ShakeAlert™
ACTIVITIES FOR FORMAL AND INFORMAL LEARNING SETTINGS

GAGE SAGE

Operated by EarthScope Consortium

# DISCOVER PLATE BOUNDARIES THROUGH GROUND MOTION AND DEFORMATION

EARTHQUAKE, VOLCANO, AND GPS DATA IN THE WESTERN UNITED STATES AND ALASKA

## OVERVIEW

Tectonic plates are always on the move. We can measure their motion using Global Positioning System (GPS) instruments firmly anchored to the ground. These GPS instruments measure how a precise location on Earth's surface moves over time. The GPS data collected from thousands of instruments around the world are used to identify broad zones of deformation (called tectonic plate boundaries), boundary types, and earthquake hazards. Scientists have identified regions where the motion rapidly changes direction or speed as having a higher risk of earthquake hazards.


FIGURE 1. GPS ground motion vector map of the San Andreas fault (transform) plate boundary.

5 min | 20 min | 50 min

Large Group | Small Group

Beginner | Learner Investigation | Web-Based | Materials Required

TIME. 5, 20, and 50 minute guided activities adaptable for audience and venue.

AUDIENCE. Novice and experienced geoscience learning groups from grades 6 to 12 or introductory college courses.

SUBJECT. Natural Hazards: Earthquakes, Geoscience, GPS, Plate Tectonics.

*Enhanced from Exploring Tectonic Motions with GPS and Visualizing Relationships with Data.*

## CONTENTS

In this activity, learners use authentic GPS data to explore plate tectonic motions in the western United States and Alaska. Three different options provide learners with skills to interpret GPS data displayed as vectors on maps. During a short **5 Minute Activity**, learners use hand movements to illustrate plate motion at different types of boundaries. In the **20 Minute Activity**, learners create and interpret vectors using a compass rose paper/pencil activity. The **50 Minute Activity** introduces learners to an online tool to visualize and interpret multiple forms of data. Using a jigsaw approach, ground motion, earthquake locations, and volcanic location data are combined to identify plate boundaries and regions most likely to have earthquakes. Learners support their choices by providing evidence from the tool. During this activity, learners are introduced to careers in geodesy, seismology, and volcanology.

Why is it important to learn about plate motions and ground deformation near plate boundaries? Regions with rapid shifts in ground movement and high levels of stored elastic energy, as revealed by GPS data, are more likely to face significant seismic hazards (**Figure 1**). Over 143 million people in the United States are at risk from earthquakes, which could lead to loss of life and extensive damage. 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 will be able to:

1. Analyze and describe plate motion as represented as vectors.
2. Interpret ground motion vector maps and use hand movements to demonstrate motion along tectonic plate boundaries.
3. Correlate GPS vectors on a map with plate tectonic boundary types.
4. Make a claim based on evidence about which locations are most likely to have earthquakes in the future.

## MATERIALS

| 5 MINUTE ACTIVITY | 20 MINUTE ACTIVITY | 50 MINUTE ACTIVITY |
|---|---|---|
| FOR DISPLAY<br>☐ **Appendix C:** Anatomy of a vector image<br>☐ **Appendix D:** Images with hand movements for boundaries and ground motion vector maps | ☐ Materials from **5 Minute Activity**<br><br>1 PER LEARNER<br>☐ **Appendix E**: Compass rose handout<br>☐ Ruler (cm)<br><br>OPTIONAL<br>☐ **Appendix F**: 20 Minute Activity Handout (1 per learner)<br>☐ **Appendix H**: Instructor Answer Key | ☐ Materials from **5 and 20 Minute Activities**<br><br>1 PER LEARNER<br>☐ **Appendix G**: 50 Minute Activity Handout<br>☐ **Webtool:** GPS Velocity Viewer<br><br>OPTIONAL (1 set per group)<br>☐ **Appendix H**: Instructor Answer Key<br>☐ **Appendix I:** Seismic hazard map<br>☐ **Appendix J:** Maps from the GPS Velocity Viewer tool |

# MEDIA RESOURCES

## INSTRUCTOR BACKGROUND

- Animation about GPS, reference frames, and Measuring Plate Tectonic Motions with GPS (5:42)

## 5 MINUTE ACTIVITY

- Video Tutorial: How GPS Measures Ground Motion (3:05) to learn about ground motion vector maps and hands illustrating plate motion

## 20 MINUTE ACTIVITY

- Video Tutorial: How GPS Measures Ground Motion (3:05) to learn about ground motion vector maps and hands illustrating plate motion

## 50 MINUTE ACTIVITY

**PARTS A AND B**

- Animation: Measuring Plate Tectonic Motions with GPS (5:42)
- Video Tutorial: How GPS Measures Ground Motion (3:05) to learn about ground motion vector maps and hands illustrating plate motion
- Video Tutorial: How to Use the GPS Velocity Viewer (4.10)
- Article: GPS Velocities & Reference Frames

**PART C**

- Article: What is a Seismologist?
- Video: Seismology (5.31)
- Article: What is a Volcanologist?
- Article Information About Volcanologists
- Video: Do You Call Yourself a Geodesist? (3:47)
- Video: Do You Call Yourself a Geodesist? Extended Version (6:28)

**PART D**

- Article: How Do I Sign Up for the ShakeAlert Earthquake Early Warning System?
- Video: Earthquake! Steps to Take When it Strikes (3:03)
- Video: Preparedness Journey (2.02)
- Guide: "Prepare in a Year" (pdf)

## TABLE OF FIGURES AND APPENDICES

For these activities, learners will practice reading maps and applying the map and vector scales. It is recommended that instructors familiarize themselves with the Media Resources and Appendices listed on the previous pages. Introduce new vocabulary (Appendix A) to meet learners' needs. The activities are designed to use the online map tool, GPS Velocity Viewer; however, instructors can print the hard-copy maps provided in the appendices.

## ABOUT GPS

The movement of land is measured very precisely by GPS or other Global Navigation Satellite Systems (GNSS) (**Figure 2**). GPS satellites send signals to GPS receiving stations permanently anchored into rock or deep into soil. If the ground moves, the GPS station moves with it. The change in position is collected every tenth of a second, every day, to precisely measure the movement in all three dimensions at the sub-millimeter level. The data are processed daily to determine a daily change of position (see Appendix B for more detail).

GPS data are represented as vectors on maps. Each vector provides the horizontal speed and direction (velocity) of a single GPS station and the ground beneath it. The GPS station is located at the tail of the vector (**Figure 3**). The longer the arrow, the faster the ground and the GPS station move.

NOTE: Learners might confuse the length of a vector with total distance. Emphasize that the length is the speed the ground is moving, typically in millimeters per year.


FIGURE 2. GPS Station P443 in Marblemount, Washington. The GPS antenna on the left is anchored to the ground. Communication equipment, solar panels, and equipment enclosure with GPS receiver and batteries are on the right. *Source: EarthScope Consortium*

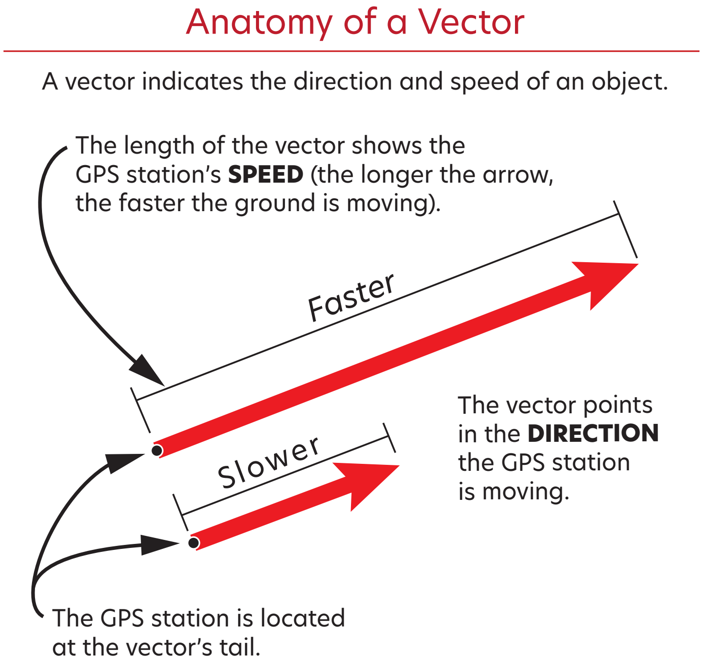



FIGURE 3. Anatomy of a vector. High-precision GPS stations anchored to the ground collect data about the ground's movement at a specific location. A vector represents the speed (length of the vector) and the direction that a specific piece of ground is moving. See Appendix C for a larger version to display.

# IF YOU HAVE 5 MINUTES

## "DID YOU KNOW?" DISCOVERY QUESTION

**Did you know that you can talk about the speed of a tectonic plate just like you can for a car?**

## INSTRUCTOR PREPARATION

In this **5 Minute Activity**, learners will use hand movements to demonstrate tectonic plate boundary types. After learning what a vector is, they will practice each type of boundary using two different real-world scenarios of plate motion. By using their hands, learners will demonstrate ground movement in areas with differences in speed and/or direction and interpret the basic tectonic motions represented by the vectors as measured by GPS instruments.

### BEFORE YOU BEGIN

- Review and be prepared to display the video How GPS Measures Ground Motion (3:05) to learn about ground motion vector maps and hands illustrating plate motion
- Be prepared to display Appendix C (Anatomy of a Vector) and Appendix D (Plate Tectonic Motion with Hand Movements & Ground Motion Vector Maps)

## DIRECTIONS FOR LEADING THE ACTIVITY

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

2. Draw attention to the "Did You Know" question: **Did you know that you can talk about the speed of a tectonic plate just like you can for a car?**

3. Show the first 32 seconds of the video How GPS Measures Ground Motion and review the tectonic plate boundary types with your learners.

4. Project the tectonic plate boundary types and hand movement images (Appendix D) and demonstrate the hand movements (**Figure 4**).
   **a.** Have learners model the movements back to you and name each type of boundary as they show you.

5. Display and briefly explain velocity vectors using the image in Appendix C: Anatomy of a Vector (**Figure 3**). Then show the same video from 00:32 to 00:58 seconds. Point out that velocity vectors represent real data.

6. Transition learners: "Now we're going to show data collected by GPS instruments permanently attached to the ground and how the same boundary types can be visualized with these data as vectors and hand motions." Display ground motion vector maps paired with hand movements on the next pages from Appendix D; notes on how the vectors change across each region are included above each map.
   **a.** Guide learners through the hand movements as a class for each boundary type using vectors on the ground motion vector maps. Point out the vector lengths on each side of the boundary for each boundary type and show this movement with your hands.

7. Wrap up with further practice (right images in **Figure 5** for reference). Show the remainder of the video How GPS Measures Ground Motion starting at 1:19. Have learners describe the boundary type and enact the hand movements for each boundary type scenario.

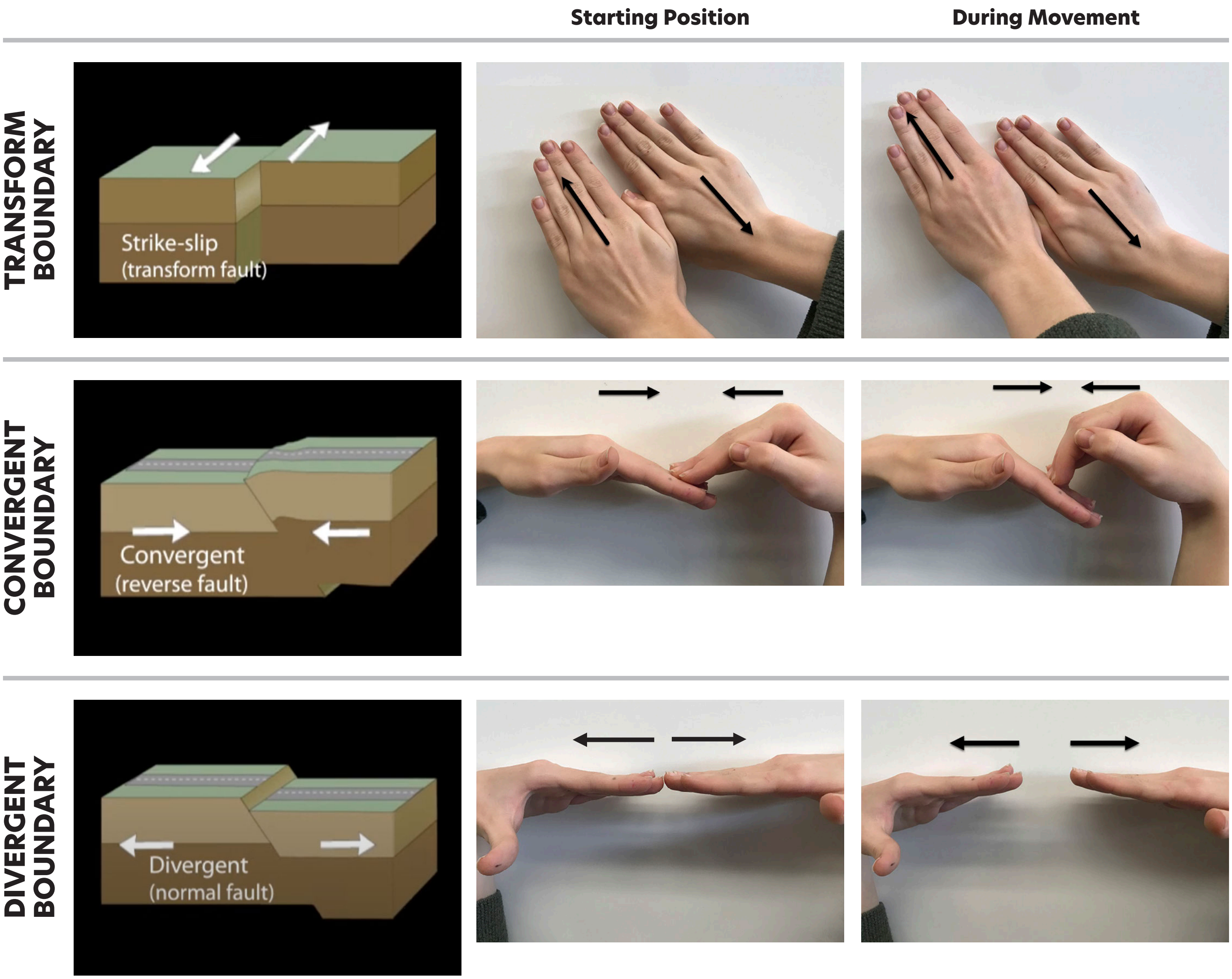



FIGURE 4. Modeling tectonic motion with hand movements. Larger images and more details are available in Appendix D.

**a.** Show 1:19 to 1:27 of the video (before the words Convergent Boundary appear on the screen). Continue with the next Convergent scenario and example of the Himalayas until 1:54. Again, have learners show the hand movements.

**b.** At 1:54, continue in a similar fashion for divergent boundary examples and discuss the vectors shown for Iceland.

**c.** At 2:22, continue in a similar fashion for transform boundary examples and discuss the vectors shown for Southern California and the San Andreas fault.

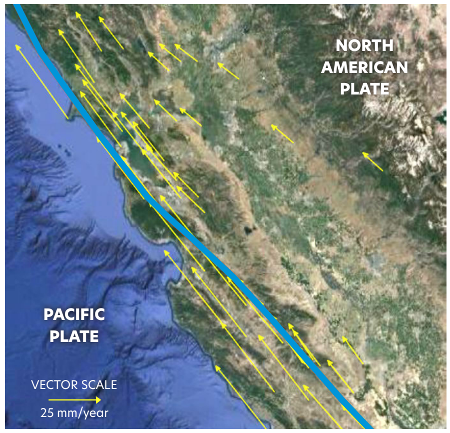
**d.** Alternative: Project the vector images in Appendix D and have learners enact the hand movements for each plate boundary type.

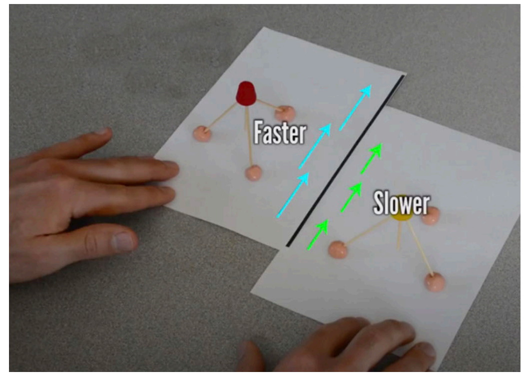
**e.** As time permits, ask learners: How are your hand movements like what you are seeing on the ground motion vector maps? How are they different?

***ANSWERS MAY VARY:*** *Similar—the hands and the maps show plate motion at different boundaries. Different—the hands are moving faster than the plates in real life, plates' directions are not exactly the same, topographic features are not exact.*

## TRANSFORM BOUNDARY

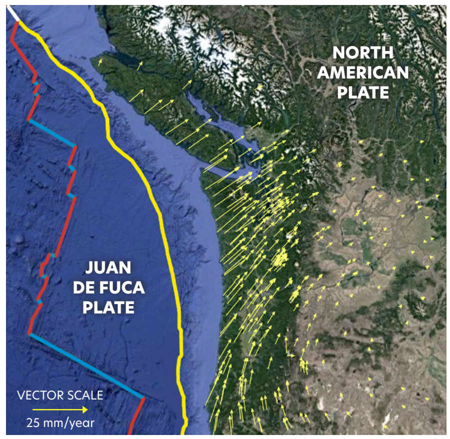
**San Andreas fault in California**

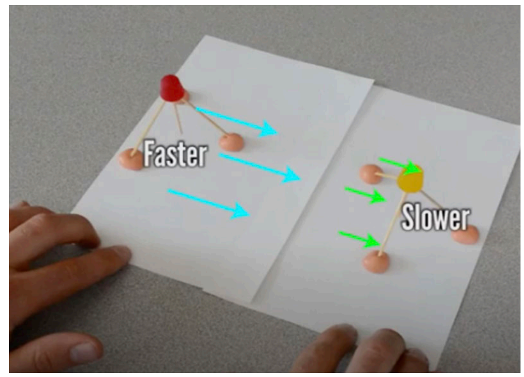



## CONVERGENT BOUNDARY

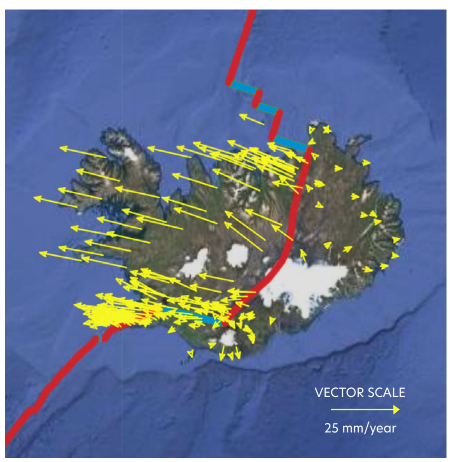
**Cascadia fault zone near Oregon and Washington**

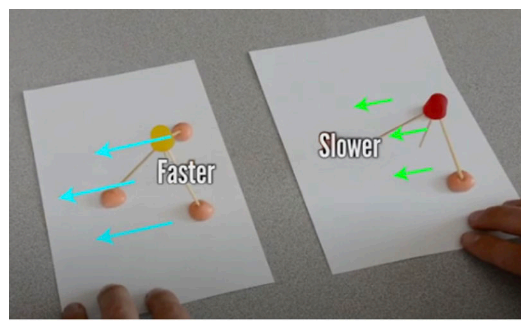



## DIVERGENT BOUNDARY

**Mid-Atlantic Ridge through Iceland**

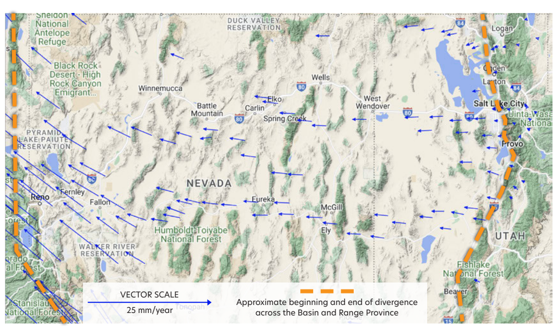



### DIVERGENCE

**Basin and Range Province**

While the Basin and Range Province has no divergent boundary, the region illustrates plate divergence spanning from eastern Utah, through Nevada, and into eastern California.



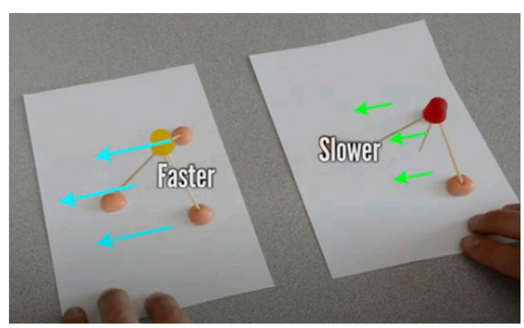




Figure 5. (left) Ground motion vector maps of: (top to bottom): San Andreas fault, Cascadia subduction zone, Mid-Atlantic Ridge, and Basin and Range. (right) Identifying plate boundary types through vector patterns. See Appendix D for larger maps and additional descriptions of vectors.

# IF YOU HAVE 20 MINUTES

**"DID YOU KNOW?" DISCOVERY QUESTION**
**Did you know that regions of the same tectonic plate can move at a different speed and direction than another part?**

## INSTRUCTOR PREPARATION

*If you are planning to do both the 5 and 20 Minute Activities, do the 20 Minute Activity first. A modified 5 Minute Activity closes this activity.*

Working in pairs, learners are introduced to the compass rose and create vectors to learn that vectors represent direction and speed. Then, learners use one (or both) of the GPS vector ground motion maps (Appendix D) or use the GPS Velocity Viewer to explore how vectors are used to study ground motion near and at tectonic plate boundaries. Learners will discover that there are areas where the ground is moving at similar speeds and in similar directions, and other areas where the speed and direction of the ground change across the region. Through a modified **5 Minute Activity**, learners use their hands to demonstrate ground movement in areas with differences in speed and/or direction and interpret the basic tectonic motions represented by the vectors on the maps.

**BEFORE YOU BEGIN**

- Print 1 per learner: Compass Rose Handout (Appendix E; optionally laminate to reuse)

OPTIONAL

- Print 1 per learner: 20 Minute Activity Handout (Appendix F). The Instructor Answer Key is in Appendix H.
- Provide learners hard copies of the Anatomy of a Vector image in Appendix C.
- Provide learners hard copies of maps in Appendix D with 1 map set per group.

## DIRECTIONS FOR LEADING THE ACTIVITY

**PART A: COMPASS ROSE** (~10 minutes)

**1** Draw attention to the "Did You Know" question: **Did you know that regions of the same tectonic plate can move at a different speed and in a different direction than another part?**
NOTE: If learners completed the **5 Minute Activity** first, they might refer to some of the vectors on the maps from the activity.

**2** Explain that they will be interpreting scientific data displayed on maps that show the direction and speed of the ground. These data were collected by GPS instruments permanently anchored to the ground. Learners will need be able to interpret the direction the ground and the GPS instrument are moving using a compass rose.

**3** Give each learner one of each of the following handouts: Compass Rose (Appendix E) and (optional) 20 Minute Activity Handout (Appendix F).

**4** Group learners into pairs (Partner A and Partner B). Confirm which learners in the pair are Partner A and which are B (have A's raise their hands or something similar).

**5** Display the compass rose (Appendix E). See **Figure 6** for reference.

**6** Give learners the following directions:

**a.** Annotate the small compass rose with the cardinal and intercardinal directions (while you describe the compass rose):
- A compass rose is an image on a map, nautical chart, or compass that displays the orientation of the cardinal directions (north, east, south, and west).
- The compass rose can also show intermediate compass directions located halfway between each pair of cardinal directions: northeast, southeast, southwest, and northwest. These are called intercardinal directions.
- Most compass roses show the cardinal degrees: 0, 90, 180, and 270, and many show all of the degrees from 0 to 360 clockwise. Direct learners to underline increments of 45 degrees on the large compass rose.

**b.** Looking at the Compass Rose handout, find the dot in the center of the compass.

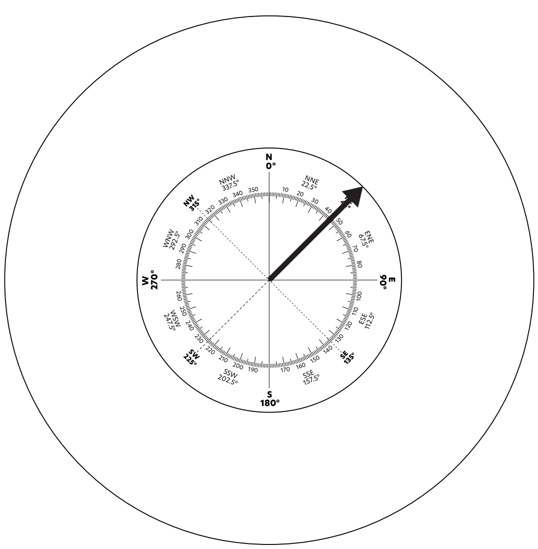



FIGURE 6. Compass rose example with 5 cm vector at 45 degrees (northeast). Figure is not to scale.

**c.** Draw a dot at 45 degrees on either the 5 cm or 10 cm circle. (Partner A draws the dot on the 5 cm circle; Partner B draws a dot on the 10 cm circle.)

**d.** Use your ruler to draw the length of the lines from the center dot to the dot on the circle. When I say "[start]", you will draw a line from the dot in the center through the dot you just made at 45 degrees. Partner A will draw a 5 cm line and Partner B will draw a 10 cm line.
- It must take precisely two seconds to get there. You cannot finish earlier.
- "We'll do this together. I will be clapping or counting to two. Draw the line as I count." (Practicing once or twice will give learners an idea of how long 2 seconds is.) Explain your commands and what they will do after you tell them to stop, for example: "When I say "stop," put down your pencils/pens and listen for the next set of instructions."
- Check for understanding; learners need to think about the precision of the length of the line AND they need to stop drawing their lines at 2 seconds.

**7** Start the activity with learners.

**8** After they have drawn their line, ask: Which direction did you go? Southeast, southwest, northeast, northwest?

***ANSWER:*** *For 45º, it is northeast.*

**9** Have them add an arrowhead to the end of the line and write a #1 (or current line number) on the line, the direction in degrees, the direction in words, and the length of the vector on the line they just drew.

***ANSWER:*** *45°, northeast, 5 cm.*

**10** Let your learners know that they have just drawn a vector! Point out that:
- A vector shows speed and direction.
- The tail of this vector is where your dot is.
- The longer the line, the faster the object is moving.

**11** Remind them that they will use this skill to interpret the vectors on the maps. Ask learners: What do velocity vectors show? What partner has the vector showing fast movement?
***ANSWER:*** *Speed and direction; Partner B.*

**12** Repeat Steps 3-7 a few more times, but give learners a different degree to draw.

- Alternate which partner draws the 5 cm and who draws the 10 cm line.
- OPTIONAL. Once you are confident that learners can determine the direction on their own, have each learner choose the direction in which they want to draw their lines; partners can draw lines in different directions. Learners continue numbering the lines and writing the direction next to the number.

**13** After several more times, ask learners to confer with each other to answer the question: "Which line had to be drawn faster?" Or, "For which line did the pencil move faster?" And then ask "Why?"
***ANSWER:*** *The 10 cm line because it had to go farther in the same amount of time, in two seconds.)*
NOTE: Learners might confuse "faster" with less time instead of faster speed. Make sure to clarify this when asking the question.

## PART B: APPLYING COMPASS ROSE AND VECTORS TO MAPS (5 minutes)

**1** Display and discuss the Anatomy of a Vector in Appendix C.

**a.** Connect the figure to activity Part A that they just finished. Remind learners that they've drawn vectors.

- A vector shows speed and direction.
- The longer the line, the faster the object is moving.

**b.** Remind learners that the Compass Rose activity demonstrates what we see on the ground motion vector maps.

**2** Display the maps with ground motion vectors in Appendix D, use the GPS Velocity Viewer, or optionally provide learners hard copies of the maps in the Appendix D section: Specific Examples of Plate Tectonic Motion, with 1 map set per group:

- San Andreas fault (transform boundary),
- Cascadia fault zone (convergent boundary, subduction)
- Basin and Range and Iceland (divergent boundaries)

**3** Ask learners the following questions or optionally direct learners to answer Question 1 on the 20 Minute Activity Handout:

**a.** How is what you did in the Compass Rose activity, similar to what you saw on these maps?
NOTE: The map on the handouts uses a single color for the plate boundaries.
***ANSWERS MAY VARY:*** *We drew vectors in a specific direction and with a certain speed.*

**PART C: PRACTICE HAND MOVEMENTS WITH GROUND MOTION VECTOR MAPS** (5+ minutes)

*NOTE: This is a modification of the 5 Minute Activity.*

1. For guided practice, have learners show you the hand movements for what they drew first on the Compass Rose handout. (This can be done either as a whole group or as pairs as you walk around.)

2. Complete the **5 Minute Activity** as stated above.

3. OPTIONAL: Direct learners to answer Questions 1-4 on the 20 Minute Activity Handout (Appendix F) after they determine the correct hand movements. Direct students to also circle the associated plate boundary from each question on their map and label the plate boundary type.

4. (On Models) Ask learners: How are your hand movements like what you're seeing on the ground motion vector maps? How are they different? ***ANSWERS MAY VARY.*** *Similar—the hands and the maps show plate motion at different boundaries. Different—the hands are moving faster than the plates in real life, plates' directions are not exactly the same, topographic features are not exact.*

5. OPTIONAL: Direct learners to answer Questions 5 and 6 on the 20 Minute Activity Handout (Appendix F).

# IF YOU HAVE 50 MINUTES

**"DID YOU KNOW?" DISCOVERY QUESTION**

**Did you know that differing speeds and directions of interior plate motion can increase the chance of an earthquake happening?**

## INSTRUCTOR PREPARATION

When two tectonic plates interact (collide, pull apart, or slide past each other), the edges of both plates deform. The North American plate interacts with multiple tectonic plates, resulting in different rates and types of deformation in different locations (**Figure 7**).

The regions where there are greater differences in length and direction of vectors indicate where more deformation is happening and where strain is building up for an earthquake. See Appendix B for more on plate motions.

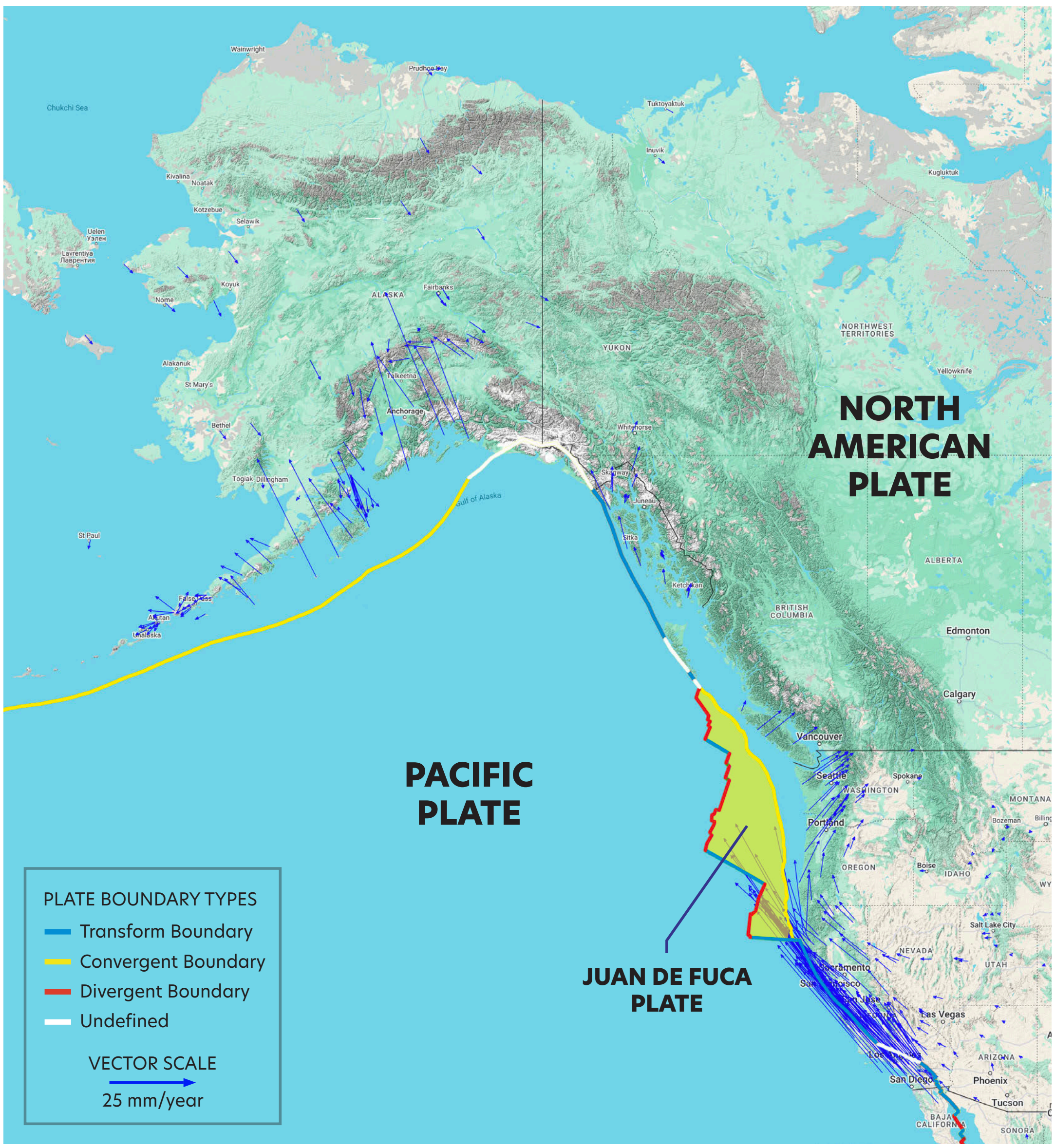



FIGURE 7. The heterogeneous forces acting on the North American plate cause the plate to deform in different ways in different regions. Sources: Google Maps, USGS, EarthScope Consortium

In this **50 Minute Activity**, learners will explore GPS data evidence that the western United States is moving and find answers to the following questions: How are earthquakes and volcanoes related? What do these data they tell you about plate movement? Learners will then consider how these different types of crustal motions have influenced the area's topography, earthquake hazards, and resulting societal impacts. Learners role play different geoscience careers as they jigsaw the data from different data maps. Then, they will be introduced to the ShakeAlert Earthquake Early Warning System and website.

1. Review and familiarize yourself with:
   - The data tool: GPS Velocity Viewer
   - Animation: Measuring Plate Tectonic Motions with GPS (5:42)
   - Video Tutorial: How GPS Measures Ground Motion (3:05) to learn about ground motion vector maps and hands illustrating plate motion
   - Video Tutorial: How to Use the GPS Velocity Viewer (4.10)

2. The **50 Minute Activity** is written as an instructor-guided activity. Although learners collaborate to determine the answers, they complete their handouts individually.

3. Print/copy 1 per learner: 50 Minute Activity Handout (Appendix G; answer key is in Appendix H).

4. Prepare to display or print the Seismic Hazard Maps, ideally in color (Appendix I).

5. Confirm that learners can access the GPS Velocity Viewer tool.
   OPTIONAL: If you don't have computers or internet, print and copy (1 per pair/group) maps from the GPS Velocity Viewer tool are available in Appendix J. Ideally, it would be easier to differentiate map features if color copies were used; however, black and white copies will work.

6. Part C: Familiarize yourself with the geoscience roles by watching the following:
   - Article: What is a Seismologist?
   - Video: Seismology (5.31)
   - Article: What is a Volcanologist?
   - Article Information About Volcanologists
   - Video: Do You Call Yourself a Geodesist? (3:47)
   - Video: Do You Call Yourself a Geodesist? Extended Version (6:28)

7. Part D. Familiarize yourself with the ShakeAlert Earthquake Early Warning System and its activities within it using the following resources:
   - Article: How Do I Sign Up for the ShakeAlert Earthquake Early Warning System?
   - Video: Earthquake! Steps to Take When it Strikes (3:03)

   As time allows, show and discuss:
   - Video: Preparedness Journey (2.02)
   - Guide: "Prepare in a Year" (pdf)

## DIRECTIONS FOR LEADING THE ACTIVITY

1. Tell learners they will be completing a handout in a group and individually.

2. Provide learners with the 50 Minute Activity Handout.

### PART A: TECTONIC MOVEMENT AND VELOCITY VECTORS (~20 minutes)

1. Complete the **20 Minute Activity**. Give learners the 50 minute handout to fill in instead of the 20 minute handout; learners complete Part A of the 50 minute handout.

## PART B. USING THE GPS VELOCITY VIEWER (~ 10 minutes)

**1** Introduce learners to the GPS Velocity Viewer or have users watch the short video How to Use the GPS Velocity Viewer (4.10)

**2** Direct learners to open the GPS Velocity Viewer. Depending on your instructional environment, guide learners through the following steps or have them work independently through Part B.

**3** As they are doing this, project the map in Appendix D: Transform Boundary—San Andreas Fault in California.

**4** Direct learners to answer Question 7 in Part B of the Activity Handout.

- **a.** Direct learners to find the scale on the map
- **b.** Direct learners to find the longest vector on the map, and circle it. Determine the direction the vector is pointing and measure its length. Though velocity vectors are measured in mm/yr, the length of the chosen vector and vector scale bar is measured in mm.
- **c.** Direct learners to input their measurements into the speed formula to determine the speed of the plate.

**5** Direct learners to answer Question 8.
HINT: They can use what they learned in Part A to help them.

**6** Part A will also help them answer Question 9.

**7** Direct learners to read or read with them, the short "NOTE" paragraph after Question 9.

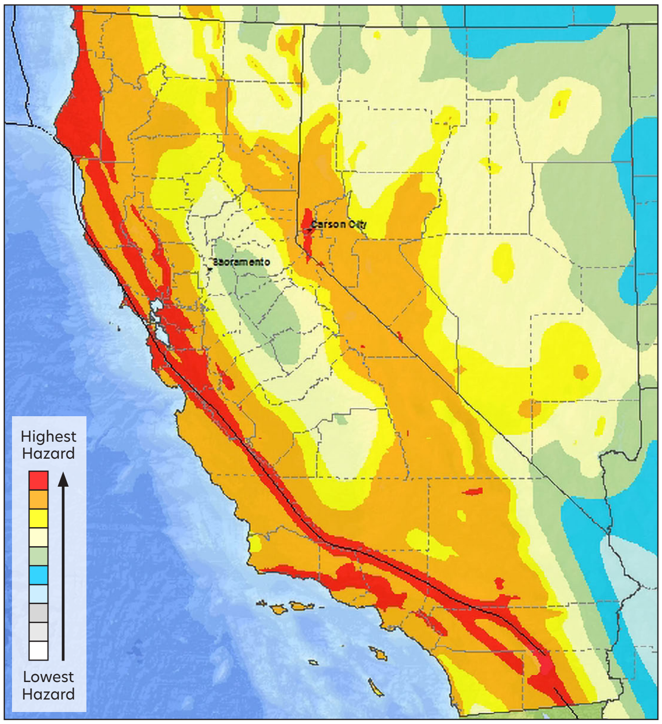
- **a.** Direct learners to use the GPS Velocity Viewer as follows or distribute hard copy maps (Appendix D).
  - Select
    - GNSS DATA SOURCE: N. America, NAM14, NSF GAGE
    - DISPLAY VECTORS: Make sure is checked
    - VECTOR COLOR: Blue
    - VECTOR LENGTH (SCALING): 1x
    - HOW MANY MARKERS DISPLAYED: Show one in twenty
    - MORE TYPES OF DATA: Display plate boundaries
  - Click "Draw Map"
  - Direct learners to zoom into the area they circled in Question 8.
  - Direct learners to answer Question 10.
  - Ask learners to share their answers to Question 10 to explain how the evidence from the Velocity Viewer demonstrates the plate boundary type.

**8** Display the California maps with the seismic hazard map next to the ground motion vector map (as shown in **Figure 8**; larger maps available in Appendix I), or hand out copies of the two maps.

- **a.** Briefly explain that the hazard map shows areas with the highest and lowest hazard potential for California. Point out the key to learners to help them interpret the map.
- **b.** Ask learners to compare the hazard map with the ground motion vector map.
- **c.** Ask: "What do you notice about where you find the greatest seismic hazard potential and the vectors?"

  ***ANSWERS MAY VARY:*** *Learners should arrive at the conclusion that the greatest earthquake hazard potential is in regions where vector length or direction change rapidly.*
- **d.** Direct learners to answer Question 11.

**California Seismic Hazard Map**




**California Ground Motion Vector Map**

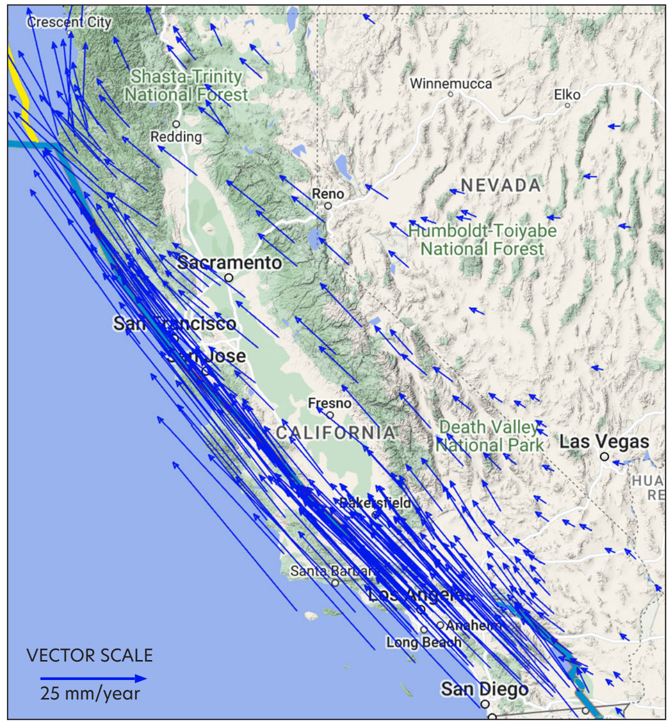



FIGURE 8. Seismic hazard map (left) and ground motion vector map (right) for California (Appendix I).

## PART C. EXPLORING GROUND MOTION, EARTHQUAKES, AND VOLCANOES JIGSAW (~15 minutes)

**1** Explain to learners that they will be completing Part C of the handout.

**2** Group learners in teams of 3.

**a.** Assign each member of each team a geoscience role.

**b.** Describe what each career does.

SEISMOLOGIST

- Article: What is a Seismologist?
- Video: Seismology (5.31)

VOLCANOLOGIST

- Article: What is a Volcanologist?
- Article Information About Volcanologists

GEODESIST

- Video: Do You Call Yourself a Geodesist? (3:47)
- Video: Do You Call Yourself a Geodesist? Extended Version (6:28)

**c.** OPTIONAL: Provide opportunity to research these roles further or explore careers **within** each role. (NOTE: This will add time to this activity.)

**3** Direct learners to gather in like-role groups (e.g., seismologists, volcanologists, and geodesists). They will be answering questions 12-13a with this group. NOTE: Within each like-role group, learners may work in pairs or smaller groups.

**a.** Make sure you have enough maps for each group if you are providing hard copies.

**b.** Point out that each group only answers the questions listed under their role on the handout. They check the boxes with the correct answers and write any observations/notes that they think will help them understand what they are seeing.

**c.** Learners also sketch data they observed for their role only (either earthquakes, volcanoes, or vectors).

**d.** Give them 5-10 minutes to complete the "Prepare your Map" and answer Question 12 in Part C of the handout. NOTE TO INSTRUCTORS: Help learners with the concept of cluster and grouping. Some groupings are tight, such as the earthquakes along the San Andreas fault, while other groupings are loose, for example, the volcanoes spread throughout the continental interior.

**4** Direct learners to go back to their original team of 3 to compare and share the data they gathered with the rest of their team, including notes on the map recorded on their handout. Point out the colors of the plate boundary lines on the velocity viewer and on the handout map.

**5** Direct learners to go to the GPS Velocity Viewer tool or the previously distributed maps.

**a.** Have the learners continue to work in their teams on "Prepare a Combined Map" in Part C of the Handout. If the terrain is not displaying, have learners hover over the word **Map** in the upper left corner of the map and check that terrain is selected.

- Make sure your GNSS Data source selected is N. America, NAM14, NSF GAGE.
- Check the "Display vectors" box.
- Under "More types of data" select "Display volcanic centers," "Display plate boundaries," and "Display earthquakes."
- Select "Show one in twenty" under "How many markers displayed."
- Click on "Draw Map."
- Move the map to show Washington, Oregon, and California.

**b.** Refer to this map to answer Questions 15-17.

**6** Direct learners to refine their map using the GPS Velocity Viewer tool (or use the maps in Appendix J).

**a.** Keep the same setting as Step 5 above, except under "How many markers displayed," select "Show half."

**b.** Click on "Draw Map."

**c.** Direct learners to answer Question 18.

**d.** For younger learners, you may need to lead them through this question to include specific examples by asking guided questions. (For example, remind learners that GPS does not work under water, so there are no data displayed over the ocean. Look at the locations of the earthquakes on land—how do the vectors, showing the ground motions, change speed or direction near those earthquakes? Now focus on the volcanoes and the vectors—what patterns, if any, do you notice?)

### WRITING A CLAIM, EVIDENCE, REASONING STATEMENT

Some learners may be confused on how to write a Claim, Evidence, Reasoning statement. Ideas for helping them through it:

a. Have them answer questions with a complete sentence for each part. For example:

- Claim: Which region has the most seismic hazard?
- Evidence: Which regions on both maps show the most seismic activity? and What is it about the maps that shows you these regions have the most activity?
- Reasoning: What is it about that region makes it have the most activity?

b. Have them start with Evidence so they can see a pattern and then, work on the Claim.

**7** Display the Seismic Hazard Map for Western United States (Appendix I).

**8** Direct learners to compare the map they created with the Seismic Hazard Map for Western United States (Appendix I) and answer Question 19.

**9** Wrap up the project by exploring the Alaska Ground Motion Vector Map (found in Appendix D). Check for learner understanding with the formative assessment questions below.

**a.** Explain to learners that by studying velocity vectors and the patterns they show, we can infer how the tectonic plates move, deform, and interact. With that, we can also infer what forces accompany those interactions. This can give us an idea where the highest potential for earthquakes is throughout a region. (Refer to the image of Alaska.)

**b.** Direct learners to look at the ground motion vector map for Alaska.

- ALTERNATIVE: Show them the Seismic Hazard Map for Alaska side by side with the ground motion vector map of Alaska and map with all of the data (Appendix I). Ask learners to tell you why there is an increased seismic hazard potential on the south side of Alaska.

**c.** Direct learners to think about how they interpreted the vectors and hazards in California in Part B and the western United States in Part C. Looking at the velocity vectors for Alaska, where would the highest potential hazard be?

- Allow learners a few moments to answer and ask them to give you the reasons why they think this.

  ***ANSWERS MAY VARY:*** *This region has a convergent boundary (subduction zone). One way we can identify convergence is that vectors are pointing toward each other (see vectors on land vs. ones that are along the coast). Compressive forces accompany convergence. Increased seismic hazard is associated with higher velocities (notice the long vector lengths in the coastal regions).*

## PART D. SHAKEALERT (~10 minutes)

**1** Read through the short paragraph at the beginning of Part D on the handout as an introduction to the ShakeAlert Earthquake Early Warning System.

**2** Explain to learners that cell phones in the region will automatically receive ShakeAlert-powered alerts through the wireless emergency alerts (WEA) app built into their phones.

**a.** Ask: Why might this technology be incredibly useful?

***ANSWER:*** *It can give enough time for you to take protective actions, such as drop, cover, and hold on. (Refer to https://www.shakealert.org/ for more information.)*

**3** Additionally, they can download the ShakeAlert app from the website: How do I Sign Up for the ShakeAlert Earthquake Early Warning System? Reiterate that they, their families, and their friends might live or visit California, Oregon, or Washington in the future, thus it is important to be familiar with the ShakeAlert system.

**4** Show the video: Earthquake! Steps to Take When it Strikes (3:03)

As time allows:

**5** Show video: Preparedness Journey (2.02)

**6** Introduce the "Prepare in a Year" Guide (you may only have time to show it to them).

**a.** Direct learners to the Communications Plan page in the guide.

- Ask who would be their Out-of-Area Contact OR direct them to ask their parents (Question 20 in the Activity Handout).
- What communication sources can they use? (Question 21 in the Activity Handout.)

**b.** Direct learners to the Water page in the guide.

- Answer Questions 22 and 23 in the Activity Handout.

**c.** Direct learners to the Grab and Go Kit page in the guide and answer Question 24 in the Activity Handout. Make sure you confirm with them that they are:

- Adding a check for the items they already have.
- Circling what they need.
- Adding a question mark for what they need to ask their parents about.

# APPENDIX A. VOCABULARY

**Asthenosphere:** The ductile part of Earth just below the lithosphere. It is about 180 km thick and is found 100–250 km (60–150 mi) below Earth's surface. The asthenosphere yields to persistent stresses more than the rigid crust or the core.

**Compression:** When stress is applied to an area, there is a decrease in volume and an increase in potential energy. Watch the animation Faults, Plate Boundaries, & 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. Watch the animation Plate Boundary: Convergent Margin.

**Crust:** The outermost major layer of Earth, ranging from about 10 to 65 km in thickness worldwide. Oceanic crust is thinnest; continental crust is thickest. Often mistaken for comprising the tectonic (lithospheric) plate. Watch the animation Take 2: Plate vs. Crust.

**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."

**Divergent Boundary**: A place where two tectonic plates are moving away from each other. Watch the animation Plate Boundary: Divergent. See also Convergent Boundary.

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

**Geodesist:** A scientist who measures Earth's shape, size, gravity, motion, and coordinates of any point on it. They also study the gravitational field, Earth's orientation in space, and how the changes through time.

**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.

**Lithosphere:** The solid, rocky outer part of Earth, composed of the crust and the solid upper portion of the mantle. On average, the lithosphere is 100 km (60 miles) thick. The lithosphere below the crust is brittle enough at some locations to produce earthquakes by faulting, such as within a subducted oceanic plate.

**Plate Boundary:** The tectonically active contact between tectonic plates can be convergent, divergent, and transform.

**Plate Tectonics.** The theory supported by a wide range of evidence that considers Earth's lithosphere to broken up into several large, relatively rigid plates that move relative to one another. Slip on faults that define the plate boundaries commonly results in earthquakes. Watch the animations A Brief History of Plate Tectonics Theory and What are the Forces that Drive Plate Tectonics.

**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.

**Seismic Hazard:** Includes natural hazards associated with earthquakes that have potential to cause harm and affect the normal activities of people such as surface faulting, ground shaking, landslides, liquefaction, tsunamis, and seiches. See Seismic Risk. Watch the animation Take 2: Hazard vs. Risk

**Seismic Risk:** The probability (chance) that humans will incur loss or harm if someone or something that is vulnerable is exposed to a seismic hazard.

**Seismologist:** A scientist who studies earthquakes, seismic waves, and their environmental effects. They use data from seismographs and other instruments to understand the causes of earthquakes, forecast future seismic activity, and assess the potential hazards of different areas. The study of earthquakes and seismic waves provided evidence for plate tectonics and Earth's internal structure and composition.

**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 and object moves 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 the animation How Stress is Related to Plate Boundaries.

**Tectonic Plates:** The large, relatively thin, rigid slabs that move relative to one another on the outer surface of Earth. They care composed of the solid section of Earth's crust and uppermost mantle (lithosphere) that moves over the deeper mantle. Also known as lithospheric plate or plate. Watch the animation Take 2: Plate vs. Crust.

**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, usually used for an object that cannot be expressed by a single number. Velocity, force, and acceleration are examples of vectors. When describing plate motion, vectors are used to describe its speed and direction of motion.

**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.

**Volcanologist:** A scientist who studies volcanoes: how and why they erupt, their behavior, and all the formations and processes that are related to them.

# APPENDIX B. INSTRUCTOR BACKGROUND

## GEODESY, GPS, AND INTEGRATION INTO THE SHAKEALERT EARTHQUAKE EARLY WARNING SYSTEM

Geodesy is the study of Earth's shape, size, motion, orientation in space, and gravity field, and how these properties change over time. This is one of the oldest science disciplines, having been a primary focus of early Greek scientists. To learn more, view this short video produced by NASA, outlining the history of geodesy: NASA's Brief History of Geodesy (2.25).

Global Positioning System (GPS) satellites (the U.S. portion of the Global Navigation Satellite System, or GNSS) send electromagnetic signals that are received by devices on Earth and used to determine position. Simple GPS "receivers" such as those in smart phones give general positions. Research-grade receivers are anchored to the ground surface to determine precise positions on Earth's surface and measure how those positions move over time. If the ground moves, the GPS moves with the ground and records that movement. 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 data processing is complicated. Background noise, tidal forces moving the ground up and down, seasonal water and snow loading, post-glacial rebound, and other non-tectonic motions hidden in the "raw" data collected from the GPS are removed as part of the data processing so that the dominant motion in the data are from tectonic motions. The data from GPS are often represented as velocities in three directions, up-down, north-south, and east-west, allowing the calculation of an average annual velocity.

GPS data are now combined with data collected by seismometers to more accurately size up big earthquakes as part of the ShakeAlert Earthquake Early Warning System. Operated by the United States Geological Survey (USGS), the system is operational in California, Oregon, and Washington. ShakeAlert is not earthquake prediction; a shake alert message issued by the USGS indicates that an earthquake has begun and shaking is imminent. ShakeAlert-powered alerts are delivered to cell phones and trigger automated actions that could protect people before strong shaking arrives, such as slowing trains and opening firehouse doors. As soon as you receive an alert or feel shaking, take action to protect yourself. The best way to do so is to drop, cover, and hold on.

Learn more about the ShakeAlert System and how to prepare:

- Using GPS to Enhance the ShakeAlert Earthquake Early Warning System | Overview (5:52)
- ShakeAlert Gets a Boost with GPS Technology | What You Need to Know (2:17)
- How GPS Found Its Way into Earthquake Early Warning (5:42)

## VISUALIZING GPS DATA ON MAPS

When the GPS data are displayed on maps, the horizontal velocities are added together to create a single vector. Vectors show key pieces of information about the magnitude and direction of movement. The tail of the vector indicates the location of the GPS instrument. The direction of movement is shown by the arrow point. The speed of movement is shown by the length of the vector. The longer the vector, the faster the ground and GPS move.

Learners may confuse the length of the vector with total distance moved or strength of an earthquake; practice with interpreting the vectors with units (mm/year) and examples. If you have younger learners, it might help to demonstrate the measuring of one of the vectors and move a model of a GPS in millimeters—while explaining the motion is fast forwarded—they are seeing in seconds what it takes a year in real motion. Multiply by 100 years in that spot to make the movement more obvious.

## ABOUT MEASURING GROUND DEFORMATION WITH GPS

Some parts of the land can move more quickly or in different directions from nearby regions within a tectonic plate. Typically, the land closer to a tectonic plate boundary, such as a subduction zone or a transform boundary, will deform more than the land in the middle of the plate.

GPS stations are installed over much of the western United States to monitor the ground's fast and slow motions. Land movement is measured by precise communication from GPS satellites and other Global Navigation Satellite Systems (GNSS) to GPS receiving stations permanently anchored into rock or deep soil.

Using GPS, scientists can detect compressional movement at GPS stations over 200 miles inland from the Cascadia subduction zone in Yakima, Washington, and Redmond, Oregon. In the Basin & Range region, GPS detects the prolonged extension of the region, from infinitesimal movement in eastern Utah to movements of approximately 3 millimeters per year in mid-Nevada to 6.5 millimeters per year movement at the Nevada-California border. Compared to the rates of motion of ~44 mm/year at the California coast, ~20 mm/yr near the San Andreas fault, and 10 mm/year west of the Sierra Nevada, the extension measured in the Basin & Range might seem inconsequential. However, the evidence of the constant motion can be observed in the presence of nearly parallel mountain ranges and valleys in the landscape of Nevada and Utah. Now, with permanently installed GPS stations, scientists can continuously measure this motion and help pinpoint the locations of earthquakes in a region with few seismic sensors.

To learn more about the various aspects of GPS, please see the following resources:

- NASA > How Does GPS Work?:
- NOAA Tutorial on Global Positioning

## REFERENCE FRAMES

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.

The animation Measuring Plate Motions with GPS provides an overall explanation of reference frames to help interpret plate motions.

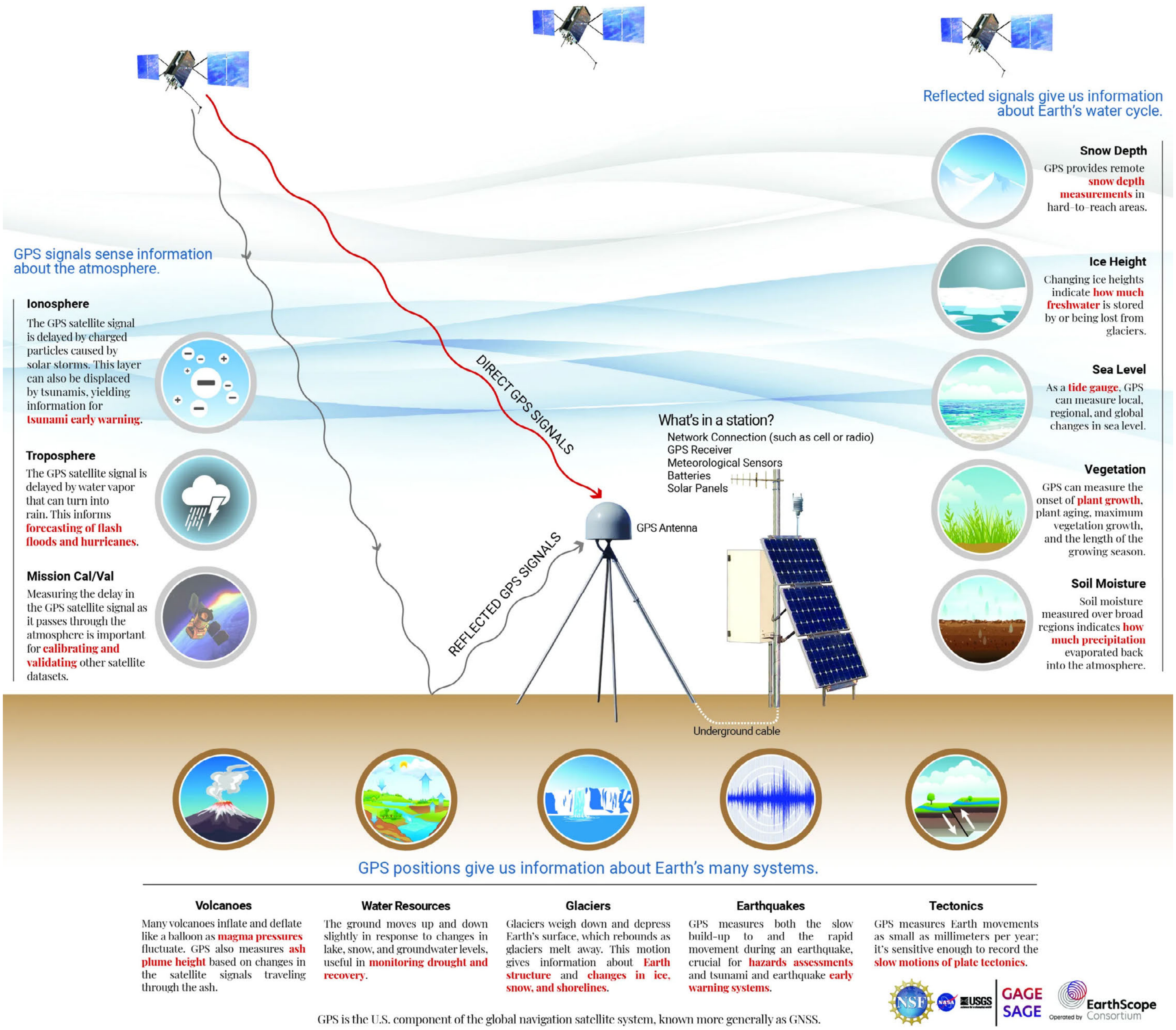
For activities where we are studying North American tectonics, we use the mid-continent North America as our fixed region because the stations are not moving compared to each other and are non-deforming. Using mid-continent North America as a fixed region removes the average background tectonic motion 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, or diverging). By studying the GPS motions in different areas, we can learn much about how strike-slip, convergent, and divergent regions deform and the associated earthquake hazards.

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.

Read more on the web page about how reference frames are used in the GPS Velocity Viewer.

## WHAT CAN GPS TELL US ABOUT EARTH

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



## ABOUT MODELS AND DEMONSTRATIONS

Models are tools for sense-making to understand our world. There are 2 types of models to describe phenomena. The first type, mental models, also called cognitive models, are the understandings and beliefs about objects and processes that we hold. Mental models provide a tool for thinking about, making predictions, and making sense of a process or phenomena.

The second type of models are expressed models, also called conceptual models. Conceptual models are "explicit representations that are in some ways analogous to the phenomena they represent" (NASEM, 2012*). They are effective tools for illustrating complex concepts. All models (e.g., physical models, mechanical models, mathematical models, and computer simulations) have limitations compared to the real-world phenomena they depict. Mechanical models are used to represent natural processes that cannot be directly observed in the instructional setting.

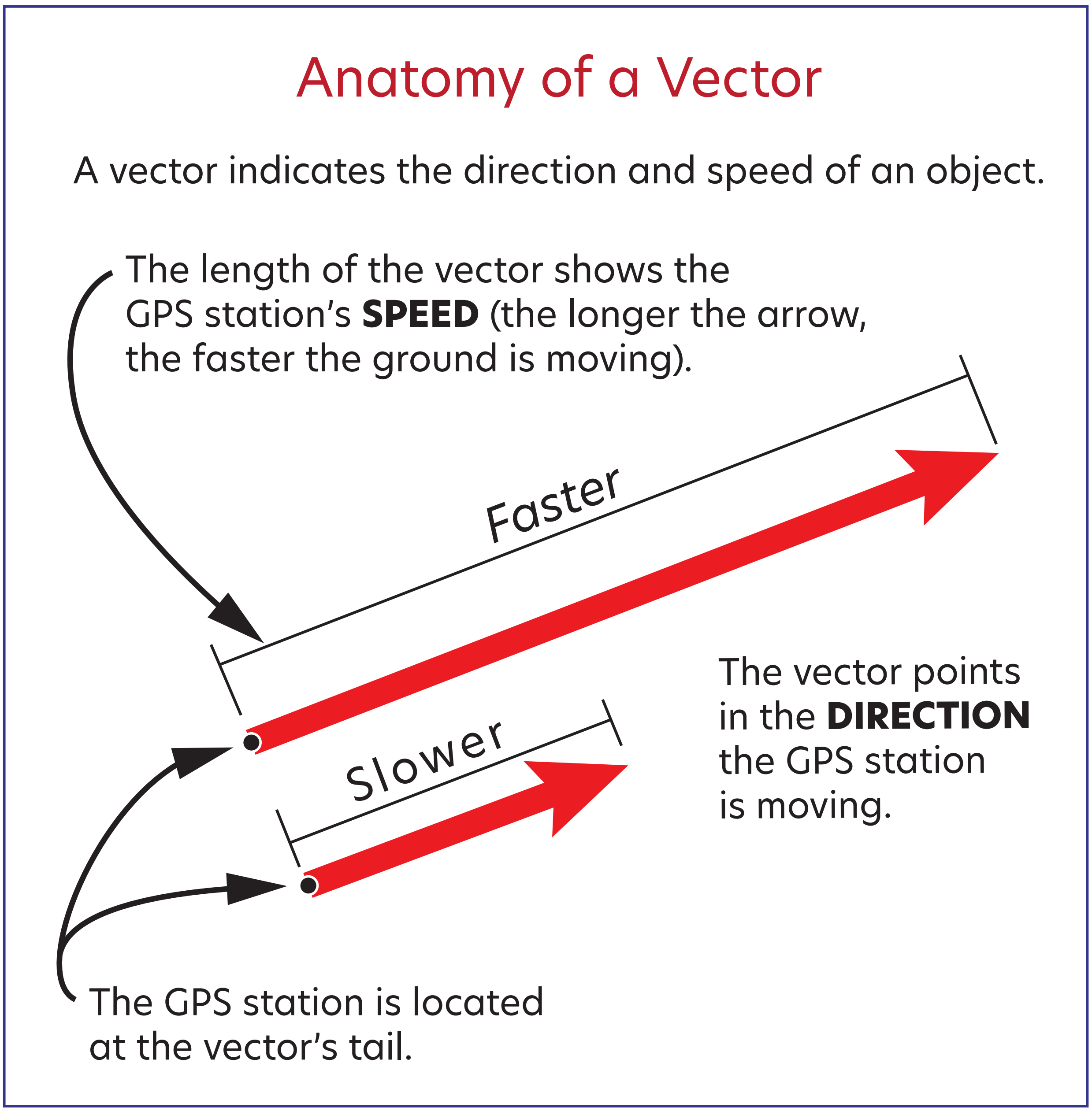
It is important for learners to explicitly map similarities and differences between the model and the actual concept to avoid misconceptions or confusion. To make these differences explicit, have learners create a T-chart and title the columns "Similarities" and "Differences" or "Like" and "Unlike" to record the comparisons. This process helps clarify how models serve as representations rather than exact replicas of natural processes.

*NASEM (National Academies of Sciences, Engineering, and Medicine). 2012. *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*. National Academies Press, Washington, DC, https://doi.org/10.17226/13165.

# APPENDIX C. 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 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.

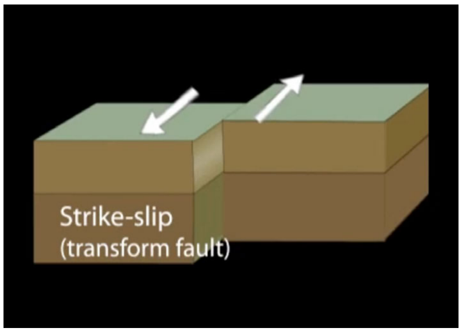
The data from GPS are often represented as velocities in three directions, up-down, north-south, and east-west, allowing calculation of an average annual velocity. When the data are displayed on maps, the horizontal velocities are added to create a single vector. A vector represents the speed (length 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.

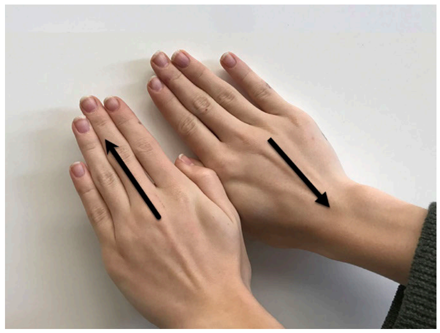


# APPENDIX D. PLATE TECTONIC MOTION WITH HAND MOVEMENTS & GROUND MOTION VECTOR MAPS

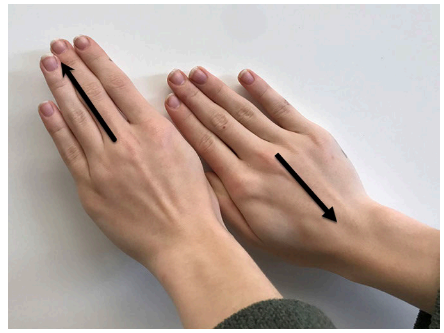
## MODELING TECTONIC MOTION WITH HAND MOVEMENTS

**TRANSFORM BOUNDARY**



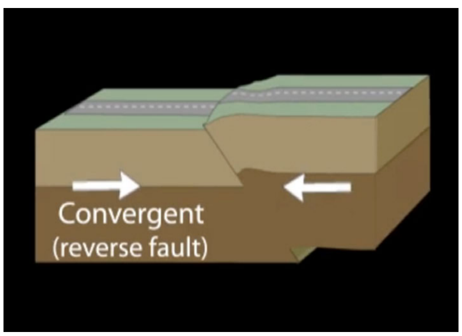



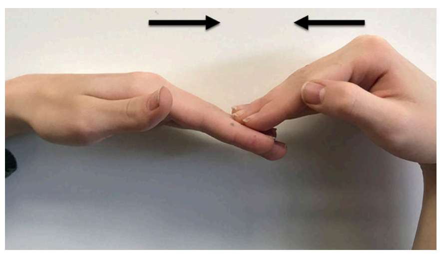
**Starting Position**



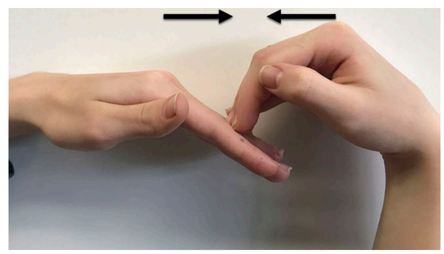
**During Movement**
The left hand moves forward and the right hand moves backward.

**CONVERGENT BOUNDARY**



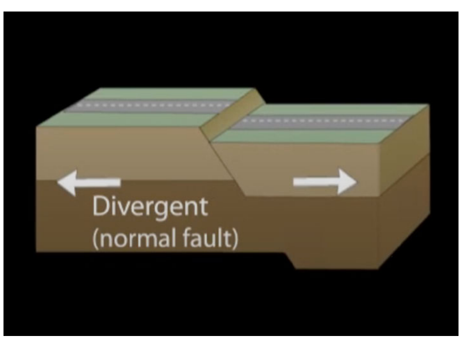



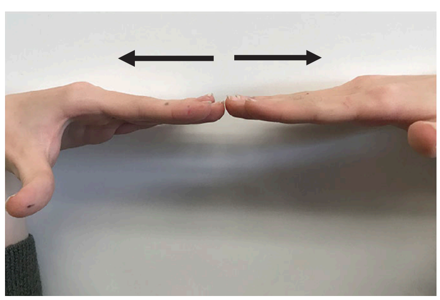
**Starting Position**



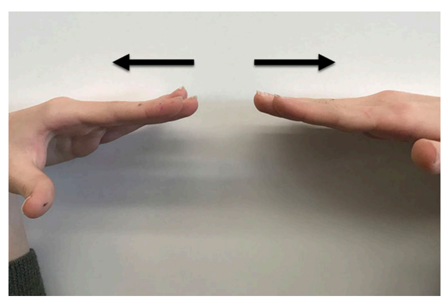
**During Movement**
The left and right hands move toward each other.

**DIVERGENT BOUNDARY**



**Starting Position**

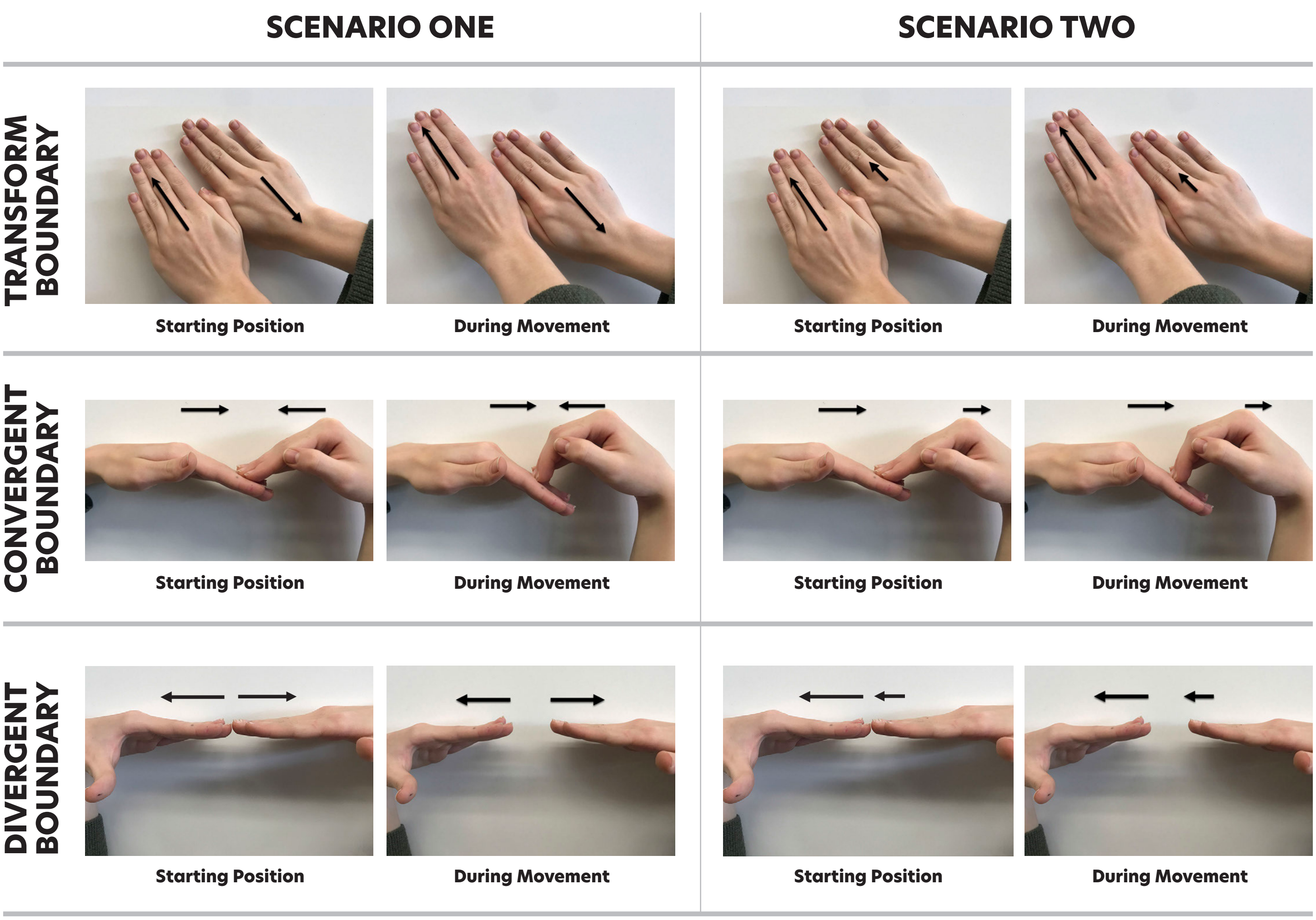


**During Movement**
The left and right hands move away from each other.

## THE SUBTLETIES OF PLATE TECTONIC MOTION

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. Note that not every plate boundary is just one type of motion. For example, a transform boundary could also include some convergent motion (as seen in Southern California, northeast of Los Angeles).

In the scenarios of plate boundary interaction shown below, note the direction of the two plates (shown by the direction of the vectors over the hands).



## SPECIFIC EXAMPLES OF PLATE TECTONIC MOTION

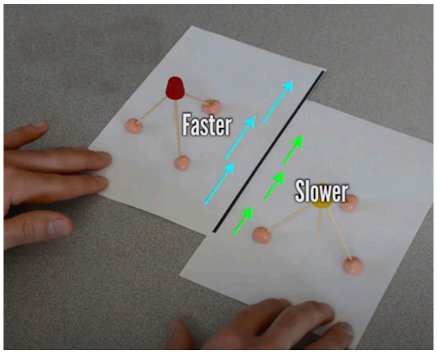
In the following examples of plate boundary interaction, note two details: the direction of the two plates (shown by the direction of the vectors) and the speed of the plates (shown as the length of the vectors).


### TRANSFORM BOUNDARY

**San Andreas Fault in California**

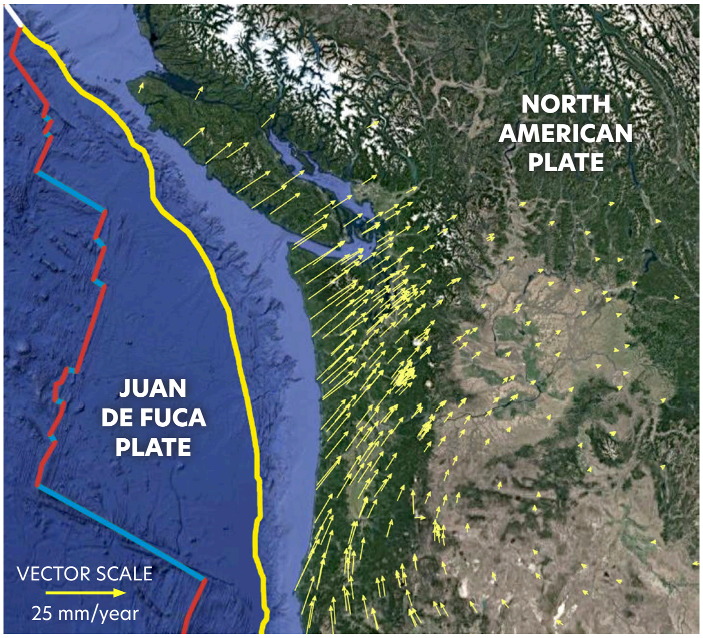
In the map the boundary between the Pacific plate and the North American plate is indicated by the red line. Note that the vectors west of the fault are longer, and the vectors east of the fault are shorter and decrease in length even more as you move further east.

The edge of the North American plate is being dragged along by the Pacific plate when the plates are locked together between earthquakes.




**Starting Position**

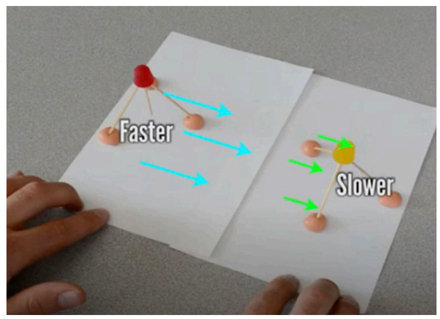
**During Movement**
Both hands move parallel with the left hand moving faster while the right hand moves slower.

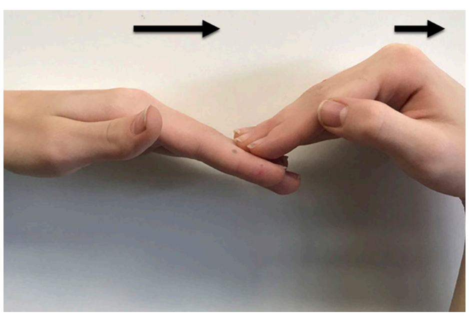



## CONVERGENT BOUNDARY

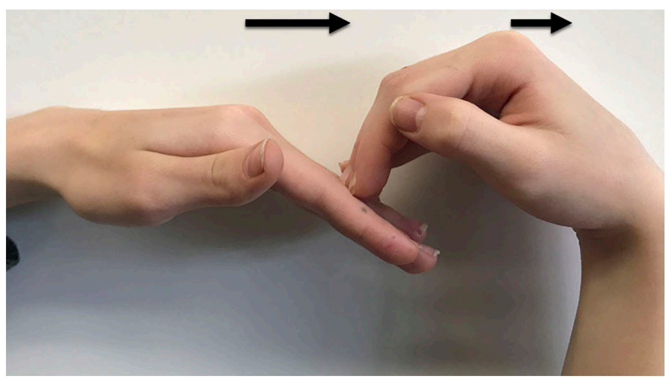
### Cascadia Fault Zone Near Oregon and Washington

In the map, the boundary between the Juan de Fuca plate and the North American plate is indicated by the blue line. The Juan de Fuca plate is subducting under the North American plate. Note that the vectors decrease in length from west to east—indicating that the region is being pushed inland.



**Starting Position**



**During Movement**

Both hands move to in the same direction. The left hand (subducting plate) is moving toward the right hand (overriding plate) faster than the right hand is moving away. Thus, the left hand is "overtaking" or crashing into or under the right hand. While the plates are locked together, the right hand is being pushed inland.

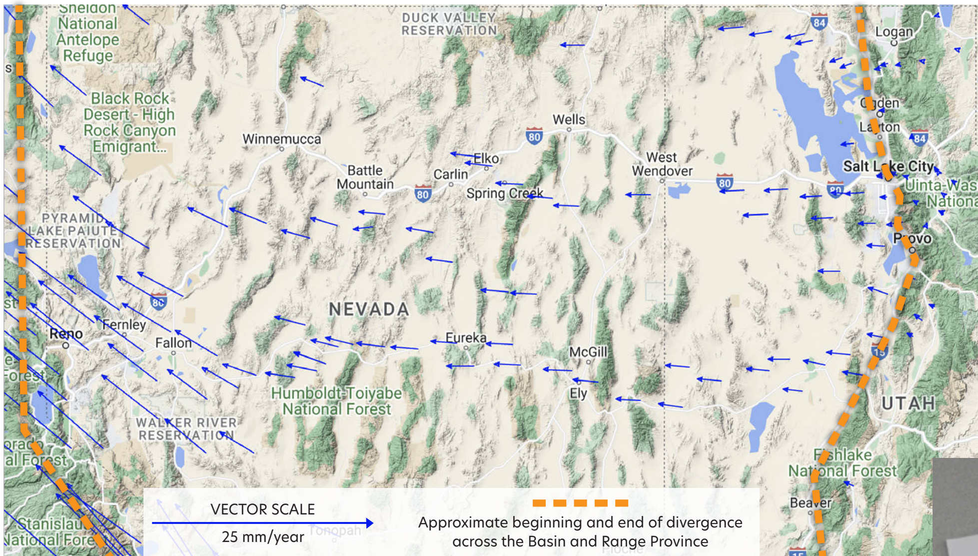
## DIVERGENT BOUNDARY

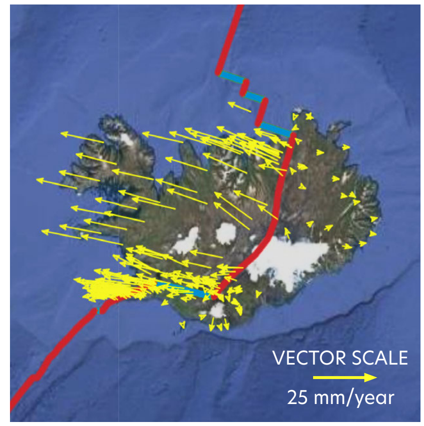
### Basin and Range

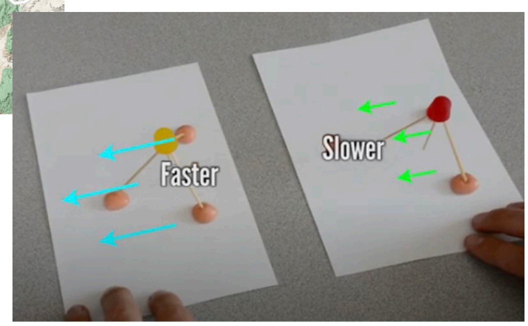
While not a divergent boundary yet, the extension of the Basin and Range region, spanning eastern Utah, through Nevada to eastern California, illustrates plate divergence. Note that the vectors increase in length from east to west—the region is pulling away from the non-moving areas further east.

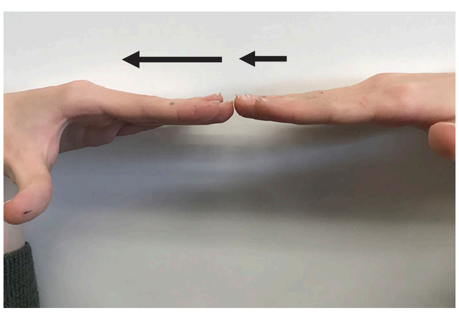
### Iceland

Note the vectors are short to the east of the boundary and longer to the west. They are also pointing away from each other.

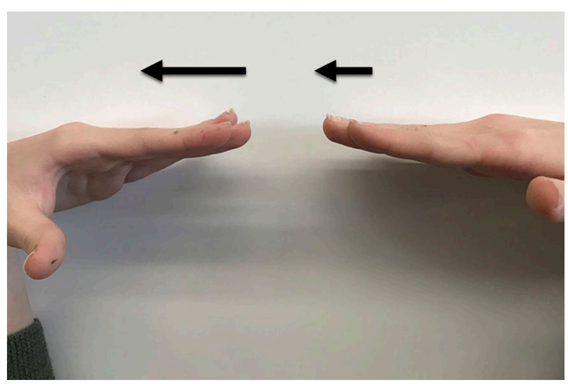


**Starting Position**



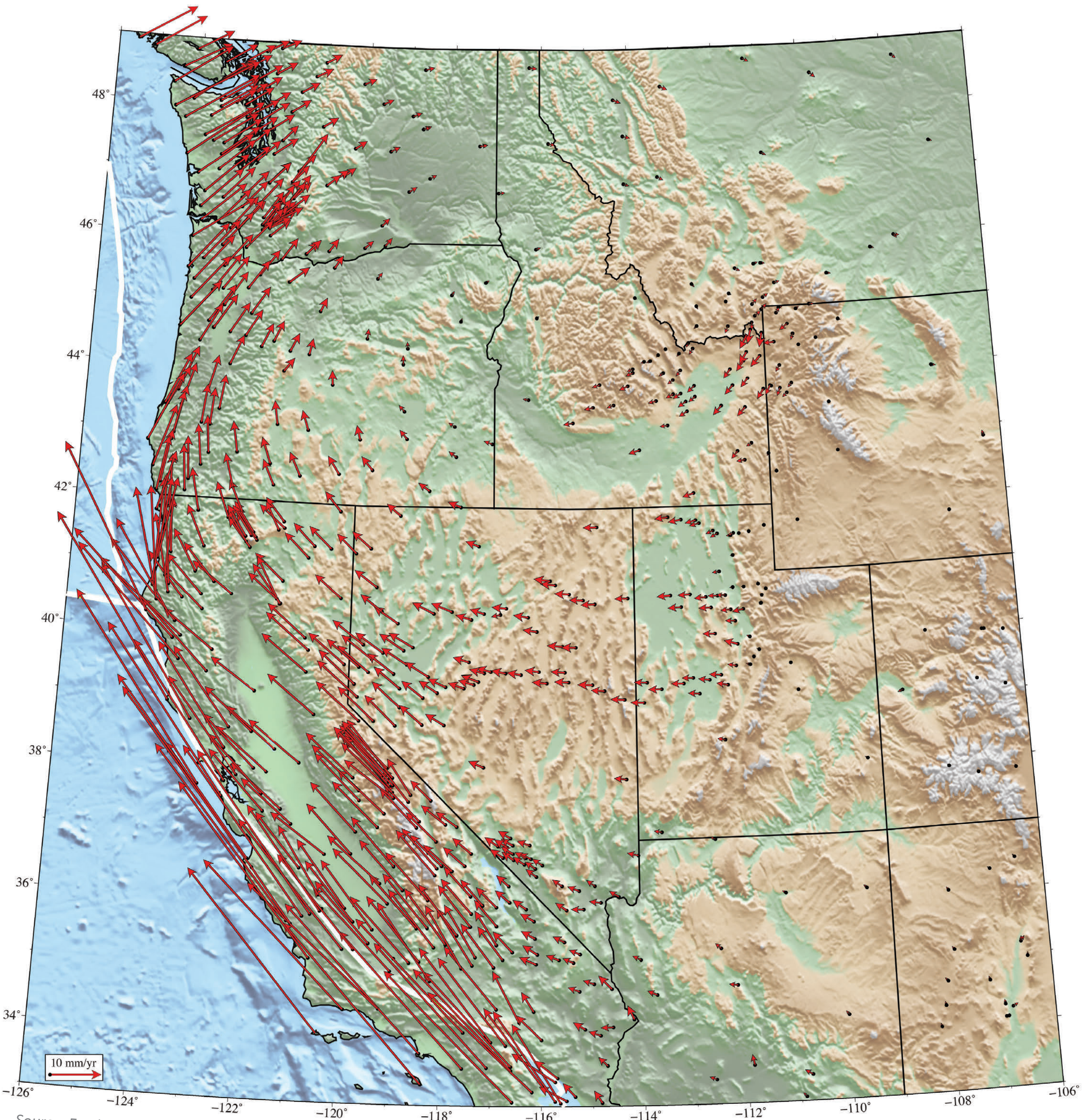
**During Movement**

Both hands move in the same direction. The left hand (plate) is moving faster AWAY from the right hand, while the right hand is moving more slowly.

## TRANSFORM BOUNDARY: SAN ANDREAS FAULT IN CALIFORNIA

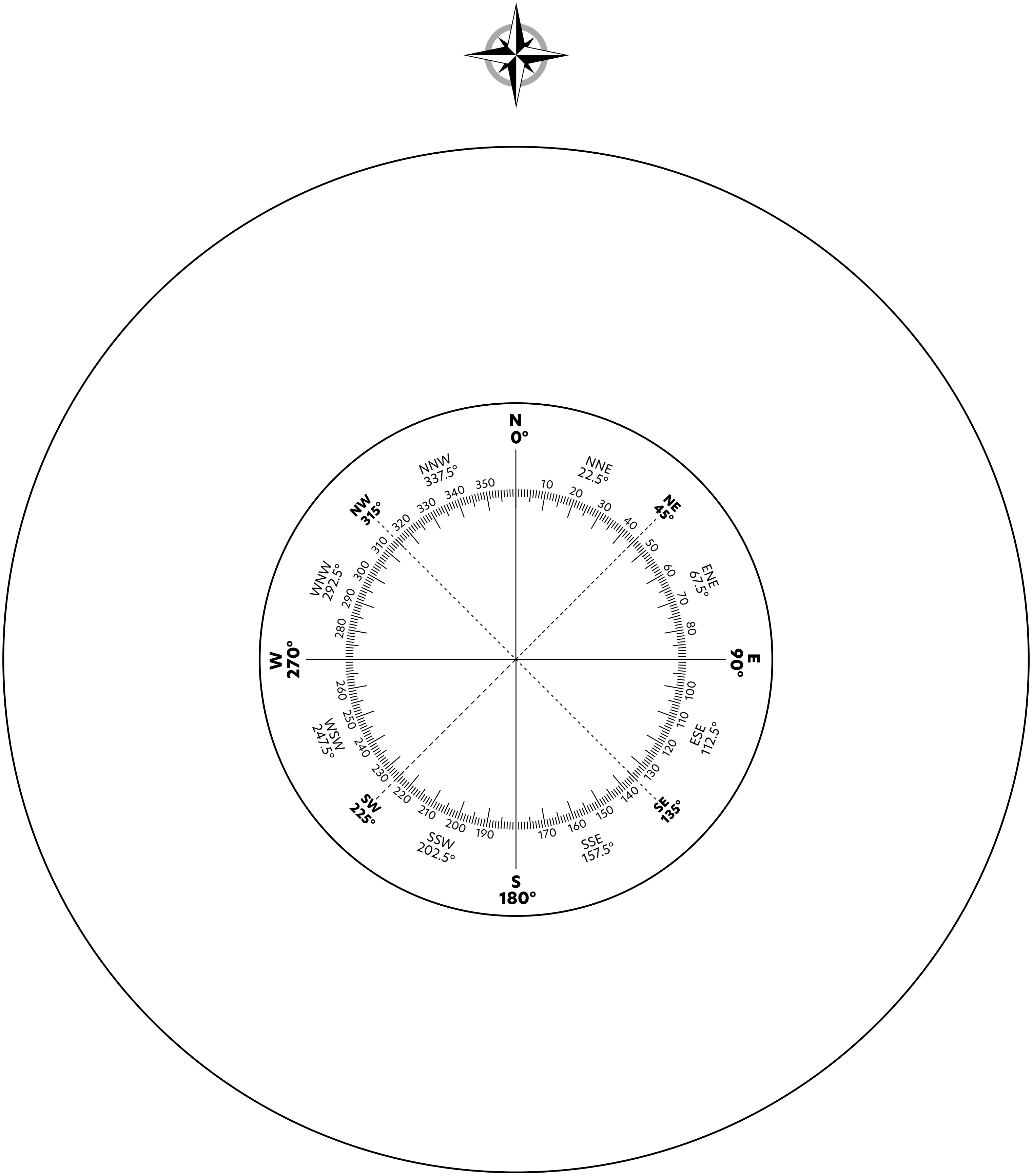

*Sources: EarthScope GPS data, USGS Plate boundaries, and Google base map*

## TECTONIC MOTIONS OF THE WESTERN UNITED STATES




Source: EarthScope Consortium

# APPENDIX E. COMPASS ROSE HANDOUT

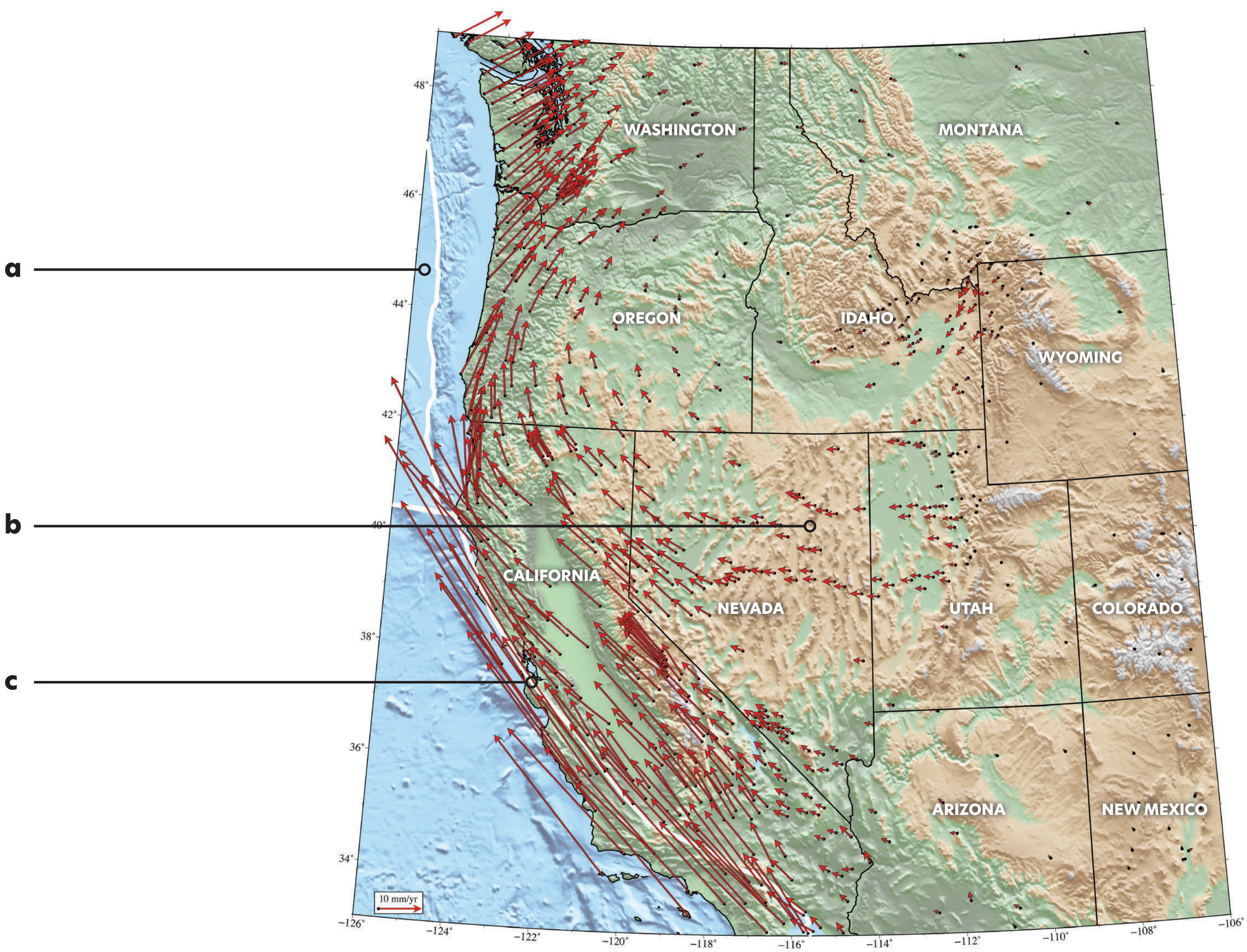


# APPENDIX F. 20 MINUTE ACTIVITY HANDOUT

## PLATES DEFORM AT THEIR BOUNDARIES

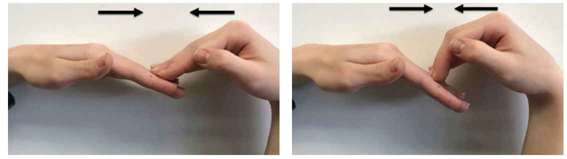
NAME: ______________________________ PERIOD: __________ DATE: ________________

**1** Refer to the printouts showing the three boundary types. Using the vectors to help, label each plate boundary type on the map below at a, b, and c.



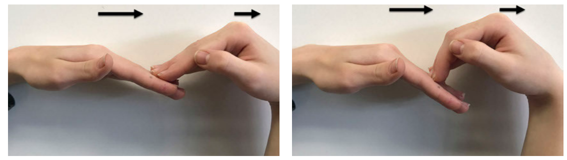
**2** Look at the map in Question 1. Circle the option on the right that matches the **convergent boundary** shown by the vectors in Oregon and Washington. If available, also refer to the printouts of the different plate boundaries.

**OPTION A**



Starting Position — During Movement

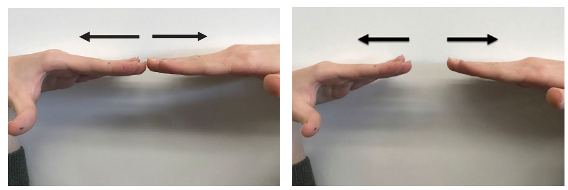
**OPTION B**



Starting Position — During Movement

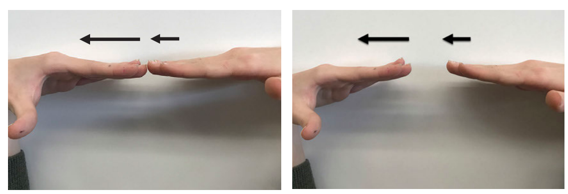
**3** Look at the map in Question 1. Circle the option on the right that matches the **divergent boundary** shown by the vectors in northern Utah and Nevada on the Basin and Range. If available, also refer to the printouts of the different plate boundaries.

**OPTION A**



Starting Position — During Movement

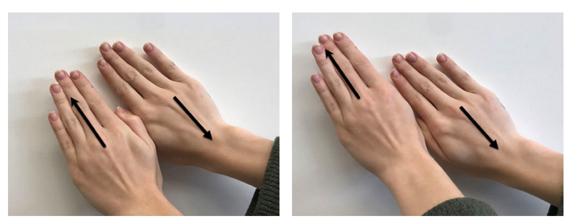
**OPTION B**



Starting Position — During Movement

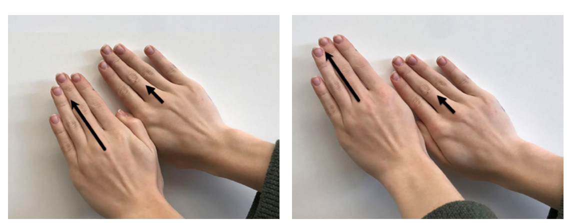
**4** Look at the map in Question 1. Circle the option on the right that matches the **transform boundary** shown by the vectors along the San Andreas fault in California. If available, also refer to the printouts of the different plate boundaries.

**OPTION A**



Starting Position — During Movement

**OPTION B**

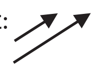


Starting Position — During Movement

**5** Compare the model to the real thing.

How are the hand movements from above **LIKE** what you see on ground motion vector maps?

How are the hand movements from above **DIFFERENT** from what you see on ground motion vector maps?

**6** Place Partner A's compass rose next to Partner B's compass rose. If you placed the first vectors you drew side-by-side, which one of the examples from Questions 2, 3, or 4 is the type of boundary that you and your partner demonstrated? (hint:  )

# APPENDIX G. 50 MINUTE ACTIVITY HANDOUT

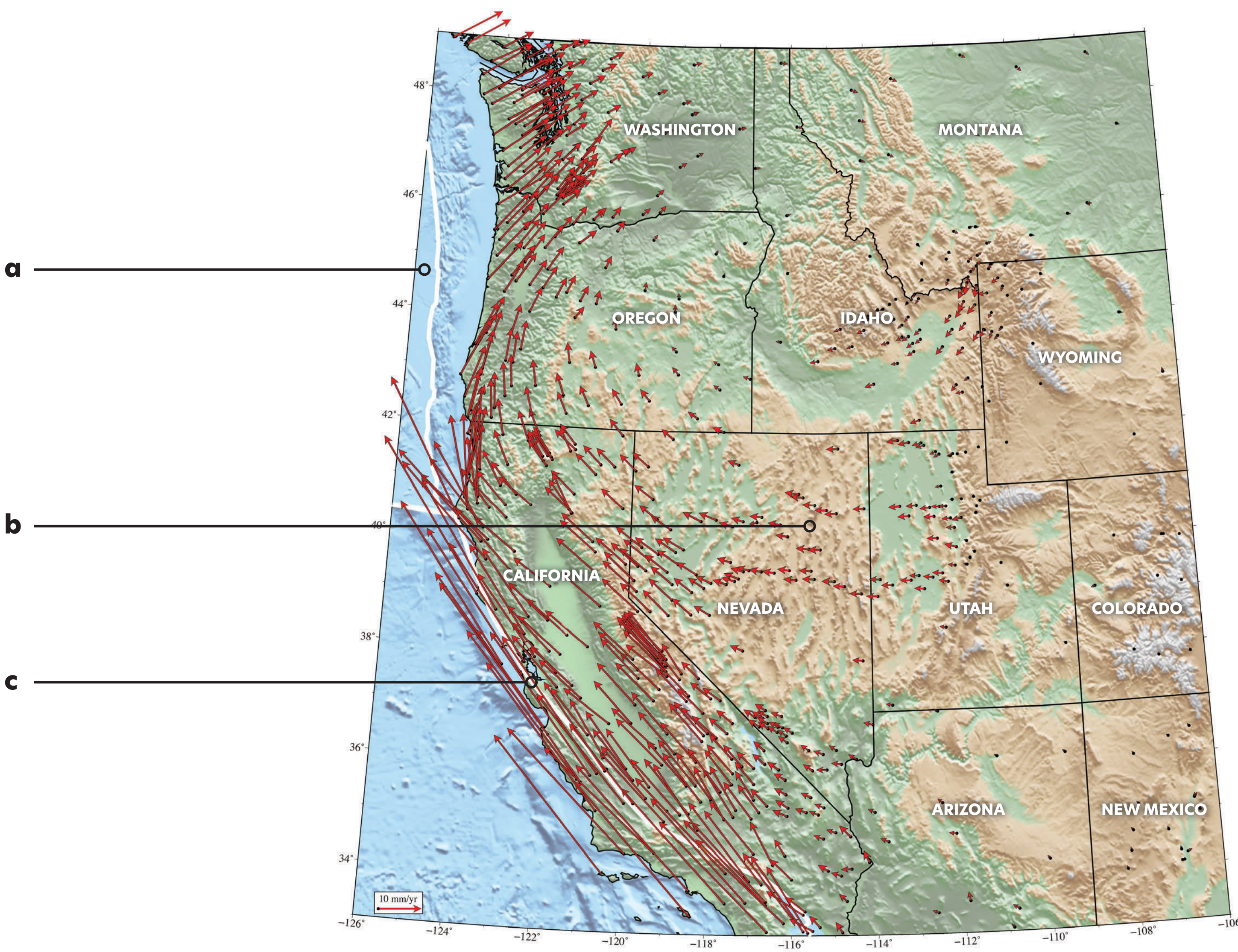
## PLATES DEFORM AT THEIR BOUNDARIES

NAME: ________________________________________ PERIOD: ___________ DATE: ____________________

How do we know tectonic plates are moving? In this activity, we will explore evidence using current Global Positioning Systems (GPS) data to see how the land beneath your feet is moving and how earthquakes and volcanoes are related.

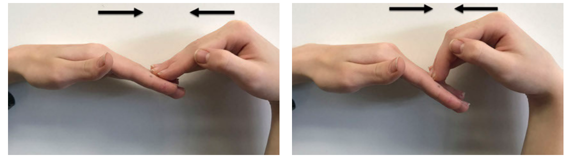
### PART A: TECTONIC MOVEMENT AND VELOCITY VECTORS

**1** Refer to the printouts showing the three boundary types. Using the vectors to help, label each plate boundary type on the map below at a, b, and c.



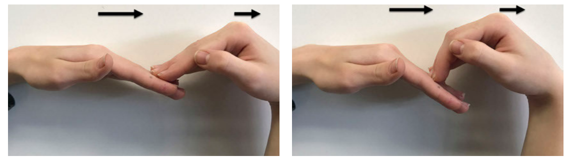
**2** Look at the map in Question 1. Circle the option on the right that matches the **convergent boundary** shown by the vectors in Oregon and Washington. If available, also refer to the printouts of the different plate boundaries.

**OPTION A**



Starting Position | During Movement

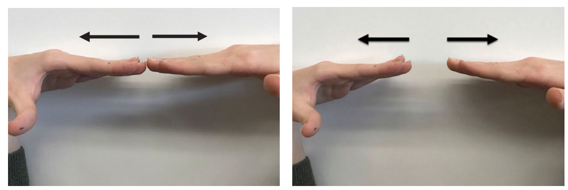
**OPTION B**



Starting Position | During Movement

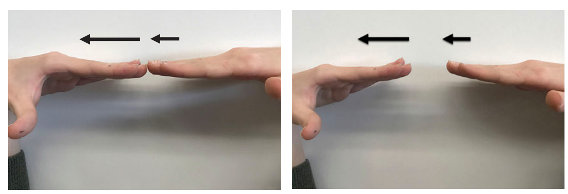
**3** Look at the map in Question 1. Circle the option on the right that matches the **divergent boundary** shown by the vectors in northern Utah and Nevada on the Basin and Range. If available, also refer to the printouts of the different plate boundaries.

**OPTION A**



Starting Position | During Movement

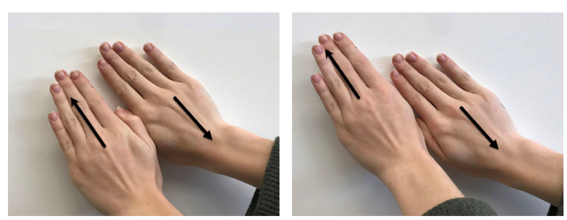
**OPTION B**



Starting Position | During Movement

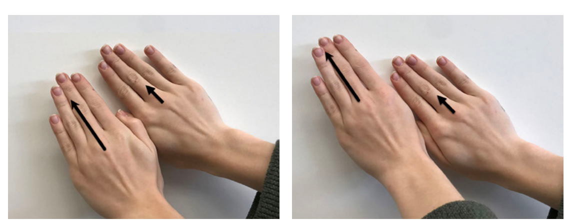
**4** Look at the map in Question 1. Circle the option on the right that matches the **transform boundary** shown by the vectors along the San Andreas fault in California. If available, also refer to the printouts of the different plate boundaries.

**OPTION A**



Starting Position | During Movement

**OPTION B**

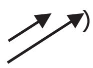


Starting Position | During Movement

**5** Compare the model to the real thing.

How are the hand movements from above **LIKE** what you see on ground motion vector maps?

How are the hand movements from above **DIFFERENT** from what you see on ground motion vector maps?

**6** Place Partner A's compass rose next to Partner B's compass rose. If you placed the first vectors you drew side-by-side, which one of the examples from Questions 2, 3, or 4 is the type of boundary that you and your partner demonstrated? (hint: )

## PART B: USING THE GPS VELOCITY VIEWER

Open the GPS Velocity Viewer.

---

**7** On the map below:

a. What is the scale for the vectors? ___________

Hint: The vector starts at the tail (where the GPS instrument is installed) even if the yellow vector crosses the plate boundary line.

b. Which plate has the longest vectors?
1. Pacific plate
2. North American plate

c. Find the longest vector you see on the map and circle it.

d. In which direction is this vector is pointing? _______

e. Calculate the speed of the plate at the longest vector's location:

- Measure the length of the vector you circled in mm.

  Longest Vector Length: ____________

- Measure the length of the vector scale bar in mm.

  Scale Bar Length: __________

- Using the speed formula provided below, calculate the speed of the plate at the longest vector's location in mm/yr.

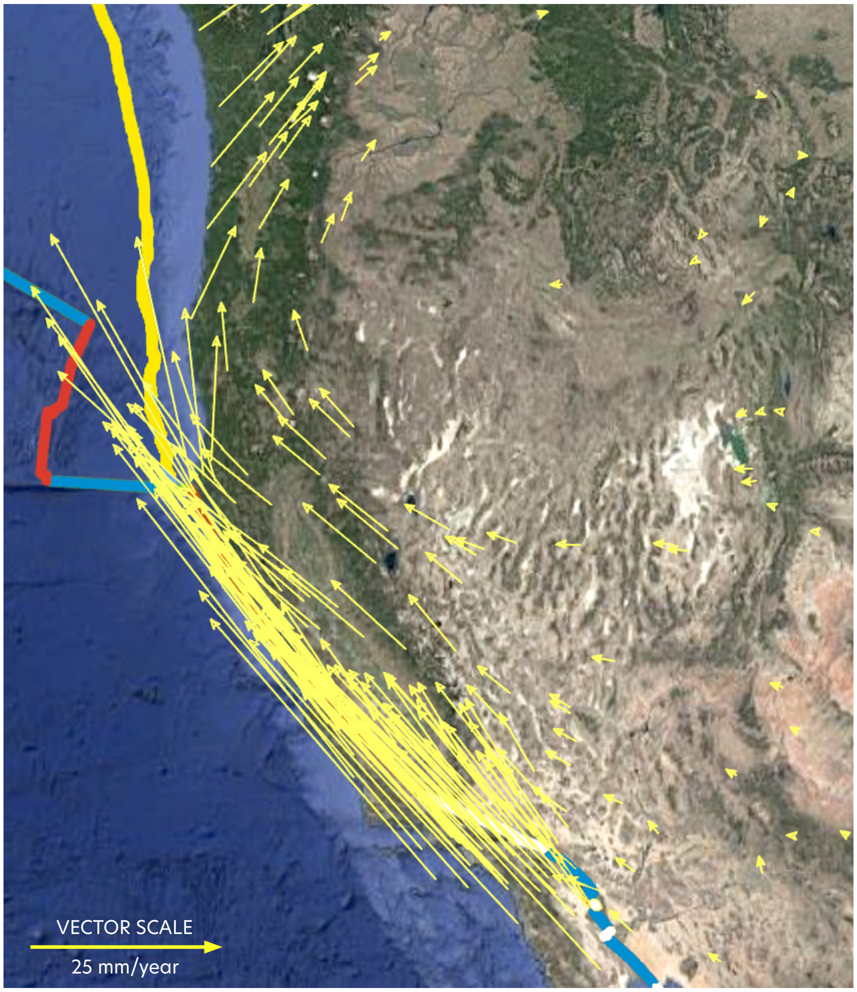
  Speed of Plate: ___________

$$\text{Speed of plate} = 25 \text{ mm/yr} \times \frac{\text{Length of longest vector}}{\text{Length of scale bar}}$$

**8** Abrupt changes in velocity across the land surface usually occur at or near plate tectonic boundaries. These changes in velocity could be indicated in two main ways:

- Vectors on opposite sides of the boundary point in similar directions but have different lengths.
- Vectors point in similar directions AND speeds (lengths) are decreasing or increasing.

a. Locate one example of these two scenarios on the map to the right, and circle its general location.




**9** Make a claim based on the region you circled in Question 8. What do the relative motions of adjacent vectors suggest is happening to the land between them? (HINT: Are they being compressed, moving apart, or sliding past each other?)

**CLAIM:**

NOTE: The nature of the tectonic forces in a region are related to the relative plate motions and the type of plate boundaries nearby. For example, compressional forces lead to convergent boundary zones, strike-slip (sliding-past) movements occur in transform boundary zones, and divergent boundary zones are subject to extensional forces.

**10** In the GPS Velocity Viewer:

a. Select
- GNSS DATA SOURCE: N. America, NAM14, NSF GAGE
- DISPLAY VECTORS: Make sure it is checked
- VECTOR COLOR: Blue
- VECTOR LENGTH (SCALING): 1x
- HOW MANY MARKERS DISPLAYED: Show one in twenty
- MORE TYPES OF DATA: Display plate boundaries

b. Click "Draw Map"

c. On the resulting map, zoom into the area you circled in Question 8 and answer the following: Which plate boundary type is nearby? Explain how the evidence you see in the Velocity Viewer demonstrates the type of forces you would expect to see in this plate boundary type.

**11** Large differences in velocity across short distances of land surface indicate stored strain within Earth that may be released over time through earthquakes.

a. Look at the seismic hazard map provided by your instructor.

b. Answer the following: How does the level of seismic hazard on this map compare to the areas you identified (in Question 8) as storing strain?

Continue once your instructor has given you a role for Part C:

- **SEISMOLOGIST**: A scientist who studies earthquakes and all seismic wave activity. This includes seismic waves from volcanoes and/or anything human-made.
- **VOLCANOLOGIST**: A scientist who studies volcanoes and all processes related to their creation and the deposits from them.
- **GEODESIST**: A scientist who measures the size, shape, and motion of Earth, and coordinates of any point on it. They also study the gravitational field and Earth's orientation in space.

---

# Prepare a Map Using the GPS Velocity Viewer

Open the GPS Velocity Viewer in a web browser. Below, circle the role and steps for your assigned role.

### SEISMOLOGISTS

a. Uncheck the "Display vectors" box.
b. Click the "Draw Map" button.
c. Move the map to show Washington, Oregon, and California.
d. Click on "Display earthquakes" under "More types of data."
e. Select "Show all" under "How many markers displayed."
f. Click on "Draw Map."

### VOLCANOLOGISTS

a. Uncheck the "Display vectors" box.
b. Click the "Draw Map" button.
c. Move the map to show Washington, Oregon, and California.
d. Click on "Display volcanic centers " under "More types of data."
e. Select "Show all" under "How many markers displayed."
f. Click on "Draw Map."

### GEODESISTS

a. Confirm the "Display vectors" box is selected.
b. Move the map to show Washington, Oregon, and California.
c. Click on "Display plate boundaries" under "More types of data."
d. Select "Show half" under "How many markers displayed."
e. Click on "Draw Map."

---

## 12 Answer the questions below for your assigned role.

### SEISMOLOGISTS

a. Where have earthquakes occurred in large groups? Check all that apply and draw the clusters on the map.
- ☐ Near the edge of the continent in California
- ☐ Near the edge of the continent in Oregon and Washington
- ☐ Continental interior
- ☐ In the ocean

b. How deep do the earthquakes occur? Check all that apply. If there are clusters of earthquakes at different depths, use another color or icon for each depth. Add this to your legend.
- ☐ Shallow (0-70 km)
- ☐ Middle (70-300 km)
- ☐ Deep (300+ km )

### VOLCANOLOGISTS

a. Where are volcanoes located close together? Check all that apply and draw the groupings on the map.
- ☐ Near the edge of the continent in California
- ☐ Slightly inland extending from Washington, Oregon, and Northern California
- ☐ Loose groupings throughout the continental interior
- ☐ In the ocean

### GEODESISTS

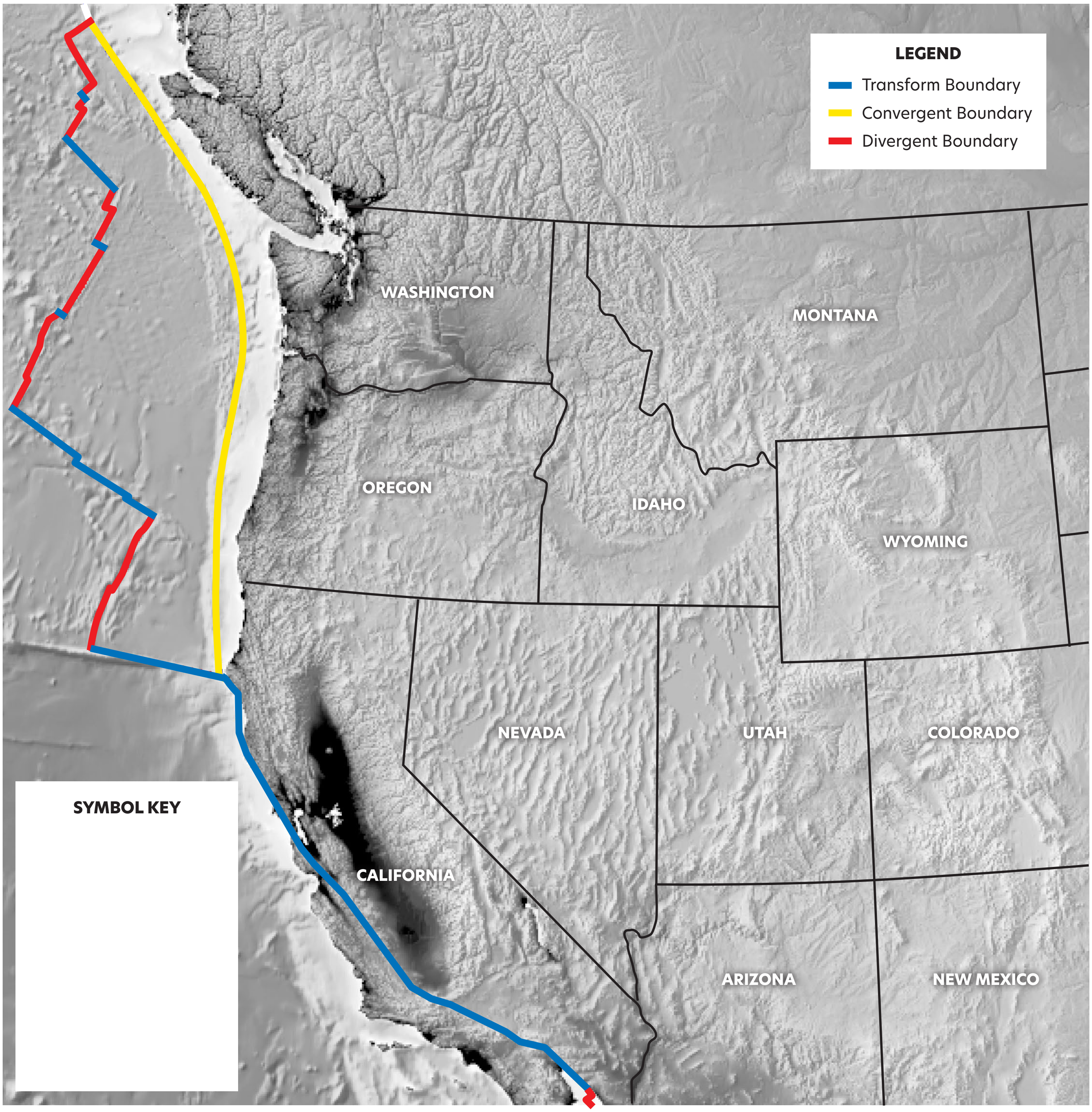
a. Where are the longest velocity vectors? Check all that apply and draw long vectors where you observe the longest vectors on the map.
- ☐ Near the edge of the continent in California
- ☐ Near the edge of the continent in Oregon and Washington
- ☐ Continental interior

b. Where are most of the shortest velocity vectors? Check all that apply and draw short vectors where you observe the shortest vectors on the map.
- ☐ Near the edge of the continent in California
- ☐ Near the edge of the continent in Oregon and Washington
- ☐ Continental interior

**13** a. In your role as a seismologist, volcanologist, or geodesist, sketch in clusters of data on the map below. Note the symbol and the data type it represents in the white symbol key box.

b. ***When the instructor tells you***, get back together with your original team. Share and compare your answers to Question 12 and, using different symbols for each type of data, sketch in the other two types of data on the map below. Add each new symbol and data type to the symbol key box. *NOTE: Refer to the legend to identify the types of plate boundaries.*

## TEAM MAP



## Prepare a Combined Map Using the GPS Velocity Viewer

Go back to the Velocity Viewer and create a new map.

a. Check the "Display vectors" box.
b. Under "More types of data" select "Display volcanic centers," "Display plate boundaries," and "Display earthquakes."
c. Select "Show half" under "How many markers displayed."
d. Click on "Draw Map."
e. Move the map to show Washington, Oregon, and California.
f. Study the data, continue to work in your team to answer the following questions. (Hint: Zoom in and out to see terrain and topography.)

**14** Compare the Team Map with the new combined map in the Velocity Viewer. If there are crucial data missing, add it to your Team Map, using the same symbols in your key for earthquakes, volcanoes, and vectors.

**15** Discuss the following with your teammates and come to a consensus.

a. Draw an oval around the region where both earthquakes and volcanoes occur close together on a plate boundary.
b. What type of plate boundary is this? ______________________________
c. BONUS! If we could use GPS underwater, what would you expect the vectors to look like for a divergent boundary? (circle) Would the vectors be: pointing towards each other, in the same direction, or away from each other? Draw vectors on the map in another color.

**16** Discuss with the following with your teammates and come to a consensus on the answer. Consult the legend on the maps.

a. Draw an oval around the region(s) which show only earthquakes occurring on a plate boundary.
b. What type of plate boundary is this? ______________________________
c. Draw a large rectangle around the plate boundary that has very few earthquakes on it.
d. What type of plate boundary is this? ______________________________

**17** How does the speed (the length of the vector) and direction of the vectors change from the coast to inland? What other regions have differing speeds? What about differing directions? What patterns to the vectors do you notice in different regions?

**18** Compare the plate boundaries you identified in Questions 15 and 16 with the vectors on the map. How do the vectors provide additional evidence for the plate boundary types you identified? Summarize below.
(Hint: Look at your answers for Questions 1 through 4)

**19** Compare what you see with the Seismic Hazard Map for the region. Using the Claim, Evidence, Reasoning format as shown below: Which region of the western United States has the highest seismic hazard?

**CLAIM**

*In the space below, write down the region you claim to have the highest seismic hazard (near the edges of the continent, mid-continent, or in the ocean).*

**EVIDENCE**

*Present evidence from the Seismic Hazard Map that supports your claim.*

**REASONING**

*Describe why that region would have the highest seismic hazard.*

## PART D: SHAKEALERT

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 of seismic hazards 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.

- Review the article How Do I Sign Up for the ShakeAlert Earthquake Early Warning System? Even if you don't live in California, Oregon, or Washington, you might visit there or have friends and family in those states.
- Watch the video Earthquake! Steps to Take When it Strikes (3:03)

As time allows:

- Watch the video Preparedness Journey (2.02)
- Open the "Prepare in a Year" guide (pdf)
- Answer the questions below.

---

**20** Who is your out-of-the-area contact?

---

**21** What other communication sources can you use?

---

**22** How much water is recommended that you store?

---

**23** Where can you store the water where you live?

---

**24** 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).

---

## 20 MINUTE ACTIVITY HANDOUT ***ANSWERS***

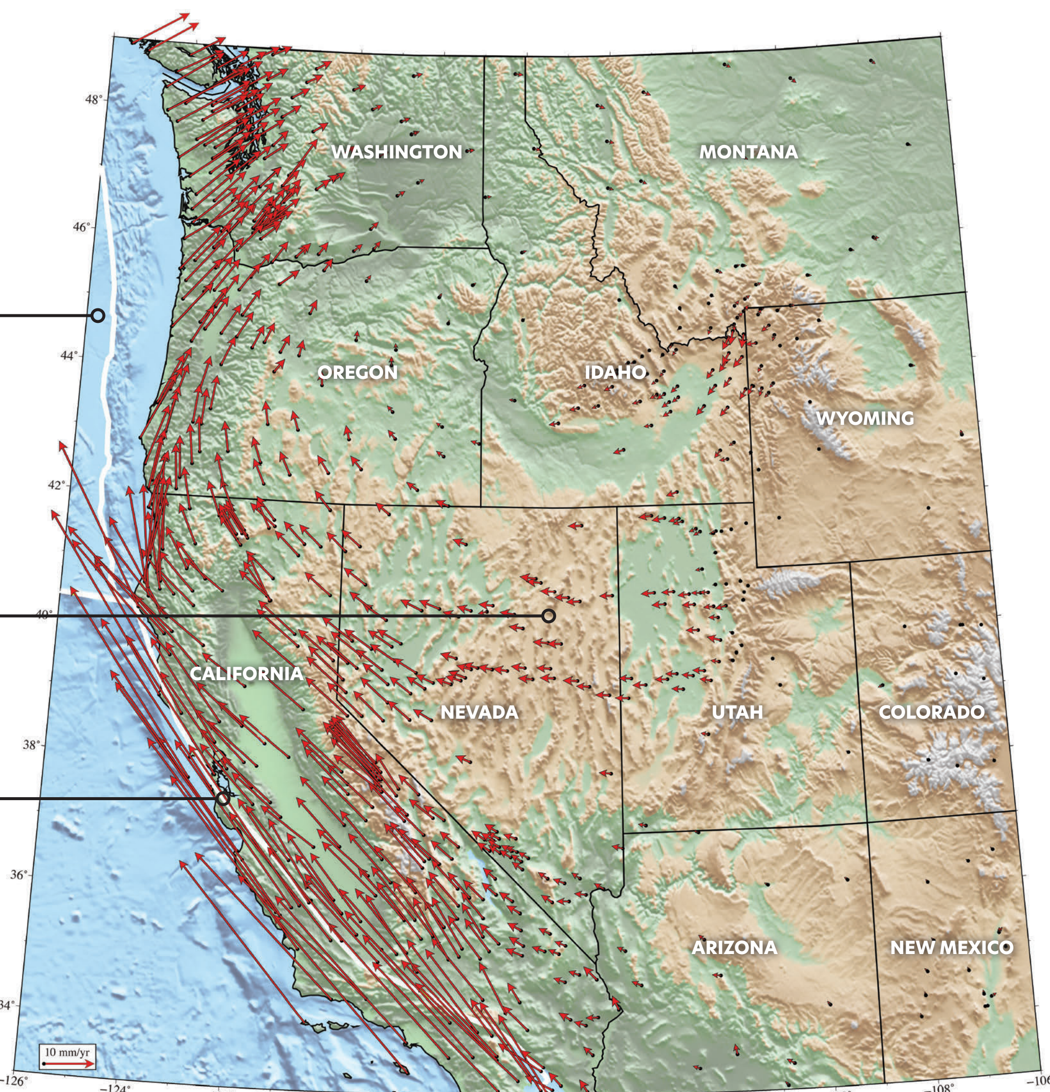
NAME: ______________________________ PERIOD: __________ DATE: ________________

**1** Refer to the printouts showing the three boundary types. Using the vectors to help, label each plate boundary type on the map below at a, b, and c.

**a** *Convergent Boundary*

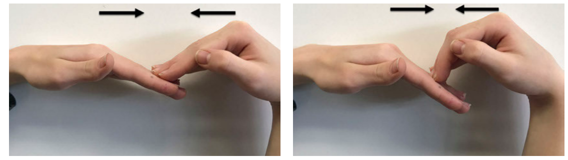
**b** *Divergent Boundary*

**c** *Transform Boundary*



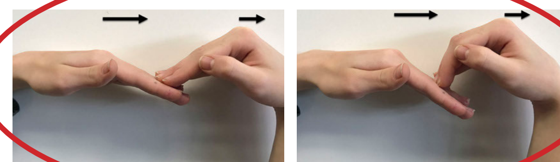
**2** Look at the map in Question 1. Circle the option on the right that matches the **convergent boundary** shown by the vectors in Oregon and Washington. If available, also refer to the printouts of the different plate boundaries.

**OPTION A**



Starting Position | During Movement

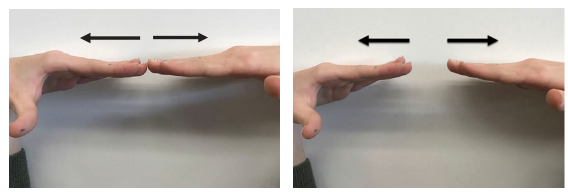
**OPTION B**



Starting Position | During Movement

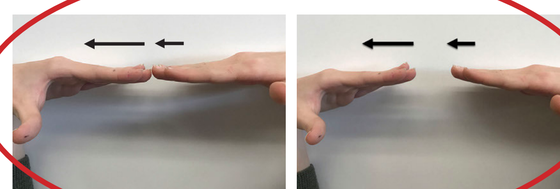
**3** Look at the map in Question 1. Circle the option on the right that matches the **divergent boundary** shown by the vectors in northern Utah and Nevada on the Basin and Range. If available, also refer to the printouts of the different plate boundaries.

**OPTION A**



Starting Position | During Movement

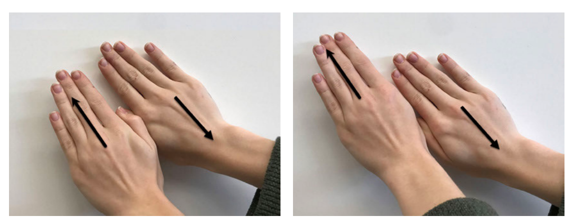
**OPTION B**



Starting Position | During Movement

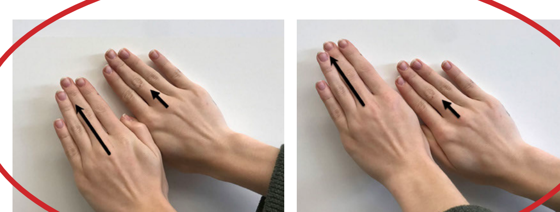
**4** Look at the map in Question 1. Circle the option on the right that matches the **transform boundary** shown by the vectors along the San Andreas fault in California. If available, also refer to the printouts of the different plate boundaries.

**OPTION A**



Starting Position | During Movement

**OPTION B**



Starting Position | During Movement

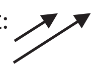
5 Compare the model to the real thing.

How are the hand movements from above **LIKE** what you see on ground motion vector maps?

***Answers will vary, but should show understanding that they were demonstrating the relative speed and direction of plates at each type of boundary.***

How are the hand movements from above **DIFFERENT** from what you see on ground motion vector maps?

***Answers will vary but should show understanding that their hands have different features than actual tectonic plates. Also, their hands may be moving at a faster speed, directions are not exactly the same, forces used by their hands are not as strong or may be different. Topographic features are not being made in the same way (e.g., their anatomical features aren't breaking to form mountains and valleys whereas rock will break)***

6 Place Partner A's compass rose next to Partner B's compass rose. If you placed the first vectors you drew side-by-side, which one of the examples from Questions 2, 3, or 4 is the type of boundary that you and your partner demonstrated? (hint:  )

***Question 4: Transform Boundary***

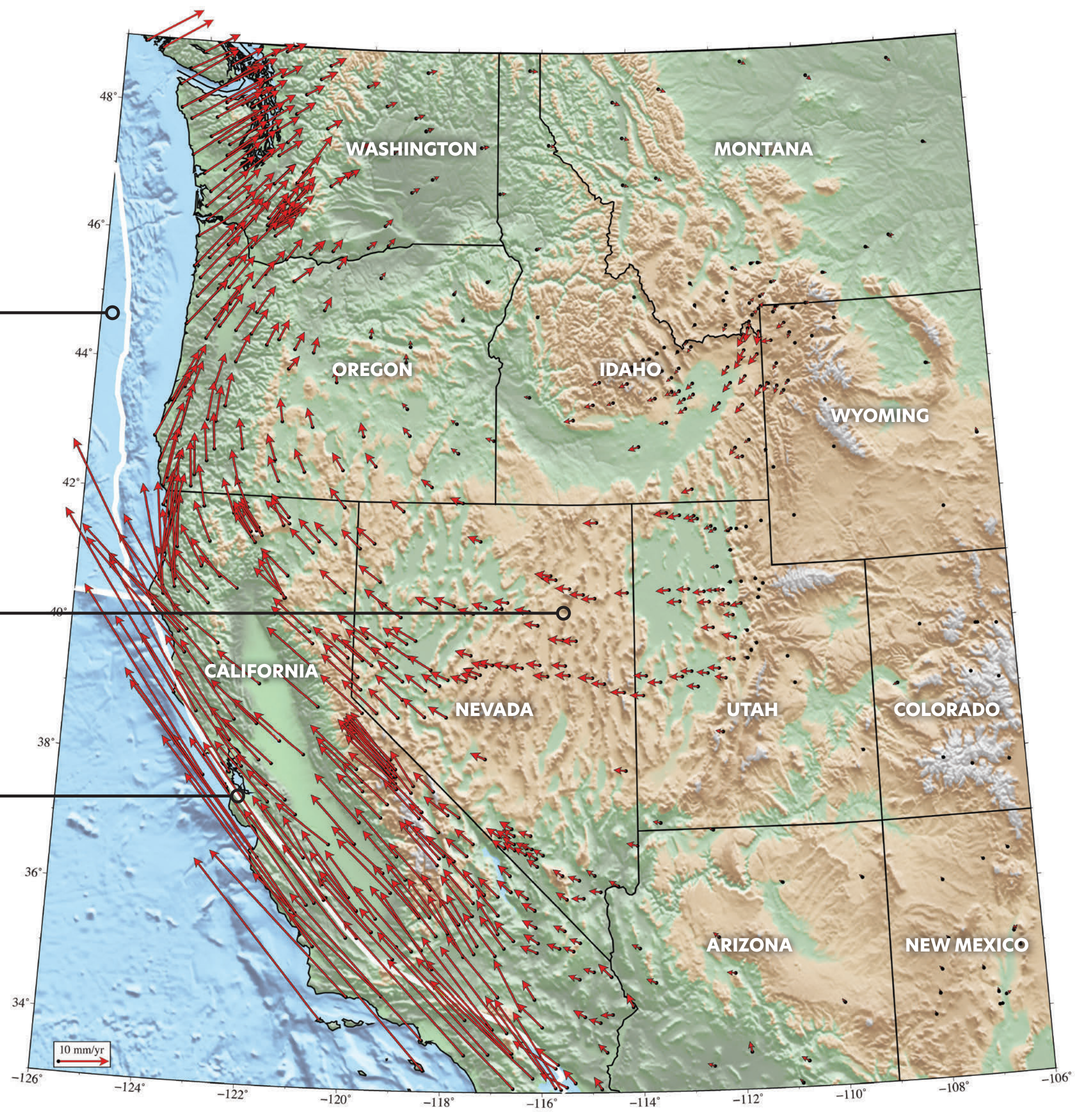
# 50 MINUTE ACTIVITY HANDOUT ***ANSWERS***

NAME: ______________________________ PERIOD: __________ DATE: ________________

How do we know tectonic plates are moving? In this activity, we will explore evidence using current Global Positioning Systems (GPS) data to see how the land beneath your feet is moving and how earthquakes and volcanoes are related.

## PART A: TECTONIC MOVEMENT AND VELOCITY VECTORS

**1** Refer to the printouts showing the three boundary types. Using the vectors to help, label each plate boundary type on the map below at a, b, and c.



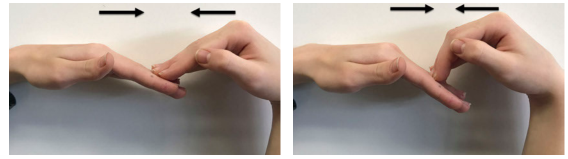

**a** *Convergent Boundary*

**b** *Divergent Boundary*

**c** *Transform Boundary*

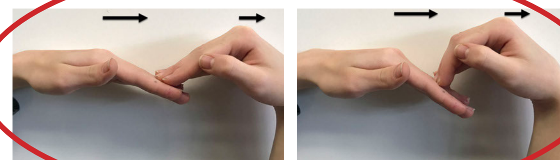
**2** Look at the map in Question 1. Circle the option on the right that matches the **convergent boundary** shown by the vectors in Oregon and Washington. If available, also refer to the printouts of the different plate boundaries.

**OPTION A**



Starting Position — During Movement

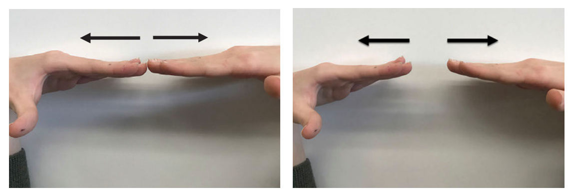
**OPTION B**



Starting Position — During Movement

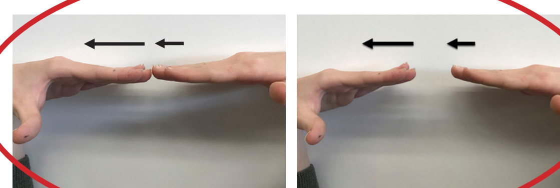
**3** Look at the map in Question 1. Circle the option on the right that matches the **divergent boundary** shown by the vectors in northern Utah and Nevada on the Basin and Range. If available, also refer to the printouts of the different plate boundaries.

**OPTION A**



Starting Position — During Movement

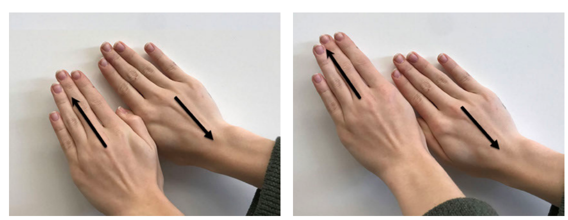
**OPTION B**



Starting Position — During Movement

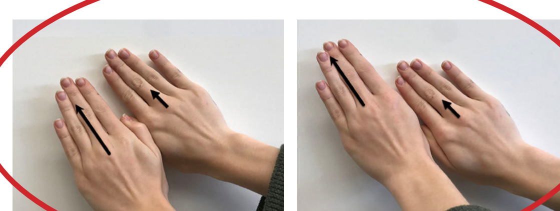
**4** Look at the map in Question 1. Circle the option on the right that matches the **transform boundary** shown by the vectors along the San Andreas fault in California. If available, also refer to the printouts of the different plate boundaries.

**OPTION A**



Starting Position — During Movement

**OPTION B**



Starting Position — During Movement

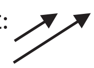
**5** Compare the model to the real thing.

How are the hand movements from above **LIKE** what you see on ground motion vector maps?

***Answers will vary, but should show understanding that they were demonstrating the relative speed and direction of plates at each type of boundary.***

How are the hand movements from above **DIFFERENT** from what you see on ground motion vector maps?

***Answers will vary but should show understanding that their hands have different features than actual tectonic plates. Also, their hands may be moving at a faster speed, directions are not exactly the same, forces at the boundaries are not as strong or may be different. Topographic features are not being made in the same way (e.g., their anatomical features aren't breaking to form mountains and valleys whereas rock will break)***

**6** Place Partner A's compass rose next to Partner B's compass rose. If you placed the first vectors you drew side-by-side, which one of the examples from Questions 2, 3, or 4 is the type of boundary that you and your partner demonstrated? (hint:  )

***Question 4: Transform Boundary***

## PART B: USING THE GPS VELOCITY VIEWER

Open the GPS Velocity Viewer.

***Answers will vary, but should show understanding that they were demonstrating the relative speed and direction of plates at each type of boundary.***

**7** On the map below:

a. What is the scale for the vectors? ____________

Hint: The vector starts at the tail (where the GPS instrument is installed) even if the yellow vector crosses the plate boundary line.

b. Which plate has the longest vectors?
1. Pacific plate
2. North American plate

c. Find the longest vector you see on the map and circle it.

d. In which direction is this vector is pointing? ***Northwest***

e. Calculate the speed of the plate at the longest vector's location:

- Measure the length of the vector you circled in mm.

  Longest Vector Length: ____________

- Measure the length of the vector scale bar in mm.

  Scale Bar Length: ____________

- Using the speed formula provided below, calculate the speed of the plate at the longest vector's location in mm/yr.

  Speed of Plate: ____________

***In the western United States, locations on the Pacific plate in southwestern California are moving 42-47mm/yr to the northwest.***

$$\text{Speed of plate} = 25 \text{ mm/yr} \times \frac{\text{Length of longest vector}}{\text{Length of scale bar}}$$

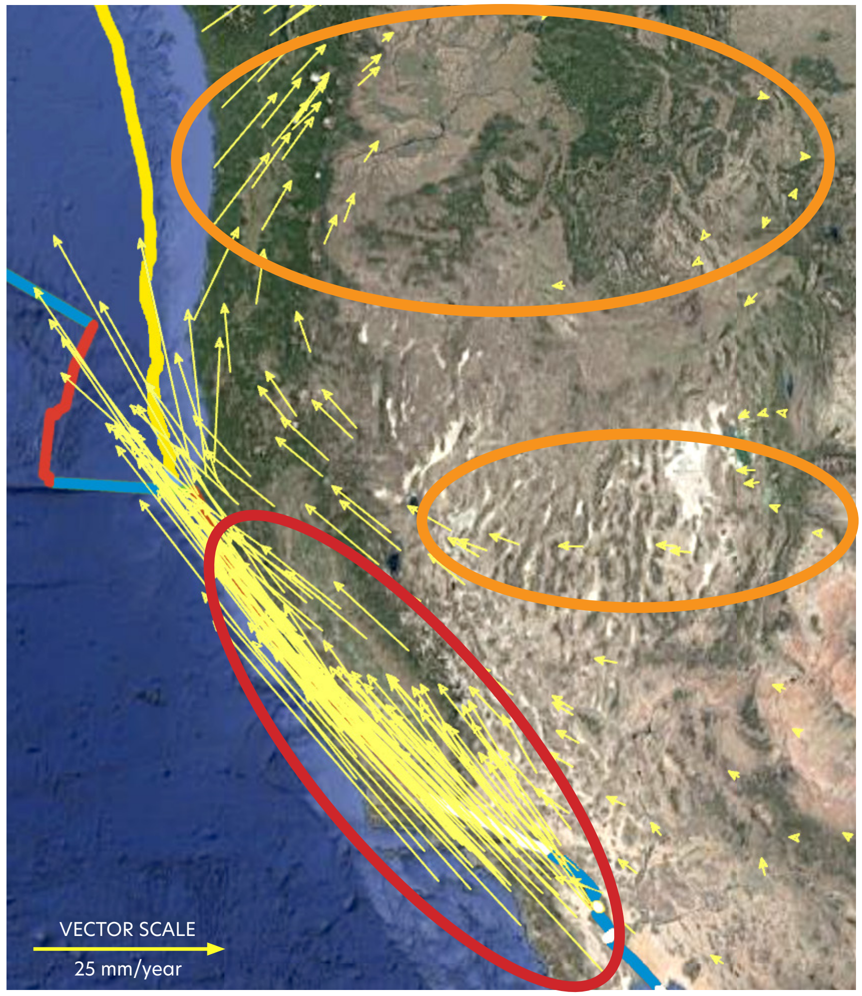
**8** Abrupt changes in velocity across the land surface usually occur at or near plate tectonic boundaries. These changes in velocity could be indicated in two main ways:

- Vectors on opposite sides of the boundary point in similar directions but have different lengths.
- Vectors point in similar directions AND speeds (lengths) are decreasing or increasing.

a. Locate one example out of these two scenarios on the map to the right, and circle its general location.

***Answers will vary. Some examples include:***

- ***RED CIRCLE. Western United States, western California coast—locations on the Pacific plate are moving northwest very fast and, as you move to the east, the vectors are still pointing northwest, but at slower rates [strike-slip]***
- ***ORANGE CIRCLES. Western Nevada-Utah—vectors point in roughly the same direction, with the eastern vectors being shorter than vectors to the west (the land is pulling away) [extension]. Oregon-Washington—vectors point in roughly the same direction, with the western vectors being longer than vectors to the east (crunching the ground inland) [convergent].***




**9** Make a claim based on the region you circled in Question 8. What do the relative motions of adjacent vectors suggest is happening to the land between them? (HINT: Are they being compressed, moving apart, or sliding past each other?)

***CLAIM: The Pacific plate side of the San Andreas fault is sliding past the North American Plate. EVIDENCE: Vectors are longer on the Pacific plate side, but moving in the same direction as the North American plate side. REASONING: The GPS stations on the west side of the San Andreas fault are moving faster than the GPS stations on the east, which means the west side is sliding, forming strike-slip faults.***

***CLAIM: Oregon-Washington is experiencing convergence. EVIDENCE: Vectors to the west are longer than vectors to the east, and they point in roughly the same direction. REASONING: The GPS stations to the west are moving toward the GPS stations to the east more quickly, which means the land between them compressing.***

NOTE: The nature of the tectonic forces in a region are related to the relative plate motions and the type of plate boundaries nearby. For example, compressional forces lead to convergent boundary zones, strike-slip (sliding-past) movements occur in transform boundary zones, and divergent boundary zones are subject to extensional forces.

**10** In the GPS Velocity Viewer:

a. Select

- GNSS DATA SOURCE: N. America, NAM14, NSF GAGE
- DISPLAY VECTORS: Make sure it is checked
- VECTOR COLOR: Blue
- VECTOR LENGTH (SCALING): 1x
- HOW MANY MARKERS DISPLAYED: Show one in twenty
- MORE TYPES OF DATA: Display plate boundaries

b. Click "Draw Map"

c. On the resulting map, zoom into the area you circled in Question 8 and answer the following: Which plate boundary type is nearby? Explain how the evidence you see in the Velocity Viewer demonstrates the type of forces you would expect to see in this plate boundary type.

***Transform Boundaries: RED CIRCLES. Expect to see strike-slip, or shear forces, which are evidenced by the western GPS stations moving northward at faster rates than the GPS stations to the east.***

***Divergent Boundary: This localized extensional regime results from heating the crust under the Utah and Nevada regions, stretching and extending it. (Note to instructor: If time, show the Iceland region: zoom to Iceland in the Velocity Viewer, change the data type to Eurasian, show all of the vectors, display plate boundaries, and click on Draw Map)***

***Convergent Boundary: This is a convergent regime due to subduction of the Juan de Fuca plate.***

**11** Large differences in velocity across short distances of land surface indicate stored strain within Earth that may be released over time through earthquakes.

a. Look at the seismic hazard map provided by your instructor.

b. Answer the following: How does the level of seismic hazard on this map compare to the areas you identified (in Question 8) as storing strain?

***The highest hazard areas correlate with the convergent and transform boundary locations.***

***The very largest earthquakes occur at convergent boundaries (up to magnitude 9). Transform boundaries can have earthquakes up to magnitude 7-8. However, earthquakes at transform boundaries tend to be particularly shallow.***

Continue once your instructor has given you a role for Part C:

- **SEISMOLOGIST**: A scientist who studies earthquakes and all seismic wave activity. This includes seismic waves from volcanoes and/or anything human-made.
- **VOLCANOLOGIST**: A scientist who studies volcanoes and all processes related to their creation and the deposits from them.
- **GEODESIST**: A scientist who measures the size, shape, and motion of Earth, and coordinates of any point on it. They also study the gravitational field and Earth's orientation in space.

---

# Prepare a Map Using the GPS Velocity Viewer

Open the GPS Velocity Viewer in a web browser. Below, circle the role and steps for your assigned role.

### SEISMOLOGISTS

a. Uncheck the "Display vectors" box.
b. Click the "Draw Map" button.
c. Move the map to show Washington, Oregon, and California.
d. Click on "Display earthquakes" under "More types of data."
e. Select "Show all" under "How many markers displayed."
f. Click on "Draw Map."

### VOLCANOLOGISTS

a. Uncheck the "Display vectors" box.
b. Click the "Draw Map" button.
c. Move the map to show Washington, Oregon, and California.
d. Click on "Display volcanic centers " under "More types of data."
e. Select "Show all" under "How many markers displayed."
f. Click on "Draw Map."

### GEODESISTS

a. Confirm the "Display vectors" box is selected.
b. Move the map to show Washington, Oregon, and California.
c. Click on "Display plate boundaries" under "More types of data."
d. Select "Show half" under "How many markers displayed."
e. Click on "Draw Map."

---

**12** Answer the questions below for your assigned role.

***[Note to instructors, help learners with the concept of cluster and grouping]***

## SEISMOLOGISTS

a. Where have earthquakes occurred in large groups? Check all that apply and draw the clusters on the map.

- ☑ Near the edge of the continent in California
- ☐ Near the edge of the continent in Oregon and Washington
- ☐ Continental interior
- ☑ In the ocean

b. How deep do the earthquakes occur? Check all that apply. If there are clusters of earthquakes at different depths, use another color or icon for each depth. Add this to your legend.

- ☑ Shallow (0-70 km)
- ☑ Middle (70-300 km)
- ☐ Deep (300+ km )

## VOLCANOLOGISTS

a. Where are volcanoes located close together? Check all that apply and draw the groupings on the map.

- ☐ Near the edge of the continent in California
- ☑ Slightly inland extending from Washington, Oregon, and Northern California
- ☑ Loose groupings throughout the continental interior
- ☑ In the ocean

## GEODESISTS

a. Where are the longest velocity vectors? Check all that apply and draw long vectors where you observe the longest vectors on the map.

- ☑ Near the edge of the continent in California
- ☑ Near the edge of the continent in Oregon and Washington
- ☐ Continental interior

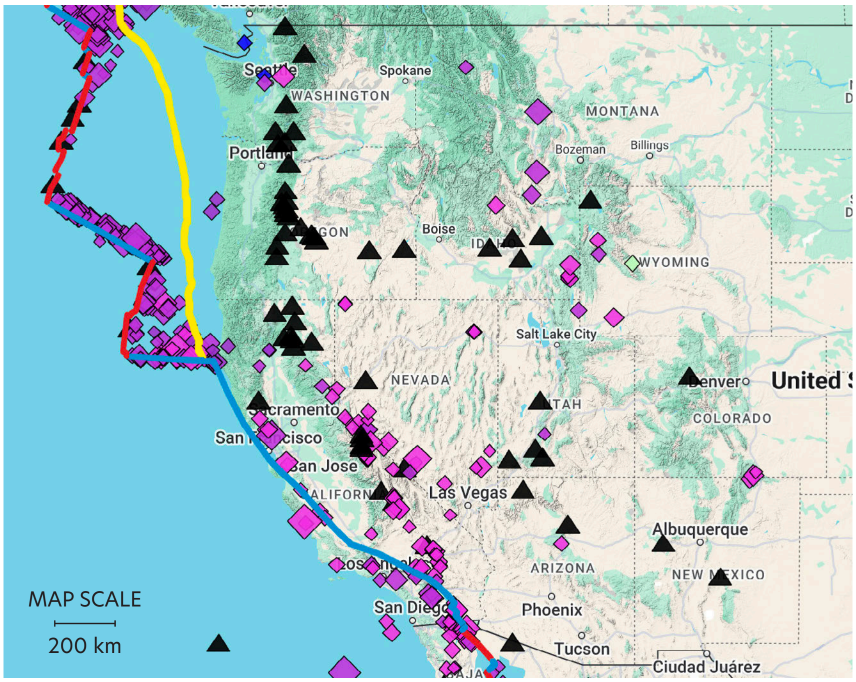
b. Where are most of the shortest velocity vectors? Check all that apply and draw short vectors where you observe the shortest vectors on the map.

- ☐ Near the edge of the continent in California
- ☐ Near the edge of the continent in Oregon and Washington
- ☑ Continental interior

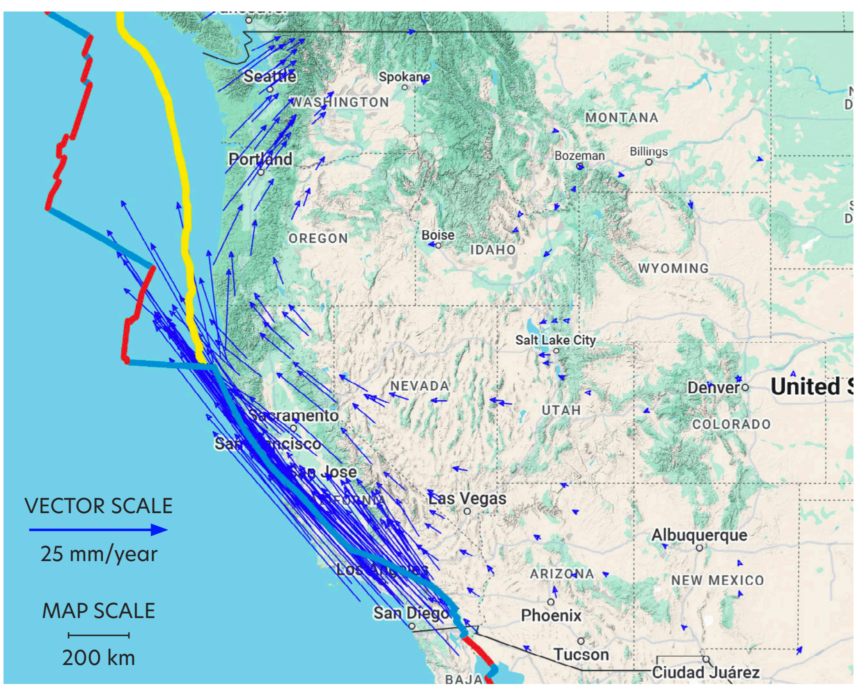
**13** a. In your role as a seismologist, volcanologist, or geodesist, sketch in clusters of data on the map below. Note the symbol and the data type it represents in the white symbol key box.

b. ***When the instructor tells you***, get back together with your original team. Share and compare your answers to Question 12 and, using different symbols for each type of data, sketch in the other two types of data on the map below. Add each new symbol and data type to the symbol key box. *NOTE: Refer to the legend to identify the types of plate boundaries.*

***Key for earthquakes and volcanoes.***




***Key for velocity vectors.***



# Prepare a Combined Map Using the GPS Velocity Viewer

Go back to the Velocity Viewer and create a new map.

a. Check the "Display vectors" box.
b. Under "More types of data" select "Display volcanic centers," "Display plate boundaries," and "Display earthquakes."
c. Select "Show half" under "How many markers displayed."
d. Click on "Draw Map."
e. Move the map to show Washington, Oregon, and California.
f. Study the data, continue to work in your team to answer the following questions. (Hint: Zoom in and out to see terrain and topography.)

**14** Compare the Team Map with the new combined map in the Velocity Viewer. If there are crucial data missing, add it to your Team Map, using the same symbols in your key for earthquakes, volcanoes, and vectors.

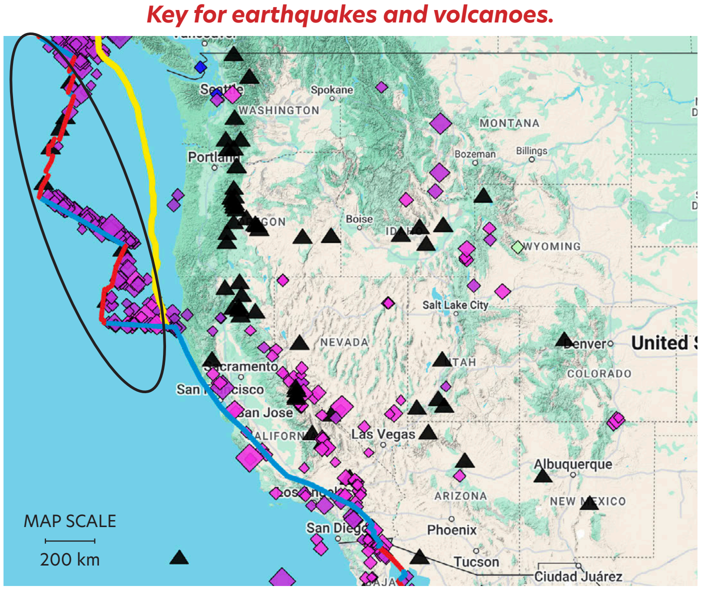
**15** Discuss the following with your teammates and come to a consensus.

a. Draw an oval around the region where both earthquakes and volcanoes occur close together on a plate boundary.

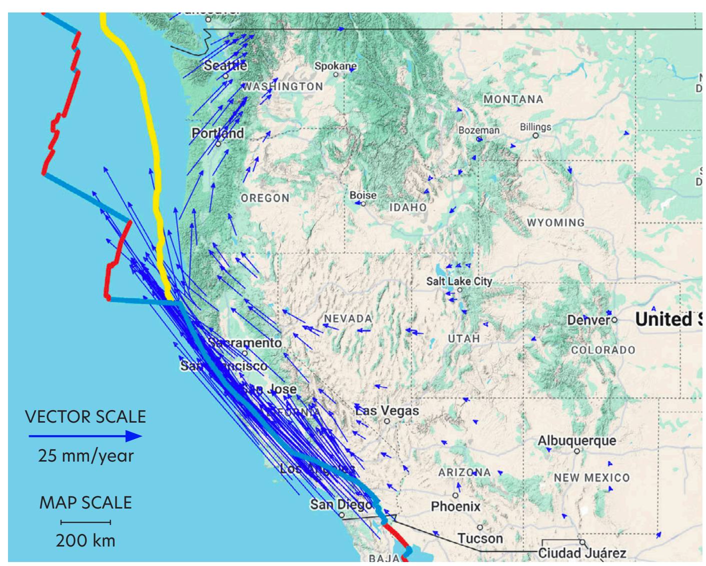
b. What type of plate boundary is this? ***Divergent Boundary***

c. BONUS! If we could use GPS underwater, what would you expect the vectors to look like for a divergent boundary? (circle) Would the vectors be: pointing towards each other, in the same direction, or away from each other? Draw vectors on the map in another color.

***Key for earthquakes and volcanoes.***




***Key for velocity vectors.***



# 16

Discuss with the following with your teammates and come to a consensus on the answer. Consult the legend on the maps.

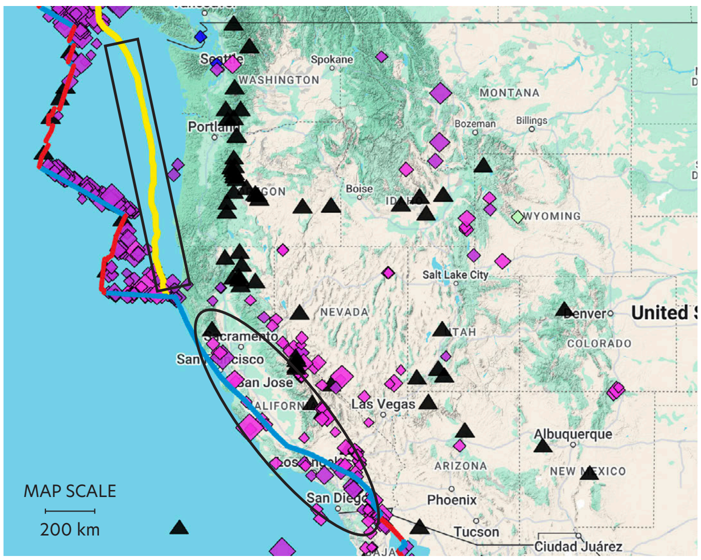
a. Draw an oval around the region(s) which show only earthquakes occurring on a plate boundary.

b. What type of plate boundary is this? ***Transform Boundary***

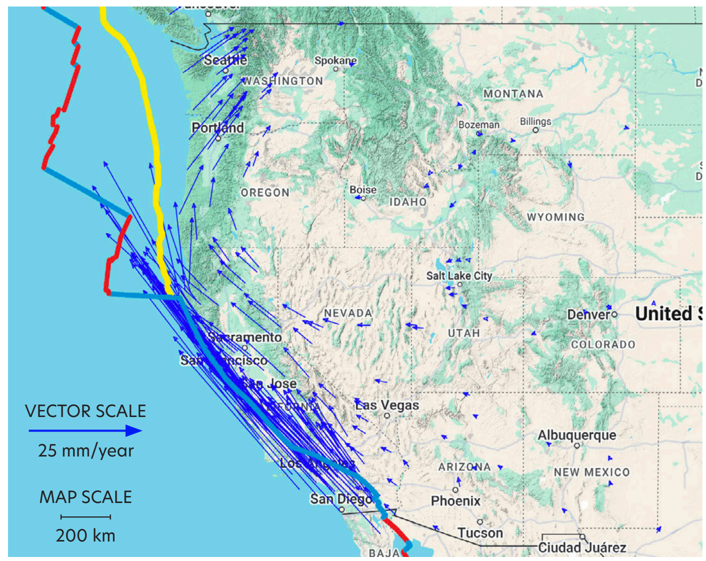
c. Draw a large rectangle around the plate boundary that has very few earthquakes on it.

d. What type of plate boundary is this? ***Convergent Boundary***

***Key for earthquakes and volcanoes.***




***Key for velocity vectors.***




# 17

How does the speed (the length of the vector) and direction of the vectors change from the coast to inland? What other regions have differing speeds? What about differing directions? What patterns to the vectors do you notice in different regions?

***The length of the vectors decrease from west to east in Oregon and Washington, while also changing direction in Northern California, through Oregon, and Washington.***

***Vectors also change direction from mostly west to northwest near the Nevada and California border. They go from short to long east to west across Utah and Nevada, and quickly change length across California across the San Andreas fault.***

**18** Compare the plate boundaries you identified in Questions 15 and 16 with the vectors on the map. How do the vectors provide additional evidence for the plate boundary types you identified? Summarize below.
(Hint: Look at your answers for Questions 1 through 4)

***The vector data support and agree with the earthquake & volcano data! The vectors identify the same boundary types as the answers in 15 and 16.***

**19** Compare what you see with the Seismic Hazard Map for the region. Using the Claim, Evidence, Reasoning format as shown below: Which region of the western United States has the highest seismic hazard?

**CLAIM**

*In the space below, write down the region you claim to have the highest seismic hazard (near the edges of the continent, mid-continent, or in the ocean).*

***The edges of the continent have the highest seismic hazard.***

**EVIDENCE**

*Present evidence from the Seismic Hazard Map that supports your claim.*

***Near the edge of the continent due to the location of the plate boundary. The seismic hazard map shows red in these areas, which means there is a high amount of seismic activity.***

**REASONING**

*Describe why that region would have the highest seismic hazard.*

***More plate interaction = more earthquakes and volcanoes = higher seismic hazard.***

**PART D: SHAKEALERT**

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 of seismic hazards 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.

- Review the article How Do I Sign Up for the ShakeAlert Earthquake Early Warning System? Even if you don't live in California, Oregon, or Washington, you might visit there or have friends and family in those states.
- Watch the video Earthquake! Steps to Take When it Strikes (3:03)

As time allows:

- Watch the video Preparedness Journey (2.02)
- Open the "Prepare in a Year" guide (pdf)
- Answer the questions below.

---

**20** Who is your out-of-the-area contact?
***Answers will vary***

---

**21** What other communication sources can you use?
***Answers will vary***

---

**22** How much water is recommended that you store?
***14 gallons/person for a 2 week supply***

---

**23** Where can you store the water where you live?
***Answers will vary***

---

**24** 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).

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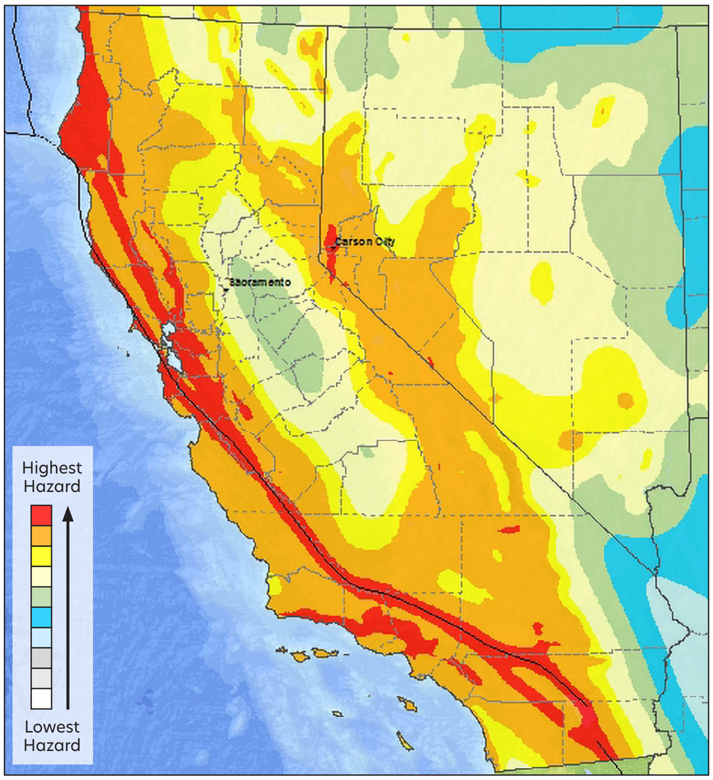
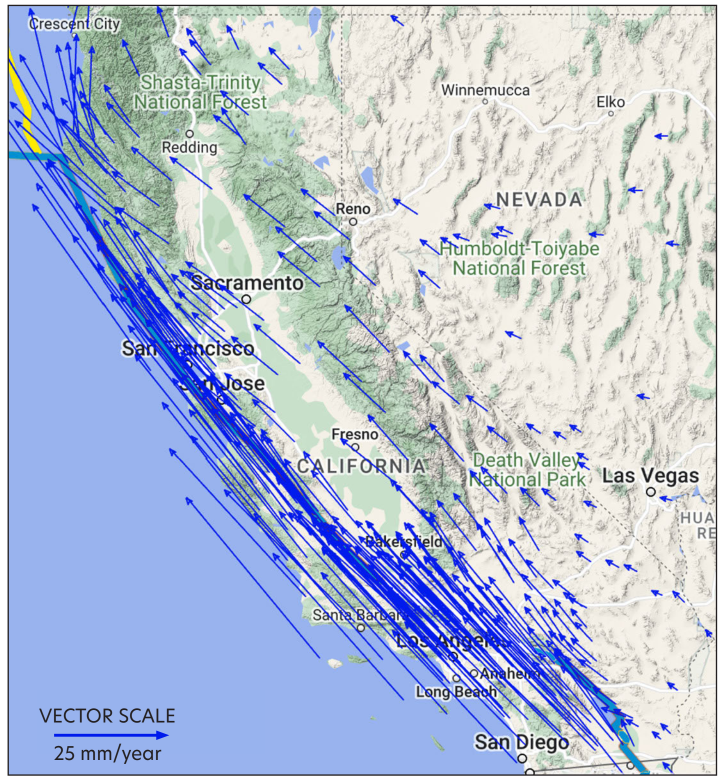
# APPENDIX I. SEISMIC HAZARD MAPS

**CALIFORNIA SEISMIC HAZARD MAP**



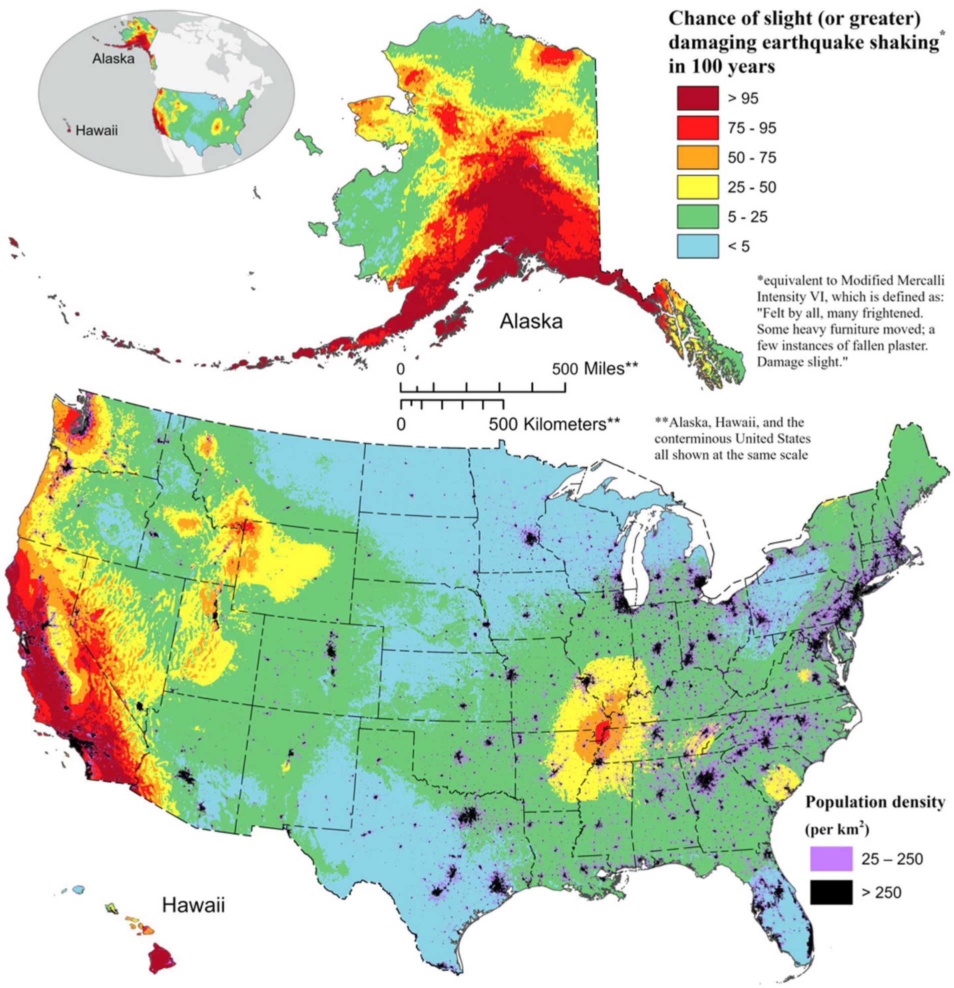

*Source: USGS*

**CALIFORNIA GROUND MOTION VECTOR MAP**




*Source: EarthScope GPS data, USGS Plate Boundary data, Google: base map*

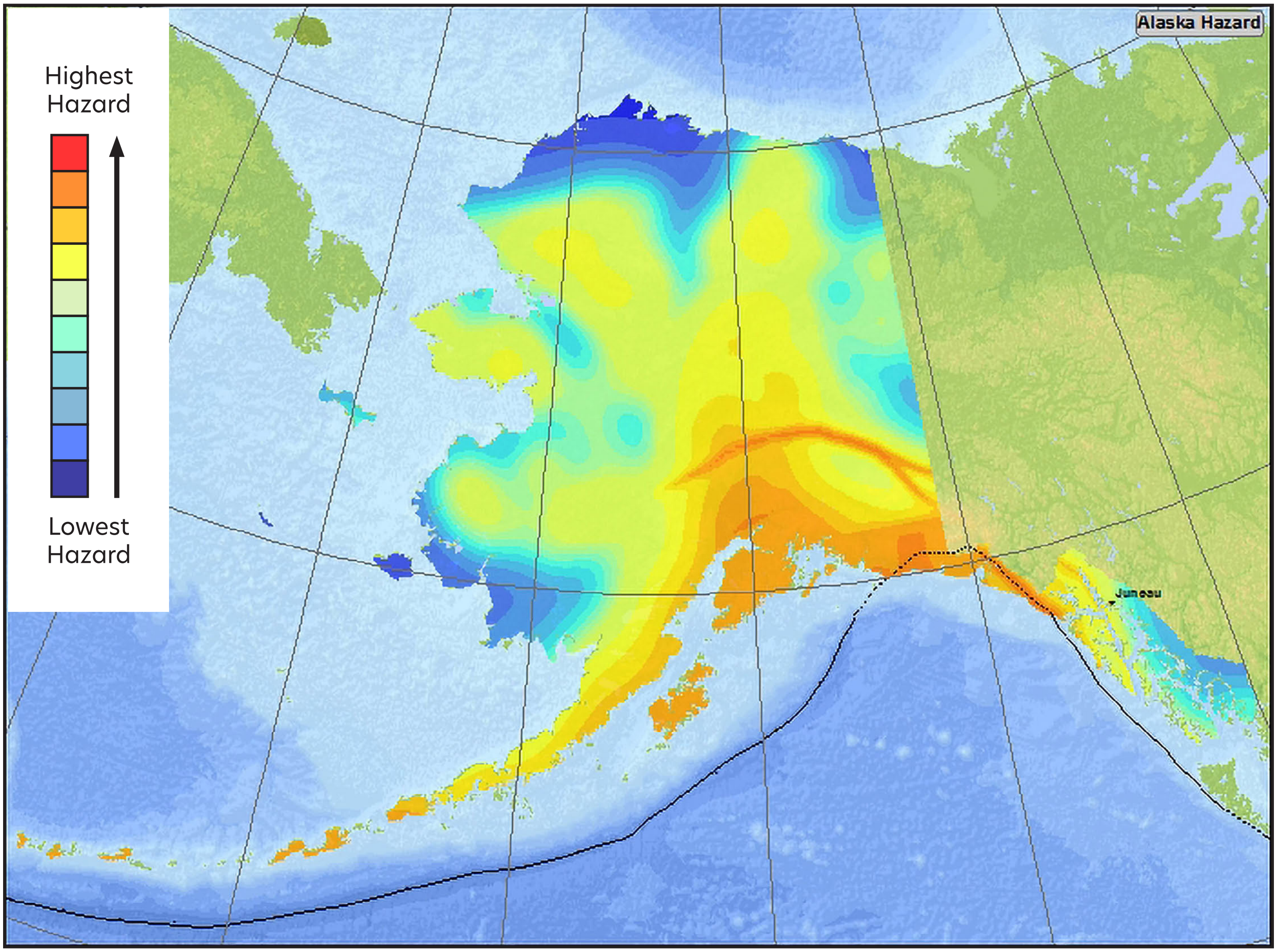
## USGS NATIONAL SEISMIC HAZARD MAP (2023)




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

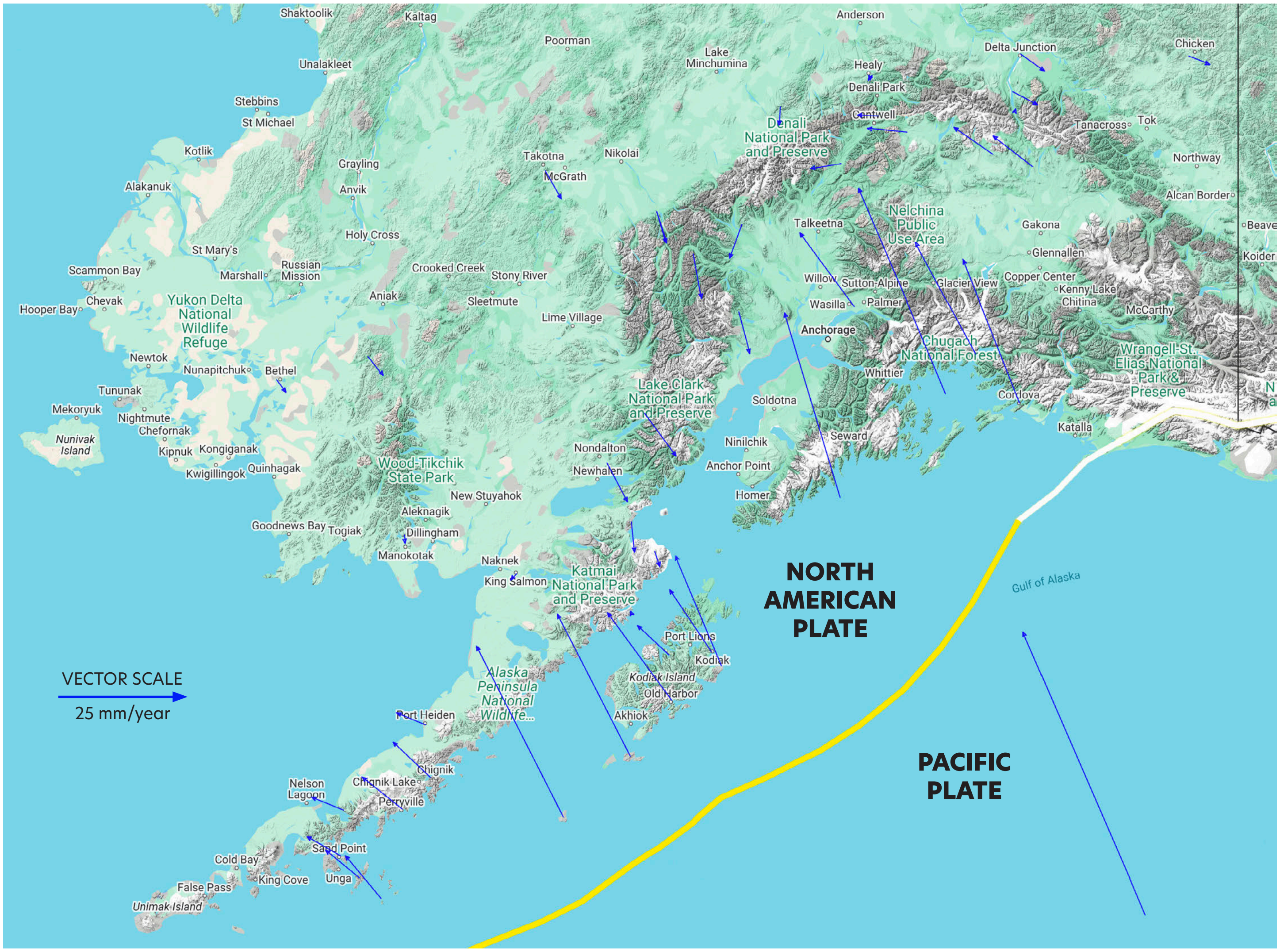
To learn more about how the Seismic Hazard Maps are made, visit Introduction to the National Seismic Hazard Maps or visit the USGS site on Earthquake Hazards.

**ALASKA SEISMIC HAZARD MAP**



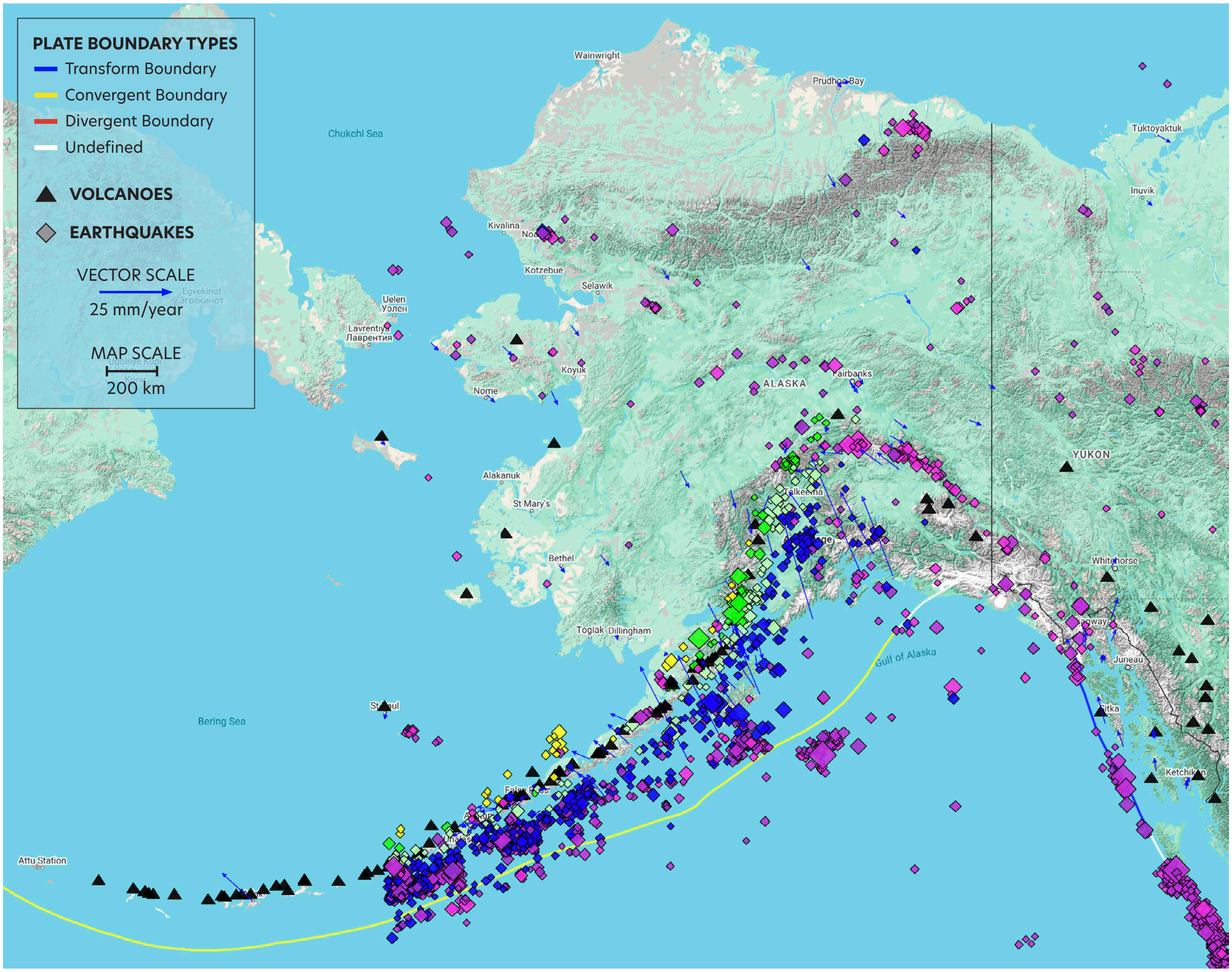

*Source: USGS*

## ALASKA GROUND MOTION VECTOR MAP




*Source: EarthScope Consortium*

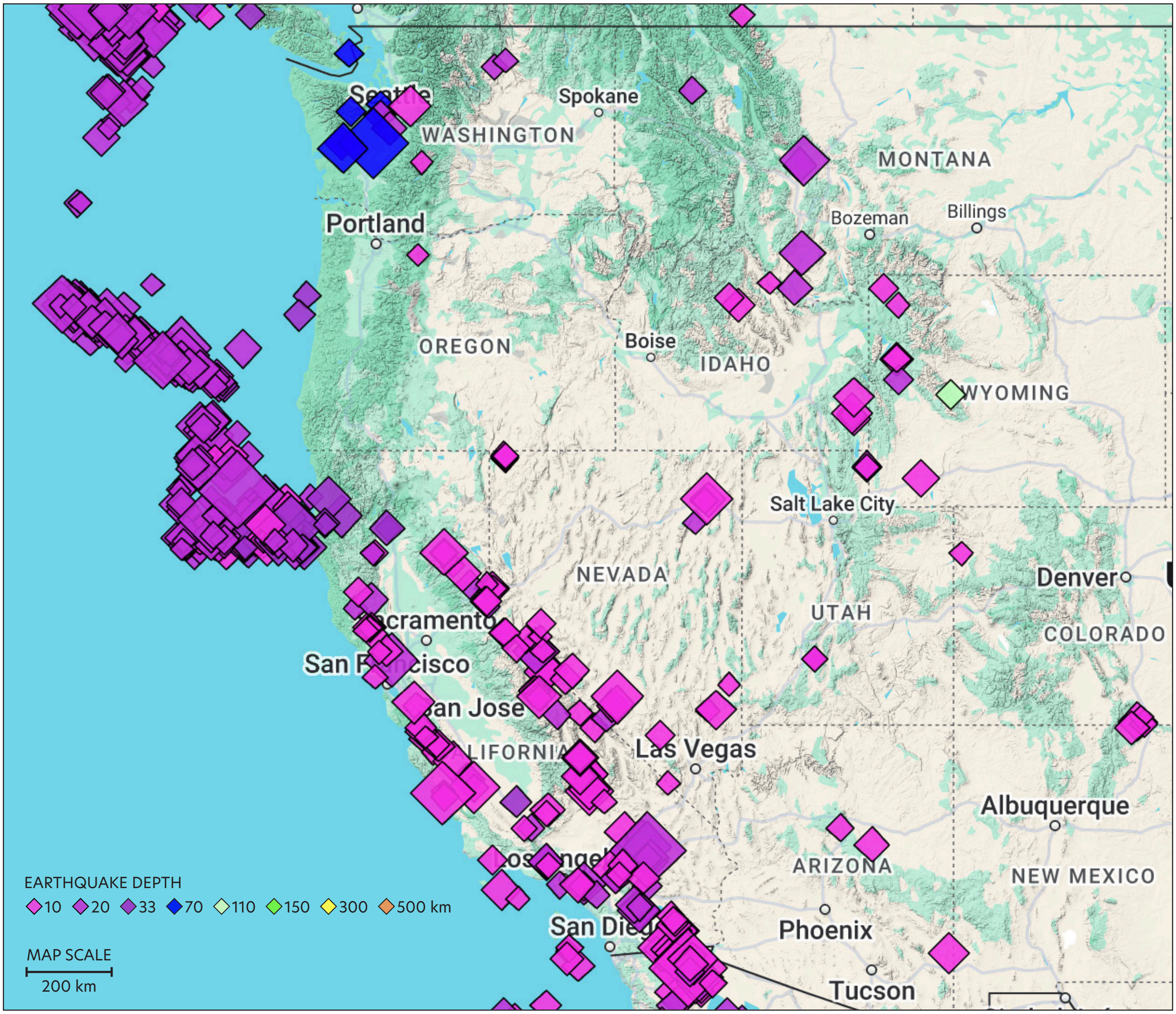
## ALASKA EARTHQUAKES, VOLCANOES, PLATE BOUNDARIES, AND VELOCITY VECTORS MAP




*Sources: EarthScope Consortium (GPS data), USGS (Plate boundaries and earthquakes), Smithsonian (Volcano data), Google (base map)*

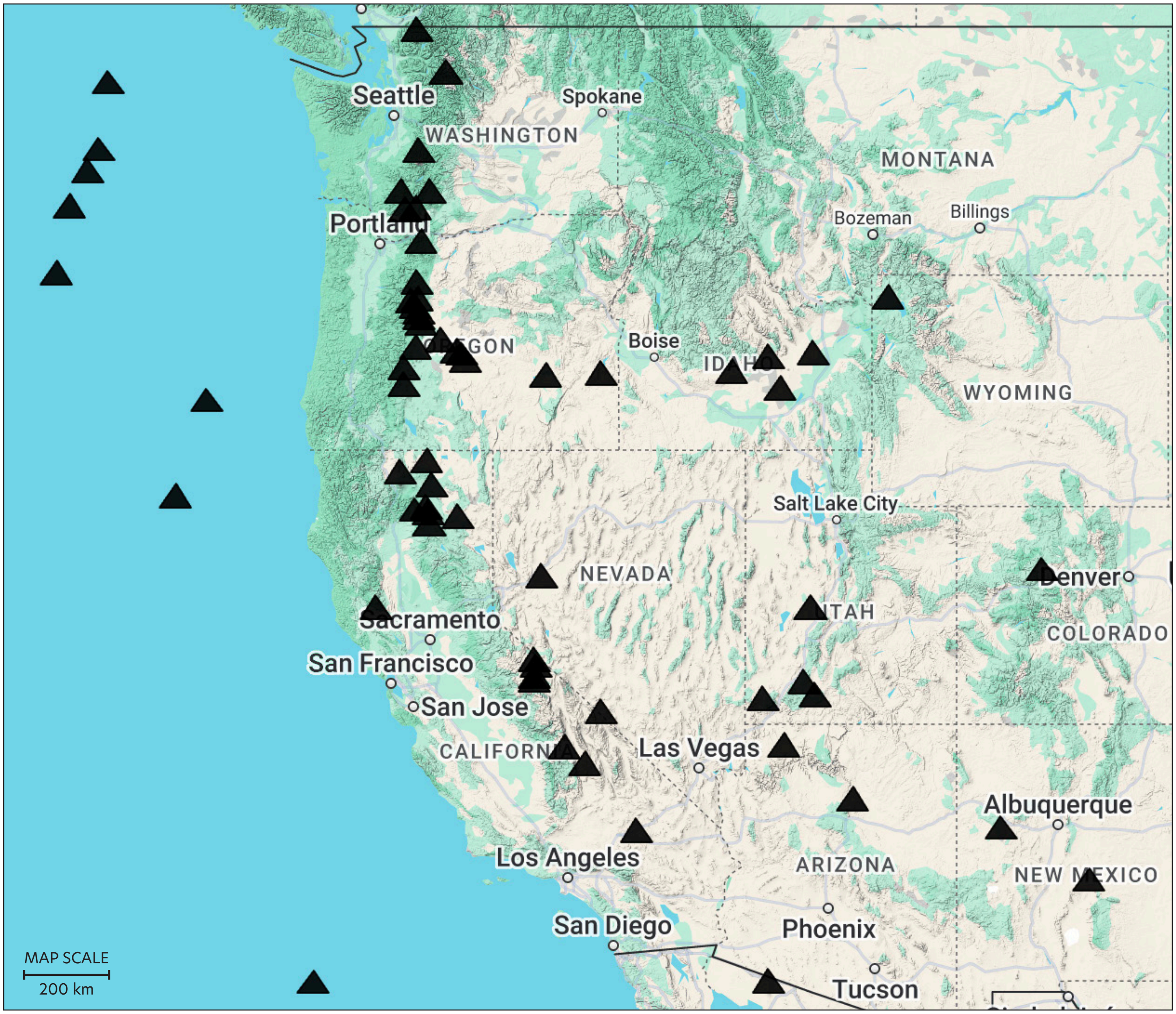
# APPENDIX J. MAPS FROM THE GPS VELOCITY VIEWER TOOL

WESTERN UNITED STATES — EARTHQUAKES ONLY



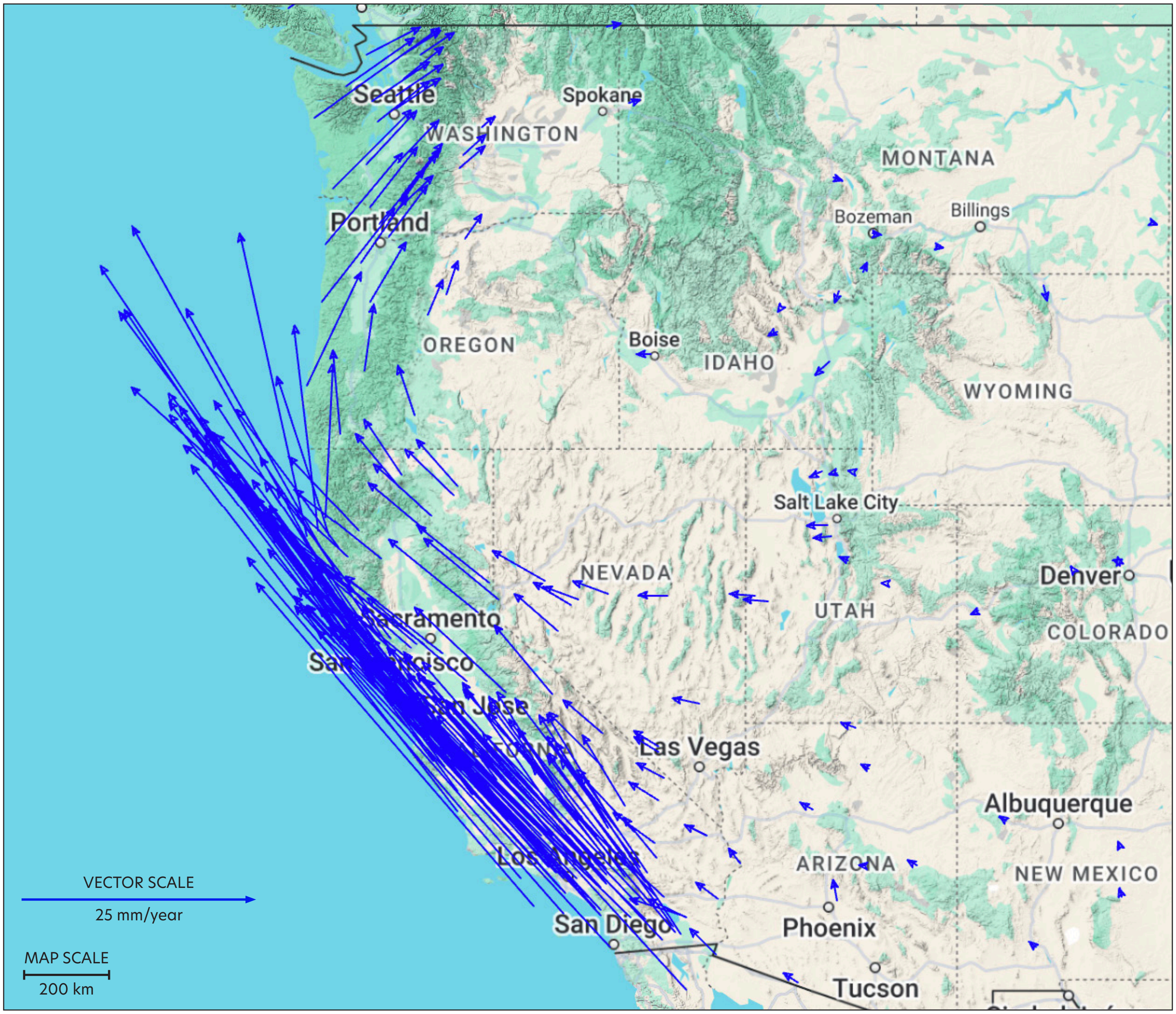

*Sources: USGS (earthquakes), Google (base map)*

## WESTERN UNITED STATES — VOLCANOES ONLY



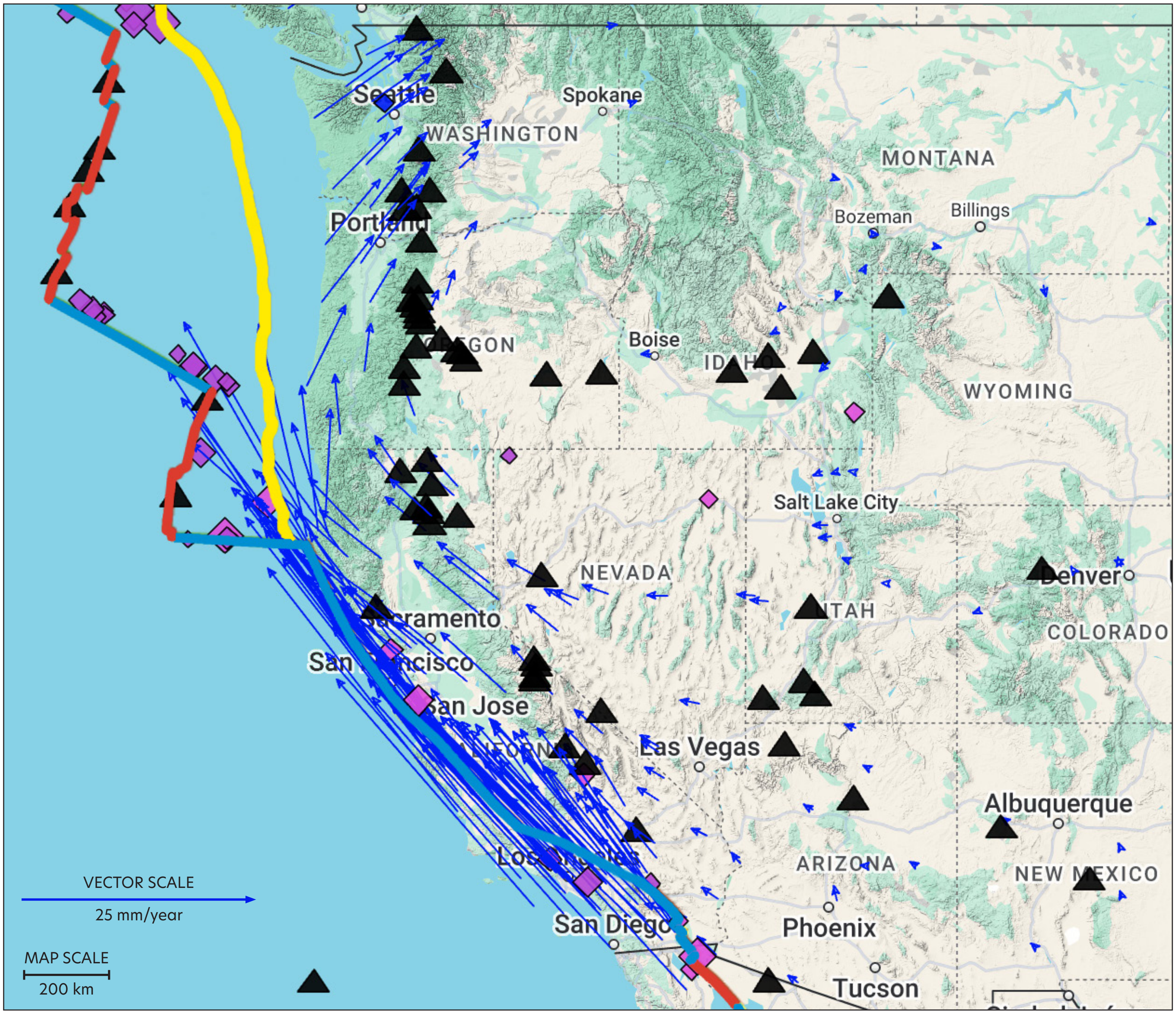

*Sources: Smithsonian (Volcano data), Google (base map)*

## WESTERN UNITED STATES — VECTORS ONLY




*Sources: EarthScope Consortium (GPS data), Google (base map)*

## WESTERN UNITED STATES — EARTHQUAKES, VOLCANOES, VECTORS, AND PLATE BOUNDARIES




*Sources: EarthScope Consortium (GPS data), USGS (Plate boundaries and earthquakes), Smithsonian (Volcano data), Google (base map)*

# APPENDIX K. NEXT GENERATION SCIENCE STANDARDS AND 3-DIMENSIONAL LEARNING

## NGSS ALIGNMENT

**Earth's Systems:** MS-ESS2-2, HS-ESS2-1
**Earth and Human Activity:** MS-ESS3-2, HS-ESS3-1
**Earth's Place in the Universe:** HS-ESS1-5

### PERFORMANCE EXPECTATIONS

- **MS-ESS2-2:** Construct an explanation based on evidence for how geoscience processes have changed Earth's surface at varying temporal and spatial scales.
- **MS-ESS3-2:** Analyze and interpret data on natural hazards to forecast future catastrophic events and inform the development of technologies to mitigate their effects.
- **HS-ESS1-5:** Evaluate evidence of the past and current movements of continental and oceanic crust and the theory of plate tectonics to explain the ages of crustal rocks.
- **HS-ESS2-1:** Develop a model to illustrate how Earth's internal and surface processes operate at different spatial and temporal scales to form continental and ocean-floor features.
- **HS-ESS3-1:** Construct an explanation based on evidence for how the availability of natural resources, occurrence of natural hazards, and changes in climate have influenced human activity.

### SCIENCE AND ENGINEERING PRACTICES

- Developing and Using Models (HS-ESS2-1)
- Constructing Explanations and Designing Solutions (MS-ESS2-2)
- Analyzing and Interpreting Data (MS-ESS3-2)
- Engaging in Argument from Evidence (HS-ESS1-5)
- Constructing Explanations and Designing Solutions (HS-ESS3-1)

### CROSSCUTTING CONCEPTS

- Scale Proportion and Quantity (MS-ESS2-2)
- Stability and Change (HS-ESS2-1)
- Patterns Graphs (MS-ESS3-2)
- Engaging in Argument from Evidence (HS-ESS1-5)
- Cause and Effect (HS-ESS3-1)

### CCSS.MATH.CONTENT.HSN.VM.A.1

(+) Recognize vector quantities as having both magnitude and direction. Represent vector quantities by directed line segments, and use appropriate symbols for vectors and their magnitudes (e.g., v, |v|, ||v||, v).

GAGE
SAGE
Operated by EarthScope Consortium