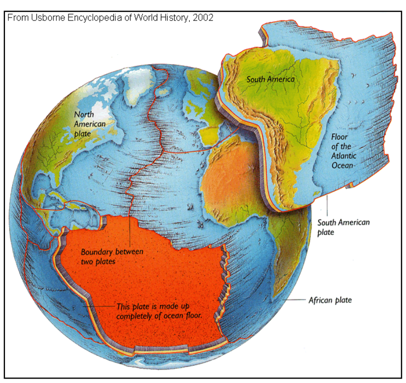
Learning goals:

Predict types of earthquakes that will happen at different plate boundaries based on relative plate motion vector vs. strike (vector subtraction)

Understand interseismic and coseismic deformation, slip rate, locking depth, and other terms

Bring laptop computers Friday

Two ways to describe layers of the shallowest 100 to 200 km of the Earth



- crust
- mantle

} based on composition

- lithosphere
- asthenosphere

} based on strength

When we say "plate" we mean the lithosphere

Most faulting occurs in the <u>upper part of the crust (top 20 km)</u>: that is, the shallowest part of the lithosphere

In the upper crust, the steady relative motion of plates is allowed by the episodic earthquakes. At greater depths, the relative motion is allowed by creeping fault "zones".

Faults or fault networks bound tectonic plates

Tiny Juan de Fuca Plate offshore
from BC, OR and WA

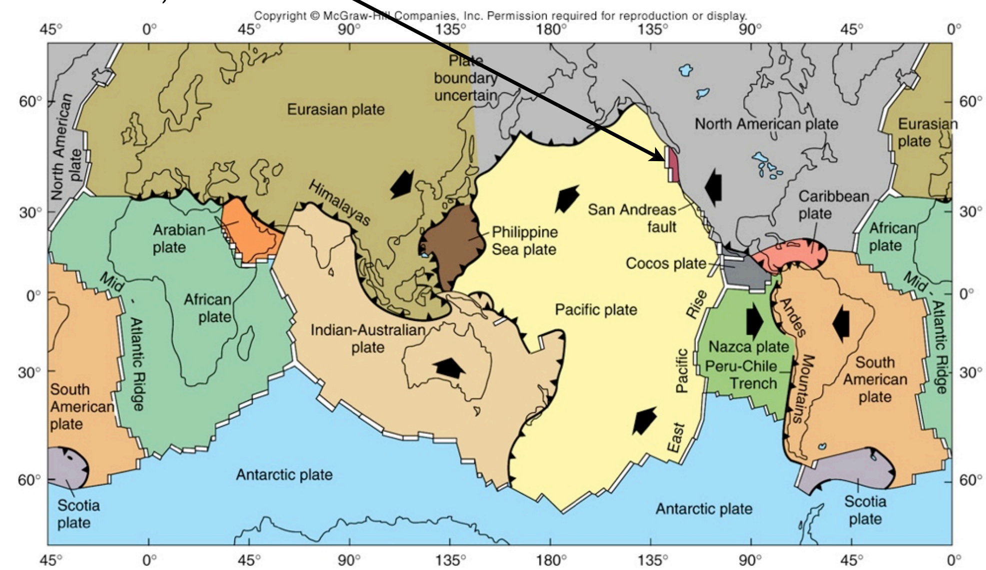
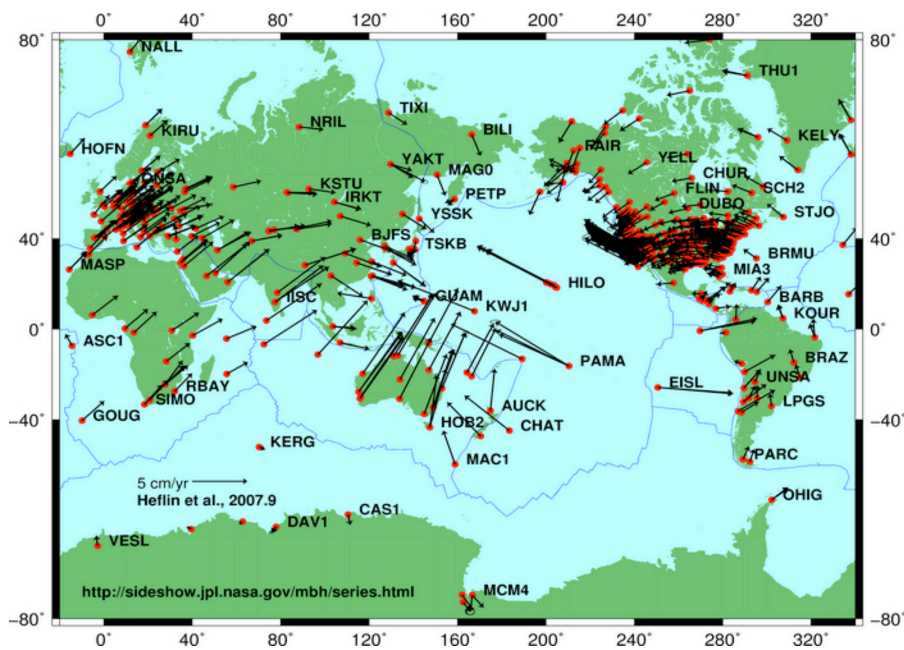


Plate motions from GPS

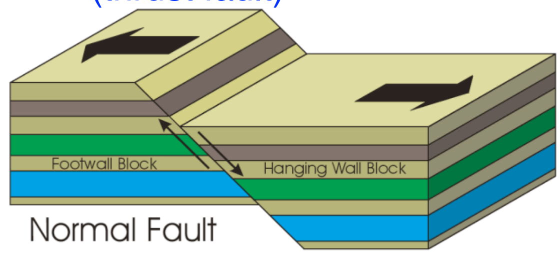


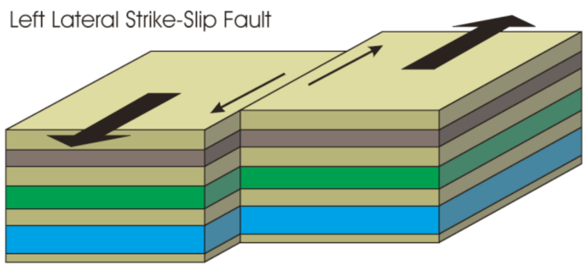
From GPS velocity vectors we can estimate the pole of rotation and rotation rate for each plate, assuming plates are rigid.
This model fits additional GPS data really well AND (where there are no GPS data) it is consistent with the kinds of earthquakes we see.

Relating fault type to tectonic plate boundaries

Note the horizontal component of the relative motion for different fault types

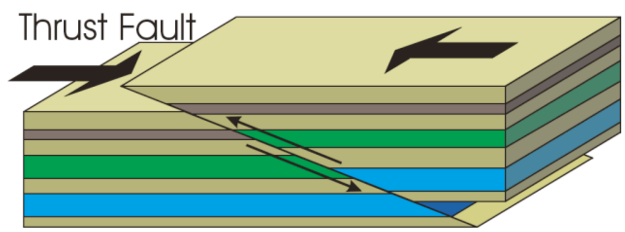
divergent plate boundary
(thrust fault)



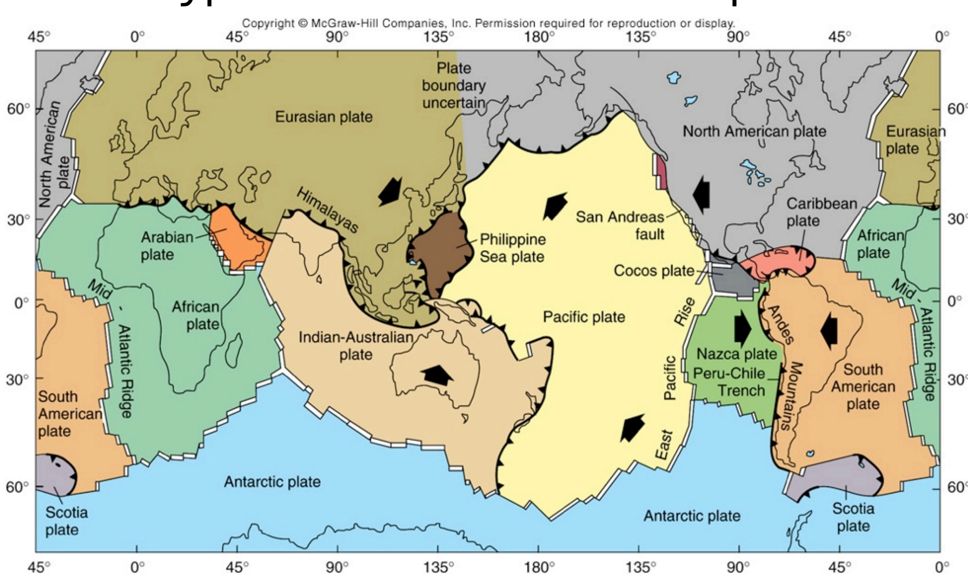


transform plate boundary
(strike-slip fault)

convergent plate boundary
(thrust fault)



Types of faults at tectonic plate boundaries



These cartoon vectors are relative to mantle hotspots (Earth's deep interior)

"No Net Rotation" reference frame

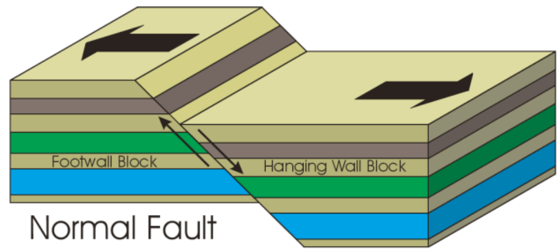
Compare the orientation of the relative plate motion vector to the strike of the the plate-boundary fault(s).

Vector subtraction gives motion of one plate relative to the other.

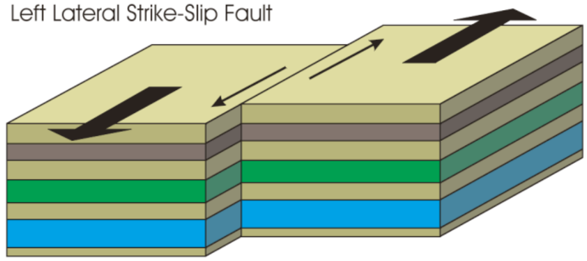
Relative motion can vary along a plate boundary, as can the strike of a plate-boundary fault.

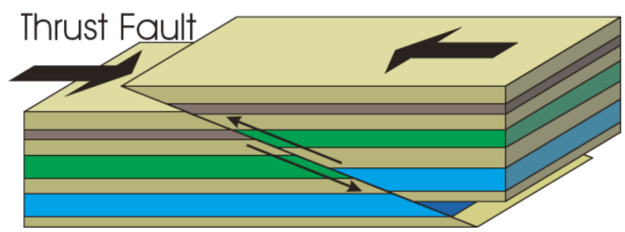
Relative horizontal displacements and the type of faulting

these diagrams show how both plates move relative to some fixed reference frame



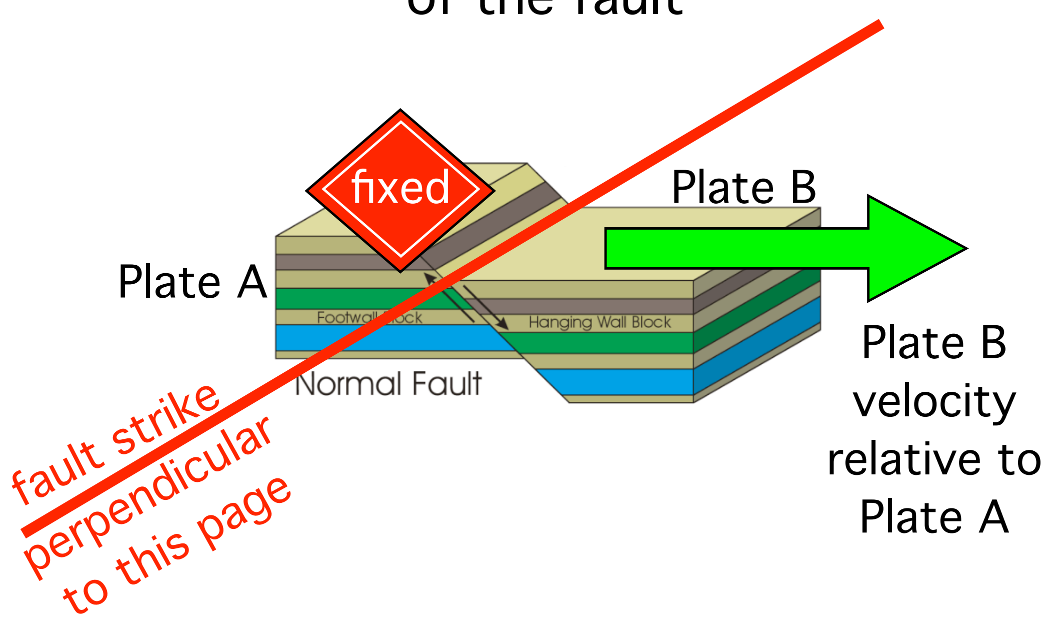
Left Lateral Strike-Slip Fault





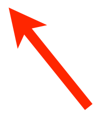
use vector subtraction to show how a plate moves relative to the other plate

Compare the relative horizontal velocity vector's azimuth to the strike of the fault



A velocity vector on the Earth's surface

(Pacific Plate,
NNR frame)



3.8 cm yr
318°

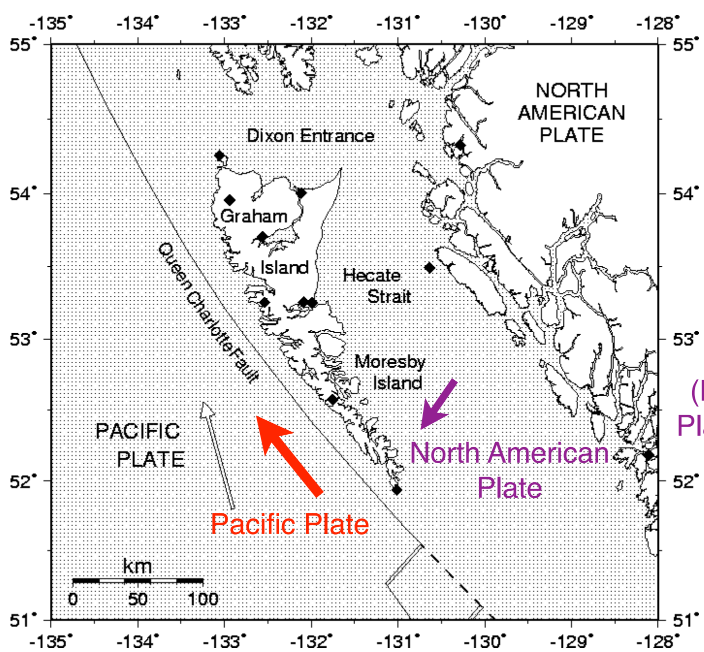
$$\begin{bmatrix} -2.5 \\ 2.8 \end{bmatrix} \begin{matrix} \text{E} \\ \text{N} \end{matrix}$$

Queen Charlotte Fault - What kind?

What is the Pacific Plate velocity relative to a "fixed" (stationary) North American plate?

(Pacific Plate,
NNR frame)

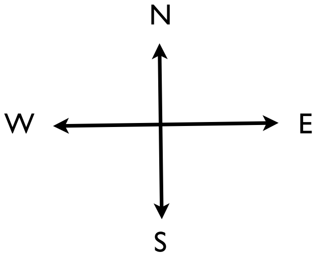
3.8 cm yr
318°



(North American
Plate, NNR frame)

2.1 cm yr
220°

Images are from the Geological Survey of Canada



Finding the Pacific plate velocity relative to North America where they meet in NW BC: vector subtraction

(Pacific Plate, NNR frame)

3.8 cm yr
318°

minus

(North American Plate, NNR frame)

2.1 cm yr
220°

equals

Pacific Plate relative to the North American Plate (in NW BC)

4.7 cm yr
345°

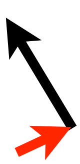
$$\begin{bmatrix} -2.5 \\ 2.8 \end{bmatrix} \begin{array}{c} \mathsf{E} \\ \mathsf{N} \end{array} \text{ minus } \begin{bmatrix} -1.3 \\ -1.6 \end{bmatrix} \begin{array}{c} \mathsf{E} \\ \mathsf{N} \end{array} \text{ equals } \begin{bmatrix} -1.2 \\ 4.4 \end{bmatrix} \begin{array}{c} \mathsf{E} \\ \mathsf{N} \end{array}$$

(cm/yr)

(Mostly) transform boundary

fault-parallel component is
4.7 cos(15 degrees) cm/yr
= 4.5 cm/yr

this is the strike-slip Queen Charlotte Fault slip rate

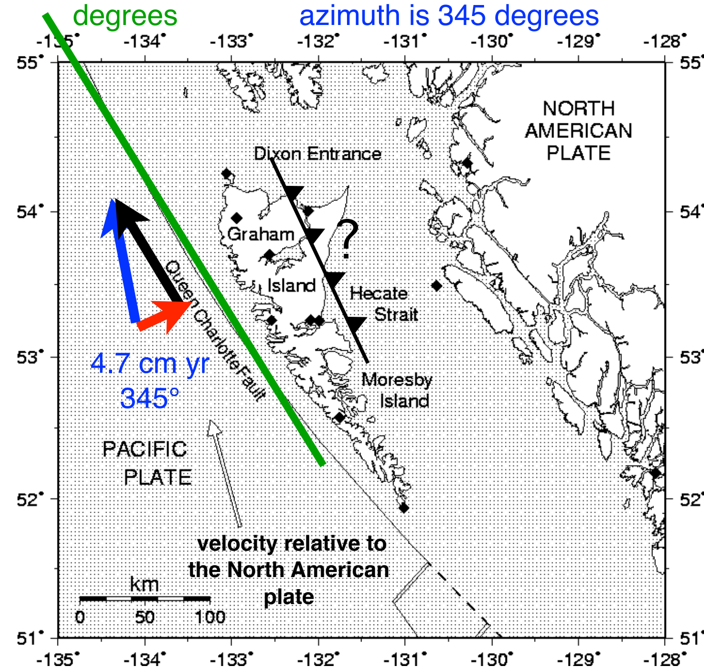


fault-normal component is
4.7 sin(15 degrees) cm/yr
= 1.2 cm/yr

this is accommodated by thrust faults more or less parallel to the plate boundary

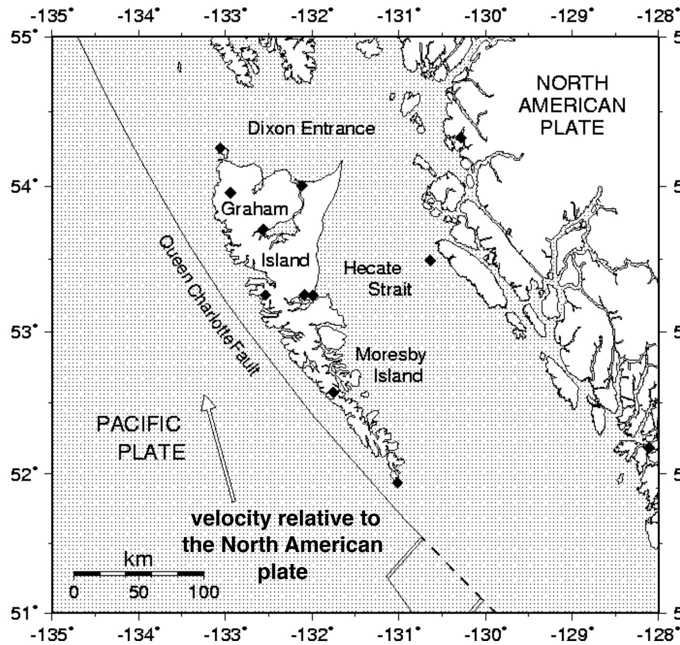
QCF strike is 330 degrees

relative plate velocity vector azimuth is 345 degrees



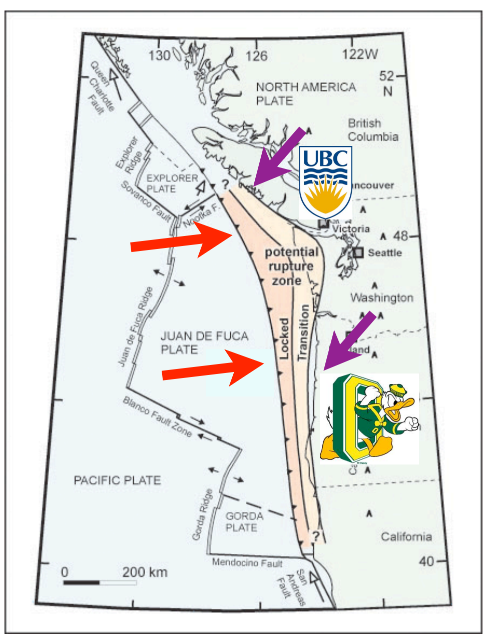
Images are from the Geological Survey of Canada

(Mostly) transform boundary



Images are from the Geological Survey of Canada

Motion of Juan de Fuca plate relative to North America: Vancouver Island and Oregon*



*actually, Oregon's motion is a bit different but we will ignore this for now.

A closer look - more quantitative

(Juan de Fuca Plate, NNR frame)

(North American Plate, NNR frame)

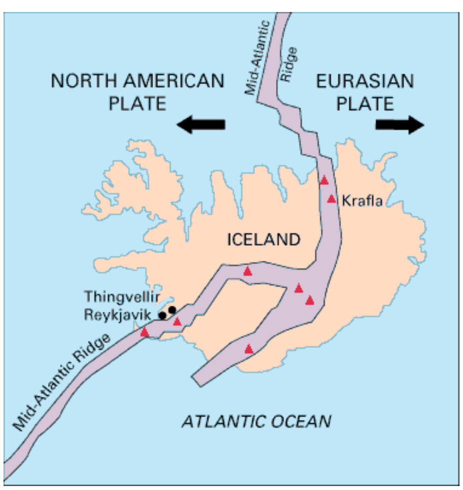
(JDF Plate, relative to NA Plate)

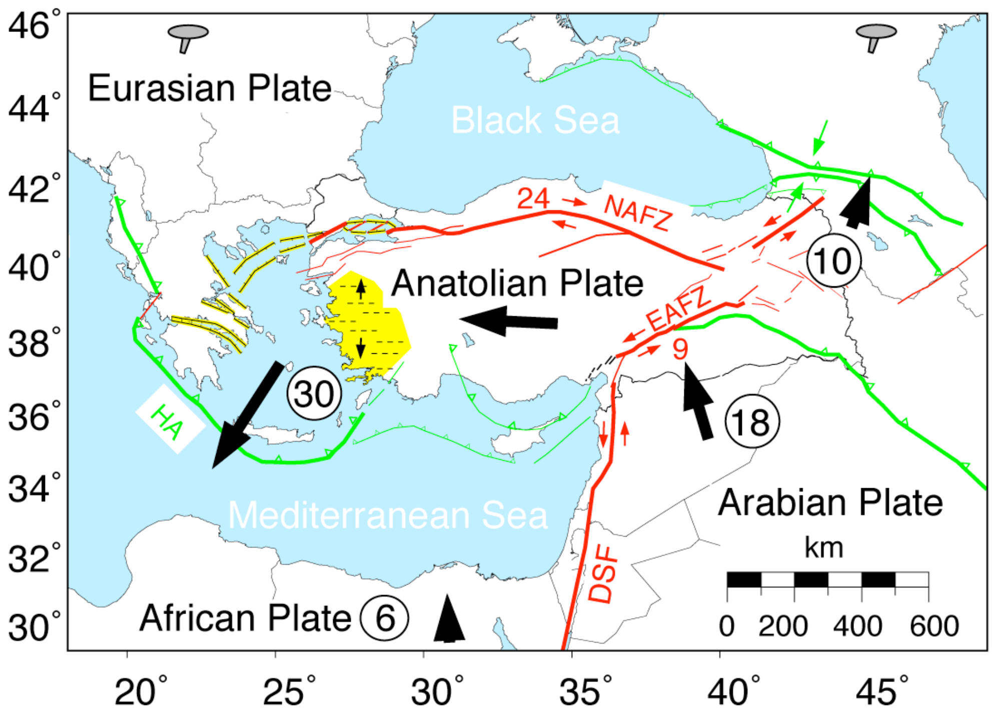
minus =

2.3 cm yr
70°

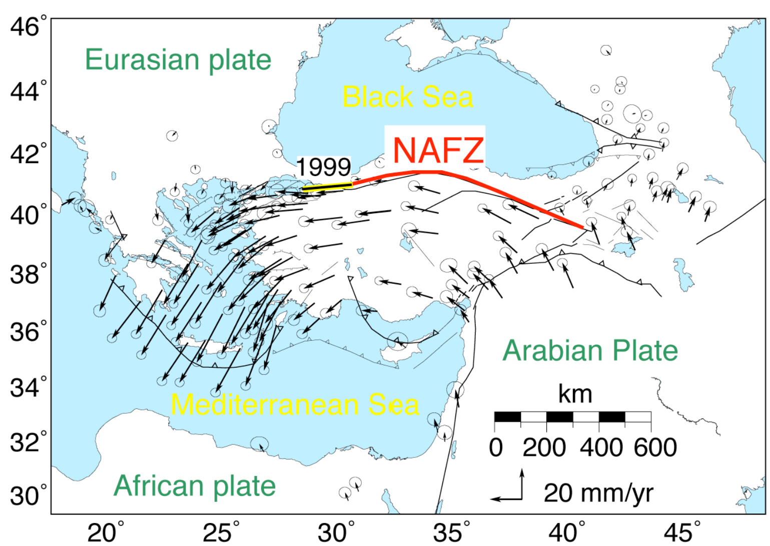
2.1 cm yr
220°

$$\begin{bmatrix} 2.2 \\ 0.4 \end{bmatrix} \begin{array}{l} \text{E} \\ \text{N} \end{array} \quad \text{minus} \quad \begin{bmatrix} -1.3 \\ -1.6 \end{bmatrix} \begin{array}{l} \text{E} \\ \text{N} \end{array} =$$





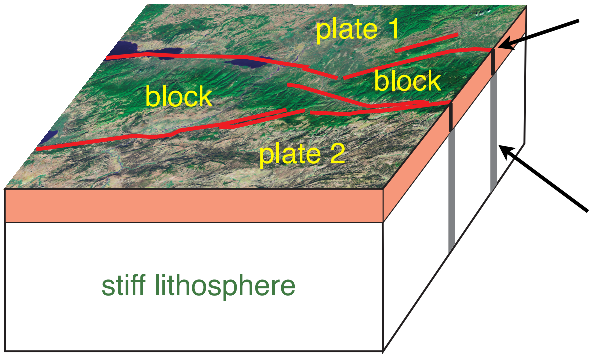
GPS horizontal velocities relative to Eurasia 1988-1997



from McClusky et al., JGR, 2000

Near the edges of plates, they do <u>not</u> behave rigidly.
This is because of strain associated with faults.

One idea about how faults work at depth



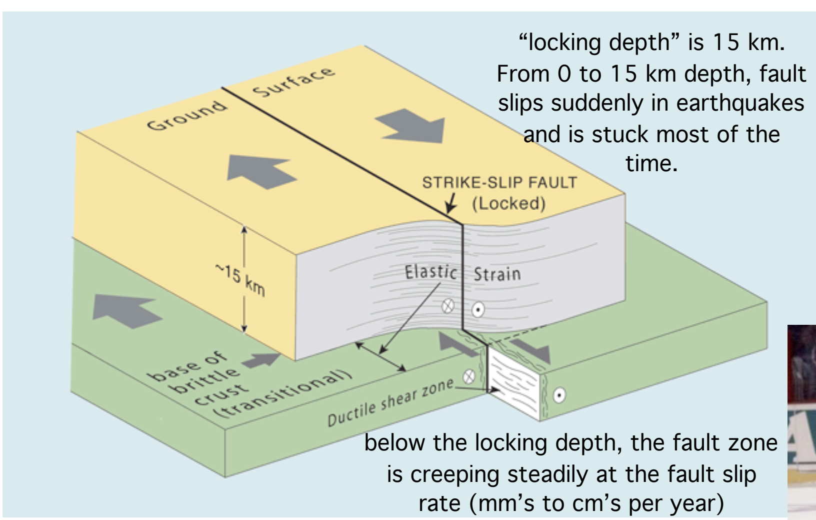
gooey (creeping)
asthenosphere

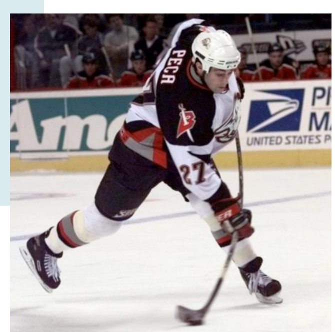
faults and earthquakes in the upper crust
plates are STUCK together in the top 15 km, except when an earthquake allows relative motion

slowly flowing (creeping) narrow fault zone at depth:
extends plate boundary down to the asthenosphere

STEADY "interseismic" relative motion of plates at this depth

Slow creep of the fault zone allows plates to move past each other, <u>except</u> in the top 20 km where the plates are stuck together. Result measured at the surface is "interseismic deformation".



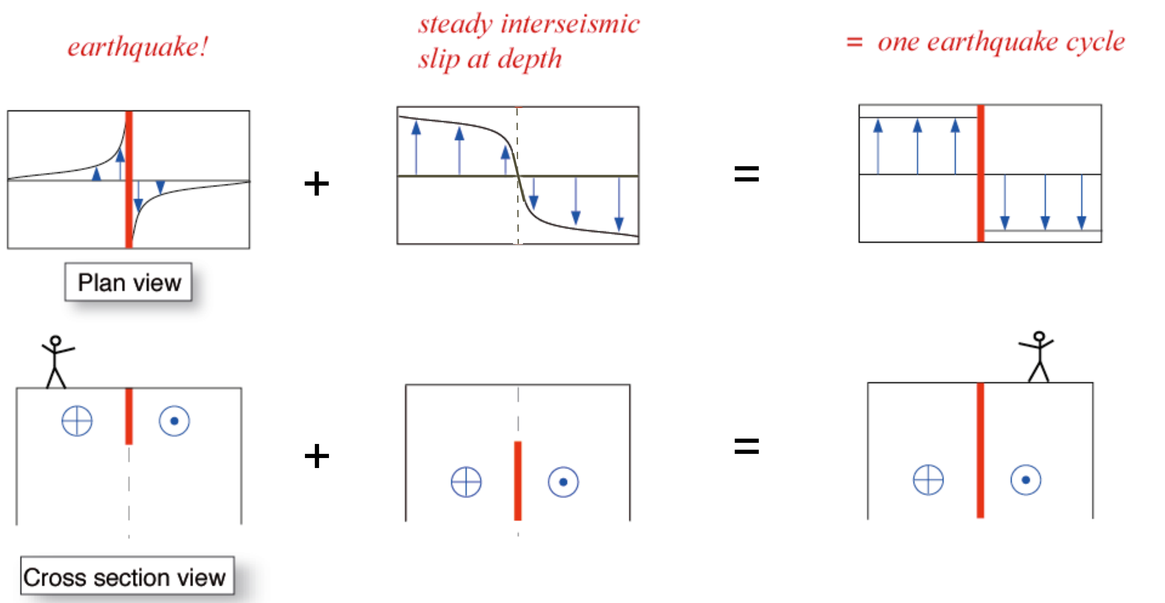


If the upper crust is elastic, then stresses
build up as it warps (deforms). Example: hockey stick.

(remember Hooke's Law)

"interseismic deformation" of the upper crust is determined by "locking depth" and slip rate. These two parameters can be estimated from observing and modeling the interseismic deformation.

San Andreas Fault model based on survey data in the Lawson Report

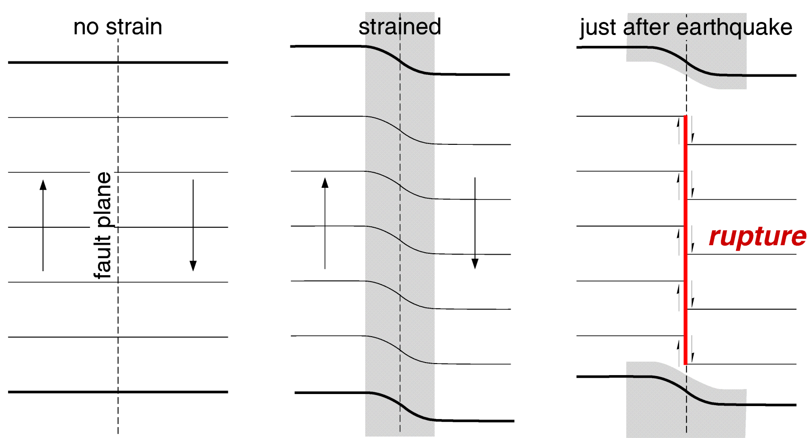


(1906 coseismic displacements)

slow steady motion
(creeping at slip rate below the locking depth)
(seen before 1906)

relative motion of rigid plates

Elastic Rebound Theory of Reid (1908), based on survey data from the 1906 Lawson Report



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")