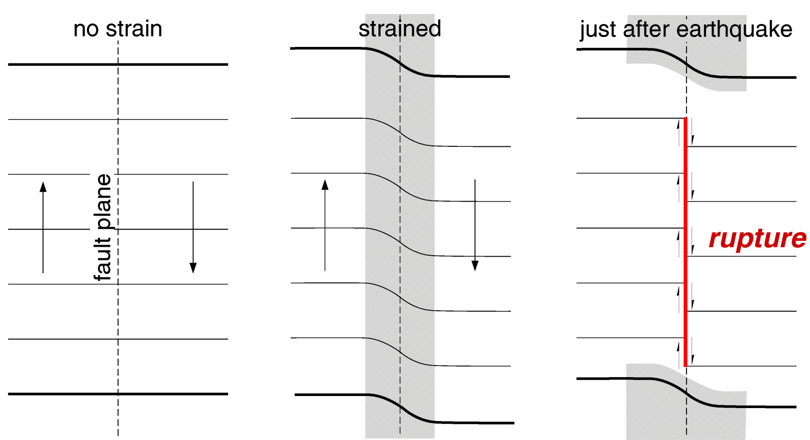
Today (Mon Feb 27): Key concepts are

(1) how to make an earthquake: what conditions must be met? (above and beyond the EOSC 110 version)

(2) strain (matrix: cannot be represented as a scalar or a vector quantity)

Elastic Rebound Theory of Reid (1908)
EOSC 110 version

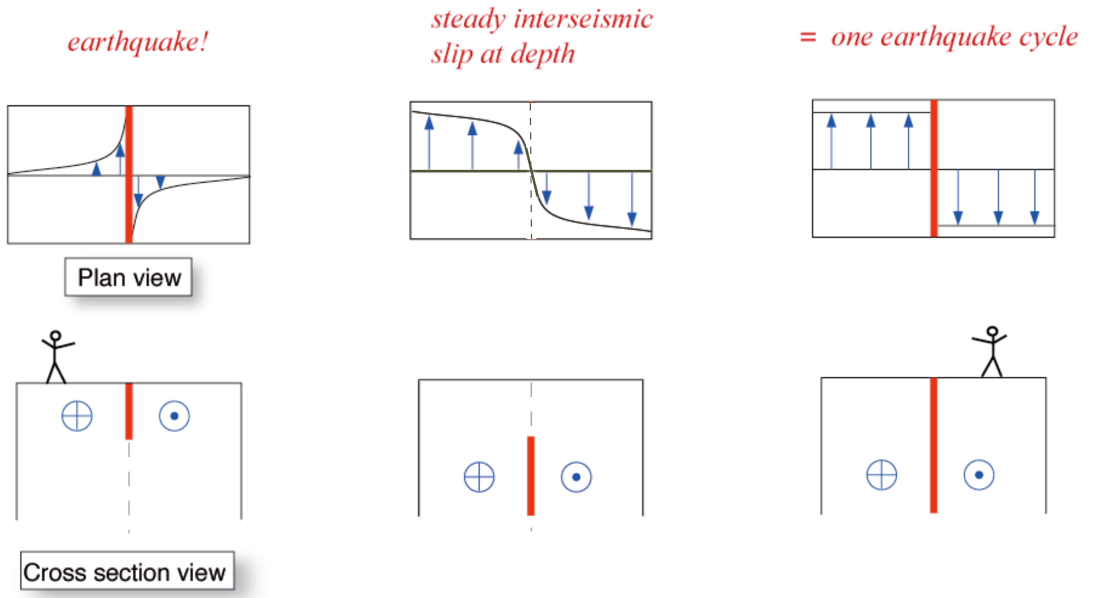


Elastic stresses build up as rock deforms slowly over time

Rupture occurs when elastic stresses exceed what the fault can bear (friction).

Rocks along fault spring back to undeformed state (“elastic rebound”)

Surface velocities from survey data in the 1908 Lawson Report, and the earthquake cycle

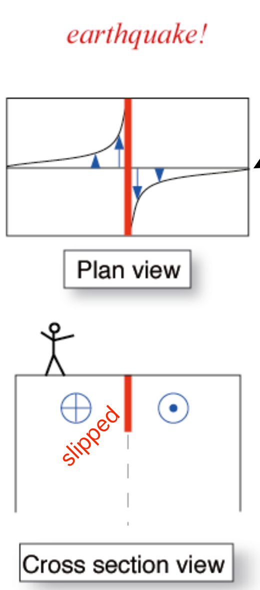


(1906 coseismic displacements)

slow, steady interseismic ground deformation (noted 1857-1906)

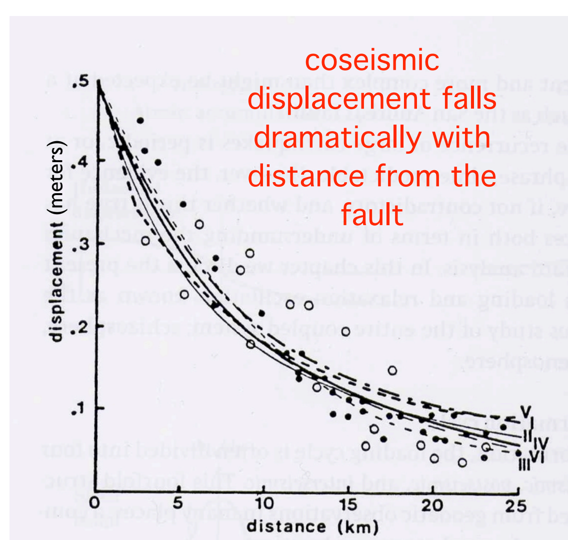
relative motion of rigid plates

Coseismic surface displacements from a typical, large strike-slip earthquake.

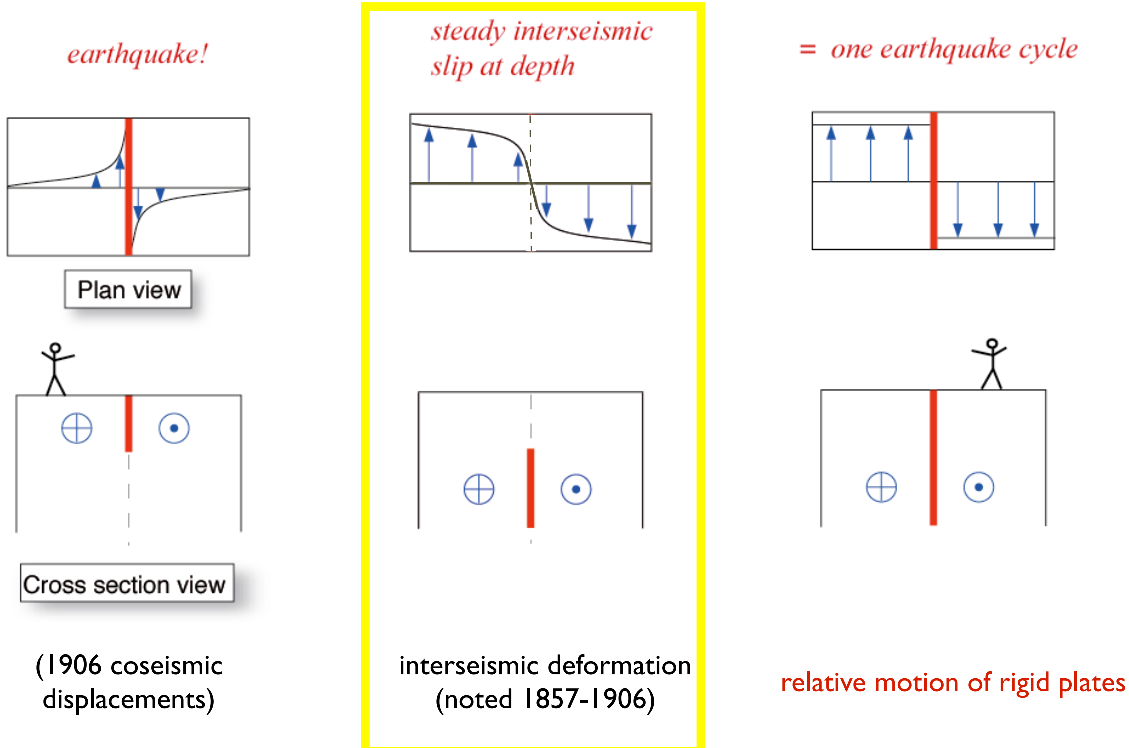


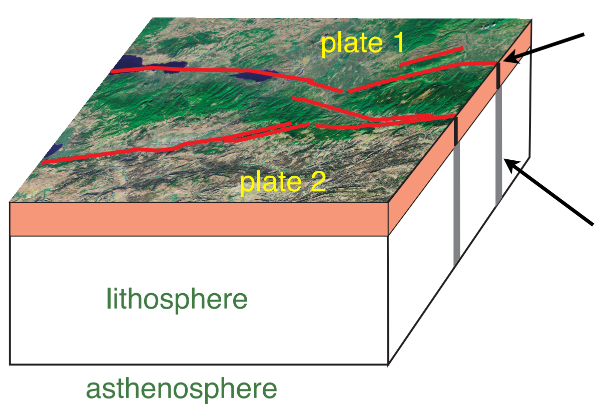
Homework 1: your coseismic displacement versus distance plots

Fault-parallel coseismic surface displacement versus distance data from a 1927 strike-slip earthquake in Japan



Surface velocities from survey data in the 1908 Lawson Report, and the earthquake cycle

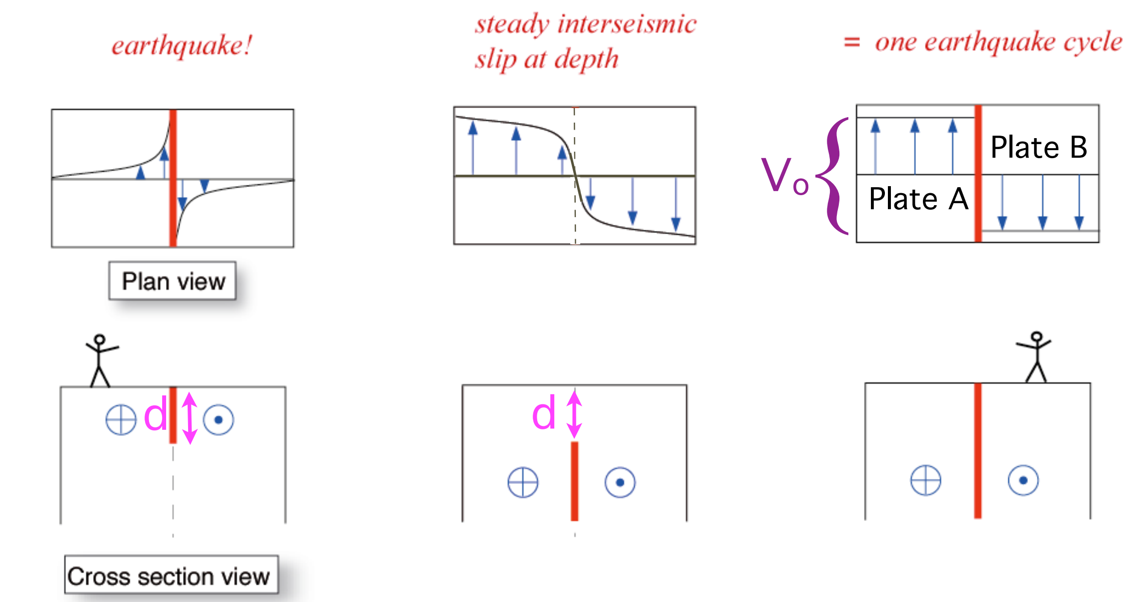




faults and earthquakes in the upper crust
plates are STUCK together in the top 20 km, except when an earthquake allows sudden relative motion

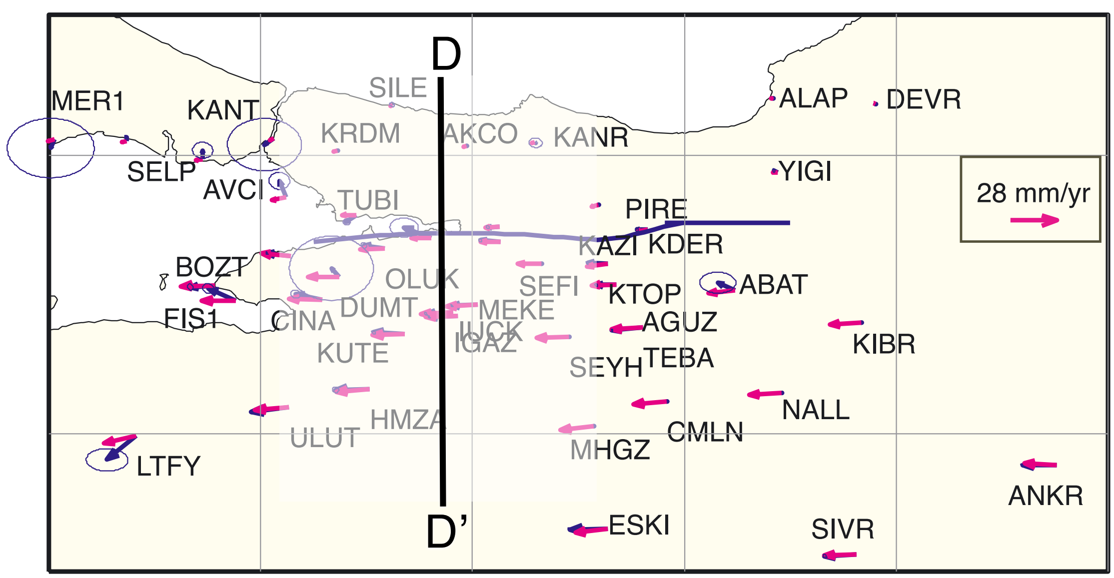
slowly flowing (creeping) narrow zone at depth:
extends plate boundary down to the asthenosphere
STEADY* “interseismic” relative motion of plates at this depth

*not exactly... but ok for now



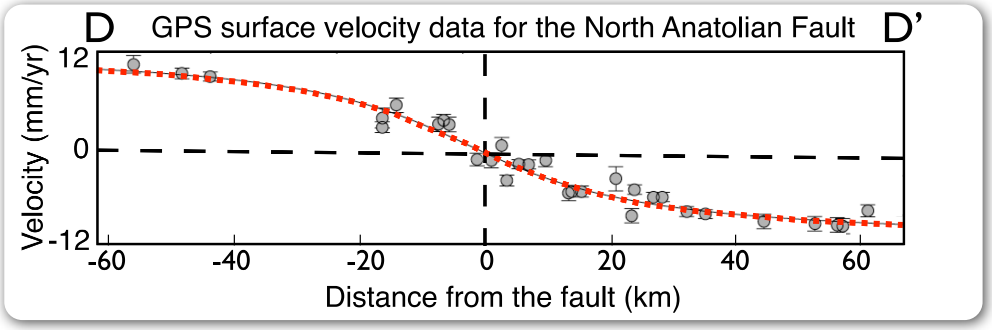
V_o is the velocity of Plate A relative to Plate B (averaged over many earthquake cycles). "Locking depth" is d.

Here is what interseismic (between-earthquake) velocities of points on the ground around a fault look like



Blue = pre-Izmit earthquake GPS site velocities, 1-sigma errors. Pink = modeled velocities.

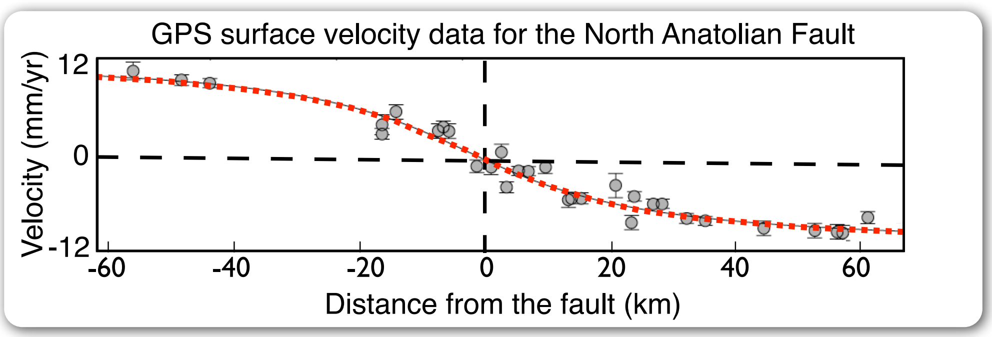
Interseismic velocities of points on the ground: fault-parallel velocity versus distance



these velocities can be modeled using a simple arctangent function that depends on V_o (relative plate velocity), distance to the fault, and "locking depth" d.

the relative plate motion rate V_o for the NAFZ is 25 mm per year

there is no sudden jump in velocity across the plate-boundary fault



$$V = V_o \ atan(\frac{x}{d})$$

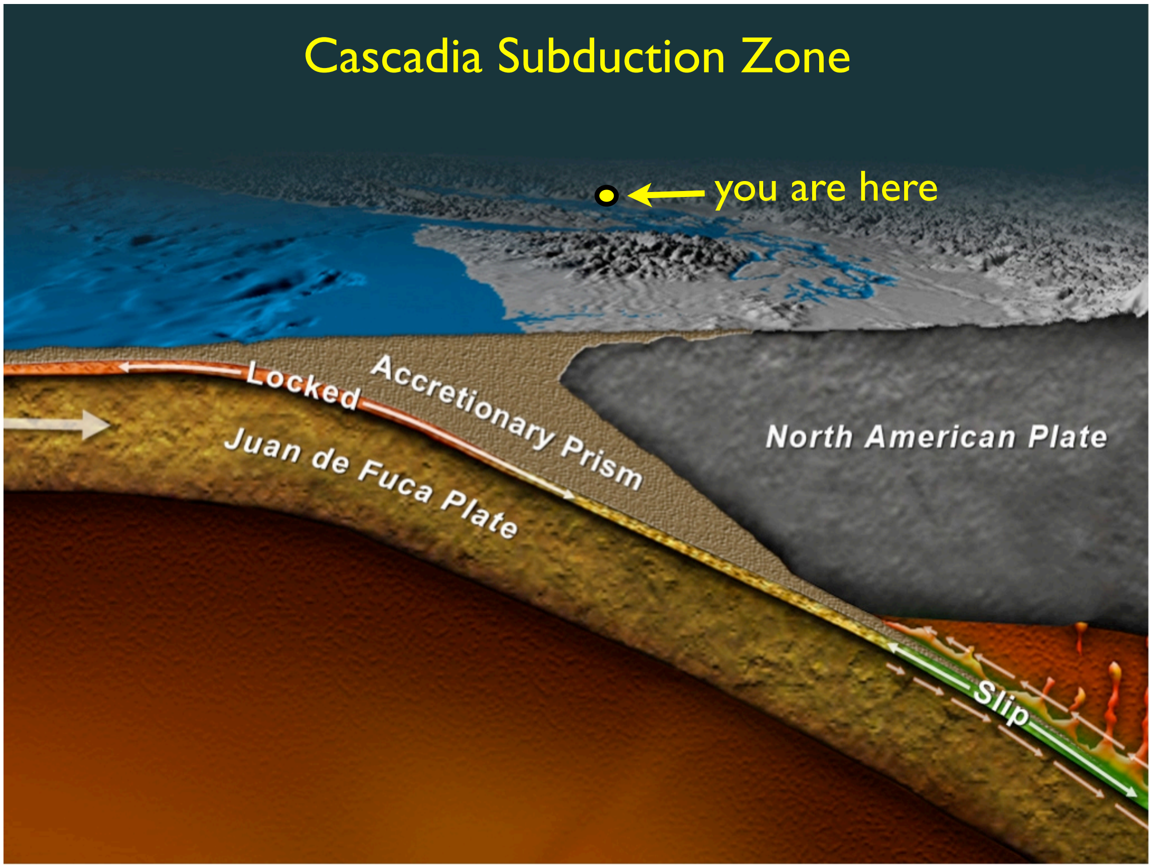
$V =$ surface velocity (set to be 0 at the fault)

$x =$ distance from the fault

$V_o =$ relative plate velocity

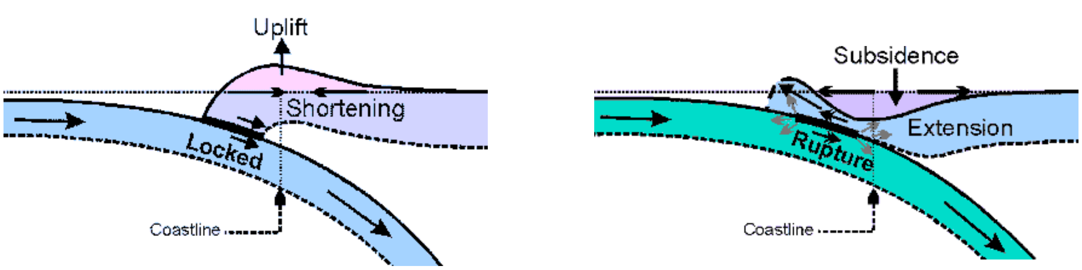
$d =$ locking depth

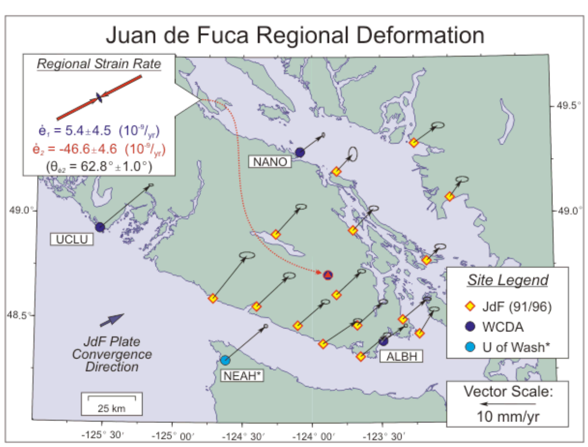
So - you can get Vo and d with a few GPS sites (if everything goes right). VERY handy to know for earthquake forecasting.



Cascadia subduction zone earthquake cycle

interseismic (300-600 yr) | coseismic (minutes)





How to make an earthquake:
Build up enough shear stress to exceed the frictional strength of a fault, *over a large enough spatial surface area of a frictionally unstable ("velocity weakening") fault*

(1) Building up shear stress (interseismic period):

We must define strain, elasticity, and stress (shear stress and normal stress). First: strain and how we measure it with GPS.

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(2) Frictional strength of the fault:

We must define friction and (with normal stress) the strength of the fault

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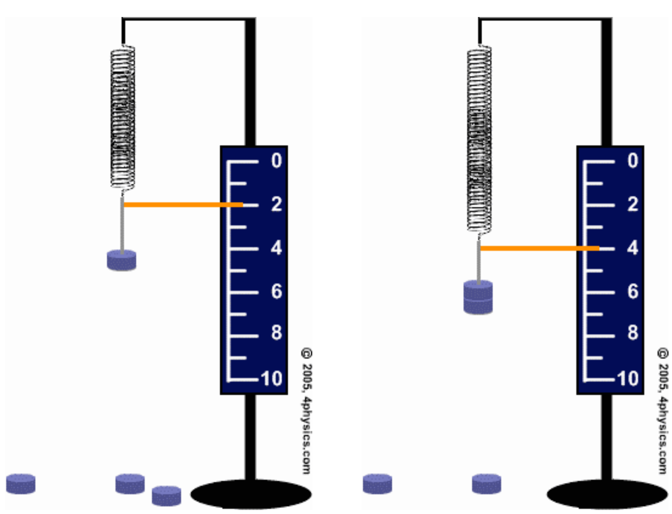
(3) Other required conditions ("velocity-weakening friction", "large enough area" of the fault:

We must understand the stability criteria for failure on the fault, that is, conditions leading to an earthquake rather than steady frictional creep on the fault

(1) Building up shear stress:

We must define strain, elasticity, and stress (shear stress and normal stress). **First: strain and then how we get it from GPS displacement data.**



Hooke's Law in 1D:
all that matters is the lengthening of the spring.

In the Earth, stretching and distortion is three-dimensional.

We describe this as strain.

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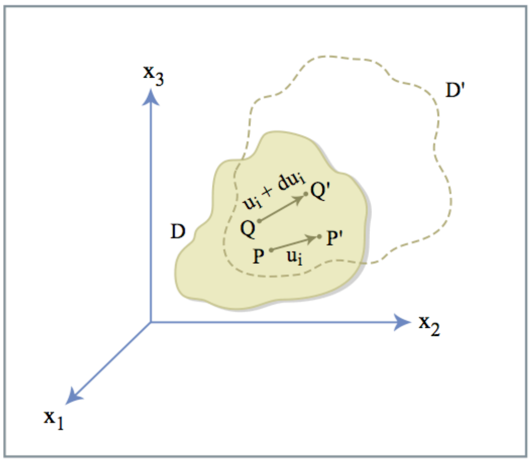


Figure 12.1

Figure by MIT OCW.

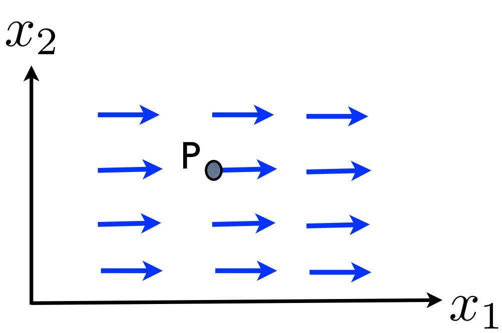
D and D' contain the same material but all points have moved

Think of D as before the earthquake and D' as after it

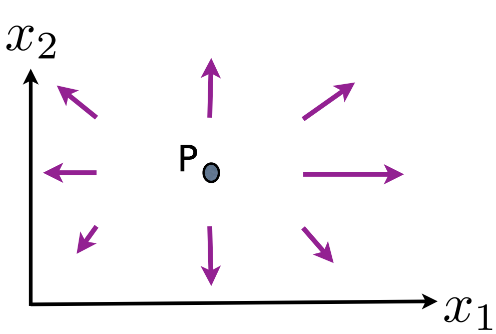
What are the possible ways to change the configuration of this stuff?

- translation
- rotation
- **strain** (distortion, i.e. change in shape and/or volume)

Strain indicates distortion. We express it in terms of how points in the material move relative to each other



- translation - no strain
  - What are we looking at? A "vector field". Each displacement vector shows how that point in space moved. The origin of each vector has coordinates in x_1 - x_2 space.

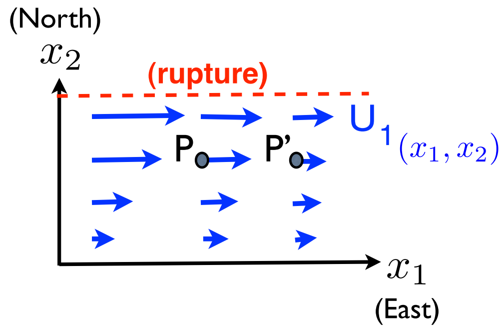


- expansion - yes there is strain

note that each displacement vector "**u**" has two components: u_1 in the x_1 direction and u_2 in the x_2 direction.

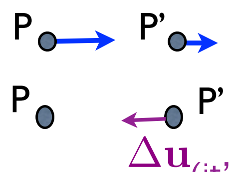
$$\mathbf{u} = \begin{bmatrix} u_1 \\ u_2 \end{bmatrix}$$

Suppose you know the coseismic displacements at equally spaced points on a grid



Map View

GPS coseismic displacement field U right next to a long strike-slip fault

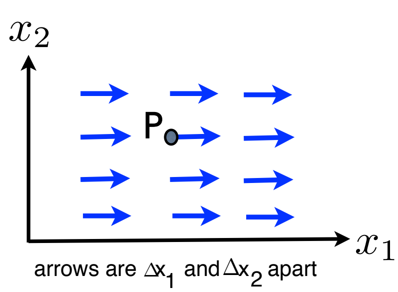


P' moved toward P, in the x_1 direction

(it's our old friend vector subtraction!)

$$\Delta\mathbf{u} = \begin{bmatrix} \Delta u_1 \\ \Delta u_2 \end{bmatrix}$$

is the displacement of one point relative to another. For example, the displacement at point P' relative to the displacement at point P.

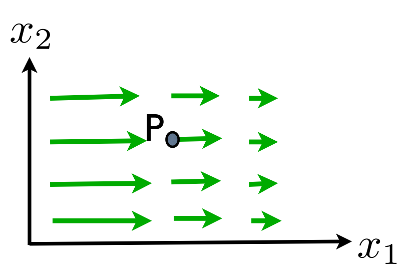


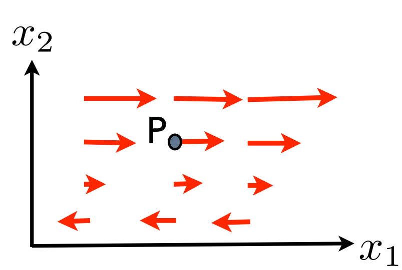
How does displacement vary with position?

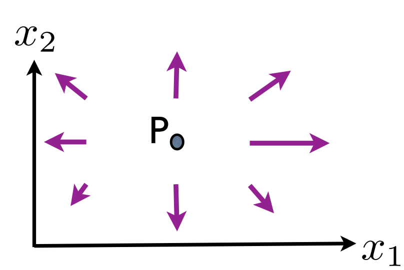
+, -, or 0?

$$\frac{\Delta u_1}{\Delta x_1} \quad \frac{\Delta u_1}{\Delta x_2}$$

$$\frac{\Delta u_2}{\Delta x_1} \quad \frac{\Delta u_2}{\Delta x_2}$$







Congratulations! Now you know what the "displacement gradient matrix" is.
This is ALMOST the strain matrix.

	column 1	column 2
row 1	$\frac{\Delta u_1}{\Delta x_1}$	$\frac{\Delta u_1}{\Delta x_2}$
row 2	$\frac{\Delta u_2}{\Delta x_1}$	$\frac{\Delta u_2}{\Delta x_2}$

A matrix: a bunch of numbers arranged in rows and columns.

This is a matrix with 2 rows and 2 columns.

Do not fear the matrix - we have to use it to describe strain and stress in the Earth.

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	column 1	column 2
row 1	$\frac{\Delta u_1}{\Delta x_1}$	$\frac{\Delta u_1}{\Delta x_2}$
row 2	$\frac{\Delta u_2}{\Delta x_1}$	$\frac{\Delta u_2}{\Delta x_2}$

Suppose we named this matrix B.

Convention is to use boldface: **B**

Individual numbers in the matrix are indicated with subscripts showing the row and the column that the number is in:

B_{12} is the entry in ROW 1 COLUMN 2