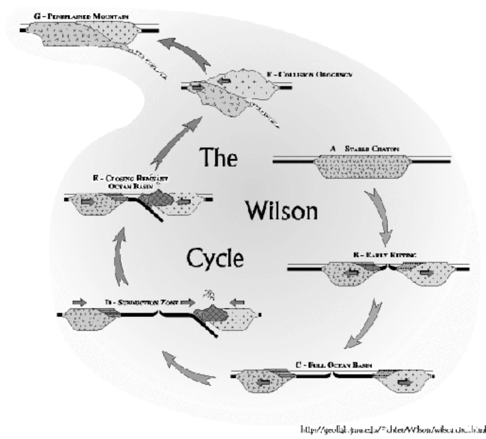
PLATE TECTONICS

Review picture in NVE-96 (IT WILL BE ON THE TEST)

Notice - San Andreas fault is a PA-NA transform. Plate names and boundaries covered on FINAL!

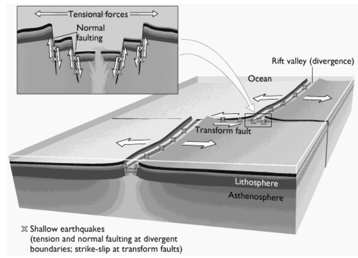
The concept of opening and closing continents, called the "Wilson cycle", explains a major question - why are continents much older than oceans ? (No oceanic plates (DSDP ages) older than *few hundred Ma*! The contents are too light to be subducted, and are up to 3.9 *Billion* years!) A very important discovery in the 1950s! (before a lack of age difference was realized!)

Plate (oceanic) life cylce -- The Wilson Cycle.

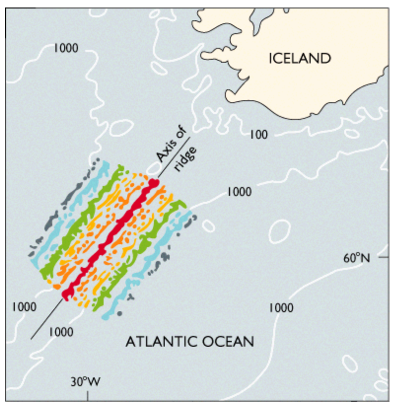


Largest ocean as about Pacific 10^4 km across. A resonable half-spreading rate is ~5 cm/yr = 50 km/Ma. So the oceanic plate dies in $\frac{10^4}{50} = 200$ Ma!

RIDGES

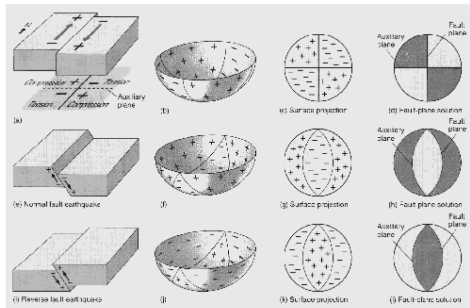


Lots of profiles were recognized by 1953, also offset magnetics were observed.



How could they tell what was happening? They couldn’t, the magnetic data was not yet good enough to provide the answer. So... they used the earthquakes to tell which way the fault moves!

How - focal mechanisms - sense of motion on seismogram tells us if the ground motion is "toward" or "away" from observer.



The confirmation of transform faults explained the offset magnetics and provided the 3rd kind of plate boundary. Now, the magnetic data is good enough to show this result. Also, rift valley faults display a normal (down faulting) sense of motion.

Rates reflect a morphologic difference between the East Pacific Rise (EPR) and the Mid-Atlantic Ridge (MAR):

MAR ~ 1cm/yr halfrate, with earthquakes along rift, and a sharp peak.
EPR ~ 10 cm/yr, with no normal earthquakes, and a gradual axial rise.

PLATE MOTION GEOMETRIES

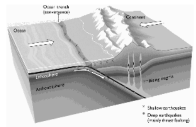
We want to see how plates can move *relative* to each other. Assumption: Plates are rigid, as shown by seismicity. Different boundaries are produced by different *relative* motions. The motions are *relative* because how do we define absolute motion (discuss later)?

Since relative assume A is fixed, look at B with respect to (wrt) A! All of this must actually be done on sphere, but that will come later.

At a divergent boundary the motion is away from the boundary, so it is a spreading ridge.

Motion is parallel (side-ways slip) along a transform boundary and always gives the relative motion direction.

Convergent boundaries are subduction zone. Along a subduction zone motion is towards the boundary.



None of these boundaries must be *exactly* perpenducluar to subduction or spreading, but transform boundaries must be parallel to the motion.

To estimate velocities, the best way is using the magnetic anomalies distances and ages to give a velocity in mm/yr = km/my.

How does this evolve through time? Mark two sets of points on the plates.

Interpreting magnetics shows how seafloor evolved... A normal faulting, divergent boundary like the Mid Atlantic, looks like this

Ridges and transforms need not be perpendicular, but different transforms *must* be parallel. *Transform direction gives* spreading direction!

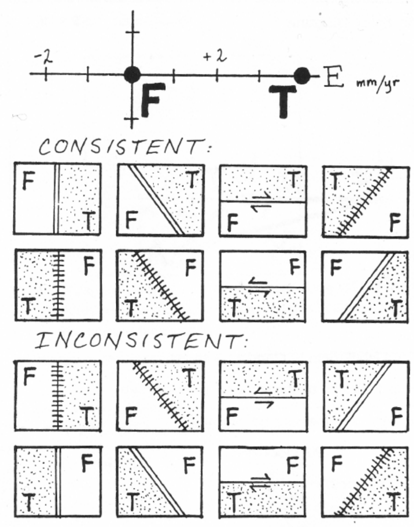
velocity space seems simple, and is *very* useful to analyze complicated plate interactions. Fantastic amount can be learned just from geometry! Consider three plates in relative motion.

1) Fix one plate (B) and the *velocities* (vectors) of others are wrt B

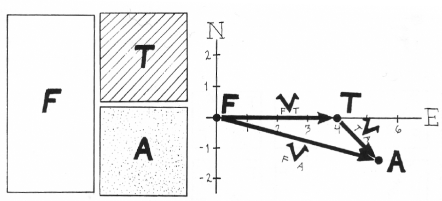
2) Now we can find, A wrt C (V_{AC})

3) This is just simple *vector addition*. $V_{AC} = V_{AB} + V_{BC}$

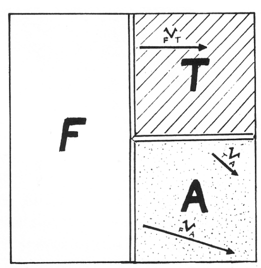
The boundary situation depends on the velocity!



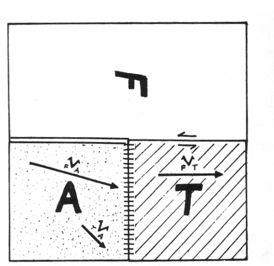
If we know the orientation of the boundary, we can find the plate boundary's *nature* from the motions.



Thus, these boundaries must be ridges (divergent).



Now we'll use the same velocities in a different geometry

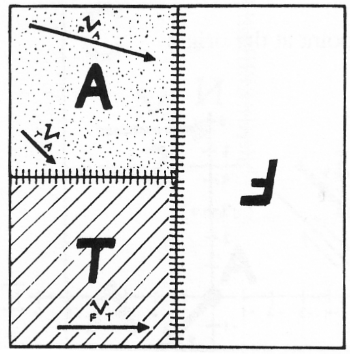


1) V_{FT} is parallel to the F-T boundary. Thus, F-T is a transform.

2) V_{AF} is away from the F-A boundary. Thus, F-A is a ridge.

3) V_{AT} is toward the A-T boundary. So this is a trench.

The next example is all trenches!



Here’s a real example.

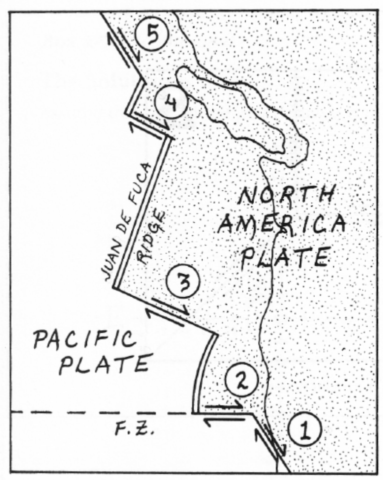


Figure 2-12.
The Juan de Fuca Ridge and some offsetting transforms (2, 3, and 4) link the San Andreas fault (1) with a major transform (5) west of Canada. Note, however, that the transforms are not all parallel.

As of the mid-1960s we knew the San Andreas was a NA-Pacific transform. There is a ridge offshore.

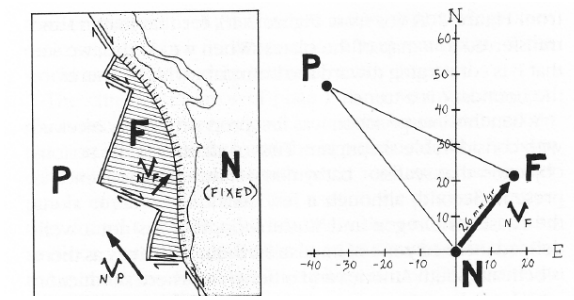
What’s fishy? 1 is parallel to 5, and 3 is parallel to 4, but 3 and 4 are not parallel to 1 and 5. Must be another plate, call it F, for all the transforms to be parallel for the same plate. What is F doing? $\longrightarrow$ Juan De Fuca Plate

Velocity space, with the Pacific plate (P) fixed

Get V_{NP} azimuth from San Andreas trend and its speed from geodetic (56 mm/yr).

Get V_{FP} azimuth from transforms and its rate from magnetics (58 mm/yr).

Now, find V_{FN} (26 mm/yr), points NE. Thus, must have a trench there!



Good, since there are volcanoes (Rainer, Lassen, Baker, Shasta, etc) with andesite, a typical subduction zone rock. However, there is no Benioff zone that clearly reveals dipping seismicity? *How come*

Argument *slow* subduction (26 mm/yr) heats up the plate before it gets too deep. Or, it's a young plate - same thing! Confirmation from some earthquakes and marine survey shows trench fill type sediments along coast. This result is now generally accepted.

Trenches eat plates and may leave strange anomaly pattern for us to observe at the earth's surface.

Given three plates A, B, C. How will this evolve? Assume A is fixed and the velocities are simple and colinear. Thus, B must subduct under C.

This configuration will eventually break up.

The ridge hits the trench and dies (the physics of this are unclear) when one whole side is subducted. This leaves magnetics that young toward the continent (the west coast of the U.S. looks like this).

We have no measured rates at transforms and subduction zones. How can we check any of the rates?

Recall that size of earthquake is given by its *moment*.

$$M_0 = NDS$$

Measure M_0 from seismograms, estimate the fault area (S), assume the rigidity (N), and find the fault slip (D). Here's an example: San Francisco 1906

$$D = \frac{M_0}{NS} = \frac{6 \times 10^{27} \text{ dyne cm}}{(3 \times 10^{11})(320 \times 15)} \times 10^5 \times 10^5 \text{ (cm/km)}^2 \sim 4 \times 10^2 \sim 4\text{m slip}$$

If we know about how often such earthquakes happen, we can estimate the slip rate. For example - San Andreas ~150 yrs

$$\frac{4\text{m}}{150\text{ yr}} \sim 3 \text{ cm/yr}$$

this need not be exactly the same. Some slip is not released in earthquakes. Also, some motion on faults other than SAF $\longrightarrow$ leads to deformation in western US.

How to study? The usual method is to use surface-ship seismic profiler and a towed magnetometer.

1) Deep tow sled: "flies" right above bottom cameras, magnetometers (lights) side scan sonar

2) Alvin - special reasearch sub can dive to great depths (3,600m!) with 3 people and use its arms to retrieve samples. This provides very precise position finding (25 m!).

3) Multibeam (Seabeam-16 beams) narrow beams - dedicated computer system makes *very precise* real time map (~10m). The computer also matches echos with correct source.