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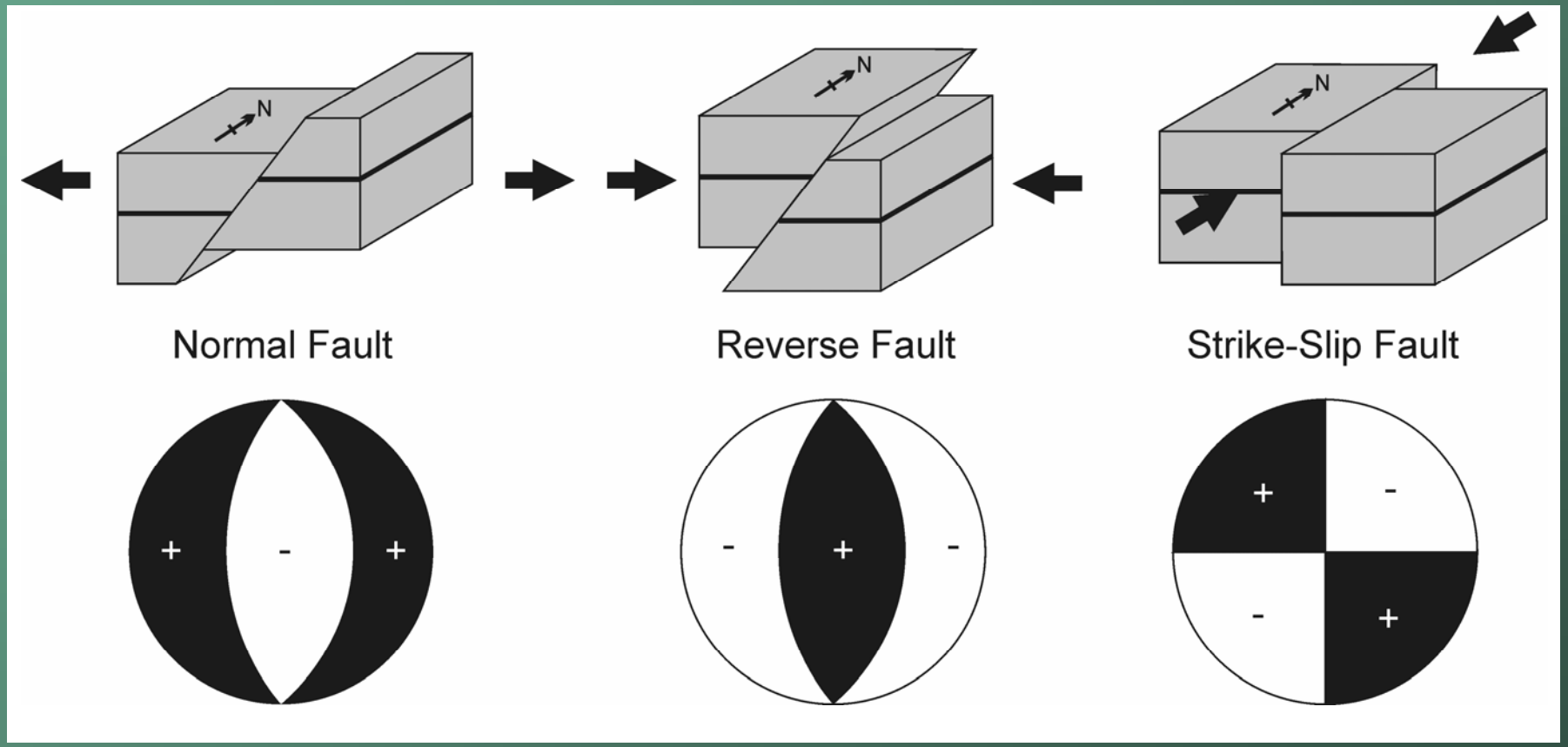
Earthquake Focal Mechanisms

U.S. Department of the Interior
U.S. Geological Survey

Focal Mechanism Solutions

- Also called “beachball diagrams” “fault plane solutions”
- Tell us the geometry and mechanism of the fault in a simple diagram
- Generally reconstructed from waveform data derived from the moment tensor (which is more general), but originally calculated using first motions – done here to illustrate the concepts

Examples



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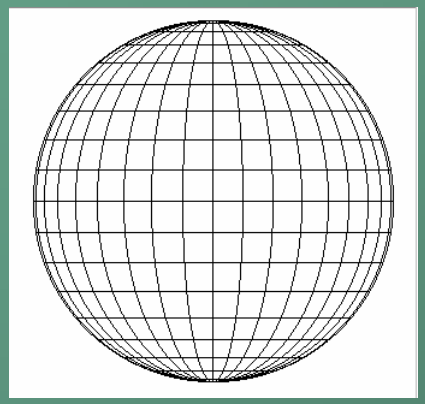
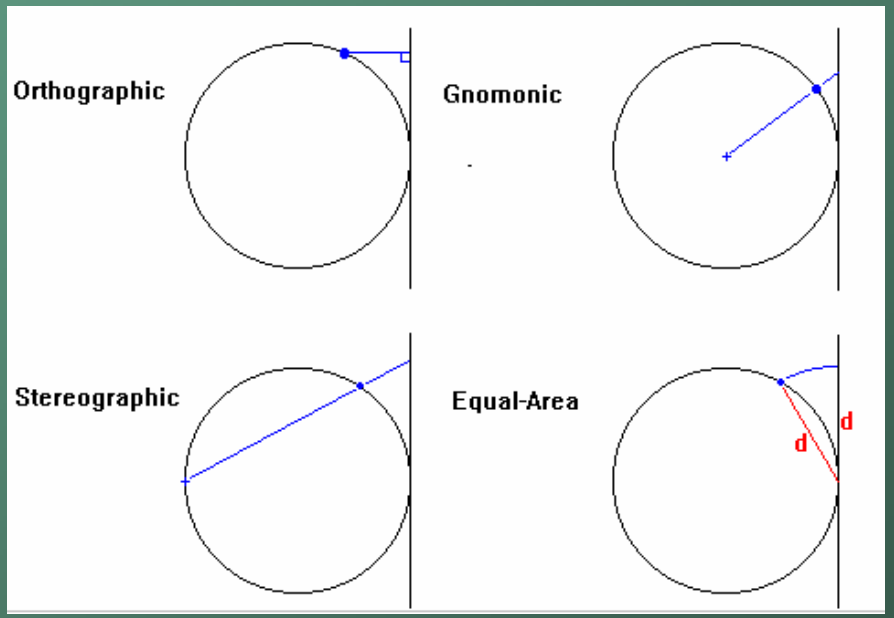
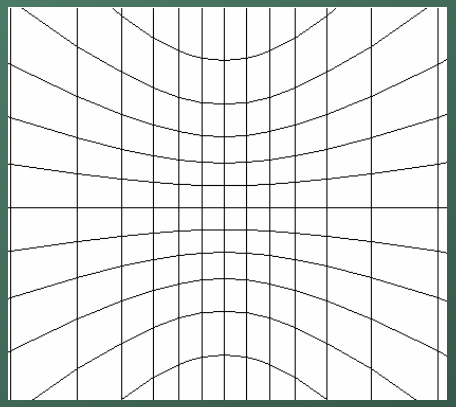
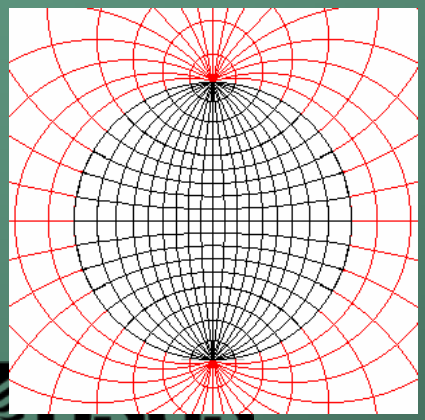
Two steps to understanding

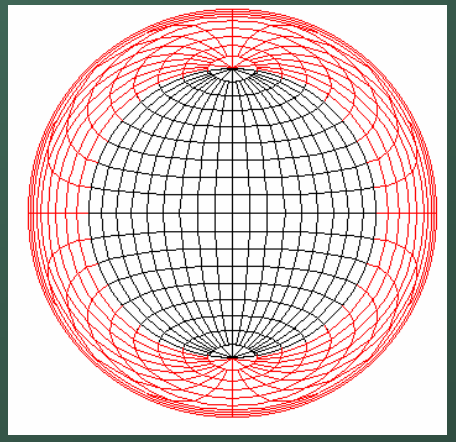
1) The stereographic projection
2) The geometry of first motions and how this is used to define fault motion.







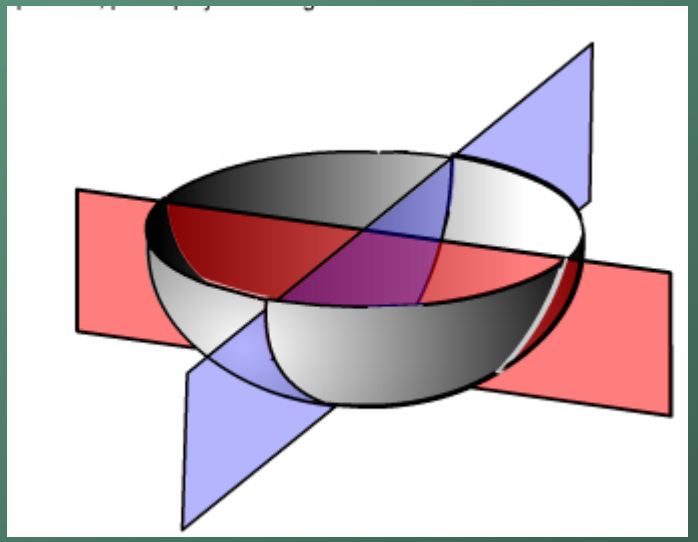


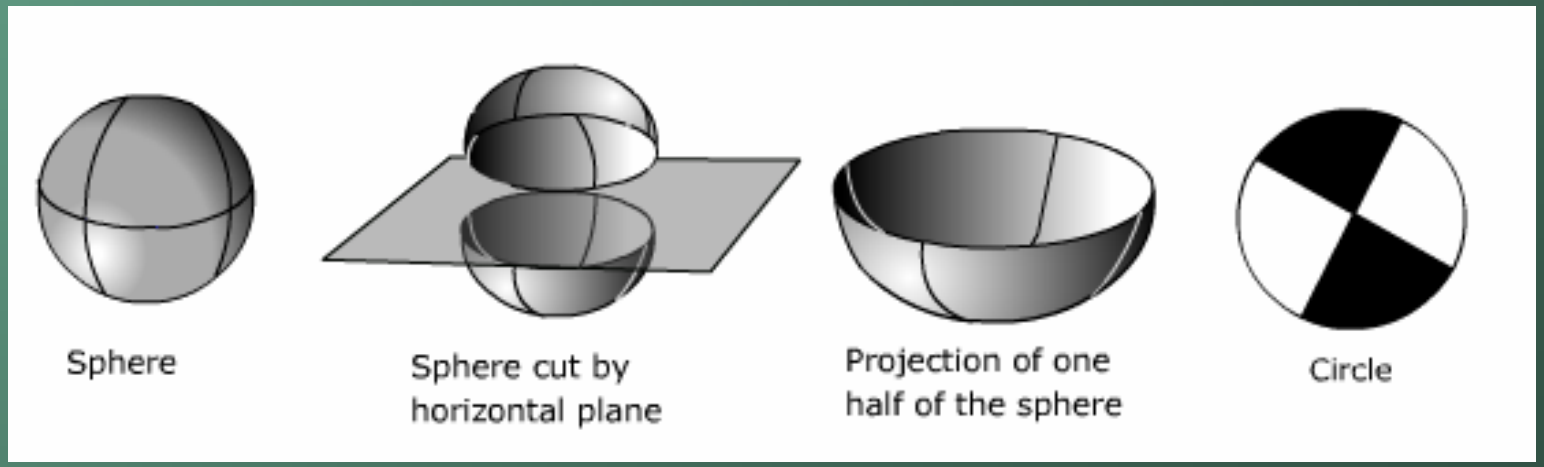


http://www.uwsp.edu/geo/projects/geoweb/participants/dutch/STRUCTGE/sphproj.htm

Stereographic projection

- A method of projecting half a sphere onto a circle.
- e.g. planes cutting vertically through the sphere plot as straight lines





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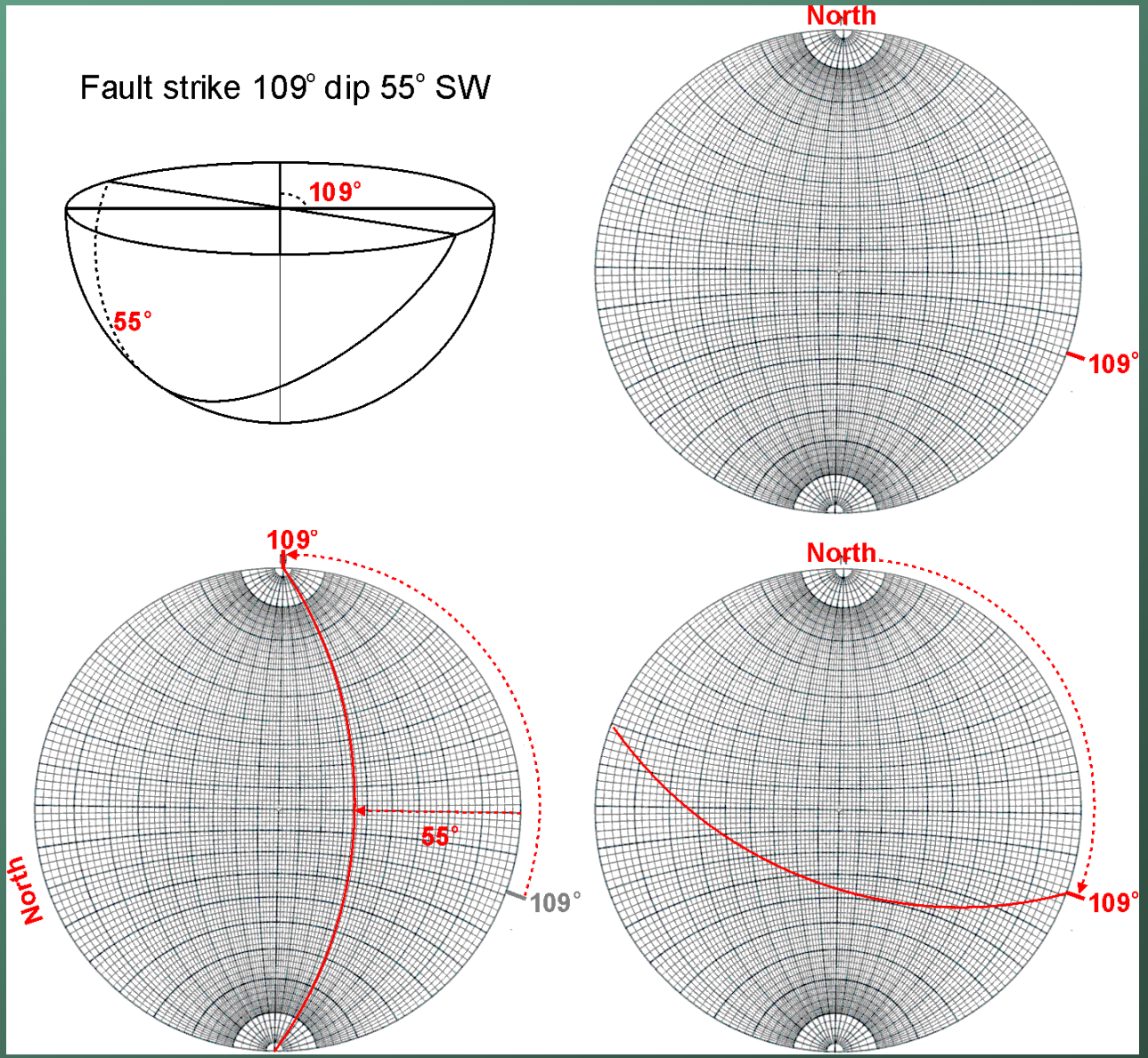
Images from http://www.learninggeoscience.net/free/00071/index.html

Stereonets

- A template called a stereonet is used to plot data.
- Example – plotting planes (e.g. faults)



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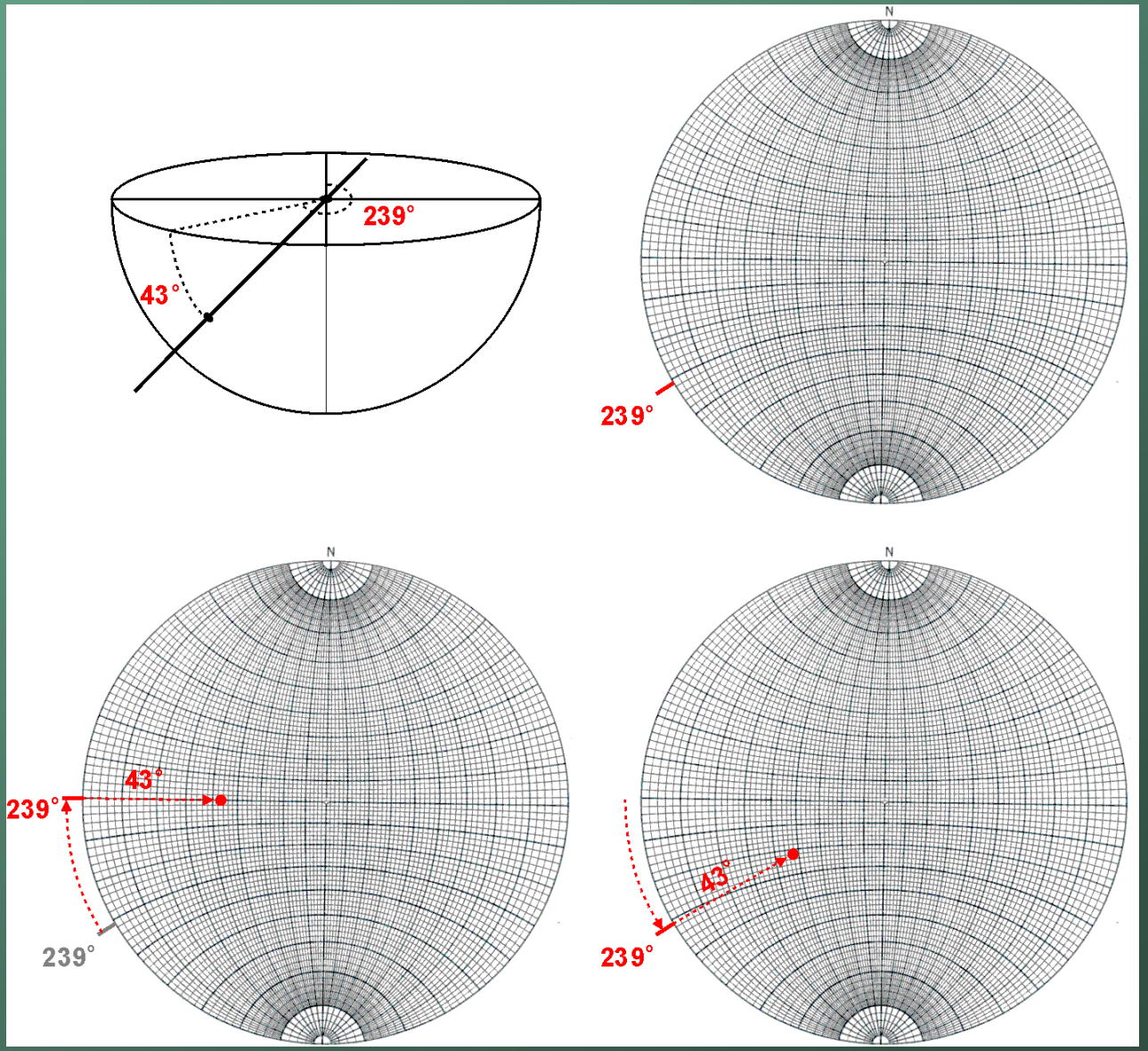
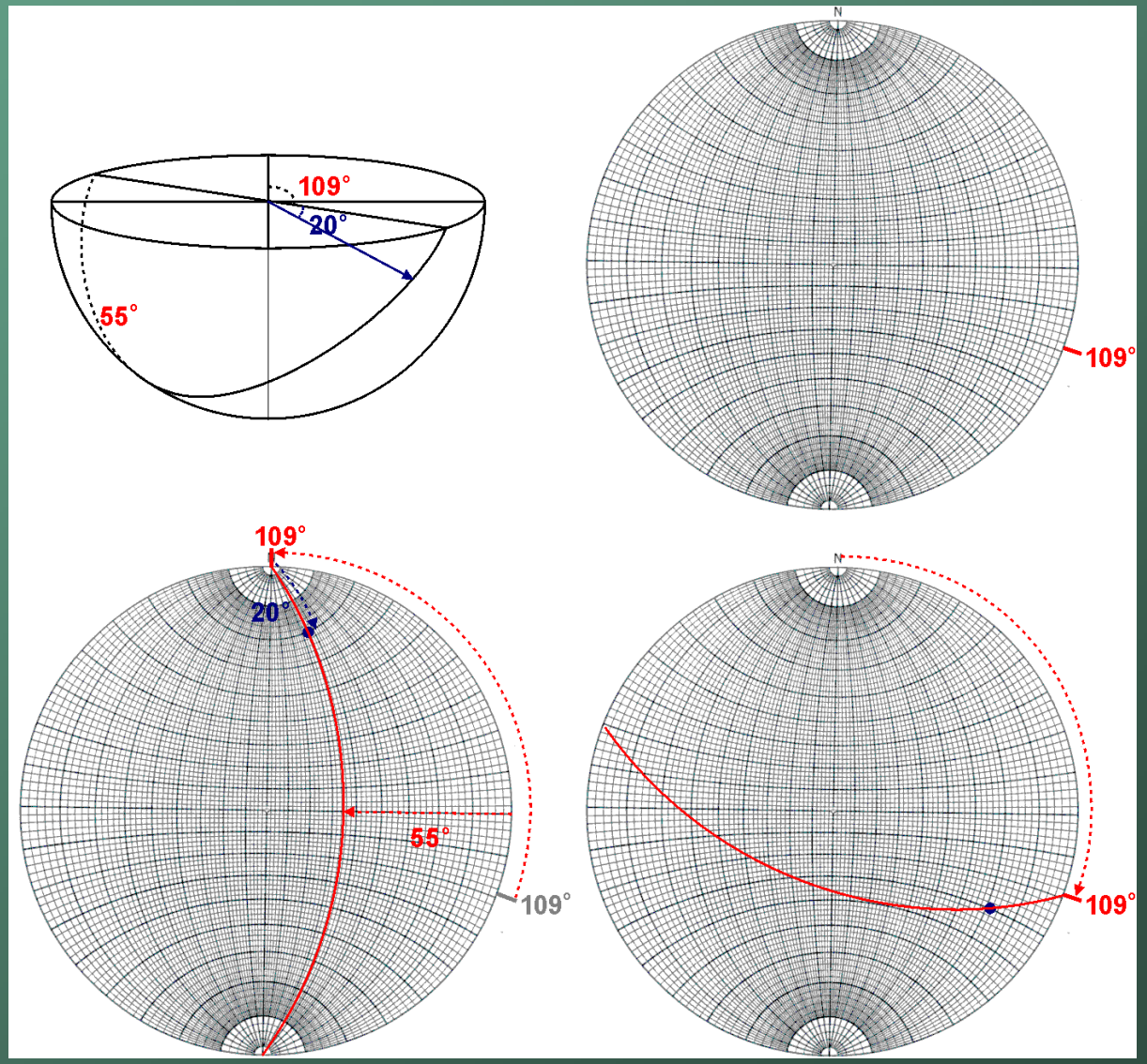
Stereonets

- Example – plotting lines (e.g. ray paths)

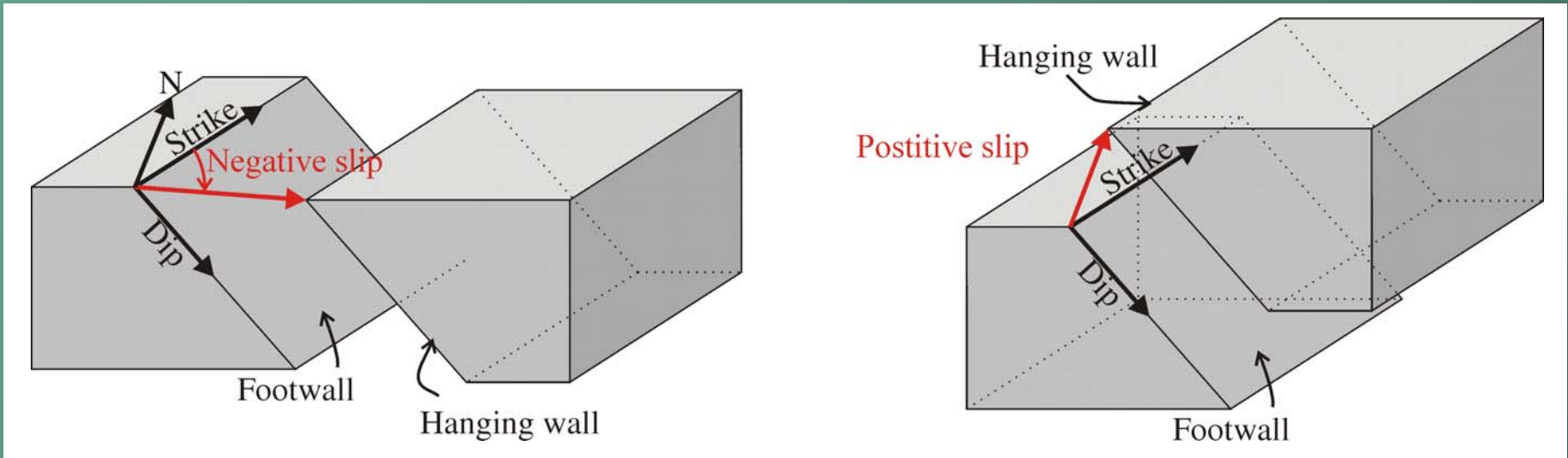


Stereonets

- Example – pitch (or rake) of a line on a plane (e.g. the slip direction on a fault)



Refresher on terminology



- Slip angle is measured from horizontal (positive for thrusts)

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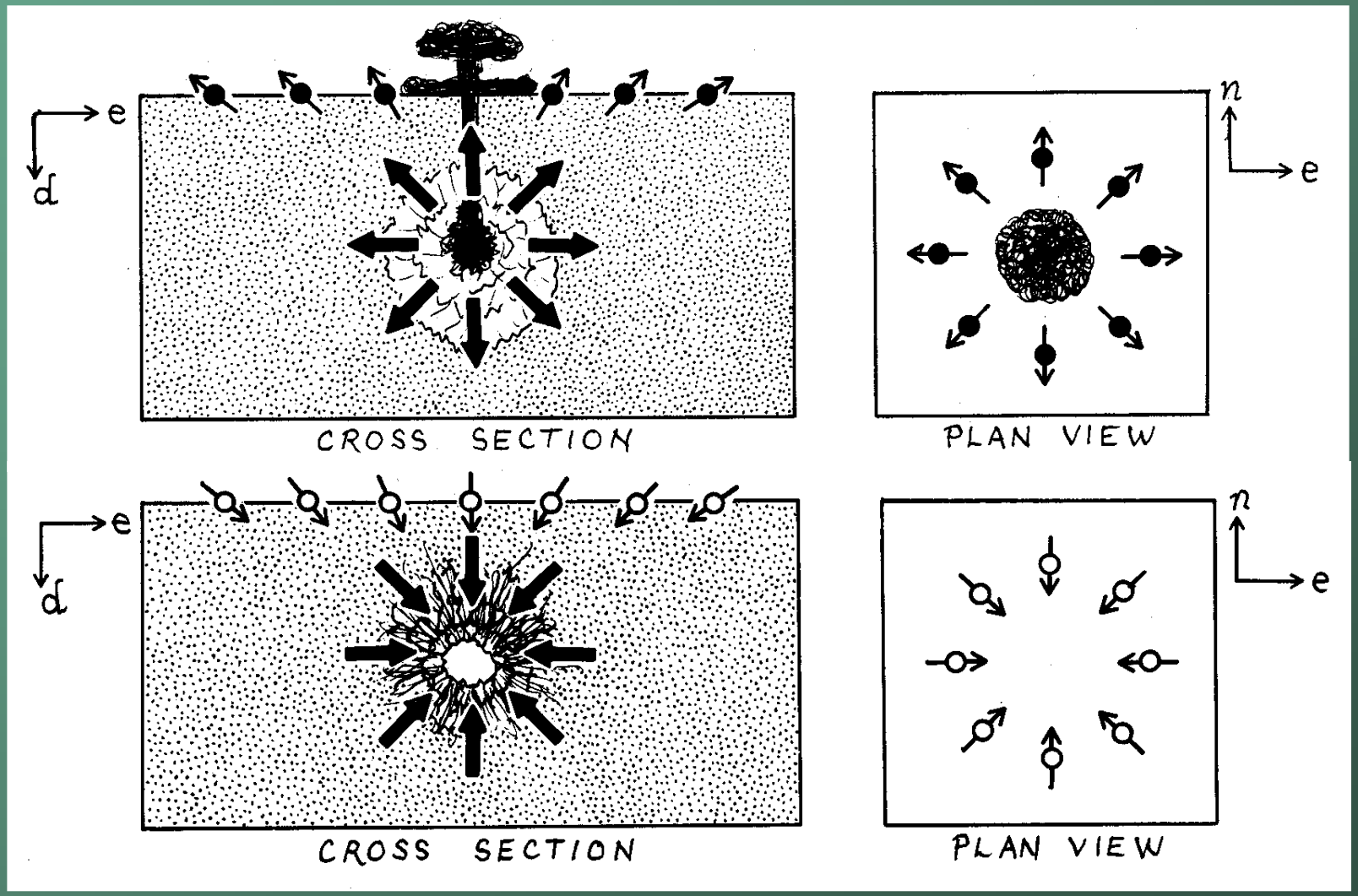
Energy and Polarity of “First Motions”



Cox and Hart. Plate Tectonics – How it works.

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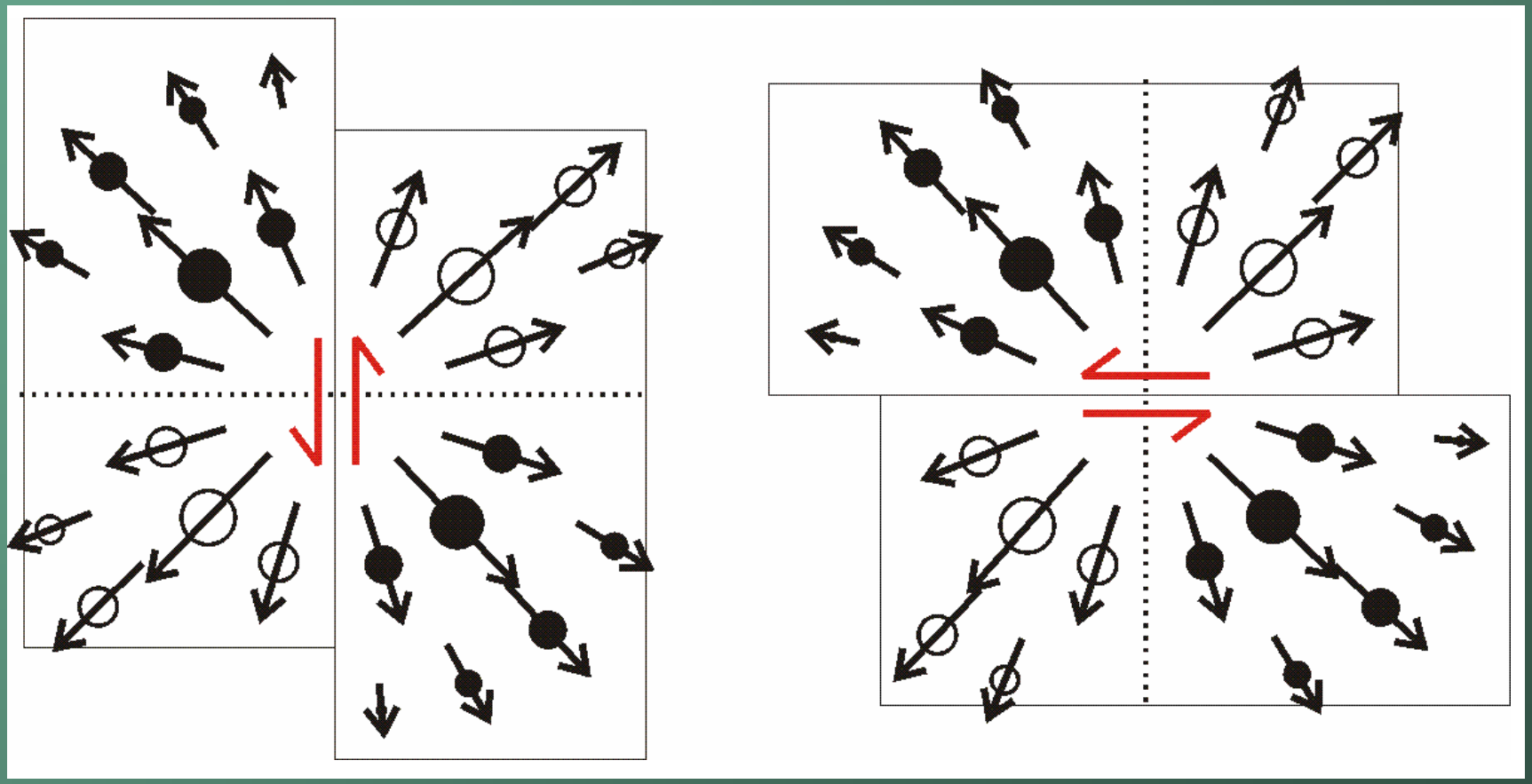
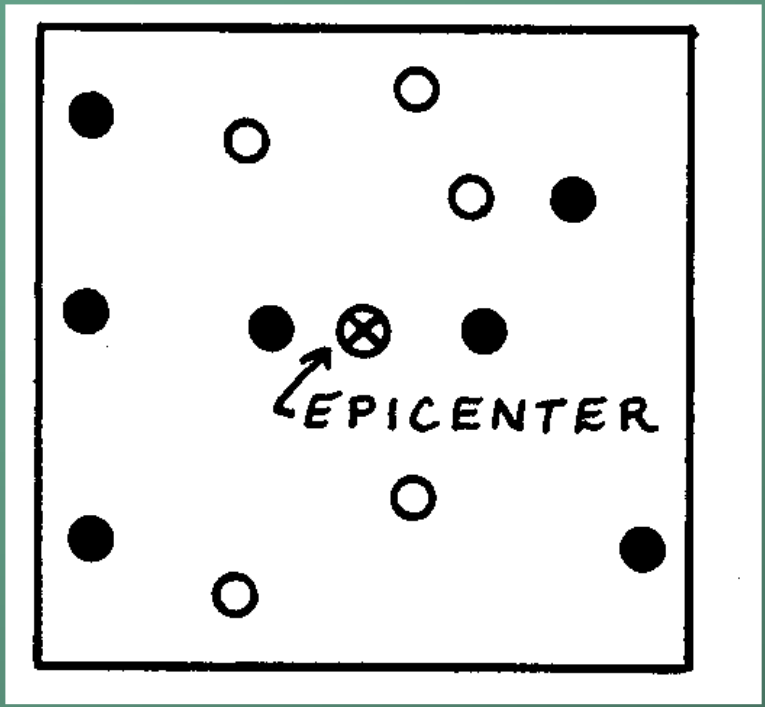
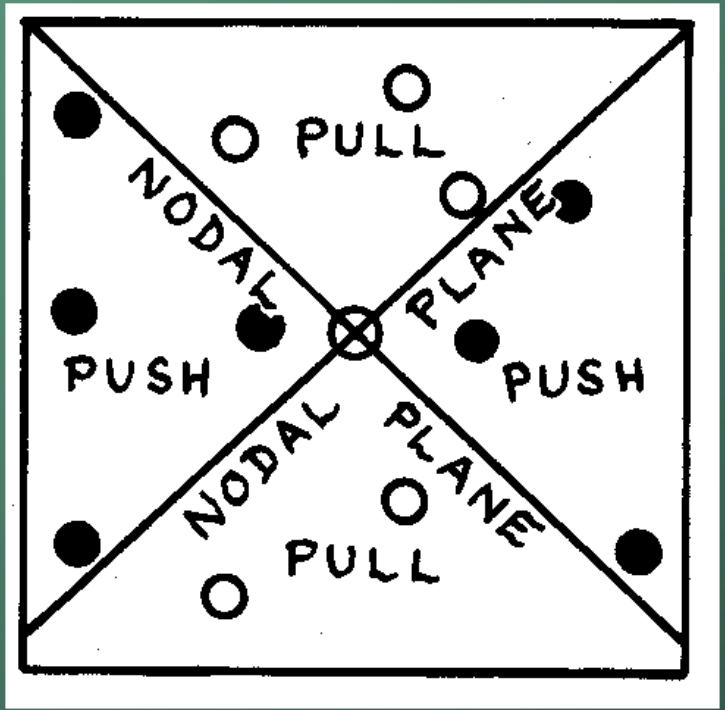
Earthquake on a vertical plane



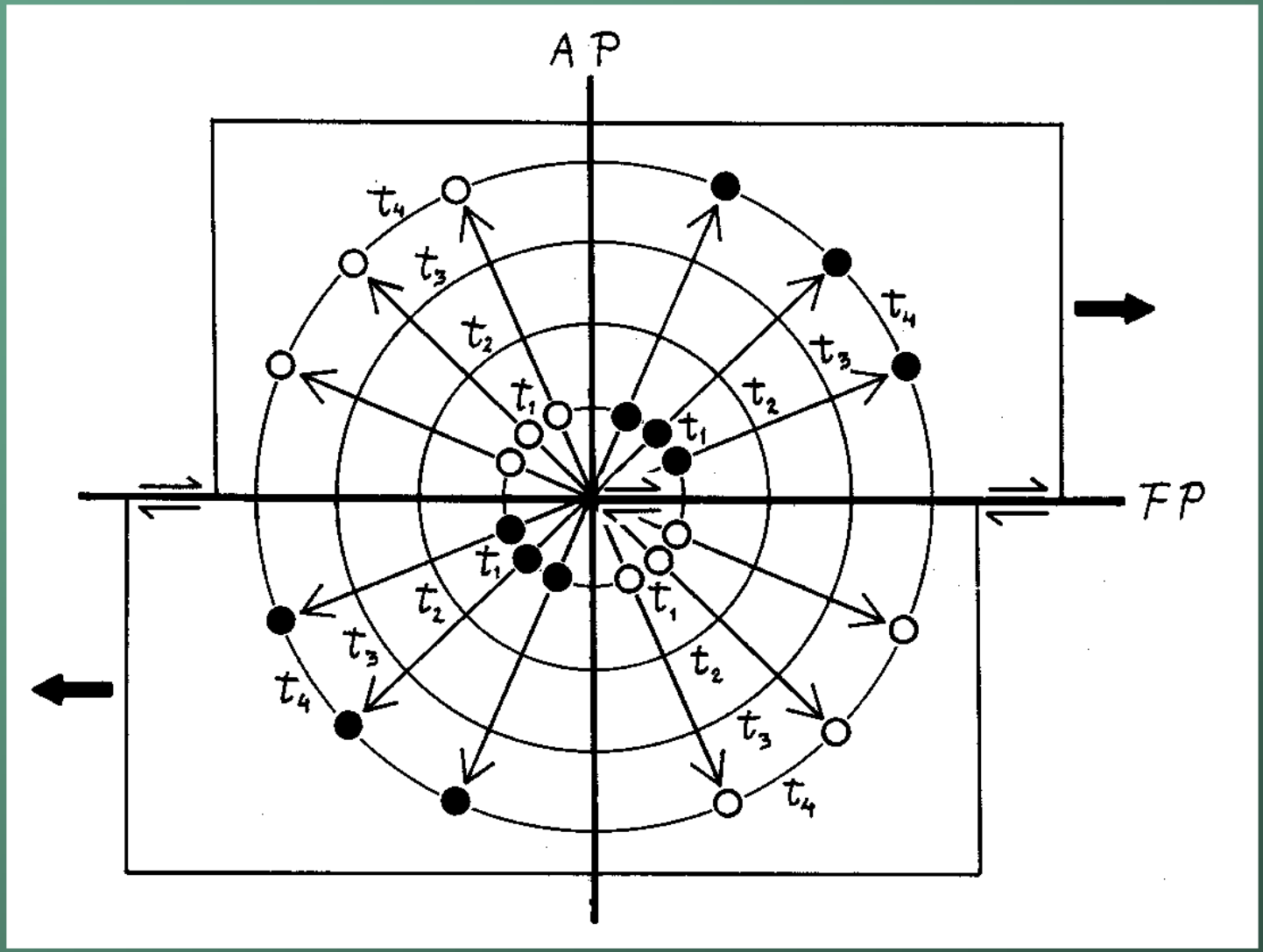
Edited from Cox and Hart. Plate Tectonics – How it works.

Determination of nodal planes





Spreading of the seismic wave



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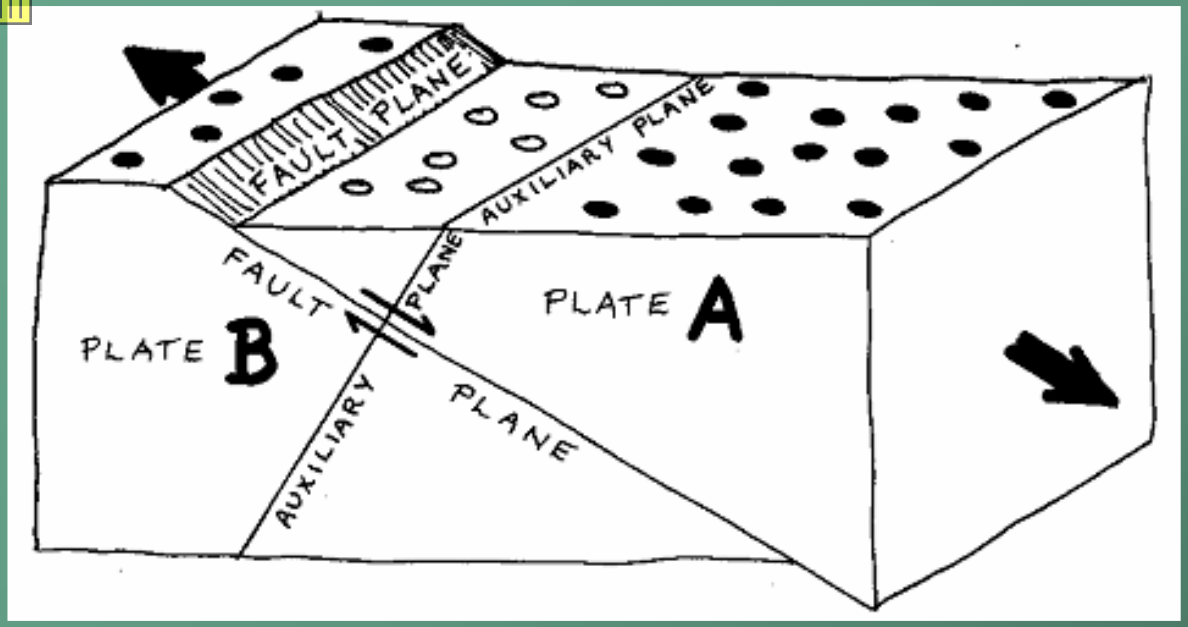
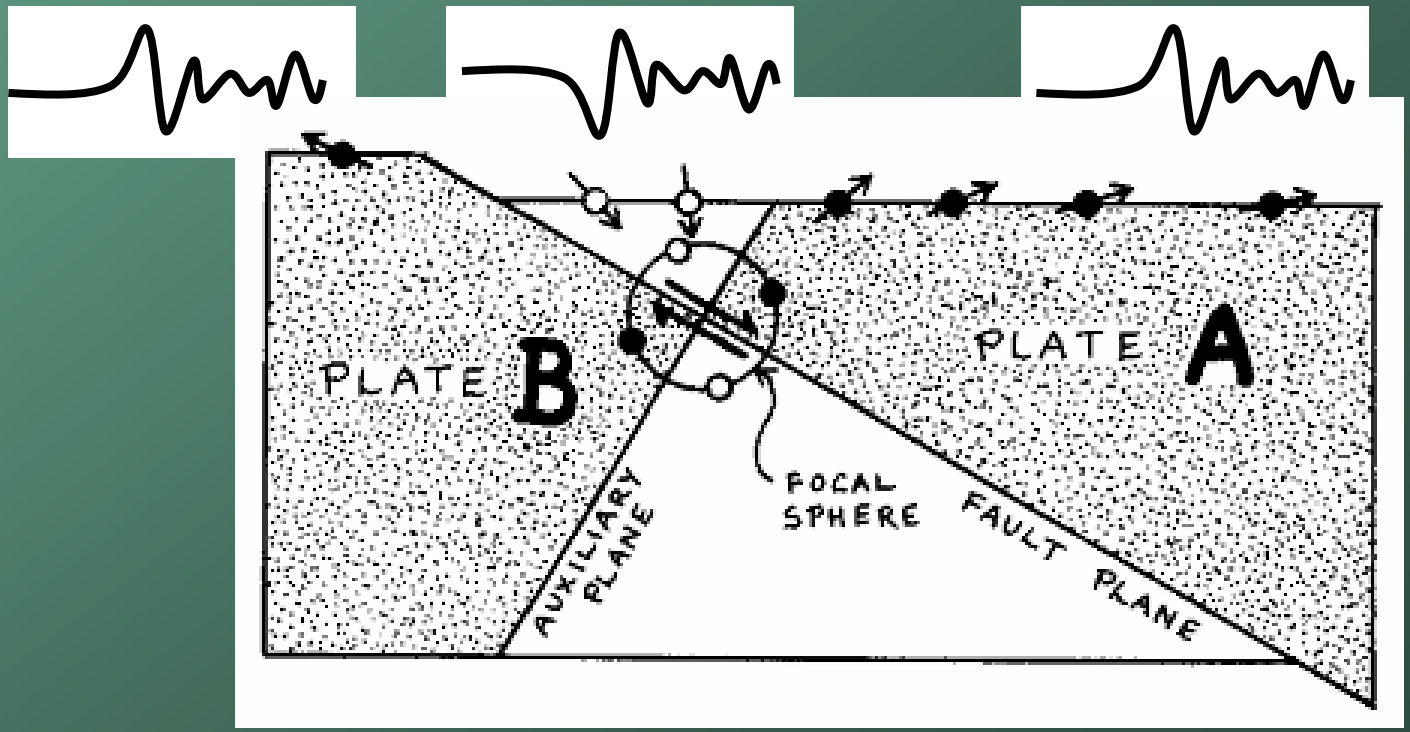


Data on the surface, interpreted in 3D



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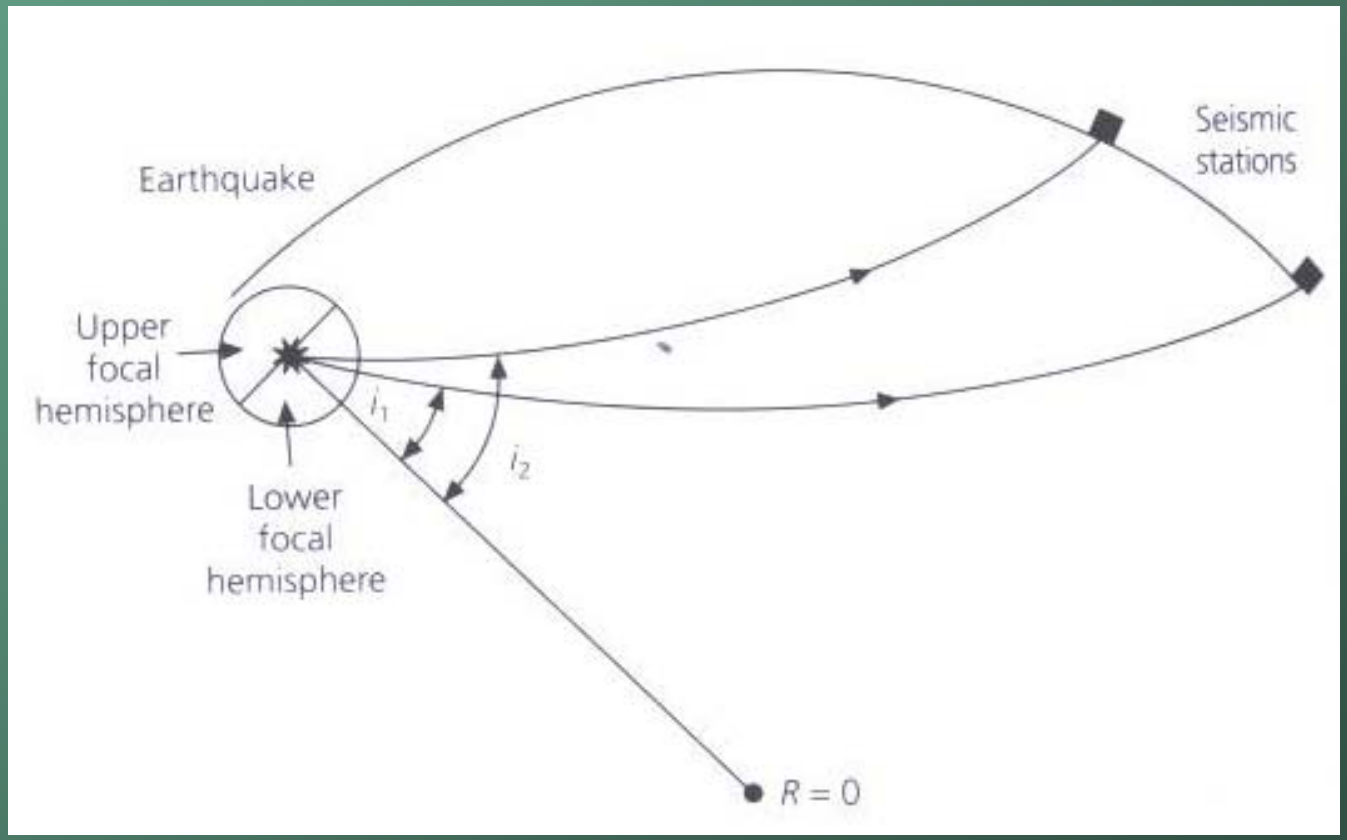
Take-off angle

- The angle (from vertical) that the ray leaves the earthquake = take-off angle



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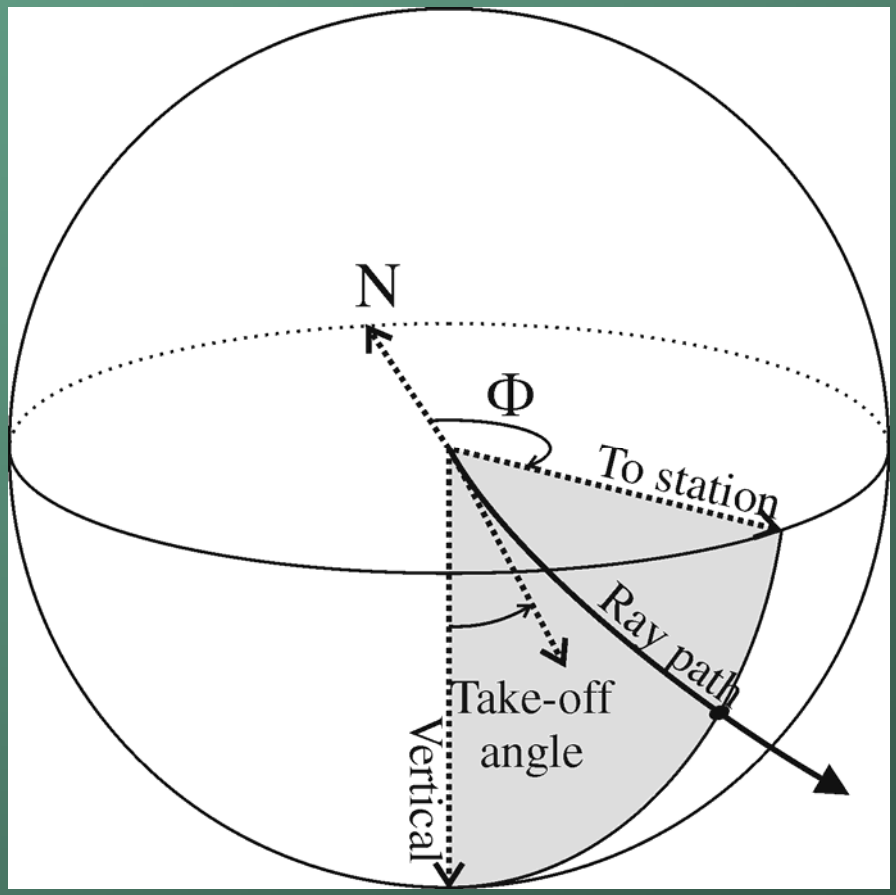
Azimuth (ϕ) and take-off angle



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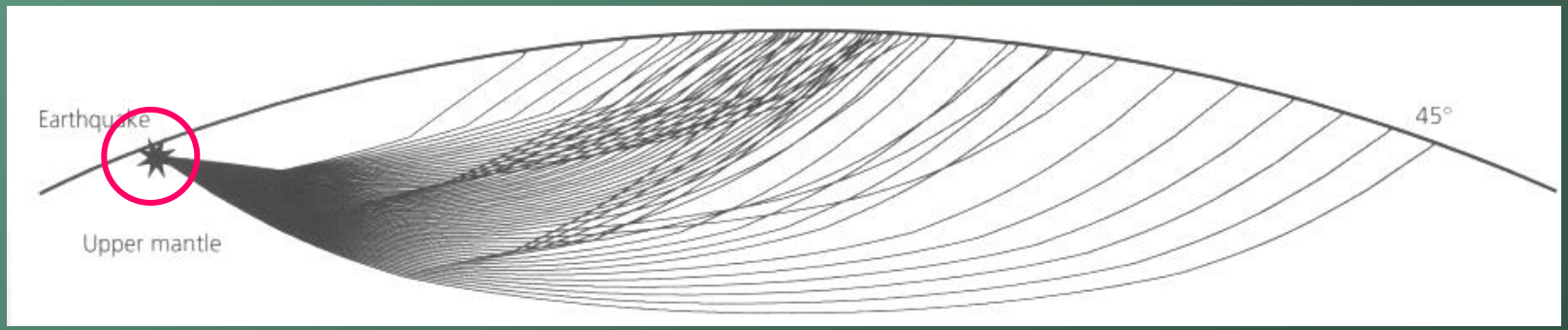

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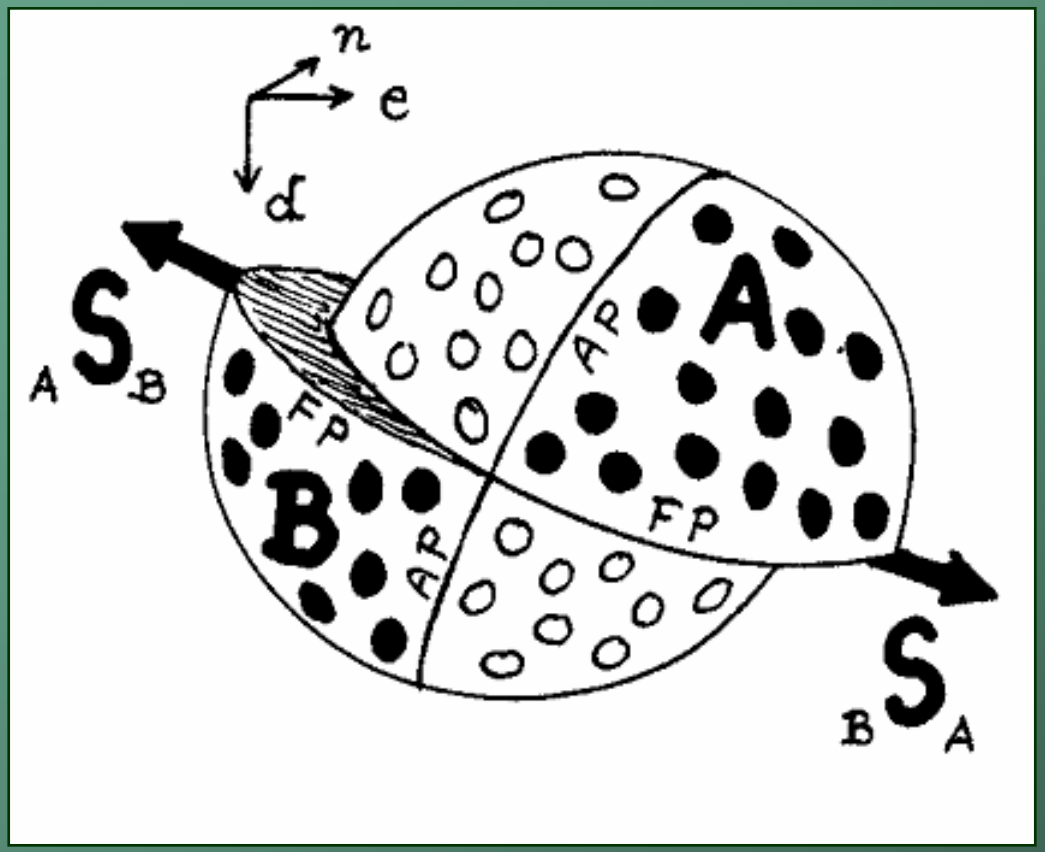
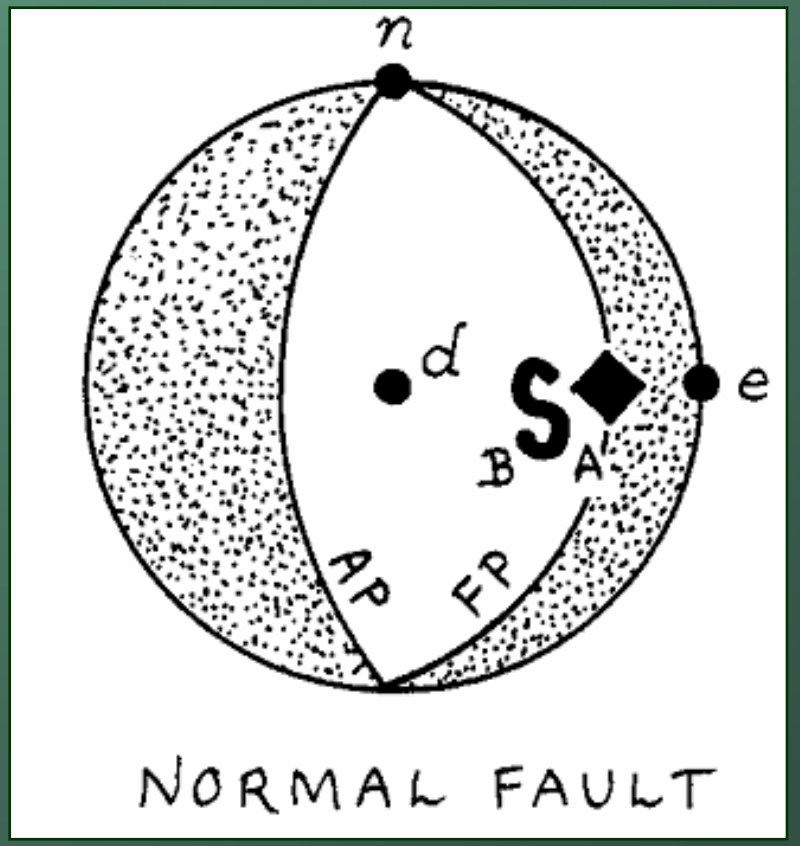
With a lot of recordings we can reconstruct faults with any orientations





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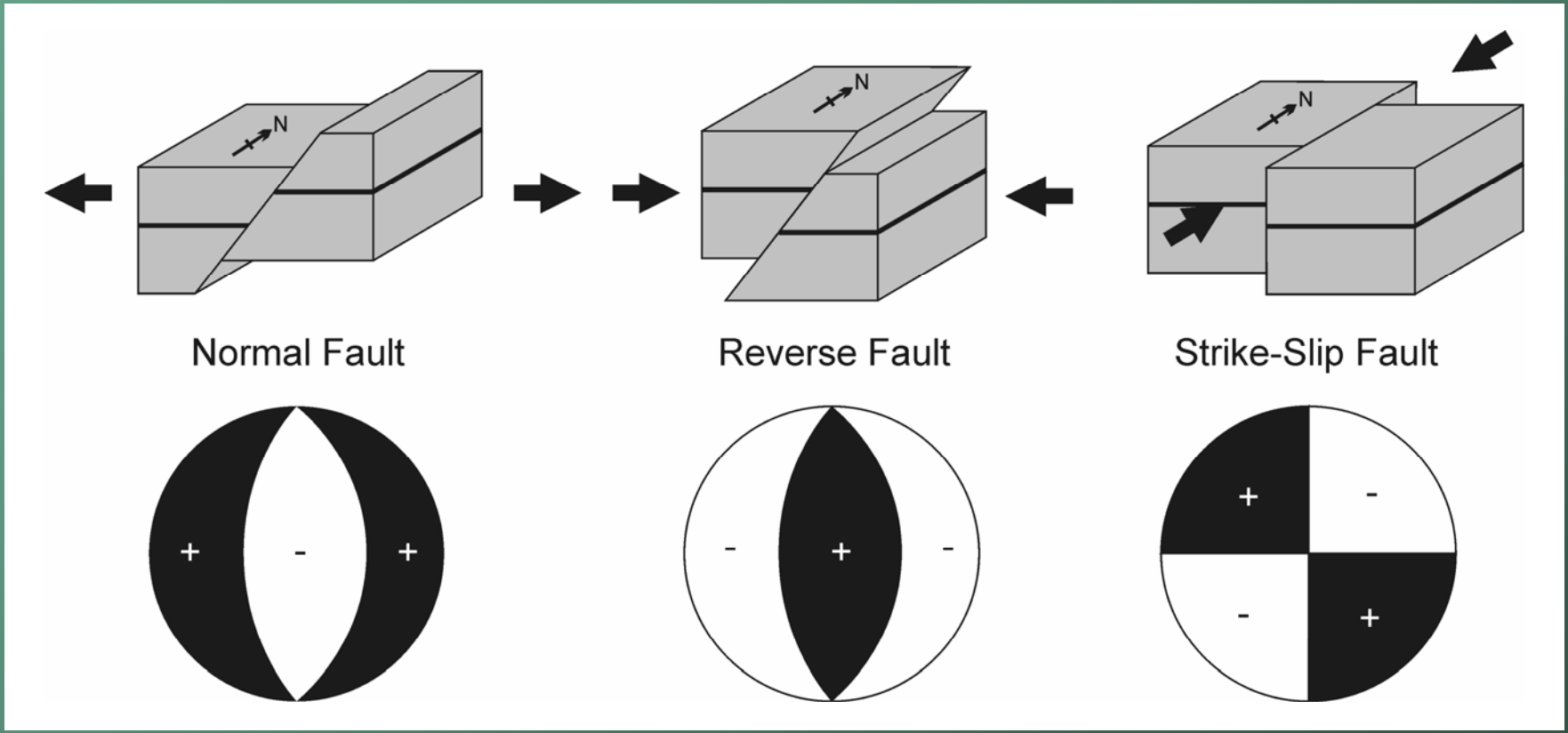
Fault types and “Beach Ball” plots



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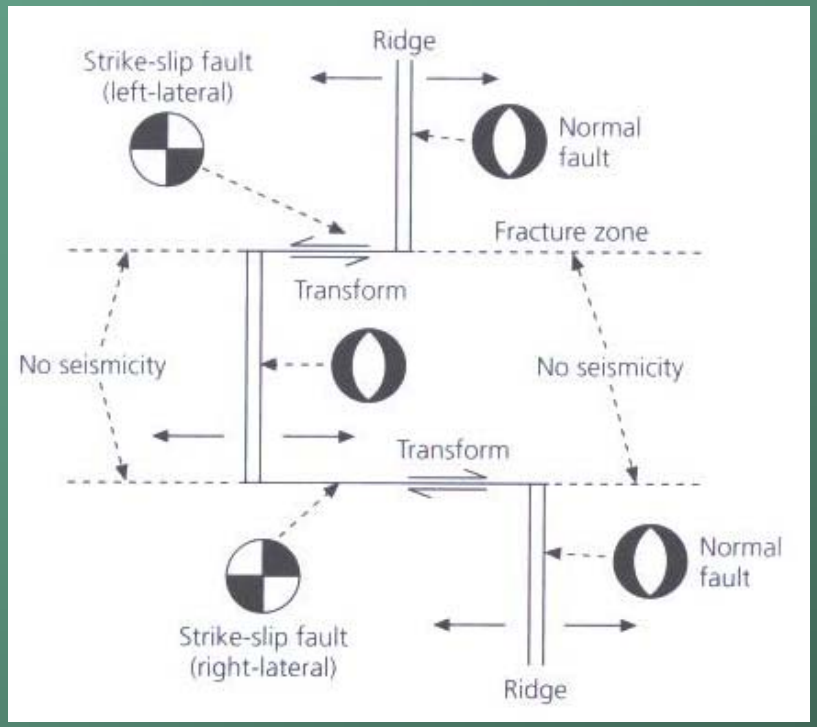
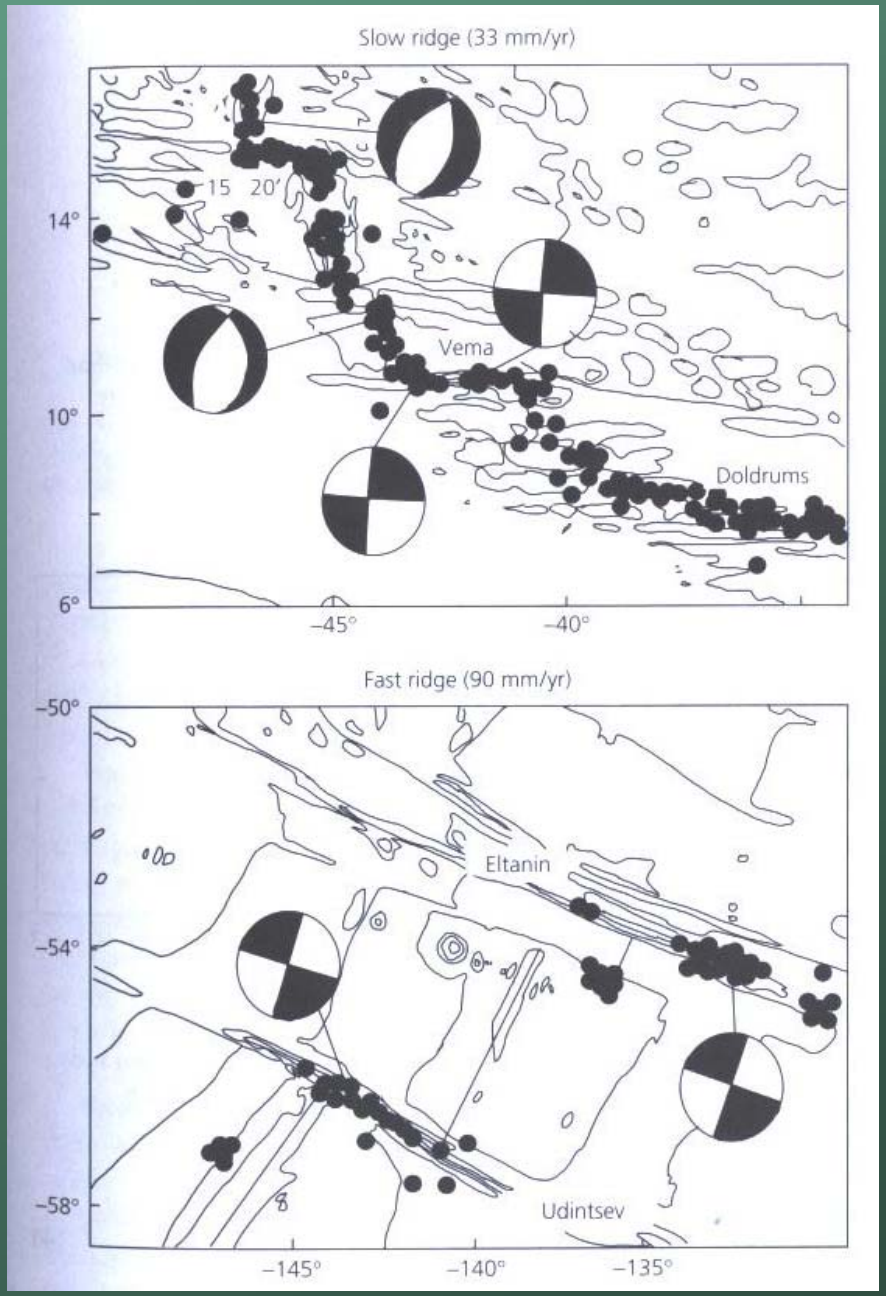
Example Focal mechanism diagrams on mid-ocean ridges





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

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

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

$\lambda = 180°$ Pure strike-slip (right lateral)

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

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

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

Same N-S fault, different slip direction

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Great review on the web at:

http://www.learninggeoscience.net/free/00071/

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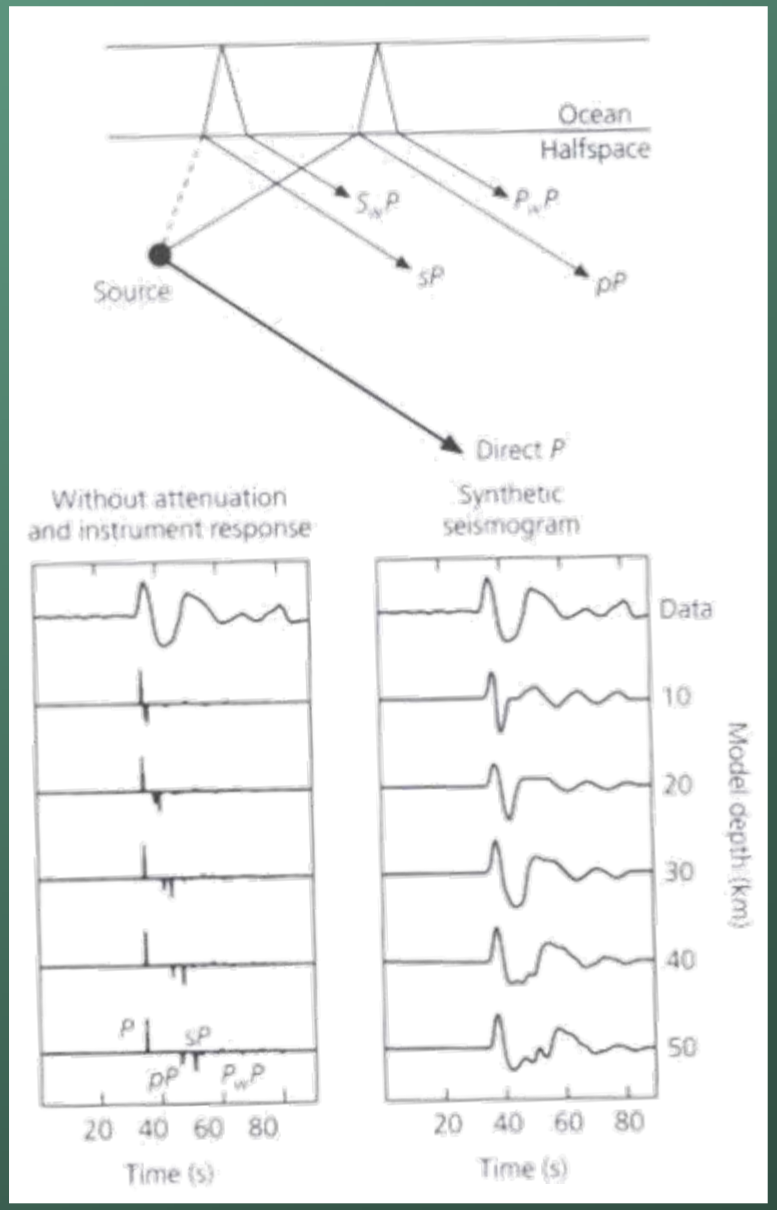
Waveform modeling

- By constructing synthetic seismograms and comparing them to the recorded data we use more of the information in the seismogram, not just the arrival time and first motion data



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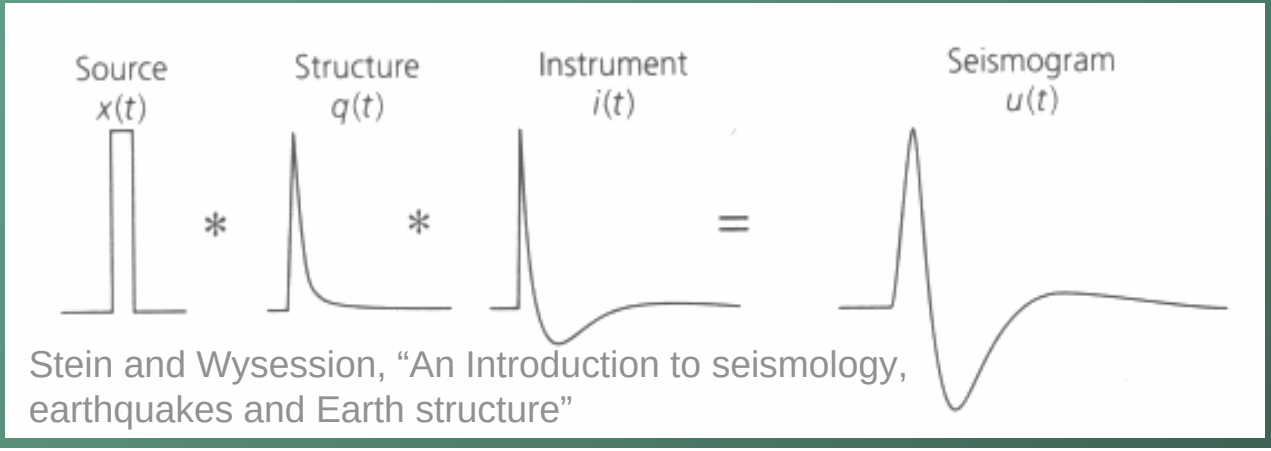
Waveform modeling

Construction of the synthetic seismogram



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$$u(t) = x(t) * e(t) * q(t) * i(t)$$

$$U(\omega) = X(\omega)\, E(\omega)\, Q(\omega)\, I(\omega)$$

- $U(\omega)$: seismogram
- $X(\omega)$: source time function
- $E(\omega)$: reflections & conversions at interfaces
- $Q(\omega)$: attenuation
- $I(\omega)$: instrument response

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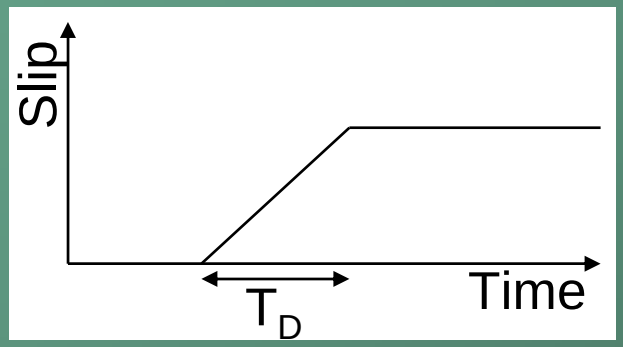
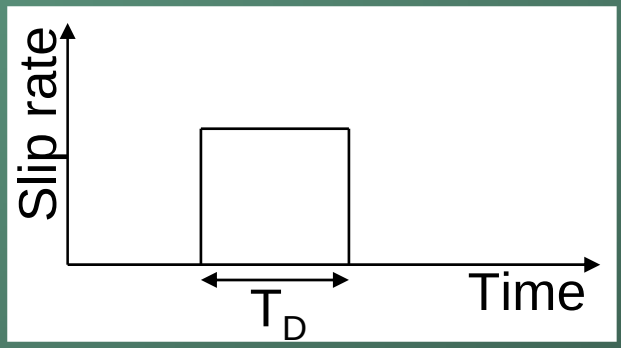
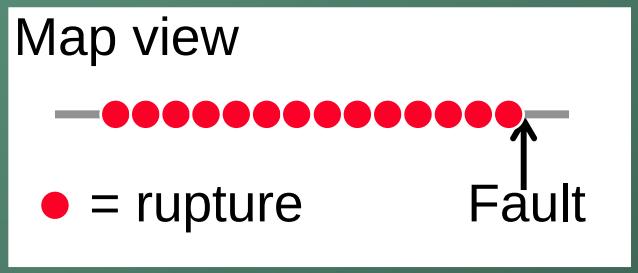
Source-time function

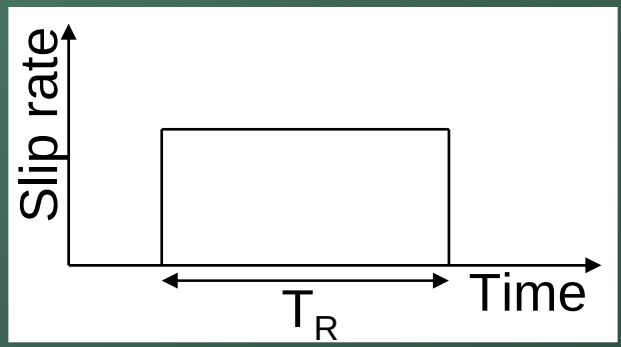
- At one point on the fault slip takes a finite time (called “rise time”):





- The slip travels along the fault at rupture velocity vr, so there is also a finite “rupture time”





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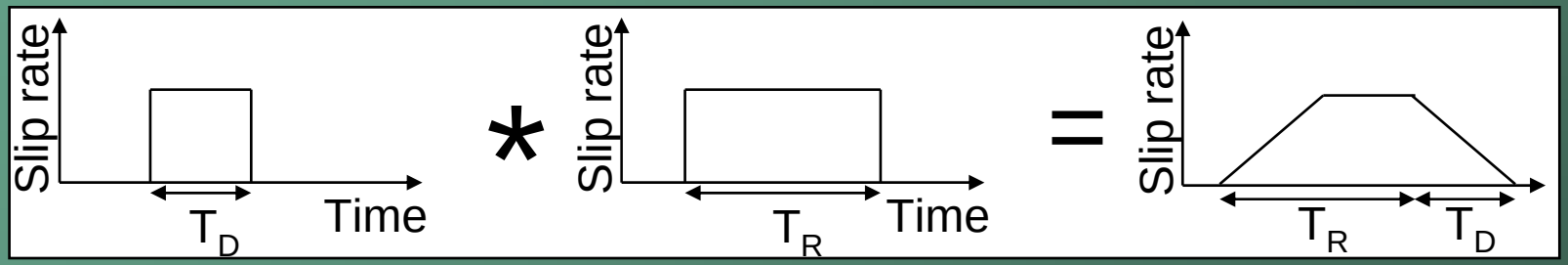
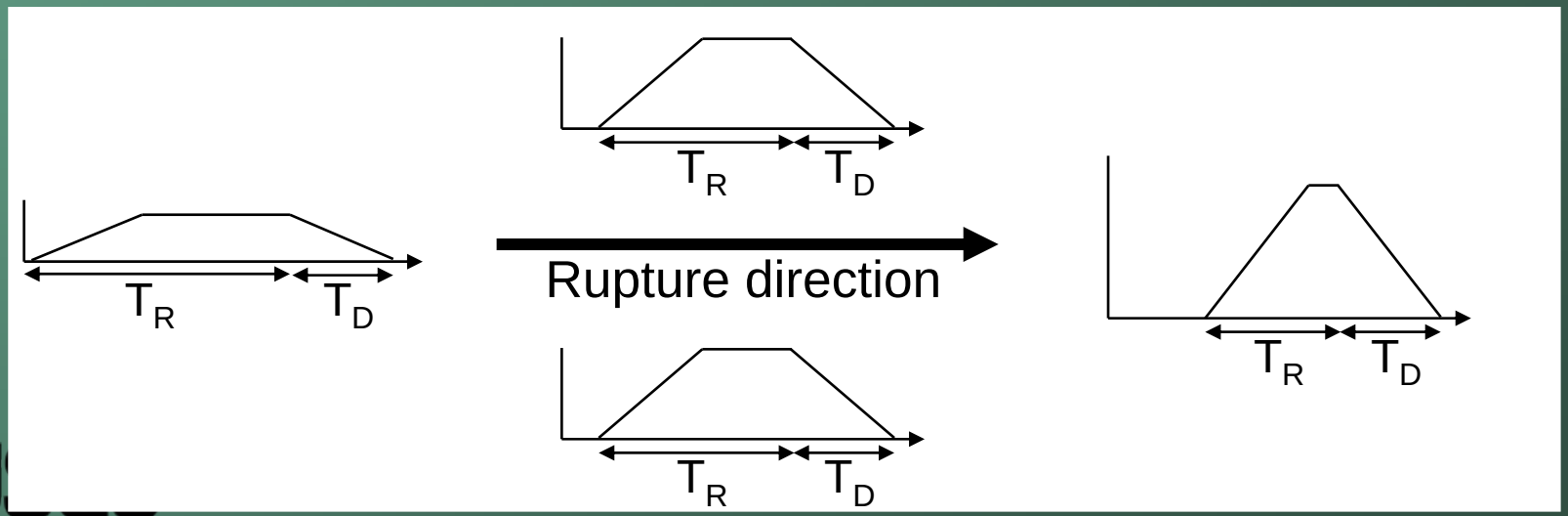
Source time function

- The source time function is the combination of the rise time and the rupture time:

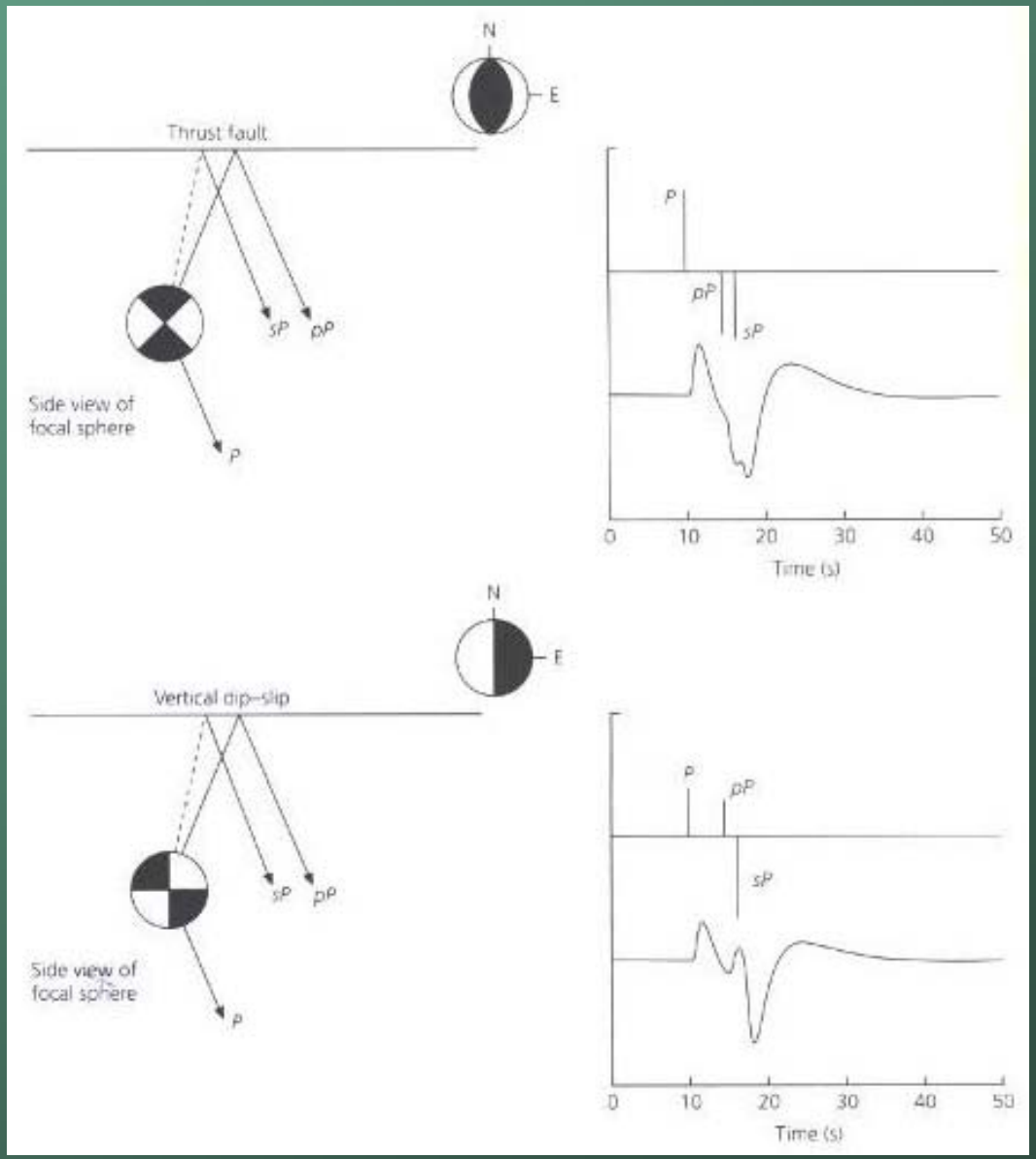


- Directionality affects the rupture time



phase reflections

- e(t) represents reflections due to the Earth structure
- If modeling only the P arrival, it's only needed for shallow events



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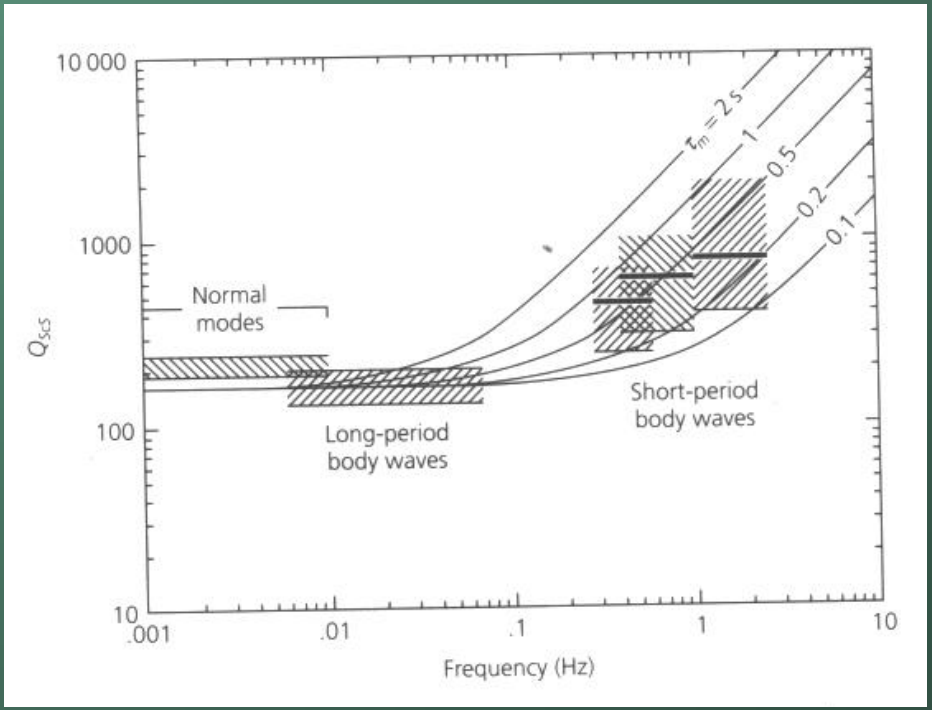
Attenuation

- The loss of energy with time

$$A(t) = A_0 e^{-\omega_0 t/2Q}$$

- Q controls the amount of loss



Sipkin and Jordan 1979, copywrite Seismological Society of America

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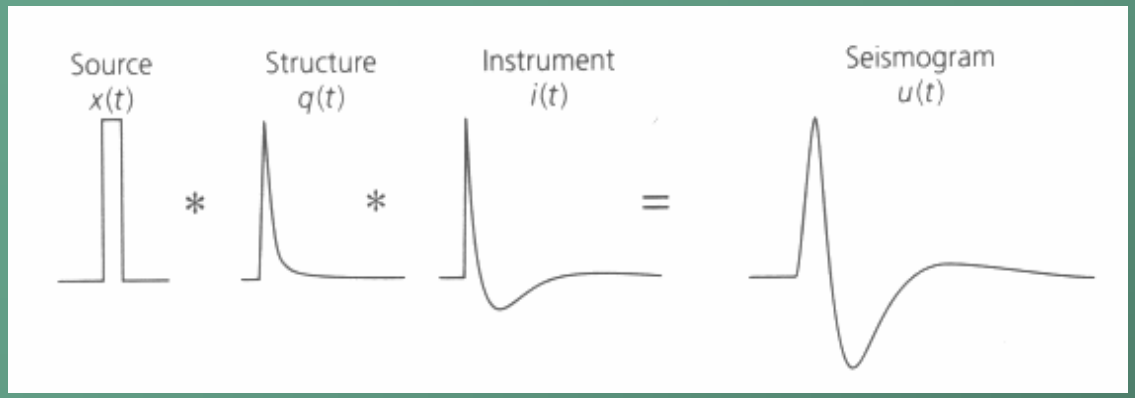
Instrument response function



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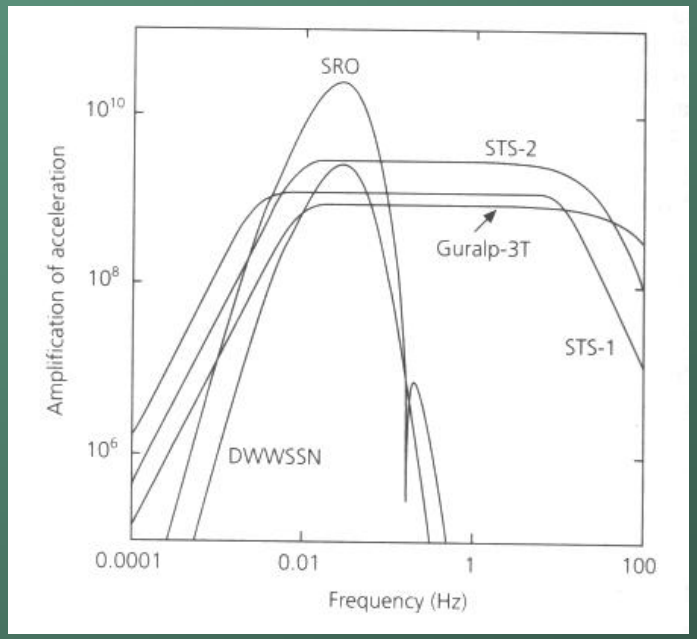

- **The response of the seismometer is different for different frequencies so it also filters the data.**

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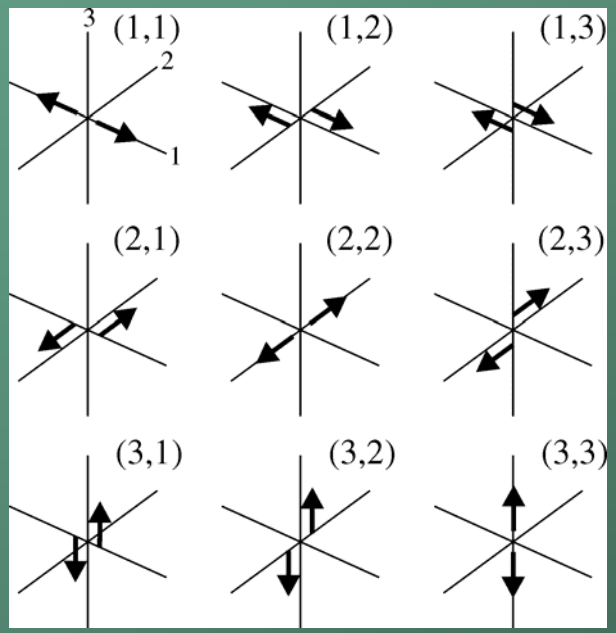
Moment Tensor Inversion

- The Moment tensor describes the fault as set of equivalent forces
- Calculated from the amplitude of surface waves



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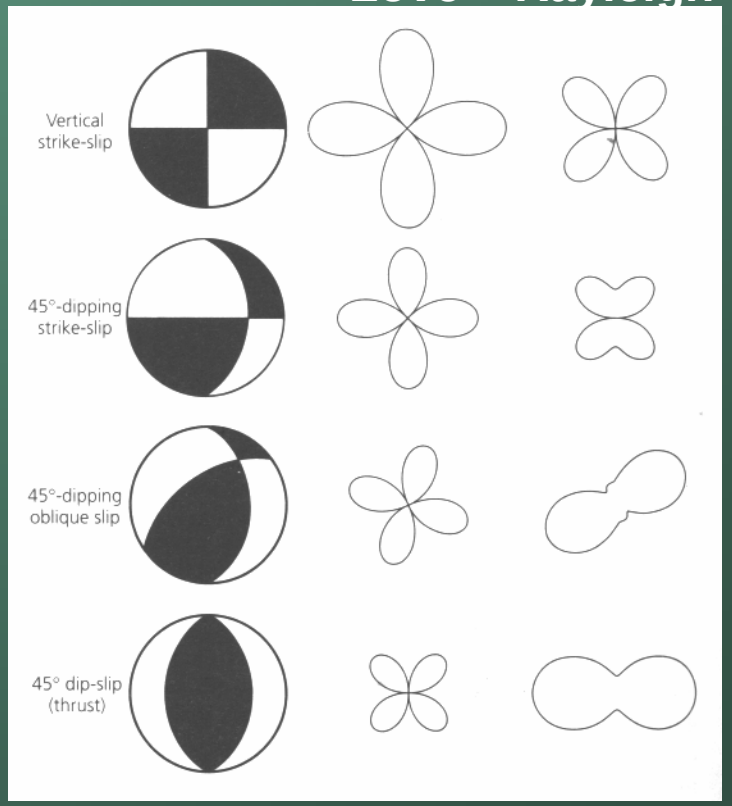

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