INSTRUCTOR'S RESOURCE GUIDE

Richard M. Busch
West Chester University of Pennsylvania

LABORATORY MANUAL IN PHYSICAL GEOLOGY

NINTH EDITION

Produced under the auspices of the
AMERICAN GEOLOGICAL INSTITUTE
and
NATIONAL ASSOCIATION OF
GEOSCIENCE TEACHERS

Published by Pearson Prentice Hall
Pearson Education, Inc.
Upper Saddle River, New Jersey 07458

ISBN n-nn-nnnnnn-n

Printed in the United States of America

10 9 8 7 6 5 4 3 2 1

Prentice Hall
is an imprint of
PEARSON

www.pearsonhighered.com

Table of Contents

TIPS FOR GETTING STARTED

Please consider these tips to help you use the *Laboratory Manual in Physical Geology—AGI/NAGT* (9th edition) and this *Instructor Manual* more effectively.

1. **Have your students use a loose-leaf notebook** with loose-leaf paper for recording lab notes and organizing lab handouts and graded activity sheets.

Obtain all of the instructor materials that you want to use courtesy of the publisher.
Contact your Prentice Hall field representative for these materials by phone or via the manual web site at http://www.prenhall.com/agi.
   a. Desk copy of *Laboratory Manual in Physical Geology*, 9th Edition.
   b. Instructor Resource Center (IRC) on CD-ROM.

Check the lab manual home page (at http://www.prenhall.com/agi) to see what materials may be useful for your teaching.

4. Check each lab in the laboratory manual to see how it has changed from the last edition that you may have used, and modify your teaching plans and materials accordingly. **All labs have undergone revision on the basis of peer review and student use in pilot tests, so you cannot assume that any chart, graph, or text material is the same as it was in any previous edition. The number, order, and topic of labs in this eighth edition is the same as it was in the eighth edition.**

5. Review and modify the lists of Students Materials and Instructor Materials provided in this instructor manual, so they reflect the actual lists of items that you or your students must assemble for your laboratory. **The current lists are generic lists only and must be modified by you to avoid confusion and insure that you know exactly what to assemble for the laboratory.**

Review the Instructor Notes and References provided in this instructor manual for each lab.

Review the Answers to Questions that are provided in this instructor manual for each question that you assign your students. Some questions have more than one right answer depending on how you have presented material for students to read or explore.

Please send comments, criticisms, and suggestions regarding the laboratory manual or this instructor manual directly to Rich Busch, Department of Geology and Astronomy, West Chester University, West Chester, PA 19383 or rbusch@wcupa.edu. Thank you!

LABORATORY ONE

Observing and Measuring Earth Materials and Processes

OBJECTIVES AND ACTIVITIES

A. Know how to make a scale model of Earth, calculate its fractional scale, and use it to understand the relative proportions of Earth's physical spheres.

ACTIVITY 1.1: Basketball Model of Earth's Spheres (p. 1-7, 21-22)

B. Understand some basic principles and tools of direct and remote observation that are used by geoscientists and apply them to identify Earth materials, observe and describe processes of change, make a prediction, and describe a plan of field geology and lab work that you could use to test your prediction.

ACTIVITY 1.2: Remote Sensing of Earth and Exploring for Copper (p. 8-13, 22)

C. Measure or calculate length, area, volume, mass, and density of Earth materials using basic scientific equipment and techniques.

ACTIVITY 1.3: Measuring Earth Materials and Relationships (p. 14-16, 23-24)

D. Develop and test physical and quantitative models of isostasy based on floating wood blocks and icebergs. Then apply your quantitative model and your measurements of basalt and granite density to calculate the isostasy of average blocks of oceanic and continental crust.

ACTIVITY 1.4: Density, Gravity, and Isostasy (p. 17-18, 25-26)

E. Analyze Earth's global topography in relation to your work and a hypsographic curve, and infer how Earth's global topography may be related to isostasy.

ACTIVITY 1.5: Isostasy and Earth's Global Topography (p. 18-20, 27-29)

STUDENT MATERIALS **(Remind students to bring items you check below.)**

_____ laboratory manual
_____ laboratory notebook
_____ pencil with eraser
_____ metric ruler (cut from GeoTools sheet 1 or 2)
_____ calculator
_____ blue pencil or pen

INSTRUCTOR MATERIALS (Check off items you will need to provide.)

ACTIVITY 1.1: Basketball Model of Earth's Spheres (p. 1-7, 21-22):
_____ drafting compasses (one per student)
_____ extra metric rulers (for students who forgot them)
_____ extra blue pencils (for students who forgot them)

ACTIVITY 1.2: Remote Sensing of Earth and Exploring for Copper (p. 8-13, 22):
_____ extra metric rulers (for students who forgot them)

ACTIVITY 1.3: Measuring Earth Materials and Relationships (p. 14-16, 23-24):
_____ extra metric rulers (for students who forgot them)
_____ small (10 mL) graduated cylinders (one per group of students)
_____ waterproof modeling clay (at least 1 cubic cm. per student)
_____ gram balance (one per group of students)
_____ wash bottle or dropper bottle, filled with water (one per group)
_____ paper towels to clean up spills

ACTIVITY 1.4: Density, Gravity, and Isostasy (p. 17-18, 25-26):
_____ extra metric rulers (for students who forgot them)
_____ gram balance
_____ wood blocks about 8 cm x 10 cm x 4 cm. **Do not use cubes** because they float diagonally. Pieces of pine 2 x 4 studs work well. For variety, give some groups pine and others a more dense wood like walnut (one block per group of students).
_____ small bucket or plastic basin of water to float wood block (one per group of students)
_____ paper towels to clean up spills

ACTIVITY 1.5: Isostasy and Earth's Global Topography (p. 18-20, 27-29):
_____ large (500 mL) graduated cylinders (one per group of students)
_____ pieces of basalt and granite that will fit into the large graduated cylinders (one piece of each per group of students)
_____ gram balance
_____ wash bottle filled with water or dropper (one per group)
_____ paper towels to clean up spills

INSTRUCTOR NOTES AND REFERENCES

1. Refer to Laboratory 1 on the Internet site at http://www.prenhall.com/agi for additional information and links related to all parts of this laboratory.

2. Metric and International System of Units (SI): refer to laboratory manual page x.

3. Mathematical conversions: refer to laboratory manual page xi.

4. In Activity 4 of this laboratory, students explore the isostasy of a floating wood block. You can make this more of a real-world inquiry by providing students with two or more densities of wood. For example, pine and walnut work well because students can easily see that the pine blocks float higher than the walnut blocks. This makes it easier for students to conceptualize how isostatic differences between granitic and basaltic blocks may explain Earth's hypsographic curve.

5. Hydrous minerals of Earth's Mantle. Hydrous minerals include not only the obviously hydrous minerals like gypsum, but also minerals like amphibole and pyroxene that are "nominally hydrous" (actually hydrous even though they are generally regarded as anhydrous). See David R. Bell and George R. Rossman's 1992 paper on this (*Science*, v. 255, p. 1391–1397). Shortly after the *Science* article was published, *Science News* quoted Bell and Rossman as estimating that the mantle may contain a volume of water equal to 80% of the volume of the world's oceans. Even if this Bell and Rossman estimate of mantle water seems high, one must still account for the hydrous and nominally hydrous minerals in Earth's crust. Therefore, having students assume that the solid Earth may contain water equal to 80% of the volume of the world's oceans may be a conservative estimate.

   For information on recycling of water into Earth's mantle, refer to: C. Meade and R. Jeanloz. 1991. Deep-focus earthquakes and recycling of water into Earth's mantle. *Science* 252:68–72.

ACTIVITY 1.1 ANSWERS AND EXPLANATIONS

1.1A. See completed basketball model on next page**.** Students should realize that it is nearly impossible for them to draw separate lines for hydrosphere and atmosphere (because they are so narrow compared to the diameter of the basketball. Crust will be about the thickness of a pencil/pen line. You could have students use another color of pencil for crust (i.e., as done in red on the completed model on the next page).

1.1B. Have students refer to manual page 7 for help. The radius of the basketball model is 0.119m (119 mm) but the actual radius of Earth is 6,371,000 m, so the ratio scale of model to actual Earth is 0.119 to 6,371,000. Dividing 6,371,000 by 0.119 reduces the ratio scale to 1: 53,537,815. Thus, the basketball model is 1/53,537,815th of the actual size of Earth.

Fractional scale: 1/53,537,815 **Ratio scale**: 1:53,537,815

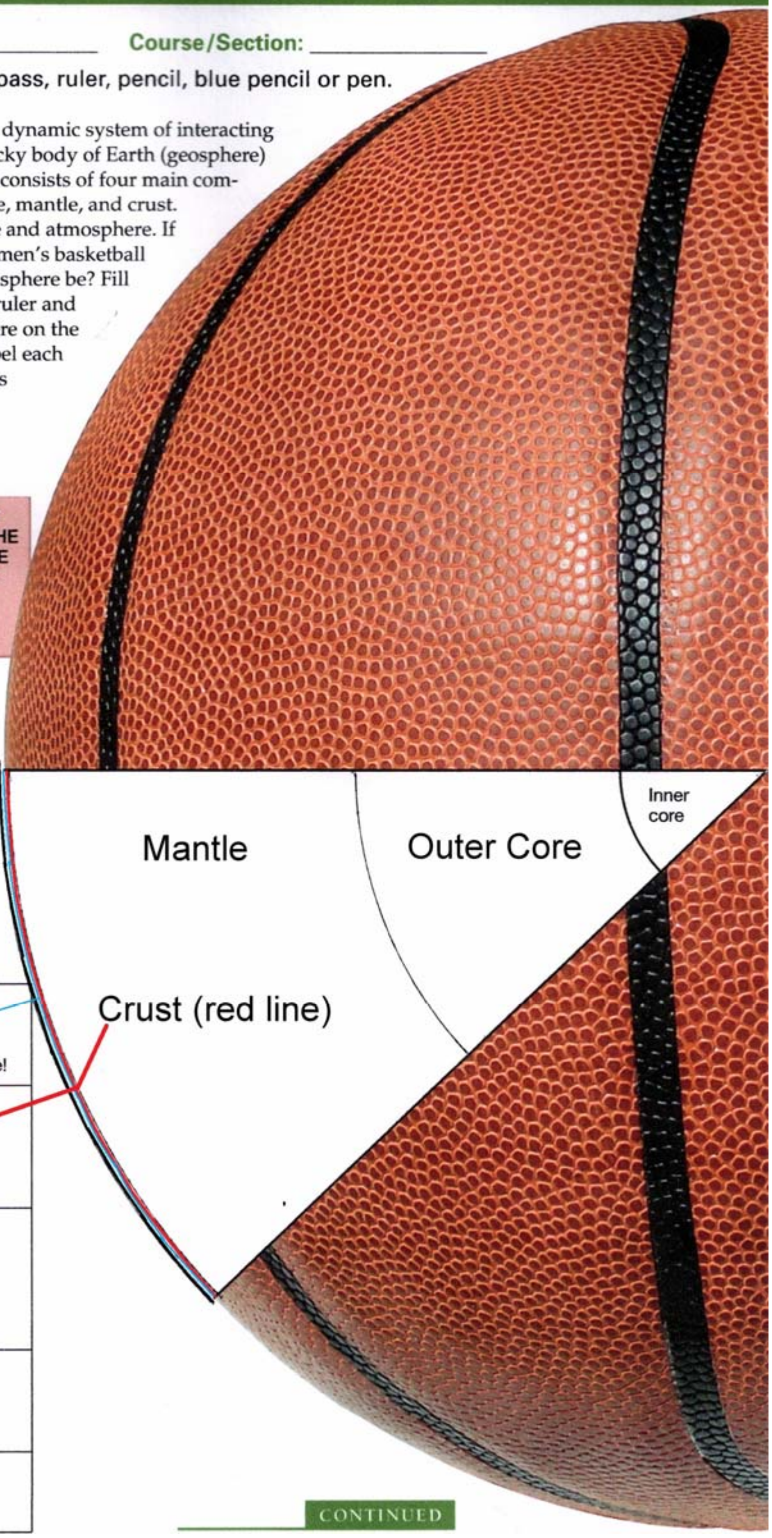
ACTIVITY 1.1 Basketball Model of Earth's Spheres

Name: ______________________________ **Course/Section:** ______________

Materials: Calculator, drafting compass, ruler, pencil, blue pencil or pen.

A. Geoscientists conceptualize Earth as a dynamic system of interacting material spheres (subsystems). The rocky body of Earth (geosphere) has an average radius of 6371 km and consists of four main compositional layers: inner core, outer core, mantle, and crust. These are overlain by the hydrosphere and atmosphere. If Earth's geosphere had the radius of a men's basketball (119 mm), then how thick would each sphere be? Fill in the chart below, then draw (with a ruler and drafting compass) and label each sphere on the pie-shaped slice of this basketball. Label each sphere. For example, the inner core has already been done.

SPHERE	ACTUAL THICK-NESS	THICKNESS IN MM, IF THE GEOSPHERE IS THE SIZE OF A BASKET-BALL
Atmosphere: mostly nitrogen (N), oxygen (O), and argon (Ar) gases in air. Nearly all of the materials in air occur in a sphere just 16 km (10 mi) thick (troposphere). "Space" (no air) begins about 1000 km above sea level.	16 km	0.3
Hydrosphere: mostly water (H_2O, ocean) in a liquid state.	3.7 km	0.07 Draw in blue!
Crust: mostly oxygen (O), silicon (Si), aluminum (Al), and iron (Fe).	25 km	0.47
Mantle: mostly oxygen (O), silicon (Si), magnesium (Mg), and iron (Fe) in a solid state.	2900 km	54.2
Outer Core: mostly iron (Fe) and nickel (Ni) in a liquid state.	2250 km	42.0
Inner Core: mostly iron (Fe) in a solid state	1196 km	22.3 mm



CONTINUED

ACTIVITY 1.2 ANSWERS AND EXPLANATIONS

1.2A. Analysis of Figure 1.9, an astronaut's photograph and MODIS satellite image of the eruption of Sicily's Mt. Etna in the Mediterranean Sea in 2002.

1. Students should observe that some vents are erupting plumes of white material while others are erupting brown material. The white material is likely **steam or hot volcanic gases**. the brown material is likely **volcanic ash** (rock particles).

2. Using the graphic bar scale on the color reference map, students will estimate that the extruded brown material (volcanic ash, rock particles) has traveled 500 to 700 miles. It will land on Africa and parts of the Mediterranean Sea.

3. How did this eruption affect the atmosphere and hydrosphere?

Effects on the atmosphere:

- Water, carbon dioxide, and other gases are added to the atmosphere.
- Rock particles/dust/ash are added to the atmosphere.
- Carbon dioxide and sulfur dioxide can mix with water vapor in the atmosphere to make acid rain (rain with carbonic and sulfuric acid).
- Volcanic gases and rock particles form clouds in the atmosphere, preventing sunlight from reaching Earth's surface.

Effects on the hydrosphere:

- Water from inside Earth has been cycled to Earth's surface.
- Volcanic gases like carbon dioxide and sulfur dioxide lead to acid rain (rain abnormally rich in carbonic and sulfuric acid), which falls to Earth and acidifies lakes and streams.
- Parts of the ocean may be clouded with fallen rock particles/dust/ash.

1.2B. Analysis of Figure 1.10, true and false colored ASTER images of Chile's Escondida Mine and vicinity. This is primarily a copper mine, but it also produces some silver and gold. The copper ore is mined from large open pits. Notice how these pits appear in the images.

1. Location C. The existing pits are a bright pink color in the false-color image, and location C has that color. Locations A and B are green in the false-color image.

2. Plan of investigation for location C:

- Go to location C and collect rock samples (field work).
- Analyze the rock samples from location C to see if they contain copper ore (as in manual Figure 1.7).

ACTIVITY 1.3 ANSWERS AND EXPLANATIONS

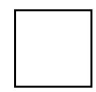
1.3A. The mathematical conversions (using the table on laboratory manual page xi) are:

1. 110.0 miles x 1.609 km/mi = **16.09 kilometers** (or rounded to **16.1 km**)
2. 1.0 foot x 0.3048 m/ft = **0.3048 meters** (or rounded to **0.3 m**)
3. 16 kilometers x 1000 m/km = **16,000 meters**
4. 25 meters x 100 cm/m = **2500 centimeters**
5. 25.4 mL x 1.000 cm^3/mL = **25.4 cm^3**
6. 1.3 liters x 1000 cm^3/L = **1300 cm^3**

1.3B. Students should be able to use a metric ruler (cut from GeoTools sheet 1 or 2) to draw a line segment like this one that is exactly 1 cm long.

1 cm

1.3C. Students should be able to use a metric ruler to draw a square that is exactly 1 cm long by 1 cm wide. [Note that this is a two-dimensional shape called a square centimeter, or cm^2.]



1 cm

1 cm

1.3D. Students will have some difficulty drawing a three-dimensional cubic centimeter on two-dimensional paper because the dimensions must be distorted to give the drawing its perspective view. However, their drawing of a cubic centimeter should be as close as possible to actual size. Some students will try to trace the cubic centimeter in Figure 1.11B (which is correct, but must be traced exactly).

1.3E. Students should explain a procedure similar to this one and determine that water has a density of about 1 g/cm^3:

a. Fill a small graduated cylinder about halfway with water and record this starting volume of water in the cylinder. The graduated cylinder will probably be graduated in mL (which equals cm^3), so students should record the starting volume of water in cm^3.

b. Weigh the graduated cylinder of water from step **a** and record the starting mass of water in grams.

c. Add a small amount of water to the graduated cylinder and:

- Read and record this ending volume of water.
- Weigh and record this ending mass of water.

d. Use the following mathematical formula to determine the density of water:

$$\frac{\text{Ending mass of water (g)} - \text{starting mass of water (g)}}{\text{Ending volume of water (cm}^3\text{)} - \text{starting volume of water (cm}^3\text{)}} = \text{about } 1 \text{ g/cm}^3$$

1.3F. Students will determine that their clay has a density greater than 1 g/cm^3. Most brands are between 2 g/cm^3 and 4 g/cm^3. There are two main methods/procedures that students use to determine this.

Method 1 procedures:

a. Construct a cubic centimeter of clay (1 cm^3 of clay).

b. Weigh the cm^3 of clay in grams. This is the grams per cubic centimeter (density) of the clay.

Method 2 procedures:

a. Weigh a small lump of clay (that will fit in a graduated cylinder) and record its mass in grams.

b. Fill the graduated cylinder about halfway with water and record the exact starting volume of water in cubic centimeters.

c. Place the lump of clay into the water (do not splash) of the graduated cylinder and record this ending volume of water in cubic centimeters.

d. Determine the volume of the clay by subtracting the starting volume of water in the graduated cylinder (**b**) from the ending volume of water in the graduated cylinder (**c**).

e. Determine the density of the clay by dividing the mass of the clay sample (**a**) by the volume of the clay sample (**d**).

1.3G. **1.** Clay sinks in water because it is more dense than water (it has a density greater than 1 g/cm^3).

2. Some students will try to flatten the clay into a sheet that can float on the surface tension of the water. Other students will try to make a boat or a clay sphere. (If students are having great difficulty getting the entire lump of clay to float, then you can ask them to consider how the Navy gets steel to float—i.e., it makes the steel into ship shapes.)

3. When students eventually make a ship shape (or sphere) and get their clay to float, then they should realize that the clay floated because it took on a new shape with a larger volume. This decreased the density of the clay and increased its buoyancy.

1.3H. Since students determined in Question 9 that the density (ρ) of water is about 1g/cm^3, they should be able to infer:

1. $\rho_{atmosphere}$ = ___< 1___ g/cm^3

2. $\rho_{lithosphere}$ = ___>1___ g/cm^3

1.3I. The hydrosphere (liquid water) is less dense than the lithosphere, so it sits on top of the lithosphere. The atmosphere is the least dense of them all, so it occurs above them. In summary, the spheres are most dense at Earth's center and less dense with position away from Earth's center. Many students will draw this relationship and label the spheres.

ACTIVITY 1.4 ANSWERS AND EXPLANATIONS

1.4A. Student answers will vary according to the type of wood. However, students should realize that they can determine the mass of the wood block by weighing it in grams (g). They should be able to determine the volume of the wood block by using a ruler to measure its three linear dimensions in cm, then multiplying the dimensions together to find the volume in cubic centimeters (cm^3). The density of the wood block is its mass in grams divided by its volume in cubic centimeters.

1.4B. The sketches made by students should resemble lab manual Figure 1.13A, but:

1. The proportions of wood above and below the waterline will vary according to the type of wood. Pine floats higher than walnut.
2. Exact measurements recorded by students will also vary according to type of wood and size of the block.
3. Exact measurements recorded by students will also vary according to type of wood and size of the block.
4. Exact measurements recorded by students will also vary according to type of wood and size of the block.

1.4C. The exact form of equations will vary from student to student. The common form is:

$$H_{below} = (P_{wood} \div P_{water})\, H_{block}$$

1.4D. The exact form of equations will vary from student to student. Using the equation above (answer to Question 17), the common form would be:

$$H_{above} = 1 - [\, (P_{wood} \div P_{water})\, H_{block}\,]$$

1.4E. The density of water ice (in icebergs) is 0.917 g/ . The average density of (salty) ocean water is 1.025 g/ .

1. $\%_{below} = (0.917\ g/cm^3 \div 1.025\ g/cm^3)\ 100\% = 89.5\%$

2. $\%_{above} = 100\% - [(0.917\ g/cm^3 \div 1.025\ g/cm^3)\ 100\%] = 10.5\%$

3. Students will generally find that their grid estimations of the percentages of the iceberg below and above sea level are consistent with their calculations above.

4. As the top of the iceberg melts, its submerged base will rise to establish a new isostatic equilibrium.

5. Where mountains have been eroded, their “roots” are still rising very slowly, so ancient shorelines become elevated above the levels where they originally formed.

ACTIVITY 1.5 ANSWERS AND EXPLANATIONS

1.5A. Student values for the density of pieces of basalt that they personally analyze will vary from about 2.9 g/cm^3 to 3.3 g/cm^3. However, they should still determine that the average density of all 10 basalt samples is about 3.1 g/cm^3.

1.5B. Student values for the density of pieces of granite that they personally analyze will vary from about 2.7 g/cm^3 to 3.2 g/cm^3. However, they should still determine that the average density of all 10 granite samples is about 2.8 g/cm^3.

1.5C. **1.** $H_{above} = 5\text{ km} - \left[(3.1\text{ g/cm}^3 \div 3.3\text{ g/cm}^3)\ 5\text{ km} \right] = 0.3\text{ km}$

2. $H_{above} = 30\text{ km} - \left[(2.8\text{ g/cm}^3 \div 3.3\text{ g/cm}^3)\ 30\text{ km} \right] = 5.0\text{ km}$

3. 5.0 km – 0.3 km = 4.7 km

4. The calculated value of 4.7 km in part c is close to the actual difference between the average height of the continents and the average depth of the oceans on the hypsographic curve in Figure 1.14.

1.5D. Earth has a bimodal global topography because its granitic continental blocks of lithospheric rock have an average density that is less than the average density of basaltic sea floor rocks. Thus, on average, the continental blocks sit about 4.53 kilometers higher in the mantle than the basaltic blocks. Oceans cover the basaltic blocks, but the tops of continental blocks remain above sea level.

1.5E. As a mountain forms, it establishes a level of isostatic equilibrium in the denser mantle—a sort of "mantle line" (like the waterline on an iceberg). In other words, most of the mountain is a submerged "root," just as most of an iceberg is its "root" below sea level.

As a mountain is eroded, its root rises to establish a new level of isostatic equilibrium.

1.5F. Students can take and defend any inference, but the best and most correct inference is one that is supported by data and good logic. The most correct proposal (according to their work in this laboratory) is a compromise hypothesis stating that:

Blocks of Earth's crust (actually lithosphere) have different densities (Pratt) and different thicknesses (Airy), so they sink to different compensation levels.

LABORATORY TWO

Plate Tectonics and the Origin of Magma

OBJECTIVES AND ACTIVITIES

A. Infer whether expanding-Earth or shrinking-Earth hypotheses could explain plate tectonics and how mantle convection plays a role in causing plate tectonics.

ACTIVITY 2.1: Is Plate Tectonics Caused by a Change in Earth's Size? (p. 31-34, 43-44)
ACTIVITY 2.2: Evaluate a Lava Lamp Model of Earth (p. 34-35, 45-46)

B. Understand how plate boundaries are identified and be able to measure and calculate some plate tectonic processes.

ACTIVITY 2.3: Using Earthquakes to Identify Plate Boundaries (p. 35, 47-48)
ACTIVITY 2.4: Analysis of Atlantic Seafloor Spreading (p. 35, 49-50)
ACTIVITY 2.5: Plate Motions Along the San Andreas Fault (p. 35, 51-52)
ACTIVITY 2.6: The Hawaiian Hot Spot and Pacific Plate Motion (p. 35, 53)
ACTIVITY 2.7: Plate Tectonics of the Northwest United States (p. 35, 54)

C. Use physical and graphical models of rock melting to infer how magma forms in relation to pressure, temperature, water, and plate tectonics.

ACTIVITY 2.8: The Origin of Magma (p. 40-41, 55-56)

STUDENT MATERIALS (Remind students to bring items you check below.)

_____ laboratory manual
_____ laboratory notebook
_____ pencil with eraser
_____ metric ruler (cut from GeoTools sheet 1 or 2)
_____ calculator
_____ colored pencils (red and blue)
_____ visual estimation of percent chart (cut from GeoTools sheet 1 or 2)

_____:

_____:

INSTRUCTOR MATERIALS (Check off items you will need to provide.)

ACTIVITY 2.1: Is Plate Tectonics Caused by a Change in Earth's Size? (p. 31-34, 43-44)

_____ extra metric rulers (for students who forgot them but want to use one)

ACTIVITY 2.2: Evaluate a Lava Lamp Model of Earth (p. 34-35, 45-46)

_____ extra blue pencils (for students who forgot them)
_____ extra red pencils (for students who forgot them)
_____ lava lamp (turned on at least 1 hour ahead of time) and/or lava lamp video clip on IRC-DVD

ACTIVITY 2.3: Using Earthquakes to Identify Plate Boundaries (p. 35, 47-48)

_____ extra metric rulers (for students who forgot them)
_____ extra red pencils or pens (for students who forgot them)

ACTIVITY 2.4: Analysis of Atlantic Seafloor Spreading (p. 35, 49-50)

_____ extra metric rulers (for students who forgot them)
_____ extra blue pencils or pens (for students who forgot them)
_____ extra red pencils or pens (for students who forgot them)

ACTIVITY 2.5: Plate Motions Along the San Andreas Fault (p. 35, 51-52)

_____ extra metric rulers (for students who forgot them)

ACTIVITY 2.6: The Hawaiian Hot Spot and Pacific Plate Motion (p. 35, 53)

_____ extra metric rulers (for students who forgot them)

ACTIVITY 2.7: Plate Tectonics of the Northwest United States (p. 35, 54)

_____ extra metric rulers (for students who forgot them)

ACTIVITY 2.8: The Origin of Magma (p. 40-41, 55-56)

_____ extra metric rulers (for students who forgot them)
_____ hot plate (one per group of students)
_____ sugar cubes (two per group of students)
_____ dropper with water or dropper bottle (one per group of students)
_____ aluminum foil (one sheet per group of students) or foil baking cups (two per group of students)
_____ crucible tongs (one per group of students)
_____ permanent felt-tip marker (one per group of students)

INSTRUCTOR NOTES AND REFERENCES

1. Refer to Laboratory 2 on the Internet site at http://www.prenhall.com/agi for additional information and links related to all parts of this laboratory.

2. Metric and International System of Units (SI): refer to laboratory manual page x.

3. Mathematical conversions: refer to laboratory manual page xi.

4. To model Kinetic Theory, place small plastic or glass marbles in a clear plastic box or tray on an overhead projector. Hold the model still and elevated at one end, so the marbles form a close-packed array resembling a crystalline solid structure. Vibrate the model slightly to model a rise in kinetic energy and to start moving the marbles apart, as if melting is initiating. Vibrate the model more to model a greater rise in kinetic energy and to cause all of the marbles to move about independently, as if total melting or vaporization has occurred. (To model crystallization by decreasing kinetic energy, repeat these tasks in reverse.) Note: be sure to remind students that plumes of Earth's mantle are rock, not liquid magma or lava.

5. One lava lamp, or two, or three? Most lava lamps must be lighted for at least 1 hour before they exhibit active and obvious convection. It helps to have two or more lamps that have been turned on at different times, so the "lava" (wax) has varying amounts of kinetic energy. This helps students understand kinetic theory and how unequal amounts of heating affect the development and rate of convection. A lava lamp video clip is provided on the IRC-DVD. Note: be sure to remind students that Earth's mantle is rock, not liquid magma or lava.

6. Decompression melting. To help students visualize decompression melting, have them mix corn starch and water to make a corn starch suspension. Then have them try to roll some of the suspension into a ball and watch the suspension flow through their fingers. So long as the suspension is under pressure (i.e., while it is being rolled into a ball), it remains in a solid-like state. When the suspension is not under pressure (i.e., when a ball of suspension is placed on the palm of a hand), it flows in a liquid state. This is NOT decompression melting, but it helps students understand that pressure can prevent flowing even in materials that are normally fluid.

7. To model mantle plumes and hot spots, make a model of Earth's compositional layering first by placing clear corn syrup in a clear plastic cup (to represent Earth's mantle) and then by adding a few mm of water on top of it (to represent Earth's crust). To prepare material for a mantle plume, heat a small amount of corn syrup (with a few drops of red food coloring) on a hot plate. Fill a dropper with the hot red corn syrup, then squeeze some of it out onto the bottom of the plastic cup containing the cool syrup and water. Watch as the hot red corn syrup rises through the cooler corn syrup to form a long narrow plume and a pool of red syrup just beneath the water (crust). This is especially useful for having students entertain ideas about the origin of hot spots.

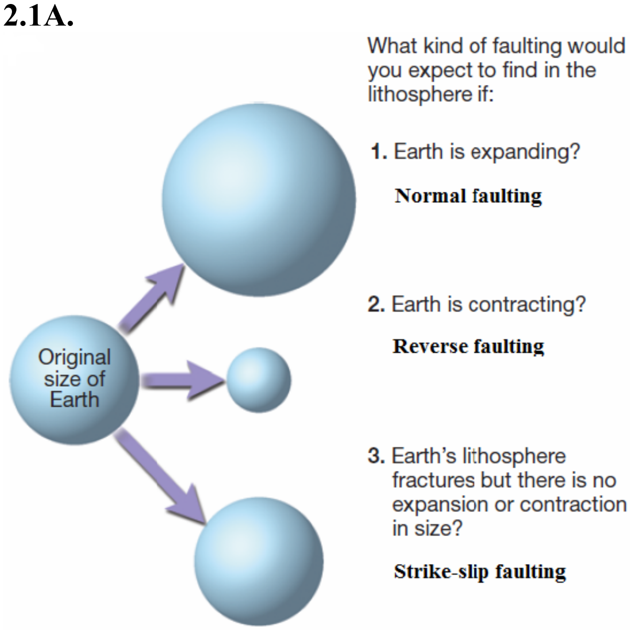
8. Flux melting. In the smelting industry, the term "flux" refers to materials such as "fluxstone" that are added to raw ore in order to lower the fusion (melting) temperature and produce slag. Experimental petrology has demonstrated that water lowers the fusion temperature of some minerals commonly found in granite, basalt, and peridotite; thereby initiating partial melting at lower, "wet solidus" temperatures.

9. Water in Earth's mantle. For information on recycling of water into Earth's mantle, refer to: C. Meade and R. Jeanloz. 1991. Deep-focus earthquakes and recycling of water into Earth's mantle. *Science* 252:68–72.

10. San Andreas fault slip rate.
    For a published estimate of the recurrence interval for very large earthquakes along the San Andreas fault north of San Francisco (221 +/- 40 yr) see: T.M. Niemi and N.T. Hall. 1992. Late Holocene slip rate and recurrence of great earthquakes on the San Andreas fault in northern California. *Geology* 20:195–198. During the recurrence interval, the accumulated strain would be about 3.2 m (10 ft). However, Niemi and Hall (1992) also estimated that the Late Holocene rate of movement on the fault is about 2.4 cm/yr.
    For a published estimate of the recurrence interval for very large earthquakes along the San Andreas fault zone 70 km northeast of Los Angeles, California, see: T.E. Fumal, S.K. Pezzopane R.J. Weldon II, and D.P. Schwartz. 1993. A 100-Year Average Recurrence Interval for the San Andreas Fault at Wrightwood, California. *Science* 259:199–203. They calculated a recurrence interval of about 100 years, a slip rate of about 2.5 cm per year, and a slip per very large earthquake of about 4 meters.

ACTIVITY 2.1 ANSWERS AND EXPLANATIONS

2.1A.



2.1B.

Plate Boundary Type	Main Stress (applied force)	Main Fault Type
Divergent	**tension**	**normal fault**
Convergent	**compression**	**reverse fault**
Transform	**shear**	**strike-slip fault**

2.1C. Students must be able to recognize divergent plate boundaries (red), transform plate boundaries (dashed, usually between segments of red divergent boundaries, but also including the San Andreas fault), and convergent boundaries (black with triangular teeth). Student estimations will vary, so it is good to have students share their estimates and obtain a class generalization. Most students correctly make the following visual estimation:
1. about 33% of Earth's plate boundaries are transform plate boundaries.
2. about 33% of Earth's plate boundaries are divergent plate boundaries.
3. about 33% of Earth's plate boundaries are convergent plate boundaries.

2.1D. Based on the answers to questions above, there is evidence for equal amounts of crustal compression, tension, and shear. Thus, it seems reasonable that Earth's size is not changing (i.e., Earth is staying about the same).

2.1E. As Earth's size does not seem to be changing (answer 2.1D), plate tectonics cannot be caused by a change in Earth's size. For Earth to remain the same size, it is moret likely that lithosphere is created at divergent boundaries, recycled back into the mantle at convergent boundaries, and neither created nor recycled at transform boundaries.

ACTIVITY 2.2 ANSWERS AND EXPLANATIONS

2.2A. Students must observe a convecting lava lamp (that has been heating at least one hour) or a movie clip of a convecting lava lamp to answer these questions.
1. The "lava" moves from the base of the lamp to the top of the lamp, where it sits temporarily before sinking back to the bottom of the lamp.
2. Lava at the base of the lamp is heated by the light bulb. As the lava is heated, its kinetic energy level rises, which causes the lava to expand to a slightly greater volume and lower density. When the density of lava is less than the surrounding fluid, the lava rises.
3. Lava at the top of the lamp is cooling. As it cools, its kinetic energy level decreases, which causes the lava to contract into slightly less volume and higher density. When the density of lava is greater than the surrounding fluid, the lava sinks.
4. convection

2.2B. **1.** Earth's mantle is like a lava lamp, because:

- mantle rocks are unequally heated like lava in the lava lamp.
- mantle rocks are heated at the base of the mantle, like lava in a lava lamp is heated at the base of the lava lamp.
- it has warmer rocks that rise like lava in a lava lamp.
- it has cooler rocks that sit atop the mantle or sink back into the mantle, like the masses of cooling lava at the top of the lava lamp.

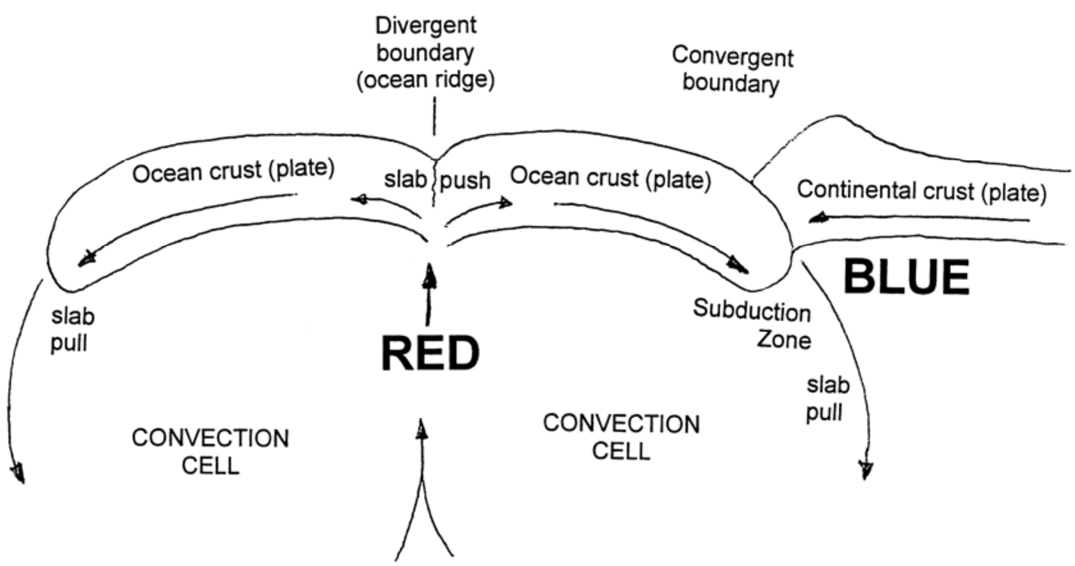
2. Earth's mantle is different from a lava lamp, because:

- the mantle is rock, not lava or wax.
- the mantle is heated by Earth's outer core, but the lava lamp is heated by a light bulb.
- the mantle convects more slowly (i.e., cm/year) than the lava lamp (cm/second or cm/minute).

2.2C. By comparing lab manual Figures 2.4 and 2.3, students should observe that:

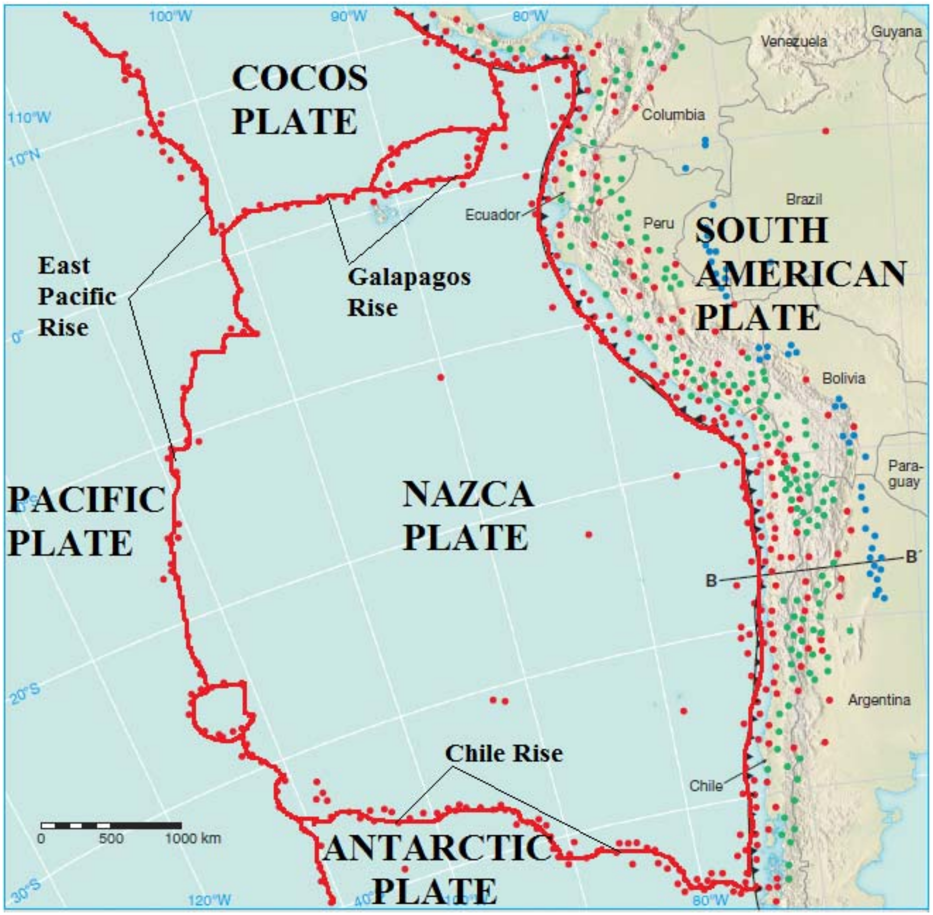
1. the warmer, less dense mantle rocks (red in Figure 2.4) mostly occur beneath divergent plate boundaries and hot spots.
2. the cooler, denser mantle rocks (blue in Figure 2.4) mostly occur beneath continents.

2.2D. The nature and detail of student cross sections will vary, but it should be at least a labeled, simple sketch like the one below.



ACTIVITY 2.3 ANSWERS AND EXPLANATIONS

2.3A.



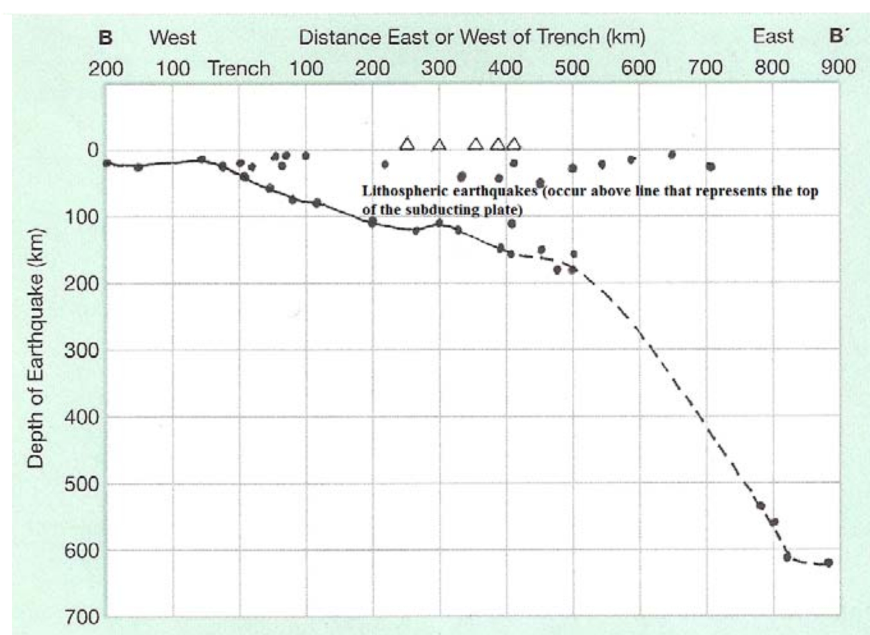
2.3B

1. convergent

2. See black line (solid and dashed) on graph.

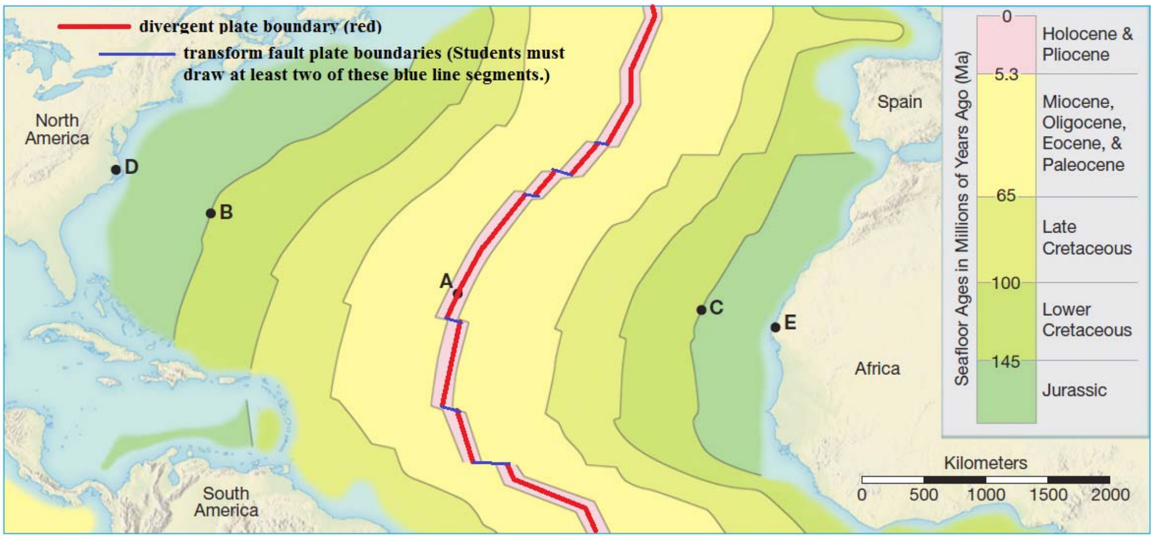
3. Lithospheric earthquakes occur above the line of the to surface of the subducting plate

4. 100 - 150 km



ACTIVITY 2.4 ANSWERS AND EXPLANATIONS

2.4A.



2.4B. Although points B and C were together 145 million years ago, they did not spread apart at exactly the same rate on opposite sides of the mid-ocean ridge. You can tell this because distance A-B is greater than distance A-C.

2.4C. How far apart are points B and C today? __~ 4000__ km

1. 4000 km ÷ 145 million years = 27.6 km/m.y.

2. There are 1000 m/km and 1000 mm/m, so there are 1,000,000 mm/km.

   27.6 km × 1,000,000 mm/km = 27,600,000 mm

   27,600,000 mm ÷ 145,000,000 yr = 0.19 mm/yr

2.4D. When Africa and North America were together as part of one continent, points D and E were at the same location. They are now about 5400 to 5500 km apart (depending on how students measure the distance).

5400 km ÷ 27.6 km/m.y. = 195 m.y. AND 5500 km ÷ 27.6 km/m.y. = 199 m.y., so students should determine that Africa and North America were part of the same continent **about 195 - 200 m.y. ago (Early part of the Jurassic Period according to Figure 1.3 on page 4 of the Lab Manual).**

2.4E. 2011 − 1776 = 235 yr AND 235 yr × 0.19 mm/yr = 44.6 mm
So, 44.6 mm × 0.001 m/mm = 0.0446 m

Students should calculate that Africa and North America have moved apart by only a small fraction of one meter since the United States formed in 1776.

ACTIVITY 2.5 ANSWERS AND EXPLANATIONS

2.5A. **1.** If the rock body formed 25 million years ago, and faulting displaced parts of it from 320 km (the minimum separation in Figure 1.10) to 380 km (the maximum separation in Figure 1.10), then the rate of motion is from

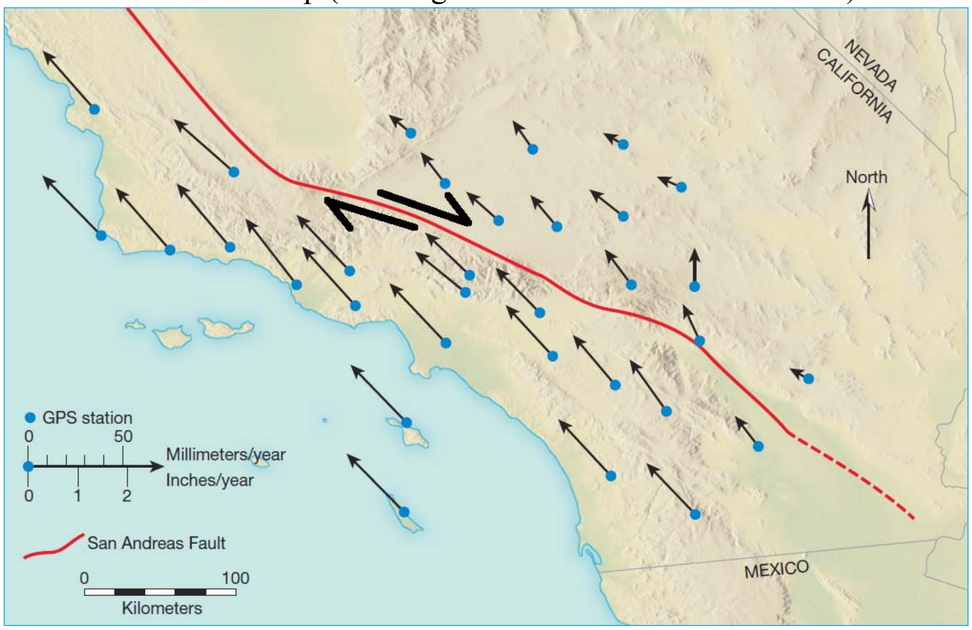
320 km /25 m.y. to 380 km/25 m.y., or
32,000,000 cm/25,000,000 yr to 38,000,000 cm./25,000,000 yr, or
32 cm/25 yr to 38 cm/25 yr, which equals: **1.2 to 1.5 cm/yr**.

2. Students have already found that offset along the fault is about 320–380 km, or 320,000–380,000 meters. So 320,000–380,000 meters ÷ 5 meters/offset equals 64,000–76,000 earthquakes with 5 meter offsets in the past 25 million years.

64,000 to 76,000 earthquakes/25,000,000 years = **64 to 76 earthquakes/25,000 yr, or one 5m earthquake every 390 to 329 years.**

2.5B. **1.** The North American Plate (north of the red San Andreas Fault) is moving about 20 mm/yr. The Pacific Plate (south of the red San Andreas Fault) is moving about 40 mm/yr. So, the **Pacific Plate is moving about twice (2 times) as fast as the Pacific Plate here.**

2. Note half arrows on map (showing the relative motion of the fault).



ACTIVITY 2.6 ANSWERS AND EXPLANATIONS

2.6A. **1.** From 4.7–1.6 million years ago the plate moved about 300 km west-northwest. This is a rate of:

30,000,000 cm ÷ 3,100,000 yr = **9.7 cm/yr west-northwest**

2. From 1.6 million years ago to now, the plate has moved about 255 km almost due northwest (as measured from the easternmost volcano on Molokai to Kilauea volcano on Hawaii). This is a rate of:

25,500,000 cm ÷ 1,600,000 yr = **15.9 cm/yr due northwest**

3. The Pacific Plate has moved about 1.6 times faster (and in a more northerly direction) over the past 1.6 million years than it moved from 4.7– 1.6 million years ago.

4. The Emperor Seamount chain and the Hawaiian Island chain seem to be one long chain of volcanic islands. The Emperor Seamount chain seems to be an older chain of islands that formed like the Hawaiian Island chain did—from volcanic activity beneath the Pacific Plate as the plate moved over the Hawaiian Hot Spot in the mantle.

Note: You can simulate how a hot spot "burns" a line of volcanoes into a plate moving over it. Remove the cover from a very large (poster size) permanent black felt-tip pen and place it tip-up on a table. Hold the pen while you slowly slide a piece of white paper over the pen tip. The ink from the pen will bleed through the paper. If you do this with a very slow motion and stop periodically, then you will create a pattern of islands separated by lines.

5. From 60 million to 40 million years ago, the Pacific Plate moved almost due north over the Hawaiian Hot Spot. Since 40 Ma, the Pacific Plate has moved nearly due northwest over the Hawaiian Hot Spot (with minor variations as noted in Question 15c above).

ACTIVITY 2.7 ANSWERS AND EXPLANATIONS

2.7A. **1.** The circular deformation zones that formed over the Yellowstone Hot Spot have ages ranging from 13.8 million years old in the southeast to 0.5 million years old in the northeast part of the chain. Therefore, the oldest deformation zone must have formed and moved southwest away from the hot spot. The North American Plate is, therefore, moving southwest over the Yellowstone Hot Spot.

2. The North American Plate has moved about 350–400 km over the past 11 million years, so its average rate of motion has been:

35,000,000 to 40,000,000 cm ÷ 11,000,000 yr = **3.2 to 3.6 cm/yr**

2.7B **1.** The plate east of the ridge has moved about 230 km over the past 8 million years, so the average rate of seafloor spreading east of the ridge has been 23,000,000 cm ÷ 8,000,000 yr = **2.9 cm/yr**.

2. The seafloor rocks that should be present along line segment C-D must have subducted beneath the North American Plate as it moved westward (southwestward).

3. The plate boundary along the red line in Figure 2.12 must be a **convergent plate boundary** with a subduction zone.

4. As seafloor subducts along line segment C-D it undergoes heating along the geothermal gradient. The water acts as a flux to superjacent rocks of the mantle wedge and eventually causes them to undergo hydration and partial melting (flux melting). The resulting magma rises to form the Cascade Range of volcanic mountains.

ACTIVITY 2.8 ANSWERS AND EXPLANATIONS

2.8A. **1.** about 750° C
2. about 1000° C
3. solid (It is left of the solidus in the field labeled 100% solid peridotite rock.)
4. It would partially melt. If you move point X to the right until it is below the temperature of 1750° C, then it is located in the field of partial melting, between the solidus and liquidus.
5. It would melt completely because it would be located in the field to the right of the liquidus, which is labeled 100% liquid magma.

2.8B. **1.** about 40 km and 13,000 atm
2. decompression melting
3. Decompression melting could occur where a plume of hot mantle peridotite (red in Figure 2.6) rises to a shallower depth and lower pressure where melting can occur. This may be happening along divergent plate boundaries (like ocean ridges and rifts) and at hot spots.

2.8C. To begin partial melting, the peridotite at point X in Figure 2.7 must be uplifted to a depth of about 40 km (and a pressure of about 13,000 atm) or else it must be heated to about 1450° C.

2.8D. **1.** The wet sugar cube melted first.
2. water
3. The solidus, liquidus, and all fields would move to the left (to lower temperatures).
4. subduction zones

2.8E. **1.** divergent plate boundary
2. decompression melting
3. A mass/plume of hot mantle peridotite rises close to Earth's surface, where it encounters lower pressure and melts to form basaltic magma. The magma erupts along the oceanic ridge, where it pushes the existing rock plate apart. This pushes the plates and starts the process of seafloor spreading.

2.8F. **1.** convergent plate boundary
2. flux melting
3. Wet seafloor basalt subducts beneath the less dense continental edge of an adjacent plate. The basalt dehydrates and hydrates the base of the continental crust. Flux melting causes formation of magma, which rises to form a line of volcanoes (volcanic arc).

LABORATORY THREE
Mineral Properties, Uses, and Identification

OBJECTIVES AND ACTIVITIES

A. Understand how to analyze samples of minerals for seven common properties (color, crystal habit and form, luster, streak, hardness, cleavage, fracture) and six other properties (tenacity, reaction with acid, magnetism, striations, exsolution lamellae, specific gravity).

ACTIVITY 3.1: Mineral Properties (p. 57-69, 79-80)
ACTIVITY 3.2: Analysis and Classification of Crystal Forms (p. 60-78, 81)
ACTIVITY 3.3: Determining Specific Gravity (SG) (p. 69-78, 82)

B. Be able to identify common minerals (in hand samples) on the basis of their properties and infer how they are (or could be) used by people.

ACTIVITY 3.4: Mineral Analysis, Identification, and Uses (p. 78, 83-88)

STUDENT MATERIALS (Remind students to bring items you check below.)

_____ laboratory manual
_____ laboratory notebook
_____ pencil with eraser
_____ colored pencils (two different colors)
_____ calculator
_____ Cleavage goniometer cut CAREFULLY and EXACTLY from GeoTools sheet 1
_____ mineral samples with identifying numbers/letters (or provided by instructor)
_____ other mineral analysis tools (see below, or provided by instructor)
_____ hand lens (optional, or provided by instructor)

INSTRUCTOR MATERIALS (Check off items you will need or provide.)

ACTIVITY 3.1: Mineral Properties (p. 57-69, 79-80):
_____ extra colored pencils (two colors: for students who forgot them)

ACTIVITY 3.2: Analysis and Classification of Crystal Forms (p. 60-78, 81):
_____ samples of sucrose crystals (coarse table sugar), epsomite crystals (Epsom salt), and halite (coarse table salt) for part B (optional).