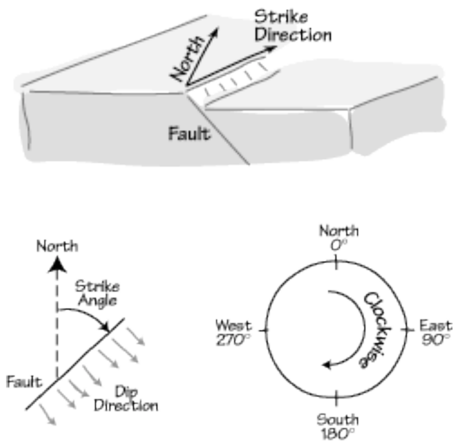
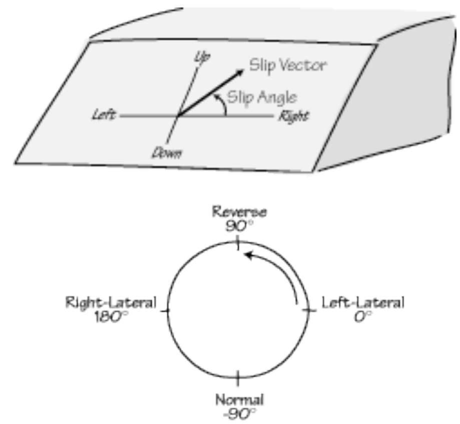
Beyond travel times and earthquake location

What else can seismograms tell us about
the nature of earthquakes on faults?

What are some of the key parameters which we describe faults?

Fault Geometry





1. Strike
2. Dip
3. Rake (slip angle)

EARTHQUAKE RUPTURE DIMENSIONS

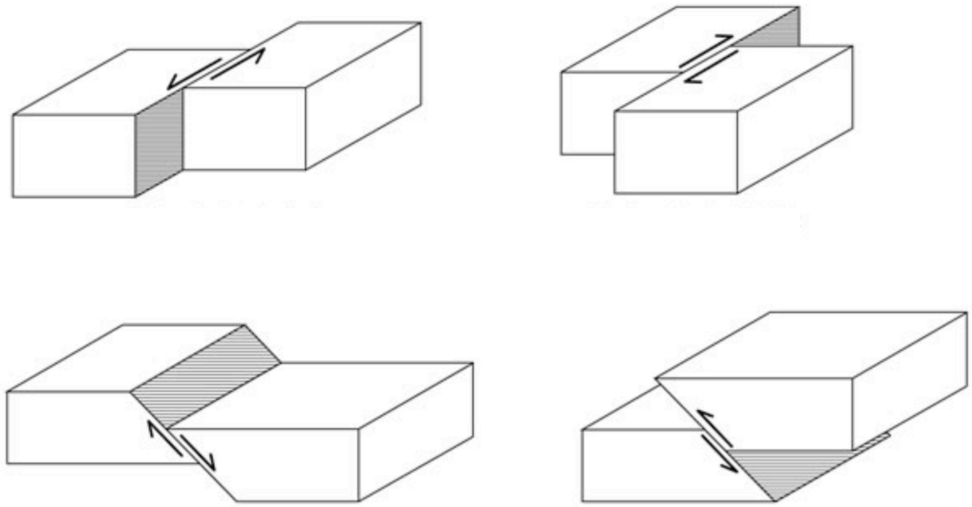
We also wish to constrain rupture dimensions (ie the actual area of rupture, usually smaller than the whole area of the fault) and the slip (offset).

This can be quite complex, so we simplify by modeling through equivalent rectangular area

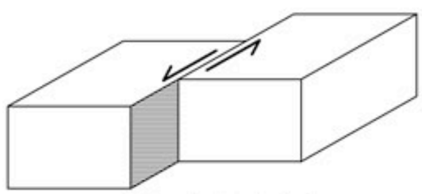
WIDTH x LENGTH

Let's look first at fault geometry...

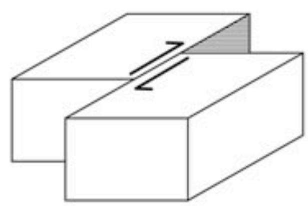
Fault Geometry



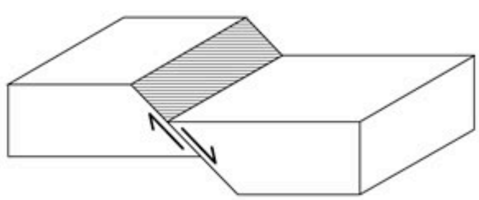
Name that fault!



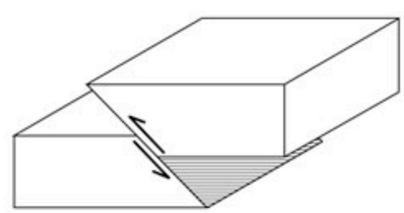
strike-slip/transform
(left lateral)



(right lateral)

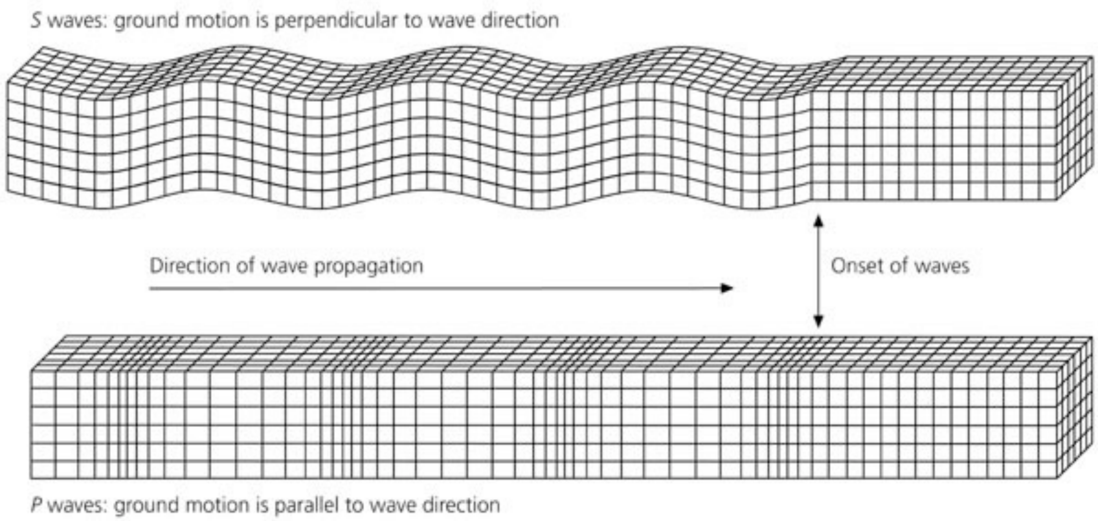


normal



thrust/reverse

P waves and S waves



What are the defining properties of P and S waves?

P waves and S waves

P-waves arrive first, S-waves second (followed by surface [Rayleigh and Love] waves)

P-waves produce compressional motion parallel to direction of propagation (Primary/Pressure waves)

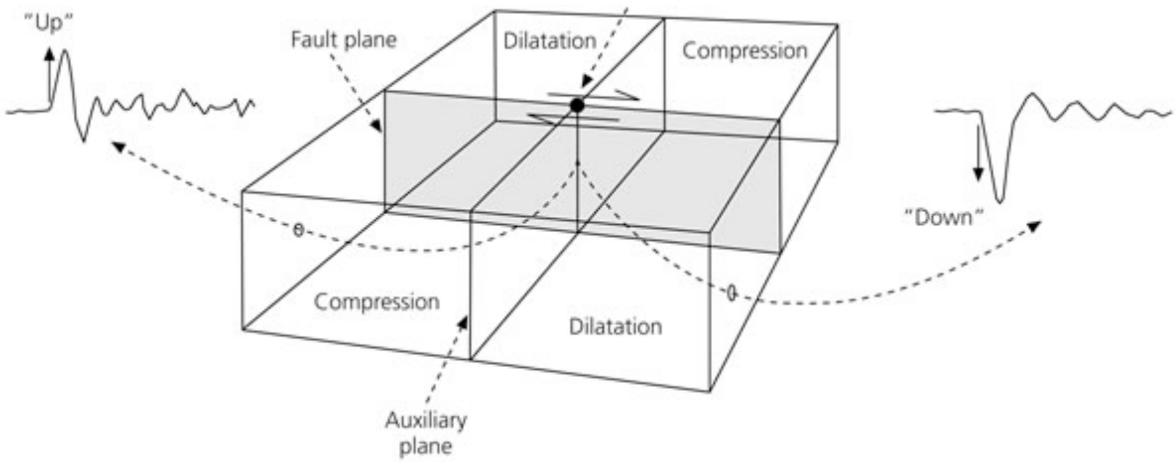
S-waves produce shear motion perpendicular to direction of propagation (Secondary/Shear waves)

S-waves are usually larger amplitude than P-waves for earthquakes, especially at lower frequencies (but their arrival times and initial polarization are harder to measure)

We will focus on P-waves to characterize faults

P wave first motions

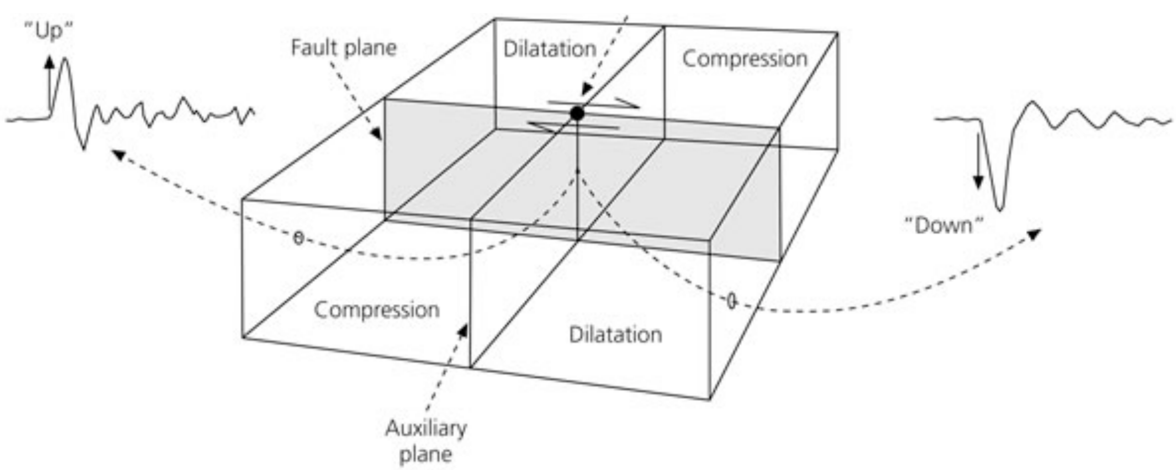
Depending on orientation of fault, receivers may see either compressional or dilatational P-wave first motion.



Thus we may constrain fault orientation with measurements of first motions from seismic networks - can you see any ambiguity?

First Motion Constraints

Define "auxillary" plane perpendicular to fault plane

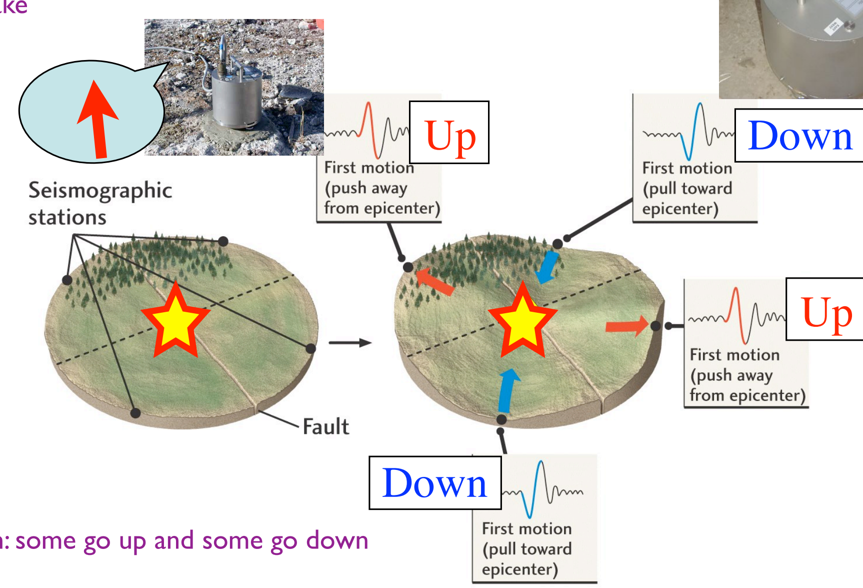


First motions define 4 quadrants from which P-waves leave with either compressional or dilatational first motions (note ambiguity between 2 planes)

Here’s another picture of the same thing (recognize from Week 1?)

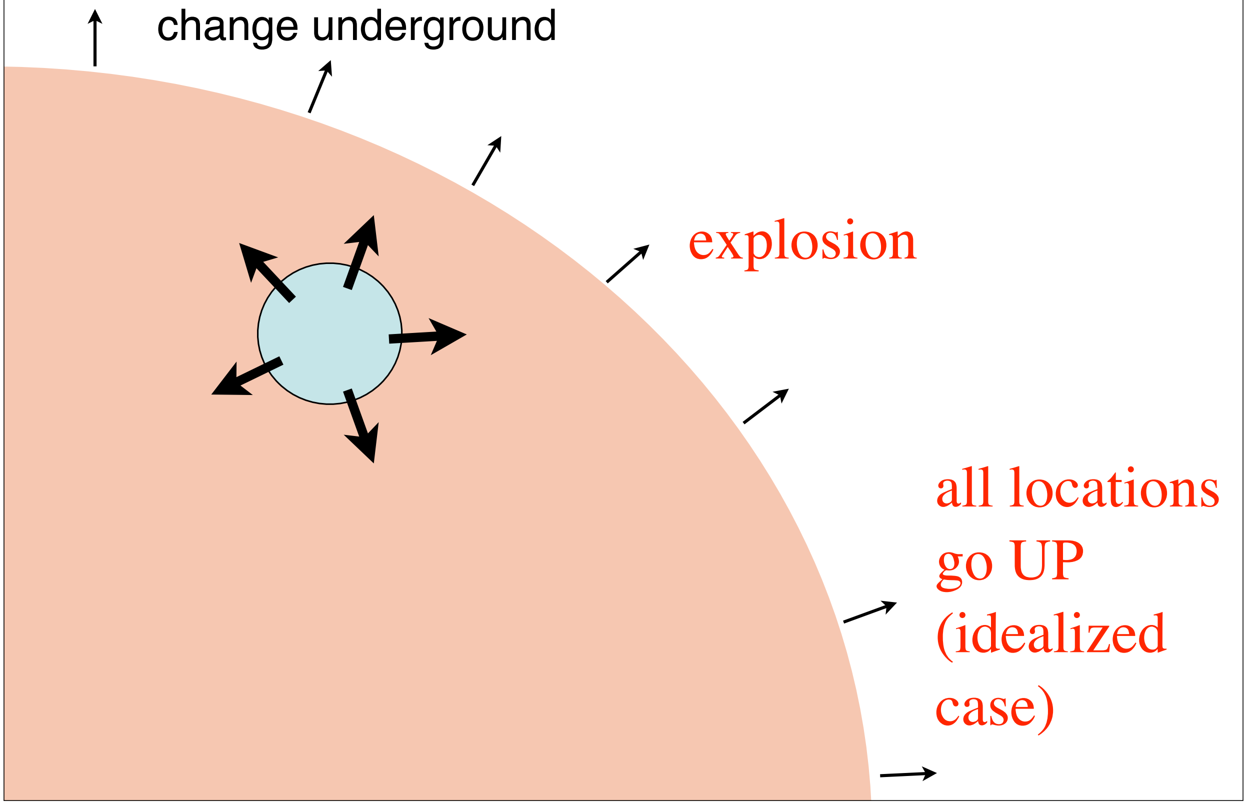
Proof that even earthquakes that don’t break the surface are also due to faults: Japan, 1923

- In Japan in the early 1900’s, there were many seismographs, and seismograms could be obtained at many locations after a local earthquake

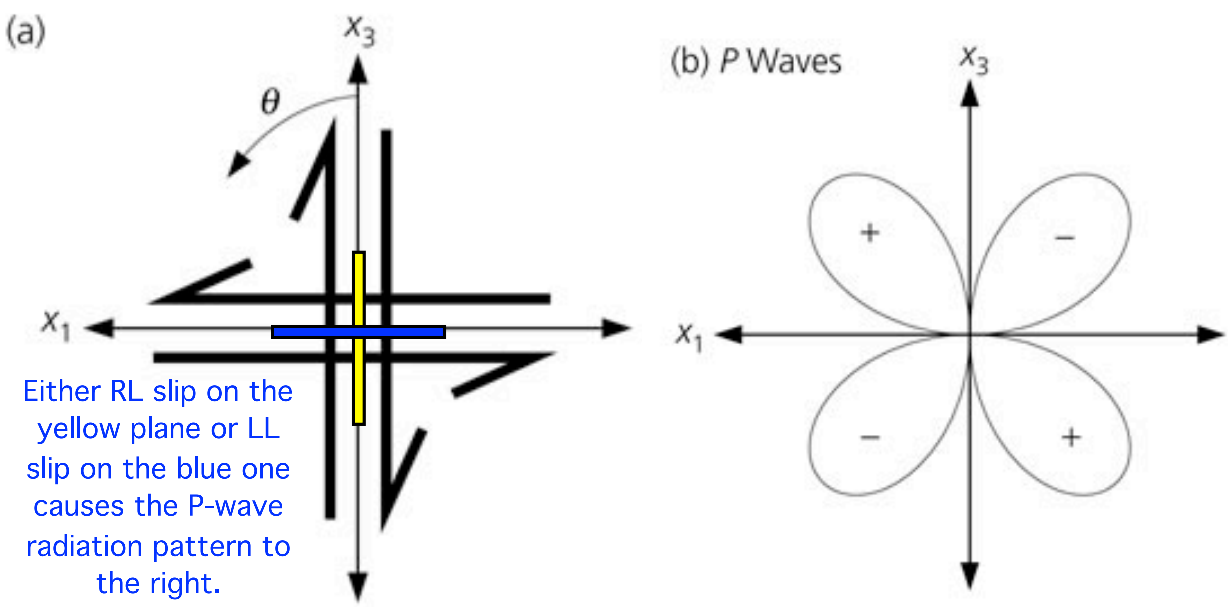


First motion: some go up and some go down

Non-earthquake source: Underground Bomb Test or Aristotle’s winds are associated with a volume change underground



FAULT PLANE AMBIGUITY

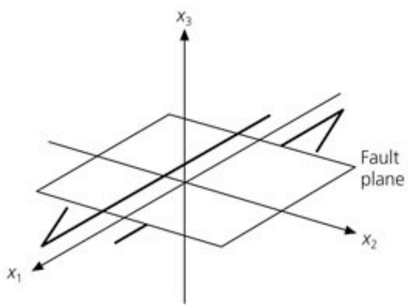


Either RL slip on the yellow plane or LL slip on the blue one causes the P-wave radiation pattern to the right.

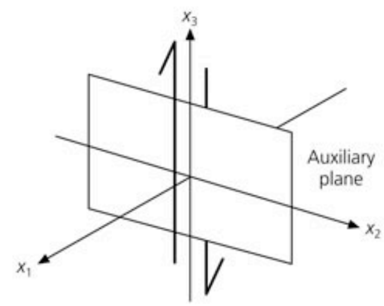
Note both fault plane and auxillary plane are often referred to as ``nodal planes’’ because radiated energy is theoretically zero.

FAULT-PLANE AMBIGUITY

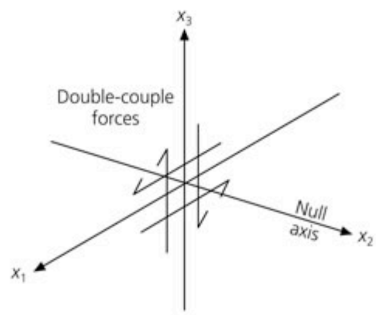
FAULT PLANE



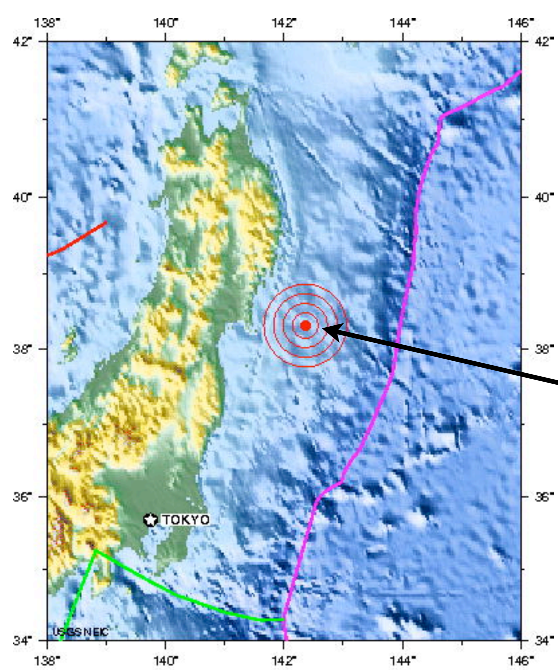
AUXILIARY PLANE



DOUBLE COUPLE FORCE



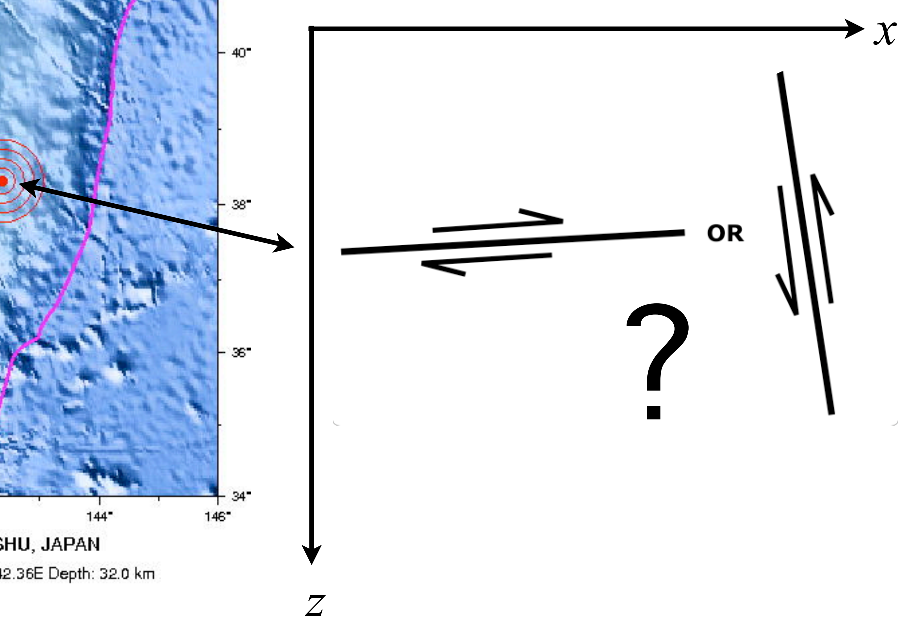
FAULT-PLANE AMBIGUITY - JAPAN



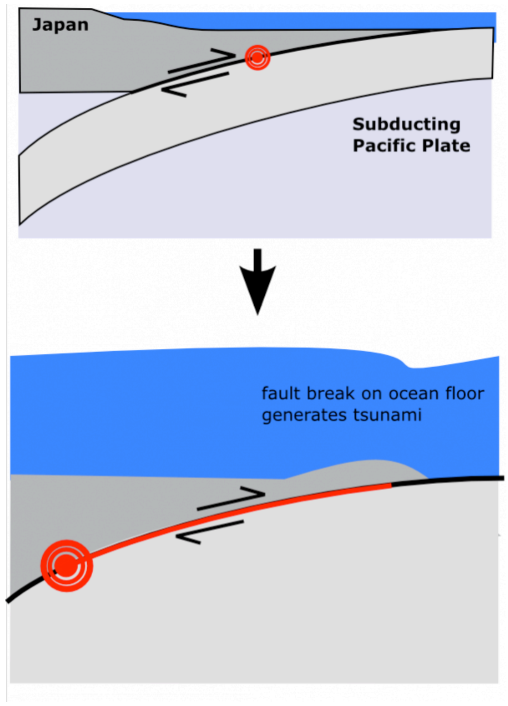
NEAR EAST COAST OF HONSHU, JAPAN

2011 03 11 05:46:23 UTC 38.32N 142.36E Depth: 32.0 km

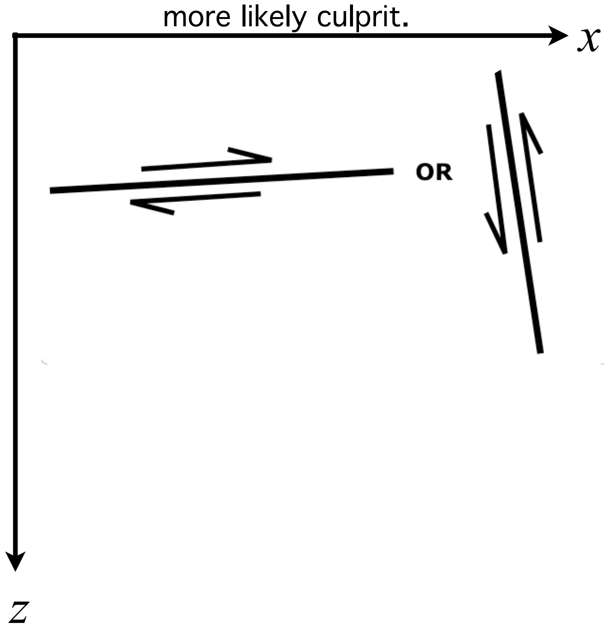
Earthquake Location



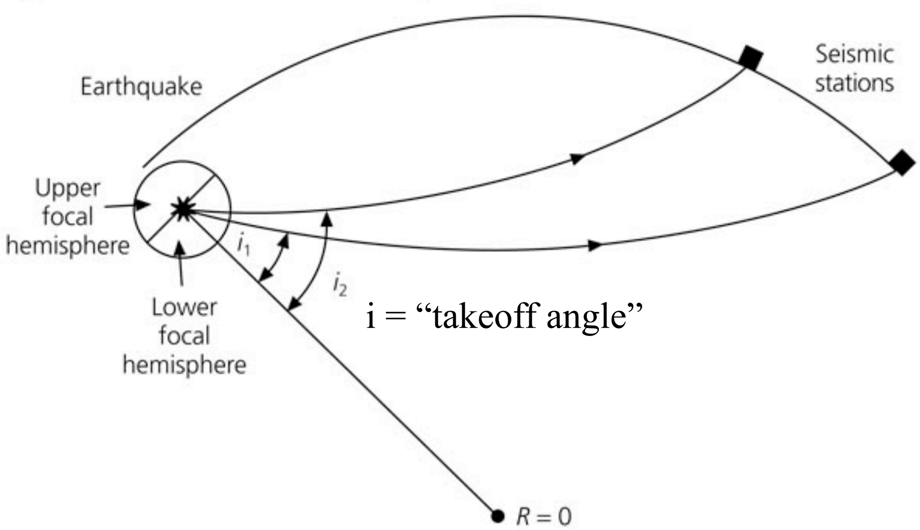
FAULT-PLANE AMBIGUITY - JAPAN



clues: what we know about the tectonics, aftershocks outline the fault plane, tsunamigenesis may make one plane the more likely culprit.

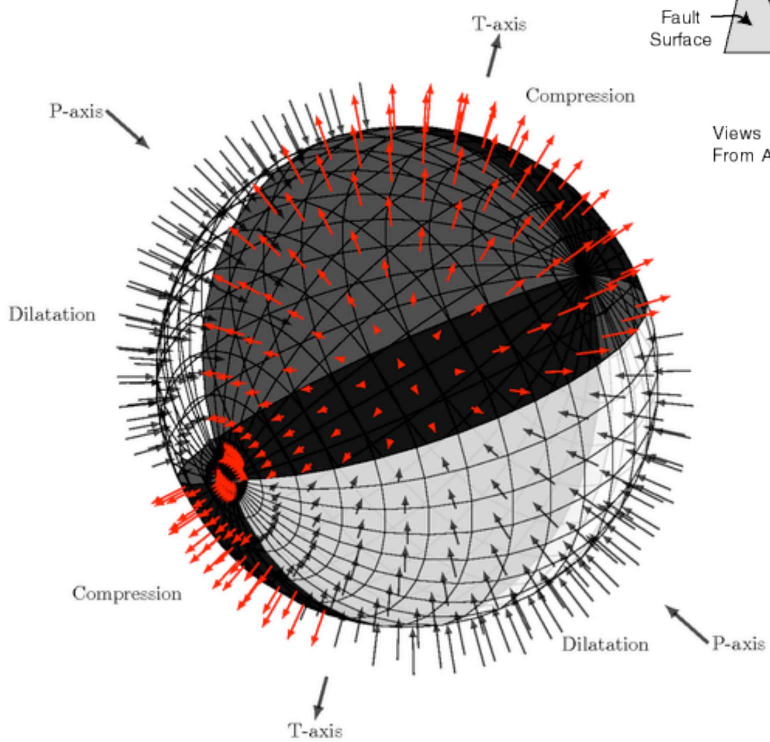


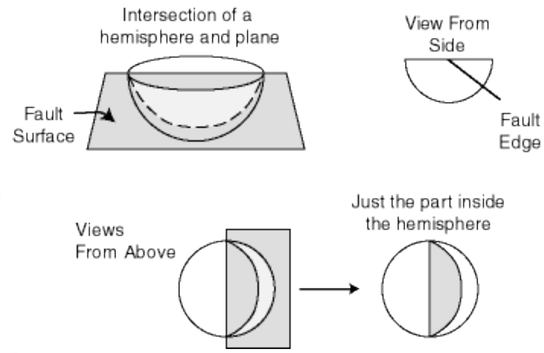
FOCAL MECHANISMS AND THE FOCAL SPHERE



The focal sphere is an imaginary sphere surrounding hypocenter that can be divided into compressional and dilatational quadrants.

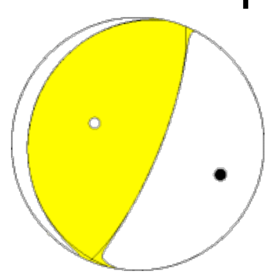
For "teleseismic" earthquakes and global networks, we map first motions back to the lower focal sphere by tracing back along ray paths; for local earthquakes we map to upper focal sphere.





Seismic focal mechanism and Pression-Tension axis.

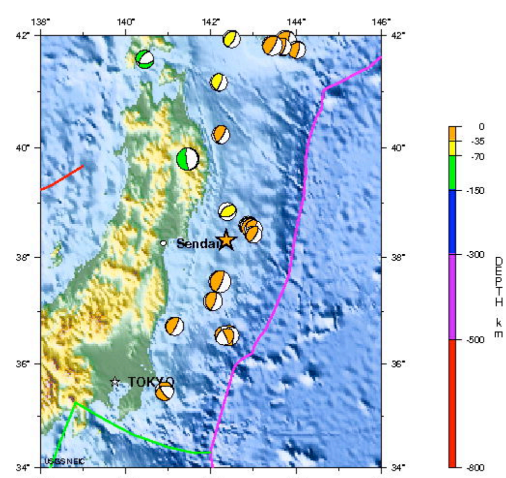
Focal Mechanisms and the Focal Sphere



We describe first-motion information using a “focal mechanism” (beach-ball diagram)

Beach-ball symbol describes either lower or upper focal sphere with compressional = shaded, dilatational = white

Symbol defines fault type, but note that fault plane ambiguity remains!



NEAR EAST COAST OF HONSHU, JAPAN
2011 03 11 05:46:23 UTC 38.32N 142.36E Depth: 32.0 km
Historic Moment Tensor Solutions

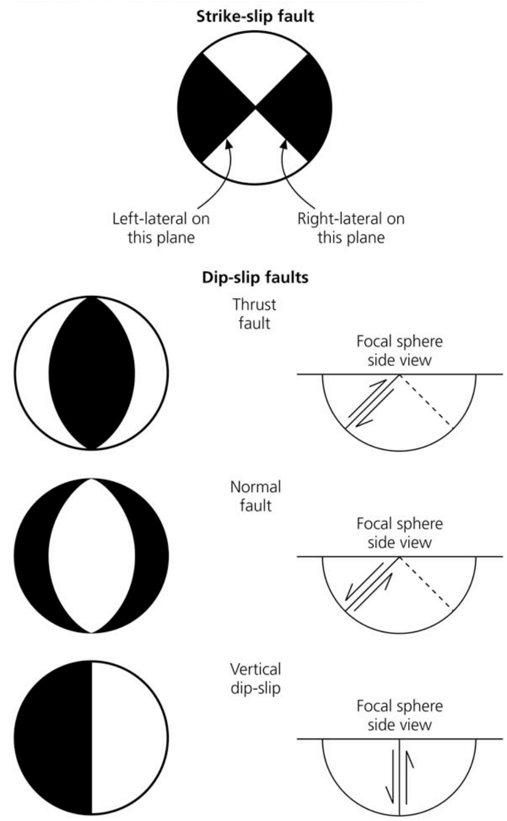
Earthquake Focal Mechanisms

Compressional quadrants in black

Which way does the strike-slip fault strike?

Which way do the normal and reverse faults strike?

What do their upper hemispheres look like?

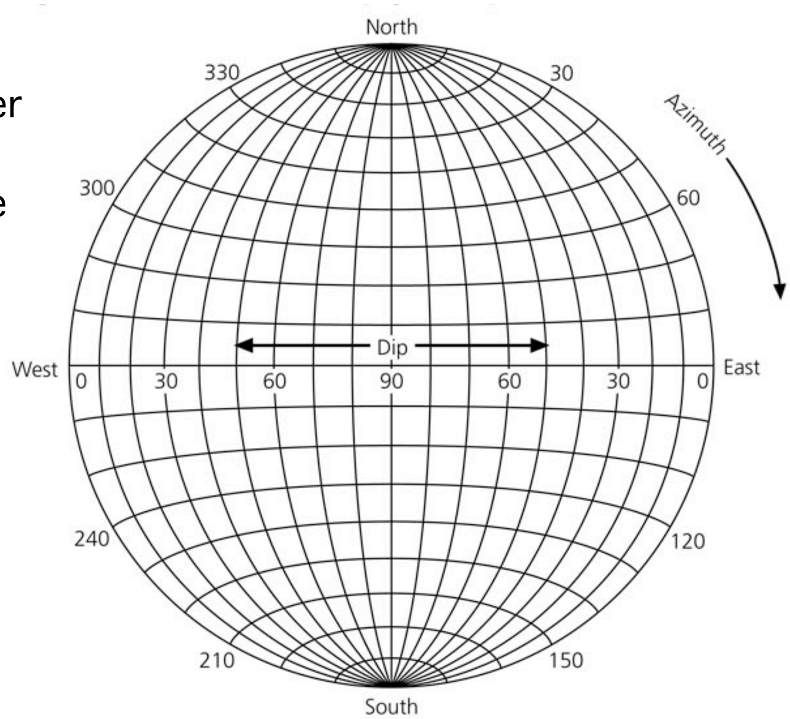


Stereonets

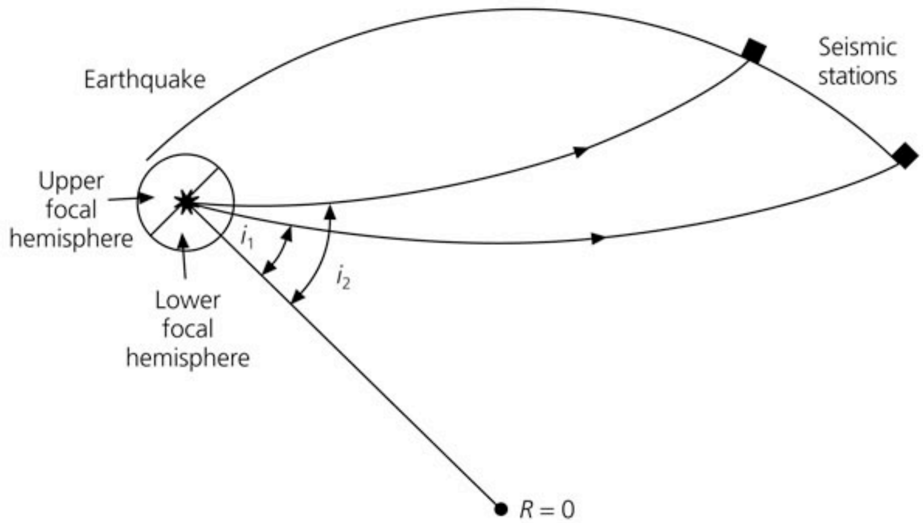
Used to display (either upper or lower) focal sphere on flat surface

Azimuth is shown by numbers around circumference

Dip angles are shown by numbers along equator



UPPER vs. LOWER FOCAL HEMISPHERES



IMPORTANT POINTS

For this week's activity, you will be plotting first motions on the upper focal hemisphere because it is simpler to visualize for the case of regional earthquakes (waves go up)

For <u>teleseismic</u> waves, waves go down before arriving at receiver, so plot lower focal hemisphere. This is the convention.

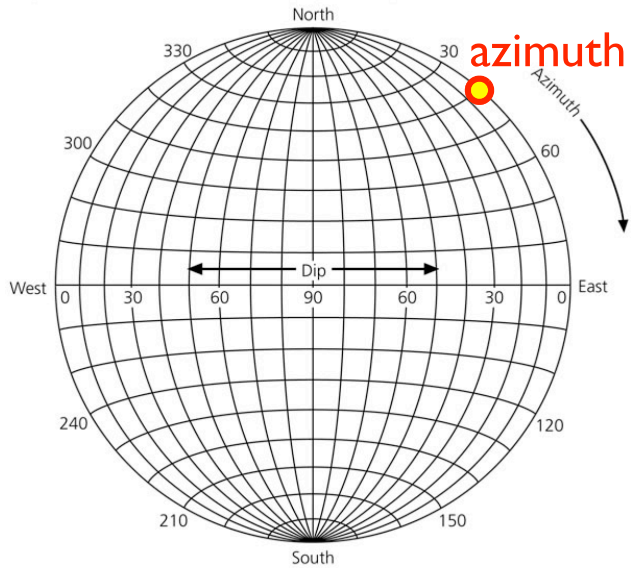
Any lower focal hemisphere can be readily transformed into a upper focal hemisphere.

PLOTTING FIRST MOTIONS ON STEREONET

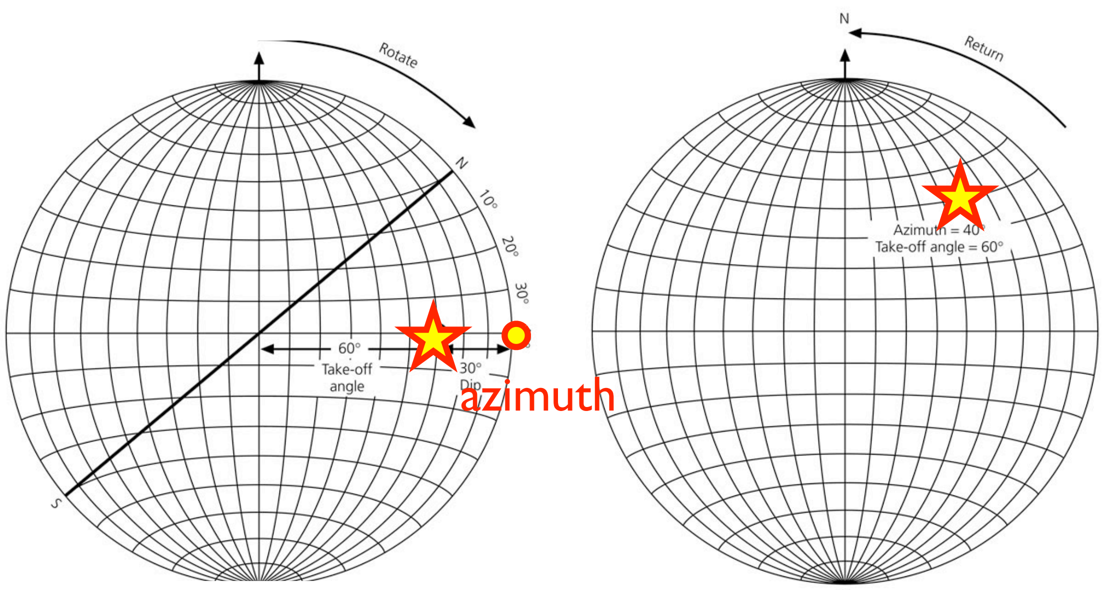
YOU HAVE AZIMUTH AND TAKE-OFF ANGLE ("RAY INCLINATION") for each seismogram, as well as C, T, or N and a grade (A or B).

First, mark the azimuth.

Figure 4.2-9: Stereonet used to display a hemisphere on a flat surface.

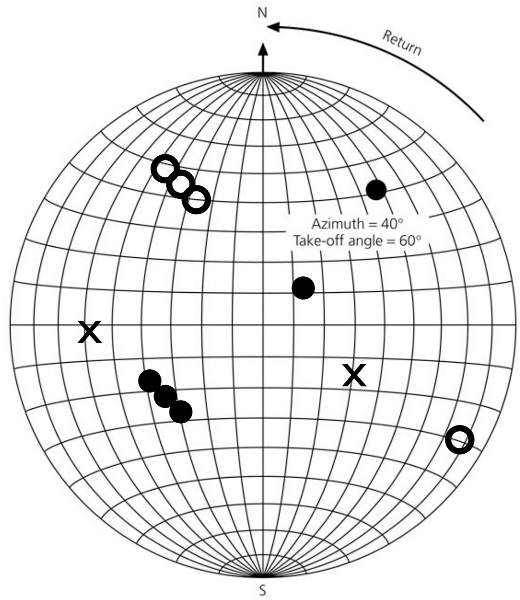


PLOTTING FIRST MOTIONS ON STEREONET

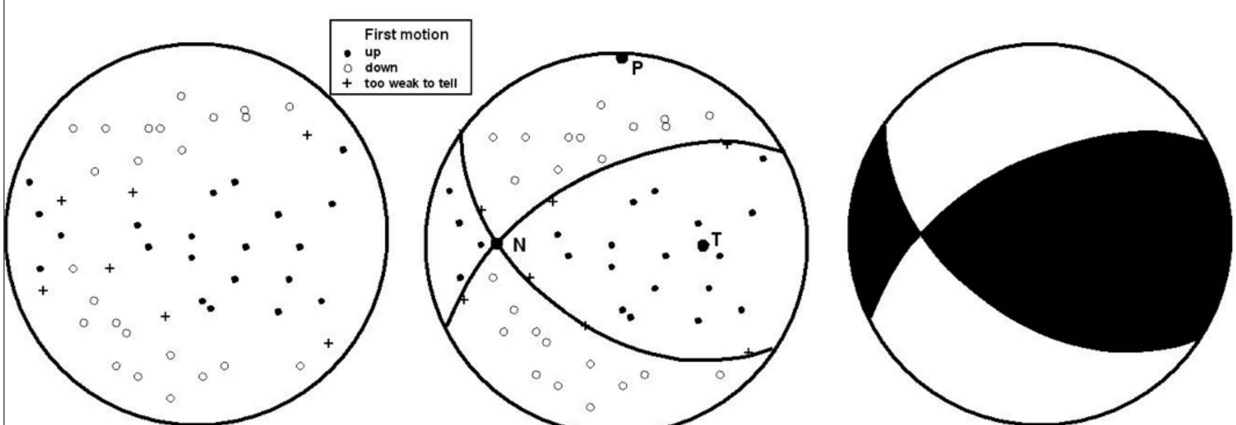


1. To plot first motion on stereonet, rotate the azimuth to the equator
2. Plot the point (count your angle from the center, as shown) and rotate back to geographic orientation (north at top)

PLOTTING FIRST MOTIONS ON STEREONET



C = filled circle ●
D = open circle o
X = nodal
Make the "A" ranked ones darker than the "B" ranked ones.



First motion data for a hypothetical earthquake from various seismograph stations

Nodal planes and N, P & T axes fitted to the data

Resultant 'beachball' plot showing that the earthquake resulted from reverse oblique movement on a fault of one of two possible orientations

Wikipedia

USGS WPhase Moment Solution

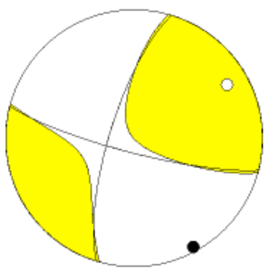
VANCOUVER ISLAND, CANADA REGION

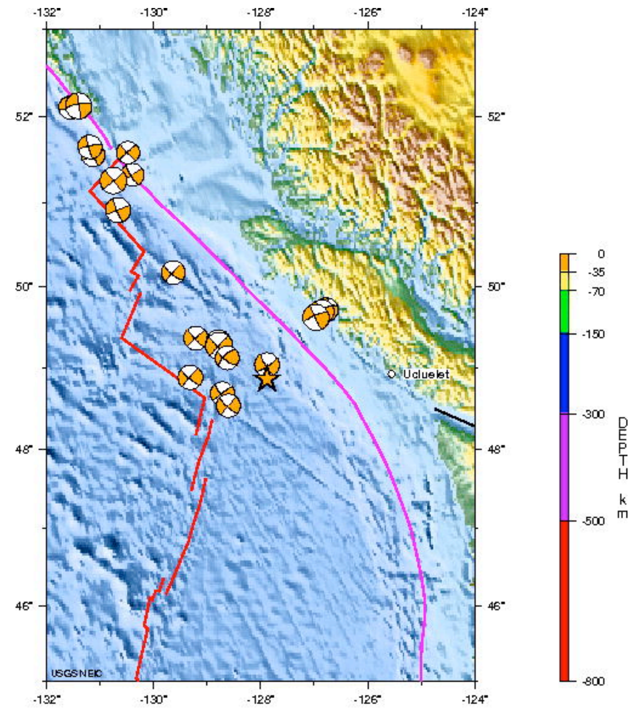
```
12/ 2/ 4 20: 5:32.00

Epicenter:  48.867 -127.875
MW 5.6

USGS/WPHASE CENTROID MOMENT TENSOR
12/ 2/ 4 20: 5:32.00
Centroid:    48.867 -128.027
Depth  15          No. of sta: 24
Moment Tensor;    Scale 10**17 Nm
  Mrr= 0.01        Mtt=-1.49
  Mpp= 1.49        Mrt= 0.68
  Mrp=-0.78        Mtp=-2.46
 Principal axes:
  T  Val=  3.19  Plg=17  Azm= 59
  N     = -0.30     71      255
  P     = -2.90      4      151

Best Double Couple:Mo=3.1*10**17
 NP1:Strike=197 Dip=74 Slip=   9
 NP2:       104     81       164
```





VANCOUVER ISLAND, CANADA REGION

2012 02 04 20:05:32 UTC 48.87N 127.88W Depth: 12.8 km

Historic Moment Tensor Solutions