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A Sneak Peek at the New Edition of the AGI/NAGT Lab Manual in Physical Geology with the Author-Editor

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The AGI/NAGT Laboratory Manual in Physical Geology, 12th Edition is now in print and available for adoption!
Available in *Spiral-bound paper*, as an *eText*, and as a *custom lab book* in which you choose the chapters you want to use.
Available in *Spiral-bound paper*, as an *eText*, and as a *custom lab book* in which you choose the chapters you want to use.

The *Instructor’s Manual* is available for the 12th edition, containing answers, hints, links, and references for the lab manual content.

*Mastering Geology*
This Laboratory Manual is unique.

- It was created and is maintained by the geosciences community as a community educational resource
This Laboratory Manual is unique.

- It was created and is maintained by the geosciences community as a community educational resource
- Proceeds from its sale provide financial support for the work of NAGT and AGI, benefitting the entire geoscience community
“the best laboratory investigations written by geology teachers”

Robert Ridky
Topographic Maps

Big IDEAS
Topographic maps are two-dimensional representations of three-dimensional landscapes viewed from above. The horizontal positions of landscape features are given relative to a coordinate reference frame and are represented at consistent scale throughout the map. The third dimension, the elevation of the ground surface, is represented with contours that join points of equal elevation relative to sea level. The three-dimensional and quantitative aspect of topographic maps make them valuable to geologists and other people who want to know the shapes, elevations, and spatial scales of Earth’s surface. They can be used in combination with orthoimages—aerial photographs that have been adjusted to the same scale as the map—in the study of Earth’s surface processes and landforms.

Lab ACTIVITIES
9.1 Map and Google Earth Inquiry (p. 253)
9.2 Map Locations, Distances, Directions, and Symbols (p. 255)
9.3 Topographic Map Construction (p. 257)
9.4 Topographic Map and Orthoimage Interpretation (p. 258)
9.5 Relief and Gradient (Slope) Analysis (p. 261)
9.6 Topographic Profile Construction (p. 263)
GPS—Global Positioning System

The Global Positioning System (GPS) is a technology that allows us to locate points on Earth with great accuracy. GPS has become woven into the fabric of our lives and is used for everything from keeping track of where people, cars, and even pets are located to its scientific use in geodesy—the science of measuring changes in Earth's size and shape and the position of points on its surface over time. The GPS technology operated by the U.S. government is based on a constellation of about 30 satellites whose orbits are designed so that a minimum of 6 satellites will be above the horizon at any point on Earth at any time. We access the GPS system through small GPS receivers—either handheld receivers like those used by hikers or receiver circuitry that is built into consumer products such as smartphones and navigation systems in cars.

The accuracy of a GPS location depends on several variables, but is generally in the range of about ±3 to 9 meters for consumer GPS receivers. The GPS systems used by surveyors and geoscientists can have uncertainties that are much less than 1 meter, but achieving that kind of accuracy is significantly more difficult and costly.

UTM—Universal Transverse Mercator System

The U.S. National Imagery and Mapping Agency (NIMA) adapted and improved on the Mercator Projection in 1945 and developed the Universal Transverse Mercator (UTM) coordinate system. Unlike the latitude-longitude grid that is spherical and measured in degrees, minutes, and seconds, the UTM grid is rectangular and measured in meters. The full specification of a location in the UTM system requires four elements: zone, latitude band (or hemisphere), easting, and northing.

UTM Zones and Latitude Bands

The UTM grid (top of Fig. 9.6) is based on 90 north–south zones, which are strips of longitude with a width of 6°. The zones are consecutively numbered from Zone 01 (between 180° and 174° west longitude) at the left margin of the grid to Zone 60 (between 174° and 180° east longitude) at the east margin of the grid. Each zone has a north–south central meridian that is perpendicular to the equator (Fig. 9.6). A version of UTM based on the Military Grid Reference System (MGRS) divides the zones into east–west segments called latitude bands that are identified by different letters (Fig. 9.6). Latitude bands are lettered consecutively from C (between 80° and 72° south latitude) through X (between 72° and 84° north latitude) and are 8° long except for band X, which is 12° long. Letters I and O are not used because they could be confused with numbers 1 and 0.

Easting and Northing

Points located along a
**Topographic Map and Orthoimage Interpretation**

**Activity 9.4**

- **Figure A5.4.1** is a portion of the 1960 SP Mountain, AZ 1:50,000 topographic quadrangle map. The black 1 km by 1 km UTM grid is NAD83, Zone 12S. Also note the 1 mi. by 1 mi. FLS85 grid sections with red numbers in their corners.

1. What is the point of highest elevation on the map, and how can you tell?

2. Draw a small "x" over the point of lowest elevation on the map, and label it with the elevation.

3. What is the total relief of SP Mountain measured from its base to the north of the peak up to its highest elevation? ___ ft.

4. Circle the four places within the map where streams (blue) begin. How can you tell which direction is upstream based on the contours?

5. Notice that there is an SP Mountain and an SP Crater. How can you tell which part is the crater? Color it red.

**DISCUSS** The elevations in Fig. 9.1C are sea level. What is the contour interval of the map? How did you determine it?
**Activity 9.4**

Topographic Map and Orthoimage Interpretation

Name: ____________________________  Course/Section: ____________________________  Date: ____________________________

**Figure A9.4.1** is a portion of the 1996 SP Mountain, AZ 7.5-minute topographic quadrangle map. The black 1 km by 1 km UTM grid is NAD27, Zone 12S. Also note the 1 mi. by 1 mi. FUSE grid sections with red numbers in their corners.

1. What is the point of highest elevation on the map, and how can you tell?

2. Draw a small "x" over the point of lowest elevation on the map, and label it with the elevation.

3. What is the total relief of SP Mountain measured from its base to the north of the peak up to its highest elevation? ______ ft.

4. Circle the four places within the map where streams (blue) begin. How can you tell which direction is upstream based on the contours?

5. Notice that there is an SP Mountain and an SP Crater. How can you tell which part is the crater? Color it red.

**DISCUSS** The elevations in Fig. 9.1C are sea level. What is the contour interval of the map? How did you determine it?
**Activity 17.5**

**The Climate Record from Cores**

**Learning Goal:** You will examine the 800,000-year record of climate indicators that are preserved in the ice of Greenland and Antarctica in marine sediments, and learn how these indicators can be used to determine past climate change.

**Course/Session:**

Name: ___________________________

1. What is the difference between the northern and southern hemispheres in terms of temperature and precipitation?

2. Calculate the CO2 concentration.

3. Use the ratio.

4. Convert the concentration to ppm.

5. Extend the concentration.

**Figure A17.5.2** also related to this lab:

1. Plot your answers.

2. This chapter is a great example of the concentration of CO2.

3. Talk with your class about the concentration of CO2.

**Figure A17.5.1** shows the carbon dioxide (CO2) and CH4 concentration over the past 800,000 years in ice cores collected in Greenland and Antarctica. The data indicates that CO2 concentration has been high during glacial periods and low during interglacial periods. The CH4 concentration has been high during interglacial periods and low during glacial periods.

1. Examine the trend in CO2 and CH4 concentration between 1000 and 1800 AD as shown in Figure A17.5.1. In the space that follows, briefly describe the characteristics of the trend.

2. Examine the trend in CO2 and CH4 concentration between 1900 and 2020 AD as shown in Figure A17.5.1. In the space that follows, briefly describe the characteristics of the trend.

**Figure A17.5.2** displays the time series of CO2 concentration from ice cores (ppm) and CH4 concentration from ice cores (ppm) with vertical stripes indicating interglacial periods.

1. Examine the time series on Figure A17.5.2, noting the time periods where CO2 concentration is highest.

2. Examine the time series on Figure A17.5.2, noting the time periods where CH4 concentration is highest.

**Figure A17.5.3** shows the time series of CO2 concentration from ice cores (ppm) and CH4 concentration from ice cores (ppm) with vertical stripes indicating interglacial periods.

1. Examine the time series on Figure A17.5.3, noting the time periods where CO2 concentration is highest.

2. Examine the time series on Figure A17.5.3, noting the time periods where CH4 concentration is highest.

---

**17 chapters (laboratories) 105 lab activities**
Students collaborating with a customized version of the Lab Manual.
What’s New in the 12th Edition?

- New Lab: *Earth’s Dynamic Climate* with 6 activities and 4 new lab videos
- Growing emphasis on Earth systems
- 17 new or significantly revised lab activities
- Over 100 new photographs. High-res specimen photos constructed using focus stacking.
- About 150 new or revised graphics by Dennis Tasa
- Learning goals stated for each lab activity
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Earth System Science

Geoscientists think about Earth as a system. Earth system science is the study of the connections and interactions between the major parts of the planet, also known as Earth’s spheres: the geosphere, atmosphere, hydrosphere, cryosphere, and biosphere. Studies of these components over the past few decades have revealed that we live in a far more dynamic and complex world than we previously imagined. The goal of Earth system science is to understand how the planet works and answer questions about global change—past, present, and future. Clearly, any attempt to construct a model of something as large, old, and complex as Earth faces some serious challenges. To achieve this goal, we must narrow our field of view, carefully sample often-widespread phenomena, and make generalizations about how the Earth system functions. Despite limitations, such studies have provided deeper insights into the interconnected nature of Earth’s major systems.

Building Better Models

Geoscientists are now able to model major global interactions, from the effects of atmospheric winds on the circulation of the oceans, the role of thermal convection on worldwide volcanism, and the effects of mountain building and uplift on climate to the transfer of carbon through Earth’s biosphere and other systems. Such integrated studies increasingly reveal that humankind is not an independent variable in the Earth system. We play an increasingly significant role, and our quest for natural resources affects systems as diverse as the rock cycle and global ecology. Humans are also affected by global change, from short-term natural hazards such as earthquakes, volcanoes, and tsunamis to processes like El Niño and changes in global climate. Looking ahead, the exponential growth in data gathering networks and computer processing power has set the stage for us to improve upon our predictions of what Earth’s future and ours might hold.

Global Connections

By looking at Earth as a system you will discover numerous connections between topics in this lab manual. Our approach will be to begin with small steps and focus on organization or structure in systems. The structure of the geosphere, or rocky part of the planet, is probably already familiar. Earth’s core, mantle, and crust form concentric layers differentiated by their physical properties. To go a step further and seek understanding about how Earth systems work, we must find out about key processes. Processes cause systems to change in some way. More specifically, we want to consider the flow or transfer of energy and matter into, within, and out of systems. To return to our geosphere example, Earth’s largest reservoir of heat is found at great depth in the core and mantle rocks.
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• 17 new or significantly revised lab activities

•

•

•
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High-resolution photograph in the Lab Manual 12th edition created using focus stacking
High-resolution photograph in the Lab Manual 12th edition created using focus stacking
High-resolution photograph in the Lab Manual 12\textsuperscript{th} edition created using focus stacking
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- About 150 new or revised graphics by Dennis Tasa
- Learning goals stated for each lab activity
Learning GOAL: You will be able to recognize the direction of motion of one plate as observed from another plate across a mid-ocean ridge, given the trends of two axial riffs and the ridge-ridge transform fault between them. You will also use vector arrows to represent plate motion in a reference frame that is external to the plates—a “no-net-rotation” or NNR reference frame—and estimate the position of this ridge-fault-ridge system ~2 million years (Myr) in the future.

Important Reminder: We can only measure a velocity or a displacement (the movement from an initial location to a different location) relative to some reference frame. Before we describe a velocity or a displacement, it’s important to ask the question “velocity relative to what?”

A Motion of Plates Relative to Each Other Across a Shared Boundary. Figure A2.1.1 is a sketch map of the Atlantis Transform Fault and adjacent axial riffs along the northern Mid-Atlantic Ridge. The parallel red lines between points 1 and 2 and points 3 and 4 represent axial riffs along the ridge, and the bold black line is the transform fault along which the two plates move past each other.

![Figure A2.1.1](image)

1. Starting at the yellow star along the axial rift between points 1 and 2, draw a vector arrow on the African Plate that is approximately parallel to the transform fault, pointing toward the interior of the African Plate. (The vector arrow is started for you.) Starting at the same yellow star, draw a vector arrow in the opposite direction on the North American Plate, pointing toward the interior of the North American Plate. These arrows indicate the sense of divergent plate motion across the ridge as the two plates spread apart. Do the same at the yellow star between points 3 and 4 along the ridge axis. (See Fig. 2.1B-C for guidance.)

2. Using the arrows you just drew as a guide, draw one arrow on each side of the transform fault, parallel to the fault line, to indicate the sense of relative plate motion across the fault.

3. As viewed from point 2, point 3 is located toward the east southeast (azimuth ~102°). Viewed in the opposite direction, point 2 is toward the west-northwest (~282°) as seen from point 3. In what general direction is the African Plate moving relative to the North American Plate?

   Direction: ________________________

   This blank space is the cut-out area for Fig. A2.1.3 on the next page.

B Plate Motion in an External Reference Frame

1. Carefully use scissors to cut along the dashed line in Fig. A2.1.3, making separate maps of the North American and African Plates near the Atlantis Transform Fault.

2. Place the two halves of the cut-out map on Fig. A2.1.2 so that points 1, 2, 3 and 4 are all aligned. The result is what the boundary looks like today.
3. Move the two cut-out maps so that points 1 and 4 on the North American Plate coincide with points 1$_n$ and 4$_n$ on Fig. A2.1.2 and points 1 and 4 on the African Plate coincide with points 1$_n$ and 4$_n$.

4. Use a pencil to trace the 1$_n$ – 2$_n$ – 3$_n$ – 4$_n$ boundary on Fig. A2.1.2 and do the same for the 1$_a$ – 2$_a$ – 3$_a$ – 4$_a$ boundary. These traced lines mark where the oceanic crust along today's plate boundary will likely be after 2 Myr, as observed in a NNR reference frame external to the plates.

5. Using the lines you just drew, assume that the ridge will be located halfway between 1$_n$ and 1$_a$ and halfway between 2$_n$ and 2$_a$ after 2 Myr of spreading. Carefully draw that ridge axis on Fig. A2.1.2 and do the same halfway between points 3$_n$ – 3$_a$ and 4$_n$ – 4$_a$.

6. Complete the picture by drawing the transform fault between the ridge ends.

7. You have now made a prediction for where the section of the Mid-Atlantic Ridge around the Atlantis Transform Fault will be located about 2 Myr from today relative to the NNR reference frame.

**C Plate Motion in Different but Related Reference Frames**

1. Draw a vector arrow on Fig. A2.1.2 from point 1 to 1$_n$. This vector is an estimate of the direction of average motion of that point along the North American Plate boundary in the next 2 Myr, as observed in the NNR reference frame. Now, draw a vector arrow from point 1 to 1$_a$, indicating the direction of average motion of the African Plate at that point in the next 2 Myr relative to the NNR frame. Do the same for points 2, 3, and 4.

2. Draw an arrow on Fig. A2.1.2 from point 1$_n$ to point 1$_a$. This vector is an estimate of the average motion of point 1 on the African Plate as observed from the North American Plate. Do the same for points 2, 3, and 4.

3. Use the map scale to estimate the distance the African Plate will move in the next 2 Myr along the Atlantis Transform Fault, as observed from the North American Plate. (Hint: Measure the 2$_n$ – 2$_a$ or 3$_n$ – 3$_a$ distances.)

   Answer: _________ km

4. Approximately what will be the width of new crust developed along the Mid-Atlantic Ridge between Africa and North America near the Atlantis transform fault during the next 2 Myr? (Hint: Think about your answer to the previous question.)

   Answer: _________ km
From the 10th Edition
B. The above map shows some Global Positioning System (GPS) reference stations and observations from the JPL-NASA GPS Time Series website at [http://sidshow.jpl.nasa.gov/post/series.html](http://sidshow.jpl.nasa.gov/post/series.html). Length of the arrows indicates absolute plate motion, the direction and rate that the plate is moving in mm/yr at the GPS station (which is attached to bedrock of the plate).
1. Velocities measured at several GPS stations in southern California are shown in Fig. A2.2.2. The length of the arrow provides the speed of the GPS site, measured in a reference frame called NAM08 that is fixed to the stable interior of the North American Plate—the area east of the Rocky Mountains. Longer arrows indicate faster motion, and an arrow that is 25 mm long on the map represents a speed of 50 mm/yr. The data for this map were derived from UNAVCO’s GPS Velocity Viewer (https://www.unavco.org/software/visualization/GPS-Velocity-Viewer/GPS-Velocity-Viewer.html) on February 28, 2019.
New/Revised in the Minerals Lab

Mineral Luster, Diaphaneity, Streak, and Color

Activity 3.1

Name: ___________________________  Course/Section: _______________  Date: __________

Learning GOAL  You will gain some practical knowledge and experience with characterizing some optical properties of mineral specimens that will be helpful to you in identifying minerals.

A. Determine whether each specimen in Fig. A3.1.1 displays a metallic or non-metallic luster. For each non-metallic specimen, decide whether one of the following additional luster terms should also be used: vitreous, silky, or earthy. Write your interpretation for each under its photograph.
Four minerals are shown in **Fig. A3.1.2**. Along with specimen 4 is a photo taken using a microscope showing a thin section of the same type of mineral. Light passes through the thin section from below before it passes into the microscope. For each mineral, characterize its diaphaneity as either opaque, translucent, or transparent. Write your interpretation for each under its photograph.

Several mineral specimens are shown in **Fig. A3.1.3** along with their streak across a streak plate. For each, use information from **Fig. 3.22** to form a tentative identification—one or two likely minerals—and write your interpretation for each under its photograph.

---

**Figure A3.1.3 ▲**
D The eight specimens shown in Fig. A3.1.4 commonly occur with a specific color or within a narrow range of colors. For each, use information from Figs. 3.19–3.22 to form a tentative identification—one or two likely minerals. Write your interpretation for each specimen under its photograph.

E Several specimens of quartz are shown in Fig. A3.1.5. Use information from Fig. 3.22 to identify the variety of quartz depicted, based on the color of each specimen. Write your interpretation for each specimen under its photograph.
Learning GOAL  You will examine some minerals that have well-developed faces so that you can determine the mineral form. Other specimens have been broken, and you will examine their cleavage or fracture. Learning to observe these characteristics provides another tool to help you identify minerals.

A  Three types of minerals are shown in Fig. A3.2.1. Use the information in Fig. 3.7 to describe whether each mineral displays a closed form or a combination of open forms. Then specify which form(s) are found in each of the three types of mineral. Write your interpretation under the corresponding photograph(s).

![Minerals](image)

Figure A3.2.1

B  Snowflakes are ice crystals that form in the atmosphere and sometimes fall to Earth’s surface. The two photographs of snowflakes in Fig. A3.2.2 were taken by Kenneth Libbrecht of Caltech and show a symmetric pattern of growth.

1. How many arms does snowflake 1 have?  
   ______. How many sides does the inner part of snowflake 2 have? ______. How many arms does snowflake 2 have? ______

2. There are six crystal families: isometric or cubic, tetragonal, orthorhombic, monoclinic, triclinic, and hexagonal. Using the number of arms on a snowflake as a hint, what crystal system do ice crystals belong to?  
   _____________. What is the basis for your interpretation?
Photographs of five mineral specimens that display cleavage are shown in Fig. A3.2.3. Dashed lines indicate the orientation of cleavage faces on the sides of most of the specimens, and the type of surface on the front of the specimens is indicated. Use your observations along with Figs. 3.7 and 3.22 to answer the following two questions for each specimen: How many directions of cleavage does each specimen have, and what mineral might this be? It’s OK if your tentative identification includes more than one possibility. Write your responses under the corresponding photograph(s).

Figure A3.2.3 ▲
Mineral & Rock ID Tables

A Flow Chart for Identifying Minerals

Flow Chart for Identifying a Mineral Specimen
Using the Tables in Figs. 3.19–3.22

1. Describe its luster
   metallic/submetallic (M) (Fig. 3.19)
   nonmetallic (NM)
   dark-to medium-color
   (Fig. 3.21)
   light color
   (Fig. 3.21)

2. Describe its hardness (H)
   harder than glass
   softer than glass
   yes

3. Does it have well-defined cleavage planes?
   In how many directions?
   no

4. What are its other major characteristics?
   color
   streak
   crystal form or habit
   density/specific gravity (SG)
   reaction with acid
   smell
   taste
   tenacity
   magnetism
   twin striations
   exsolution
   lamellae

5. Compare the set of observed characteristics with the information in Figs. 3.19–3.21 to form a tentative identification of the mineral.

Then try to refine the identification using the mineral database in Fig. 3.22

Figure 3.18 Flow chart for identifying minerals.
A Field Classification of Igneous Rocks

**Primary Observable Characteristics for Classifying Igneous Rocks**

**Step 1: Estimate the Color Index -- Percentage Mafic (Dark) Minerals in the Specimen**

<table>
<thead>
<tr>
<th>Percentage</th>
<th>Light</th>
<th>Medium</th>
<th>Dark</th>
<th>Entirely Dark</th>
</tr>
</thead>
<tbody>
<tr>
<td>10%</td>
<td>![Image]</td>
<td>![Image]</td>
<td>![Image]</td>
<td>![Image]</td>
</tr>
<tr>
<td>35%</td>
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<td>![Image]</td>
<td>![Image]</td>
</tr>
<tr>
<td>100%</td>
<td>![Image]</td>
<td>![Image]</td>
<td>![Image]</td>
<td>![Image]</td>
</tr>
</tbody>
</table>

**Step 2: Identify the Major Mineral Composition**

- **Felsic Minerals**
  - quartz: hard (H 7); translucent; colorless to gray; seems to fill space between other grains; conchoidal (glassy) fracture
  - plagioclase feldspar: hard (H 6); Na-rich varieties are white, cream or colorless; Ca-rich are gray, bluish, or colorless; might have thin parallel twins; 2 cleavage directions at ~90°
  - alkali feldspar: hard (H 6); Na-rich varieties are white, cream or colorless; K-rich varieties are salmon pink-red, white, colorless; 2 cleavage directions at 90°
  - muscovite mica: colorless, light brown or gray color; 6-sided tabular crystals that cleave into very thin flexible transparent sheets
  - amphibole (hornblende): hard (H 5-6); black, dark gray or dark green; 2 cleavage directions at 56° and 124°; tabular to diamond-shaped (parallelgram)
  - pyroxene (augite): hard (H 5-6); green, dark green, brown, or black; 2 good cleavage directions at ~90°; stubby 6-sided or tabular
  - olivine: hard (H 5.5-7); green; transparent to translucent; conchoidal (glassy) fracture
  - biotite mica: black to dark brown; 6-sided tabular crystals that cleave into very thin flexible translucent sheets

- **Mafic Minerals**

**Step 3: Describe the Texture**

- **Intrusive**
  - phaneritic: mineral grains ≥0.25 mm across and can be very large
  - phaneritic-porphyrctic: larger mineral grains (phenocrysts) in a groundmass of phaneritic grains
  - aphanitic: very small mineral grains (≤0.25 mm) that cannot be visually identified without magnification
  - aphanitic-porphyrctic: larger phenocrysts in a groundmass of aphanitic mineral grains
  - eutaxitic: glass formed by very rapid cooling; few if any mineral grains
  - porphyritic: round holes in the rock formed by gas trapped during crystallization
  - vesicular: very light weight (low bulk density); resembles foam; dry specimens float; thin vesicle walls; glassy
  - fragmental or pyroclastic: ash and other material from an eruption; transported through air and deposited

*Figure 5.21 Observable characteristics of common igneous rock types.* Refer to relevant sections in the text for full discussion of the color index, major minerals, and textures of igneous rocks. These characteristics are used in Fig. 5.22 to identify selected igneous rock types.
A Field Classification of Igneous Rock in Hand Specimen

1. Color Index (CI).
Estimate the % of mafic minerals in the rock specimen.

CI: ~0-40%*  ~15-50%*  ~35-65%  90-100%

Identify the major minerals in the rock.
Find the vertical column that includes the same minerals you see in the rock.
That column points toward a tentative interpretation in the table below.

3. Texture. Identify the texture(s).

4. Interpretation. Select the rock name below, based on data from steps 1-3 and Fig. 5.21.
Review the descriptions in the text for further details about each rock type.

**Table:**

<table>
<thead>
<tr>
<th>Intrusive</th>
<th>Extrusive</th>
<th>Peridotite</th>
</tr>
</thead>
<tbody>
<tr>
<td>granite</td>
<td>rhyolite</td>
<td>basalt</td>
</tr>
<tr>
<td>porphyritic granite</td>
<td>porphyritic rhyolite</td>
<td>porphyritic basalt</td>
</tr>
<tr>
<td>diorite</td>
<td>andesite</td>
<td>vesicular basalt</td>
</tr>
<tr>
<td>porphyritic diorite</td>
<td>porphyritic andesite</td>
<td>scoria or cinder</td>
</tr>
<tr>
<td>gabbro</td>
<td>pumice</td>
<td>obsidian</td>
</tr>
<tr>
<td>porphyritic gabbro</td>
<td>pumice resembling froth or foam</td>
<td>tuff</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>obsidian</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*The CI ranges for the two columns on the left are from IUGS classification for field identification of granitic and dioritic rocks.

**Figure 5.22** Igneous rock classification chart. Follow steps 1 through 4 to develop a tentative rock identification, based on observable characteristics summarized in Fig. 5.21.
### A Field Classification of Sedimentary Rocks

<table>
<thead>
<tr>
<th>A</th>
<th>Observed Characteristics</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organic Solids</td>
<td>Brown to black. Partially decayed plant material, can resemble a soil.</td>
<td>peat</td>
</tr>
<tr>
<td></td>
<td>Brown to black. Soft and crumbles easily when dry. Leaves black smudge on fingers.</td>
<td>lignite (brown coal)</td>
</tr>
<tr>
<td></td>
<td>Black, sometimes dark brown. Generally dull luster but can have bright, shiny layers. Harder than lignite, softer than anthracite coal. Leaves black smudge on fingers.</td>
<td>bituminous coal (Fig. 6.11B)</td>
</tr>
<tr>
<td></td>
<td>Black, sometimes with a brown or blue reflection, semi-metallic luster. Harder than a fingernail but softer than copper or steel.</td>
<td>anthracite coal (Fig. 6.11C)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>B</th>
<th>Major Mineral Composition</th>
<th>Observable Texture</th>
<th>Distinguishing Characteristics and Comments</th>
<th>Rock Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calcite or aragonite</td>
<td>clay-sized carbonate grains</td>
<td>readily fizzes with acid, variable color (gray, tan, brown), mostly very fine grains</td>
<td>microcrystalline lts. or micrite</td>
<td></td>
</tr>
<tr>
<td></td>
<td>very fine, bioclastic</td>
<td>typically white or light gray, soft, generally leaves a white powder on fingers</td>
<td>chalk</td>
<td></td>
</tr>
<tr>
<td></td>
<td>intergrown crystals</td>
<td>precipitated mineral grains, typically associated with springs, caves, or geysers</td>
<td>travertine (Fig. 6.7)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>sand-size</td>
<td>carbonate sandstone; carbonate grains of any type cemented together</td>
<td>calcarenite</td>
<td></td>
</tr>
<tr>
<td></td>
<td>sand-size</td>
<td>sand-sized white spheroids (rods-Fig. 6.6) usually cemented with calcite</td>
<td>dolomitic lts.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>sand-gravel, bioclastic</td>
<td>shells and shell fragments cemented in a porous mass; looks like shell granola</td>
<td>coquina (Fig. 6.5)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>sand-gravel, bioclastic</td>
<td>abundant fossils (bivalves, gastropods, coral, etc.) in a carbonate matrix</td>
<td>fossiliferous lts. (Figs. 6.14 &amp; 6.22)</td>
<td></td>
</tr>
<tr>
<td>Dolomite</td>
<td>typically very small intergrown crystals</td>
<td>fizzes in dilute HCl strongly only if powdered; usually light colored (tan, gray); small sparkly grains</td>
<td>dolostone</td>
<td></td>
</tr>
<tr>
<td>Quartz</td>
<td>microscopic grains</td>
<td>hard, scratches glass or steel; wide range of colors; might be precipitated or bioclastic quartz</td>
<td>chert (Fig. 6.23)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>silt &amp; clay-size gr., mostly clay-sized</td>
<td>color varies; might swell when wet; &gt;50% clay-size particles; lacks fissility or obvious fine layering</td>
<td>claystone</td>
<td></td>
</tr>
<tr>
<td></td>
<td>silt &amp; clay-size gr., mostly silt-sized</td>
<td>color varies, tans, grays, &gt;50% silt-size particles; lacks fissility, breaks into blocks or layers</td>
<td>siltstone (Fig. 6.20)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>silt &amp; clay-size</td>
<td>very fine-grained rock that lacks fissility and percentage of clay or silt-size grains is unknown</td>
<td>mudstone</td>
<td></td>
</tr>
<tr>
<td></td>
<td>clay minerals, quartz + others</td>
<td>claystone that breaks along roughly planar surfaces spaced close together (has fissility)</td>
<td>shale (Fig. 6.21)</td>
<td></td>
</tr>
<tr>
<td>Mostly Quartz</td>
<td>quartz sand grains, typically with silica or calcite cement + clay, range of colors</td>
<td>quartz s.s. (Fig. 6.19)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quartz, clay, feldspar, clays, + rock fragments</td>
<td>mostly sand-size grains</td>
<td>mostly sand-size grains with a large component of clay-size grains</td>
<td>muddy s.s. (argillaceous s.s.)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>quartz, feldspar, clays, + rock fragments</td>
<td>quartz &amp; feldspar grains in a clay matrix, often with dark minerals and rock frags; dark gray-green</td>
<td>arkose s.s. (Fig. 6.13)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>fossils in matrix of quartz + other silicates</td>
<td>sandstone containing obvious fossils; range of colors possible</td>
<td>graywacke</td>
<td></td>
</tr>
<tr>
<td></td>
<td>quartz, rock fragments + other silicates</td>
<td>sandstone of any compositional variety containing rock fragments</td>
<td>fossiliferous s.s.</td>
<td></td>
</tr>
<tr>
<td>Various Silicates and Rock Fragments</td>
<td>mostly gravel-size grains</td>
<td>rounded to subrounded gravel-size grains surrounded by finer grains</td>
<td>lithic s.s.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>sandstone containing obvious fossils; range of colors possible</td>
<td>sandstone of any compositional variety containing rock fragments</td>
<td>conglomerate (Fig. 6.17)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>angular to subangular gravel-size grains surrounded by finer grains</td>
<td>coarse to medium gravel-size grains</td>
<td>breccia (Fig. 6.18)</td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>halite</td>
<td>can be clear, white, pink, red; tastes salty, evaporite deposit</td>
<td>rock salt (Fig. 6.10A)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>gypsum, anhydrite</td>
<td>soft enough to be scratched by a fingernail; evaporite deposit</td>
<td>rock gypsum (Fig. 6.54)</td>
<td></td>
</tr>
</tbody>
</table>

Figure 6.25 A system for classifying sedimentary rock in a hand specimen.
### Metamorphic Rock Analysis and Classification

**Step 1:** What are the rock’s textural characteristics?  
**Step 2:** What are the rock’s distinctive features, including composition?  
**Step 3:** Metamorphic rock name  
**Step 4:** What was the likely protolith?  
**Step 5:** What is the rock used for?

<table>
<thead>
<tr>
<th>Textural Characteristics</th>
<th>Distinctive Features</th>
<th>Metamorphic Rock Name</th>
<th>Likely Protolith</th>
<th>Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very fine-grained; slaty cleavage</td>
<td>Dull luster; common colors are black, gray, green, red</td>
<td>SLATE* (Fig. 7.7)</td>
<td>Mudstone or shale</td>
<td>Roofing slate, table tops, floor tile, and blackboards</td>
</tr>
<tr>
<td>Fine- or very fine-grained; phyllicity</td>
<td>Breaks along wrinkled or wavy foliation surfaces with silky or shiny luster</td>
<td>PHYLITE* (Fig. 7.8)</td>
<td>Mudstone, slatelike, or phylite</td>
<td>Construction stone, decorative stone, sources of gemstones</td>
</tr>
<tr>
<td>Schistose; preferred orientation of flat (platy) or elongated mineral grains to form foliation surfaces</td>
<td>Blue amphibole (glauconephane) and blue-gray lawsonite</td>
<td>BLUESCHIST</td>
<td>Mudstone, slate, or phylite</td>
<td></td>
</tr>
<tr>
<td>Mostly muscovite mica; sparkles in reflected light</td>
<td>Greenschist</td>
<td>GNEISS* (Figs. 7.10, 7.12)</td>
<td>Many possible protoliths</td>
<td>Construction stone, decorative stone, gemstone source</td>
</tr>
<tr>
<td>Alternating layers of light and dark mineral grains; might resemble a layered granite rock</td>
<td>Muscovite Schist</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medium- to coarse-grained; can be foliated or granofelsic; might display compositional banding of light and dark minerals</td>
<td>Mostly visible glossy black amphibole (hornblende) in blade-like crystals</td>
<td>AMPHIBOLITE</td>
<td>Basalt, gabbro, other rocks with mafic minerals</td>
<td>Construction stone</td>
</tr>
<tr>
<td>Medium to coarse-grained; can be foliated or granofelsic</td>
<td>Mostly green pyroxene (enstatite and hornblende)</td>
<td>ECLOGITE</td>
<td>Basalt, gabbro</td>
<td>Titanium ore</td>
</tr>
<tr>
<td>Grain size might be difficult to resolve, except for fluorite minerals; foliated or granofelsic</td>
<td>Mostly green-white serpentine minerals</td>
<td>SERPENTINITE (Fig. 7.17)</td>
<td>Basalt, gabbro, or ultramafic rocks</td>
<td>Decorative stone</td>
</tr>
<tr>
<td>Very fine-grained; commonly granofelsic but can be foliated</td>
<td>Mostly talc, but might have micas, chlorite, other minerals</td>
<td>SOAPSTONE</td>
<td>Basalt, gabbro, or ultramafic rocks</td>
<td>Art carvings, electrical insulators, talcum powder</td>
</tr>
<tr>
<td>Coarse- to very-fine-grained; often granofelsic but can be foliated</td>
<td>Mostly calcite or dolomite; calcite fizzes vigorously in HCl, dolomite fizzes weakly unless the rock is ground to a powder.</td>
<td>MARBLE* (Fig. 7.3)</td>
<td>Limestone or dolostone</td>
<td>Art carvings, construction stone, decorative stone, source of lime for agriculture</td>
</tr>
<tr>
<td>Medium- to very-fine-grained; typically granofelsic</td>
<td>Mostly quartz</td>
<td>QUARTZITE* (Figs. 7.13, 7.15)</td>
<td>Quartz sandstone</td>
<td>Construction stone, decorative stone</td>
</tr>
<tr>
<td>Conglomeratic texture; breaks across the clasts</td>
<td>Rock fragments, typically quartz or calcite</td>
<td>META-CONGLOMERATE (Fig. 7.16)</td>
<td>Conglomerate</td>
<td>Construction stone, decorative stone</td>
</tr>
<tr>
<td>Granofelsic texture, fine-grained</td>
<td>Contact-metamorphic rock</td>
<td>HORNFELS (Fig. 7.18)</td>
<td>Any rock type</td>
<td>--</td>
</tr>
<tr>
<td>Black, submetallic luster, no visible grains, layering might be indistinct or absent</td>
<td>Organic solid, no diagnostic minerals; scratched by steel blade</td>
<td>ANTHRACITE COAL</td>
<td>Bituminous coal</td>
<td>Solid fossil fuel</td>
</tr>
</tbody>
</table>

---

* Modify rock name by adding names of minerals in order of increasing abundance, for example, garnet muscovite schist is mostly muscovite with some garnet.

**Figure 7.19** Five-step chart for metamorphic rock analysis and classification.
**Activity 5.6** Estimate Mineral Composition of a Phaneritic Rock by Point Counting

**Learning Goal** You will learn how to use a form of point counting to identify the rock by its composition. This activity also gives you experience with simple counting statistics: the average (mean) and standard deviation.

Geologists sometimes classify rocks using a technique called point counting to estimate the relative abundance of different minerals in a rock. We will use a similar method adapted for this lab so that you can experience the basic idea of point counting without having to learn optical mineralogy or how to use a petrographic microscope.

A phaneritic igneous rock is shown in **Fig. A5.6.1A**. The four major minerals in the rock are identified and mapped as different-colored areas in **Fig. A5.6.1B**.

**Figure A5.6.1**

The task is to identify the mineral(s) found at each of several points on the rock. We make 25 small holes in a square grid on an opaque sheet, with each hole just large enough so that you can look through it to see what's on the other side. Then we put the grid sheet on top of the mineral map of the igneous rock (**Fig. A5.6.2A** and repeat this process three times with the grid shifted slightly each time (**Fig. A5.6.2B-D**).

Count the number of node points that are filled with each of the four major minerals (that is, with each of the four colors on the map) and use that number to estimate the total volume of each major mineral in the rock. You can see more than one mineral through the hole at some node points, so estimate how much of each mineral fills each hole: 0.25 if a mineral fills a quarter of the hole, 0.5 if a mineral fills half of the hole, and 1.0 if a mineral fills the entire hole. For example, 7.25 circles are filled with white (plagioclase feldspar) in **Fig. A5.6.2A**, so estimate that about \(7.25 \times 4\)% or \(29\%\) of the rock is composed of plagioclase feldspar.

**Point Count, Grid A**

<table>
<thead>
<tr>
<th>Number of nodes filled with the mineral</th>
<th>(\times 4)%</th>
<th>(\times 4)%</th>
<th>(\times 4)%</th>
<th>(\times 4)%</th>
</tr>
</thead>
<tbody>
<tr>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
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<td>( )</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
</tbody>
</table>

**Figure A5.6.2**
As revised in the 12th Edition

Figure A5.6.2

[Image of a diagram with a grid and colored circles]
Activity 5.8  Tectonic Setting of Some Major Volcanic Rock Types

**Learning Goal.** You will discover how different magma types might be related to tectonic setting, given information about active volcanoes in the United States and the adjacent seafloor.

A. Color each of the white circles in Fig. A5.8.1 to indicate the composition of the most felsic major rock type at that volcano (red/pink = rhyolite; gray = andesite; black = basalt), using information about active volcanoes in the United States in Fig. A5.8.2.

![Diagram of tectonic setting and volcanic activity](image)

<table>
<thead>
<tr>
<th>Volcano Number</th>
<th>Volcano Name</th>
<th>Volcano Type</th>
<th>Major Rock Type(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Kiska</td>
<td>stratovolcano</td>
<td>andesite</td>
</tr>
<tr>
<td>2</td>
<td>Kasatochi</td>
<td>stratovolcano</td>
<td>basalt-andesite</td>
</tr>
<tr>
<td>3</td>
<td>Sequoia</td>
<td>stratovolcano</td>
<td>basalt-andesite</td>
</tr>
<tr>
<td>4</td>
<td>Cleveland</td>
<td>stratovolcano</td>
<td>andesite</td>
</tr>
<tr>
<td>5</td>
<td>Makushin</td>
<td>stratovolcano</td>
<td>basalt-andesite</td>
</tr>
<tr>
<td>6</td>
<td>Amak</td>
<td>stratovolcano</td>
<td>andesite</td>
</tr>
<tr>
<td>7</td>
<td>Vantarni</td>
<td>stratovolcano</td>
<td>andesite</td>
</tr>
<tr>
<td>8</td>
<td>Fourpeaked</td>
<td>stratovolcano</td>
<td>andesite</td>
</tr>
<tr>
<td>9</td>
<td>St. Augustine</td>
<td>domed cluster</td>
<td>andesite</td>
</tr>
<tr>
<td>10</td>
<td>Ridgett</td>
<td>stratovolcano</td>
<td>basalt-andesite</td>
</tr>
<tr>
<td>11</td>
<td>Baker</td>
<td>stratovolcano</td>
<td>andesite</td>
</tr>
<tr>
<td>12</td>
<td>Rainier</td>
<td>stratovolcano</td>
<td>andesite</td>
</tr>
<tr>
<td>13</td>
<td>St. Helens</td>
<td>stratovolcano</td>
<td>basalt-rhyolite</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Volcano Number</th>
<th>Volcano Name</th>
<th>Volcano Type</th>
<th>Major Rock Type(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>14</td>
<td>Three Sisters</td>
<td>complex</td>
<td>andesite-rhyolite</td>
</tr>
<tr>
<td>15</td>
<td>Crater Lake</td>
<td>caldera</td>
<td>basalt-rhyolite</td>
</tr>
<tr>
<td>16</td>
<td>Shasta</td>
<td>stratovolcano</td>
<td>andesite</td>
</tr>
<tr>
<td>17</td>
<td>Lassen</td>
<td>stratovolcano</td>
<td>andesite</td>
</tr>
<tr>
<td>18</td>
<td>Yellowstone</td>
<td>caldera</td>
<td>basalt-rhyolite</td>
</tr>
<tr>
<td>19</td>
<td>Endeavour Segment</td>
<td>fissure vent(s)</td>
<td>basalt</td>
</tr>
<tr>
<td>20</td>
<td>Axial Seamount</td>
<td>caldera &amp; fissure</td>
<td>basalt</td>
</tr>
<tr>
<td>21</td>
<td>Chaff Segment</td>
<td>fissure vent(s)</td>
<td>basalt</td>
</tr>
<tr>
<td>22</td>
<td>Ni Gorda Segment</td>
<td>fissure vent(s)</td>
<td>basalt</td>
</tr>
<tr>
<td>23</td>
<td>Escanaba Segment</td>
<td>fissure vent(s)</td>
<td>basalt</td>
</tr>
<tr>
<td>24</td>
<td>Mauna Loa</td>
<td>shield</td>
<td>basalt</td>
</tr>
<tr>
<td>25</td>
<td>Kilauea</td>
<td>shield</td>
<td>basalt</td>
</tr>
</tbody>
</table>
Figure 5.2 Bowen’s reaction series. See text for explanation.

Bowen’s reaction series as represented in the 12th edition of the Lab Manual

Revised graphic in the 12th Edition
Figure 5.3 Typical order that certain major minerals crystallize from cooling magma. Details of the sequence and type of minerals that crystallize from a particular magma might differ from those shown in this figure. (Adapted from a figure by Allen Glazner)
Figure 11.4 **Seismogram of an earthquake in Mexico.** Example of a seismogram associated with the 2017 Ayutla-Puebla earthquake as recorded at station LRAL at Lakeview Retreat, Alabama. This trace shows the first arrivals of the P-, S-, and surface waves and records the vertical (up-and-down) motion measured by the seismometer during this magnitude-7.1 earthquake. (Digital data for this trace were provided by John Taber at IRIS.)
New graphic in the 12th Edition

**Figure 11.5 Travel-time curves.** A. Travel-time curves for P, S, and surface waves with a set of traces from 17 different seismographs at various distances from the epicenter of the magnitude-7.1 Ayutia-Puebla earthquake of September 19, 2017. The seismograms illustrate how the curves can be derived using empirical data. B. Travel-time curves for use within ~1000 km of an epicenter. This graph is used in Activity 11.3. Notice that an S-minus-P time of 70 seconds corresponds to a distance to the epicenter of approximately 667 km.
 Locate the Epicenter of an Earthquake  

**Activity 11.3**

**Learning GOAL.** You will use a set of seismograms and travel-time curves to locate the epicenter of an earthquake and gather some information about the event from web sources.

A widely felt moderate earthquake occurred on August 23, 2011, and was detected by seismographs at Standing Stone, Pennsylvania (SSPA); Wyandotte Cave, Indiana (WCI); and Waverly, Tennessee (WVT). Seismograms of the vertical component of motion at those three seismograph stations are shown in Fig. A11.3.1. Times are expressed in Coordinated Universal Time (UTC). Seismologists express time in hours:minutes:seconds. See if you can use these seismograms and a seismic-wave travel-time curve (Fig. 11.5) to locate the epicenter of the earthquake that produced the seismograms.

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Figure A11.3.1

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Figure A11.3.2
Earth’s Dynamic Climate

Contributing Author
Mark Carpenter • American Geosciences Institute

Big IDEAS
Advances in science and technology over the past century have enabled us to measure changes in the Earth system, providing us with a strong base of reliable information. Superimposed on the natural rhythms of a planet that has been in an “ice age” for the past ~2.6 million years are extraordinary changes in the chemistry and temperature of the atmosphere and oceans that pose significant challenges to human society worldwide, now and for the foreseeable future. With our expanding knowledge of the history of Earth’s climate before human involvement, scientists draw data-based interpretations of the contribution of human activities to global environmental change. Geoscience has an extraordinary opportunity to contribute to the health and welfare of both human society and the Earth ecosystem by continuing to provide reliable information and informed advice to a growing global community so that, together, we can navigate toward a more sustainable and just future.

Lab ACTIVITIES
17.1 How Does Rising Temperature Affect Sea Level? (p. 445)
17.2 Melting Ice and Rising Sea Level (p. 448)
17.3 Using Tide Gauge Data to Model Sea-Level Change (p. 450)
17.4 Carbon Dioxide in the Atmosphere (p. 453)
17.5 The Climate Record from Cores (p. 456)
17.6 Local Effects of Sea-Level Rise (p. 459)

Ice calving from the terminal face of Perito Moreno Glacier into Lago Argentino, Parque Nacional Los Glaciares, Patagonia, southern Argentina (near 50.467°S, 73.041°W). Photo taken 25 April 2017 by David Wall/Alamy.
A new chapter-opening video by Callan Bentley
Figure 17.2  *Argo robotic float*.  
**A.** *Argo* robotic float being prepared for deployment. Photo: Allamy.  
**B.** The ~10-day cycle of *Argo* drifting, sampling, and reporting on the environmental conditions in the upper 2000 m of the oceans.  
**C.** Location of 3890 *Argo* floats (blue dots) contributed by 25 nations in May 2019. Map: *Argo* Information Centre.
How we measure changes in the Greenland Ice Sheet

Figure 17.3 Estimating Greenland ice sheet volume. A. Extent of the Greenland ice sheet and ice shelves. B. Digital elevation model of the upper surface of Greenland, including the top of the ice sheet. C. Relief map of the top of the bedrock under the Greenland ice sheet. D. Map of the thickness of the ice sheet. Base maps from Morlighem and others (2017).
Figure 17.4 Graph of ice mass loss, Greenland and Antarctica. Maps showing changes in ice mass of the Greenland and Antarctic ice sheets between 2002 and 2016, using gravity data from the GRACE satellite system. Darker red-brown areas indicate greater ice mass loss. NASA maps.

Measured ice mass change in Greenland and Antarctica
How we measure relative sea level changes.

**Figure 17.5 Trends in relative sea level.** Relative sea level recorded locally at NOAA tide-gauge stations as of August 2018. Based on NOAA Sea Level Trends ([https://www.tidesand-currents.noaa.gov/sltrends/sltrends.html](https://www.tidesand-currents.noaa.gov/sltrends/sltrends.html)).
A brief introduction to ice cores

Figure 17.9 Ice core. A. Core barrel and bit used to collect ice cores in Antarctica. B. Ice core from the West Antarctic Ice Sheet Divide, showing a layer of ash (dark band near the closer end of the core) preserved in the ice from a volcanic eruption ~21,000 years ago. C. Short (19 cm) section the GISP2 ice core from Greenland showing annual layers with lighter summer layers sandwiched between darker winter layers. Photos: Steven Profaizer, Heidi Roop, and Anthony Gow, National Science Foundation.
Figure 17.10 800,000 years of climate record. Time-series graphs of peer-reviewed published data relevant to the study of climate change over the past 800,000 years.

Record of environmental change from analysis of ice cores
Learning GOAL. You will use observations from an experiment, orbital satellites, and floating robotic sensors to develop a basic understanding of how increasing the temperature of water can change its volume and hence the level of its upper surface in a container (or in an ocean basin).

A. What happens to the volume of liquid water when its temperature is raised? To answer this question, either perform the following simple experiment or watch the brief video available at https://qrgo.page.link/Hd51t

You need the following items for the experiment (Fig. A17.1.1): a small glass Erlenmeyer flask, a two-hole rubber stopper sized for the top of the flask, a digital or alcohol thermometer that can be inserted through a hole in the stopper, a glass tube that can be inserted through the other hole in the stopper, a heat source such as a hotplate or a heat lamp, cold tap water (fresh water), and food coloring.

Step 1. Fill the flask to the top with cold water mixed with food coloring so you can easily see the water level.

Step 2. Carefully insert the thermometer and glass tube through the holes in the stopper and place the stopper assembly in the top of the flask. The stopper will displace some water at the top of the flask, and some of that displaced water should move up into the glass tube. If you can’t see water in the tube, add drops of water until the water level is visible above the stopper in the tube.

Step 3. Before heating the assembly, mark the initial water level in the tube.

Step 4. Apply heat to the bottom of the flask either by setting the flask on a hotplate or by pointing the heat lamp toward the base of the flask.

Step 5. After a few minutes of heating, observe whether heating causes a change in water volume by seeing whether the water in the tube rises, falls, or remains at a constant level.
Does raising the temperature of water change its volume?

2-minute video to support Activity 17.1A
2-minute video to support Activity 17.1A
current water level —

original water level —

2-minute video to support Activity 17.1A
Figure A17.1.2

- Total global mean sea level change
- Contribution from change in water temperature and salinity
Activity 17.2  Melting Ice and Rising Sea Level

Learning GOAL  You will use simple experiments to investigate the effects of melting continental glaciers and ice sheets versus melting ice floating in the ocean. You will consider how this melting affects sea level (if at all). You will use data from orbital satellites to explore these effects on a global scale.

A Does sea level rise, fall, or remain the same when a floating iceberg melts? To investigate this matter, either perform the following simple experiment or watch the brief video available at https://qrco.page.link/Mr42z

To perform the experiment, you need a glass container, some tap water, and ice that has sufficient volume that it might have an obvious effect on the water level in the container (Fig. A17.2.1A).

Figure A17.2.1

Step 1. Fill the container about half full of tap water and add the ice. All of the ice should be floating in the water, not touching the bottom of the container.

Step 2. On the side of the glass container, mark the level of the liquid water in the container.

Step 3. When the ice melts completely, observe the level of the liquid water in the container.

1. How did the water level in the container change, if at all, during the experiment?

2. Based on your observations, infer how the melting of floating icebergs might affect global sea level and write a brief statement explaining that inference in the space provided.
Does sea level change when sea ice or a floating iceberg melts?
2-minute video to support Activity 17.2A
2-minute video to support Activity 17.2A
initial water level — 2-minute video to support Activity 17.2A — final water level
Does sea level change when continental ice sheets and glaciers melt?

2-minute video to support Activity 17.2B
2-minute video to support Activity 17.2B
2-minute video to support Activity 17.2B

initial water level —
Figure A17.2.2

Total global mean sea level change
Contribution from ice mass loss on Antarctica and Greenland
Activity 17.3  Using Tide Gauge Data to Model Sea-Level Change

Name: ___________________________  Course/Section: ___________________  Date: __________

Learning GOAL  You will use information provided by the USGS, NOAA, and other public agencies to model changes in local sea level along the coastlines of the continental United States with scenarios for global mean sea-level change that bracket conditions that are considered to be likely for the next couple of centuries.

A Use a web-enabled device to navigate to https://js-169-194.jetstream-cloud.org/terriamap. After this web app loads, use the zoom controls and position the map so that it looks approximately like Fig. A17.3.1, with the continental United States centered on the map window and with both the west and east coast tide gauge locations visible. Along the left side of the window is a frame called the Workbench in which you can select options for display on the map. A colorful map legend or explanation in the workbench identifies the colors associated with different amounts of local relative sea-level rise (RSL). For example, the range associated with the dark maroon color at the top of the scale in Fig. A17.3.1 is from 0.51 m up to 2.12 m.

Figure A17.3.1
Learning GOAL You will become familiar with the record of atmospheric carbon dioxide (CO₂) as measured since 1958 at the Mauna Loa Observatory as well as a longer record from an ice core that extends back about 2000 years and explore the trends evident in these data. How does CO₂ concentration in the atmosphere seem to correlate (if at all) with Earth’s surface temperature?

A What is the most recently measured concentration of atmospheric CO₂ at the Mauna Loa Observatory? On the web, navigate to https://scripps.ucsd.edu/programs/keelingcurve/ to find the latest reading, which is expressed in units of parts per million.

date of latest reading: ______________  CO₂ concentration: __________ ppm

B Figure A17.4.1 shows a two-year record of atmospheric CO₂ measurements at Mauna Loa Observatory.

![Graph showing atmospheric CO₂ concentrations from 2018 to 2019]

Figure A17.4.1
Monthly Average Atmospheric Concentrations of CO₂ Measured In Situ at Mauna Loa Observatory, Hawaiʻi, from March 1958 through March 2019

Data from Dr. Pieter Tans, NOAA/ESRL (www.esrl.noaa.gov/gmd/ccgg/trends/), and Dr. Ralph Keeling, Scripps Institution of Oceanography (scrippscsi2.ucsd.edu/)

Figure A17.4.2
Global average concentration of CO₂ in the atmosphere

Global average surface temperature anomaly relative to the average temperature from 1951 to 1980

Average temperature from 1951 to 1980

Figure A17.4.3
Activity 17.5
The Climate Record from Cores

Learning Goal: You will examine the 800,000-year record of climate indicators that are preserved in the ice of Greenland and Antarctica and in marine sediments, and learn how these indicators increase or decrease with changing temperature. You will describe how this long record compares with recent trends in temperature and carbon compounds that are greenhouse gases in the atmosphere.

![Graph showing CO₂, CH₄, and global mean surface temperature over time.](Figure A17.5.1)
Local Effects of Sea-Level Rise

**Learning Goal** You will learn to use NOAA’s Sea Level Rise Viewer to investigate how global mean sea level (GMSL) rise will affect coastal communities in the United States, which should help you appreciate the likely impact of sea-level rise worldwide.

Use a web-enabled device (best if larger than a smartphone) to access NOAA’s Sea Level Rise Viewer at [https://coast.noaa.gov/slr/](https://coast.noaa.gov/slr/). Click on the green button labeled “Get Started,” and you should see a window that looks approximately like **Fig. A17.6.1**.

For each of the following exercises, do the following steps.

**Step 1.** Type the given place name in the white location input box, and then select (click on) the corresponding place name in the menu that will appear below the location input box. Wait until the new map loads completely.

**Step 2.** Adjust the map so that its extent includes the area shown in the map provided with each exercise. Any bright green areas on the map are lowlands that are near sea level.

**Step 3.** Click on the white circle of the “units switch” (see **Fig. A17.6.1**) until the units displayed along the water level slide bar are meters (m).

**Step 4.** Follow the directions for each of the following exercises.

**Step 5.** After completing an exercise, move to the next exercise (if any) by typing the new place name in the location input box.

**A San Francisco, California**

1. Type “San Francisco, CA” in the location input box, and then follow steps 1–3 (described previously).

2. Move the water level slider up to 1.5 m to visualize the coastline after a 1.5-m rise in global mean sea level (GMSL). The “high intermediate” estimate of sea-level rise in this area by the year 2100 is ~1.4 m—close to the 1.5-m step along the slider.

   (a) Use a colored pencil or highlighter to fill in the coastal areas in **Fig. A17.6.2** that will be under water (inundated) if GMSL rises by 1.5 m (~5 ft).

   (b) What is likely to happen to the San Francisco (SFO) and Oakland (OAK) airports after a 1.5-m rise in GMSL?

   (c) The area around Foster City includes homes, businesses, and important transportation infrastructure. What do you think society’s response to this perceived threat should be?
Coastline near Naples at current mean sea level.
Coastline near Naples at 1.8 m higher mean sea level.
Summary

- The 12\textsuperscript{th} edition of the AGI/NAGT Laboratory Manual in Physical Geology \textit{is now in print and available for course adoption}.
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We want to hear from you as you review and use the Lab Manual 12\textsuperscript{th} edition. What are your ideas and suggestions?

Vince_Cronin@baylor.edu
Questions?
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R. Quinn Thomas, Virginia Tech

Wednesday, April 29, 2020
Time: 10:00 am PT | 11:00 am MT | 12:00 pm CT | 1:00 pm ET
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