ShakeAlert™
ACTIVITIES FOR FORMAL AND INFORMAL LEARNING SETTINGS

GAGE SAGE Operated by EarthScope Consortium

GPS AND SLOW EXTENSION ACROSS THE BASIN AND RANGE PROVINCE

OVERVIEW

Ground deformation can occur along plate boundaries as well as within the interior of plates. Both are driven by processes within the mantle. An example of internal plate deformation is the extension and rifting observed in the Basin and Range Province that is located in Nevada, Utah, and California. This extension can be measured using the Global Positioning System (GPS).

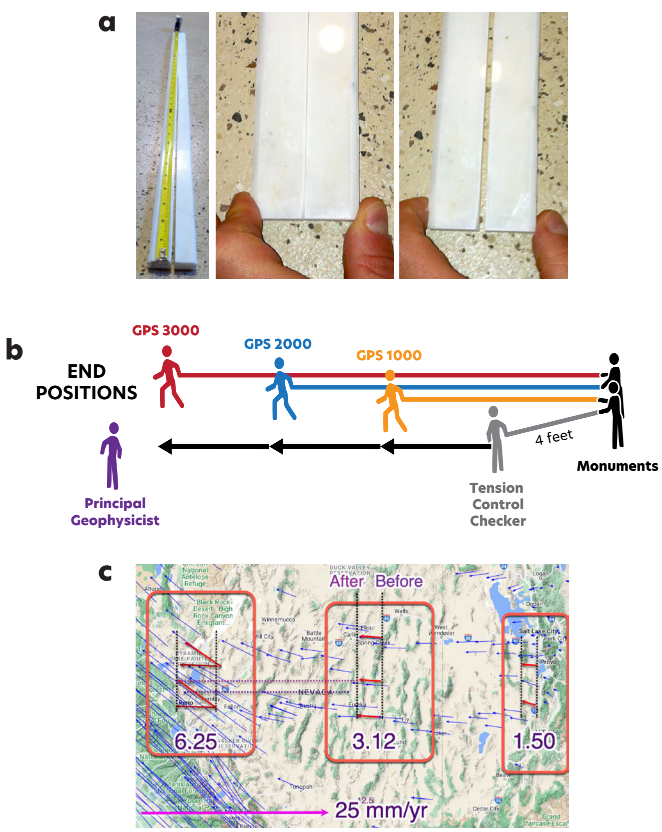


FIGURE 1. (a) The 5 Minute Activity marble tongs demonstration shows the elastic nature of rock. (b) This concept continues through the 20-25 Minute Activity kinesthetic model demonstration and (c) the 50 Minute Activity exploration using ground motion maps.

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 that can be adapted for audience and venue.

AUDIENCE. Novice and experienced geoscience learning groups.

SUBJECT. Natural Hazards: Earthquakes, Geoscience.

Based on Seeing IS Believing. Rocks Are Elastic! by Michael Hubenthal (EarthScope), inspired by John Lahr (USGS) and Rod Allen (DaVinci Academy).

CONTENTS

In the **5 Minute Activity**, learners observe a hands-on model, marble tongs, to explore how solid rock can deform elastically. They then kinesthetically model the extensional ground motion found in the Basin and Range Province in the **20-25 Minute Activity**. In the **50 Minute Activity**, learners explore quantitative measurements of this ground movement derived from GPS positions and represented as vectors. Additionally, they use earthquake hazard maps to explore the connection between deformation, seismic hazards, and societal impacts. A vocabulary list is provided in Appendix A.

Why is it important to learn about ground deformation and plate motions? Over 143 million people in the United States are at risk from earthquakes and accompanying hazards. Impacts range from little to no damage from mild shaking to extensive damage and loss of life during a major earthquake. It is important to identify areas where movement of the ground quickly changes across a region and where there is stored elastic energy as evidenced by GPS data, because these locations are more likely to be at risk from seismic hazards. The ShakeAlert Earthquake Early Warning System, which integrates GPS data, detects and processes earthquakes quickly so that warning alerts of impending shaking can be delivered to people as well as trigger automated actions that could protect people before strong shaking arrives, such as slowing trains and opening firehouse doors.

OBJECTIVES

Learners should be able to:

1. Describe how the elasticity of rocks is fundamental to deformation.
2. Explain that extensional forces within the interior of a tectonic plate can lead to ground deformation resulting in continental rifting.
3. Analyze and interpret GPS ground motion maps to determine relative speed and direction of regional ground movement.
4. Identify regions that face higher earthquake hazards using evidence from GPS.

MATERIALS

5 MINUTE ACTIVITY	20-25 MINUTE ACTIVITY	50 MINUTE ACTIVITY
☐ 2 or 3 marble thresholds (2" × 36") for the tongs (see Step 1 on page 6 for details). ☐ Rubber bands: 1 for instructor and 2-4 for your learner group ☐ Mini compression spring (cat toy): 1 for the instructor and 2-4 for your learner group ☐ OPTIONAL: A camera connected to a projection system may be useful to allow a large group of learners to see the demonstration. OPTIONAL EXTENSION ☐ Pieces of spaghetti to experiment with elastic rebound and brittle fracture	☐ Vector Components for Kinesthetic Activity (Appendix C) ☐ 4 × 4-foot-long very stretchy exercise elastic bands ☐ 1 per group: GPS ground motion vector maps (Appendix D) ☐ 1 per group: Rulers (mm scale), paper, binder clips ☐ OPTIONAL. 20-25 Minute Activity Handout (Appendix E)	☐ Materials from 5 and 20-25 Minute Activities ☐ 1 per group: Basin and Range map and western United States GPS ground motion vector maps (Appendix D) ☐ 1 per group: Seismic hazard maps (Appendix H) ☐ 1 per learner: Ruler (mm) ☐ 1 per learner: 50 Minute Activity Handout (Appendix F) ☐ Colored pencils (3 different colors) for each person

MEDIA RESOURCES

PRE-ACTIVITY

- Online Activity: Measuring Ground Motion With GPS: How GPS Works
- Video Tutorial: How GPS Measures Ground Motion (3:05)

5 MINUTE ACTIVITY

- Video: Elastic Rebound (1:21)
- Video: Elastic Rebound using a Yardstick (1:56)

20–25 MINUTE ACTIVITY

- Video Tutorial: Hands-on Demonstration How GPS Measures Ground Motion (3:05)
- Web Page: What is Geophysics? Geophysics, Seismology, and Geodesy
- Video: Basin and Range: Structural Evolution (1:04)

50 MINUTE ACTIVITY

- Web Pages: Introduction to the National Seismic Hazard Maps or USGS Site on Earthquake Hazards
- Web Page: What is Geophysics? Geophysics, Seismology, and Geodesy
- Education and Training Materials: ShakeAlert Educational Resources
- Web Page: How Do I Sign Up for the ShakeAlert Earthquake Early Warning System?
- Video: Earthquake Alert Times in the Pacific Northwest (5:46)
- Animation: ShakeAlert: Earthquake Early Warning System for the West Coast (4:35)
- Video: Earthquake! Steps to Take When it Strikes (3:03)
- Guide: "Prepare in a Year" (pdf)

TABLE OF FIGURES AND APPENDICES

FIGURES

APPENDICES

Learners will receive practice with reading maps and applying map and vector scales throughout these activities. It is recommended that instructors familiarize themselves with the Media Resources and Appendices listed on the previous page. Introduce new vocabulary (Appendix A) to meet learners' needs.

Rocks are elastic. In fact, all solids are elastic; we just don't notice the elasticity in solids like a pencil, a rock, or a steel beam as much as in something like rubber bands and springs, which are very elastic. When tectonic plates move, small amounts over long periods of time, the rocks they are made up of deform. This deformation, or change in size, shape, or volume of an object due to stress, is called strain. When these rocks deform elastically, like huge springs, they store potential energy. Then, when an earthquake occurs, the stored potential energy is released as kinetic energy (motion), heat (thermal), and acoustic energy (sound). Ground movement is recorded by seismometers and GPS sensors.

ABOUT GPS

The movement of the land is measured very precisely by GPS or other Global Navigation Satellite Systems (GNSS) (**Figure 2**). GPS satellites send signals to GPS receiving stations that are permanently anchored into rock or deep soil. If the ground moves, the GPS station moves with it. Any change in position is collected every tenth of a second, every day, to precisely measure the movement in three spatial dimensions (up-down, north-south, and east-west) 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 often 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 moved. Emphasize that the length of the vector is proportional to the speed the ground is moving, typically in millimeters per year.

ABOUT MODELS

In the following activities, models are used to represent concepts that cannot be directly observed in the classroom. Models are effective tools for illustrating ideas, though they have limitations compared to the real-world phenomena they depict. It's important to assist learners in identifying similarities and differences between the model and the actual concept to avoid misconceptions or confusion.

FIGURE 2. GPS Station P073 in TwinSpring, Nevada. 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*

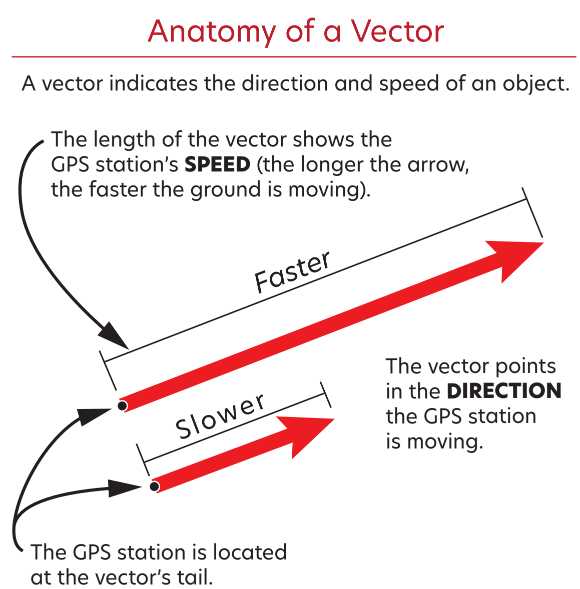


FIGURE 3. Anatomy of a vector. High-precision GPS stations attached to the ground collect data about the ground's motion at a specific location. A vector represents the speed (length of the vector) and the direction that a specific piece of ground is moving. See Appendix B for a larger version to display.

PRE-ACTIVITY

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

- Show plate motions with hand movements and vectors using The Subtleties of Plate Boundary Motion section of Appendix B.
- Online Activity: Measuring Ground Motion With GPS: How GPS Works or Video Tutorial: How GPS Measures Ground Motion (3:05)

IF YOU HAVE 5 MINUTES

"DID YOU KNOW?" DISCOVERY QUESTIONS

Did you know that rocks, rubber bands, and springs can deform elastically?

What happens when you bend a rock?

The way that rocks respond to stress is a fundamental concept, critical to forming explanatory models in the geosciences (e.g., elastic rebound theory). While learners are likely to have lots of experience with rocks, few will have directly experienced them behaving elastically. As a result of this "missed experience," most learners conceptualize rocks as rigid solids, a concept that generally serves them well in everyday life but impedes learning some geologic concepts. We don't notice that rocks and other solids are elastic, because it typically takes a long time for rocks to bend. However, it is possible to bend rocks to demonstrate their elastic properties in the classroom.

In this **5 Minute Activity**, learners observe and feel the elasticity of a rock using a long, narrow marble tong, like a springless clothespin. Pinching and releasing the notched end allows learners to directly "see and feel" that rocks do deform and return to their original position. This direct experience challenges and changes their preconceptions of rocks. They compare and contrast their marble tong observations to those of a rubber band and compression spring. While rocks, rubber bands, and springs can deform elastically, their elastic properties are not similar.

INSTRUCTOR PREPARATION

BEFORE LEADING THIS ACTIVITY

1. Create a set of marble tongs for your instructional environment (see next section for directions).

2. Watch a demo of this marble-tong activity in John Lahr's explanation of elastic rebound: Elastic Rebound—Earthquake Machine & Rocks-Can-Bend Demo (1.21). He demonstrates squeezing the sides of the rock together, and when he lets go, the sides spring back to their original positions. This ability to deform and then spring back is the definition of something being **elastic**.

CONSTRUCTION OF MARBLE TONGS

1 Homogeneous and fine-grained natural stone such as marble (or engineered fine-grained stone such as a silestone product will work). These can be found in the flooring or bath sections of most "big box" home improvement stores. Sold as a threshold (e.g., 36'' long × 2"–4'' wide × ½'' thick), this marble is an off-the-shelf item available for less than $20. Alternatives to try are marble tile and other engineered tiles, such as 12'' × 24'' marble floor tile.

TIP: Fine-grained samples will tolerate more use than samples with larger mineral grains, and/or other heterogeneities. Despite this, having several on hand is strongly recommended as the tongs will eventually wear out and fracture unexpectedly.

2 Cuts to make using a wet saw (**Figure 4**).

NOTE: If you don't have a wet saw, many "big box" home improvement stores have the equipment to cut tile in-house and will do several cuts for free. Or, a countertop shop may make the cuts for you for a small fee.

a. Start by cutting four 2'' long pieces off one end of the threshold as illustrated in **Figure 4** (cuts marked a–d). These pieces will become hand samples to pass around the class.

TIP: Most marble thresholds, or even scraps from countertops, will have smooth edges and polished surfaces. The presence of these human-made alterations has been shown to lead younger learners to believe that marble is human-made rather than naturally occurring. To overcome this misconception, hammer the edge of the hand samples to expose the "raw" inside edges before passing them around.

b. Next, cut a lengthwise slot, 22'' long in the threshold as illustrated in **Figure 4** (cut marked e). This will leave several inches of uncut material at the end.

3 Your "marble tongs" are now finished!

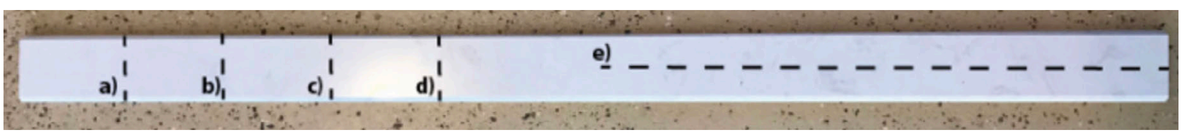


FIGURE 4. Cutting guide for the marble tongs demonstration. Dashed lines [a] through [d] indicate cuts to create hand samples to pass around the room. Cut [e] is made lengthwise to notch the threshold like a spring-less clothespin.

STRENGTHS AND LIMITATIONS OF THE DEMONSTRATION

Although this demonstration has a number of strengths, you will also want to be mindful of its limitations and address those explicitly with learners.

- **STRENGTH:** The demonstration provides a direct experience with marble deforming elastically. **LIMITATION:** The demonstration uses only one type of rock.
- **STRENGTH:** Various types of stress can be demonstrated: compression by squeezing the tongs together, tension by pulling them apart. **LIMITATION:** The scale of this demonstration is much smaller than the deformation that occurs as a result of plate tectonic motions.
- **STRENGTH:** The tongs can also demonstrate brittle failure of rocks in Earth if an arm breaks during the demonstration. **LIMITATION:** The scale of brittle deformation shown with the tongs is much smaller than what occurs as a result of plate tectonic motions.

NOTE: Keep a backup set of tongs handy.

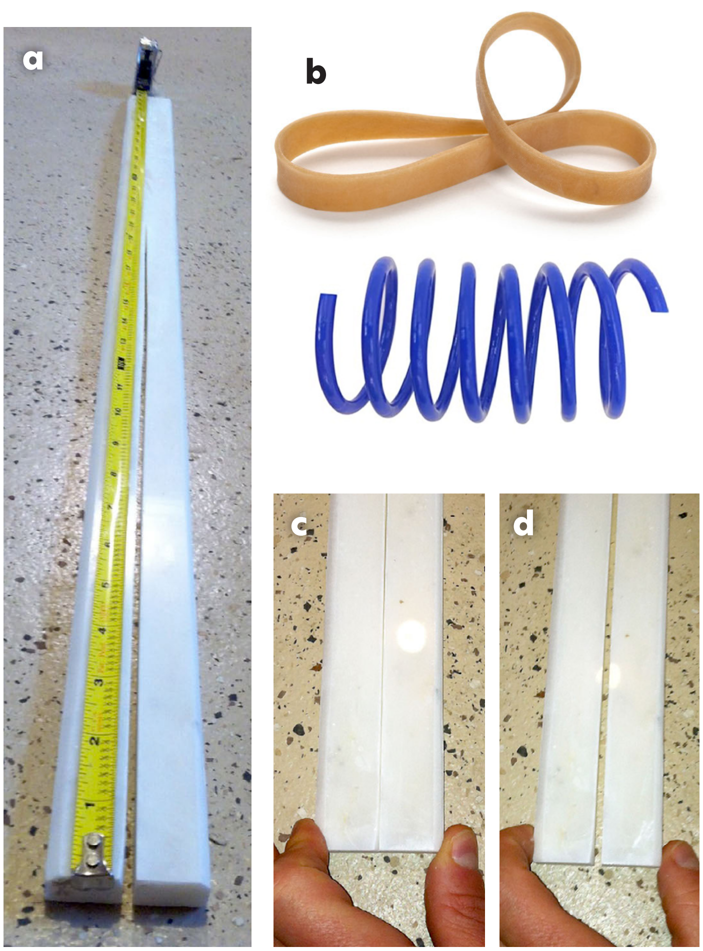
DIRECTIONS FOR LEADING THE ACTIVITY

1 Ask: **"What happens when you bend a rock?"** ***ANSWERS WILL VARY:*** *If you bend a slab of rock, it will fracture. Some rocks will bend and stay bent. Most students will say that rocks do not bend.*

2 Draw attention to the "Did You Know" question: **Did you know that rocks, rubber bands, and springs can deform elastically?** You may need to introduce the term "elastic."

3 Begin by holding up a small hand sample of marble. Ask learners what it is, and lead them to conclude it is a rock. Probe to elicit learners' ideas about rocks by asking learners to explain why they believe what they do.

4 Show, pull, and push on a rubber band and a compression spring (**Figure 5b**). Ask learners how these are similar and different to marble.



5 If there is time, pass around the small rock samples, rubber band, and spring. In your own words say, "Before I show you that I can bend rock with just these two fingers, I want you to try."

- **a.** Ask: "Can you bend a rock? What does this rock feel like?" ***ANSWERS WILL VARY:*** *Many learners will say no.*

  NOTE: Make sure learners are aware of any consequences for deliberately shooting a rubber band or the spring at someone.

6 Next, ask learners if they think you could deform a piece of marble with your fingers only and have it spring back to its original shape when you let go.

7 Introduce the marble tongs (**Figure 5a**) to the learners and indicate that they are made from the same, or similar, rock as the hand sample.

NOTE: If there is time, walk around the room with the tongs, allowing learners to feel the unnotched end so all learners can see and physically feel that the material is similar to the rock they just touched.

8 Next, flex and release the marble tongs elastically in class for learners to see (**Figure 5c,d**). Better yet, circulate with the marble tongs to allow learners to pinch the tongs closed and watch it spring back to its original position when they let go.

- **a.** You are filling in an experience with rocks that most learners do not normally have. Point out that when the tongs are pinched there is a maximum deformation that can occur as the tongs close.

  WARNING: Make it clear that they may only squeeze the tongs, not expand the tongs outward. The outward stress on it will break the tongs.

FIGURE 5. (a) Marble tongs and (b) rubber band and mini compression spring. (c) Stress is applied to the cut end of the marble tong, deforming the marble when closing the tongs. (d) When stress is removed, the marble springs back as the stored energy is released.

9 **OPTIONAL:** Discuss the demo and show the images of rock deformation in Appendix B (see **Figure 6** for reference):

a. When you pinch the tongs, you apply stress, a force/unit area, to the tongs. The stress is compressional stress as you squeeze the open end of the tongs together.

b. In response to the stress, the tongs deform or change shape. Energy is stored in the tongs as potential energy.

c. When you release the ends of the tongs, you remove the stress and the deformation is reversed as the ends return to their original position. In this process the tongs return to their original position.

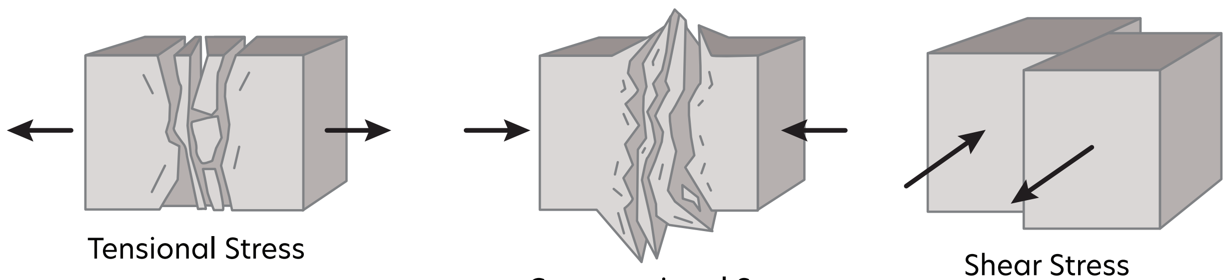


FIGURE 6. Deformation of rock due to different types of stress. Modified from Michael Kimberly, North Carolina State University.

EXTENSION

1 **If the tongs break during the demonstration:** There is a possibility that the marble tongs will break during the demonstration. If they do, that is also a teachable moment due to the element of surprise. Discuss that the tongs breaking is similar to an earthquake in rocks. If the tongs don't break, and you don't foresee needing them for a future demo, this could be a great way to actually demonstrate an earthquake occurring. For example, if you were to place an iPhone on one end with an accelerometer app running, you would certainly record the seismic waves from the break.

a. If learners wish to explore elastic-brittle concepts more, the video Elastic Rebound Demonstration Using a Yardstick (1.56) is a good follow-up to help show that objects can be both rigid and elastic.

2 Finally, build on learners' new experience with rocks. Begin by introducing the concept of **elastic response** to stress as a name for the rock's behavior. Most learners will be familiar with the concept of elasticity and will be able to give examples (e.g., rubber bands, springs, or balls.)

a. Have learners use their hands to demonstrate the stress applied to the tongs. What are the directions of stress being applied to the tongs? How do the tongs deform in response to the stress? *Learners should indicate and describe that the stress is pushing inward while the rock tong arms are being pushed together. The rock of the tongs bend elastically.*

b. Ask learners:

- When the stress is released, how do the tongs respond?
  ANSWERS MAY VARY: *The arms of the tongs return to their original position.*

- What common objects might show a similar response to stress and its removal?
  ANSWERS MAY VARY: *A rubber band can be stretched (tensional stress) and a spring can be compressed. As long as the stress is applied, it will be deformed, but when the stress is removed it will return to its original shape.*
- Would rocks always behave in this manner? What might make a rock break rather than deform elastically? What would be represented by one rock tong arm breaking?
  ANSWERS MAY VARY: *Lead learners to the idea that not all rocks have the same strength and so break when different amounts of stress are applied. They also tend to break when strain rates are high. Think about breaking or bending a twig.*
- Can rocks bend permanently?
  ANSWERS MAY VARY: *Show Figure 7 and mention this type of ductile deformation (folding). All rocks are elastic, though their degree of elasticity will vary depending on the type of rock, the bonding between particles, and the temperature and pressure conditions that they are subjected to. Rocks at the surface are unlikely to bend; however, many kilometers below the surface, rocks can bend because of the high pressure and temperature.*

FIGURE 7. Folded rocked from the Permian in New Mexico, USA. The rock was deep beneath Earth's surface when the deformation occurred. At great depth, high pressure and temperature softens the rock and allows the layers to bend and fold. *Source: James St. John; https://commons.wikimedia.org/wiki/File:Folded_gyprock.jpg*

IF YOU HAVE 20-25 MINUTES

"DID YOU KNOW?" DISCOVERY QUESTIONS
Did you know that a tectonic plate can stretch?
How can the ground stretch?

INSTRUCTOR PREPARATION

Regions within and between plates can move at different rates and in different directions, causing stress to build between these regions. Scientists use GPS stations to measure the movement of many locations over time to determine the likelihood of seismic activity in a region.

In this activity, learners will be able to infer that different strain across the Basin and Range Province of the western United States is the result of changing ground motion velocity. They will establish that measuring the velocity with GPS stations helps scientists explain that extensional forces acting over a long period of time result in rifting and associated earthquake activity. The GPS data also reveal regions with a higher likelihood of future seismic events.

BEFORE YOU BEGIN

1. Prep for the **5 Minute Activity**.
2. Review the background information in Appendix B.
3. Watch the video Basin and Range: Structural Evolution (1.04).
4. Review the web page What is Geophysics? Geophysics, Seismology, and Geodesy.

PREPARE THE MODEL

1. Print and copy the vector parts to make three sets of 3-foot vectors (Appendix C). Ideally, laminate the vector parts to make them more durable or make extra copies, as learners will be walking on them.
   ALTERNATIVE: Use blue painter's tape to make vectors.
2. Project the Basin and Range Ground Motion Map (from Appendix D) to help you determine where to place the vectors on the floor (**Figure 8a**). The learners will be modeling the strain buildup across the Basin and Range from eastern Utah to the California/Nevada border.
   NOTE: It would be optimal if instructors could tape the vectors on the floor in front of where this map will be projected.
3. Referring to the projected Basin and Range map on the screen, mark a spot on the floor that corresponds to the fixed monuments on the border of Colorado and Utah; these monuments are not moving and will be where two learners will be standing (**Figure 8b**).
4. Approximately 4 feet away from these monuments, tape three 3-foot long vectors to the floor (**Figure 8c**). Lay them out head to tail in a straight line pointing "west" (each vector represents 20 feet of movement per 1000 years). See **Figure 8a** for the layout of the model. The vectors at the California/Nevada border are each 3 feet in length.

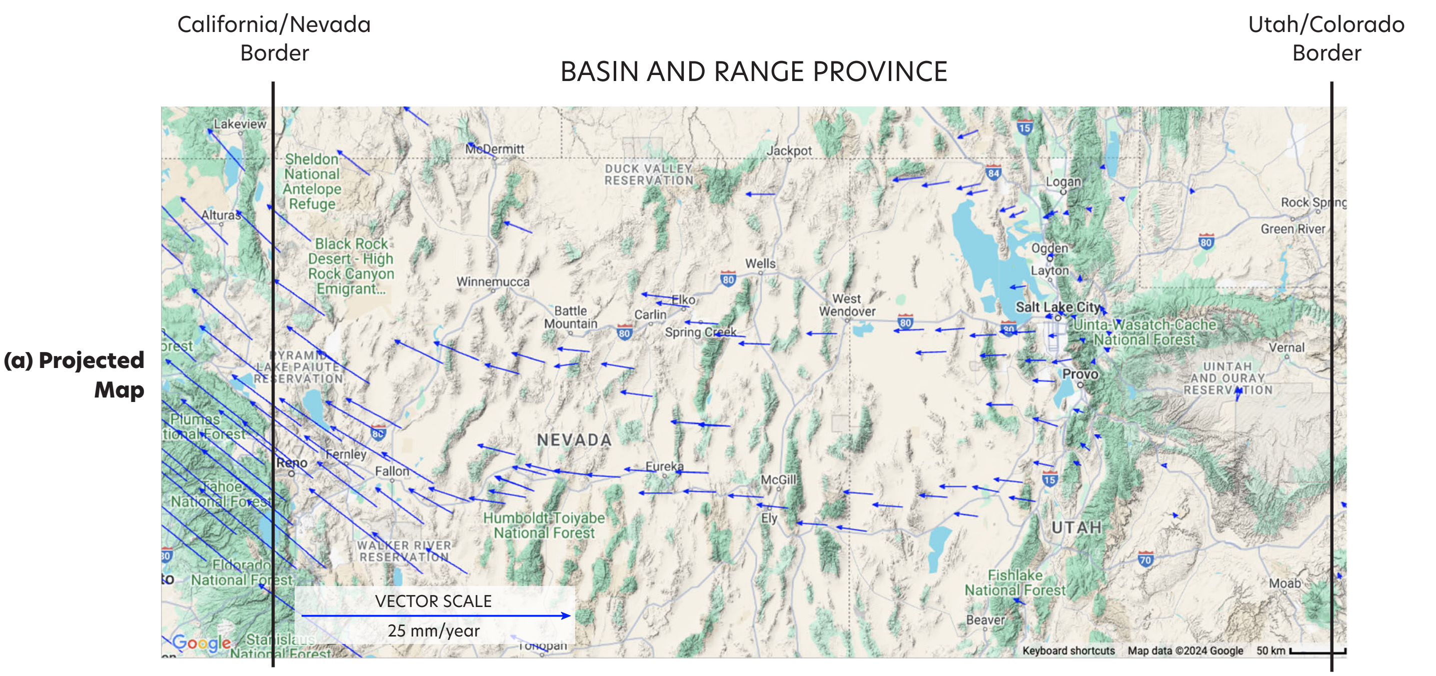
5 Cut 4 elastic exercise bands of the SAME color elasticity/density to equal lengths.

- **a.** Bands must be at least 4 feet long but cut so they can be stretched to 13 feet without becoming dangerously tight and so volunteers can still hold them.
- **b.** Yellow extra-light exercise bands are recommended, as they are very stretchy (the color for extra-light bands may differ depending on the brand).
- **c.** **SAFETY CONSIDERATION:** Be careful not to make the band too tight when stretching it to 13 feet to decrease the likelihood that it will snap back at the volunteers holding the ends. Do not add or include any metal on the bands or tubes.

6 Prepare for projection or print the Basin and Range Ground Motion Map (from Appendix D) ***or*** set up to show the video Basin and Range: Structural Evolution (1.04) so that all learners can see and hear it.

7 OPTIONAL. Print and make copies of the 20-25 Minute Activity Handout (Appendix E) if this fits your instructional environment. The instructor answer key is available in Appendix G.

- **a.** Provide 3 different colored pencils and a ruler to each learner.
- **b.** Adaptations for visually impaired learners: use 3 different types of writing utensils (i.e., colored pencils, crayons, and small felt markers) to make it easier to distinguish between the lines, or use different types of lines or line thickness.
- **c.** **NOTE:** Allow time for learners participating in the demonstration to complete the handout questions.



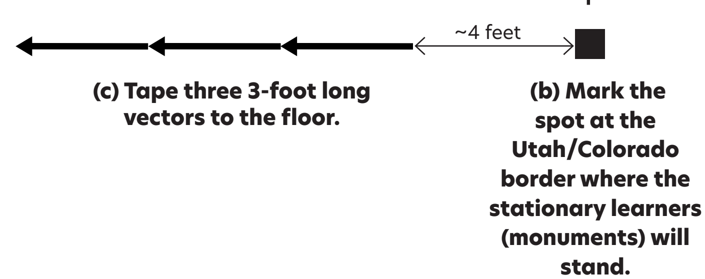


FIGURE 8. Lay out of model. (a) Projected map. (b) Mark for the monuments. (c) Vectors taped to floor. Using the ground motion map to determine where to place the vectors on the floor. ON THE MAP. Extension begins in eastern Utah and ends near the border of California and Nevada. Earthquakes occur across the full region (as normal fault/rifting). Rifting occurs across these states, mostly throughout Nevada, due to the extensional forces created by the stretching of the lithosphere from rising magma in the mantle and the tectonic forces from the movement of the Pacific plate. Note: the vector scale is 25 mm/year.

DIRECTIONS FOR LEADING THE ACTIVITY

PART A. INTRODUCTION TO ACTIVITY

1 Complete the **5 Minute Activity** to demonstrate that rocks are elastic.

2 Explain that, in the next demonstration, you will need 7 volunteers. They will be modeling how the ground moves and feel how the forces within the crust are affected by this movement.

3 Show the image "What GPS Can Tell Us About Earth" in Appendix B and **briefly** explain how GPS works. **NOTE:** Refer to the Instructor Background and Preparation section and Appendix B for more information on GPS.

4 Draw attention to the "Did You Know" question, **Did you know that a tectonic plate can stretch?,** and then to the 3 large vectors on the ground.

a. Project the ground motion Basin and Range map in Appendix D (refer to **Figure 8**).

b. Discuss that across the Basin and Range the land is moving toward the west but at different speeds. Point to the vectors on the map and point out (or ask what they observe on the map) that the speed is very slow in eastern Utah and is much faster on the western edge of Nevada.

c. Remind learners that speed is a distance over a period of time.

d. Hand one of the elastic bands around and direct learners to stretch the band and gently let it go back to its non-stretched state. Ask learners to describe what they notice.

ANSWERS WILL VARY. *Learners should notice that the band is stretchy; the longer or further it stretches, the more tension there is; that loosening the tension, the band goes back to its original shape.*

NOTE: Make sure learners know the consequences of snapping the elastic band at others.

PART B. SETTING UP THE KINESTHETIC MODEL AND EXPLANATION OF LEARNER ROLES (~5 minutes)

1 Choose seven individuals to volunteer for this activity. Three to model GPS stations, one to be a Tension Control Checker, two as Monuments, and one as the Principal Geophysicist. All other learners will be Geophysicists and will make observations.

2 Ask two volunteers to stand at the spot marked as the border of Utah and Colorado (refer to **Figure 9**). These individuals will be the Monuments.

a. Instruct each Monument to hold one end of two elastic bands.

b. Once the GPS Station learners (explained in the next step) start walking, the Monuments will need to hold their end tightly for as long as they can. If it gets too hard to hold, they can **gently** let go, making sure to NOT let it snap back at their partners.

c. The Monuments must stay stationary and try to keep holding their ends of the elastic bands through the whole demonstration.

3 Ask one person to be the Tension Control Checker. They are in charge of keeping a constant tension on a separate band that extends from one of the Monuments and the start of the first GPS Station (GPS 1000) located at the tail of the first vector. (Refer to **Figure 9**)

NOTE: This elastic band is used as a control so resultant forces inferred from GPS motion can be compared to an initial force.

4 Ask three volunteers to portray the GPS Station through time. Each represents the movement of the same GPS Station over 1000 years. GPS 1000 is the GPS from now through 1000 years; GPS 2000 is the GPS from 1000 years to 2000 years; and GPS 3000 is the GPS from 2000 to 3000 years.

a. Position one GPS Station at the tail of each vector. They are lined up like a relay race. (Refer to the start positions in **Figure 9**)

b. Instruct GPS 1000 to hold the ends of three elastic bands. The opposite ends of the 3 bands are being held by the Monuments. The fourth band is being held by the Tension Control Checker.

5 Tell the GPS Stations they will each have to reach the arrow head of their vector, at the pace of 1 clap or 1 count per second while holding onto the elastic band. They must reach the end of their vector at the end of the second clap or count. (Refer to the end positions in **Figure 9**.)

a. Explain that each clap represents 500 years. Each person moves a total of 1000 years (2 claps) along their 3-foot vector.

b. Have them practice the motions. Explain that they have to keep moving forward, and all end at 2 claps or counts. *They cannot get to the arrow head and then wait. They cannot move forward and then back. They can only move forward ideally at the same pace for both steps.*

6 When instructed, use clapping or counting to guide the learners' movement. (Refer to the end positions in **Figure 9**.)

a. GPS 1000 will take two steps to reach the end of the 3-foot vector (top of the arrow head). They then hand off 2 of the elastic bands to GPS 2000 (think of a relay). GPS 1000 continues holding one band and remains stationary.

b. GPS 2000 will take two steps to reach the end (using the claps for timing), and will then hand off one band to GPS 3000. GPS 2000 continues holding one band and remains stationary.

c. GPS 3000 will take two steps to the end of their vector.

d. The GPS Stations must continue to hold their bands while they wait for the Principal Geophysicist to "measure" the forces (tension) of the elastic band (described in Step 7).

7 The Principal Geophysicist will check and describe the tension of each elastic band starting with the Tension Control Checker.

8 Meanwhile, the remaining learners (Geophysicists) will be observing the process and noting the differences in the resulting tension in each elastic band.

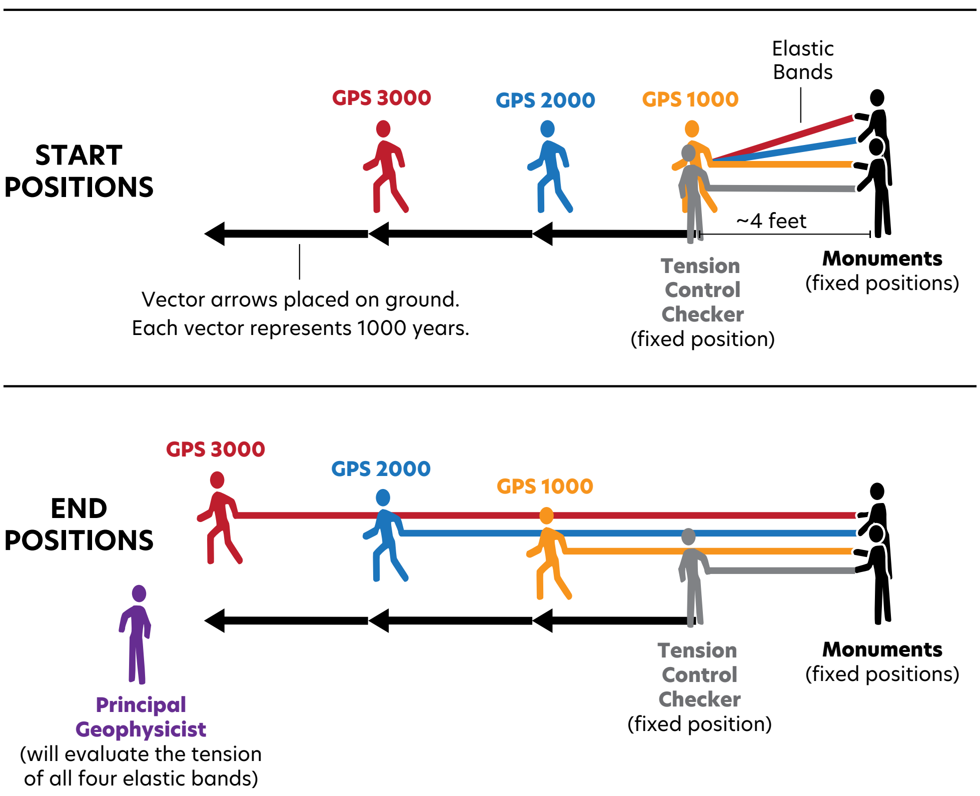


FIGURE 9. Setup of learners for modeling extension across the Basin and Range. Very light exercise bands are recommended. The top shows the start positions, and the bottom shows the end positions of each person after 3000 years. The elastic bands have different colors to illustrate the stretch of the land over 3000 years. Western Nevada is moving 6.25 mm/year. Over 3000 years, if no earthquakes occur, the land will stretch by nearly 18.75 meters or 61.5 feet.

PART C. RUNNING THE KINESTHETIC MODEL (~15 minutes)

1 After the GPS Stations practice moving to the claps, have all of the volunteers stand in their starting and observing positions.

2 Ask the entire group of learners to describe the model.

a. What do the vectors taped to the floor represent?
Each vector represents the speed and direction the land is moving. They are all the same length.

b. What does the tail of the vector represent?
The initial position of the GPS station.

c. What do the Monuments represent?
The Monuments represent fixed monuments not moving at the border of Colorado and Utah.

d. What does the elastic band held by the Tension Control Checker represent?
The elastic band is the background tension so that the observers can compare how the tension is increasing after 1000, 2000, and 3000 years of extensional movement.

e. What does each GPS Station person represent? What will they be doing?
Each GPS Station represents the movement of one GPS Station over 1000 years. One after the other, they will walk to the end of their vector on the floor by the end of 2 counts or claps. Like a relay race.

f. What do the elastic bands represent?
The stretching of the land. The land is getting stretched over 3000 years in this model. The length of each band held by the GPS's represent 1000, 2000, and 3000 years of total movement.

g. What is the Principal Geophysicist doing during the demonstration?
They are checking on the tension changes on the elastic bands for each starting and ending GPS position.

h. Have the Principal Geophysicist check the elastic bands and relay how they feel to the other geophysicists.
They should feel slightly taut. All four bands have the same level of light tension.

i. What is the rest of the learning group doing?
Observing the speed of each GPS Station and how the bands are changing tension.

3 Do a final run with observers all clapping together.

a. If one of the bands breaks or one person lets go due to increased tension, ask what this represents.
An earthquake.

4 As the Monuments and GPS Stations are standing at their ending positions, **direct the following questions to:**

a. Tension Control Checker: How has the tension of your "control" band changed (or has the tension of the control band changed)?
It hasn't changed tension.

b. GPS Stations and Monuments: How does the tension on their bands feel now? How has it changed?
Tension increases.

c. Principal Geophysicist: Have them check the tension of each elastic band and report on the differences between them.
They should confirm what those holding the bands feel. The tension on the shortest distance is the lightest while the band on the furthest distance is the most taught.

d. Geophysicists (the entire learning group): What did you notice about the tension in the elastic bands?
The further the GPS walked, the stronger the tension on the elastic band became.

e. Guide with additional questions as needed:

- What do you notice about the elastic bands that makes you think this?
  Refer to what the observers saw regarding the tautness of the bands.
- Mention how the scientists are making conclusions from data (their observations).
  Make the connection that they are making inferences from the data (observations).

5 **SUMMARIZE THEIR OBSERVATIONS:** The GPS near the border of California and Nevada moved over a 3000-year period. Because each vector represents 20 feet of movement per 1000 years, this GPS would have moved over 60 feet. (If the mid-Nevada vectors were also modeled, their total distance would be around 30 feet in 3000 years)

6 **QUESTION TO ALL**

a. Which band is most likely to break? Why?
The band held by GPS 3000.

b. When it breaks, what does this represent?
Earthquake.

c. Bonus thought question: Where would the earthquake most likely occur?
We can't really tell if there's only one monitoring station (California)...it could happen anywhere in the Basin and Range. If the mid-Nevada GPS station were also modeled, then we've "constrained" the likely location to the western portion of Nevada. Learners will explore seismic hazards in the 50 Minute Activity, Part C.

d. Ask, does this seem realistic? (Optional exploration of historical earthquakes in the Basin and Range.)

7 Direct the GPS 3000 to take 2-3 steps in a diagonal direction from the arrow head to represent the changing directions in that region (left or right depending on how much room there is).

a. Ask all, what happened to the tension in the band?
The tension gets stronger.

b. Connect this to the change in direction also increasing. Refer to the vectors on the map at the Nevada/California boundary, point out how these vectors are pointing mostly west and slightly to the north.

8 Volunteers can be seated at this point.

PART D. PUTTING IT ALL TOGETHER (~5 minutes)

1 OPTIONAL. Distribute the 20-25 Minute Activity Handout and colored pencils. Have the learners write their observations on the handout or give them a blank piece of paper.

2 Show the video Basin and Range: Structural Evolution (1.04).

3 **QUESTION TO ALL**

a. What have our volunteers modeled today?
The GPS and ground movement due to extensional forces that created the rifting seen across the Basin and Range Province.

b. How is this model like the actual events that took place to create this region?
Extensional forces increase as the ground movement in one region speeds up or changes direction or both (longer vectors) relative to an adjacent region. Learners holding the elastic bands feel the increase in extensional force as the band stretches with each step. When the extensional force exceeds the strength of the rocks, the rocks will break—converting the potential energy to kinetic energy that is released in an earthquake.

c. How is this model unlike them?
The ground in the model moves much faster than actual ground movement in the Basin and Range; rifting happens over hundreds of thousands of years. Thus, you cannot see actual rifting occurring because it takes so long. If we get an "earthquake" in this demonstration, it's just the bands breaking or someone letting a band go. Earth is not actually shaking.

4 Focus learners' attention again to the Basin and Range ground motion map (**Figure 10a**).

a. Ask learners: what do you notice about the topography?
Answers may vary, but they should say there are a lot of ridges/smaller mountain ranges in Nevada; it looks wrinkled.

b. Direct learners to compare what the animation said with what they are seeing on the map. Focus on where the vectors are going.

Vectors show a northward turn on the west because of the transverse movement along the San Andreas fault as the Pacific plate and North American plate slide past each other.

c. Direct learners to compare the topography on the Basin and Range map to the cross section of extension image (**Figure 10b**).

d. Direct learners to use different colors to shade in the following areas on the map (**Figure 10a**) and use the same colors to shade the corresponding regions in cross section image (**Figure 10b**).

- The Wasatch Utah/Colorado border
- Basin and Range in Nevada
- Sierra Nevada Mountains on the California side

e. Make it a point that these mountain ranges took millions of years to form, and the ground is still moving.

5 Focus on the vectors on the map (**Figure 10a**). Discuss the northward motion that the vectors show near eastern California. How does the Earth movement, as depicted by the vectors, add to the earthquake hazard?

The vectors display not just an increase in speed, but also a change in direction in eastern California. In this region, additional shear and compressional forces are present because the Pacific plate is pushing into the North American plate. Frictional forces are at work here, too; the faults stick (build up potential energy) until the frictional forces between the two sides of the fault are overcome. An earthquake occurs when this potential energy is released and converted into kinetic energy (motion), heat (thermal), and acoustic energy (sound).

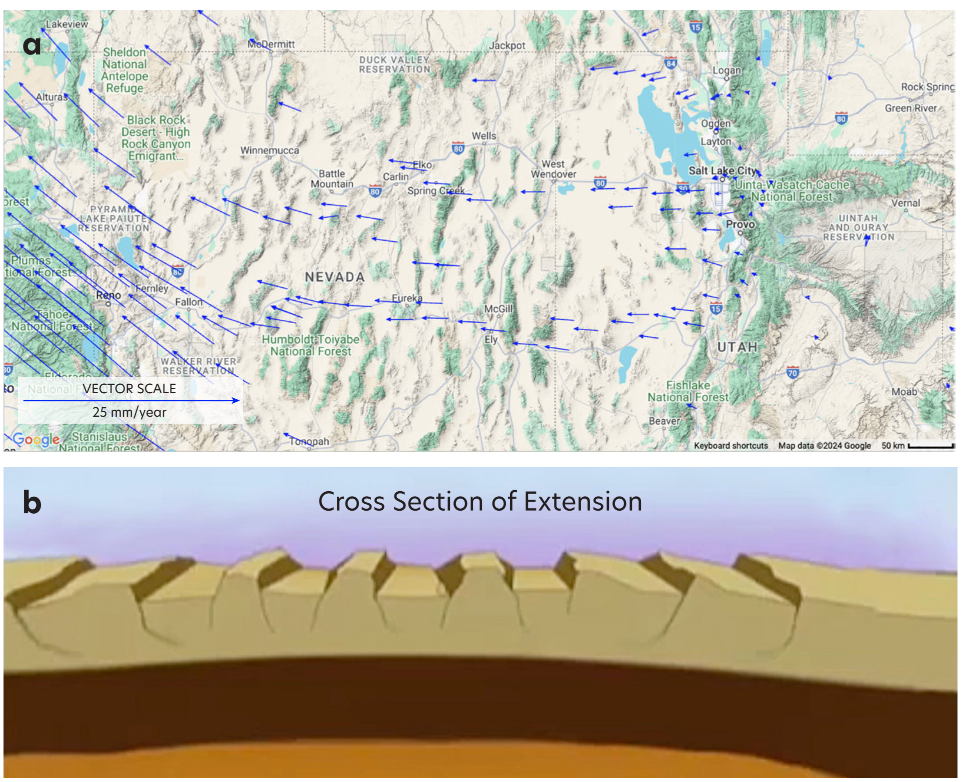


FIGURE 10. (a) Basin and Range ground motion map with (b) a cross section of extension illustrating the structure of the topography. Available in larger size in Appendix D.

ALTERNATIVE SET UPS

1 Set up a second group of learners to model extension across mid-Nevada. The land in mid-Nevada is moving at half the speed of western Nevada. Rather than using 3-foot vectors (representing 6.5 meters/1000 years), use vectors that are 1.5-feet long (representing 3.25 meters/1000 years). Multiple groups could move at the same time, or do each vector length separately. Learners compare the tension after 3000 years of extension in mid-Nevada to tension in the elastic band of the group demonstrating Western Nevada near the border of California.

a. Tape three 1.5-foot-long vectors, head to tail, pointing west, similar to **Figure 9**.

b. Prepare 4 elastic bands, approximately 4–7 feet long. Use the same color as used in the main activity.

2 Have multiple groups do the same thing at the same time. You will need more vectors taped to the floor and more bands. This will take more time to prepare the learners since there will be more of them to manage.

a. More learners will be engaged and will be able to feel the tensional forces created by the elastic bands.

b. You will need a strategy for class management.

- Give bonus points or some other reward for good behavior, staying on task, and getting things done without incident.
- Instruct some volunteer learners on what you will be doing before the planned day. On the day of the activity, have them be group leaders so they can help their group. (They may still need to follow along with your guidance, but they will be able to pull from their previous experience to help with any confusion.)

EXTENSION

1 Ask learners to draw what they think the Basin and Range looked like before expansion and rifting began.

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

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

IF YOU HAVE 50 MINUTES

"DID YOU KNOW?" DISCOVERY QUESTIONS
Did you know that changes in velocity within a plate can increase earthquake hazards? How might GPS data help geologists identify hazards?

Earthquake hazards increase where adjacent regions within and between tectonic plates move. The more pronounced the differences in speed, direction, or both, the greater the earthquake hazard. Using the marble tongs in the **5 Minute Activity**, learners begin with the concept that rocks are elastic. They then move to the **20-25 Minute Activity** using a kinesthetic activity to model the extensional forces in the Basin and Range Province and discuss strengths and weaknesses of the model. Learners will then compare their observations to the GPS ground motion map of the Basin and Range Province, noting the longest vectors are closest to its western edge of Nevada near the California/Nevada border, and the vectors decrease in length as they look further east (toward eastern Utah). Referring to the ground motion map as evidence, learners will identify the regions with the highest seismic hazard. Finally, they will discuss earthquake preparedness strategies, including enabling ShakeAlert-powered alerts on cell phones.

INSTRUCTOR PREPARATION

1. Prepare for the **5 Minute Activity**.
2. Prepare for the **20-25 Minute Activity**, but do not print the 20-25 Minute Activity Handout.
3. Print and copy the 50 Minute Activity Handout (Appendix F). The instructor answer key is provided in Appendix G.
4. Print a full size Basin and Range ground motion map (found in Appendix D) on 8.5 x 11-inch paper. If possible, laminate the maps and have enough copies available for pairs or groups, depending on how the instructor organizes their instructional space. **ALTERNATIVE.** Use sheet protectors and guide learners to keep the maps in the sheet protectors.
5. Print in color (color is needed for the key) or prepare to display the seismic hazard maps for California, Nevada, Utah, and the United States (found in Appendix H).
6. Refer to the following web page about what geophysicists study: What is Geophysics? Geophysics, Seismology, and Geodesy.
7. EXTENSION: Demonstrate the liquefaction example from the online activity: Geologic Hazards Related to Earthquakes: Identifying Geologic Hazards in Your Community. In this activity, learners view a demonstration of liquefaction, a process by which shaking (e.g., during a large earthquake) makes loosely packed, water-saturated soil act like a fluid. Liquefied soil loses strength as grains separate and become suspended in the soil-water matrix, reducing the soil's load-bearing capacity.

DIRECTIONS FOR LEADING THE ACTIVITY

PART A. MOTION AND DEFORMATION WITH EXTENSION FORCES (~20 minutes)

1 Complete the **5 Minute Activity**.

2 Complete the **20-25 Minute Activity** stopping at the end of Part C Step 8. Volunteers can be seated. **NOTE.** Do not print/distribute the 20-25 Minute Activity Handout. You will be using the 50 Minute Activity Handout for this activity.

3 Show animation Basin and Range: Structural Evolution (1.04).

4 Ask learners: What have our GPS Station volunteers modeled today?
The GPS and ground movement due to extensional forces that created the rifting seen across the Basin and Range Province.

5 Give each learner a blank piece of paper. Ask learners the questions below. Give them a few minutes to think about them and jot down their ideas and confer with their neighbor, before you ask for verbal responses. Have them think about each role and part of the model: the GPS Stations, Monuments, Tension Control Checker, and Principal Geophysicist, and the elastic bands and vector arrows. This will help solidify their ideas and also, give them notes to refer back to when they answer Question 12 on the 50 Minute Activity Handout.

a. How is this model like the actual events taking place to create this region?
Extensional forces increase as the ground movement in one region speeds up or changes direction or both (longer vectors) relative to an adjacent region. When the extensional force exceeds the strength of the rocks, the rocks will break—converting the potential energy to kinetic energy that is released in an earthquake. Learners holding the elastic bands feel the increase in extensional force as the band stretches with each step.

b. How is this model unlike them?
The ground in the model moves much faster than actual ground movement in the Basin and Range; rifting happens over hundreds of thousands of years. Thus, you cannot see actual rifting occurring because it takes so long. If we get an "earthquake" in this demonstration, it's just the bands breaking or someone letting a band go. Earth is not actually shaking.

6 Provide learners with the 50 Minute Activity Handout.

7 Focus the learners' attention on the Basin and Range ground motion map, cross section of extension illustration, and the simplified illustration of the model (**Figure 11**).

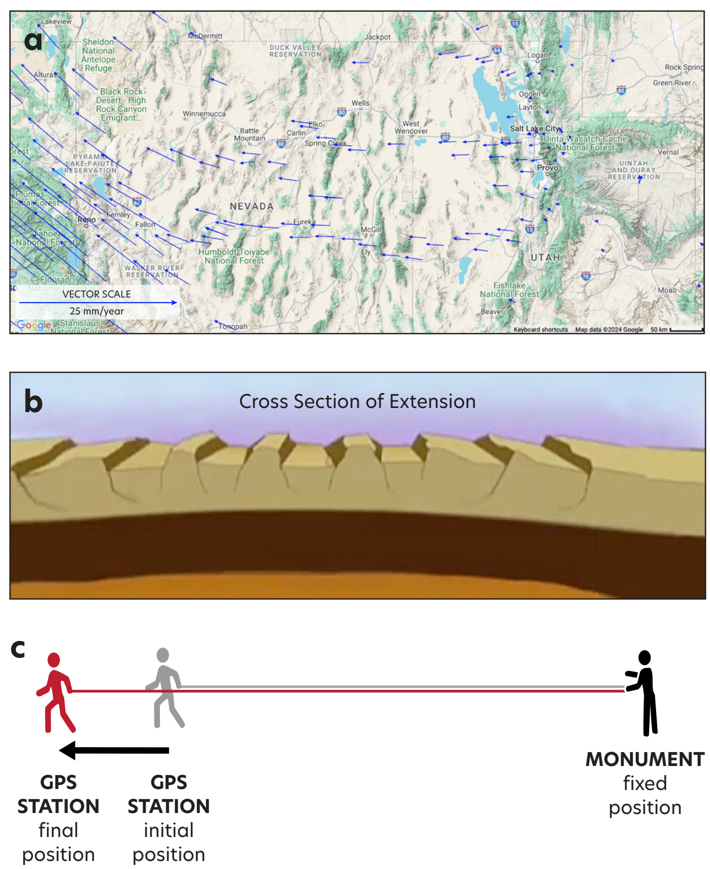


FIGURE 11. (a) Basin and Range ground motion map. (b) Cross section of extension illustrating the structure of the Basin and Range topography. (c) Simplified version of the model. Available in larger size in Appendix D.

8 Ask learners: What do you notice about the topography?

Answers may vary but they should say there are a lot of ridges/smaller mountain ranges. It looks like it's wrinkled. It's mostly in Nevada.

NOTE. This may be an area of misconception to address. Learners' normal experiences with tension is that it flattens or smooths things rather than wrinkling it. Come back to this idea when you show the animation on the Basin and Range in Part B Step 5.

9 Discuss/define vectors (see Anatomy of a Vector in Appendix B).

a. Vectors are arrows that represent the direction of movement and its relative speed. The faster the movement, the longer the arrow.

b. **ALTERNATE.** Guide learners to the definition using the kinesthetic model they just performed as a reference.

10 Direct learners to answer Question 1 in the 50 Minute Activity Handout (refer to **Figure 11a**): Thinking about how the model you saw and how the "GPS Stations" modeled by the volunteers moved, draw what you think the vectors would look like on this map.

11 Direct learners to answer Question 2 in the handout.

a. Lightly color the topography of the Basin and Range on the map to the similar areas in the Cross Section of Extension image in Question 3.

b. Lightly color the topography of the Basin and Range Province on the map below. Use different colors for each of the following areas:

- The Wasatch Mountains to the Utah/Colorado border
- The Sierra Nevada Mountains on the eastern side of California
- The Basin and Range Province (the space between a and b). Use a darker color to show the ridges (they appear like lines in the map). The valleys are the smooth areas between the ridges.

12 Direct learners to answer Question 3: Use the same colors to shade in the corresponding regions in the Cross Section of Extension image below the map. (HINT: You may need to color "outside the lines".)

PART B. UNDERSTANDING CRUSTAL MOTION USING VECTORS (~10 minutes)

1 Distribute the Basin and Range map (found in Appendix D) to learners.

a. Point out to learners that the vector scale on the map is different from the map scale.

b. Ask what units are used for the vectors depicted on the map (this reinforces using the legend that shows the velocity in mm/year).

2 Direct learners to answer Questions 4-6 in the 50 Minute Activity Handout.

a. Measure the labeled vector within each region (A. Utah, B. Eastern Nevada, and C. Western Nevada) on the Basin and Range GPS vectors map (using mm, not inches) for Question 4.

NOTE. Measure from the tip of the vector to the middle of the corresponding dot.

b. Measure the length of the scale vector (white legend box) in mm for Question 5.

c. Calculate the speed the plate is moving at each region for Question 6 using the formula in the box below.

$$\text{Plate speed (mm/yr)} = \frac{\text{GPS station vector length (mm)}}{\text{Vector scale length (mm)}} \times 25 \text{ mm/yr}$$

d. Point out that these speeds will differ from the average values because scientists use more precise measurements and calculate averages. Here we are using only one vector for each region.

3 Have learners compare what they see on the map to the kinesthetic model to answer Question 7 (refer to **Figure 11**).

4 Direct learners to answer Questions 8 and 9.

a. Have learners redraw their vectors (emphasize to the learners to keep their original answer in Question 1 — DO NOT erase what you drew before) after seeing the ground motion map. Have learners use a different color or use a different writing utensil than they used for their first vector drawings so they know it's their second/revisited iteration. **NOTE.** They are showing either that they are confirming or changing their conceptual model of vectors in that region.

5 Show the video(s):

a. Basin and Range: GPS Measures Extension (1.00)

b. OPTIONAL. Basin and Range: Structural Evolution (1:04)

6 Direct learners to answer Question 10 after watching the video.

a. What is causing the extensional forces?

Heat from the mantle is rising toward Earth's surface, causing the plate to dome upward and stretch. As the plate rises and thins, it fractures. (Bonus: Additionally, the northwest movement of the Pacific plate is dragging and deforming the western edge of the North American plate, adding to the extension.

7 Direct learners to answer Question 11 while displaying **Figure 11**.

a. Compare the before and after ground motion map to the kinesthetic modeling activity. How do the figures at the bottom of this image demonstrate what is happening in the Basin and Range? What are they modeling?

Monument people are ground; Tension Control Checker is the tension that has built up from movement through Nevada; each GPS Station person shows the GPS motion that would have occurred over three consecutive 1000 years; elastic bands indicate built up elastic force after each 1000-year span.

8 Direct learners to answer Question 12. Learners will discuss strengths and weaknesses of the models (kinesthetic, video, and map).

a. Define "model." Models are effective tools for illustrating complex ideas, though they have limitations compared to the real-world phenomena they depict. Out of the many types of expressed models (physical, mechanical, computer, mathematical), we are using a mechanical model to study the effects of extension forces on Basin and Range topography.

b. How is this model like the actual events that are taking place to create this region?

Extensional forces increase further west where the GPS stations (and ground) are moving faster (longer vectors). When the force gets too strong, the faults slip, creating an earthquake.

c. How is this model unlike them?

This model is moving faster. Rifting happens over hundreds or thousands of years. We are not seeing actual rifting occurring. If we get an "earthquake," the earth is not shaking, it's just the bands breaking or someone letting them go.

d. Emphasize how models are only representations of the real world—they have flaws.

e. OPTIONAL: Direct learners to their drawings of vectors in Question 1 of their handouts. Point out that here they are demonstrating their conceptual model or their understanding of the motion in this region. If the first and second versions look different, their conceptual model changed with information they got between Questions 1 and 9. If they look the same, they have confirmed their conceptual model.

PART C. USING GPS DATA TO DETERMINE POTENTIAL HAZARDS (~10 minutes)

1 Discuss and relate the average length of the vectors in each region to the potential energy held by the ground in each region relative to each other. Direct learners to answer Question 13.

a. Ask: Thinking about your answer to Question 11, which region has the most potential energy stored within the rock?

ANSWERS MAY VARY. *The eastern California vectors are longer relative to the mid-Nevada and Utah vectors. There is a great change in velocities near the California-Nevada border in western Nevada, there is more elastic potential energy stored within the rock in this location.*

b. Ask: Which region is more likely to experience an earthquake?

ANSWERS MAY VARY. *The region with the highest chance of an earthquake is near the border of Nevada and California in western Nevada, where the velocities change most quickly. (NOTE: Other factors such as rock type also determine the chance of an earthquake. The stored potential energy becomes kinetic energy [motion], heat [thermal], and acoustic energy [sound].)*

c. OPTIONAL. Show learners the animation Fault: Normal Basin and Range with Seismic Stations (0.30) or the excerpt from the animation (0.19).

2 Give learners the seismic hazard maps (found in Appendix H) to identify the regions with the highest seismic hazard in the Basin and Range Province. Explain that the different colors show the chances that a damaging earthquake will happen. Let learners know that the seismic hazards maps synthesize many types of data, such as historical seismicity, and ground type. Learners use what they see on the ground motion map to explain why these areas have a higher potential for earthquakes.

a. Point out the maps' keys, making sure learners understand the coding system used. Point out that the lightest colors are regions with the least chance of a damaging earthquake. The regions with the greatest chance of a damaging earthquake are which colors? (Answer: red, deep orange, and yellow)

b. Direct learners to compare the regions they identified in Question 13 in western Nevada with the regions of the seismic hazard map colored in red, deep orange, and yellow. Encourage learners to sketch in the space for Question 14, a single map showing some of the vectors and the regions with increasing chances of a damaging earthquake from the seismic hazard map.

c. Ask: How does the seismic hazard map support or not support your conclusion from Question 13? What can you conclude about the relationship between the chances of a damaging earthquake occurring in the region and where the vectors are changing direction quickly?

ANSWERS MAY VARY. *The regions with the greatest chances (red and orange) of a damaging earthquake support the conclusion of Question 13—they overlap the same regions with the vectors changing directions, although not perfectly. The ground motion map indicates areas of northwestern Nevada that have vectors changing directions, too.*

Remind learners that other factors, such as historical seismicity and rock type, are used to make the seismic hazard maps. It does not mean that the vector data is incorrect, rather we need many types of data to understand how earthquakes happen.

d. If needed, remind learners that the northwest motion of the Pacific plate in California is pulling the western edge of the North American plate to the northwest. This is observed in the vectors all the way to the border of California and Nevada.

3 Summarize the lesson, direct learners to answer Question 15

a. Ask: Why is it so important for us to understand how the tectonic plates are moving?

If we can determine how the plates are moving and interacting, we can forecast where the stronger earthquakes might take place. People living in regions with seismic hazards can then prepare and take mitigation efforts to decrease their risk of impact from an earthquake.

(~10 minutes)

1 Discuss earthquake preparedness strategies, including enabling ShakeAlert-powered alerts on cell phones.

2 Example introduction to ShakeAlert and earthquake preparedness: What are the impacts of an earthquake on life and society? How can we prepare for an earthquake?

An earthquake could cause a lot of destruction and loss of life. That's why it's important to be prepared. To prepare, people can sign up for free for ShakeAlert-powered early earthquake warnings, which can provide seconds to tens of seconds of extra time for people to protect themselves. These alerts can also prompt systems to automatically turn off natural gas, slow down trains, and open firehouse doors, among other protective actions. People should also prepare for emergencies by storing water, practicing protective actions like drop-cover-hold on in a variety of settings, and preparing emergency plans and kits.

NOTE TO INSTRUCTOR. Cell phone signals are radio waves that travel at the speed of light; they are much faster than seismic waves, which are slower and have to travel through Earth. Because of this, cell phone signals are capable of warning individuals who are **not** in the immediate vicinity of the epicenter seconds before the first seismic waves arrive. This is enough time for individuals to drop, cover, and hold on.

3 Introduce learners to the ShakeAlert Early Warning System and show them the web page How Do I Sign for the ShakeAlert Earthquake Early Warning System? Even if learners don't live in Washington, Oregon, or California, they might have family or travel there.

4 Show the first 1 minute and 30 seconds of the video ShakeAlert: Earthquake Early Warning System or show the animation How the ShakeAlert System Works (2.18).

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

a. Review the Action Plan (section 2 in the guide). Choose some activities from the Action Plan. Think of how much time you have.

b. Summarize the Communication Plan (section 1 in the guide; Question 16 in the Handout).

- Have learners think of who their contact person would be—they need to ask parents if they don't know.

c. Summarize the Water Plan (section 3 in the guide; Question 17 in the Handout).

- If you are looking for a demonstration to show them, you can look at the distillation method for purifying water.
- Where is a safe place to store water in your home?

EXTENSION

1 Continue the "Prepare in a Year" Guide.

a. Have learners go through the list of kit supplies in the Grab and Go Kit (section 4 in the guide). and:

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

2 Show the video Preparedness Journey (2.02).

3 Lead learners through the 5 and/or 15 minute demonstration Geologic Hazards Related to Earthquakes to extend learner understanding of additional hazards that can happen during an earthquake.

4 Use the ShakeAlert Educational Resources for more resources and activities.

APPENDIX A. VOCABULARY

Brittle Deformation: Strain where a material fractures.

Compressive Stress: The stress that is generated when forces squeeze or push an object inward, causing the material to shorten or compress.

Ductile (Plastic) Deformation: Irreversible strain. When the stress is removed the deformation remains.

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

Elastic Response: A temporary deformation or change in shape due to acting forces. When forces are removed, it returns to the original state.

Elastic Strain: A form of strain that, when the deforming force is removed, the distorted body returns to its original shape and size. Earthquakes are caused by the sudden release of energy as strain is overcome and the sides of the fault move past each other. This form of energy release is the only kind that can be stored in sufficient quantity to be regionally damaging.

Fault: A fracture or zone of fractures in rock along which the two sides have been displaced relative to each other.

Fold: A bend or flexure in a rock that is a result of permanent deformation.

Fracture: Irreversible strain when the material separates into two or more pieces due to stress.

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

Mineral: A naturally occurring, inorganic, homogeneous solid with a crystalline structure.

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

Rock: A naturally occurring solid composed of a combination of one or more minerals.

Solid: Anything that retains a fixed volume and shape.

Strain: Changes in size, shape, or volume of an object due to stress.

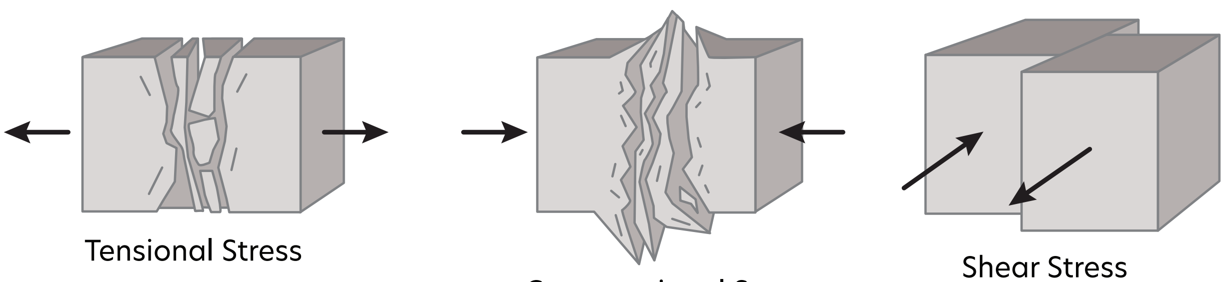
Stress: The amount of force per unit area applied to an object.

Tension, Tensional Force: Refers to a stress that stretches rocks in opposite directions. The rocks become longer in a lateral direction and thinner in a vertical direction. One important result of tensile stress is jointing (fractures due to overstretching) in rocks.

APPENDIX B. INSTRUCTOR BACKGROUND

ABOUT ROCK DEFORMATION AND EARTHQUAKE FORMATION

The rock comprising the tectonic plate is partially elastic, like a rubber band. It can deform—stretch, compress, and twist—until it breaks, releasing stored energy. We call this sudden release of stored energy an earthquake. Once the rock breaks, a fault is created with the two sides stuck together in places by friction. The rocks that make up Earth's outer shell are continually subjected to stresses. Stress is the amount of force per unit area applied to an object. Three types of stress affect rocks. Rocks can be squeezed by compressional stress, stretched by tensional stress, or sheared by shear stress**.** In response to the ongoing stress, rocks are said to strain or change in their size, shape, or volume. For a more thorough explanation, see the activity Seeing IS Believing. Rocks are Elastic!.



Rocks are subjected to three types of stress: tensional stress, compressional stress, and shear stress. Modified from Michael Kimberly, North Carolina State University.

Rocks can permanently deform, not just break. This photo shows an example of deformed rock from the Permian located in New Mexico, USA. The rock was deep beneath Earth's surface when the deformation occurred. At great depth, high pressure and temperature softens the rock and allows the layers to bend and fold. Thinking question: What type(s) of and direction(s) were the forces that folded this rock? *Source: James St. John; https://commons.wikimedia.org/wiki/File:Folded_gyprock.jpg*

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

Geodesy is the study of Earth's shape and area. It is one of the oldest scientific disciplines, having been a primary focus of early Greek scientists. To learn more, view this short video NASA's Brief History of Geodesy (2.25).

Global Positioning System satellites (the U.S. portion of the Global Navigation Satellite System, or GNSS) transmit electromagnetic signals that are received by devices on Earth and are used to determine position. Simple "receivers" such as those in smart phones give general positions. Research-grade receivers are anchored into rock or deep into the soil, gather data at a specific location 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. The GPS data are collected in three spatial directions: *up-down, north-south, and east-west*. 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 are removed as part of the data processing so that the dominant motion in the data is tectonic. The GPS data allow calculation of an average annual velocity for ground movement.

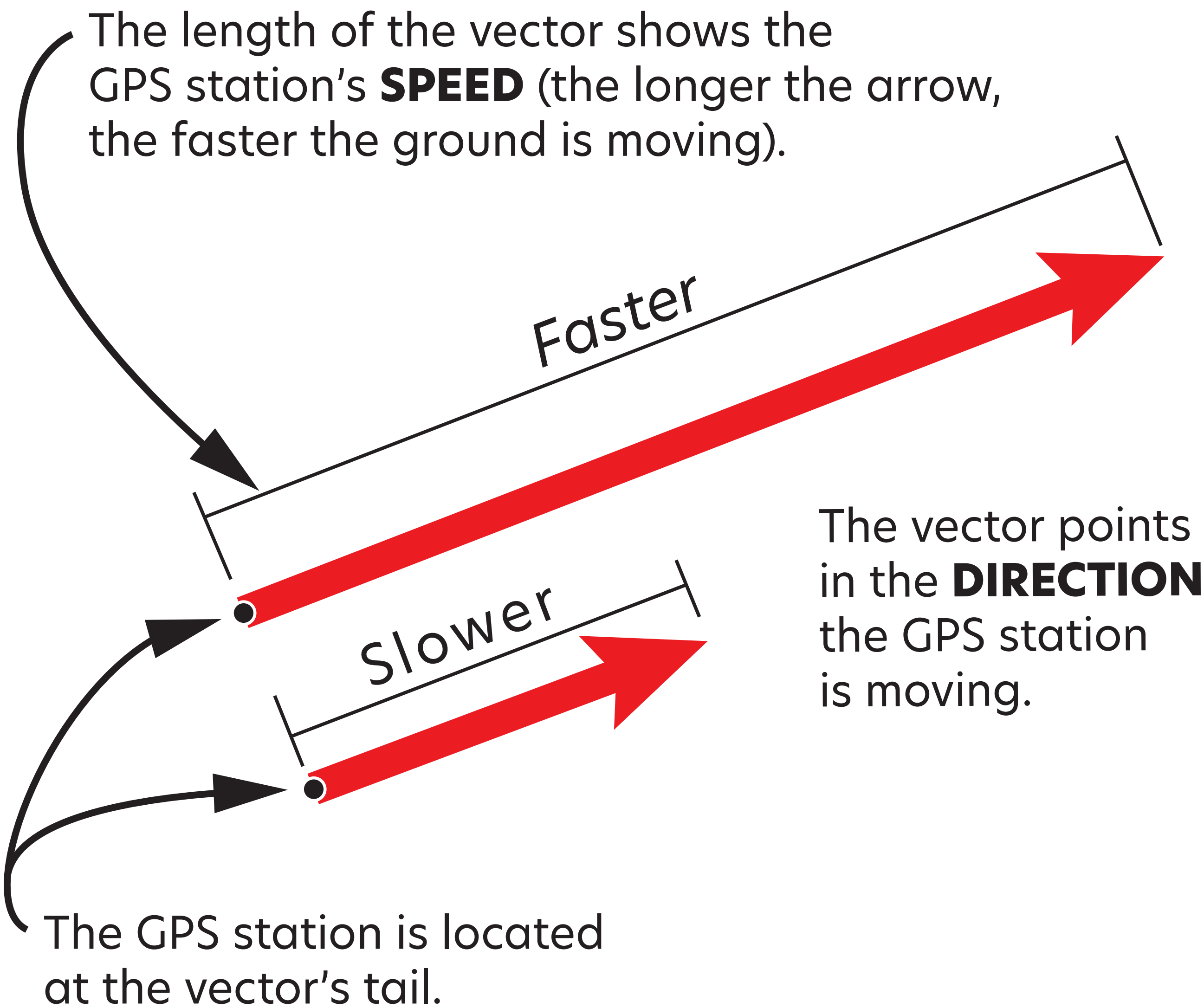
GPS data are now combined with data collected by seismometers to more accurately size up big earthquakes as part of the ShakeAlert Earthquake Early Warning System. Operated by the United States Geological Survey (USGS), the system is operational in California, Oregon, and Washington. ShakeAlert is not 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 Earthquake Early Warning System and how to prepare:

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

Anatomy of a Vector

A vector indicates the direction and speed of an object.



VISUALIZING GPS DATA ON MAPS

When the data are displayed on maps, the horizontal velocities are added together to create a single vector. Vectors show key pieces of information. The tail of the vector indicates the location of the GPS instrument. The arrow head shows direction of movement. The length indicates speed of movement. The longer the arrow, the faster the ground and GPS move. This movement is displayed on maps as displacement over time, usually in mm/year.

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.

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.

Notice two details In each example of plate boundary interaction: 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 about how reference frames are used in the GPS Velocity Viewer.

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.

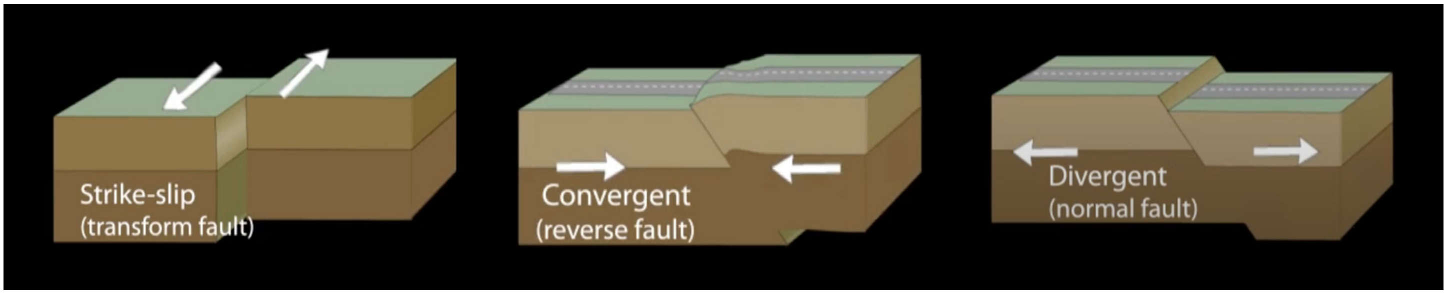
Using GPS, scientists can detect compressional movement at GPS stations over 200 miles inland from the Cascadia subduction zone in Yakima, Washington, and Redmond, Oregon. In the Basin and Range region, GPS detects the prolonged extension, from infinitesimal movement in eastern Utah to movements of approximately 3 mm/year in mid-Nevada to 6.5 mm/year in western Nevada near 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 and Range might seem inconsequential. However, 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 these GPS, please see the following resources:

- NASA Web Page: How Does GPS Work?
- NOAA Tutorial: Global Positioning

THE SUBTLETIES OF PLATE BOUNDARY MOTION: SHOWING PLATE MOTIONS WITH HAND MOVEMENTS AND VECTORS

DIAGRAMS OF MOTION AT PLATE BOUNDARIES

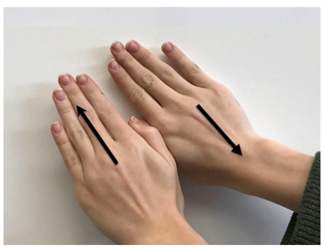


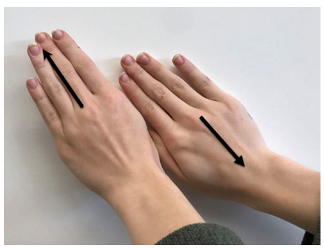
HAND MOVEMENTS ILLUSTRATING PLATE BOUNDARIES

SCENARIO ONE / SCENARIO TWO

TRANSFORM BOUNDARY

Scenario One:


Starting Position


During Movement

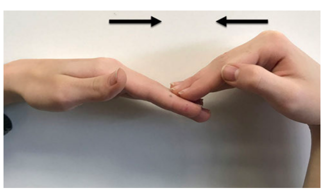
Scenario Two:

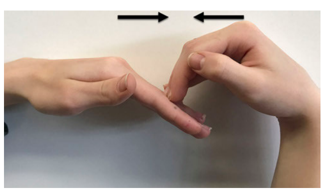

Starting Position


During Movement

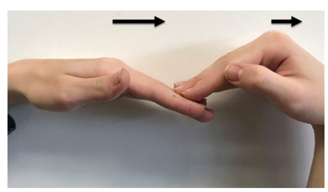
CONVERGENT BOUNDARY

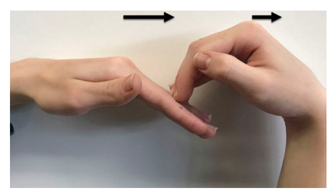
Scenario One:


Starting Position


During Movement

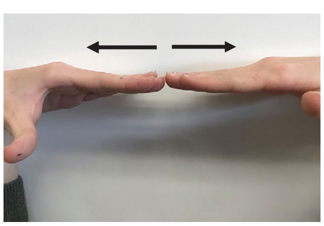
Scenario Two:

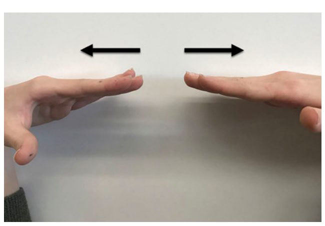

Starting Position


During Movement

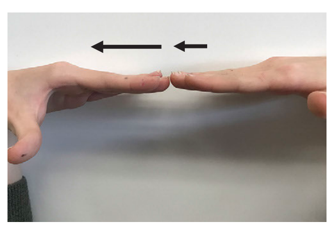
DIVERGENT BOUNDARY

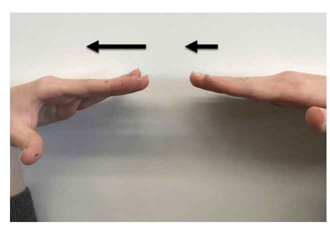
Scenario One:


Starting Position


During Movement

Scenario Two:


Starting Position


During Movement

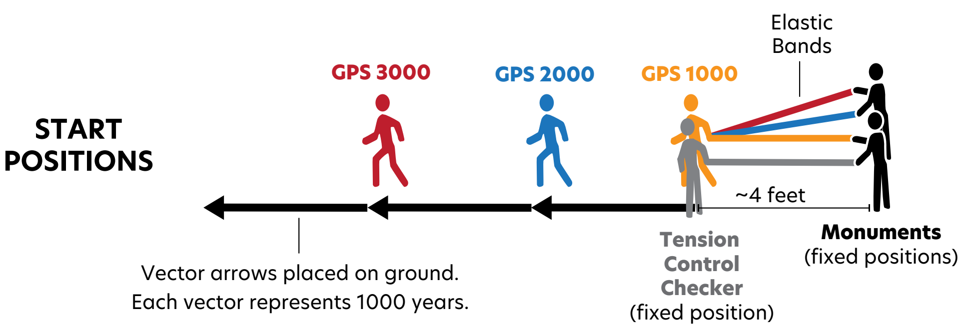
APPENDIX C. VECTOR COMPONENTS

- Print out copies of the vector components provided on the next two pages to create three 3-foot-long vectors. Tape them to the floor near the eastern California/ Nevada border starting in western Nevada.
- Vectors need to be large enough to see from a distance and survive being walked on.
- If printing is not possible, use tape on the floor.

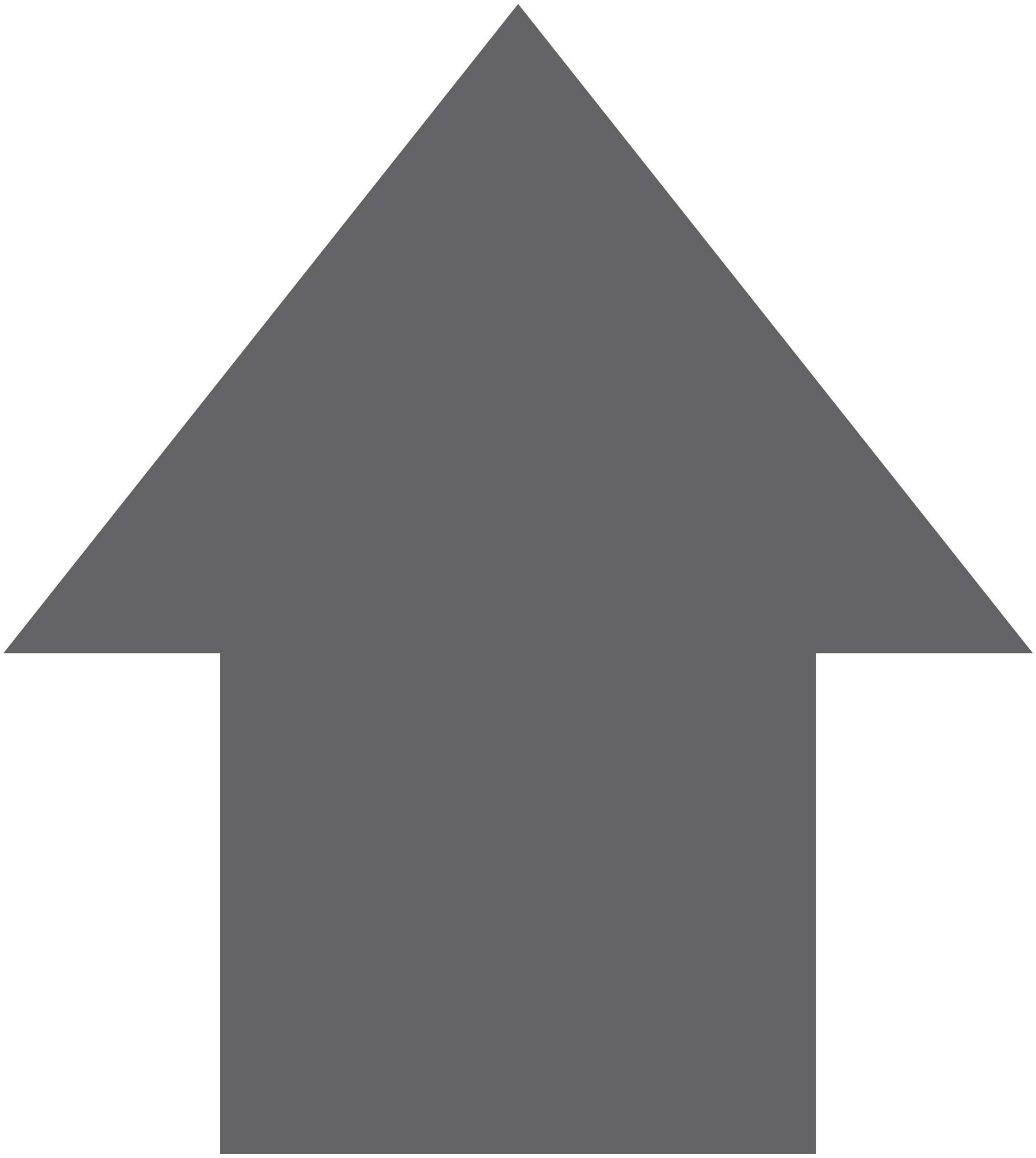
OPTIONAL

- Make an additional set of three 1.5-foot-long-vectors, (mid-Nevada vectors).
- Make an additional set of three 9-inch-long vectors, (eastern Utah vectors).

EXAMPLE LAYOUT ON GROUND

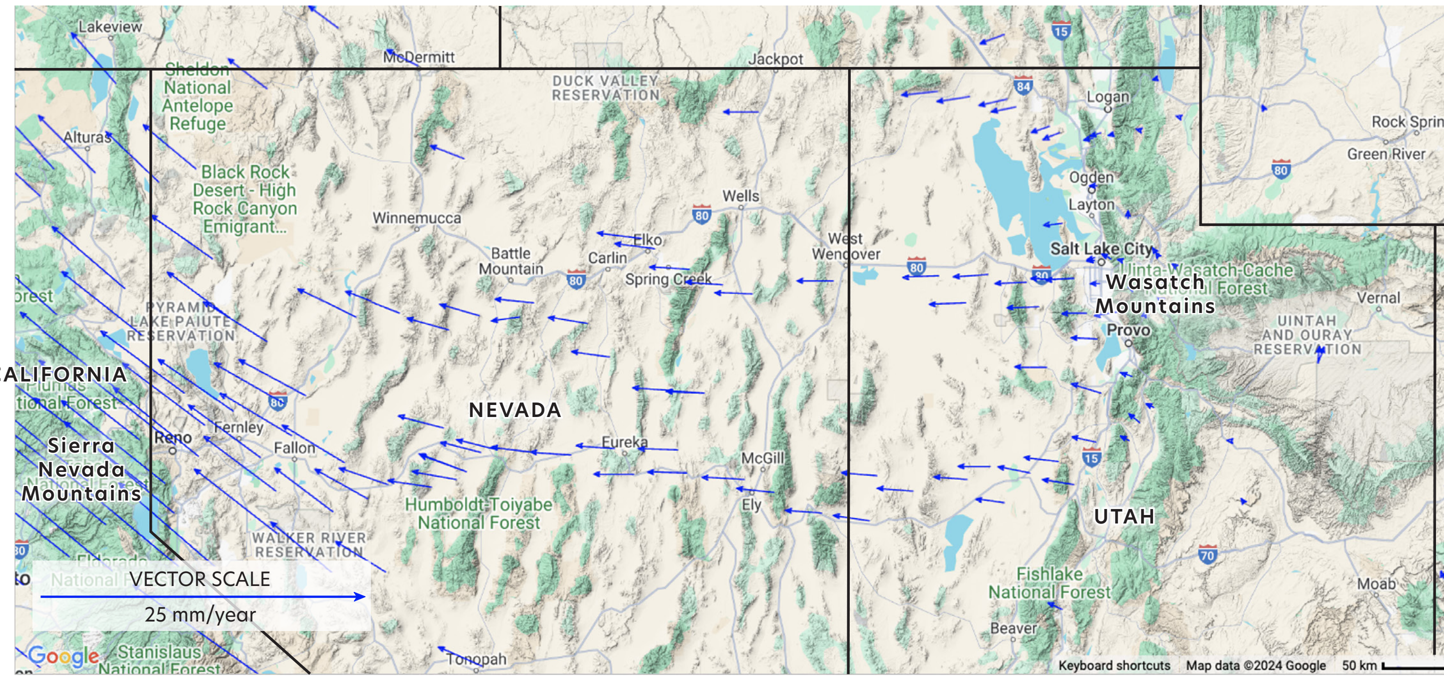


ARROW HEAD

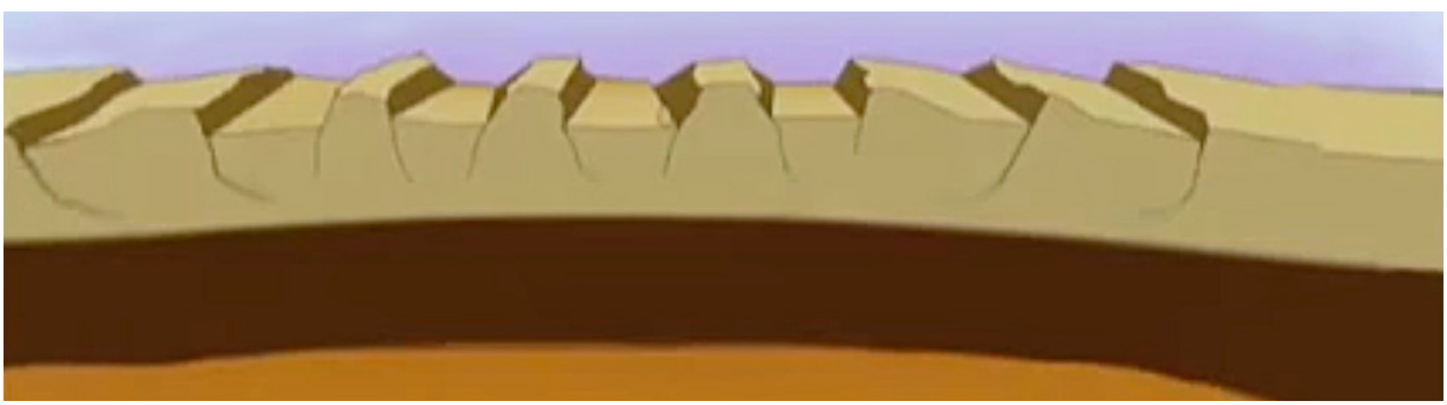


APPENDIX D. GROUND MOTION MAPS, CROSS SECTIONS, AND MODEL SETUP

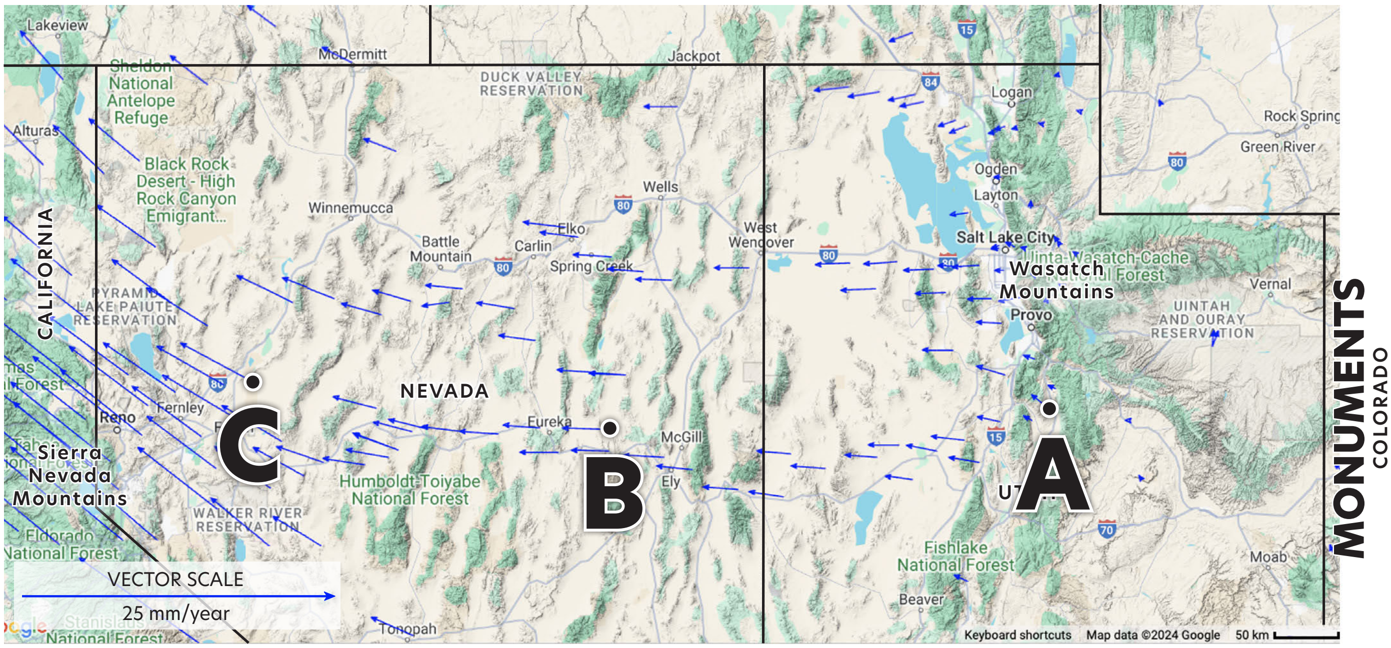
BASIN AND RANGE GROUND MOTION MAP

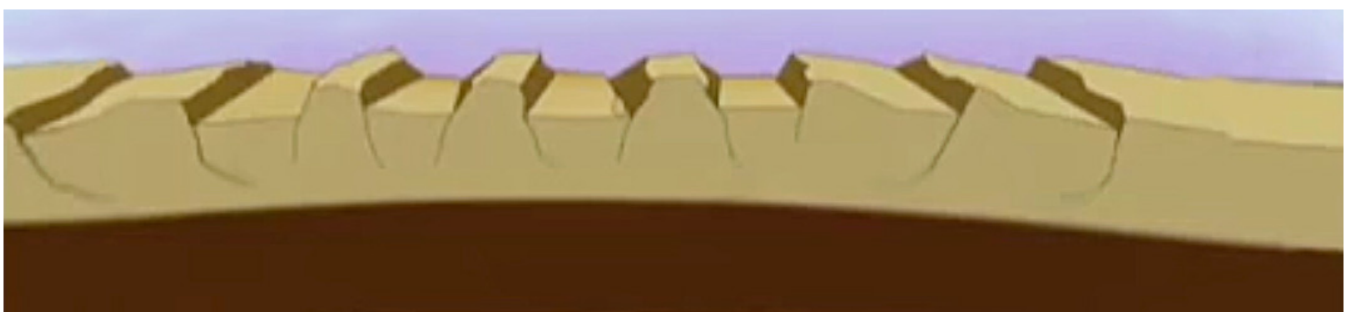


CROSS SECTION OF EXTENSION

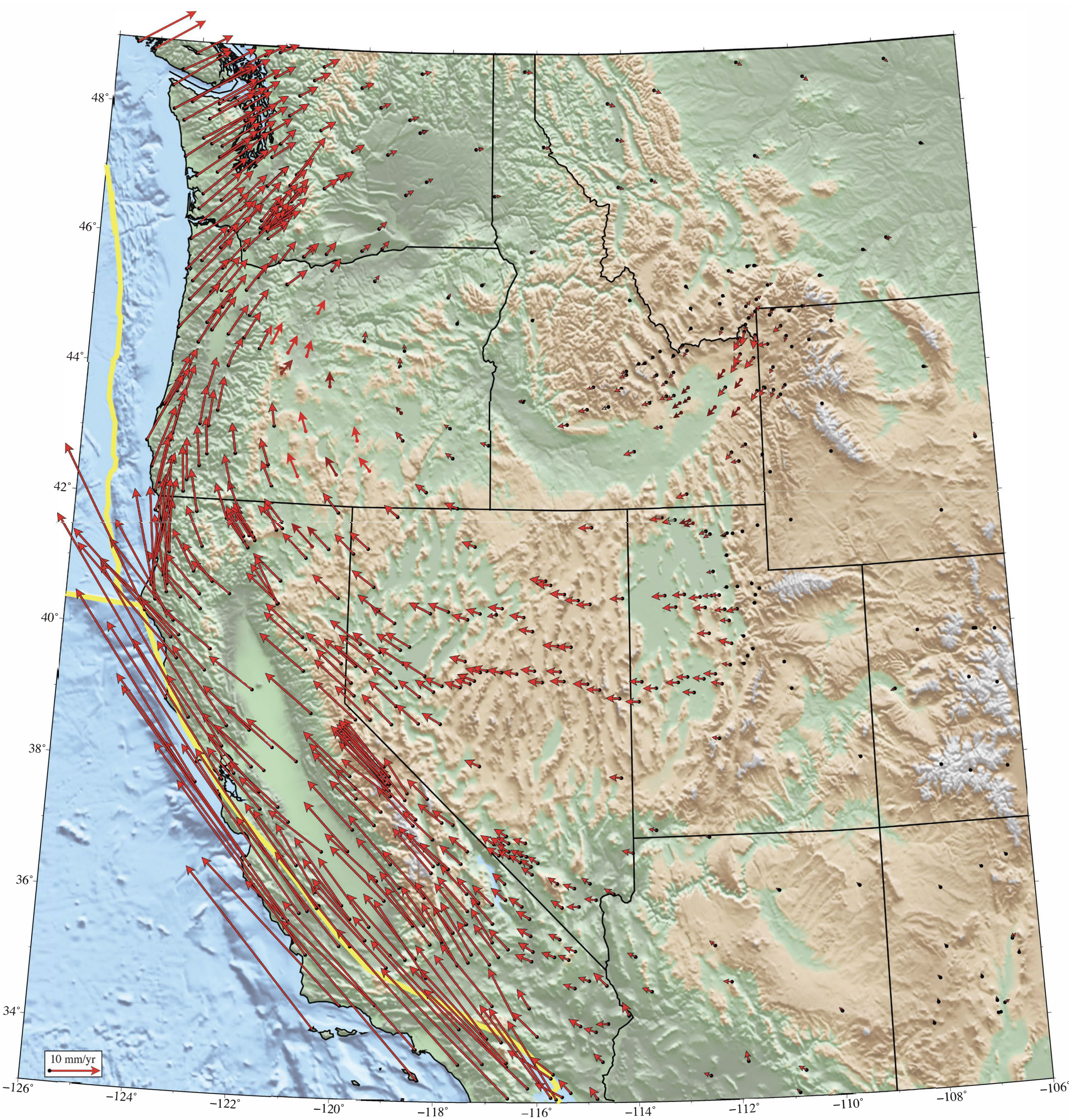


EXTENSION THROUGHOUT THE BASIN AND RANGE USING A KINESTHETIC MODEL





WESTERN UNITED STATES GPS VECTOR MAP



APPENDIX E. 20–25 MINUTE ACTIVITY HANDOUT

GPS AND SLOW EXTENSION ACROSS THE BASIN AND RANGE PROVINCE

NAME: ______________________________________ PERIOD: __________ DATE: ________________

1 What does each part of the model represent?

a. The vectors:

b. The tails of the vectors:

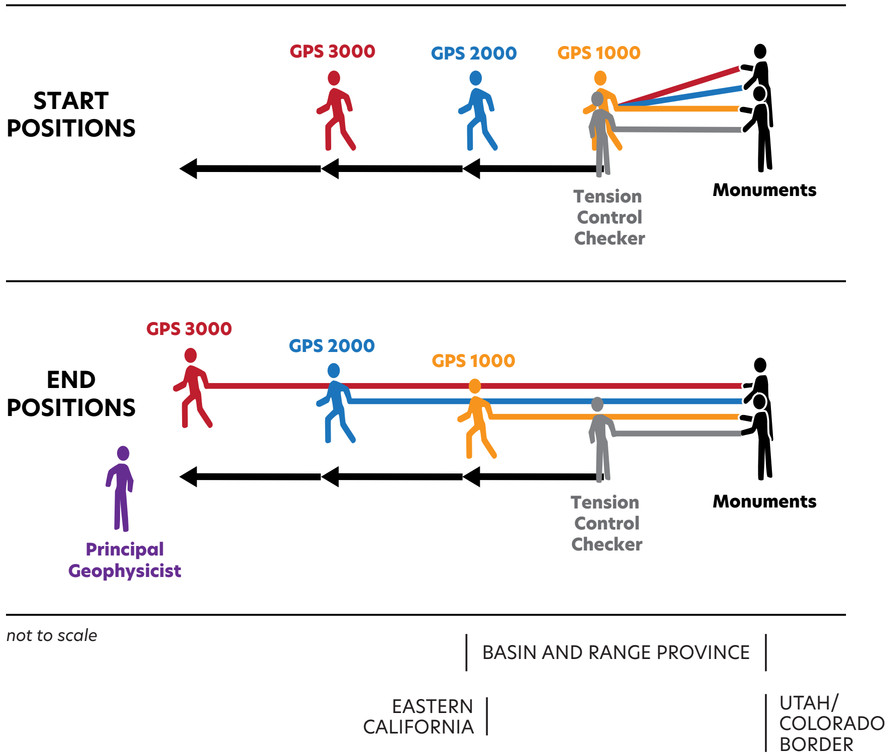
c. The Monuments:

d. The elastic band held by the Tension Control Checker:

e. Each GPS Station:

f. The elastic bands:

GPS AND SLOW EXTENSION MODEL



2 What is happening across the Basin and Range Province?

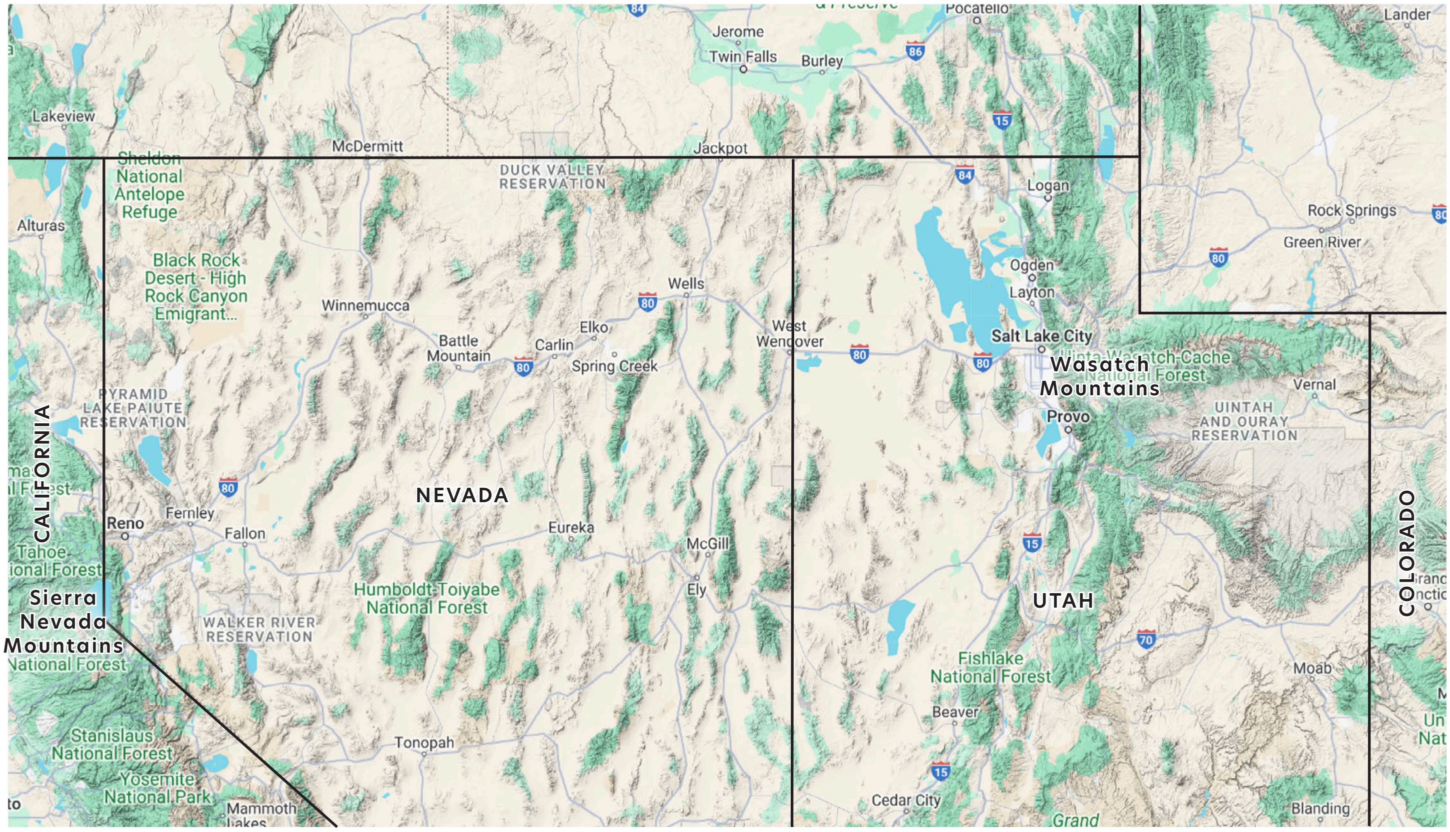
3 Lightly color the topography of the Basin and Range Province on the map below. Use different colors for each of the following areas:

a. The Wasatch Mountains to the Utah/Colorado border

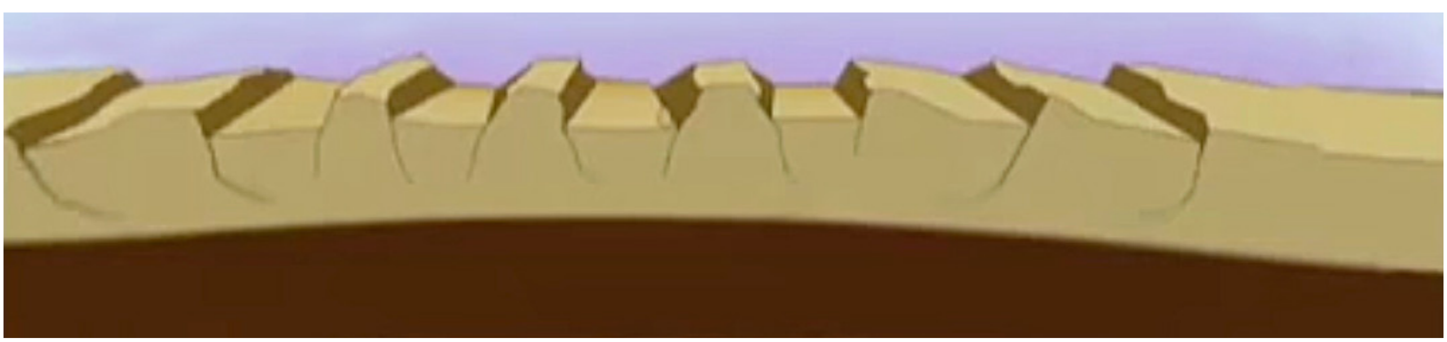
b. The Sierra Nevada Mountains on the eastern side of California

c. The Basin and Range Province (the space between a and b)

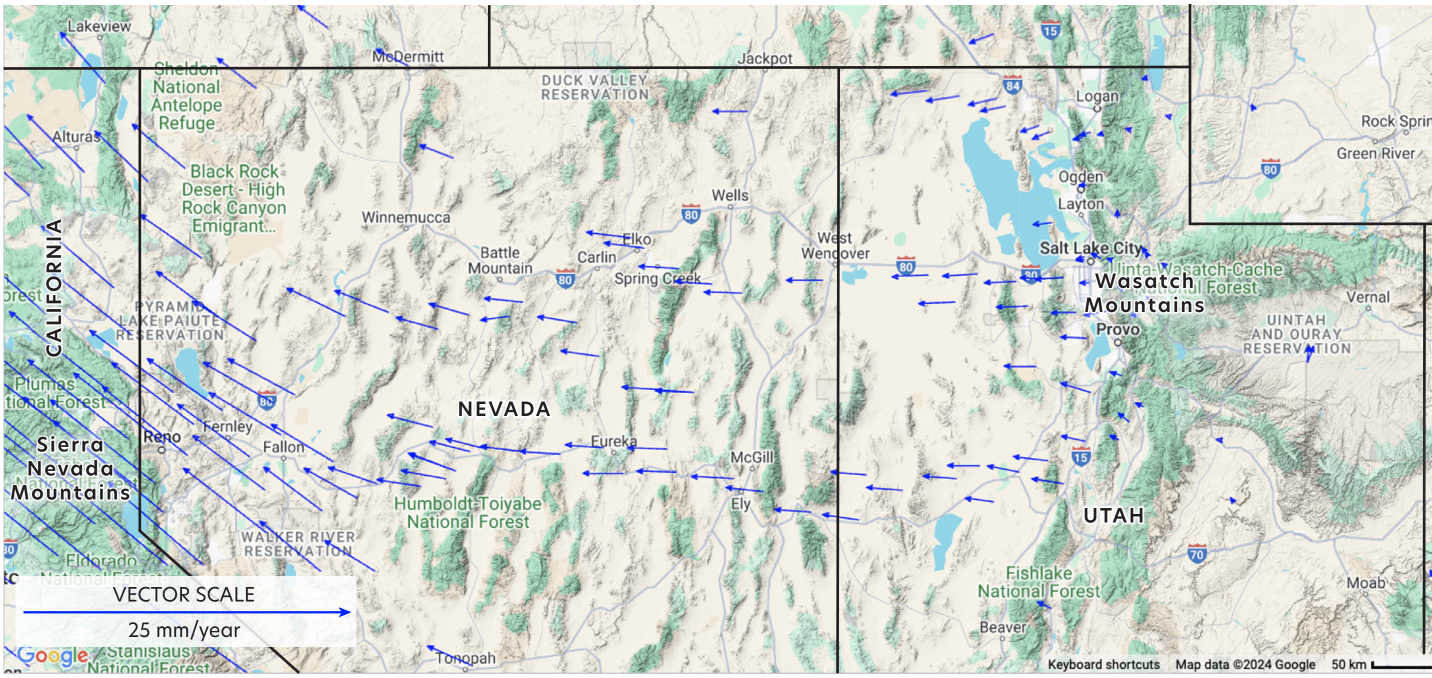
d. The ridges within the Basin and Range Province (draw them like lines on the map)



4 Use the same colors to shade in the corresponding regions in the Cross Section of Extension image below. (Hint: you may need to color "outside the lines.")



5 Focus on the vectors on the map below. How does the change in direction near eastern California show an added earthquake hazard compared to Utah?



6 Compare the model using elastic bands to the real world. List what you observe.

How is the Model **LIKE** the Basin and Range?

How is the Model **UNLIKE** the Basin and Range?

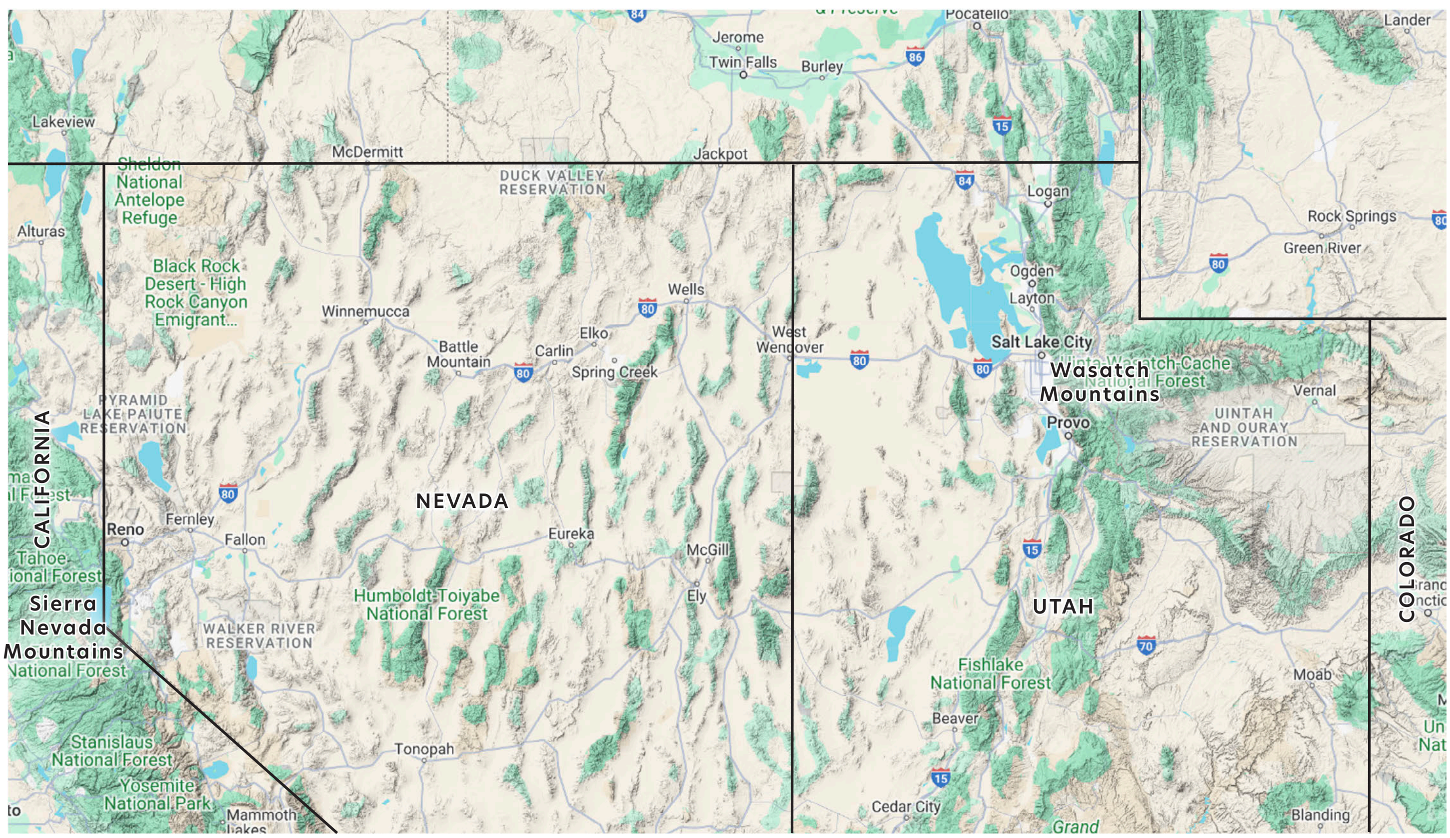
APPENDIX F. 50 MINUTE ACTIVITY HANDOUT

GPS AND SLOW EXTENSION ACROSS THE BASIN AND RANGE PROVINCE

NAME: ______________________________ PERIOD: __________ DATE: ________________

PART A. MOTION AND DEFORMATION WITH EXTENSION FORCES

1 Think about the model you observed or participated in. Consider how the volunteers moved and the elastic bands stretched; draw what you think the vectors* would look like on this map. **HINT:** Start by marking the locations of the monument and the eastern California vector. Then estimate a few more vectors between the two.



*Vectors are arrows that represent the direction of movement and relative speed. The faster the movement, the longer the arrow.

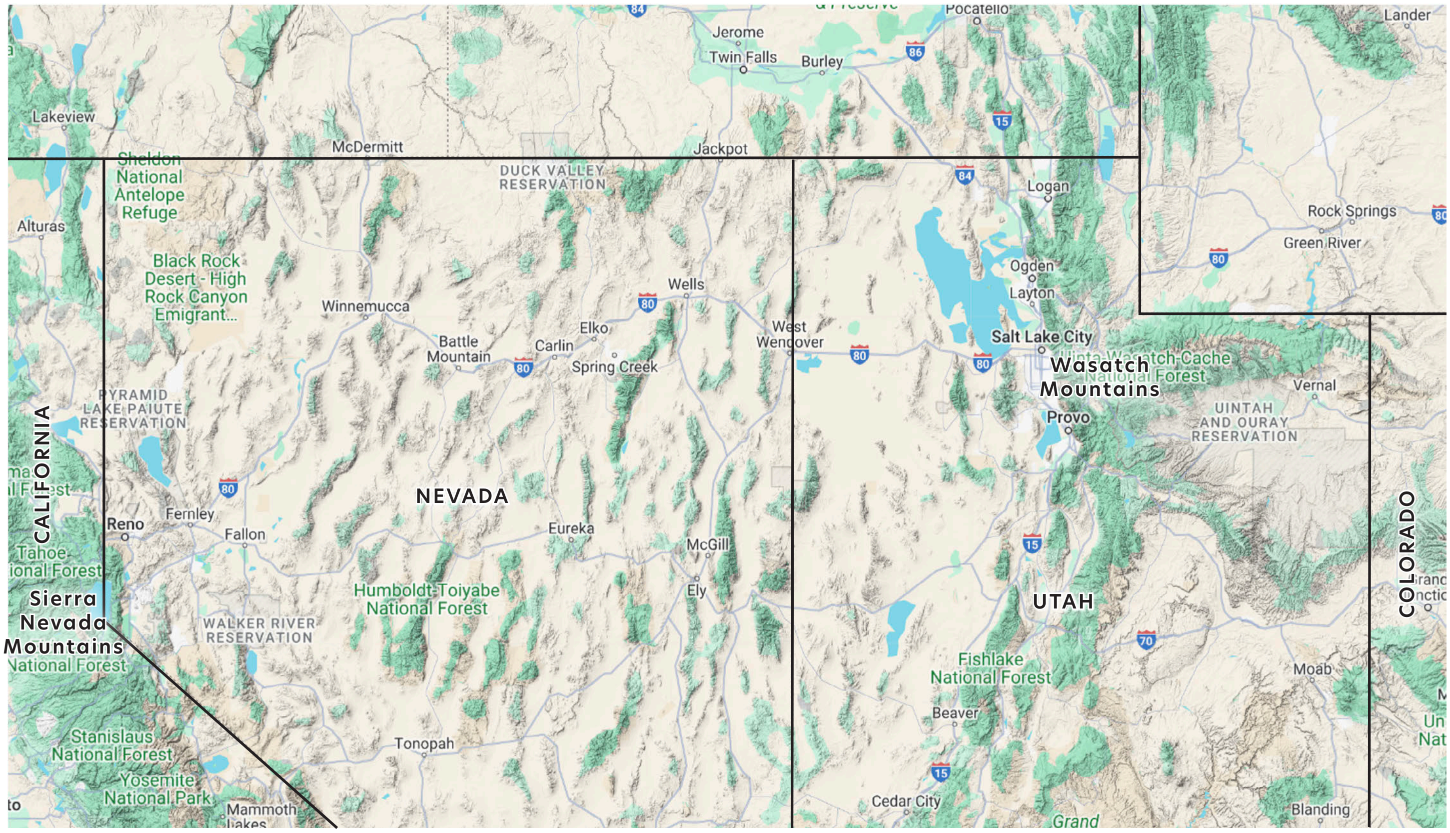
2 Lightly color the topography of the Basin and Range Province on the map below. Use different colors for each of the following areas:

a. The Wasatch Mountains to the Utah/Colorado border

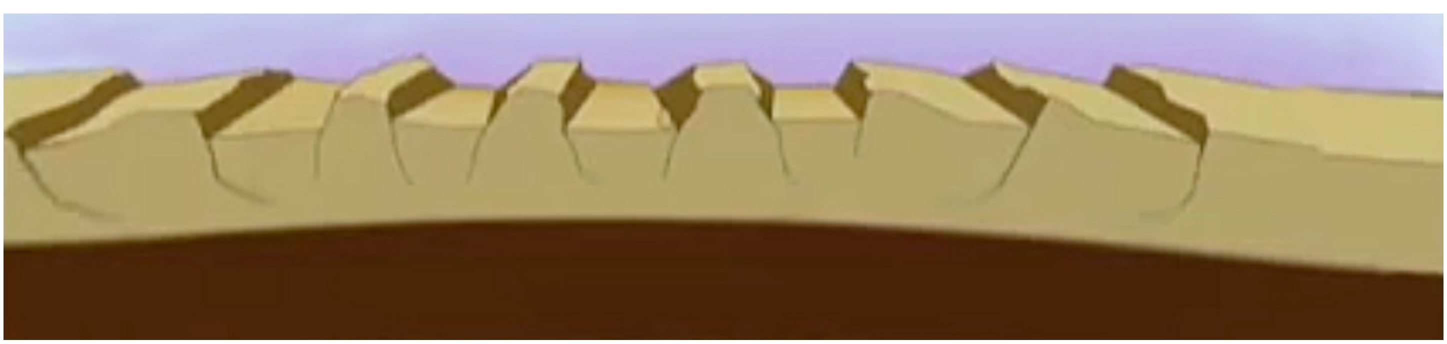
b. The Sierra Nevada Mountains on the eastern side of California

c. The Basin and Range Province (the space between a and b)

d. The ridges within the Basin and Range Province (draw them like lines on the map)



3 Use the same colors to shade in the corresponding regions in the Cross Section of Extension image below. (Hint: you may need to color "outside the lines.")

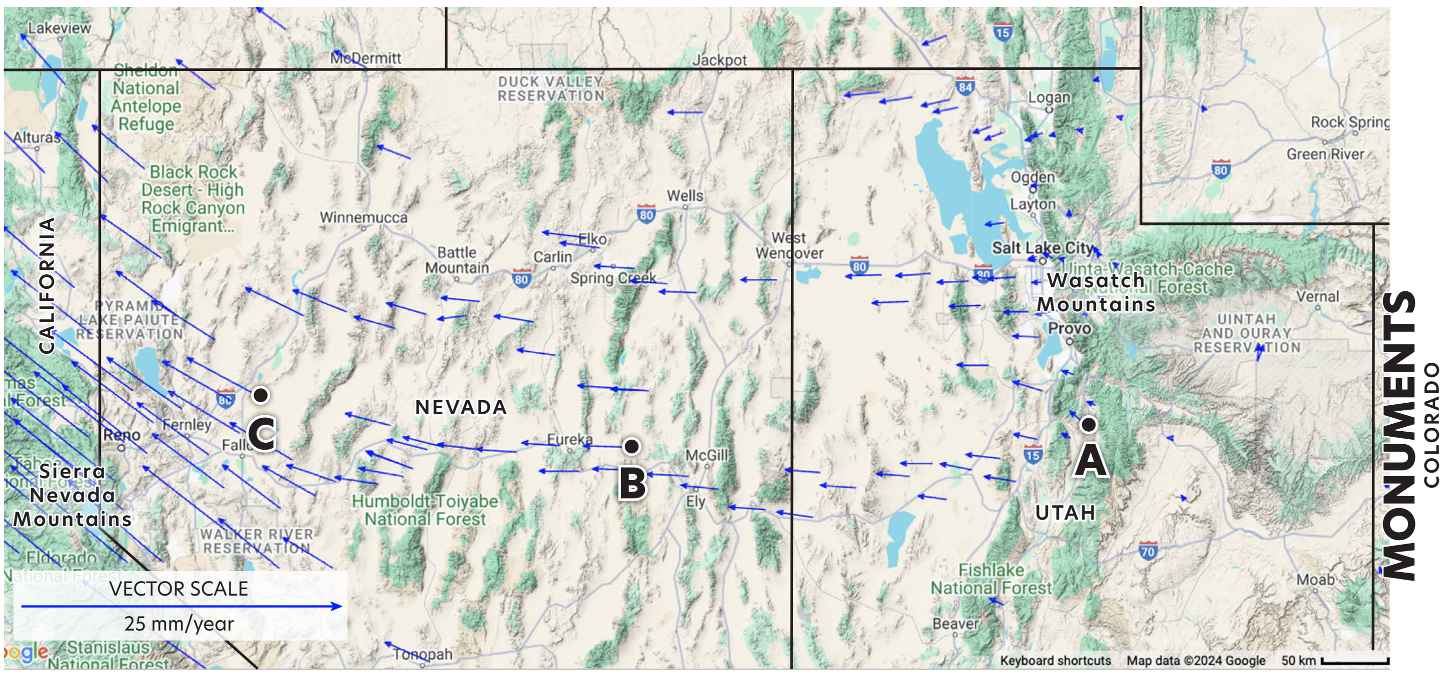


4 There are three GPS stations labeled A, B, and C on the map below. Measure the length of the vectors that start at each black dot. Record the measurements in the table below the map. Measure in mm from the tip of the vector to the middle of the corresponding dot.

5 Measure the vector scale in mm (blue vector in white box at bottom left corner of map). _______

6 Calculate the speed at each GPS station using the plate speed formula and record the speed in the table below.

$$\text{Plate speed (mm/yr)} = \frac{\text{GPS station vector length (mm)}}{\text{Vector scale length (mm)}} \times 25 \text{ mm/yr}$$



	C Western Nevada	B Nevada	A Utah
Vector Length (mm)			
Speed (mm/yr)			

7 How do the vectors in the 3 different regions you just measured compare to what you saw people doing in the extension and vector model?

8 Focus on the vectors on the map in Question 4 above. How does the change in direction near the California-Nevada border show an added earthquake hazard compared to Utah?

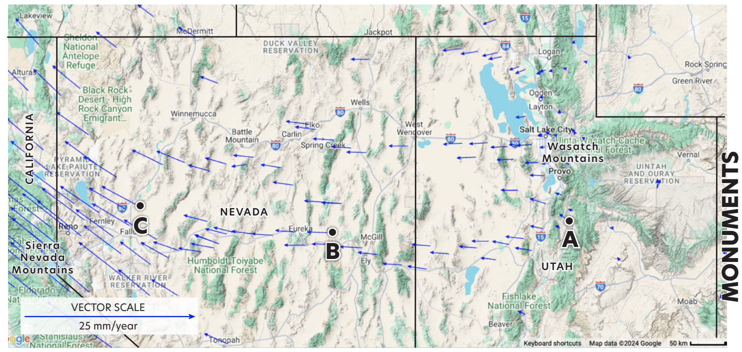
9 Draw new vectors on the Basin and Range map in Question 1 using a new color. Don't erase the older vectors, you are updating your understanding with more data.

10 What is causing the extension forces in the Basin and Range Province?

11 How do the figures in the GPS and Slow Extension model image demonstrate what is happening in the Basin and Range Province? (What are they modeling?)

The Monuments:

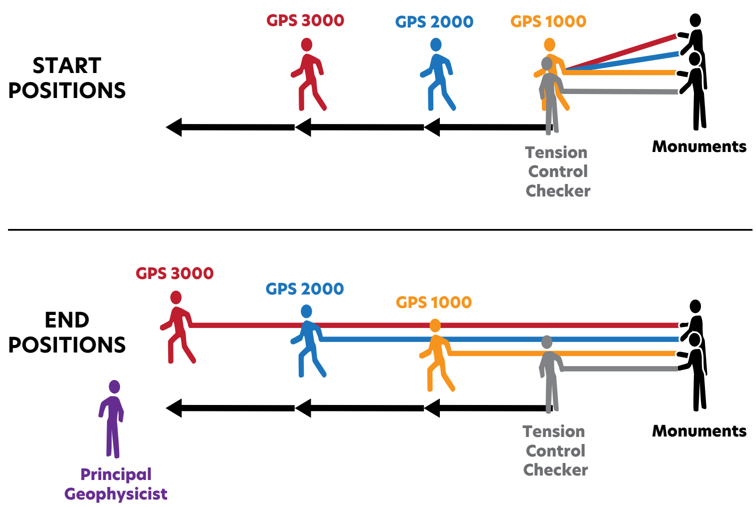
Tension Control Checker:



Each GPS Station person?

The elastic bands?

GPS AND SLOW EXTENSION MODEL



12 Compare the model using elastic bands to the real world. List what you observe.

How is the Model **LIKE** the Basin and Range?	How is the Model **UNLIKE** the Basin and Range?

PART C. USING GPS DATA TO DETERMINE POTENTIAL HAZARDS

13 Thinking about your answer to Question 11 above: (a) Which region has the most potential energy stored within the rock? (b) Which region is more likely to experience an earthquake?

14 Compare the seismic hazard maps with the ground motion map. What can you conclude about the relationship between what the vectors are showing you and the earthquake shaking potential?

15 Why is it so important for us to understand how the tectonic plates are moving?

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

16 Who is your contact person?

17 Where is a safe place to store water in your home?

GPS AND SLOW EXTENSION ACROSS THE BASIN AND RANGE PROVINCE

20–25 MINUTE ACTIVITY HANDOUT ***ANSWERS***

1 What does each part of the model represent?

a. The vectors:

Speed and direction

b. The tails of the vectors:

Initial GPS positions

c. The Monuments:

Fixed position of ground

d. The elastic band held by the Tension Control Checker:

In charge of holding the amount of force at the California-Nevada border.

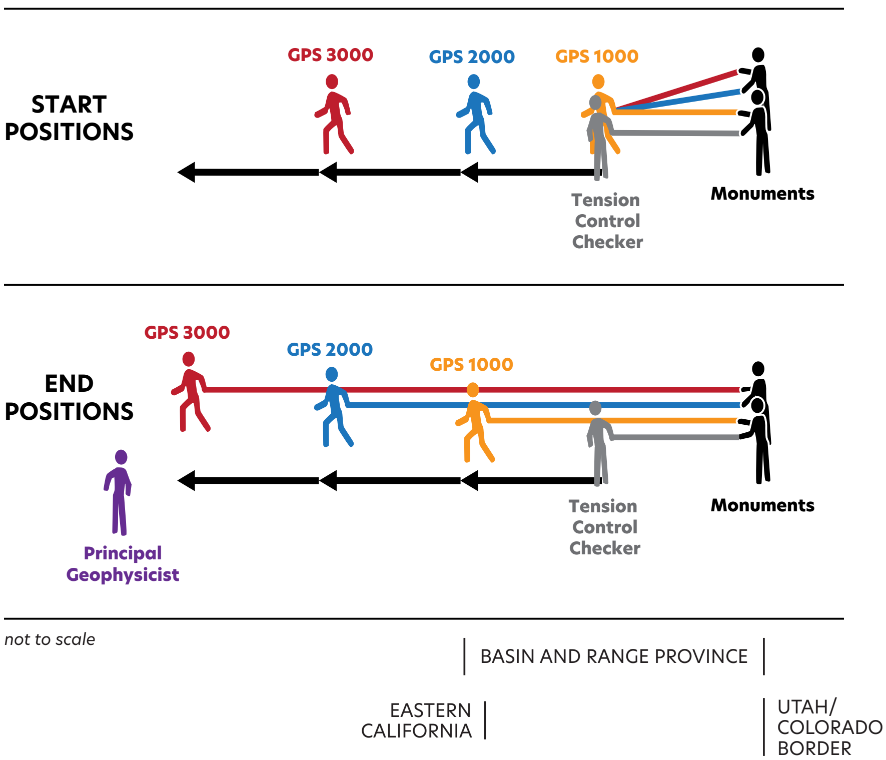
e. Each GPS Station:

GPS movement per 1000 years

f. The elastic bands:

Extension forces that have built up to that point

GPS AND SLOW EXTENSION MODEL



2 What is happening across the Basin and Range Province?

Rifting. A new plate boundary may be forming within the North American plate.

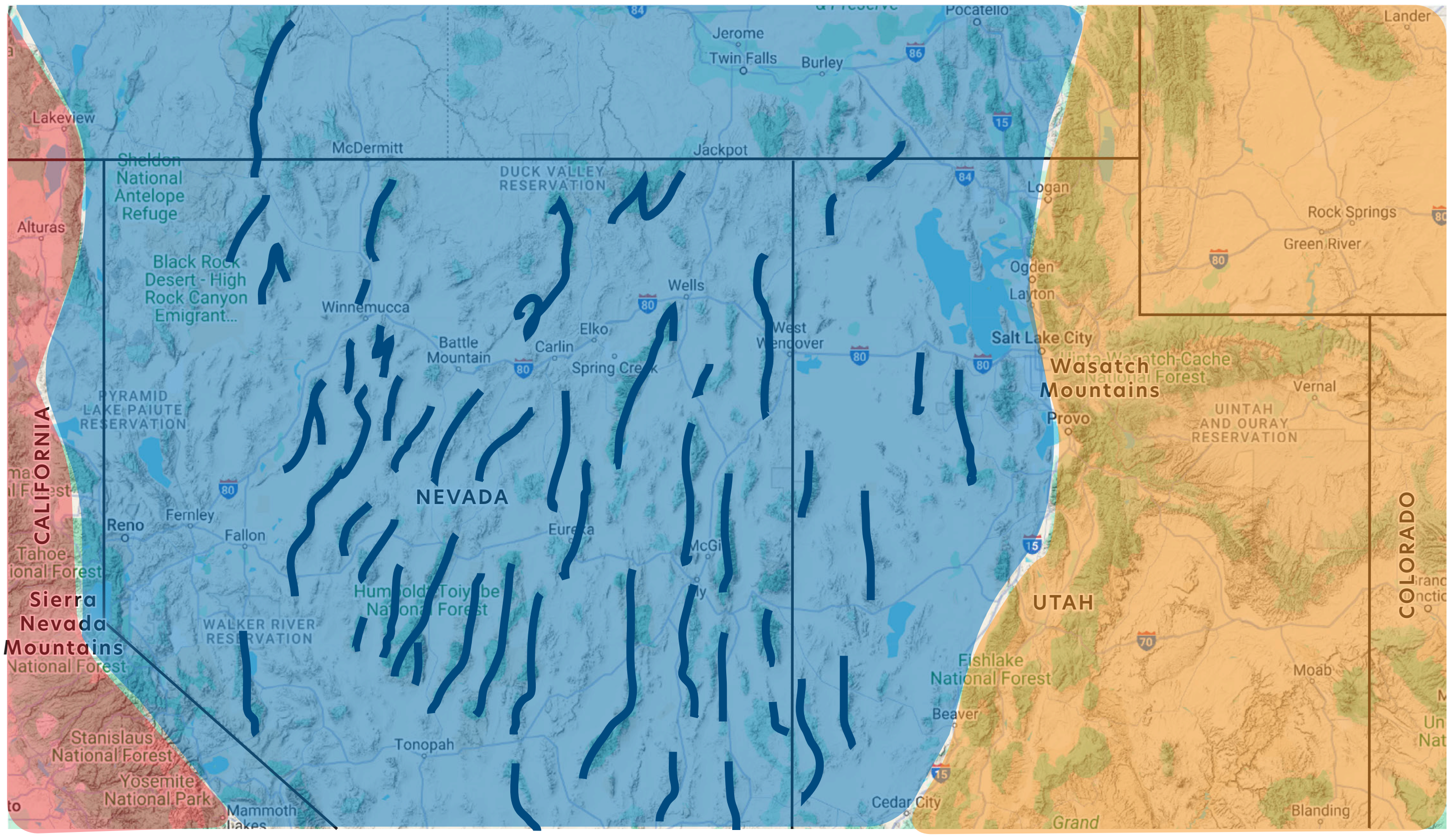
3 Lightly color the topography of the Basin and Range Province on the map below. Use different colors for each of the following areas:

a. The Wasatch Mountains to the Utah/Colorado border

b. The Sierra Nevada Mountains on the eastern side of California

c. The Basin and Range Province (the space between a and b)

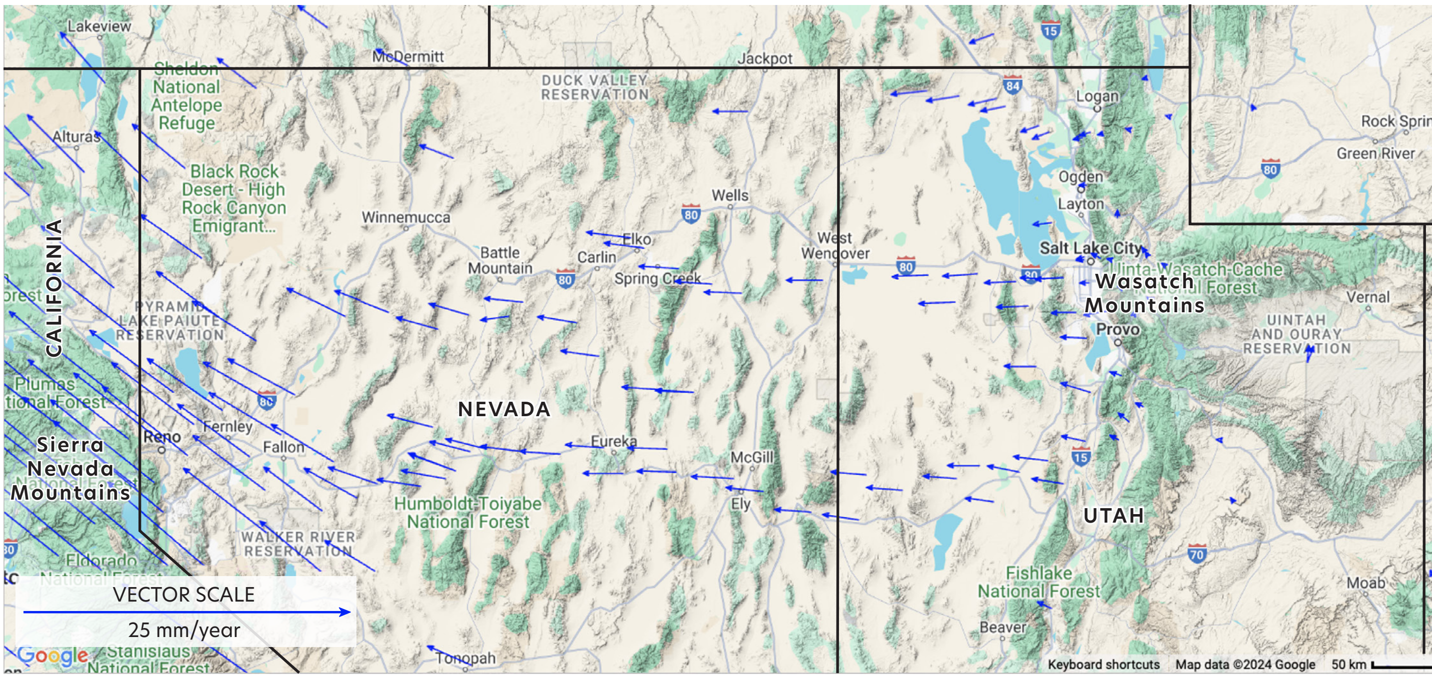
d. The ridges within the Basin and Range Province (draw them like lines on the map)



4 Use the same colors to shade in the corresponding regions in the Cross Section of Extension image below. (Hint: you may need to color "outside the lines.")

5 Focus on the vectors on the map below. How does the change in direction near eastern California show an added earthquake hazard compared to Utah?

The velocity changes in two ways: the speed increases and the vectors change direction. Here, there are additional shear forces from the Pacific plate moving northwest, dragging the North American plate northwest as well, due to the frictional forces along the plate boundary. The rocks in faults stick until the potential energy is greater than the frictional force holding the two sides of the fault together. When the fault suddenly moves, the potential energy is released in an earthquake.



6 Compare the model using elastic bands to the real world. List what you observe.

How is the Model **LIKE** the Basin and Range?

- ***The straps (extensional forces) get tighter as velocity increases (longer vectors or change in direction).***
- ***Potential energy converts to kinetic energy (motion), heat (thermal), and acoustic energy (sound) when forces become too great.***

How is the Model **UNLIKE** the Basin and Range?

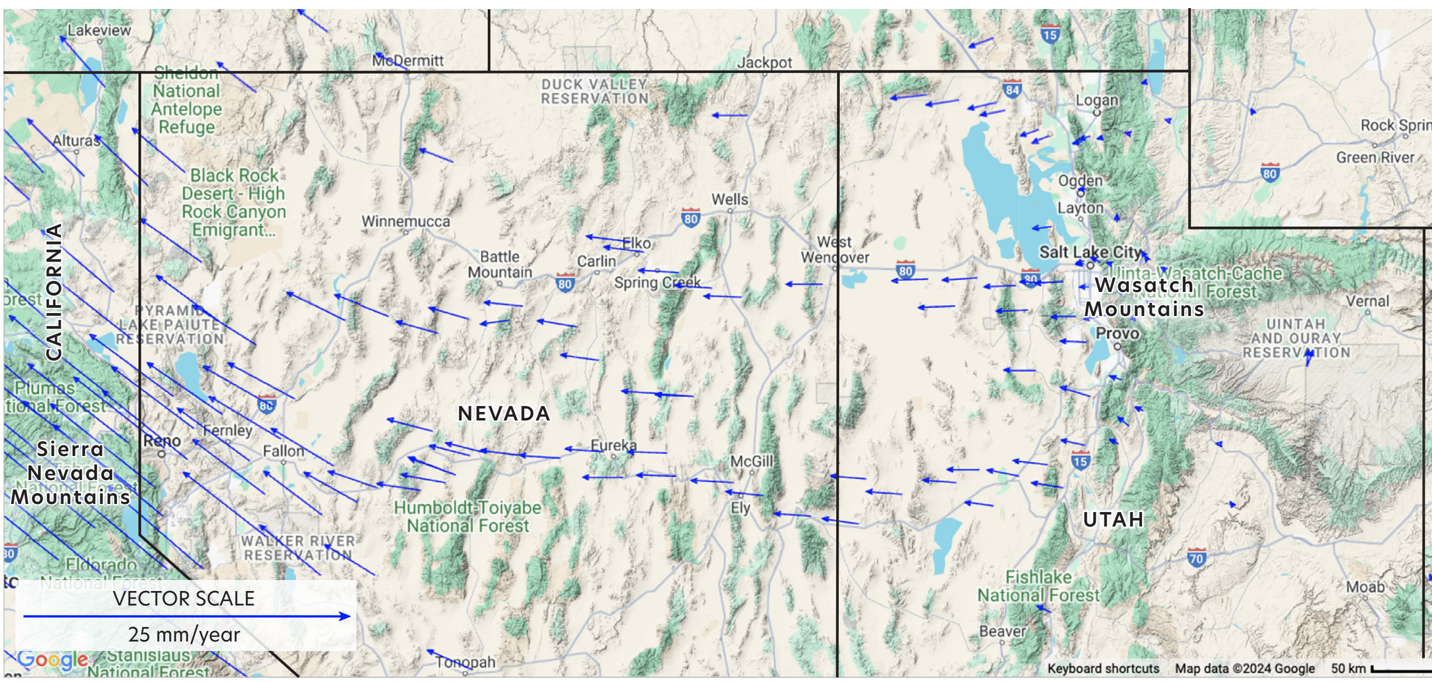
- ***The model takes less time. Rifting takes thousands to millions of years.***
- ***Not seeing the effects of rifting.***
- ***The earth is not shaking when the model has an earthquake.***
- ***The stretching of the elastic bands results in the extension. Most of the extension in the Basin and Range is caused by heat rising in the mantle, pushing the plate up.***

GPS AND SLOW EXTENSION ACROSS THE BASIN AND RANGE PROVINCE

50 MINUTE ACTIVITY HANDOUT ***ANSWERS***

PART A. MOTION AND DEFORMATION WITH EXTENSION FORCES

1 Think about the model you observed or participated in. Consider how the volunteers moved and the elastic bands stretched; draw what you think the vectors* would look like on this map. **HINT:** Start by marking the locations of the monument and the eastern California vector. Then estimate a few more vectors between the two.



Initial vector drawings might be in different places, final vectors should look something like this.

*Vectors are arrows that represent the direction of movement and relative speed. The faster the movement, the longer the arrow.

2 Lightly color the topography of the Basin and Range Province on the map below. Use different colors for each of the following areas:

a. The Wasatch Mountains to the Utah/Colorado border
b. The Sierra Nevada Mountains on the eastern side of California
c. The Basin and Range Province (the space between a and b)
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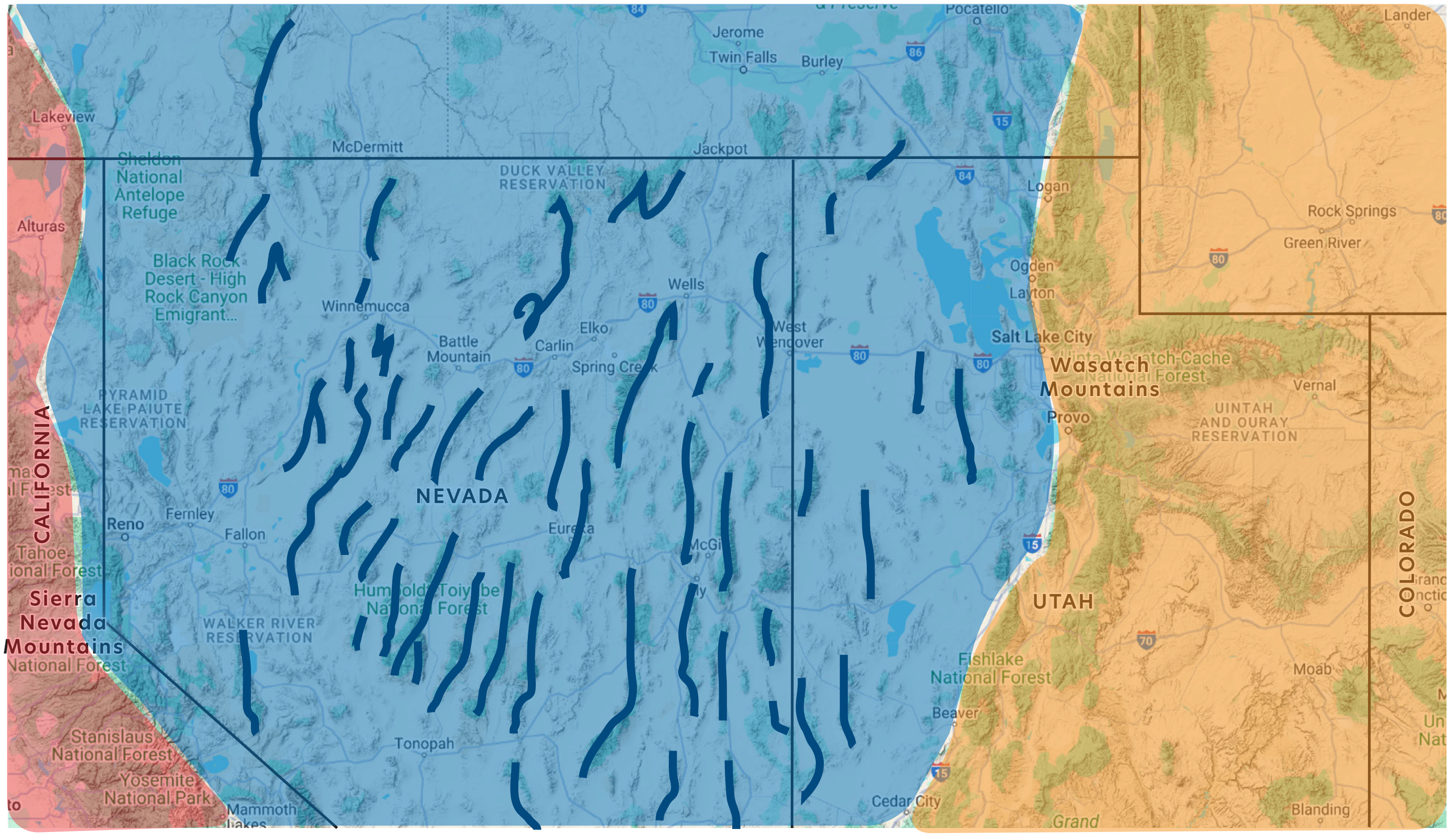


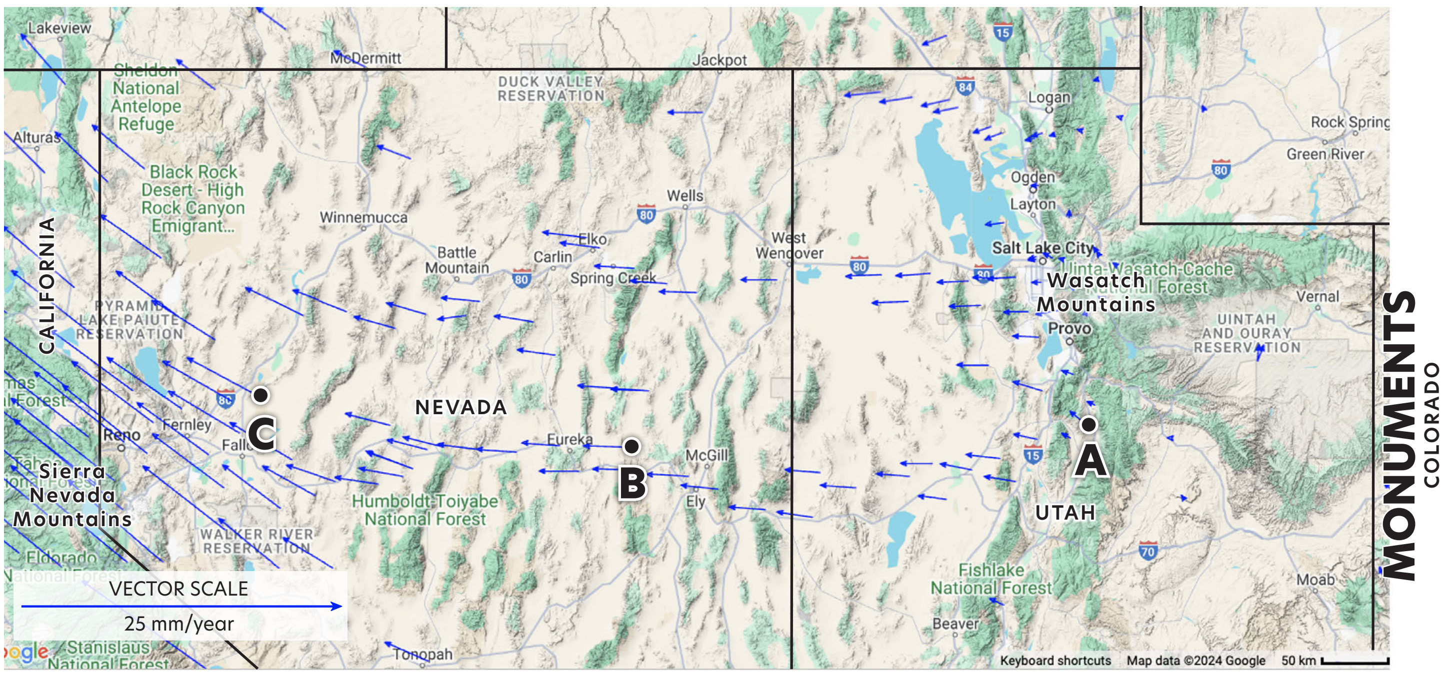
3 Use the same colors to shade in the corresponding regions in the Cross Section of Extension image below. (Hint: you may need to color "outside the lines.")

4 There are three GPS stations labeled A, B, and C on the map below. Measure the length of the vectors that start at each black dot. Record the measurements in the table below the map. Measure in mm from the tip of the vector to the middle of the corresponding dot.

5 Measure the vector scale in mm (blue vector in white box at bottom left corner of map). ***18 mm***

6 Calculate the speed at each GPS station using the plate speed formula and record the speed in the table below.

$$\text{Plate speed (mm/yr)} = \frac{\text{GPS station vector length (mm)}}{\text{Vector scale length (mm)}} \times 25 \text{ mm/yr}$$



	C Western Nevada	**B** Nevada	**A** Utah
Vector Length (mm)	***5 mm***	***3.5 mm***	***1.5 mm***
Speed (mm/yr)	***6.9 mm/yr (accepted 6.25 mm/yr)***	***4.9 mm/yr (accepted 3.12 mm/yr)***	***2.0 mm/yr (accepted 1.5 mm/yr)***

Note: differences occur because scientists use more precise instruments and accepted values are averages.

7 How do the vectors in the 3 different regions you just measured compare to what you saw people doing in the extension and vector model?

The farther away the "GPS Station" was from the initial position (where the Tension Control Checker is), the stronger the extensional force became.

8 Focus on the vectors on the map in Question 4 above. How does the change in direction near the California-Nevada border show an added earthquake hazard compared to Utah?

The velocity changes in two ways: the speed increases and the vectors change direction. Here, there are additional shear forces from the Pacific plate moving northwest, dragging the North American plate northwest as well, due to the frictional forces along the plate boundary. The rocks in faults stick until the potential energy is greater than the frictional force holding the two sides of the fault together. When the fault suddenly moves, the potential energy is released in an earthquake

9 Draw new vectors on the Basin and Range map in Question 1 using a new color. Don't erase the older vectors, you are updating your understanding with more data.

10 What is causing the extension forces in the Basin and Range Province?

Most of the extension in the Basin and Range is caused by heat rising in the mantle, pushing the plate up.

11 How do the figures in the GPS and Slow Extension model image demonstrate what is happening in the Basin and Range Province? (What are they modeling?)

The Monuments:

Fixed position of ground

Tension Control Checker:

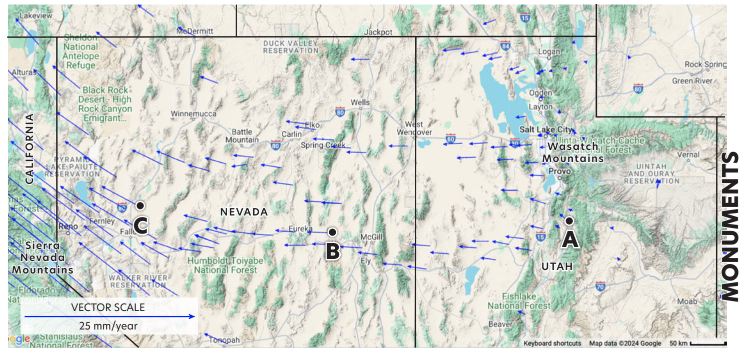
In charge of holding the amount of force at the California-Nevada border.

Each GPS Station person?

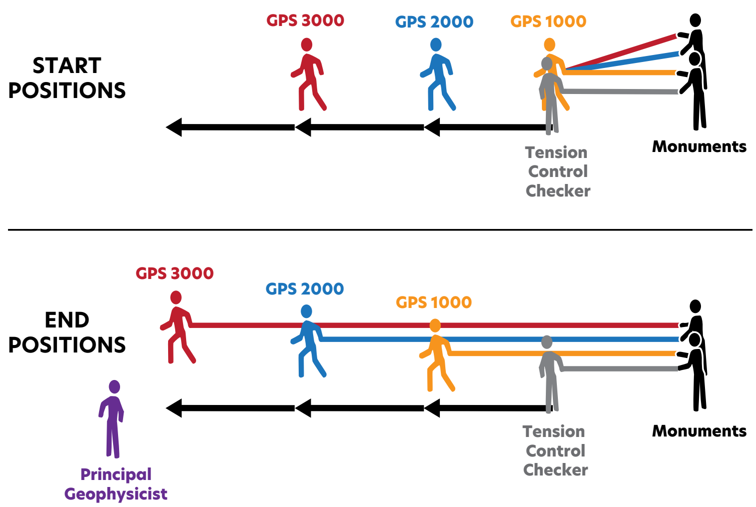
GPS movement per 1000 years

The elastic bands?

Extension forces that have built up to that point



GPS AND SLOW EXTENSION MODEL



12 Compare the model using elastic bands to the real world. List what you observe.

How is the Model **LIKE** the Basin and Range?

- ***The straps (Extension forces) get tighter as velocity increases (longer vectors or change in direction).***
- ***Potential energy converts to kinetic energy (motion), heat (thermal), and acoustic energy (sound) when forces become too great.***

How is the Model **UNLIKE** the Basin and Range?

- ***The model takes less time. Rifting takes thousands to millions of years.***
- ***Not seeing the effects of rifting.***
- ***The earth is not shaking when the model has an earthquake.***
- ***The stretching of the elastic bands results in the extension. Most of the extension in the Basin and Range is caused by heat rising in the mantle, pushing the plate up.***

PART C. USING GPS DATA TO DETERMINE POTENTIAL HAZARDS

13 Thinking about your answer to Question 11 above: (a) Which region has the most potential energy stored within the rock? (b) Which region is more likely to experience an earthquake?

(a) Answers may vary: Vectors in western Nevada near the California-Nevada border are longer relative to the mid-Nevada and Utah vectors. There is a great change in velocities in western Nevada near the CA-NV border in the speed and direction of the vectors. There is more elastic potential energy stored within the rock in this location.
(b) The area near the California-Nevada border is more likely to experience earthquakes.

14 Compare the seismic hazard maps with the ground motion map. What can you conclude about the relationship between what the vectors are showing you and the earthquake shaking potential?

Answers may vary: The change in length of the vectors and direction is near the California-Nevada border. This area is holding the most potential energy, creating the highest hazard.

The regions with the greatest chances (red and orange) of a damaging earthquake support the conclusion of Question 13—they overlap the same regions with the vectors changing directions, although not perfectly. The ground motion map indicates areas of northwestern Nevada that have vectors changing directions, too.

Remind learners that other factors, such as historical seismicity and rock type, are used to make the seismic hazard maps. It does not mean that the vector data is incorrect, rather we need many types of data to understand how earthquakes happen

15 Why is it so important for us to understand how the tectonic plates are moving?

If we can determine how the plates are moving and interacting, we can forecast where the stronger earthquakes might take place. People living in regions with seismic hazards can then prepare and take mitigation efforts to decrease their risk of impact from an earthquake.

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

16 Who is your contact person?

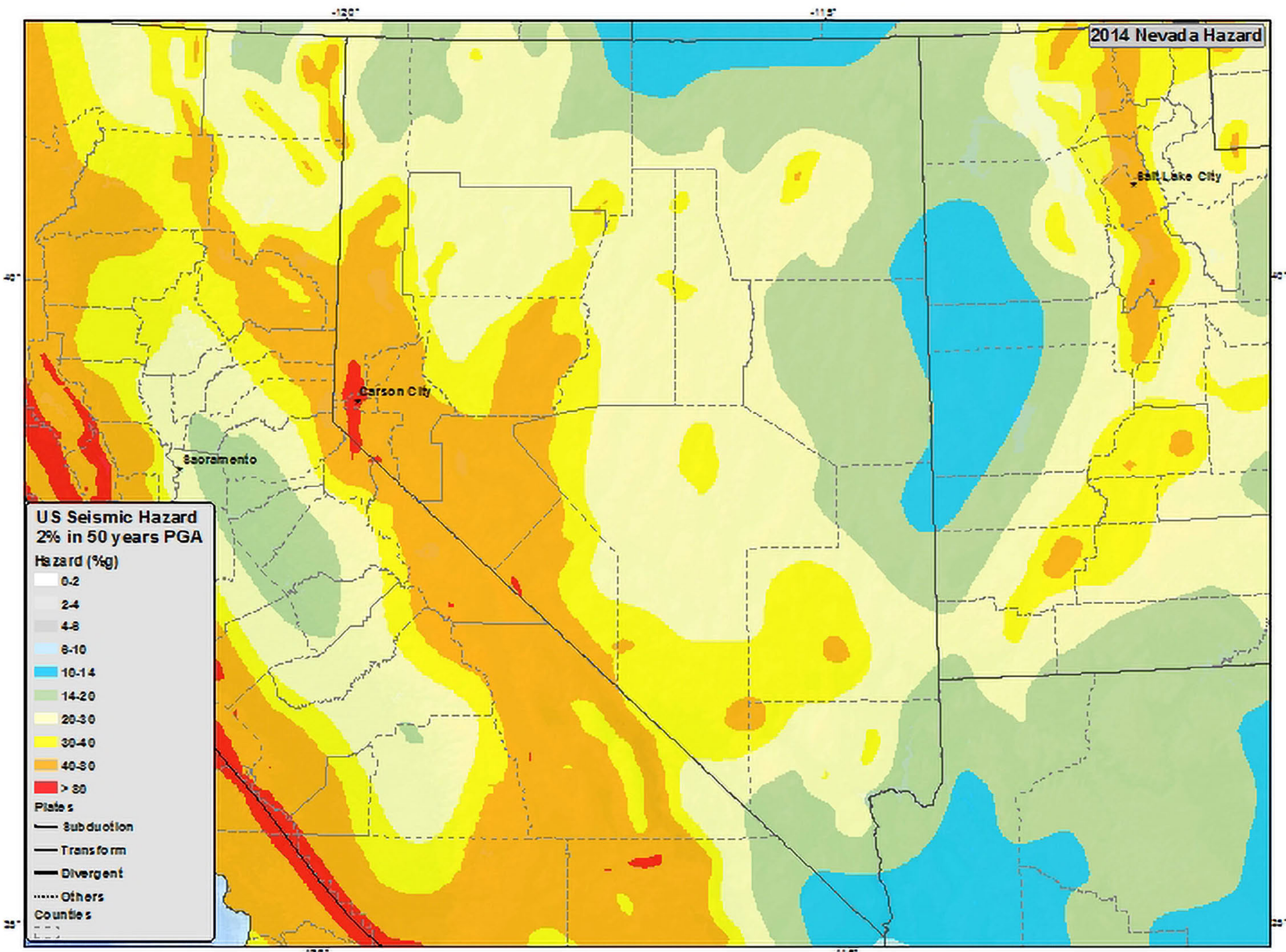
Answers will vary.

17 Where is a safe place to store water in your home?

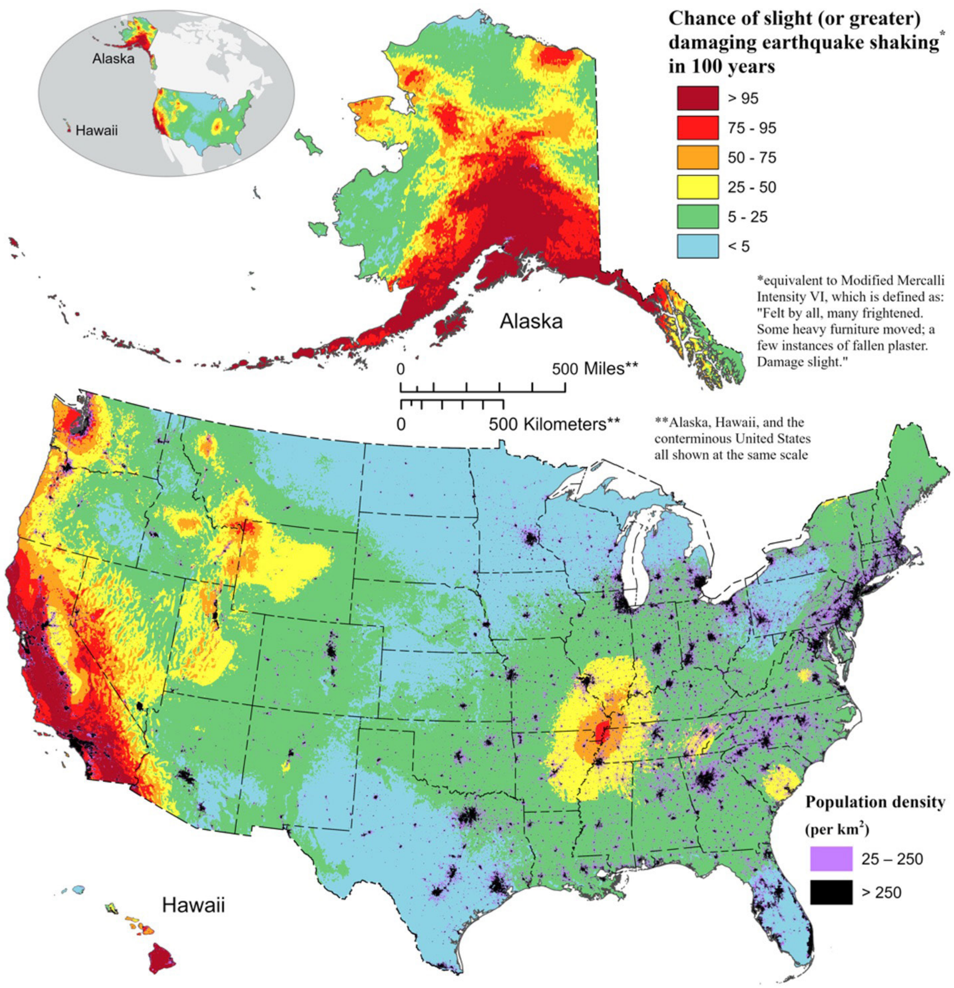
Answers will vary.

APPENDIX H. SEISMIC HAZARD MAPS

SEISMIC HAZARD MAP FOR NEVADA AND PORTIONS OF CALIFORNIA AND UTAH



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.

APPENDIX I. 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).