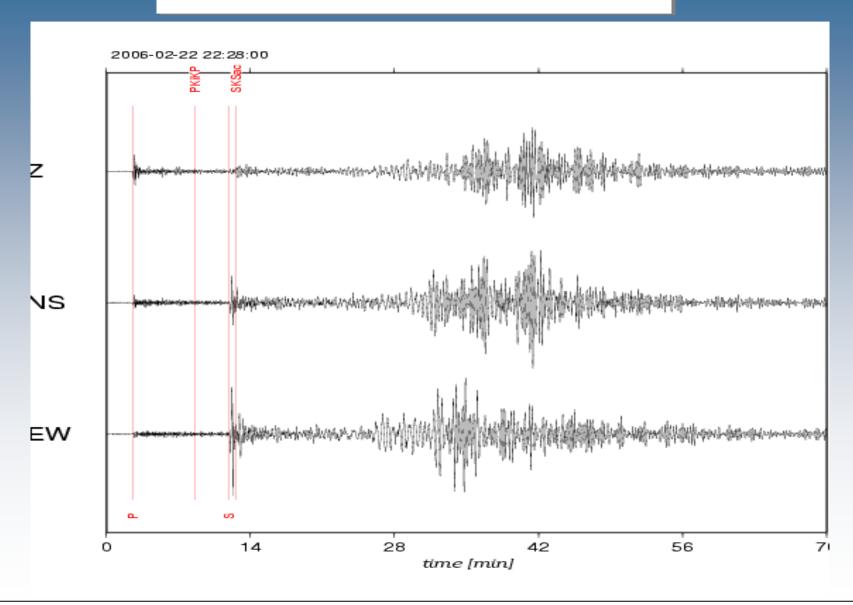


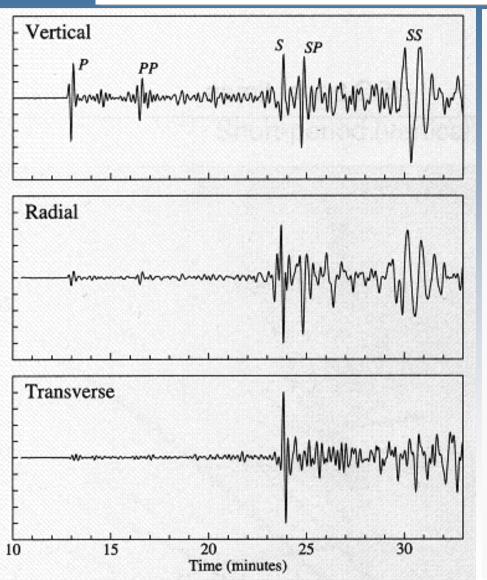
Seismologie - Erdbeben

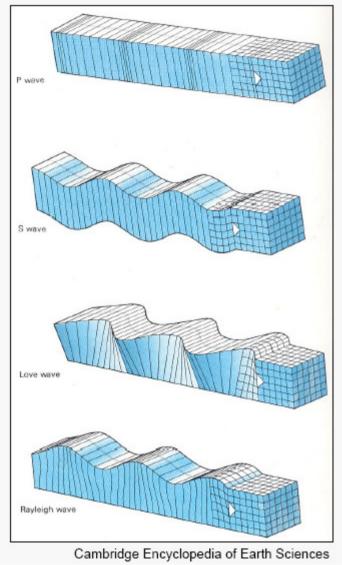
- Wie kann man die Herdzeit eines Erdbebens bestimmen?
- Wie das Epizentrum und die Tiefe eines Erdbebens?
- Wie kann man die Stärke eines Erdbebens abschätzen (Richter Skala)?
- Wie kann man die durch Erdbeben verursachten Schäden kategorisieren (seismische Intensität, Mercalli Skala)?
- Erdbebenvorhersage, Erdbebengefährdung

22.02.2006 - Mozambique



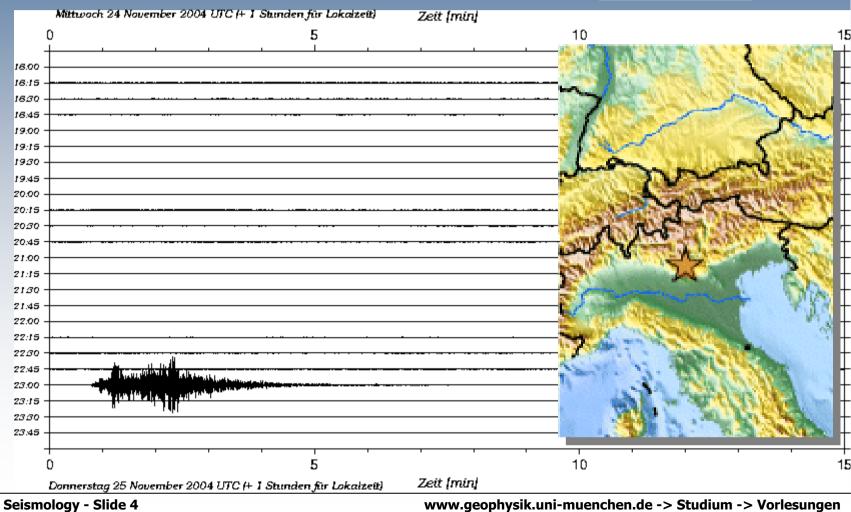






Gardasee Beben 2004

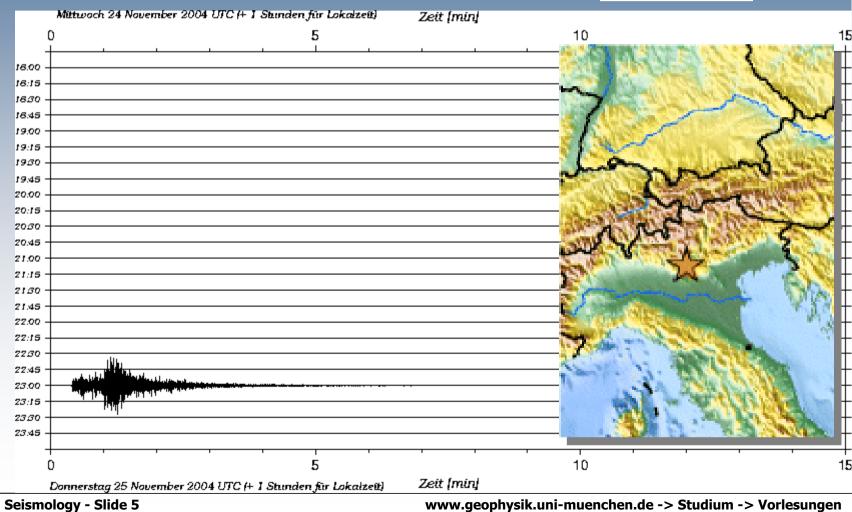


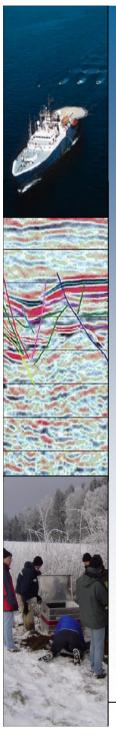




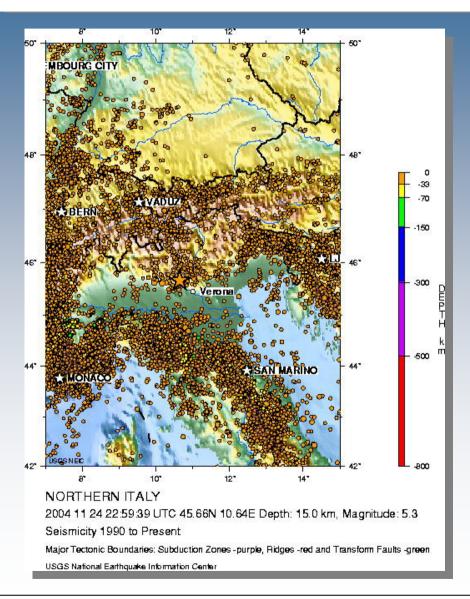
Gardasee Beben 2004







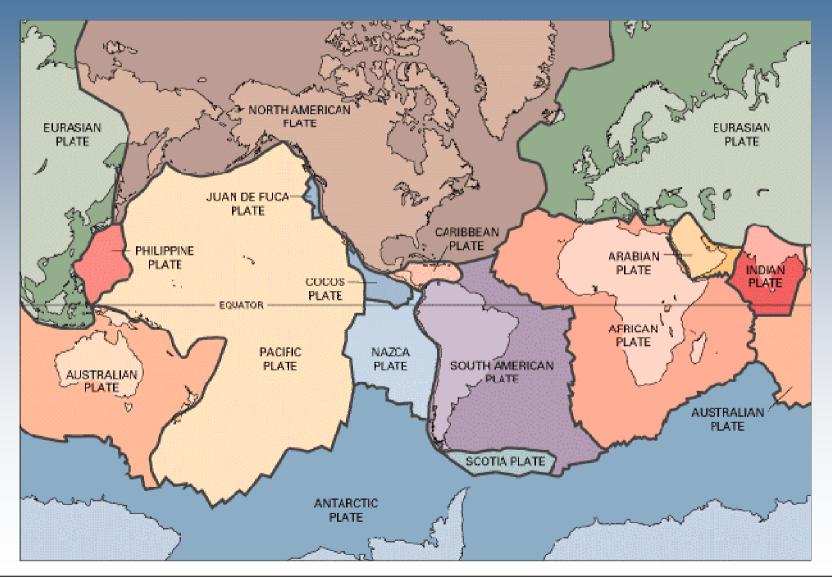
Epizentrum

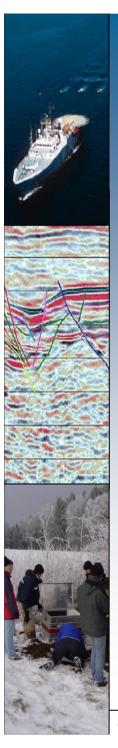






Plattentektonik - Plattengrenzen





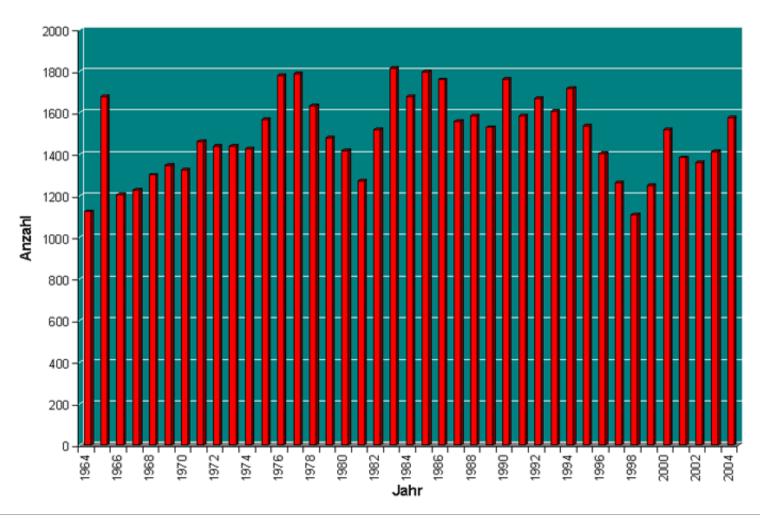
Erdebenverteilung

verbunden mit tektonischer Aktivität

- aktive Kontinentalränder
- mittelozeanische Rücken
- Grenzen der Lithosphärenplatten, aber auch im Inneren
- 80% der seismischen Energie in zirkum-pazifischer Randzone
- 70% aller Beben in der Erdkruste
- Mitteltiefe (60-300 km) und tiefe Beben (>300 km) sind meist an die sog. Benioff-Zonen gebunden
- Hypozentrum: Ort des Bebens in der Tiefe
- Epizentrum: Projektion an die Erdoberfläche

Erdbebenhäufigkeit weltweit

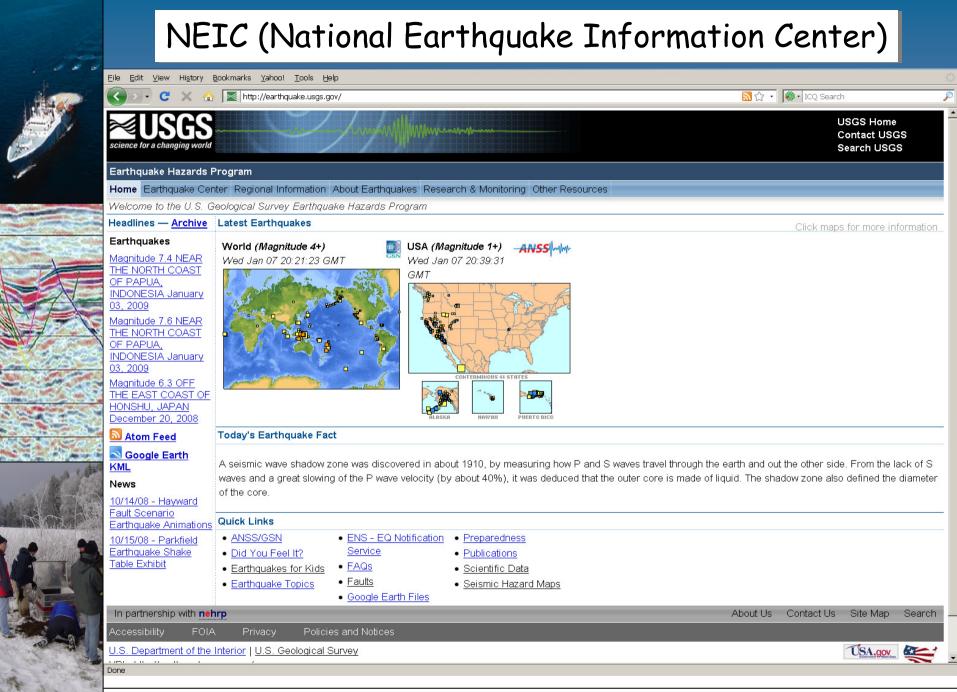
Erdbeben pro Jahr mit Magnitude >= 5.0 (NEIC)

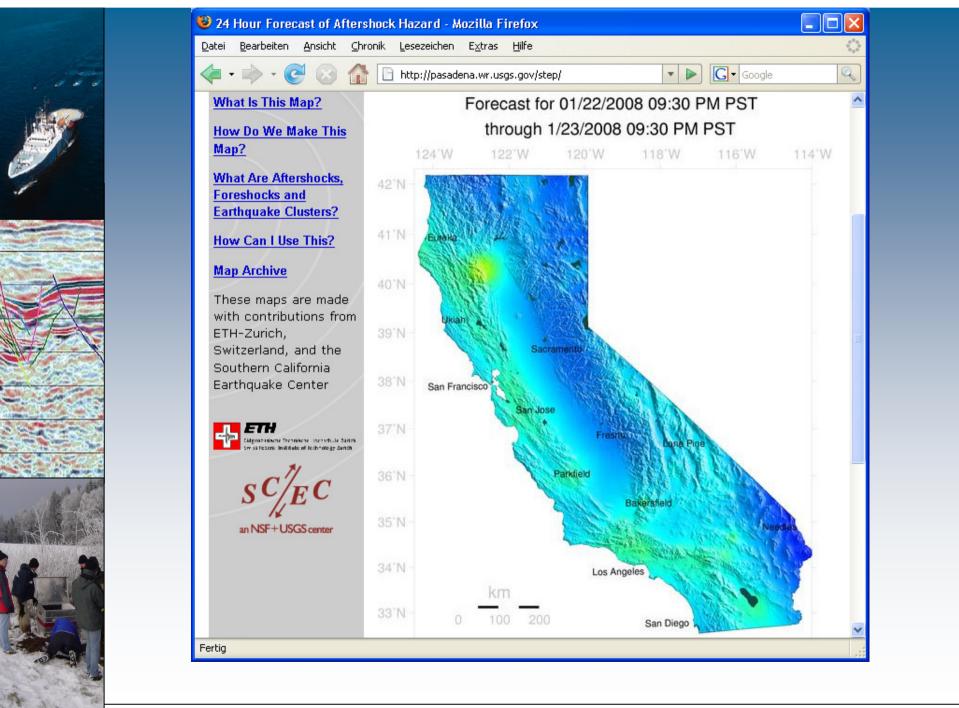


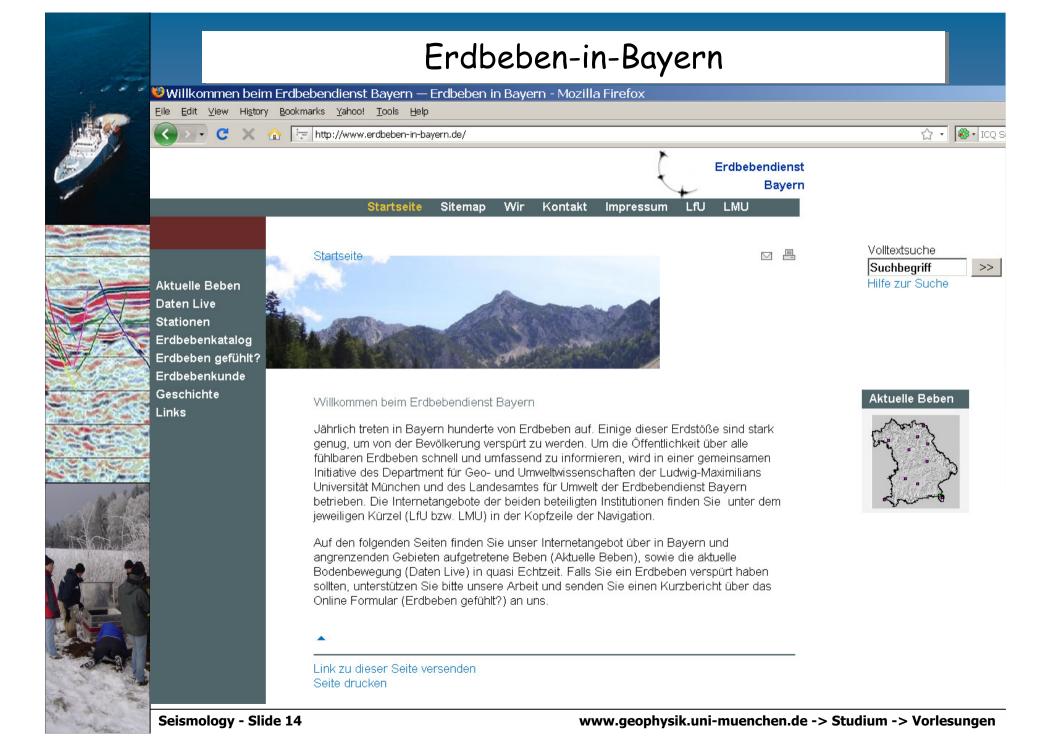


Was steuert die Bodenbewegung durch Erdbeben

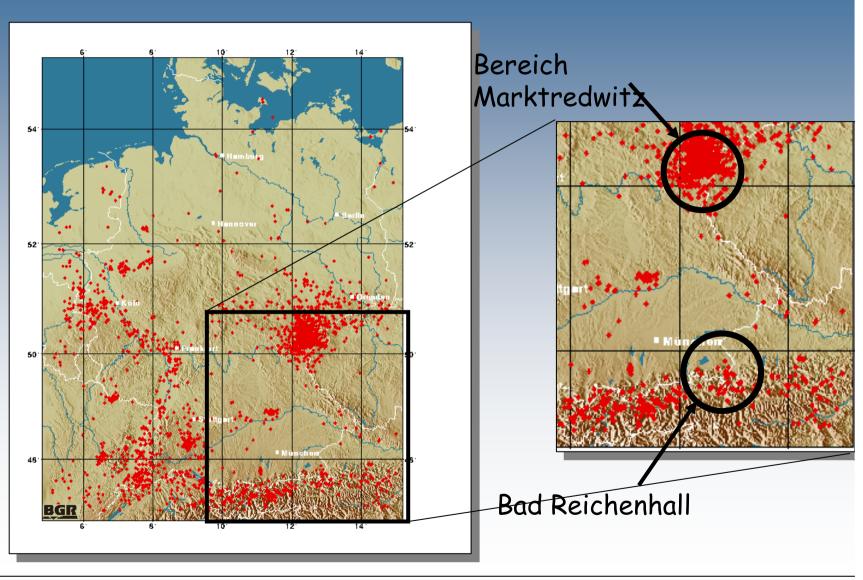
- · Magnitude
 - Maß für die freigesetzte Energie
- · Entfernung
 - Wellenamplituden nehmen mit der Entfernung ~1/D ab
- · Lokaler Untergrund
 - Resonanzen z.B. bei weichem Untergrund

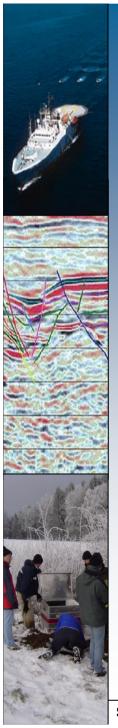




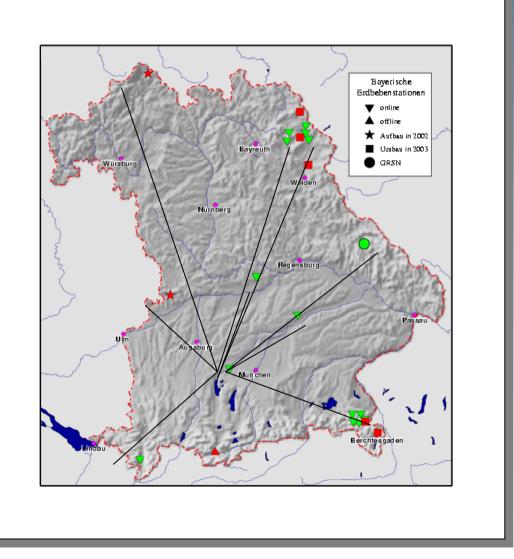


Erdbeben in Bayern?



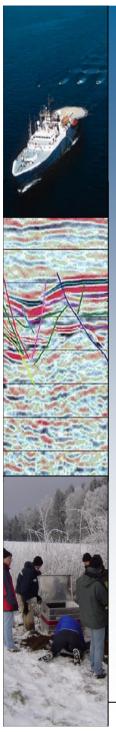


Seismische Stationen in Bayern

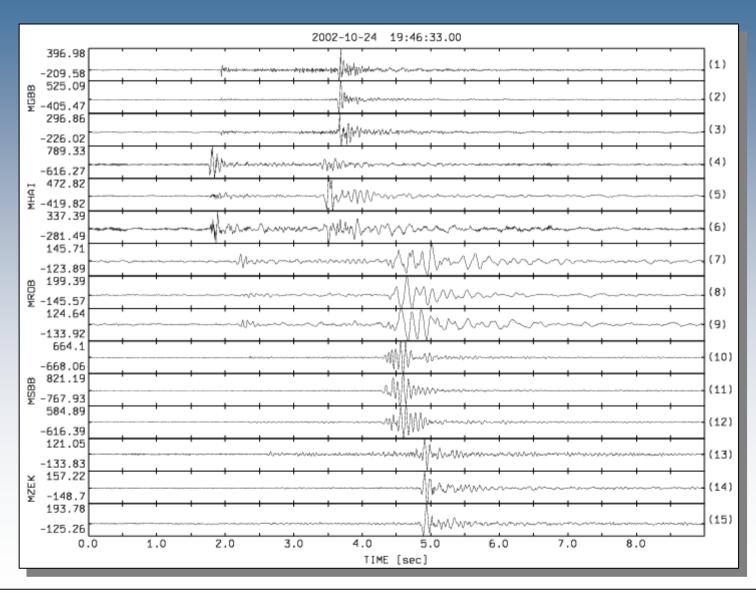


Früher: ISDN Verbindung mit Stationen alle 20Min.

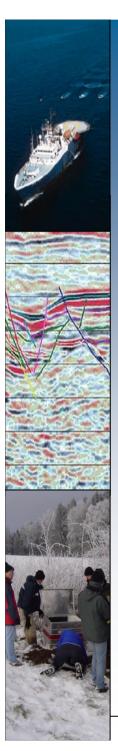
Heute: DSL permanent online



Erdbeben nahe Marktredwitz, 24.10.2002



Seismograms 2006-02-22 22:28:00 time [min] time [min] Seismology - Slide 18 www.geophysik.uni-muenchen.de -> Studium -> Vorlesungen



Erdbebenlokalisierung

Was beobachten wir?

- Ankunftszeiten von P und S Wellen an verschiedenen Stationen

Was wollen wir wissen?

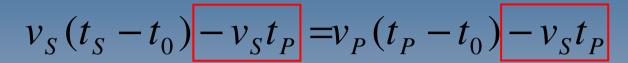
- Herdzeit des Erdbebens
- Epizentrum und Tiefe

Wir nehmen an das Erdbeben passiert zur Zeit t_0 und wir kennen die seismischen Eigenschaften des (homogenen) Mediums v_p (Wellen) and v_s (Wellen). Für eine Station mit der Herddistanz D gilt:

$$v_S = \frac{D}{t_S - t_0} \qquad v_P = \frac{D}{t_P - t_0}$$

$$v_S(t_S - t_0) = v_P(t_P - t_0)$$

Erdbebenlokalisierung

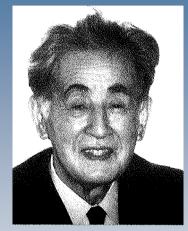


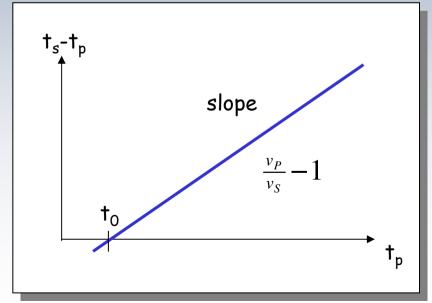
$$t_S - t_P = \frac{v_P}{v_S} (t_P - t_0) - t_P + t_0$$

$$t_S - t_P = (\frac{v_P}{v_S} - 1)(t_P - t_0)$$

y = mx

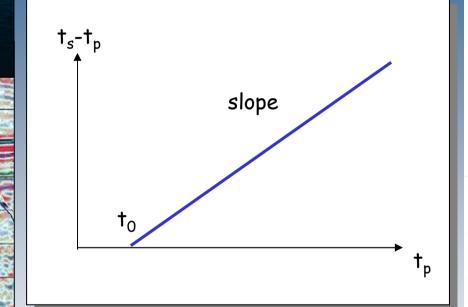
Wadati Diagramm



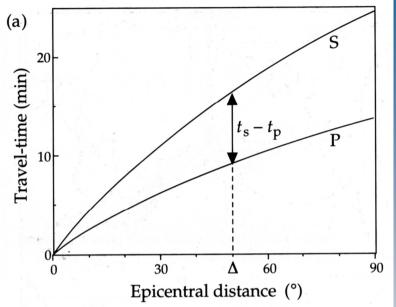


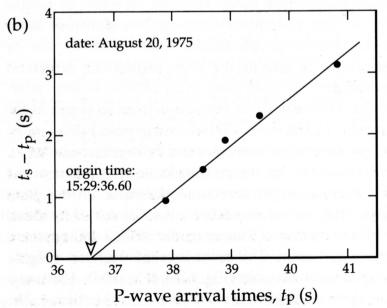
Kiyoo Wadati 1902 - 1995

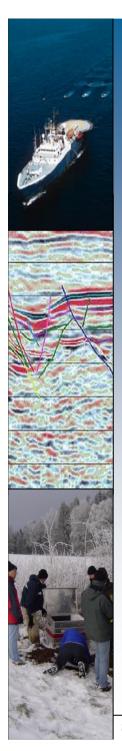
Wadati Diagramm



$$(t_S - t_P) = (\frac{v_P}{v_S} - 1)(t_P - t_0)$$
$$y = mx$$







Erdbebenlokalisierung

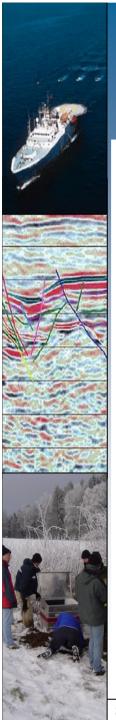
Mit der Steigung v_p/v_s -1 des Wadati Diagrams können wir v_p/v_s bestimmen. Damit ergibt sich für die Herdzeit:

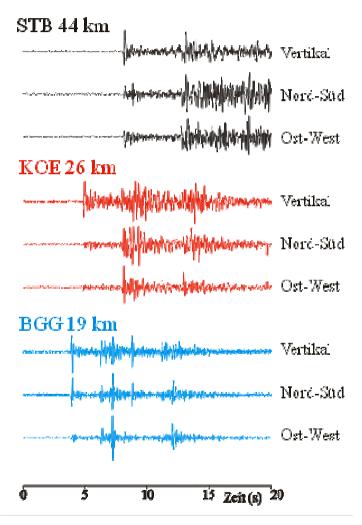
$$\begin{vmatrix} t_0 = t_P - \frac{t_S - t_P}{v_P} \\ \frac{v_P}{v_S} - 1 \end{vmatrix}$$

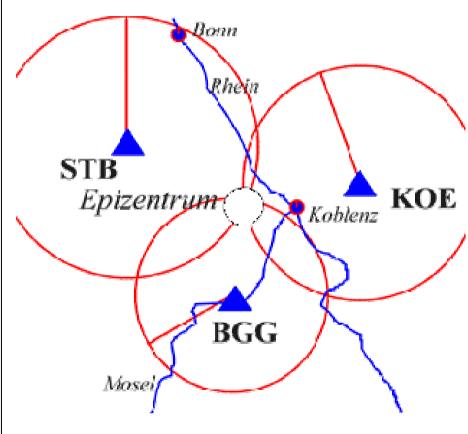
Und die Entfernung D_i des Erdbebens von der Station i mit Ankunftszeit $t_{P,i}$ der P-Wellen

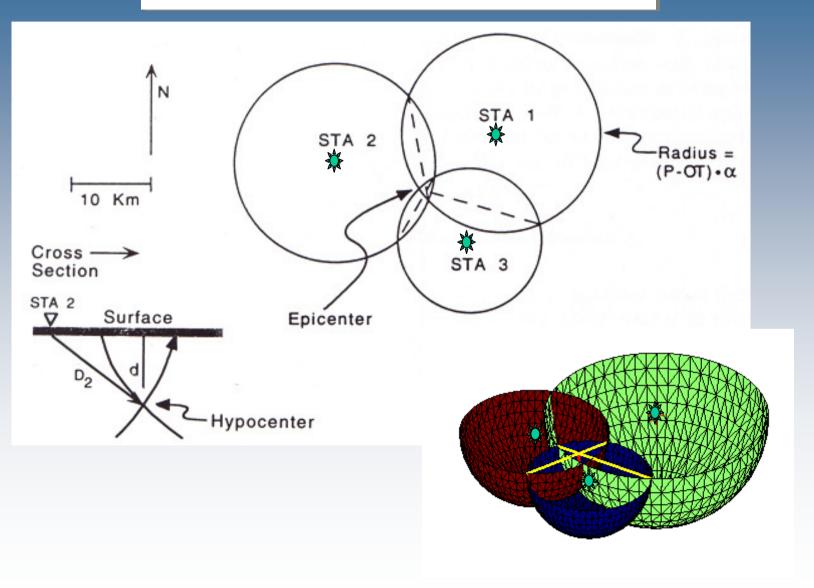
$$D_i = v_P (t_{P,i} - t_0)$$

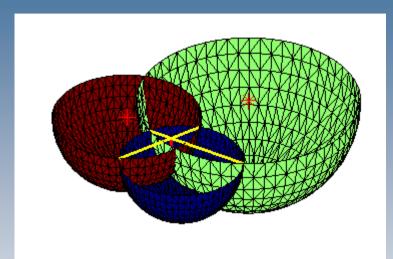
Wir können wir Epizentrum und Tiefe bestimmen?

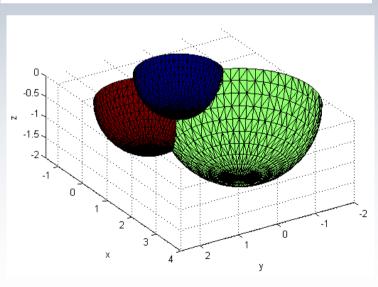


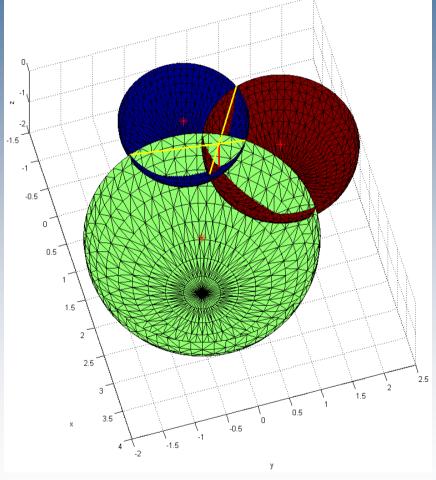




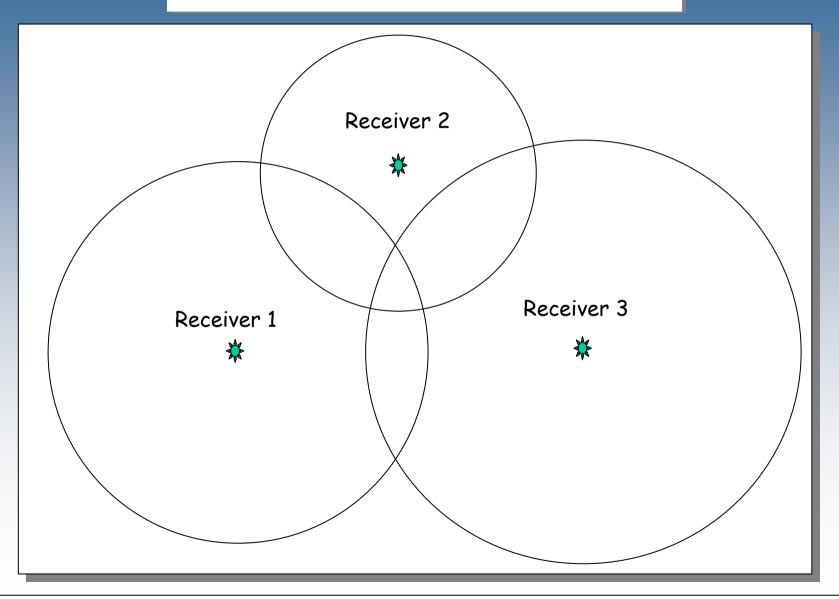


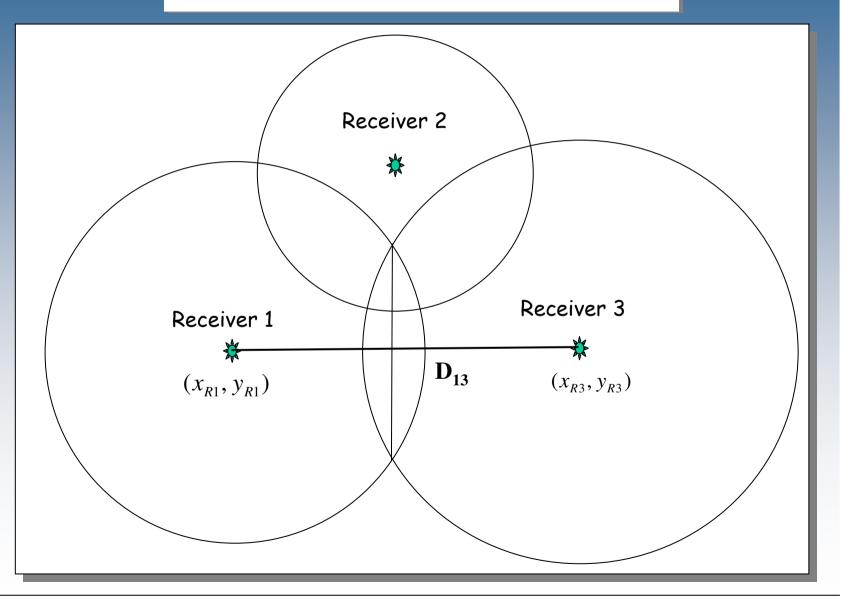




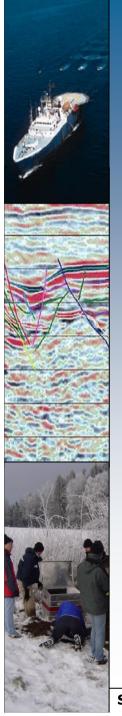


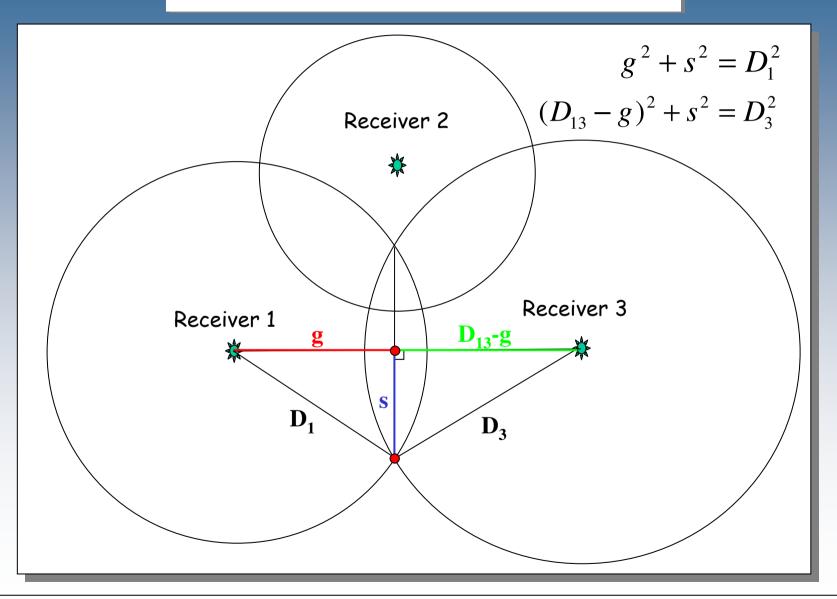




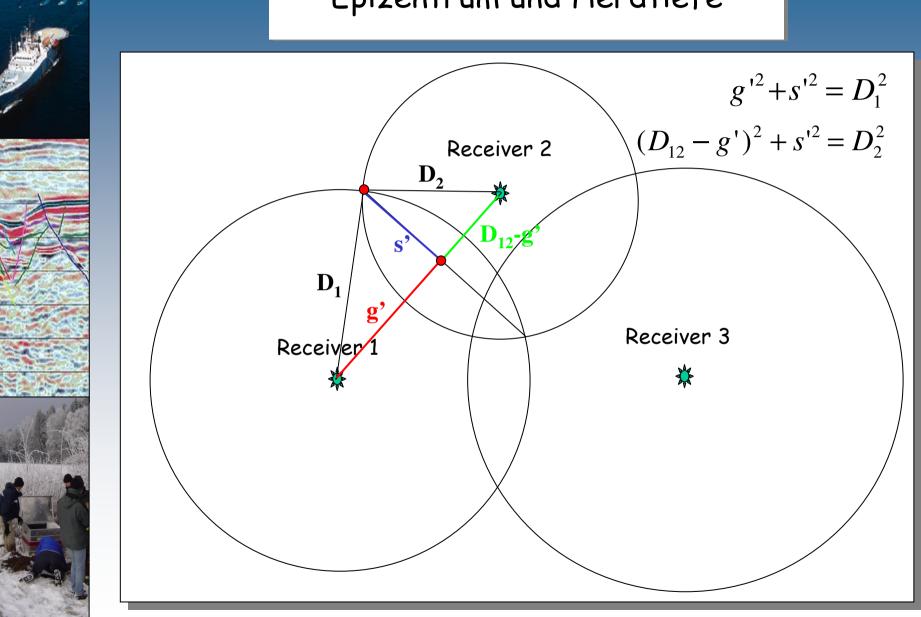




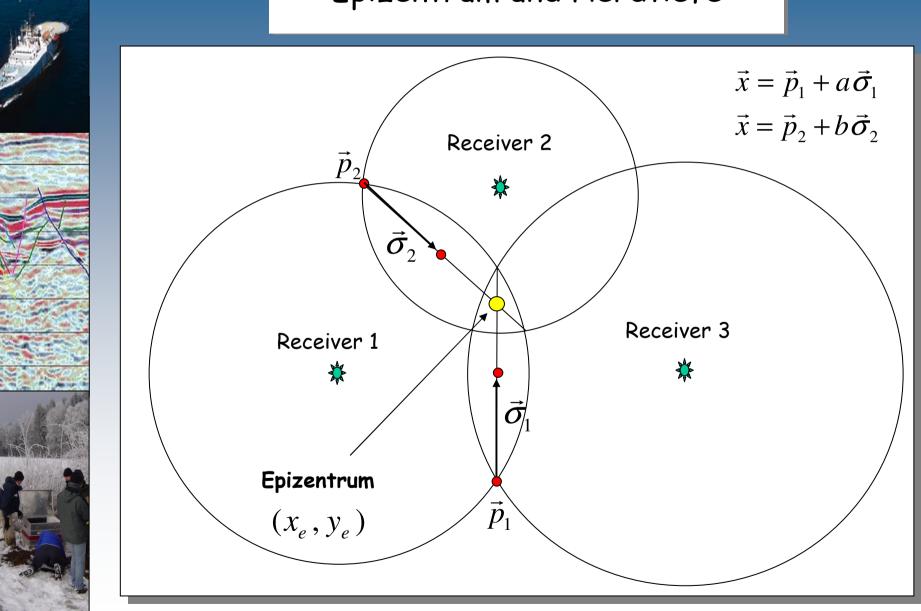


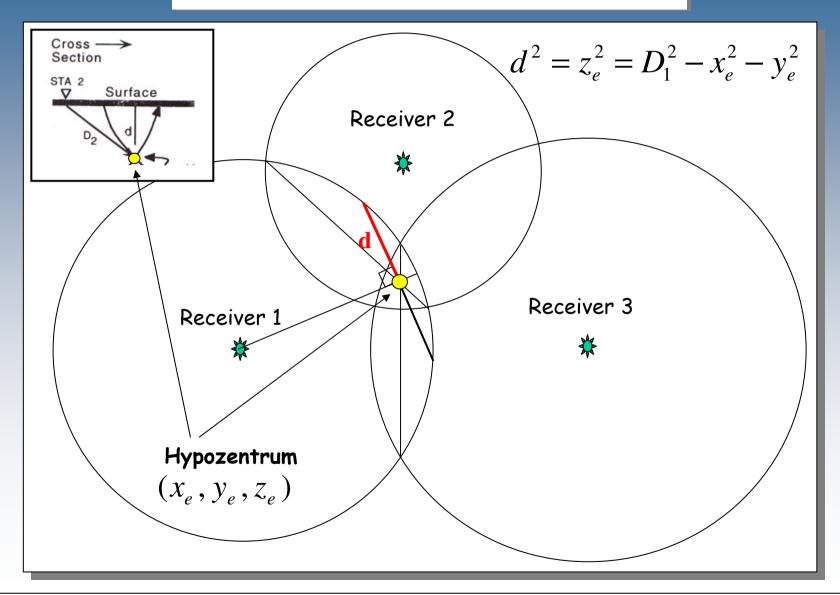


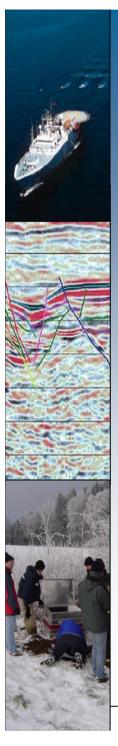




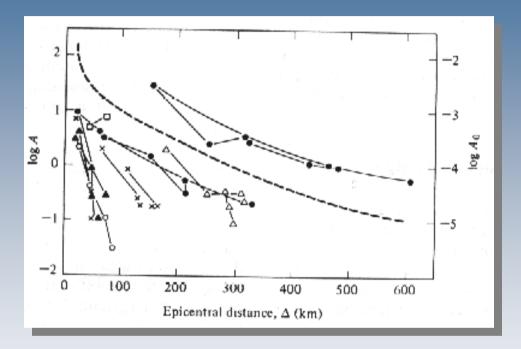








Magnitude - Richter



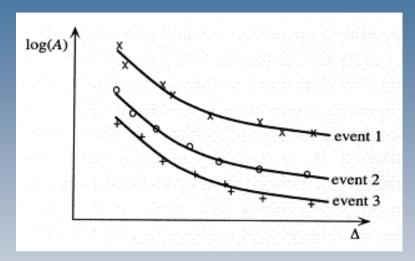


Charles Richter 26.04.1900 - 30.09.1985

Maximalamplituden als Funktion des Abstands für Beben in Kalifornien

Die Amplituden nehmen systematisch ab mit der Distanz von der Quelle.

Richter Skala - Lokalmagnitude



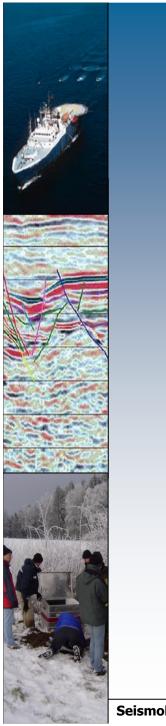
$$\begin{aligned} \frac{A_1}{A_0} &= const. \\ \log \frac{A_1}{A_0} &= \log A_1 - \log A_0 = const \\ M_L &= \log A_1(\Delta) - \log A_0(\Delta) \end{aligned}$$

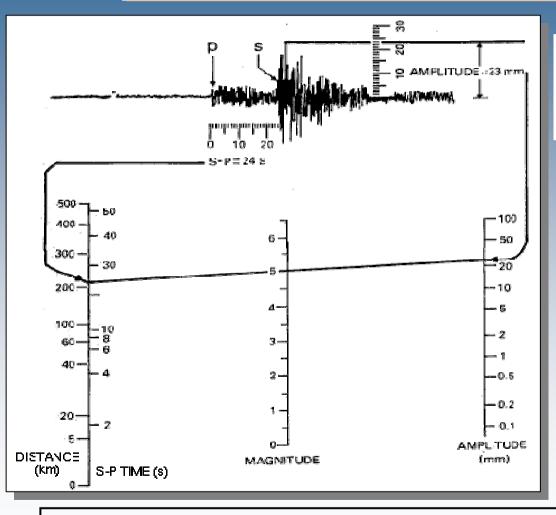
1930: Richter beobachtet, daß der Logarithmus der maximalen Amplituden der Bodenbewegung für verschiedene Erdbeben mit der Entfernung entlang paralleler Linien abnimmt.

Referenzbeben: Ein Beben – aufgezeichnet mit einem Wood-Anderson Seismometer in einer Distanz von Δ =100km erzeugt eine Amplitude von A_0 = 1mm und hat die Magnitude M_L =3.

M_L- in ursprünglicher Form - wird in der Seismologie kaum mehr benutzt, bleibt aber wichtig im Zusammenhang mit Erdbebenschäden und anderen Magnituden-Skalen.

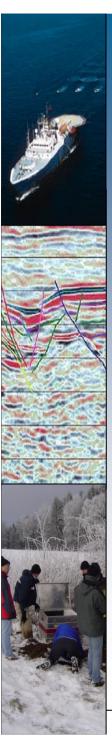






Grafische Bestimmung der Magnitude

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



Magnituden Skalen

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

M seismische Magnitude

A Amplitude

T Periode

Q Korrektur für epizentrale Distanz Δ und Tiefe h

 c_s Korrektur für Standort (Variabilität des Gesteins!)

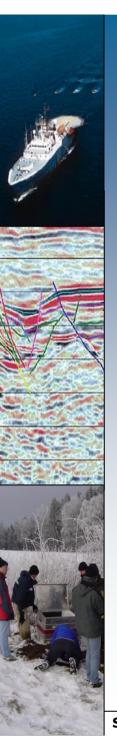
c, Korrektur für Quellregion

M_L Local magnitude

M_b body-wave magnitude

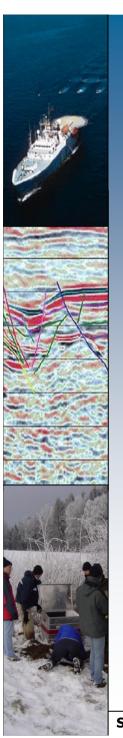
 M_s surface wave magnitude

 M_w energy release



Seismische Energie (Beispiele)

Richter TNT for Seismic Example Magnitude Energy Yield (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		(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)



Magnituden Skala - Richter und andere

Alle Skalen beziehen sich auf die Maximalamplitude eines Seismogramms.

Local Magnitude M

 $M_L = \log A - \log A_0$

 $M_L = \log A + 0.003\Delta + 0.7$

Surface wave magnitude M_S

 $M_S = \log(A / T) + 1.66 \log \Delta + 3.3$

Body wave magnitude M_b $M_b = log(A / T) + Q(D,h)$ log Ao aus Tabellen oder

 Δ als Entfernung in km, A in mm

Anwendugsgebiet: Δ < 600km

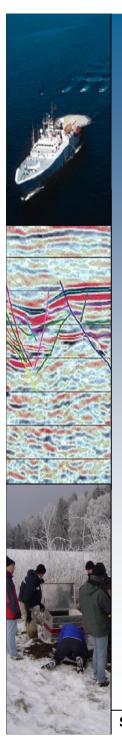
Mittelung über viele Stationen oft

nötig.

T=18-22s, Δ=20-160°, h < 50km

Rayleigh-Wellen (Vertikalkomponente)

T=0.1-3.0s



Magnitude - Intensität

Magnitude ist ein instrumentell bestimmter Wert und ein objektiver Wert für die Stärke eines Erdbebens.

Intensität ist ein subjektiver Parameter, basierend auf Erdbebenauswirkungen u. Schäden laut Augenzeugen (z.B. Fragebögen).

~1890: Rossi-Forel Intensitäts Skala (10 Stufen)

1902: Mercalli Skala (12 Stufen)

1931: Modified Mercalli (MM) Skala

für Bauvorschriften in den USA

1964: Medvedev-Sponheuer-Karnik (MSK) Skala

mit detaillierteren Unterscheidungen

1992: European Macroseismic Scale (EMS)

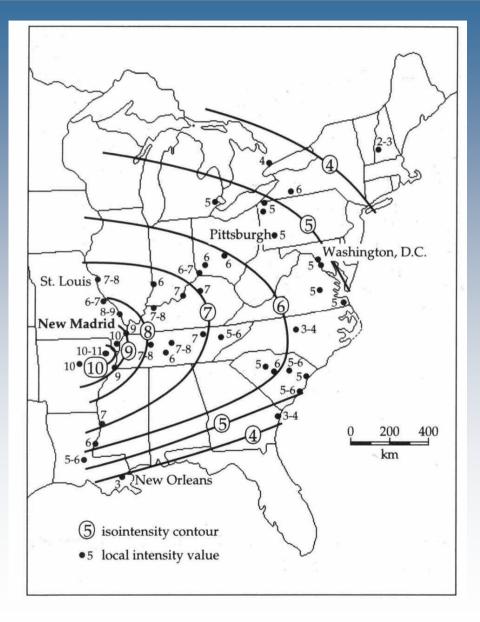
basiert auf MSK inkl. neuer Bauvorschriften

und Schadensbeschreibungen

Mercalli Intensity und Richter Magnitude

	4 5 5					
	Magnitude	Intensity	Description			
0	1.0-3.0	I	I. Not felt except by a very few under especially favorable conditions.			
	3.0 - 3.9	II - III	II. Felt only by a few persons at rest, especially on upper floors of buildings. III. Felt quite noticeably by persons indoors, especially on upper floors of buildings. Many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibrations similar to the passing of a truck. Duration estimated.			
WAT I	4.0 - 4.9	IV - V	 IV. Felt indoors by many, outdoors by few during the day. At night, some awakened. Dishes, windows, doors disturbed; walls make cracking sound. Sensation like heavy truck striking building. Standing motor cars rocked noticeably. V. Felt by nearly everyone; many awakened. Some dishes, windows broken. Unstable objects overturned. Pendulum clocks may stop. 			
	5.0 - 5.9	VI - VII	VI. Felt by all, many frightened. Some heavy furniture moved; a few instances of fallen plaster. Damage slight. VII. Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable damage in poorly built or badly designed structures; some chimneys broken.			
	6.0 - 6.9	VII - IX	VIII. Damage slight in specially designed structures; considerable damage in ordinary substantial buildings with partial collapse. Damage great in poorly built structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned. IX. Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb. Damage great in substantial buildings, with partial collapse. Buildings shifted off foundations.			
Winter -	7.0 and higher	VIII or higher	 X. Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations. Rails bent. XI. Few, if any (masonry) structures remain standing. Bridges destroyed. Rails bent greatly. XII. Damage total. Lines of sight and level are distorted. Objects thrown into the air. 			

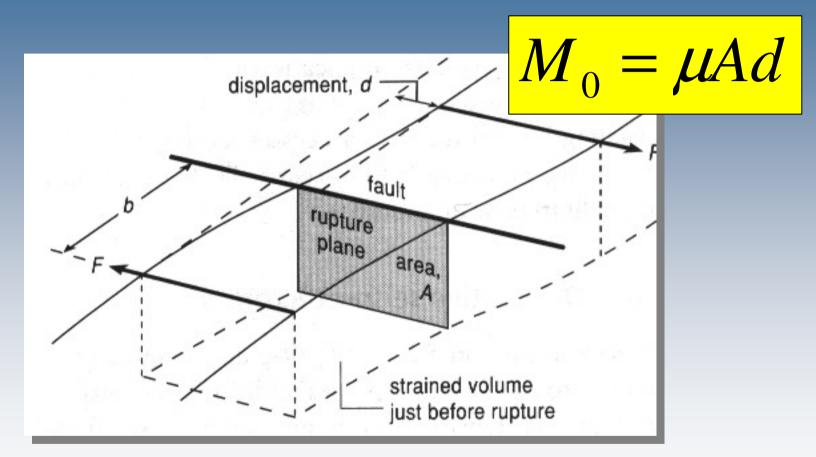
Intensität - isoseismische Karten - Gefährdung



- Verstärkung der Bodenbewegung in lockeren Sedimenten (Liquifaction)
- Bausubstanz als entscheidender Faktor
- Erkundung historischer Seismizität
- Erstellung von
 Gefährdungskarten
- unverzichtbare Daten für Versicherungsgesellschaften

 $I_{max} = 1.5 M_S - 1.8 log(h) + 1.7$

Skalares Seismisches Moment



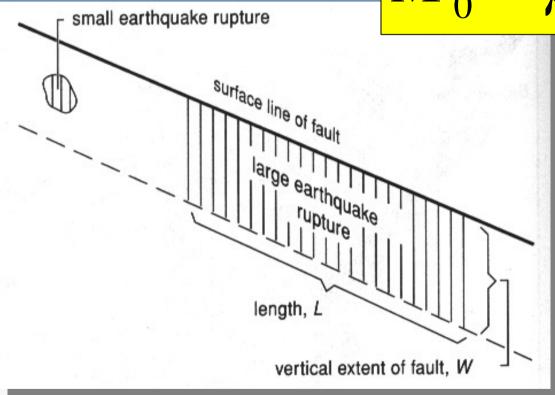
μ: Schermodul

A: Bruchfläche

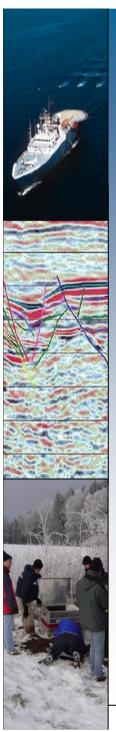
d: Verschiebung

Skalares Seismisches Moment

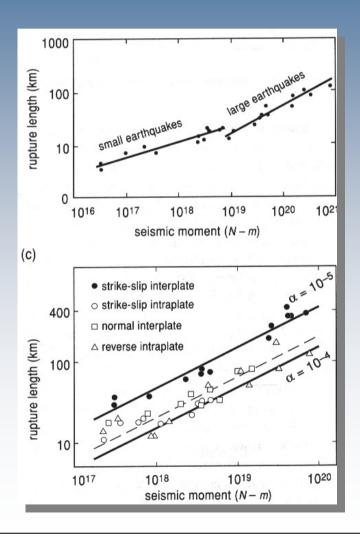




$$M_{\rm w} = \frac{2}{3} \left(\log_{10} \frac{M_0}{\rm N \cdot m} - 9.1 \right) = \frac{2}{3} \left(\log_{10} \frac{M_0}{\rm dyn \cdot cm} - 16.1 \right)$$



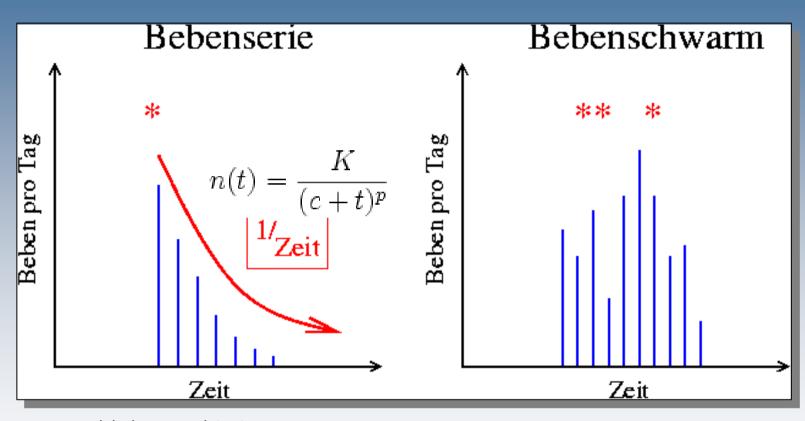
Skalares Seismisches Moment



$$M_0 = \mu Ad$$

Starke und schwache Erdbeben skalieren Unterschiedlich bzgl. der Bruchlänge.

Schwarmbeben - Omori's Law



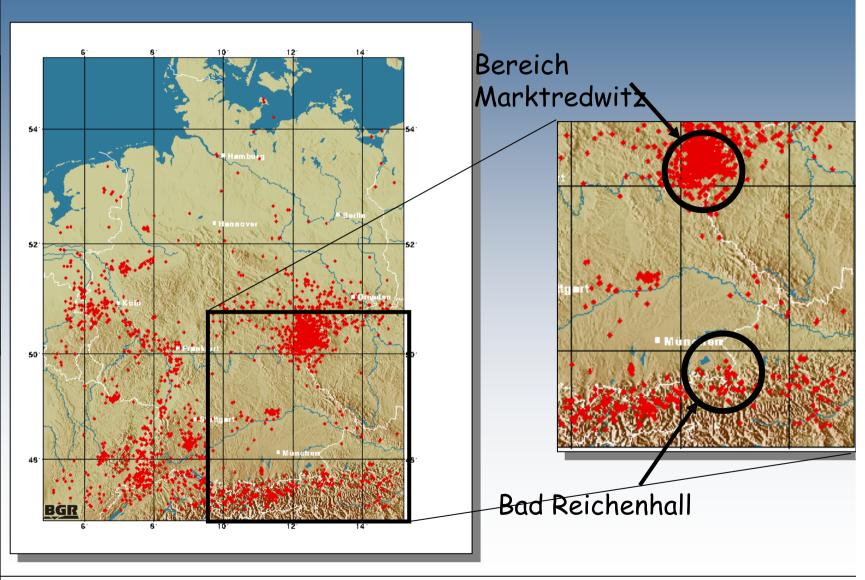
n: Zahl der Nachbeben

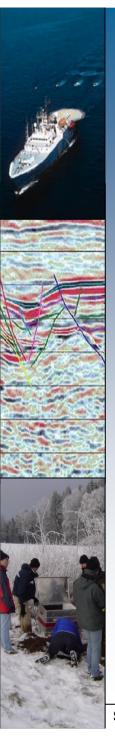
K,c: Konstanten, die von der Größe des Hauptbebens abhängen

p: Exponent (~ 1.0 bis 1.4)

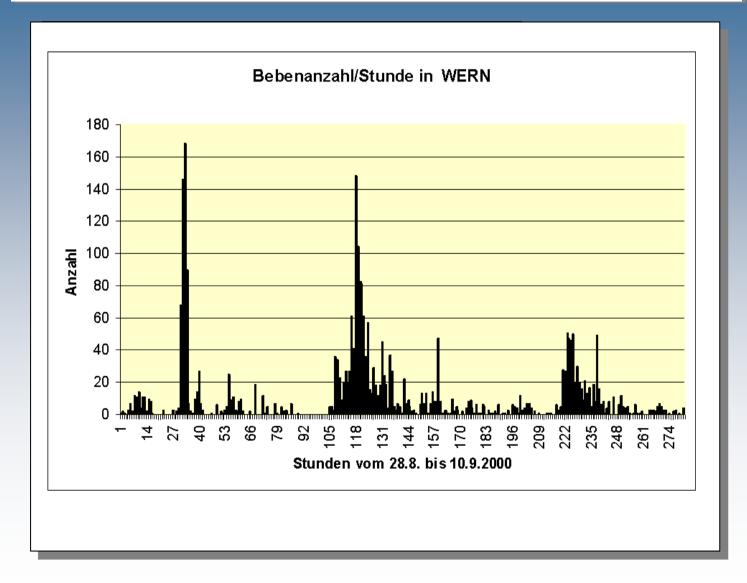
Bath's law: Größtes Nachbeben ca. 1 Magnitude geringer als Hauptbeben

Erdbeben in Bayern?



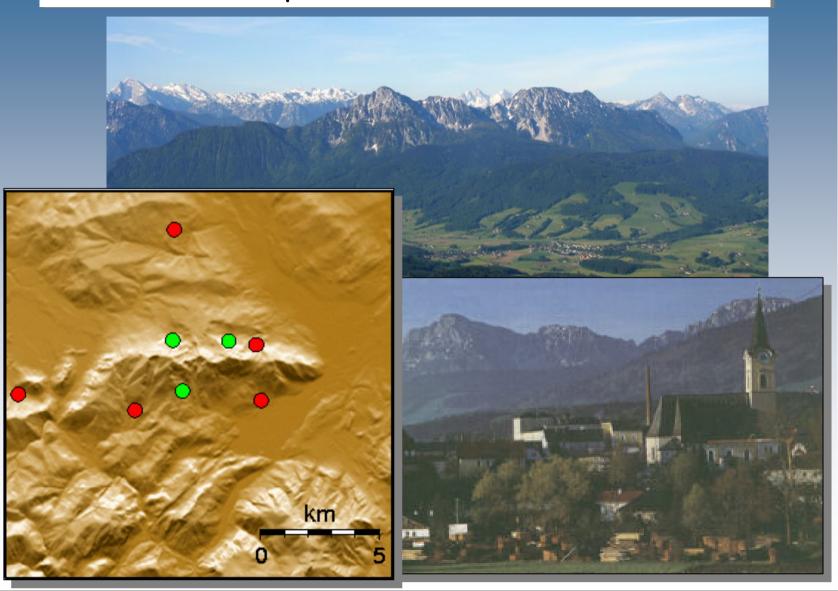


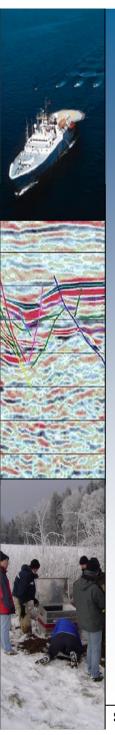
Was sind Schwarmbeben? Beispiel: Vogtland



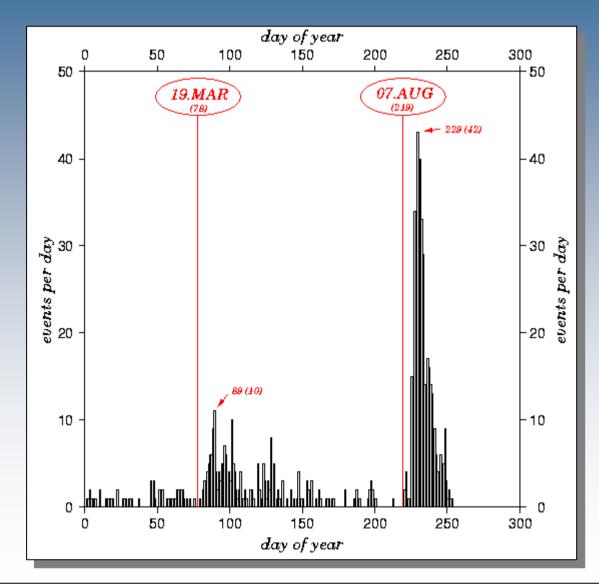
Schwarmbeben

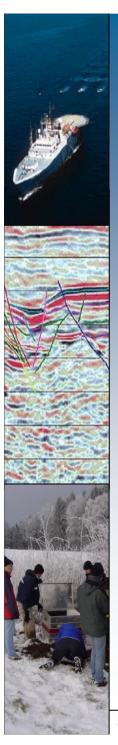
Beispiel: Bad Reichenhall





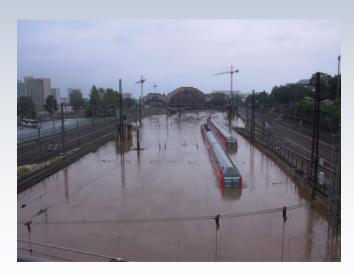
Schwarmbeben Beispiel: Bad Reichenhall

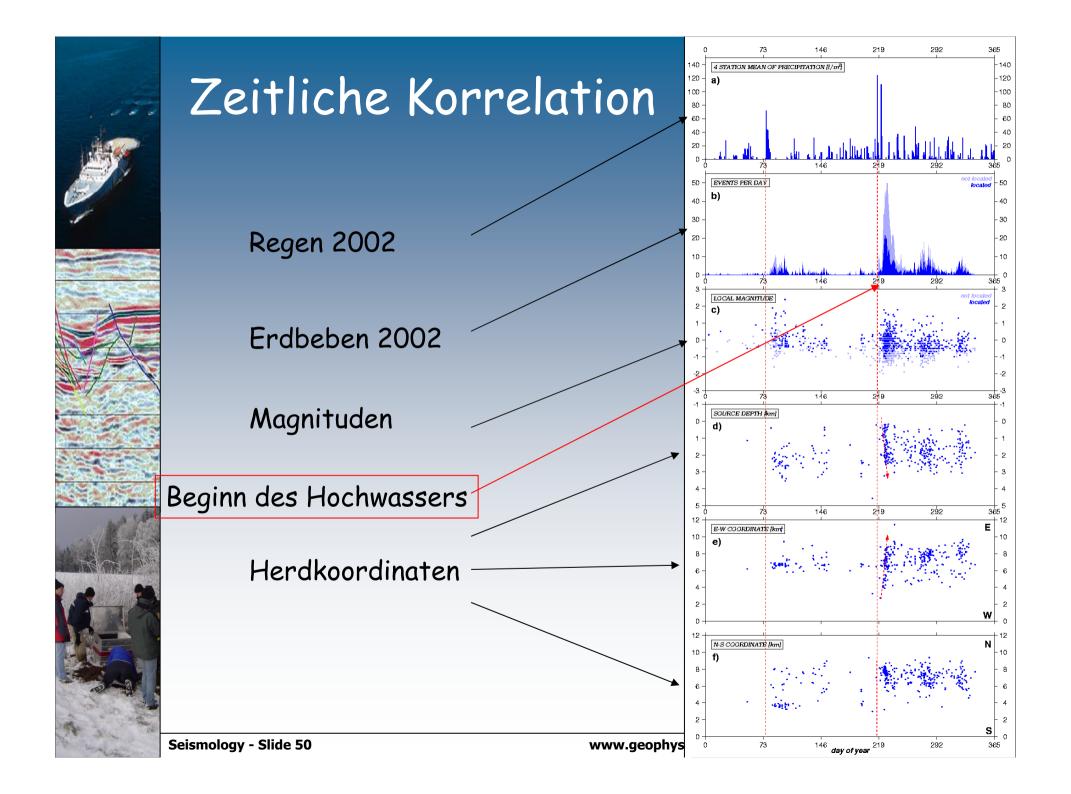


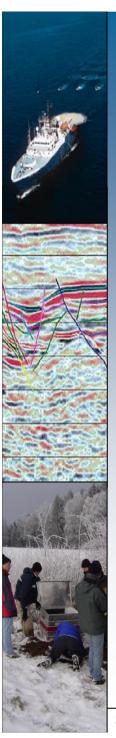


Seismizität 2002 - Hochstaufen

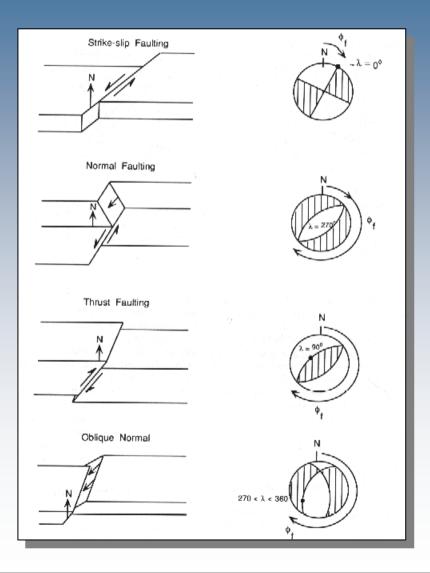
... die Regenfälle, die im August zum Hochwasser führten, hatten ihren Höhepunkt am Tag 218 ...







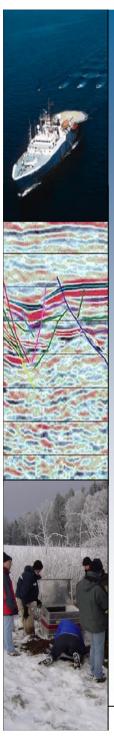
Verwerfungen -Herdmechanismen



Die Grundtypen der Verwerfungen und die entsprechenden Herdmechanismen. Die dunklen Regionen entsprechen Kompressionen.

Verwerfung





Fault scarps



California

Fault scarps

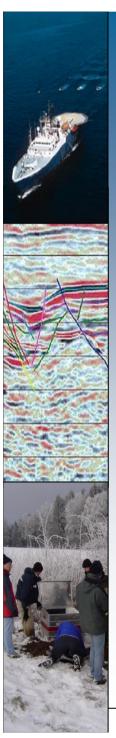


California

Fault scarps



Taiwan



Dislokationsquelle "Double Couple" (Scherbruch)

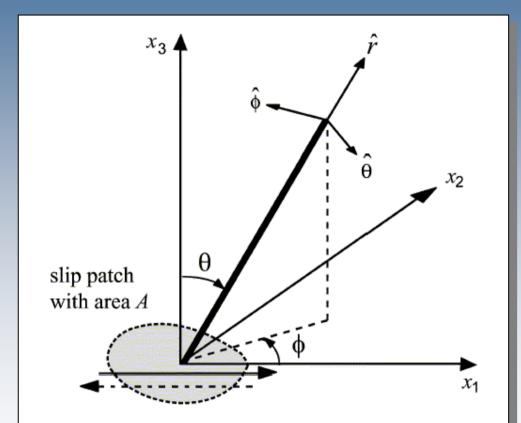
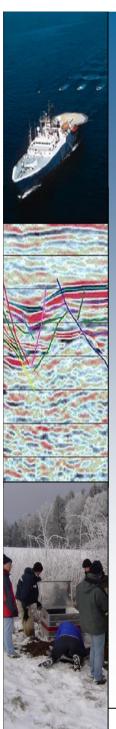
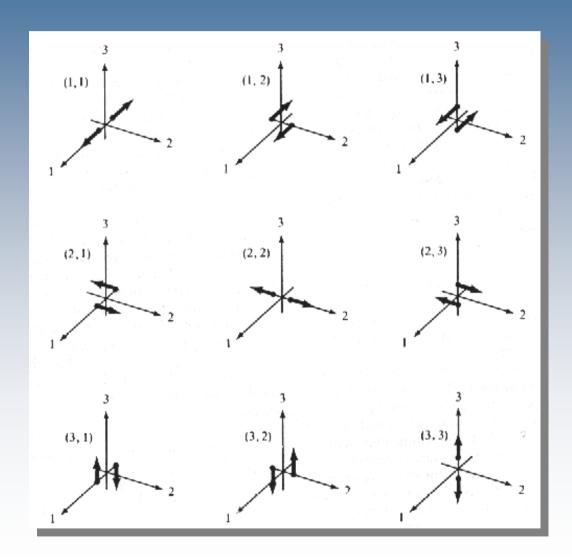


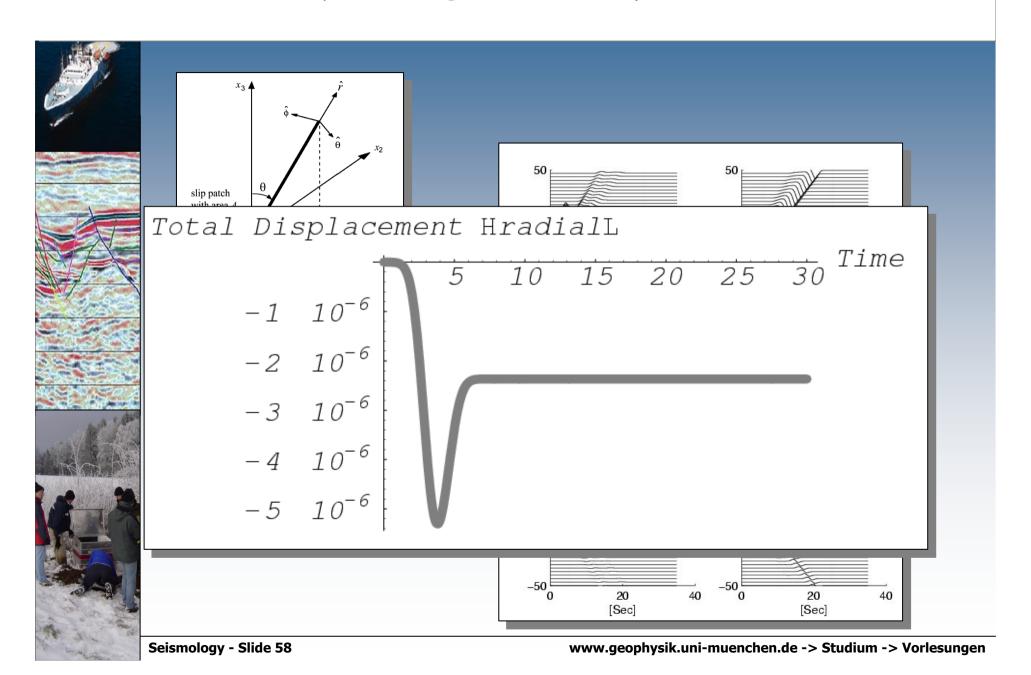
FIGURE 5 Cartesian and polar coordinate systems for analysis of radiation by a slip patch with area A and average slip $\langle \Delta u(t) \rangle$.

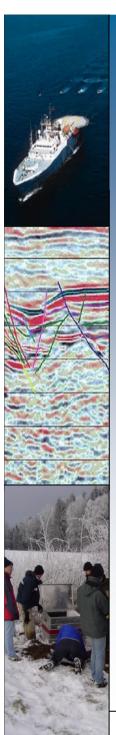


Momententensor Kräftepaare



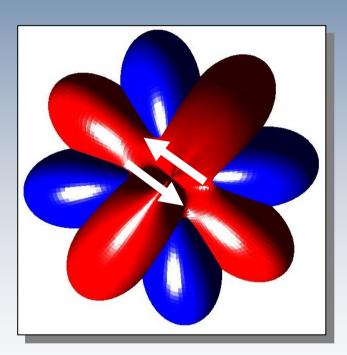
Velocity seismograms-M6.5 point source

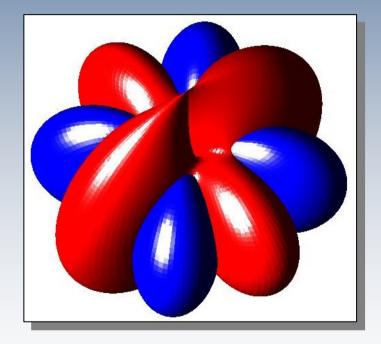


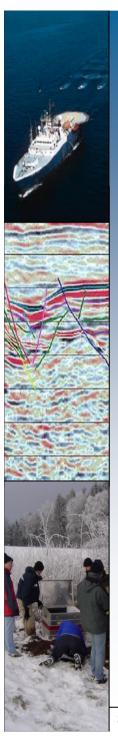


Abstrahlcharakteristika von Punktquellen

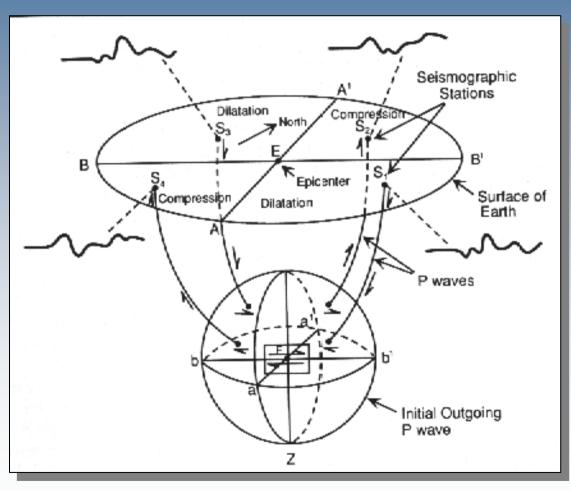
P - blue S - red



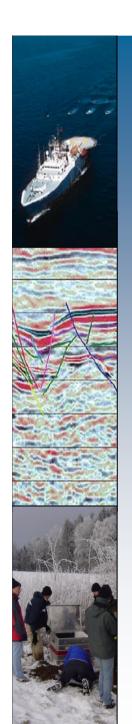




Scherdislokation - Bestimmung von Herdmechanismen



P Polarisationen in verschiedenen Richtungen werden zur Abschätzung der Lage der Verwerfungsfläche herangezogen



Beachballs und Momententensoren

Moment Tensor	Beachball	Moment Tensor	Beachball	
$\frac{1}{\sqrt{3}} \left(\begin{array}{ccc} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{array} \right)$		$\begin{bmatrix} -\frac{1}{\sqrt{3}} \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix}$		
$ -\frac{1}{\sqrt{2}} \left(\begin{array}{ccc} 0 & 0 & 0 \\ 0 & 0 & 1 \\ 0 & 1 & 0 \end{array} \right) $		$\begin{array}{c cccc} \frac{1}{\sqrt{2}} \left(\begin{array}{cccc} 0 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & -1 \end{array} \right)$		
$\begin{array}{cccccccccccccccccccccccccccccccccccc$		$\frac{1}{\sqrt{2}} \left(\begin{array}{ccc} 0 & 0 & 1 \\ 0 & 0 & 0 \\ 1 & 0 & 0 \end{array} \right)$		
$\begin{array}{c cccc} \frac{1}{\sqrt{2}} \left(\begin{array}{cccc} 1 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & 0 \end{array} \right) \end{array}$		$\frac{1}{\sqrt{2}} \left(\begin{array}{ccc} 1 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & -1 \end{array} \right)$		
$\begin{array}{c cccc} \frac{1}{\sqrt{6}} \left(\begin{array}{cccc} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & -2 \end{array} \right) \end{array}$		$\begin{array}{c ccccccccccccccccccccccccccccccccccc$	9	
$\frac{1}{\sqrt{6}} \left(\begin{array}{ccc} -2 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{array} \right)$	0	$ \begin{array}{c ccccccccccccccccccccccccccccccccccc$		

explosion - implosion

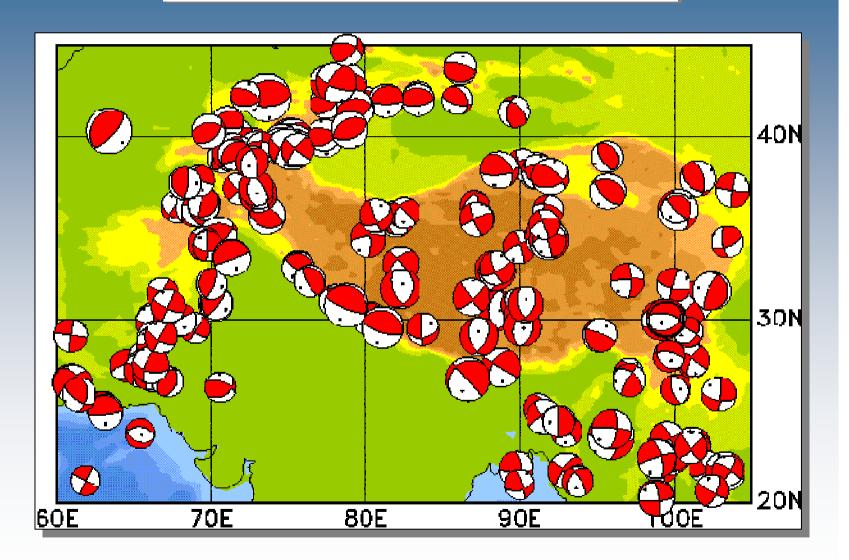
vertical strike slip fault

vertical dip slip fault

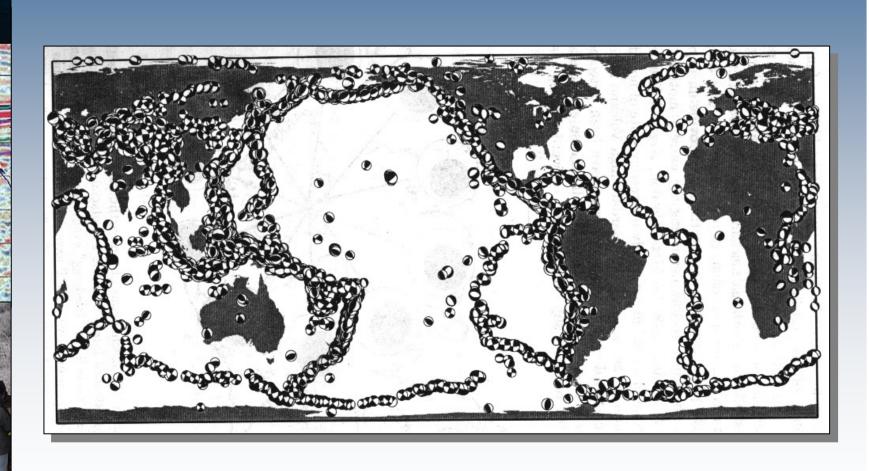
45° dip thrust fault

compensated linear vector dipoles

Beachballs - Himalaya

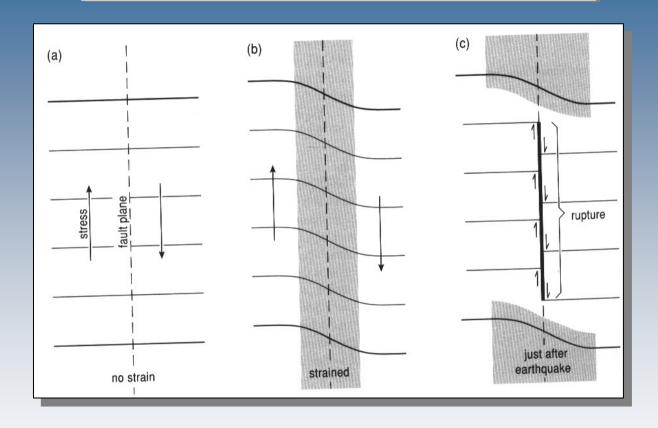




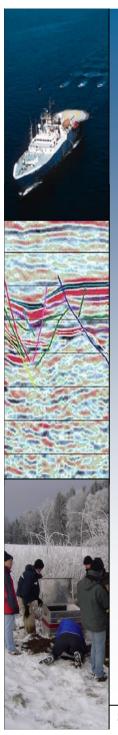




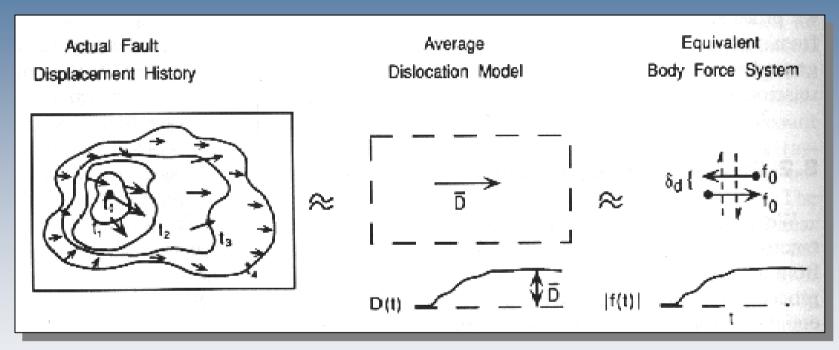
Elastic rebound (Reid, 1910)



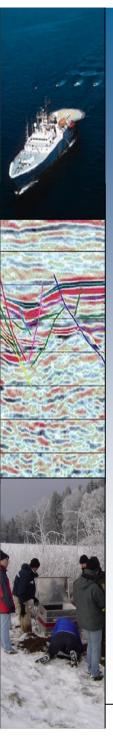
Wir wollen die beobachtete Verschiebung an der Oberfläche mit der Stärke (Magnitude) eines Bebens in Zusammenhang bringen! Wie können wir die Stärke quantifizieren?



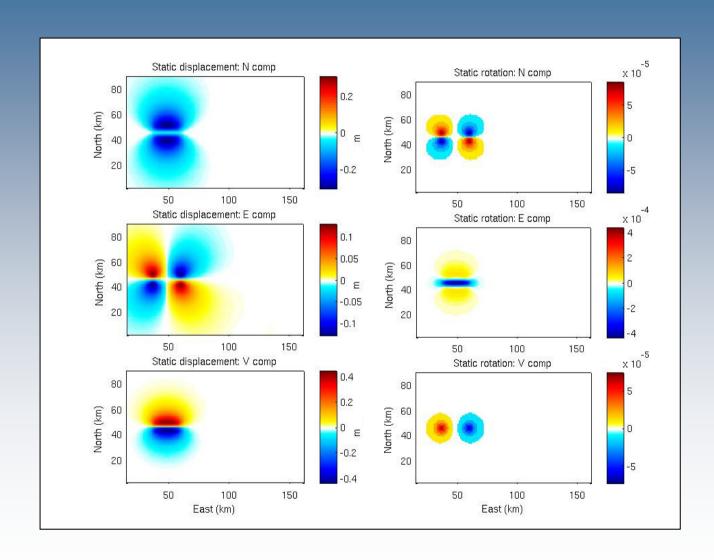
Equivalent Forces: concepts



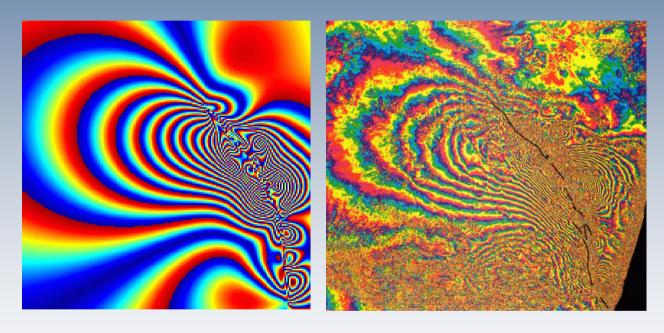
The actual slip process is described by superposition of equivalent forces acting in space and time.



Statische Deformation - Rotation



Co-seismische Deformation



Simulierte Deformation

Beobachtete Deformation

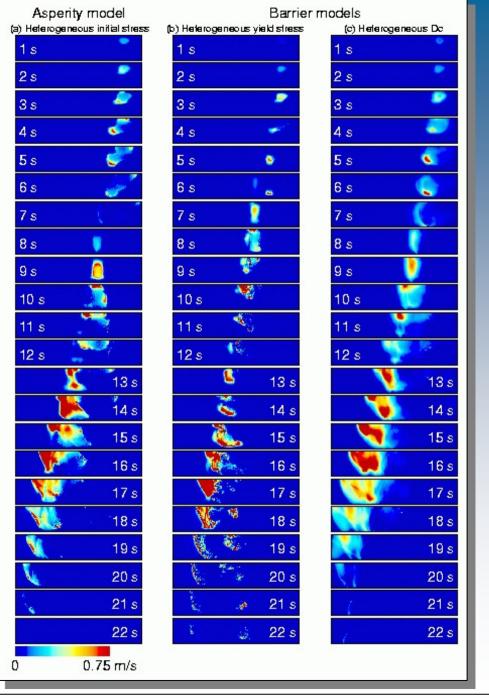
Source Kim Olsen, UCSB

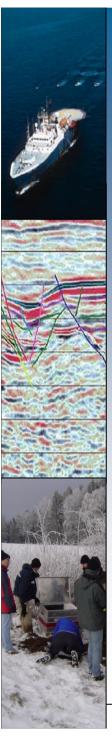


Source kinematics

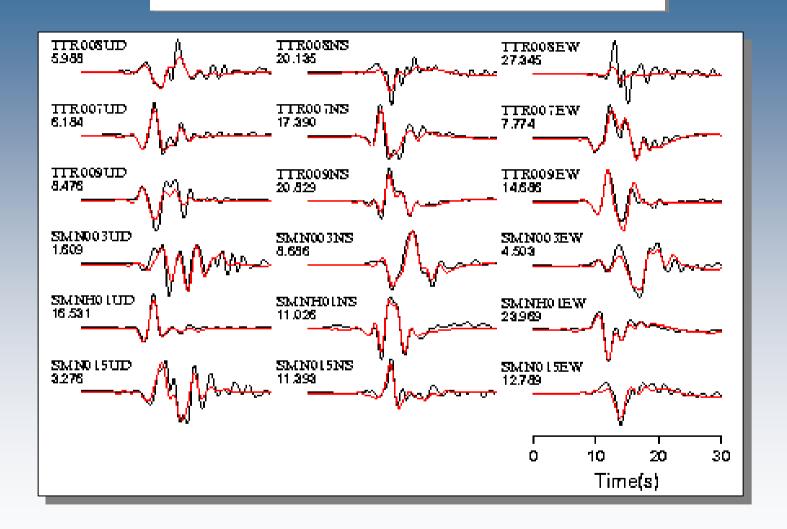
Slip rate as a function of various fault conditions (Landers earthquake)

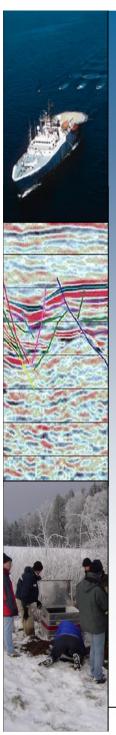
Source: K Olsen, UCSB





Source kinematics

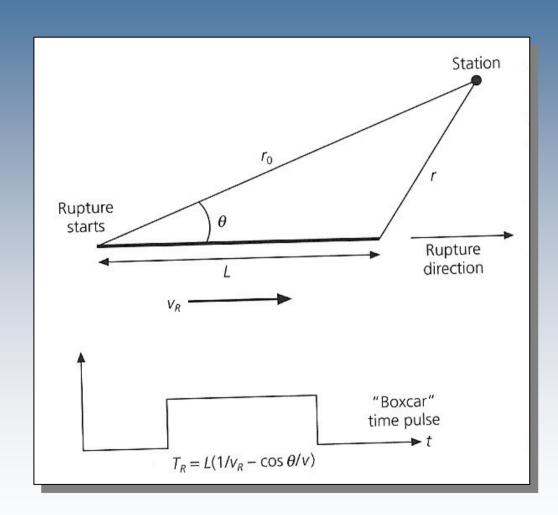




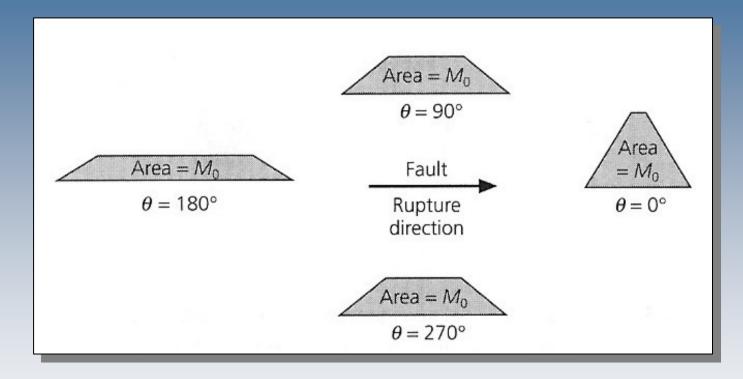
Source directivity

When a finite fault ruptures with velocity v_r , the time pulse is a boxcar with duration

$$T_R = L(1/v_r - \cos(\theta/v))$$

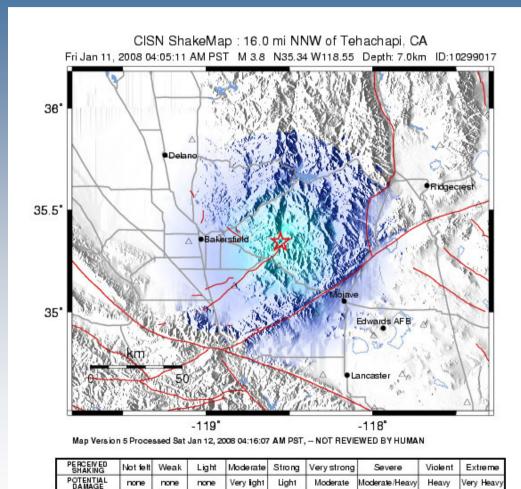


Source directivity



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





PEAK ACC.(%g)

PEAK VEL.(cm/s)

INSTRUMENTAL INTENSITY <.17

.17-1.4

II-III

<0.1 0.1-1.1

1.4-3.9

1.1-3.4

IV

3.9-9.2

3.4-8.1

9.2-18

8.1-16

18-34

16-31

VII

34-65

31-60

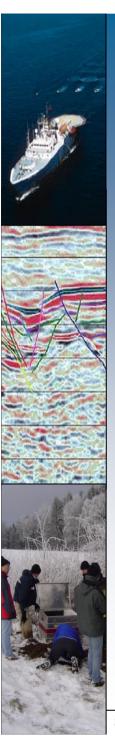
VIII

65-124

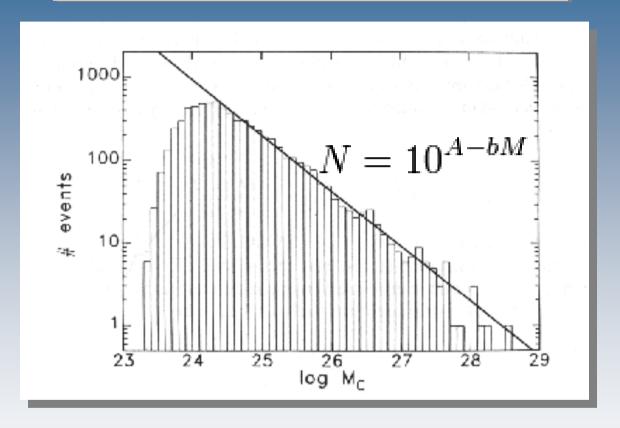
60-116

>124

>116

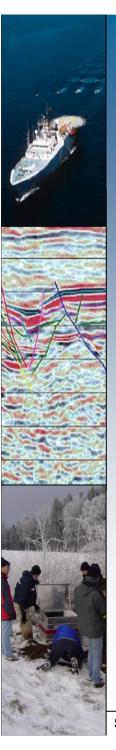


Erdbebenstatistik Das Gutenberg Richter Gesetz



Zahl der Erdbeben als Funktion des seismischen Moments für globale Daten.

"b-Wert" in der Regel um 1



Zusammenfassung - Seismologie

- Die Herdzeit von Erdbeben kann über die Differenzlaufzeit von P und S Wellen berechnte werden (Wadati Diagramm)
- Das Epizentrum eines Bebens und dessen Tiefe kann graphisch ermittelt werden übder die Distanzen der the Seismometer von der Quelle
- Die Magnitude eines Erdbebens wird über den Log der lokalen Veschiebung und einer Distanzkorrektur berechnet (Richter Skala)
- Der Erdbebenherd wird charakterisiert über die Orientierung der Verwerfungsfläche und die Richtung der Verschiebung
- Diese Information lässt sich aus den Polaritäten der P und S Wellen (Abstrahlcharakteristik) abschätzen
- Die Häufigkeit von Erdbeben als Funktion der Magnitude ist durch das Gutenberg-Richter Gesetz beschrieben