

## Determining strain graphically

### Student Worksheet

We know that Earth's crust deforms because we

- 1) handle rocks that have changed shape. Linear features stretched, circular features became ovals, or symmetrical features became misshapen (Fig. 1);
- 2) record earthquakes daily and note offsets along faults (Fig. 2); and
- 3) measure changes in position of GPS units fastened to the crust (Fig. 3).



Figure 1a. Trilobite.  
Smithsonian, 2002.

Figure 1b. Strained trilobite.  
Smithsonian, 2002.



Figure 3. High-resolution GPS station (the dome), with solar charger and receiver. UNAVCO.



Figure 2. Offset in fence caused by the 1906 San Francisco earthquake. Total offset was 11 feet. Gilbert, 1906.

Recall that deformation arises from wholesale motion of a block of crust as well as its distortion--or strain.

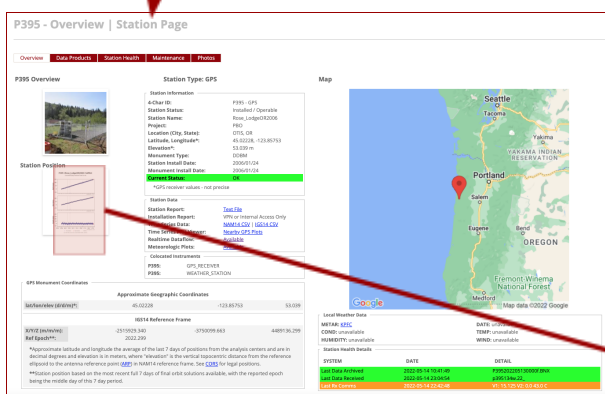
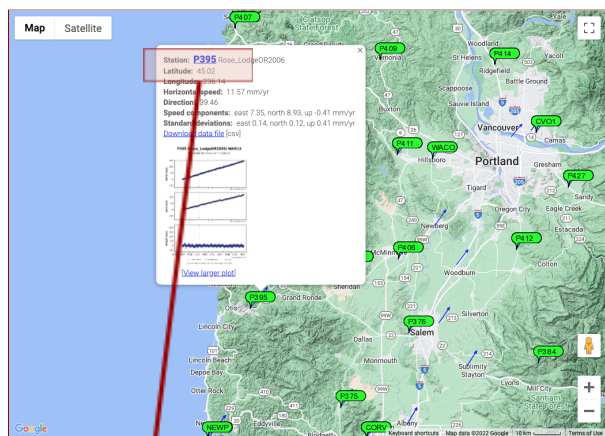
Data from a triangle of GPS stations

allows us to analyze the deformation. This exercise uses real data from three real places to determine that deformation. By graphing triangles, you'll be able to pull out the translation component accurately. You'll also be able to judge roughly how the area has rotated and strained. However, by adding in the use of a spreadsheet-based calculator, you can also find the exact length of strain axes and exactly how much they have rotated. You will be able to describe exactly how Earth's crust is deforming now—today.

## Finding strain

### Getting the data

You will need horizontal velocity data for three GPS sites. Your teacher might give this to you or you might retrieve it yourself. If you're hunting for it, here's what you do:



On this graph (similar to those at right), look at the horizontal axis. Write the span of time for which there is data on your data sheet.

Look at the top graph, North. Is it increasing or decreasing over time? Does it have a positive or negative slope? In short, is the station moving farther north or south over time?

Look at the middle graph, East. Is it increasing or decreasing over time? A positive slope means that the station is moving east.

Scroll to the "Most Recent Detrended Data Time Series Plot". From this data, record the velocity and error for all three parts of the chart on your data sheet.

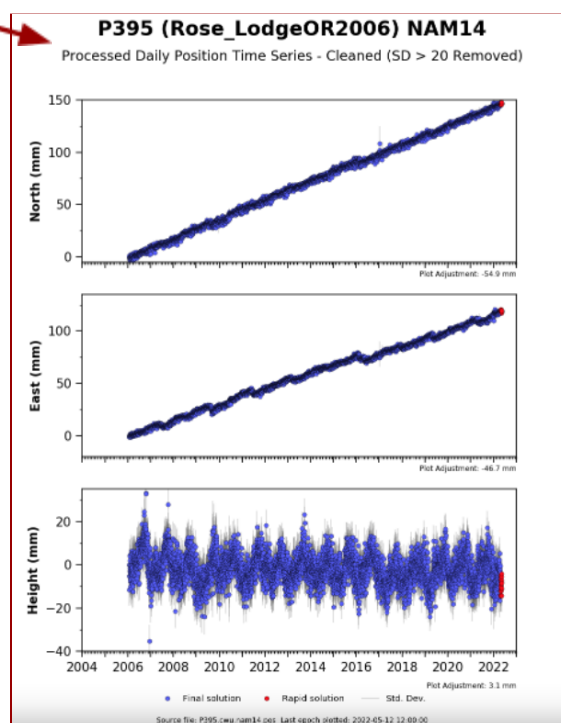
Repeat this for the other two GPS stations.

Go to [UNAVCO's Velocity Viewer](#). (Search for "UNAVCO Velocity Viewer.") The Velocity Viewer shows all of the GPS stations that are available.

Once you have found a station that you are looking for, click the green station icon and then click the station identifier in the upper left of pop-up that appears. This will launch the station's web page.

Copy the latitude and longitude (to three decimal places along with the sign) as well as the elevation for the first site into the data sheet. A positive latitude is in the northern hemisphere; a negative longitude is in the western hemisphere. Elevation is in meters.

Click on the graphs labeled "Station Position." A series of graphs that you can scroll through pop-up. Make sure that you are looking at the "Most Recent Cleaned Data Times Series Plot". This shows you data about how the GPS station has moved in the last several years.

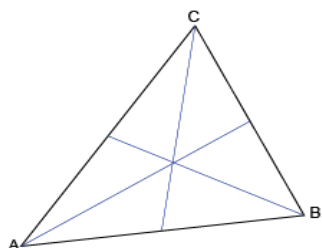


**Analyzing the data**

- ☐ First, you'll make intuitive sense of the data by looking at the north and east velocities together. You'll combine them and look at them on a map. **Do this by completing the separate activity "Velocity maps."**
- ☐ Discuss your results with your group or entire class. What do you think the three vectors mean for the plot of land bounded by the three GPS stations?

Now you'll analyze the data quantitatively. That means that you'll figure out exactly—with numbers—how the land has been strained.

- ☐ Connect the GPS stations to make a triangle.



A triangle with lines connecting the midpoint of sides to the opposite vertex. Lines cross at the centroid.

- ☐ Measure and mark the middle of each side of the triangle. (Or, bisect each side.)
- ☐ Draw a very faint line from the midpoint of the side to the vertex opposite for each line. The three lines intersect in what's called the "centroid" of the triangle. (See figure at left)
- ☐ At the centroid, draw an x-axis oriented E - W and a y-axis oriented N - S.
- ☐ Also, use a compass or stencil to draw a circle inside the triangle with the center on the centroid.

- ☐ Lay a piece of graph paper over the map you have been working on. Make sure the edges of the pages line up, and N is at the top of the page. Temporarily tape the papers together.
- ☐ Looking through the graph paper to the map below, mark the ends of the arrows on the total velocity vectors. Connect the three points in a triangle.
- ☐ As before, find the centroid of this *deformed* triangle. Punch a hole with a pin through the centroid of the *deformed* triangle into the map below. Separate the papers.
- ☐ On the *map*, draw a new vector from its centroid to the pinhole. This vector shows the translation of the region over time. (Remember moving the tee-shirt without changing its shape?) The vector is the "translation vector."
- ☐ Measure and record the length of the translation vector.
- ☐ Use a protractor or compass to measure the direction ("bearing" or "azimuth") of the translation vector. Record this.
- ☐ Now, stack the centroid of the *deformed* triangle on top of the centroid of the *undeformed* triangle (on the map). Keep the x-axis parallel to the grid on the paper. By doing this, you are removing the translation component of the deformation.

- ☐ While the centroids are perfectly stacked up, poke pinholes in the vertices of the *deformed* triangle through the map. Separate the papers. To see the pinholes, hold the map up to the light.
- ☐ On the *map*, connect the three new pinholes into a triangle using a different color. This triangle shows the strain by itself—without any translation. It shows the change in size and shape of the crust in the region over time.
- ☐ How would you describe the type of deformation? Is there any rotation? Does it appear to be pure shear or simple shear? Discuss this with your classmates, and describe in a sentence or two on your graph paper what you see.

Think about how the circle you drew on the map deformed over the years that your data represents. The circle you drew on the map would become an ellipse on the graph paper. With some triplets of GPS stations, you might even be able to sketch a strain ellipse and its major and minor axes. But, we can determine them exactly.

- ☐ Plug your data into the GPS Triangle Strain Calculator and let your computer use matrix algebra to determine strain axes and rotation quantitatively. (It is the same matrix algebra you might use a graphing calculator for in Algebra II or pre-Calculus.)
- ☐ On your graph paper, in the center of the triangle, plot the two strain axes that were just calculated for you. Use the azimuth to do this, and don't worry about the absolute length of the lines. Show their lengths relative to each other, however, and label them.
- ☐ Turn in your map, your graph paper, and your data sheet, and congratulate yourself on working through a problem in crustal deformation.

## Image Sources

Figure 1a. "Slate with undeformed trilobite fossil." Smithsonian, National Museum of Natural History, Geogallery. Image 2002-1177. [http://www.mnh.si.edu/earth/text/dynamicearth/6\\_0\\_0\\_GeoGallery/geogallery\\_specimen.cfm?SpecimenID=26&categoryID=4&categoryName=Rocks&browseType=group&groupID=8&groupName=Metamorphic](http://www.mnh.si.edu/earth/text/dynamicearth/6_0_0_GeoGallery/geogallery_specimen.cfm?SpecimenID=26&categoryID=4&categoryName=Rocks&browseType=group&groupID=8&groupName=Metamorphic) Retrieved 25 February 2013.

Figure 1b. "Slate with deformed trilobite fossil." Smithsonian, National Museum of Natural History, Geogallery. Image 2002-11799. [http://www.mnh.si.edu/earth/text/dynamicearth/6\\_0\\_0\\_GeoGallery/geogallery\\_specimen.cfm?SpecimenID=103&categoryID=4&categoryName=Rocks&browseType=group&groupID=8&groupName=Metamorphic](http://www.mnh.si.edu/earth/text/dynamicearth/6_0_0_GeoGallery/geogallery_specimen.cfm?SpecimenID=103&categoryID=4&categoryName=Rocks&browseType=group&groupID=8&groupName=Metamorphic) Retrieved 25 February 2013.

Figure 2. Gilbert, G.K. 1906. ID Gilbert, G.K. 2845. [http://libraryphoto.cr.usgs.gov/cgi-bin/show\\_picture.cgi?ID=ID.%20Gilbert,%20G.K.%202845](http://libraryphoto.cr.usgs.gov/cgi-bin/show_picture.cgi?ID=ID.%20Gilbert,%20G.K.%202845) Retrieved 25 February 2013.

Figure 3. UNAVCO

**Datasheet**

Name: \_\_\_\_\_

Time span of data: \_\_\_\_\_

Date data obtained: \_\_\_\_\_

Geographic coordinates using NAM14 datum, (NOTA)

Site	Latitude (decimal degrees)	Longitude (decimal degrees)

GPS site velocities relative to NOTA, expressed in mm/year

Site	N Velocity $\pm$ Uncert	E Velocity $\pm$ Uncert	Height Velocity $\pm$ Uncert

Length of translation vector		Azimuth of translation vector	

**Deformation data from digital spreadsheet calculations**

Translation vector	Azimuth	Speed

Rotation	Degrees/yr	Direction

	Magnitude (nano-strain)	Azimuth
Max horizontal (e1)		
Min horizontal (e2)		

