LABORATORY TWO
Plate Tectonics

BIG IDEAS: Earth's solid outermost layer is the lithosphere, which includes the crust and the uppermost part of the upper mantle. The lithosphere is divided into plates that move relative to each other, and we can detect those motions using GPS and other technologies. Interactions between lithospheric plates along their boundary zones produce earthquakes, volcanoes, mountain ranges, mid-ocean ridges, and deep ocean trenches. Plate tectonics is the study of the motion of lithospheric plates and the geologic effects of those motions.

THINK ABOUT IT (Key Questions):

- How do we detect and measure plate motion? (Activities 2.1–2.3)
- How does our knowledge of how materials deform help us to understand plate tectonics? (Activity 2.4)
- How does rock magnetism help us date the oceanic crust and measure sea-floor spreading? (Activities 2.5 & 2.6)
- How do earthquakes help us locate and understand plate boundaries? (Activity 2.7)

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 (also available on GeoTools sheet 1 or 2)
_____ calculator or smartphone with calculator app
_____ a web-enabled device (Activities 2.2 & 2.3)
_____ colored pencils (red, orange, blue)

INSTRUCTOR MATERIALS

(Check off items you will need to provide.)

ACTIVITY 2.1: Reference Frames and Motion Vectors

_____ extra metric rulers (for students who forgot them)

ACTIVITY 2.2: Measuring Plate Motion Using GPS

_____ extra metric rulers (for students who forgot them)
_____ a web-enabled device and an internet connection

ACTIVITY 2.3: Hotspots and Plate Motions

_____ extra metric rulers (for students who forgot them)
_____ a web-enabled device and an internet connection

ACTIVITY 2.4: How Earth's Materials Deform

_____ bits of Silly Putty TM just under the size of a golf ball, kept at room temperature.
_____ bits of *cold* Silly Putty just under the size of a golf ball. They will have to be kept cold, so either a small refrigerator or a cooler with ice will be needed.
_____ bits of *warm* Silly Putty just under the size of a golf ball. They will have to be kept warm, which might entail putting them in sealable plastic sandwich bags and immersing them in a bucket of medium-hot water.
_____ a lava lamp or a video of a lava lamp that shows the motion of the colored wax from the bottom of the lamp to the top and back down again over at least 1 minute of time.

ACTIVITY 2.5: Paleomagnetic Stripes and Sea-Floor Spreading

_____ extra metric rulers (for students who forgot them)

ACTIVITY 2.6: Atlantic Sea-Floor Spreading

No instructor-supplied materials are needed for this activity.

ACTIVITY 2.7: Using Earthquakes to Identify Plate Boundaries

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

INSTRUCTOR NOTES

1. Students might voice concerns about having to use mathematical reasoning in this lab. The skills needed in this lab include the ability to measure accurately with a ruler, arithmetic, solving the Pythagorean Equation to find the length of a hypotenuse ($c = \sqrt{a^2 + b^2}$), and solving proportion problems. Proportions are covered in Laboratory 1 and the Pythagorean Equation is described in this lab. Vectors are introduced, but only at the level at which they are considered to be described by drawn arrows of a specified length that are directed toward a specified azimuth. All of these skills should be accessible to college students, with some kind assistance from their instructor as needed.

2. Activity 2.1. After completion of the work in sections A–C when all of the vectors are plotted on Figure A2.1.2, the length of each vector arrow is our best estimate for the distance each plate moves each year relative to the various reference frames (NNR, fixed Pacific Plate, fixed Juan de Fuca Plate, the plate boundary along the ridge axis) as determined at the location of the reference point. Hence, questions like "What is the speed of the Pacific Plate relative to the Juan de Fuca Plate at the reference

point?" are answered simply by using a ruler to measure the length of the corresponding vector on Figure A2.1.2. The azimuth is simply obtained by extending the vector until it reaches the edge of the figure, and interpreting the azimuth from the tick marks printed inside the edge.

The source of the "no-net-rotation" or NNR velocities is Argus and others (2010).

3. Activity 2.3A4. The estimated rate of Pacific Plate motion relative to the Hawaiian hot spot between 65 and 42 Myr is about 10 cm/yr, and the rate between 42 and 0.8 Myr is slightly less at 8.7 cm/yr. The estimated rate since 0.8 Myr is a whopping 27 cm/yr, which is about triple the previous estimated rates. What might explain this difference?

(a) The Pacific Plate velocity relative to the hot spot might have increased during the last 800,000 years.

A significant acceleration of the Pacific Plate would be recorded along its boundaries with other plates, and in particular the divergent boundaries along the East Pacific and Antarctic Ridges with the Nazca, Cocos, and Antarctic Plates. A dramatic acceleration of the Pacific Plate during the last 800,000 years is not supported by those boundary data.

(b) The input data (listed ages, locations of the relevant points on the Pacific Plate) might be incorrect or inconsistent.

We were given ages without information about what those ages actually mean. Are they the ages of the oldest volcanic rock at the surface of the volcano, or are they estimates of when volcanism began to occur on the ocean floor beneath the current volcano? What are the uncertainties in those ages?

We were given point locations on a map, but what do those locations signify? Modern mapping techniques allow us to find the location of points on Earth's surface with sufficient accuracy for this analysis, but we used the locations given on the map as if they marked the location of the hot spot under the Pacific Plate at the specified time. In fact, they marked the summit of various volcanoes. It might also be an issue that we used a map whose map projection (the method used to represent part of the near-spherical surface of Earth on a 2-dimensional map) might introduce measurement errors.

(c) The resolution of the analysis might be poor over small time intervals.

The overall trend in ages of the islands in the Emperor and Hawaiian Islands seems quite clear. This analysis seems to assume that the dimensions of the hotspot are small, and that discreet volcanoes are developed periodically and very quickly. If true, these two characteristics should allow us to measure the motion of the plate relative to the hotspot with reasonable precision. But what if the width of the hotspot is on the order of a hundred km, and the magma it generates feeds several volcanoes at the same time? (The Hawaiian hotspot has apparently resulted in eruptions at Haleakala, Hualalai, Mauna Loa, Kilauea, and Loihi Volcanoes in the past 500 years—a chain of volcanoes arrayed over ~225 km along the chain.) If the effects of the hotspot are manifest over more than 200 km of distance along the Hawaiian chain, it seems unreasonable to try to extract precise information about plate motion over short time intervals.

(d) The fact that we did not include uncertainties in our calculations might have led us astray.

Scientists are excited by unexpected results, which generate new questions. Sometimes they find that there is a flaw in their data or analysis techniques—perhaps an error in a computer code. But other times they find that there is a more important flaw in their understanding of the underlying process, and this can lead to new scientific advances.

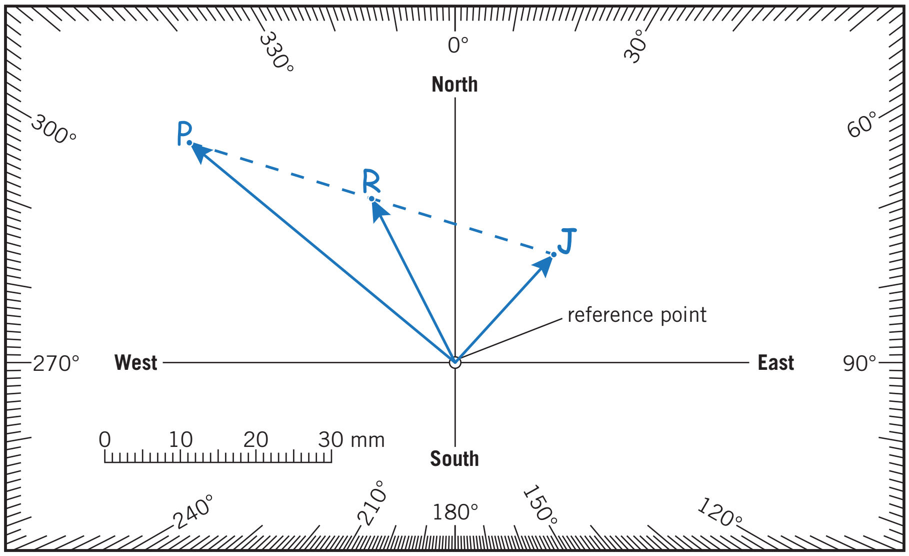
4. Activity 2.3B3(b). The area along the Snake River Plain is part of the northern Basin and Range Province and has been subjected to east-west extensional deformation during the past ~20–40 Myr. The increase in distance between the oldest caldera and Yellowstone due to Basin and Range extension during the past 13.8 Myr might account for some of the difference between the two velocity results.

5. Activity 2.3B4. Hotspots are still the focus of research, and it is fair to say that there is much that we do not yet understand about them. We will assume for the sake of argument that the locations of hotspots remain relatively constant in the upper mantle below the lithosphere, in a reference frame that is in some way fixed to the constellation of all major hotspots.

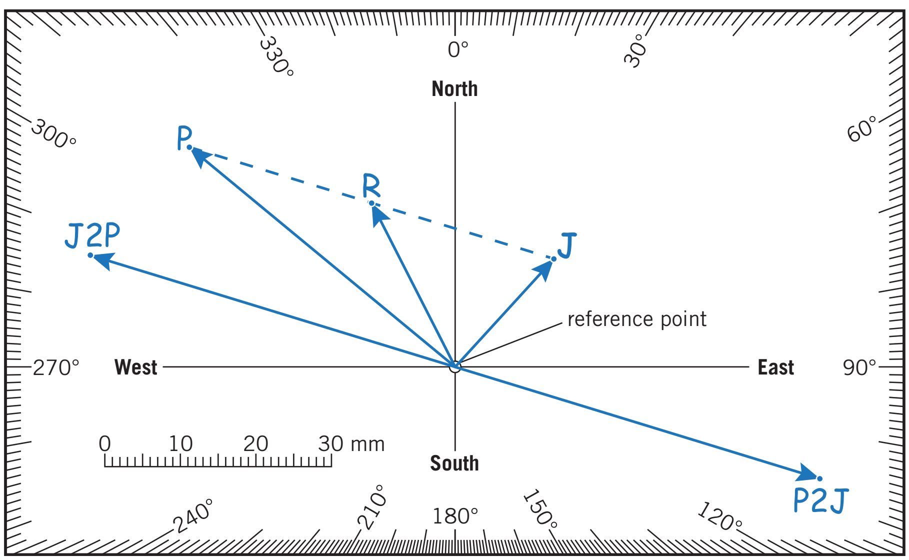
   Because that reference frame is external to the lithospheric plates, and hotspots leave geologic evidence of their general locations relative to the moving plates, they have been used to help us understand the motion of individual plates relative to Earth's interior. This has been helpful in trying to investigate the mechanisms that might contribute to the motion of plates, such as slab pull, ridge push, and trench pull (asthenospheric counterflow).

LAB 2 ANSWER KEY

ACTIVITY 2.1: Reference Frames and Motion Vectors



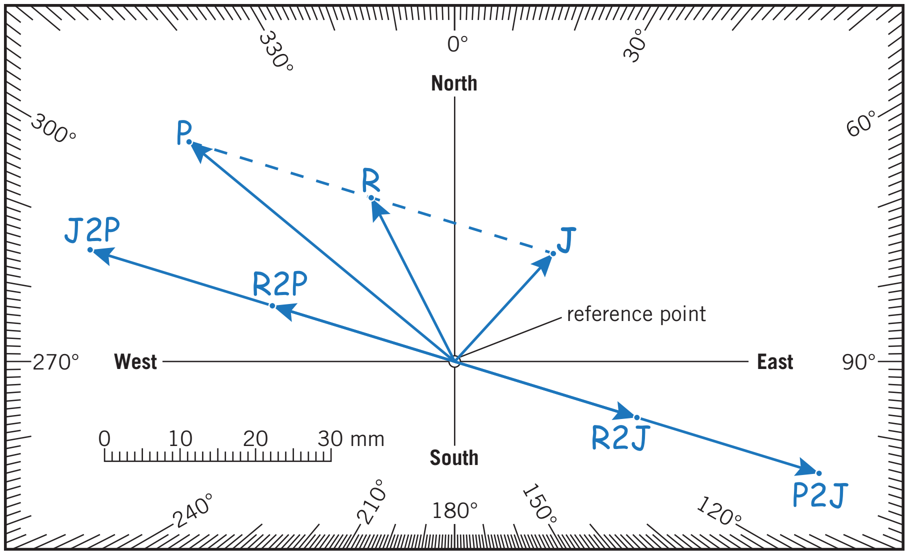
2.1A 1–3. Refer to the illustration above.



2.1B **1.** Refer to the illustration above for the vector plots.

2. speed *P2J*: ~50 to 51 mm/yr azimuth: ~107°

3. speed *J2P*: ~50 to 51 mm/yr azimuth: ~287°



2.1C Refer to the illustration above for the vector plots.

1. speed *R2P*: ~25 mm/yr azimuth: ~287°

2.1D **Reflect & Discuss** In a reference frame that is fixed to Earth, the Sun moves in a near-circular, slightly elliptical trajectory or path whose focus/center is the same as Earth's center. The Sun moves in a near-circular arc from our vantage point on Earth's surface.

Copernicus recognized that in a reference system that is fixed to the Sun, Earth and all the other planets move in slightly elliptical orbits around the Sun. The gravity associated with the Sun's great mass keeps the planets in their orbits.

ACTIVITY 2.2: Measuring Plate Motion Using GPS

2.2A The answer to this question depends on the student.

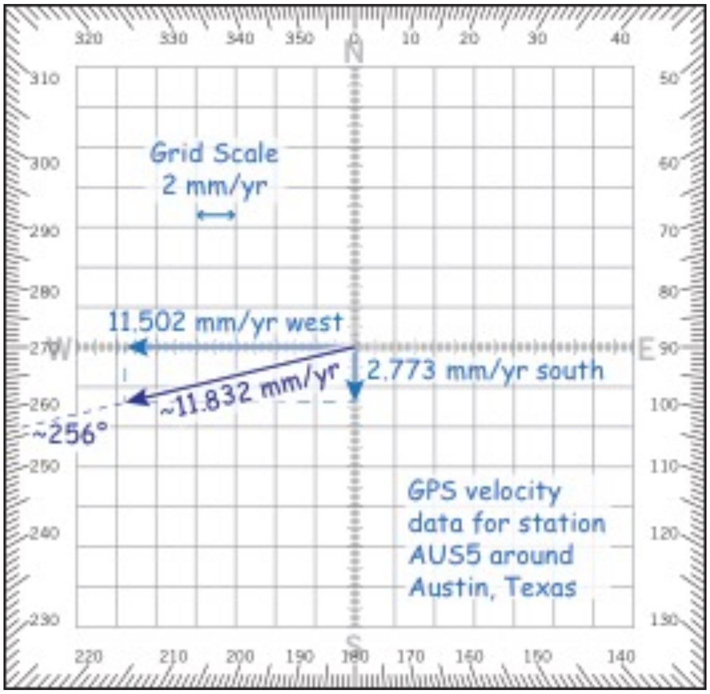
2.2B Answers will likely vary by student. An example is given for a student living in central Texas, whose closest GPS station is in Austin.

1. AUS5

2. The station is moving south at 2.773 mm/yr with an uncertainty of 0.415 mm/yr.

3. The station is moving west at 11.502 mm/yr with an uncertainty of 0.392 mm/yr.

4. The station is moving toward azimuth ~256°. This can be measured using the graph below, or can be computed using trigonometry.



5. The station is moving at a rate of 11.832 mm/yr. This rate can be measured directly from the graph above, or computed directly using the Pythagorean Equation.

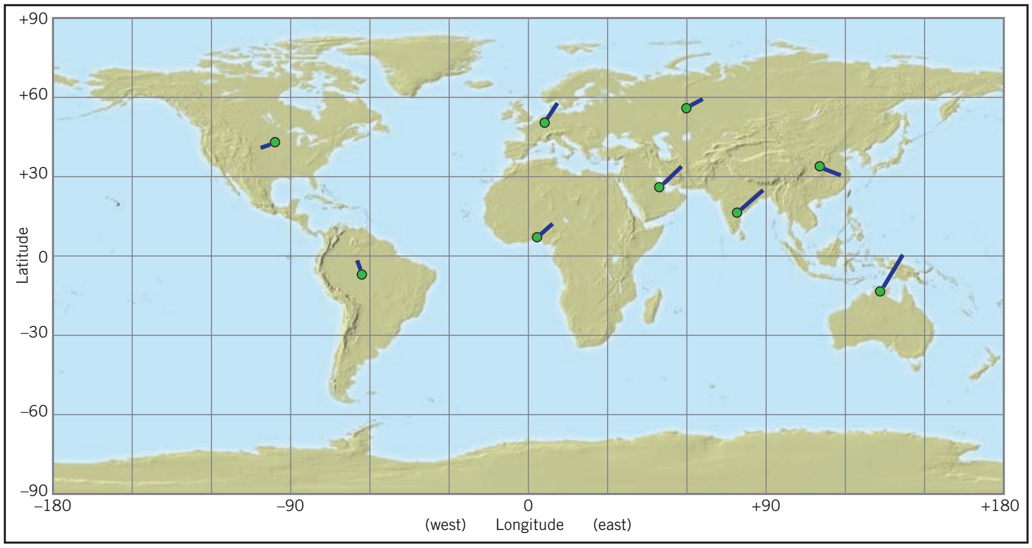
$$\text{speed} = \sqrt{11.502^2 + 2.773^2} = 11.832 \text{ mm/yr}$$

6. Current latitude: 30.311695801° Current longitude: −97.756319358°

7. N velocity: −6.81 mm/yr E velocity: −12.80 mm/yr
Speed: 14.50 mm/yr Azimuth: 242.00° clockwise from north

The Plate Motion Calculator estimated a faster rate of motion to the south (6.81 mm/yr versus 2.773 mm/yr), a slightly faster rate west (12.80 mm/yr versus 11.502 mm/yr), a faster total speed (14.50 mm/yr versus 11.832 mm/yr) and a slightly different azimuth (242° versus 256°) than the GPS data.

2.2C Refer to the map below. The direction and relative speeds in the NNR reference frame are indicated by the blue lines extending from each of the green circles.



2.2D **Reflect & Discuss** Plates are pieces of near-spherical shells that move along the near-spherical surface of Earth. The motion of an individual plate relative to any reference frame must be established at more than one point in order to represent the entire plate, assuming that the entire plate is rigid—that is, there is no motion of points within the plate relative to each other. In fact, the motions of three points that are not located along the same line are necessary to be certain that the motion of the entire plate can be estimated. That is, the three points must form a triangle in order to be useful in this analysis.

ACTIVITY 2.3: Hotspots and Plate Motions

2.3A **1.** The motion of the Pacific Plate relative to the hotspot might have changed around 42 Myr ago.

2. First, we need to convert the distance along the Emperor Chain (2300 km) to centimeters. There are 1000 meters in a kilometer, and 100 centimeters in a meter; hence, there are 100,000 cm in a km. We multiply the length in km by 100,000 to obtain the equivalent length in cm.
2300 km × 100,000 cm/km = 230,000,000 cm
Second, we need to determine the time interval in years between 65 Myr and 42 Myr.
(65 Myr − 42 Myr) = 23 Myr = 23,000,000 yr
The requested rate is in units of cm/yr, so…
(230,000,000 cm/23,000,000 yr) = 10 cm/yr
The rate of Pacific Plate motion relative to the hotspot from 65 Myr to 42 Myr is estimated to have been about 10 cm/yr.

3. On Figure 2.13, the distance between the point marked 5.1 Myr on Kaua'i and the point marked 0.8 Myr on Maui is about 8.0 cm. The bar scale on the map indicates that 150 km in the Hawaiian Islands is represented by 3.2 cm on the map. We want to know the distance in km between the specified points on Kaua'i and Maui—call that distance *x* km. If we approach this as a proportions problem, we can state that 150 km is to 3.2 cm as *x* km is to 8.0 cm. Hence,
   $(150 \times 8.0)/3.2 = 375$ km
   Now we convert the length in km to cm.
   $375 \text{ km} \times 100{,}000 \text{ cm/km} = 37{,}500{,}000$ cm
   $5.1 \text{ Myr} - 0.8 \text{ Myr} = 4.3 \text{ Myr} = 4{,}300{,}000$ yr
   $(37{,}500{,}000 \text{ cm}/4{,}300{,}000 \text{ yr}) = 8.7$ cm/yr
   The rate of Pacific Plate motion relative to the hotspot from 5.1 Myr to 0.8 Myr is estimated to have been about 8.7 cm/yr.

4. On Figure 2.13, the distance between the point marked 0.8 Myr on Maui and the point marked 0.0 Myr on Lo'ihi Seamount is about 4.6 cm. Following the logic used in the previous question, we can state that 150 km is to 3.2 cm as *x* km is to 4.6 cm. Hence,
   $(150 \times 4.6)/3.2 = 216 \text{ km} = 216{,}000 \text{ m} = 21{,}600{,}000$ cm
   0.8 Myr = 800,000 yr
   $(21{,}600{,}000 \text{ cm}/800{,}000 \text{ yr}) = 27$ cm/yr
   The rate of Pacific Plate motion relative to the hotspot from 0.8 Myr to the present is estimated to have been about 27 cm/yr.

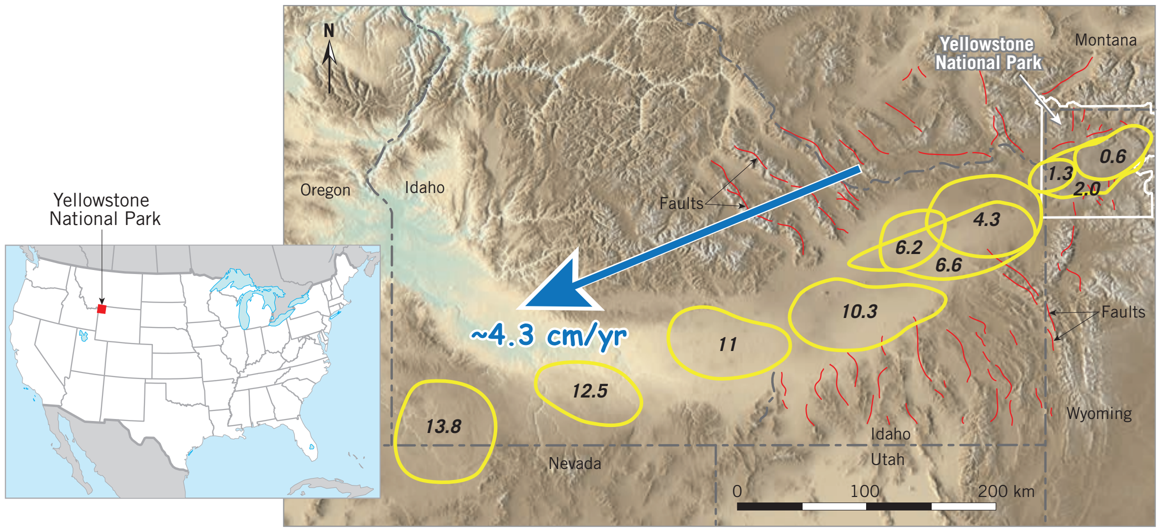
5. **a.** On the JPL-NASA GPS map, the yellow line (vector) extending from the HNLC site on Oahu is approximately coincident with the Hawaiian Islands trend, and points to the adjacent island of Kaua'i. Hence, the current motion of the Pacific Plate relative to the NNR reference frame is similar to the motion of the Pacific Plate relative to the Hawaiian hotspot over the past 42 Myr.

   b. The current speed of GPS station HNLC on Oahu relative to the NNR reference frame is…

   $$\text{speed} = \sqrt{3.6602^2 + 6.2665^2} = 7.2571 \text{ cm/yr}$$

6. **Reflect & Discuss** From about 65 Myr to 42 Myr, the Pacific Plate moved generally northward along a path that coincides with the Emperor Seamount chain at a rate of about 10 cm/yr relative to the Hawaiian hotspot. Since about 42 Myr, the Pacific Plate has moved generally northwest along a path that coincides with the Hawaiian Islands chain at an average rate that seems to be around 7–9 cm/yr.

2.3B **1.** The ages of the caldera vary in a systematic way, decreasing from west-southwest to east-northeast toward Yellowstone. This might be interpreted as a hotspot trail, and the volcanism at Yellowstone might be related to heating of the lithosphere above a mantle hotspot.



2. On Figure A2.3.1, the distance between the middle of the 13.8 Myr caldera and the 0.6 Myr caldera is about 11 cm. The bar scale on the map indicates that 200 km in Idaho and adjacent states is represented by about 3.9 cm on the map. We want to know the distance in km between the middles of the two outermost caldera in this trend—call that distance *x* km. If we approach this as a proportions problem, we can state that 200 km is to 3.9 cm as *x* km is to 11.0 cm. Hence,
$(200 \times 11.0)/3.9 = 564$ km
Now we convert the length in km to cm.
$564 \text{ km} \times 100{,}000 \text{ cm/km} = 56{,}400{,}000$ cm
$13.8 \text{ Myr} - 0.6 \text{ Myr} = 13.2 \text{ Myr} = 13{,}200{,}000$ yr
$(56{,}400{,}000 \text{ cm}/13{,}200{,}000 \text{ yr}) = 4.3$ cm/yr (rounded from 4.2735)
The rate of North American Plate motion relative to the inferred Yellowstone hotspot from 13.8 Myr to 0.6 Myr is estimated to have been about 4.3 cm/yr.

3. a. The current speed of GPS station P717 at Yellowstone relative to the NNR reference frame is…

$$\text{speed} = \sqrt{0.8200^2 + 1.4783^2} = 1.6905 \text{ cm/yr}$$

b. The current direction of P717 relative to NNR is similar to the trend of the calderas that extend west-southwest of Yellowstone, but the speed calculated from the GPS data is much slower: 1.7 cm/yr compared with 4.3 cm/yr.

4. **Reflect & Discuss** Hotspots and hotspot trails on plates provide a reference frame that is useful in characterizing the motion of plates relative to Earth's deep interior, below the plates.

ACTIVITY 2.4: How Earth's Materials Deform

2.4A **1.** **a.** This step requires students to do something. No answer is recorded.

b. (1) The putty might crack like a typical brittle solid. If it remains intact, it might show little evidence of permanent deformation.

(2) Cold putty is somewhat difficult to pull quickly—it is stronger than warm putty at higher strain rates—and might snap as a result of a brittle extension fracture after the putty stretches as a result of ductile flow.

(3) Cold putty is easier to pull at a slower rate, and is less likely to snap or break. (Its strength depends on temperature and strain rate.)

c. (1) Warm putty is rather easy to pull at a high strain rate, and might thin to a thread in the middle. It usually deforms by ductile flow when warm, without snapping or breaking.

(2) Warm putty deforms very easily at a slow strain rate.

(3) Cold putty is more difficult to deform. Cold putty is stronger.

d. (1) The sphere of putty will have flattened and spread on the tabletop.

(2) The sphere of putty deformed by ductile flow, without any fractures or faults.

e. (1) The putty will not have any fractures or faults, and will typically not even have a dent from where the ball impacted the tabletop.

(2) At the very high strain rate experienced while it bounced against the table, the putty behaves like an elastic solid and returns to its original shape.

f. The putty best exhibits brittle-elastic behavior when cold and at a high strain rate. The putty best exhibits ductile-viscous behavior when warm and at a slow strain rate.

2. **Reflect & Discuss** The lithosphere is cooler than the mantle beneath the lithosphere—the asthenosphere. The experiment with putty suggests that the cooler lithosphere might be stronger and subject to brittle deformation, whereas the warmer asthenosphere might be weaker and more likely to deform through ductile flow.

2.4B 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 wax "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.

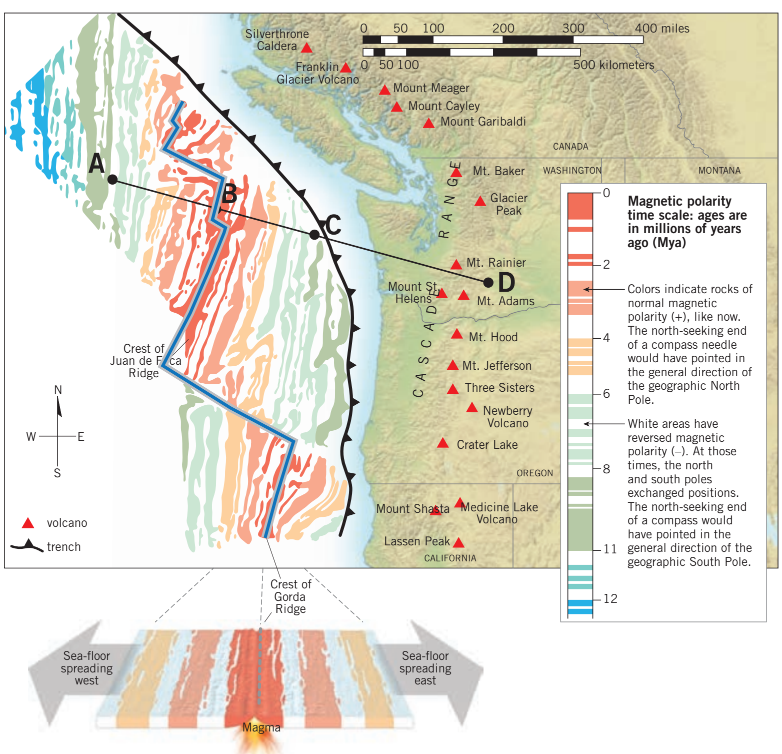
2. Wax at the base of the lamp is heated by the light bulb. As the wax is heated, its kinetic energy level rises, which causes the wax to expand to a slightly greater volume and lower density. When the density of the wax is less than the surrounding fluid, the wax rises.

3. Wax at the top of the lamp is cooling. As it cools, its kinetic energy level decreases, which causes the wax to contract into slightly less volume and higher density. When the density of the wax is greater than the surrounding fluid, the wax sinks.

4. convection

2.4C Under the same pressure conditions, molten rock is less dense than solid rock of the same composition. Hence, molten rock tends to rise toward lower pressure conditions closer to Earth's surface.

ACTIVITY 2.5: Paleomagnetic Stripes and Sea-Floor Spreading



2.5A 1. Refer to the illustration above.

2. On Figure A2.5.1, the distance between points A and B is about 2.4 cm. The bar scale on the map indicates that 500 km on the sea floor is represented by 4.8 cm on the map. We want to know the distance in km between the specified points—call that distance *x* km. If we approach this as a proportions problem, we can state that 500 km is to 4.8 cm as *x* km is to 2.4 cm. Hence,
$(500 \times 2.4)/4.8 = 250$ km
Now we convert the length in km to cm.
$250 \text{ km} \times 100{,}000 \text{ cm/km} = 25{,}000{,}000$ cm
Point A is on crust that formed around 8 Myr ago, and point B is on crust that is forming today (0 Myr). 8 Myr = 8,000,000 yr
(25,000,000 cm / 8,000,000 yr) = 3.1 cm/yr (rounded from 3.125 cm/yr)
The rate of Pacific Plate motion relative to the ridge from 8 Myr to the present is about 3.1 cm/yr, moving toward the west-northwest.

3. On Figure A2.5.1, the distance between points B and C is about 2.3 cm. The bar scale on the map hasn't changed, and we still want to know the distance in km between the specified points—call that distance *x* km. We can state that 500 km is to 4.8 cm as *x* km is to 2.3 cm. Hence,
$(500 \times 2.3)/4.8 = 240$ km
Now we convert the length in km to cm.
$240 \text{ km} \times 100{,}000 \text{ cm/km} = 24{,}000{,}000$ cm
Point C is on crust that formed around 8 Myr ago, and point B is on crust that is forming today (0 Myr). 8 Myr = 8,000,000 yr
(24,000,000 cm/8,000,000 yr) = 3.0 cm/yr (rounded from 2.995 cm/yr)
The rate of Juan de Fuca Plate motion relative to the ridge from 8 Myr to the present is about 3.0 cm/yr, moving toward the east-southeast.

4. The older rock on the Juan de Fuca Plate has already subducted under the North American Plate

5. **a.** You would see the seafloor along the Cascadia trench.

   b. The North American Plate is east of the Cascadia trench.

   a. The Juan de Fuca Plate is west of the Cascadia trench.

6. **Reflect & Discuss** The Juan de Fuca Plate subducts beneath the North American Plate. Water is released from the subducted Juan de Fuca Plate, rises into the mantle wedge above it at the base of the North American Plate, and has the effect of lowering the melting point of the rock in that mantle wedge. Partial melting begins, magma rises toward Earth's surface, and the magmatic arc (Cascade Range) volcanoes form.

ACTIVITY 2.6: Atlantic Sea-Floor Spreading

2.6A **1.** Average speed of B_{NA} relative to A since 67.7 Myr: 1.98 cm/yr

133,800,000 cm/67,700,000 yr = 1.98 cm/yr (rounded from 1.97637)

Average speed of B_{AF} relative to A since 67.7 Myr: 1.95 cm/yr

132,000,000 cm/67,700,000 yr = 1.95 cm/yr (rounded from 1.94978)

Over the past 67.7 Myr, the North American Plate might have moved slightly faster than the African Plate relative to the ridge.

2. The time between 154.3 and 67.7 Myr is

154,300,000 yr − 67,700,000 yr = 86,600,000 yr

Average rate of accretion to North American Plate between B_{NA} and C_{NA} from 154.3 Myr to 67.7 Myr: 1.56 cm/yr

135,400,000 cm/86,600,000 yr = 1.56 cm/yr (rounded from 1.56351)

Average rate of accretion to African Plate between B_{AF} and C_{AF} from 154.3 Myr to 67.7 Myr: 1.48 cm/yr

127,900,000 cm/86,600,000 yr = 1.48 cm/yr (rounded from 1.47691)

Between 154.3 and 67.7 Myr, the North American Plate moved faster than the African Plate relative to the ridge.

2.6B This analysis indicates that new lithosphere was added asymmetrically along the North Atlantic Ridge in the vicinity of point A since 154.3 Myr, with more lithosphere added to the North American Plate compared with the African Plate.

2.6C The map distance between C_{NA} and the outer continental shelf of North America is about 1.0 cm. The map length of 1500 km on the bar scale is 2.65 cm, to the nearest half millimeter. We can use proportions to estimate the actual distance between C_{NA} and the outer continental shelf of North America, which we will call x_{NA} km. We know that 1500 km is to 2.65 cm as x_{NA} km is to 1.0 cm, so

$x_{NA} = (1500 \times 1)/2.65 = 566.038$ km

At a rate of 1.56 cm/year (the same as the average rate that crust accreted on the North American Plate from 154.3 Myr to 67.7 Myr), 566 km of crust would have taken about (56,600,000 cm/1.56 cm/yr) = 36,282,100 yr or 36.3 Myr to accrete between the edge of the North American continental shelf and the 154.3 Myr isochron on the sea floor.

The map distance between C_{AF} and the outer continental shelf of Africa is about 0.6 cm. We can use proportions to estimate the actual distance between C_{AF} and the outer continental shelf of Africa, which we will call x_{AF} km. We know that 1500 km is to 2.65 cm as x_{AF} km is to 0.6 cm, so

$x_{AF} = (1500 \times 0.6)/2.65 = 340$ km (rounded from 339.623)

At a rate of 1.48 cm/year (the same as the average rate that crust accreted on the African Plate from 154.3 Myr to 67.7 Myr), 340 km of crust would have taken about (34,000,000 cm/1.48 cm/yr) = 22,947,500 yr or 22.9 Myr to accrete between the edge of the African continental shelf and the 154.3 Myr isochron on the sea floor.

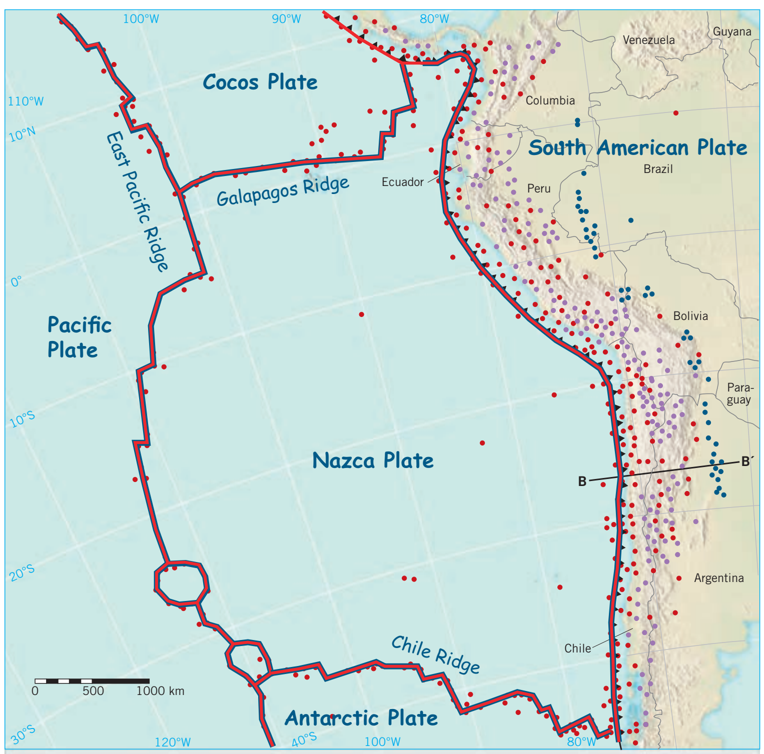
An estimate for initial opening based on the North American side would be about 191 Myr: 154.3 Myr + 36.3 Myr = 190.6 Myr
An estimate for initial opening based on the African side would be about 177 Myr: 154.3 Myr + 22.9 Myr = 177.2 Myr

An estimate for the initial opening of the North Atlantic, based on the limited data provided, is between 177 Myr and 191 Myr ago. There is substantial uncertainty about the location of points on North America and Africa that were originally next to each other at the time the continents began drifting apart, and the map projection and scale are another source of measurement uncertainty.

2.6D **Reflect & Discuss** As of 2017, it has been 241 years since 1776. At a rate of 1.98 cm/yr, it is estimated that approximately (241 yr × 1.98 cm/yr) = 477 cm or 4.77 m of lithosphere has accreted to the North American Plate. In that same time at a rate of 1.95 cm/yr, approximate (241 yr × 1.95 cm/yr) = 470 cm or 4.70 m of lithosphere has accreted to the African Plate. Since 1776, North America and Africa have moved apart by about (4.77 + 4.70) = 9.47 m.

Note that the estimated distance varies along the boundary, and is greater in the south than in the north.

ACTIVITY 2.7: Using Earthquakes to Identify Plate Boundaries

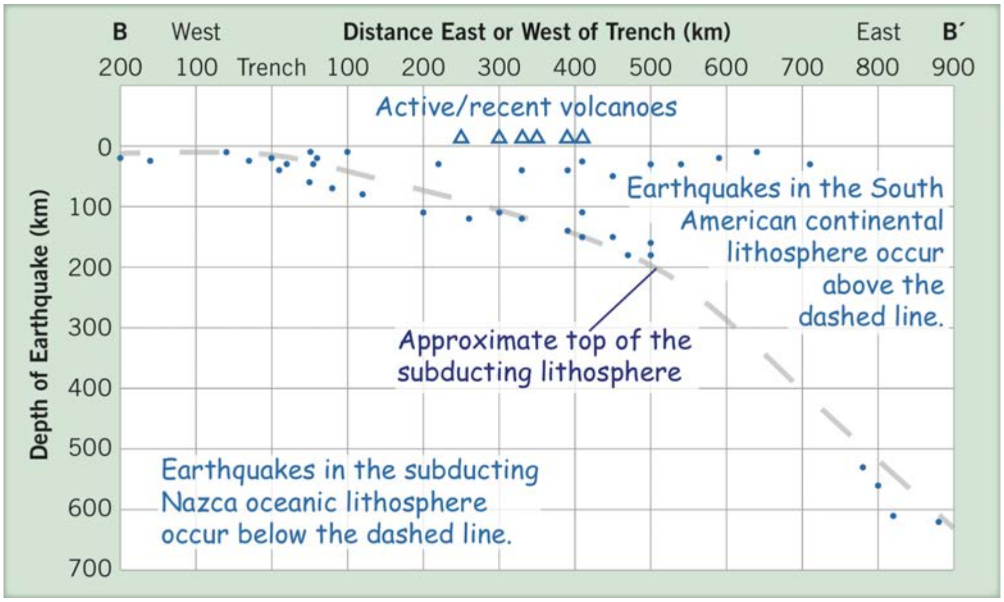


Map of Earthquake Activity in the Eastern Pacific Ocean and South America

Shallow-focus earthquakes 0–69 km deep; Intermediate-focus earthquakes 70–299 km deep; Deep-focus earthquakes 300–700 km deep; Trench

(Data from U.S. Geological Survey)

2.7A Refer to the illustration above.



2.7B Refer to the illustration above.

1. The cross section depicts a subduction boundary.

2. Refer to the dashed curve illustration above.

3. Refer to the labels in the illustration above.

4. Based on the dashed line above, magma might be generated above the subducting plate at depths between about 90 km and 150 km.

5. **Reflect & Discuss** The deepest earthquake in the cross section occurred at a depth of 620 km. The cooler lithosphere of the subducting slab is surrounded by warmer mantle material at that depth, and the cooler temperature and (possibly) higher strain rate in the slab compared with the adjacent mantle might result in earthquakes within the slab.

WEB RESOURCES

GeoMapApp—http://www.geomapapp.org

Google Earth—https://www.google.com/earth/

GPlates by Dietmar Müller and his research group—http://www.gplates.org

JPL-NASA GPS time series—http://sideshow.jpl.nasa.gov/post/series.html

MORVEL and NNR-MORVEL56 plate velocity estimates by Chuck DeMets, Don Argus, and Richard Gordon—http://geoscience.wisc.edu/~chuck/MORVEL/

PALEOMAP Project by Chris Scotese—http://www.scotese.com

SI system of units—http://www.bipm.org/en/publications/si-brochure/

The Math You Need When You Need It—http://serc.carleton.edu/mathyouneed/index.html

UNAVCO GPS Velocity Viewer—http://www.unavco.org/software/visualization/GPS-Velocity-Viewer/GPS-Velocity-Viewer.html

UNAVCO Plate Motion Calculator—http://www.unavco.org/software/geodetic-utilities/plate-motion-calculator/plate-motion-calculator.html

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