INSTRUCTOR’S RESOURCE GUIDE

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LABORATORY MANUAL IN PHYSICAL GEOLOGY

NINTH EDITION

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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.

2. 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.
   - Instructor Resource Center (IRC) on CD-ROM.

3. 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 ninth edition is the same as it was in the eighth edition.**

5. Review and modify the lists of Student 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 ensure that you know exactly what to assemble for the laboratory.**

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

7. **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.

8. **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)

_____ 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.


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.


**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.

<table>
<thead>
<tr>
<th>SPHERE</th>
<th>ACTUAL THICKNESS</th>
<th>THICKNESS IN MM, IF THE GEOSPHERE IS THE SIZE OF A BASKETBALL</th>
</tr>
</thead>
<tbody>
<tr>
<td>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.</td>
<td>16 km</td>
<td>0.3</td>
</tr>
<tr>
<td>Hydrosphere: mostly water (H₂O, ocean) in a liquid state.</td>
<td>0.7 km</td>
<td>0.07 (Draw in blue)</td>
</tr>
<tr>
<td>Crust: mostly oxygen (O), silicon (Si), aluminium (Al), and iron (Fe).</td>
<td>25 km</td>
<td>0.47</td>
</tr>
<tr>
<td>Mantle: mostly oxygen (O), silicon (Si), magnesium (Mg), and iron (Fe) in a solid state.</td>
<td>2900 km</td>
<td>54.2</td>
</tr>
<tr>
<td>Outer Core: mostly iron (Fe) and nickel (Ni) in a liquid state.</td>
<td>2250 km</td>
<td>42.0</td>
</tr>
<tr>
<td>Inner Core: mostly iron (Fe) in a solid state.</td>
<td>1196 km</td>
<td>22.3 mm</td>
</tr>
</tbody>
</table>

### 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**

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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 cm³/mL = 25.4 cm³
6. 1.3 liters x 1000 cm³/L = 1300 cm³

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 cm².)

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/cm³:

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 cm³), so students should record the starting volume of water in cm³.

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:

\[
\text{Ending mass of water (g) – starting mass of water (g)} \div \text{Ending volume of water (cm}^3\text{) – starting volume of water (cm}^3\text{)} = \text{about 1 g/cm}^3
\]

1.3F. Students will determine that their clay has a density greater than 1 g/cm³. Most
brands are between 2 g/cm³ and 4 g/cm³. There are two main methods/procedures that students use to determine this.

**Method 1 procedures:**

a. Construct a cubic centimeter of clay (1 cm³ of clay).

b. Weigh the cm³ 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/cm³).

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 the shape of a ship.)

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 1 g/cm³, they should be able to infer:

1. \( ρ_{\text{atmosphere}} = \_\_\_ < 1 \_\_\_ g/cm³ \)

2. \( ρ_{\text{lithosphere}} = \_\_\_ > 1 \_\_\_ g/cm³ \)

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 (cm³). 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.

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

\[ H_{\text{below}} = \left( \frac{\rho_{\text{wood}}}{\rho_{\text{water}}} \right) H_{\text{block}} \]

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:

\[ H_{\text{above}} = 1 - \left[ \left( \frac{\rho_{\text{wood}}}{\rho_{\text{water}}} \right) H_{\text{block}} \right] \]

1.4E. The density of water ice (in icebergs) is 0.917 g/cm³. The average density of (salty) ocean water is 1.025 g/cm³.

1. \% below = \( \left( \frac{0.917 \text{ g/cm}^3}{1.025 \text{ g/cm}^3} \right) \times 100\% = 89.5\% \)

2. \% above = \( 100\% - \left[ \left( \frac{0.917 \text{ g/cm}^3}{1.025 \text{ g/cm}^3} \right) \times 100\% \right] = 10.5\% \)

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/cm³ to 3.3 g/cm³. However, they should still determine that the average density of all 10 basalt samples is about 3.1 g/cm³.

1.5B. Student values for the density of pieces of granite that they personally analyze will vary from about 2.7 g/cm³ to 3.2 g/cm³. However, they should still determine that the average density of all 10 granite samples is about 2.8 g/cm³.

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

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

3. \[ 5.0 \text{ km} - 0.3 \text{ km} = 4.7 \text{ km} \]

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 one 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)