Seismotectonics

Seismic moment and magnitude

- Fault scarps
- Elastic rebound
- Richter scale
- Energy of earthquakes
- Seismic moment
- Fault area, horizontal slip

Fault plane solutions

- Fault displacement and double couple
- Source radiation pattern
- Beach balls
- Fault plane solutions

Fault scarps

California

Fault scarps

Grand Canyon

Fault scarps

California

Fault scarps

California

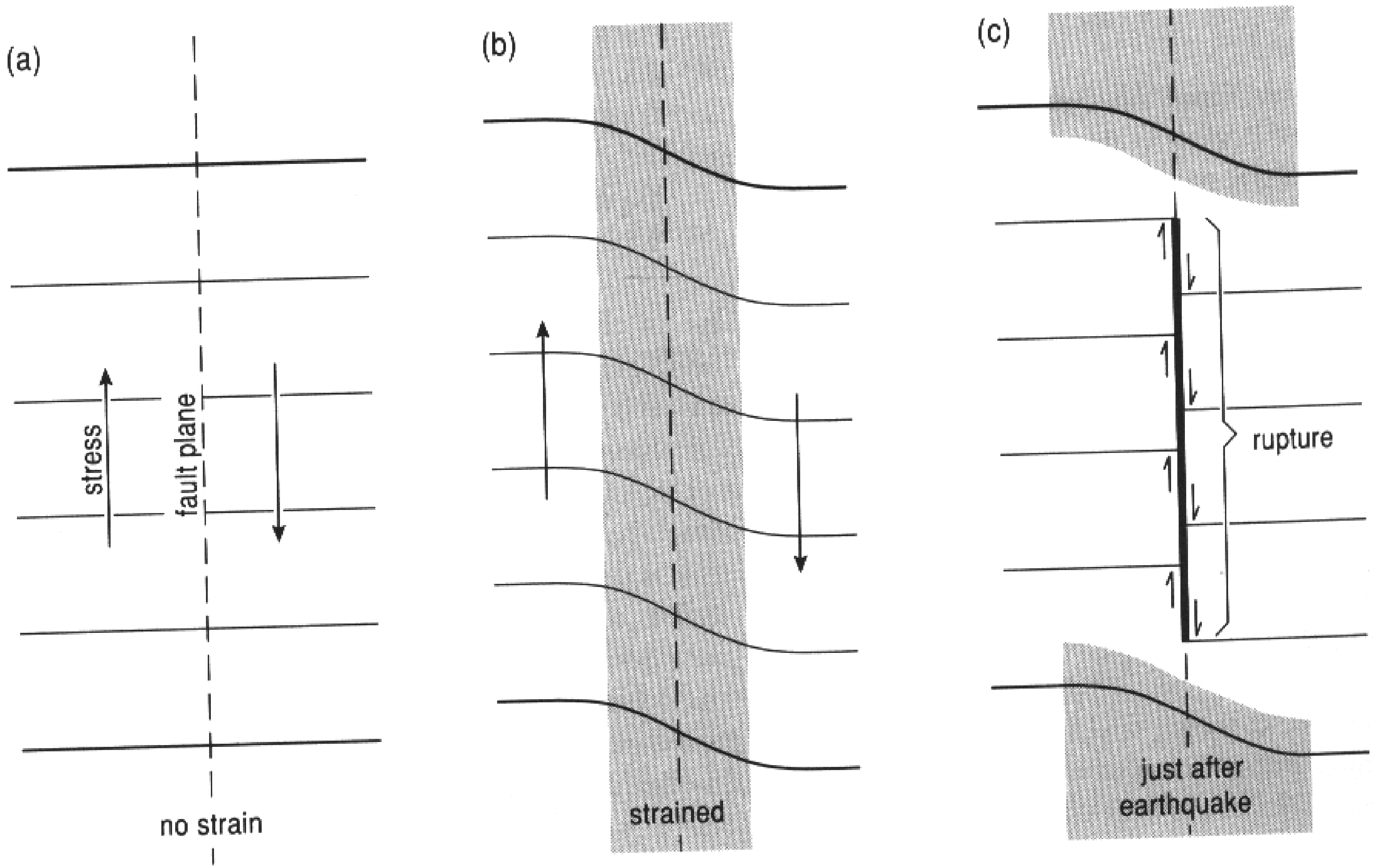
Fault scarps

Taiwan

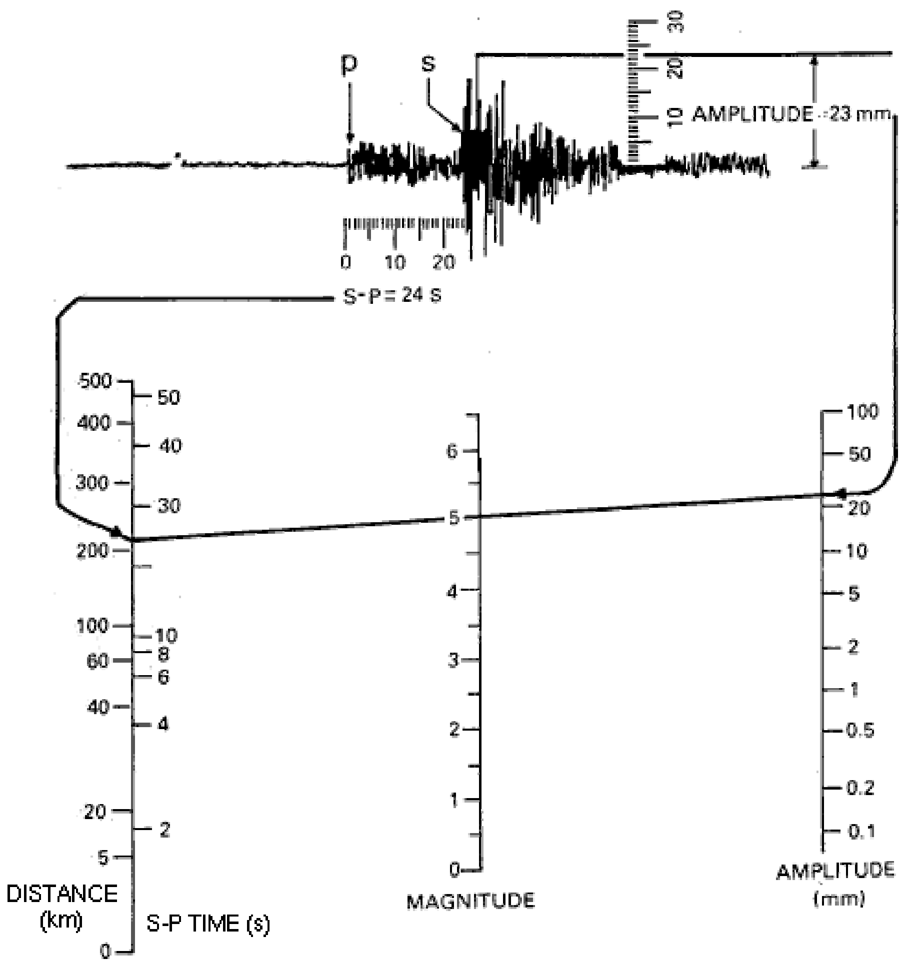
Fault scarps

Taiwan

Elastic rebound



Richter Scale



Determination of the magnitude of an earthquake graphically.

$$M_L = \log_{10} A(mm) + (\text{Distance correction factor})$$

Seismic moment

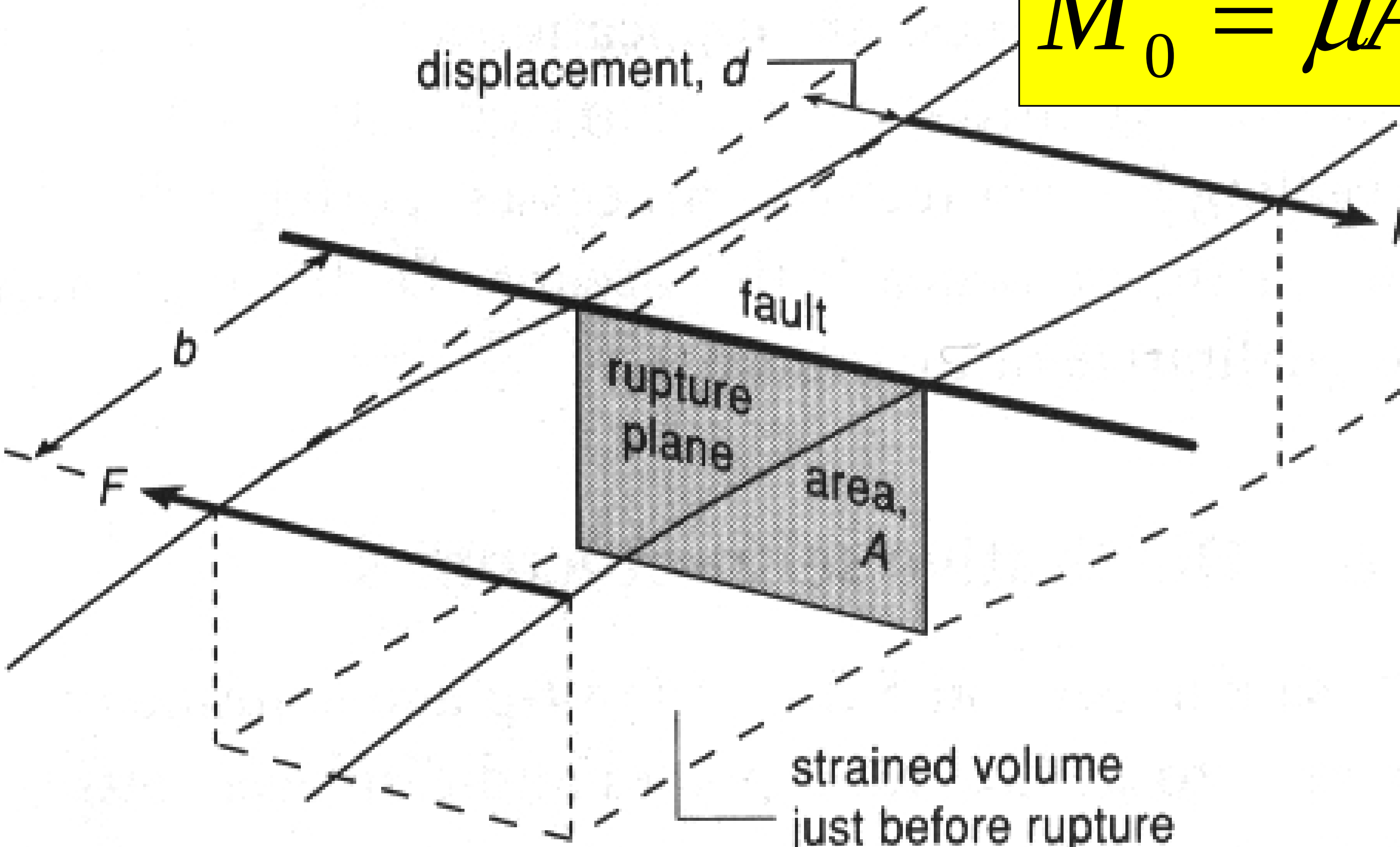
Seismologists measure the size of an earthquake using the concept of seismic moment. It is defined as the force times the distance from the center of rotation (torque). The moment can be expressed suprisingly simple as:

$$M_0 = \mu A d$$

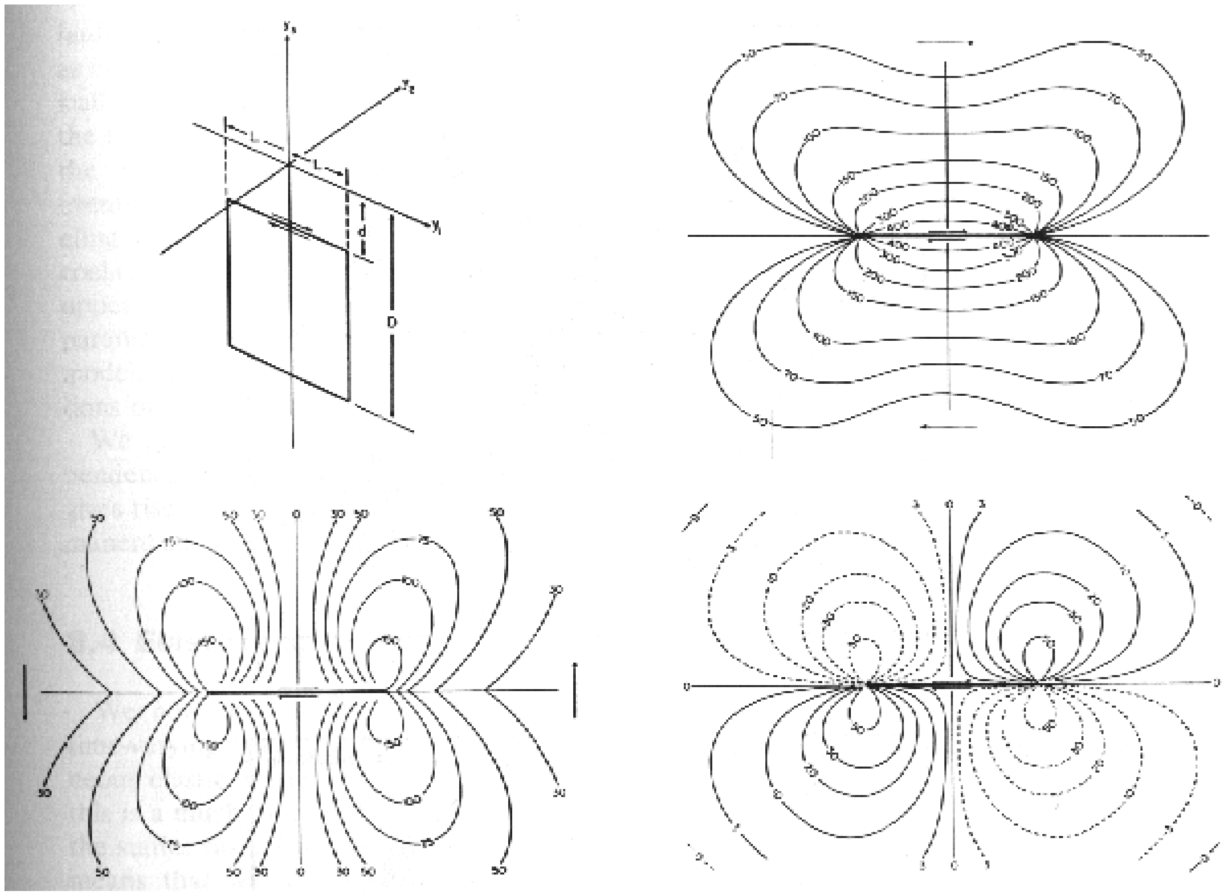
M_0 seismic moment
μ Rigidity
A fault area
d slip/displacement

Seismic moment

$$M_0 = \mu A d$$



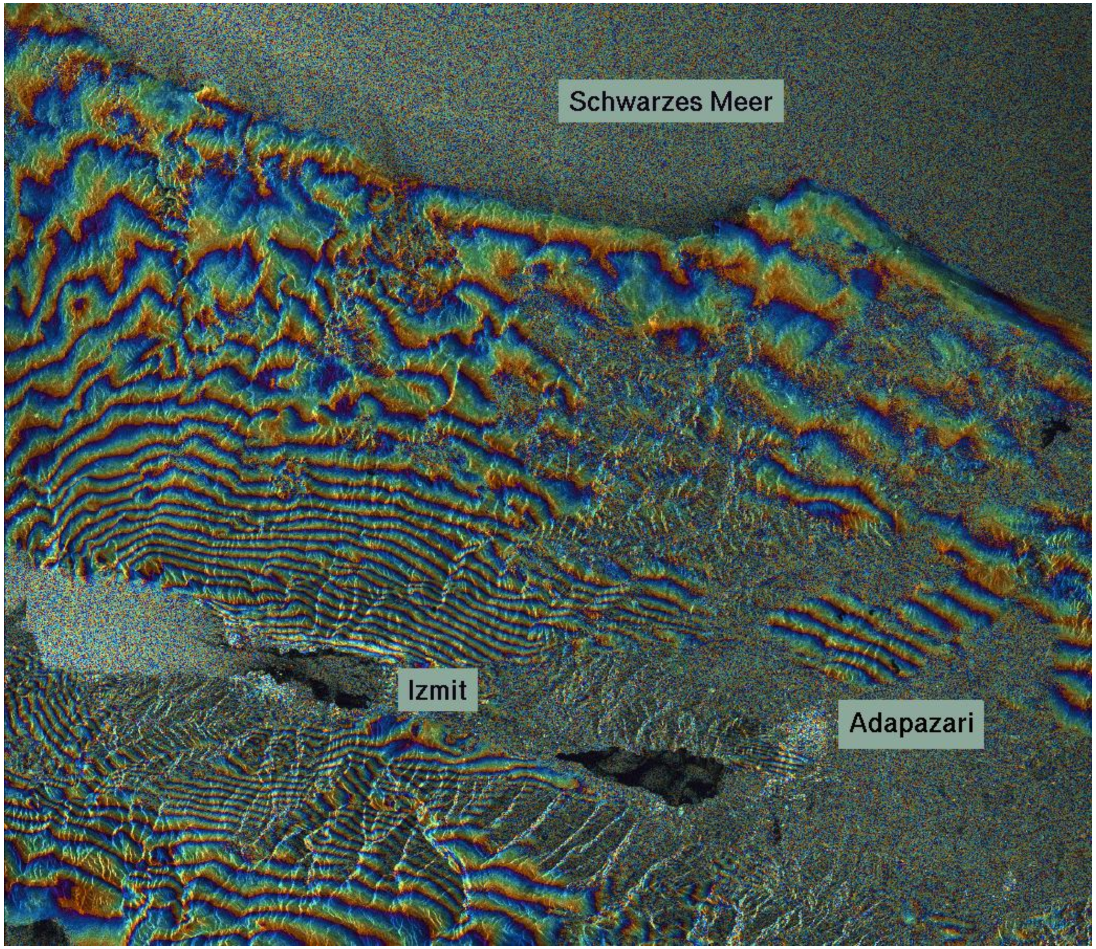
Static Displacements



Ground displacement at the surface of a vertical strike slip.

Top right: fault parallel motion
Lower left: fault perpendicular motion
Lower right: vertical motion

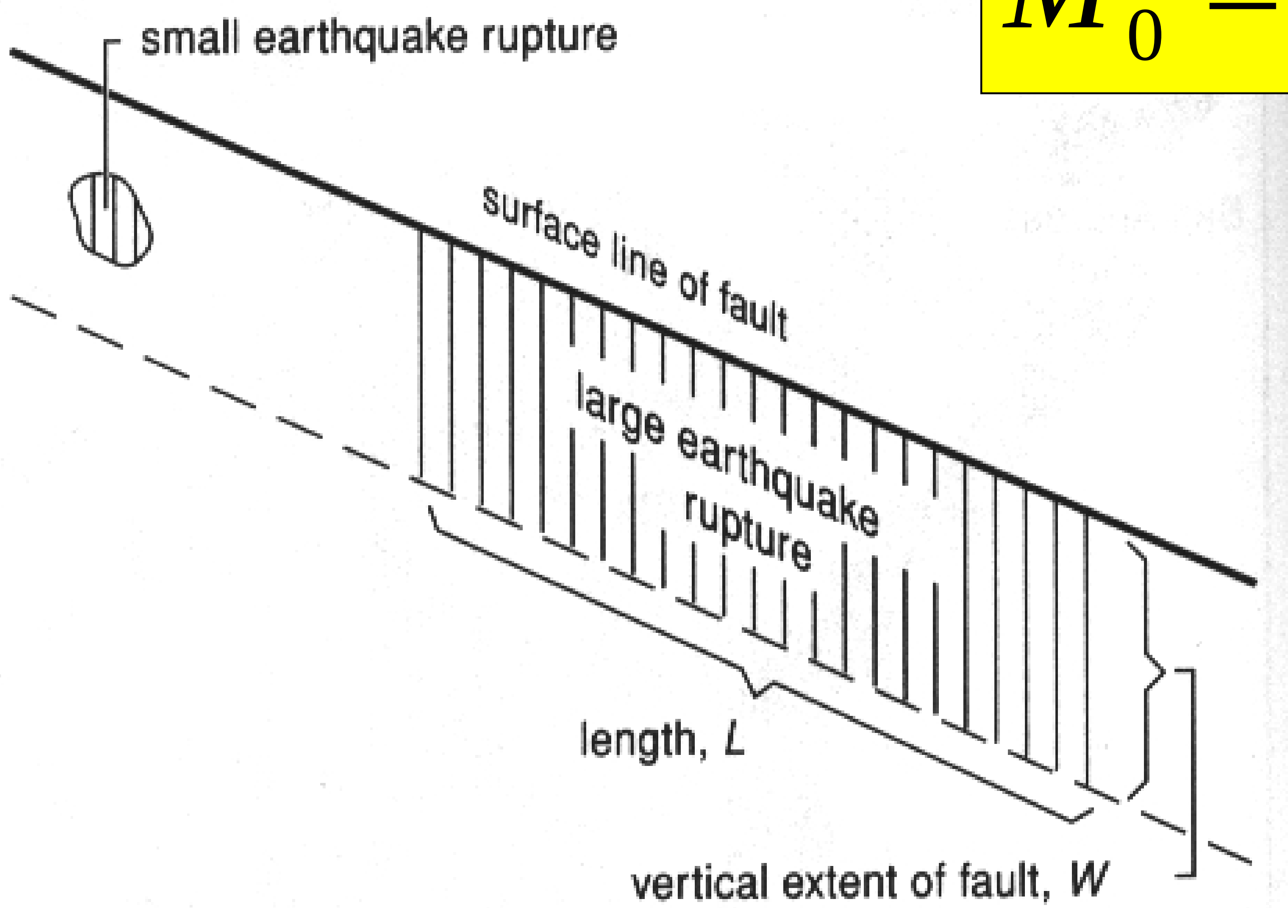
Static Displacements



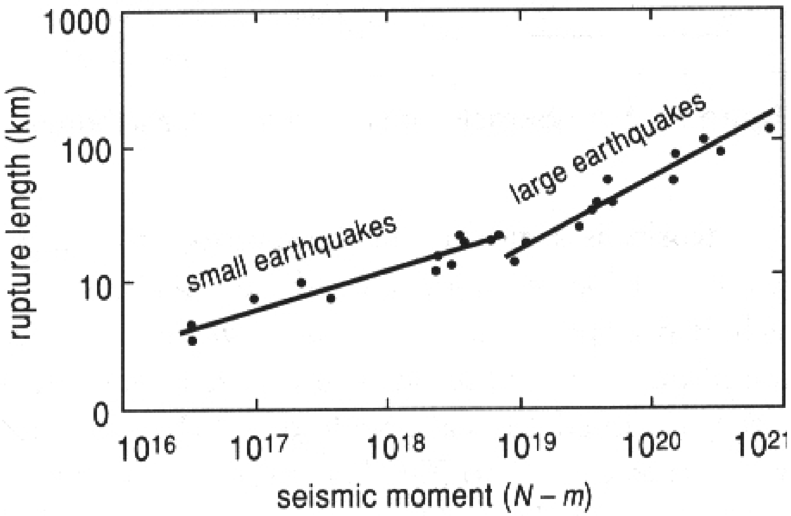
Displacements after Turkey earthquake 1999.

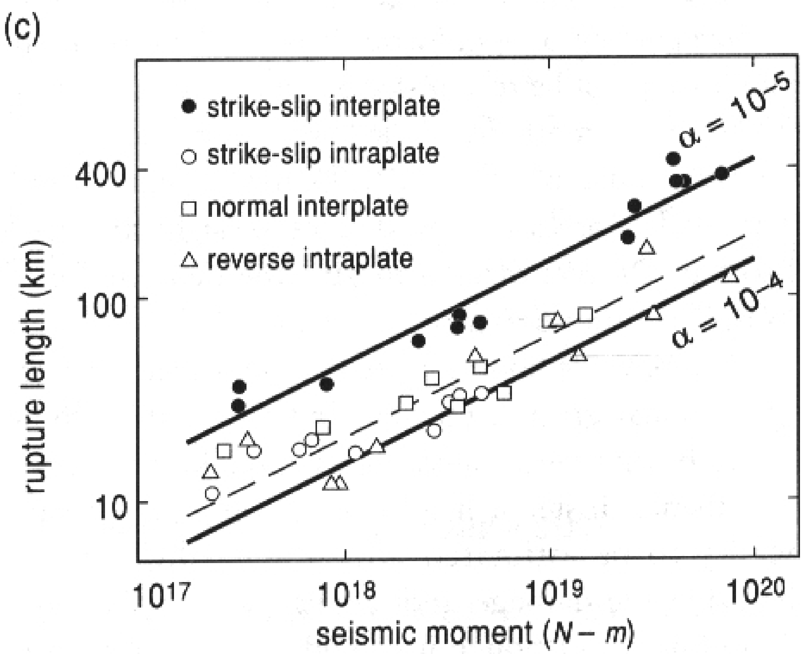
Seismic moment

$$M_0 = \mu A d$$



Seismic moment





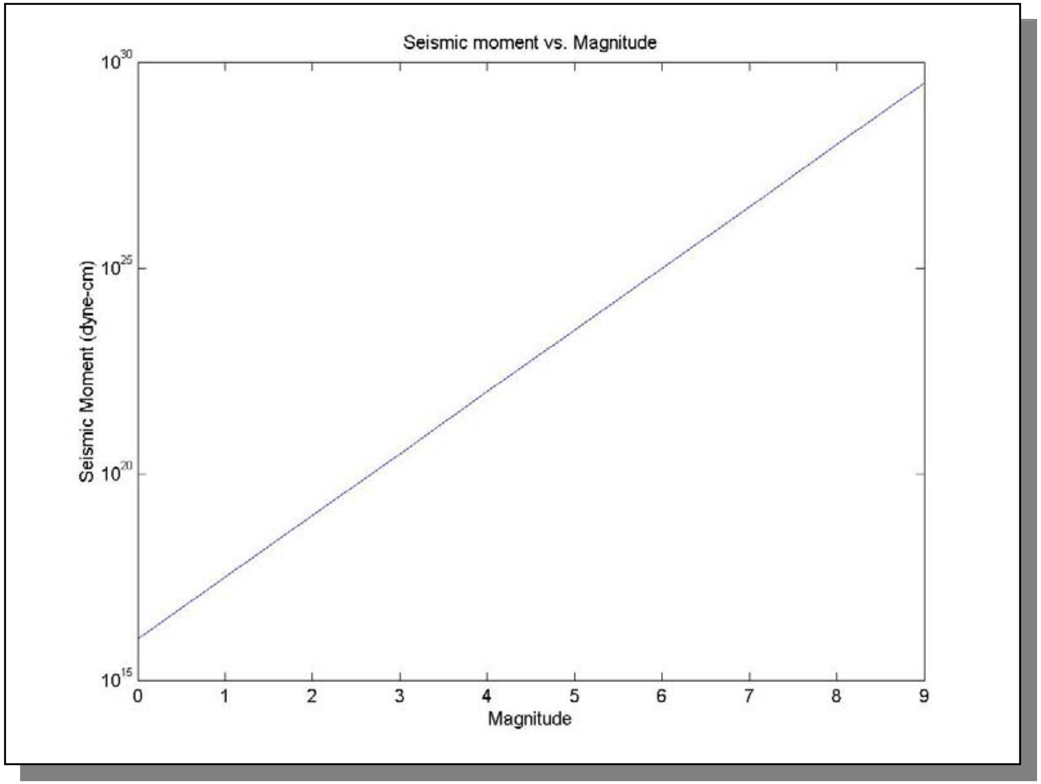
$$M_0 = \mu A d$$

There are differences in the scaling of large and small earthquakes

Seismic moment - magnitude

There is a standard way of converting the seismic moment to magnitude M_w:

$$M_w = \frac{2}{3}\left[\log_{10} M_0(dyne-cm) - 16.0\right]$$



Seismic energy

Richter developed a relationship between magnitude and energy (in ergs)

$$\boxed{\log E_S = 11.8 + 1.5M}$$

... The more recent connection to the seismic moment (dyne-cm) (Kanamori) is

$$\boxed{Energy = Moment / 20000}$$

Seismic energy (Examples)

Richter Magnitude	TNT for Seismic Energy Yield	Example (approximate)
-1.5	6 ounces	Breaking a rock on a lab table
1.0	30 pounds	Large Blast at a Construction Site
1.5	320 pounds	
2.0	1 ton	Large Quarry or Mine Blast
2.5	4.6 tons	
3.0	29 tons	
3.5	73 tons	
4.0	1,000 tons	Small Nuclear Weapon
4.5	5,100 tons	Average Tornado (total energy)
5.0	32,000 tons	
5.5	80,000 tons	Little Skull Mtn., NV Quake, 1992
6.0	1 million tons	Double Spring Flat, NV Quake, 1994
6.5	5 million tons	Northridge, CA Quake, 1994
7.0	32 million tons	Hyogo-Ken Nanbu, Japan Quake, 1995; Largest Thermonuclear Weapon
7.5	160 million tons	Landers, CA Quake, 1992
8.0	1 billion tons	San Francisco, CA Quake, 1906
8.5	5 billion tons	Anchorage, AK Quake, 1964
9.0	32 billion tons	Chilean Quake, 1960
10.0	1 trillion tons	(San-Andreas type fault circling Earth)
12.0	160 trillion tons	(Fault Earth in half through center, OR Earth's daily receipt of solar energy)

Fault plane solutions

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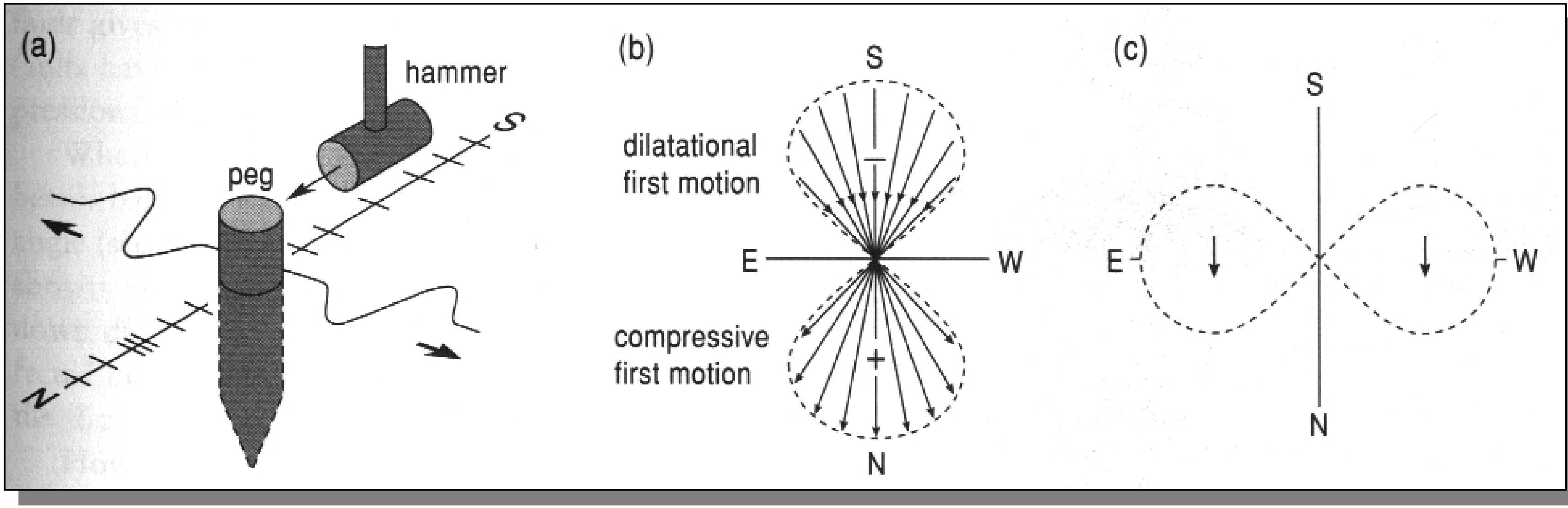
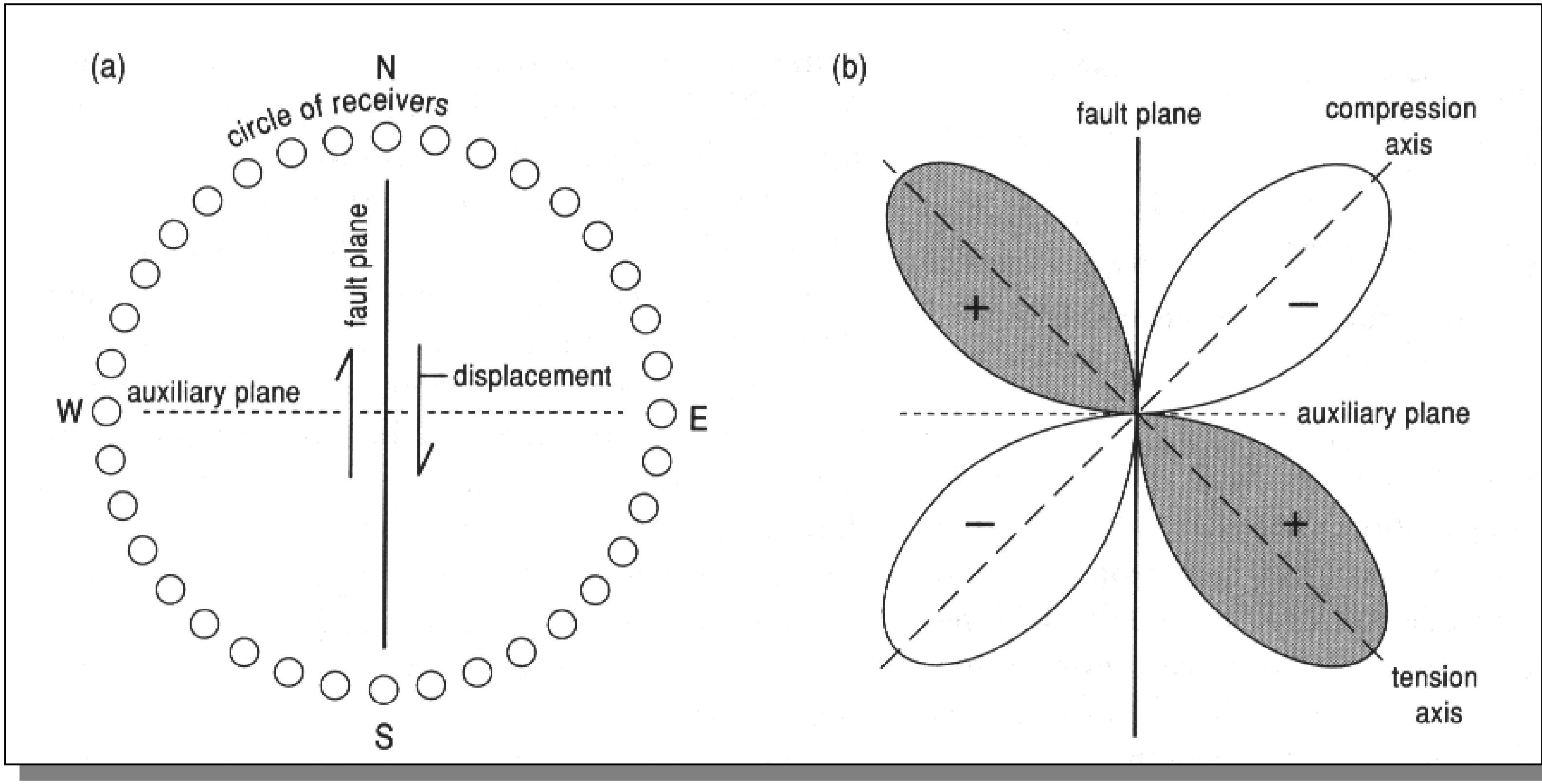
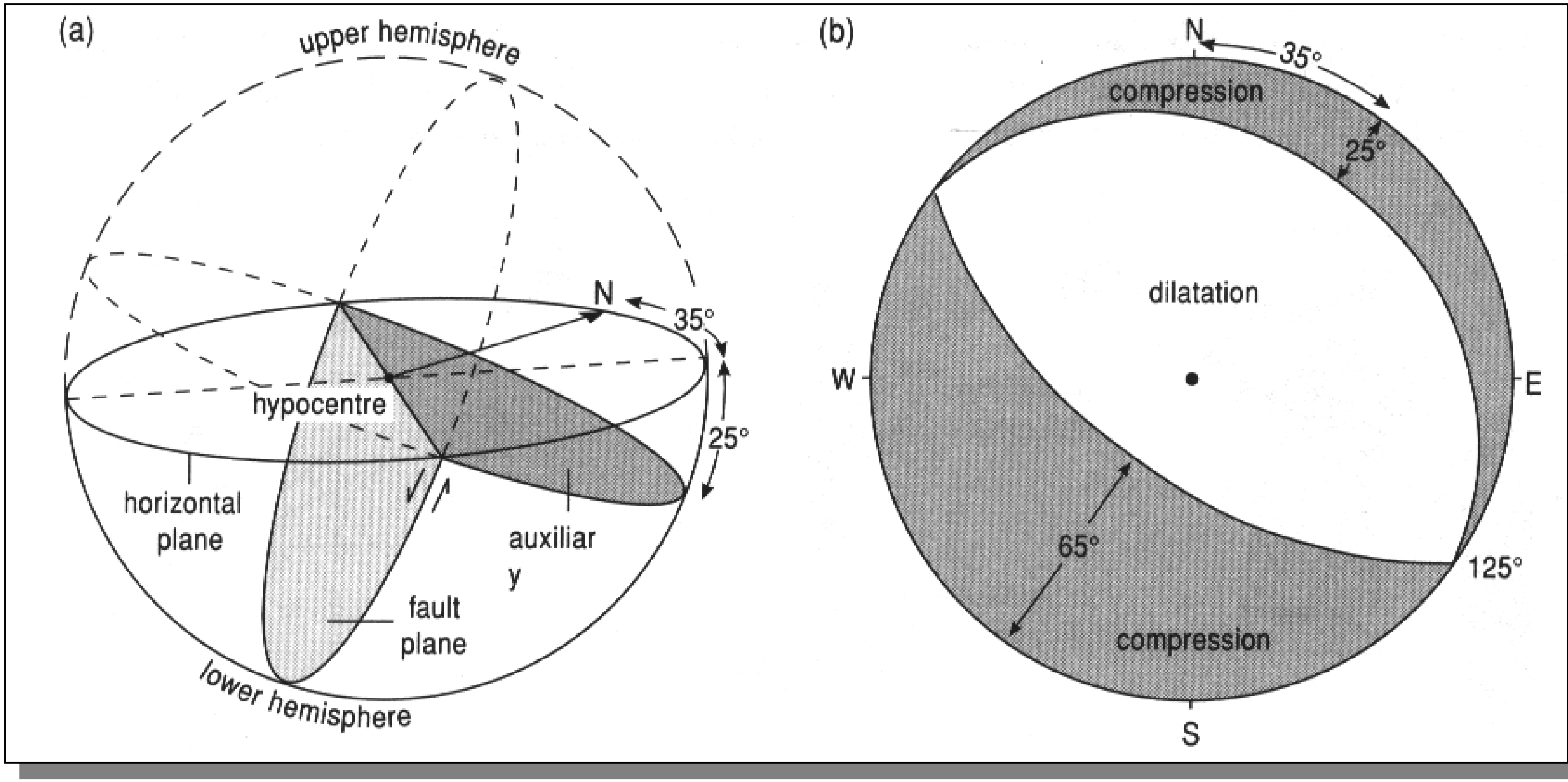


The radiation from seismic sources is in general strongly direction-dependent



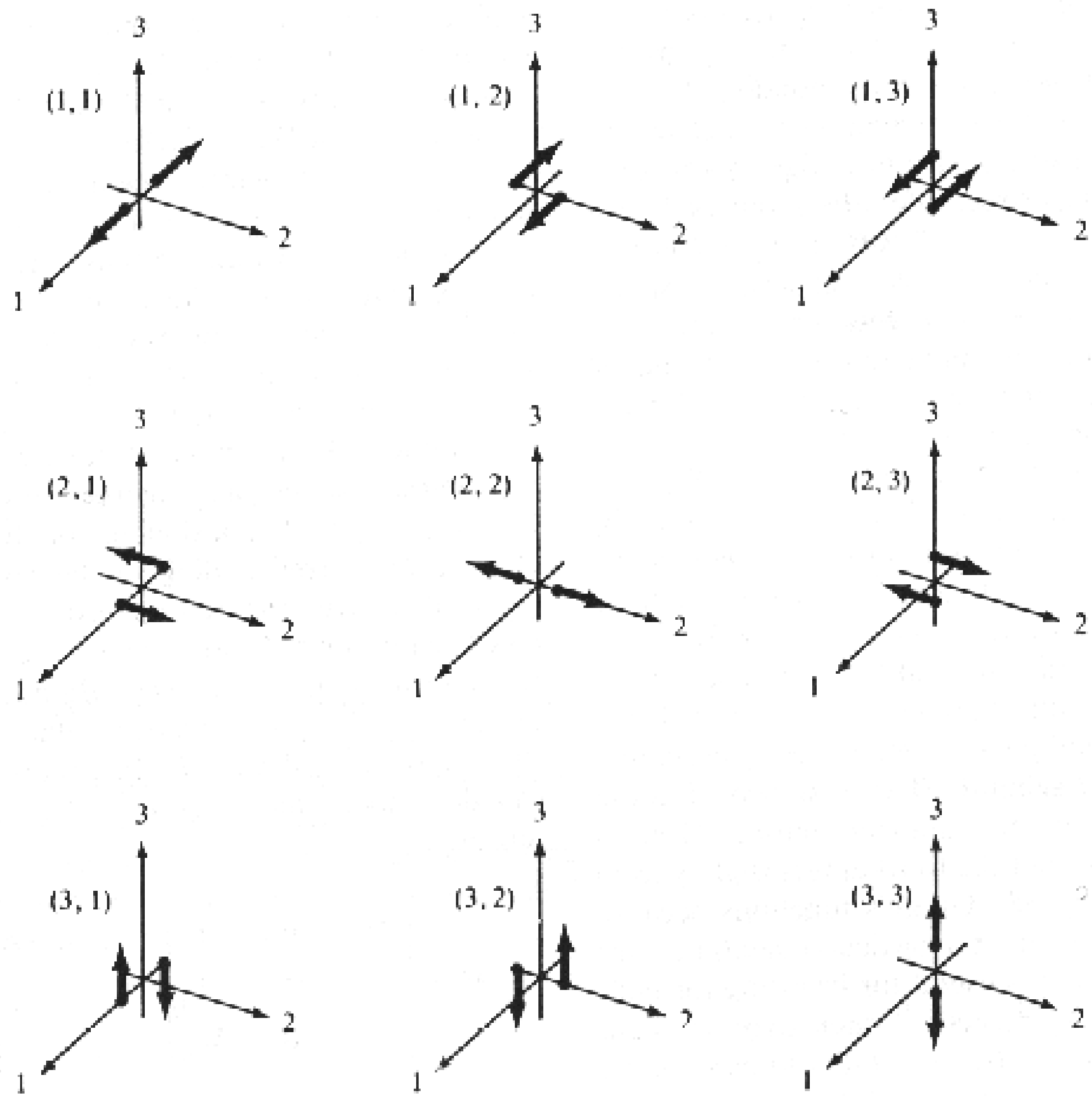
The basic physical model for a source is two fault planes slipping in opposite directions

Seismic sources



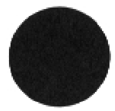
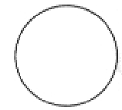
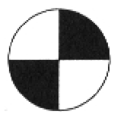
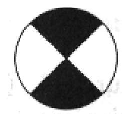
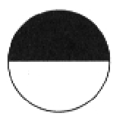
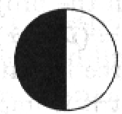
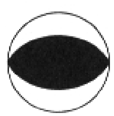
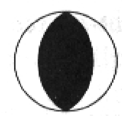
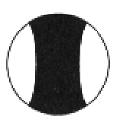
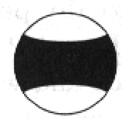
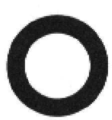
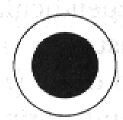
Our goal: find the **fault plane** and the **slip direction**

Moment tensor components



Point sources can be described by the seismic moment tensor M. The elements of M have clear physical meaning as forces acting on particular planes.

Beachballs and moment tensor

Moment Tensor	Beachball	Moment Tensor	Beachball
$\frac{1}{\sqrt{3}}\begin{pmatrix}1&0&0\\0&1&0\\0&0&1\end{pmatrix}$		$-\frac{1}{\sqrt{3}}\begin{pmatrix}1&0&0\\0&1&0\\0&0&1\end{pmatrix}$	
$-\frac{1}{\sqrt{2}}\begin{pmatrix}0&0&0\\0&0&1\\0&1&0\end{pmatrix}$		$\frac{1}{\sqrt{2}}\begin{pmatrix}0&0&0\\0&1&0\\0&0&-1\end{pmatrix}$	
$\frac{1}{\sqrt{2}}\begin{pmatrix}0&1&0\\1&0&0\\0&0&0\end{pmatrix}$		$\frac{1}{\sqrt{2}}\begin{pmatrix}0&0&1\\0&0&0\\1&0&0\end{pmatrix}$	
$\frac{1}{\sqrt{2}}\begin{pmatrix}1&0&0\\0&-1&0\\0&0&0\end{pmatrix}$		$\frac{1}{\sqrt{2}}\begin{pmatrix}1&0&0\\0&0&0\\0&0&-1\end{pmatrix}$	
$\frac{1}{\sqrt{6}}\begin{pmatrix}1&0&0\\0&1&0\\0&0&-2\end{pmatrix}$		$\frac{1}{\sqrt{6}}\begin{pmatrix}1&0&0\\0&-2&0\\0&0&1\end{pmatrix}$	
$\frac{1}{\sqrt{6}}\begin{pmatrix}-2&0&0\\0&1&0\\0&0&1\end{pmatrix}$		$-\frac{1}{\sqrt{6}}\begin{pmatrix}-2&0&0\\0&1&0\\0&0&1\end{pmatrix}$	

explosion - implosion

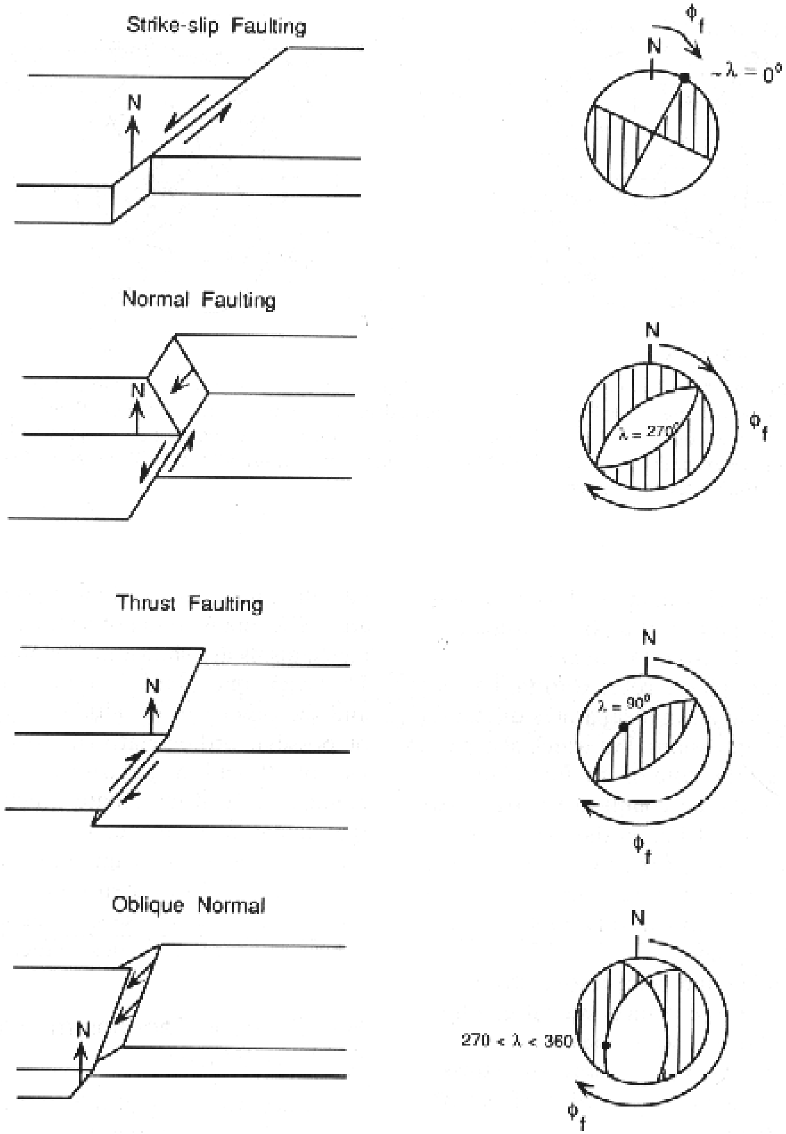
vertical strike slip fault

vertical dip slip fault

45° dip thrust fault

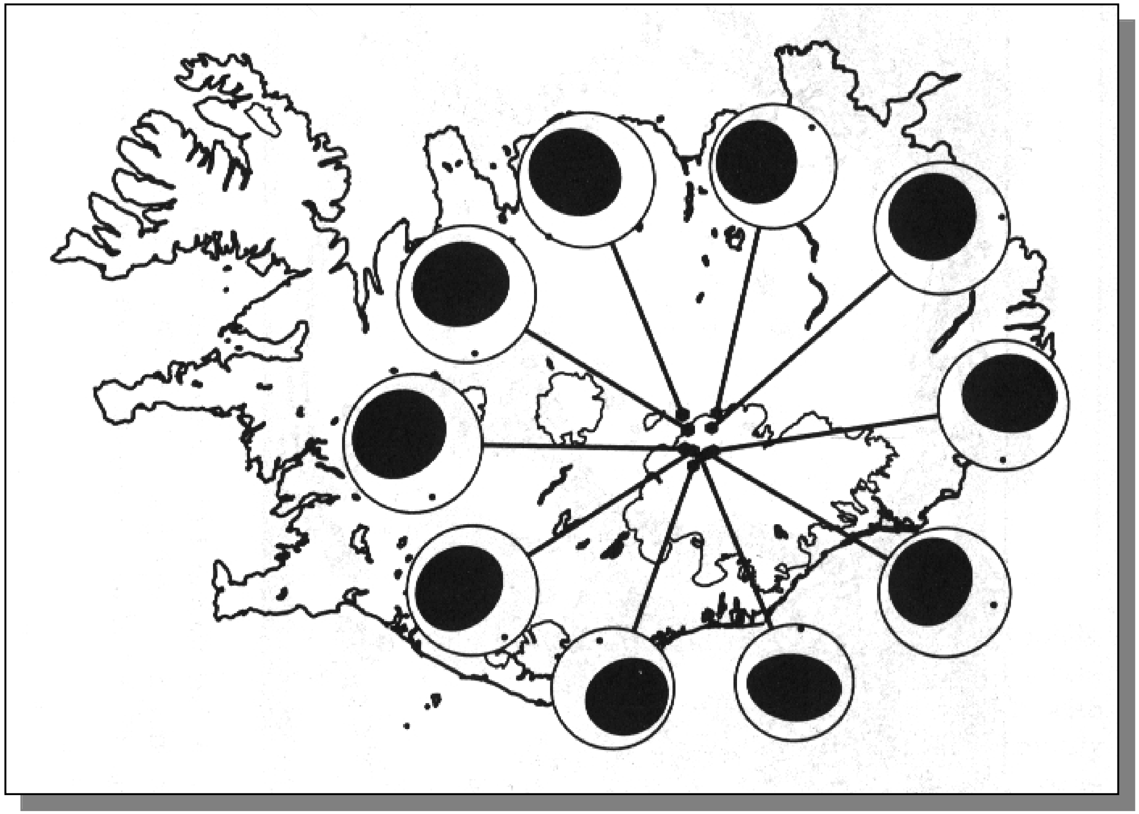
compensated linear vector dipoles

Fault types



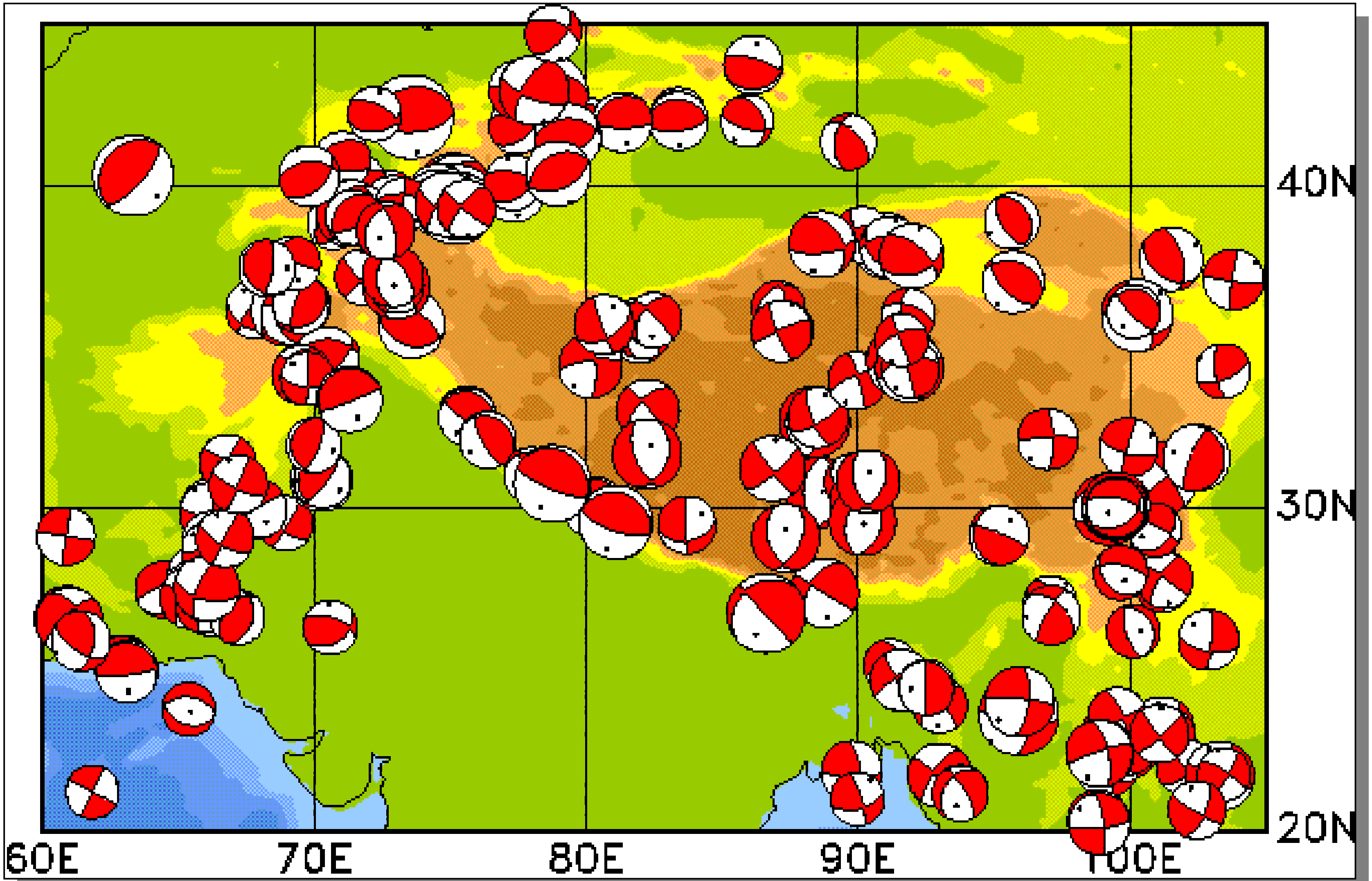
Basis fault types and their appearance in the focal mechanisms. Dark regions indicate compressional P-wave motion.

Beachballs - Iceland

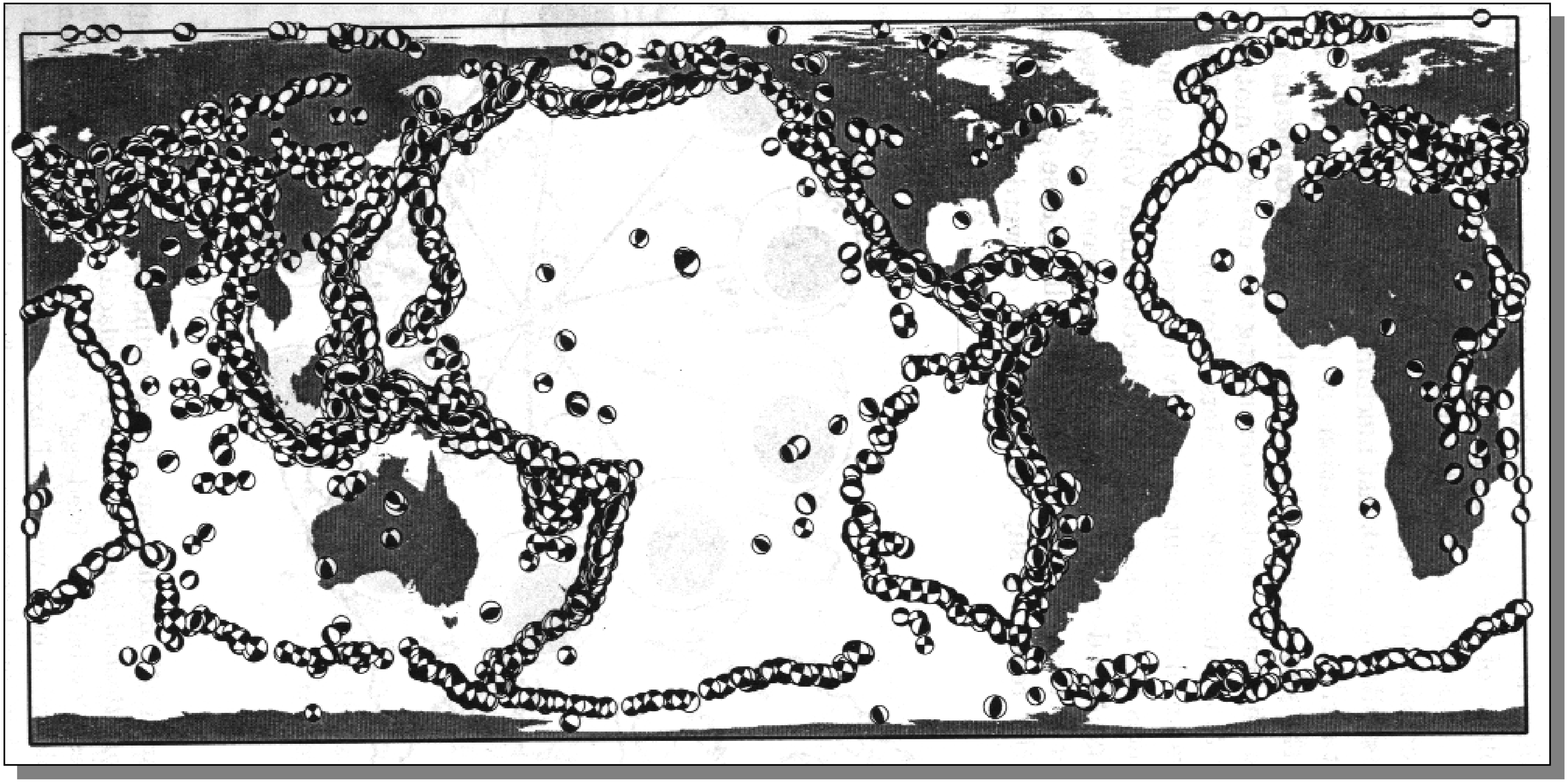


Fried eggs: simultaneous vertical extension and horizontal compression

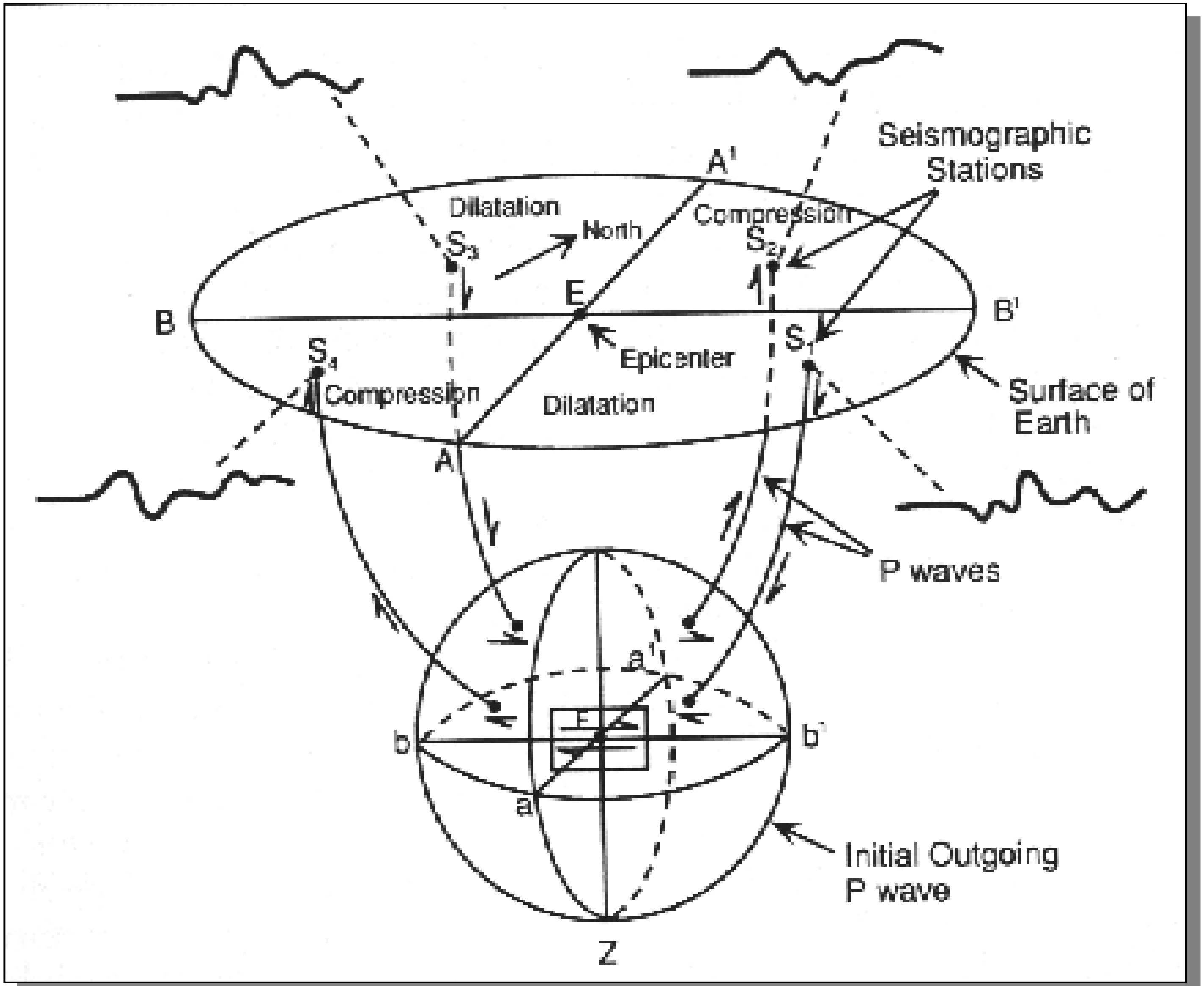
Beachballs - Himalaya



Beachballs - global



Radiation from shear dislocation

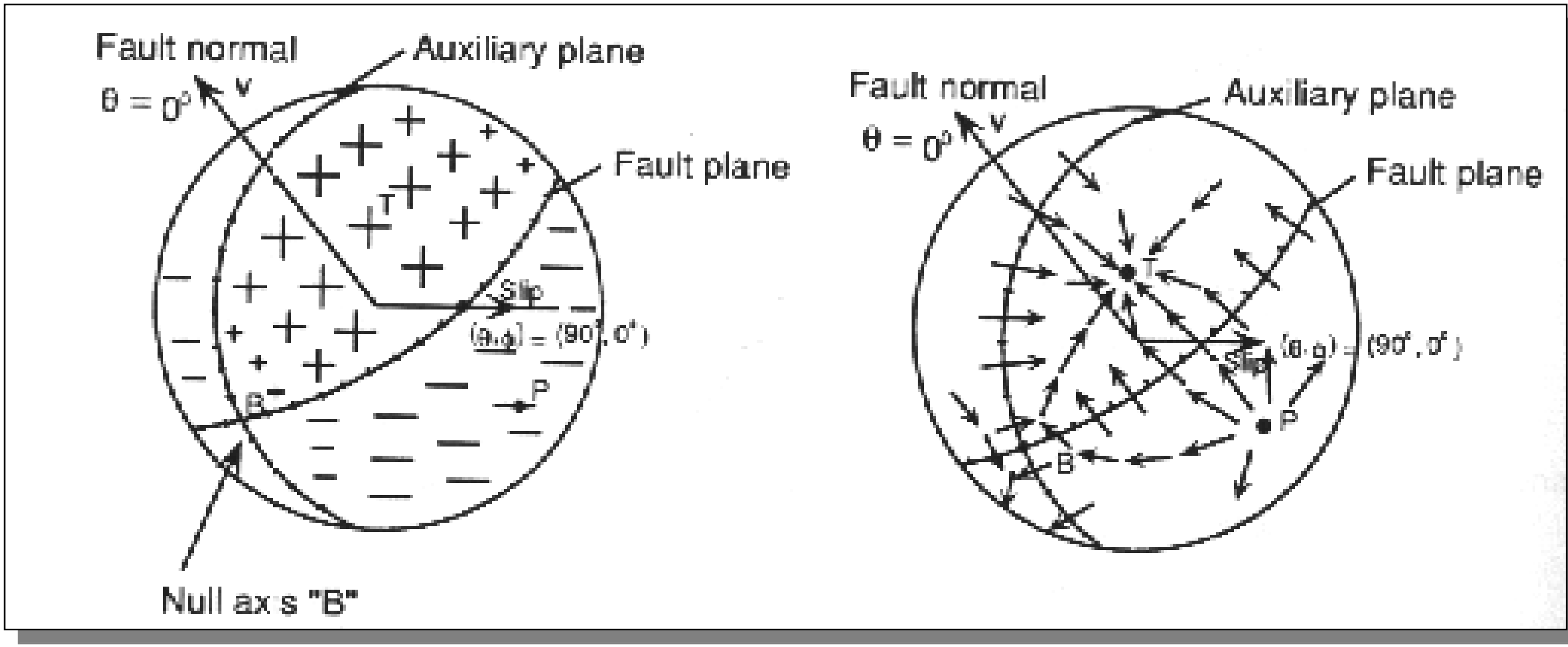


First motion of P waves at seismometers in various directions.

The polarities of the observed motion is used to determine the point source characteristics.

Focal Mechanisms

Focal mechanism for an oblique-slip event.



P-wave polarities and relative amplitudes

S-wave polarizations and amplitudes

Seismic sources

Far away from the source (far-field) seismic sources are best described as point-like double couple forces. The orientation of the inital displacement of P or S waves allows estimation of the orientation of the slip at depth.

The determination of this focal mechanism (in addition to the determination of earthquake location) is one of the routine task in observational seismology. The quality of the solutions depends on the density and geometry of the seismic station network.

The size of earthquakes is described by magnitude and the seismic moment. The seismic moment depends on the rigidity, the fault area and fault slip in a linear way. Fault scarps at the surface allow us to estimate the size of earthquakes in historic times.