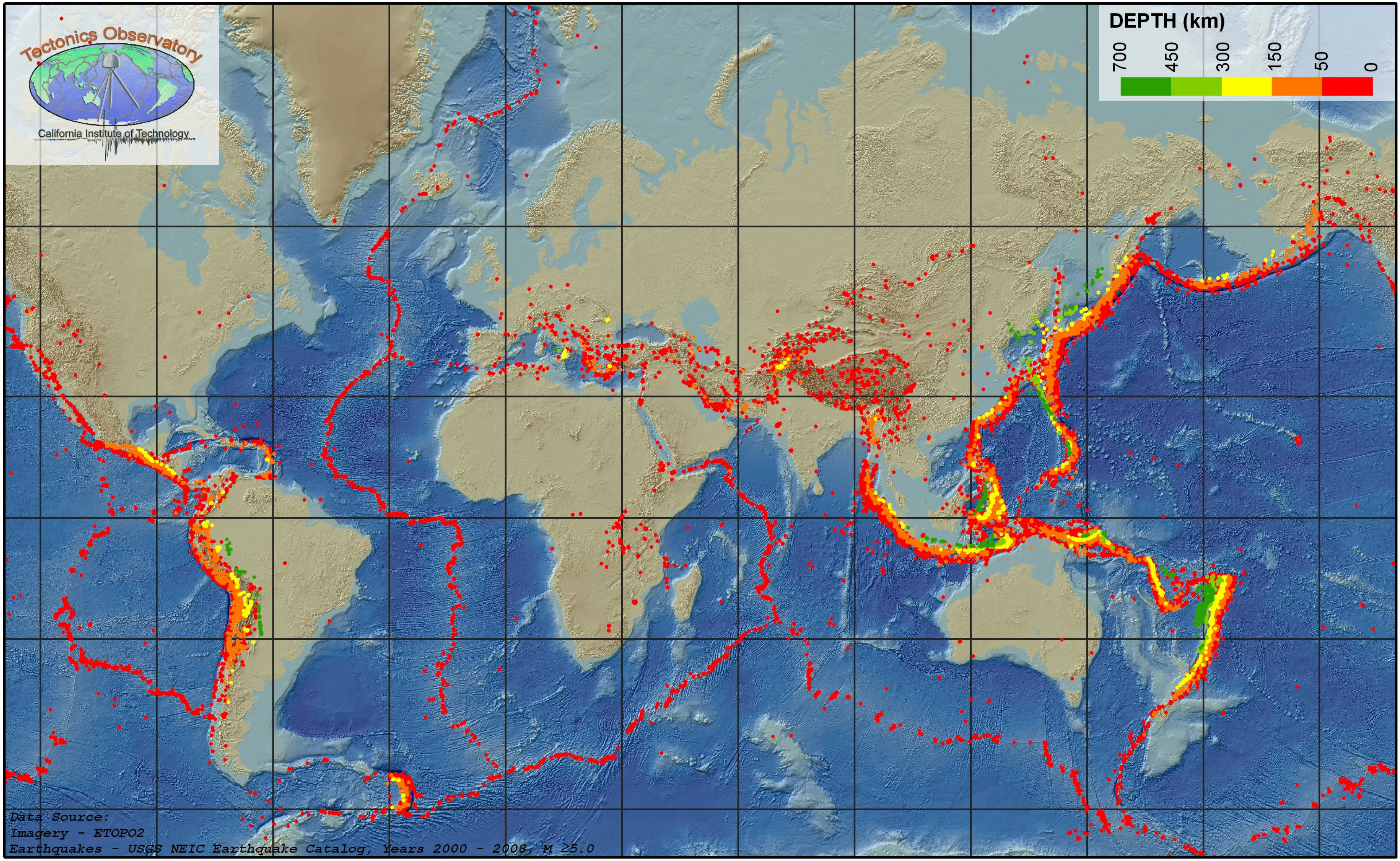
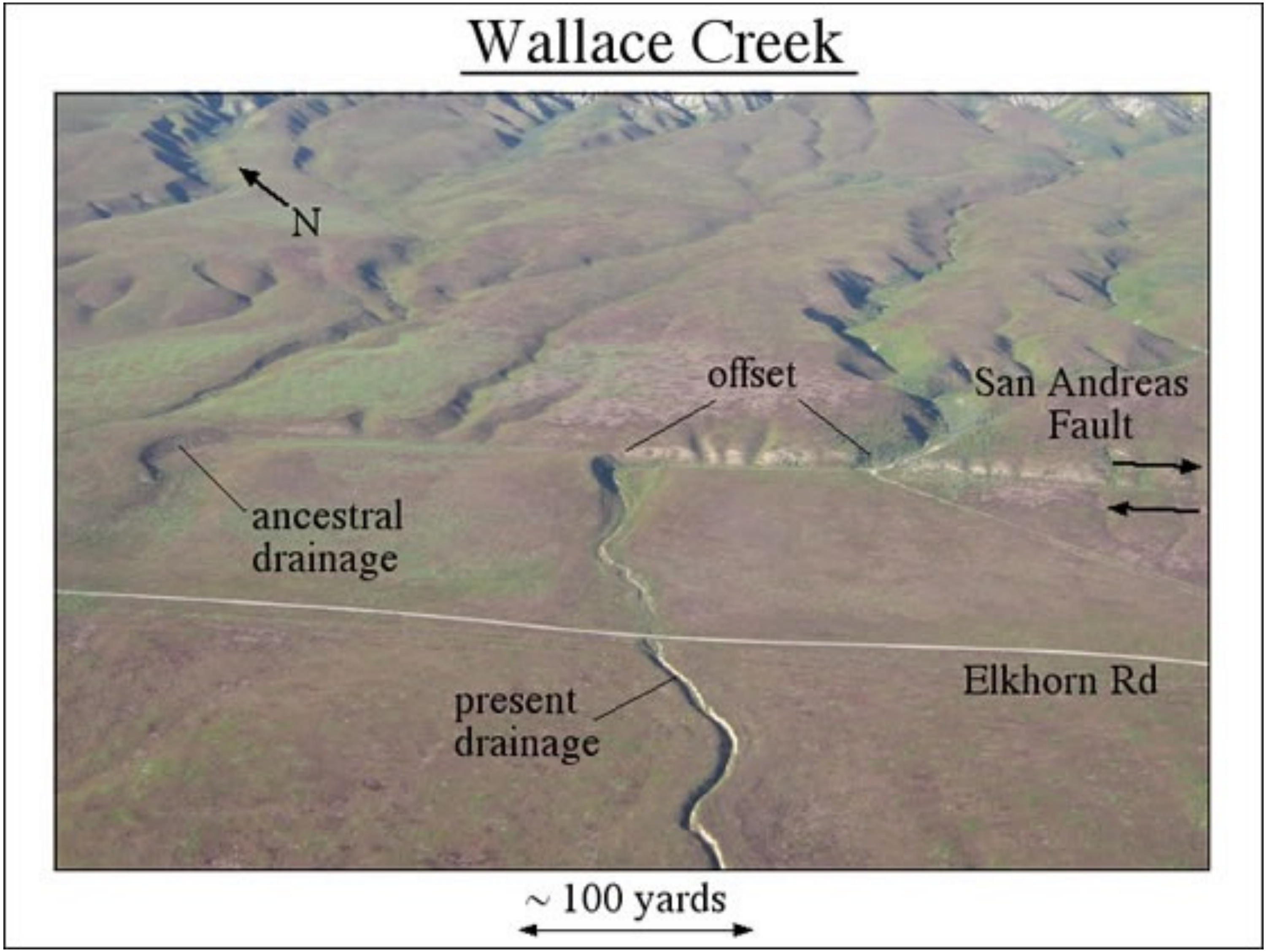
Earthquakes and focal mechanisms

Earthquake distribution

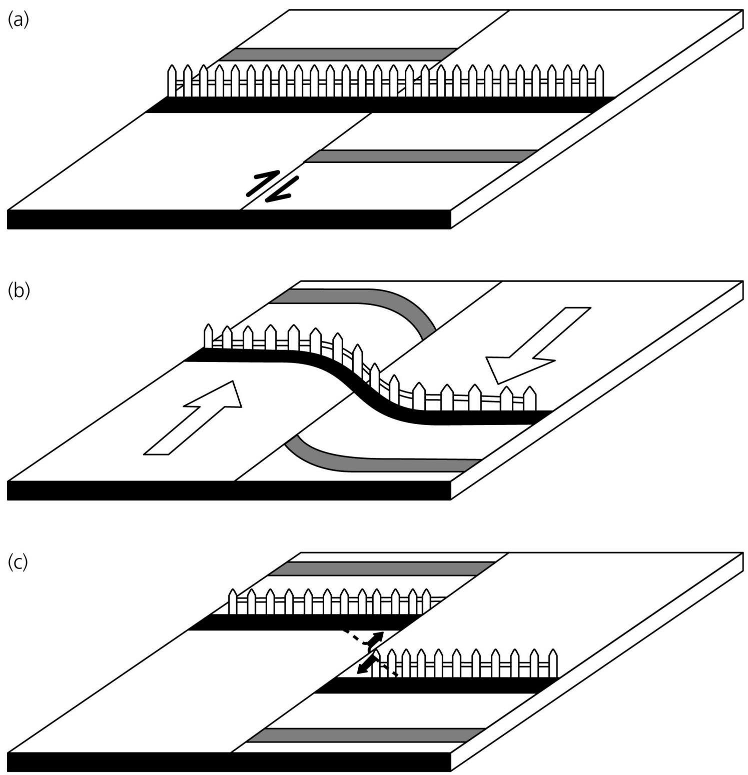


Earthquakes occur along faults



Elastic rebound theory

- *Elastic rebound theory* (H.F. Reid, 1906 San Francisco earthquake): stress increases until the strength of the material is reached -> sudden movement (slip) occurs along a fault



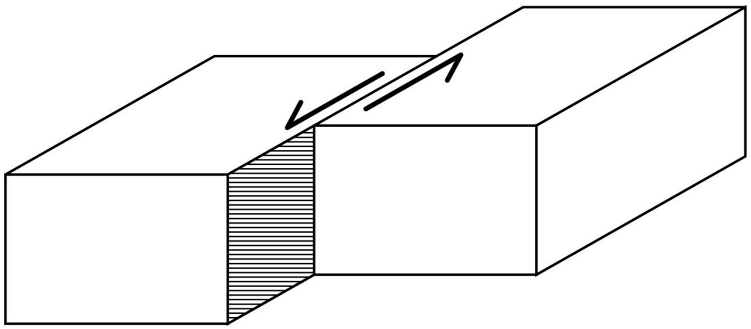
San Francisco earthquake of 1906

The 1906 San Francisco earthquake split the fence.

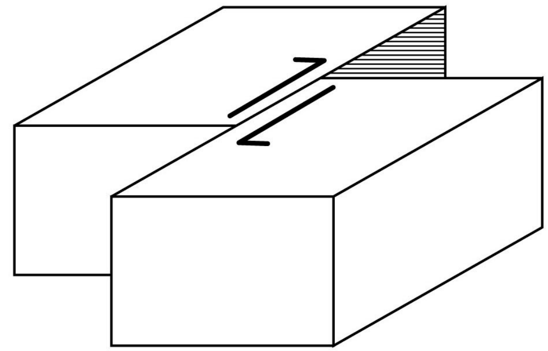
1979 Imperial Valley earthquake

Imperial Valley earthquake, 1979-10-15, M 6.5

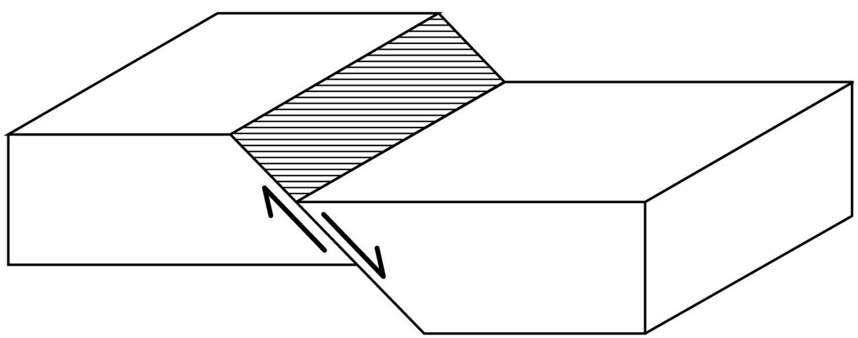
Types of faulting



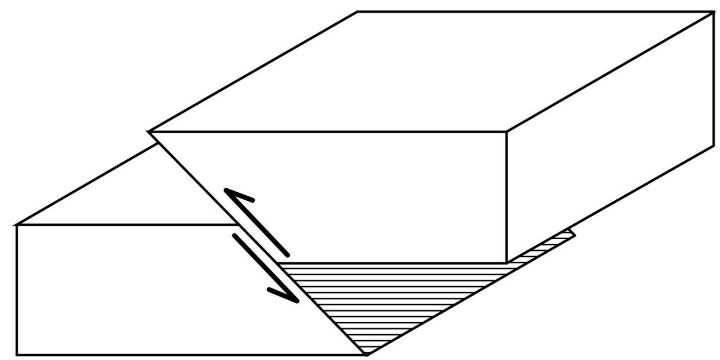
Left-lateral strike-slip fault
($\lambda = 0°$)



Right-lateral strike-slip fault
($\lambda = 180°$)



Normal dip-slip fault
($\lambda = -90°$)

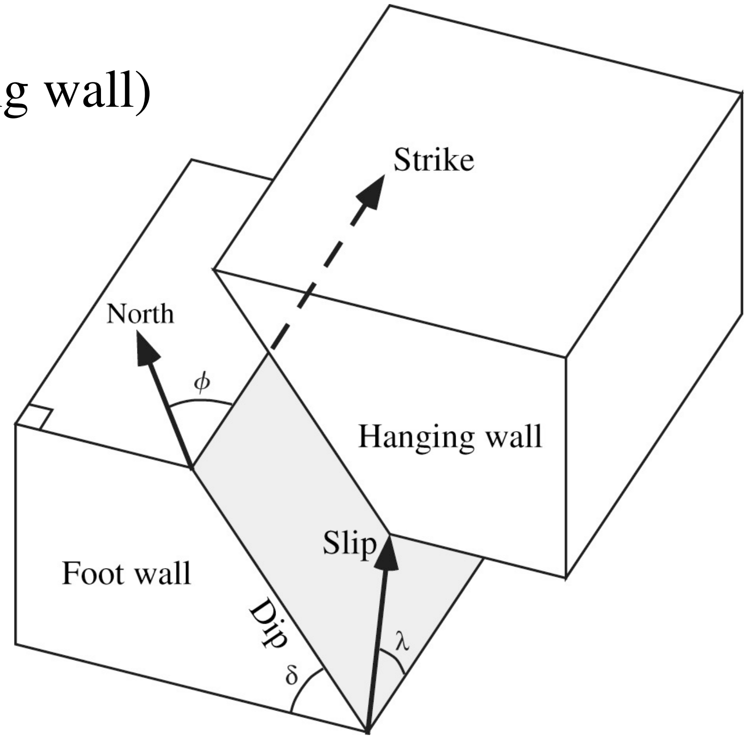


Reverse dip-slip fault
($\lambda = 90°$)

thrust fault

Fault geometry and fault movement

Fault plane is defined by *strike* φ and *dip* δ.
Slip (vector) is movement of upper block (hanging wall) with respect to lower block (foot wall).
The *rake* λ is angle of the slip vector with strike.



Strike φ: fault plane dips to the right when looking in the direction of the strike:
$0 \leq \phi < 360^\circ$ (Different from geological convention!)

Dip δ: dip of fault plane is measured from horizontal: $0 \leq \delta \leq 90^\circ$

Rake λ: slip angle λ is measured with respect to strike: $-180 < \lambda \leq 180^\circ$

Normal fault: $\lambda = -90^\circ$ Reverse fault: $\lambda = 90^\circ$

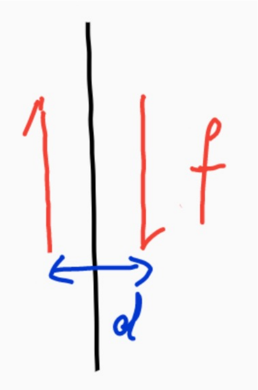
Left lateral: $\lambda = 0^\circ$ Right lateral $\lambda = 180^\circ$

Focal mechanism representation

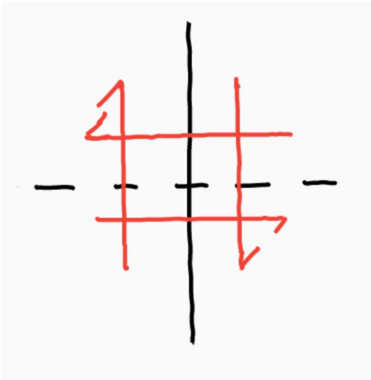
Consider earthquake as point source
Assume an equivalent body force system that simulates the earthquake

Hypothesis 1: Single force couple model
Problem: It has a net torque M = f d, but conservation of angular momentum
Where does this torque originate from at the time of the earthquake?

Hypothesis 2: Double couple model that includes an opposite torque



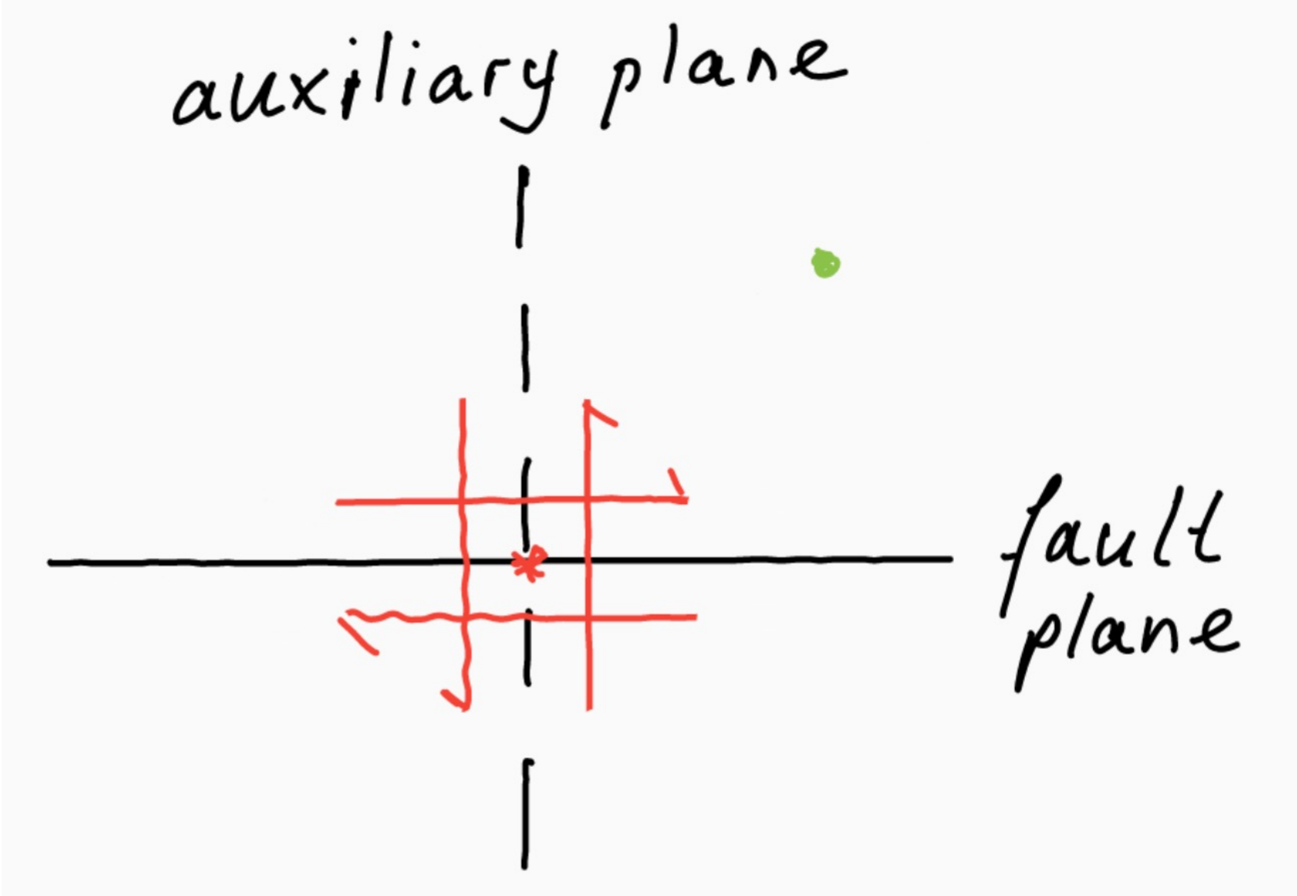
Single couple model



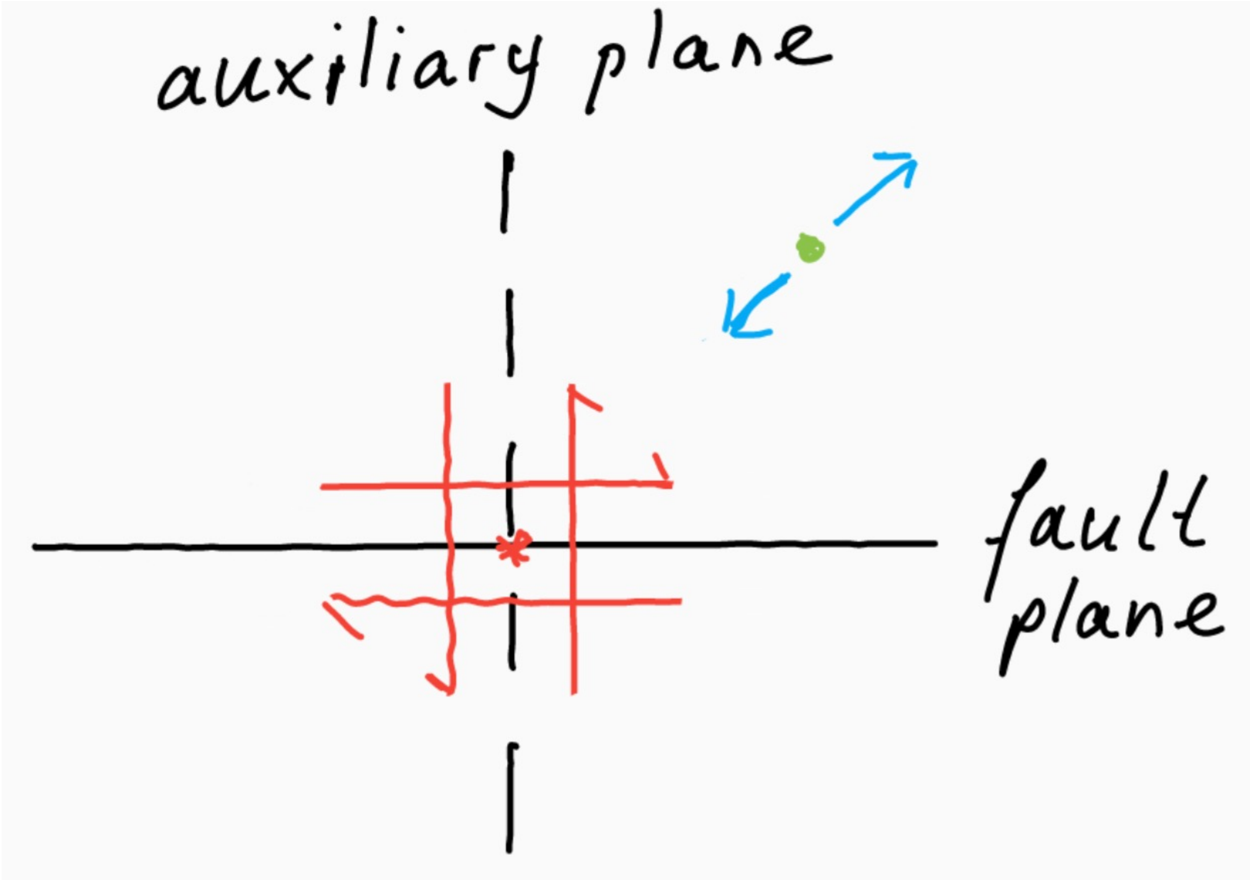
Double couple model

Double couple model in agreement with observations radiation pattern
S waves and theoretical basis (1960s)

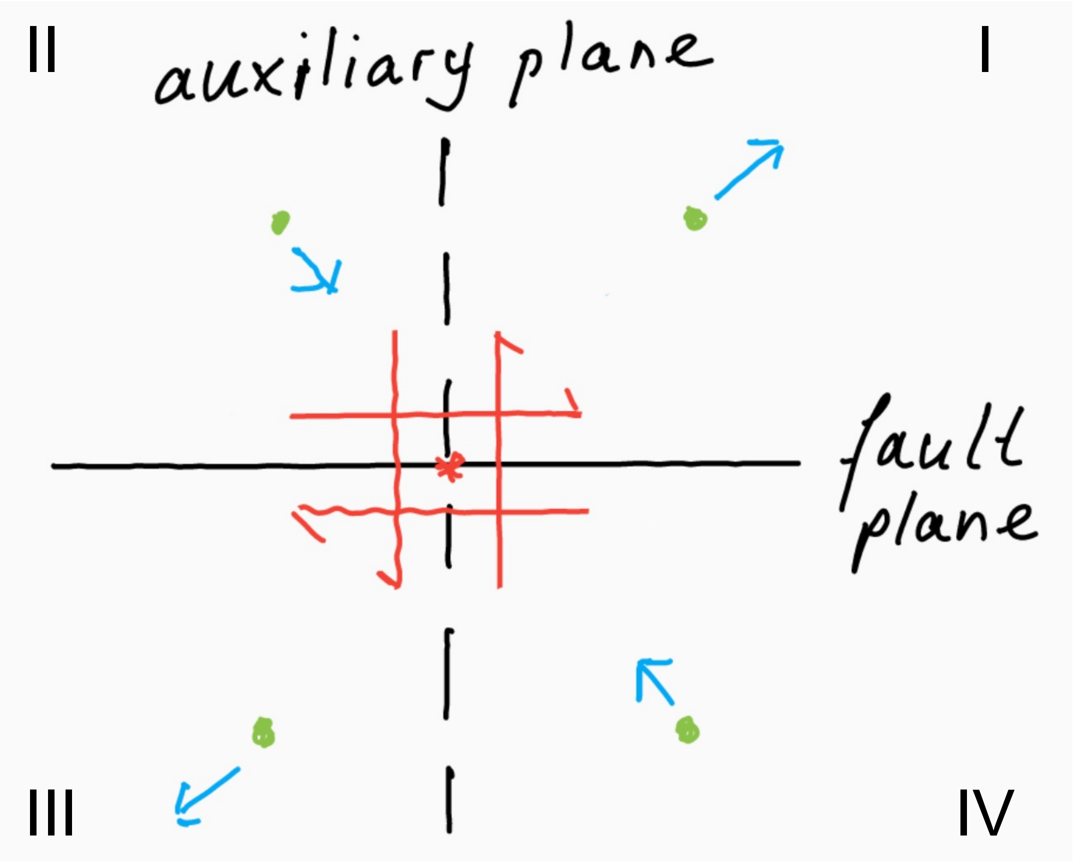
Radiation pattern P waves



Radiation pattern P waves

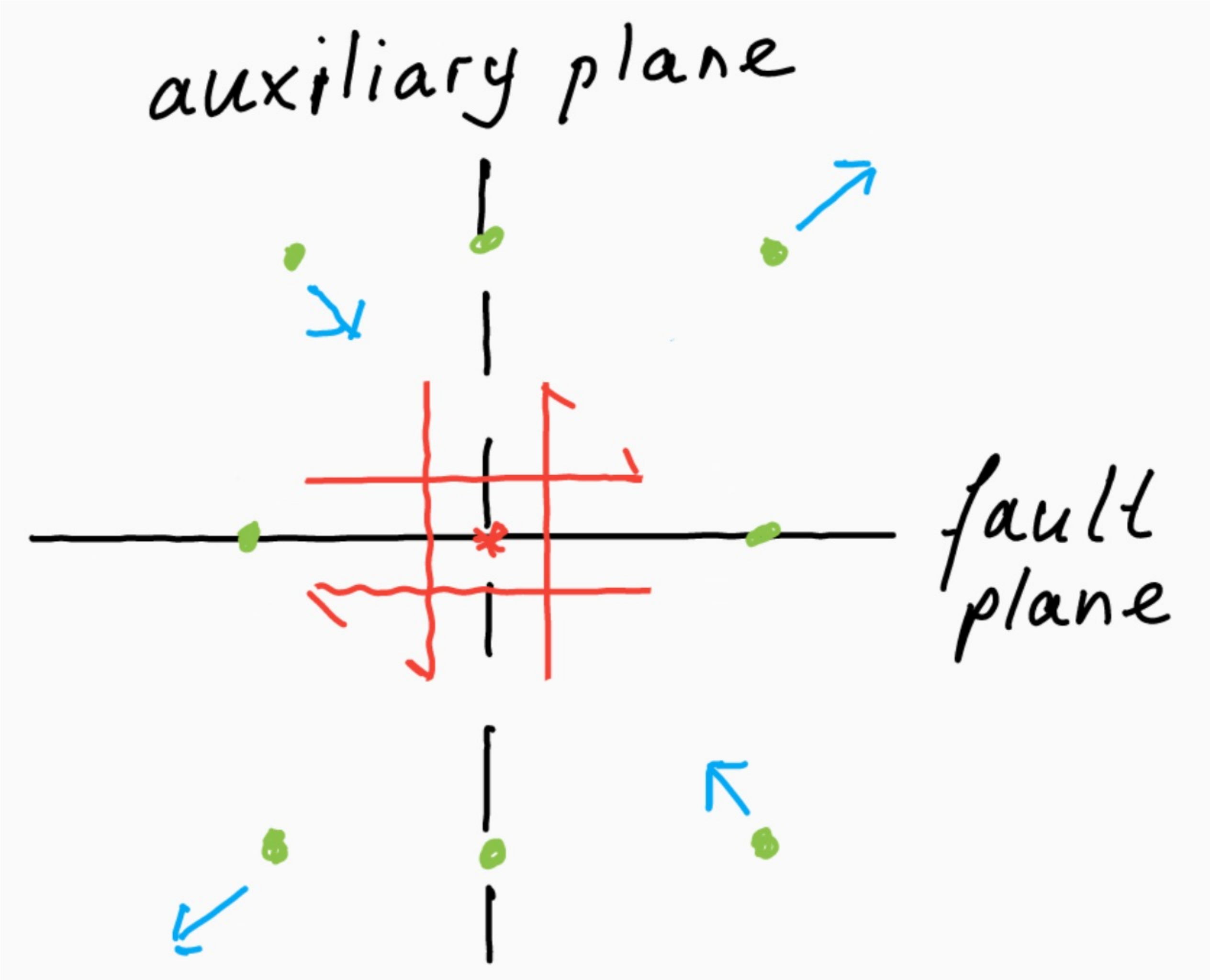


Radiation pattern P waves

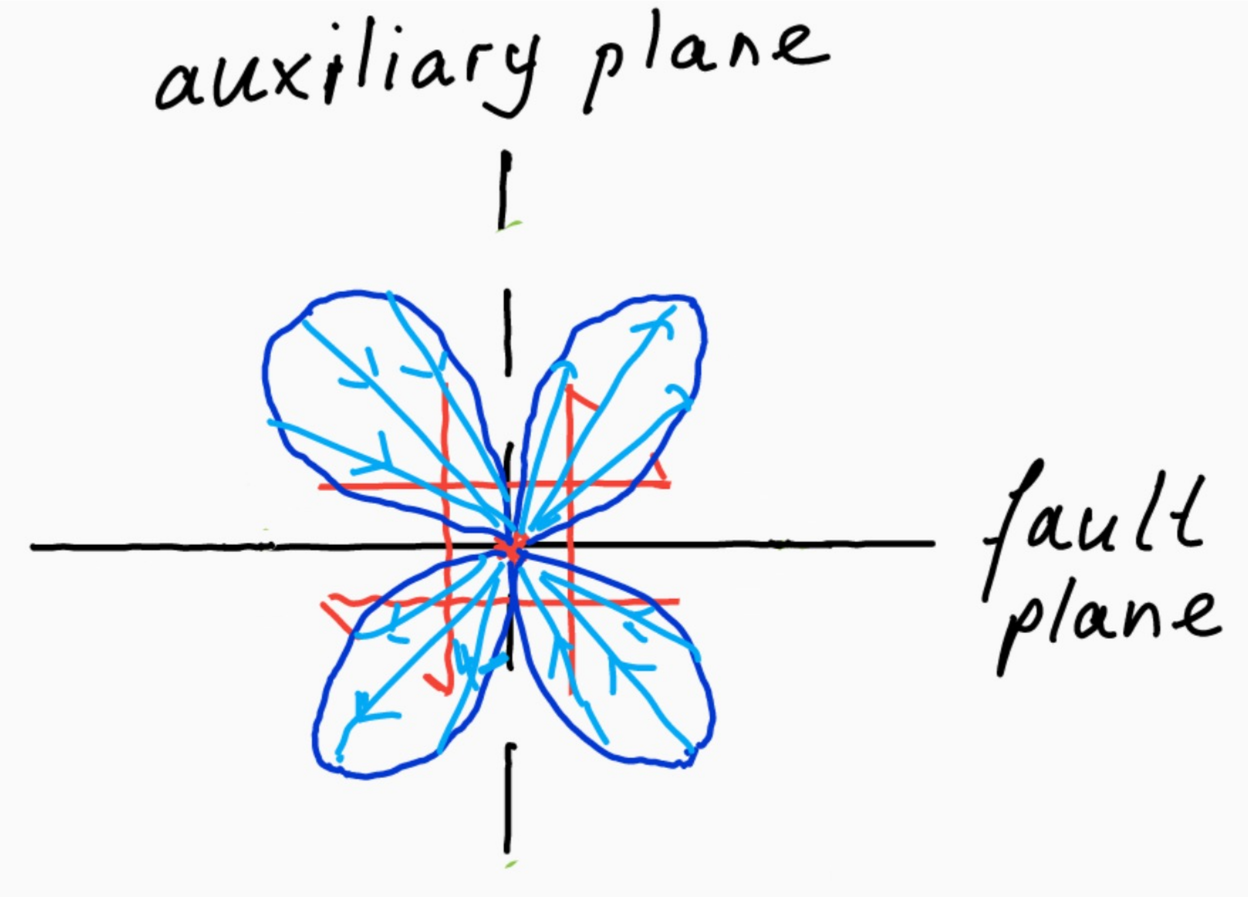


I, III : first P-wave motion away from source
II, IV: first P-wave motion towards source

Radiation pattern P waves

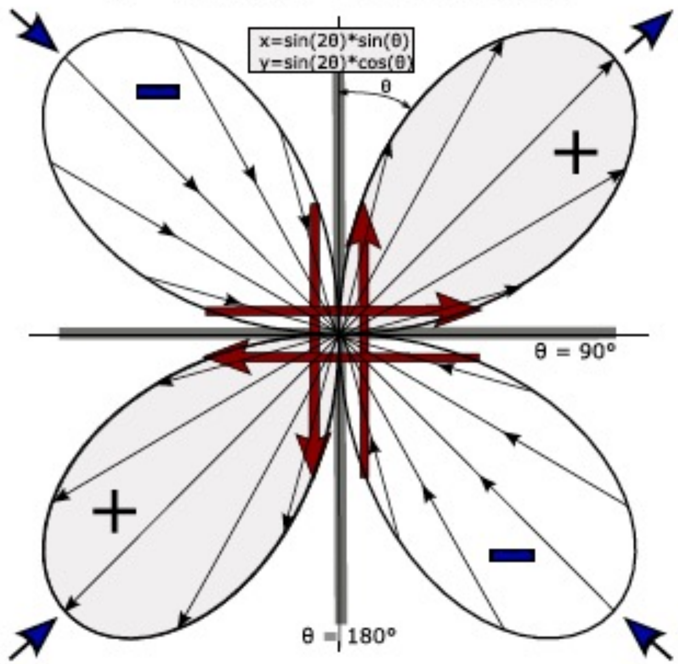


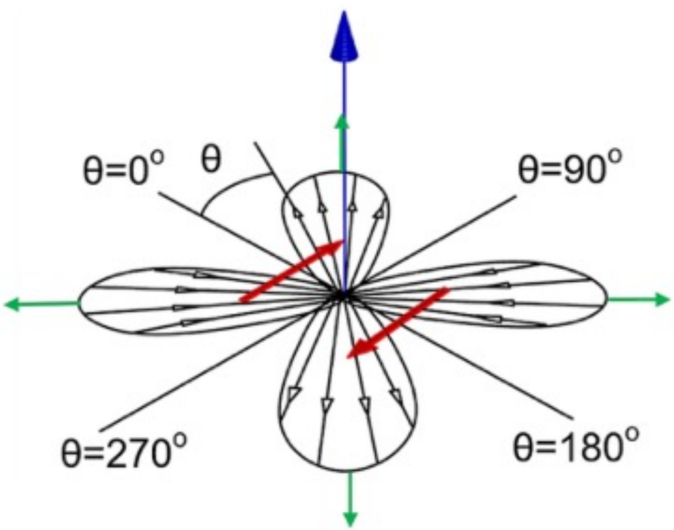
Radiation pattern P waves

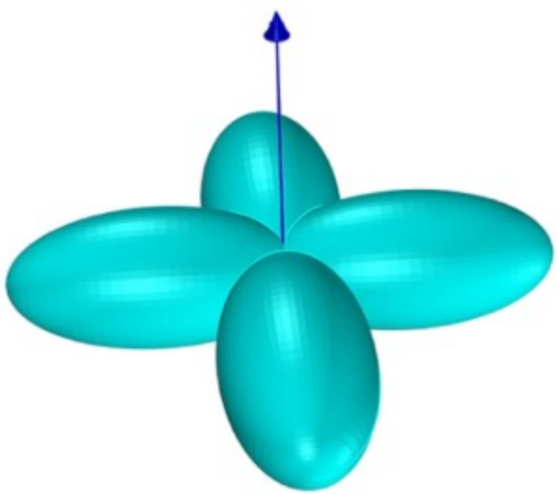


Fault plane and auxiliary plane define the two *nodal planes* of the P wave radiation pattern

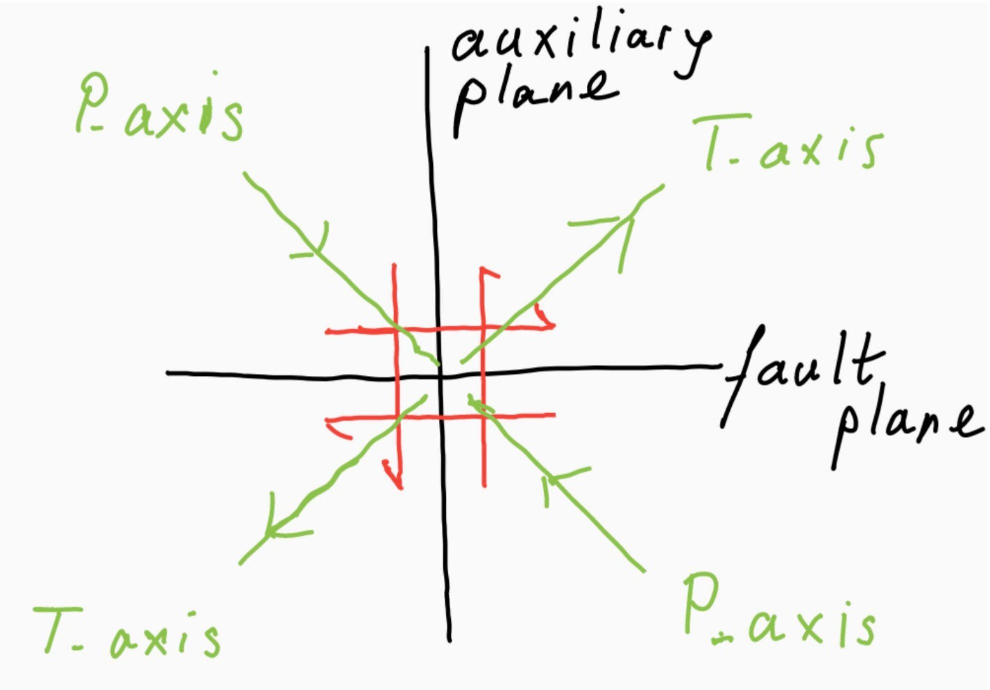
Radiation pattern P waves







Principal stress axes of earthquake

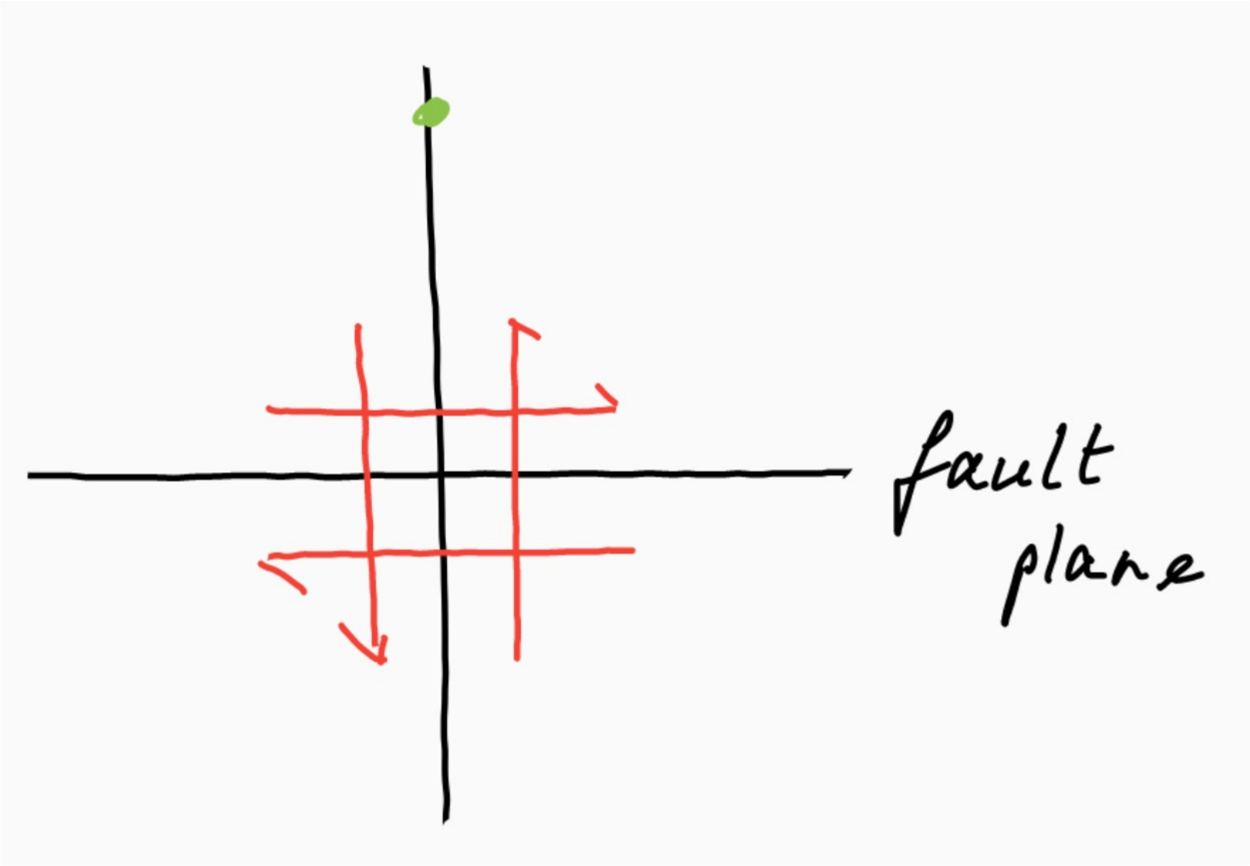


P axis: Pressure axis
T axis: Tension axis
N axis: Neutral/null axis
(a.k.a. *B* axis)

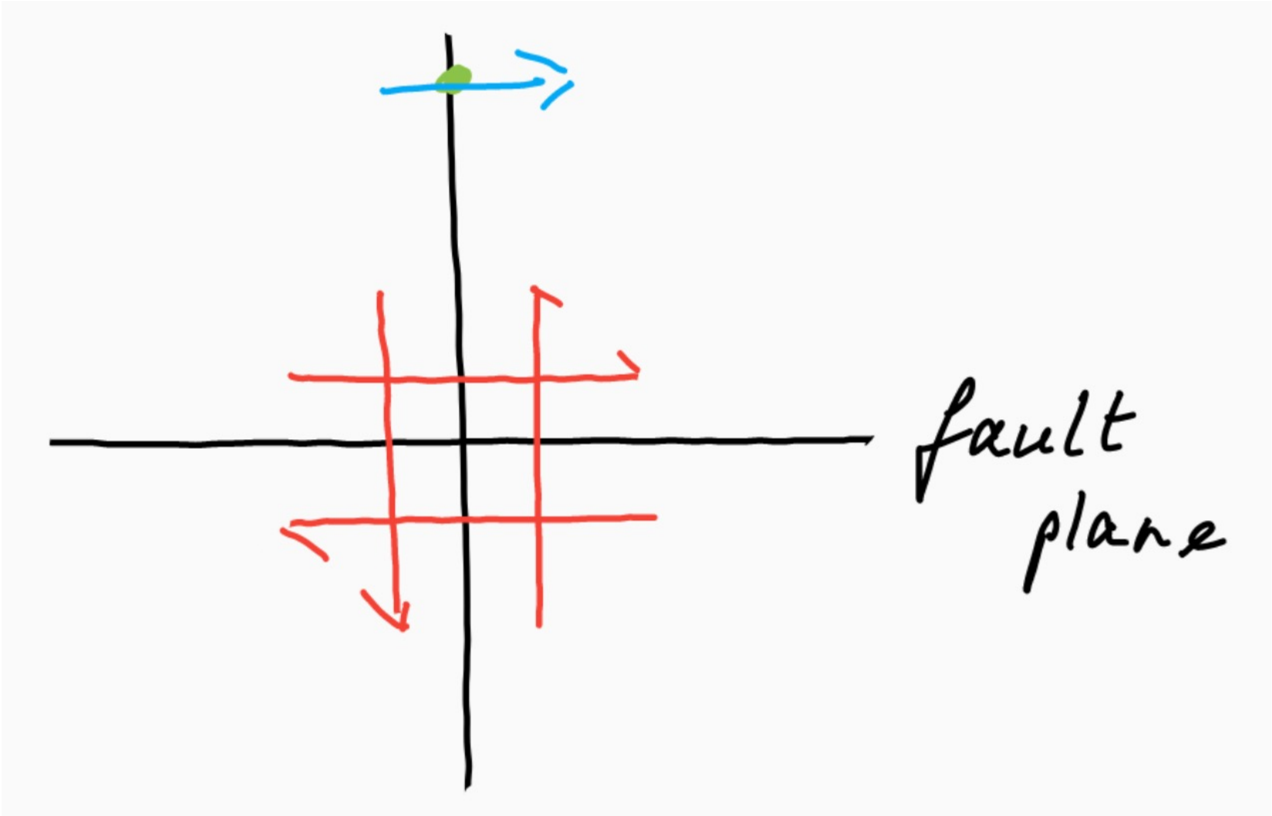
P and T axes are at angles of 45° with the nodal planes
N axis is perpendicular to P and T axes → in intersection direction of the two nodal planes

Note that P, T and N axes do not necessarily coincide with the principal stress axes of the surrounding medium. They are associated to the earthquake that occurs along the pre-existing fault plane (within the stress regime).

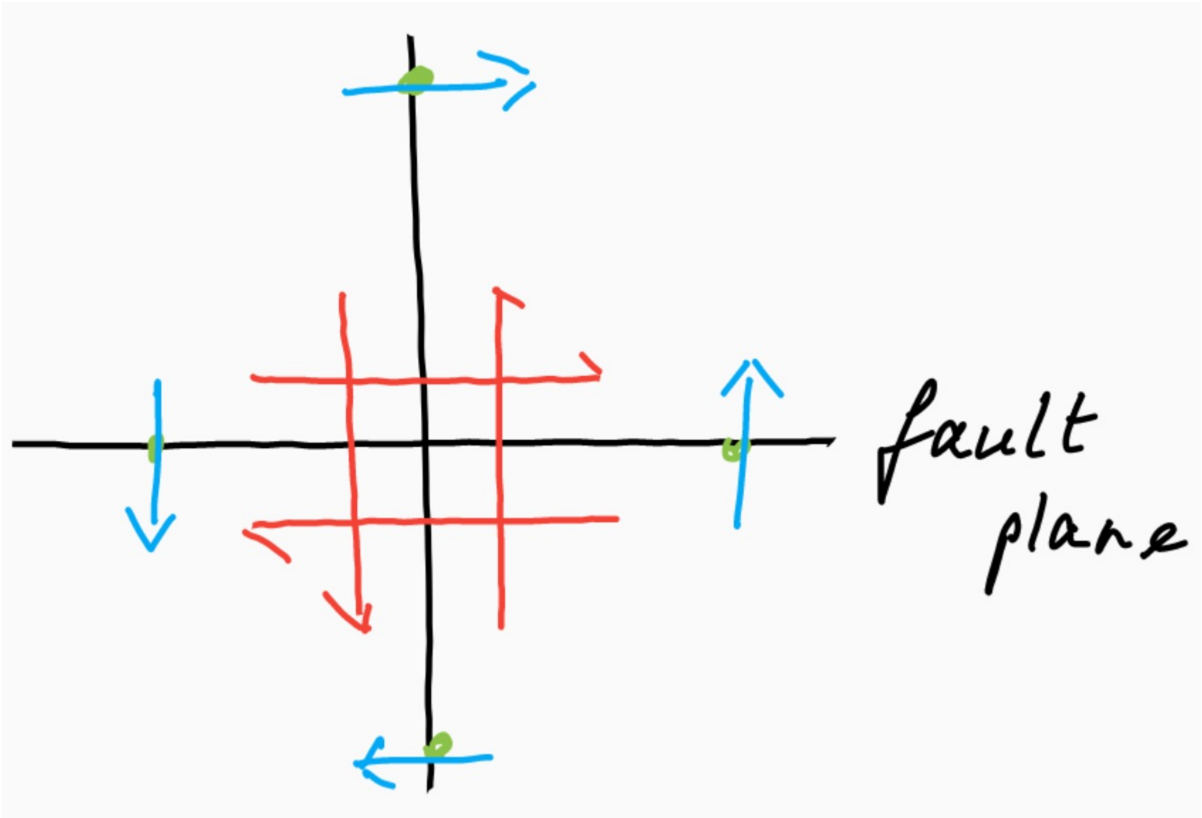
Radiation pattern S waves



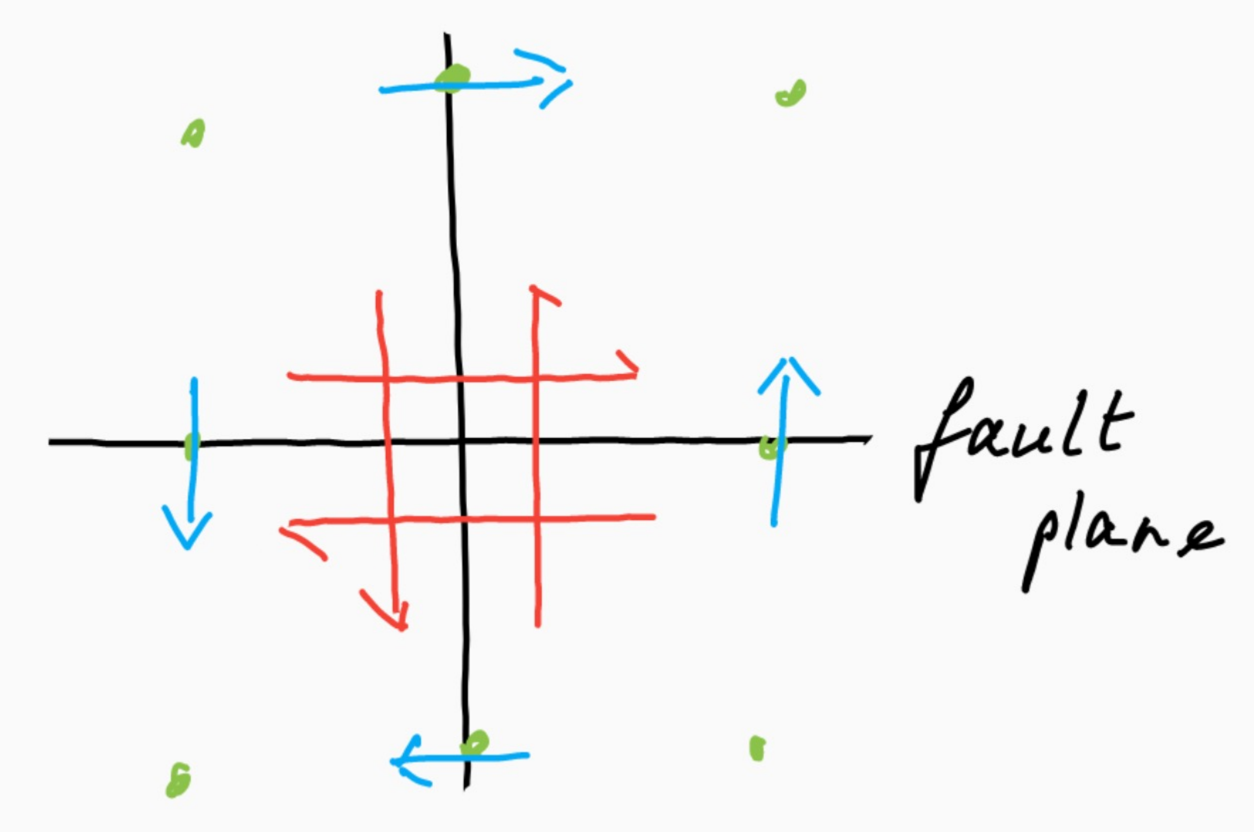
Radiation pattern S waves



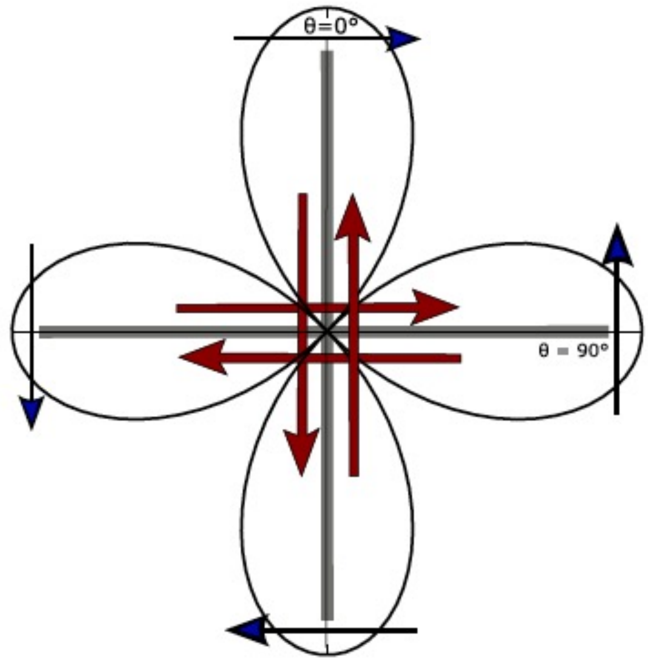
Radiation pattern S waves

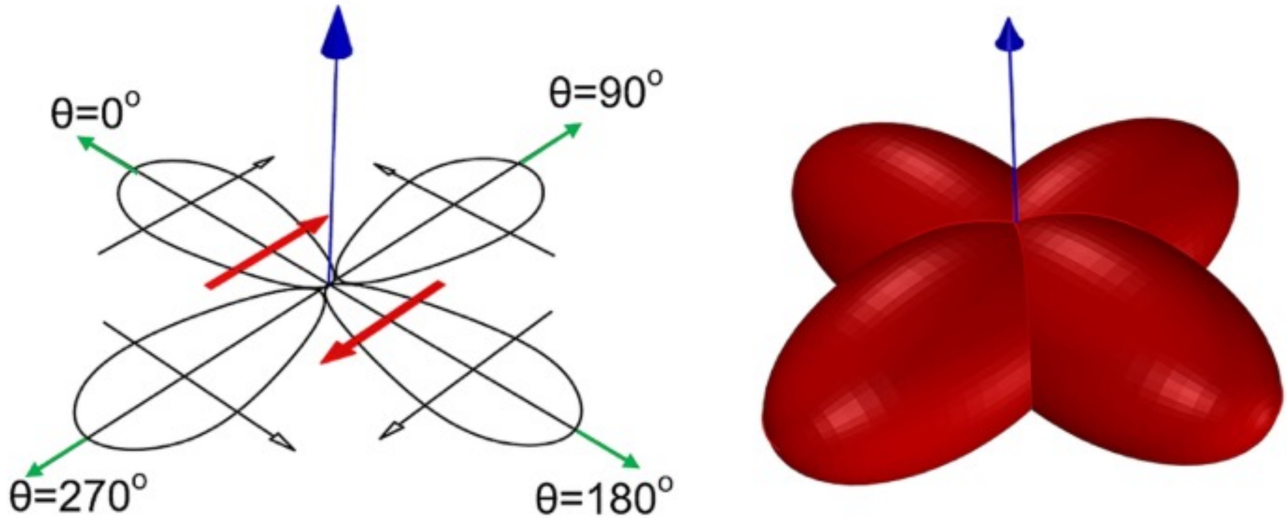


Radiation pattern S waves

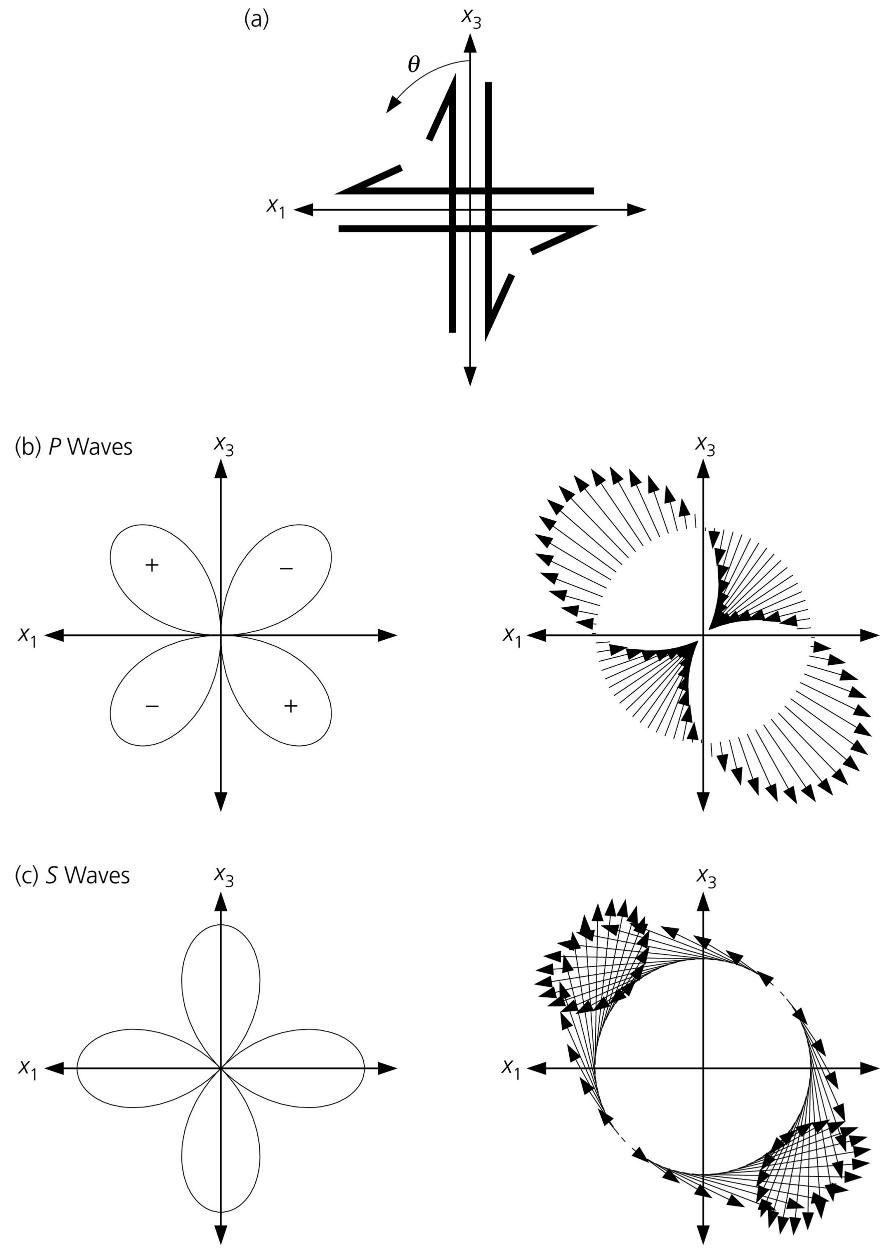


Radiation pattern S waves

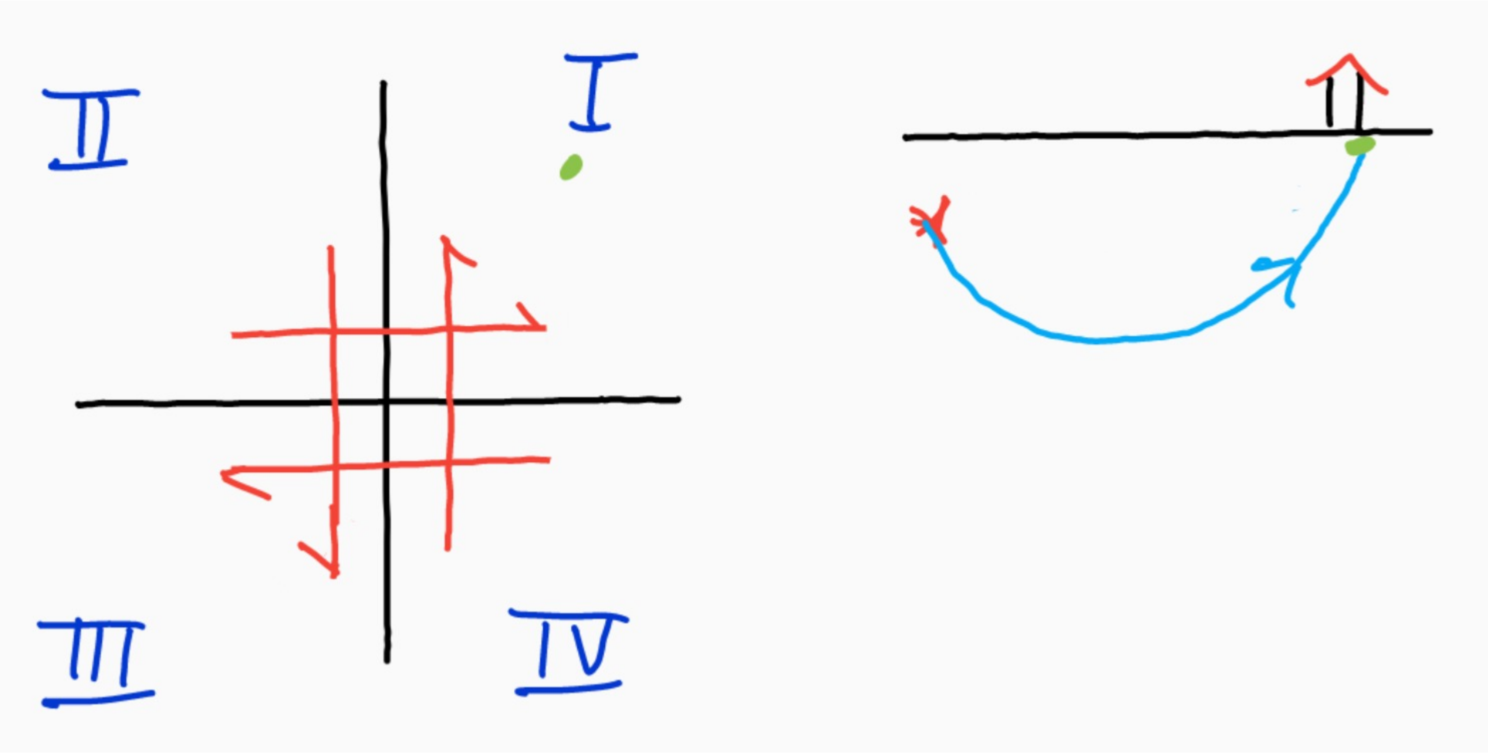




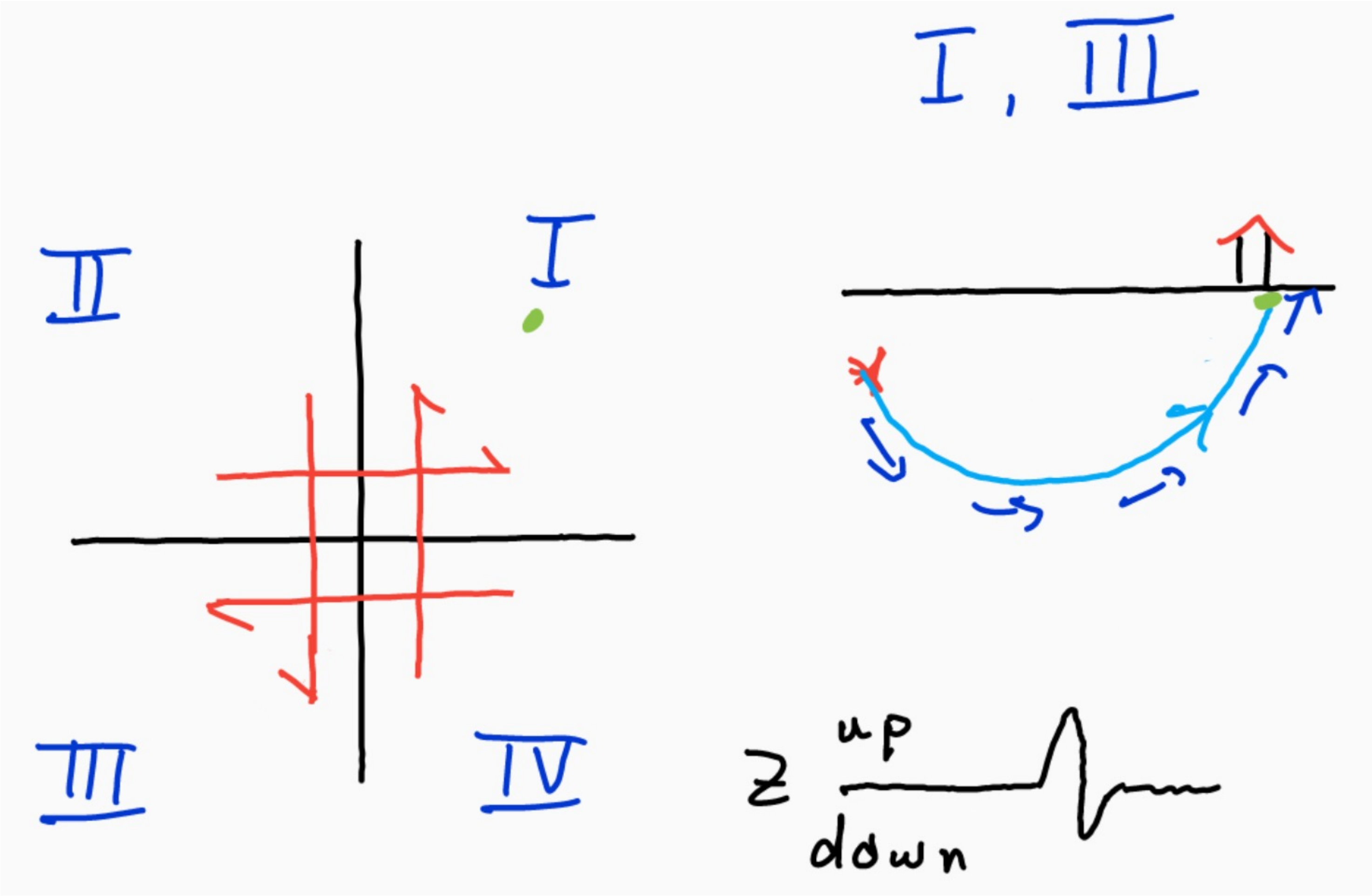
P and S wave radiation patterns



Reconstruction focal mechanism from radiation pattern P waves

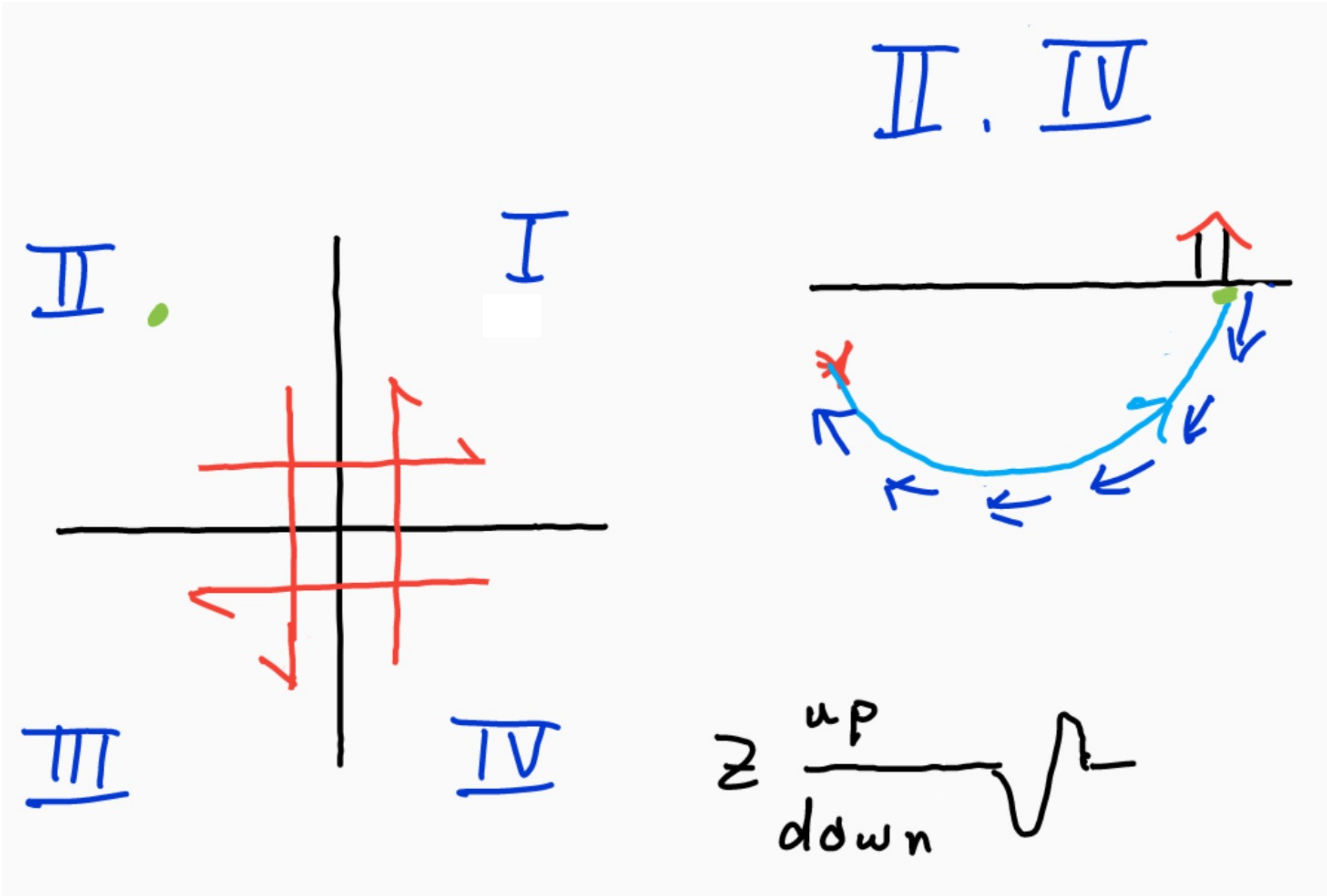


Reconstruction focal mechanism from radiation pattern P waves



First motion upward: *compression*

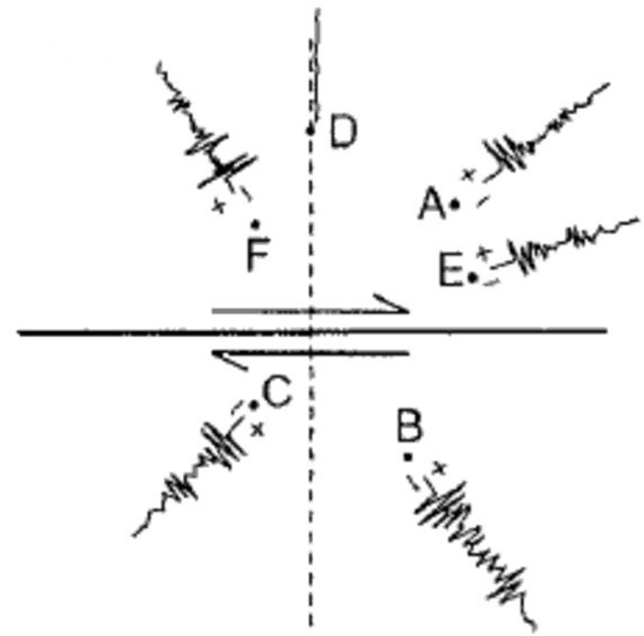
Reconstruction focal mechanism from radiation pattern P waves



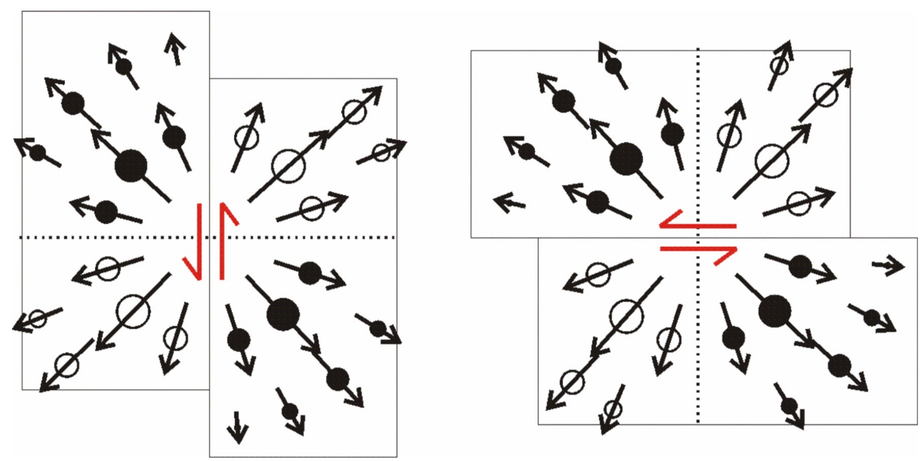
First motion downward: *dilatation*

Reconstruction focal mechanism from radiation pattern P waves

Determine 4 quadrants by P wave first motions:
compressions and dilatations are separated by the nodal planes.



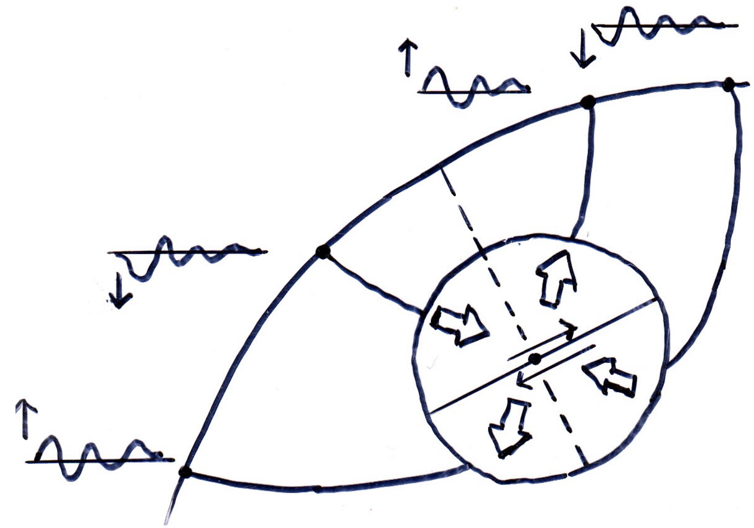
One of the two nodal planes is the fault plane the other the auxiliary plane.
Additional information (e.g. geology, historical seismicity) is needed to distinguish the two.



Focal mechanism from radiation pattern P waves

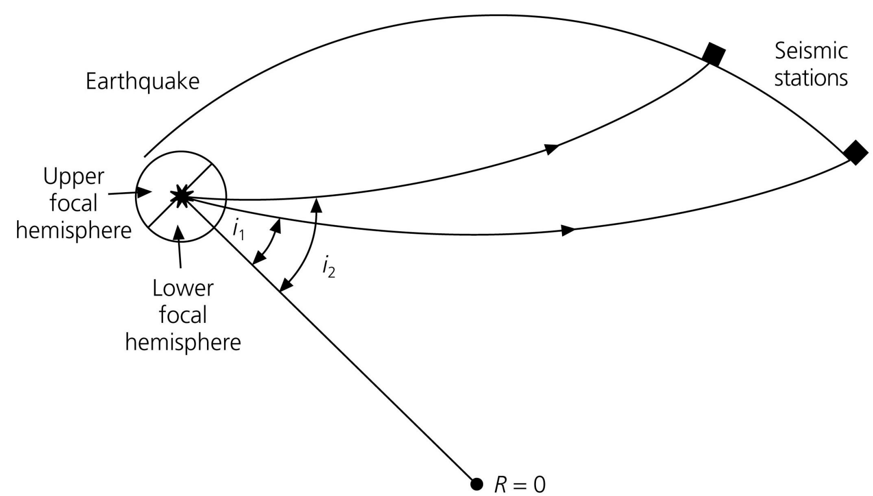
For arbitrary orientation use
stereographic projection (Wulff net)

Assume *focal sphere* around focus

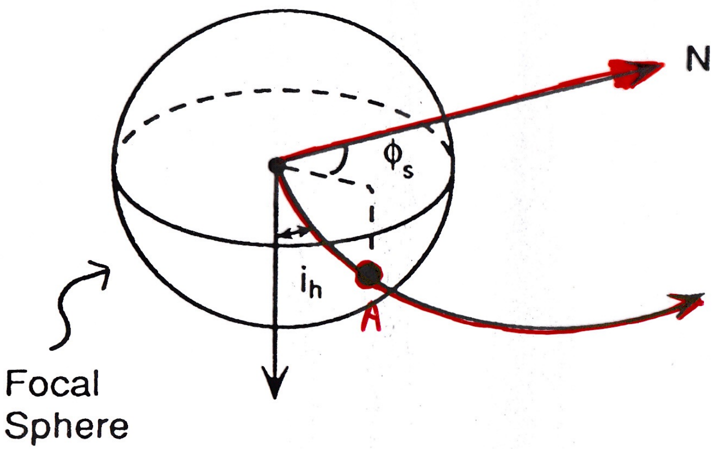


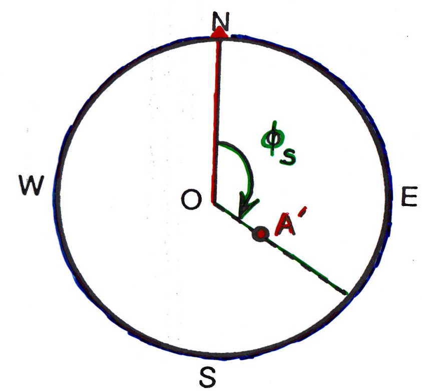
Determine the direction of the
ray to the station at the focal sphere

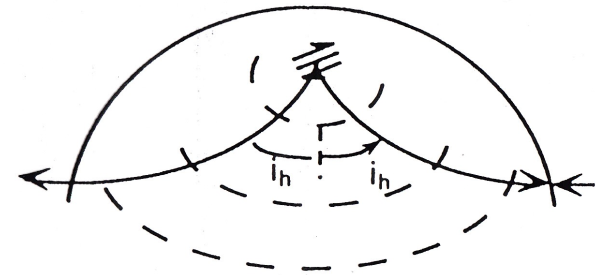
Apply a lower hemisphere
stereographic projection
(most rays leave source in downward
direction)



Ray leaving focal sphere







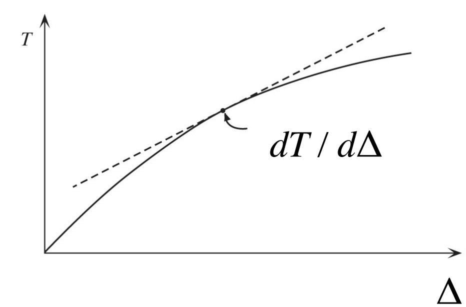
Determine location where ray leaves focal sphere

- *Azimuth* Φ_s from source to seismic station (angle from North, positive towards East). Obtained from source and station locations.
- *Take-off angle* i_h (ray angle with vertical at source). Obtained from ray parameter

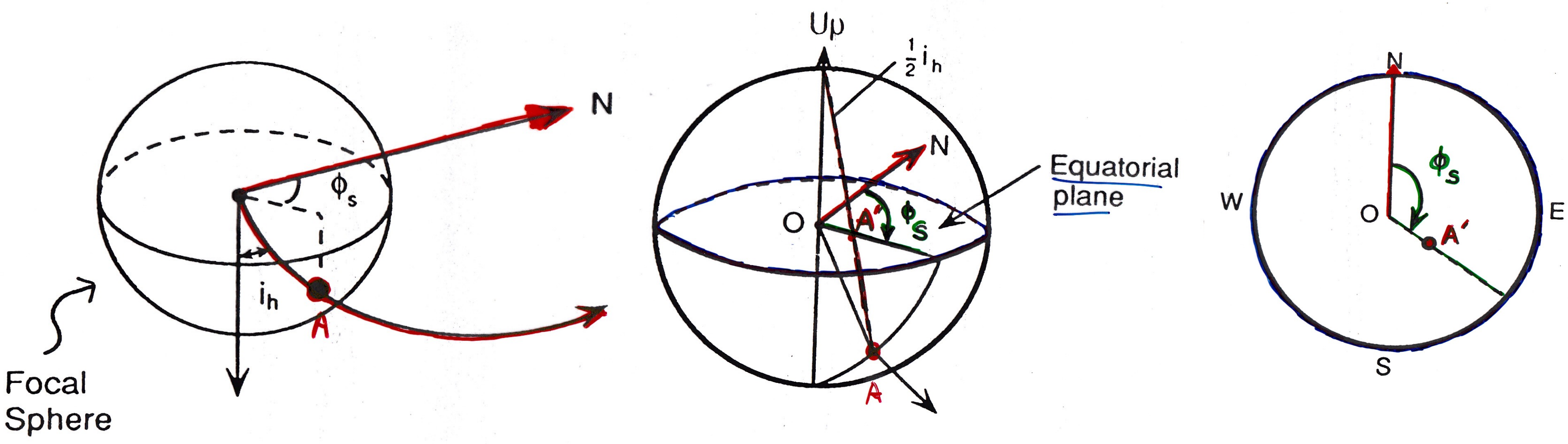
$$p = \frac{r_h \sin i_h}{v(r_h)}$$

p from epicentral distance Δ (and Earth model)

$\Delta \rightarrow p \rightarrow i_h$



Stereographic projection

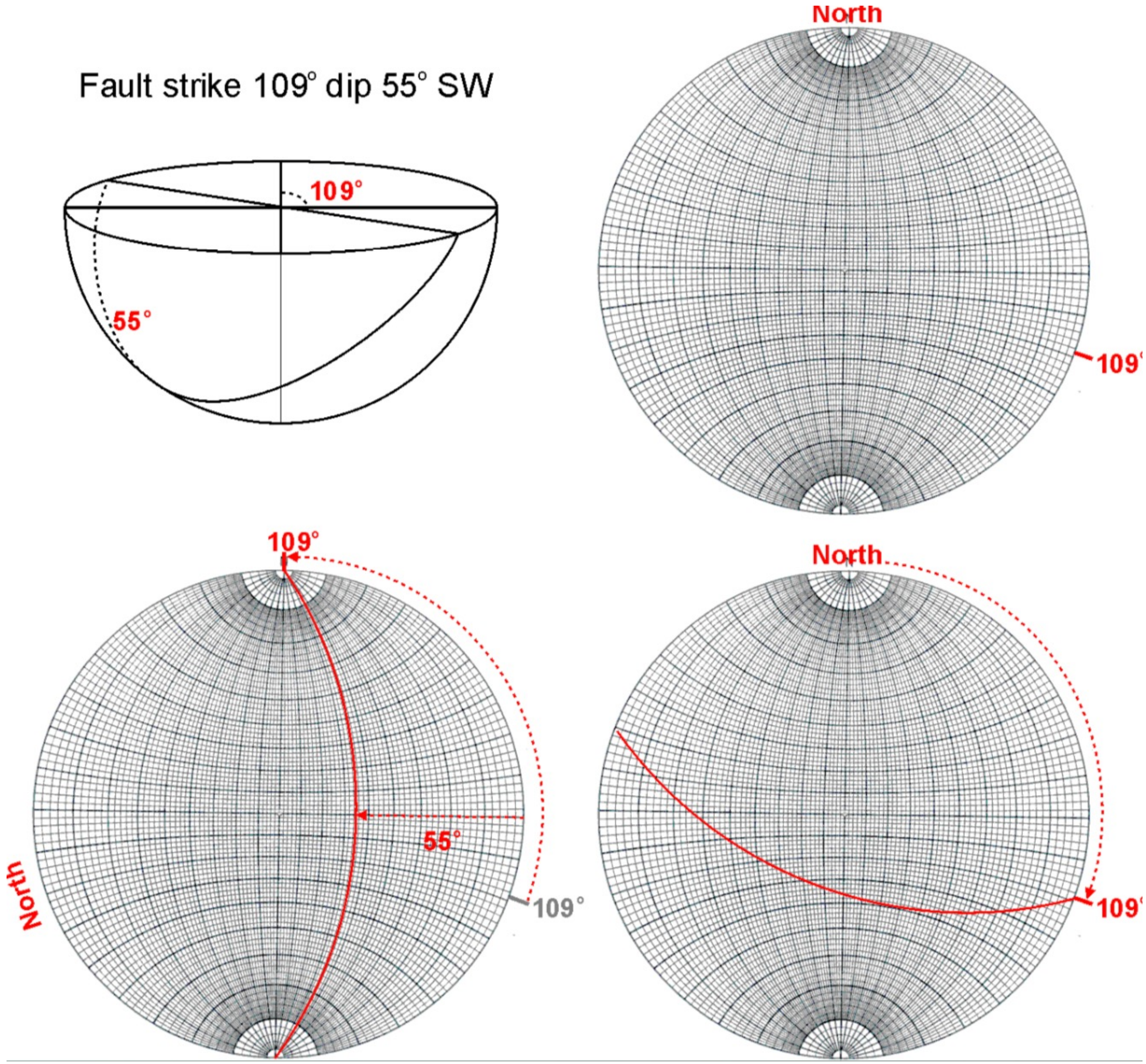


The lower hemisphere stereographic projection is illustrated in the middle figure.

Azimuth from North is the angle along the outer circle of the steronet.

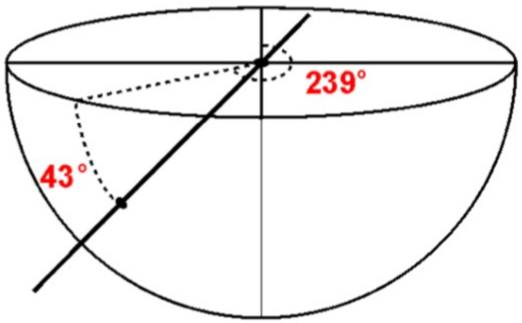
Take-off angle is angle with vertical, it is the angle from the center of the stereonet.

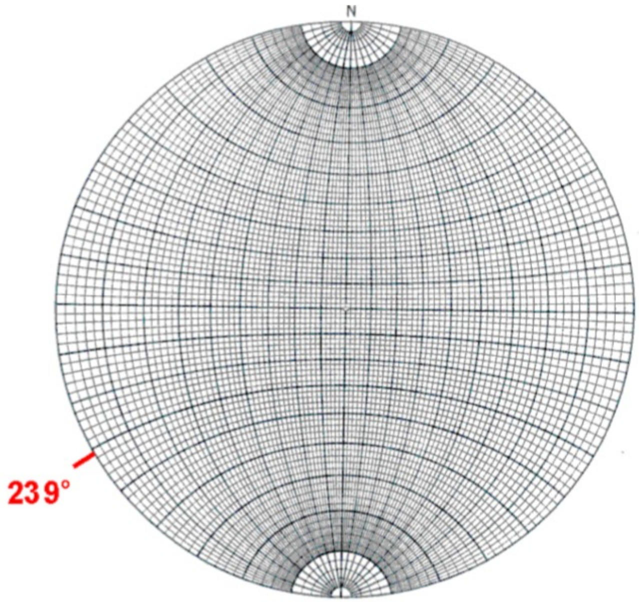
Stereonet projection of a plane



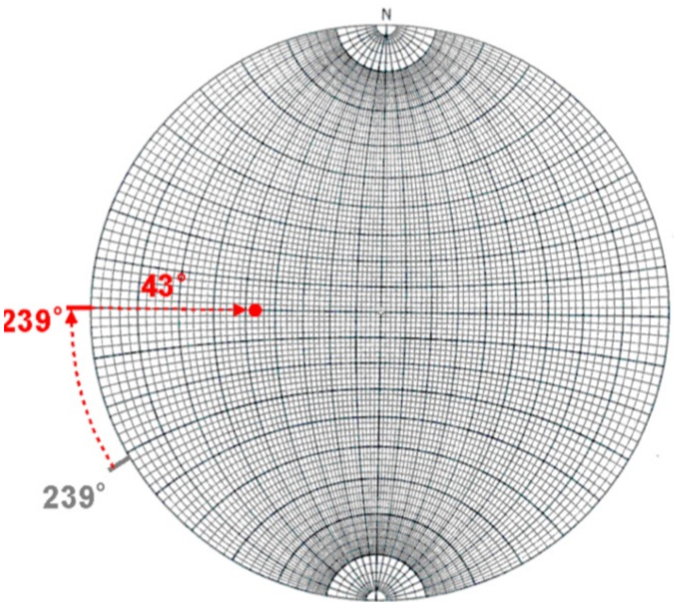
Stereonet projection of a line

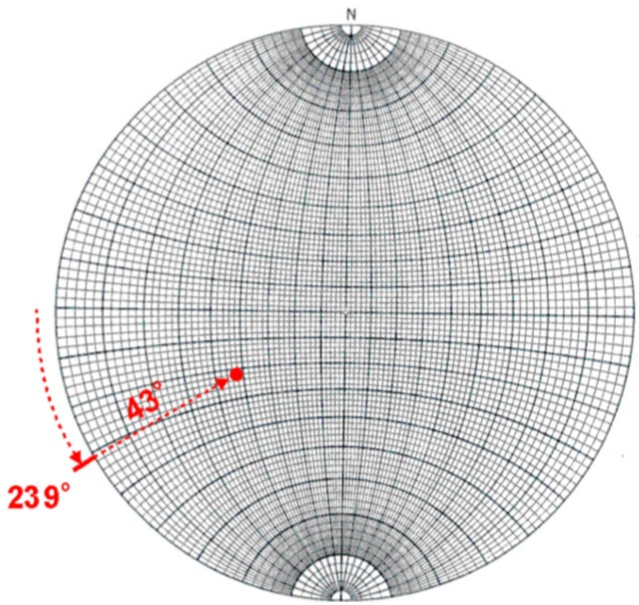
Azimuth 239°, dip 43°





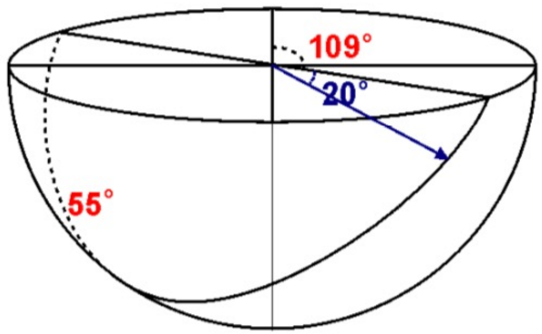
(Note that take-off angle is angle w.r.t. vertical)

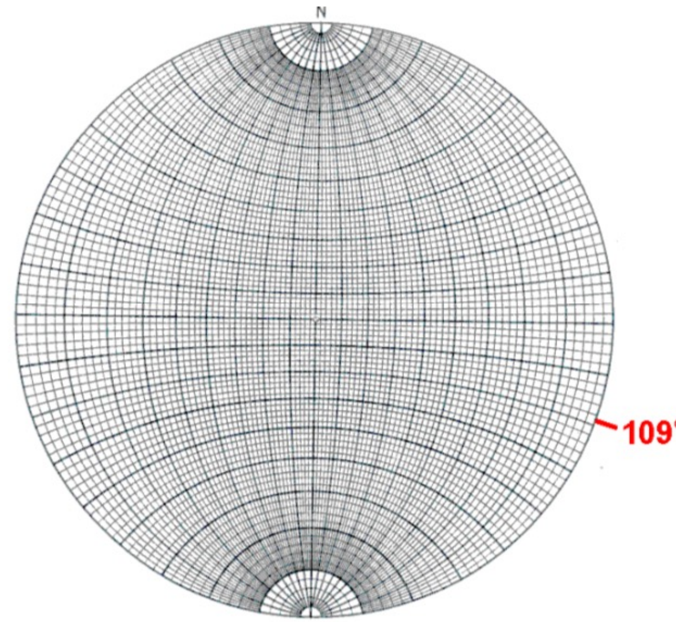


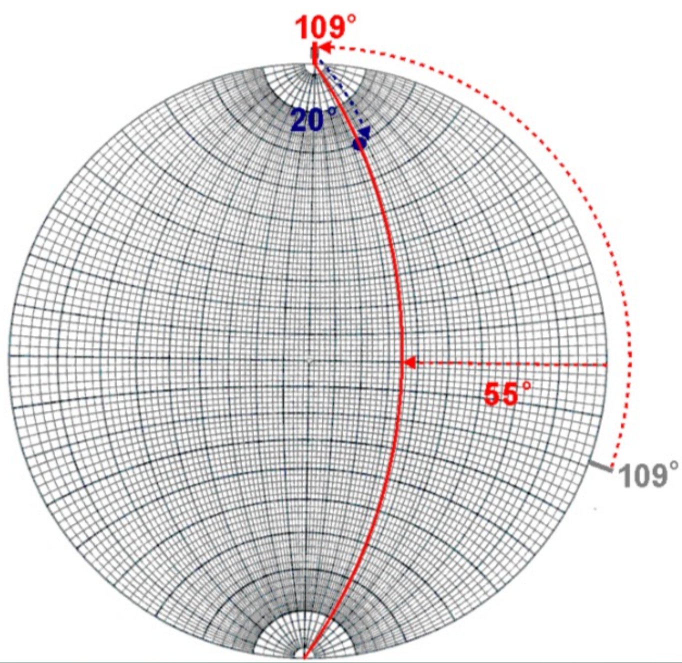


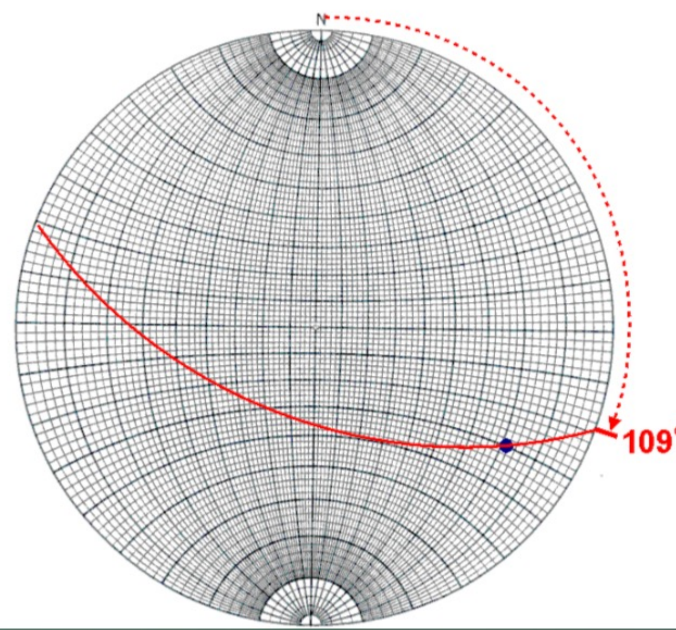
Stereonet projection of a rake

Strike 109°, dip 55º, rake -20º

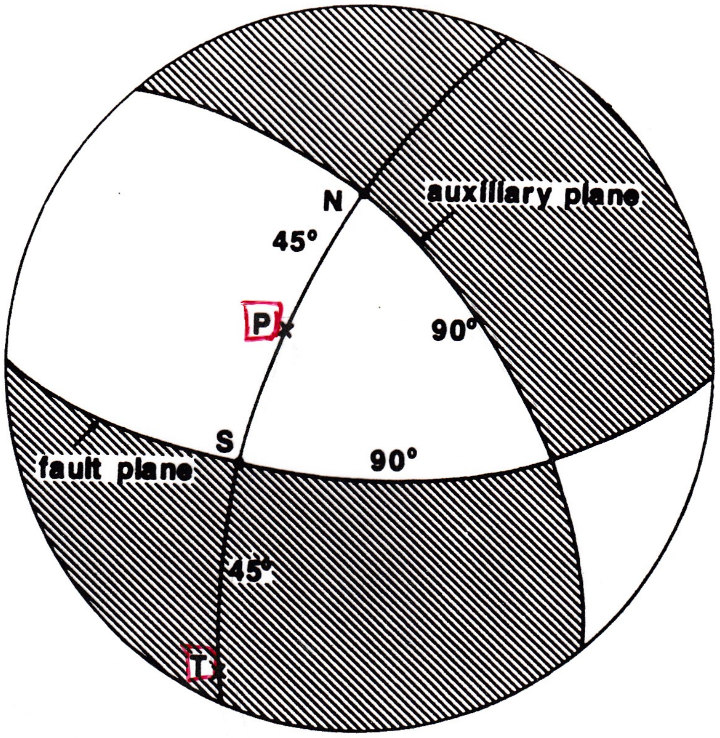








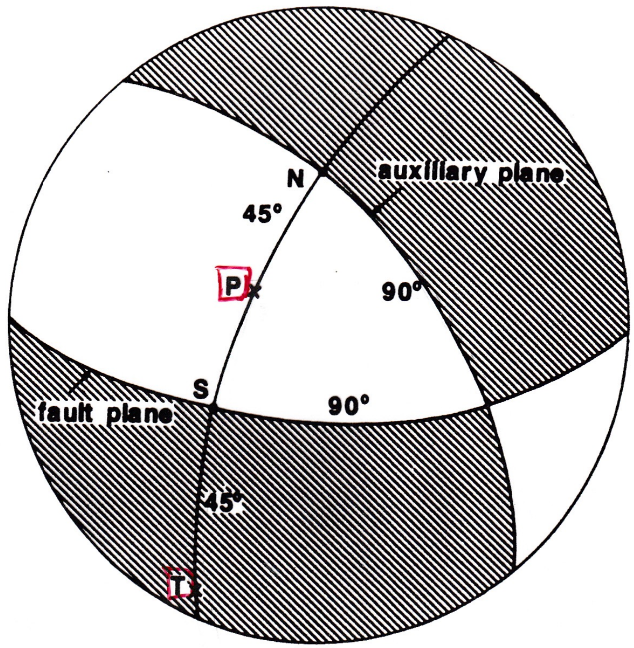
Stereographic projection



Determine 2 nodal planes that separate compressions and dilatations in 4 quadrants. The nodal planes should be perpendicular to each other.

The quadrants with compressions are black, the quadrants with dilatations are white.
The result is often called a 'beach ball'.

Beach ball

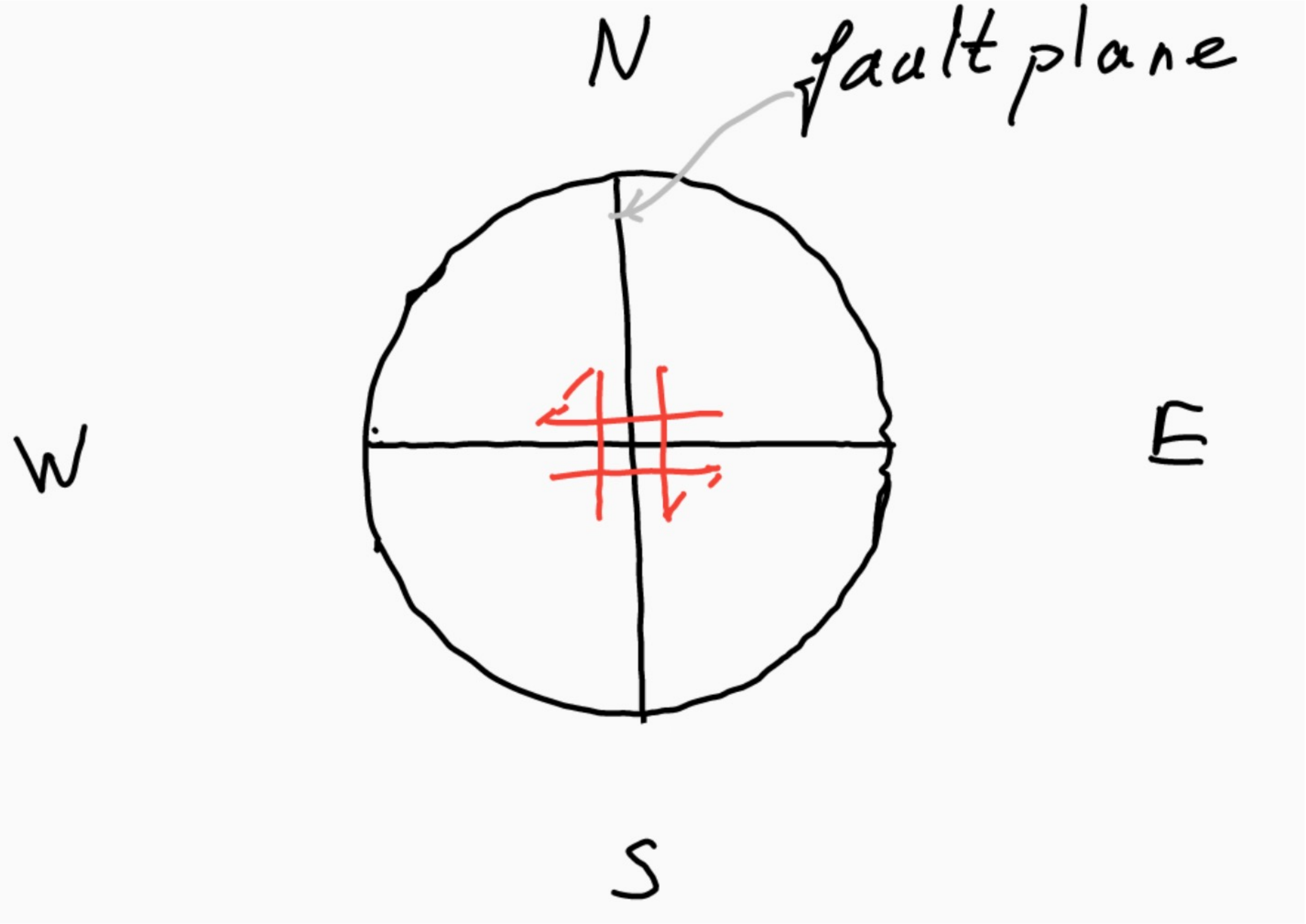


The N axis is given by intersection of the two nodal planes.

The P and T axis are perpendicular to the N axis.
They have an angle of 45° with the nodal planes.

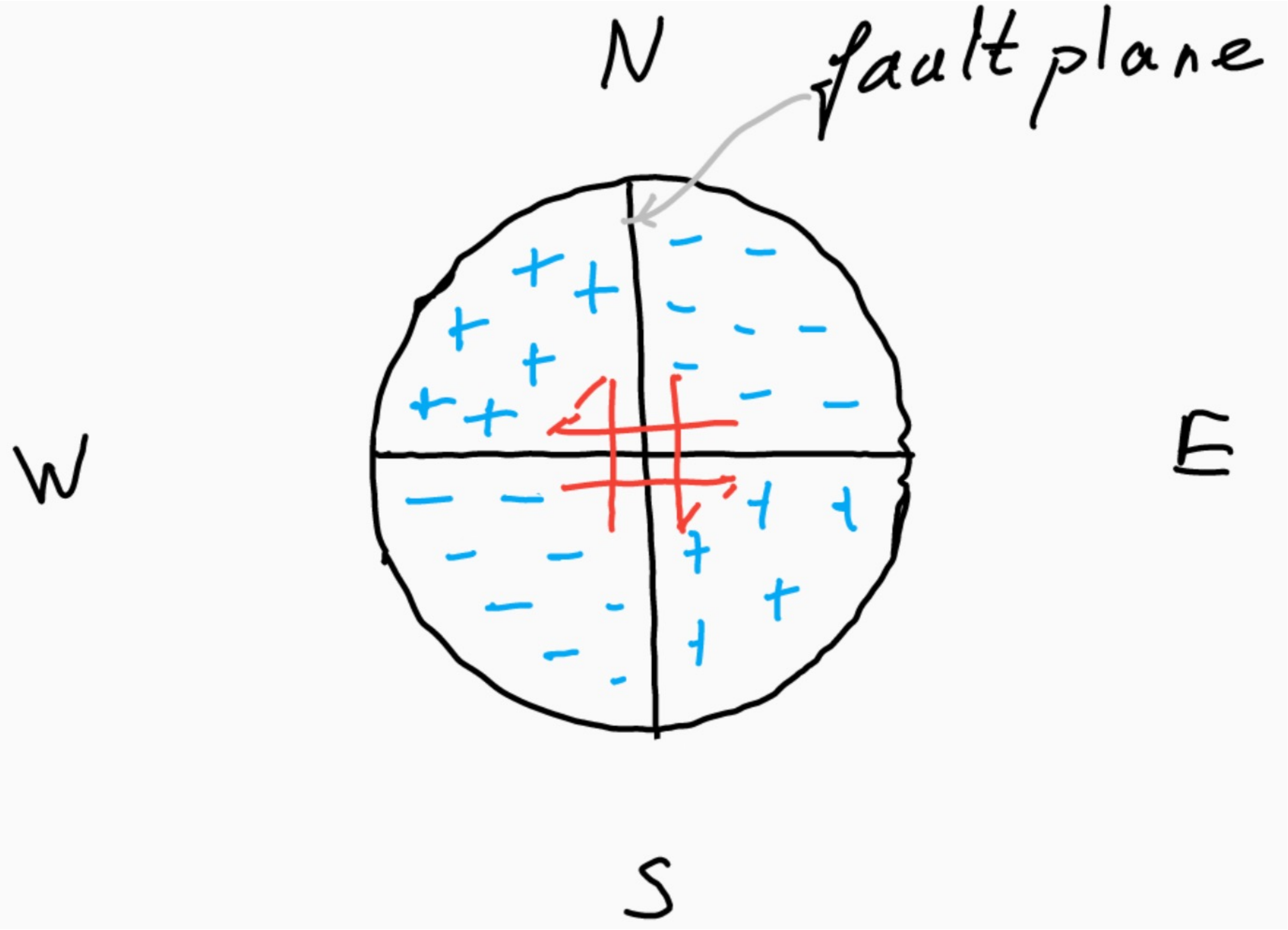
The P axis lies in the quadrant with dilatations,
the T axis in the quadrant with compressions.

Focal mechanism strike-slip earthquake



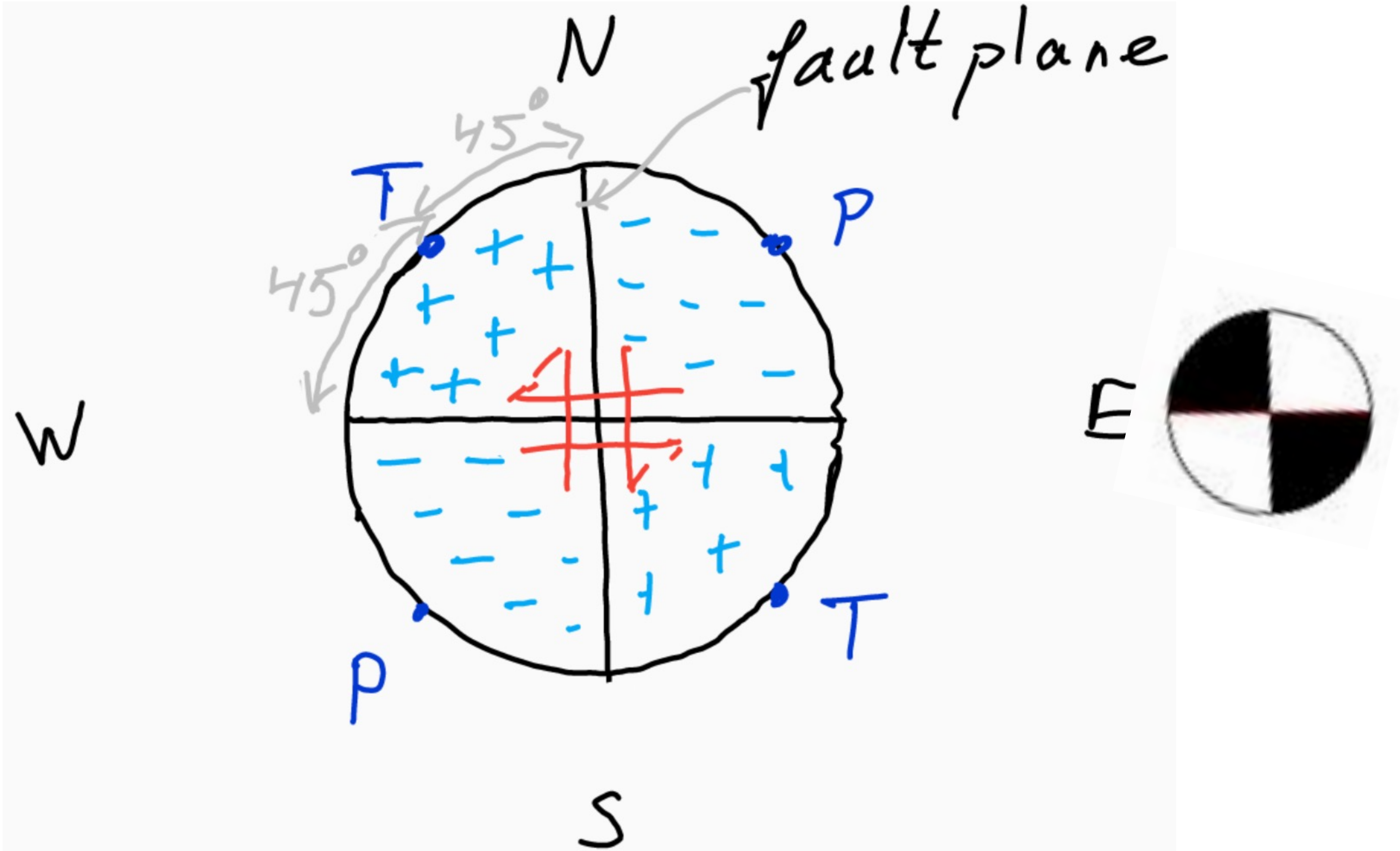
Right-lateral strike slip earthquake with vertical fault plane and strike of 0º (North).

Focal mechanism strike-slip earthquake



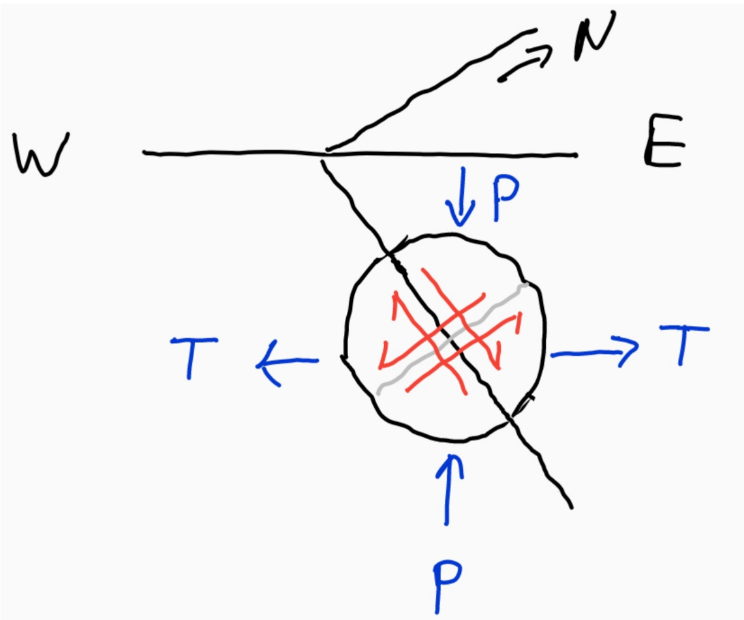
Right-lateral strike slip earthquake with vertical fault plane and strike of 0º (North).

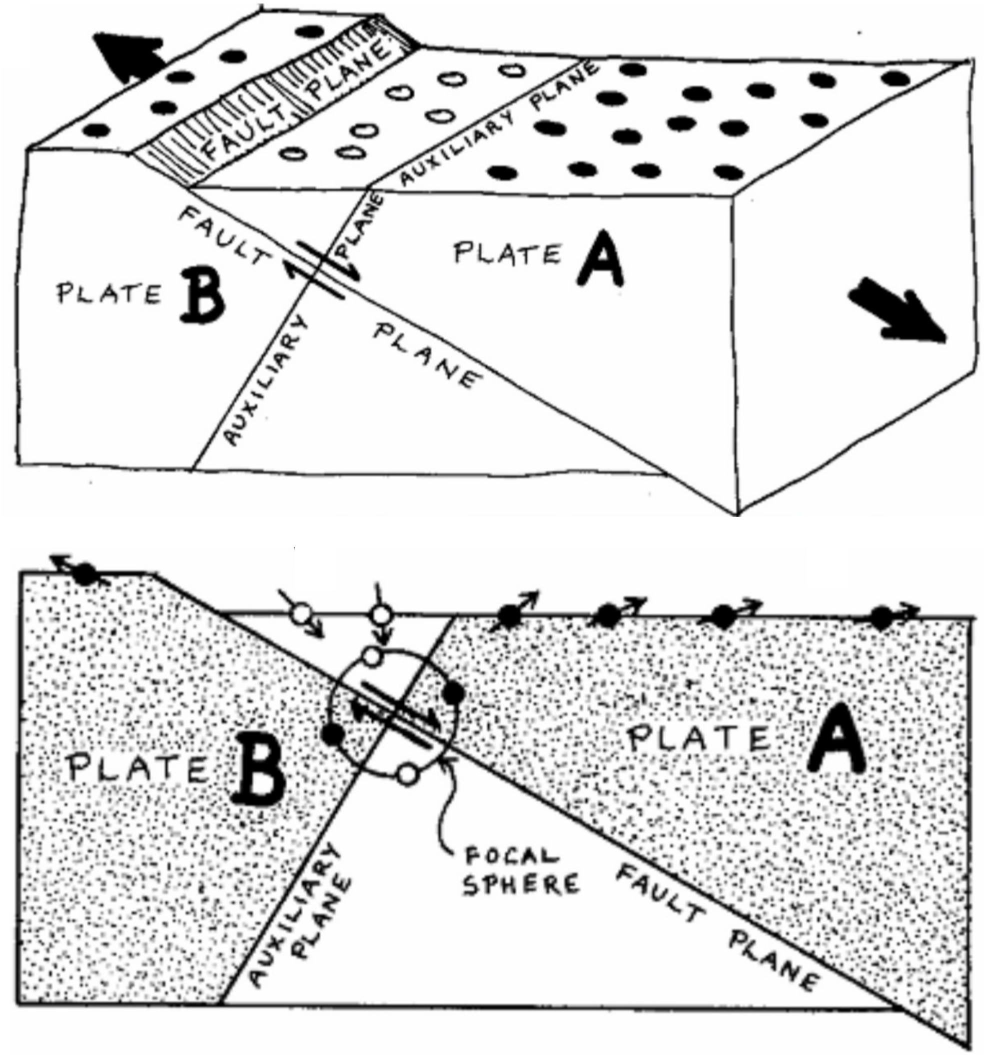
Focal mechanism strike-slip earthquake



Right-lateral strike-slip earthquake with vertical fault plane and strike of 0º (North).

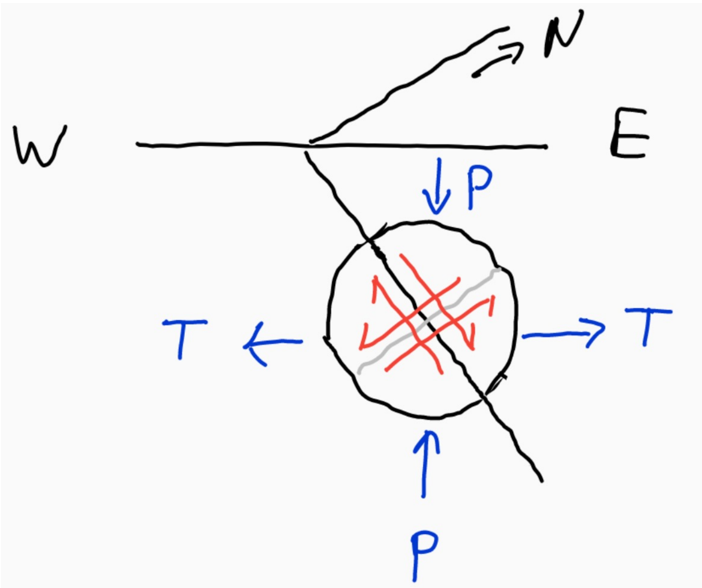
Focal mechanism normal fault



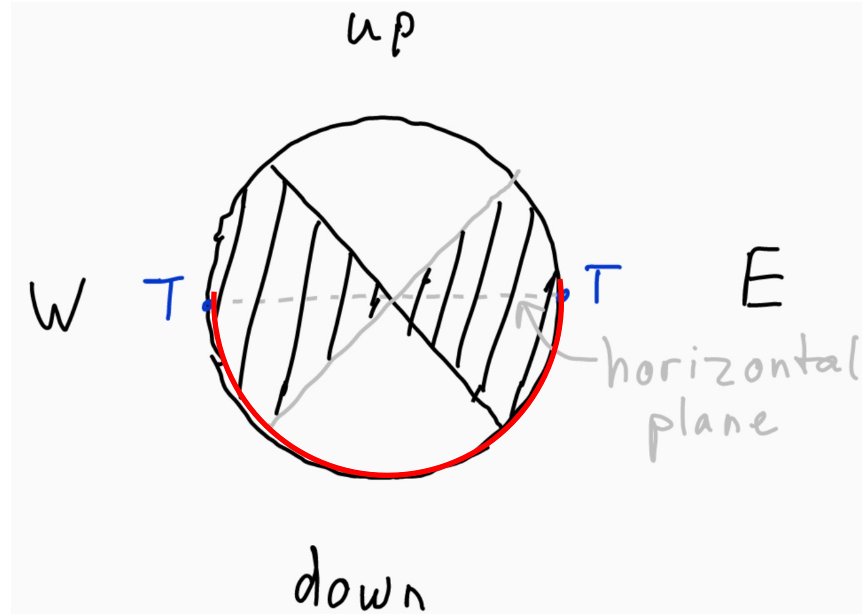


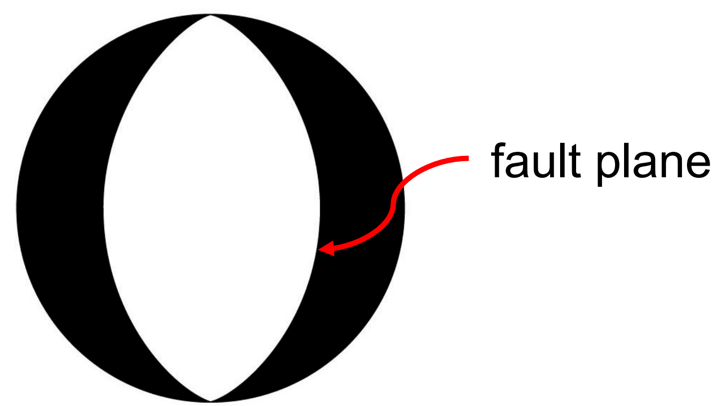
Normal fault with a strike of 0º (North) and a dip of 45º

Focal mechanism normal fault



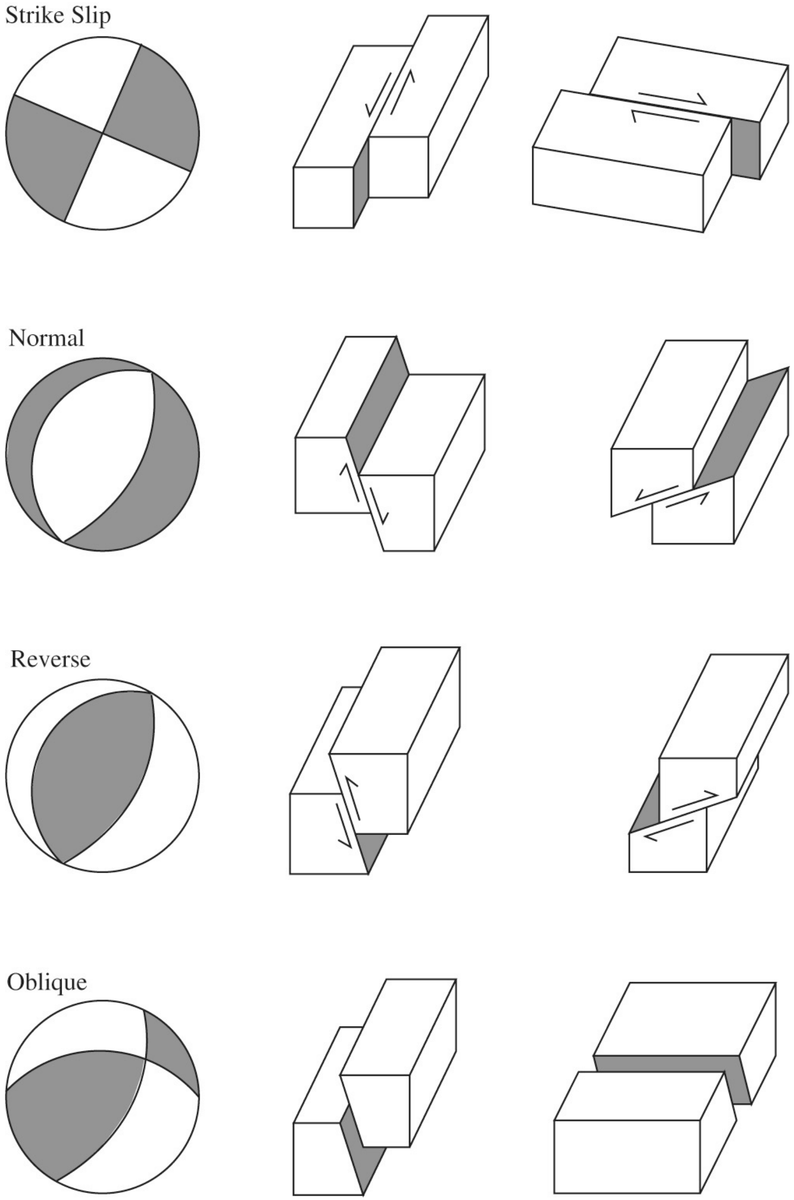
Side view of beach ball

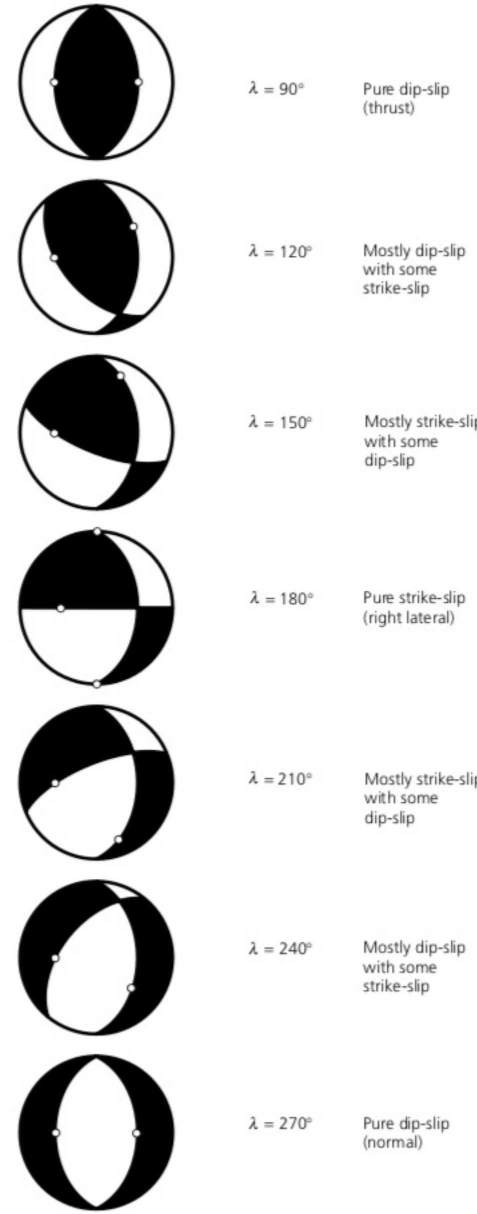




Focal mechanism

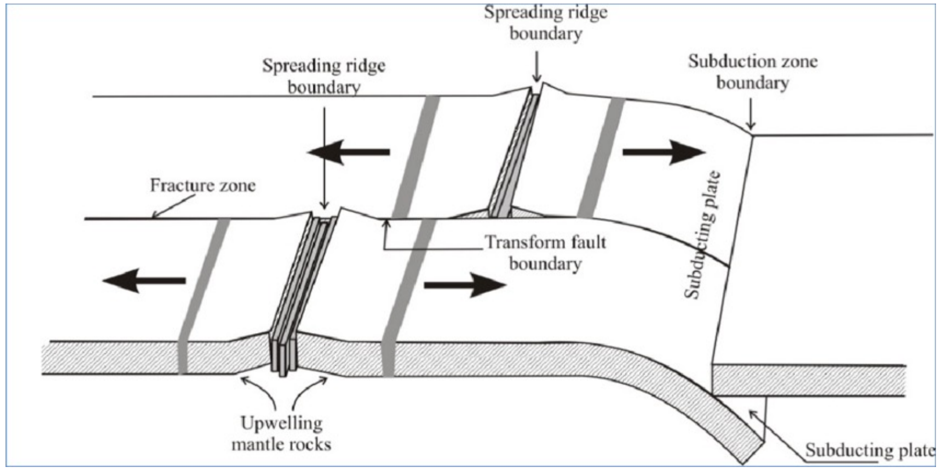
Focal mechanisms various types of faults

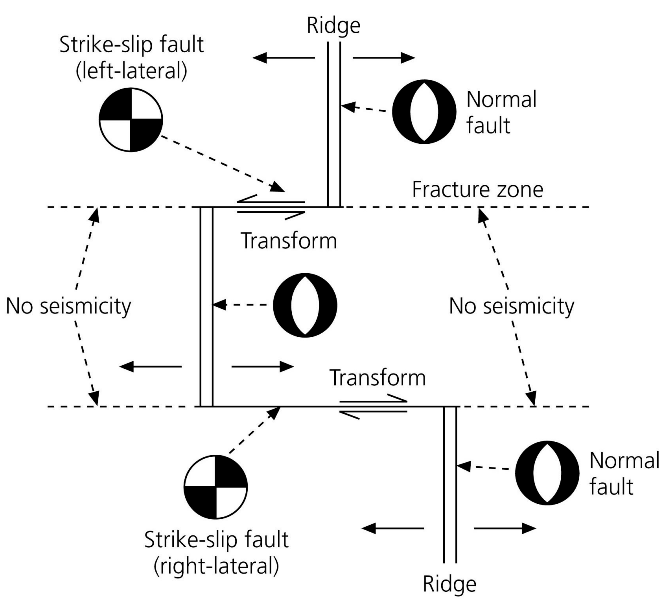


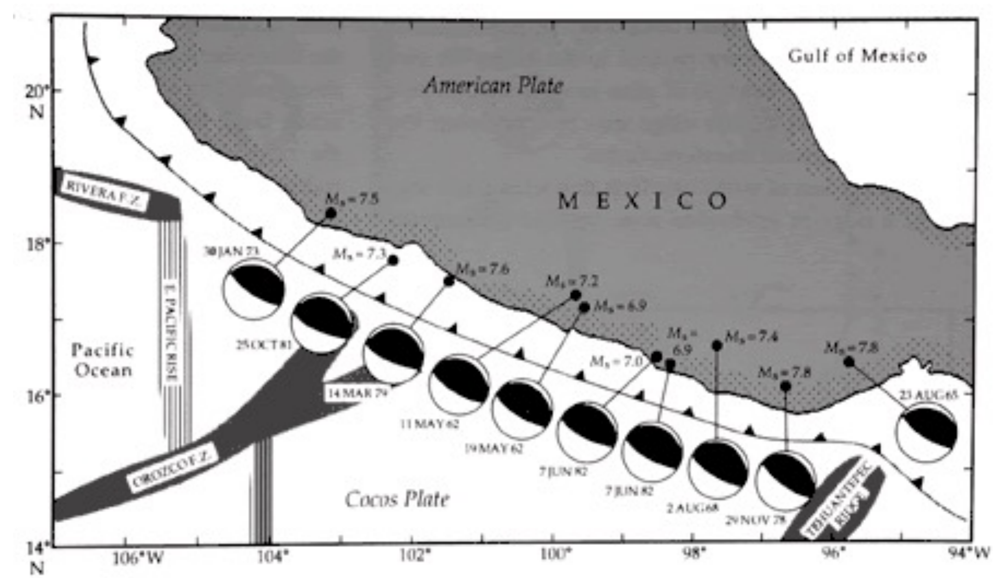


Same NS fault plane, different rakes

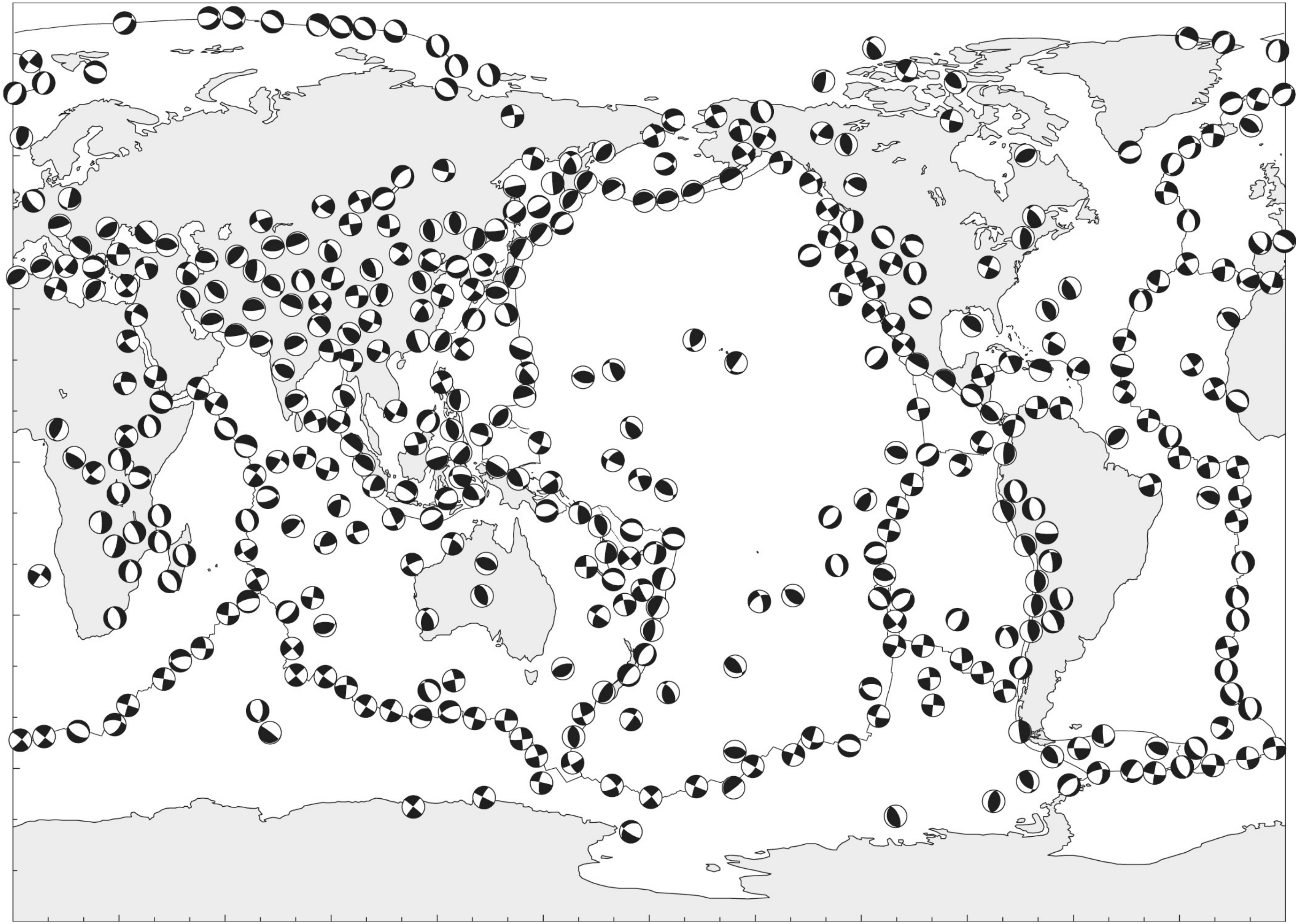
Focal mechanisms and plate tectonics





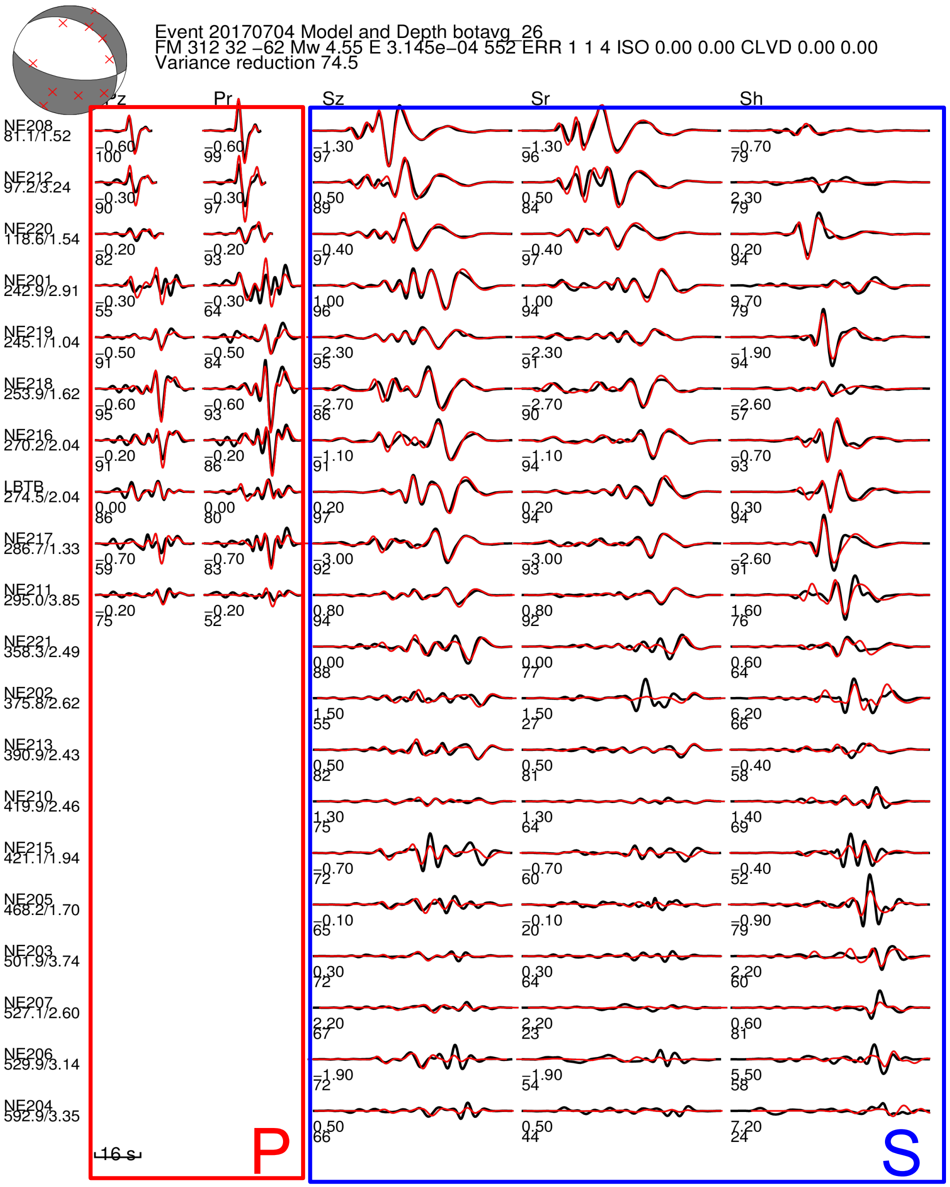


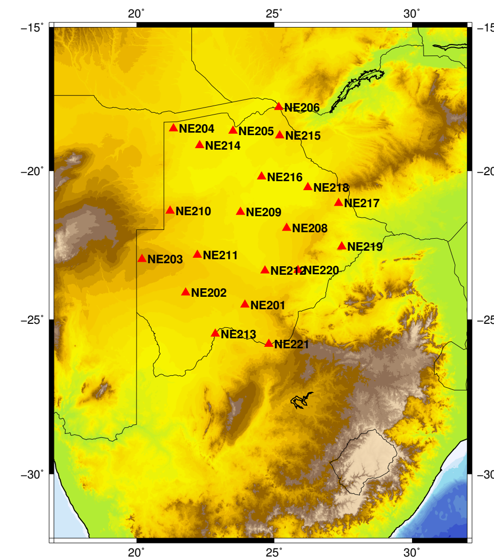
Focal mechanisms around the world

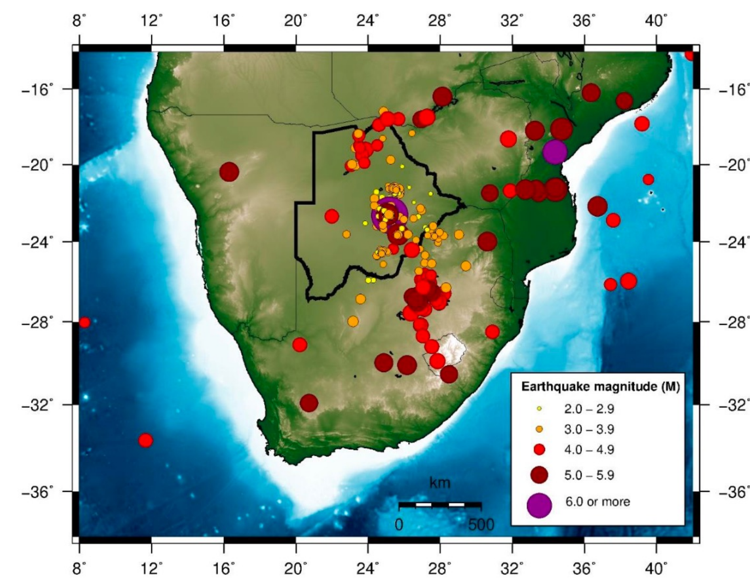


Shearer (2009)

Focal mechanisms from waveforms







Waveforms better constrain focal mechanisms: seismic network Botswana