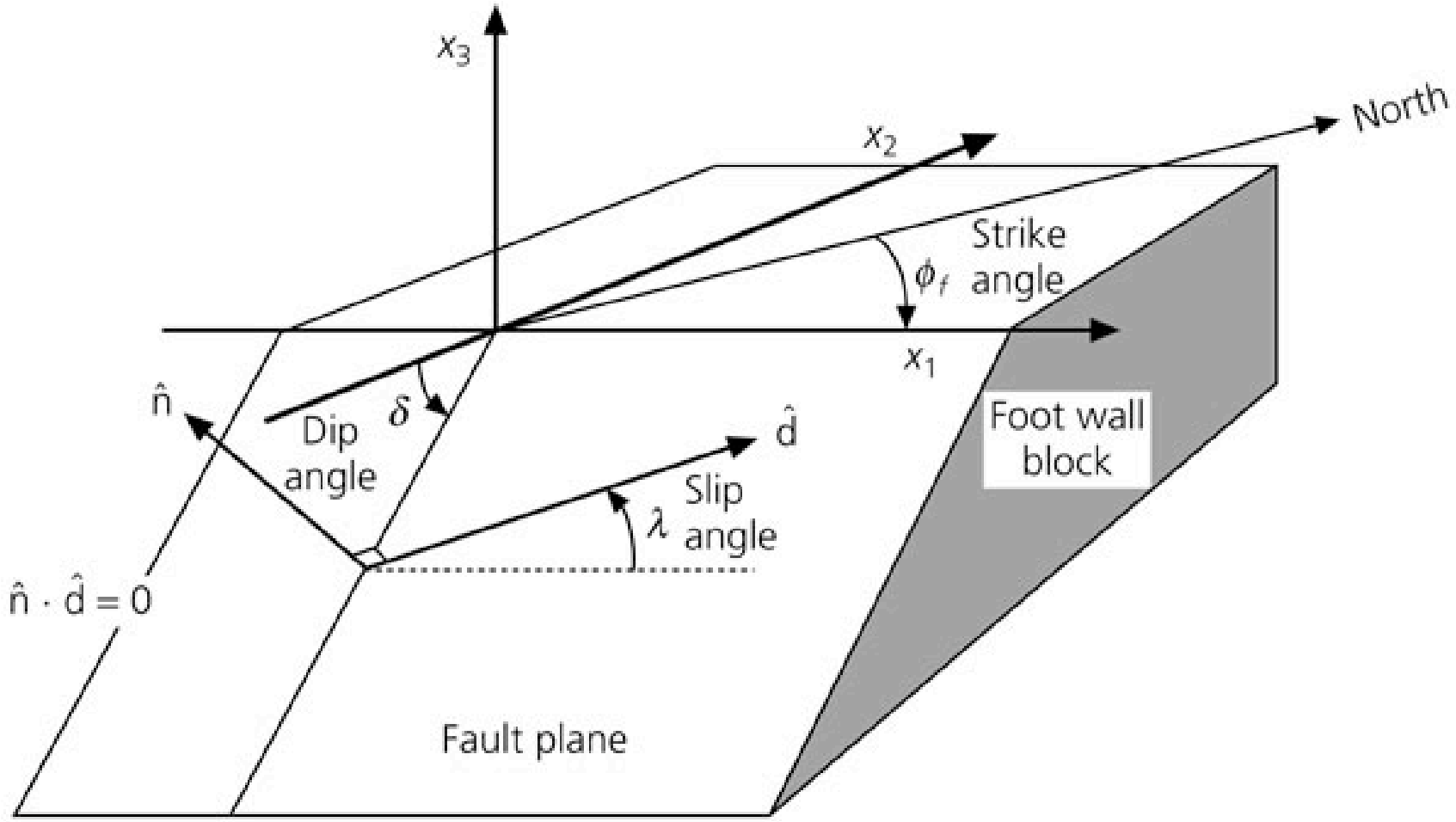
BEYOND TRAVELTIMES AND EARTHQUAKE LOCATION

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

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

GEOMETRICAL PROPERTIES



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

FAULT DIMENSIONS

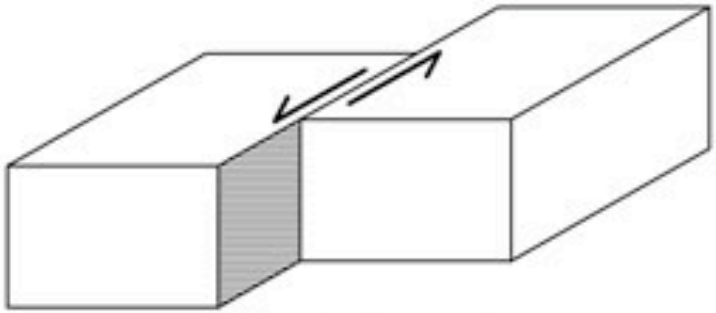
We also wish to constrain fault dimensions (ie the actual area of rupture).

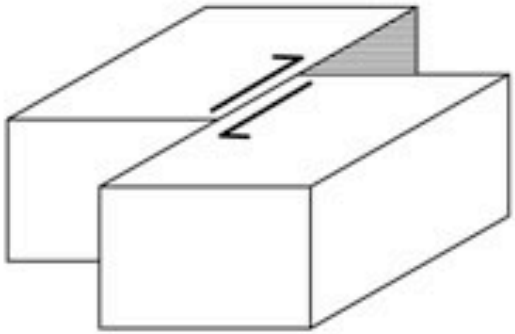
This can be quite complex, so we simplify by modelling through equivalent rectangular area

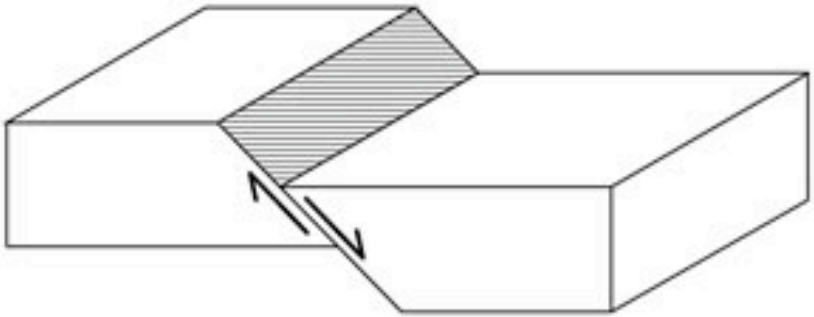
WIDTH X LENGTH

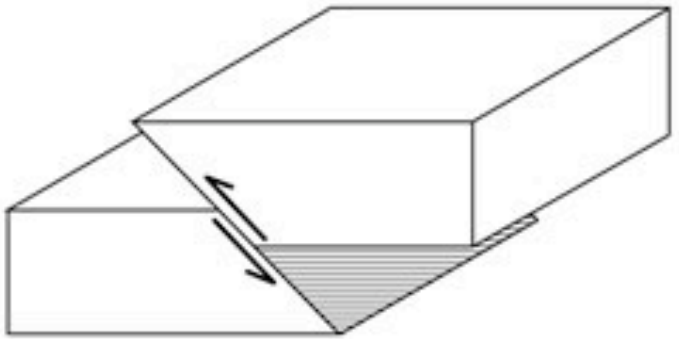
Let's look first at fault geometry...

FAULT TYPES



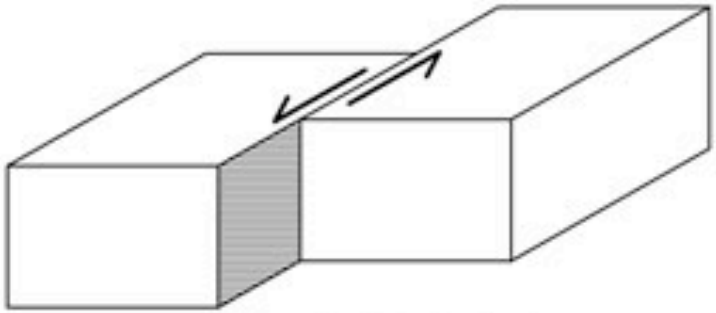




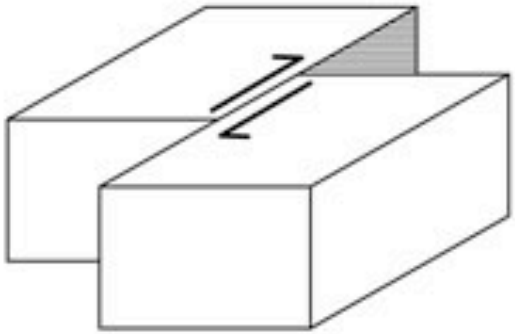


Name that fault!

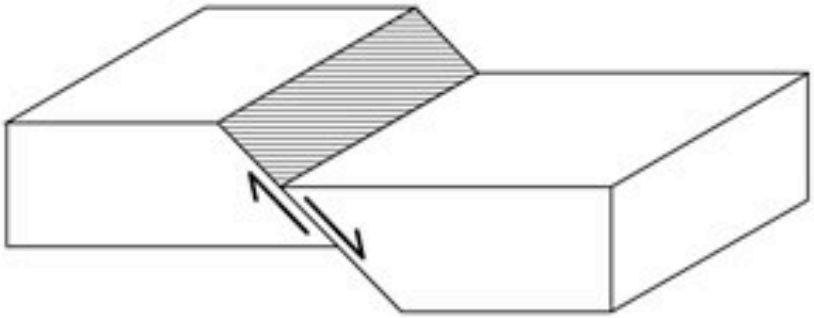
FAULT TYPES



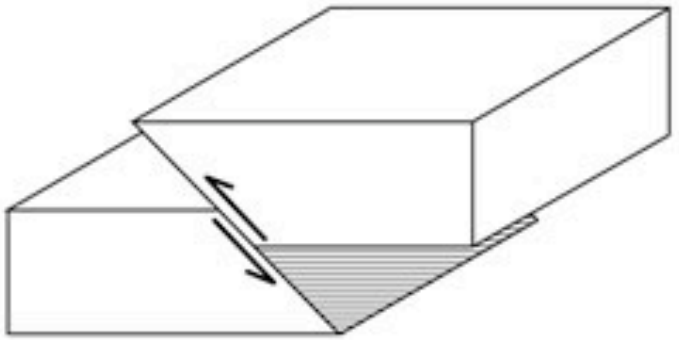
strike-slip/transform
(left lateral)



(right lateral)

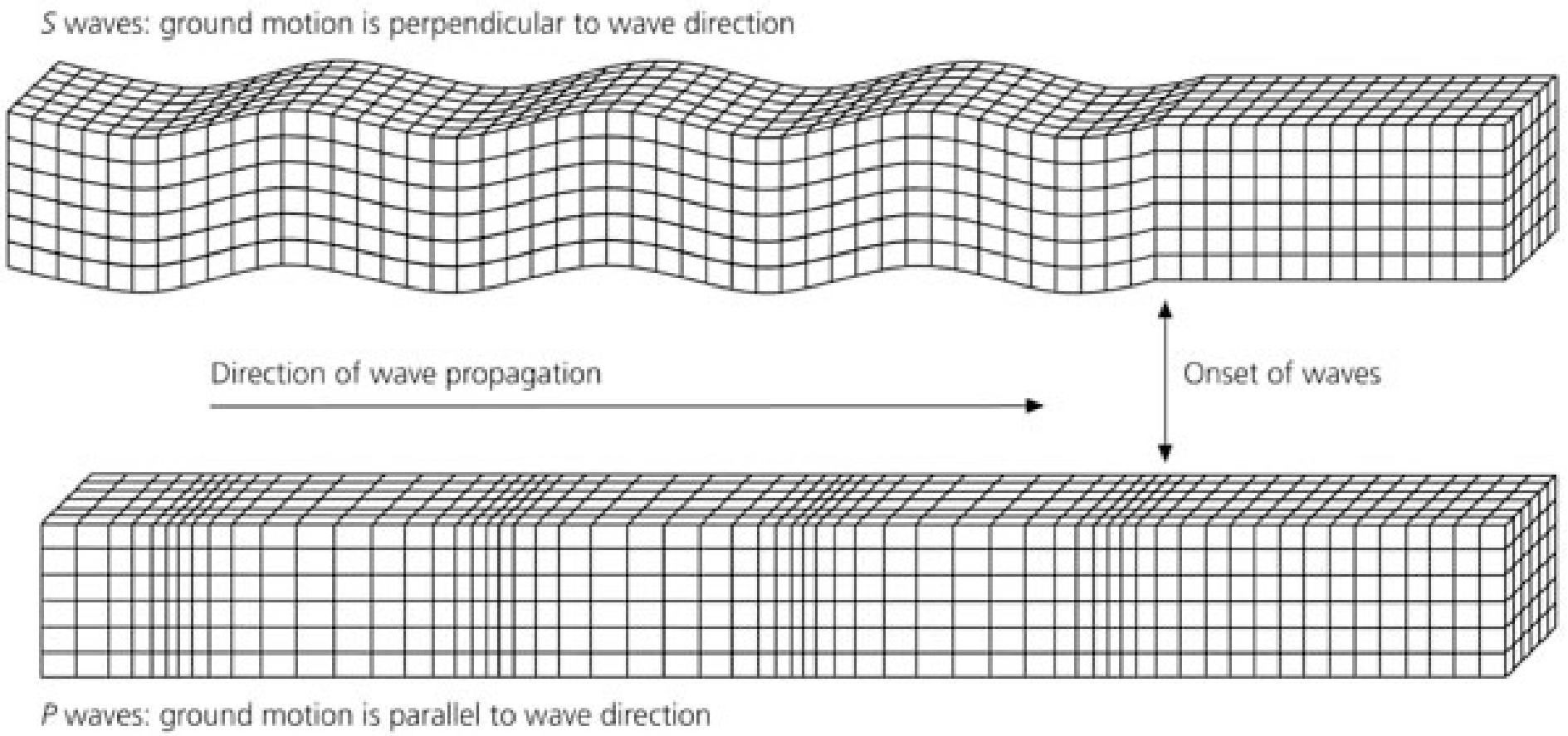


normal



thrust/reverse

P-WAVES & S-WAVES



What are defining properties of P and S waves?

P-WAVES VERSUS S-WAVES

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

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

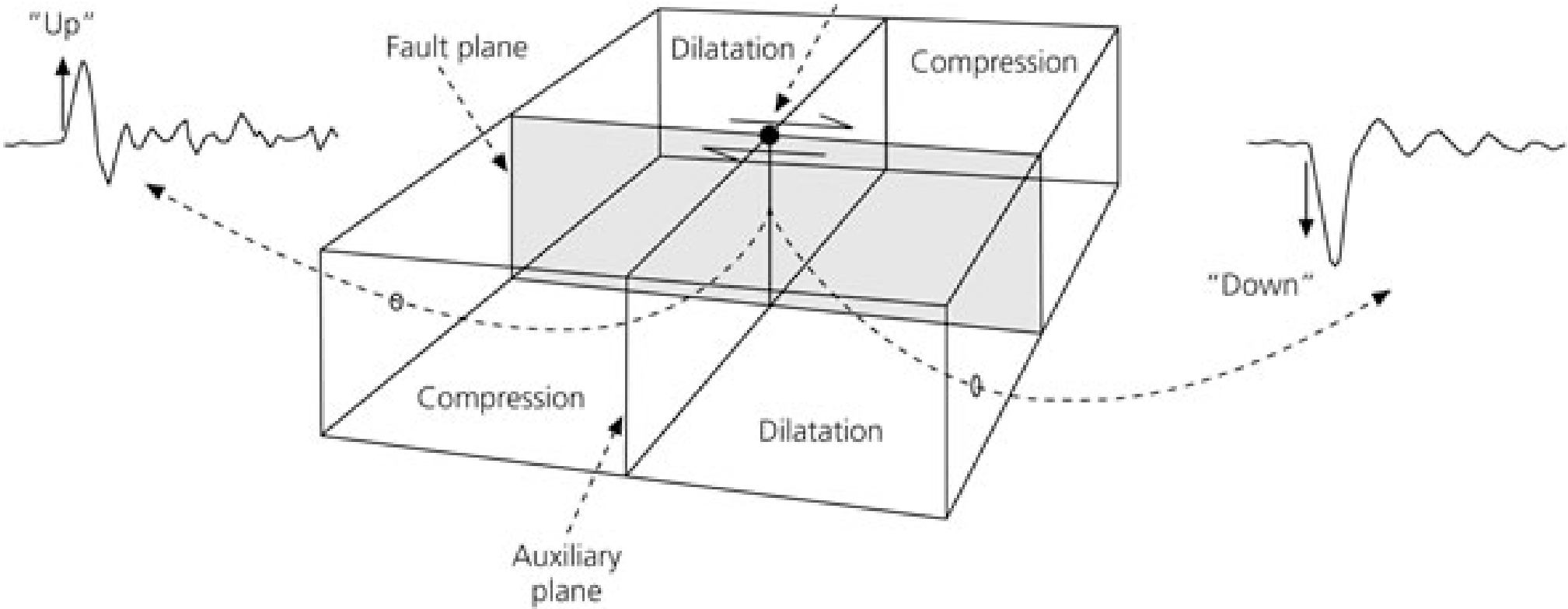
> S-waves produce shear motion perpendicular to direction of propagation (Secondary/Shear waves)

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

> we will focus on P-waves to characterize faults

FIRST MOTION CONSTRAINTS

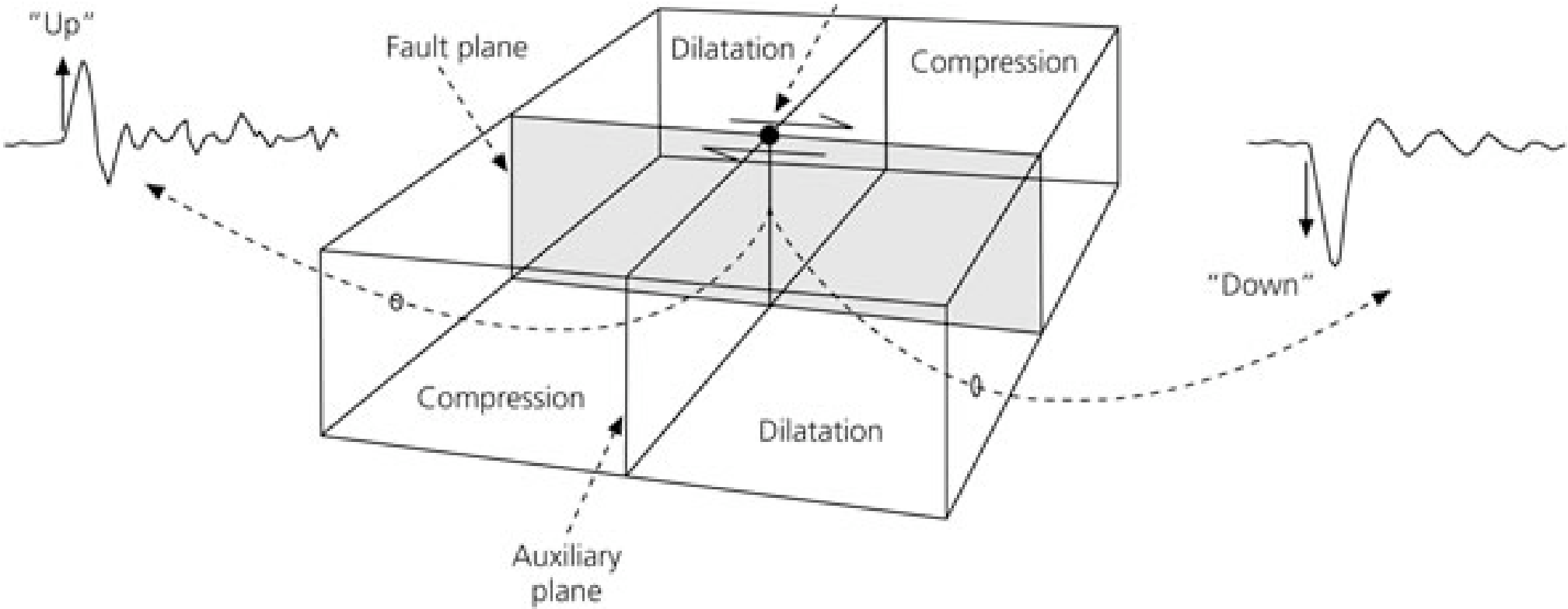
> Depending on orientation of fault, receivers may see either ``compressional'' or ``dilatational'' P-wave first motion



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

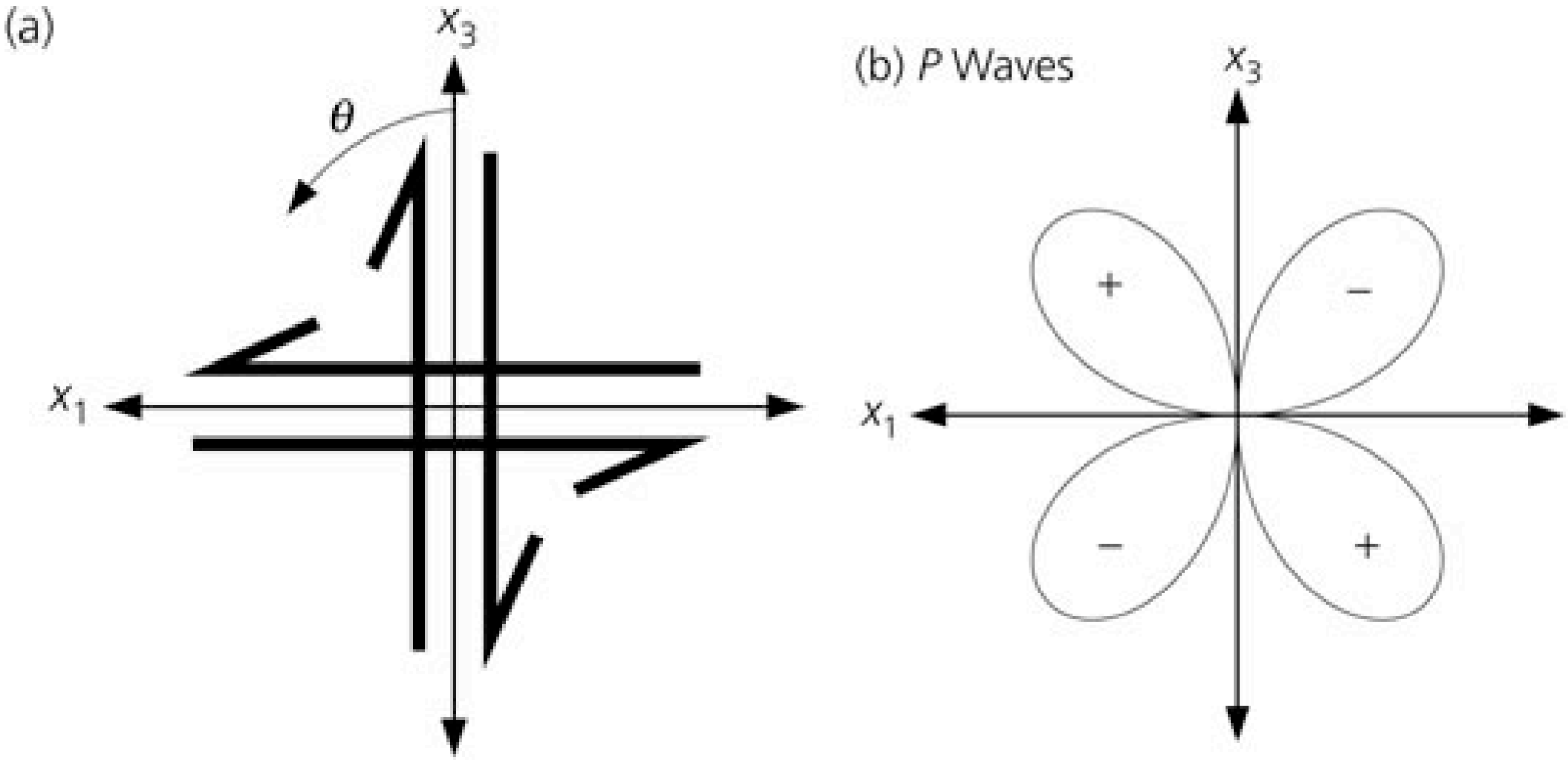
FIRST MOTION CONSTRAINTS

> define ``auxillary" plane perpendicular to fault plane and slip direction



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

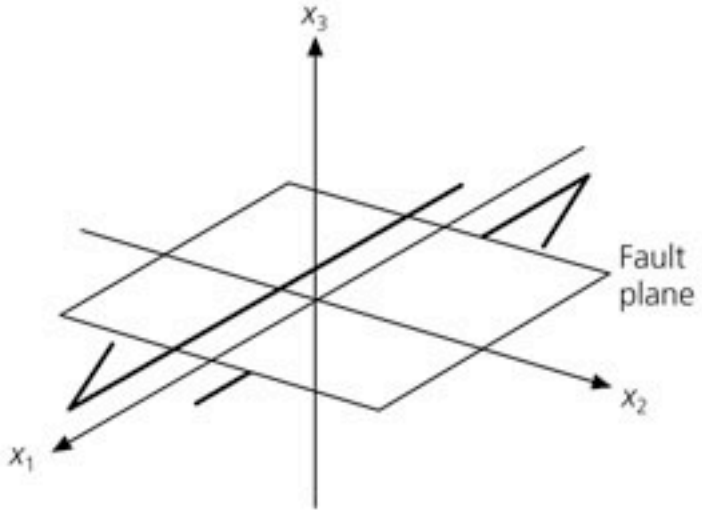
FAULT PLANE AMBIGUITY



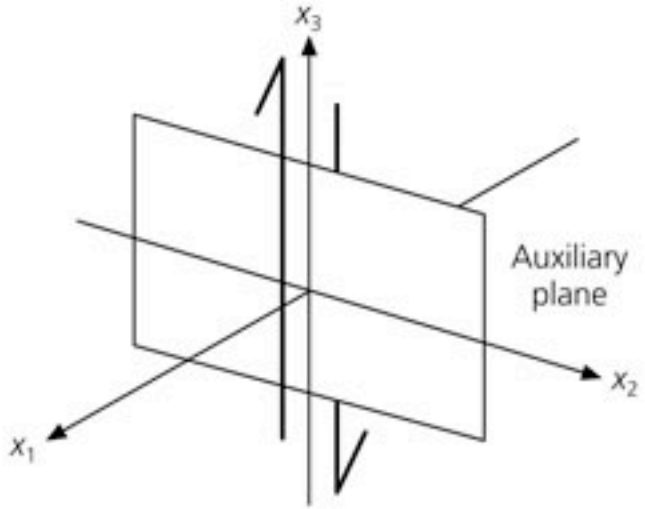
> Note both fault plane and auxillary plane are often referred to as ``nodal planes" because radiated energy is theoretically zero

FAULT-PLANE AMBIGUITY

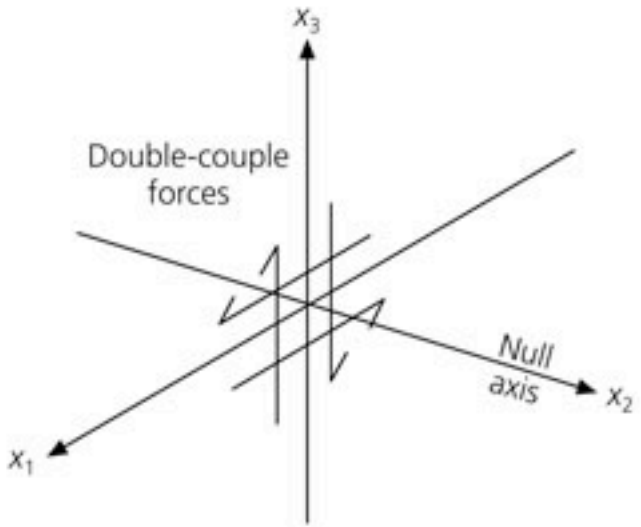
FAULT PLANE



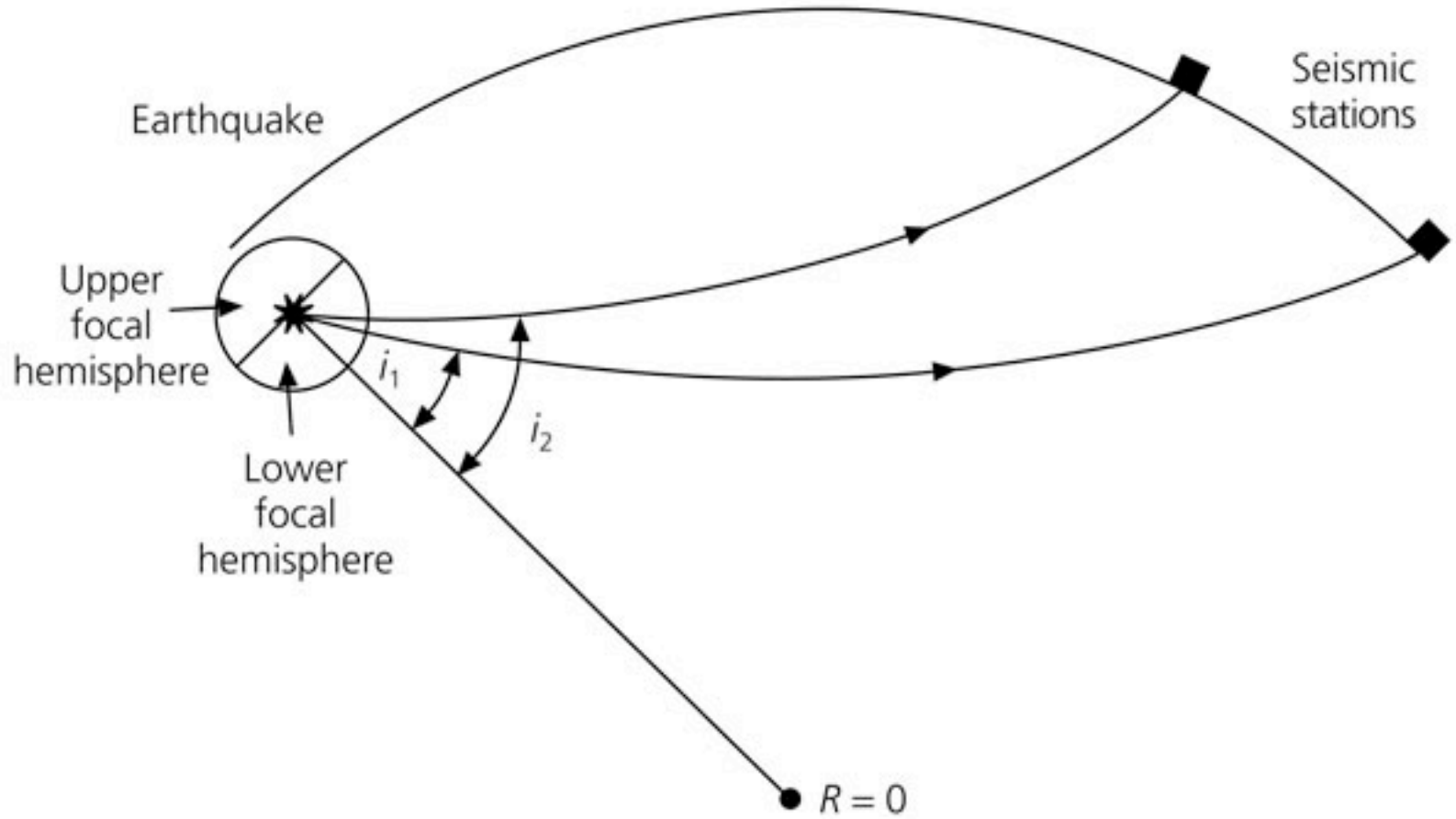
AUXILIARY PLANE



DOUBLE COUPLE FORCE



FOCAL MECHANISMS AND THE FOCAL SPHERE



> focal sphere is imaginary sphere surrounding hypocenter that can be divided into compressional and dilatational quadrants

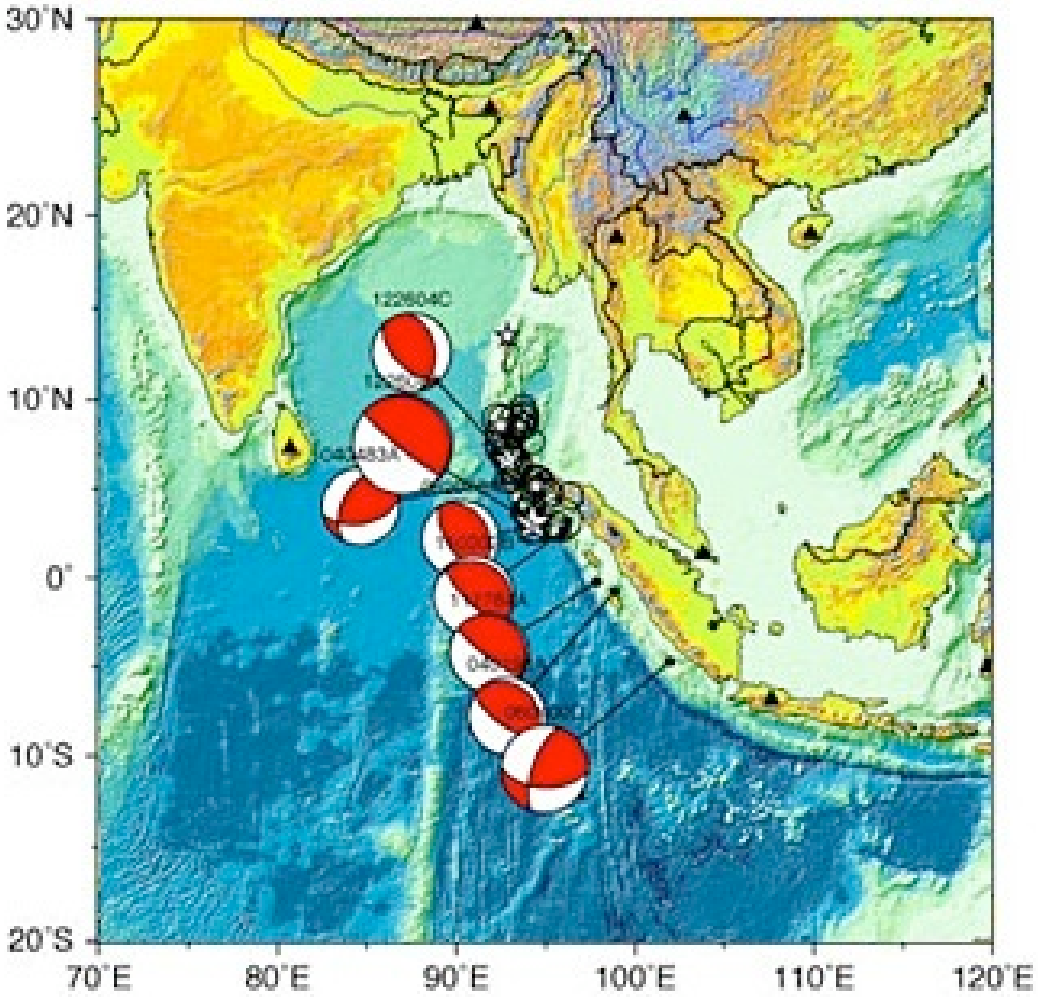
> for "teleseismic" earthquakes and global networks, we map first motions back to the lower focal sphere by tracing back along ray paths; for regional earthquakes map to upper focal sphere

FOCAL MECHANISMS & THE FOCAL SPHERE

> can 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

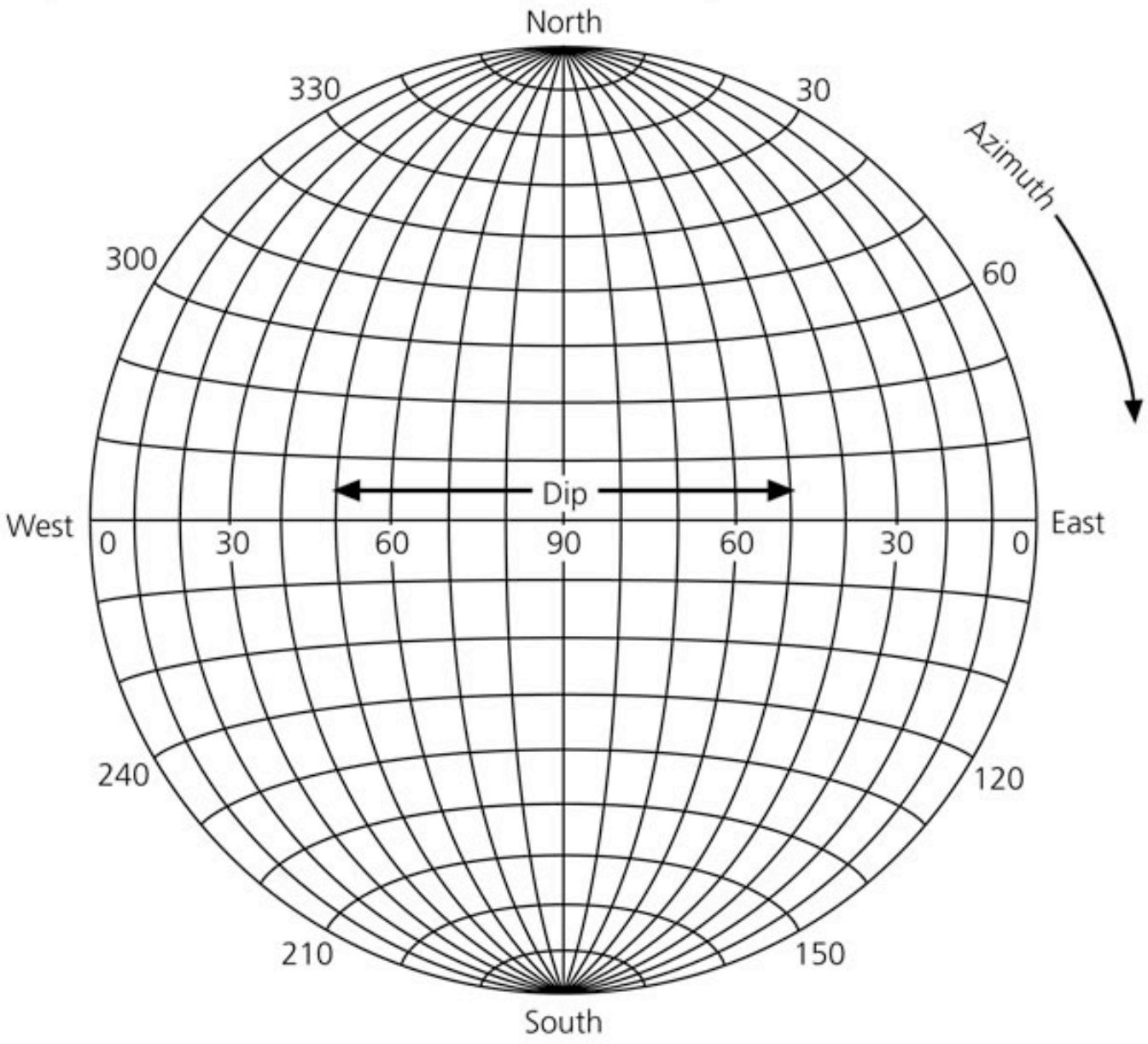


STEREONETS

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

> azimuth is shown by numbers around circumference

> dip angles shown by numbers along equator



EOSC 256 - APRIL 6, 2009

> Assignment due Wednesday, April 8

> need to fit two focal planes to first-motion data according to 4 quadrant model

> trial and error: choose 1 plane and find set of perpendicular ones (hint: consider tectonic environment)

> today:

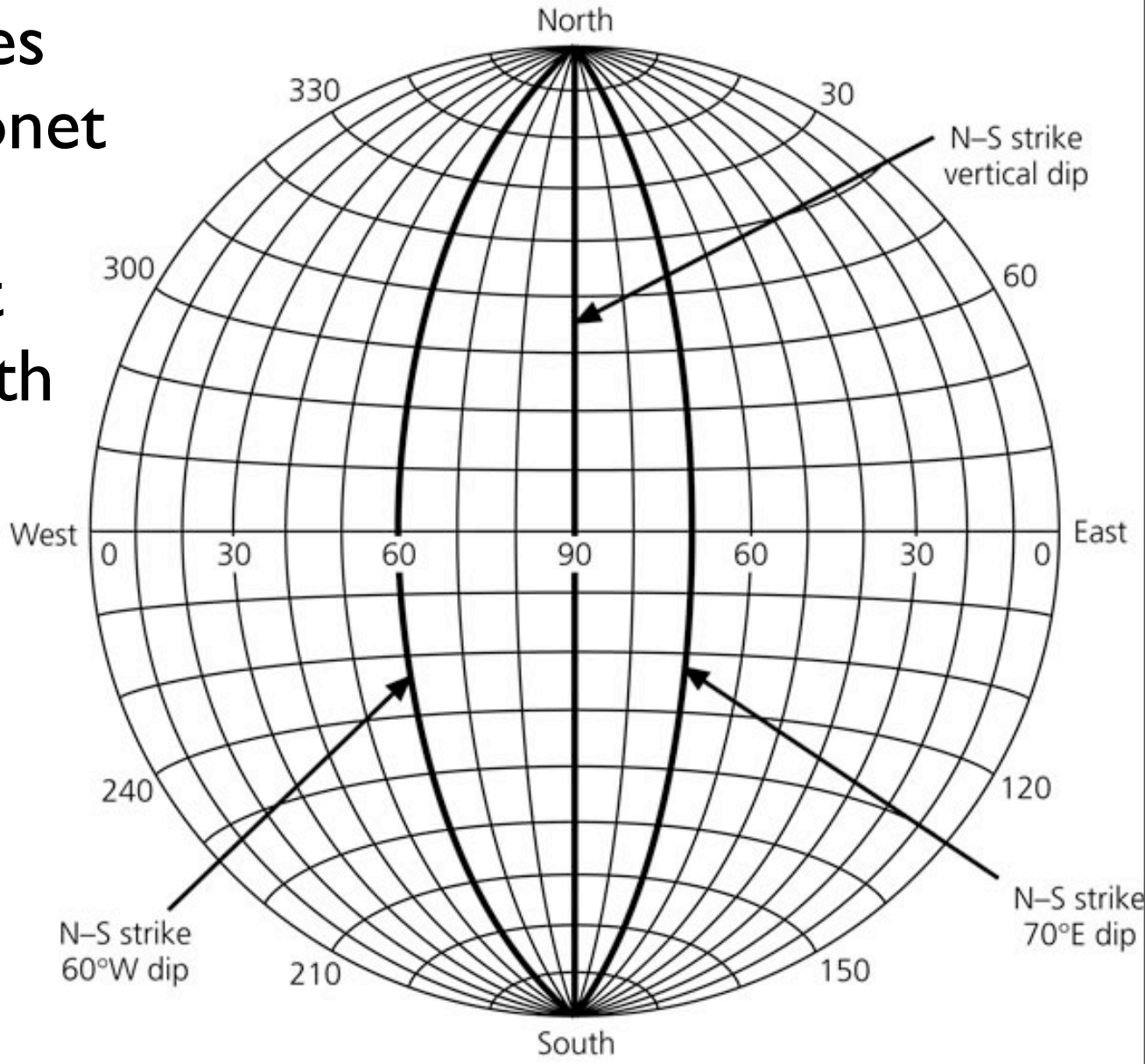
1. review upper and local focal hemispheres
2. examine focal mechanisms for different fault styles
3. data examples
4. non-double couple focal mechanisms

FAULT PLANE REPRESENTATION ON STEREONET

> figure shows 3 planes striking N-S on stereonet

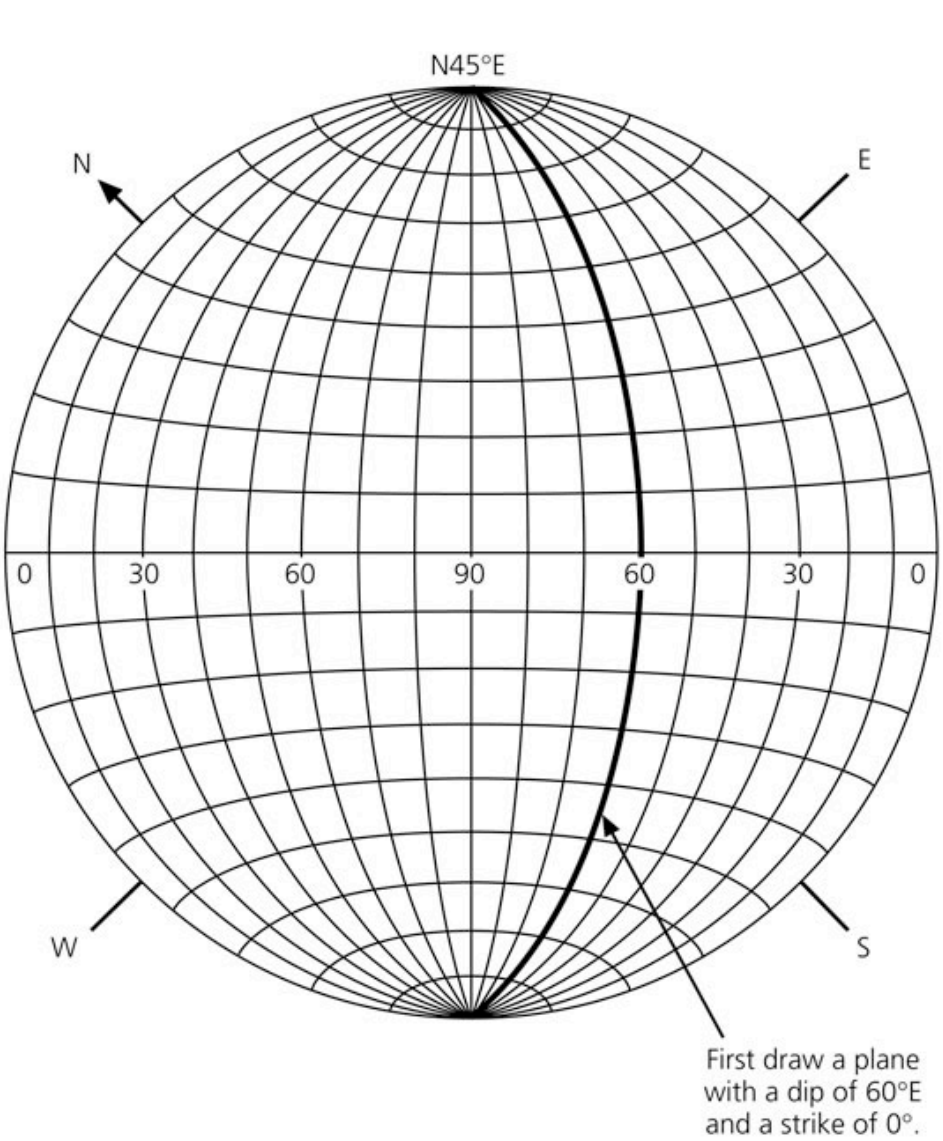
> meridians represent N-S striking planes with different dips

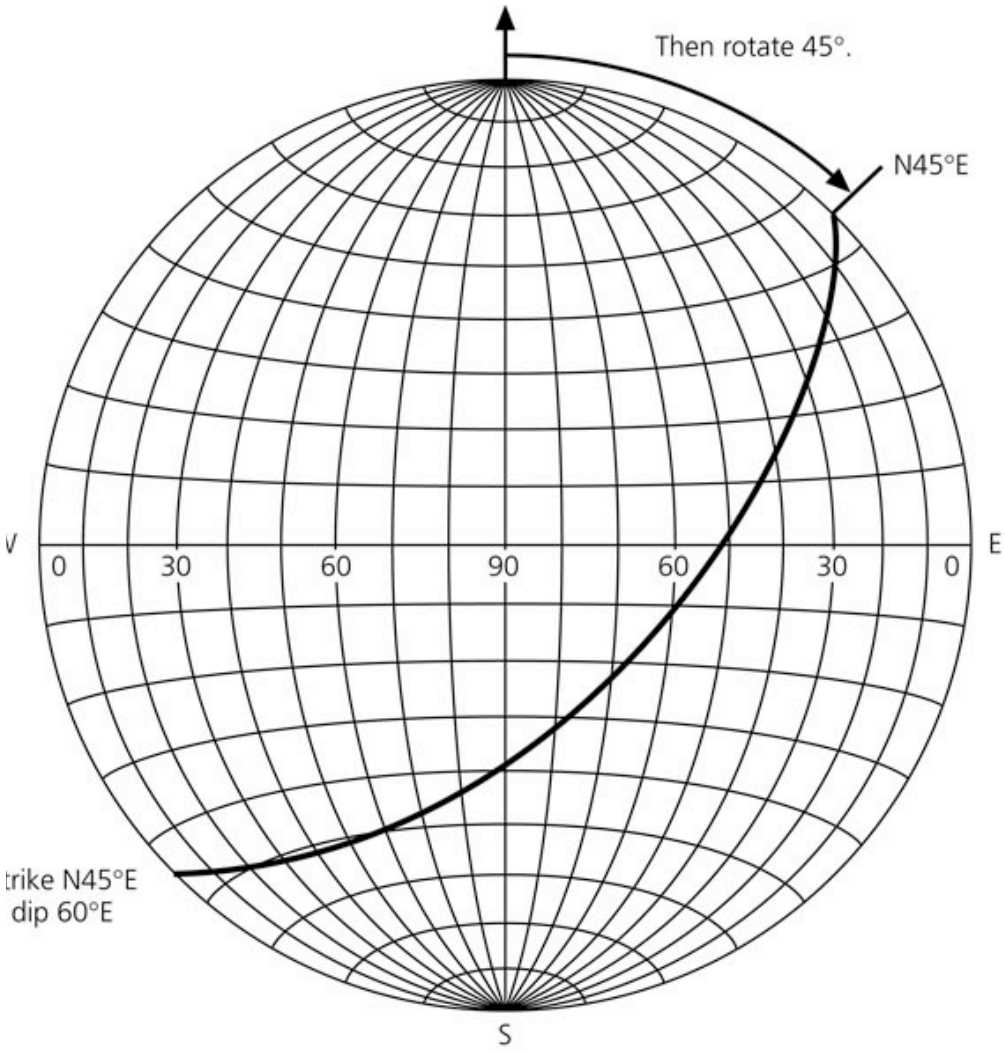
> note interpretation of dip depends on whether we assume lower or upper focal sphere



Does anyone know how to plot a plane that is perpendicular to another plane?

PLOTTING GENERAL FAULT PLANES ON STEREONETS





1. First draw plane with plane striking N-S and desired dip
2. Then rotate net back to proper strike

PLOTTING PERPENDICULAR PLANES ON A STEREONET

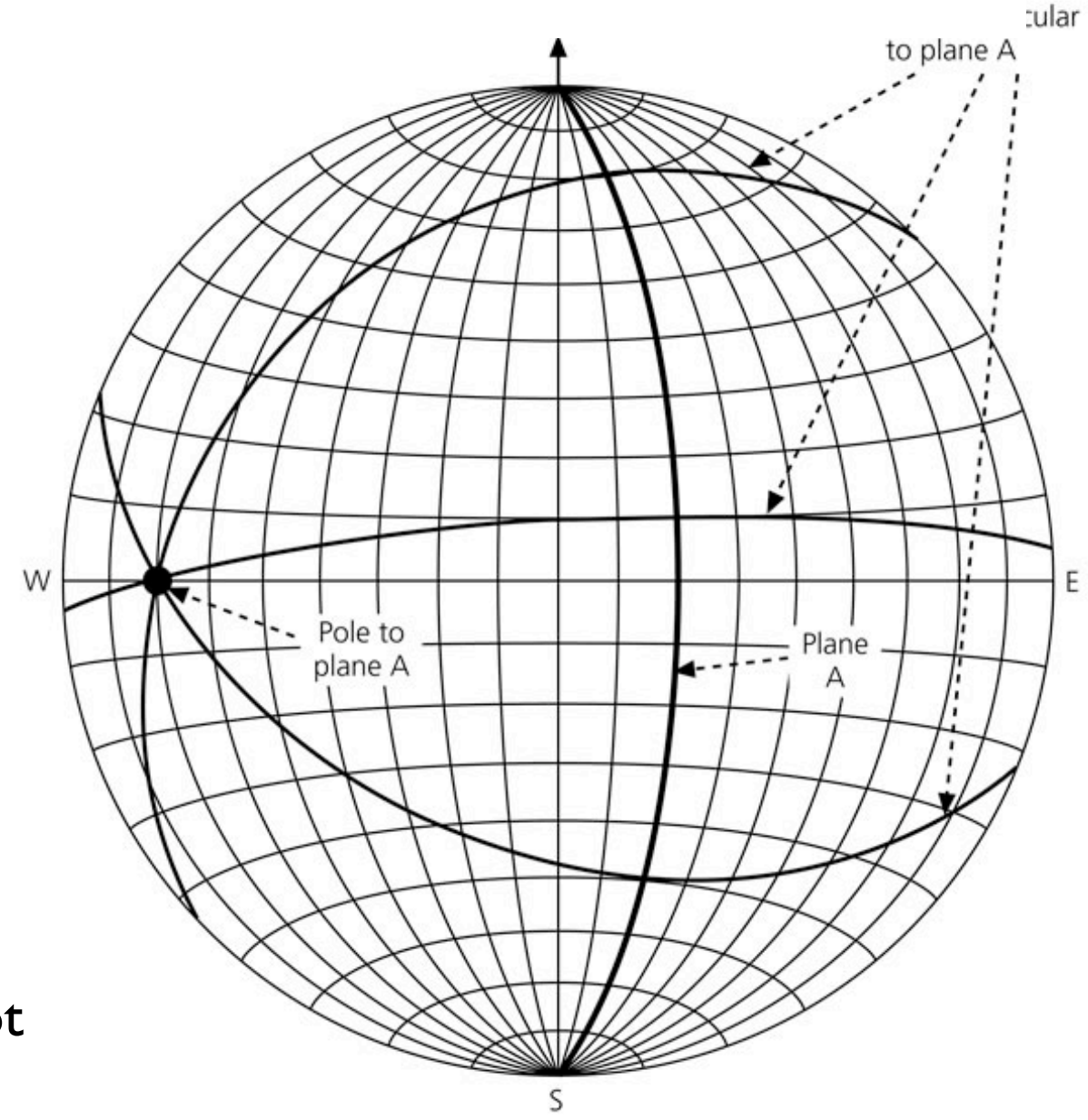
1. First rotate the first plane's strike to top of stereonet and plot plane

2. Next find the pole, pt on equator 90 degrees away

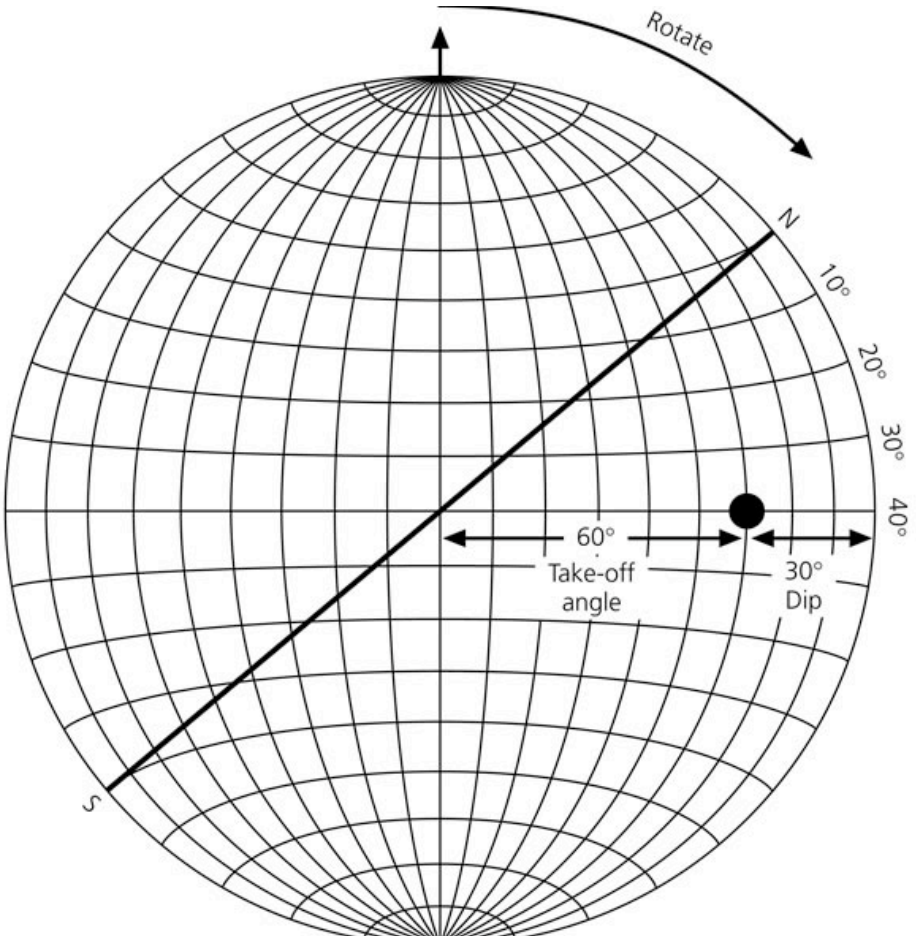
3. Any plane through pole is perpendicular to first plane

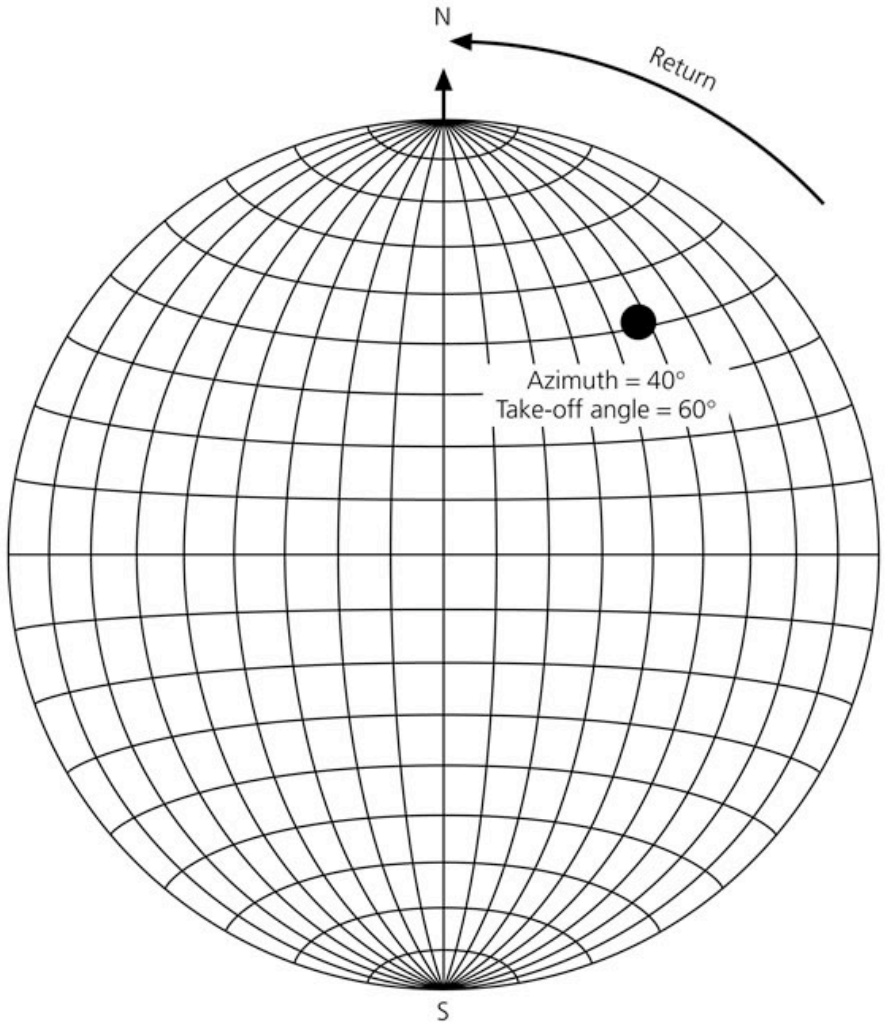
4. Several such planes shown

5. Note that slip vector is pole to auxillary plane and so must plot on fault plane



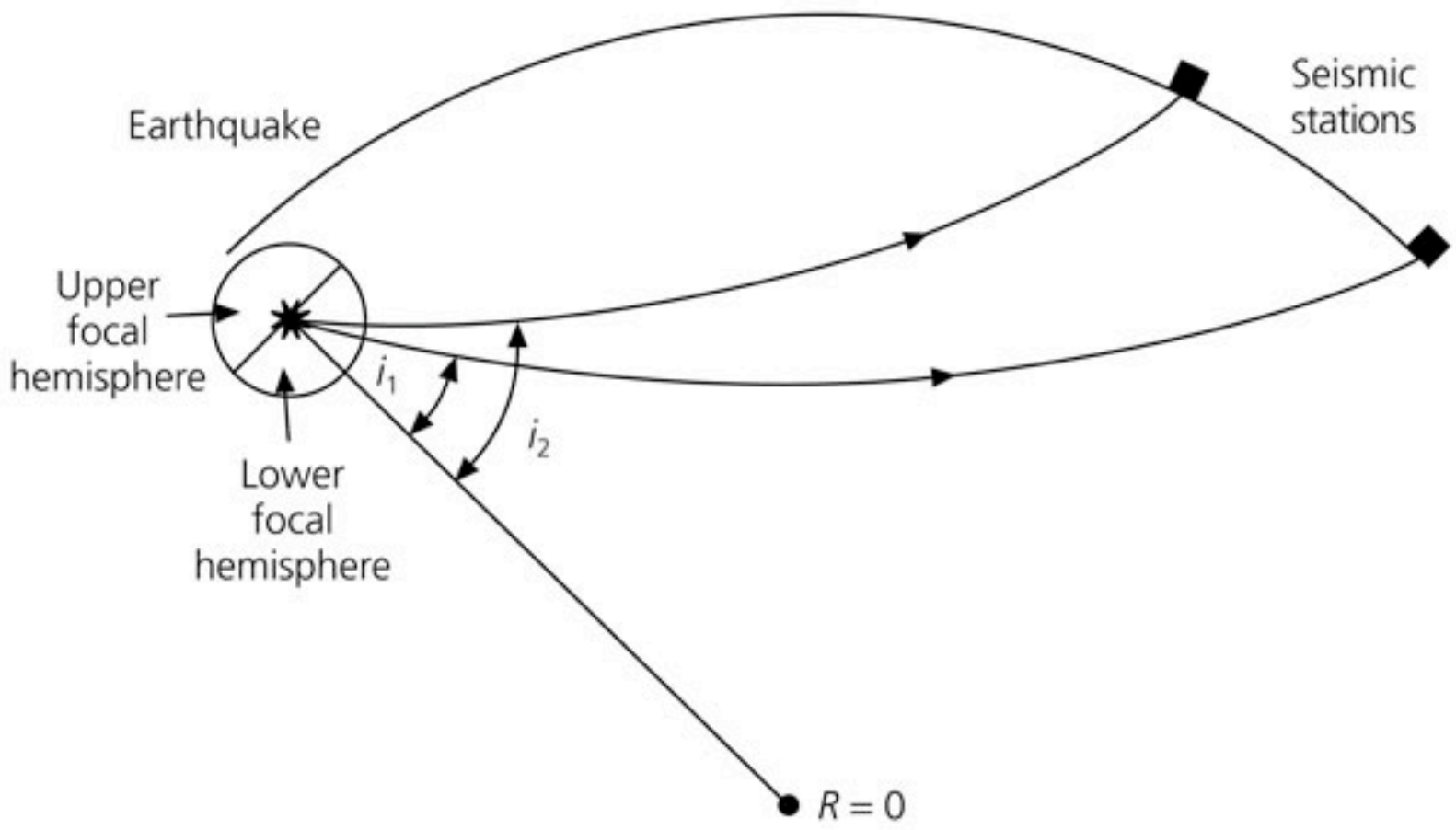
PLOTTING FIRST MOTIONS ON STEREONET





1. To plot first motion on stereonet, rotate the azimuth to the equator
2. Plot the point and rotate back to geographic orientation (north at top)

UPPER vs LOWER FOCAL HEMISPHERES



IMPORTANT POINTS

> on your assignment we have been plotting first motions on the *upper* focal hemisphere because it is simpler to visualize for the case of regional earthquakes (waves go up)

> for teleseismic 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 - how?

IMPORTANT POINTS 2

> every focal sphere has 4 equally divided quadrants, 2 compressional (shaded), 2 dilatation (transparent)

> of fault and slip vector determine what part of focal sphere we plot

> this will help you to visualize what the lower hemisphere looks like given the upper one (and vice versa)

> alternatively, you can imagine every point on upper sphere projected through center to another point 180 degrees away

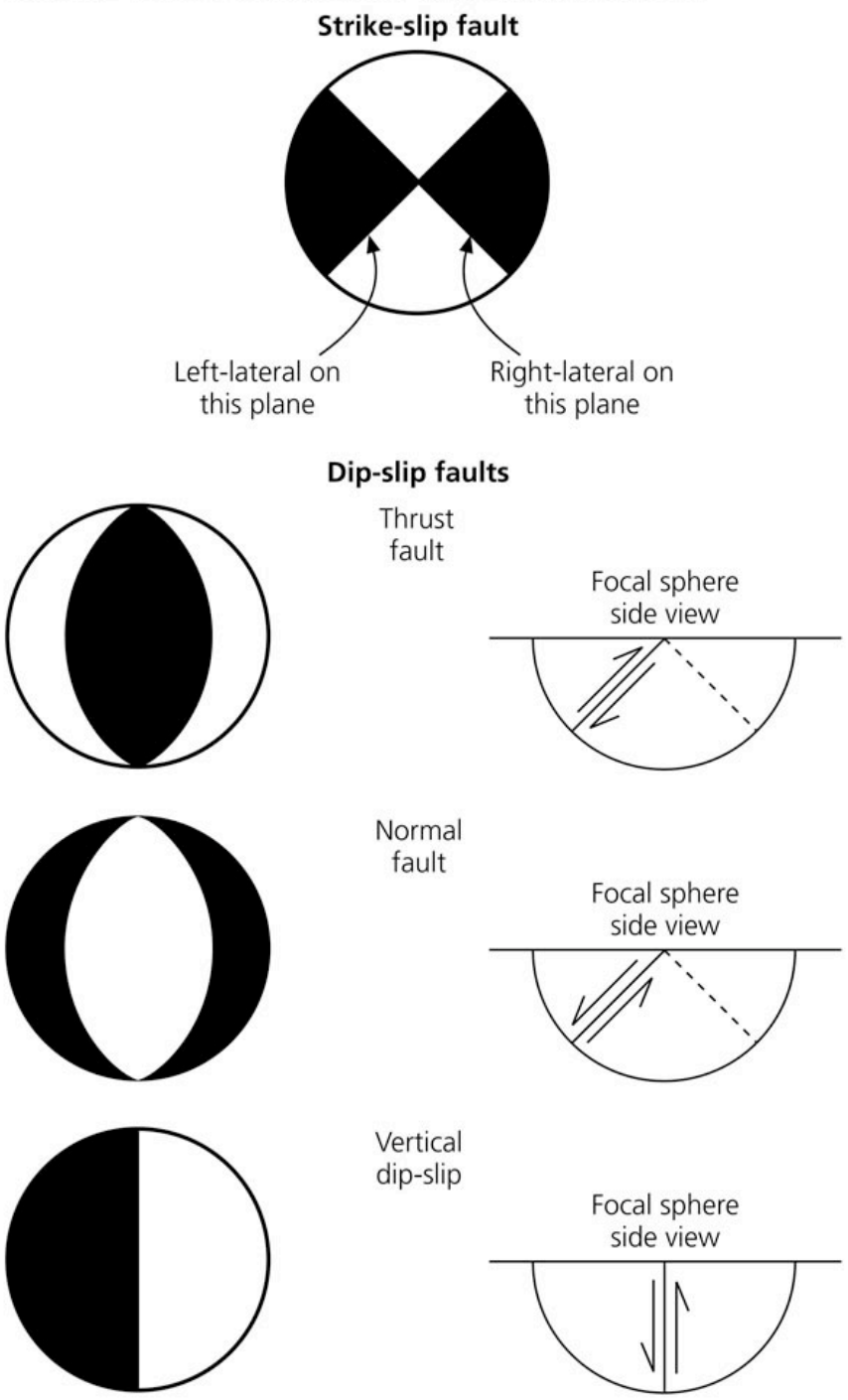
EARTHQUAKE FOCAL MECHANISMS

> compressional quadrants in black

> which way does the strike-slip fault strike?

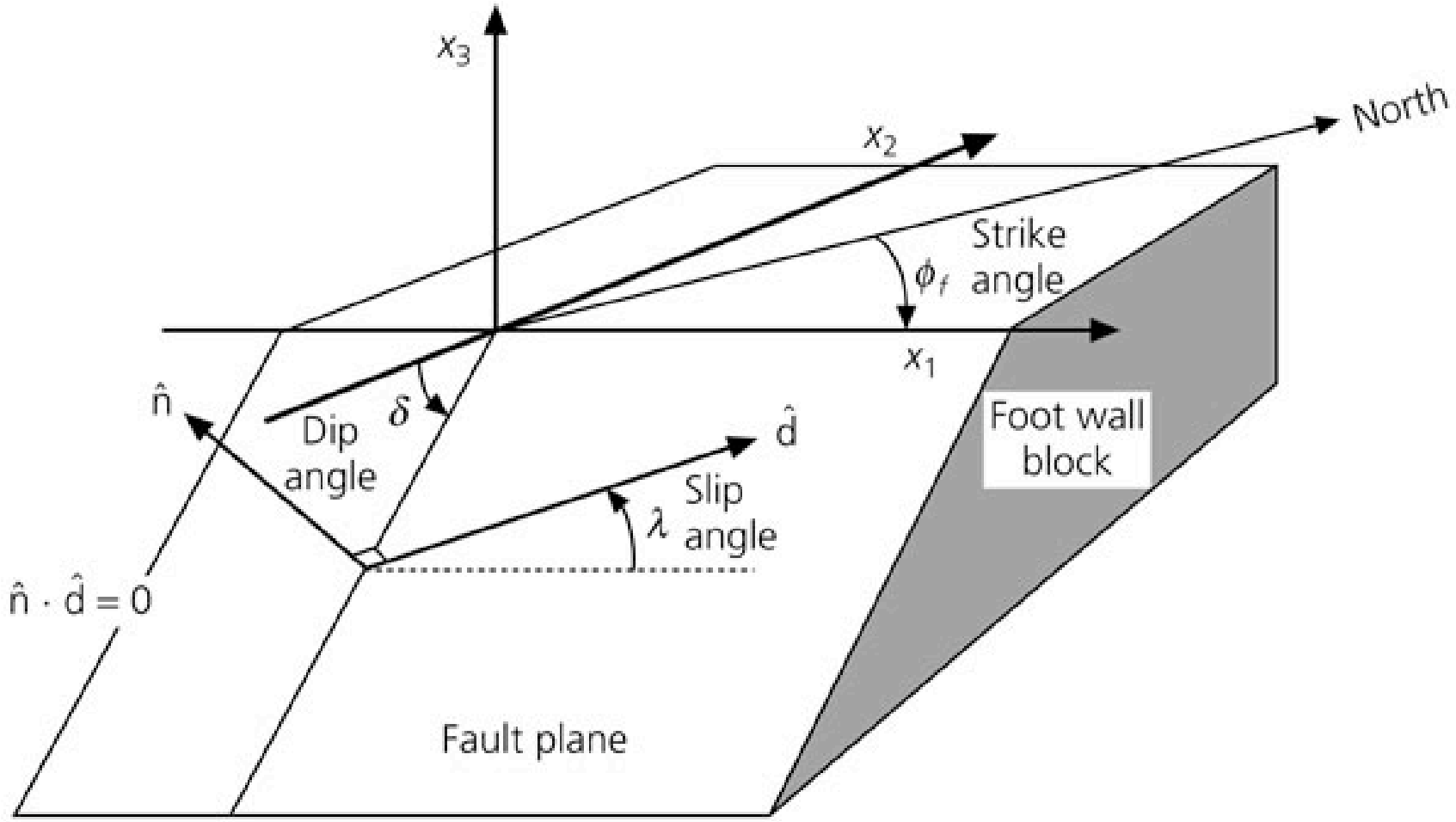
> which way do the normal and reverse faults strike?

> what do their upper hemispheres look like?



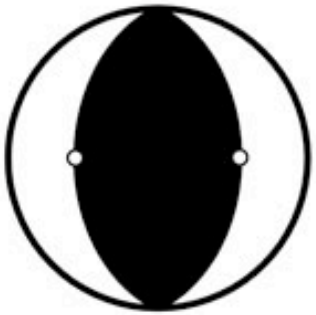
FOCAL MECHANISMS FOR DIFFERENT EARTHQUAKES ON ONE FAULT - WHAT ARE THE DIP & RAKE?

GEOMETRICAL PROPERTIES



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

FOCAL MECHANISMS FOR DIFFERENT EARTHQUAKES ON ONE FAULT - ESTIMATE THE DIP/RAKE



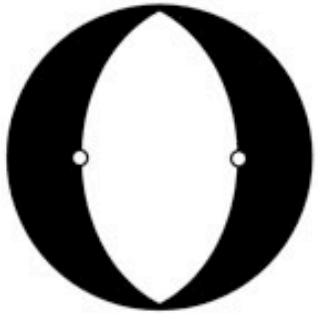
$\lambda = 90°$ Pure dip-slip (thrust)

$\lambda = 210°$ Mostly strike-slip with some dip-slip

$\lambda = 120°$ Mostly dip-slip with some strike-slip

$\lambda = 240°$ Mostly dip-slip with some strike-slip

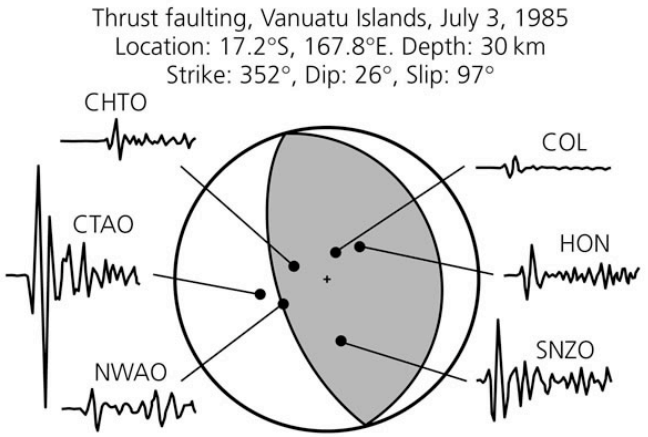
$\lambda = 150°$ Mostly strike-slip with some dip-slip



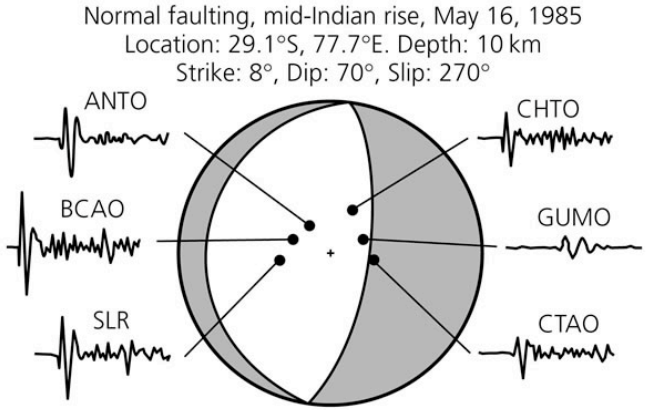
$\lambda = 270°$ Pure dip-slip (normal)

FOCAL MECHANISM EXAMPLES

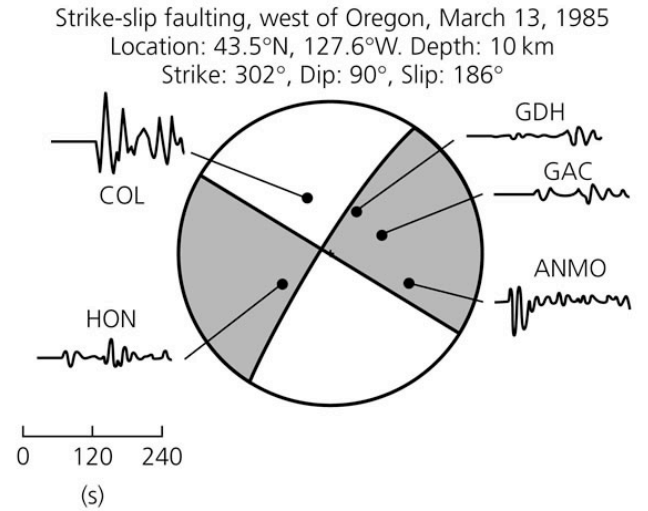
> thrust fault, Vanuatu Islands



> normal fault, mid-Indian rise



> strike-slip fault, off Oregon



EOSC 256 - April 8, 2009

> final exam: some mixture of multiple choice and short answer

> assignment due today - pay attention to information on strike and aftershock distribution

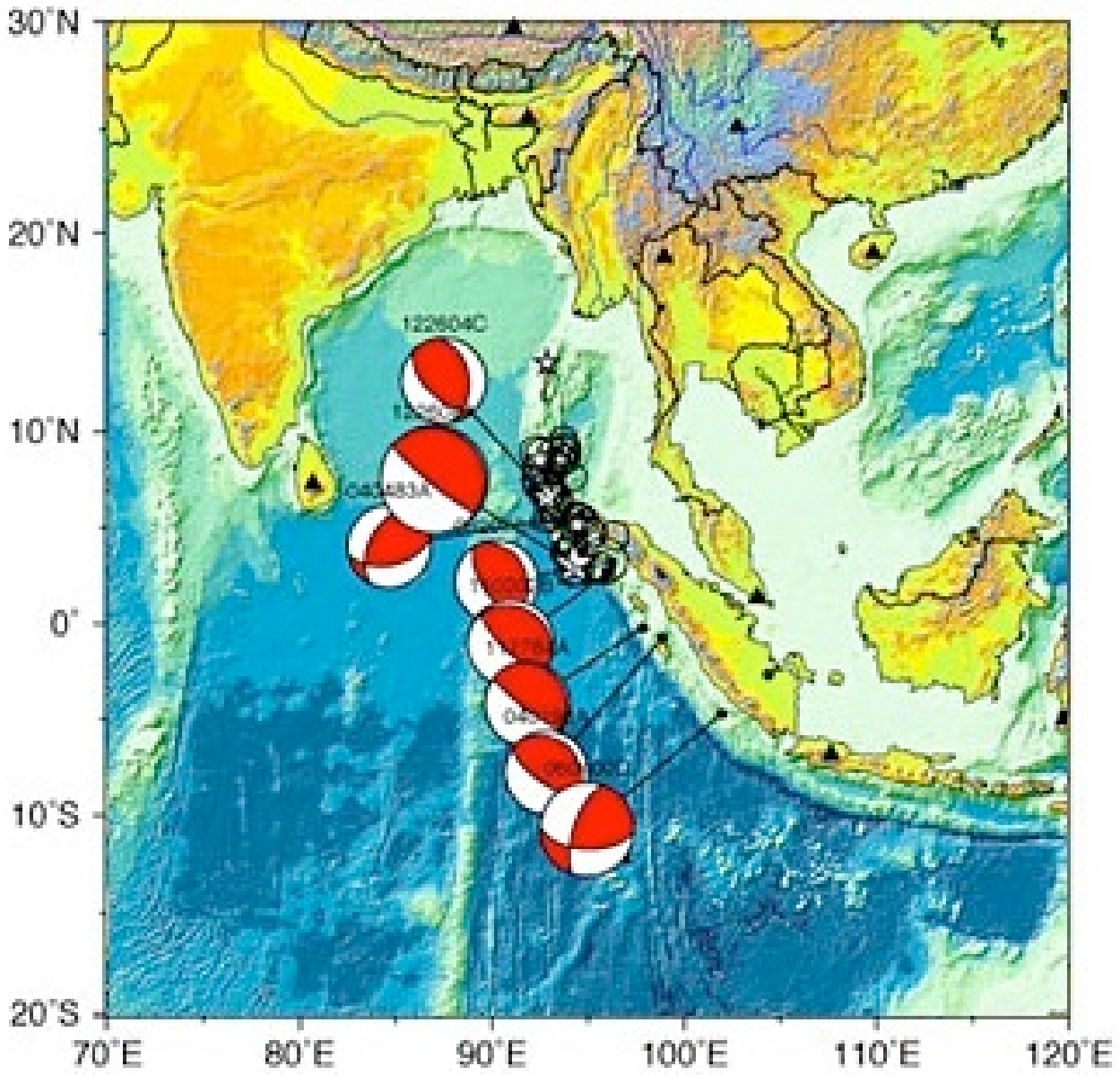
> Today:

1. focal mechanisms and P/T axes

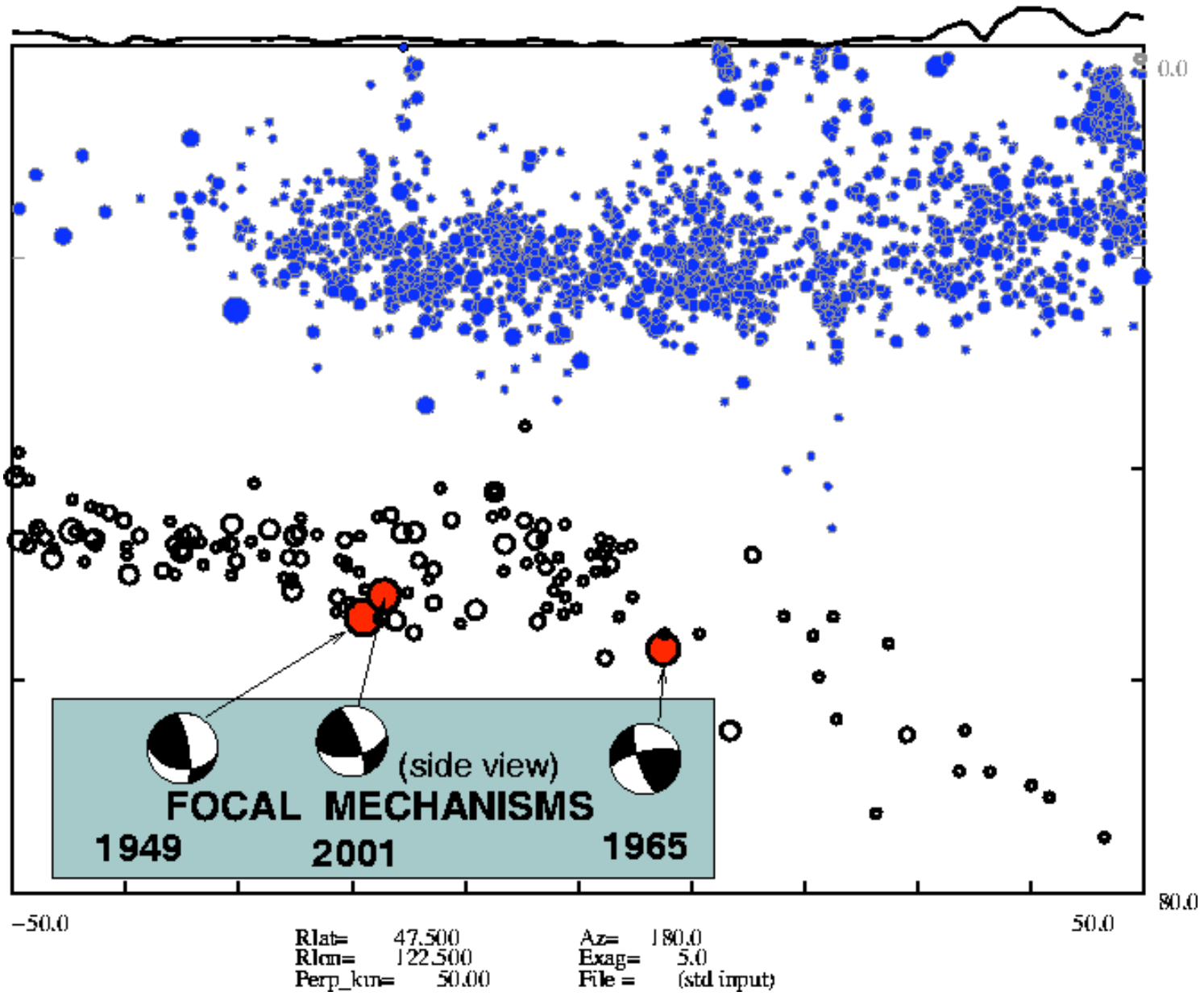
2. earthquake magnitudes

3. L' Aquila (Italy) earthquake

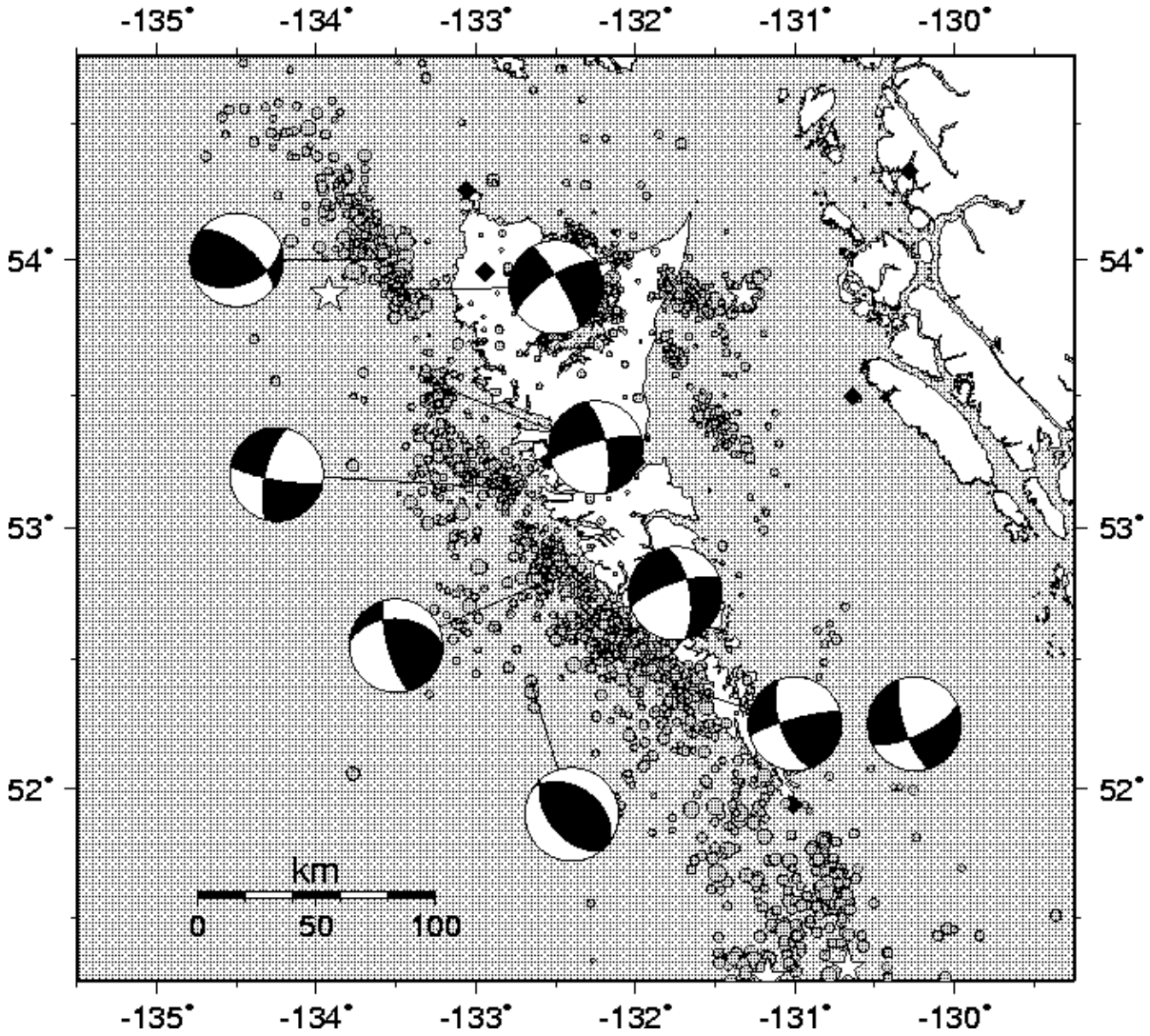
SUMATRA EARTHQUAKE



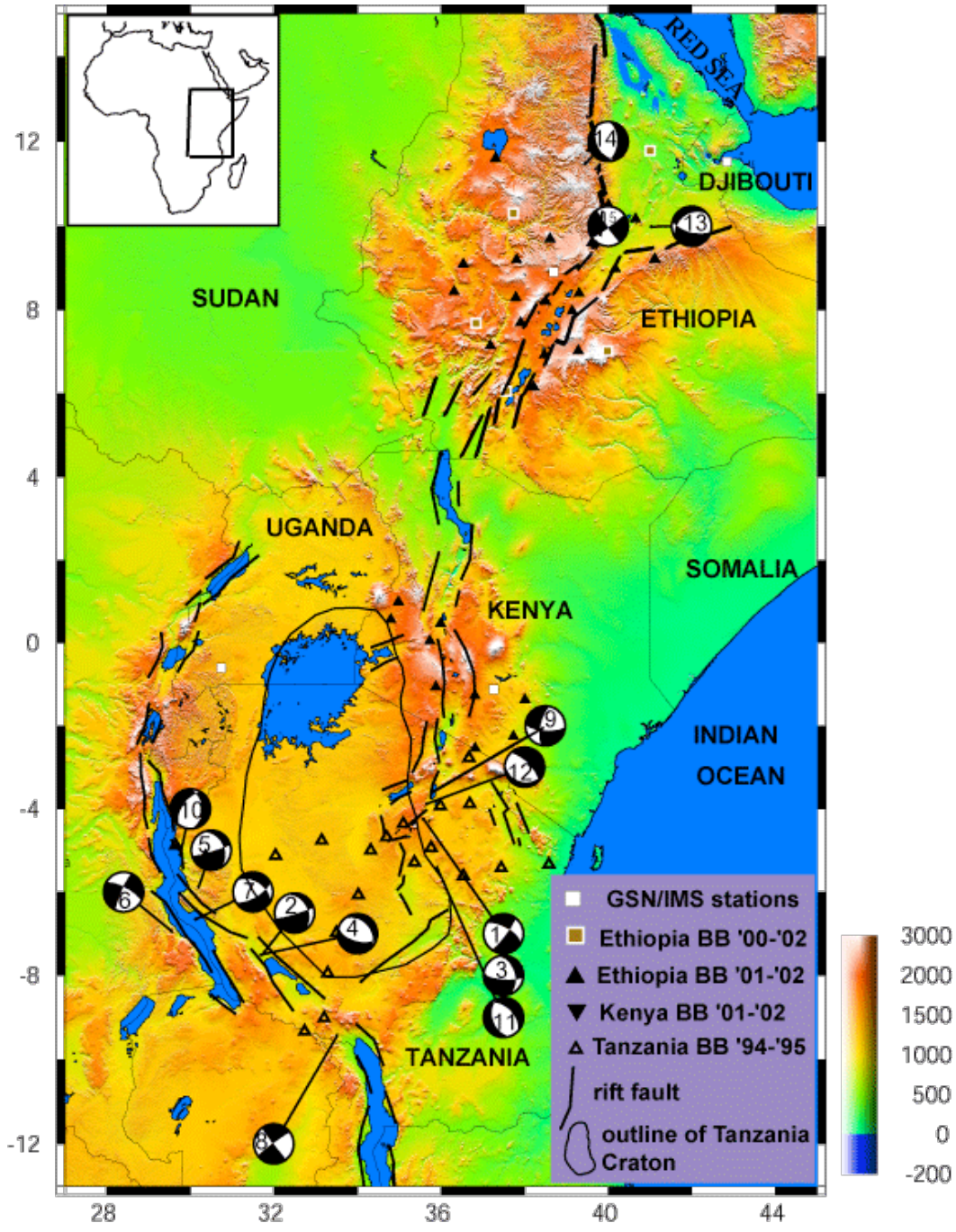
CASCADIA ``SIDE-HEMISPHERES''



QUEEN CHARLOTTE FAULT



AFRICAN RIFT VALLEY MECHANISMS



ROCK UNDER COMPRESSION

> consider rock under compression with principal stresses

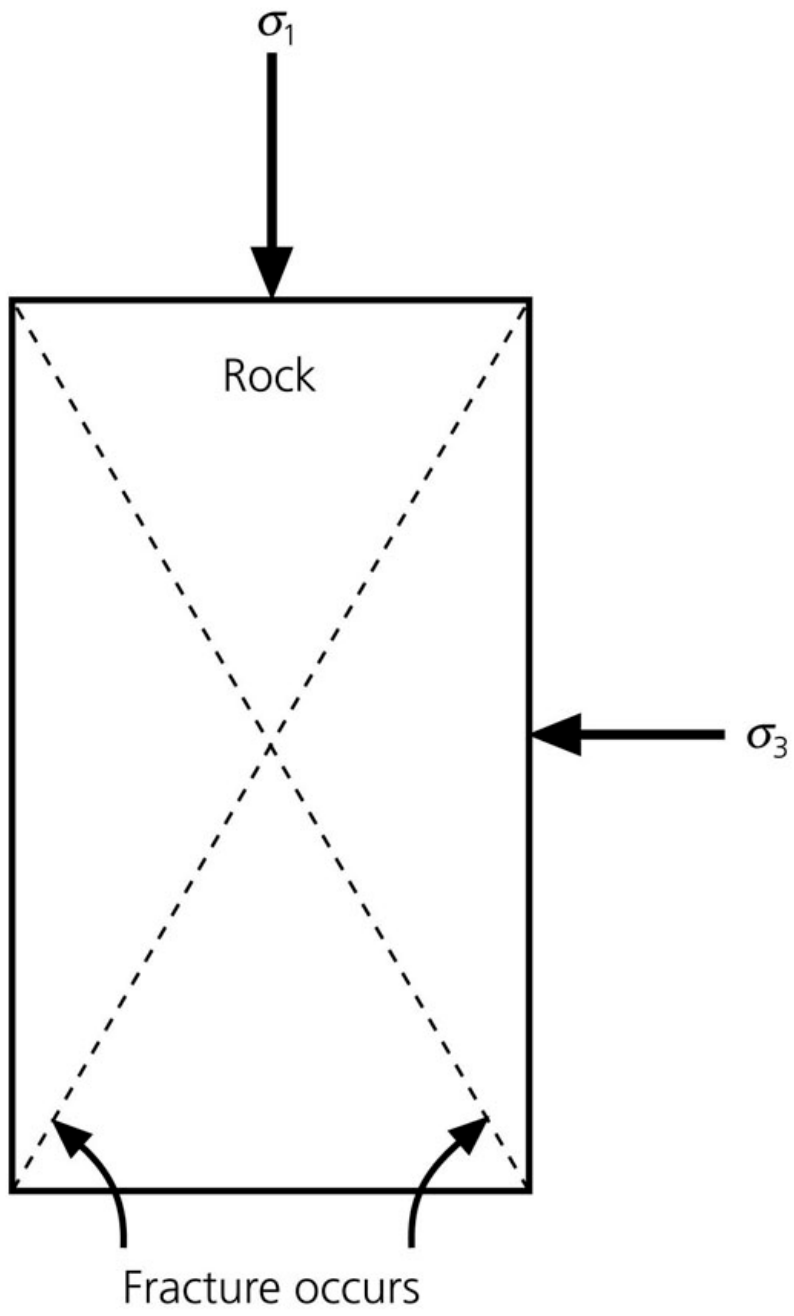
$$|\sigma_1| \geq |\sigma_2| \geq |\sigma_3|$$

$$\sigma_1, \sigma_2, \sigma_3 \leq 0$$

> maximum principal stress σ_1 in direction of "pressure axis", minimum principal stress σ_3 in direction of "tension axis"

> rock will fracture on planes of maximum shear stress (dashed lines) near 45 degrees from principal stresses

> either plane is likely to fracture



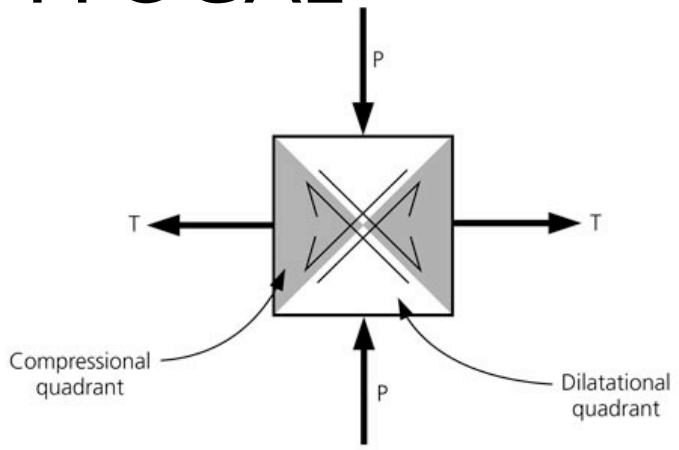
STRESS ORIENTATION FROM FOCAL MECHANISMS

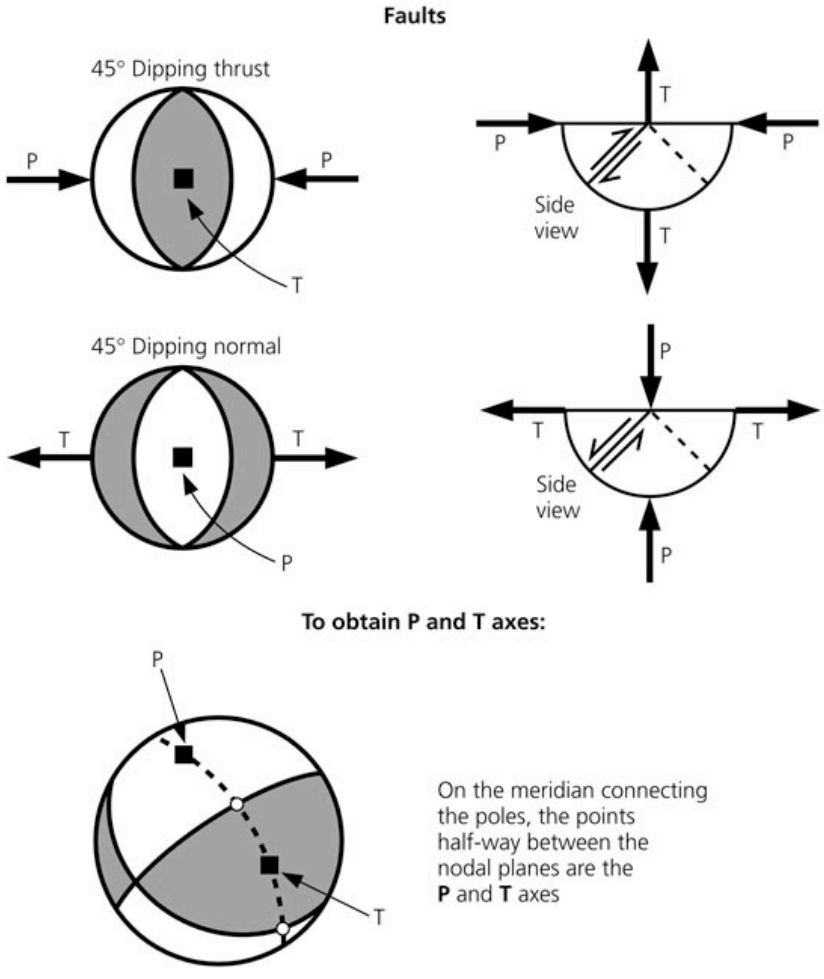
> define P and T axes as directions of maximum and minimum principal stress

> where do these axes lie on focal mechanisms?

> bisect the dilatational and compressional quadrants

> on stereonet, find poles to fault/auxilary planes, find meridian, plot P/T axes 1/2 way between poles





FOCAL MECHANISMS FROM ``UNUSUAL'' EARTHQUAKES