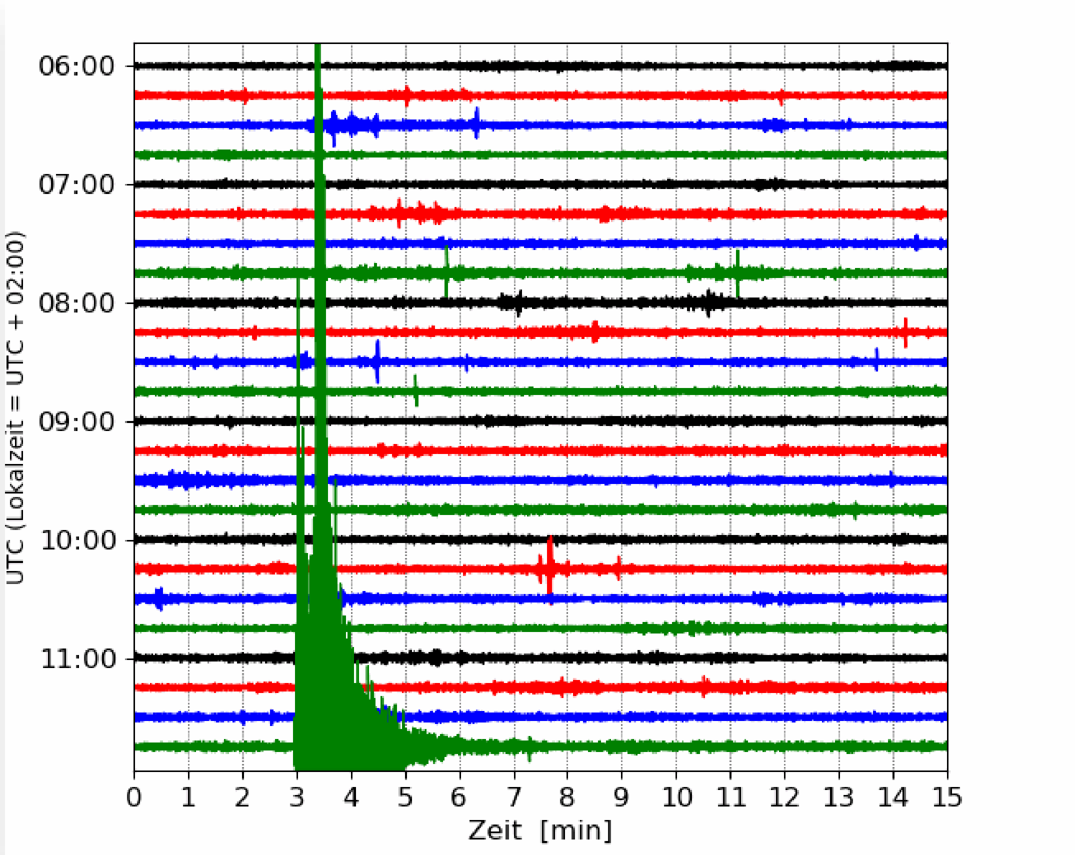
Schwäbischen Alb bei Beuren, Deutschland | Bild: picture allian

09.07.2022, 17:20 Uhr

Erdbeben erschüttert Schwäbische Alb - Stärke 4,1 gemessen

Die Schwäbische Alb ist am Samstag von einem kräftigen Erdbeben erschüttert worden. Das Beben hatte eine Stärke von 4,1, sein Epizentrum lag nahe der Stadt Hechingen im Zollernalbkreis. Laut Berichten war das Beben auch in Bayern zu spüren.

Von BR24 Redaktion



Seismic sources

Welche Spuren hinterlassen Erdbeben im Gelände?

Gibt es einfache Modelle dafür (-> elastic rebound)?

Was ist das einfachste physikalische Modell für ein Erdbeben?

Wie kann ich Erdbeben*herd*parameter bestimmen?

Was bestimmt die Ernergie (Magnitude, Stärke) von Erdbeben?

Sind kleine und große Erdbeben anders?

Was kann man über die Statistik von Erdbeben sagen?

Fault Scarps

Verwerfungen an der Oberfläche

Fault scarps

California

Fault scarps

Grand Canyon

Fault scarps

California

Fault scarps

California

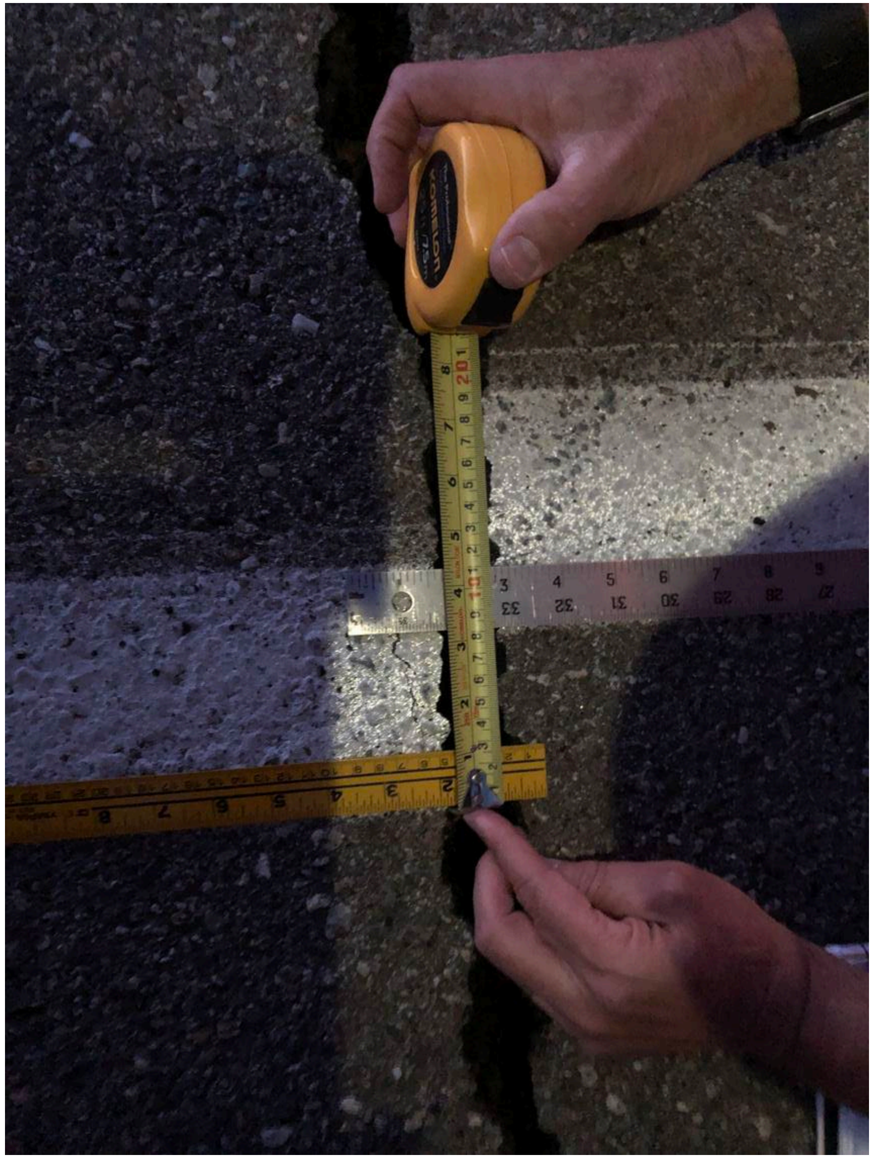
Fault scarps

Taiwan

Fault scarps

Taiwan

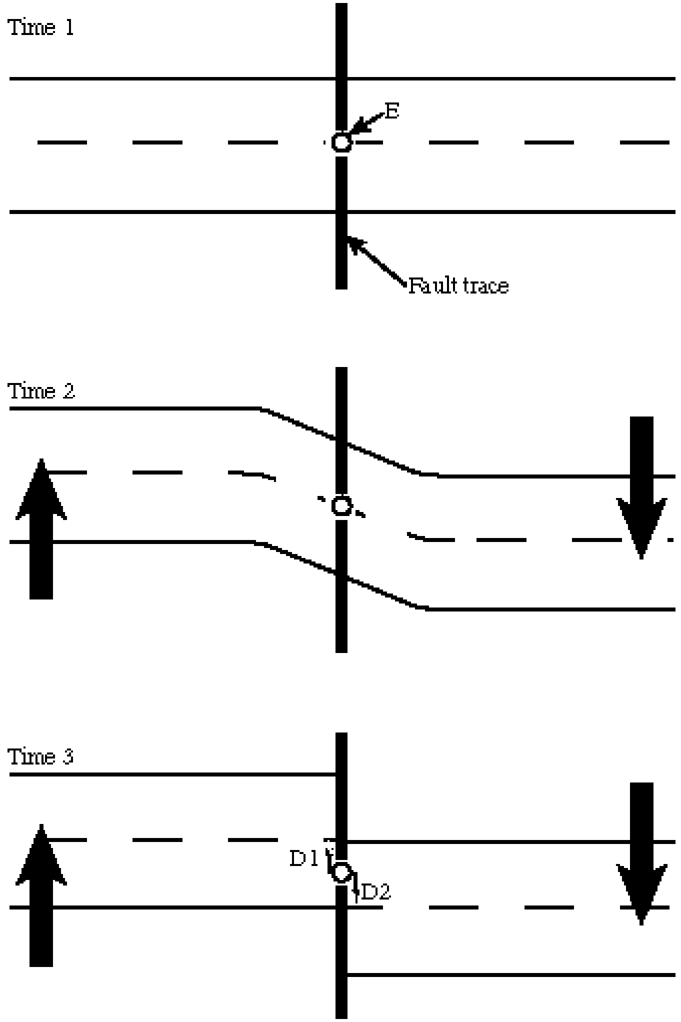
Epicentre Landers, CA



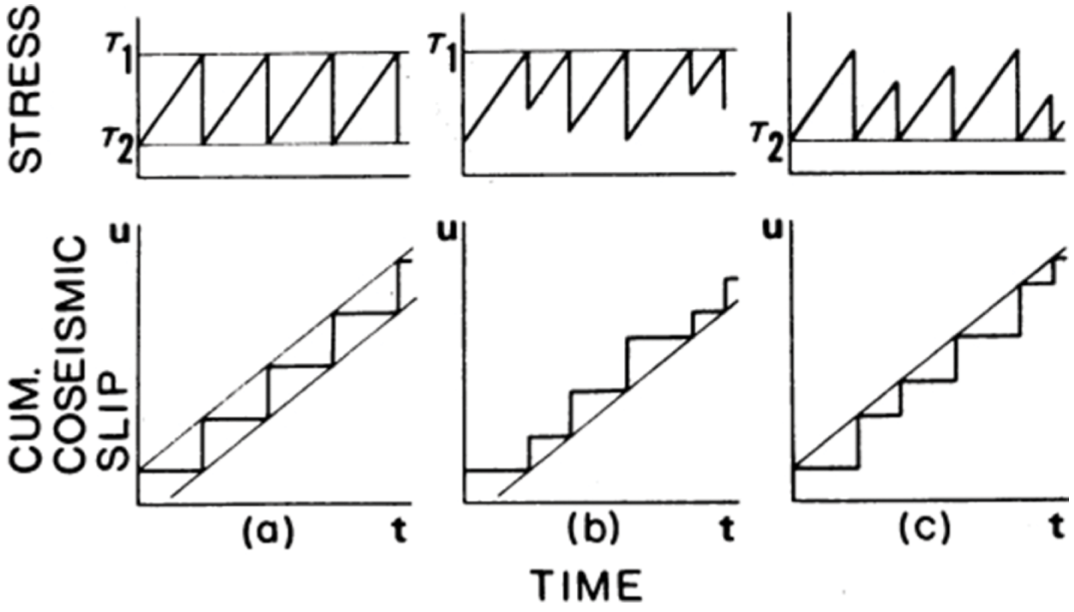
Gibt es einfache Modelle dafür (-> elastic rebound)?

... Great timing for engineers after the 1906 earthquake in San Francisco ...

Elastic rebound

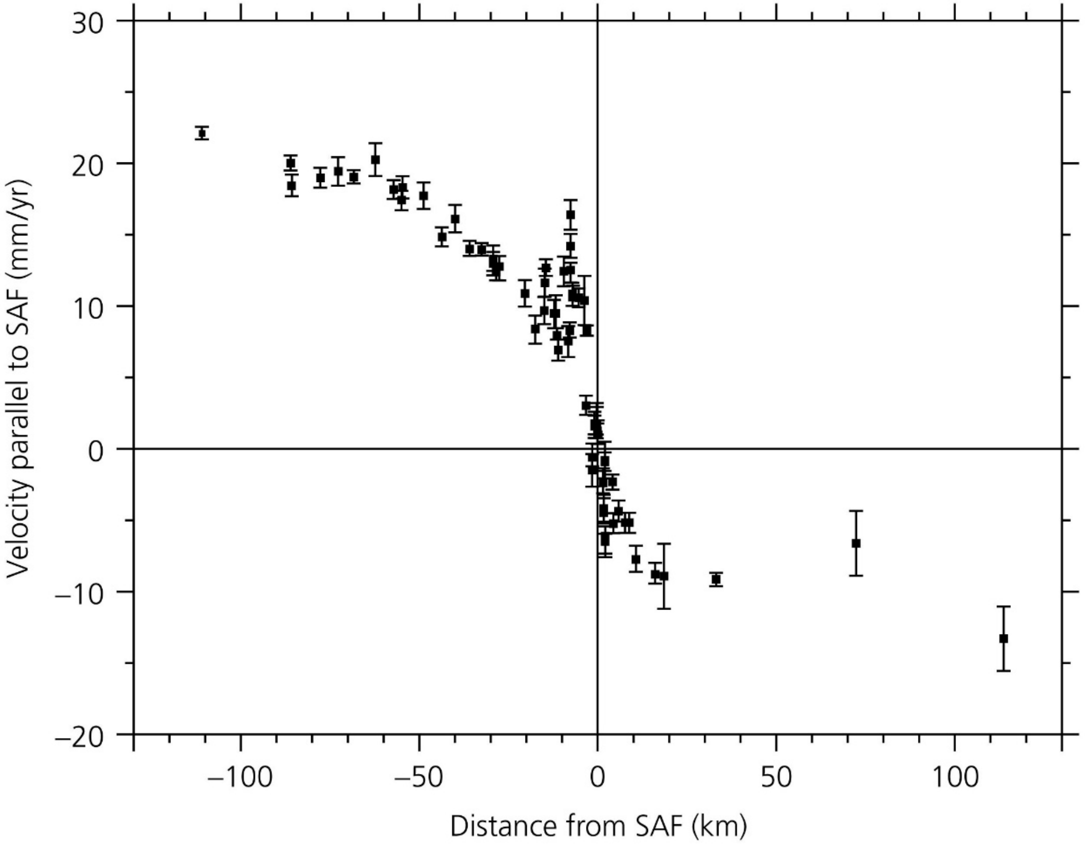


Recurrence model

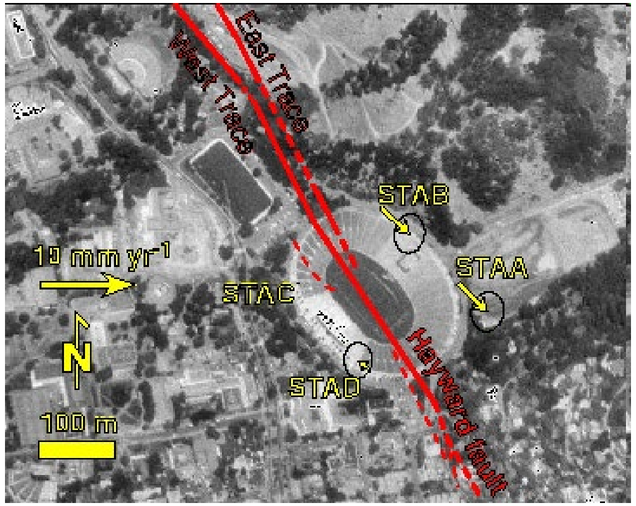


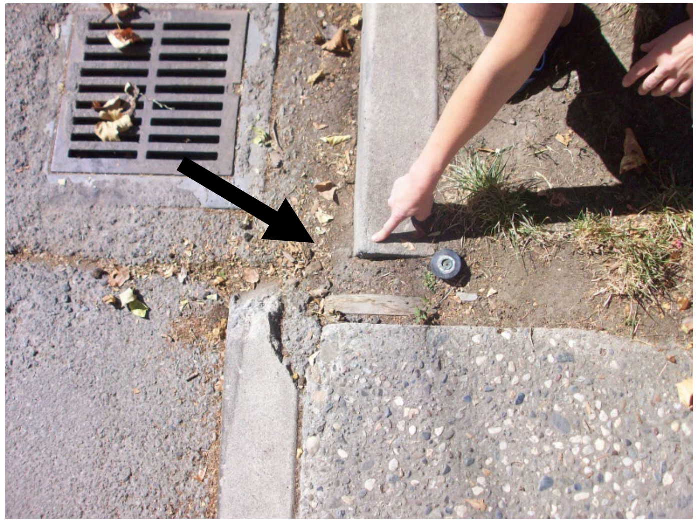
Deformation - Strain

Figure 4.5-13: Fault-parallel horizontal interseismic motion across the San Andreas fault.



Berkeley Football Stadium



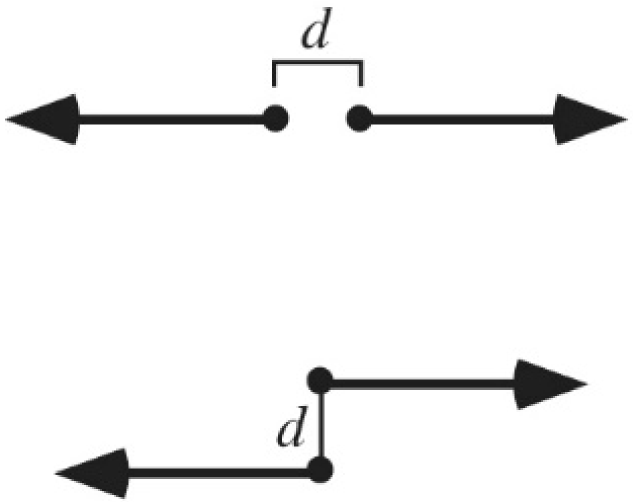


Erdbeben Modell

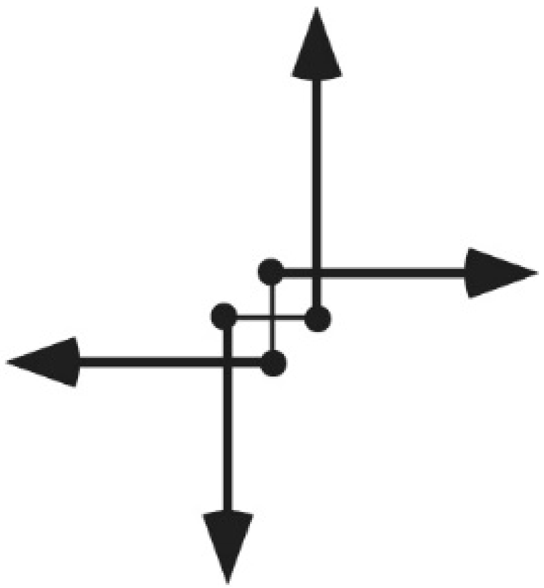
Punktquelle

Scherdislokation

Single and double couples

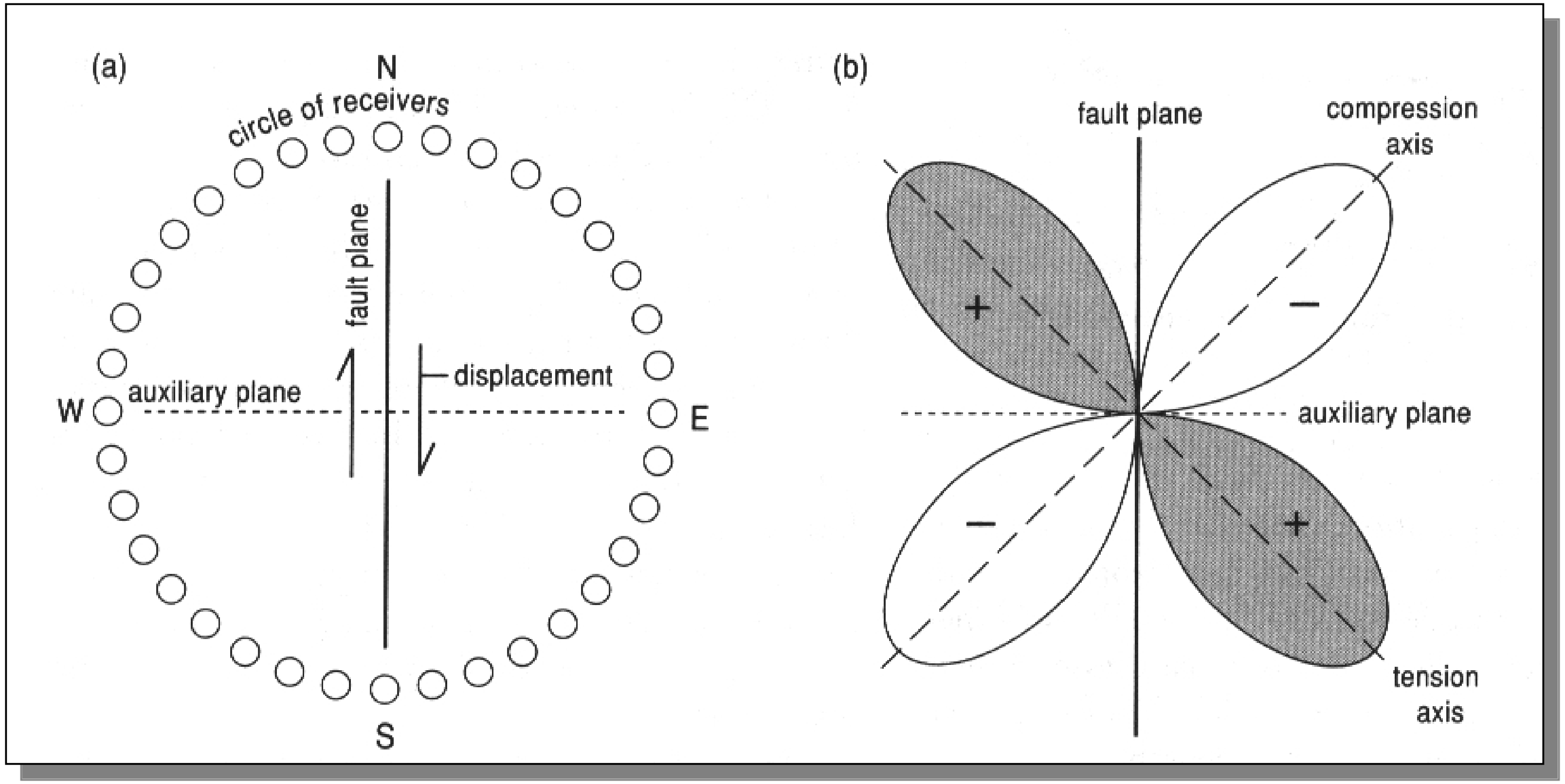


Force Couples



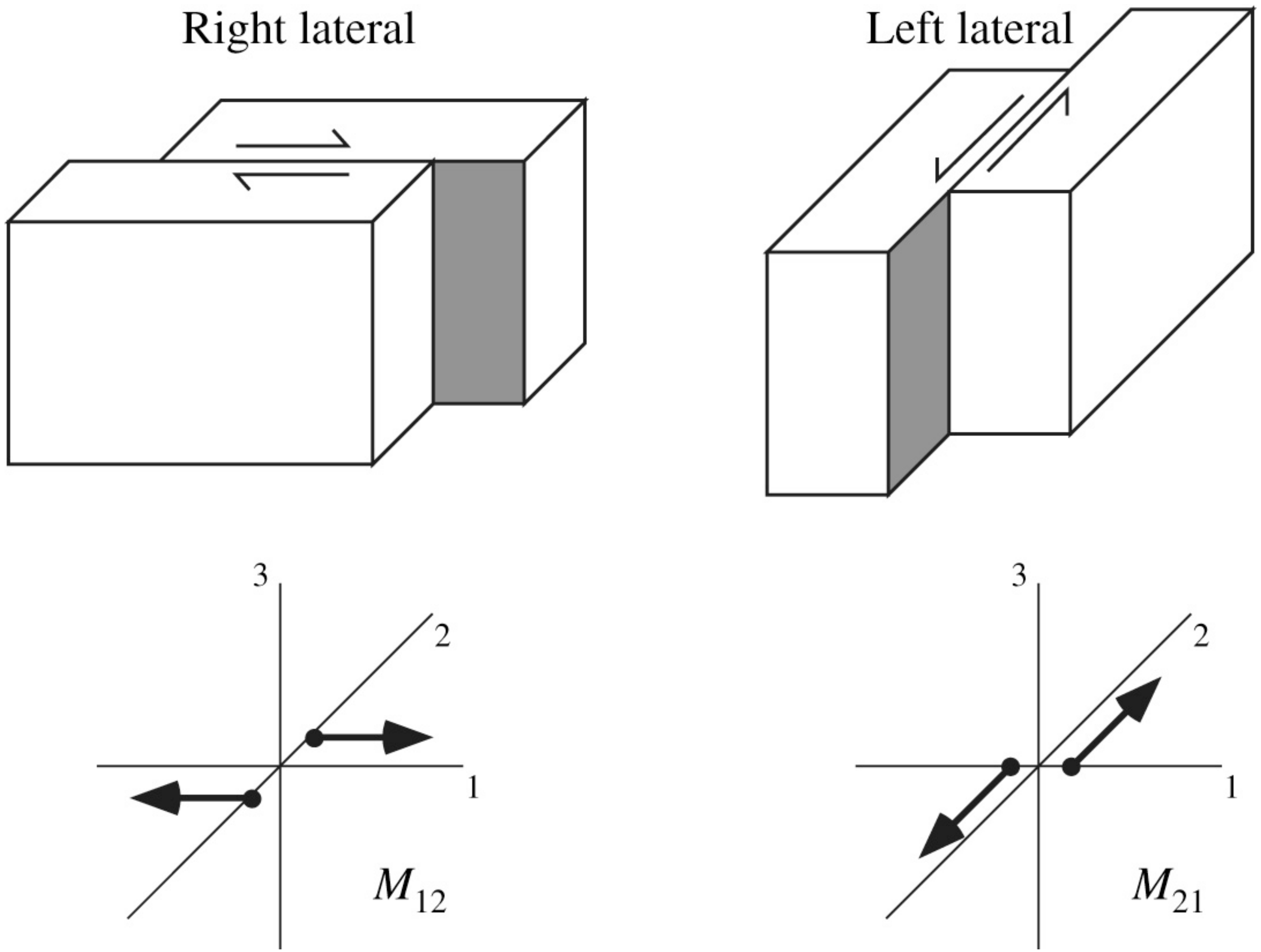
Double Couple

Seismic sources



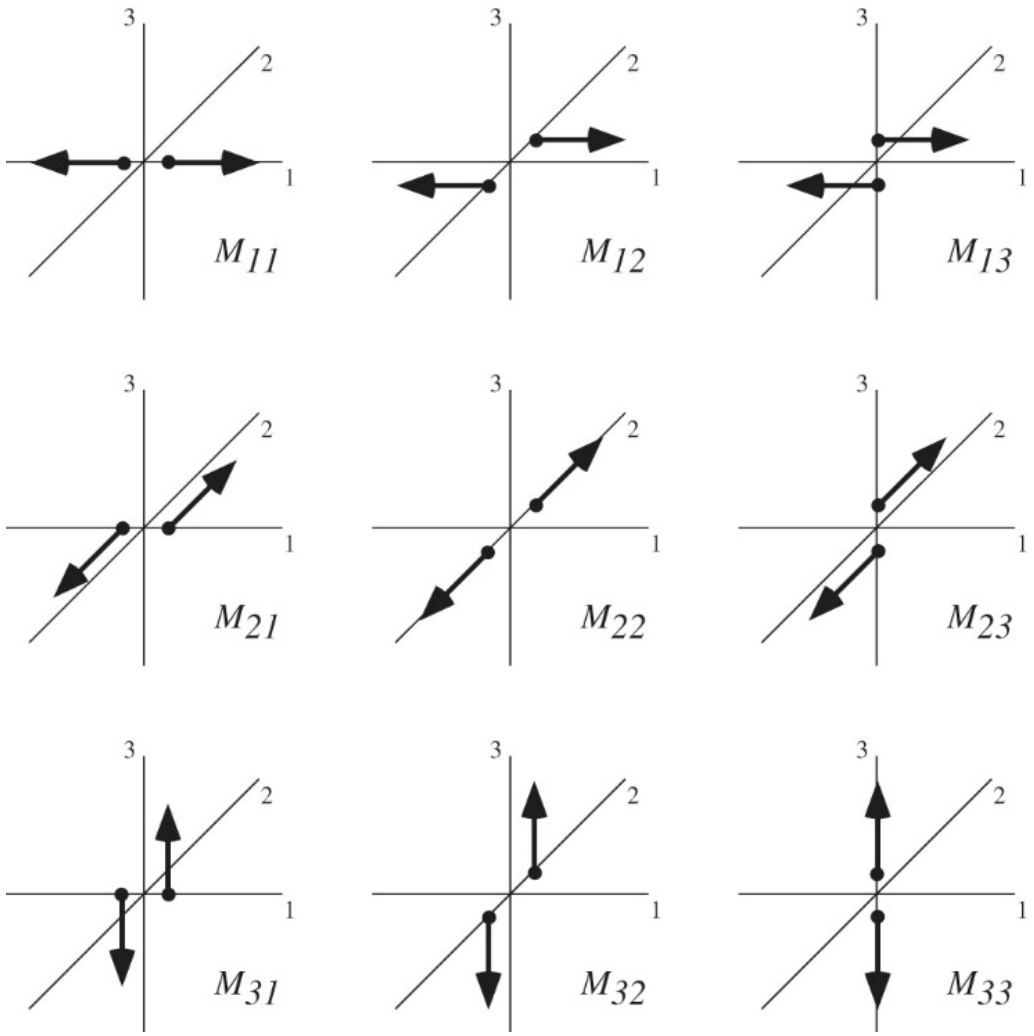
The basic physical model for a source is two fault planes slipping in opposite directions

The ambiguity

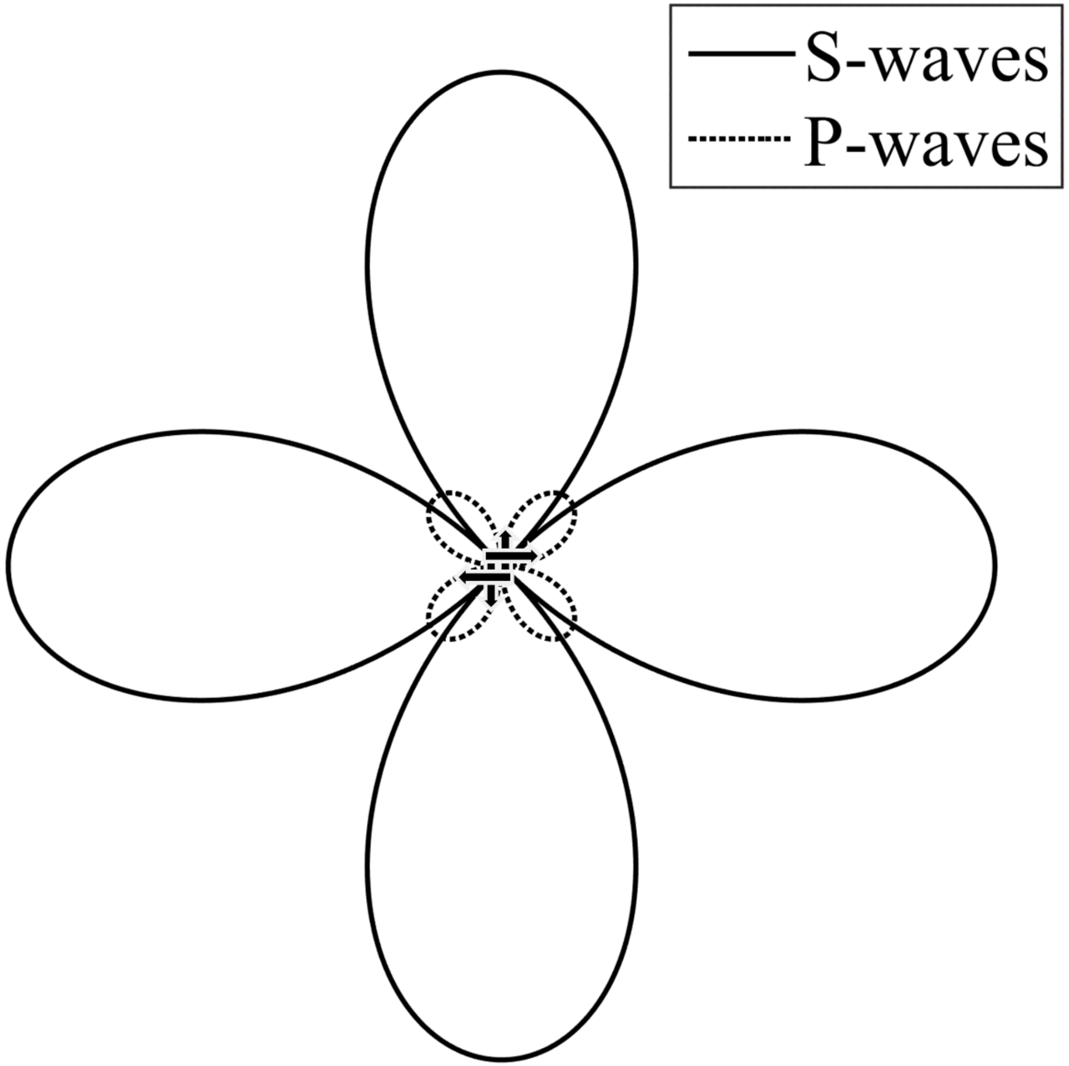


Same moment tensor, same radiation pattern!

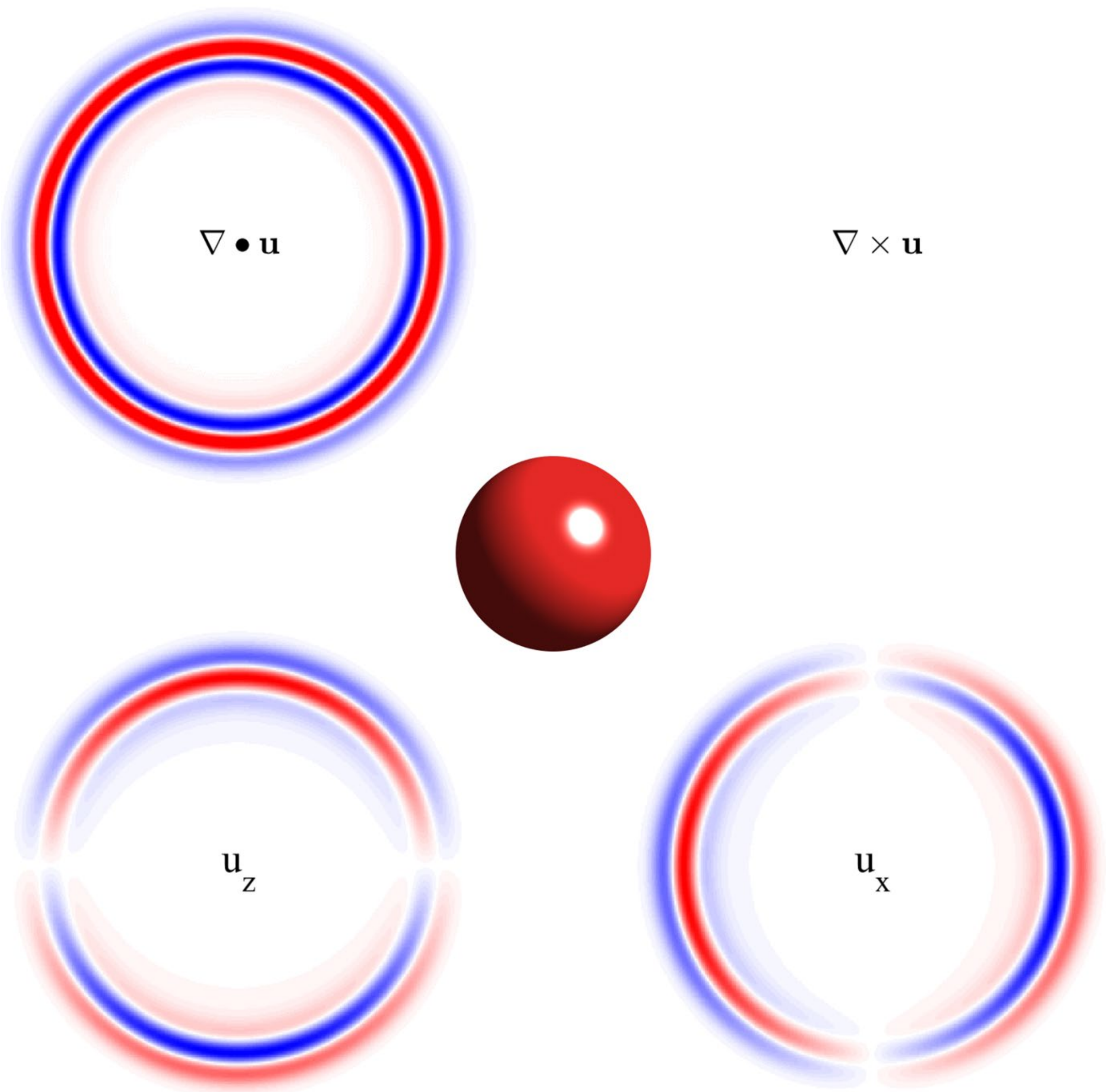
Possible double couples – Moment tensor



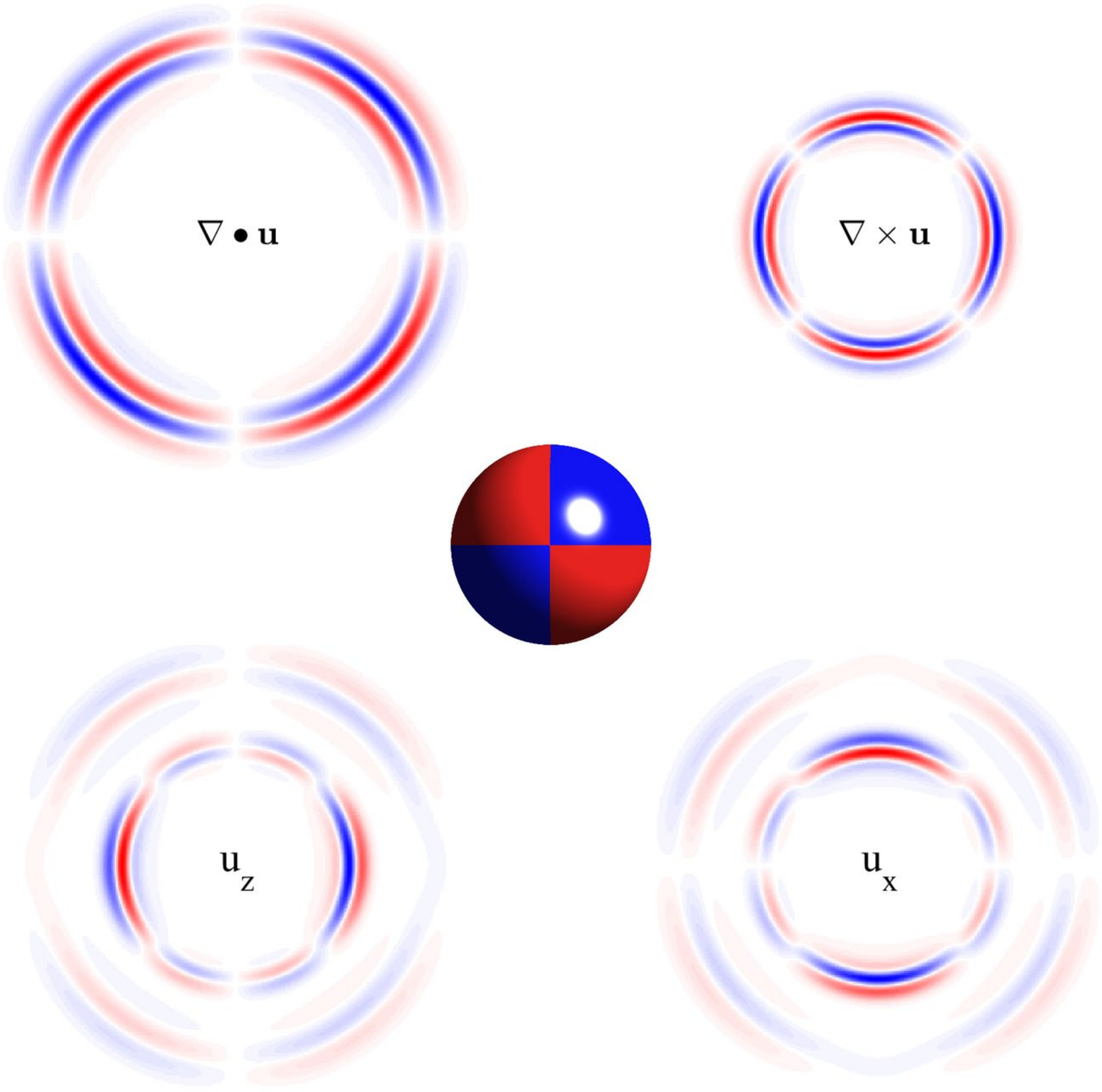
Radiation pattern



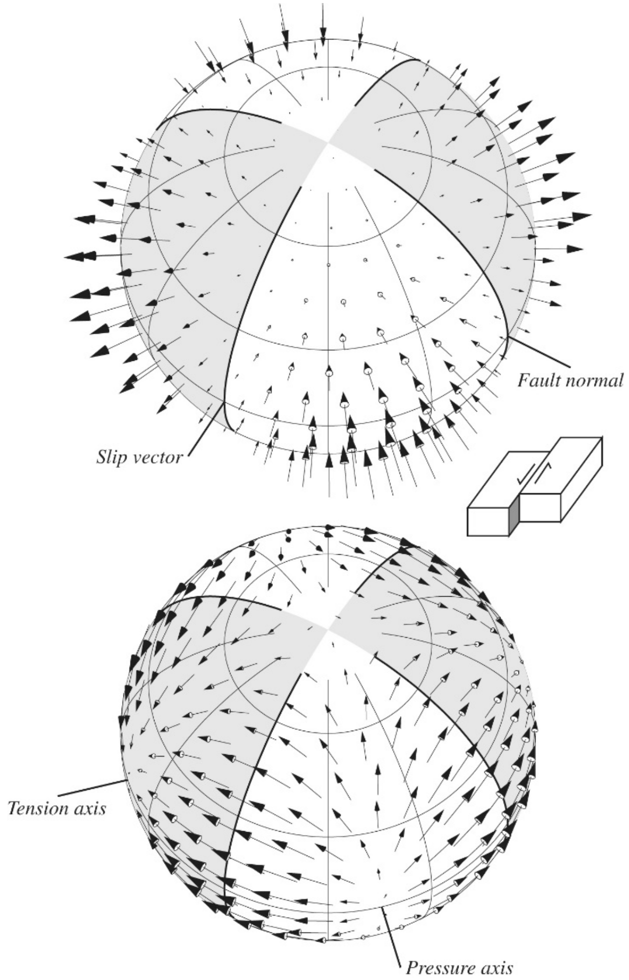
Wavefield explosion

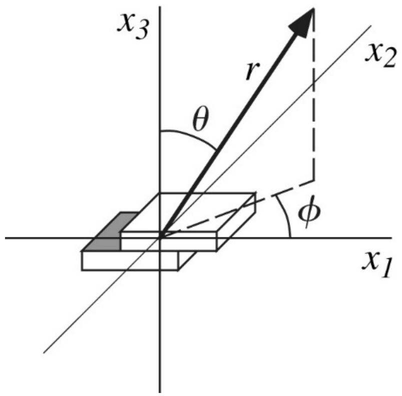


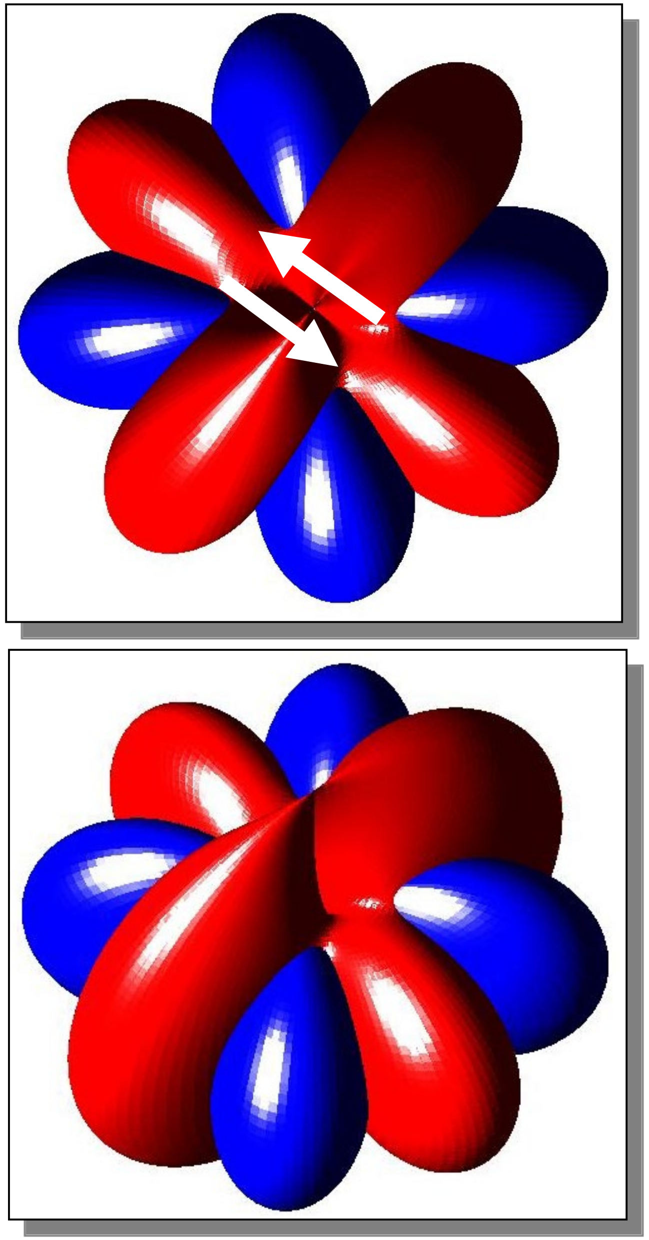
Wavefield double couple



Radiation pattern – first motions

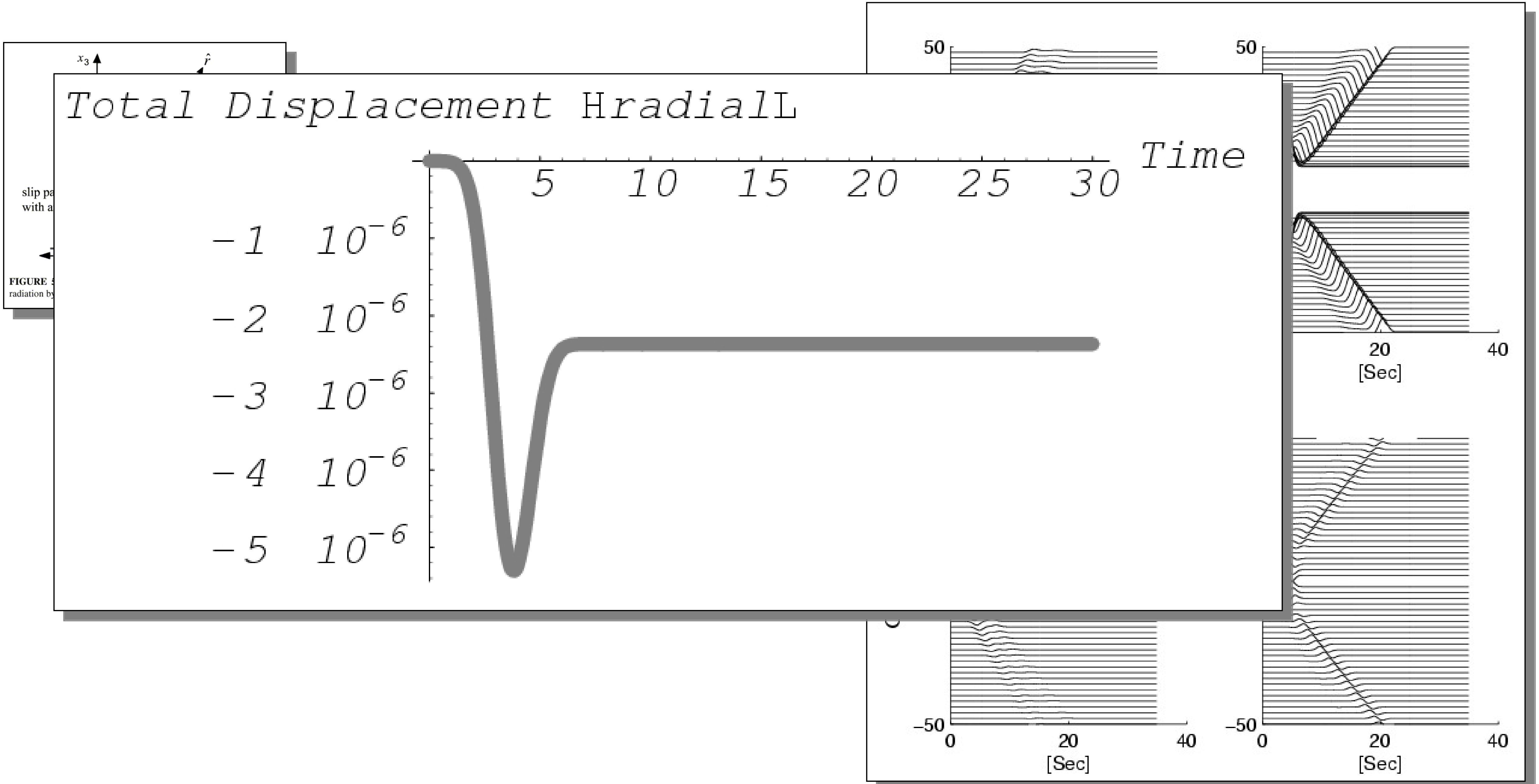






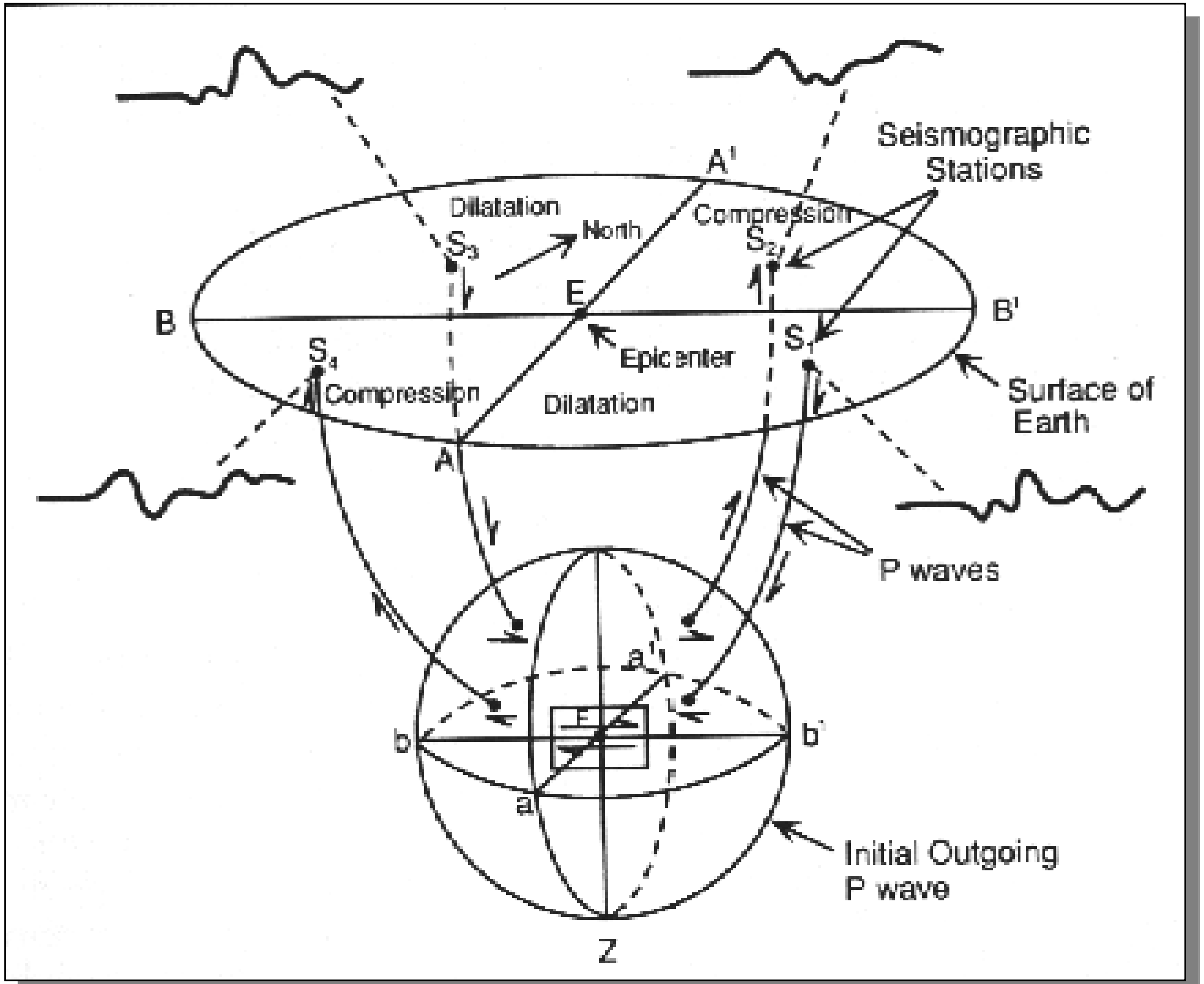
Far field P – blue
Far field S - red

Velocity seismograms-M6.5 point source



Wie kann ich die Quellgeometrie aus Bebachtungen ableiten?

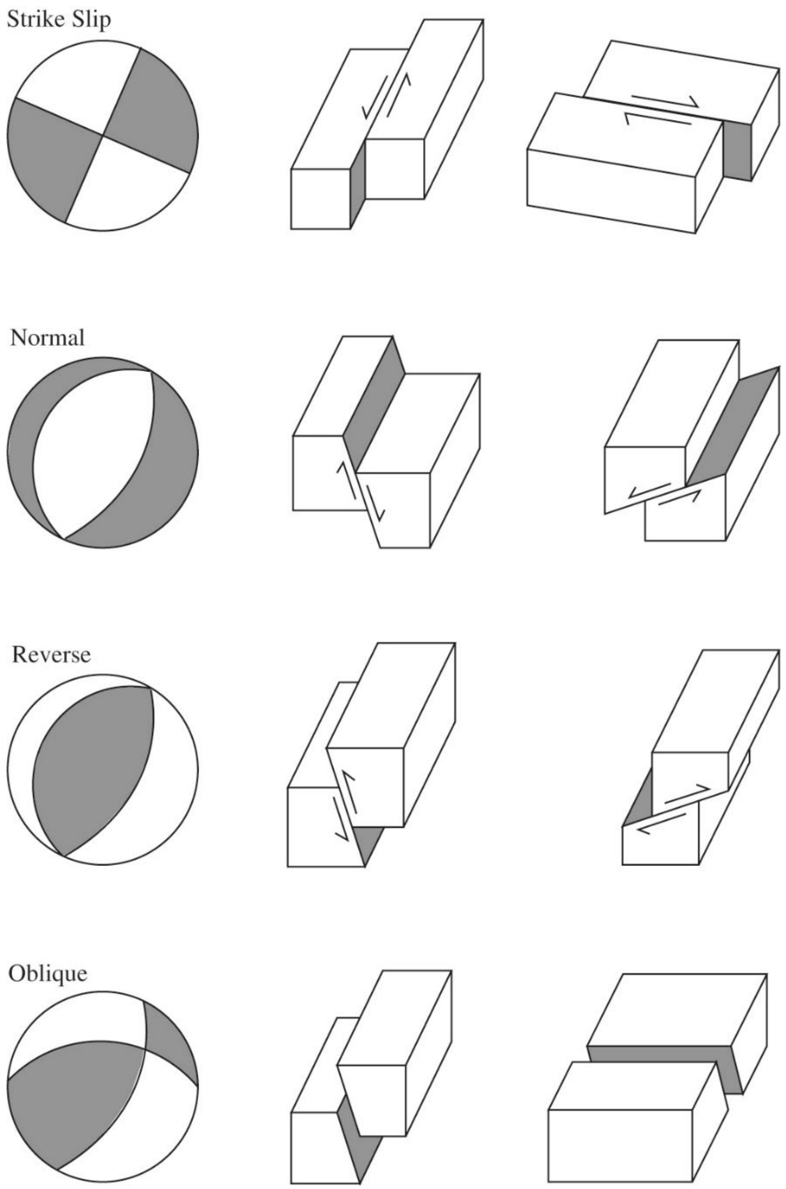
Radiation from shear dislocation – Moment tensor inversion



First motion of P waves at seismometers in various directions.

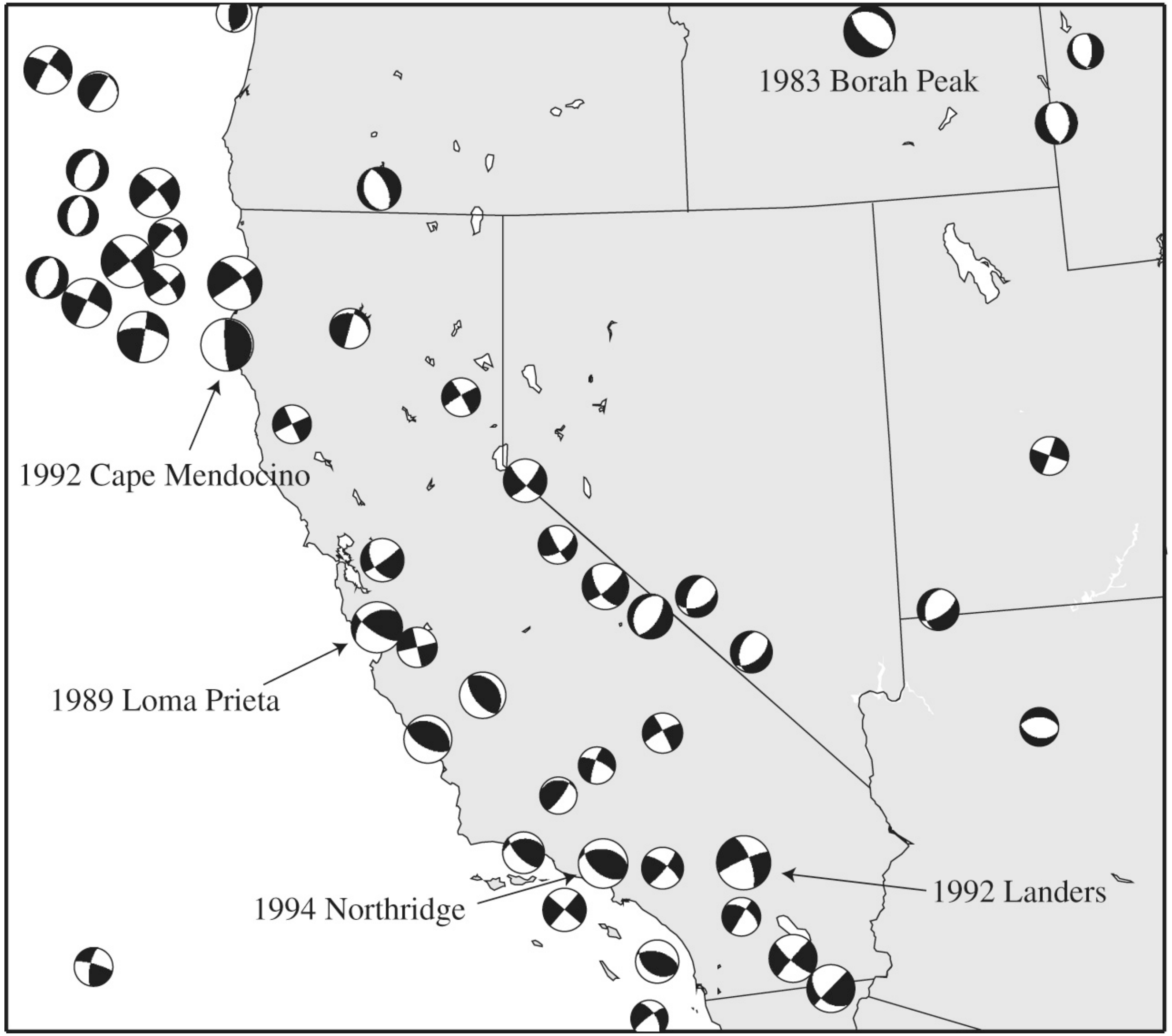
The polarities of the observed motion is used to determine the point source characteristics.

Beach balls and Fault types

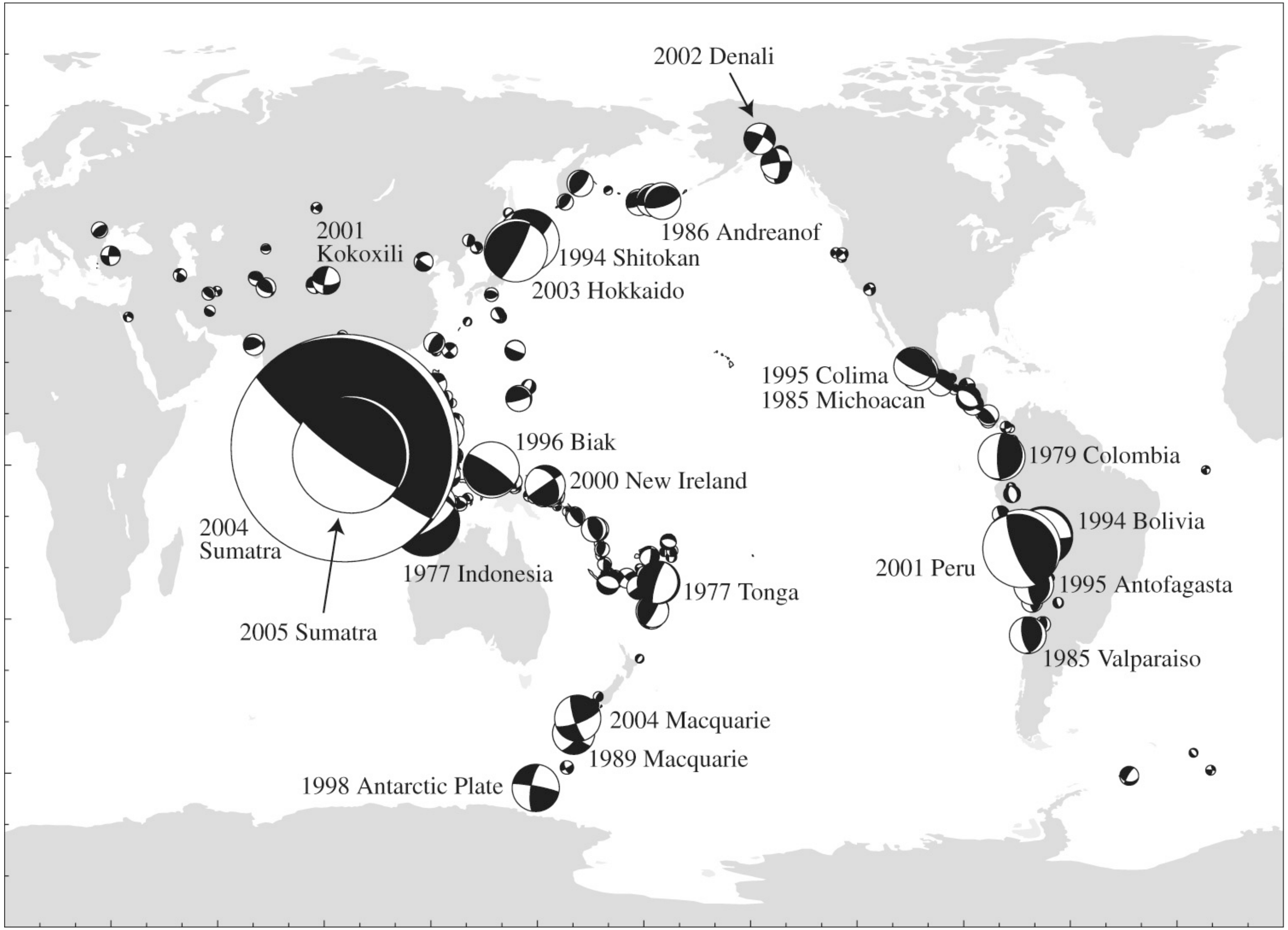


Basis fault types and their appearance in the focal mechanisms. Dark regions indicate compressional P-wave motion.

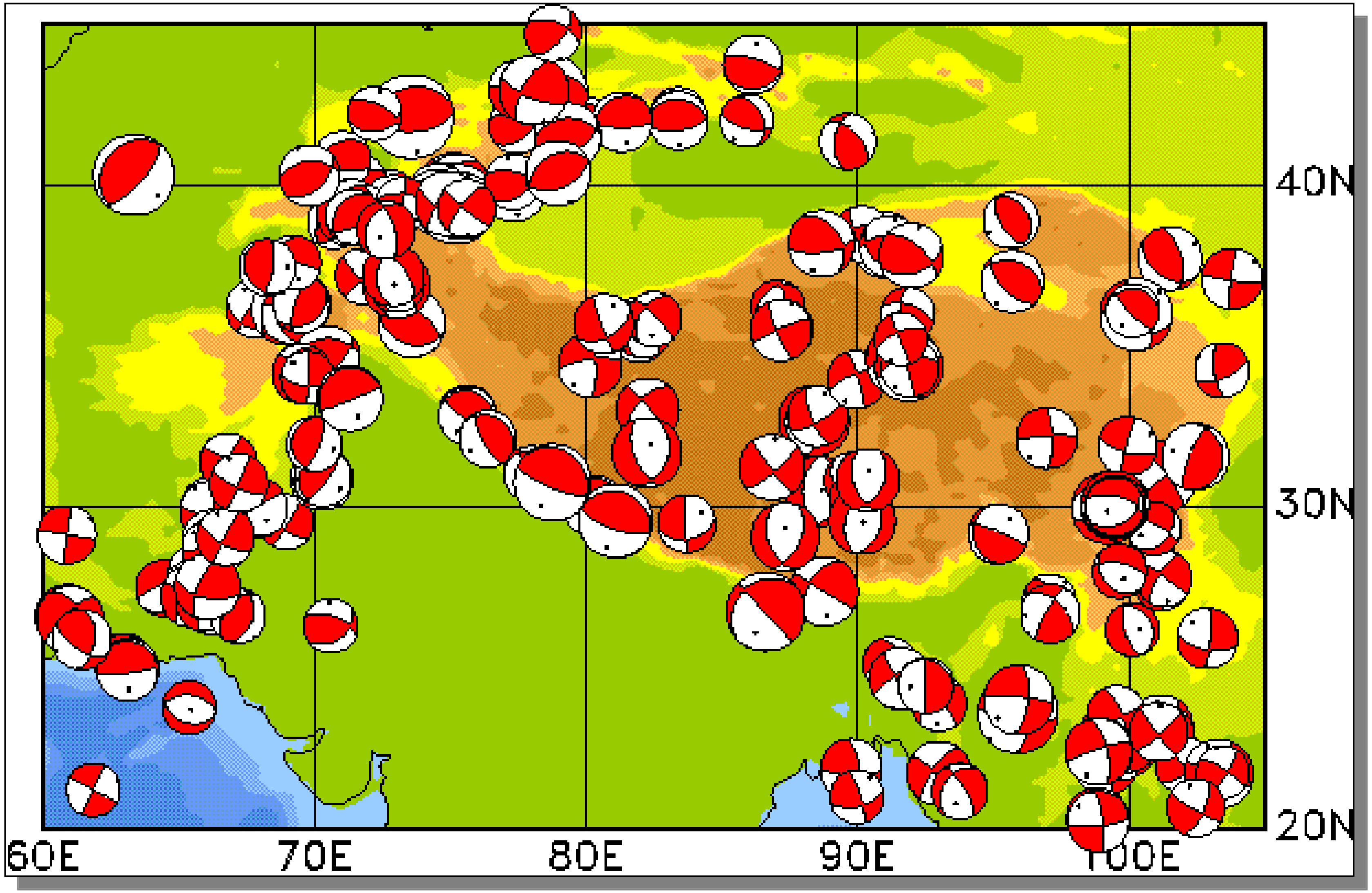
Beachball in California



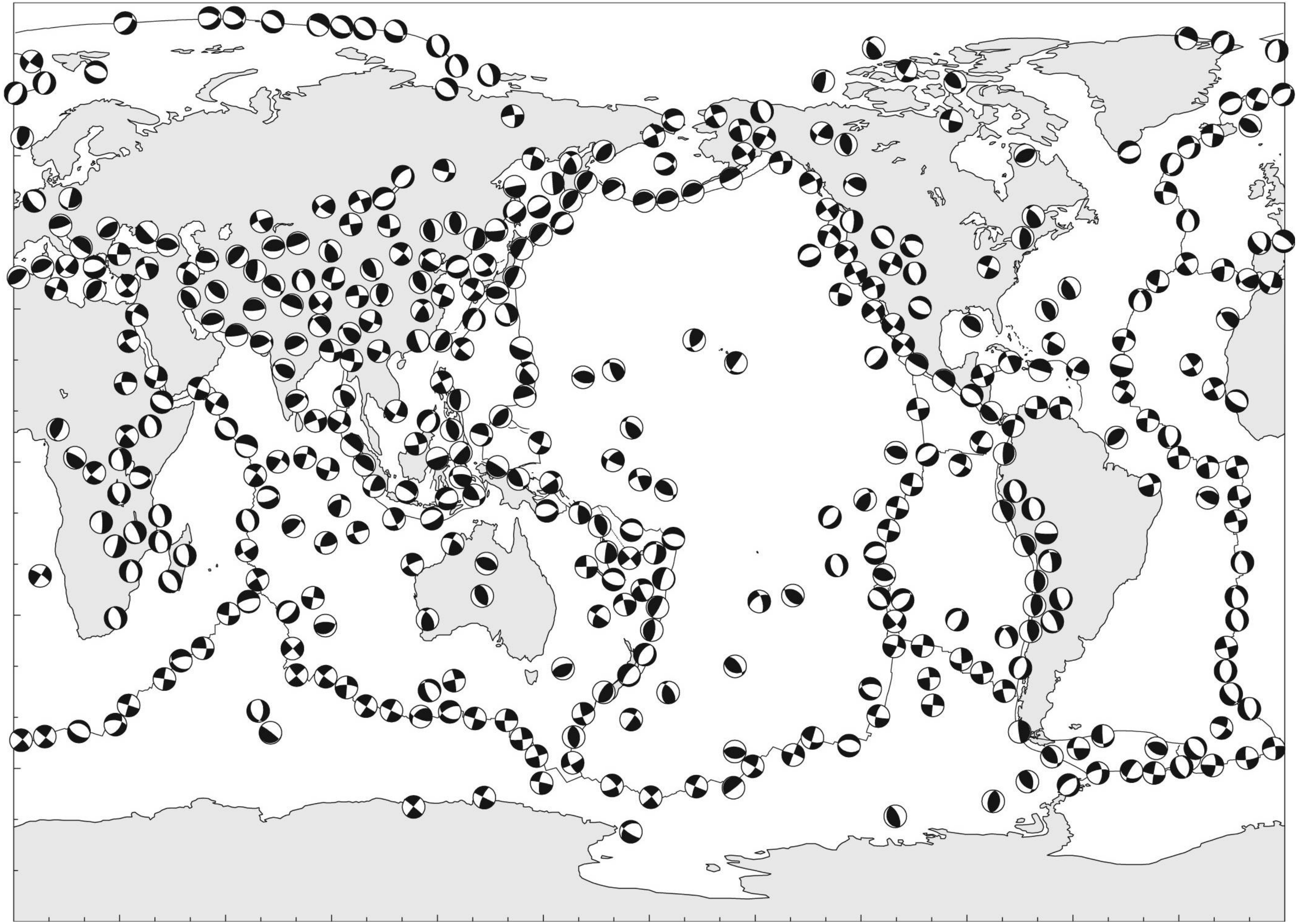
Big earthquakes



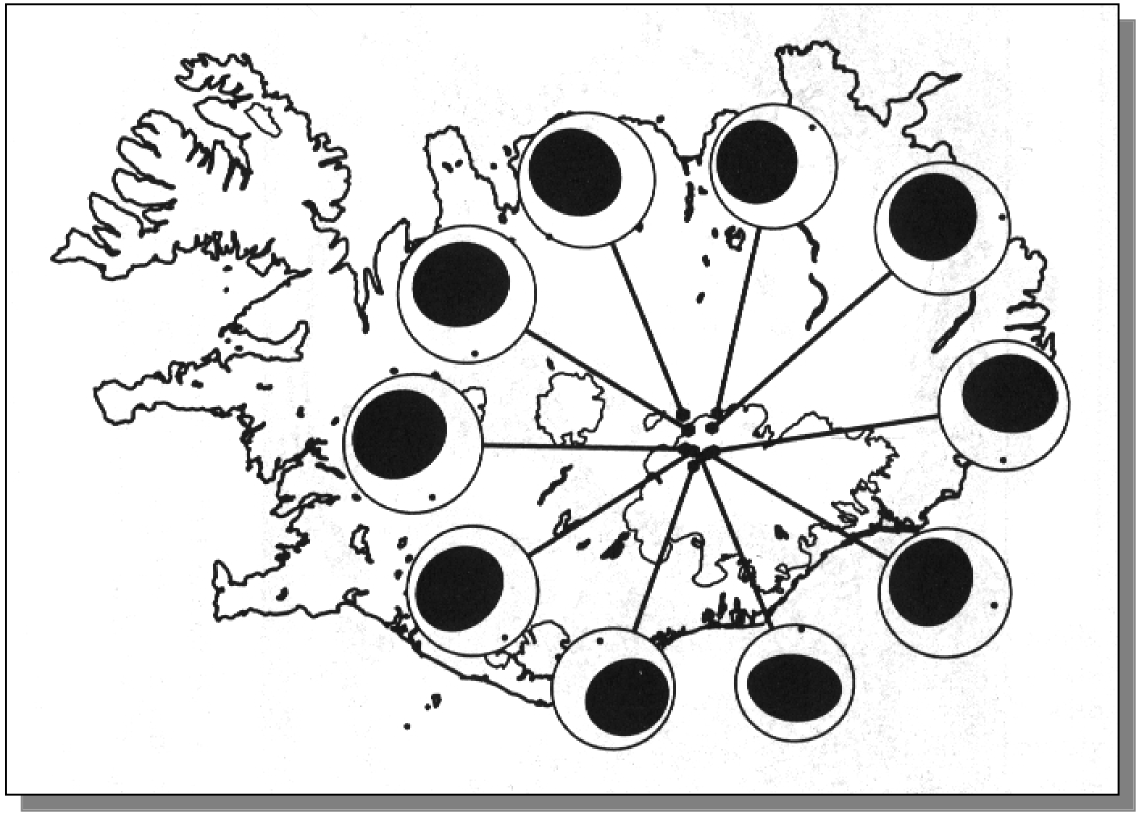
Beachballs - Himalaya



Beachballs - global



Beachballs - Iceland



Fried eggs: simultaneous vertical extension and horizontal compression

Was ist mit GROSSEN Erdbeben?

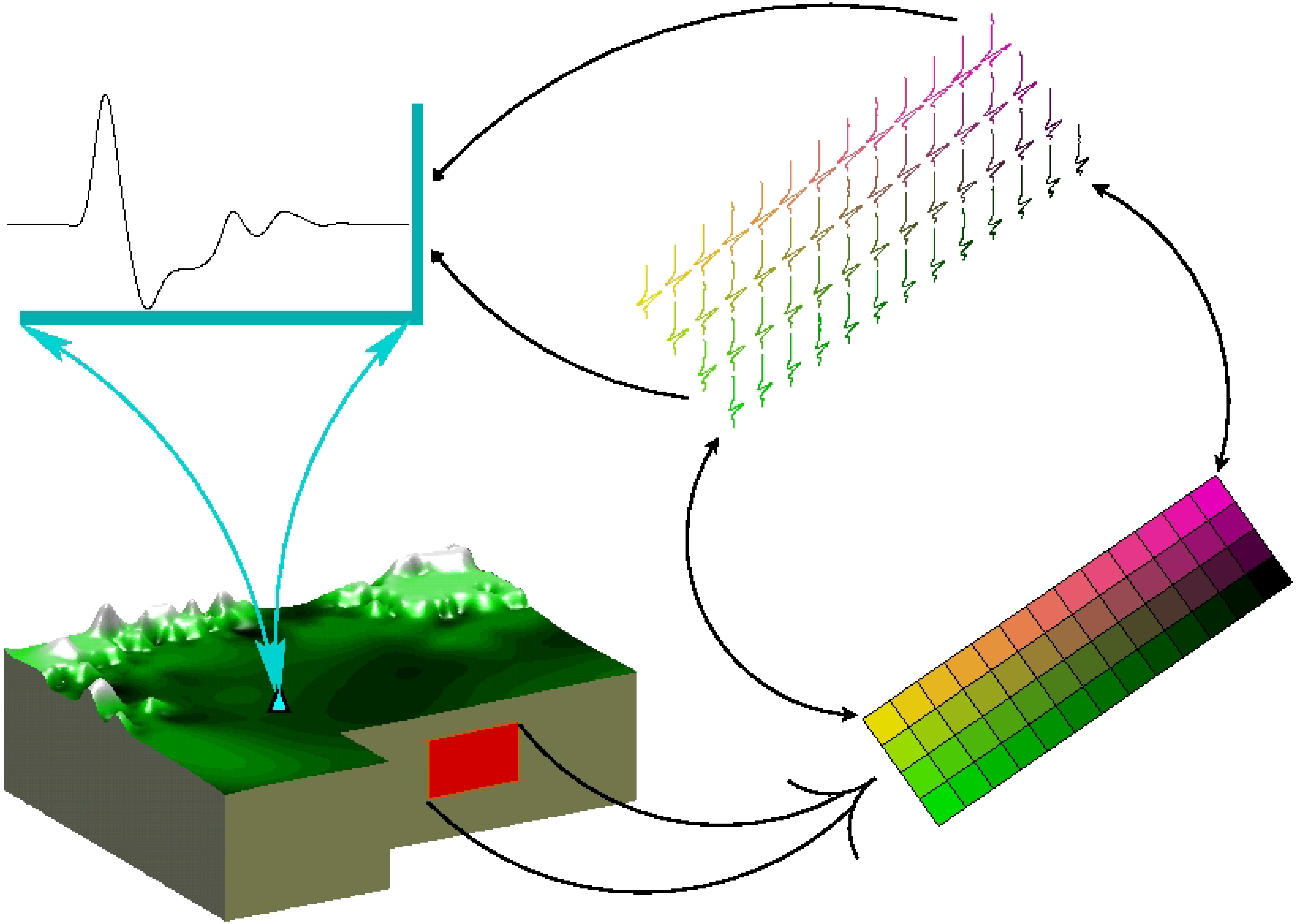
Source kinematics

Point source characteristics (source moment tensor, rise time, source moment, rupture dimensions) give us some estimate on what happened at the fault. However we need to take a closer look. We are interested in the space-time evolution of the rupture.

Here is the fundamental concept:

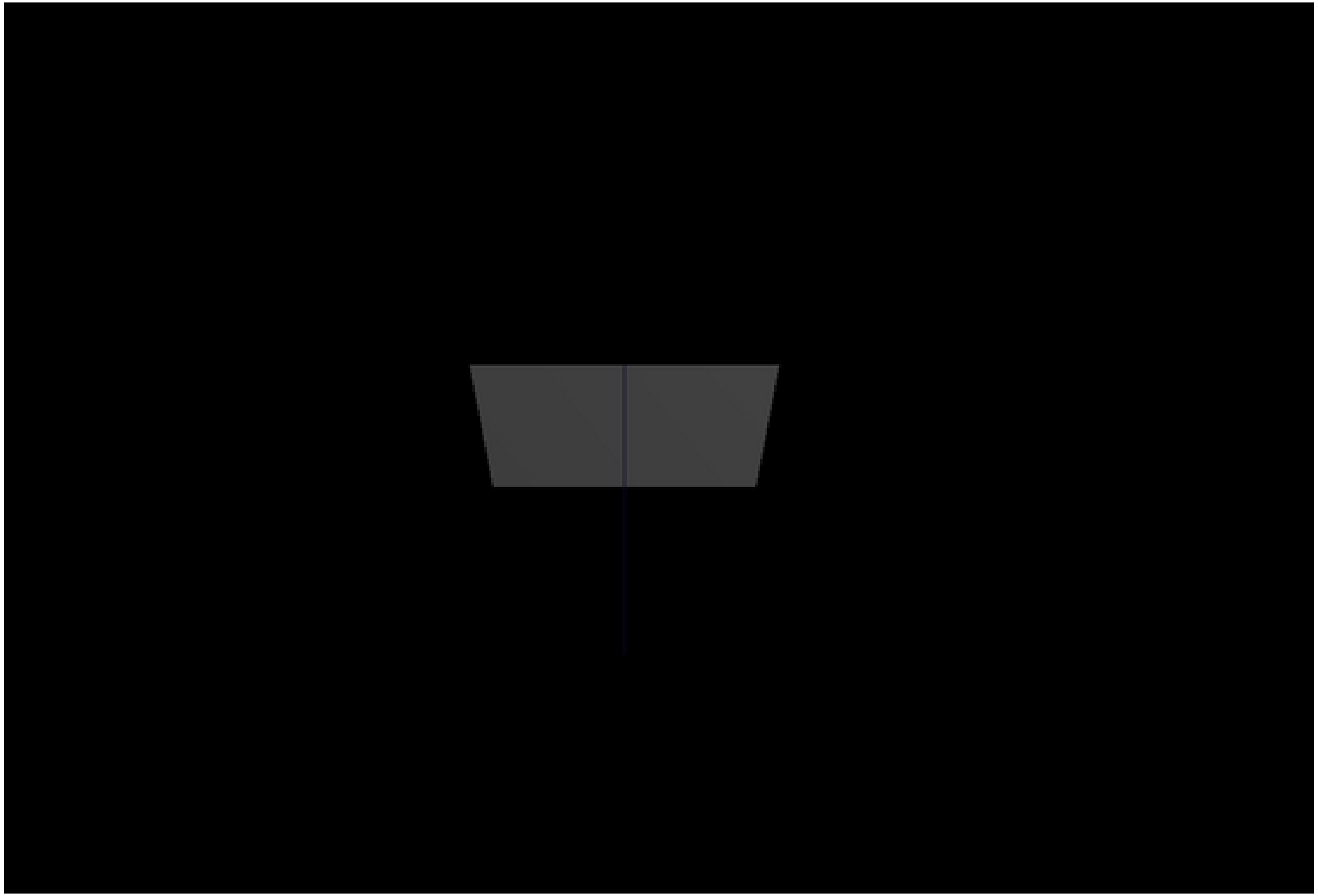
The recorded seismic waves are a superpositions of many individual double-couple point sources.

This leads to the problem of estimating this space-time behavior from observed (near fault) seismograms. The result is a kinematic description of the source.

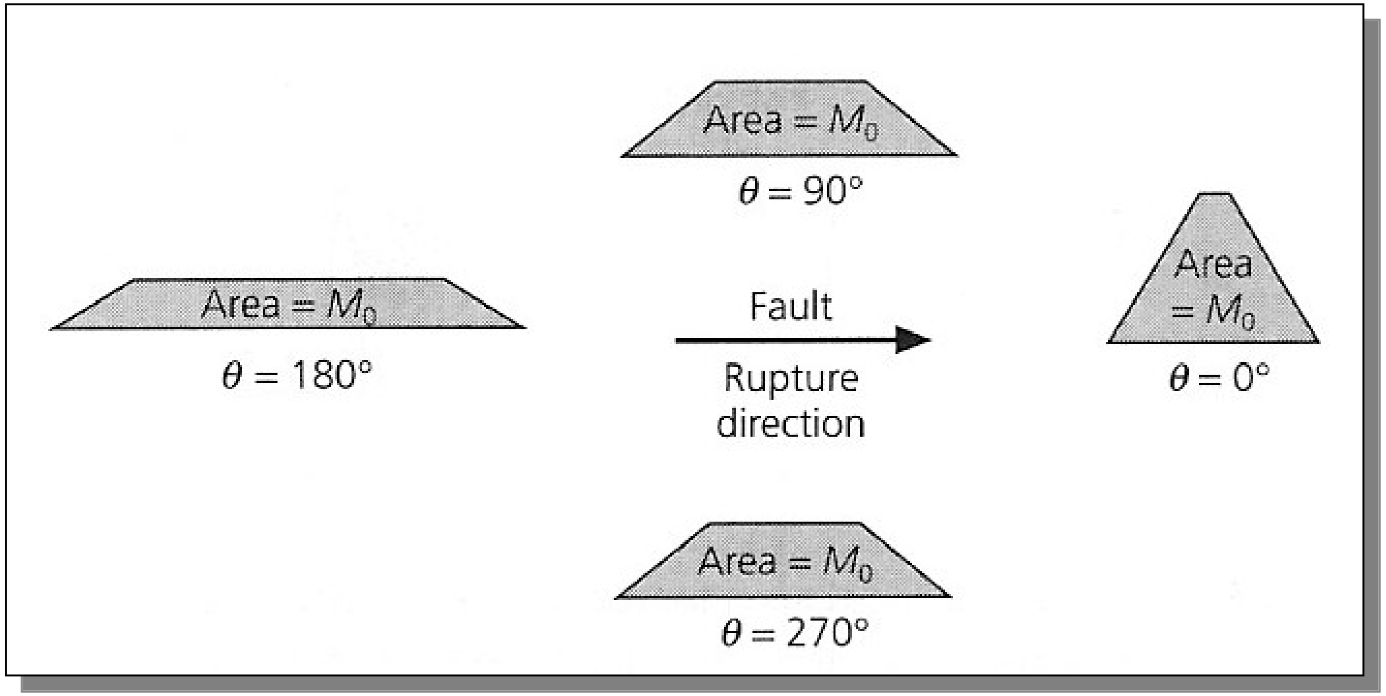


Seismic sources

Dynamic rupture

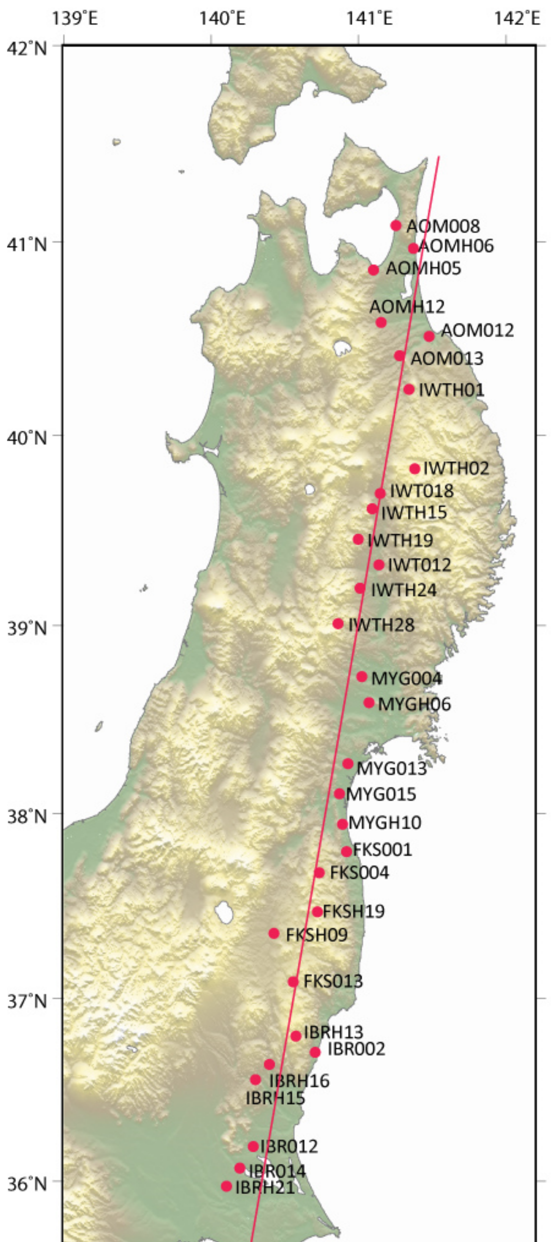


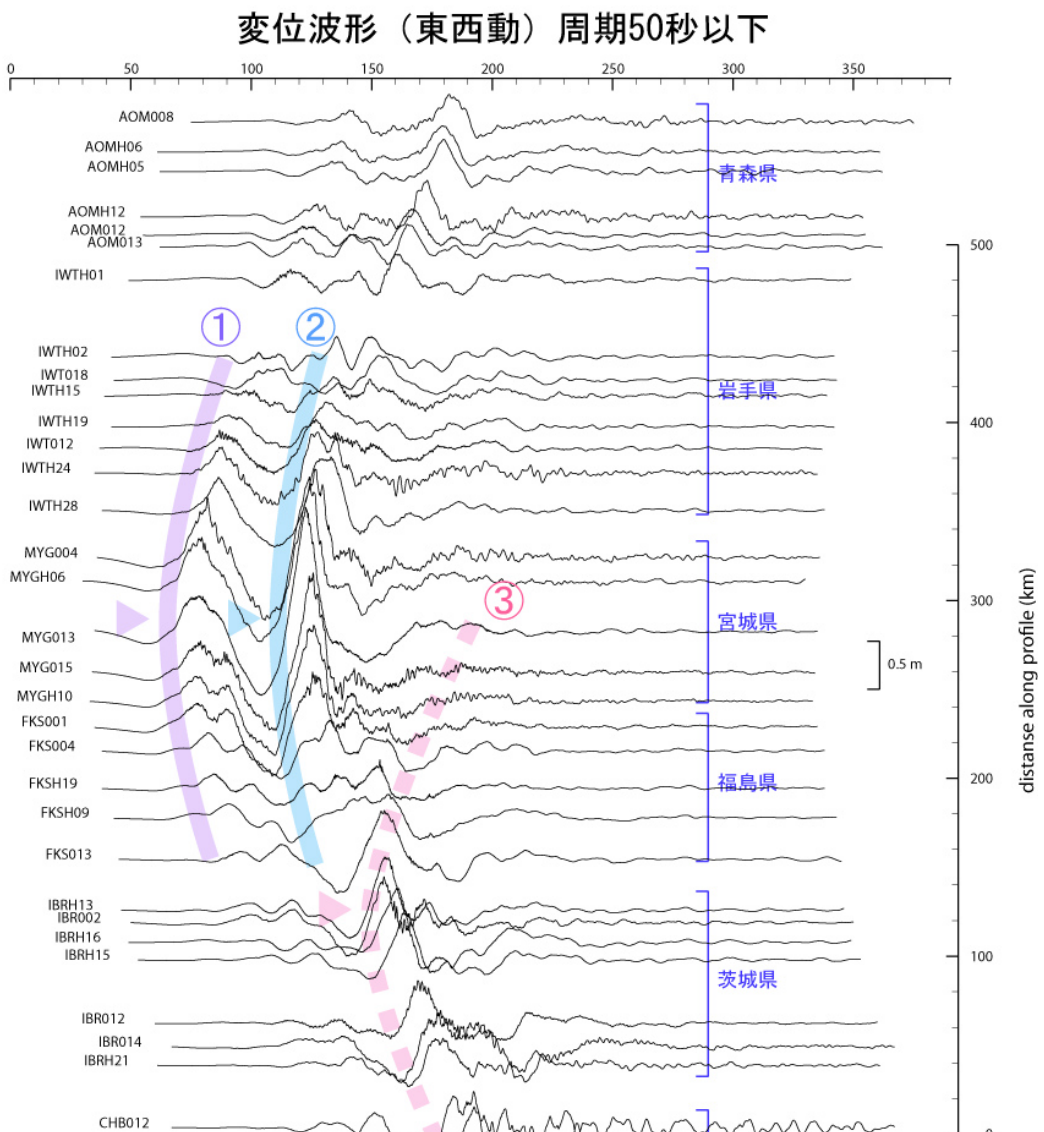
Source directivity



The energy radiation becomes strongly anisotropic (Doppler effect). In the direction of rupture propagation the energy arrives within a short time window.

M9 Japan 2011

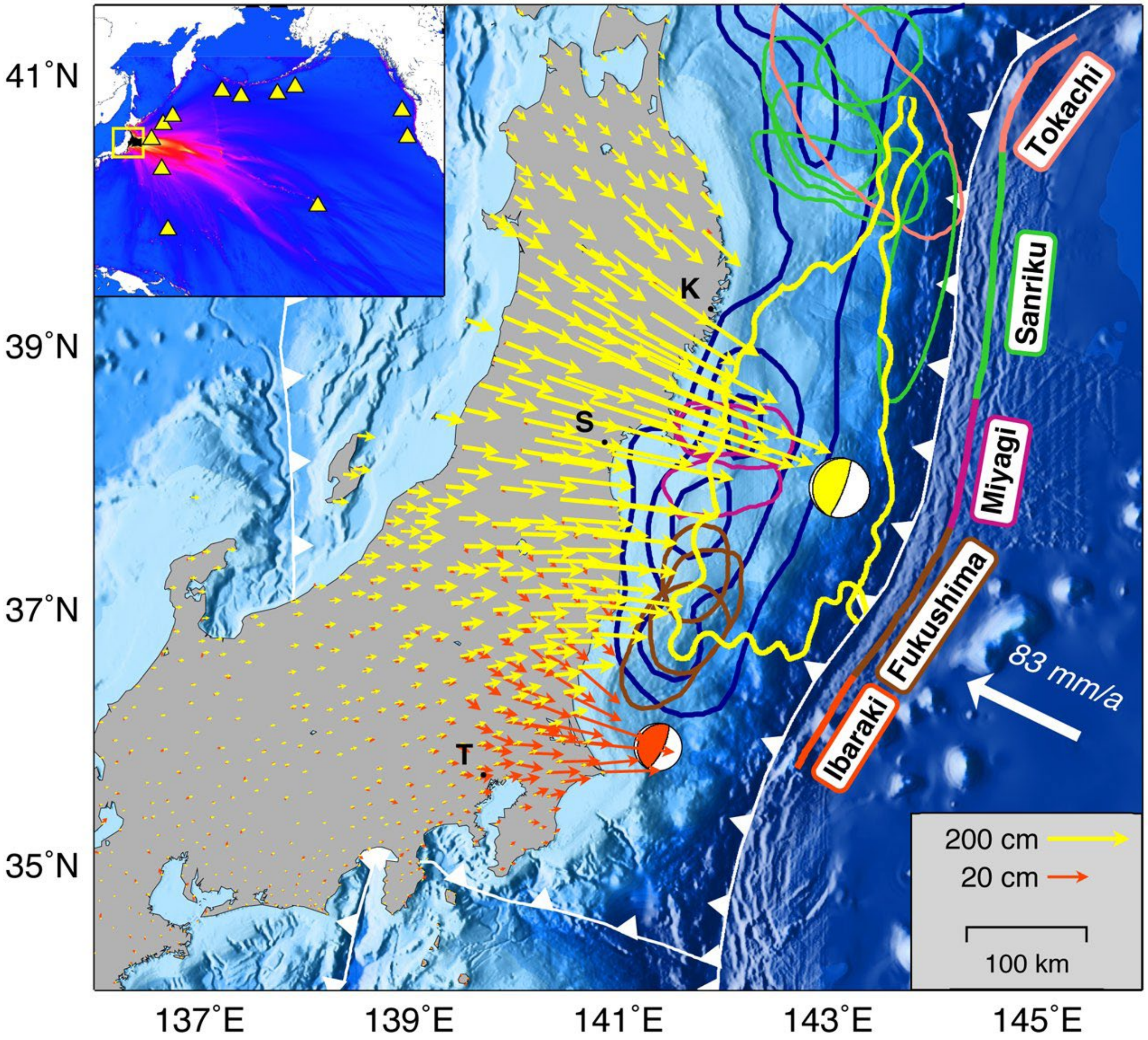




Seismic sources

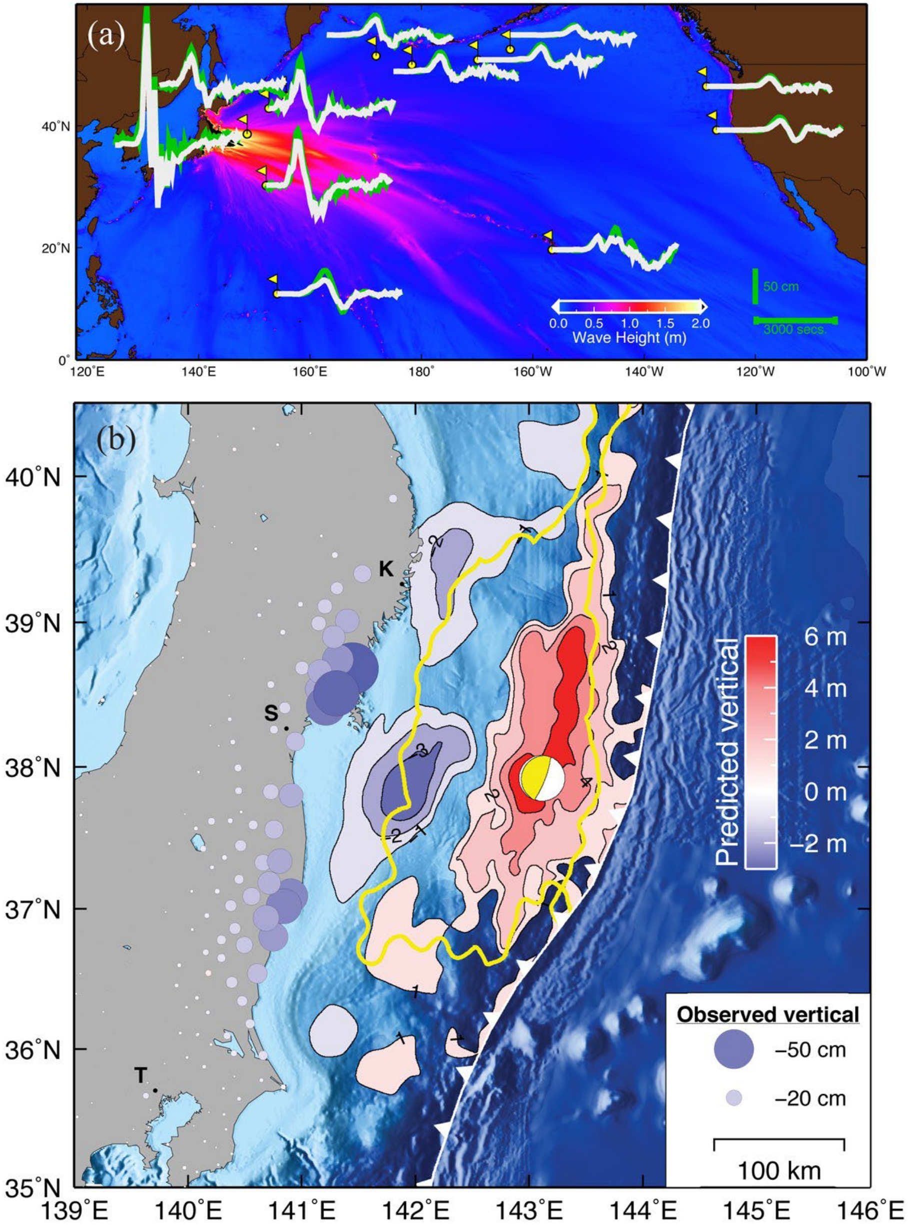
Horizontal displacements

Beobachtete Verschiebungen
(Simons, Science,
2011)

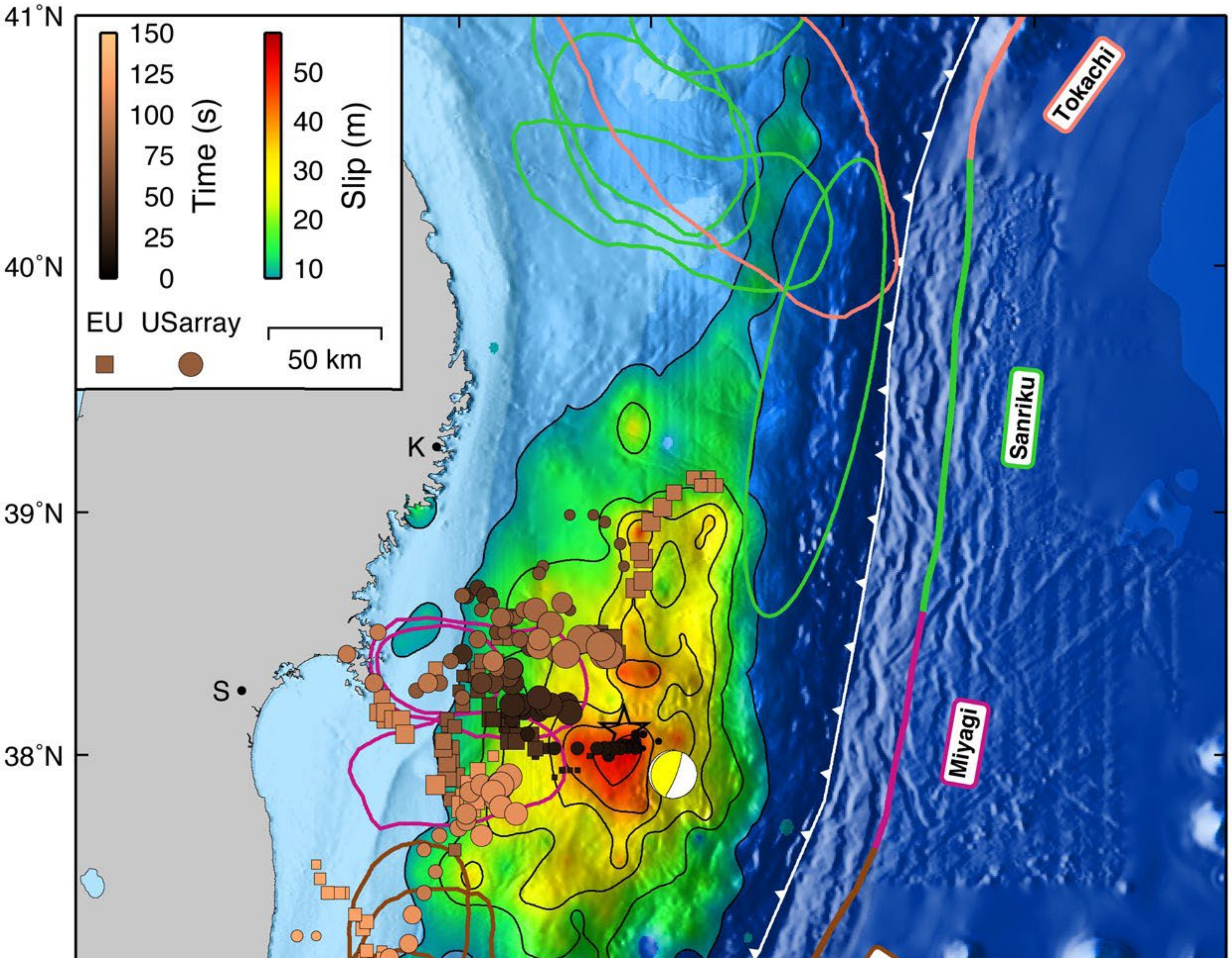


Vertical displacements

Beobachtete Verschiebungen
(Simons, Science,
2011)



50m slip on the fault!

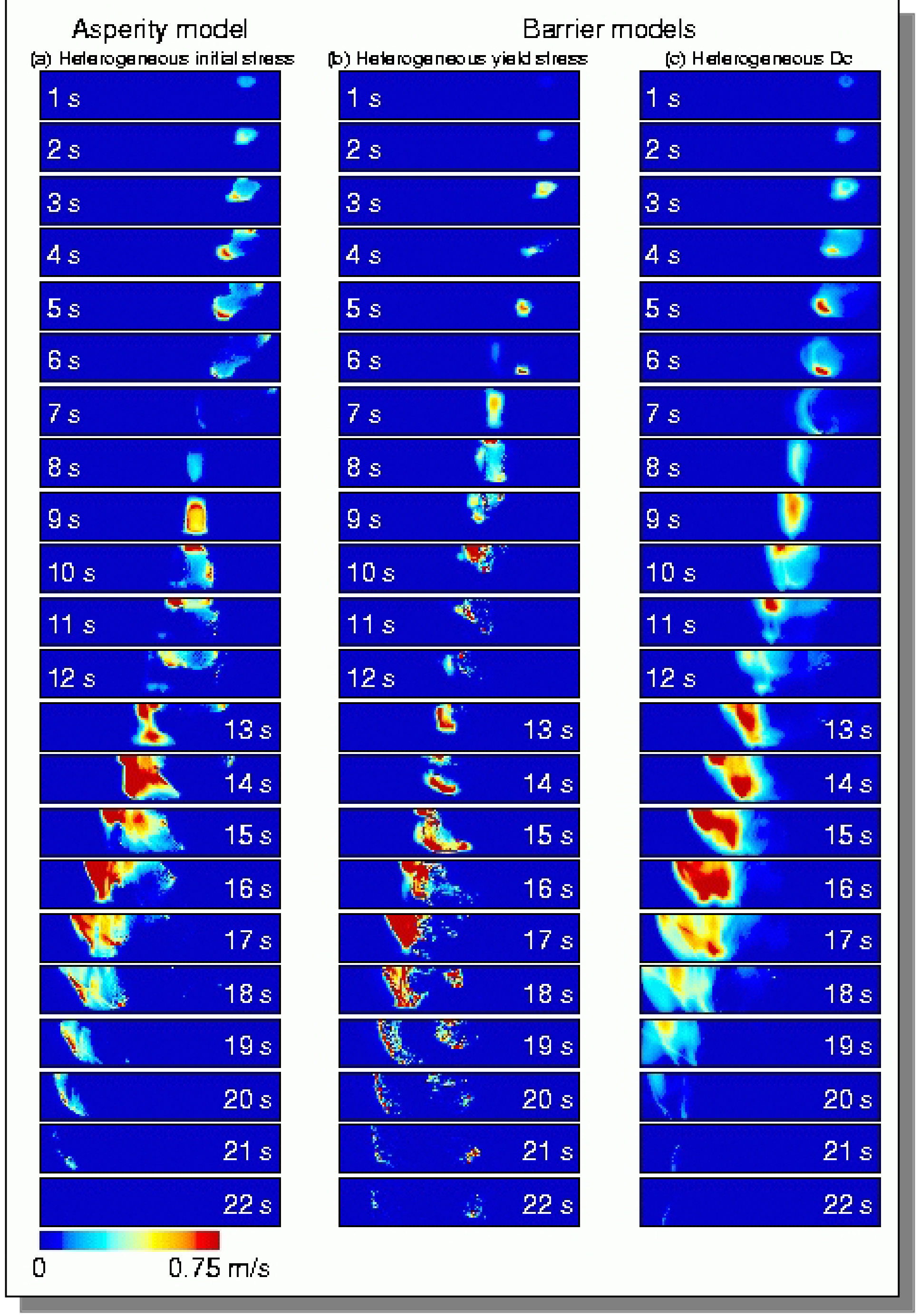


Seismic sources

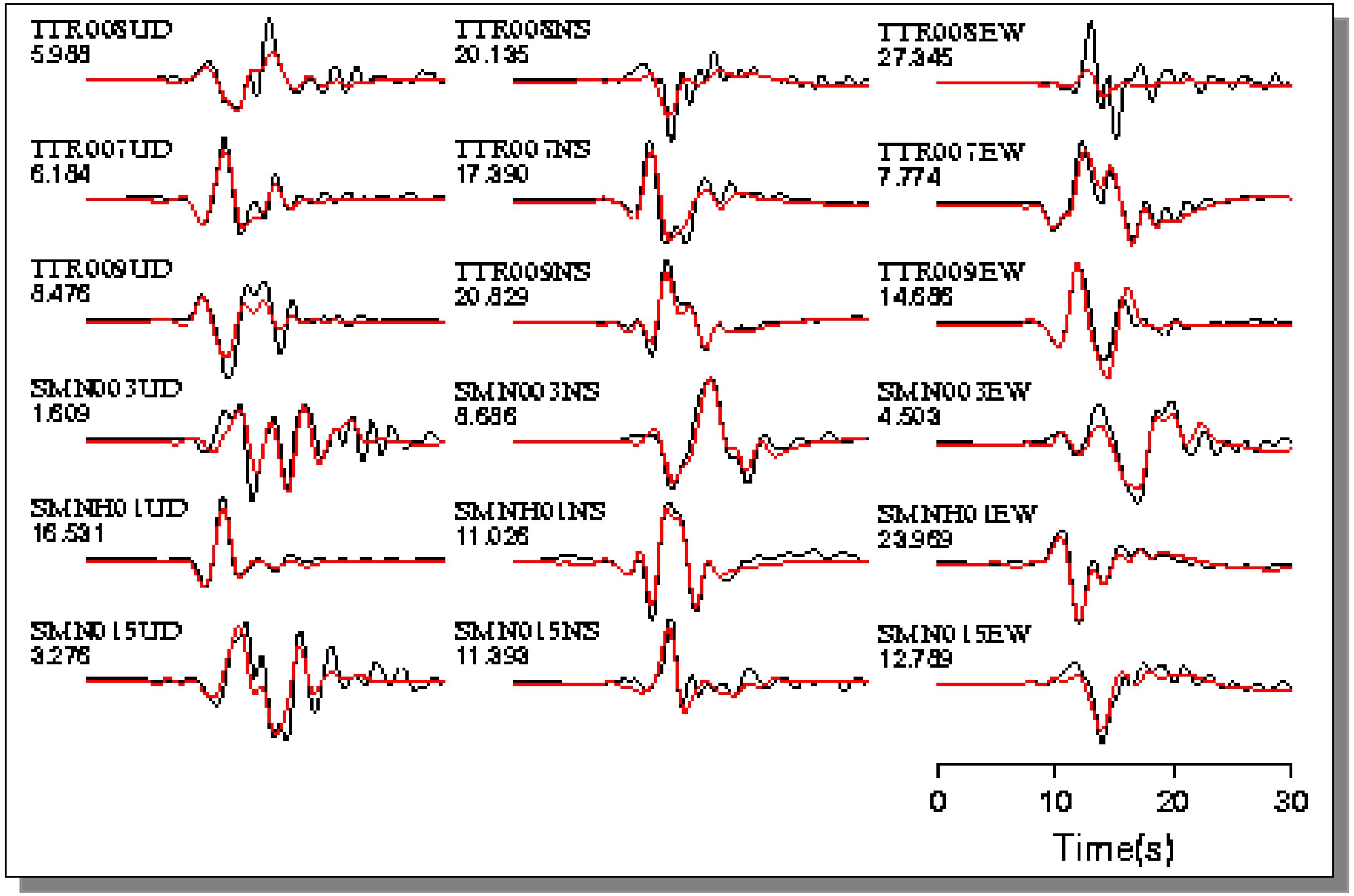
Source kinematics

Slip rate as a function of various fault conditions (Landers earthquake)

Source: K Olsen, UCSB

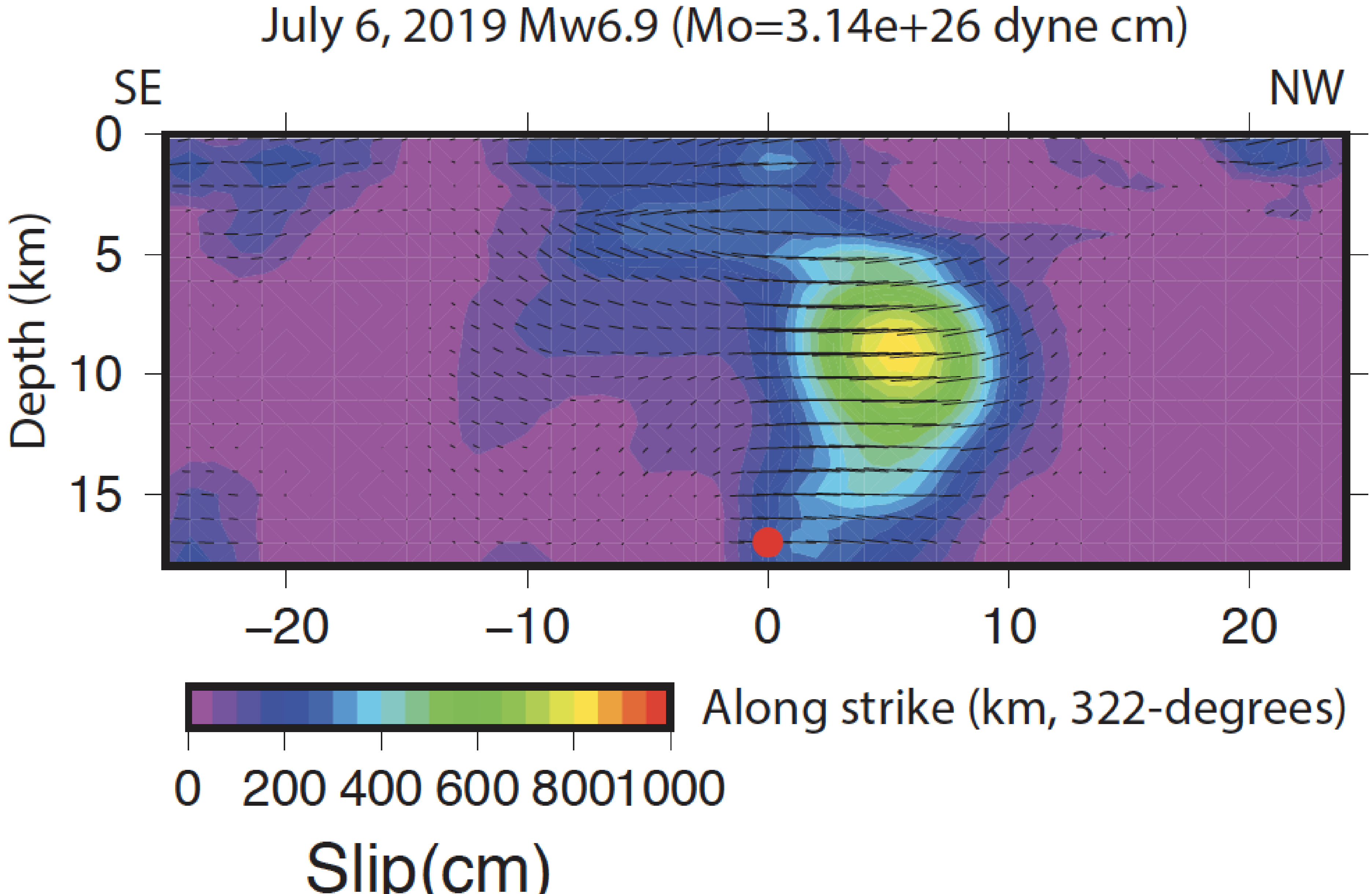


Source kinematics



Fit between observations (red) and finite fault simulations (black)

The California Event (D. Dreger, Berkeley)



Energie von Erdbeben

Magnitude

Seismic moment

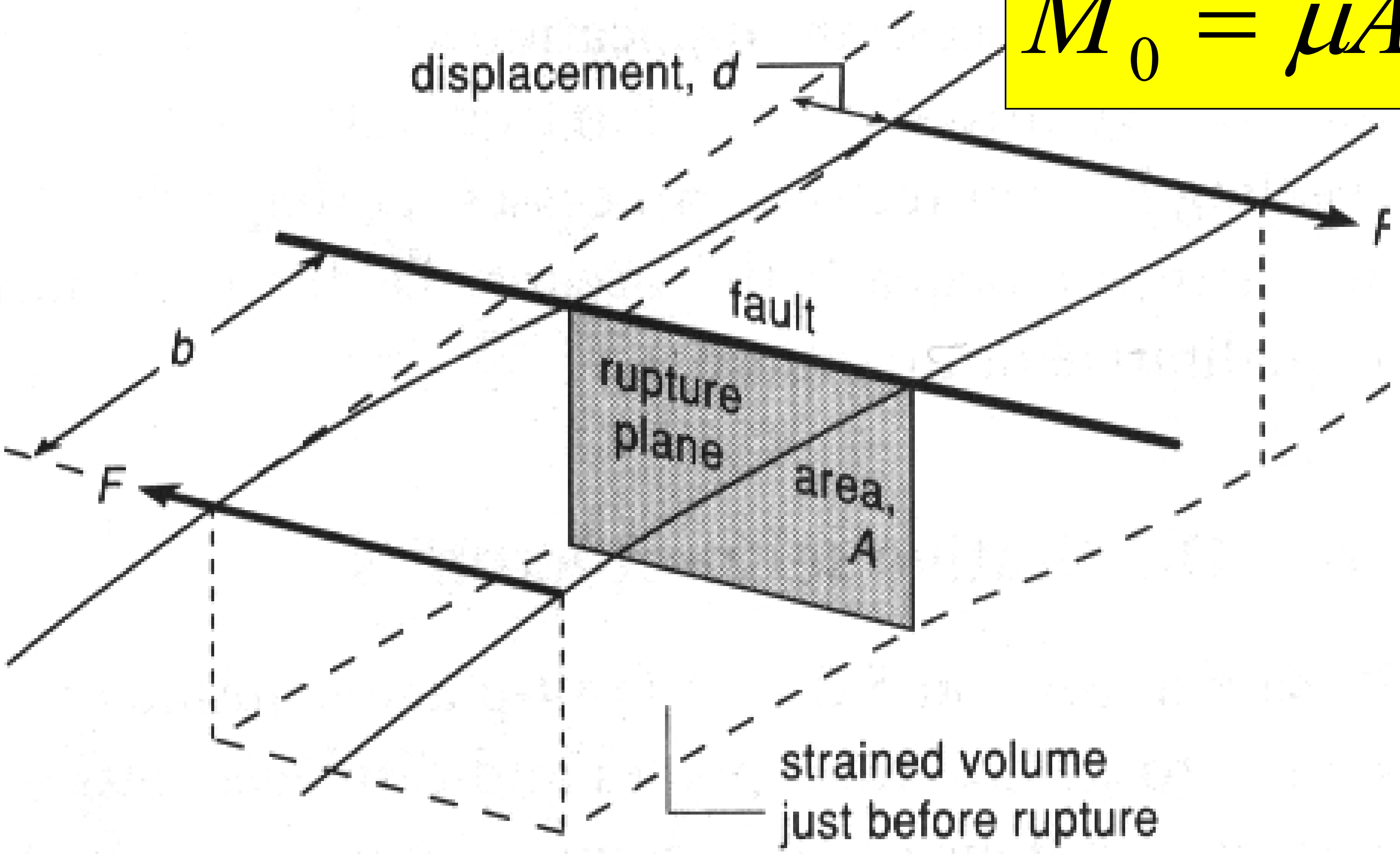
Seismologists measure the size of an earthquake using the concept of seismic moment. It is defined as the force times the distance from the center of rotation (torque). The moment can be expressed suprisingly simple as:

$$M_0 = \mu A d$$

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

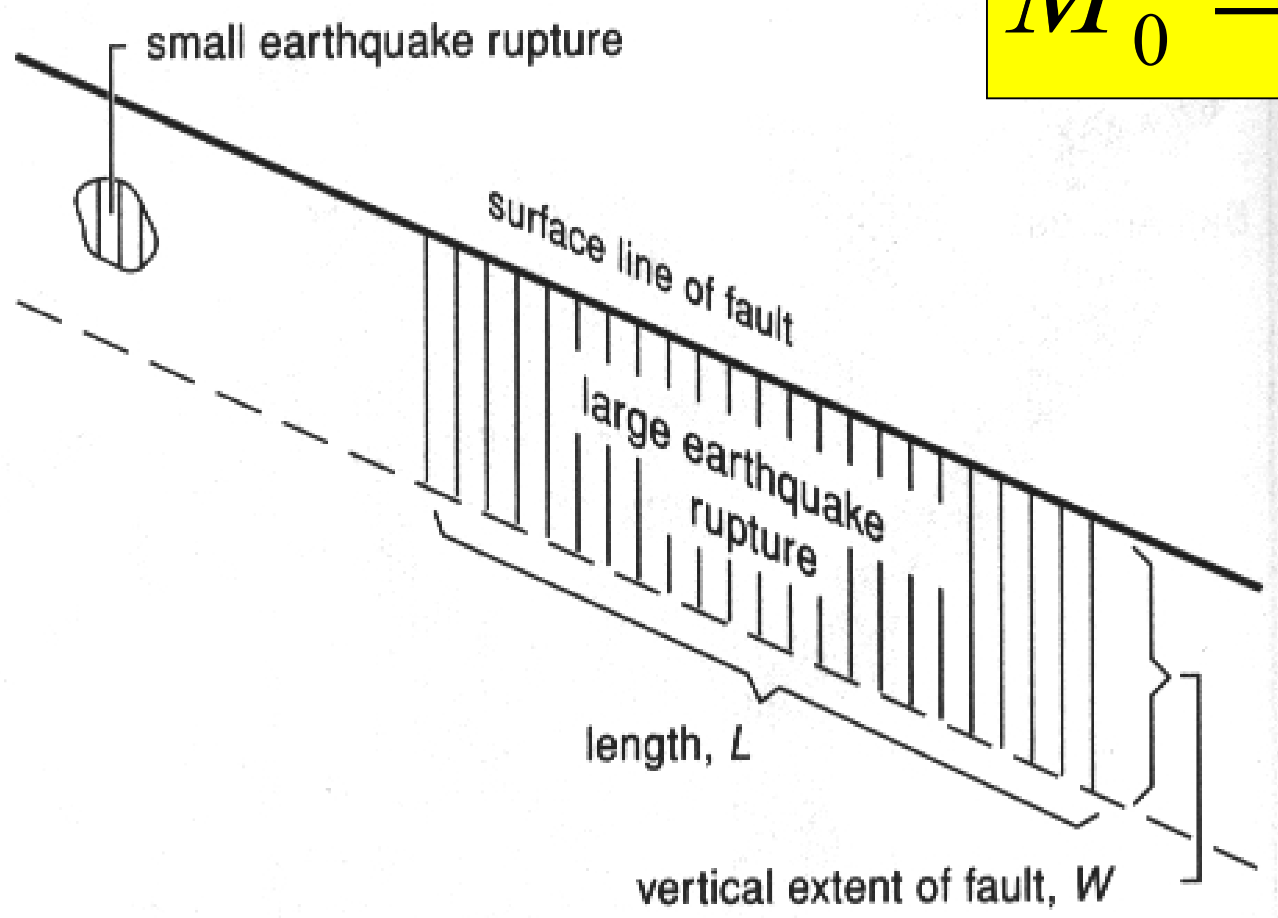
Seismic moment

$$M_0 = \mu A d$$

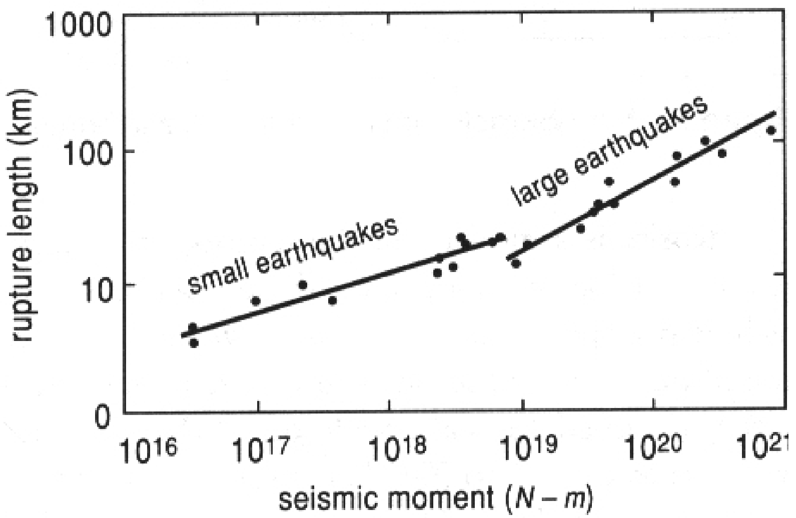


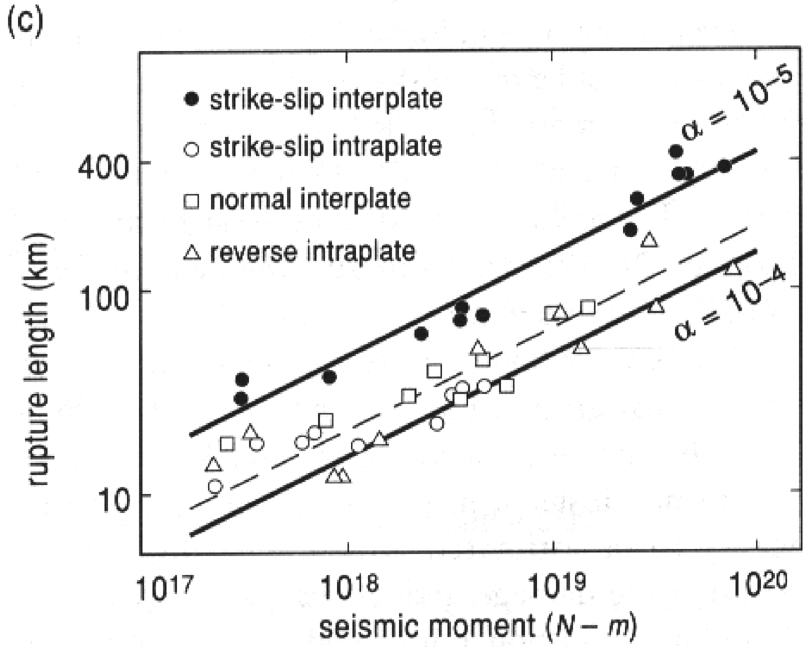
Seismic moment

$$M_0 = \mu A d$$



Seismic moment

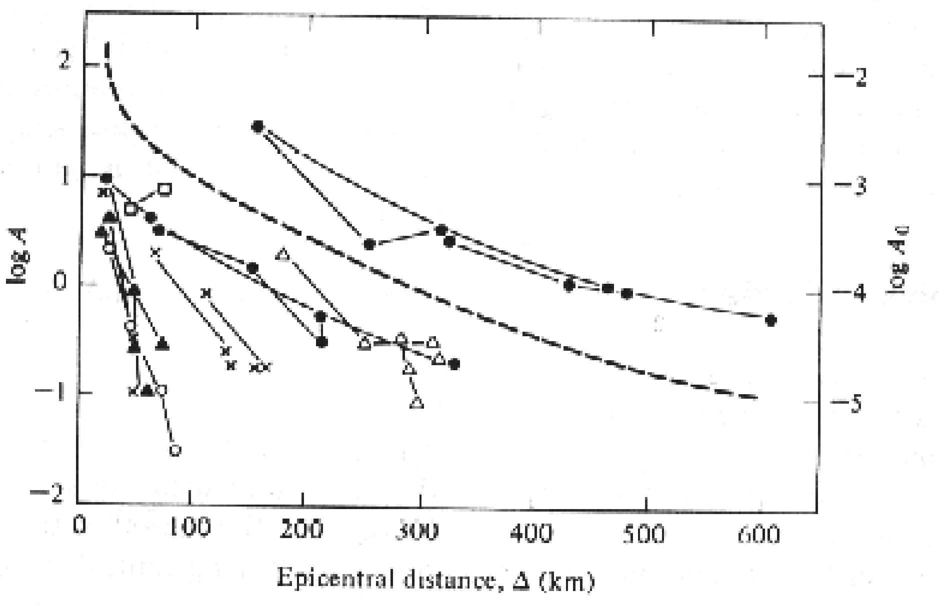




$$M_0 = \mu A d$$

There are differences in the scaling of large and small earthquakes

Magnitude Scales - Richter



Data from local earthquakes in California

The original Richter scale was based on the observation that the amplitude of seismic waves systematically decreases with epicentral distance.

Magnitude Scales - Richter

$$M = \log(A/T) + f(\Delta, h) + C_s + C_r$$

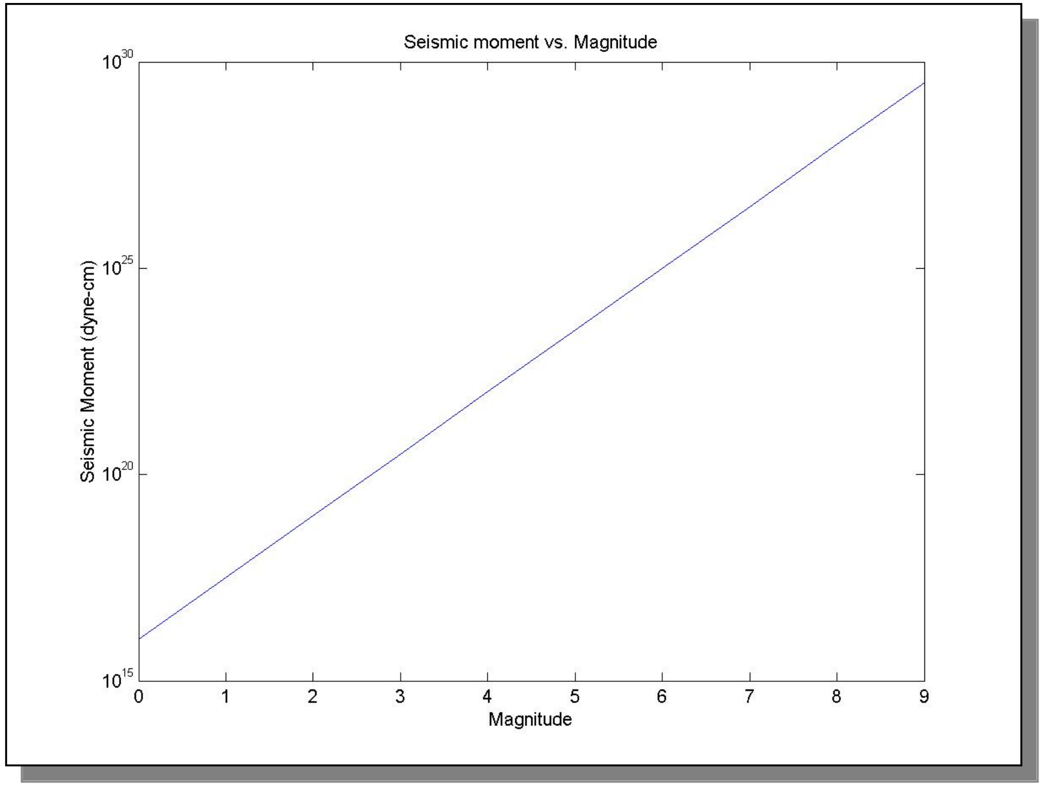
M seismic magnitude
A amplitude
T period
f correction for distance
C_s correction for site
C_r correction for receiver

M_L Local magnitude
M_b body-wave magnitude
M_s surface wave magnitude
M_w energy release

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)

$$\log E_S = 11.8 + 1.5M$$

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

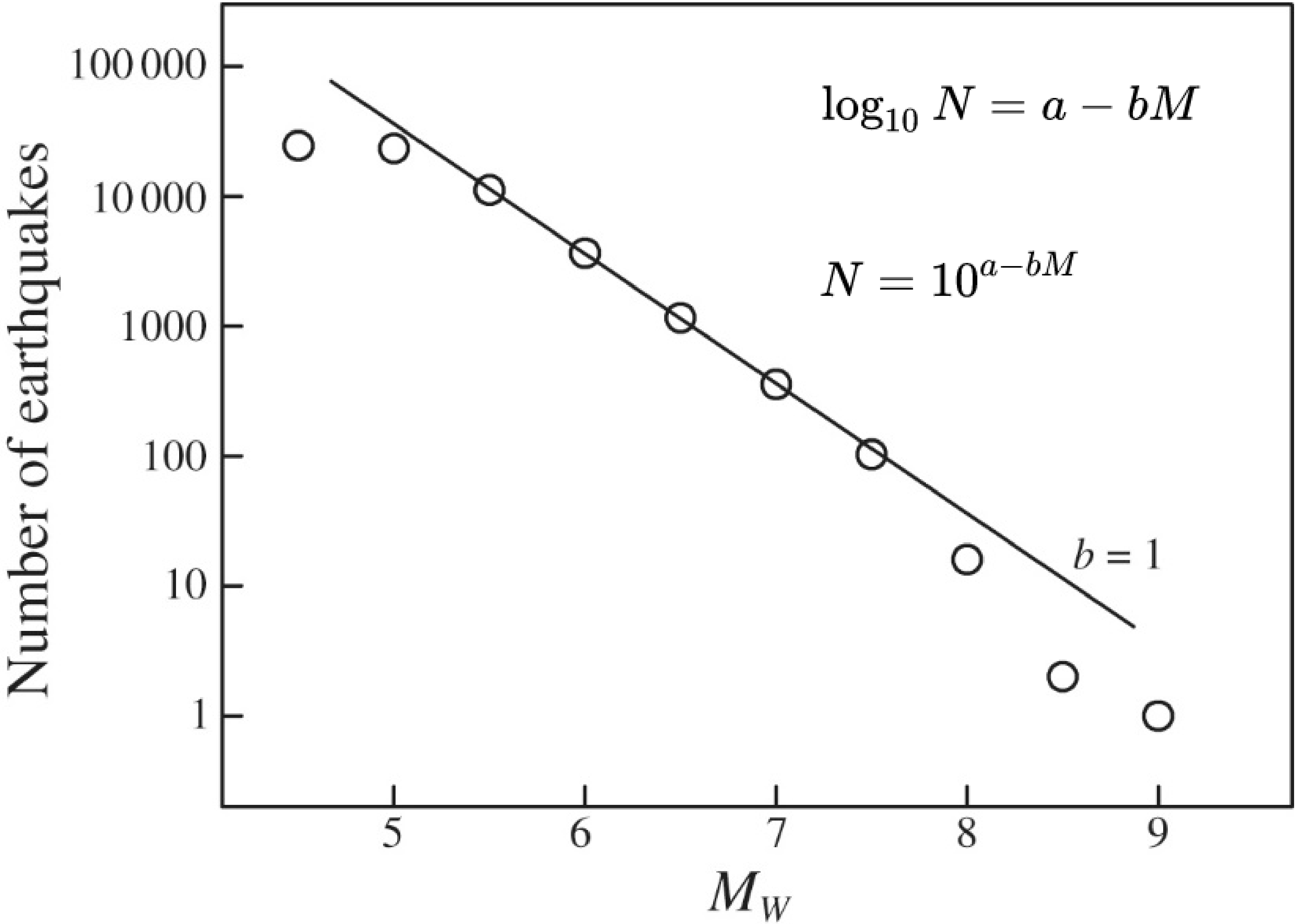
$$Energy = Moment / 20000$$

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)

Erdbebenstatistik

Gutenberg-Richter Gesetz



Seismic sources

Far away from the source (far-field) seismic sources are best described as point-like double couple forces. The orientation of the initial 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.