GAGE
SAGE
Operated by EarthScope Consortium

ShakeAlert™
ACTIVITIES FOR FORMAL AND INFORMAL LEARNING SETTINGS

PACIFIC NORTHWEST AND THE BIG SQUEEZE

DEFORMATION, EARTHQUAKES, AND GPS

OVERVIEW

Earthquakes in the Pacific Northwest are not as common as earthquakes in California, but they do happen. The potential of a major subduction zone earthquake and ensuing tsunami is real and omnipresent. Using hand movements, simple manipulatives, and data from the Global Positioning System (GPS) and maps, learners explore ground deformation at a convergent plate boundary and within the plate itself. This ground deformation is then related to seismic hazards.

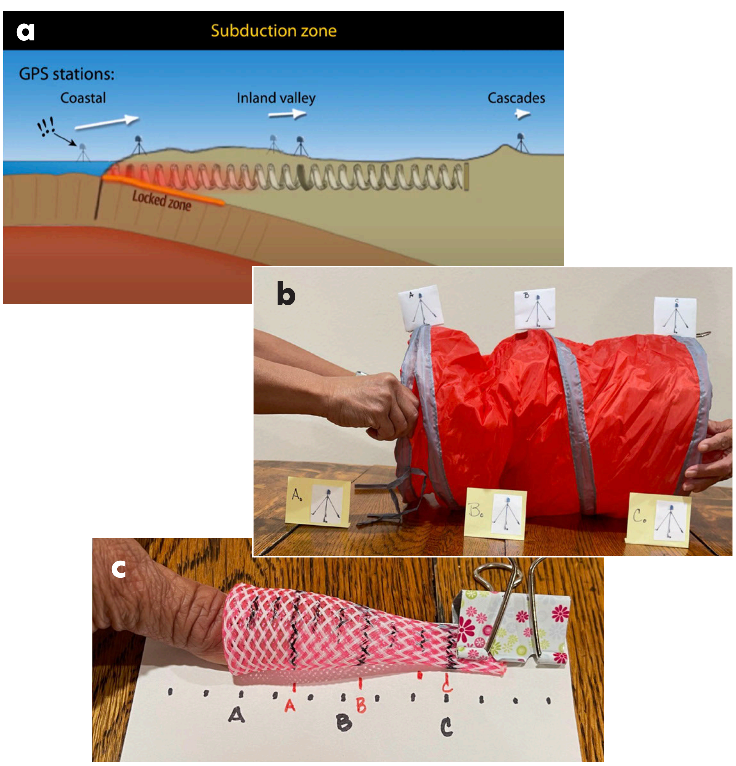


FIGURE 1. Modeling land compression with springs. (a) Compression of the land in the Pacific Northwest can be modeled using (b and c) compression springs of various sizes.

5 min | 20-30 min | 60+ min

Large Group | Small Group

Beginner | Learner Investigation | Web-Based | Materials Required

TIME. 5, 20-30, and 60+ minute guided activities adaptable for audience and venue.

AUDIENCE. Novice and experienced geoscience learning groups from grades 6 to 16.

CONTENTS

In this activity, learners make observations and discover compression patterns using spring-like devices. The **5 Minute Activity** introduces learners to the concept that the amount of land deformation varies with the distance from the plate boundary. The **20-30 Minute Activity** extends this idea by having learners collect data using a minispring cat toy. The **60+ Minute Activity** moves into quantitative detail to measure the ground movement vectors within tectonic plates. Learners discuss the connection between deformation and seismic hazards, and then identify regions most likely to have earthquakes. Finally, they compare their findings to earthquake shaking potential maps and explore societal impacts. A vocabulary list is provided in Appendix A.

Why is it important to learn about plate motions and ground deformation near plate boundaries? More than 143 million people are exposed to potential earthquake hazards in the United States that pose risks to thousands of lives and may lead to billions of dollars in damage. It is important to identify areas where the motion of the ground quickly changes across a region and where there is stored elastic energy because they are more likely to have greater seismic hazards. This ground deformation can be measured using GPS. The ShakeAlert Earthquake Early Warning System, which integrates GPS data, is an important tool used for hazard preparedness for the U.S. West Coast. It detects and processes earthquakes quickly so that alerts can be delivered to people and automated systems.

OBJECTIVES

Learners should be able to:

1. Describe, either orally or in writing, how the movement of tectonic plates at a convergent plate boundary can cause crustal deformation by interpreting GPS vector maps.
2. Explain that velocity has two components, the speed and direction of ground movement.
3. Interpret speed and direction of ground motion from GPS ground motion vector maps.
4. Identify regions more likely to have earthquake hazards using relevant GPS evidence.

MATERIALS

5 MINUTE ACTIVITY	20-30 MINUTE ACTIVITY	60+ MINUTE ACTIVITY
☐ 1 compressible springy laundry basket or pet tunnel (see Figure 1)—it looks like a large compression spring ☐ 3 folded GPS station cards printed on cardstock (Appendix C) ☐ 3 sticky notes ☐ 3 binder clips ☐ Oregon and Washington GPS vector map for projection (Appendix D) OPTIONAL EXTENSIONS ☐ Vector components (Appendix E) ☐ 1 stretchy/elastic band (3'-4'), exercise-resistance band, or tube	☐ Mini compression springs (cat toys)—1 for the instructor and 1 for each 1-2 learners depending on age level (they must be prepped; see instructions in the instructor background and preparation section) ☐ For each minispring: 1 centimeter ruler or paper with centimeter markings; binder clips ☐ (Optional) 1 Activity Handout per learner (Appendix F) ☐ 1 large Oregon and Washington GPS vector map per learner (Appendix D) OPTIONAL EXTENSIONS ☐ Any additional ShakeAlert resources that were not covered earlier ☐ For the Minispring/Ramp Demonstration: 1 each minispring, ramp, ruler, box, comb ☐ Any of the Convergent Boundary resources	☐ Materials from **20-30 Minute Activity** ☐ Oregon and Washington and western United States GPS vector maps (Appendix D) ☐ 1 Activity Handout per learner (Appendix G) ☐ Display or print 1 per minispring: Oregon earthquake shaking potential map (Appendix I) ☐ Display or print 1 per minispring: Washington earthquake shaking potential map (Appendix I) ☐ 1 long measuring tape ☐ Colored pencils (3 different colors) for each learner

MEDIA RESOURCES

BACKGROUND AND PRE-ACTIVITY

- Animation: Measuring Plate Tectonic Motions with GPS (5:42)
- Animation: Pacific NW—The Cascadia Subduction Zone (Geomorphology) (2:40)
- Video tutorial: How GPS Measures Ground Motion: Hands-On Demonstration (3:05)
- Video: Plate Boundary: Convergent Margin (1:15)

5 MINUTE ACTIVITY

- Activity: Kinesthetic Modeling & Interpreting GPS Data Maps
- Animation: Measuring Plate Tectonic Motions with GPS (5:42)
- Animation: Pacific NW—The Cascadia Subduction Zone (Geomorphology) (2:40)
- Web Page: How Do I Sign Up for the ShakeAlert Earthquake Early Warning System?

20-30 MINUTE ACTIVITY

- Video: Measuring Plate Tectonic Motions with GPS (show from 3:25-4:35)

EXTENSION

- Animation: ShakeAlert: Earthquake Early Warning System for the West Coast (3:05)
- Animation and Activity: Earthquake! Steps to Take When it Strikes (3:03)

60+ MINUTE ACTIVITY

PART B

- Video: Measuring Plate Tectonic Motions with GPS (show from 3:25-4:35)
- Video: Pacific NW—The Cascadia Subduction Zone (Geomorphology) (2:40)

PART D

- Animation: ShakeAlert: Earthquake Alert Times in the Pacific Northwest (5:46)
- Web Page: How Do I Sign Up for the ShakeAlert Earthquake Early Warning System?
- Video: Preparedness Journey (2:02)
- Guide: "Prepare in a Year" (pdf)

EXTENSION

- Animation: ShakeAlert Gets a Boost with GPS Technology (2:05)
- Animation: How the ShakeAlert System Works (2:18)
- Activity: Geologic Hazards Related to Earthquakes: Identifying Geologic Hazards in Your Community
- Activity: Emergency Backpack and Earthquake Preparedness Actions

OPTIONAL SHAKEALERT RESOURCES

Additional ShakeAlert Educational Resources hosted by EarthScope to consider.

- Earthquake! Steps to Take When it Strikes (3:03)
- Pet Preparedness (1:48)
- Emergency Backpack and Earthquake Preparedness Actions
- Home Hazard Hunt (1:39)
- Engineering Earthquake Mitigation Activities
  - Designing Earthquake Resistant Structures
  - Tsunami Vertical Evacuation Structures

GOING FURTHER

Additional videos, publications, and online tools as relevant background.

- USGS's ShakeAlert Resources
- NASA's Brief History of Geodesy (2:24)
- EarthScope's GPS Velocity Viewer Tool
- USGS's Understanding Plate Motions for Plate Tectonics Primer
- How Seismic Hazard Maps are Made
  - Introduction to the National Seismic Hazard Maps
  - USGS Website on Earthquake Hazards
- Plate Tectonic Boundaries: Three Types Differentiated

TABLE OF FIGURES AND APPENDICES

INSTRUCTOR PREPARATION

It is recommended that instructors familiarize themselves with the Media Resources and Appendices listed on the previous pages. If time is tight, the three most important videos to review are:

- Animation: Measuring Plate Tectonic Motions with GPS (5:42)
- Animation: Pacific NW—The Cascadia Subduction Zone (Geomorphology) (2:40)
- Video Tutorial: How GPS Measures Ground Motion (3:05) to learn about ground motion vector maps and hands illustrating plate motion

ABOUT GROUND DEFORMATION, GPS, GROUND VELOCITY VECTORS

Within a tectonic plate, some parts of the land can move more quickly or in different directions from other regions nearby. The rock comprising the tectonic plate is elastic, like a rubber band. It can deform—stretching, compressing, and twisting—until it breaks and moves at a fault, releasing stored energy. We call this sudden release of stored energy an earthquake. Typically, at subduction zones, the land closer to a tectonic plate boundary will deform more than the land in the middle of the plate.

Land movement is measured by very precise communication from GPS satellites or other Global Navigation Satellite Systems (GNSS) to GPS receivers (**Figure 2**) on Earth. Data are collected every tenth of a second every day to precisely measure tectonic movement at the sub-millimeter level. In regions that experience more earthquakes, data are collected more frequently. GPS receiving stations are permanently anchored into rock or deep into soil so that if the ground moves, the GPS station moves with the ground and records that movement. **Figure 3** is an example of a GPS station in Forest Grove, Oregon.

For example, the Juan de Fuca plate is subducting beneath the North American plate. Over hundreds of years, the western edge of the North American plate has been compressed inland. Using GPS, scientists can detect this compression in stations over 200 miles inland in Yakima, Washington, and Redmond, Oregon. Eventually, the energy stored in the rocks will overcome the friction along the Cascadia subduction fault, causing sudden ground shaking as the energy releases in an earthquake.

On maps, the velocity (speed + direction) for horizontal motion of the ground is depicted as a vector (see **Sidebar 1**). Emphasize that a vector shows key pieces of information. Direction of movement is shown by the arrowhead. The length indicates speed of movement.

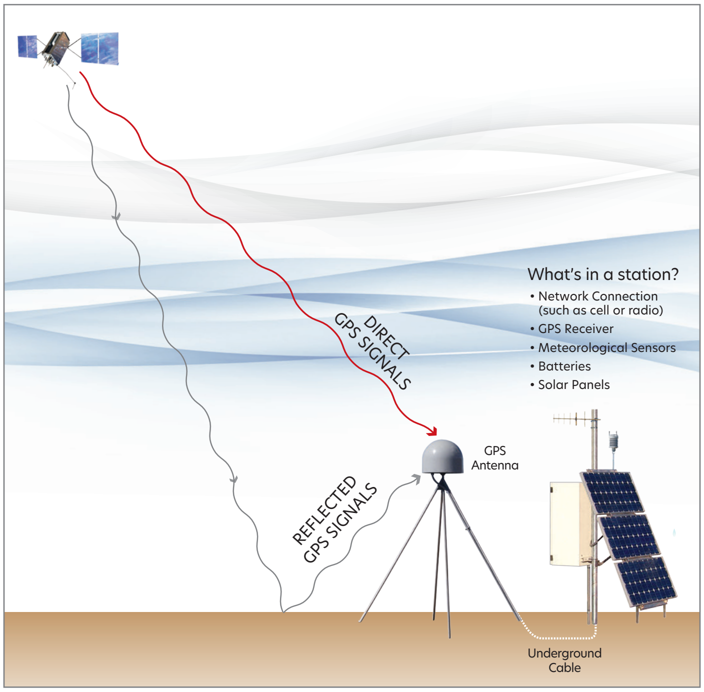


FIGURE 2. GPS satellite to GPS receiver communication. GPS determines the precise location for positions on Earth. Learn more about what GPS can tell us about Earth's atmosphere, hydrosphere, cryosphere, and changes to Earth's topography in Appendix B.

FIGURE 3. GPS Station P411 in Forest Grove, Oregon, a typical GPS station installation. The GPS antenna on the left is anchored to the ground. Solar panels, GPS receiver, and communication equipment are on the right. *Source: EarthScope Consortium*

Learners may confuse the length of the vector with total distance moved or strength of an earthquake. The longer the arrow, the faster the ground and GPS station move.

During the **20–30 Minute Activity** extension, learners simulate stick and slip behavior as the Juan de Fuca plate subducts beneath the North American plate. Between earthquakes, the two plates are "stuck together." The North American plate continues to be compressed inland, with the edge that touches the Juan de Fuca plate bulging slightly upward. When the friction between the plates is finally overcome, an earthquake will occur as the North American and Juan de Fuca plates rapidly slip past each other. During this earthquake, the ground will spring back toward the ocean, with the coast potentially moving 3 to 4 meters horizontally. Additionally, the coastal areas will drop a meter or more, causing immediate flooding. A subsequent tsunami may impact the region even more.

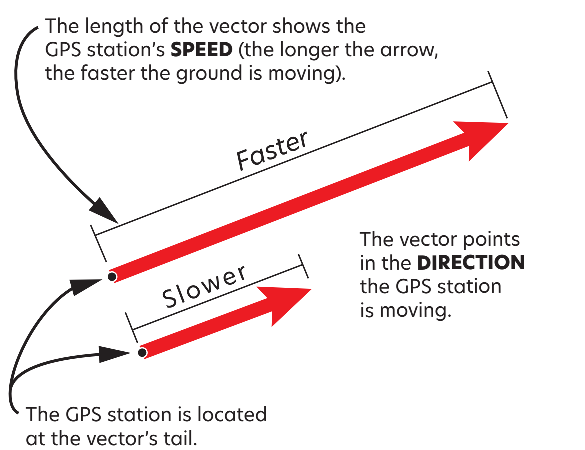
SIDEBAR 1. WHAT'S A GPS VECTOR? WHAT DO THE ARROWS SHOWN ON THE MAPS REPRESENT?

A vector is a type of arrow that shows the direction and speed of an object. In this case, GPS stations are anchored into rock or deep into the soil so we can observe and record how the whole area is moving. If the GPS stations are moving, then the ground they are attached to must be moving.

The tail of each vector indicates the location of a GPS station and points in the direction of movement. Its length is proportional to the station's speed; the longer the arrow, the faster the GPS station and ground are moving.

Anatomy of a Vector

A vector indicates the direction and speed of an object.



High-precision GPS stations attached to the ground collect data about the ground's motion at a specific location. A vector represents the speed (length of the vector) and the direction that a specific piece of ground is moving. See Appendix B for a larger version to display.

GEOMORPHOLOGY OF THE REGION

Learners might ask if the Cascades or Oregon's Coast Range are created by this vertical flexing of the land. The Coast Range has been created over millions of years from terrane accretion and long-term buckling of the landscape, while the Cascade Range is a result of volcanic activity. An area of active research is determining the amount of compressed land that rebounds versus added by long-term accretion. To learn more, view the animation on the geomorphology of the Cascadia Subduction Zone (Pacific NW—The Cascadia Subduction Zone (Geomorphology)). Appendix B provides more background information about plate boundaries, vectors, reference frames, and GPS.

ABOUT MODELS AND DEMONSTRATIONS

Expressed models, which include physical models, mechanical models, mathematical models, and computer simulations, are effective tools for illustrating complex ideas, though they have limitations compared to the real-world phenomena they depict. In the following activities, mechanical models are used to represent natural processes that cannot be directly observed in the classroom. It is important for learners to explicitly map similarities and differences between the model and the actual concept to avoid misconceptions or confusion.

For instance, in the activities, compression springs, such as a toy tunnel and minisprings, are used to simulate Earth's response to compressive forces from the Juan de Fuca plate. The minispring behaves similarly to Earth by crumpling and thickening closer to the origin of the force and moving less further away. However, it differs in material (plastic), speed of movement, and ease of deformation compared to Earth's actual response, which takes hundreds of years, not seconds. When force is removed, the minispring springs back similar to Earth, but springs back faster.

To make these differences explicit, have learners create a T-chart and title the columns "Similarities" and "Differences" or "Like" and "Unlike" to record the comparisons. This process helps clarify how models serve as representations rather than exact replicas of natural processes.

PRE-ACTIVITY

Before any activities are completed, learners should know the different types of plate boundaries. If not, explain convergent boundaries/subduction zones using one of the following:

- **WHAT IS A CONVERGENT BOUNDARY?**
  Explain that at a convergent boundary, two plates are colliding. Diagrams often display convergent boundaries with the plates moving toward each other; however, there are multiple ways a convergent boundary can be modeled. One plate can stay still while the other plate collides with it, causing either subduction or mountain building. An example is the Juan de Fuca plate moving toward the North American plate when viewing their movement using the North American Reference Frame.
- **VIDEO.** Plate Boundary: Convergent Margin (1:15)
- **APPENDIX B.** See Appendix B for information on the subtleties of plate boundary motion and for guidance on using hand movements and vectors to explain plate motions.

IF YOU HAVE 5 MINUTES

"DID YOU KNOW?" DISCOVERY QUESTION

Did you know that the ground can be compressed and spring back into place? What is happening when the ground springs back?

There are places where Earth is being compressed like a spring, building up energy. Normally, we can't feel this compression because it is happening very, very slowly. While the North American plate is frictionally stuck to the subducting Juan de Fuca plate, the Cascadia Subduction Zone in the Pacific Northwest compresses as the North American plate is pushed inland.

In this 5-minute demonstration, learners will use a giant compression spring, such as a pop-up laundry basket or collapsible pet tunnel, to model the ground movement of the Pacific Northwest caused by the subduction of the Juan de Fuca plate beneath the North American plate. They will explore the properties of a giant spring, noting that as the spring is compressed, the area closest to the force (the subducting plate) moves the most, and areas further away move less. When the force on the spring is removed suddenly, for example, when an earthquake occurs, it rebounds to its initial position.

Learners will then connect this elastic behavior of the model to ground motion in the Pacific Northwest by examining a map with ground motion vectors. Learners will note that areas on the coast closest to the subducting Juan de Fuca plate have the longest vector arrows, indicating they move the most, whereas areas further inland move less and have shorter vectors. Learners will then brainstorm what will happen when the plate springs back and brainstorm ways to prepare for the resulting earthquake. As an extension, learners will explore vectors through kinesthetic modeling.

INSTRUCTOR PREPARATION

BEFORE YOU BEGIN

Before beginning the activity, watch the relevant media resources on GPS data and plate motion for your background information.

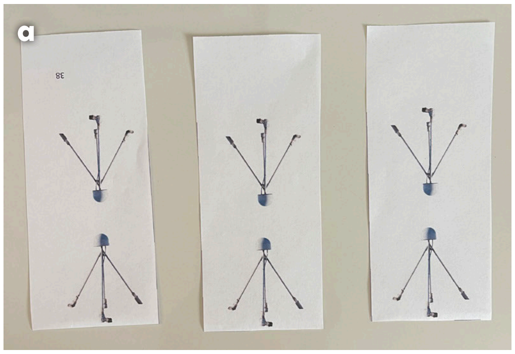
- Review animation Measuring Plate Tectonic Motions with GPS
- Review animation Pacific NW—The Cascadia Subduction Zone (Geomorphology) (2:40) to be able to relate the topography of the area to the Juan de Fuca plate subduction.

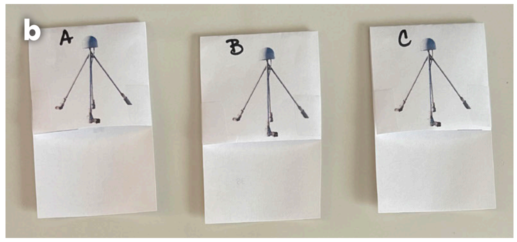
PREPARE THE MODEL

Prepare the giant spring model and GPS model (compressible laundry basket or pet tunnel with GPS models attached) as shown in **Figure 4** and explained in detail on the next page. **NOTE:** You are showing learners a side view of the pet tunnel/laundry basket; the viewer is seeing the Juan de Fuca subduction looking north. Make sure you are setting up the model and the stations so the demonstration is properly oriented.

FIGURE 4. Final setup of compression spring (tunnel) and GPS stations. Position the spring so the spacing between wires is approximately equal at the top. Your tunnel should also be arranged for your audience to see a side view with GPS images on top and on the ground aligned.

1 Print out 3 generic GPS stations (Appendix C) and label them: A for Coastal, B for Inland Valley, and C for East of Cascade Mountains. Cut, fold, and make a paper tail as shown in **Figure 5a-c**.





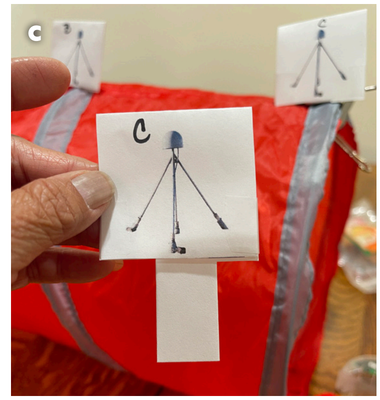


FIGURE 5. (a) GPS STATION CUT OUTS. When you cut out the GPS images, leave space around the GPS; do not cut off the extra paper from the top and bottom of the page. (b) FOLDED DOUBLE-SIDED GPS IMAGE. Fold the paper down so there is extra paper on the bottom of one side. Tape the flap with the GPS image so it stays in place. (c) PAPER GPS WITH TAIL. Cut each side of the extra paper inward approximately ¾" and fold the extra paper in so it makes a tail. Fold this up and attach it to the wire of the tunnel/laundry basket using binder clips.

2 Attach the GPS stations at 3 points along the top of the spring, using a binder clip to the inside of the spring until the GPS station card stands up facing sideways as shown in **Figure 6a, 6b**.

- The Coastal GPS should be attached at the "western" edge of the spring.
- Stations should be approximately equidistant down the length of the spring (**Figure 7**). You may need to rotate the tunnel/basket so that GPS B (Inland Valley) can attach to the inner spring, equidistant from GPSs A and B.
- For the stations on top of the tunnel, keeping extra paper on the bottom of the GPS images makes it easier to clip onto the tunnel as shown in **Figures 5c and 6a**.

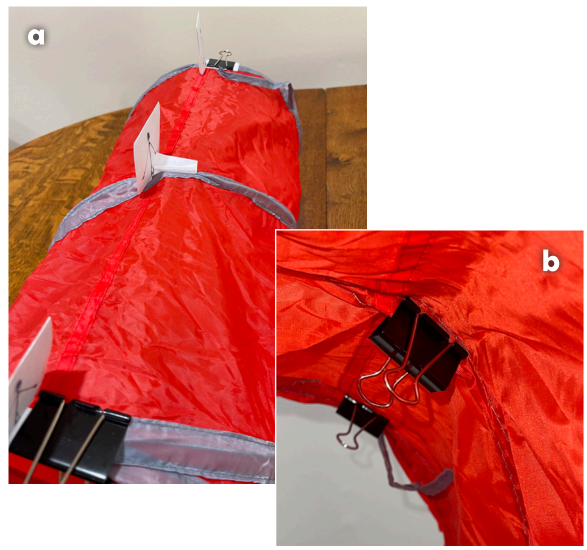


FIGURE 6. BINDER PLACEMENT FOR GPS IMAGES. (a) Attach the two end GPS stations using binder clips from the open tunnel ends. (b) Attach the middle GPS image using a binder clip from the inside.

FIGURE 7. ORIGINAL GPS POSITION MARKERS. Attach the sticky notes with GPS stations on the ground or table, aligned with the stations on the spring.

3 Print out 3 generic GPS stations and tape to three sticky notes. Label each station as A_o, B_o, and C_o for original GPS positions at A, B, and C locations. Attach the sticky notes with GPS stations on the ground or table, aligned with the stations on the spring (**Figure 7**) so learners can see how much each GPS on the spring has moved after the addition of a force (from the Juan de Fuca plate).

FIGURE 8. Uncompressed (top) and compressed (bottom) spring tunnel. Notice that the spring is pushed halfway between the first 2 GPS images on the ground. The first 2 GPS stations on top have moved, with the GPS A, closest to the force (on the left), moving the most. The image at position C shows no movement from the original position shown on the ground below. This depicts the compression of the North America plate due to the subducting Juan de Fuca plate.

TIPS FOR SET UP

- Put the tunnel on a table for easier viewing.
- Have someone else hold the opposite end (where GPS station C is)
- Have the sticky notes right below the cut outs—facing the learners.
- Before you compress the tunnel and while it is on the table, add a weight to the tunnel near GPS C so it doesn't roll over.
- See **Figure 8** for before and with compression.

ADDITIONAL STEPS

1. Plan to project the maps in Appendix D.
2. Plan to display this web page: How do I sign up for the ShakeAlert Earthquake Early Warning System?

PREP FOR EXTENSION DEMONSTRATION

Print out copies of the vector components (Appendix E) and tape them to the floor.

- Refer to the activity Kinesthetic Modeling & Interpreting GPS Data Maps for more detail of this demonstration.
- Both vectors point in the same direction, spaced such that people can see them and then walk on them. If possible, laminate the arrows before taping.
- One short vector should be approximately 90 cm (3 feet) long.
- One long vector should be approximately 180 cm (6 feet) long.
- Vectors need to be large enough to see from a distance and survive being walked on. Alternatively, vectors could be drawn on butcher paper or made with tape on the floor.

DIRECTIONS FOR LEADING THE ACTIVITY

NOTE: Bring in new vocabulary (Appendix A) to meet your learner's needs.

1 Draw attention to the "Did You Know" question: **Did you know that the ground can be compressed and spring back into place?**
LANGUAGE MODIFICATION: You may have to say "pressed together" or "squeezed" instead of "compressed" OR introduce the term "compression" using the vocabulary in Appendix A.
SUGGESTION: Show a smaller compression spring or a video of a spring being compressed and released available to demonstrate for your visual or English language learners.

2 Explain that the GPS cards represent locations on Earth, sticky notes on the floor or table top represent initial positions of GPS stations.

3 Observe and predict the action of a large spring (laundry basket or pet tunnel).

a. Compress one end of the spring while the other is held stationary by a learner. See **Figure 9**.
TIP 1: Only compress Side A to half-way between the first and second sticky-note GPS (A_o and B_o).
TIP 2: Make sure the compressed face is "flat" and evenly compressed.

b. Guide learners to observe the following:

- **OPTIONAL** (add 5 minutes to include this): Have a few learners compress the ends of the spring together and describe the feeling of the spring as it compresses. As the spring is compressed, there is buildup of potential energy in the spring. **NOTE:** The spring will most likely spring back and fly out of the learner's fingers. Focus learners on the stored potential energy converting to kinetic energy. This is similar to what happens when an earthquake occurs.

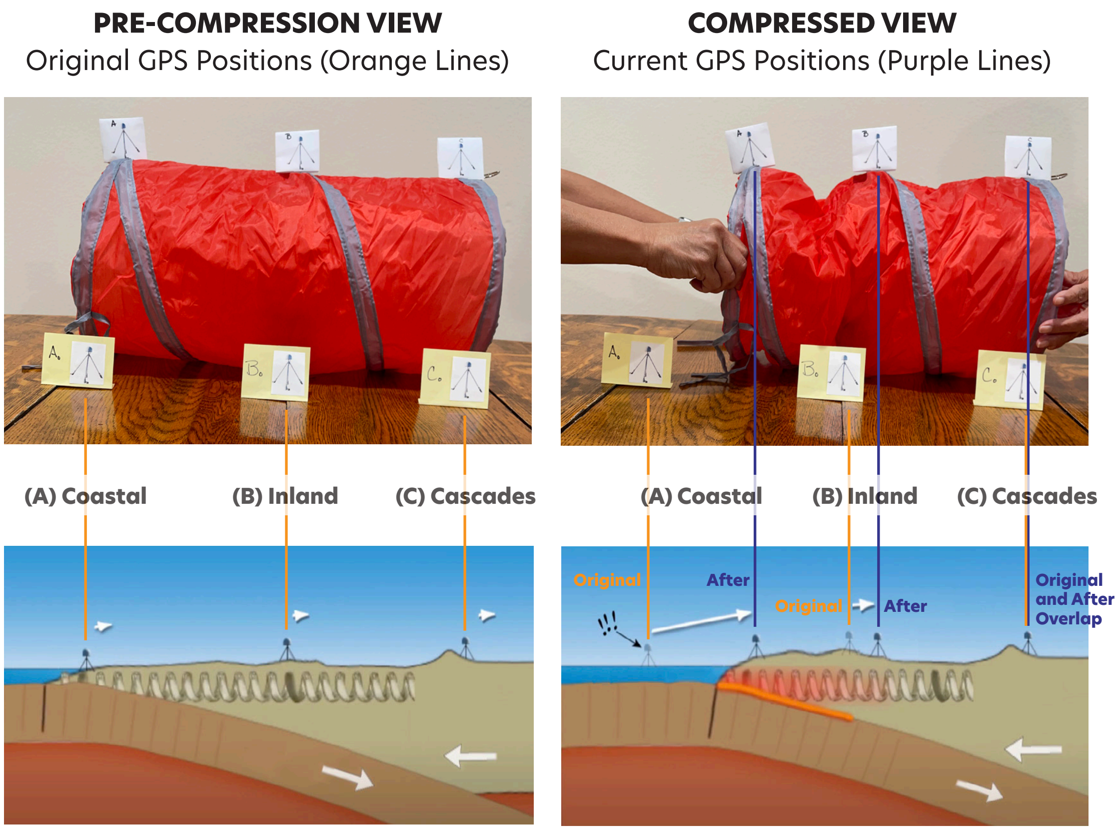


FIGURE 9. Modeling ground deformation with compressible pet tunnel/laundry basket. Photos at top show the setup (left) before compression begins on the giant spring and tectonic plate and (right) after compressing the tunnel and tectonic plate. Notice the positions of GPS stations before (orange lines) and after (purple lines) the plate is compressed. The scale of compression is greatly exaggerated to illustrate the process. See Appendix B for full-size image.

- Focus learners on the Coastal GPS station (A) and its associated sticky note. As you compress the spring, focus learners on how far the position of the GPS on the spring moves from the original position marked by the sticky note on the floor.
- Now have learners focus on the Inland Valley GPS station (B) and compare its original position to its position after "plate" movement.

c. Ask learners to compare the motion of the three GPS stations.

ANSWERS MAY VARY: *The GPS station closest to the force moved the most. The stations further away from the coast moved less.*

4 Release the end of the tunnel quickly to create an "earthquake" and ask what this could mean if a tectonic plate suddenly moved like this spring.

a. Relate this stored potential energy in the deformed rocks to the sudden release of the spring (kinetic energy).

5 Display the image of compression models with the Oregon and Washington GPS vector map (Modeling Ground Deformation section in Appendix B) and point out the different components from the model.

a. Explain that this demonstration models the compressive force applied to the North American plate (and buildup of elastic energy) and deformation (the spring compressing) as the Juan de Fuca plate subducts.

b. As the Juan de Fuca plate subducts beneath the North American plate, the ground closest to the plate boundary is compressed the most. The further inland, the less the ground moves.

c. Point out the vectors on the map and explain that each vector represents the data collected about the ground motion at that location. Relate the length of the vectors on the map to the motion of the GPS stations on the spring. Emphasize that the vectors represent speed and direction.

d. Ask learners: Why is the ground compressed? If the Juan de Fuca plate is subducting under the North American plate, why does the North American plate become compressed like this?

ANSWERS MAY VARY: *The plates are stuck together due to friction between the Juan de Fuca and North American plates. The North American plate is slightly elastic, allowing the ground to be compressed. (Instructor reference video Pacific NW—The Cascadia Subduction Zone (Geomorphology))*

e. Ask learners what will happen to the GPS stations and the ground beneath them when the plates slip (the friction is overcome) and there is an earthquake.

ANSWERS MAY VARY: *The ground, and therefore GPS stations, will lurch back toward their initial positions.*

- Model this earthquake by letting go of the giant spring.

6 If there is time, discuss this model and why there is a need for the ShakeAlert Earthquake Early Warning System (Appendix A).

a. Explain to learners that because of the risk of earthquakes in the Pacific Northwest, it is important to prepare. One way to do this is to sign up to receive ShakeAlert-powered Earthquake Early Warning Alerts (show learners the website: How do I sign up for the ShakeAlert Earthquake Early Warning System?), which can give you seconds to protect yourself before dangerous shaking arrives.

b. Ask learners what else they can do to be prepared for an earthquake.

ANSWERS MAY VARY: *Prepare emergency supplies like water and food. Know or have copies of emergency contacts. Have first aid supplies, including medications. Practice correct protective actions such as DROP, COVER, HOLD ON.*

EXTENSION: EXPLORING VECTORS

Explain that a GPS station is a tool to measure ground movement. Precise locations on land can be calculated through communications between a system of navigation satellites and GPS antennas anchored to the ground. When the ground moves, the GPS station moves with the ground and records that movement.

1 Explain vectors:

a. On the Oregon and Washington GPS vector map (**Figure 10**; larger version is found in Appendix D), the tail (point to the tail of one vector) indicates the location of a GPS station.

b. The vector arrowhead points in the direction that the station is moving.

c. Emphasize that the vectors indicate the average speed over a period of time, not the total distance moved. These maps show the movement in mm/year.

d. The length of the vector is proportional to the station's speed; the longer the arrow, the faster the ground and the GPS station are moving.

OREGON AND WASHINGTON GPS VECTOR MAP

Note: Vector scale is 1:1
Measured vector length equals actual annual movement

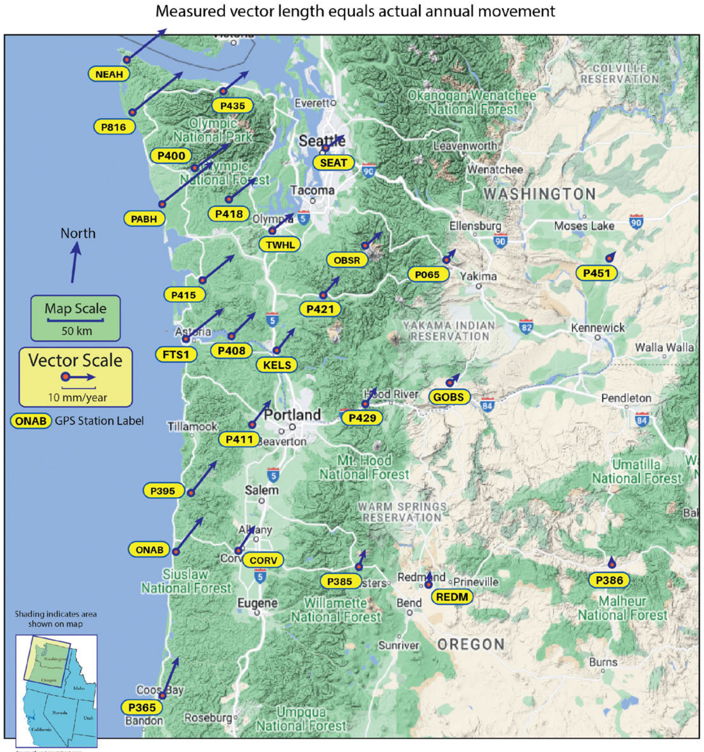


FIGURE 10. GPS vector map of Oregon and Washington. For a higher resolution version of this map to print or project, see Appendix D.

2 Ask learners: Where are the longest and shortest vectors on the map, and what does that mean? ***ANSWERS MAY VARY:*** *Longest vectors: Closer to the coast, meaning those areas are moving the fastest. Shortest vectors: Farther north/inland vectors indicate less motion per year.*

3 Model vector motion (see Appendix E):

a. Ask a learner to stand at the tail of the short vector and move in the direction the vector is pointing. Instruct the learner to move the length of the vector quickly in two steps (three steps if younger learners).

b. Ask another learner to stand at the tail of the long vector and move in the direction the vector is pointing, and to cover the length of the long vector in the same amount of time as the learner took for the short vector.

c. Now ask both learners, or another set of learners, to stand at the tails of the vectors. Tell learners that they will each have to reach the end of their vector in the same amount of time.

d. At the pace of 1 clap per second, each learner should make it to the end of the vector with 2 or 3 steps. Have the learners practice the motions first. The learner with the longer vector will walk more quickly. Meanwhile, the remaining learners are observing the process and noting the differences in speed of the people on the vectors.

e. Do a final run with observers all clapping together.

4 **Question for Discussion:** Ask learners what they noticed about their movements.
ANTICIPATED ANSWERS: *The learner with the longer vector has to move more quickly to travel the length of the longer arrow, compared to the person walking the shorter vector. They have demonstrated the speed of movement; the longer the vector, the faster the speed. Learners should also observe that the vector indicates the direction of movement.*

IF YOU HAVE 20-30 MINUTES

"DID YOU KNOW?" DISCOVERY QUESTION

Did you know that the ground below your feet can crumple?

As one tectonic plate subducts under the other, the more dense subducting plate scrapes against the less dense one. The plate on top "catches" and buckles, creating a slight bulge near the edge of the plate. Learners experience this by using a small spring to model not only ground movement but the deformation of the land due to tectonic forces.

Learners will relate this to ground motion in the Pacific Northwest by examining a map with ground motion vectors. Learners will note that areas on the coast closest to the subducting Juan de Fuca plate have the longest vector arrows, indicating they move the fastest, whereas areas further inland move slower and have shorter vectors.

INSTRUCTOR PREPARATION

1 Prep for the **5 Minute Activity** or demonstrate the concepts of compression, potential energy stored in the rocks, and earthquakes.

2 Prepare the minispring models. If there is time, have learners prepare one minispring for each learner (or one per 2-person group for younger learners). If there is not time, prepare the minisprings ahead of time (**Figure 11**).

- **a.** Tuck 0.5 cm of one end of the minispring (cat toy) in, and use a permanent marker to mark a line at the tucked end. Use this as your 0 cm line.
- **b.** Mark the minispring in 1 cm increments.
- **c.** OPTION 1. Attach the minispring to a ruler using a binder clip (**Figure 11a**).
  OPTION 2. Attach the minispring to a piece of paper marked in 1 cm increments. Label the 3 cm, 6 cm, and 9 cm lines with A, B, and C (**Figure 11b**).

3 **OPTIONAL:** Print and copy the 20-30 Minute Activity Handout (Appendix F). Answer key is provided in Appendix H.

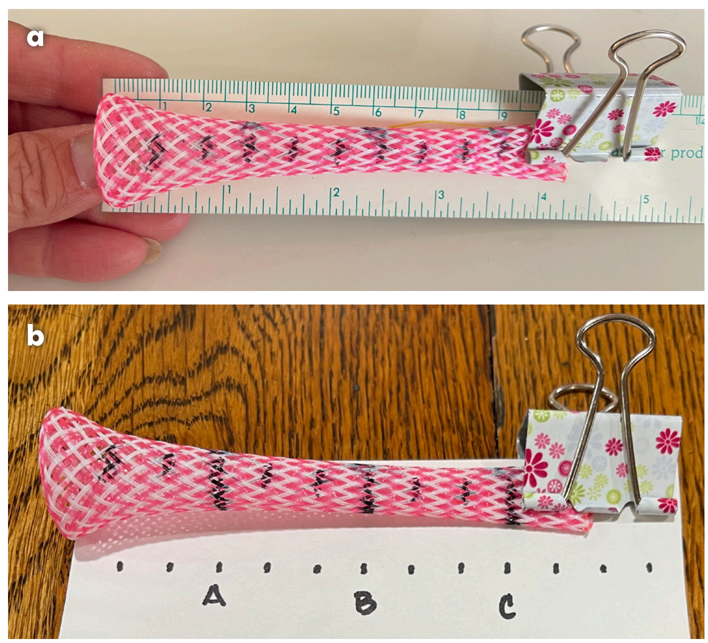


FIGURE 11. Minispring model (a) option 1 and (b) option 2.

4 Print the Oregon and Washington GPS vector map (found in Appendix D) on 8.5 x 11-inch paper so that vectors are at a 1:1 scale when printed (e.g., measuring a 10 mm vector on the vector scale on the printed map represents 10 mm/year of movement). And prep to project the map.

5 Measure and mark a length of 3 meters (9 feet, 10 inches) in your room to demonstrate how far the coast is compressed inland between earthquakes.

6 Show this animation (from: 3:25-4:35) illustrating the compression of the North American plate, potential energy held in the land (using a spring as a model), and GPS stations: Measuring Plate Tectonic Motions with GPS.

7 If there is time, prepare to show:

a. Web page: How Do I Sign Up for the ShakeAlert Earthquake Early Warning System?

b. Animation: ShakeAlert: Earthquake Early Warning System for the West Coast (3:05)

c. Animation and activity: Earthquake! Steps to Take When it Strikes (3:03)

8 For the EXTENSION: Practice the instructor demo with the cat toy minispring and a comb. View the video demonstrating this model. (0:18)

DIRECTIONS FOR LEADING THE ACTIVITY

NOTE: Bring in new vocabulary (Appendix A) to meet your learner's needs.

1 Draw attention to the "Did You Know" question. **Did you know that the ground below your feet can crumple?**

2 Complete the **5 Minute Activity** skipping the discussion step at the end as this topic is covered later in this 20-30 Minute Activity.

3 Tell learners that they will now experiment with a minispring model.

4 **3-5 minutes:** Give each learner a minispring model (for younger learners, have 2 learners per group). If there is time, the learners can put together the minisprings themselves.

a. Lay ground rules about working with the spring, (e.g., use only as directed). Include safety issues (e.g., don't point it at anyone).

b. **OPTIONAL** (this will add time to the activity): Give learners just a few minutes to play with the spring and observe what the spring can do. Let them know that they have a finite number of minutes to play. Watch your time and refocus them by asking what the "springiness" might represent. ***ANSWER:*** *Quick springing back represents an earthquake. Slow compression represents the elastic compression of the land and rocks.*
Plan extra time for refocusing.

c. Explain that each mark is 1 cm away from the other. Each letter represents a GPS station, which is a tool to measure ground movement. When the ground moves, the GPS station moves with the ground and records that movement.

d. Connect to the **5 Minute Activity** by having learners observe how this spring and the very large spring are similar and different. Each letter represents a different GPS station. Letters are on the paper while the minispring has longer lines.

- The Coastal GPS is marked with an A.
- The Inland Valley GPS is marked with a B.
- The GPS east of the Cascade mountains is marked with a C.

5 **5-10 minutes:** Direct learners to keep the minispring and ruler/paper together with the binder clip. If they aren't clipped together, explain to learners that to experiment with the model, they will:

a. Line up the folded end of the minispring with the ruler or 1 cm marked paper. Each mark on the minispring should now be lined up with a mark on the ruler or paper.

b. Pinch the unfolded end of the spring between their finger and the table to hold it steady.

- Make sure the marks on the minispring stay lined up with the ruler or paper as they continue through this activity.
- Learners can write A, B, and C on the paper to mark the starting position of the GPS stations.
- **SUGGESTION:** Use a binder clip to hold the end of the minispring and paper together so marks stay aligned (**Figure 11b**).

c. Push the folded end of the minispring slowly with their other hand. Emphasize that they need to push it slowly enough to see the movement of the marks on the minispring.

d. Observe how each GPS station moves relative to their initial positions (the marks on the paper or the ruler; **Figure 12**).

e. Ask them to identify each part of the model.

- What does the minispring represent?
  ANSWERS MAY VARY: *A tectonic plate, the North American tectonic plate, the plate overlapping the subducting plate at the western edge.*

FIGURE 12. Compressed minispring.

- What does the hand applying the force represent?
  ANSWERS MAY VARY: *A subducting plate, the Juan de Fuca plate.*
- What does each letter represent?
  ANSWER: *GPS stations*
- What does the hand holding the spring to the table represent?
  ANSWER: *The portion of the tectonic plate with no motion, for example, no compression.*
- **OPTIONAL:** Discuss how the model is "like" and "unlike" the actual subduction zone.

f. Ask learners: What did you observe? How did each GPS station move? (The observations for the minisprings should be similar to the large spring.)
ANSWERS MAY VARY: *The area of the minispring closest to the force bunched up and became thicker. The GPS stations closest to the force moved the most. The further from the force a GPS station was, the less it moved.*

6 Refer to the large printed or projected Oregon and Washington GPS vector map (found in Appendix D).

a. Remind learners that arrows are vectors that represent data collected about the motion of the ground. Relate the arrows on the map to the motion of the GPS stations on the spring.

- Explain that a GPS station is a tool to measure ground movement. Precise locations on land can be calculated through communications between a system of navigation satellites and GPS antennas anchored to the ground. When the ground moves, the GPS station moves with the ground and records that movement.
- On the map, the tail (point to the tail of one vector) indicates the **location** of a GPS station.
- The vector arrowhead points in the **direction** that the station is moving.
- Emphasize that the vectors indicate the average **speed** over a period of time, not the total distance moved. These maps show the movement in mm/year.
- The **length** of the vector is proportional to the station's speed; the longer the arrow, the faster the ground and the GPS station are moving.

b. Ask learners to compare how the vectors on the GPS vector map relate to their observations of the minispring.

ANSWERS MAY VARY: *The GPS stations on the coast are moving the fastest. The stations further inland move slower. Some learners may also be aware of the Coast Range in Oregon. While most of the thickening of the minispring at the folded end snaps back during an earthquake, a very tiny amount of the deformation stays deformed—adding to the Coast Range. Over millions of years, the cycle of crunch and release has built up the Coast Range.*

7 Point out that we can measure how far the areas on the map move annually by using the vectors.

a. The map used in this activity shows the vectors at a 1:1 scale when printed on 8.5 x 11-inch paper (e.g., measuring a 10 mm vector on the printed map represents 10 mm/year of movement.)

- Ask what the units of the vectors depicted on the map are (this reinforces that the legend shows the velocity in mm/year).

b. Learners might not appreciate the significance of millimeters (mm) of movement per year (similar to the rate that your fingernails grow). Emphasize that the movement can be significant over long periods, for instance 500 years.

c. One vector on the map measures 6 mm, so in 500 years it will move approximately 3 meters (9'10") or more.

- The instructor should show learners how far that is and ask what could happen if the ground moved that distance right now.
  NOTE: Depending on your learners, they may want to act this out; if this is OK with you, give them ground rules surrounding safety.
- Alternate question: How many of you can jump that distance?
- Alternate question: Show western United States GPS vector map (found in Appendix D). Ask what directions different regions are moving.

d. **OPTIONAL:** Ask learners to answer Questions 1-3 on the Activity Handout (Appendix F).

8 **7-10 minutes:** Discuss with learners:

a. How does this activity relate to earthquake hazards?

ANSWERS MAY VARY: *Learners should recognize that where the land is compressed or stretched the greatest, there is a higher danger of the land breaking and producing an earthquake.*

b. How can GPS data showing areas of different velocities help inform earthquake preparedness, especially for scientists and emergency planners?

ANSWERS MAY VARY: *The instructor can point toward developing a warning system for higher risk areas, such as the USGS ShakeAlert Earthquake Early Warning System.*

c. Ask learners what else they can do to be prepared for an earthquake.

ANSWERS MAY VARY: *Prepare emergency supplies, like water and food. Know or have copies of emergency contacts. Have first aid supplies, including medications. Practice correct protective actions (DROP, COVER, HOLD ON).*

d. If time permits show:

- Website: How do I sign up for the ShakeAlert Earthquake Early Warning System?
- Animation: ShakeAlert: Earthquake Early Warning System for the West Coast (3:05)
- Animation and Activity: Earthquake! Steps to take when it strikes (3:03)

9 To wrap up this activity, show this animation (from 3:25-4:35) illustrating the compression of the North American plate, potential energy held in the land (using a spring as a model), and GPS stations: Measuring Plate Tectonic Motions with GPS. If continuing with the EXTENSION, show this animation after the EXTENSION demonstration.

EXTENSION: MODELING THE SUBDUCTING PLATE

1 Demonstrate the motion of the Juan de Fuca plate subducting beneath the North American plate using the ramp, comb, and minispring. Set up the model of the subduction with a minispring and ramp.

a. Create a roughly 35-degree angle ramp using a book or other flat object, which will model the subducting Juan de Fuca plate (**Figure 13a**).

- Tape a minispring to a ruler so the minispring sticks out. (The minispring models the North American plate.)
- Place the minispring/ruler assembly on a stack of books or a box, sticking out over the edge. (This represents the leading edge of the tectonic plate.)

b. Hold the comb on the ramp (**Figure 13b**). (The comb tines represent imperfections on the subducting plate and models the friction between the two plates.)

- Slide the ruler and minispring westward until the minispring touches the comb.
- Gently push the comb down the ramp.

c. Continue to slide the comb down and hold the minispring against the comb (**Figure 13c**). A bulge will form and then, spring back creating an earthquake.

- If you continue to slide the comb down, it will repeat this process.

d. **OPTIONAL:** Show the video of this model in motion (0:18).

2 Ask learners what the ramp, comb, and minispring represent in the model.

ANSWERS MAY VARY: *The ramp guides the comb, which is the subducting Juan de Fuca plate. We use a comb to cause the friction between the two plates. The minispring is the North American plate.*

3 Allow the minispring to catch on a tooth of the comb and slide the comb downward toward the minispring so the minispring bulges. Ask learners what this is representing.

ANSWERS MAY VARY: *The comb is pushing against the minispring. The flexing and compressing of the minispring mimics the downward flex and compression (bulging or thickening) of the edge of the North American plate.*

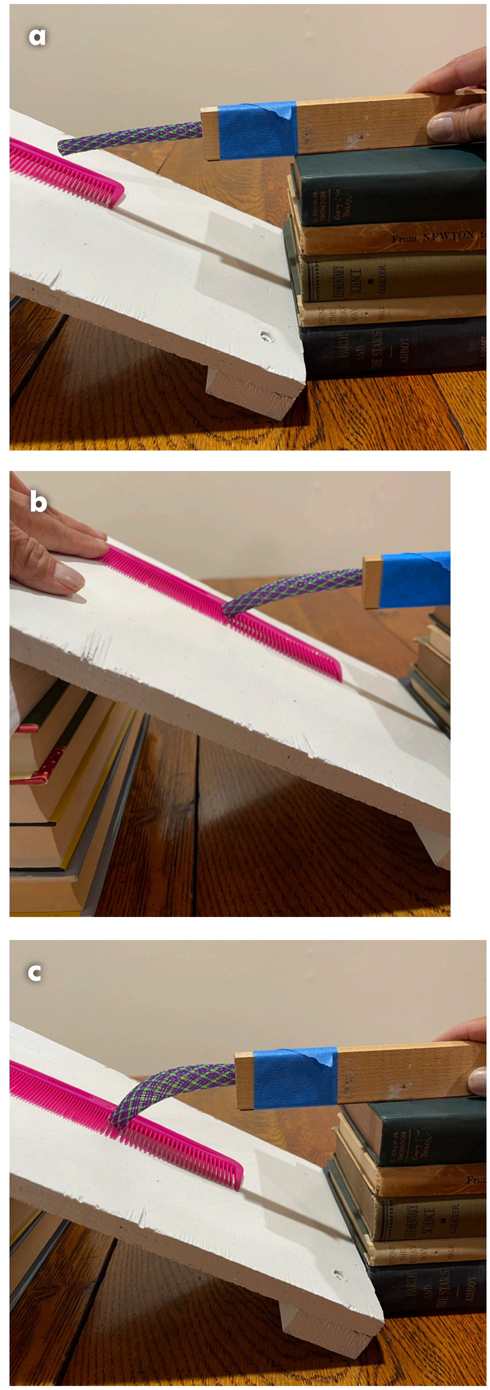


FIGURE 13. (a) Subduction plate model set up: Create a ramp in subduction (Juan de Fuca plate). Tape minispring to a ruler and place it on a stack of books or a box. (b) Hold the comb against the ramp, slide the minispring/ruler until it touches the comb, and slide the comb down slowly. The minispring will catch on the comb. (c) The comb has been sliding down the ramp, causing the minispring to flex downward, compressing it, and creating a bulge.

4 Continue to push the comb down the ramp and discuss observations. Notice how the minispring catches on the comb, compresses and bulges upward, and then overcomes friction and springs upward (an earthquake). The minispring flattens out again. Most of the flex is a temporary bulge between earthquakes; however, a tiny bit of the compressed land helps to create the Coast Range over millions of years. **NOTE:** It is important to point out that the actual bulge within the plate is not as big as they think, only a few meters. The Cascade Range includes mountains that are much higher in elevation than the Olympic Mountains, which are closer to the coast (the tallest of these is 2,432 meters, or 7,980 feet, while the tallest in the Cascade Range is 4,392 meters, or 14,411 feet).

5 Show this animation from 3:55–4:35 to review the model: Measuring Plate Tectonic Motions with GPS.

IF YOU HAVE 60+ MINUTES

"DID YOU KNOW?" DISCOVERY QUESTION
Did you know that being able to precisely measure the rate of tectonic motion enables geologists to identify earthquake hazards?

Earthquake hazards increase in regions where adjacent areas within tectonic plates move with different velocities or different directions. The more pronounced the differences in speed, direction, or both, the greater the earthquake hazard. This 60+ minute activity addresses this important issue and is written for a flexible instructional environment to fit either a classroom or more open forum.

Learners begin by modeling the effects of the compressive forces along the Juan de Fuca-North American plate boundary using the minispring model from the **20-30 Minute Activity**. Like the **20-30 Minute Activity**, the minispring is pushed in on one side to show the slight bulge that forms as a result of the North America plate "catching" on the Juan de Fuca plate. In this 60+ minute activity, learners will measure the distance differences between the original and current positions. Learners will then compare their observations of the spring to the GPS vector map of Oregon and Washington, noting the longest vectors are closest to the subducting Juan de Fuca plate, and the vectors decrease in length as they look further inland. Learners will discover the geomorphic effects of the differing plate velocities through a short video. Learners will discuss strengths and weaknesses of all of the models they experienced. Referring to the vector map as evidence, learners will identify the regions with the highest seismic hazard. Finally, the class will discuss earthquake preparedness strategies, including enabling ShakeAlert-powered alerts on cell phones.

INSTRUCTOR PREPARATION

1. Complete instructor preparation for minisprings as for the **20-30 Minute Activity**.

2. Print and copy the 60+ Minute Activity Handout (Appendix G). Answer key is provided in Appendix H.

3. Print the full size GPS vector maps found in Appendix D on 8.5 x 11-inch paper.
   - **a.** If possible, laminate the maps and have enough copies of each map available for each learner, pair, or group, depending on how the instructor organizes their instructional space. **ALTERNATIVE:** Use sheet protectors.

4. Print in color (color is needed for the key), one set per table, or prepare to display the earthquake shaking potential maps for Oregon and Washington, and the USGS national seismic hazard map (Appendix I).
   - **a.** To learn more about how the shaking potential maps are made, visit Introduction to the National Seismic Hazard Maps or visit the USGS site on Earthquake Hazards.

5. Make sure you can play the video so that all learners can see and hear it.
   - **a.** Video: Pacific NW—The Cascadia Subduction Zone (geomorphology) (2:40)
   - **b.** Enable captions and/or share the video in advance with ASL interpreters to ensure that learners who are deaf or hard of hearing can understand the video content.

6. Provide colored pencils and a ruler to each learner.
   - **a.** Adaptations for visually impaired learners: use colored pencils, crayons, and small felt markers to make it easier to distinguish between the lines, or use different types of lines or line thickness.

7 Print and ideally laminate vectors to tape on the floor (Appendix E). Alternatively, place tape on the ground with arrow heads to represent vectors:

a. Very short vector for Inland Valley region of Oregon and Washington—1 meter

b. Long length vector for Coastal Oregon and Washington—about 2 meters

8 Prepare optional EXTENSION to Part D. Activity and Video: Geologic Hazards Related to Earthquakes: Identifying geologic Hazards in Your Community (5:00)

a. Fill a sturdy rectangular plastic or metal container—about the size of a shoe box (7.5 qt.) 3.5" deep with sand.

b. Gradually add water to the sand until the top of the sand is saturated, but no water lays on the top.

c. Place a brick (which has squares drawn on with felt tipped pen to represent windows) on end onto the sand as seen in Figure 6 of the Geologic Hazards Related to Earthquakes activity.

d. Bury a ping-pong ball about a ½" below the level of the sand near the brick as seen in Figure 6 of the Geologic Hazards Related to Earthquakes activity.

e. Experiment to find the best option you have available to create vibrations into the sand-filled shoe box. Options:

- Rapidly tap the edge of the box with a hammer or rubber mallet.
- Place an electric reciprocating saw (blade removed) on the side of the box next to the brick.
- Use two rubber mallets to create a vibration (rapidly strike a table similar to playing a kettle drum) This works best if the box is placed on a lightweight table or desk to amplify the vibrations.

DIRECTIONS FOR LEADING THE ACTIVITY

1 Bring in new vocabulary (Appendix A) to meet your learner's needs.

2 Complete the **5 Minute Activity** or demonstrate the concepts of compression, potential energy stored in the rocks, and earthquakes.

PART A: MOTION AND DEFORMATION WITH COMPRESSIVE FORCES (15–20 minutes)

1 Learners begin by modeling the effects of the compressive forces along the Juan de Fuca-North American plate boundary. This is the **20-30 Minute Activity** with the addition of measuring the distance that each labeled GPS station travels from their initial positions.

a. Tell learners they will now experiment with a minispring model that has marks every 1 cm that represent GPS stations. Explain that a GPS station is an instrument to measure ground position and movement. Precise locations on land can be calculated through communications between a system of navigation satellites and GPS antennas anchored to the ground. When the ground moves, the GPS station moves with the ground and records that movement.

b. If they have not completed the **20-30 Minute Activity**, show learners the minispring. Have learners predict what will happen to the shape of the minispring when they push on the end.

- Will the distances between marks be equal as the minispring is compressed?
- Will the shape of the minispring stay the same?

c. Give springs out, 1 spring per 2 learners.
- Give learners a few minutes to play with the spring and let them know that they have a finite number of minutes to play and then it's time to work so it's not a problem later. (Only if they have NOT done the **20-30 Minute Activity**.)
- Lay some ground rules about working with the spring (e.g., don't point the spring at anyone's face).
- Refocus them by asking what the "springiness" might represent (earthquakes).
- Watch your time.

d. Instruct the learners to use a binder clip to clip the paper and spring together so that the markings align.

e. Push the end of the minispring (0 cm) to the 3 cm mark (marked A). Measure the distance, in millimeters, that GPS stations A, B, and C traveled from their initial positions (**Figure 14**). Direct learners to answer Question 1 in the Activity Handout (Appendix G).

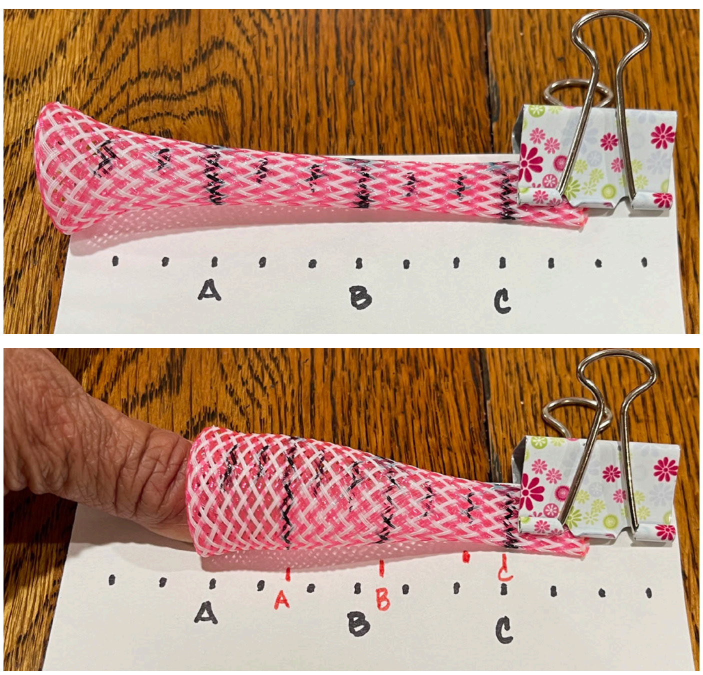


FIGURE 14. Measuring the distance between the initial position and the ending position of GPS marks on the minispring. Have learners mark the new positions with a different color. Note how GPS station C remained stationary, and the mark preceding C moved a shorter distance compared to B.

- Because learners are working in pairs, one learner can hold the binder clip and push in the spring while the other can measure the distances (in mm) between where each GPS station (A, B, and C) is to where they initially started OR
- Using a different color than the "ruler" (marks on the paper), draw a mark on the "ruler" where each GPS station (A, B, and C) landed and measure the distance in mm from where it landed to its initial position.
- Demonstrate how to take this measurement if needed; some learners will need to see how to measure the distance traveled for each GPS station.

2 Have learners draw the shape of the minispring when compressed, noting the thickening of the spring closest to the force. Direct learners to answer Questions 2 and 3.

a. Label your drawing with Oregon and Washington regions (A for Coastal; B for Inland; C for Cascades).

3 Ask learners to compare the movement of their three model GPS stations along the minispring to the vectors/arrows on the map.

a. Ask learners what did you observe? How did each GPS station move? Direct learners to answer Question 4.

ANSWERS MAY VARY: *Focus learners on the ideas that the area closest to the force of compression moved the most, while further away, the less the minispring (and GPS station) moved. So, the GPS stations on the coast are moving the most. The stations further inland move less.*

PART B: UNDERSTANDING CRUSTAL MOTION USING VECTORS (10–15 minutes)

1. Discuss/define vectors. Display the Anatomy of a Vector image (found in Appendix B).

2. **OPTIONAL:** Learners model the movement along a short and long vector (arrow) to build their understanding that vectors represent the speed and direction of motion.
   - **a.** See Extension to **5 Minute Activity**: Exploring Vectors.
   - **b.** Repeat the demonstration holding hands or with both people holding onto a short elastic band.
   - **c.** Relate the stretching of the short strap to the strain that occurs at faults: When the strain is too great, the strap would break or slip out of a learner's hands—this slip is an earthquake.

3. Before showing the maps with the vectors showing ground motion for Oregon and Washington, have learners go back to Question 2 and draw what *they think* the vectors for each region look like based on their minispring experiments.

4. Distribute the Oregon and Washington GPS vector map (found in Appendix D) to learners.
   - **a.** Point out to learners that the vector scale on the maps is different from the map scale. The map used in this activity shows the vectors at a 1:1 scale when printed on 8.5 x 11-inch paper, for example, measuring a 10 mm vector on the printed map represents 10 mm/year of movement.
   - **b.** Ask what the units of the vectors depicted on the map are (this reinforces that the legend shows the velocity in mm/year).

5. Learners compare their observations of the minispring to the GPS map of Oregon and Washington, noting the longest vectors are closest to the subducting Juan de Fuca plate, and the shortest vectors are inland.
   - **a.** Direct learners to measure one vector within each region (Coastal, Inland Valley, East of Cascade Mountains) on the Oregon and Washington GPS vector map (using millimeters, not inches).
   - **b.** Direct the learners to answer Questions 5–8.
   - **c.** Have learners compare what they see to the minispring model.
   - **d.** Have learners redraw their vectors (in Question 2) on minispring drawing after seeing the vector map (in a different color or use a different writing utensil than they used for their first vector drawings so they know it is their second/revisited iteration.

6. Show the video of subduction that compares the motion of the plates to a spring. Learners will discuss strengths and weaknesses of all of the models they experienced.
   - **a.** Show from: 3:25–4:35: Measuring Plate Tectonic Motions with GPS
     - Note that what is depicted is the temporary deformation and that the very long-term effect of the tiny permanent deformation over millions of years resulted in the Coastal Range.
     - Discuss: Why is the minispring model and visual model in the video like and unlike the vector map (real data)?
     - Emphasize how models are representations of the real world—they have flaws.
     - Answer Questions 11 and 12.

7. Wrap up by showing and discussing the video: Pacific NW—The Cascadia Subduction Zone (Geomorphology) (2:40). Remember to enable captions and/or share the video in advance with ASL interpreters to ensure that learners who are deaf or hard of hearing can understand the video content.

PART C: USING GPS DATA TO DETERMINE POTENTIAL HAZARDS (10–15 minutes)

1 Learners identify three regions on the Oregon and Washington GPS vector map (found in Appendix D). Direct learners to answer Question 13a–d.

a. Draw an oval around the entire area along the coast that shows a greater amount of movement. LIGHTLY shade in your oval with the same color.

b. Using a new color, Do the same for the Inland Valley area that shows motion in the same direction, but in general has less motion. LIGHTLY shade in your Inland Valley oval with the same color.

c. Do the same for the area east of the Cascades.

d. Draw the fault line where the Juan de Fuca plate and the North American plate meet.

2 Remind learners where the plate boundary is between the Juan de Fuca plate and the North American plate. Discuss and relate the average length of the vectors in each region to the potential energy held by the ground in each region relative to each other. Have them think back to the minispring model.

a. Ask: Which region has the most strain stored within the rock? Direct learners to answer Question 13e.

ANSWERS MAY VARY: *The vectors near the coast are longer relative to Inland Valley and east of the Cascades, suggesting that more potential energy may be stored elastically within the rock in this location, which means higher stress along the coast.*

b. Ask: Which region will feel the jolt of the subduction earthquake the most, when the North American and Juan de Fuca plates slip past each other?

ANSWER: *The coastal region.*

And why do you think this?

ANSWERS MAY VARY: *The velocities change most quickly near the coast and is compressing the most quickly. This area will snap back the most when the stored potential energy becomes kinetic energy (movement and shaking).*

3 Give learners the earthquake shaking potential maps for Oregon and Washington (Appendix I). They will identify the regions with the highest seismic hazard and use what they see on the vector map to explain why these areas have high seismic hazard.

a. Have learners compare the regions they identified in the GPS vector map to the earthquake shaking potential maps.

- What can you conclude about the relationship between what the vectors are showing you and the earthquake shaking potential? Answer Question 14.
- Remind learners about the force pushing the minispring (the force is the Juan de Fuca plate pushing against the North American plate; plus the Juan de Fuca plate is moving 40 mm/year).

  ANSWERS MAY VARY: *The region where the velocities change most quickly is near the coasts of Oregon and Washington, where the velocity changes from 40 mm/year on the Juan de Fuca plate to approximately 13 to 19 mm/year. The coastal region has the highest earthquake potential and has the potential to slip the most when the stored potential energy becomes kinetic energy (movement of rock, heat, and seismic waves).*

b. Direct learners to answer Question 15. Remind learners of the clip they saw. Discuss GPS and how they give us data on plate movements or show the first 1:40 minutes of the Measuring Plate Tectonics with GPS animation. Direct them to answer Question 16.

PART D: EARTHQUAKE SAFETY AND THE SHAKEALERT EARTHQUAKE EARLY WARNING SYSTEM

(15 minutes)

1 Finally, discuss earthquake preparedness strategies, including enabling ShakeAlert powered alerts on cell phones.

2 Example introduction to ShakeAlert and earthquake preparedness: What are the impacts on life and society? How can we prepare for an earthquake?
ANSWER: *A subduction zone earthquake in the Pacific Northwest could cause a lot of destruction and loss of life. That's why it's important to be prepared. To prepare, people can sign up for free for ShakeAlert-powered early earthquake warnings, which can provide seconds to tens of seconds of extra time for people to protect themselves. Automated systems can also automatically turn off natural gas, slow down trains, open firehouse doors, among other protective actions. People should also prepare for emergencies by storing water, practicing protective actions like drop-cover-hold on in a variety settings, and preparing emergency plans and kits.*
NOTE TO INSTRUCTOR: Seismometers and GPS sensors that are part of the ShakeAlert Earthquake Early Warning System collect the data and send these data to processing centers then to cell phones and other devices through radio waves. Radio waves travel at the speed of light; they are much faster than seismic waves, which are slower and have to travel through Earth. Because of this, cell phone signals are capable of warning individuals who are *not* in the immediate vicinity of the epicenter. A ShakeAlert-powered alert can be delivered to areas surrounding the epicenter seconds before shaking arrives. This is enough time for individuals to drop, cover, and hold on.

3 Start by showing the Earthquake Preparedness videos.

- **a.** Show ShakeAlert Earthquake. Alert Times in the Pacific Northwest (5:46)
- **b.** Show learners How Do I Sign Up for the ShakeAlert Earthquake Early Warning System?.
- **c.** Show and discuss the video Preparedness Journey (2.02)

4 If time allows, share with learners the "Prepare in a Year" guide.

- **a.** Review the Action Plan (section 2 in the guide). Choose some activities from the Action Plan. Think of how much time you have.
- **b.** Introduce learners to the guide.
  - Give learners a quick tour.
  - Give learners the link.
- **c.** Summarize the Communication Plan (section 1 in the guide)
  - Have learners think of who their contact person would be—they need to ask parents if they don't know.
- **d.** Summarize Water (section 3 in the guide).
  - If you are looking for a demonstration to show them, you can look at the distillation method for purifying water.
- **e.** Have learners go through the list of kit supplies in the Grab and Go Kit (section 4 in the guide). and:
  - Add a check next to the items they already have at home.
  - Circle what they need.
  - Add a "?" for what they need to ask their parents about (i.e., tow chain, jumper cables, documents).

EXTENSIONS

1. Use these animations to show learners how the ShakeAlert system works: ShakeAlert Gets a Boost with GPS Technology (2:05) and How the ShakeAlert System Works (2:18).

2. Lead learners through the 5-minute demonstration and other activities Geologic Hazards Related to Earthquakes to extend learner understanding of additional hazards that can happen during an earthquake.

3. Depending on the amount of time you need, use Emergency Backpack and Earthquake Preparedness Actions for a 5, 20–30, or 60+ minute activity.

4. View the ShakeAlert Educational Resources hosted by EarthScope for more resources and activities.

APPENDIX A. VOCABULARY

Compression: When stress is applied to an area, there is a decrease in volume and an increase in potential energy. See the animation on stress. Strain is the resulting deformation due to the applied stress.

Convergent Boundary: Where two or more tectonic plates move toward each other and are either shortened or elevated due to compression, or where subduction takes place.

Crustal Deformation: When Earth's surface changes shape due to tectonic forces. Rocks can be folded, faulted, sheared, and/or compressed by Earth stresses. Deformation can be elastic (temporary) or permanent. This is the same as "ground deformation."

Elastic Deformation: Reversible strain. When stress is removed, the material will return to its original position or shape.

Geodetic Instrument: An instrument, such as a permanently installed GPS instrument, that precisely measures the movement of Earth's surface.

Global Positioning System (GPS): A U.S.-owned constellation of satellites and ground tracking stations, along with receiver equipment, that provides positioning, navigation, and timing services.

Global Navigation Satellite Systems (GNSS): Any of, or some combination of, the operational satellite constellation systems that provides positioning, navigation, and timing, at this time including GPS, Galileo (EU), BeiDou (China), GLONASS (Russia), QZSS (Japan), IRNSS-NAVIC (India).

Kinetic Energy: The energy of an object due to its motion.

Potential Energy: Stored energy of an object due to its position or condition.

Reference Frame: An area set as a stationary point so that all other plate motions can be measured with respect to it.

ShakeAlert Early Warning System: This system detects earthquakes within seconds, estimates the location, size, and strength of shaking. It delivers alerts to individuals in areas surrounding the epicenter before shaking arrives. It is active in California, Oregon, and Washington.
Learn more.

Speed: The distance of movement in a specified amount of time.

Strain: Changes in size, shape, or volume of an object due to stress. Strain is defined as the amount of deformation an object experiences compared to its original size and shape. For example, if a block 10 cm on a side is deformed so that it becomes 9 cm long, the strain is (10-9)/10 or 0.1 (sometimes expressed in percent, in this case 10 percent).

Stress: The amount of force applied across the area of an object. It is a measure of forces acting on a body. Stress is defined as force per unit area. It has the same units as pressure, and in fact pressure is one special variety of stress. However, stress is a much more complex quantity than pressure because it varies both with direction and with the surface it acts on. Learn more. Watch How Stress is Related to Plate Boundaries.

Transform Boundary: When two tectonic plates are moving horizontally with respect to each other with little vertical movement.

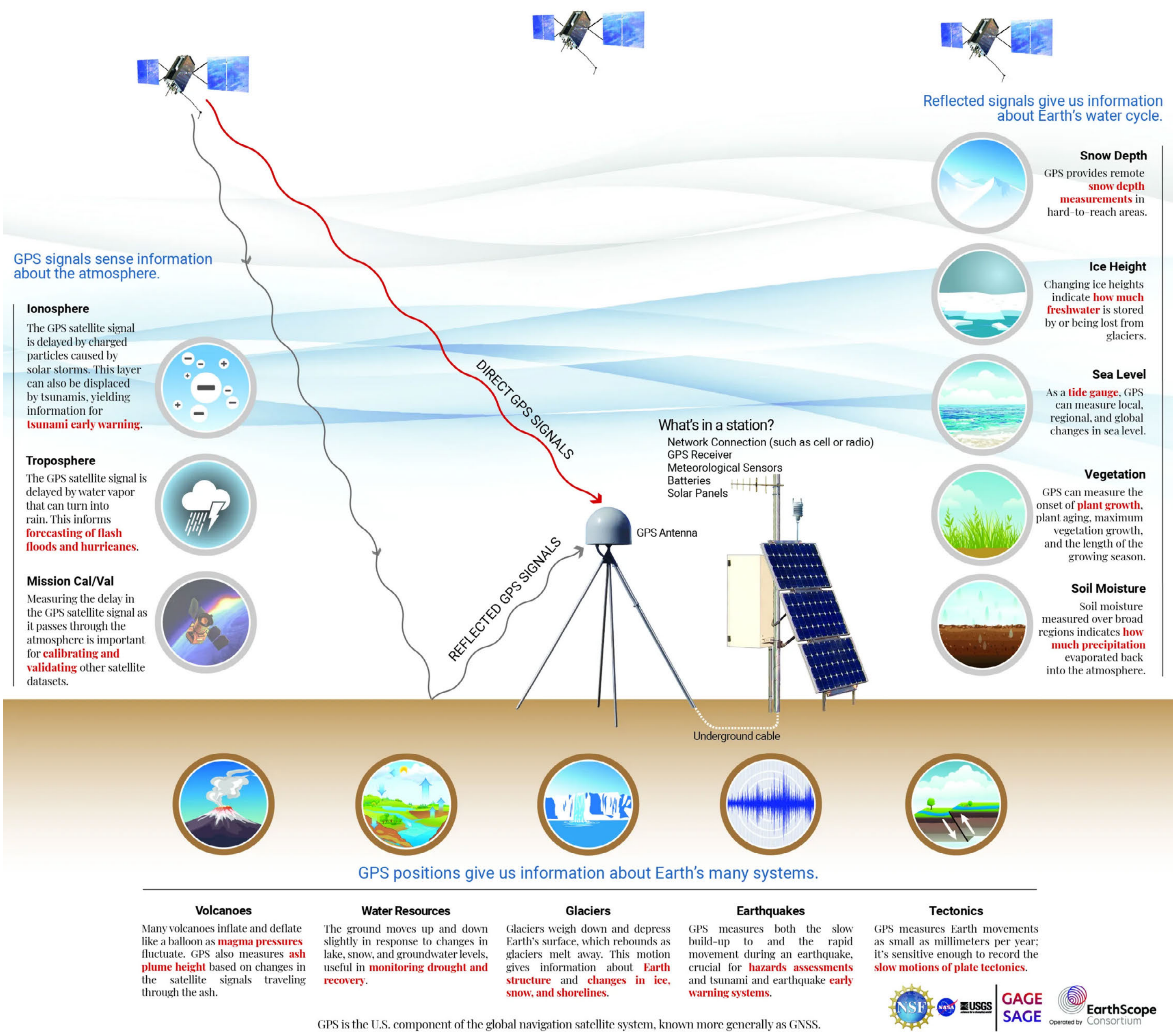
Vector: A quantity with both a magnitude and direction.

Velocity: The speed and direction of movement.

Velocity Vector: A visual representation of the velocity of movement, with speed indicated by the length of the vector and the direction indicated by the direction of movement from north.

WHAT CAN GPS TELL US ABOUT EARTH

GPS data can be used to study many Earth phenomena. View the poster below.



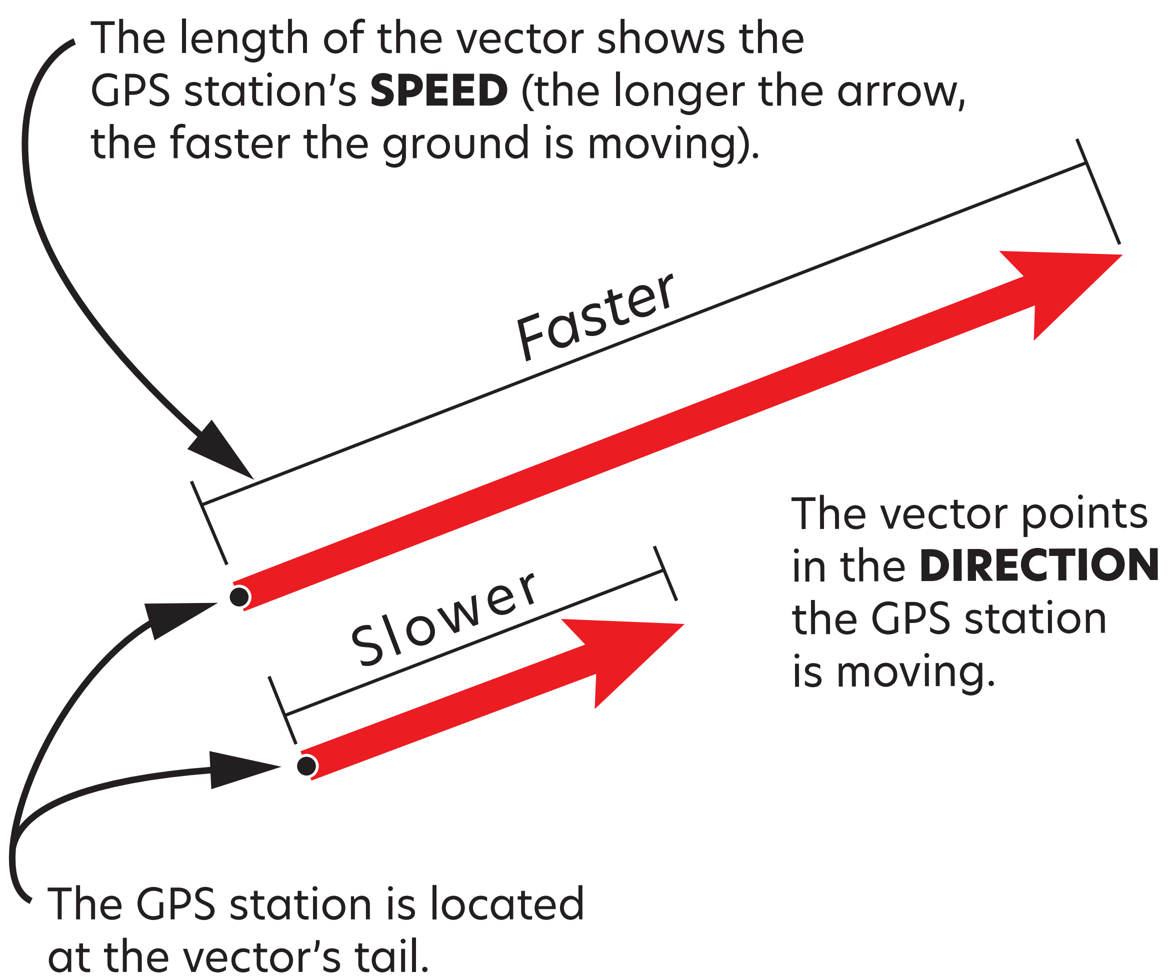
WHAT IS A GPS VECTOR?

High-precision GPS stations attached to the ground collect data about the ground's motion at their locations. GPS data collection and processing are much more complicated than what is explained in these activities. Background noise, tidal forces moving the ground up and down, seasonal water and snow loading, post-glacial isostatic rebound, and other non-tectonic motions are hidden in the "raw" data collected from the GPS and are removed as part of the data processing so that the dominant motion in the data is from tectonic motions.

The data from GPS are often represented as velocities in three directions, up-down, north-south, and east-west, allowing calculation of an average annual velocity. When the data are displayed on maps, the horizontal velocities are added together to create a single vector. A vector represents the speed (length of the vector) and the direction that a specific piece of ground is moving. This movement is displayed as vectors on maps showing displacement over time, typically in mm/year.

Anatomy of a Vector

A vector indicates the direction and speed of an object.



Typical diagrams of plate boundary motion indicate vectors moving as shown in **Figure B1**. However, there are subtleties of motion where the vectors are actually pointing in the same direction but are still transform, convergent, or divergent boundaries depending on the relative speeds of each set of vectors.

Watch EarthScope's video on How GPS Measures Ground Motion for visual examples showing regions around the world and their respective plate motions.

An overall explanation of reference frames to help interpret plate motions can be found in the animation: Measuring Plate Motions with GPS. Every tectonic plate on Earth is in motion. Because every location on Earth is moving, how do we know how fast a single place is moving? For plate motions, we designate one plate or region as fixed (not moving). We then compare the motions of other places to this fixed place.

For activities where we are studying North American tectonics, we use the mid-continent North America as our fixed region because the stations are not moving compared to each other and are non-deforming. Using mid-continent North America as a fixed region removes the average background tectonic motion of the mid-continent, making it easier to observe the interactions between the western North American tectonic plate, the Pacific plate, and the Juan de Fuca plate (e.g., subducting, sliding past each other, colliding). By studying the GPS motions in different areas, we can learn a lot about how strike-slip, convergent, and divergent regions deform and the associated earthquake hazard.

In each example of plate boundary interaction, notice two details: the direction of the two plates (shown by the direction of the vectors) and the speed of the plates (shown as the length of the vectors). Not every plate boundary is just one type of motion. For example, a transform boundary could also include some convergent or divergent motion.

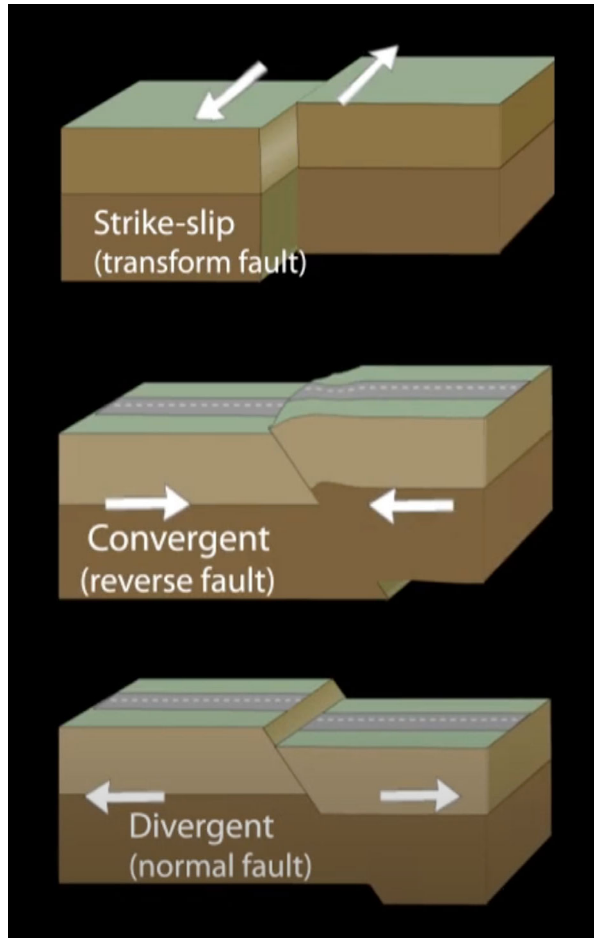


FIGURE B1. Typical plate boundary motion diagrams do illustrate subtleties of motion. *Source: EarthScope Consortium*

TRANSFORM BOUNDARY

The typical diagram in textbooks often show a transform boundary like **Figure B2 Scenario 1**. *Note the length of the arrows on the two "plates" are the same length and pointed in opposite directions. Both sets of arrows are parallel to each other.*

Another way to show a transform boundary is shown in **Figure B2 Scenario 2**. The plates are moving in the same direction and are moving parallel to each other, with one plate moving faster past the other plate. This still indicates a transform boundary. This is what we experience in the Kinesthetic Modeling Activity for Southern California and see on the GPS vector maps in Appendix D.

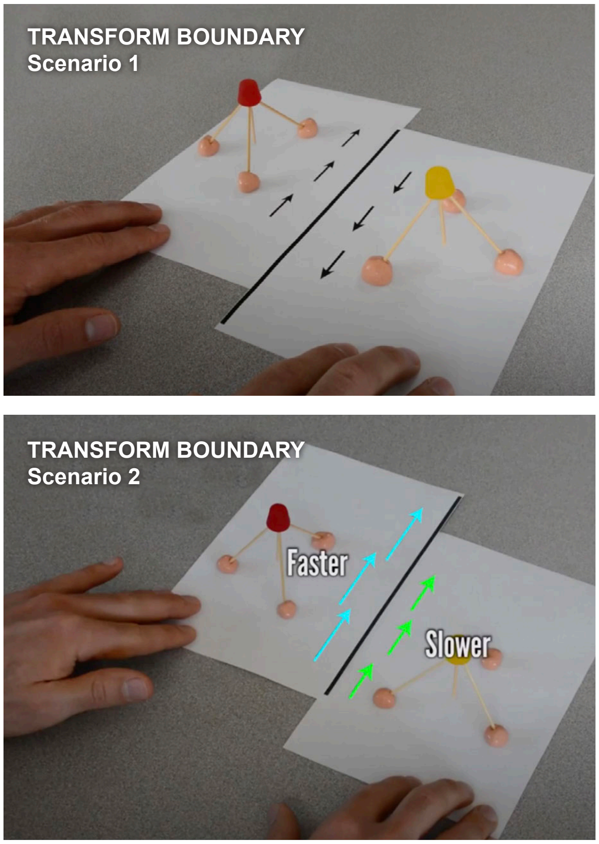


Figure B2. Comparison of transform boundary scenarios.

CONVERGENT BOUNDARY

In a convergent boundary, two plates are colliding. Diagrams often display convergent boundaries with the plate moving together like **Figure B3 Scenario 1**. *Note: the vectors are pointing toward each other.*

Another way to show convergent boundary is displayed in **Figure B3 Scenario 2**. Two plates moving in the same direction (both sets of vectors are pointed in the same direction), with one plate more quickly moving toward the other plate, indicating a convergent boundary. The left plate is moving faster and "overtaking" or crashing into or under the right plate. An example is the Juan de Fuca plate moving toward the North American plate when using the North American Reference Frame.

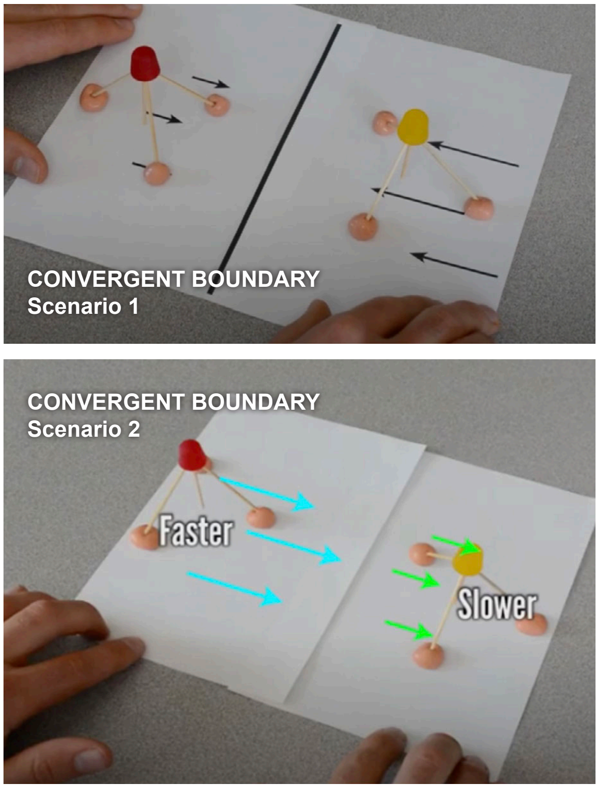


Figure B3. Comparison of convergent boundary scenarios.

DIVERGENT BOUNDARY

For a divergent boundary, the typical diagrams show the arrows pointing away from each other (**Figure B4 Scenario 1**).

Another way to show a divergent boundary is displayed **Figure B4 Scenario 2**. The plates are moving in the same direction, with one plate moving away from the other plate more quickly. This indicates a convergent boundary. The left plate is moving slower and the right plate is moving more quickly.

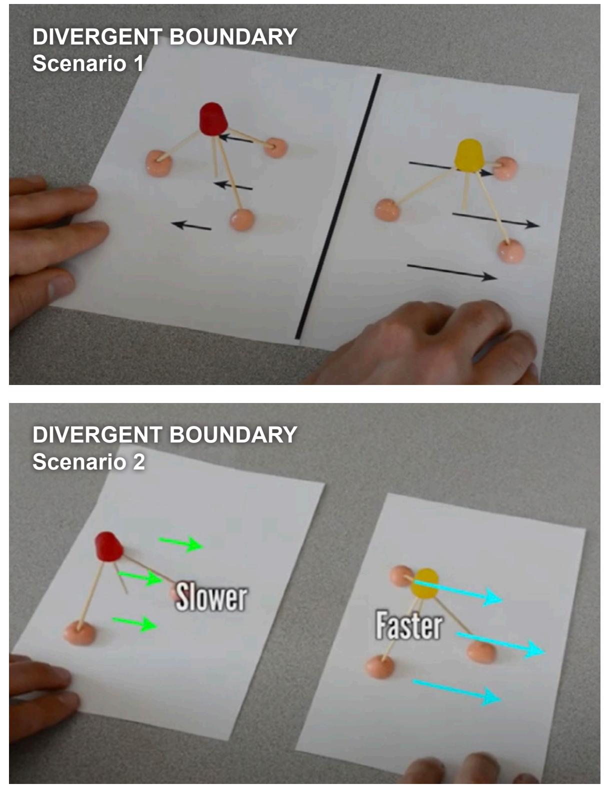
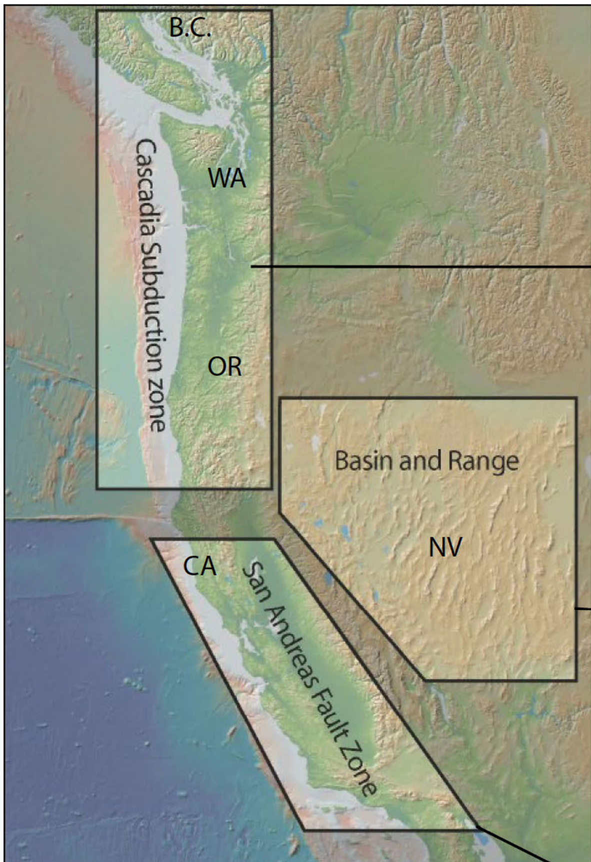


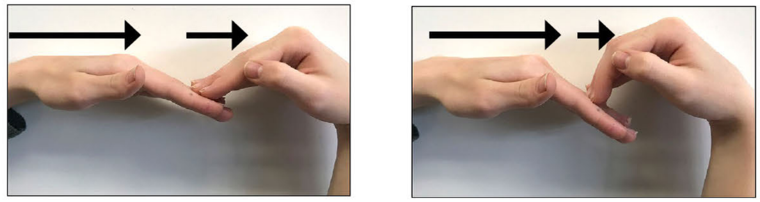
Figure B4. Comparison of divergent boundary scenarios.

HAND MOVEMENTS FOR PLATE BOUNDARIES

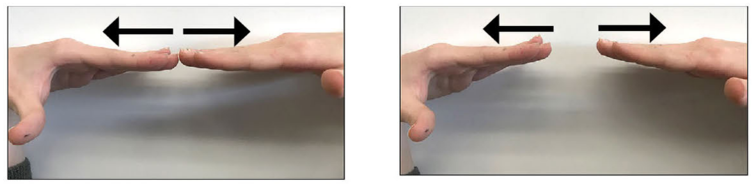


Map of the Western United States with hand motions depicting the relative motion of the major three tectonic margins: A) Convergent, B) divergent, and C) transform

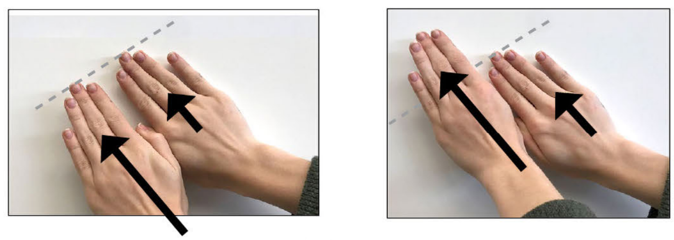
Before movement | **After**



***A**. Convergence: The left-hand tectonic plate is moving towards and "subducting" (diving) beneath the right-hand plate. Example: the Juan De Fuca Plate is causing the coastline of Washington, Oregon, and northern California to slowly be pushed inland and to bulge upwards slightly.*



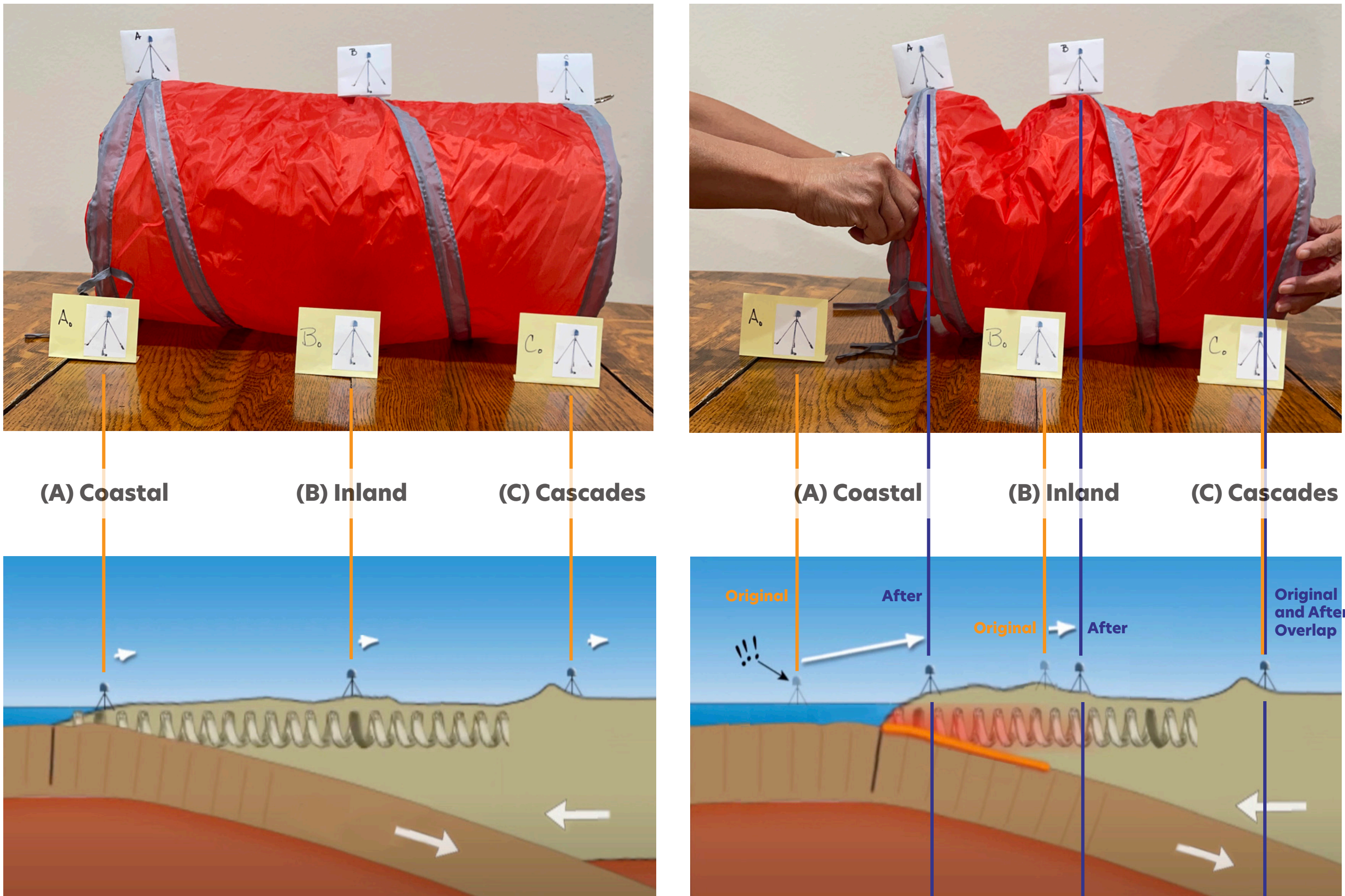
***B**. Divergence: The basin and range region of Nevada is being pulled apart as the western side is moving west faster compared to the eastern side.*



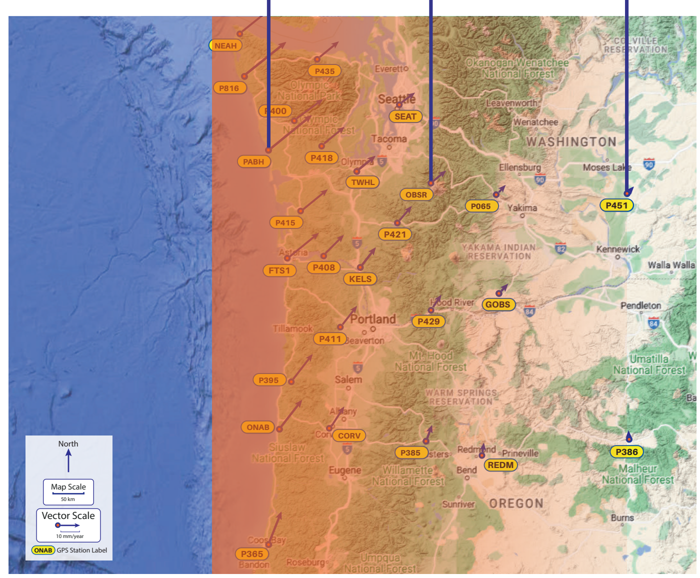
***C**. Transform: Tectonic plates slide horizontally past each other with "strike-slip" motion without significant vertical motion. Example: the San Andreas Fault in California.*

PRE-COMPRESSION VIEW
Original GPS Positions (Orange Lines)

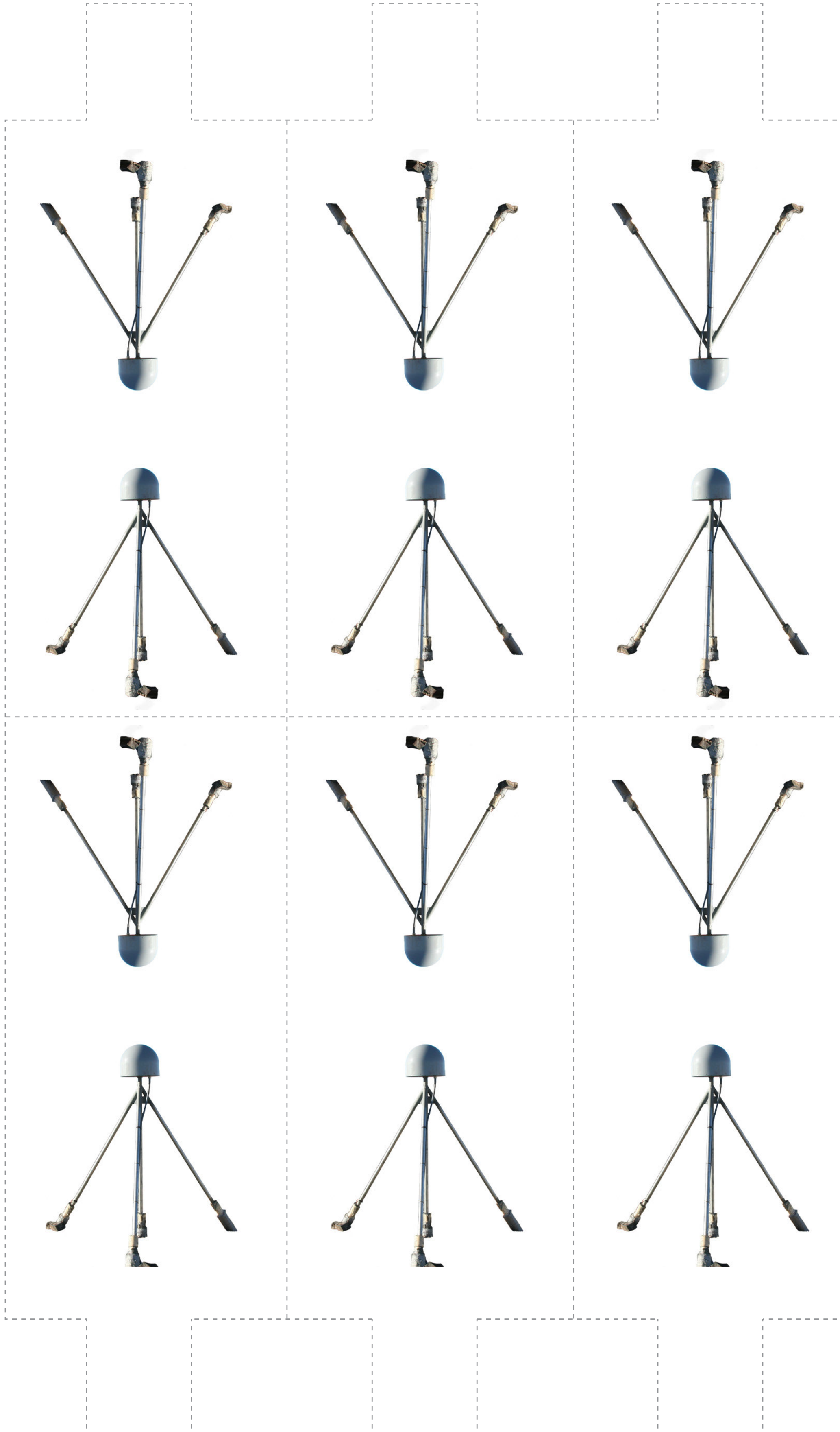
COMPRESSED VIEW
Current GPS Positions (Purple Lines)



Modeling ground deformation with compressible pet tunnel/laundry basket. Photos at top show the setup (left) before compression begins on the giant spring and tectonic plate and (right) after compressing the tunnel and tectonic plate. Notice the positions of GPS stations before (orange lines) and after (purple lines) the plate is compressed. The scale of compression is greatly exaggerated to illustrate the process.



APPENDIX C. GPS STATION CARDS

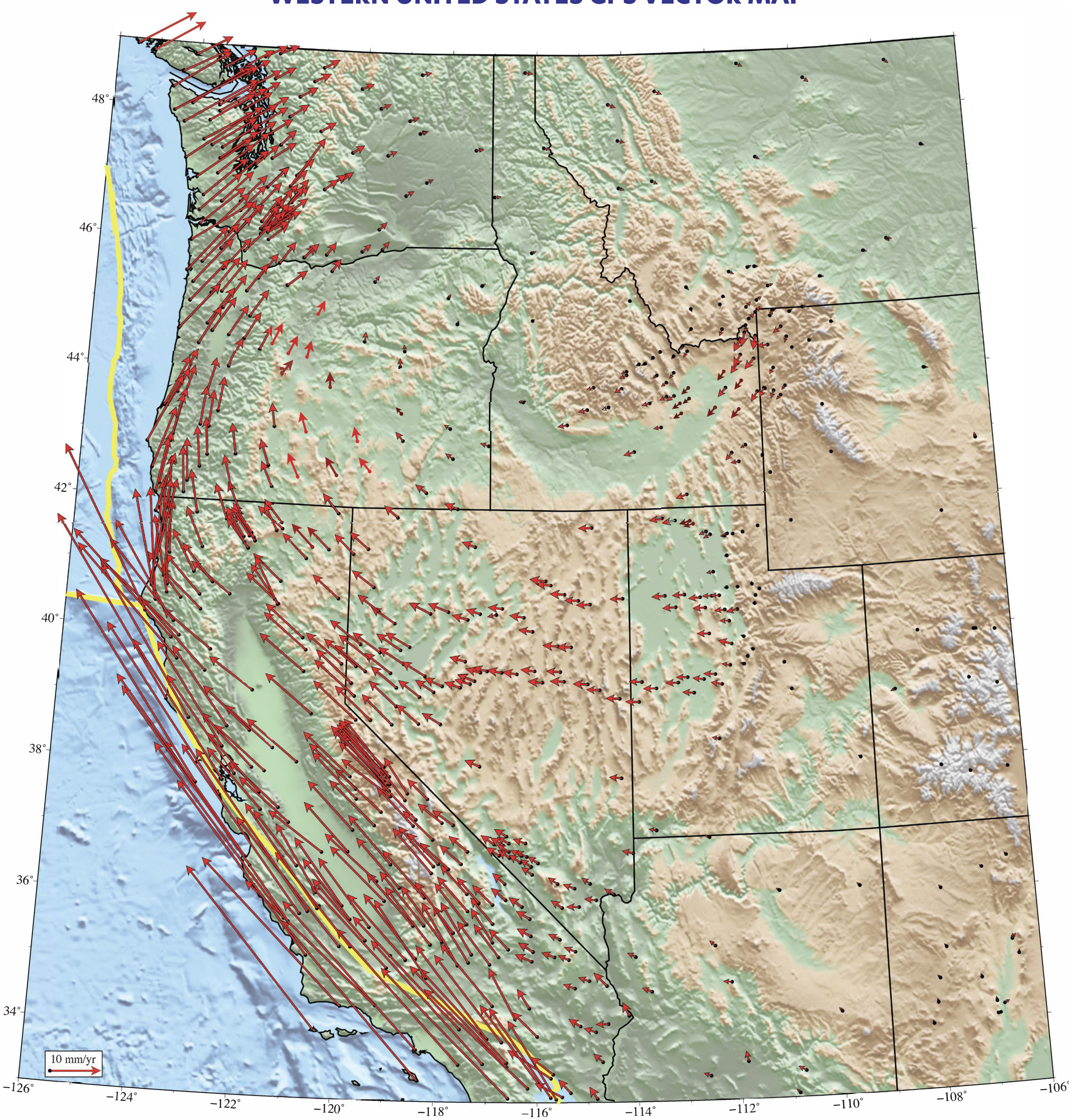


OREGON AND WASHINGTON GPS VECTOR MAP

Note: Vector scale is 1:1
Measured vector length equals actual annual movement

Source of west coast inset map: https://pubs.usgs.gov/of/2005/1305/

WESTERN UNITED STATES GPS VECTOR MAP

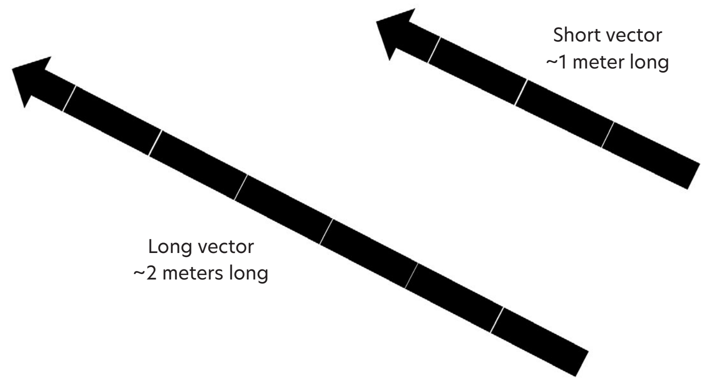


APPENDIX E. VECTOR COMPONENTS

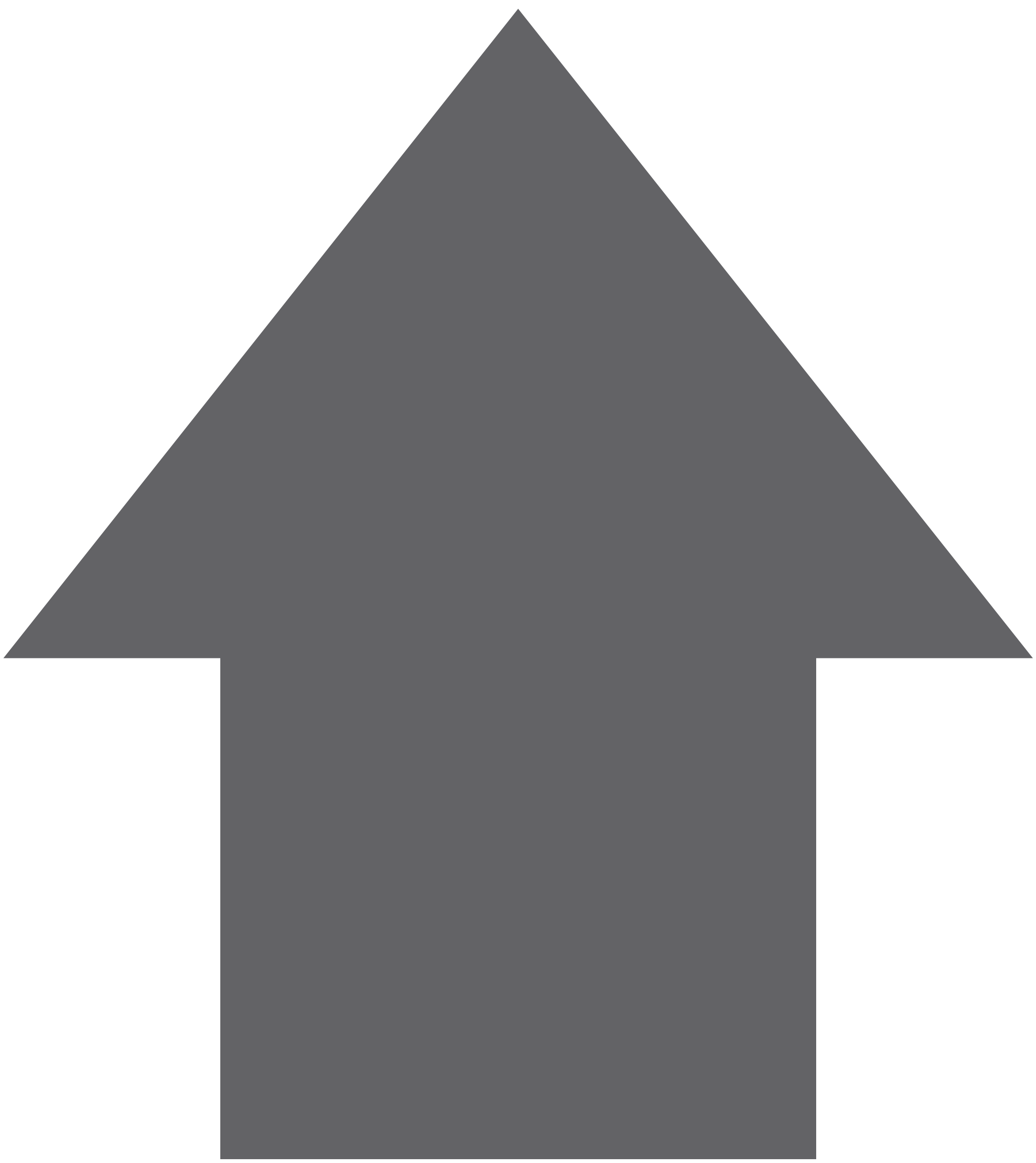
Print out copies of the vector components and tape them to the floor. **ALTERNATIVE:** Vector could be drawn on butcher paper).

- Both vectors point in the same direction, spaced such that people can see them and then walk on them. If possible, laminate the arrows before taping.
- Short vector should be approximately 1 meter long
- Long vector should be approximately 2 meters long
- Vectors need to be large enough to see from a distance and survive being walked on.

EXAMPLE LAYOUT ON GROUND



ARROW HEAD



APPENDIX F. 20-30 MINUTE ACTIVITY HANDOUT

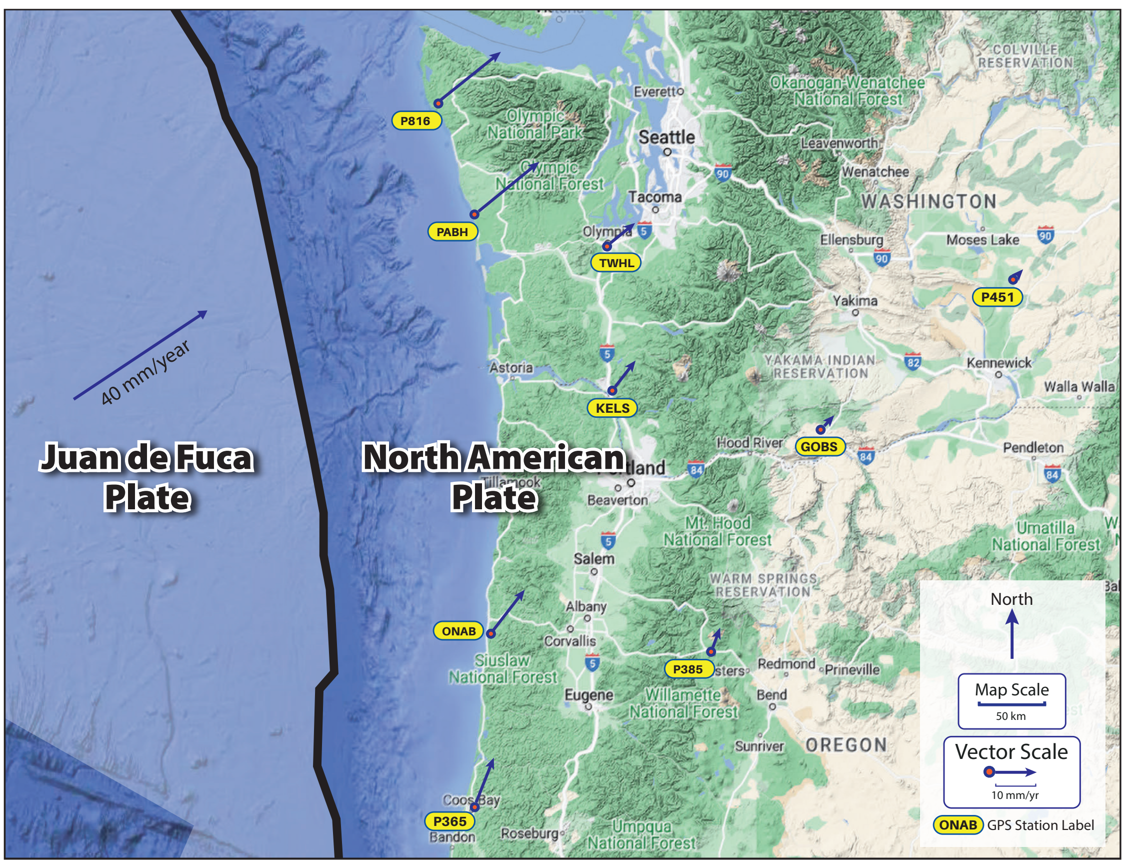
PACIFIC NORTHWEST AND THE BIG SQUEEZE

NAME: ________________________________ PERIOD: __________ DATE: ________________

Review the kinesthetic activity using current GPS data to show how the land beneath our feet is moving, crumpling, sliding, and stretching.

---

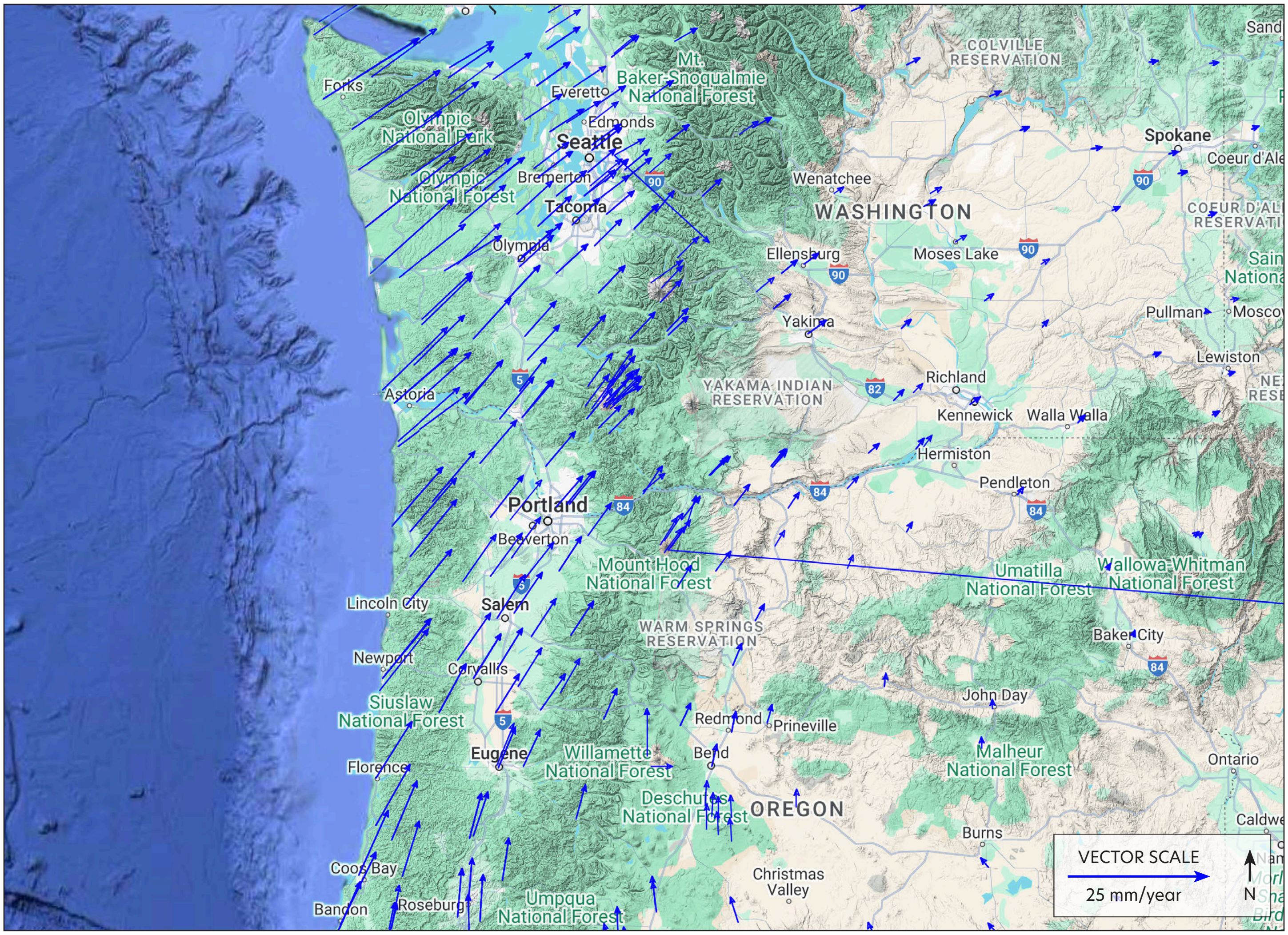
1 The map below shows the motions of the major tectonic plates in the Pacific Northwest. Locate the Juan de Fuca and North American plates. Examine the vector on the Juan de Fuca plate. In your own words, explain what the vector on the Juan de Fuca plate indicates.



Where two tectonics plates collide is known as a **convergent boundary**. The dense Juan de Fuca plate will **subduct** beneath the less dense North American plate.

---

2 In your own words, explain what is happening to the land along the Juan de Fuca-North American subduction zone. Feel free to draw on the image below to help explain your thinking.



3 Explain how the vectors are evidence that there is land deformation happening along this zone.

APPENDIX G. 60+ MINUTE ACTIVITY HANDOUT

PACIFIC NORTHWEST AND THE BIG SQUEEZE

NAME: ______________________________ PERIOD: __________ DATE: ______________

How do we identify the regions with high earthquake hazards? One method that we will explore today is using high precision GPS to determine the speed and direction of tectonic plate movement.

PART A: MOTION AND DEFORMATION WITH COMPRESSIVE FORCES

1 What are the distances that the GPS stations on the minispring traveled? Measure distances in millimeters (mm).

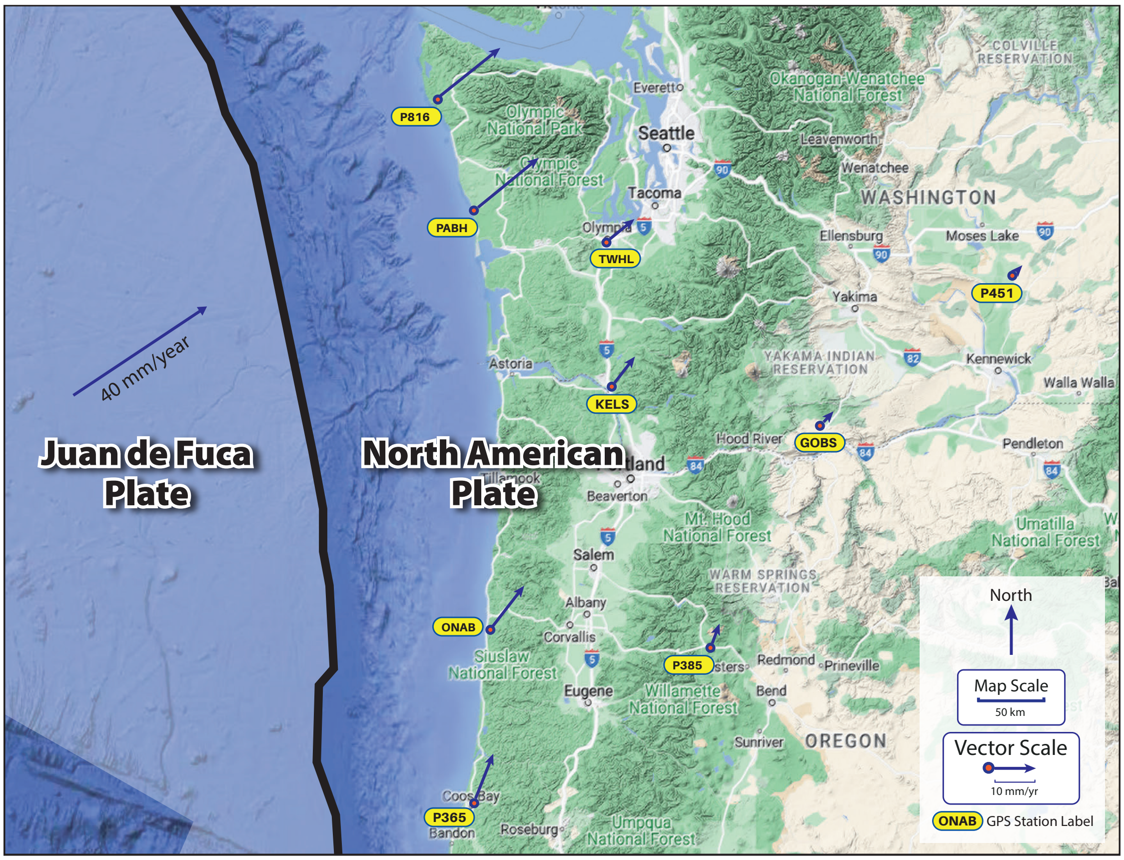
A. Coastal: __________ B. Inland Valley: __________ C. East of the Cascade Mountains: __________

2 Draw the shape of the compressed minispring. Don't forget to include the thickened (crumpled) part.

3 Label your drawing above with the A, B, C locations before and after compression:
A = Coastal, B = Inland Valley, C = East of the Cascade Mountains

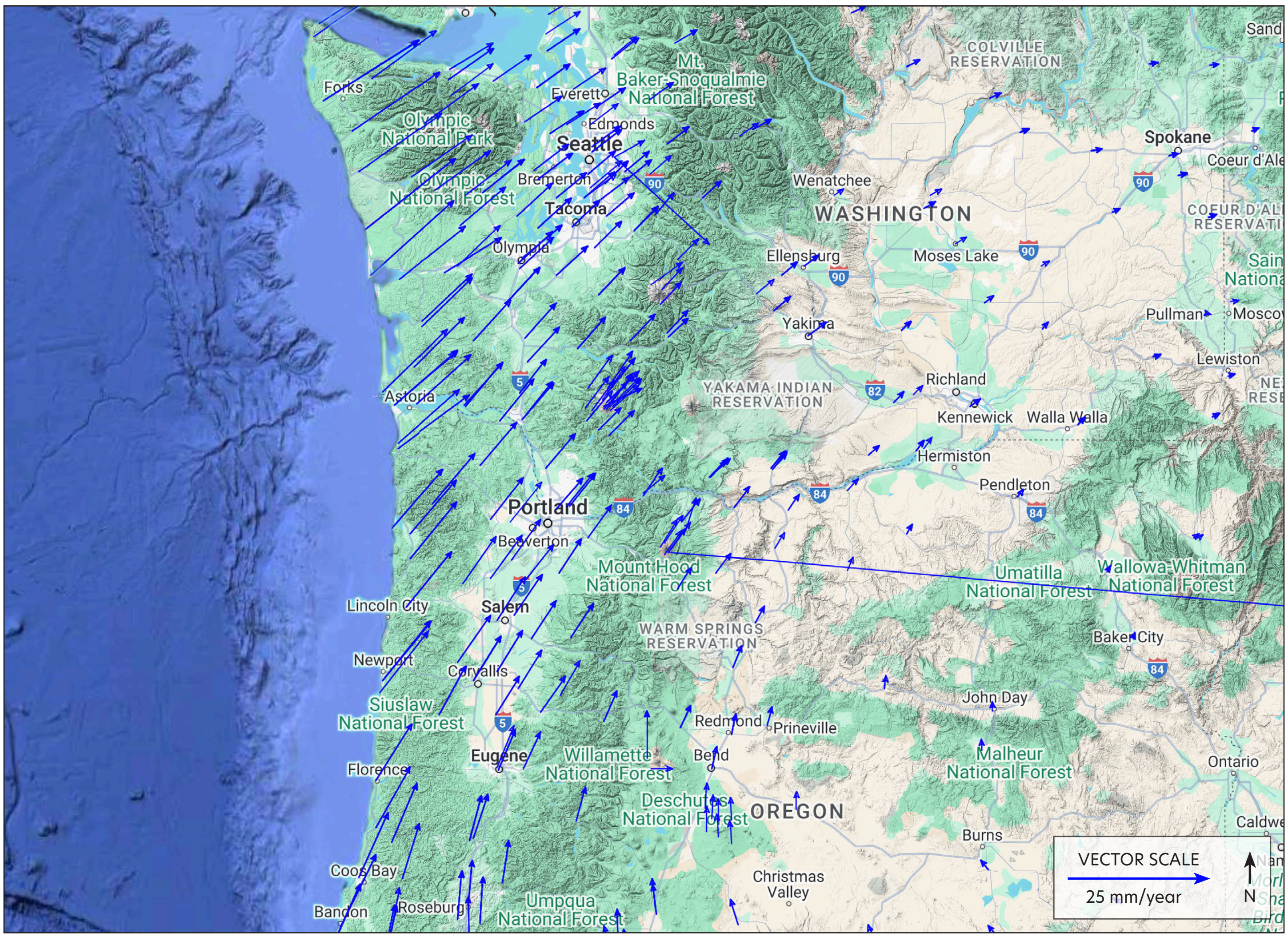
4 What do you notice about how far each GPS station moves?

5 The map below shows the motions of the major tectonic plates in the Pacific Northwest. Locate the Juan de Fuca and North American plates. Examine the vector on the Juan de Fuca plate. In your own words, explain what the vector on the Juan de Fuca plate indicates.



Where two tectonics plates collide is known as a **convergent boundary**. The dense Juan de Fuca plate will **subduct** beneath the less dense North American plate.

6 In your own words, explain what is happening to the land along the Juan de Fuca-North American subduction zone. Feel free to draw on the image below to help explain your thinking.



7 In the map in Step 6 above:

a. Measure the length (in mm) of the vector scale shown in the box on the bottom right of the map.

The vector scale length measures ___________ mm.

b. Pick a vector in the **coastal area** of the map. Using one of the colored pencils, circle it and measure the length of the vector in mm. Record the measurement in the space below and use the formula to calculate the annual movement of that GPS station.

Vector length (mm) = ___________ Annual movement of GPS station (mm/year) = ___________

c. Pick a vector in an **Inland Valley area** that is clearly a different size than the coastal one. In a different color, circle it and measure the length of the vector in mm. Record the measurement in the space below and use the formula to calculate the annual movement of that GPS station.

Vector length (mm) = ___________ Annual movement of GPS station (mm/year) = ___________

d. Pick a vector in the **area east of the Cascade mountains**. In a different color, circle it and measure the length of the vector in mm. Record the measurement in the space below and use the formula to calculate the annual movement of that GPS station.

Vector length (mm) = ___________ Annual movement of GPS station (mm/year) = ___________

$$\text{Annual movement of GPS station (mm/year)} = \frac{\text{Vector length}}{\text{Vector scale length}} \times 25 \text{ mm/year}$$

8 Complete the statement below using the data you calculated.

The coastal GPS station moved _______ mm in one year, the Inland Valley GPS station moved _______ mm in one year, and the GPS station east of the Cascades moved ______ mm in one year.

9 Go back to the drawing you made for Step 2. Add vectors for each region of your drawing.

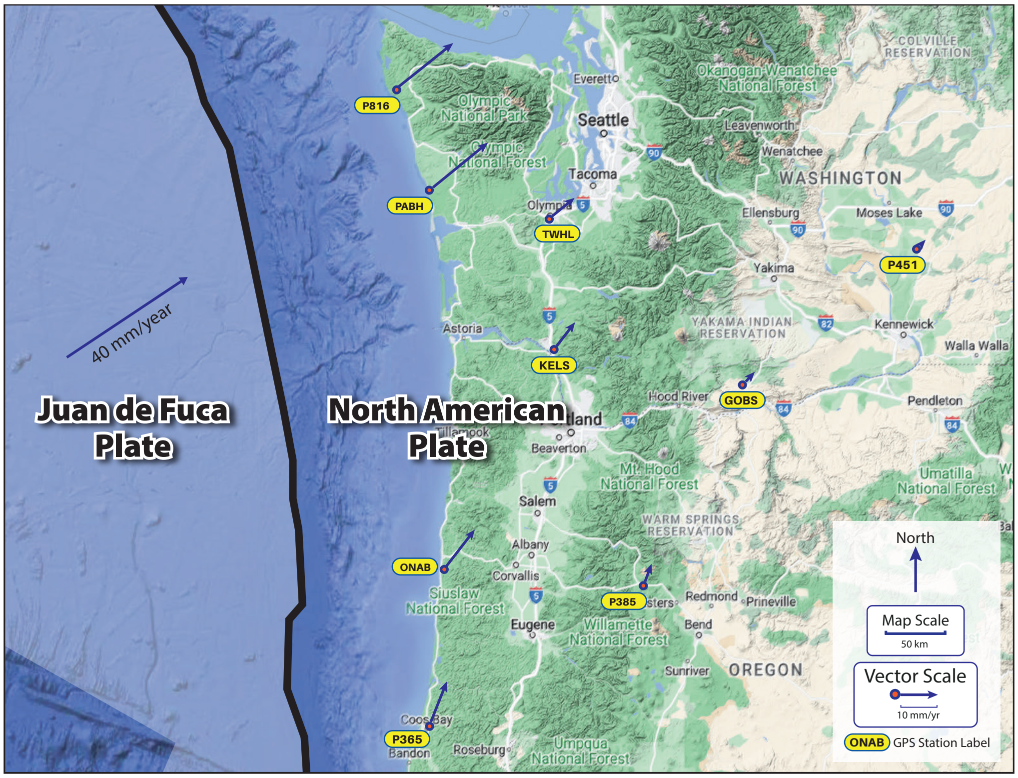
10 Explain why vectors can be used as evidence that there is land deformation happening along this zone.

11 Which of the following choices best describes the motion that the tectonic plates are showing? Circle the choice.

a. Tectonic plates are moving in opposite directions and are getting farther away from each other.

b. One tectonic plate is moving toward another one and running into it.

c. One tectonic plate is sliding past another one that's moving in the same direction, but slower.



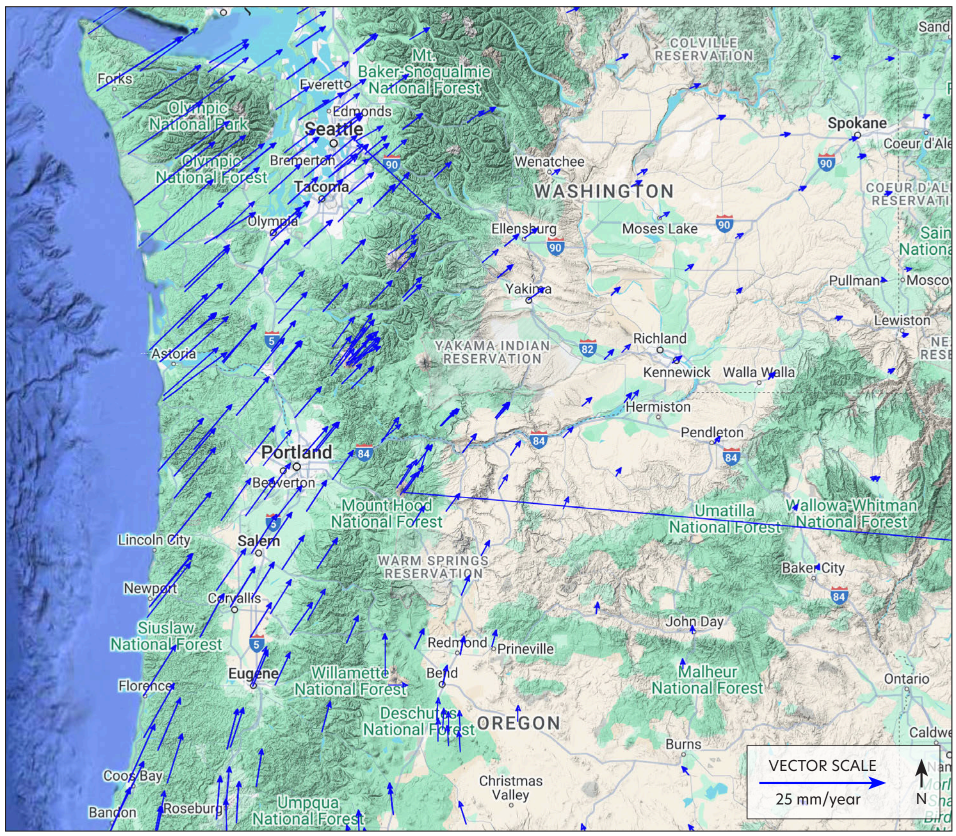
12 Where two or more tectonic plates interact, it is called a **plate boundary**. Based on the information provided by your instructor, what type of plate boundary exists between the Juan de Fuca plate and the North American plate?

PART C: USING GPS DATA TO DETERMINE POTENTIAL HAZARDS

GPS data show that some regions of Earth's surface are moving faster than others. This causes the ground surface to deform in those areas, and it leads to earthquakes as the ground finally breaks. Knowing where the ground motions are unequal paints a picture of greater danger along those areas.

Below is a ground motion map for the same region you have been studying. The difference between the maps is simply in the number of GPS vectors that are shown. The first maps display a limited the number of vectors to make it easier to find and measure individual vectors. On this map, nearly all of the GPS data in Oregon and Washington are displayed. It paints a slightly different picture. The density and number of GPS stations do not necessarily indicate the areas with the highest risk.

13



a. Draw an oval around the entire area along the coast that shows a greater amount of movement. LIGHTLY shade in your oval with the same color. Label this area Coastal.

b. Using a new color, draw an oval around the Inland Valley region that shows motion in the same direction, with less speed. LIGHTLY shade in your Inland Valley oval with the same color and add the label Inland Valley Region.

c. Do the same for the area east of the Cascades.

d. Draw the fault line where the Juan de Fuca plate and the North American plate meet. *Hint: Copy the black fault line from the map in Question 11.*

e. Which region is storing the most potential energy and will feel the jolt of the subduction earthquake the most, when the North American and Juan de Fuca plates slip past each other?

f. Why do you think this?

---

14 Compare your circled areas above on your maps to the Earthquake Shaking Potential Maps of Oregon and Washington provided by your instructor. What can you conclude about the relationship between what the vectors show you and the earthquake shaking potential?

15 Circle the statement, or statements, to the right that you believe to be true.

16 After discussion, shade in the statements that are true.

A. The number of GPS stations in an area automatically means there is more danger there.

B. The density of GPS stations is just that—there are more GPS stations in a given area.

C. A GPS station with the longest vector will be the place with the largest earthquake potential.

D. Areas with a big difference between the lengths of GPS vectors are the areas of higher risk of earthquake shaking.

PART D: EARTHQUAKE SAFETY AND THE SHAKEALERT EARTHQUAKE EARLY WARNING SYSTEM

The ShakeAlert Early Earthquake Warning System incorporates high-precision GPS data. Being aware of higher risk areas allows scientists and public health officials to mitigate the risk and produce far more favorable outcomes in the case of a major earthquake. For more information about the ShakeAlert system, refer to the USGS Website on Earthquake Hazards.

Open the "Prepare in a Year" guide.

---

17 Who is your out-of-the-area contact?

---

18 What other communication sources can you use?

---

19 How much water is recommended that you store?

---

20 Where can you store the water where you live?

---

21 Go to the Grab and Go Kit page (section 4 in the guide).

- Add a check next to the items you already have at home.
- Circle what you need.
- Add a "?" for what you need to ask your parents about (i.e., tow chain, jumper cables, documents).

PACIFIC NORTHWEST AND THE BIG SQUEEZE

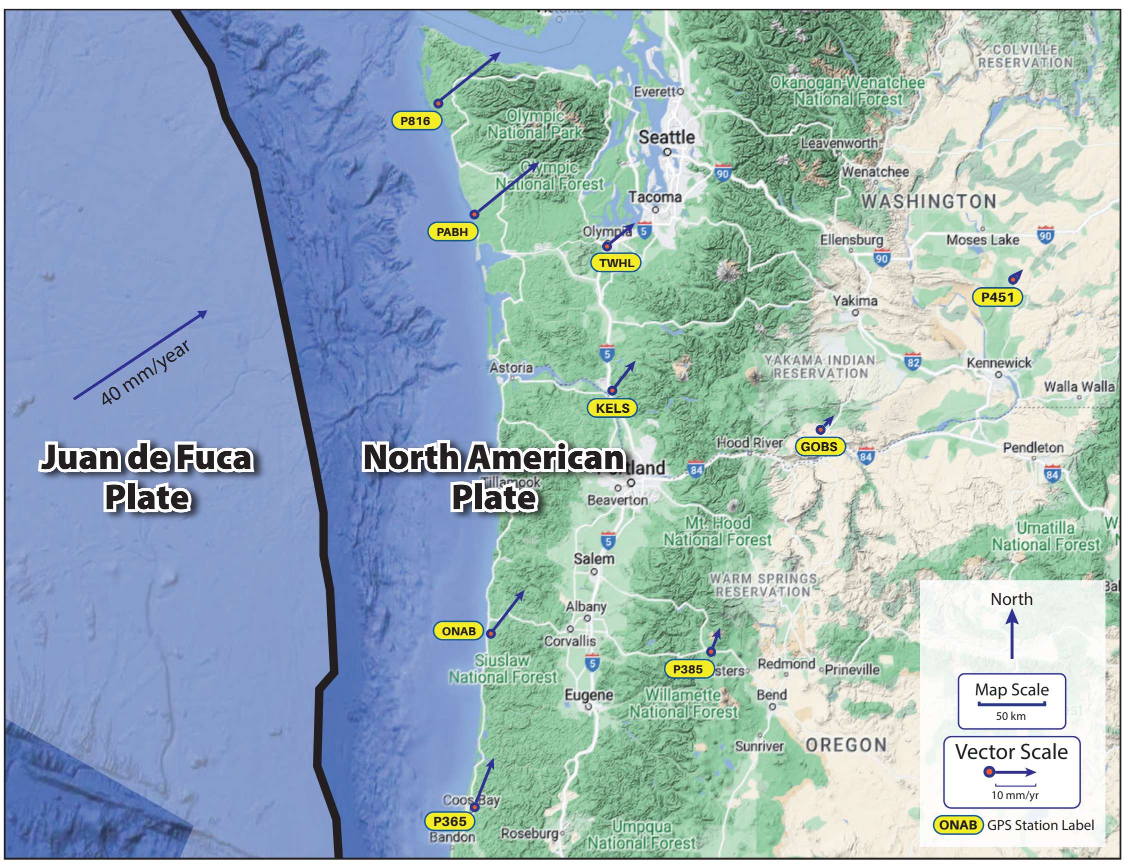
20–30 MINUTE ACTIVITY HANDOUT ***ANSWERS***

NAME: ______________________ PERIOD: __________ DATE: ______________

Review the kinesthetic activity using current GPS data to show how the land beneath our feet is moving, crumpling, sliding, and stretching.

1 The map below shows the motions of the major tectonic plates in the Pacific Northwest. Locate the Juan de Fuca and North American plates. Examine the vector on the Juan de Fuca plate. In your own words, explain what the vector on the Juan de Fuca plate indicates.

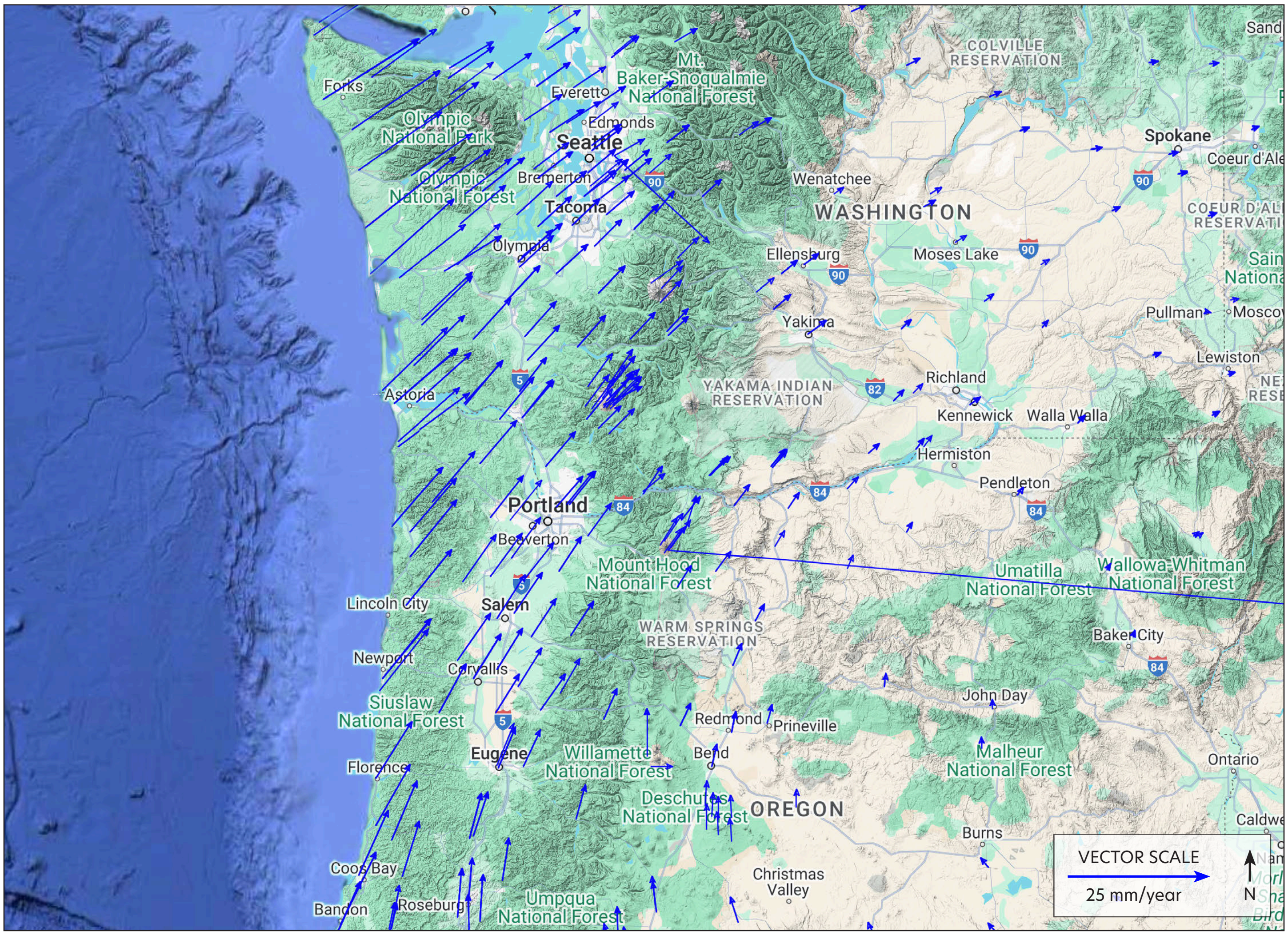
The vector indicates the speed and direction of the Juan de Fuca plate and that it is moving toward the North American plate.



Where two tectonics plates collide is known as a **convergent boundary**. The dense Juan de Fuca plate will **subduct** beneath the less dense North American plate.

2 In your own words, explain what is happening to the land along the Juan de Fuca-North American subduction zone. Feel free to draw on the image below to help explain your thinking.

The land closest to the coast or subduction zone is getting pushed northeast faster than the land further inland.



3 Explain how the vectors are evidence that there is land deformation happening along this zone.

The different vector lengths are evidence that different regions are moving at different speeds. Because of the frictional stresses this causes, land deformation is occurring. Earthquakes occur when stresses become too great and need to be released.

PACIFIC NORTHWEST AND THE BIG SQUEEZE

60+ MINUTE ACTIVITY HANDOUT ***ANSWERS***

PACIFIC NORTHWEST AND THE BIG SQUEEZE

NAME: ______________________________ PERIOD: __________ DATE: ______________

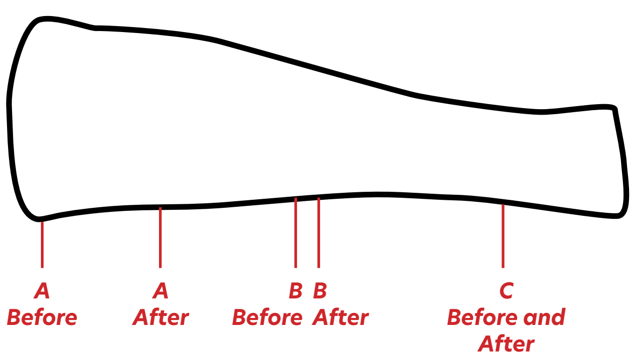
How do we identify the regions with high earthquake hazards? One method that we will explore today is using high precision GPS to determine the speed and direction of tectonic plate movement.

PART A: MOTION AND DEFORMATION WITH COMPRESSIVE FORCES

1 What are the distances that the GPS stations on the minispring traveled? Measure distances in millimeters (mm).

A. Coastal: __________ B. Inland Valley: __________ C. East of the Cascade Mountains: __________

2 Draw the shape of the compressed minispring. Don't forget to include the thickened (crumpled) part.



Minispring drawing with thicker and crumpled beginning (Coastal), and compressed areas in the middle (Inland Valley) and inland (East of Cascade Mountains), but less compression as the drawing shows inner locations.

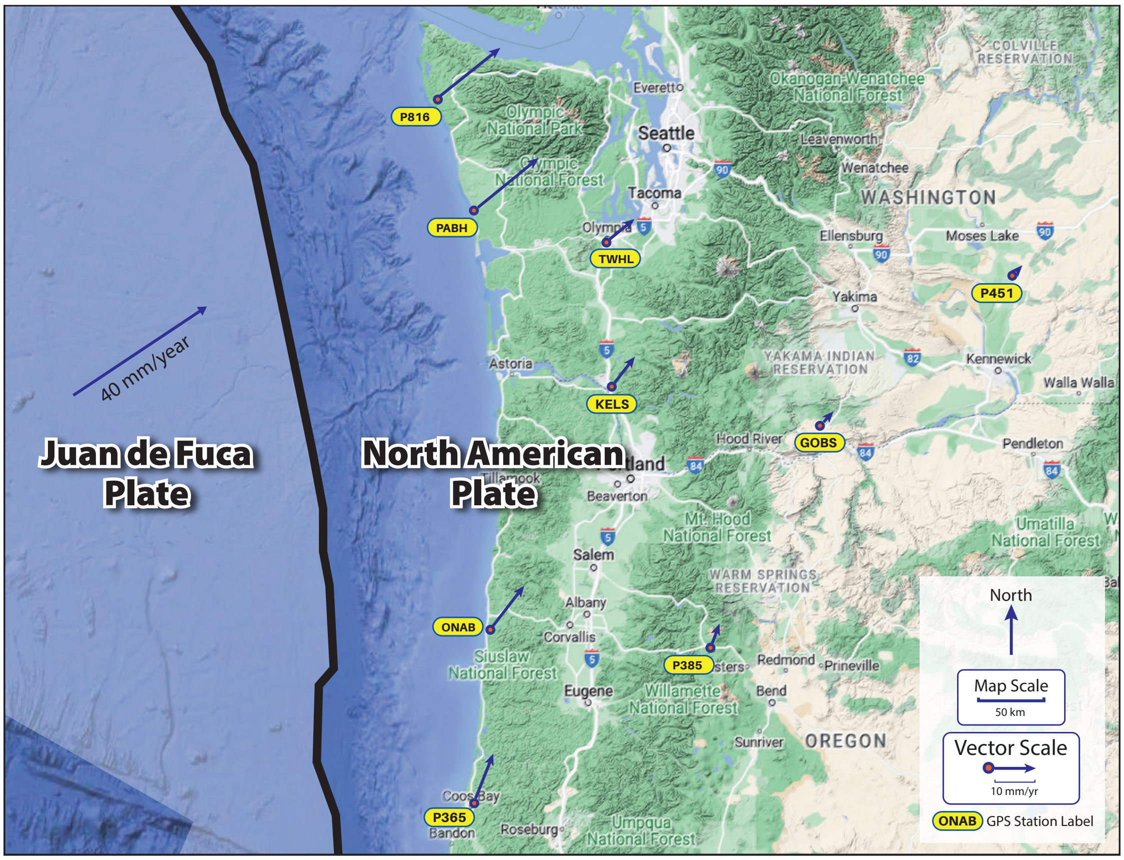
3 Label your drawing above with the A, B, C locations before and after compression:
A = Coastal, B = Inland Valley, C = East of the Cascade Mountains

4 What do you notice about how far each GPS station moves?

The station closest to the compression force (Coastal) moves farther than the station east of the Cascade mountains.

5 The map below shows the motions of the major tectonic plates in the Pacific Northwest. Locate the Juan de Fuca and North American plates. Examine the vector on the Juan de Fuca plate. In your own words, explain what the vector on the Juan de Fuca plate indicates.

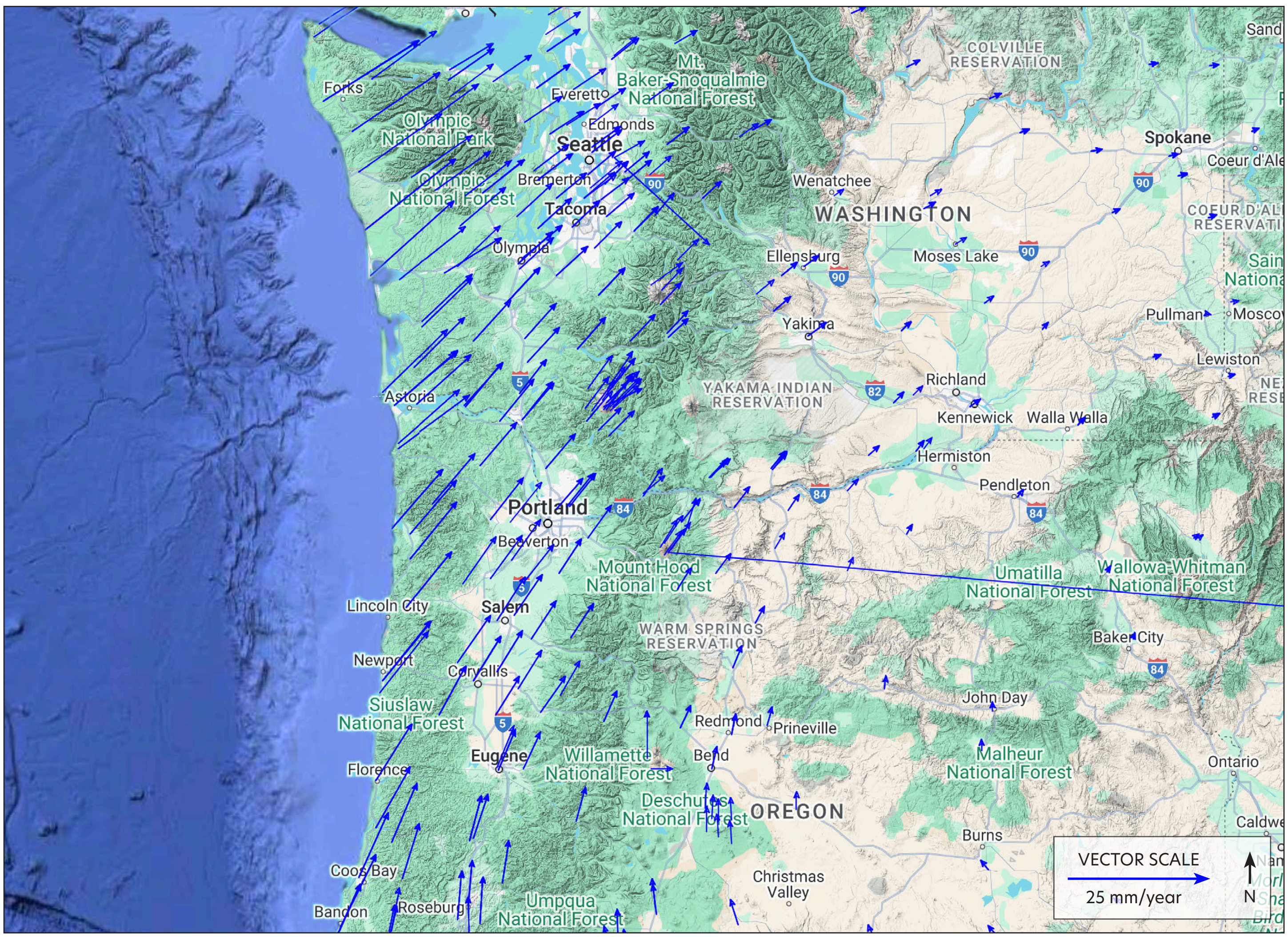
The vector indicates the speed and direction of the Juan de Fuca plate and that it is moving toward the North American plate.



Where two tectonics plates collide is known as a **convergent boundary**. The dense Juan de Fuca plate will **subduct** beneath the less dense North American plate.

6 In your own words, explain what is happening to the land along the Juan de Fuca-North American subduction zone. Feel free to draw on the image below to help explain your thinking.

The land closest to the coast or subduction zone is getting pushed northeast faster than the land further inland.



7 In the map in Step 6 above:

a. Measure the length (in mm) of the vector scale shown in the box on the bottom right of the map.

The vector scale length measures ___________ mm.

b. Pick a vector in the **coastal area** of the map. Using one of the colored pencils, circle it and measure the length of the vector in mm. Record the measurement in the space below and use the formula to calculate the annual movement of that GPS station. ***Answers will vary depending on the vector chosen, ranging between 11 and 19 mm/year. The measurements should decrease as they move inland.***

Vector length (mm) = ___________ Annual movement of GPS station (mm/year) = ___________

c. Pick a vector in an **Inland Valley area** that is clearly a different size than the coastal one. In a different color, circle it and measure the length of the vector in mm. Record the measurement in the space below and use the formula to calculate the annual movement of that GPS station.

Answers will vary depending on the vector chosen, ranging between 6.5 and 8 mm/year. The measurements should decrease as they move inland.

Vector length (mm) = ___________ Annual movement of GPS station (mm/year) = ___________

d. Pick a vector in the **area east of the Cascade mountains**. In a different color, circle it and measure the length of the vector in mm. Record the measurement in the space below and use the formula to calculate the annual movement of that GPS station. ***Answers will vary depending on the vector chosen, less than 5 mm/year, mostly near zero. The measurements should decrease as they move inland.***

Vector length (mm) = ___________ Annual movement of GPS station (mm/year) = ___________

$$\text{Annual movement of GPS station (mm/year)} = \frac{\text{Vector length}}{\text{Vector scale length}} \times 25 \text{ mm/year}$$

8 Complete the statement below using the data you calculated. ***Answers will vary, but they should be the same as the measurements for 7 above.***

The coastal GPS station moved _______ mm in one year, the Inland Valley GPS station moved _______ mm in one year, and the GPS station east of the Cascades moved ______ mm in one year.

9 Go back to the drawing you made for Step 2. Add vectors for each region of your drawing.

10 Explain why vectors can be used as evidence that there is land deformation happening along this zone.

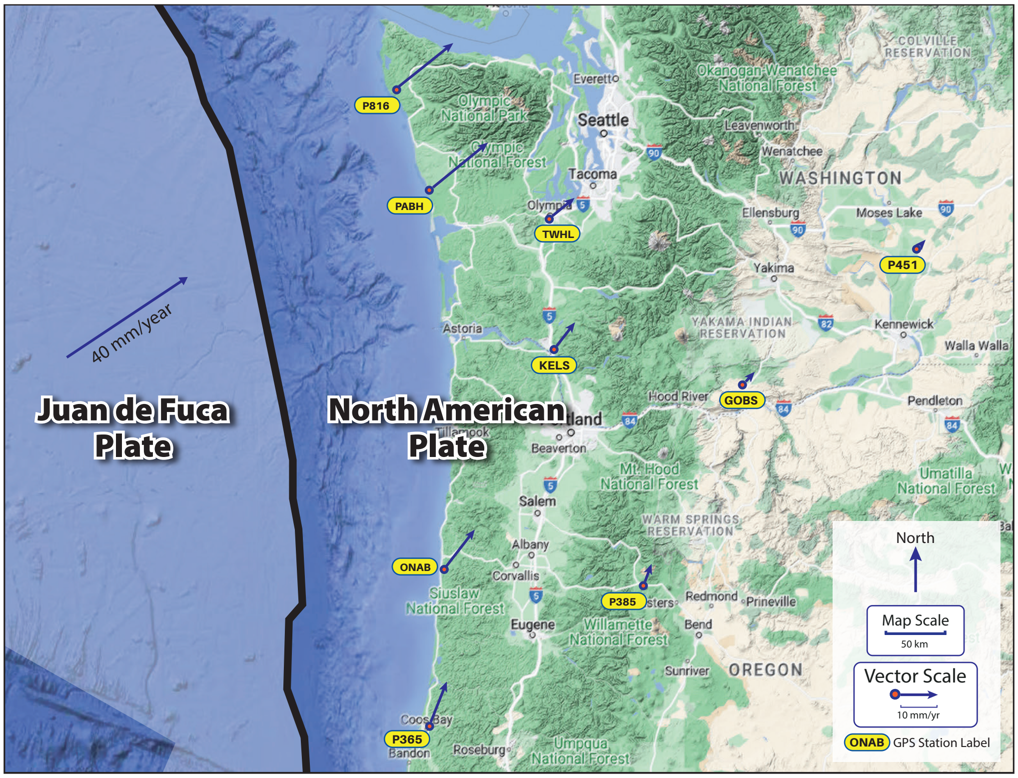
Different speeds will cause warping just like an oar in the water on only one side of a boat. The oar creates friction which slows the boat on just that one side which causes you to turn. Looking at the vectors on the Oregon/Washington map, this is what is happening to the land.

11 Which of the following choices best describes the motion that the tectonic plates are showing? Circle the choice.

A. Tectonic plates are moving in opposite directions and are getting farther away from each other.

B. One tectonic plate is moving toward another one and running into it.

C. One tectonic plate is sliding past another one that's moving in the same direction, but slower.



12 Where two or more tectonic plates interact, it is called a **plate boundary**. Based on the information provided by your instructor, what type of plate boundary exists between the Juan de Fuca plate and the North American plate?

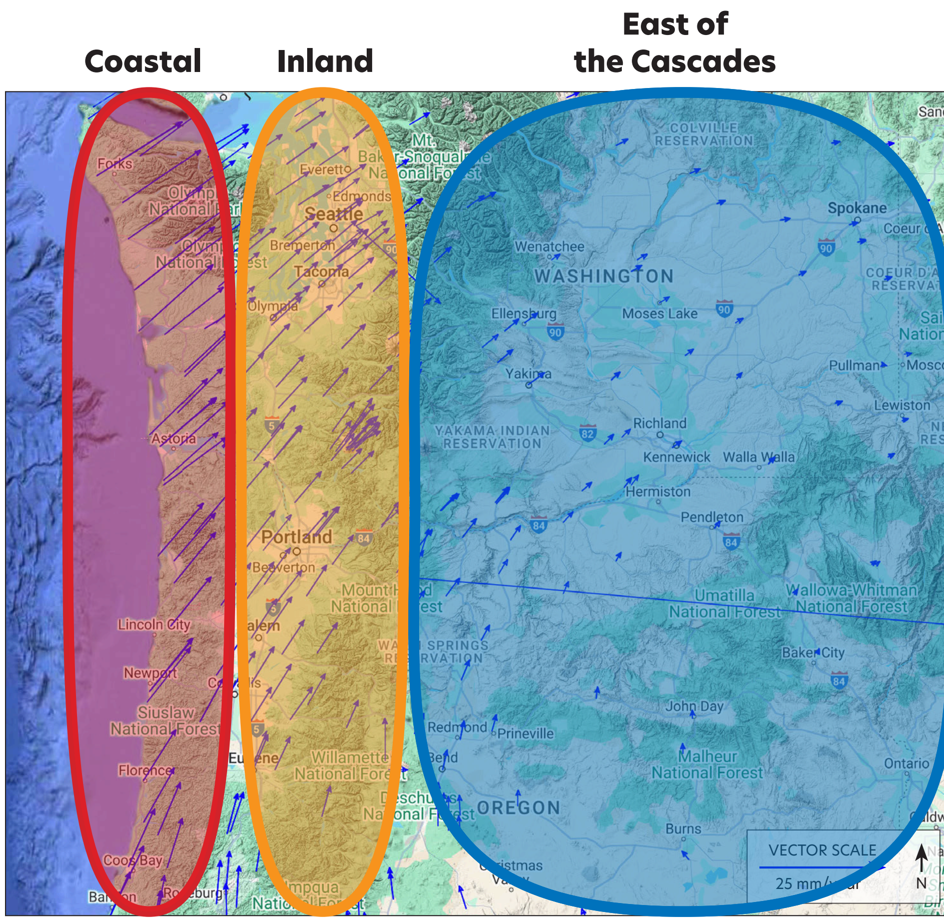
Convergent boundary/subduction

PART C: USING GPS DATA TO DETERMINE POTENTIAL HAZARDS

GPS data show that some regions of Earth's surface are moving faster than others. This causes the ground surface to deform in those areas, and it leads to earthquakes as the ground finally breaks. Knowing where the ground motions are unequal paints a picture of greater danger along those areas.

Below is a ground motion vector map for the same region you have been studying. The difference between the maps is simply in the number of GPS vectors that are shown. The first maps display a limited the number of vectors to make it easier to find and measure individual vectors. On this map, nearly all of the GPS data in Oregon and Washington are displayed. It paints a slightly different picture. The density and number of GPS stations do not necessarily indicate the areas with the highest risk.

13



a. Draw an oval around the entire area along the coast that shows a greater amount of movement. LIGHTLY shade in your oval with the same color. Label this area Coastal.

b. Using a new color, draw an oval around the Inland Valley region that shows motion in the same direction, with less speed. LIGHTLY shade in your Inland Valley oval with the same color and add the label Inland Valley Region.

c. Do the same for the area East of the Cascades.

d. Draw the fault line where the Juan de Fuca plate and the North American plate meet. *Hint: Copy the black fault line from the map in Question 11.*

e. Which region is storing the most potential energy and will feel the jolt of the subduction earthquake the most, when the North American and Juan de Fuca plates slip past each other?

The coastal region.

f. Why do you think this?

ANSWERS MAY VARY: The vectors near the coast are longer relative to Inland Valley and east of the Cascades, suggesting that more potential energy may be stored elastically within the rock in this location. Also, the velocities change most quickly near the coast, so this region is compressing the most. For these two reasons, this area will snap back the most when stored potential energy becomes kinetic energy—2 sides of a fault or plate boundaries overcome the friction and slip, which causes the movement and shaking we feel—an earthquake.

---

14 Compare your circled areas above on your maps to the Earthquake Shaking Potential Maps of Oregon and Washington provided by your instructor. What can you conclude about the relationship between what the vectors show you and the earthquake shaking potential?

ANSWERS MAY VARY: The region where the velocities change most quickly is near the coast of Oregon and Washington, where the velocity changes from 40 mm/year on the Juan de Fuca plate to approximately 13 to 19 mm/year. The coastal region has the highest earthquake potential and has the potential to slip the most when the stored potential energy becomes kinetic energy (movement of rock, heat, and seismic waves).

15 Circle the statement, or statements, to the right that you believe to be true.

16 After discussion, shade in the statements that are true.

A. The number of GPS stations in an area automatically means there is more danger there.

B. The density of GPS stations is just that—there are more GPS stations in a given area.

C. A GPS station with the longest vector will be the place with the largest earthquake potential.

D. Areas with a big difference between the lengths of GPS vectors are the areas of higher risk of earthquake shaking.

PART D: EARTHQUAKE SAFETY AND THE SHAKEALERT EARTHQUAKE EARLY WARNING SYSTEM

The ShakeAlert Early Earthquake Warning System incorporates high-precision GPS data. Being aware of higher risk areas allows scientists and public health officials to mitigate the risk and produce far more favorable outcomes in the case of a major earthquake. For more information about the ShakeAlert system, refer to the USGS Website on Earthquake Hazards.

Open the "Prepare in a Year" guide.

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17 Who is your out-of-the-area contact?

Answers will vary

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18 What other communication sources can you use?

Social media: Facebook, Instagram, Snapchat...

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19 How much water is recommended that you store?

Answers will vary: At least two weeks' worth of water for your household. Fourteen gallons per person.

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20 Where can you store the water where you live?

Answers will vary

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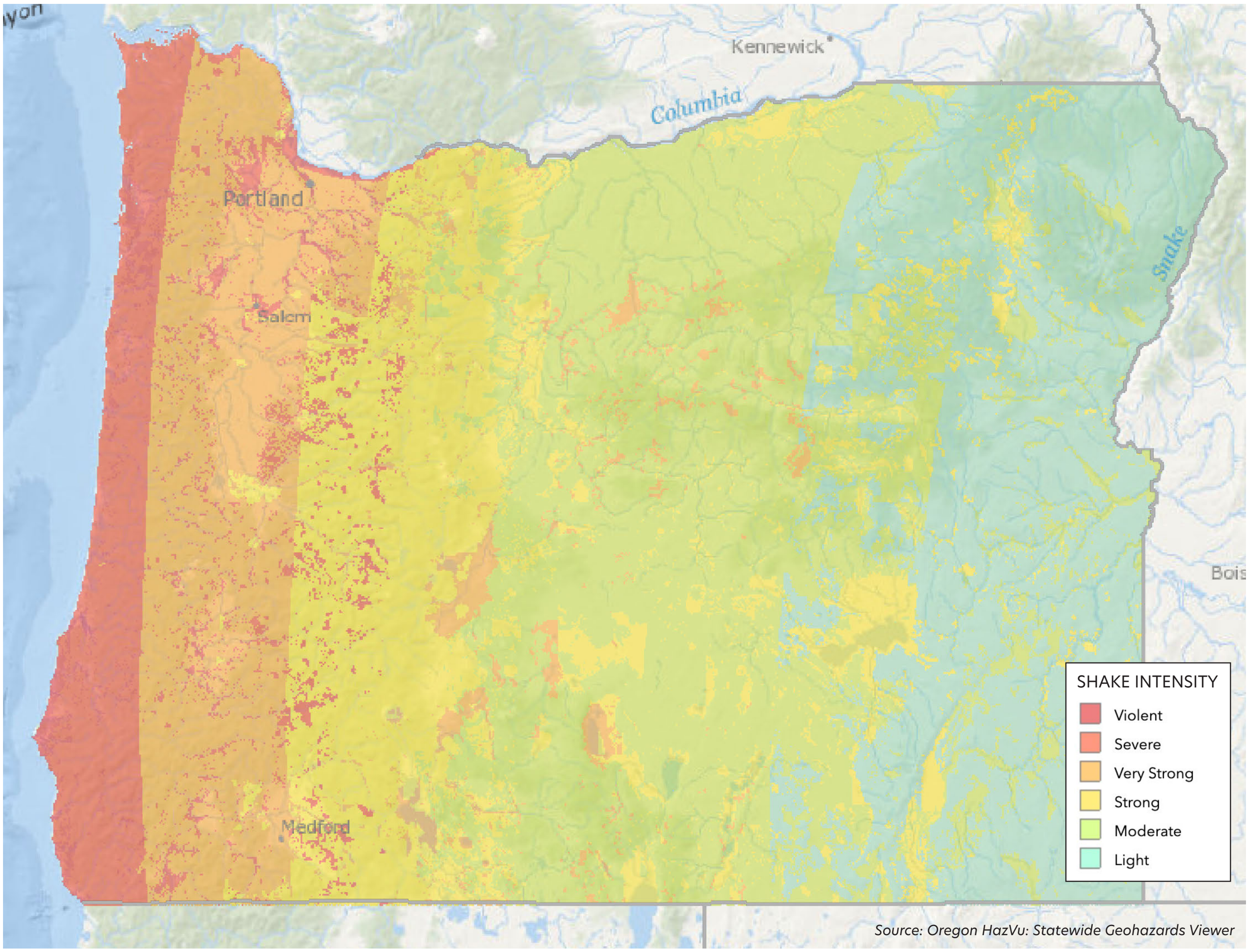
21 Go to the Grab and Go Kit page (section 4 in the guide).

- Add a check next to the items you already have at home.
- Circle what you need.
- Add a "?" for what you need to ask your parents about (i.e., tow chain, jumper cables, documents).

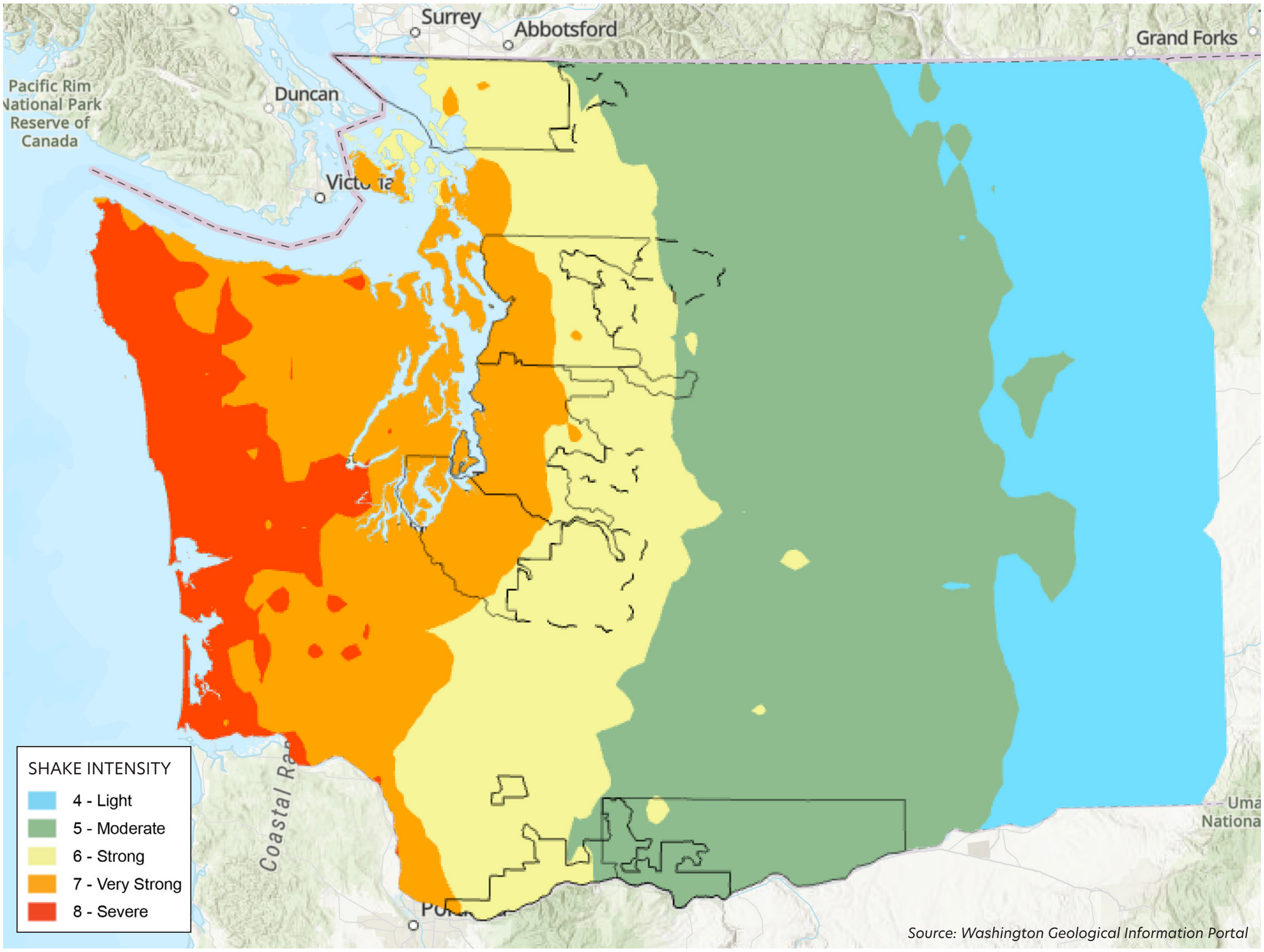
APPENDIX I. EARTHQUAKE SHAKING POTENTIAL AND HAZARD MAPS

OREGON EARTHQUAKE SHAKING POTENTIAL MAP

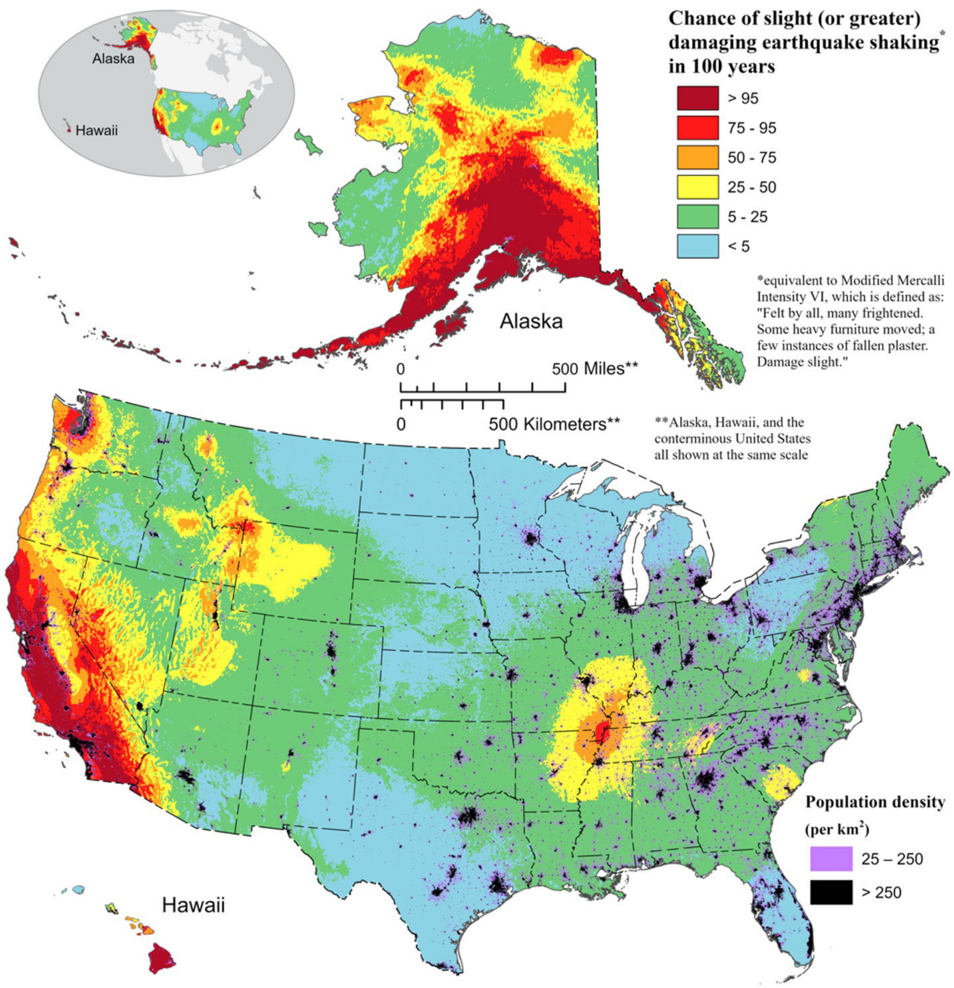


Source: Oregon HazVu: Statewide Geohazards Viewer

WASHINGTON EARTHQUAKE SHAKING POTENTIAL MAP



USGS NATIONAL SEISMIC HAZARD MAP (2023)



From https://www.usgs.gov/media/images/national-seismic-hazard-model-2023-chance-damaging-earthquake-shaking

APPENDIX J. NGSS SCIENCE STANDARDS AND 3-DIMENSIONAL LEARNING

NGSS ALIGNMENT

Disciplinary Core Ideas
History of Earth: HS-ESS1-5
Earth's Systems: MS-ESS2-2
Earth and Human Activity: MS-ESS3-2, HS-ESS3-1
Science and Engineering Practices
4. Analyzing and Interpreting Data
5. Using Mathematics and Computational Thinking
6. Constructing Explanations and Designing Solutions
Crosscutting Concepts
4. Systems and System Models
7. Stability and Change

PERFORMANCE EXPECTATIONS

- MS-ESS2-2, MS-ESS3-2, HS-ESS2-1-5, and HS-ESS3-1.

CROSSCUTTING CONCEPTS

- Patterns: HS-ESS1-5;
- Cause and effect: HS-ESS3-1;
- Scale, proportion, and quantity: MS-ESS2-2;
- Energy and matter: HS-ESS2-3; and
- Influence of science, engineering, and technology on society and the natural world: HS ETS1-3.

SCIENCE & ENGINEERING PRACTICES IN THE NGSS

- Developing and Using Models; HS-ESS2-1,
- Analyzing and interpreting data; MS-ESS3-2,
- Using mathematics and computational thinking;
- Constructing explanations (for science) and designing solutions (for engineering); MS-ESS2-2, HS-ESS3-1
- Engaging in argument from evidence; and
- Obtaining, evaluating, and communicating information.

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