

# GPS Strain & Earthquakes Unit 5: 2014 South Napa earthquake GPS strain analysis – student exercise

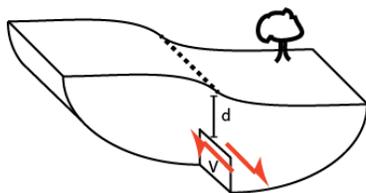
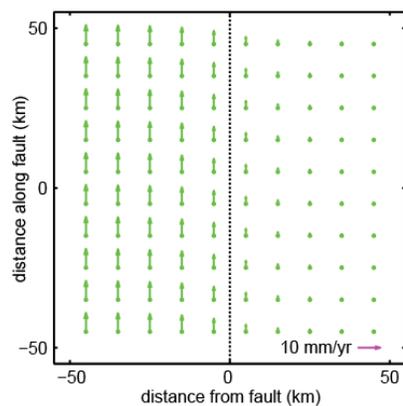
## Strain Analysis

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

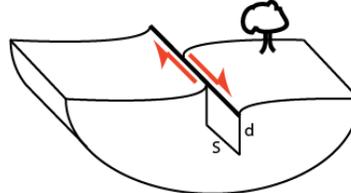
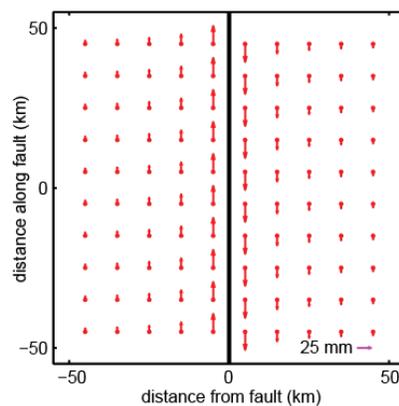
### Introduction

The earthquake cycle can be viewed as a process of slow strain accumulation (interseismic) followed by rapid strain release during (coseismic), and to a lesser extent immediately after (postseismic), an earthquake. This slow accumulation and sudden release of strain was first recognized by Reid (1908), who developed the elastic rebound theory using survey observations from the 1906 San Francisco earthquake. Figure 1 shows the patterns of surface deformation associated with a relatively simple model of this process (first proposed by Savage and Burford, 1970). During the interseismic period (Fig. 1a) the upper portion of the fault is locked, but continues to slip at depth. Strain is continuous across the fault. During the earthquake (coseismic, Fig. 1b) the fault slips and strain is discontinuous across the fault. In the ideal case, the sum of the interseismic deformation and the coseismic deformation will result in block motion across the fault over a seismic cycle (Fig. 1c).

A. Interseismic velocity



B. Coseismic offset



C. Displacement over seismic cycle (100 years\*A+B)

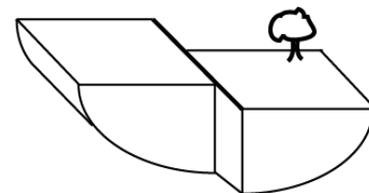
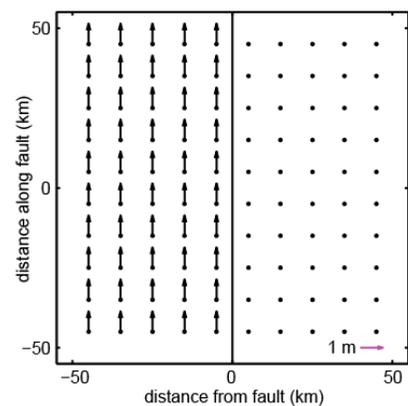


Figure 1. Model of the earthquake cycle for a long north-trending right-lateral strike-slip fault. Top: velocities or displacements for a simulated GPS network on a 10 km grid spanning the fault relative to a fixed eastern block. Bottom: Block diagram sketch of the model geometry. A. Interseismic velocities due to continuous slip (velocity,  $V = 10 \text{ mm/yr}$ ) below the locking depth ( $d = 10 \text{ km}$ ). B. Coseismic offsets due to sudden slip ( $S = 1 \text{ m}$ ) on a fault above the locking depth ( $d = 10 \text{ km}$ ). C. Block motion associated with the sum of 100 years of interseismic slip (A) and a single earthquake (B). [Image: Phil Resor]

Please complete the following Steps to estimate, calculate, and interpret the strain for a triangle defined by three GPS stations located west of the South Napa earthquake epicenter.

### **Step 1. Complete the attached South Napa earthquake data sheet**

Use the provided data tables to find the location, velocity, displacement, and uncertainty values for each of the three GPS stations. Plot the interseismic velocity and coseismic displacement data on the attached vector maps. (Geographic coordinates are in WGS 1984 datum and velocities/displacements are in the reference frame fixed to the stable interior of North America.)

#### **Site Locations**

<b>Site</b>	<b>Decimal Latitude</b>	<b>Decimal Longitude</b>
P198*	_____	_____
P200*	_____	_____
SVIN**	_____	_____

#### **Interseismic GPS site velocities relative to the stable interior of North America, expressed in mm/year**

<b>Site</b>	<b>N Velocity</b>	<b>N Vel Uncert.</b>	<b>E Velocity</b>	<b>E Vel Uncert.</b>
P198*	_____	_____	_____	_____
P200*	_____	_____	_____	_____
SVIN**	_____	_____	_____	_____

#### **Coseismic GPS site displacements relative to the stable interior of North America, expressed in mm**

<b>Site</b>	<b>N Velocity</b>	<b>N Vel Uncert.</b>	<b>E Velocity</b>	<b>E Vel Uncert.</b>
P198*	_____	_____	_____	_____
P200*	_____	_____	_____	_____
SVIN**	_____	_____	_____	_____

**Plot the interseismic site velocities on one copy of the map, and the coseismic site displacements on the other copy.**

\*Data from Plate Boundary Observatory <http://www.unavco.org/instrumentation/networks/status/pbo/gps>

\*\*Data from San Francisco Bay Network <http://earthquake.usgs.gov/monitoring/gps/SFBayArea/>

**Step 2a. Estimate the interseismic deformation from the velocity field**

Use your group's map of the velocity field to infer the instantaneous interseismic deformation for this set of stations.

Translation Speed (m/yr): \_\_\_\_\_ Azimuth: \_\_\_\_\_

Rotation direction (counter-clockwise or clockwise): \_\_\_\_\_

Given the trend of the causative fault and the location of the epicenter and fault, does the interseismic deformation appear to be consistent with a left-lateral or right-lateral fault?

Answer: \_\_\_\_\_

**Step 2b. Calculate the interseismic deformation from the velocity field**

Use the strain calculator provided by your instructor to find the following parameters that describe the interseismic deformation of the area.

	E component $\pm$ uncert (m/yr)	N component $\pm$ uncert (m/yr)
Translation Vector	_____	_____
	Azimuth (degrees)	Speed (m/yr)
	_____	_____
	magnitude $\pm$ uncertainty (deg/yr)	magnitude $\pm$ uncertainty (nano-rad/yr) direction
Rotation	_____	_____
	Magnitude ( $e_{1H}$ ) (nano-strain)	Azimuth of $S_{1H}$ (degrees)
Max horizontal extension	_____	_____
	Magnitude ( $e_{2H}$ ) (nano-strain)	Azimuth of $S_{2H}$ (degrees)
Min horizontal extension	_____	_____
	Magnitude (nano-strain/yr)	Azimuth (degrees) ( $= S_{1H} + 45^\circ$ )
Max shear strain rate*	_____	_____
Area strain (nano-strain):	_____	

\* Note that for tensor strain the maximum shear strain is balanced by a shear with the opposite sense oriented 90 degrees from the maximum. Positive (+) shear strain is right-lateral; negative (-) is left-lateral.

**Step 3a. Estimate the coseismic deformation from the displacement field**

Use your group's map of the velocity field to infer the coseismic displacement for this set of stations.

Translation Distance (m): \_\_\_\_\_ Azimuth: \_\_\_\_\_

Rotation direction (counter-clockwise or clockwise): \_\_\_\_\_

Given the trend of the causative fault and the location of the epicenter and fault, does the interseismic deformation appear to be consistent with a left-lateral or right-lateral fault?

Answer: \_\_\_\_\_

**Step 3b. Calculate the coseismic deformation from the displacement field**

Use the strain calculator provided by your instructor to find the following parameters that describe the coseismic deformation of the area. Note the change in units for the offset data.

	E component $\pm$ uncert (m)	N component $\pm$ uncert (m)
Translation Vector	_____	_____
	Translation Distance (m)	Azimuth (degrees)
	_____	_____
	magnitude (deg)    uncertainty (deg)	magnitude (n-rad)    uncertainty (n-rad)    direction
Rotation	_____	_____
	Magnitude ( $e_{1H}$ ) (nano-strain)	Azimuth of $S_{1H}$ (degrees)
Max horizontal extension	_____	_____
	Magnitude ( $e_{2H}$ ) (nano-strain)	Azimuth of $S_{2H}$ (degrees)
Min horizontal extension	_____	_____
	Magnitude (nano-strain)	Azimuth (degrees) (= $S_{1H} + 45^\circ$ )
Max shear strain*	_____	_____
Area strain (nano-strain):	_____	

\* Note that for tensor strain the maximum shear strain is balanced by a shear with the opposite sense oriented 90 degrees from the maximum. Positive (+) shear strain is right lateral; negative (-) is left lateral.

**Step 4. Compare your qualitative and quantitative results from Steps 2 and 3.**

How well did you estimate the length and direction of the respective translation vectors from the velocity- and displacement-vector maps, as compared with the calculated values?

**Step 5. Interpret the results**

In the following questions we will explore how well our strain data from the South Napa earthquake fit the elastic-rebound model described in the introduction, and what the results imply about earthquake hazard in the region.

1. Describe how the interseismic strain rate and coseismic strain for our GPS triangle (P198-P200-SVIN) can be explained by the earthquake cycle model above (Fig. 1) assuming that deformation is due to slip on the West Napa fault (trending 175°).

The model of the earthquake cycle above suggests a simple means to estimate average earthquake recurrence\*:

Recurrence time (yr) = coseismic maximum shear strain (n-strain) / interseismic maximum shear strain rate (n-strain/yr)

2. Use this equation and the results of your strain calculations to estimate a recurrence rate for the South Napa earthquake.

The timing of the last earthquake on this portion of the West Napa fault is unknown (USGS, 2014); however, the last historic earthquakes near the epicentral area with  $M > 5.5$  were the 1891 M 5.8 Napa earthquake and the 1898 M6.4 Mare Island earthquake (California Geological Survey, 2013).

3. How does your estimate of the recurrence interval fit with this historical data?

We have ignored several important aspects of the problem in our simple recurrence model. One is that the length of the fault that ruptured during the earthquake was relatively small (*i.e.*, compare model displacements in Fig. 1b. with the observed displacements in Fig. 2)

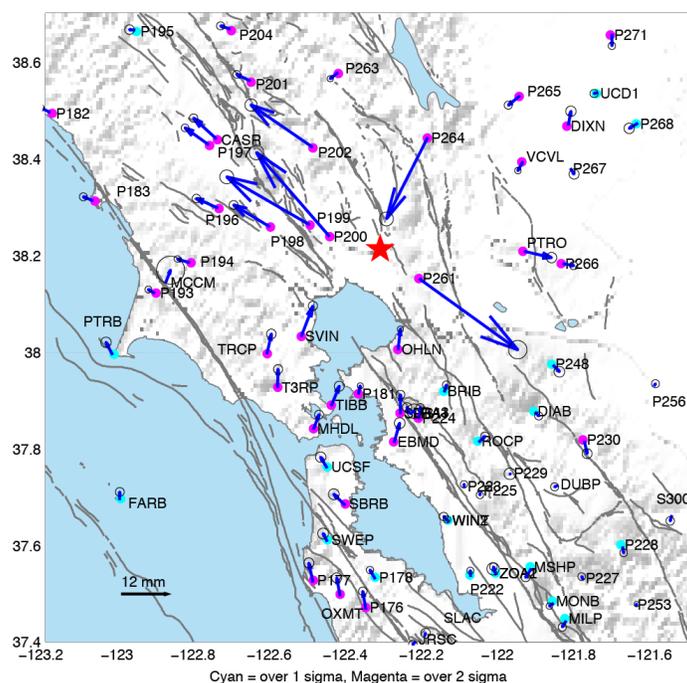


Figure 2. Coseismic offsets (displacements) of GPS stations estimated two days after the event using 24 hours of post-earthquake data. The offsets were estimated as the difference between the means of the coordinates for time intervals before and after the event. Uncertainties in the offsets were estimated using the scatter of each time series. Cyan and magenta dots in the vector plot indicate displacements that are greater than the  $1\text{-}\sigma$  /  $2\text{-}\sigma$  uncertainty, respectively (Nevada Geodetic Laboratory, 2014).

Our GPS triangle extends well to the south of the mapped surface ruptures. The coseismic displacement at station SVIN thus reflects not only its distance away from the fault in a perpendicular direction ( $\sim$  east-west), but also its distance from the rupture in the fault parallel direction ( $\sim$  north-south). Figure 3 on the next page suggests a second, perhaps more important problem.



Figure 3. Quaternary fault map of the northern San Francisco Bay area (USGS, 2014). All slip rates are from the USGS Quaternary fault and fold database and references therein. Black triangle defined by GPS stations P198-P200-SVIN. [Background image: USGS]

The principle of superposition states that for linear elastic models, such as the earthquake model shown in figure 1, the combined effects of multiple loads (faults) can be modeled by adding together the effects of the individual loads (faults) acting separately. In fact, Fig. 1c showing the full seismic cycle displacement field was constructed in this way by multiplying 100 times the displacements over a single year (Fig. 1a) and then adding the displacements associated with a single earthquake (Fig. 1b). In a similar manner, the interseismic strain associated with a series of parallel faults, such as those shown in Fig. 3, can be constructed by adding together the effects of a number of individual faults (Fig 1a) located below each surface fault location with the appropriate slip rates.

4. Which fault would cause the greatest interseismic shear strain rate in the region bounded by our 3 GPS stations? Explain your answer using the patterns of deformation illustrated in Fig. 1 and the information in Fig. 3.

5. What effect does the interseismic strain associated with these nearby faults have on our calculation of recurrence time for the South Napa earthquake?

*\*Note that this simple recurrence model should provide a reasonable estimate of average earthquake recurrence as long as postseismic and inelastic strains in the surrounding crust (the geologic structures!) are relatively small, but the model does not appear to reasonably forecast individual earthquakes (e.g. the 2004 Parkfield earthquake).*

### **Selected References**

U.S. Geological Survey and California Geological Survey, 2014, Quaternary fault and fold database for the United States, accessed 10/14/2014, from USGS web site:

<http://earthquake.usgs.gov/hazards/qfaults/>

California Geological Survey, 2013, California Historical Earthquake Online Database, accessed 10/14/2014, <http://www.conservation.ca.gov/cgs/rghm/quakes>

Nevada Geodetic Laboratory, 2014, Preliminary Coeseismic Offsets for American Canyon Earthquake, Northern California Bay Area, accessed 10/14/2014,

<http://geodesy.unr.edu/billhammond/earthquakes/nc72282711/nc72282711.html>