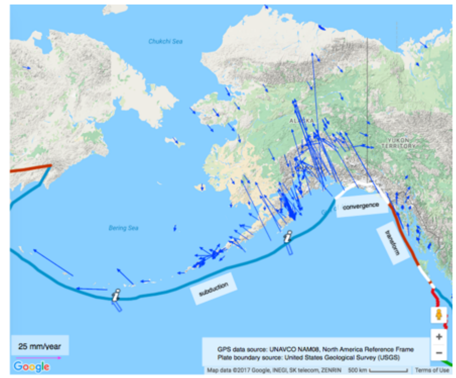
Exploring Tectonic Motions with GPS

How do we know tectonic plates are moving?



Learners study plate tectonic motions by analyzing Global Positioning System (GPS) data, represented as vectors on a map. The activity is designed to use the online map tool *GPS Velocity Viewer*, but instructors can instead print the provided hard-copy maps for Alaska or Western United States. By observing changes in vector lengths and directions, learners interpret whether regions are compressing, extending, or sliding past each other. To synthesize their findings, learners identify locations most likely to have earthquakes, and defend their choices by providing evidence based on the tectonic motions from the GPS vector and seismic hazards maps.

Essential Questions:

- What does a GPS station measure?
- What can GPS data tell us about how the earth's surface is changing?

Essential Understandings:

- GPS stations measure how a precise location on the earth's surface is changing over time
- GPS data is reported as vectors that provide the speed and direction (velocity) that a point is moving
- Changes in velocity across a region provide evidence for tectonic forces such as compression, extension and shear
- The magnitude of the velocity gradients provides evidence for the relative risk of seismic activity in a location

Goals

Learners will be able to:

- Analyze and describe regional plate motion data as represented by vectors
- Interpret crustal deformation based on velocity vector map
- Correlate GPS vector gradients on a map with plate tectonic boundary types
- Make a claim based on evidence about which locations are most likely to have earthquakes.

Materials

- ***USGS Photos of land surface changes during the 1964 Good Friday Earthquake*** https://earthquake.usgs.gov/earthquakes/events/alaska1964/1964pics.php
- ***Video: How GPS Works to Pinpoint Location*** https://www.youtube.com/watch?v=hqxwYWr879s&list=PLzmugeDoplFOWUv5oeaqi3vqXoZ0GmTiD&index=4&t=3s
- ***Video: How GPS Measures Ground Motions*** https://www.youtube.com/watch?v=ucEOAR6U2js&t=162s
- ***GPS Velocity Viewer*** https://www.unavco.org/software/visualization/GPS-Velocity-Viewer/GPS-Velocity-Viewer.html
- ***Computers*** *(unless printed GPS maps are used instead)*
- ***Student handout*** (below)
- ***Seismic Hazard maps for Alaska & Western US*** (below)
- ***Optional: Tectonic Ground Motion half-sheets*** (below), gumdrops, toothpicks, modeling clay
  Presentation: How GPS Measures Ground Motions
- ***Optional: GPS maps of Alaska and Western US*** (below)
- Editable versions of the student handout, key, and additional supporting resources can be found at https://serc.carleton.edu/ANGLE/educational_materials/activities/206043.html

NGSS Science Standards

- **MS-ESS2-2** Construct an explanation based on evidence for how geoscience processes have changed Earth's surface at varying time 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-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

Teacher Background & Instructions

What is Geodesy?

Geodesy is the study the shape and area of the earth. This is one of the oldest science disciplines, having been a primary focus of early Greek scientists. To learn more, view this short video produced by NASA, outlining the history of Geodesy:
https://www.youtube.com/watch?v=Ramawc3uKgM

Background on how GPS works

Global Positioning Systems satellites send electromagnetic signals that are received by devices on Earth and used to determine position. Simple "receivers" such as those in smart phones give general positions, whereas research-grade receivers, anchored to the ground surface, can determine precise positions on the Earth's surface and measure how those positions move over time.

To learn more about the various aspects of these complicated systems, please see the following resources:

NASA How Does GPS Work?:
https://spaceplace.nasa.gov/gps/en/

NOAA Tutorial on Global Positioning:
https://oceanservice.noaa.gov/education/tutorial_geodesy/

Reference Frames

All parts of the earth are moving. To quantify how one part moves with respect to another, we need to choose an arbitrary point as being "stationary," and measure all other motions in relation to this fixed point. This abstract coordinate system is called a reference frame. Read more about how reference frames are used in the *GPS Velocity Viewer*:
https://www.unavco.org/software/visualization/GPS-Velocity-Viewer/GPS-Velocity-Viewer-frames.html

Suggested Prior Knowledge

Ideally, learners would already be familiar with vector quantities. Prior experience with GPS vectors in particular will be helpful before expecting learners to interpret the meaning of changes in GPS vectors as you cross a tectonic boundary zone.

It is recommended that prior to this lesson, you instruct on how GPS works, and how a GPS vector for a station is determined from individual component time series data. A suggested activity to accomplish this would be at least the first part of *Alaska GPS Analysis of Plate Tectonics and Earthquakes*:
https://serc.carleton.edu/ANGLE/educational_materials/activities/205656.html

Instructional Sequence

Step 1: Engage learners with a brief narrative/image about sudden changes to the land surface that occur during earthquakes. For example, during the 1964 M9.2 Good Friday Earthquake in Alaska, locations in Prince William Sound were uplifted as much as 33 feet (see photo of a dock on Hinchenbrook Island, or Cape Cleare on Montague in the USGS collection linked in Materials). Explain that during catastrophic events, earth's surface can change dramatically. Yet, most locations on earth's surface are moving almost imperceptibly all the time!

Step 2: Review how GPS works to precisely determine a location. Depending on time, you can show the video *How GPS Works to Pinpoint Location*, or gather supplies and physically do the demonstration.

Step 3: Prepare students to be able to interpret changes in velocity on the land surface, and to connect various types of velocity gradients to plate tectonic settings. Depending on the capabilities of your learners, you can show the demonstration video *How GPS Measures Ground Motions*, OR provide the *Tectonic Ground Motion half-sheets* and have them work through the different manipulations themselves rather than just watch the demonstration. You can use the slide presentation *How GPS Measures Ground Motions* to help them work through the activity.
Note: the gumdrop GPS monuments shown in the video and presentation are helpful to provide a visual of how the fixed stations move on the plates with respect to each other, but items such as paper clips or erasers would work fine to represent stations.

Step 4: Distribute the student handout and provide access to the *GPS Velocity Viewer* online data portal. Model for learners the basic functionality of the data portal, such as how to reduce the number of markers displayed (recommended before zooming out to show more of the world), and how to toggle on/off different types of additional data, such as locations of plate boundaries, earthquakes, and volcanoes. Note: a link to an instructional video on *How to Use the GPS Velocity Viewer* is located just above the map on the website.

The last question on the student handout refers to a Seismic Hazard map (provided in Materials). You can print these in color and laminate for reuse or display via projector.

Alternative to online: Instead of accessing the online *Velocity Viewer*, instructors can use the provided printable GPS maps of Alaska and the Western US.

Step 5: Wrap-up by discussing the implications for different regions: where do we expect more earthquake activity? What should people in these regions do to prepare? How can GPS data help?

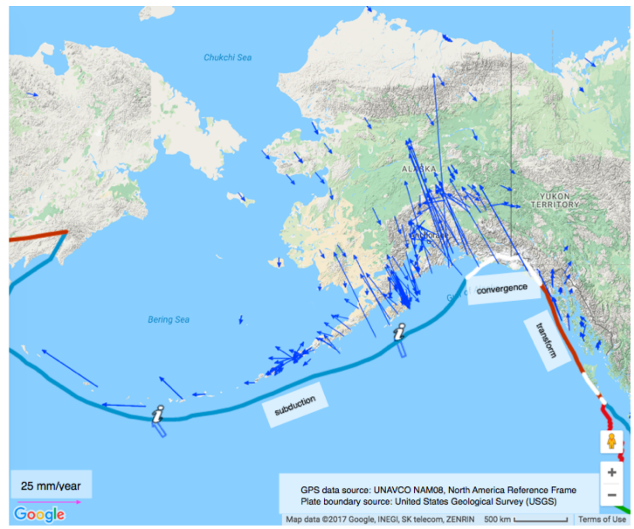
Name: ____ Period: ____ Date: __________

Exploring Tectonic Motions Using GPS

How do we know tectonic plates are moving? In this activity, we will explore evidence using current Global Positioning Systems (GPS) data to see how the land beneath your feet is moving. You will study maps with plotted GPS vectors and learn to recognize if tectonic plates are compressing, stretching, or sliding past one another. You will then consider how these different types of crustal motion relate to earthquake hazards and resulting societal impacts.

Open the GPS Velocity Viewer: https://www.unavco.org/software/visualization/GPS-Velocity-Viewer/GPS-Velocity-Viewer.html

Explore the vectors



1. What do the arrows on the map represent?

2. What is the scale for the vectors? *[Hint: find the key on the map].* Explain how you would use the scale to determine the speed of any specific location on earth.

3. Find the longest vector you see on the map and measure its length using the vector scale bar on the map. Describe the location you have chosen, and identify at what speed and in which direction this location is moving.

Explore plate motions

4. Abrupt changes in velocity across the land surface usually occur at or near plate tectonic boundaries. These changes in velocity could be indicated in two main ways:
   1) vectors point in similar directions but have different lengths
   2) vectors point in different directions from each other

   Locate one example of each of these scenarios on the map, and describe the general location.

5. What do the relative motions of adjacent vectors suggest is happening to the land between them? Pick an area that you identified in Question 4, and make a claim based on the evidence you see in the vectors: is the land between the stations compressing (i.e., the GPS stations would be getting closer together)? Is the land between the stations extending, or just sliding past each other?

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

6. On the GPS Velocity Viewer, select *Display Plate Boundaries* (under *More Types of Data*), then click “Draw Map”. For the area you chose in Question 5, which plate boundary type is nearby? Explain how the evidence you see in the velocity vectors demonstrates the type of forces you would expect to see in this plate boundary type.

Societal impacts of plate motion

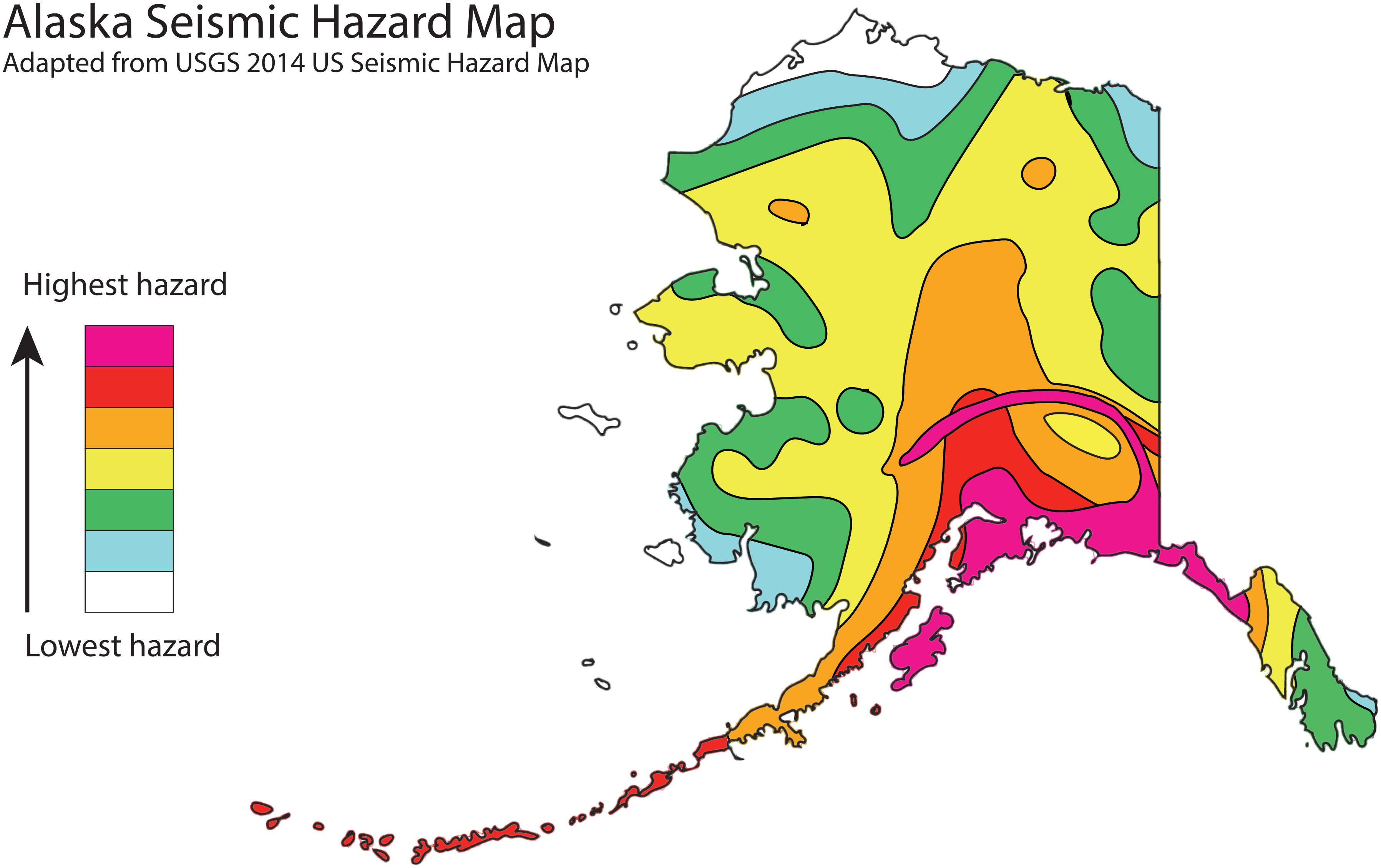
7. Large differences in velocity across short distances of land surface indicate stored strain in the earth, that may be released over time through earthquakes. Where do you see the largest changes in velocity?

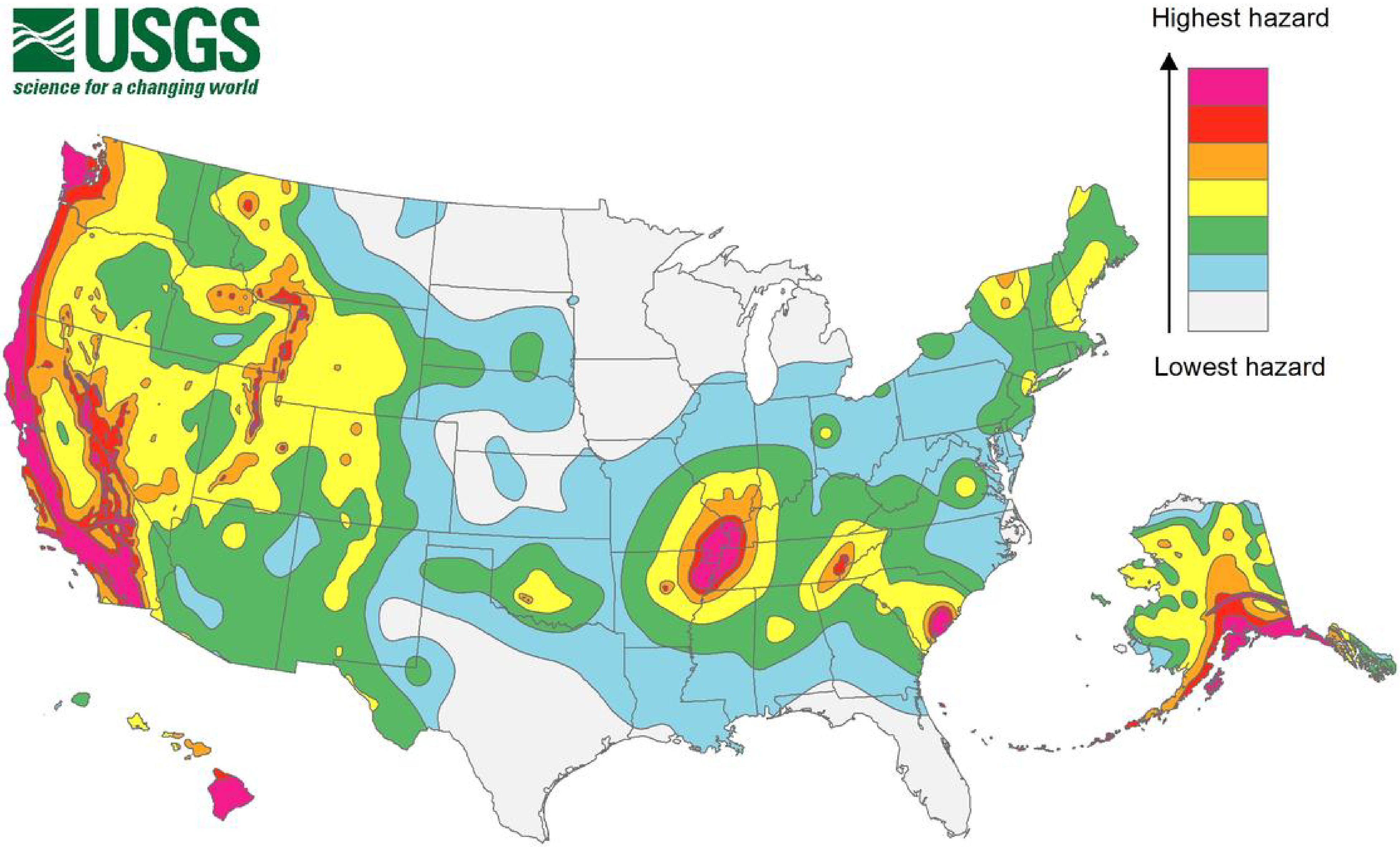
8. Is there any correlation between areas of stored strain you identified in Question 7, and plate boundary type? Explain, citing evidence from the Velocity Viewer.

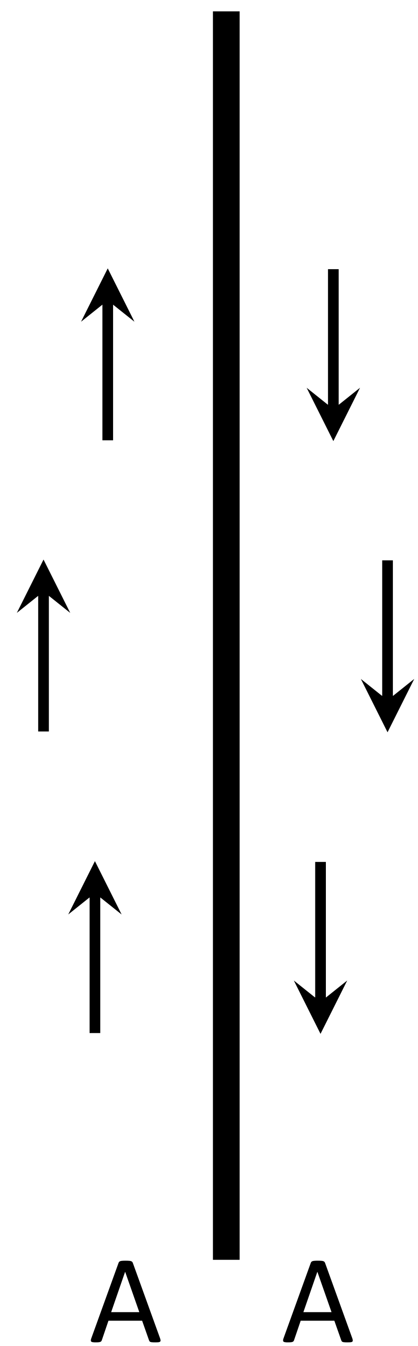
9. Look at the seismic hazard map provided by your instructor. How does the level of seismic hazard on this map compare to the areas you identified (in Question 7) as storing strain?

Alaska Seismic Hazard Map

Adapted from USGS 2014 US Seismic Hazard Map




USGS
science for a changing world
Highest hazard
Lowest hazard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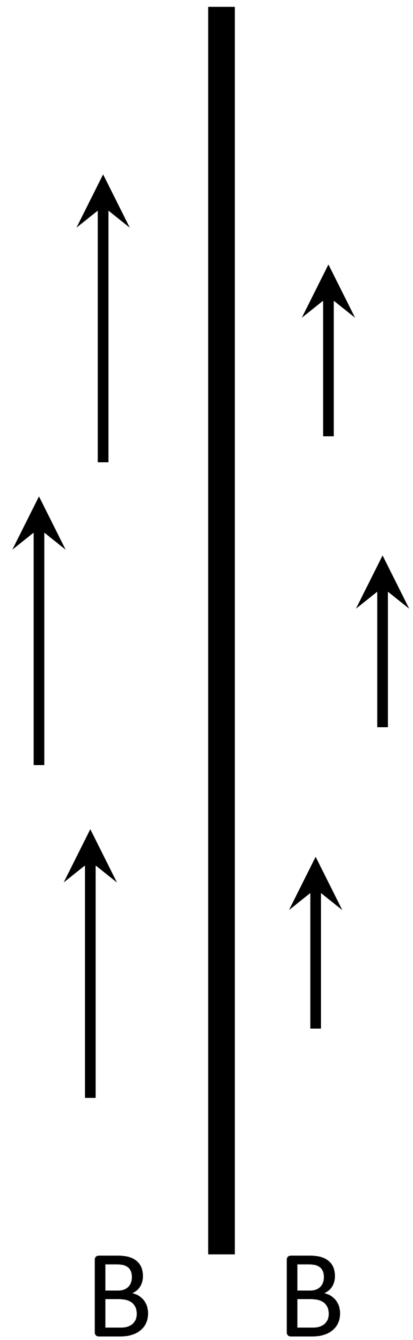
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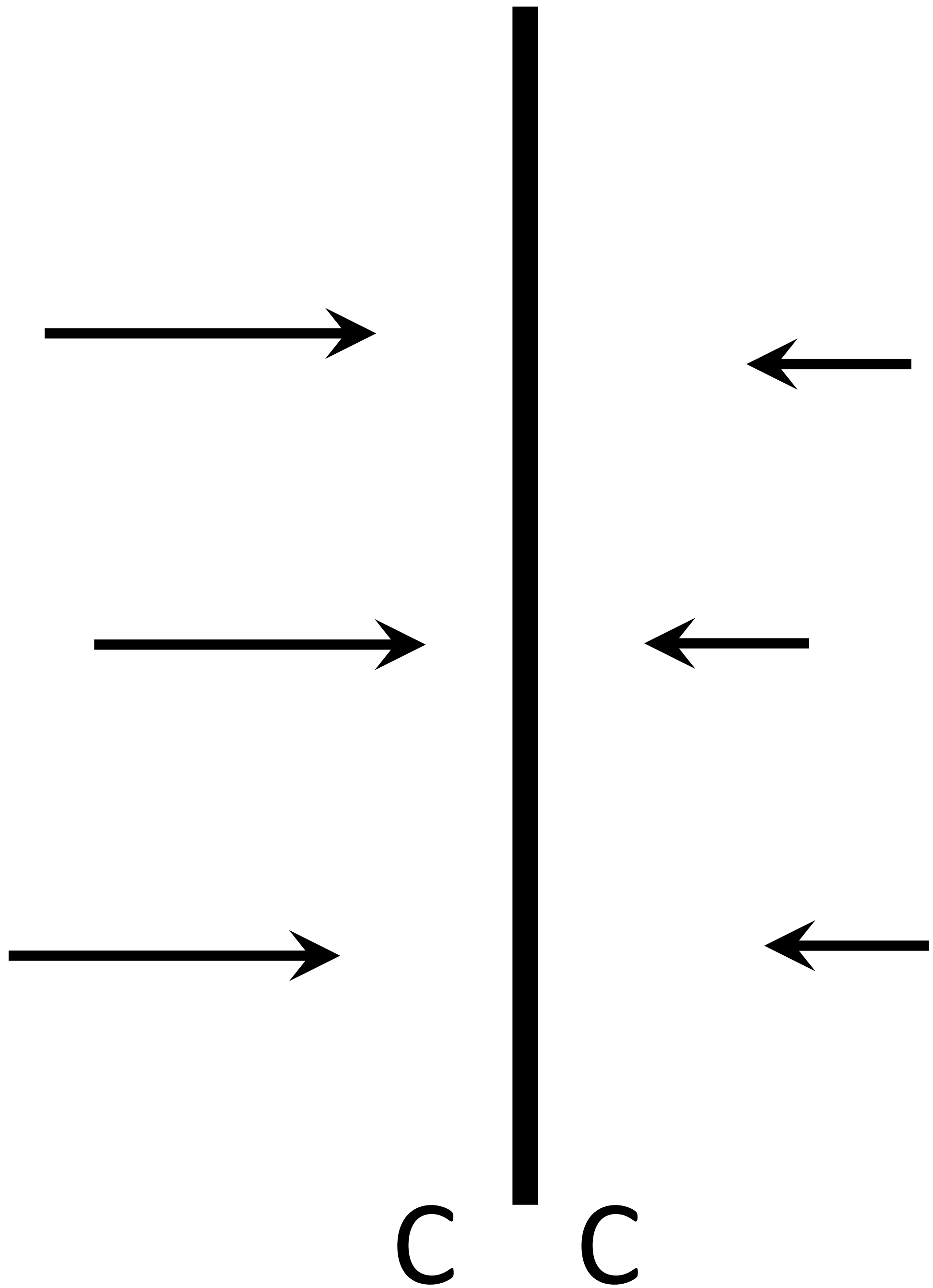
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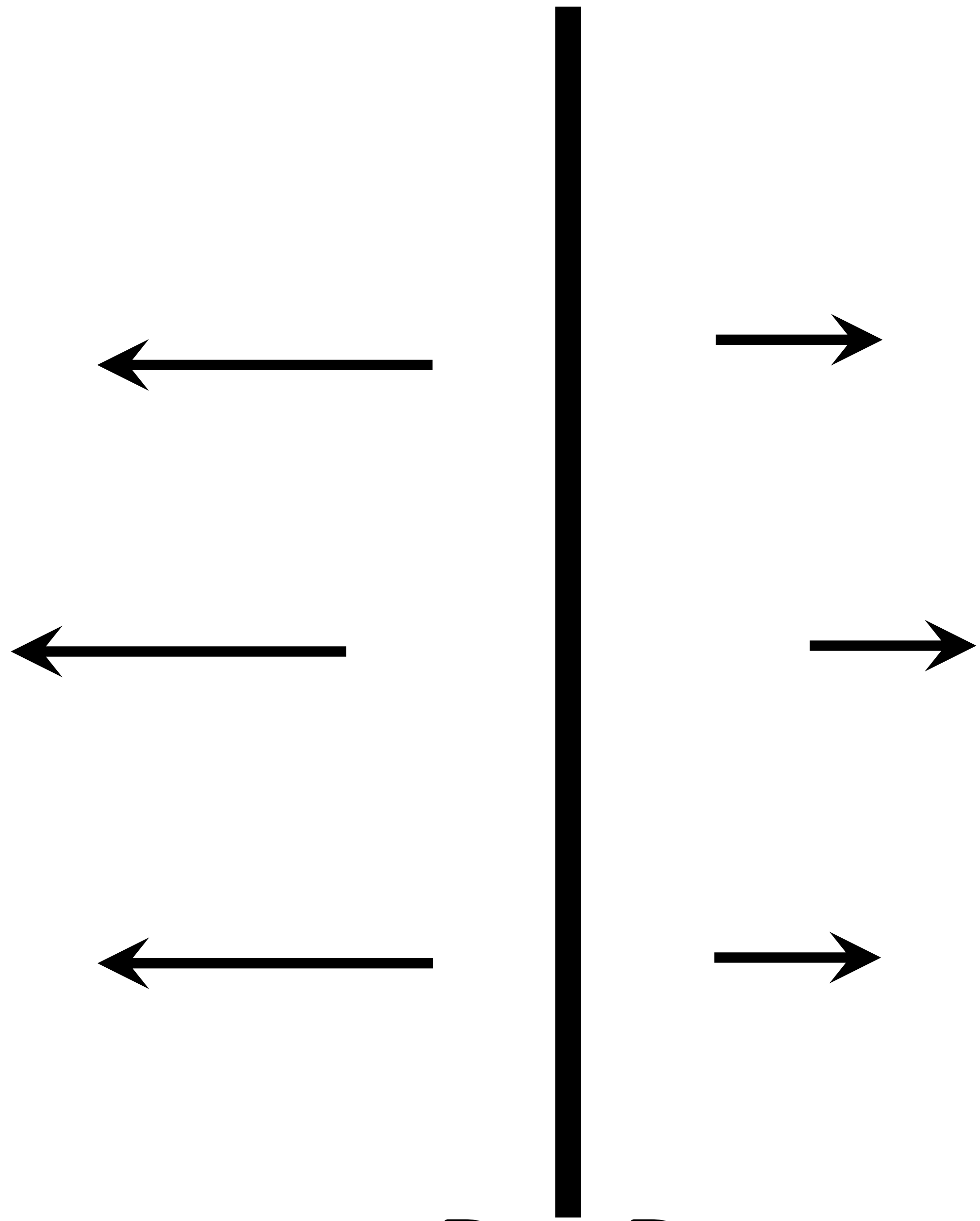

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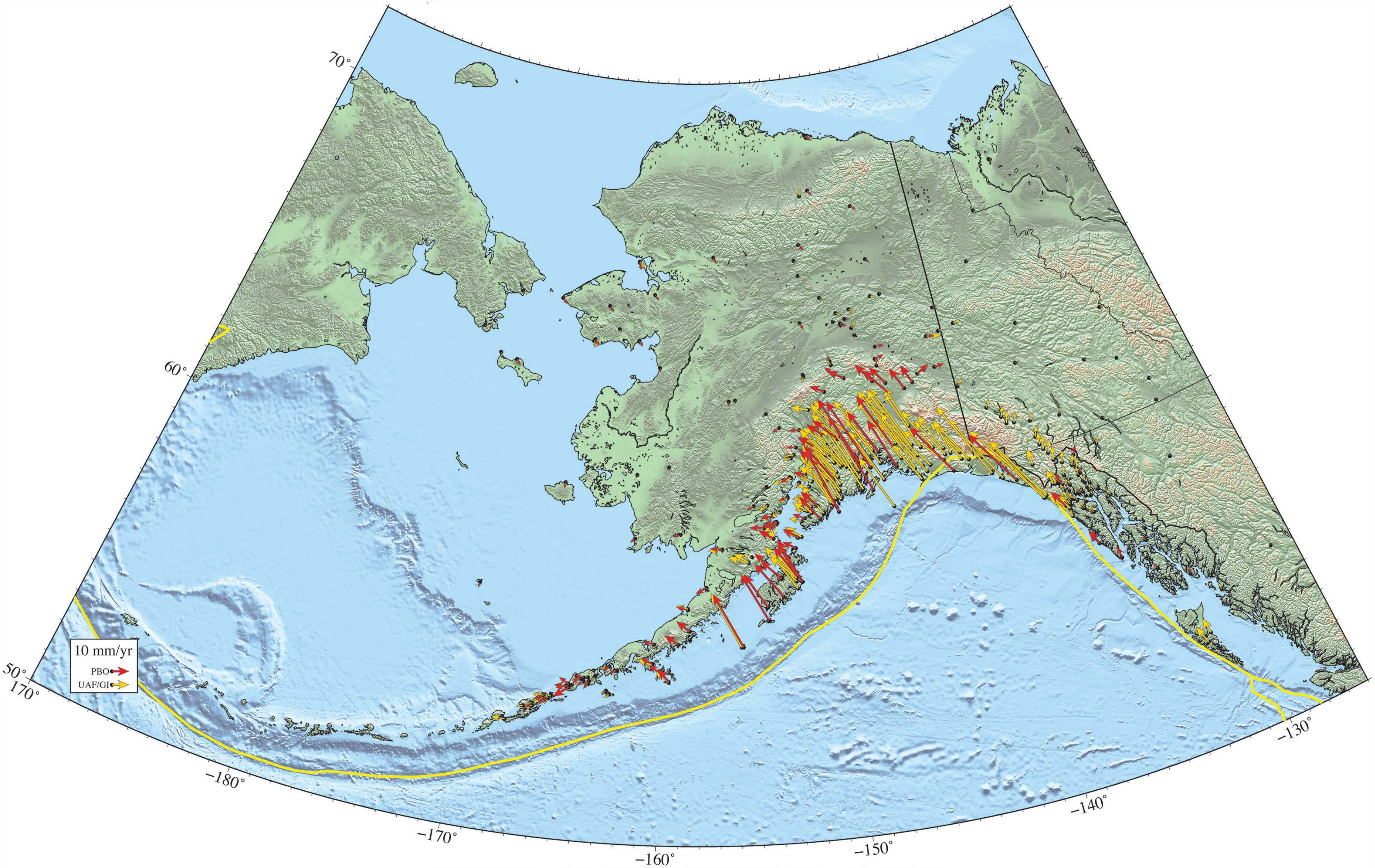
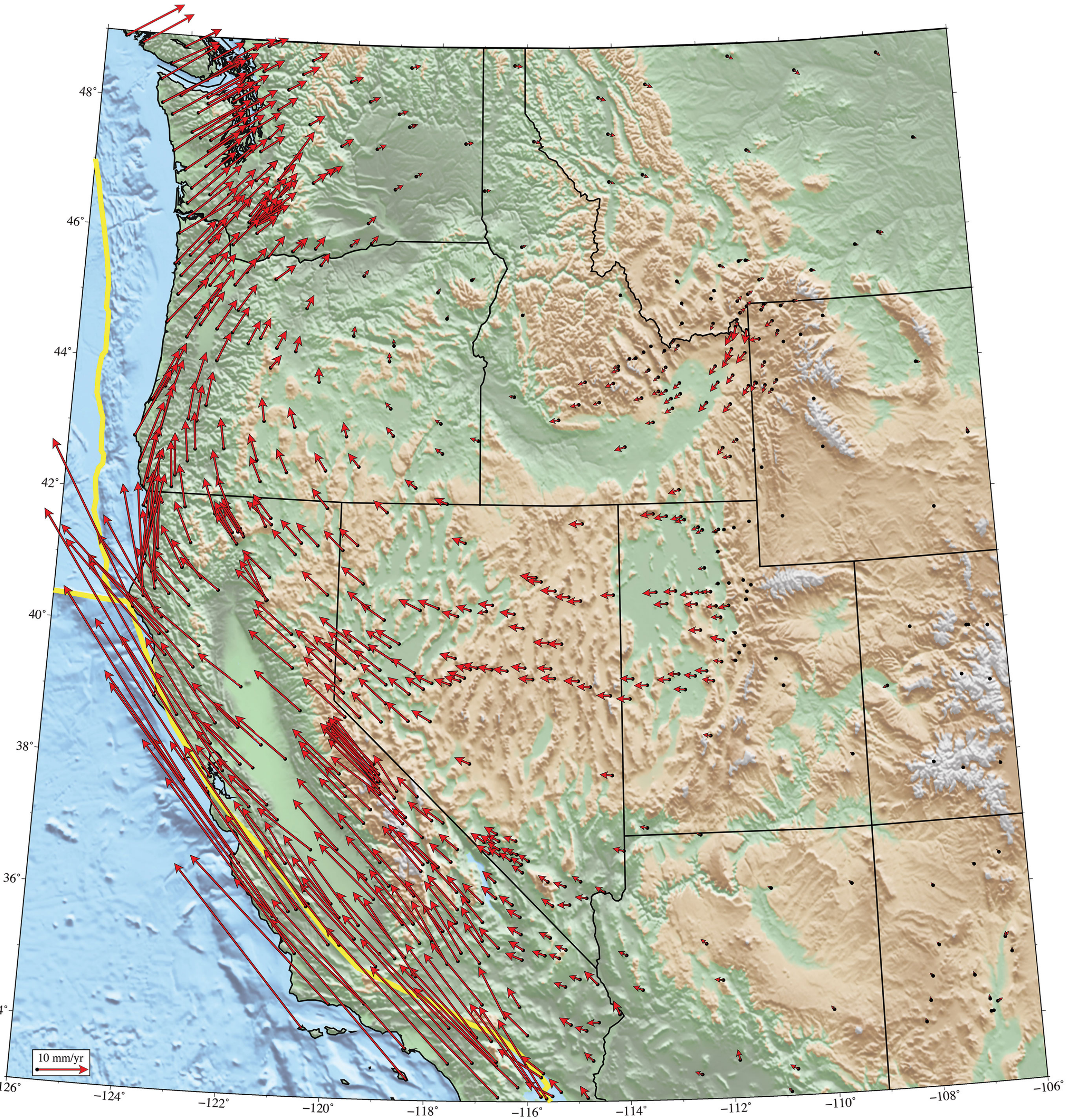
Tectonic Motions of Alaska



Tectonic Motions of the Western United States



Horizontal velocities for western United States GPS stations whose data are processed by the Geodesy Advancing Geosciences and EarthScope (GAGE) GPS Analysis Centers for the Plate Boundary Observatory at New Mexico Tech and Central Washington University. Velocities are in the North America-fixed reference frame (NAM08) and calculated by the Analysis Center Coordinator at the Massachusetts Institute of Technology. The number of stations shown in California has been greatly reduced to make it easier to see regional motion. For updated velocities, search the web for UNAVCO GPS Velocity Viewer.

For this map and related links, go to unavco.org/velocity-maps