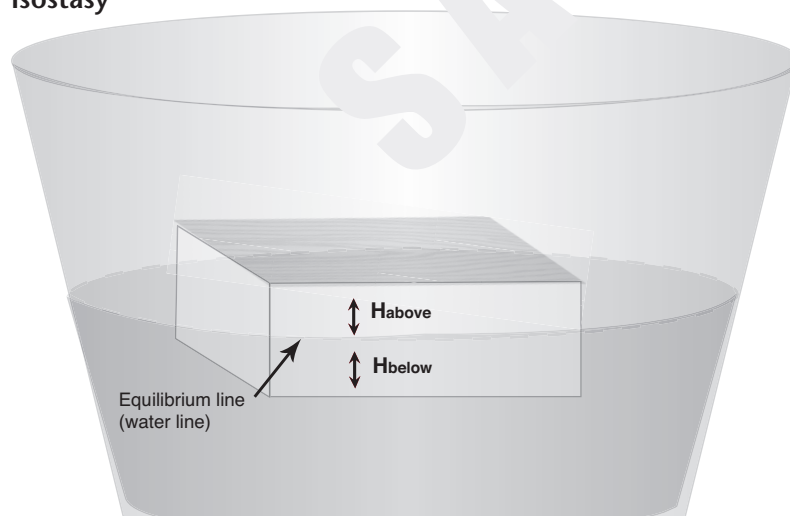
Scientists have wondered for centuries about how the distribution of Earth materials is related to their density and gravity. For example, Greek scientist and mathematician, Archimedes, experimented with floating objects around 225 B.C. When he placed a block of wood in a bucket of water, he noticed that the block floated and the water level rose (Figure 2-2).

When he pushed down on the wood block, the water level rose even more. And when he removed his fingers from the wood block, the water pushed it back up to its original level of floating. Archimedes eventually realized that every floating object is pulled down (toward the Earth's center) by gravity, so the object displaces fluid and causes the fluid level to rise. However, Archimedes also realized that every floating object is also pushed upward by a buoyant force that is equal to the weight of the displaced fluid. This is now called Archimedes' Principle.

An object will sink if it is heavier than the fluid it displaces (is denser than the fluid it displaces). An object will rise if it is lighter than the fluid it displaces (is less dense than the fluid it displaces). But a floating object is balanced between sinking and rising. The object sinks until it displaces a volume of fluid that has the same mass as the entire floating object. For example, if a wood block weighs 200g, it would displace 200g of water. When the object achieves a motionless floating condition, it is balanced between the downward pull of gravity and the upward push of the buoyant force.

FIGURE 2-2

Isostasy



In the 1880s, geologists began to realize the abundant evidence that levels of shoreline along lakes and oceans had changed often throughout geologic time in all parts of the world. Geologists like Edward Suess hypothesized that changes in sea level can occur if the volume of ocean water changes in response to climate. Global atmospheric warming leads to sea level rise caused by melting of glaciers (cryosphere), and global atmospheric cooling leads to a drop in sea level as more of Earth's hydrosphere gets stored in thicker glaciers. However, an American geologist named Clarence Dutton suggested that shorelines can also change if the level of the land changes (and the volume of water remains the same).

Dutton reasoned that if blocks of Earth's crust are supported by fluid materials beneath them, then they must float according to Archimedes' Principle (like wood blocks, icebergs, and boats floating in water). Therefore, he proposed that Earth's crust consists of buoyant blocks of rock that float in gravitational balance on top of the mantle. He called this floating condition isostasy (Greek for "equal standing"). Loading a crustal block (by adding lava flows, sediments, glaciers, water, etc.) will decrease its buoyancy, and the block will sink (like pushing down on a floating wood block). Unloading materials from a crustal block will increase its buoyancy, and the block will rise. Therefore, you can also think of isostasy as the equilibrium (balancing) condition between any floating object (like the wood in Figure 2-2), and the more dense fluid in which it is floating (like the water in Figure 2-2).

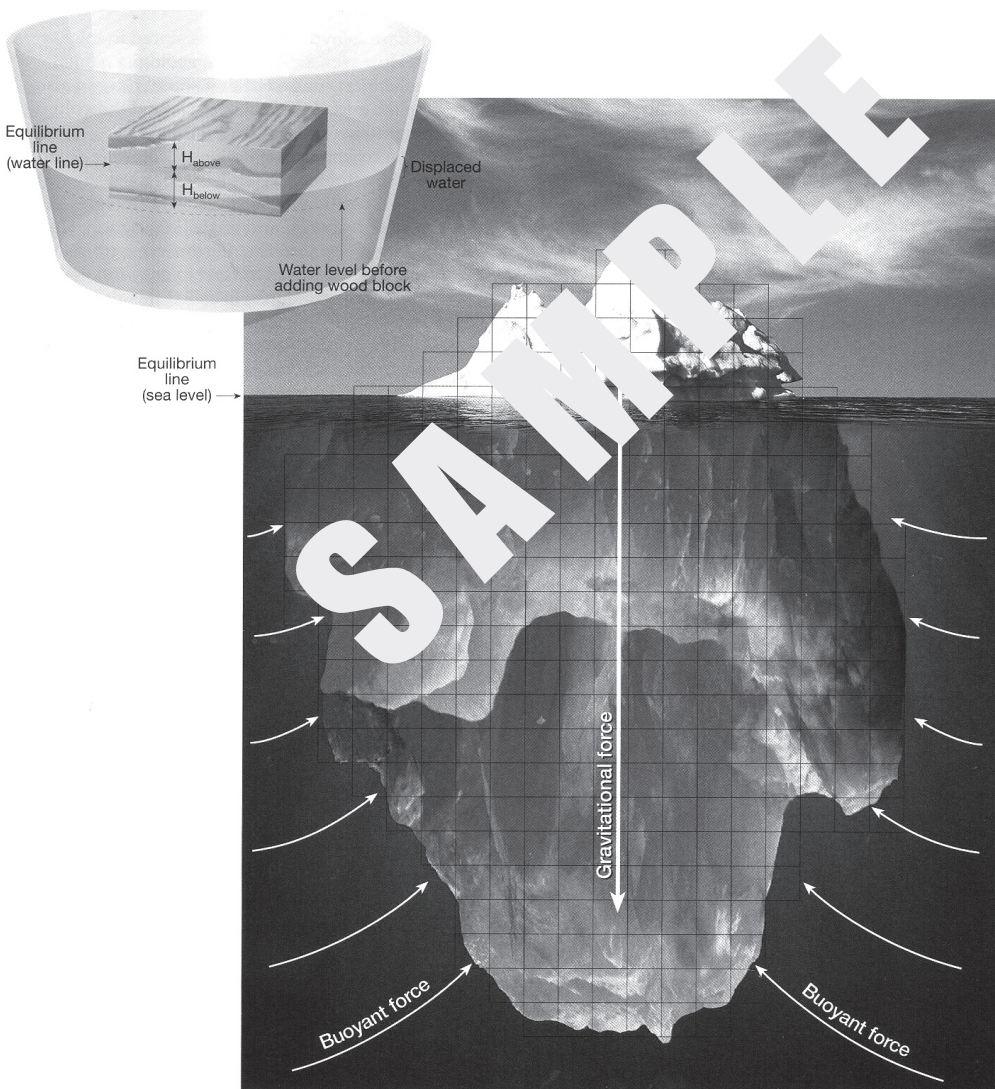
Given that the density of water in ice (in icebergs) is 0.917 g/cm^3 and the average density of (salty) ocean water is 1.025 g/cm^3 :

1. What is the density of ice, as a percentage of the density of salty ocean water? What percentage of an iceberg is submerged below water level?

2. Because ocean water temperatures near the poles can be very close to the freezing point of ice, only the portion of the ice that is exposed to the air (above the water level) tends to melt. What will happen as the top of the iceberg melts away?

3. Test your prediction on the iceberg in Figure 2-3. Do the values you calculate in question 1 make sense compared to what you observe? Why or why not? Use the grid (count boxes) to calculate what proportion of the iceberg is below sea level (the equilibrium line) and what proportion is above sea level to validate your calculations in question 1. (Count all boxes and parts of boxes.)

FIGURE 2-3



From: *Laboratory Manual in Physical Geology*, 7th Edition by American Geological Institute, National Association of Geoscience. Editors Busch, Richard M; Tasa, Dennis, Copyright ©2006. Pearson Education. Permission to copy granted by Pearson Education.



Share your answers to these questions with your group.

EXPERIMENT 2 *Isostasy simulator*

On a computer with an internet connection, go to Cornell University's "Discover Our Earth" web page http://www.discoverourearth.org/student/web_tools.html# and scroll down to Virtual Experiments, isostasy simulator. Click on it and then click on "Isostasy Basics". Note that the dimensions are representative of the actual values for the thickness and density of Earth's "blocks" and the density of the material that supports those blocks.

Refer back to your answers to the discussion questions at the end of Experiment 1. Confirm each of your answers by manipulating the block density, fluid density, and block height values on the Isostasy Simulator as follows.

However, before changing any of the values, record the initial block density, fluid density, and block height below. Then, calculate the block density as a percentage of the fluid density, and the percentage of the block that is submerged in the fluid:

Block Density: _____ g/cm³ Block Height: _____ km Fluid Density: _____ g/cm³

Block Density as a % of Fluid Density: _____ %

% of Block Submerged: _____

1. a. When you double the density of the fluid (but leave the block density and block height the same), how does that change the Block Density as a percentage of Fluid Density?

-
- b. How does that change the percentage of the block that is submerged?

2. a. When you increase the block density by 50% (but leave the block height and fluid density the same), how does that change the Block Density as a percentage of Fluid Density?

- b. How does that change the percentage that the block that is submerged?

3. a. When you double the height of the block (but leave the block density and fluid density the same), how does that change the Block Density as a percentage of Fluid Density?

- b. How does that change the percentage of the block that is submerged?

- c. How does that change the percentage of the block that is submerged?

4. a. When you reduce the height of the block by one-half (but leave the block density and fluid density the same), how does that change the Block Density as a percentage of Fluid Density?

- b. How does that change the height of the block that is submerged?

- c. How does that change the percentage of the block that is submerged?

5. How well do your Isostasy Simulator experiments confirm your answers to the discussion questions at the end of Experiment 2?

SUMMARIZING QUESTIONS

1. How does changing the density of a block affect the elevation of that block floating in a liquid?

2. How does changing the density of the liquid affect the elevation of a block floating in that liquid?

3. How does changing the block height affect the elevation of the block floating in a liquid?

4. Given what you know about isostasy, predict how _____ would _____ in both fresh water and seawater.

5. You are going to have a party and you want to make “magic” ice cubes that will sink to the bottom of your guests’ water. How _____ can you make these magic ice cubes (they must be consumable by humans)?

6. You have an ice cube floating in a glass of water. Predict what would happen to the total % submerged (and height that is submerged) if you stacked another ice cube directly on top of the first. What is your evidence?



Discuss your ideas with your group. Have your ideas changed? Write down any changes in your ideas after talking with your group.



Use your group's whiteboard to describe in words or pictures this relationship between density, block height, and elevation of a block floating in a liquid. Can you relate this back to the iceberg idea?

ACTIVITY 4

Isostasy and Earth's Global Topography

PURPOSE

Using what we have learned in the previous cycle about density and other measurements, we will see that the density of rocks on Earth's surface has a strong effect on the topography of Earth.

Q. How can we relate the density of rocks to the topography of the Earth?

INITIAL IDEAS

Once again, look at the 3-D map from Activity 1 using 3-D glasses. Write down some large-scale observations you make from looking at this map that include information about patterns in elevation of Earth's surface (i.e., oceans vs. continents). Make sure you are recording **observations** rather than **inferences**.



In your group, share and discuss these observations, and choose one or two to share with the larger group. List these on your whiteboard.



Share your group's observations with the class. Include the Earth processes or rock properties that might be responsible for the observations you have made (i.e., what inferences can you make?). Do you think density is involved? What is your evidence?

COLLECTING AND INTERPRETING EVIDENCE

EXPERIMENT 1 *How does the density of Earth rocks vary?*

YOU WILL NEED

- gram balance
- smallest graduated cylinder that a rock will fit in
- large graduate cylinder (250 mL)
- water
- small samples of granite, basalt, peridotite rock

STEP 1

Using the techniques you learned in Activity 3, measure the densities of the two different rock types that make up most of the Earth's surface as exactly as you can (to tenths of a g/cm^3). Basalt is a volcanic rock that covers the floor of the oceans. Granite is a rock that covers much of the continents. Finally, measure the density of peridotite, the rock that makes up most of the deep interior of the Earth (the Earth's mantle). Briefly describe how you made your measurements on each item below:

- Sample granite (continents): _____ g/cm^3 How determined?

- Sample basalt (ocean floor): _____ g/cm^3

- Sample peridotite (mantle): _____ g/cm^3

Write down your group's results for granite, basalt, and peridotite in the density chart below (Table 2-5) and on the table on the board provided by your instructor. Compare your results with those of your classmates.

TABLE 2-5 DENSITY CHART

GRANITE

GROUP	SAMPLE WEIGHT (g)	SAMPLE VOLUME (cm ³)	SAMPLE DENSITY (g/cm ³)
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
Worldwide Average			2.8

BASALT

GROUP	SAMPLE WEIGHT (g)	SAMPLE VOLUME (cm ³)	SAMPLE DENSITY (g/cm ³)
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
Worldwide Average			3.1

PERIDOTITE

GROUP	SAMPLE WEIGHT (g)	SAMPLE VOLUME (cm ³)	SAMPLE DENSITY (g/cm ³)
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
Worldwide Average			3.3

Are all the measurements exactly the same? Are they similar? Why or why not?

Do you think averaging the data is a good idea? Why or why not?

How do they relate to the worldwide average? If they are different, why might that be?



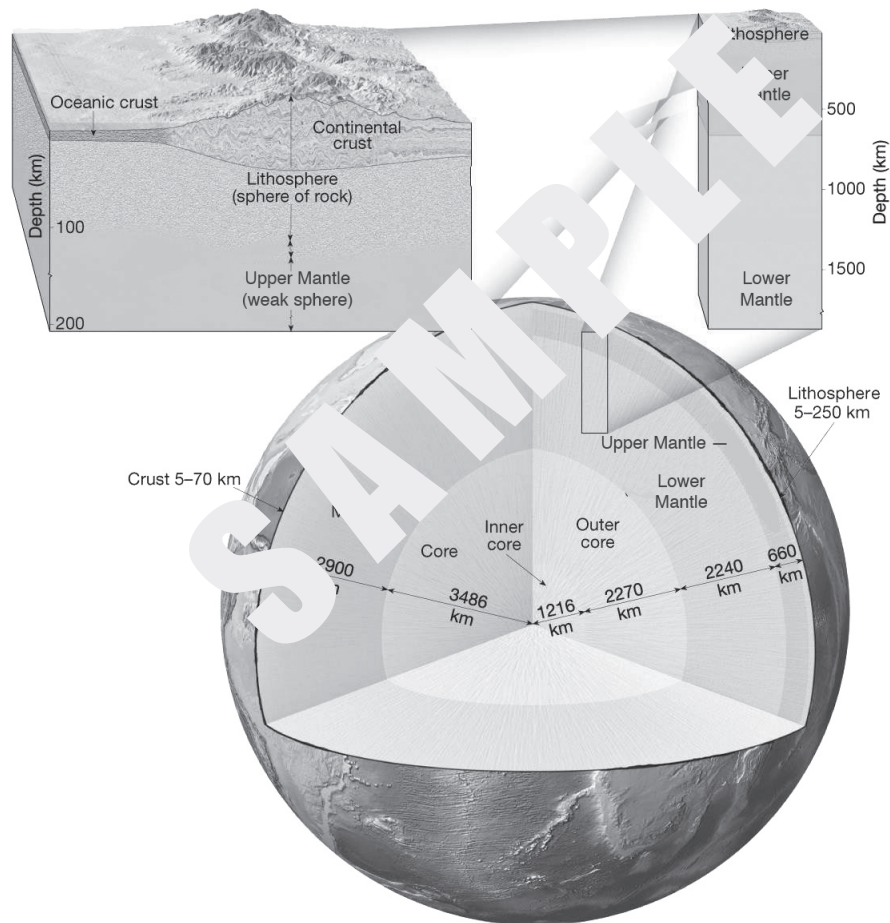
Discuss the answers to these questions in your group and be prepared to share your ideas with the class.

SCIENTISTS' IDEAS

Granite and Basalt and the Inside of Earth

If you think of the **Earth's crust** (the outermost layer) simply, it is made up of an average of two different rock types. The continental crust (the high land masses) is **Granite** (light-colored coarse-grained igneous rock) and the ocean crust (beneath the oceans) is made up of **Basalt** (dark-colored fine-grained igneous rock). This crust rests on the **peridotite** rock of the Earth's interior (the mantle) (see Figure 2-4).

FIGURE 2-4



From: *Earth: An Introduction to Physical Geology*, 8th Edition by Tarbuck, Edward J.; Lutgens, Frederick K.; Tasa, Dennis, Copyright ©2005. Pearson Education. Permission to copy granted by Pearson Education.

How do we know what is in the mantle of the Earth?

Three lines of evidence: **seismology** (the study of Earth's structure and composition using earthquake waves which you will explore in Cycle 4), **mantle xenoliths** (pieces of the mantle carried up in lava, such as the samples on display in the room), and **lab experiments** indicate that the upper part of the Earth's mantle is **peridotite** rock. The peridotite has an average density of about 3.3 g/cm³ and experiences slow flow when it is at temperatures above 800°C. Seismology also reveals the thicknesses of crust and mantle layers.

GROUP DEMONSTRATION

Have someone in your group obtain a piece of silly putty from the supply table and roll it into a ball. Cut it in half and put the flat side down on a piece of paper. Using a colored pencil, draw the outline of the shape of the silly putty onto the paper.

Fifteen minutes later, return to the silly putty and draw the outline of the shape again with a different color pencil. Now lift up the silly putty. Has the shape changed? Is the silly putty a solid? Did it flow?

You can use this as an analogy to Earth's mantle. A *flowing* solid.

WRITE DOWN YOUR THOUGHTS:

Review the 3-D map from the beginning of Cycle 2, activity 1, and Figure 2-4 on previous page. Consider what role density might be playing in the height of Earth's surface. Could differences among the three rock types that make up continental crust (granite), ocean basins (basalt) and mantle (peridotite) be responsible for Earth's distinct high and low topography? If so, how?



Share these thoughts with your group. Write down a group answer on your whiteboard.

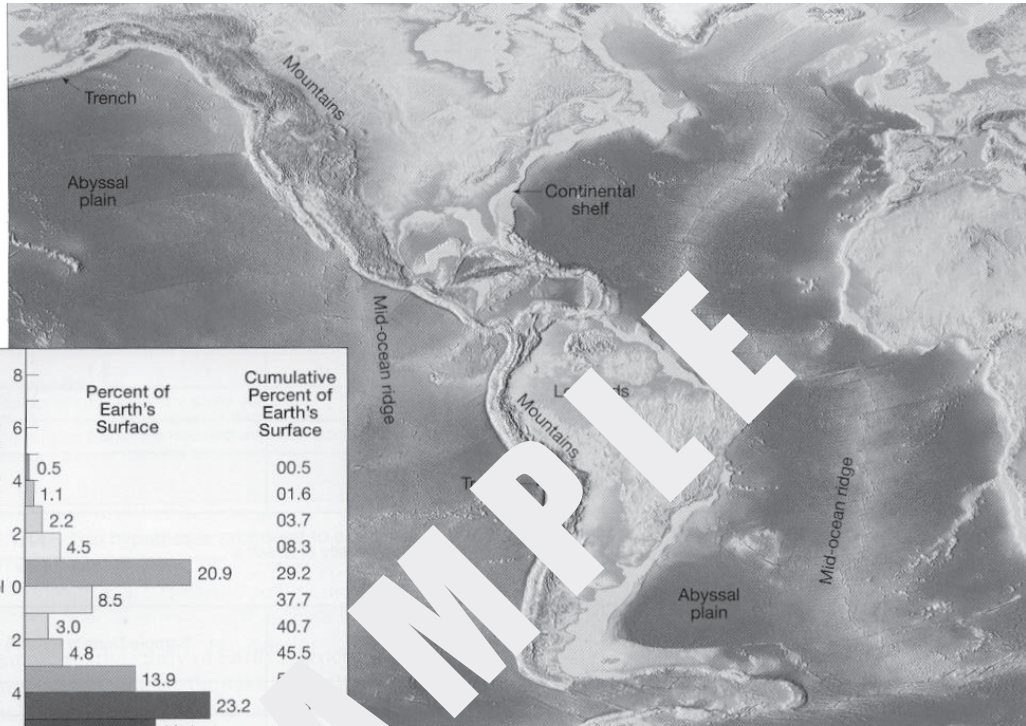
FIGURE 2-5. GLOBAL TOPOGRAPHY OF EARTH

A. Portion of Earth with ocean removed, based on satellite-based radar and laser technologies.

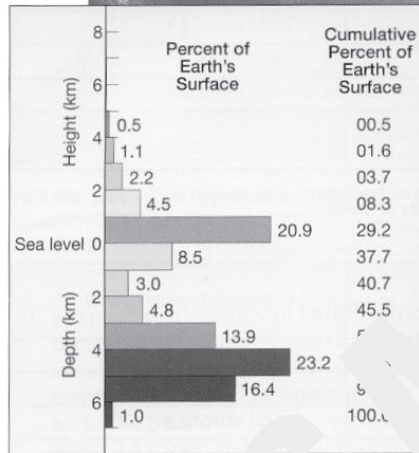
B. Histogram of global topography.*

C. Average height of continents (granite) compared to average height of ocean floor (basalt).

A.

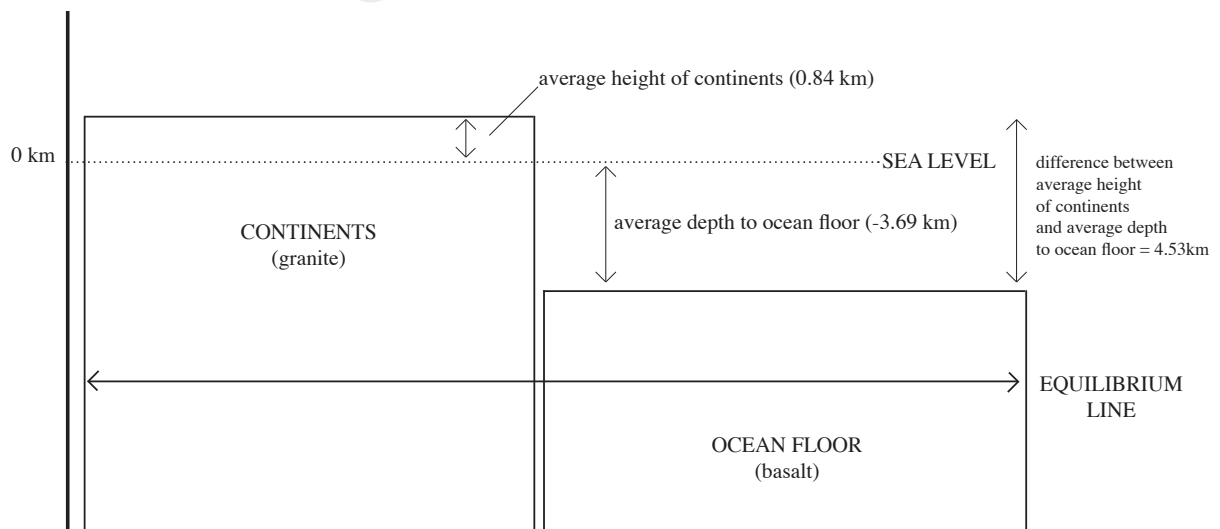


B.



*From: *Laboratory Manual in Physical Geology*, 7th Edition by American Geological Institute, National Association of Geoscience. Editors Busch, Richard M; Tasa, Dennis, Copyright © 2005. Pearson Education. Permission to copy granted by Pearson Education.

C.



SUMMARIZING QUESTIONS

1. Seismology indicates that the average thickness of basaltic oceanic crust is about 5.0 kilometers. Use the average density of basalt (3.1 g/cm^3) and an average density of of peridotite (3.3 g/cm^3) to determine how high basalt 'floats' in the mantle. Apply the same technique used in Activity 3 to determine the density of the ocean crust 'block' as a percentage of the peridotite mantle 'fluid', and the percentage of the oceanic block that would be submerged. In this case, though, we want to know how much of the block is not submerged (e.g. if 75% of the block is submerged, then the remainder of the block, 25%, 'floats' above the mantle. If the block height is 10 kilometers, then 2.5 kilometers will 'float' above the mantle. Note: recall our recent group demonstration, where we saw that silly putty flows over a period of time. A portion of the upper mantle behaves in a similar manner, allowing the continental blocks to float at different levels, depending on block height and block density.
2. Seismology indicates that the average thickness of granitic continental crust is about 30.0 km. Do the same kind of analysis as in the previous question. Use the average density of granite (2.8 g/cm^3), the average density of peridotite (3.3 g/cm^3) to determine how high granite 'floats' in the mantle. Calculate the density of the continental crust 'block' as a percentage of the peridotite mantle 'fluid', the percentage of the continental block that would be submerged, the percentage of the continental block that would 'float' above the mantle, and the height of the continental block above the mantle.
3. What is the difference (in kilometers) between your answers in 1 and 2? _____

4. How does this difference between 1 and 2 compare to the actual difference between the average height of continents and the average depth to the ocean floor (Figure 2-4)? Why might they be different/the same?

5. Why are continents higher than ocean basins?

6. What allows mountains to be higher than valleys? (Hint: Remember that all continental crust is made out of pretty much the same stuff.)



Discuss the answer to questions 4 - 6 with your group, and whiteboard your answer to the question.

CLASS DEMONSTRATION (OR GROUP ACTIVITY)

As a class (or individually if your group is ahead), we will review how isostasy relates to the Earth's surface. Go back to the *Discover Our Earth* web page (http://www.discoverourearth.org/tools/isostasy/main_content.html). Go down to "Virtual Experiments" again and click on the isostasy tool. This time click on "Isostasy Applied". Once the tool is opened, click the box that says "Display Moho Boundaries". Drag your mouse over an area for which you'd like to see the Moho depth (within the boxes). Choose someplace where there is a transition between ocean and continent, or where there is a big change in topography on a continent. If you do this on your own, find a cross section you like, and be prepared to share it with the class.

Final reflection: How have your own ideas changed about the concept of density? Where in the cycle did learning occur for you?

Handwriting practice lines with a large diagonal "SAMPLE" watermark.

CYCLE 2 HOME WORK SET

The outer portion of Earth (over 80% of Earth's volume) is made up of rocks. Rocks are a collection of minerals, which are an assemblage of elements. Silicon (Si) and oxygen (O) are the two most abundant elements within Earth, thus most minerals that form rocks are compounds of those two elements. These are the silicate minerals. Some other elements that are common in rock-forming minerals are iron (Fe), magnesium (Mg), aluminum (Al), calcium (Ca), potassium (K), and sodium (Na). The density of a mineral is determined by the type of elements (e.g., silicon, oxygen, magnesium etc.) and the packing arrangement of the elements in a mineral.

Some minerals crystallize into solids when magmas (liquid rocks) cool to certain temperatures, just like liquid water crystallizes into ice at 0°C. This forms igneous rocks (rocks are made up of minerals). The rate of cooling determines the size of the minerals. Rapid cooling produces very small-sized minerals, whereas extremely slow cooling can produce finger-sized minerals (and larger). Rapid cooling (days to years) occurs when lavas spill out onto the Earth surface. Rocks formed by this process are called extrusive rocks. Very rapid cooling (seconds) produces glass (no crystals) like when magma discharges into an ocean. Large minerals form when magma trapped deep within Earth cools slowly. Minerals may take days, years to even millions of years to grow and reach dimensions measured in feet. Rocks formed by slow cooling within Earth are called intrusive rocks.

Answer on a separate sheet

- The mass and volume of three common rock-forming silicate minerals, and magnetite, an iron oxide (a nonsilicate mineral) were measured in a lab to determine the density of each mineral and list them from highest density to lowest density for calculations.

	Mass (grams)	Volume (cm ³)	Chemical Formula	Comment
anorthite	6.25	2.00	$\text{CaAl}_2\text{Si}_2\text{O}_8$	A kind of feldspar
almandine	3.00	1.00	$\text{Fe}^{2+}_3\text{Al}_2(\text{SiO}_4)_3$	A kind of garnet
microcline	4.00	5.00	KAlSi_3O_8	A kind of feldspar
magnetite	1.00	1.71	$\text{Fe}^{2+}\text{Fe}^{3+}_2\text{O}_4$	

- What is the mass of 1 cm³ of each mineral? Be sure to show units. Explain your reasoning.
 - What is the density of a half of a 1 cm³ cube of magnetite? Explain your reasoning.
 - What is the density of two, 1 cm³ cubes of almandine? Explain your reasoning.

Listed below are the average densities of some other common rock forming silicate minerals and magnetite (http://webmineral.com/Alphabetical_Listing.shtml).

	Density	Chemical Formula (g/cm ³)
Mineral group: Feldspar		
orthoclase	2.56	KAlSi ₃ O ₈
microcline	2.56	KAlSi ₃ O ₈
anorthite	2.73	CaAl ₂ Si ₂ O ₈
albite	2.62	NaAlSi ₃ O ₈
oligoclase	2.65	(Na,Ca)(Si,Al) ₄ O ₈
Mineral group: Pyroxene		
augite	3.40	(Ca,Na)(Mg,Fe,Al,Ti)(Si,Al) ₂ O ₆
diopside	3.40	CaMgSi ₂ O ₆
enstatite	3.20	Mg ₂ Si ₂ O ₆
Mineral group: Garnet		
pyrope	3.74	Mg ₃ Al ₂ (SiO ₄) ₃
almandine	4.19	Fe ²⁺ ₃ Al ₂ (SiO ₄) ₃
Mineral group: Amphibole		
hornblende	3.60	Ca ₂ [Mg ₄ (Al,Fe ³⁺)]Si ₇ AlO ₂₂ (OH) ₂
Mineral group: Mica		
muscovite	2.82	KAl ₂ (Si ₃ Al)O ₁₀ (OH,F) ₂
biotite	3.00	K(Mg,Fe ²⁺) ₃ [AlSi ₃ O ₁₀ (OH,F) ₂
Other minerals		
magnetite	5.15	Fe ²⁺ Fe ³⁺ ₂ O ₄
quartz	2.62	SiO ₂
olivine	3.32	(Mg,Fe) ₂ SiO ₄

- A rock type that typifies the continental crust is granite. Granites have an assortment of silicate minerals that have higher percentages of potassium than other minerals. For example, one type of granite may have 65% orthoclase, 15% quartz, 15% biotite and 5% hornblende. Determine the average density of this granite based on its mineral assemblage.
- If magma of the same element makeup as granite spills out onto the surface of Earth, the minerals would be microscopic in size because it cools rapidly as an extrusive rock. Even though the extrusive rock would have the same element makeup—it is given a different name (rhyolite) because it formed on Earth's surface. Does a microscopic mineral of quartz in a rhyolite have the same density as a pea-sized mineral of quartz in granite? Explain (assume nothing else is different about the quartz in the two rocks except for their size).

5. As you will see in Activity 4, Experiment 1, basalt is another very common rock that is specific to the crust on the ocean floor. Basalts contain a collection of minerals that are different than those in granites because the element makeup of a basaltic magma is different. Basalts contain heavier silicate minerals rich in elements like magnesium, iron, aluminum and calcium. A typical ocean crust basalt may contain 50% anorthite, 45% augite, 4% olivine and 1% magnetite (ignore glass). Determine the average density of this basalt based on its mineral assemblage.
6. Deeper in Earth, in the mantle below the continental and ocean crusts (see Activity 4 Scientists Ideas), is another type of rock called peridotite. Peridotite contains a high percentage of a mineral called olivine plus other silicate minerals that are rich in magnesium and some iron. Determine the average density of a peridotite that contains 80% olivine, 18% enstatite, and 2% pyrope.
7. Would any of the minerals above float in water? Explain.
8. There is a special heavy liquid called LST that has a density of 2.85 g/cm^3 at room temperature (20°C). LST is used to separate minerals having different densities. What minerals listed above would sink, and what minerals above would float in a bath of LST? What would happen to the biotite? Explain your reasoning.
9. Extending what you did in Activity 3, if you placed a cube of quartz having side lengths of 1.0 cm in a bath of LST, and then rested a cube of microcline with the same dimensions on top of the quartz cube, how much of the total height would be above the liquid surface (equilibrium line) and how much would be below the liquid surface? What is the volume of each of those cubes?
10. Use the two-cube problem above to explain isostatic rebound, i.e., explain what would happen to the quartz cube after removing the microcline cube. Calculate the height above the equilibrium line for the remaining cube of quartz.
11. The rebound of the quartz cube in problem #10 would be instantaneous. Isostatic rebound also occurs on Earth's surface, but at a much slower rate and a much larger spatial scale. A depressed continent takes well in excess of 10,000 years to reach a new equilibrium following glacier ice loading and removal. The Puget Sound region of North America was depressed as much as 200 m during the last glaciation (about 10,000 years ago), determine the average rebound rate in cm/year if all of the rebound occurred in 10,000 years. Note that in reality, the uplift rate is not constant, it is fast in the beginning and slower near the end. For example half the rebound may occur in the first few thousand years.
12. A variation of the heavy liquid LST has a density equivalent to a peridotite (3.3 cm^3). Float a 1.0 cm^3 cube of granite (2.8 cm^3) and a 1.0 cm^3 cube of basalt (3.1 cm^3) in the heavy liquid. What percentage of each cube is above the equilibrium line? What is the difference in height above the equilibrium line between the two cubes? Draw your result.
13. Repeat problem #12 with blocks of basalt and granite that are $100 \text{ cm} \times 100 \text{ cm}$ wide and 10 cm high.
14. Repeat problem #12 with a block of basalt that is 5.0 km high and a block of granite that is 30 km high (assume an extremely huge bath of LST).

SAMPLE