Understanding Oceanic Crust Using Density

LESSON SUMMARY

This lesson focuses on density, relating it to various factors that can affect the behavior of rocks and tectonic plates. Students will use laboratory skills and data analysis to better understand density, how it is calculated, and how to use data to analyze the effect of temperature and pressure on the density of Earth's materials. This lesson can help introduce characteristics of rocks and how these relate to features and behaviors of Earth's layers.

SCIENTIFIC OCEAN DRILLING

Standards and Dimensions

NGSS: MS-ESS2-2, MS-ESS2-3

Science Engineering Practices: Constructing Explanations and Designing Solutions; Analyzing and Interpreting Data

Cross-Cutting Concepts: Scale, Proportion and Quantity; Patterns

Disciplinary Core Ideas: ESS2.A: Earth's Materials and Systems; ESS2.B: Plate Tectonics and Large-Scale System Interactions

Connections to 2050 Science Framework

Strategic Objectives: The Oceanic Life Cycle of Tectonic Plates.

Flagship Initiatives: Probing the Deep Earth.

Enabling Elements: Land to Sea.

Ocean Literacy Principle(s)

OLP 2: The ocean and life in the ocean shape the features of Earth. (2A)

Suggested Time

45-60 minutes

Preparation of Materials

Per Group

- balance or digital scale
- 100 ml graduated cylinder (preferably plastic for safety)
- small continental rock samples that can fit in the graduated cylinder (2 sedimentary [e.g., sandstone, limestone] and 2 metamorphic [e.g., schist, gneiss])
- water
- graph paper or computer
- metric ruler
- colored pencils

Per Student

- copies of "Report Sheets 1 and 2" (per student)

For Teacher Demonstration

- 20 mL of 3-4 liquids with different densities (e.g., water, corn syrup, vegetable oil)
- 100 ml graduated cylinder (clear glass or plastic)

Acknowledgements

Lesson Contributors: Lindsay Mossa, based on an original lesson by IODP.

Scientific Acknowledgement

Expedition: Leg 206 was conducted for the purpose of sampling the Cocos Plate, specifically volcanic rocks from an area of fast-spreading upper oceanic crust situated above a magma chamber.

Data source: Jarrard, R. D., & Kerneklian, M. J. (2007). Data Report: Physical properties of the upper oceanic crust of ODP Site 1256: Multisensor track and moisture and density measurements. *Proceedings of the Ocean Drilling Program, 206 Scientific Results*, *206*. **https://doi.org/10.2973/odp.proc.sr.206.011.2007**

SCIENTIFIC OCEAN DRILLING

BACKGROUND FOR THE INSTRUCTOR

Oceanic crust contains mostly igneous and metamorphic rocks that tend to be rich in iron and magnesium, which causes these rocks to be denser than most continental rocks. The average density of oceanic crust is 3.0 g/cm^3 while continental crust has an average density of 2.7 g/cm^3. Oceanic crust is relatively thin compared to continental crust. In places, continental crust is thick enough to form land masses higher than Earth's seas and oceans. Continental crust is made up of more types of rocks than oceanic crust.

For both continental and oceanic crust, the density of the rocks increases downward through their layers due to additional pressure preventing pores from forming in the rocks. The mantle can be found directly beneath the crust, but continental crust extends much farther into the mantle than does oceanic crust (due to isostasy). The mantle is denser than either type of crust, with an average density of 4.5 g/cm^3.

Supplemental Resources

Oceanic Drilling

- **Introducing the International Ocean Discovery Program** (**https://bit.ly/IODPIntro**)
- **Holes in the Bottom of the Sea: History, Revolutions, and Future Opportunities** (**https://bit.ly/GSACoringArticle**)
- **Highlights of IODP Discoveries** (**https://bit.ly/ODPLegacy**)
- **How do you measure a core?** (**https://bit.ly/MeasureCores**)

Lesson-specific

- **Chemical Composition — 'Crust' And 'Mantle'** (**https://bit.ly/41YpO3O**)
- **Tectonic Plates Map** (**https://bit.ly/MapTectonicPlates**)

Initial Inquiry

Construct a density column using an approximately equal volume of each of several liquids, such as corn syrup, oil, and water (preferably mixed with food dye, for visibility). Have students make observations as the liquids settle. Suggested questions:

1. Why did the liquids settle in the order that they did? Do you think they would always settle in this same order? Why or why not?

> Liquids settled in the order they did due to their relative densities. The densest liquid will settle to the bottom of the graduated cylinder. The least dense liquid will be the top layer. Using the same liquids each time will yield the same results, regardless of the order they are poured.

2. Discuss the density formula:

$$\rho = \frac{m}{V}$$

where:
ρ = density
m = mass
V = volume

3. If more of one of the liquids was added to the density column, would its density change? Use the formula to explain your response.

The amount of a substance does not affect its density, because as more volume is added, the mass also increases, which keeps the ratio of mass-to- volume the same. The calculation of the new mass divided by the new volume would result in the same density.

4. What factors might change the density of the liquids? Do you think these factors only affect the density of liquids?

Pressure and temperature changes can affect density. More pressure causes an increase in density, as pressure compacts materials (decreasing the volume). Raising the temperature causes density to decrease, because molecules spread out (increasing the volume) as added heat increases their energy. These factors greatly affect gases and liquids but can also affect solids. Since molecules are already very close together in solids, the effects are not as noticeable. A large enough change in one of these factors can even cause a phase change (e.g., increasing the temperature of a solid enough to cause it to melt.)

5. Imagine each liquid in the density column represents a rock layer.

   a. Which layer represents rocks that would be buried most deeply?

The layer at the bottom of the graduated cylinder.

   b. What factors or conditions might affect the density of buried rock layers?

Factors: type of rock, minerals within the rock, water content or other fluids in pores of the rock. Conditions: how far down the rocks are buried, external pressure and/or temperature.

   c. Do you think there are places on Earth where a material would be under enough pressure that its density would be affected? Why do you think so?

Students may argue yes or no, but the focus should be on their reasoning. Those that respond yes may identify the bottom of the ocean or rock layers buried within the crust (or possibly within deeper layers of the Earth).

SCIENTIFIC OCEAN DRILLING

STUDENT NAME: ....

ANNOTATED STUDENT ACTIVITY

Objective(s)/Outcome(s)

Students will be able to:

1. measure and calculate the density of rock samples to compare the densities of oceanic and continental rocks.
2. calculate the density of samples from an oceanic core to determine the relationship between density and depth in a given core.
3. explain how density affects the movement of the mantle to predict interactions of tectonic plates at convergent boundaries.

Materials

Per Group:

- balance or digital scale
- 100 ml graduated cylinder
- 4 continental rock samples
- water
- graph paper or computer
- metric ruler
- colored pencils

Background

Certain properties of a substance are distinctive and can be used to help identify it. Some properties of substances are also relatively easy to determine. **Density** is one such property. Density is the ratio of a sample's **mass** to its **volume**. Like many other properties, density can depend on certain conditions, such as temperature and pressure. Therefore, comparisons between the densities of samples must be made from measurements taken at the same temperature and pressure.

Density may vary only slightly between samples of the same type of rock. However, detailed data about the sample and **correlation** with other factors, such as depth, may reveal important information about the history of the rocks. This information can help scientists interpret an oceanic core. For example, data collected from rocks in **oceanic crust** can be compared to rocks collected from **continental crust** to understand the behavior of Earth's plates.

STUDENT NAME: ....

Activity

Part 1

1. On Report Sheet 1, record the name and descriptions of each rock sample.

2. Measure and record the mass and volume for each of the four continental rock samples. Make sure to include units when recording the measurements.

Teacher Note: Students should use displacement to find the volume of the irregularly shaped rock. Students who are not familiar with this technique may need support. This can be done by constructing another density column using two liquids. Add 20 mL of oil to a graduated cylinder. Cover the bottom (10-20 mL) of the graduated cylinder with your hand, tape, or a piece of paper and tell students to imagine there was no way they could see the bottom measurements as you add approximately 5-10 mL water to the cylinder. As the oil starts to rise, ask students how they would be able to determine the volume of water added without being able to see the measurements near the bottom of the cylinder.

3. Calculate the density for each sample.

Part 2

1. Report Sheet 2 has data on the density of rock samples taken at the bottom of the Pacific Ocean off the west coast of Central America. Make a hypothesis about the density of rocks based on the depth at which it was found.

2. Complete the data table by calculating the missing densities. Make sure to include units in your answers.

Teacher Note: It is recommended that students use 2 decimal places in their answers, as shown below.

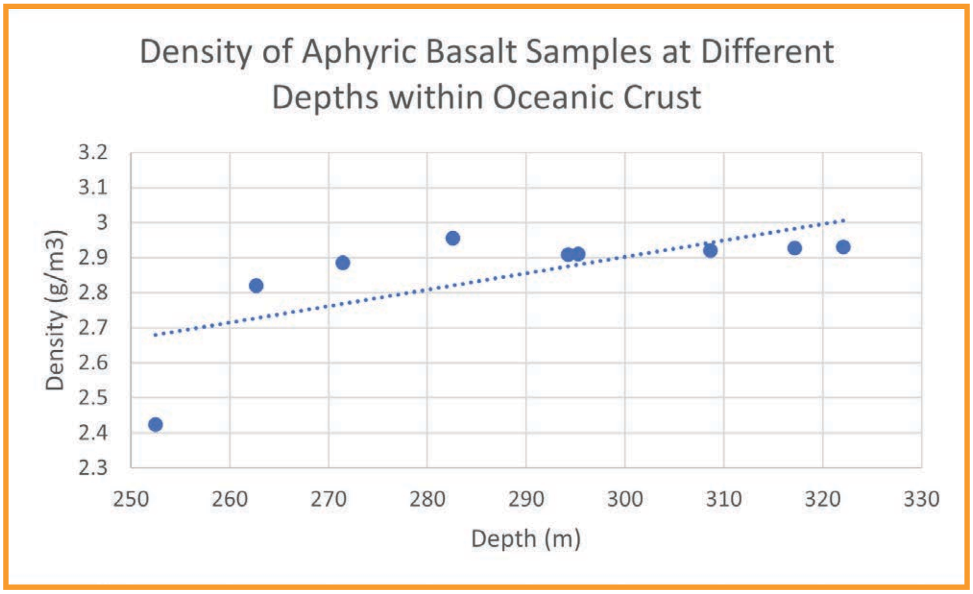
Core #	Section #	Piece #	Density (g/cm^3)
5R	1	1	2.42
6R	3	5	2.82
7R	3	5	2.89
8R	3	6	2.96
9R	4	7	2.91
10R	3	4	2.91
11R	4	4	2.92
12R	1	4	2.92
13R	1	1	2.93

3. Using the depths and densities from your chart, plot a graph on your own paper (or use an electronic graphing tool). Hint: Think about independent and dependent variables. Be sure to include a descriptive title and label the axes.

4. Using a blue colored pencil, draw a line of best fit through the plotted points.

STUDENT NAME: ....

Teacher Note: Discuss with students what elements they should include on the graph. If students use different scales on the axes, discuss the impact that has on the slope of the trend line and how it could influence their analyses.



Analysis

1. Does the shape or size of a sample affect its density? Explain how you know using the density formula and/or your data.

Shape and size do not affect density. The density formula shows that the mass and volume ratio determine density. If a sample is larger, both its mass and its volume will increase, but will do so proportionately so the density will not change.

Teacher Note: Have students compare the densities of their rock samples with each other if they are using the same rock types. They can use this data to determine if shape has an effect on density.

2. Compare the calculated oceanic crust densities with the densities of the continental crust samples (sedimentary and metamorphic rocks).

The densities of the continental crust samples should be lower than those of the oceanic crust.

3. Explain the relationship between depth and density for the samples taken from Site/Hole 1256C.

As depth increases, the density of the rocks tends to increase, as seen on the trendline. Students may also include specific observations of trends or data points, such as: There is a sharp increase in density between the first two samples. The rest of the samples have much more similar densities. There is a peak density of 2.96 g/m^3 at a depth of 282.59 m.

STUDENT NAME: ....

Synthesis

1. Expedition 206 drilled and recovered cores off the west coast of Mexico, Central America, and South America. How do you think the trend in densities of cores taken from other parts of the ocean floor would compare? Explain your reasoning.

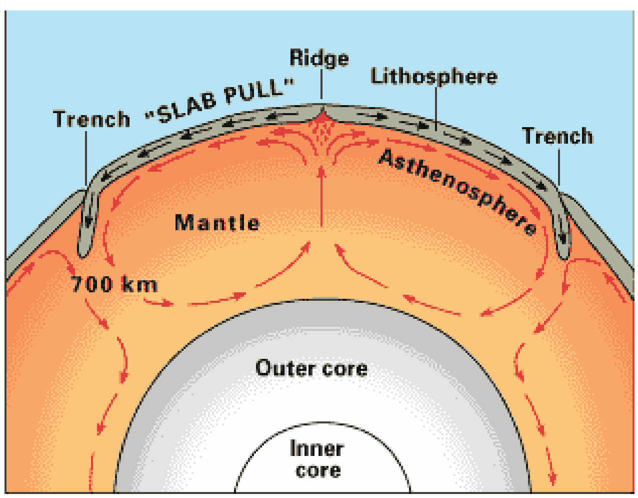
The trend of density increasing as depth increases should be similar due to an increase in pressure. The actual densities may not be identical due to different rock types, ocean depths, and drilling depths.

2. Examine the graph you made in part 2 and make a hypothesis about the density of the mantle, the layer below the crust. Explain your reasoning.

The mantle is found below the crust, which, like with the density column, would indicate the mantle is denser than the crust.

3. When fluids (like water or air) have differences in temperature, convection occurs. For example, convection causes a lava lamp to work. When the lava lamp is turned on, the lightbulb heats up and warms the material and it begins to rise. As the material moves further away, it cools down and sinks. Similar processes happen in the Earth. Figure 1 shows convection currents in the mantle. The heat source for the mantle is Earth's core.

FIGURE 1. MANTLE CONVECTION



Credit: USGS, **https://pubs.usgs.gov/gip/dynamic/unanswered.html**

a. On Figure 1, label the area of the mantle you would expect to have the highest density. Then, label the area of the mantle you would expect to have the lowest density.

The lower part of the mantle near the core would be the densest area. The upper mantle near the crust would be the least dense area.

b. Describe the effect heat has on the density of rocks in the mantle and how it relates to convection currents.

STUDENT NAME: ....

As rocks sink in the mantle, they get closer to the hot outer core, which heats the mantle rocks. Heated rocks rise through the mantle, because the heat causes them to have lower densities. As the rocks rise, they approach the cooler crust, lose heat, and sink again due to an increase in density.

c. Why does heat have an effect on the density of materials?

Heat causes molecules to speed up, which leads to them spreading out. When molecules in a substance are farther apart, the density of the material decreases.

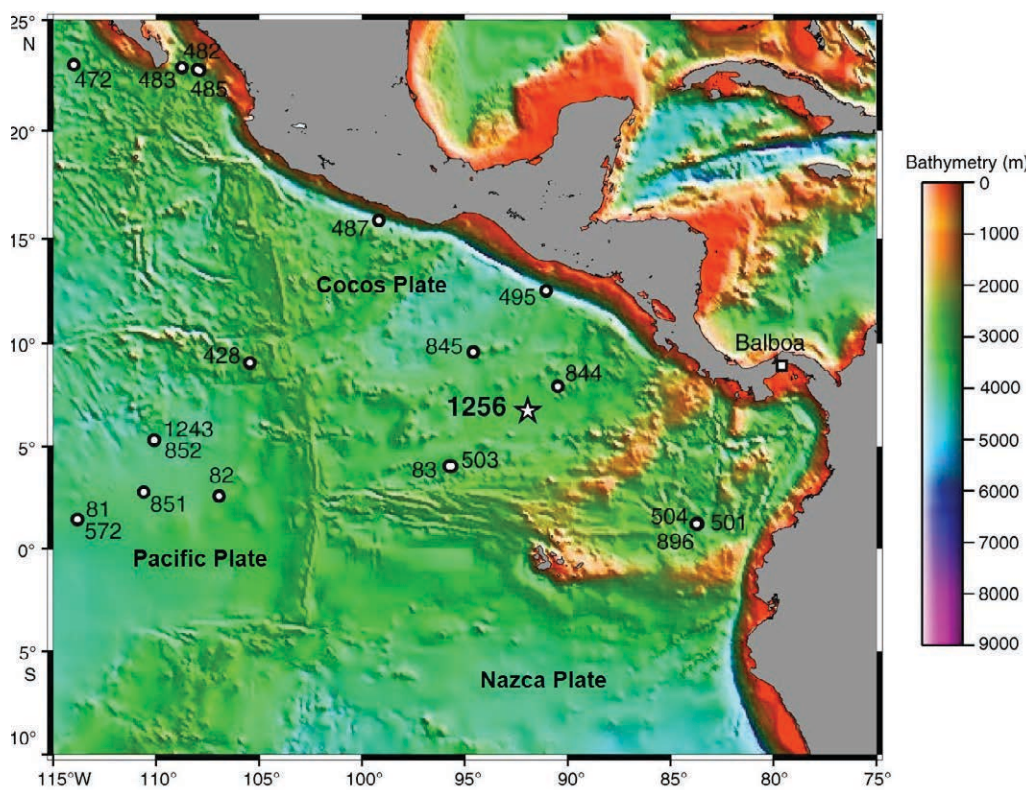
d. Do you think pressure also affects the density of the rocks in the mantle? Explain your reasoning.

Yes, pressure also affects the mantle, because the rocks are buried within the Earth, which puts them under pressure. The rocks with a higher density are near the bottom of the mantle both because they have released heat and sank down, but also because they are under more pressure as they sink, further increasing their density. The opposite is also true as rocks are heated and started to rise and are subjected to less pressure; decreasing their density.

4. Compare the map of the drilling sites from Leg 206 to the map of tectonic plates.

Teacher Note: These maps show the same region of the Pacific Ocean off the west coast of Central and South America. Figure 3 labels the borders between plates.

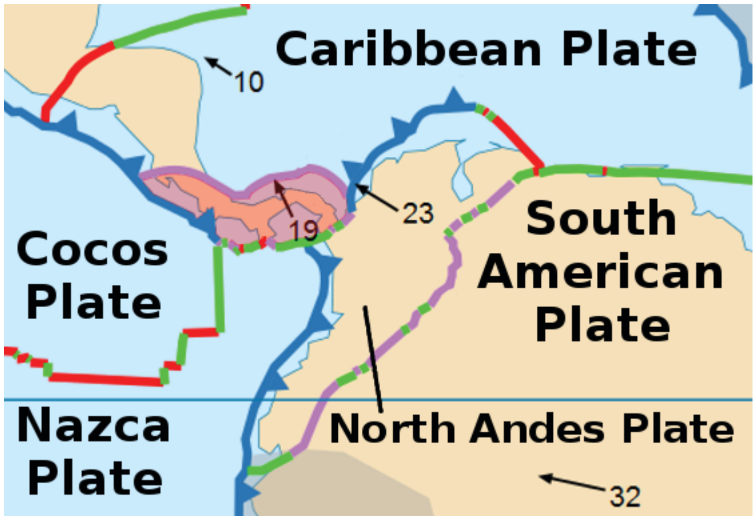
FIGURE 2. BATHYMETRY MAP OF DRILLING SITES FOR LEG 206



Credit: Modified from Teagle & Wilson (2007). **http://www-odp.tamu.edu/publications/206_IR/VOLUME/CHAPTERS/IR206_03.PDF**

STUDENT NAME: ....

FIGURE 3. MAP OF TECTONIC PLATES OF CENTRAL AND SOUTH AMERICA, INCLUDING SURROUNDING BODIES OF WATER



Credit: Alataristarion (2015), Wikimedia Commons. **https://en.wikipedia.org/wiki/Panama_Plate#/media/File:PanamaPlate.png**

a. Figure 2 shows bathymetry, the depth of the ocean floor. Use information from Figure 3 to explain why there are variations in ocean floor depth.

Coastal areas are not as deep due to sedimentation (continental rocks, dirt, and sand that erode and are carried into the ocean). The areas of oceanic floor that are not as deep align with the areas that are over a plate boundary. Students may also mention that oceanic crust with a mantle plume directly underneath may be higher, as the plume could push crust upward. Oceanic crust with a mantle plume directly underneath may be higher, as the plume could push crust upward.

b. The Nazca plate is composed of oceanic crust while the North Andes Plate is continental crust. The blue line in Figure 3 indicates a subduction zone where two plates collide and one submerges under the other. Use what you have learned about density to predict which plate will submerge, the Nazca Plate or the North Andes Plate. Explain your reasoning.

Oceanic crust is more dense than continental crust. The oceanic crust will be submerged at the subduction zone, as its higher density will cause it to move underneath the continental crust.

c. Hypothesize what may happen to the density of the plate that is being submerged. Explain your reasoning.

The plate being submerged will likely heat up from the underlying mantle and may melt. This will likely cause the density to decrease. Students may also mention that the melted crust may rise underneath the continental crust and push it upward, forming volcanoes or mountains.

Extensions

1. Compare your graph of density vs. depth during Leg 206 to the more detailed graph of bulk densities at depths of 750 to 1250 meters compiled in the Preliminary Report for Expedition 309 available through the Information by Expedition link at **https://bit.ly/Leg309**

STUDENT NAME: ....

2. Watch this video on convection currents in the mantle: https://bit.ly/3YvOXjf . Describe how convection occurs in the mantle and how it relates to the movement of tectonic plates.

Closure

1. Exit ticket options:

   a. Why might knowing the density of rocks that make up the layers of the Earth be important to scientists?

When scientists explore new areas, they can use existing density data to determine the types of rocks or conditions under which that area formed.

   b. What other properties of oceanic crust could be measured? What might these properties tell scientists about the crust or the rocks within them?

Accept all responses that are properties that could be measured (e.g., the minerals that the rocks contain, the width of each rock layer, the age of the rocks (absolute dating), the porosity of the rocks). These properties can tell the types of rocks and/or the conditions that formed the layers. These properties can also indicate changes in conditions that occurred over time by comparing the rock layers or comparing one drill site to another.

   c. Follow-up lessons:

   d. Properties of the mantle and core

   e. Convection of the core and the movement of tectonic plates (Interactive: **https://infiniscope.org/lesson/41**)

References

(2015). A map of the Panama plate (Alataristarion, Ed.) [Review of A map of the Panama plate]. **https://en.wikipedia.org/wiki/Panama_Plate#/media/File:PanamaPlate.png**

Earth's Layers: Crust, Mantle & Core, Seismic Discontinuities. (2019, December 13). PMF IAS. **https://www.pmfias.com/earths-layers-crust-mantle-core/**

Hanks, B. (1999, May 5). Some unanswered questions [This Dynamic Earth, USGS]. Pubs.usgs.gov; USGS. **https://pubs.usgs.gov/gip/dynamic/unanswered.html**

Teagle, D. A. H., & Wilson, D. S. (2007). Leg 206 synthesis: initiation of drilling an intact section of upper oceanic crust formed at a superfast spreading rate at Site 1256 in the eastern equatorial Pacific. Proceedings of the Ocean Drilling Program, 206 Scientific Results. **https://doi.org/10.2973/odp.proc.sr.206.001.2007**

Wilson, D., & Acton, D. (n.d.). Shipboard Scientific Party 2 PRELIMINARY RESULTS. Proceedings of the Ocean Drilling Program, Initial Reports, 206(3), 1. Retrieved February 15, 2023, from **http://www-odp.tamu.edu/publications/206_IR/VOLUME/CHAPTERS/IR206_03.PDF**

STUDENT NAME: ....

Report Sheets

REPORT SHEET 1: DENSITY OF LABORATORY SAMPLES

Rock Classification	Mass (g)	Volume (cm^3)	Density (g/cm^3)	Description of Rock Sample

REPORT SHEET 2: DENSITY VS. DEPTH AT SITE/HOLE 1256C

EXPEDITION 206: SITE/HOLE 1256C

Core #	Section #	Piece #	Rock Name	Depth (m)	Volume (cm^3)	Mass (g)	Density (g/cm^3)
5R	1	1	Aphyric basalt	252.5	8.0	19.384	
6R	3	5	Aphyric basalt	262.67	8.0	22.56	
7R	3	5	Aphyric basalt	271.44	8.0	23.08	
8R	3	6	Aphyric basalt	282.59	8.0	23.64	
9R	4	7	Aphyric basalt	294.27	8.0	23.264	
10R	3	4	Aphyric basalt	295.26	8.0	23.28	
11R	4	4	Aphyric basalt	308.61	8.0	23.368	
12R	1	4	Aphyric basalt	317.18	8.0	23.4208	
13R	1	1	Aphyric basalt	322.08	8.0	23.448	