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GENERAL TIPS FOR GETTING STARTED

Please consider these tips to help you use the *Laboratory Manual in Physical Geology—AGI/NAGT* (10^{th} edition) and this *Instructor Manual* more effectively.

1. **Review the lab manual Instructor Resource Materials that are available to you, and obtain the ones you need.** You can find these resources online at **www.pearsonhighered.com/irc** or you can contact your Pearson-Prentice Hall sales representative at **www.pearsonhighered.com/educator/replocator/**

2. **Review the Pedagogical Model upon which the lab manual is based (page 6).**

3. **Familiarize yourself with the following resource materials that are available to your students**:
    - **Pre-lab Videos** created by Callan Bentley help students understand how to successfully complete the lab activities by following a clear series of steps. They can be accessed with the QR code on the cover flap of the lab manual or at **mygeoscienceplace.com**
    - **GeoTools** are cardboard and transparent rulers, protractors, grain size scales, UTM grids, and more for students to cut out and use as needed. They can be found at the end of the lab manual.
    - **A Math Conversion Chart, Introduction to SI Units, pictures of lab equipment, and a map of North America** are available in the Preface of the lab manual (pages xi–xiv).
    - **TMYN™, MasteringGeology™, and Learning Catalytics**™, if used.
    - **QR Codes,** which provide students with quick access to web sites they need or may use in addition to resources provided in the lab manual.

4. **Consider personalizing your students' learning experience** by using MasteringGeology™, Learning Catalytics™, or TMYN (The Math You Need, When You Need It) remedial tutorials.

    MasteringGeology™ is an online tutorial and homework program. Pre-lab video quizzes can be assigned as formative assessments for you to analyze with a variety of tools to isolate weaknesses and misconceptions of a student or class. This allows you to build a plan for intervention and make the most of the time that students will have in the laboratory. Learn more at **www.MasteringGeology.com**

    Learning Catalytics™ is pedagogical approach in which students use any web-enabled device of their choice (smart phone, tablet, laptop, etc.) to engage in formative assessments (that guide learning) and summative assessments (that are used for grading purposes) before, during, or after the laboratory. You can create or select multiple choice questions for students to answer and/or you can create or select open-ended questions that ask for numerical, written, or graphical responses. You can build a seating chart, and then use the chart to see what students or groups of students have answered specific items and how they answered them. You can assign questions for students to answer synchronously during class/lab (one question is answered by each student, but all students address the question at the same time), or in a self-paced mode for formative or summative assessments. Learn more at **learningcatalytics.com/**

TMYN™ is an online set of modular math tutorials for students in any introductory geoscience, developed and managed by Jennifer Wenner (University of Washington–Oshkosh) and Eric Baer (Highline Community College) with funding from the National Science Foundation. You can assign the free modules for students to use on their own, or you can assign them as formative or summative assessments. You can also compare students' pre-lab and post-lab ability to solve geological problems involving mathematics and, thereby, measure the extent of their learning. Learn more at **serc.carleton.edu/mathyouneed/index.html**

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!

ERRATA

Lab 2

On page 58, part “B” (Reflect and Discuss) is actually part “D.”

On page 68, part A, item 5b, the vector motions should be in mm/yr (not cm/yr).

Lab 5

On page 136, Figure 5.4, Step 3: for the description of pegmatitic texture, change “1 mm” to “1 cm.”

On page 144, part A, change “Minerals Database (pages 000 – 000)” to “Minerals Database (Pages 93–97).”

On page 152, part C, change “200 million years ago” to “190 million years ago.”

Lab 6

On page 185, part B, change “Photograph A” to Photograph B.”

BEFORE YOU TEACH A LABORATORY

BEFORE LAB BEGINS

1. **Decide what activities your students should complete** before and during the lab. Most labs deliberately include more activities than your students could complete in a single lab period, so you can choose the activities that you think will best enable your students to learn what you expect them to learn in the lab time available.

2. **Check the list of errata** (page 4 in this Instructor Manual) for corrections that must be made in the lab that you plan to use.

3. **Assign pre-lab preparations for your students to complete.** This may include:
   a. Complete the first activity of the lab and by the start of the lab.
   b. Watch the pre-lab video for the lab.
   c. Take a pre-lab quiz using MasteringGeology**TM** or other quiz of your design.
   d. Complete assigned readings in the lab manual, class textbook, or other.
   e. Know what activities must be completed by the end of the lab period.
   f. Know what materials each student must bring to the start of the lab (as noted in the blue boxes of the lab manual that start of each activity and as noted at the start of each laboratory section of this Instructor Manual).

4. **Review and assemble the Instructor Materials that you must provide during the lab period.** A list of the Instructor Materials is provided in this instructor manual, at the start of each for each lab section. They are generic lists only and must be modified by you to avoid confusion and know exactly what to assemble for the laboratory.

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

6. **Analyze pre-lab results,** if you are assigned a pre-lab quiz using MasteringGeologyTM or a similar program. Use that information to isolate weaknesses and misconceptions of a student or class. Then build a plan for intervention that makes the most of the time that students will have in the laboratory.

7. **Develop the scope and sequence of the teaching/learning plan that you plan to follow during the lab period.**
   a. What will you do at the start the lab period? For example, you may:
      - Declare the scope and sequence of what students must do during the lab period, how they are expected to do/record their own work yet work and/or work in collaborative groups, and the safety practices that they must follow.
      - Review pre-lab weaknesses and misconceptions and/or use lab PowerPoint to introduce the lab.

- Review how and where students obtain the materials they need (the materials that you are providing in the lab).
- Address questions.

b. What will you do during the lab period? For example, you may:

- Allow students to work on activities at their own pace or according to your other plan.
- Move about the room to be sure students/groups have the materials they need and are on task.
- Address questions, use guiding questions of your own to help students scaffold from the unknown to the known (or inability to ability), and implement personal interventions as needed (especially relative to pre-lab quiz results and special-needs).

c. What will you do near/at the end of the lab period? For example, you may:

- Review the results of each activity (item by item or the Reflect and Discuss questions for formative purposes (i.e., to guide learning).
- Have students submit their individual worksheets for summative assessment (evaluation for a grade).
- Have students complete a graded post-lab quiz.
- Have students address the Think About It questions linked to the lab and/or the activities that they completed.

DURING THE LAB PERIOD

8. Carry out the plan that you developed above, in parts 7a and 7b.

AT/NEAR THE END OF THE LAB PERIOD

9. Carry out the plan that you developed above, in part 7c.

10. Grade materials and provide grades and feedback to students in a timely fashion.

11. Reflect on any feedback about the lab that students may have volunteered and use it to inform/guide your grading and future teaching.

PEDAGOGICAL MODEL

Each lab proceeds from items 1 through 4 and involves resources and assessments.

AGI-NAGT LAB MANUAL 10E PEDAGOGICAL MODEL

1. BIG IDEAS

Big Ideas are the overall conceptual theories or themes upon which a Lab is based. They are statements that help students understand and focus on how all parts of the Lab are related. They are transferrable to any Intro Geology class/textbook, major, or career.

2. THINK ABOUT IT

This is a set of **key questions** (based on the Big Ideas) for think-pair-share learning before, during, and/or after the Lab and/or specific Activities. They function as the conceptual "lenses" that frame student inquiry and promote critical thinking and discourse. **Schematic Questions** target the *cognitive domain of psychology* and are meant to help students assimilate to the topic (apply their existing schemata) and lay a constructivist conceptual foundation for scaffolding to new concepts & skills of the topic. **Engaging Questions** target the *affective domain of psychology*, are open-ended questions with no specific answer, and are meant to foster interest in the topic. Manipulatives target the *psychomotor domain of psychology* and can be used to foster curiosity & cognitive disequilibrium that lead to **Authentic Questions** by students. Manipulatives can be added during the think-pair-share and/or Activity 1 of each lab. They are also the basis for object-based Activities of the Labs.

3. ACTIVITIES

The first activity of each lab is a **Guided Inquiry Activity.** Before reading any content, students address a key question relative to images of samples (if done in lab, then use actual samples), video(s), or demonstrations. **This inquiry activity is designed to be both engaging and schematic.** It replaces the old "pre-lab" activity and is followed by reading about the topic, small-group or class cooperative discussion (pair-share), and/or viewing a student Pre-lab video or Pre-lab PowerPoint.

Subsequent activities are **Structured Inquiry Activities.** They are more like the typical structured activities that followed the pre-lab activities of past editions, but they now focus on a key think-about-it question and objective.

4. CLOSURE

Every activity now ends with a **Reflect and Discuss** item related to what students learned in the activity relative to the Think About It question linked to the activity. Students reflect and discuss in pairs, small groups, or as a class.

CONTINUOUS ASSESSMENT

Pre-assessment

- Think-pair-share (informal)
- MasteringGeology (formal)

Formative Assessment

- MasteringGeology pre-lab quiz (formal)
- During lab (informal)

Summative Assessment

- Graded materials completed in lab (formal)
- Graded closure activity (formal at end of lab)

RESOURCES

GeoTools in the Lab Manual
Instructor-provided
Student-provided

Online for Students:

- MasteringGeology
- Google Earth
- USGS
- The Math You Need (TMYN), When You Need It
- Lab Manual Website

QR Codes in Lab Manual for students to access materials with portable devices

Online for Faculty:

- MasteringGeology
- Instructor Resource Center
- Instructor Resource Guide
- Lab Manual Website

LABORATORY ONE
Thinking like a Geologist

BIG IDEAS: Geology is the science of Earth, so geologists are Earth scientists or "geoscientists." Geologists observe, describe, and model the materials, energies, and processes of change that occur within and among Earth's spheres over time. They apply their knowledge to understand the present state of Earth, locate and manage resources, identify and mitigate hazards, predict change, and seek ways to sustain the human population.

THINK ABOUT IT (Key Questions):

- How and why do geologists observe Earth materials at different scales (orders of magnitude)? (Activity 1.1)
- What materials, energies, and processes of change do geologists study? (Activity 1.2)
- How and why do geologists make models of Earth? (Activity 1.3)
- How and why do geologists measure Earth materials and graph relationships among Earth materials and processes of change? (Activity 1.4)
- How is the distribution of Earth materials related to their density? (Activities 1.4, 1.5)

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

_____ laboratory manual with worksheets linked to the assigned activities
_____ laboratory notebook
_____ pencil with eraser
_____ metric ruler (cut from GeoTools sheet 1 or 2)
_____ calculator
_____ blue pencil or pen (Activity 1.3 only)
_____ drafting compass (Activity 1.3 only)
_____ several coins (Activity 1.3 only)

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

ACTIVITY 1.1: Geologic Inquiry
_____ none

ACTIVITY 1.2: Spheres of Matter, Energy, and Change

_____ none

ACTIVITY 1.3: Basketball Model of Earth's Spheres

_____ drafting compasses (one per student)
_____ extra metric rulers (for students who forgot them)
_____ extra blue pencils (for students who forgot them)
_____ several coins/student: pennies, nickels, quarters, dimes

ACTIVITY 1.4: Measuring and Determining Relationships

_____ 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 1.5: Density, Gravity, and Isostasy

_____ 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 1.6: Isostasy and Earth's Global Topography

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

2. Mathematical conversions: refer to laboratory manual page xii.

3. In Activity 1.5 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.

4. 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.

LAB 1 ANSWER KEY

ACTIVITY 1.1: Geologic Inquiry

1.1A. Observation, analysis, and description of the parts of Figure 1.1

1.1A: Aster satellite images of Escondida mining region, Chile:

Part A consists of two satellite images of the same 40 by 90 km area of land in Chile. One image is in essentially true color--Earth tones, but the other image is a false-colored image of the short-wave infrared bands of infrared rediation. The current open pit mine and the old pits (mines) are visible in both images, along with similar shapes and textures of Earth's surface. However, the copper-bearing ore body within the mines stands out as pink to red colors in the false colored short-wave infrared image. One cannot tell where the ores begin or end in the true color image.

1.1B: Ground view of Escondida open pit mine:

Part B is a true color photograph of Escondida open pit mine taken at ground level, from the edge of the mine. There are steam-shovels and cranes operating on the floor of the mine. The walls of the mine (pit) are terraced, and each terrace is about the height of a steam-shovel or crane. Most of the rocks have a brown color, but there are two parts of the mine where the rocks have a green color. A label indicates that the green-colored rocks are the copper ore.

1.1C: Boulders in Escondida open pit mine:

Part C is a photograph of some of the rocks blasted from the mine walls. The rocks are angular, less than 0.5 meters in diameter, and are colored shades of blue, green, and brown.

1.1D: Minerals of Escondida open pit mine:

Part D is a photograph of two rocks, 6 to 10 cm in diameter), from Part C. The individual copper-bearing ore minerals are so visible that they can be identified. Azurite is blue, malachite is green, and chalcopyrite is brassy in color. There is no pure copper (native copper) visible, just chemical compounds (minerals) containing copper.

1.2E: Coin:

Part E is a photograph of a copper coin (U.S. one cent piece, or penny) shown at its actual size (x1). The outside of the penny is a freshly minted, shiny, metallic color of pure copper. The penny is 1.9 cm in diameter.

1.1F: Circuit board:

Part F is a microscopic view (photomicrograph) of part of a computer circuit board. Copper has been used in flate wires less than 1 mm wide to make the path that the circuits will follow.

1.1G: Copper atoms:

Part G is an image of copper at the atomic scale. The individual copper atoms look spherical and are about 0.25 nanometers (nm) in diameter. They are closely packed together into a regular (crystalline) pattern (not a random pattern).

1.1B. Every part of Figure 1.1 shows objects that contain copper (Cu).

1.1C. Analyze Figure 1.1 and answer the following questions.

1.1A: Aster satellite images of Escondida mining region, Chile. How could geologists use these images, at this scale of observation, to find new sources of copper ore? In the right-hand image of the Escondida mine region, the bands of electromagnetic radiation radiating from the rocks have been false colored. Rocks of the circular current mine and old pits all have a bright pink to red color, so other rocks in the image with such color may also contain copper ore.
1.1B: Ground view of Escondida open pit mine. How can geologists and miners locate copper ore when they view the mine at this scale of observation? In the walls of the mine (pit), at ground level, the copper ore appears green.
1.1D: Minerals of Escondida open pit mine. What must be done with these ore minerals to provide you with the copper you need? The copper ore is actually chemical compounds (minerals) that contain copper as one their elements. These mineral compounds must be chemically treated and/or melted so the pure copper separates from the other elements in the minerals.

1.1D. 1. The best location for a new mine (pit) is location C, because the rocks there have the same pink-red color in the false-colored satellite image as the rocks of the current and old copper mine pits.

1.1D. 2. To see if location C is actually a good source for more copper ore, one must go there to collect samples of the rock and determine if it contains copper-bearing minerals in profitable quantities to be mined.

ACTIVITY 1.2: Spheres of Matter, Energy, and Change

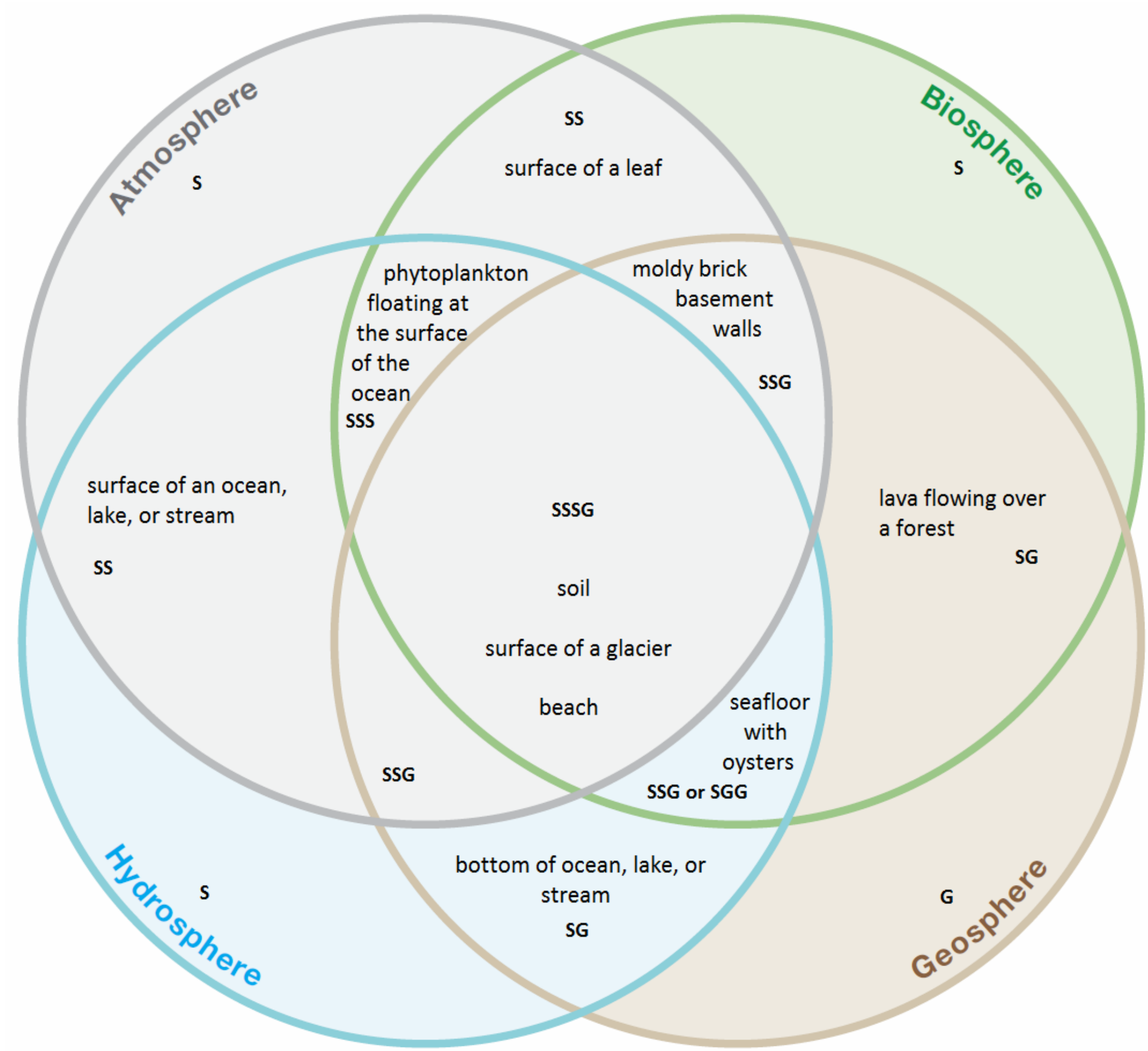
1.2A.

State of Matter	Sphere	What is the main source of energy that powers the sphere (Sun or geothermal energy)?	Give examples of named parts of this sphere that you have personally encountered.
GAS: What is a gas? A gas is a fluid material, like air, that has no specific shape or volume of its own and tends to expand in all directions to fill any space/container that it occupies.	What sphere is made mostly of gases? Atmosphere	The atmosphere is MOSTLY powered by the Sun.	air, clouds, wind, etc.
LIQUID: What is a liquid? A liquid is a fluid material, like flowing water, that has no speciic shape of its own even though it has a definite volume. It does not expand to fill a space/container (like gases do). It fills a space/container from bottom to top.	What sphere is made mostly of liquid water? Hydrosphere (Some students may also include the cryosphere.)	The hydrosphere is MOSTLY powered by the Sun.	drinking water systems, streams, lakes, ponds, puddles, oceans, floods, etc.
	What subsphere of Earth in Figure 1.8 is a mostly liquid rock? Outer core	Geothermal energy	Not encountered by humans
SOLID: What is a solid? A solid is a material, like rock, that has a specific shape and volume of its own. It does not change shape when placed into a container.	What subsphere is made mostly of water ice? Cryosphere	The cryosphere is powered mostly by the Sun.	ice cubes, snow and ice, glaciers, etc.
	What sphere is made mostly of solid rock (besides water ice)? Geosphere	The geosphere is powered mostly by geothermal energy.	clay, silt, sand, gravel, pebbles, cobbles, boulders, different kinds of rocks, rocky mountains, etc.
SOLIDS, LIQUIDS, AND GASES	What sphere consists of living parts containing solids, liquids, and gases? Biosphere	The biosphere is powered mostly by the Sun.	plants and animals (including other people)

1.2B. answer sheet

Process of Change	Sphere(s) involved in the process or product	Give an example of how you observed the process happening or how you encountered the result of the process	What caused the process to happen?
Deposition	atmosphere geosphere	I saw frost crystals on cold metal surfaces and windows of my car last winter.	The temperature of the metal was so cold that water vapor in the air formed ice crystals on contact with the metal.
	hydrosphere geosphere atmosphere	At the seashore, sand covered up my feet as waves crashed onto the beach where I was standing.	Wind caused waves. Waves carried the sand. When waves broke, they lost energy and the sand settled out.
Evaporation	geosphere hydrosphere atmosphere biosphere	Students should give examples of places where they observed that liquid was, or had already changed, to a gaseous state. They may have observed that water was evaporating from a pond (as the water level went down). They may have observed clay with mudcracks, or dried fruit, from which moisture evaporated.	As a liquid gains energy, its molecules speed up, move apart, and develop into a gaseous state.
Condensation	atmosphere Some students may argue that some plants convert water vapor into liquid water.	Students should give examples of places where they observed gases changing into a liquid state. They may refer to condensation on the outside of a cold drink container, or something similar.	As a gas loses energy, its molecules slow down and develop into a liquid state.
Decomposition reaction	geosphere hydrosphere atmosphere biosphere	A decomposition reaction is an irreversible reaction, so students must describe an example where different elements in a chemical compound are/were irreversibly split apart from one another to form new compounds.	Chemical elements split apart from one another and form now compounds that cannot be converted directly back into the original compounds from which they came.
Dissolution	geosphere hydrosphere atmosphere biosphere	Students must describe an example where a substance becomes evenly dipersed into a liquid (or gas).	The dispersed substance is called a solute, is acted upon by the liquid (or gas) that causes the dissolution, and is called a solvent.
Chemical precipitation	geosphere hydrosphere atmosphere biosphere	Students must describe an example where a solid formed when a liquid solution evaporated or reacted with another substance.	Students may describe the formation of a saturated solution of salt or sugar, or the mixing of two liquids having different chemical compositions, from which crystals precipitate.

1.2C. Completed Venn diagram

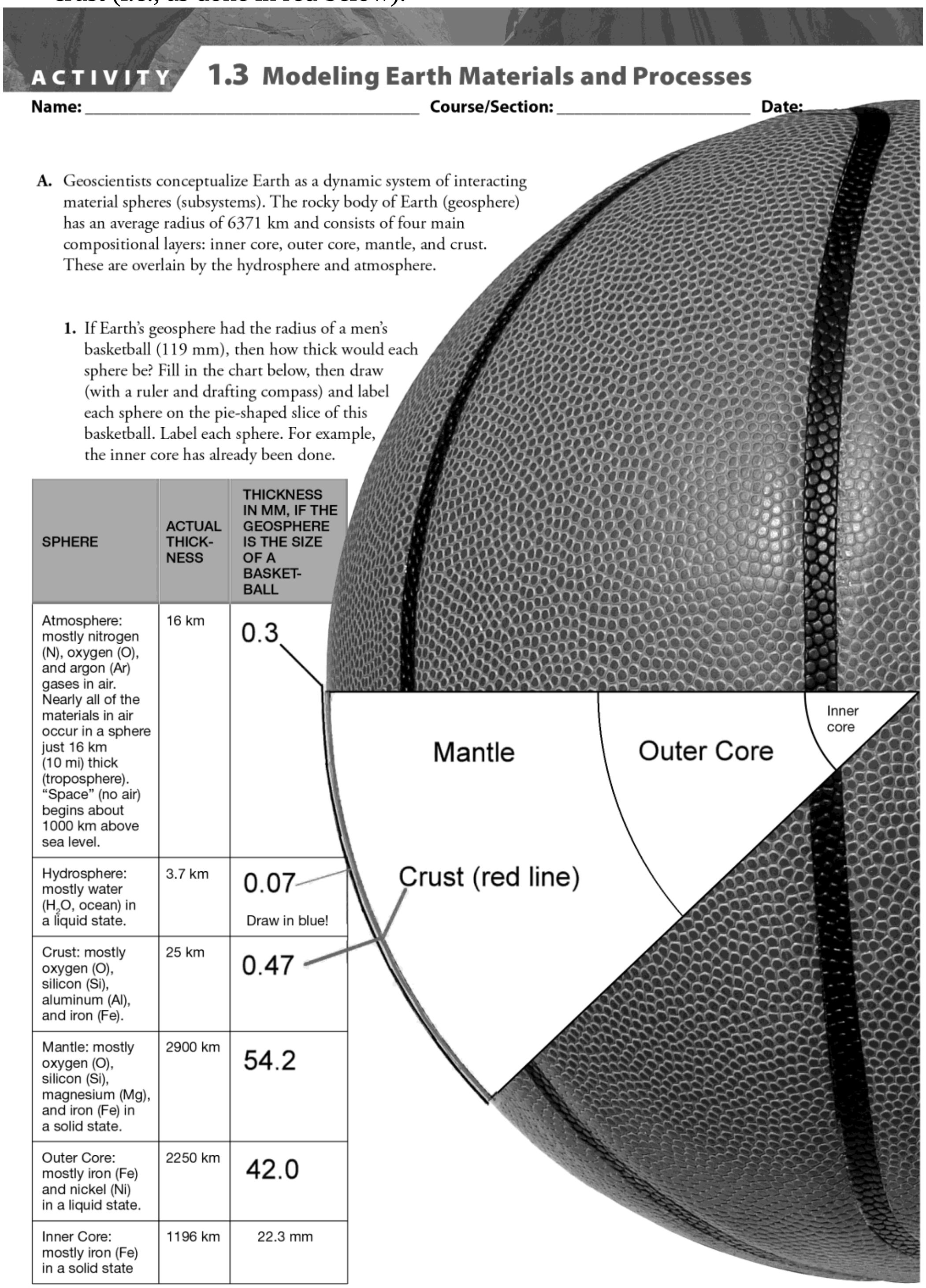


1.2D. Reflect and Discuss: Do you think that most change on Earth occurs within individual systems, at boundaries between two systems, or at the intersections of more than two systems? Why?

In general, one might expect that at the most change occurs at intersections of more than two systems, because there are more varied materials and energy forms (than in one system or the boundary between just two systems).

ACTIVITY 1.3: Modeling Earth Materials and Processes

1.3A. 1. See the completed basketball model below. 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). The crust will be about the thickness of a pencil/pen line. You could have students use another color of pencil for the crust (i.e., as done in red below).



ACTIVITY 1.3 Modeling Earth Materials and Processes

Name: ____________________ **Course/Section:** ____________________ **Date:** ________

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.

1. 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

1.3A. 2. 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

1.3B. MODELING LANDSLIDE HAZARDS

1. If you lift one end of the ruler, then the coin slides towards the opposite end.
2. The coin did not slide off of the ruler at the very second you started to lift one end of the ruler, because there was friction between the coin and the ruler.
3. The coin start sliding when the force of gravity overcame the friction between coin and ruler.
4. **REFLECT & DISCUSS:** When students describe how they would modify the ruler and coin model, their answers will vary widely.
   - Most will use different solid materials, such as rocks on a piece of marble.
   - Some will introduce water.
   - Some will introduce wind.
   - Some will want to measure values and graph results.

ACTIVITY 1.4: Measuring and Determining Relationships

1.4A. The mathematical conversions (using the table on laboratory manual page xi) are:

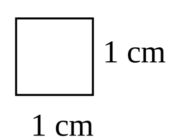
1. 10.0 miles x 1.609 km/mi = **16.09 kilometers** (or rounded to **16.1 km**)
2. 1.0 foot x 0.3048 m/ft = **0.3048 meters** (or rounded to **0.3 m**)
3. 16 kilometers x 1000 m/km = **16,000 meters**
4. 25 meters x 100 cm/m = **2500 centimeters**
5. 25.4 mL x 1.000 cm^3/mL = **25.4 cm^3**
6. 1.3 liters x 1000 cm^3/L = **1300 cm^3**

1.4B. 1. 6,555,000,000 = 6.555×10^9 **2.** 0.000001234 = 1.234×10^{-6}

1.4C. 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

1.4D. 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.]



1.4E. 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).

1.4F. 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:

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

1.4G. 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.

<u>Method 1 procedures</u>:

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.

<u>Method 2 procedures</u>:

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**).

1.4H. **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.

1.4I. **Reflect and Discuss:**
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.

1.4J. **RATES:**

1. **a.** 1.6 km x 1,000,000 mm/km = 1,600,000 mm
6 million years = 6,000,000 yr

So: 1,600,000 mm ÷ 6,000,000 yr = 0.2666666 mm/yr
= 2.666666 x 10^{-1} mm/yr

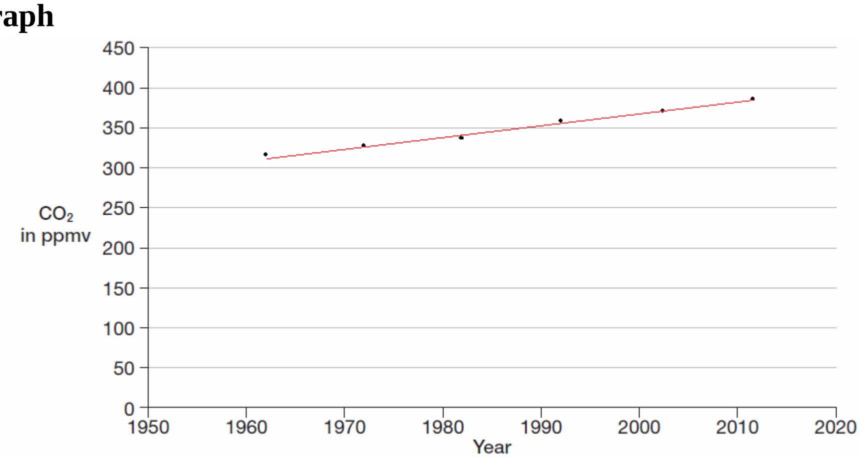
b. 0.2666666 mm/yr times the age of the student in years = answer

2. 60°C ÷ 3.9 km = 15.38°C/km

1.4K. **Single Line Graph**

Annual Average Concentration of Atmospheric Carbon Dioxide at Mauna Loa, Hawaii

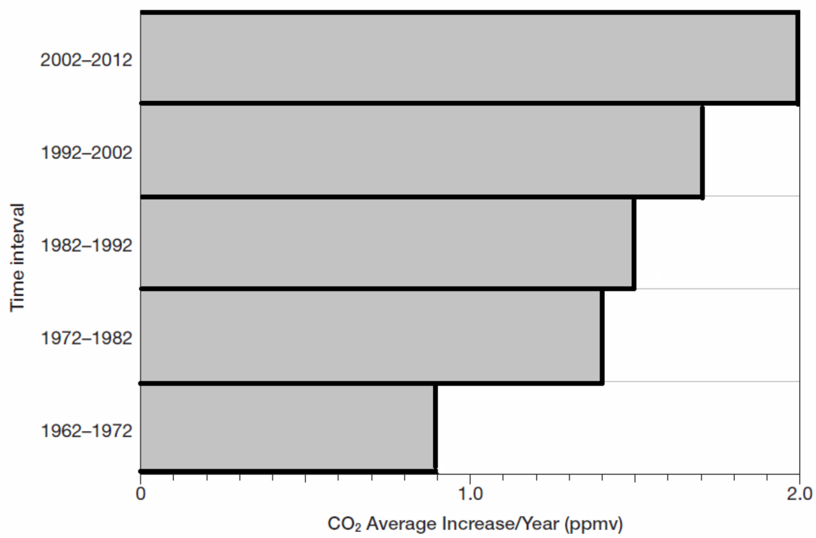
Year	CO_2 (ppmv)
1962	318
1972	327
1982	341
1992	356
2002	373
2012	393



1. The amount of CO_2 in the atmosphere at Mauna Loa Observatory, Hawaii has increased every decade since 1962.
2. The values for carbon dioxide increase as the years increase, and the line has a positive slope.

1.4L. Bar Graph

Average Yearly Rate of Increase in the Concentration of Atmospheric Carbon Dioxide at Mauna Loa, Hawaii	
Time interval	Rate of increase per year
1962–1972	0.9 ppmv/yr
1972–1982	1.4 ppmv/yr
1982–1992	1.5 ppmv/yr
1992–2002	1.7 ppmv/yr
2002–2012	2.0 ppmv/yr



1.4M. Two-line Graph

1. The relationship revealed in this graph is that there is a close correlation between atmospheric carbon dioxide (ppmv) and global temperature. When carbon dioxide levels are, the temperature is high. When carbon dioxide is low, then the temperature is low. Over the past 400,000 yr, both factors have risen and fallen together in cycles lasting about 100,000 yr. Carbon dioxide concentrations did not exceed 300 ppmv in any of those natural cycles or drop below 180 ppmv in any of those natural cycles.

1.4N. Reflect and Discuss

Graph K and M show that since at least 1962, carbon dioxide levels have been higher than at any time in the past 400,000 years and reached a level of 393 ppmv in 2012. Graph L shows that the rate of carbon dioxide increase is also rising.
One can expect the level and rate to increase in the future by extrapolating the graphs into the future. Also, based on Graph M, the levels of carbon dioxide in our atmosphere are greater than at any time in the past 400,000 years. Graph M also shows that global temperature and carbon dioxide concentrations rise and fall together, so one can infer that abnormally high global temperatures will accompany the abnormally high carbon dioxide levels of the future.

ACTIVITY 1.5: Density, Gravity, and Isostasy

1.5A. 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, and 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.

1.5B. Bear in mind that the proportions of wood above and below the waterline will vary according to the type of wood. Pine floats higher than walnut. Exact measurements recorded by students will also vary according to type of wood and size of the block.

1.5C. The exact form of equations will vary from student to student. The common form is:

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

1.5D. The exact form of equations will vary from student to student. Using the equation above (answer to Question 17), the common form would be:

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

1.5E. 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.

1.5F. 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 1.6: Isostasy and Earth’s Global Topography

1.6A. 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.

1.6B. 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.

1.6C. **1.** $H_{above} = 5\text{ km} - [(3.1\text{ g/cm}^3 \div 3.3\text{ g/cm}^3)\ 5\text{ km}] = 0.3\text{ km}$

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

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 1.11.

1.6D. **Reflect and Discuss:** 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.

1.6E. **Reflect and Discuss:** 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.

1.6F. **Reflect and Discuss:** 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

BIG IDEAS: Tectonics is the study of global processes that create and deform lithosphere. Plate tectonics is the theory that Earth's lithosphere is broken into dozens of plates (thin curved pieces). The plates are created and destroyed, move about, and interact in ways that cause earthquakes and create major features of the continents and ocean basins (like volcanoes, mountain belts, ocean ridges, and trenches).

THINK ABOUT IT (Key Questions):

- Is the lithosphere beneath your feet really moving? (Activity 2.1)
- What causes plate tectonics? (Activities 2.2, 2.3)
- How are plate boundaries identified? (Activities 2.4, 2.5, 2.6, 2.7)
- How and at what rates does plate tectonics affect earth's surface? (Activities 2.4, 2.5, 2.6, 2.7)
- What are hot spots, and how do they help us explain plate tectonics? (Activity 2.8)
- How and where does magma form? (Activity 2.9)

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

_____ laboratory manual with worksheets linked to the assigned activities
_____ computer with Internet access (Activities 2.1 and 2.8 only)
_____ laboratory notebook
_____ pencil with eraser
_____ metric ruler (cut from GeoTools sheet 1 or 2)
_____ protractor (cut from GeoTools sheet 4)
_____ calculator
_____ plastic ruler or popsicle stick (Activity 1.2)
_____ 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: Plate Motion Inquiry Using GPS Time-Series

_____ extra metric rulers (for students who forgot them)

ACTIVITY 2.2: Is Plate Tectonics Caused by a Change in Earth's Size?

_____ extra metric rulers (for students who forgot them)

ACTIVITY 2.3: Lava Lamp Model of Earth

_____ extra blue pencils (for students who forgot them)
_____ extra red pencils (for students who forgot them)
_____ extra plastic rulers or popsicle sticks, so each student has one
_____ Silly Putty ™
_____ lava lamp (turned on at least one hour ahead of time) and/or lava lamp video clip

ACTIVITY 2.4: Paleomagnetic Stripes and Seafloor Spreading

_____ extra metric rulers (for students who forgot them)

ACTIVITY 2.5: Atlantic Seafloor Spreading

_____ 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 2.6: Using Earthquakes to Identify Plate Boundaries

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

ACTIVITY 2.7: San Andreas Transform-Boundary Plate Motions

_____ extra metric rulers (for students who forgot them)

ACTIVITY 2.8: Hot Spots and Plate Motions

_____ extra metric rulers (for students who forgot them)

ACTIVITY 2.9: The Origin of Magma

_____ 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 student)

INSTRUCTOR NOTES AND REFERENCES

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

2. Mathematical conversions: refer to laboratory manual page xii.

3. 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.

4. One lava lamp, or two, or three? Most lava lamps must be lighted for at least one 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.

5. 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.

6. 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, and 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.

7. 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.

8. 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.

9. 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.

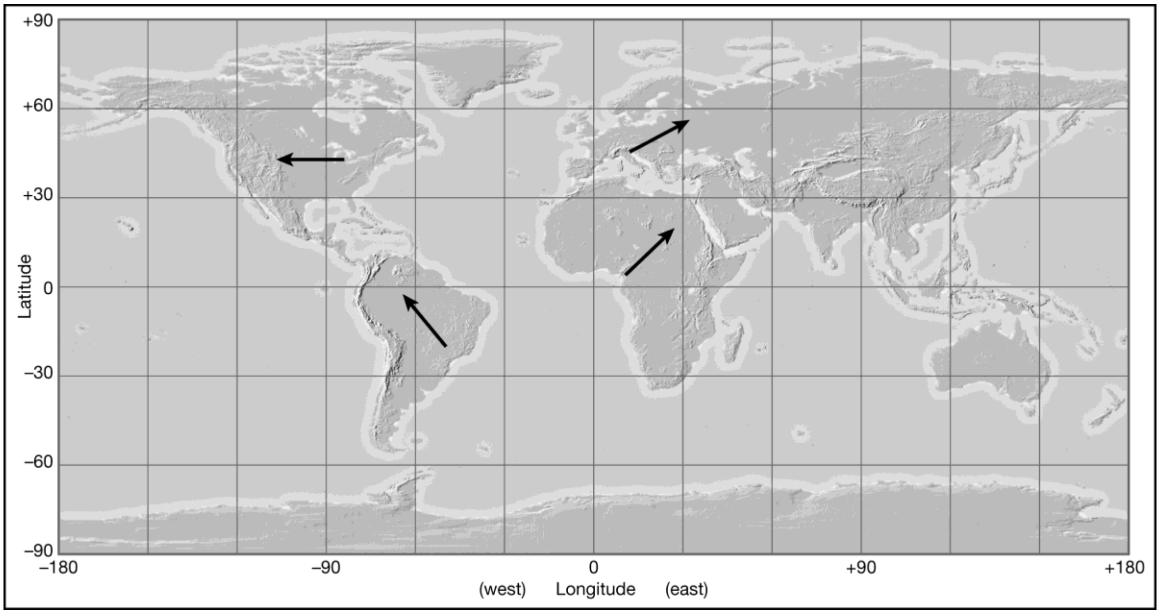
LAB 2 ANSWER KEY

ACTIVITY 2.1: Plate Motion Inquiry Using GPS Time-Series

2.1A. Answers will vary. For example, although most students in the United States live on the North American Plate, some live on the Pacific Plate.

2.1B. Answers will vary and must be checked on an individual basis.

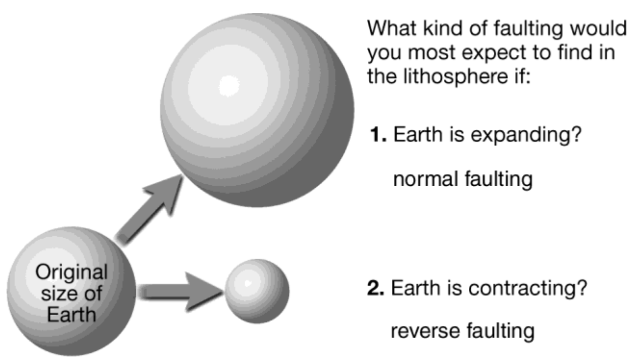
2.1C. Students will have some difficulty generalizing about the general motion of North America and South America, but most will agree on the general motion of Africa and Europe.



2.1D. **Reflect and Discuss:** Most discussions of plate tectonics describe how the Atlantic Ocean is developed around a divergent plate boundary (Atlantic Mid-Ocean Ridge), so North America and South America are moving away from Europe and Africa. The generalized plate motion vectors above (black arrows) seem to confirm that. Therefore, students generally use the above map to say that it supports the Plate Tectonic Theory.

ACTIVITY 2.2: Is Plate Tectonics Caused by a Change in Earth's Size?

2.2A.



2.2B.

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

2.2C. 1.

Lithospheric Plate Boundary Type	Total Length (kilometers)	Total Length of the three main plate boundary types	Percentage of each of the three main plate boundary types
Ocean-ocean convergent boundaries	17,449	Convergent **91762 km**	Convergent **35.2 %**
Ocean-continent convergent boundaries	51,310		
Continent-continent convergent boundaries	23,003		
Continental rift divergent boundaries	27,472	Divergent **94810 km**	Divergent **36.4 %**
Mid-ocean ridge divergent boundaries	67,338		
Ocean transform fault plate boundaries	47,783	Transform **73915 km**	Transform **28.4 %**
Continental transform fault plate boundaries	26,132		

2. Some students will notice that the percentages of convergent and divergent boundaries is nearly equal and that the percentage of transform boundaries is a bit less. However, most will conclude that there is roughly one-third of each kind of plate boundary and that Earth's size is staying about the same.

3. 510,000,000 $km^2 \div 3.4\ km^2$ /yr = 150,000,000 yr (or 1.5×10^7 yr)

2.2D. **Reflect and Discuss:** Based on the answers to questions above, there is evidence for about 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), and plate tectonics is not driven by a change in Earth's size. Some students will come to the likely conclusion that for Earth to remain the same size, there must be mantle convection, whereby lithosphere is created at divergent boundaries, recycled back into the mantle at convergent boundaries, and neither created nor recycled at transform boundaries. Most students will know about Earth's hot interior and will at least suggest that it is processes inside of Earth that are causing its change in size. Their descriptions of those processes will vary widely, and should not be graded with one strict answer in mind at this point. Their conceptions serve as working hypotheses for future parts of the lab.

ACTIVITY 2.3: Lava Lamp Model of Earth

2.3A. 1. See the completed table below.

Test	Behaves like a solid	Behaves like a liquid (fluid)
1. Roll the Silly Putty™ into a ball and bounce it on the table.	X	
2. Hold opposite ends of the mass of Silly Putty™, and pull it apart slowly.		X
3. Hold opposite ends of the mass of Silly Putty™, and pull it apart as fast as you can.	X	
4. Roll the Silly Putty™ into a ball, then press down on it with your thumb.		X
5. Roll the Silly Putty™ into a ball, and allow it to sit for 2-3 minutes, or longer.		X

Under what conditions of pressure and time does Silly Putty™ behave like a solid?	Under what conditions of pressure and time does Silly Putty™ behave like a liquid?
Silly Putty behaves like a solid when acted upon by a strong force over a very short period of time (like a bounce on the table or pulling the putty apart quickly and with all of your strength).	**Silly Putty behaves like a liquid when it is acted upon by gravity or a small amount of force over a long period of time (like when it is slowly pushed together or pulled apart, or when it simply sits on the table and flows on its own--under the influence of gravity).**

2. Rheidity is the time it takes for a solid material under stress to lose its elastic- brittle behavior, entirely, and just permanently deform (flow) like a viscous fluid. So a rheid is a solid material that can change from viscoelastic behavior to just viscous behavior. Silly Putty has such behavior, so it is a rheid.

3. Reflect and Discuss: Brittle solid rocks of the lithosphere may exhibit visco- elastic behavior and even shatter when they exceed their elastic limit (as in an earthquake). However, when the same rocks subduct into the mantle and are subjected to intense forces over long periods of time (and are hot), they can flow as a viscous fluid.

2.3B. 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

2.3C. **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:

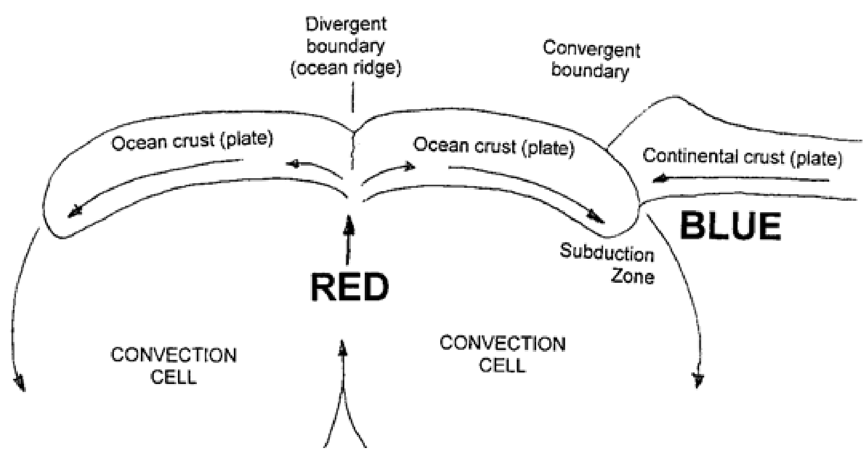
- the mantle is rock, not lava or wax.
- the mantle is heated by Earth's outer core, but the lava lamp is heated by a light bulb.
- the mantle convects more slowly (i.e., cm/year) than the lava lamp (cm/second or cm/minute).

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

1. the warmer, less dense mantle rocks (red in Figure 2.6) mostly occur beneath divergent plate boundaries and hot spots.

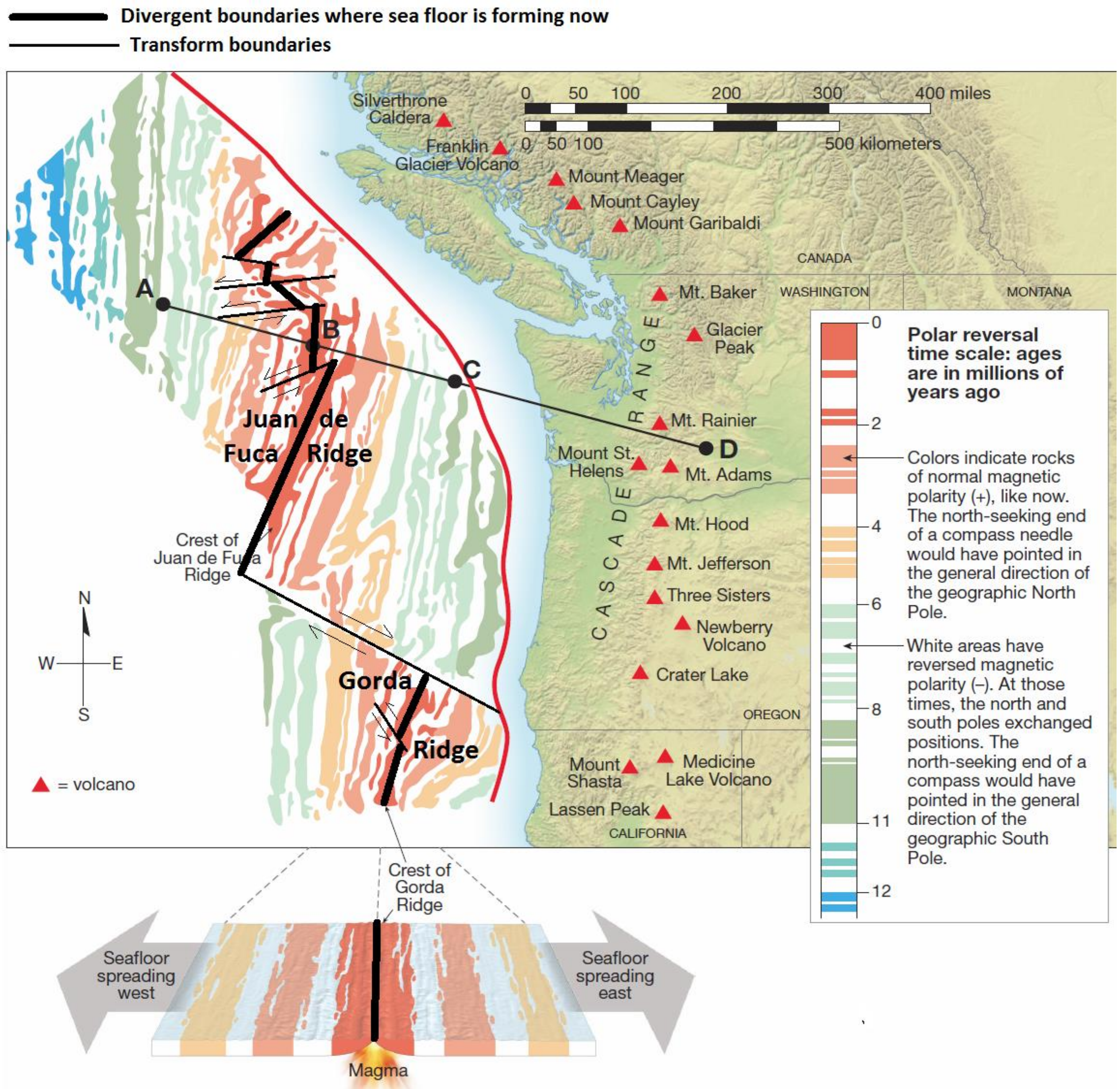
2. the cooler, denser mantle rocks (blue in Figure 2.6) mostly occur beneath continents.

2.3E. **Reflect and Discuss:** 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 2.4: Paleomagnetic Stripes and Seafloor Spreading

2.4A. **1.** The exact position of the modern divergent boundaries and transform faults connecting them is somewhat difficult to determine in some parts of the seafloor map, but maps should approximate the completed map below.



2. The distance from B to A is about 250 km and covers an age of about 8 million years. 250 km x 100 cm/km = 25000 cm. Therefore, the spreading rate is 25000 cm / 8,000,000 yr, which reduces to 3.125 cm/yr.

3. The distance from B to C is about 190 km and covers an age of about 8 million years. 190 km x 100 cm/km = 19000 cm. Therefore, the spreading rate is 19000 cm / 8,000,000 yr, which reduces to 2.375 cm/yr.

4. East of the Juan de Fuca Ridge, the rocks older than 11 million years have been subducted.

5. **a.** trench

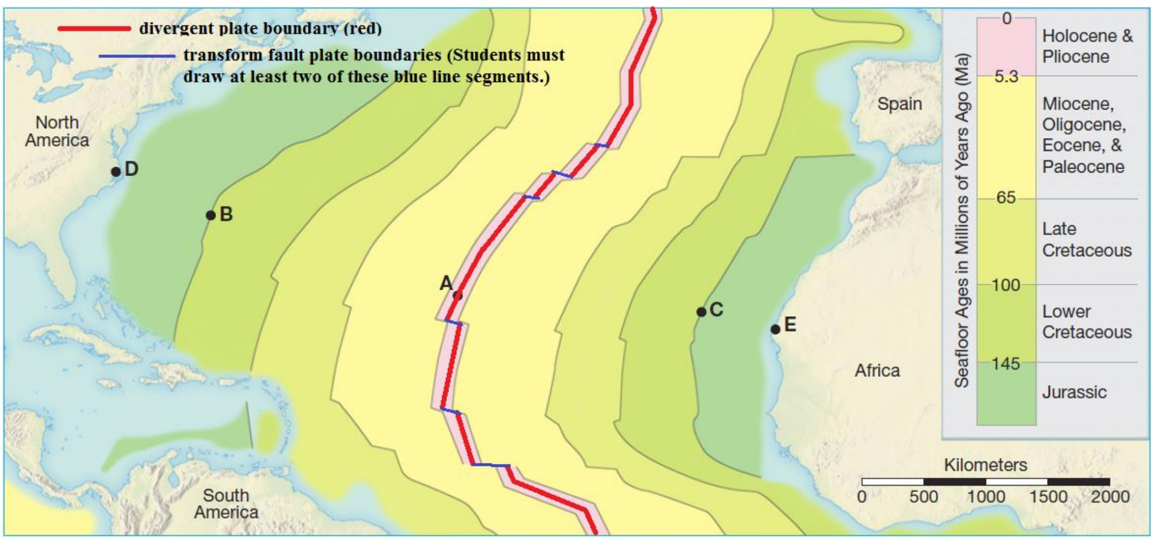
   b. North American Plate

   c. Juan de Fuca Plate

6. **Reflect and Discuss:** The Juan de Fuca Plate subducts beneath the North American Plate. Water from the subducted plate enters the mantle wedge above it and lowers the melting point of the rocks. Partial melting begins, and the magmatic arc (Cascade Range) volcanoes form as magma rises towards Earth's surface.

ACTIVITY 2.5: Atlantic Seafloor Spreading

2.5A. 1 and 2



2.5B. 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.

2.5C. How far apart are points B and C today? __~ 4300__ km

1. 4300 km ÷ 145 million years = 29.66 km/m.y.

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

   4,300,000,000 mm ÷ 145,000,000 yr = 29.65 mm/yr

   OR 29.66 km/1,000,000 yr × 1,000,000 mm/ 1 km = 29.66 mm/yr

2.5D. Reflect and Discuss: 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 5800 to 5900 km apart (about 5850 km, depending on how students measure the distance).

5800 km ÷ 29.66 km/m.y. = 195 m.y. and 5900 km ÷ 29.66 km/m.y. = 199 m.y., so students should determine that Africa and North America were part of the same continent **about 195 - 199 m.y. ago (early part of the Jurassic Period according to Figure 1.3 on page 7 of the Lab Manual).**

2.4E. Reflect and Discuss:

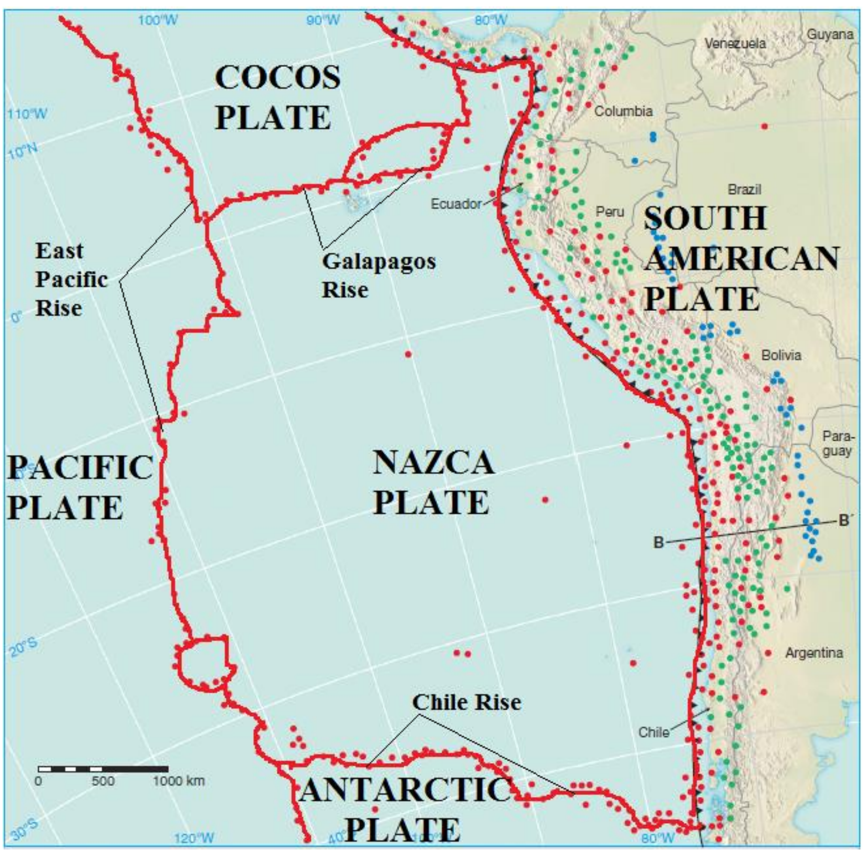
2014 − 1776 = 238 yr AND 238 yr × 29.66 mm/yr = 7059 mm

So, 7059 mm × 0.001 m/mm = 7.059 m.

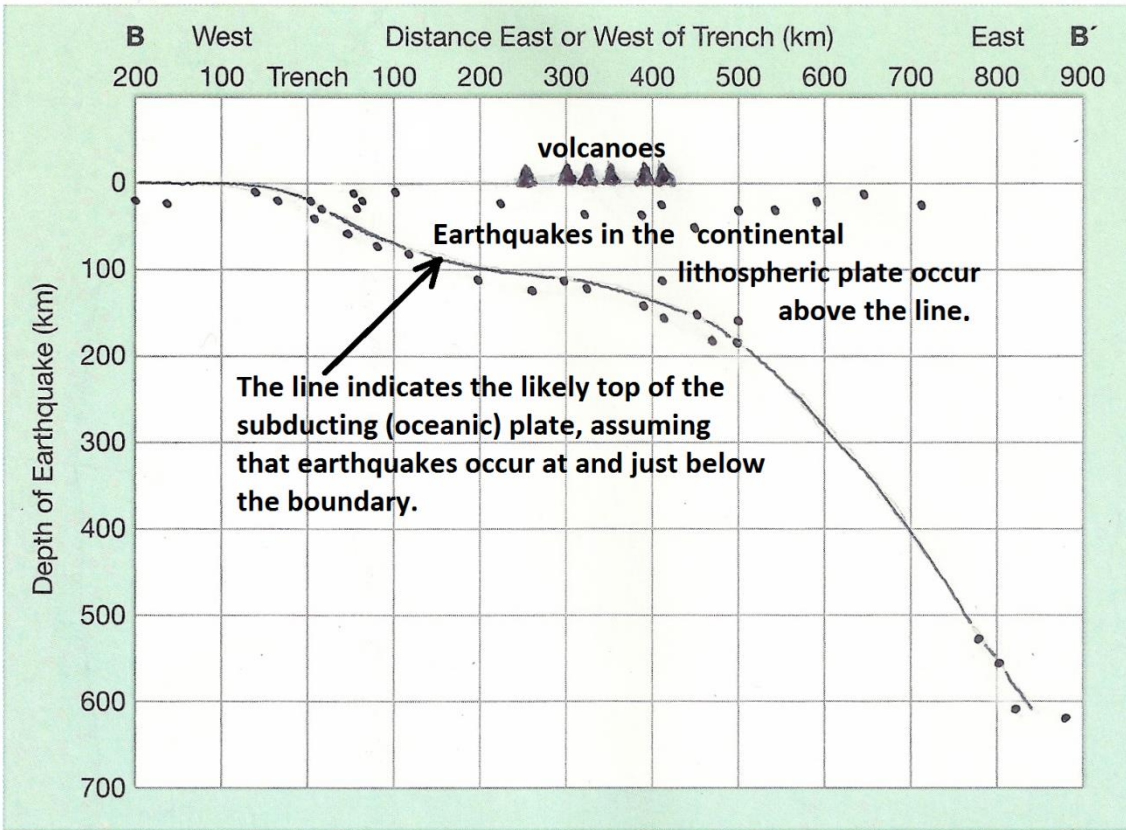
Students should calculate that Africa and North America have moved apart by about 7 meters since the United States formed in 1776.

ACTIVITY 2.6: Using Earthquakes to Identify Plate Boundaries

2.6A.



2.6B.



1. convergent

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

3. Lithospheric earthquakes occur mostly in the continental lithosphere (above the black line), but they also occur at or just below the top of the subducting lithospheric plate (so long as it remains brittle).

4. 100 – 150 km (volcanoes above it)

5. **Reflect and Discuss:** The deepest earthquake plotted on the cross section occurs at 620 km (a deep focus earthquake). It is likely that this may be at or near the lower limit, below which earthquakes are not likely to occur (in relation to the subducting plate) because the plate is no longer rigid (visco-elastic) or has been assimilated into the mantle rocks around it.

ACTIVITY 2.7: San Andreas Transform-Boundary Plate Motions

2.7A. 1. There are two main bodies of rock that have been displaced along the fault, so students can use either one to calculate a rate of fault motion.

The Oligocene sedimentary rocks (Os) have been displaced about 323 km since they formed 25 million years ago. Multiply 323 km by 100,000 cm/km to get a distance of 32,300,000 cm. Then, 32,300,000 cm ÷ 25,000,000 yr equals an **average rate of 1.29 cm/yr.**

The Oligocene volcanic rocks (Ov) have been displaced about 340 km since they formed 23.5 million years ago. Multiply 340 km by 100,000 cm/km to get a distance of 34,000,000 cm. Then, 34,000,000 cm ÷ 23,500,000 yr equals an **average rate of 1.45 cm/yr.**

2. Based on the measurements determined above:

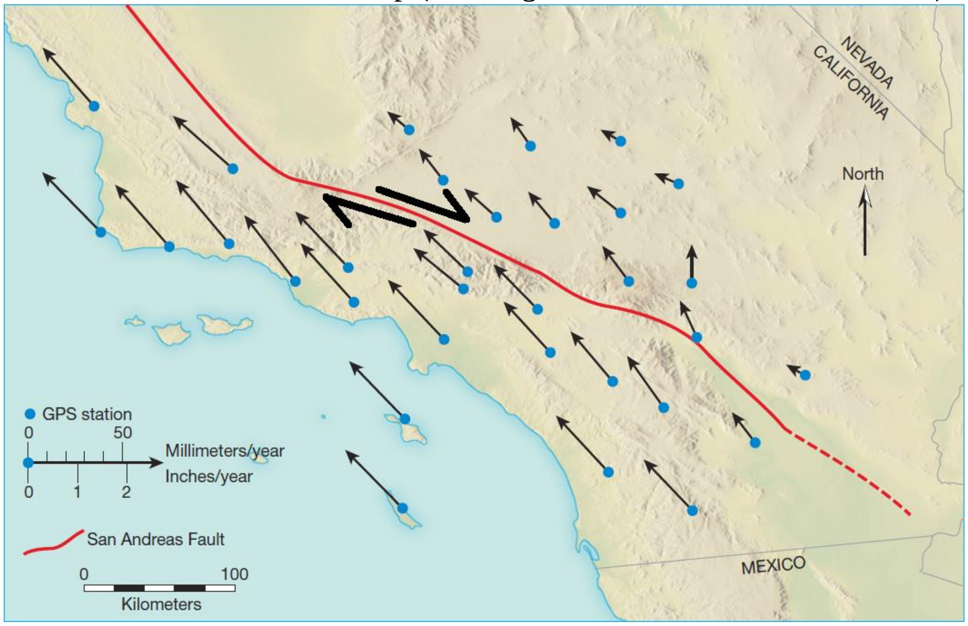
The Oligocene sedimentary rocks (Os) were displaced 323 km, which equals 323,000 meters. 323,000 meters ÷ 5 meters per displacement equals 64,600 displacements. 25,000,000 yr ÷ 64,000 displacements of 5 meters equals 390.6 years, so the average 5-meter displacement occurred once every 391 years.

The Oligocene volcanic rocks (Ov) were displaced 340 km, which equals 340,000 meters. 340,000 meters ÷ 5 meters per displacement equals 68,000 displacements. 23,500,000 yr ÷ 68,000 displacements of 5 meters equals 345.6 years, so the average 5-meter displacement occurred once every 346 years.

Students should determine that if all displacements along the fault were 5 meters, then a 5-meter displacement occurs every 346 to 391 years.

2.7B. 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 the half arrows on the map (showing the relative motion of the fault) below.



2.7C. Reflect and Discuss: Absolute plate motion refers to the movement of a lithospheric plate in relation to a fixed point on Earth or the actual motion of a point on a lithospheric plate in relation to a fixed position outside the Earth (such as the movement of a plate measured relative to known fixed geographic locations determined with the GPS satellite constellation). Relative plate motion refers to the motion of one plate in relation to another, which is assumed to be in a fixed position (even though it is likely that all of the plates are moving in relation to one another).

ACTIVITY 2.8: Hot Spots and Plate Motions

2.8A. 1. The Emperor and Hawaiian Islands form one continuous chain of islands that developed as the Pacific Plate moved over the Hawaiian hot spot. The Emperor Islands formed 60 to 40 million years ago, and the Hawaiian Islands have been forming from 40 million years ago to the present day.

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.

2. The Emperor Islands is a north-south string of islands about 2300 km (230,000,000 cm) long that formed over a period of 20 million years (40–60 Ma). For this to happen, the plate had to move north over the Hawaiian hot spot from 40–60 Ma at a rate of 230,000,000 cm/20,000,000 yr, which reduces to 11.5 cm/yr.

3. From 4.7 to 1.6 million years ago, the Hawaiian Islands moved northwest over the Hawaiian hot spot. The Pacific Plate moved 300 km northwest over 3.1 million years, so its average rate of motion was 30,000,000 cm ÷ 3,100,000 yr, which reduces to 9.67 cm/yr.

4. From 1.6 to 0 million years ago, the Hawaiian Islands moved northwest over the Hawaiian hot spot. The Pacific Plate moved 105 km northwest over 1.6 million years, so its average rate of motion was 10,500,000 cm ÷ 1,600,000 yr, which reduces to 6.56 cm/yr.

5. a. According to the NPOC plate motion vector, the Pacific Plate is still moving northwest over the Hawaiian hot spot, but it is now moving a bit more north than west compared to its motion over the past 40 million years.

5. b. The vector data for this question should be in mm/yr, not cm/yr. You should zoom in on the NPOC station at the JPL-NASA GPS Time Series website and show students that the actual vector data is mm/yr.

If students use the data in cm/yr, then the sum of $(14.825\ \text{cm/yr})^2$ plus $(-51.612\ \text{cm/yr})^2$ equals $2{,}883.578\ \text{cm/yr}^2$. The square root of $2{,}883.578\ \text{cm/yr}^2$ equals 53.698 cm/yr., so they will determine that the NPOC station is moving very fast (53.698 cm/yr). However, the correct units are mm/yr, so the NPOC station is actually moving northwest at a rate of 53.698 mm/yr, which reduces to 5.3698 cm/yr. (This plate motion was for the years 2007 to 2013.)

2.8B. Reflect and Discuss: From 60 to 40 million years ago, the Pacific Plate moved north at a rate of about 11.7 cm/yr. Since 40 Ma, the plate has moved northwest, but its rate has slowed since that time.

The plate moved 9.67 cm/yr from 4.7 to 1.6 million years ago and slowed to 6.56 cm/yr over the past 1.6 million years. [If the NPOC data were analyzed correctly (see item 5b above), then the NPOC site indicates current plate motion of just 5.3698 cm/yr.]

2.8C. 1. Yellowstone Park is volcanically active at the present time. It is part of a line of volcanic calderas that have formed since 13.8 million years ago and are successively older with distance from Yellowstone Park. Therefore, it seems that Yellowstone Park is located over a hot spot, and the North American Plate has moved west-southwest over the hot spot for at least the past 13.5 million years.

2. Over the past 10.5 million years, the North American Plate moved about 230 km over the Yellowstone hot spot. Therefore, its rate of motion was 23,000,000 cm ÷ 10,500,000 yr, which reduces to 2.19 cm/yr.

3. **Reflect and Discuss**: Hot spots help us understand plate tectonic processes and rates, because they are fixed points on Earth. This means that they can be used as a fixed reference point to determine the absolute motion of plates that have moved over them.

ACTIVITY 2.9: The Origin of Magma

2.9A. **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.

2.9B. **1.** about 40 km and 13,000 atm

2. decompression melting

3. Decompression melting could occur where a plume of hot mantle peridotite 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.

2.9C. **Reflect and Discuss:** To begin partial melting, the peridotite at point X in Figure 2.8 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.

2.9D. **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

2.9E. Reflect and Discuss:

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. Reflect and Discuss:

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).