

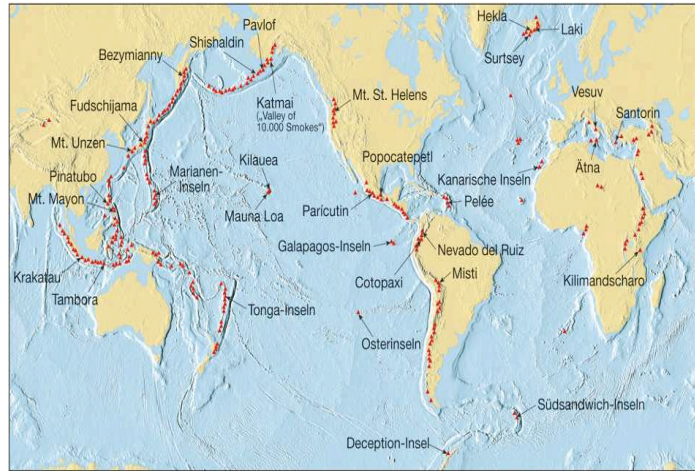
**Tatort Plattengrenze**

**5**

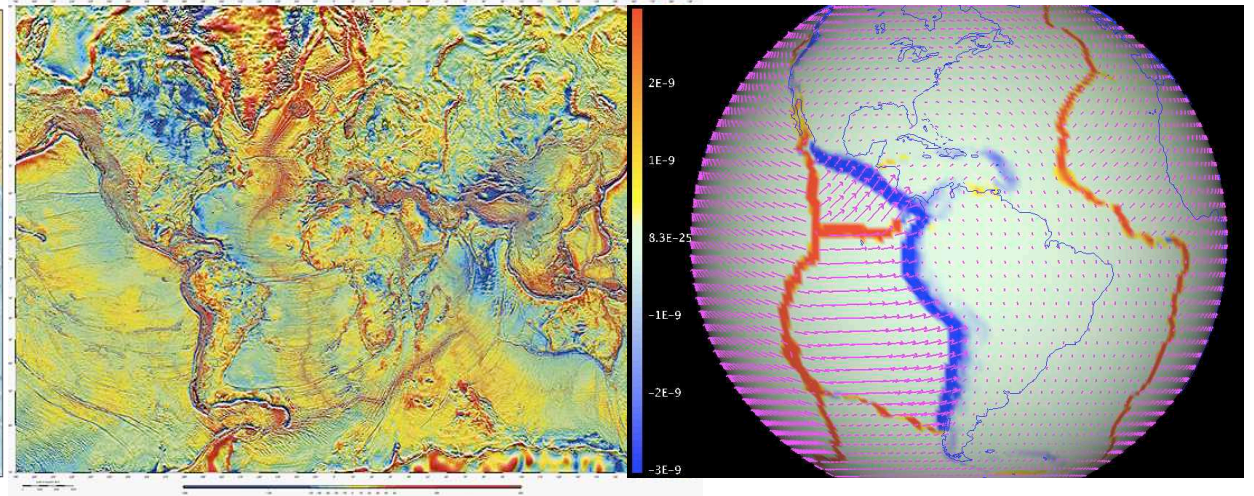
**Überwachung der Täter**

# Profiling

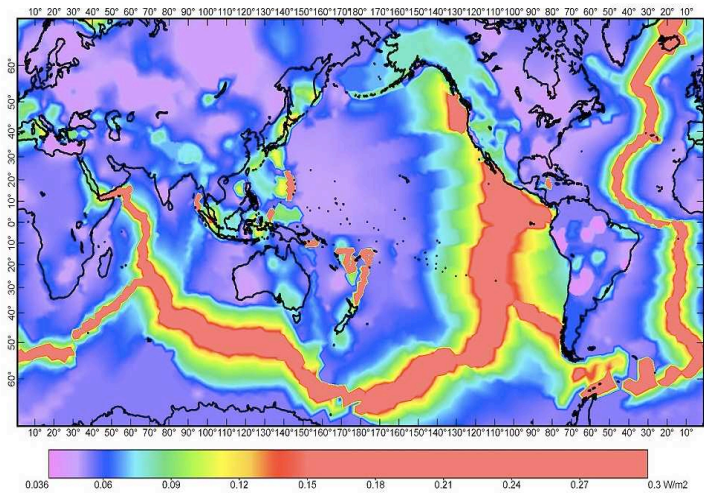
## Vulkanismus



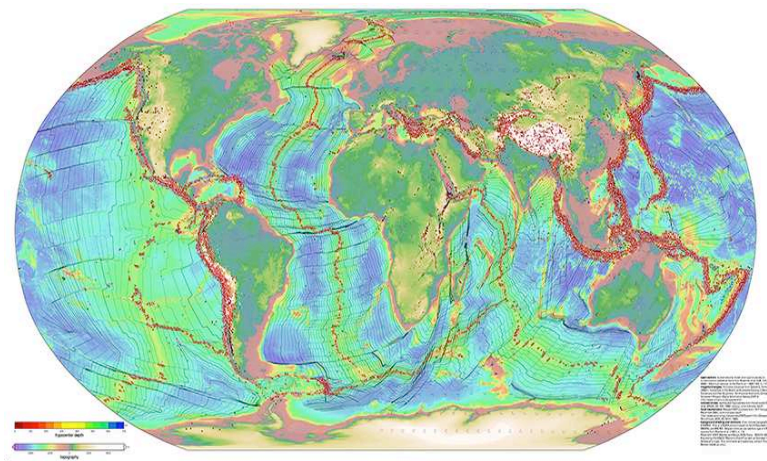
## Schwerefeld



## Wärmefluss



## Erdbeben

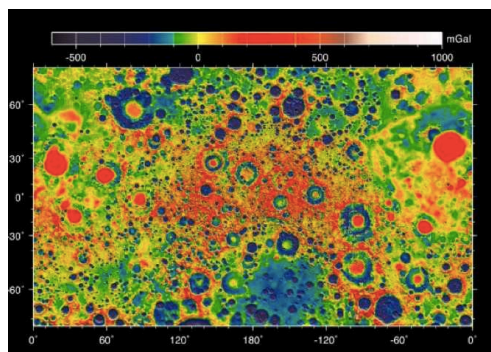
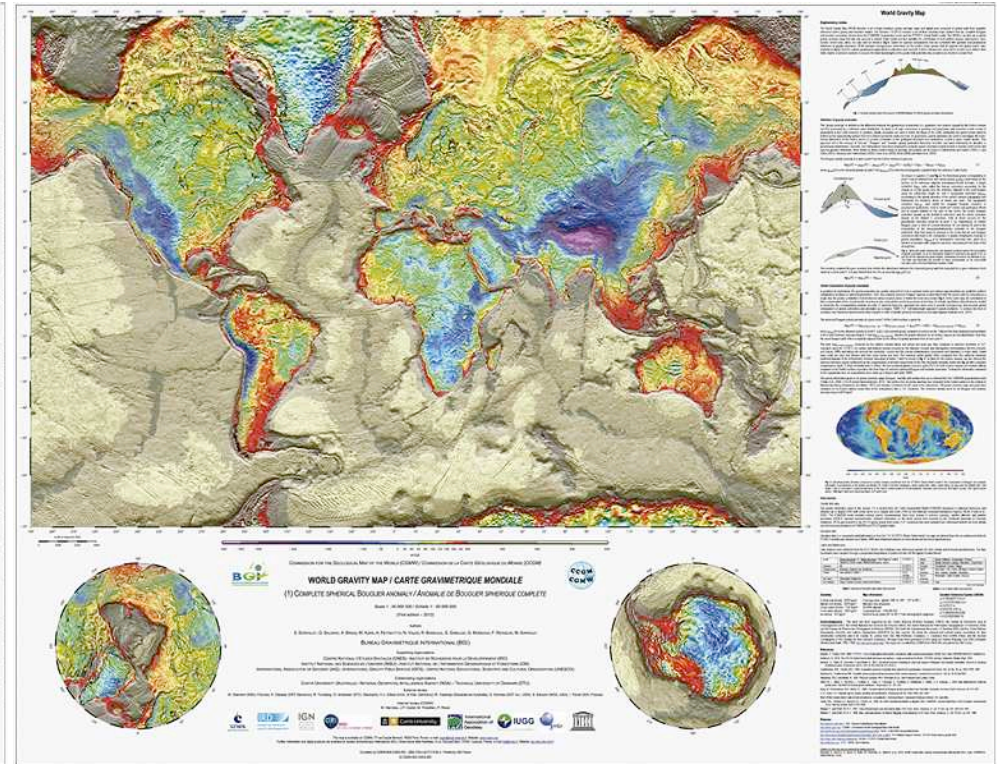
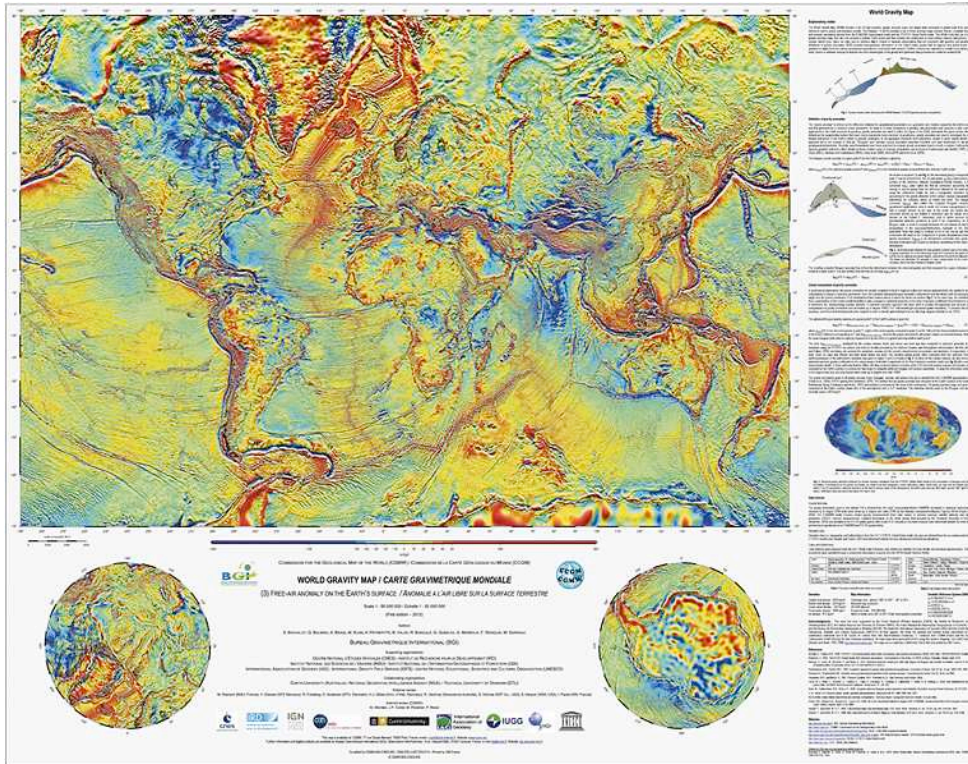




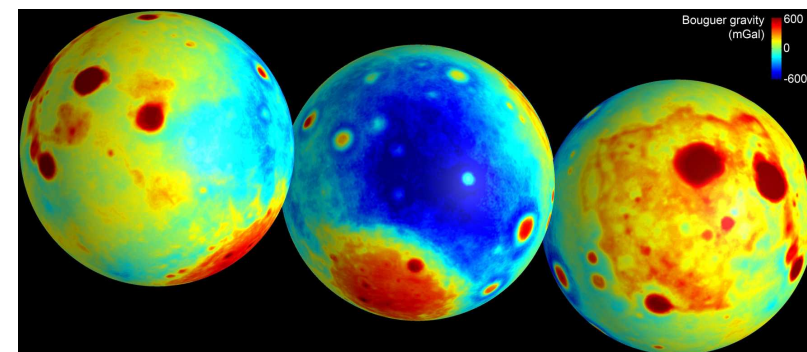
# Schwereanomalien - Karten

## Weltkarte der Freiluft-Anomalie

## Weltkarte der Bouguer-Anomalie



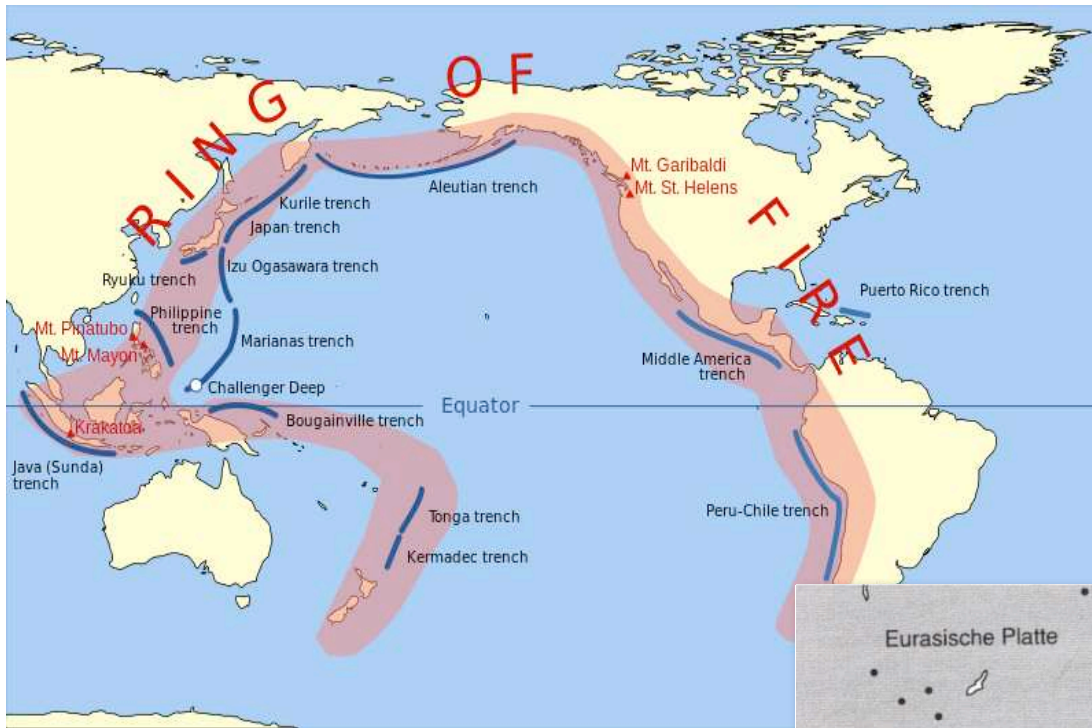
Schwerefeld des Mondes (Ausschnitt)



Bouguer-Anomalie des Mondes



# Pazifischer Feuerring

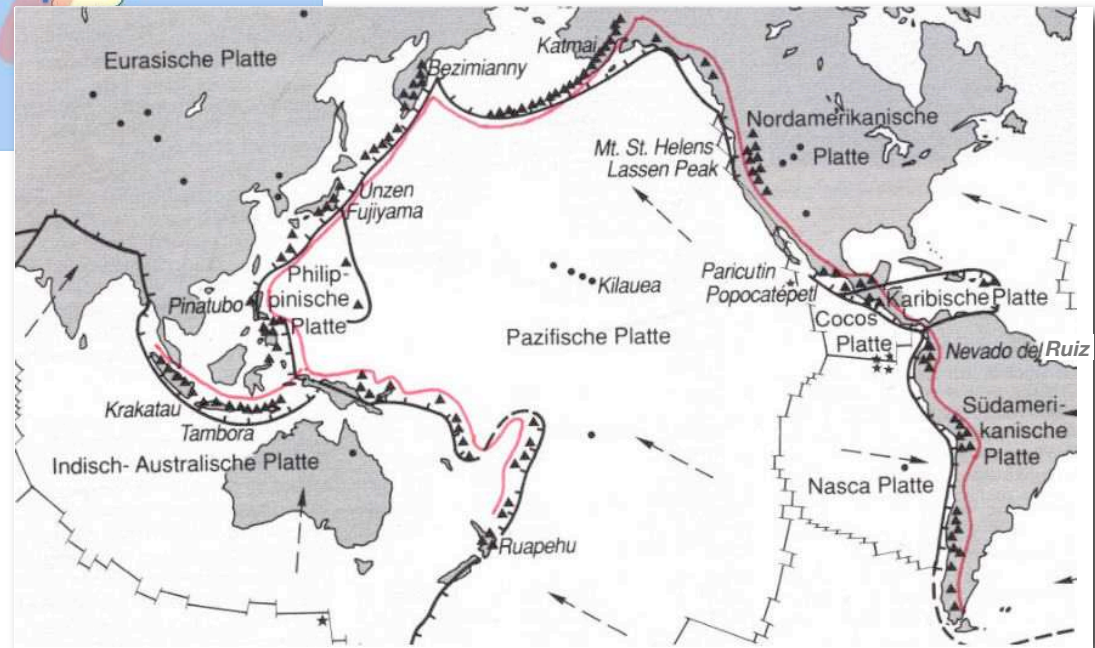
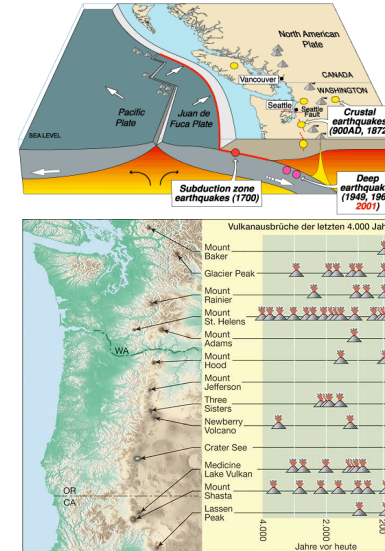


Tiefseeegräben



Vulkane

Cascadia earthquake sources

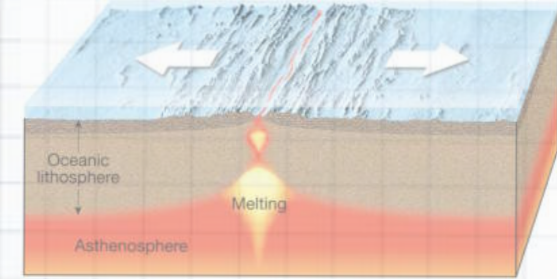




# Steckbrief: Konstruktive Plattengrenze

- Situation

- Riftingstadium im Kontinent
- nach Ozeanbildung unter Wasseroberfläche



- Vulkanismus

- basischer Vulkanismus (leichtfliessend): Schildvulkane, Pillowlaven
- mafische Gesteine: Gabbro - Basalt
- Hydrothermalquellen

- Wärmefluss

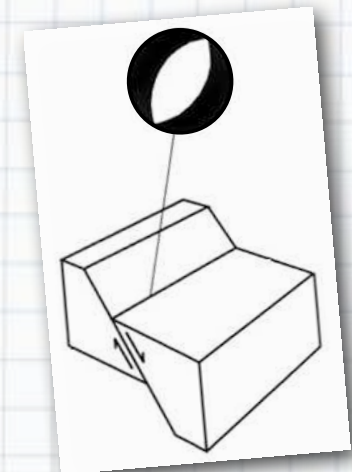
- sehr hoch > 100 mWm<sup>-2</sup>

- Schwerefeld

- Freiluft-Anomalie
  - positiv bei langsamem Spreading: Bsp. Reykjanes Rücken
  - undeutlich bei schnellem Spreading: Bsp: Ostpazifischer Rücken

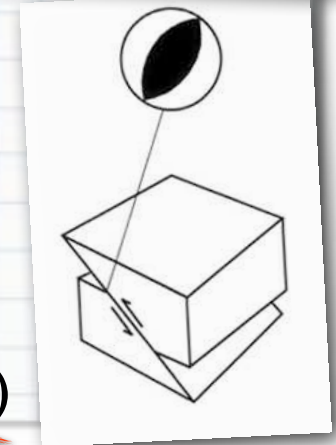
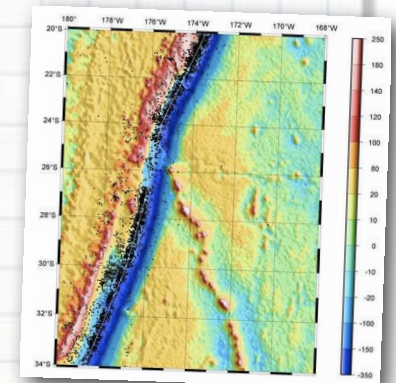
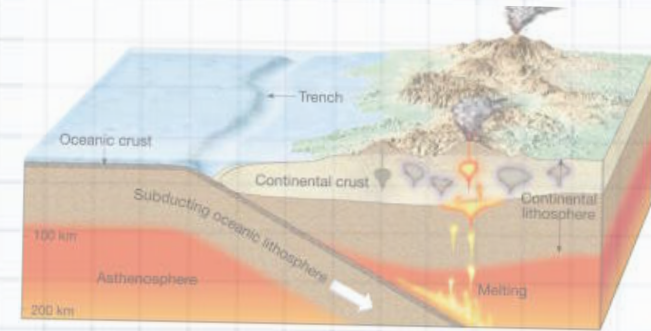
- Erdbeben

- relative seicht: Hypozentrum < 50 km
- Herdflächenlösungen zeigen Dehnung (Abschiebung)



# Steckbrief: Destruktive Plattengrenze

- Situation
  - Subduktionszone
  - Kontinent-Kontinent-Kollision
- Vulkanismus
  - explosiver Vulkanismus: Stratovulkane
  - intermediäre Gesteine: Diorit - Andesit
- Wärmefluss
  - unauffällig
    - über abtauchender Platte eher tief  $40 - 50 \text{ mWm}^{-2}$
    - über jungem Gebirge  $60 - 80 \text{ mWm}^{-2}$
- Schwerefeld
  - Freiluft-Anomalie: hoher Kontrast
    - negativ im Tiefseegraben - hoher Kontrast an Plattengrenze
    - hoch über Gebirgen (leichter Gebirgssockel)
- Erdbeben
  - sehr tief: Hypozentrum bis 700 km (Tiefbeben, Tsunami)
  - Herdflächenlösungen zeigen Kompression (Überschiebung)

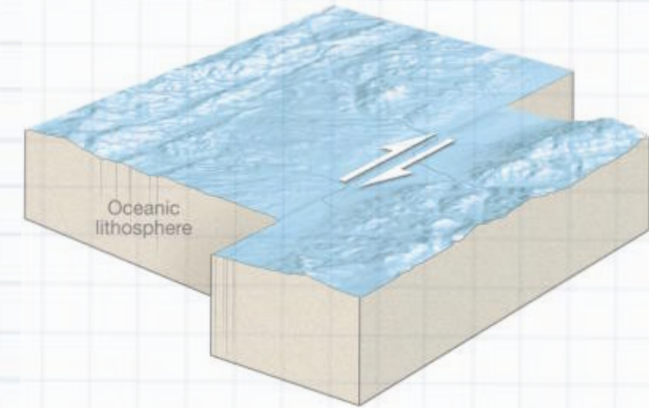




# Steckbrief: Transform-Plattengrenze

- Situation

- verbinden Spreizungsrücken
- auch an Kontinent-Grenzen
  - Bsp. San Andreas Fault
  - Nordanatolische Verwerfung

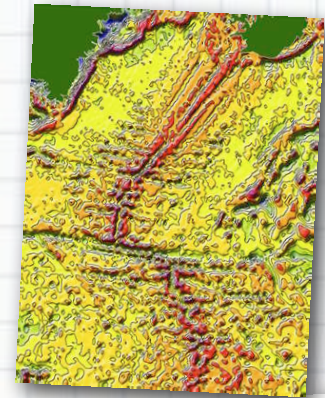


- Vulkanismus

- nicht ausgeprägt
  - in der Nähe von Spreizungsrücken: Hydrothermalquellen

- Wärmefluss

- unauffällig
  - in der Nähe von Spreizungsrücken: hoch  $> 100 \text{ mWm}^{-2}$

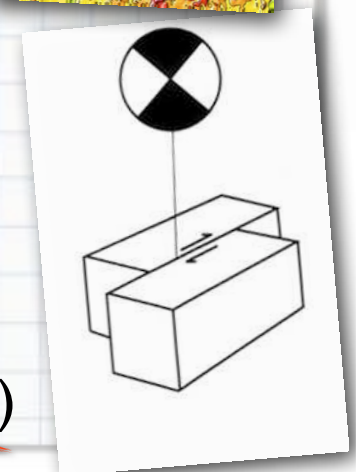


- Schwerefeld

- unauffällig
  - versetzen Anomalien: Bsp. Gibbs Fracture Zone, (Reykjanes Rücken)

- Erdbeben

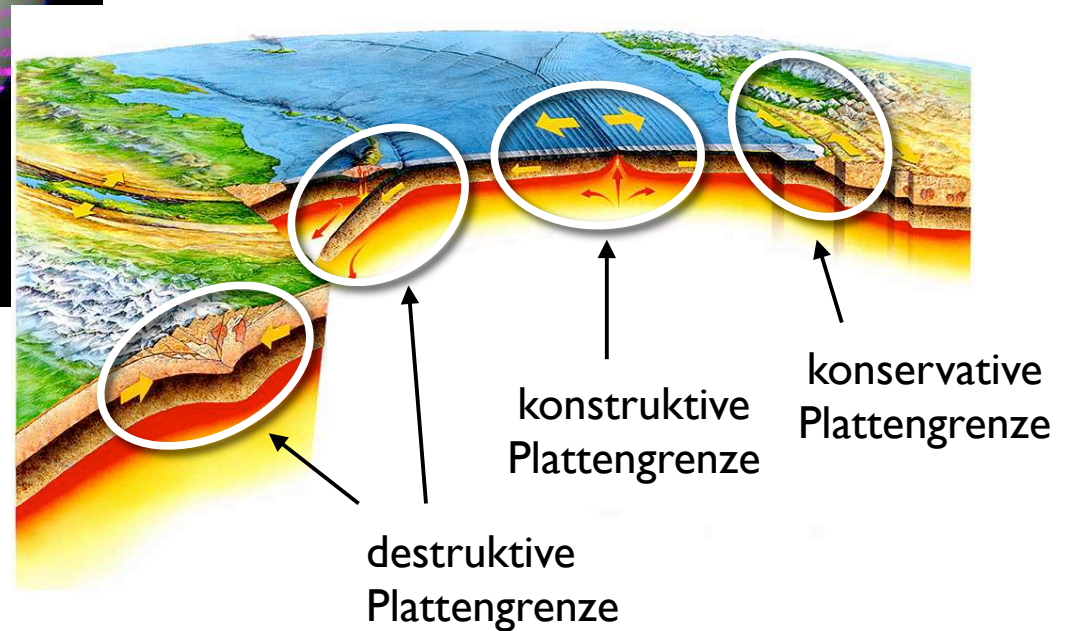
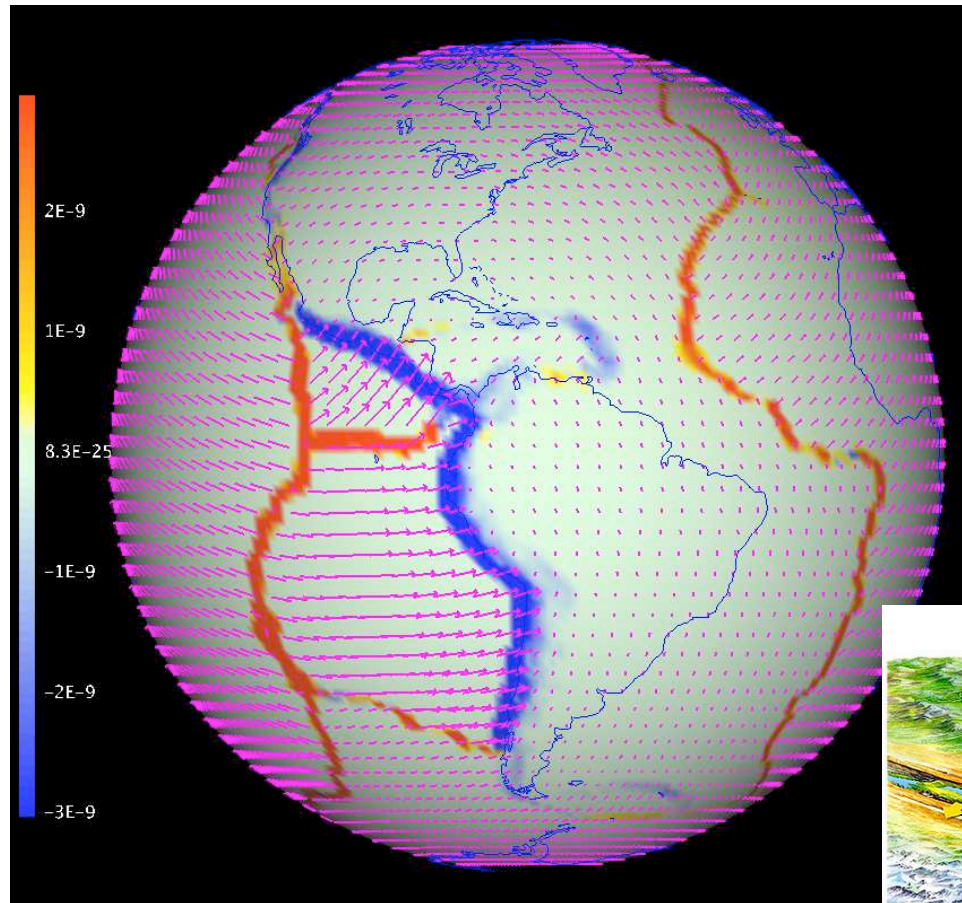
- relativ seicht: Hypozentrum  $< 50 \text{ km}$
- Herdflächenlösungen zeigen Scherung (Seitenverschiebung)



# Plattenbewegungen



# Steife Platten - deformierte Ränder



# Was ist langsam - was ist schnell ?

Geschwindigkeit = Meter / Sekunde

Auto:	100 km / h	$\sim 30 \text{ ms}^{-1}$
zu Fuss:	3.6 km / h	$1 \text{ ms}^{-1}$
tektonische Platten:	3 cm / Jahr	$\sim 10^{-8} \text{ ms}^{-1}$
	= 0.03 m / a	

1 Jahr	= 365 · 24 h	= 8760 h	
	= 8760 · 3600 s	= 31'536'000 s	$\approx 3 \cdot 10^7 \text{ s}$

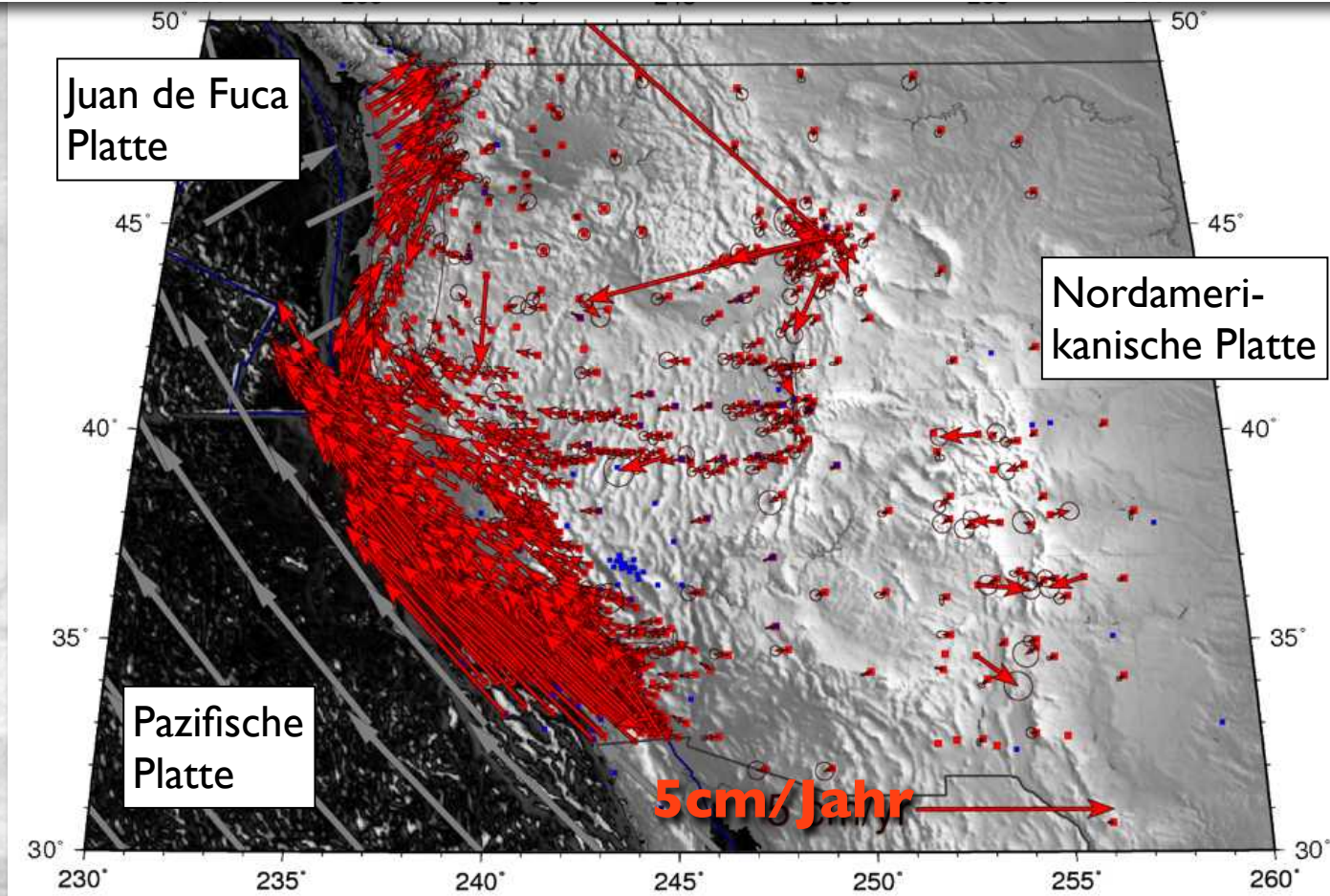


# Was ist langsam - was ist schnell ?

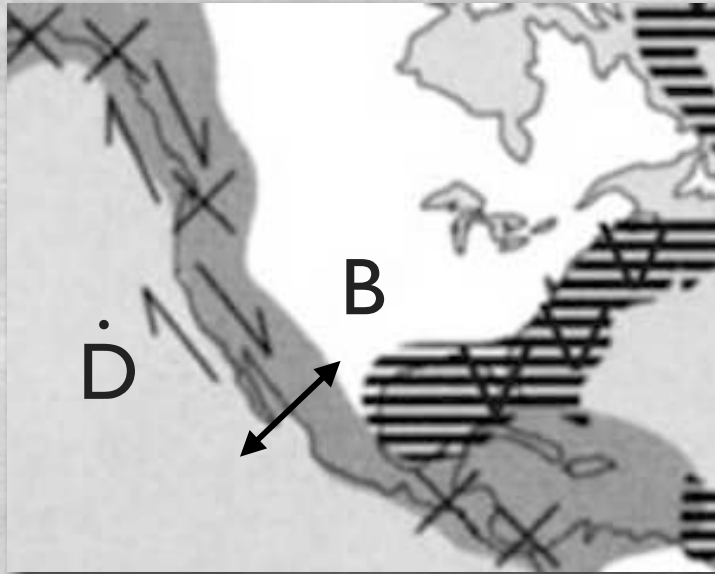
Momentane Geschwindigkeiten:

**1 bis 10 cm / Jahr**

= 0.01 - 0.10 m / 31'536'000 s  $\approx 10^{-8}$  ms<sup>-1</sup>



# Deformationsraten an Plattengrenzen



Verformungsrate

$$\dot{\gamma} = \frac{\text{Geschwindigkeit}}{\text{Breite}}$$

Deformationsraten  
(strain rates)

A diagram illustrating shear deformation. A rectangular block of height  $B$  is shown. A horizontal arrow above the block is labeled  $\dot{D}$ , representing the shear rate. The block is shaded to show its deformation into a parallelogram shape. Below the diagram, the equation for shear strain rate is given:

$$\dot{\gamma} = \frac{\dot{D} \text{ [m/s]}}{B \text{ [m]}}$$

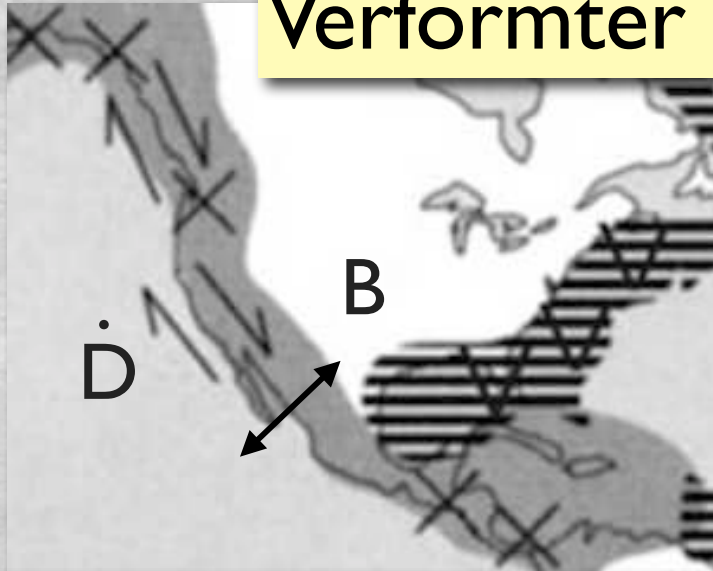
Einheit: 1/s oder  $s^{-1}$



# geologische Deformationsraten

Plattenbewegung pro Jahr  
Verformter Bereich

$D = 10 \text{ cm}$   
 $B = 100 \text{ km}$



Plattengeschwindigkeit:

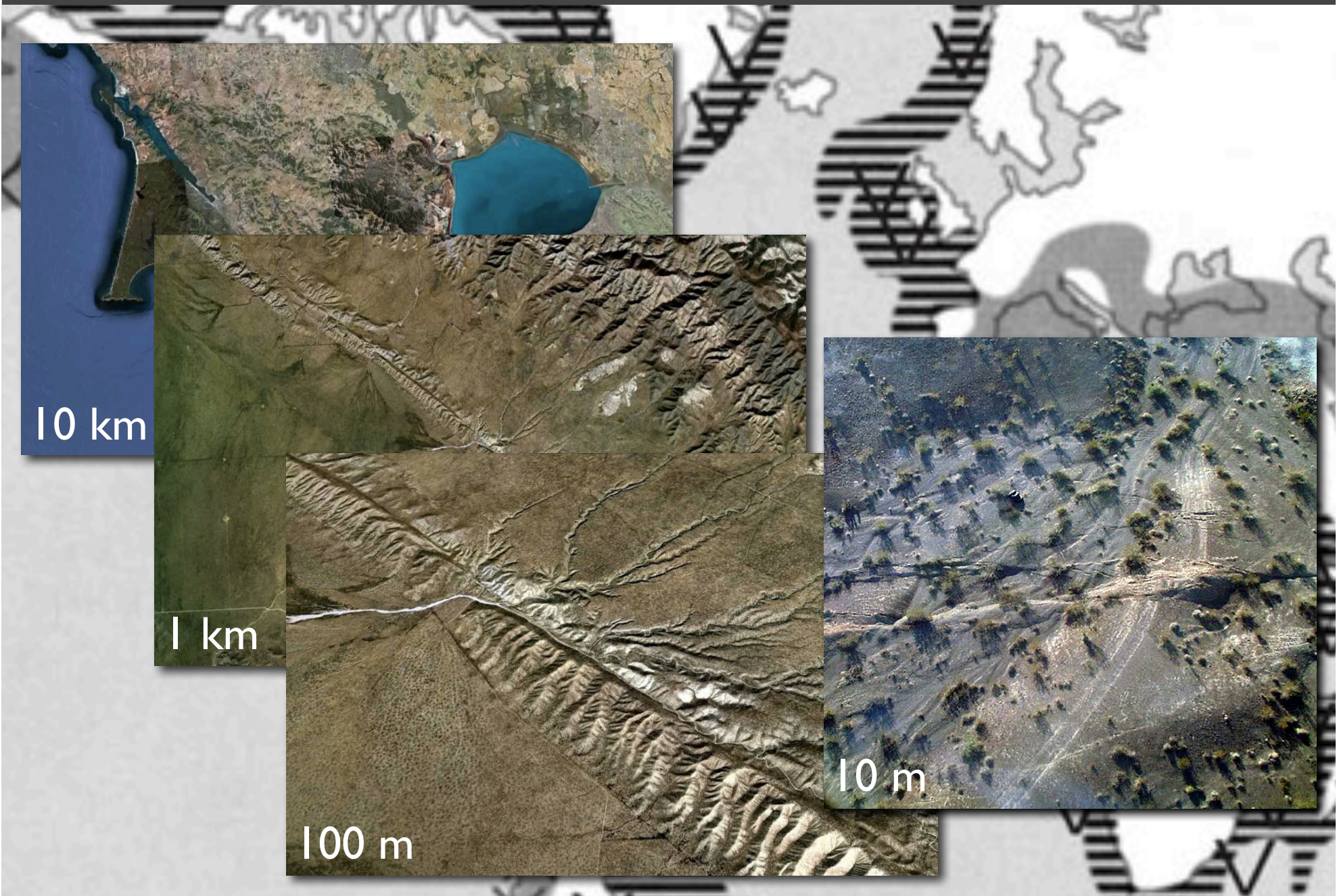
$$\dot{D} = D / t = 10^{-1} \text{ m} / 3 \cdot 10^7 \text{ s} = 3 \cdot 10^{-9} \text{ s}^{-1}$$

Verformungsrate ( $B = 100 \text{ km}$ ):

$$\dot{\gamma} = \dot{D} / B = 3 \cdot 10^{-9} / 10^5 \text{ m} \Rightarrow \dot{\gamma} \approx 10^{-14} \text{ s}^{-1}$$



# Lokalisierung der Deformation





# vom Grossen ins Kleine: m bis cm





vom Grossen ins Kleine: cm bis mm



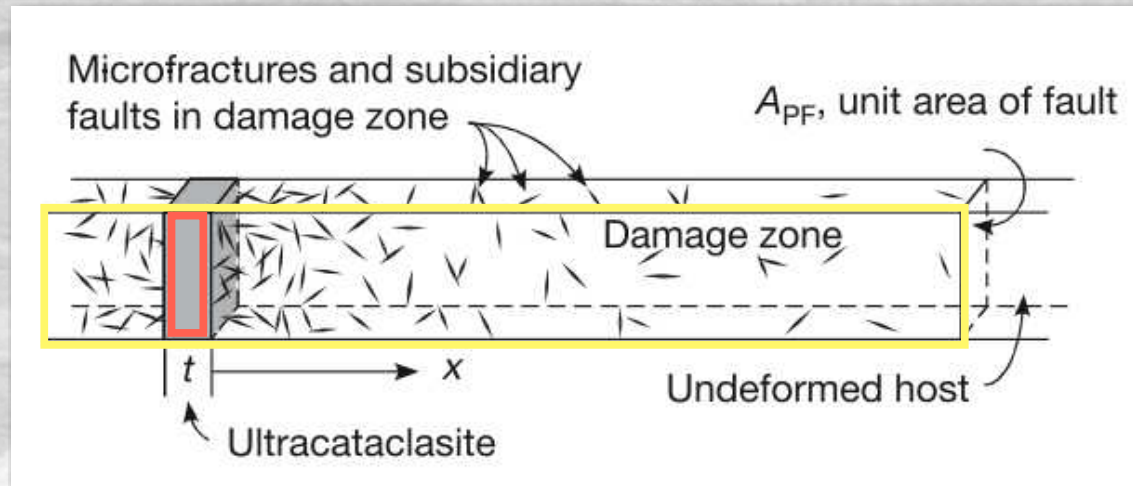
Dünnschliff: Kataklastit

5 mm



# Örtlich lokalisiert...

Verformung auf 100 km Breite:  $\dot{\gamma} \approx 10^{-14} \text{ s}^{-1}$



auf 100 m konzentriert:  
(Faktor  $10^3$ )

$$\Rightarrow \dot{\gamma} = 10^{-11} \text{ s}^{-1}$$

auf 1 mm konzentriert:  
(Faktor  $10^8$ )

$$\Rightarrow \dot{\gamma} = 10^{-6} \text{ s}^{-1}$$

## ... und zeitlich lokalisiert

Typische Dauer eines Erdbebens: 30 s

Spitzengeschwindigkeit während 3 s

30'000'000 s (1 Jahr)  $\rightarrow$  3 s (= Faktor  $10^7$ )

$$\dot{\gamma} \approx 10^{-6} \text{ s}^{-1} \Rightarrow \dot{\gamma} \approx 10 \text{ s}^{-1}$$

$\dot{\gamma}=10$  heisst: 10 mm Versatz auf 1 mm dicker Schicht in 1 Sekunde

Zeit zwischen Erdbeben 100 Jahre:

3'000'000'000 s (100 Jahr)  $\rightarrow$  3 s (= Faktor  $10^9$ )

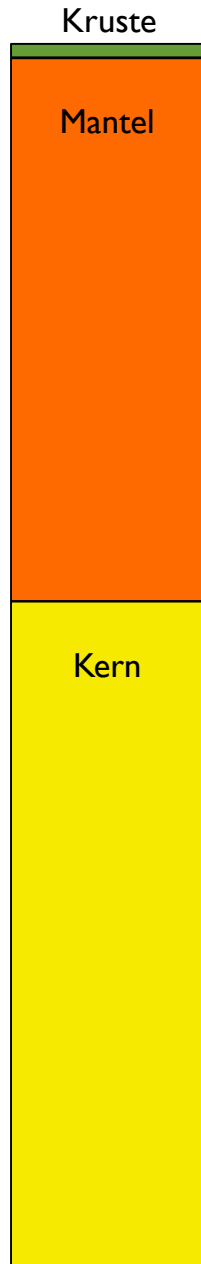
$$\dot{\gamma} \approx 10^{-6} \text{ s}^{-1} \Rightarrow \dot{\gamma} \approx 1000 \text{ s}^{-1}$$

$\dot{\gamma}=1000$  heisst: 1 m/s = 3.6 km/h

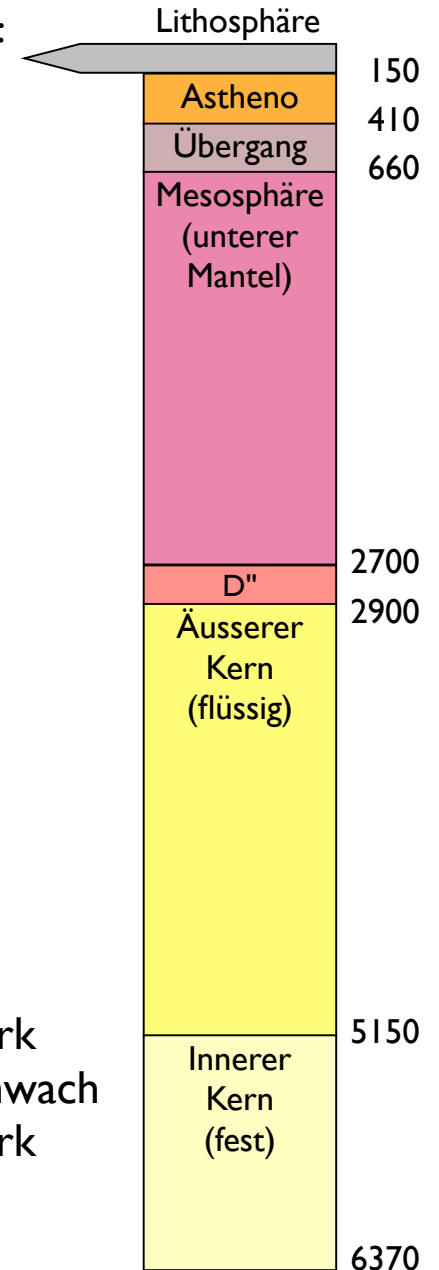
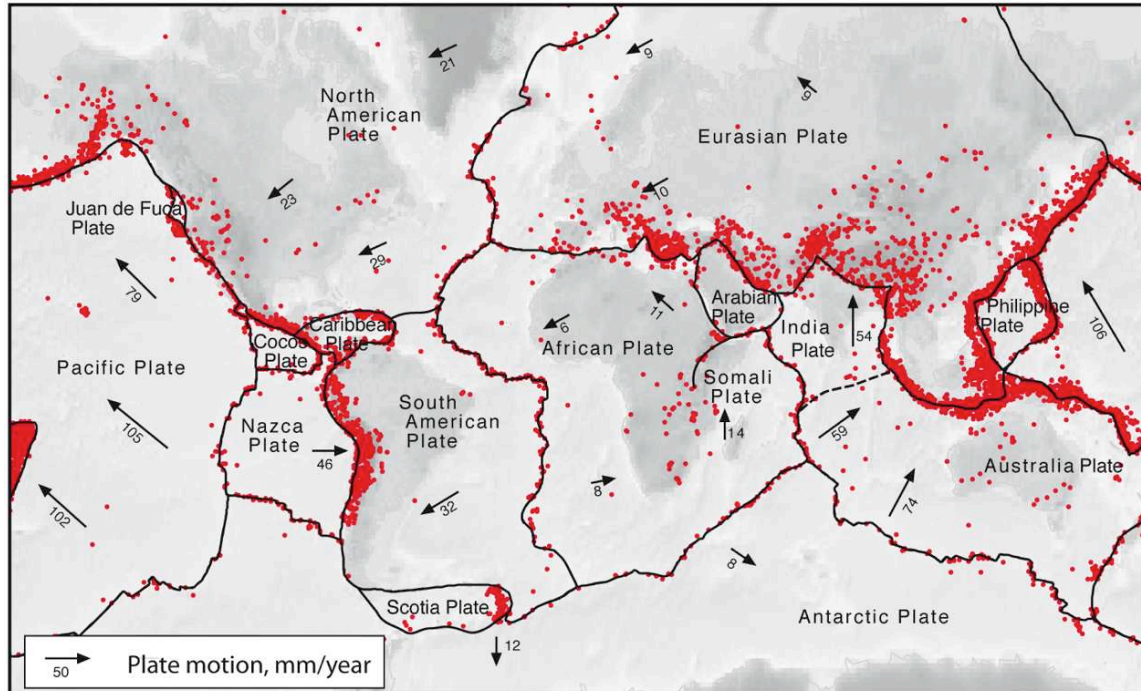
Totaler aufgestauter Versatz = 3m:  $3\text{m}/3\text{s} = 1\text{m/s} = 3.6 \text{ km/h}$



# Mechanik der Platten



Plattengeschwindigkeiten:  
1 bis 10 cm / Jahr



chemischer Aufbau der Erde:

Kruste  
Mantel  
Kern

physikalische Eigenschaften:

Lithosphäre fest, stark  
Asthenosphäre fest, schwach  
Unterer Mantel fest, stark  
Äusserer Kern flüssig  
Innerer Kern fest

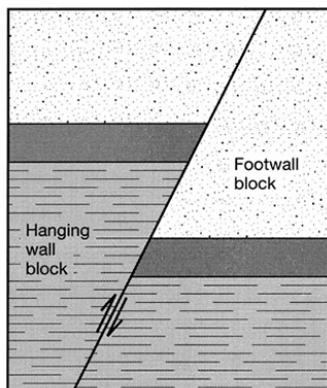
# wie bewegen sich Gesteine ?

**Spröd:** Bruchbildung, an Fläche gebunden  
Bedingungen: schnell, kalt, seicht

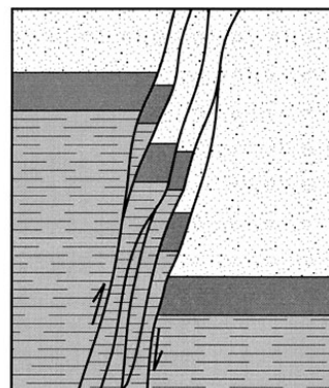
**Duktil:** Fließen, im Volumen verteilt  
Bedingungen: langsam, heiss, tief



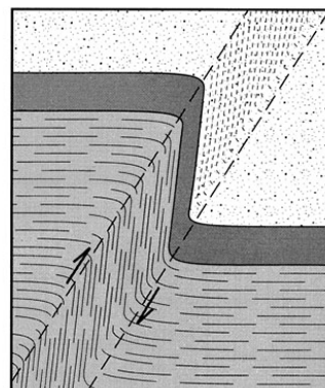
langsame Deformation einer Kalplatte (Geologisches Institut, Universität Toulouse)



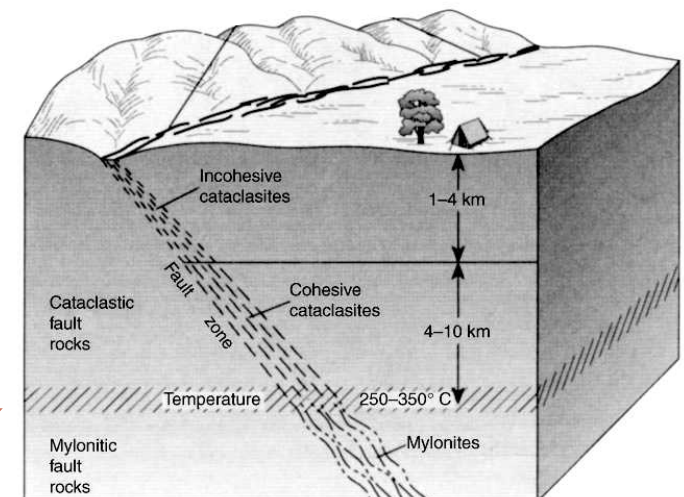
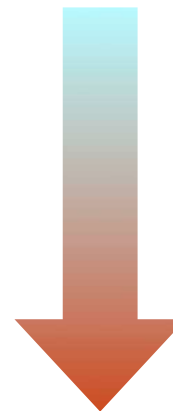
Bruch



Bruchzone

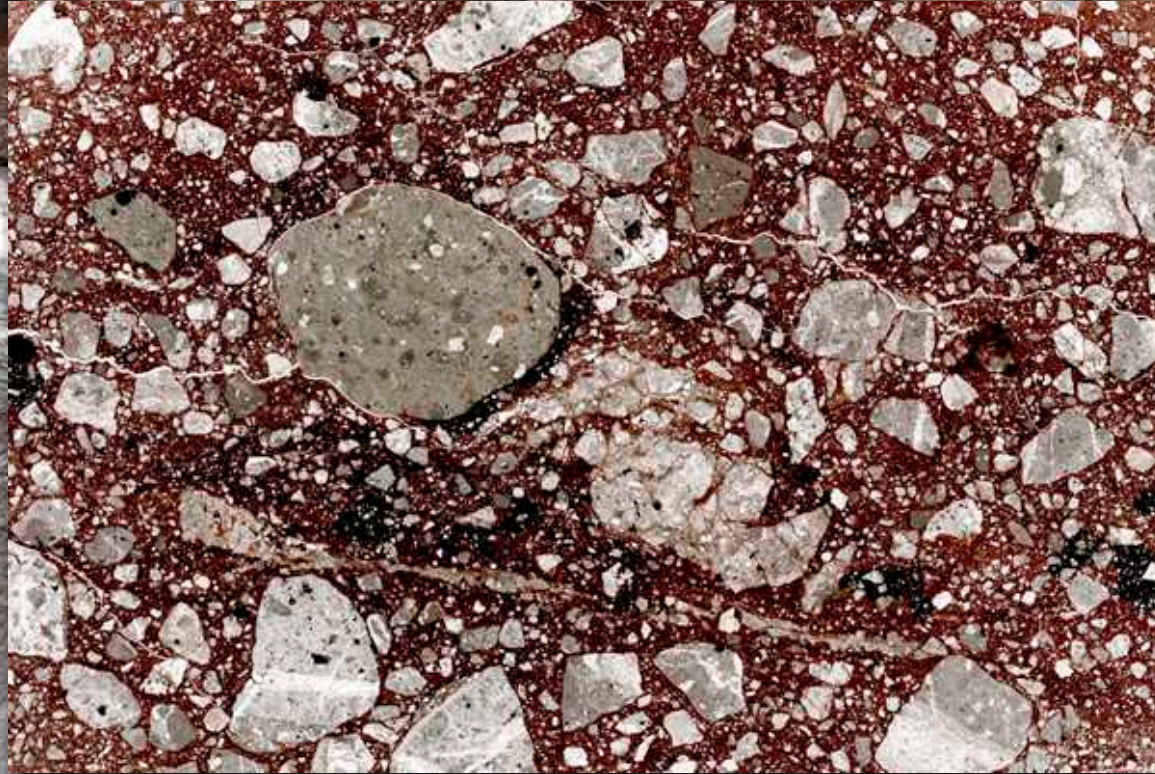


Duktile Scherzone

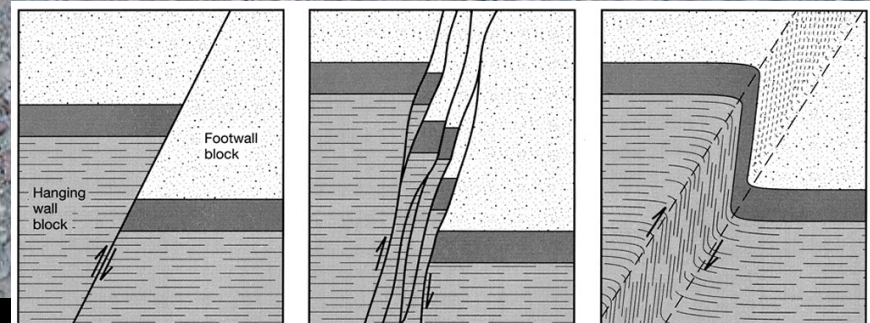




# Spröd - Duktill Übergang



spröd: Kataklastit

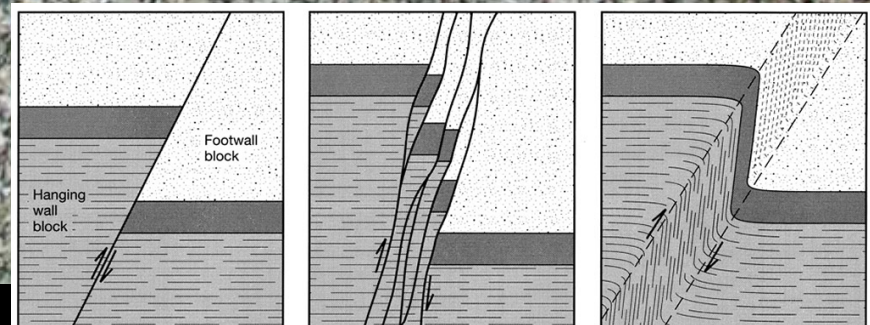




# Spröd - Duktill Übergang



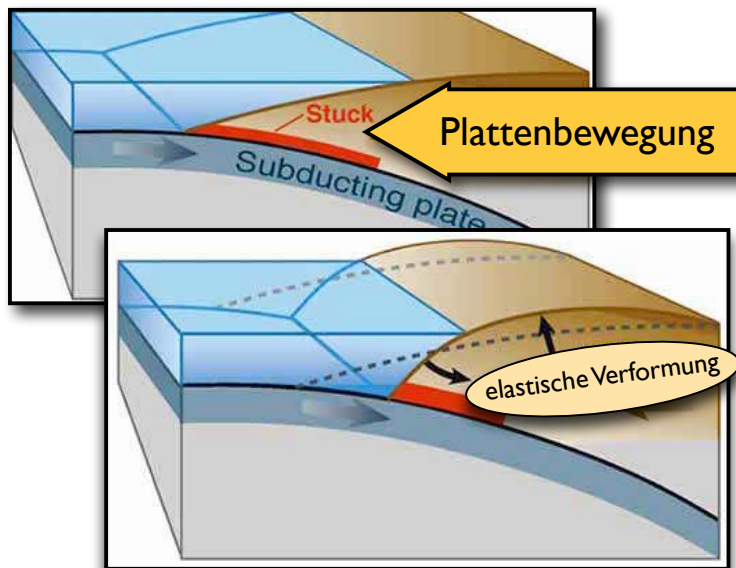
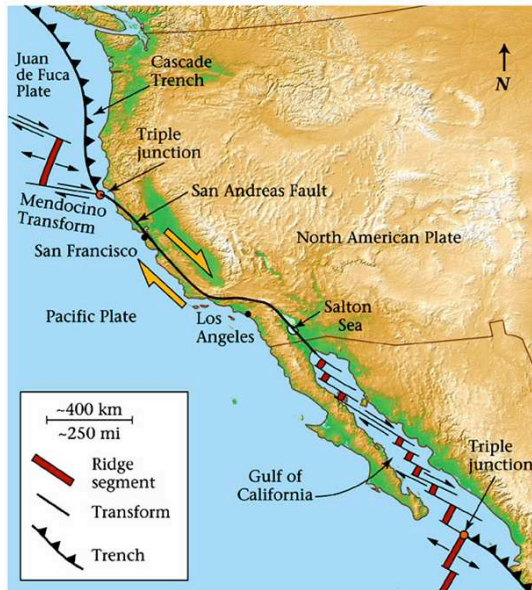
duktill: Mylonit





# Anatomie eines Erdbebens

# Platten bewegen sich gegeneinander

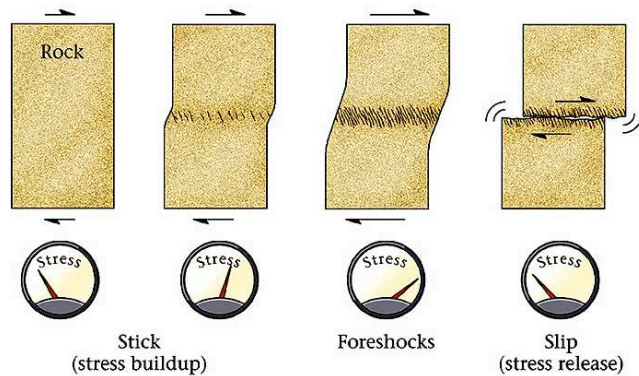
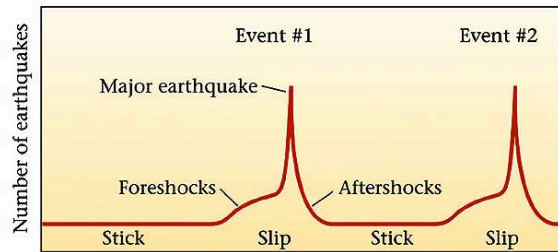


Bewegung ist nicht kontinuierlich:

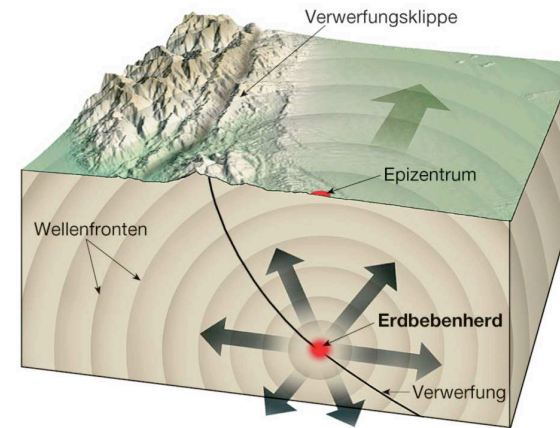
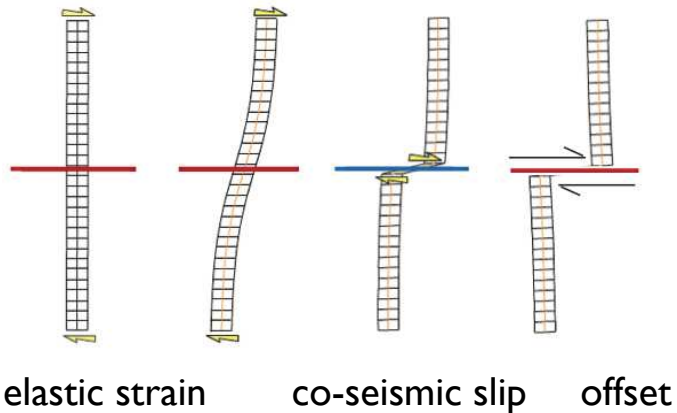
- Hindernisse
- Festigkeit des Materials
- Reibung an der Bruchfläche



# Zeitlicher Ablauf



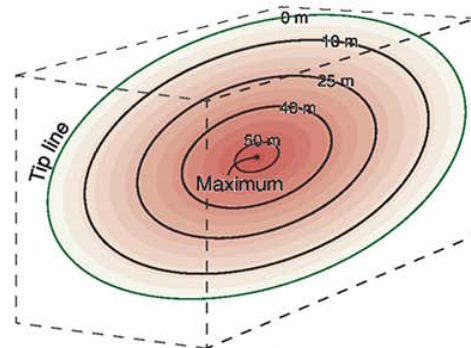
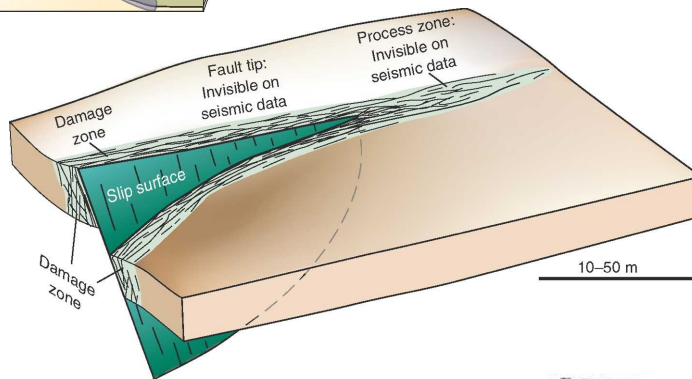
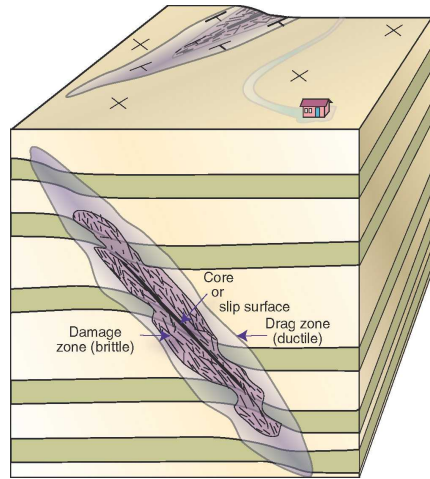
→ Zeit



Verschiedene Bewegungen:

1. Plattenbewegung
2. Ausbreitung der Bruchfläche
3. Bewegung auf der Verwerfung
4. Ausbreitung seismischer Wellen

# mit Erdbeben assoziierte Geschwindigkeiten



Plattengeschwindigkeit:

$$v_{\text{plate}} = 10 \text{ cm/Jahr}$$

Bruchbildung:

$$v_{\text{rupture}} = 3-4 \text{ km/s}$$

Relativbewegung der  
Gesteinskörper

$$v_{\text{slip}} \approx 1 \text{ ms}^{-1}$$
$$\approx 5 \text{ km/Stunde}$$

Seismische Wellen:

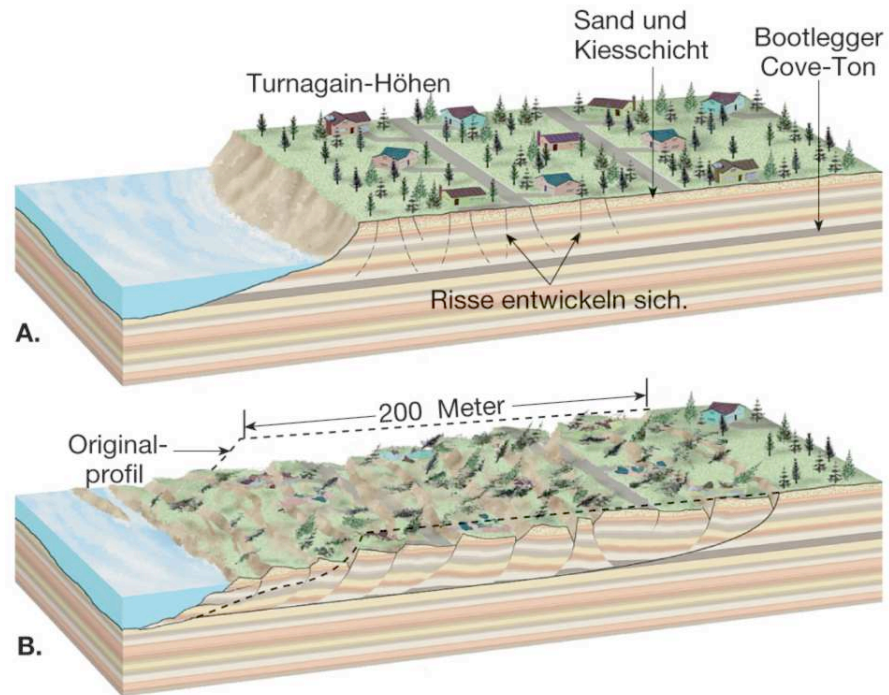
$$v_p \ v_s = 5-6 \text{ km/s}$$

$$v_{\text{surface}} = 3-4 \text{ km/s}$$



# mögliche Folgen eines Erdbeben

# Erdrutsch



Turnagain Height Erdrutsch  
Alaska 1964

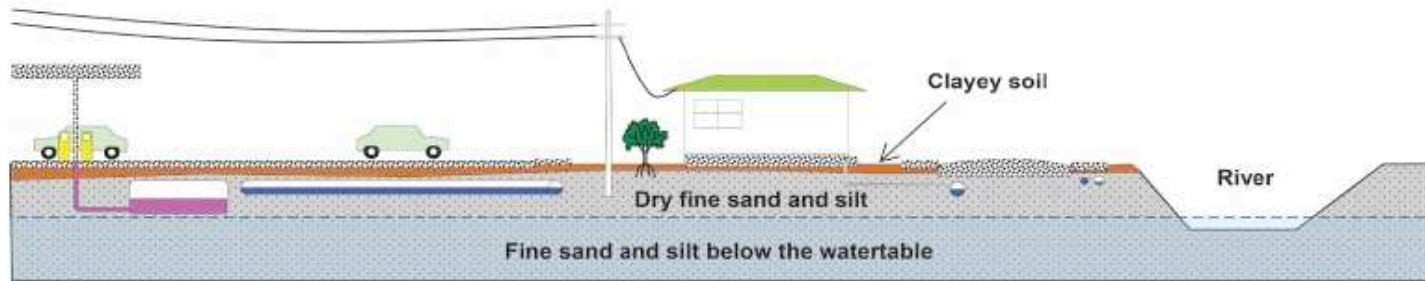




# Bodenverflüssigung

## Before the Earthquake

Areas of flat, low lying land with groundwater only a few metres below the surface, can support buildings and roads, buried pipes, cables and tanks under normal conditions.



## During and after the Earthquake

During the earthquake fine sand, silt and water moves up under pressure through cracks and other weak areas to erupt onto the ground surface. Near rivers the pressure is relieved to the side as the ground moves sideways into the river channels.

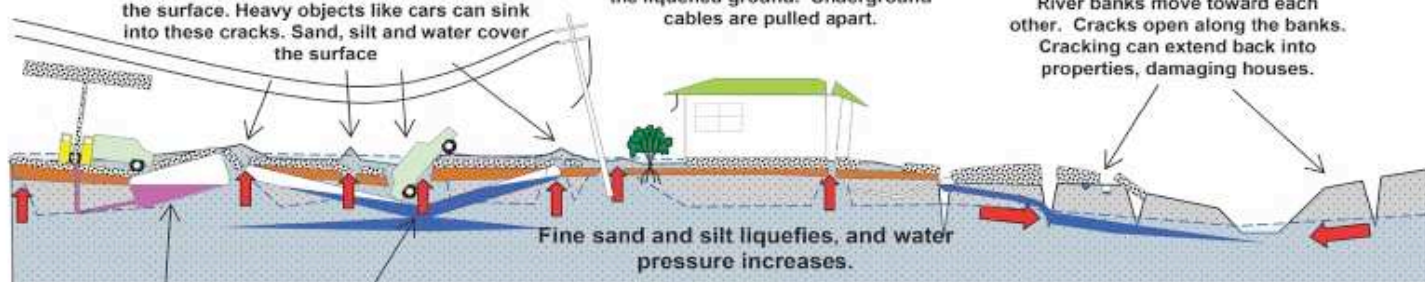
### Sand Boils (Sand Volcanoes)

Sand, silt and water erupts upward under pressure through cracks and flows out onto the surface. Heavy objects like cars can sink into these cracks. Sand, silt and water cover the surface

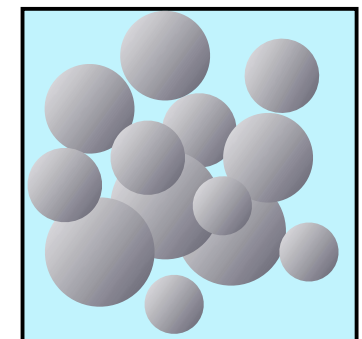
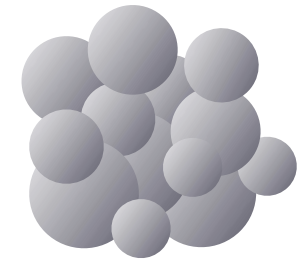
Power poles are pulled over by their wires as they can't be supported in the liquefied ground. Underground cables are pulled apart.

### Lateral Spreading

River banks move toward each other. Cracks open along the banks. Cracking can extend back into properties, damaging houses.



Tanks, pipes and manholes float up in the liquefied ground and break through the surface. Pipes break, water and sewage leaks into the ground.



Porendruck



# Bodenverflüssigung



Niigata 1964



Chuetsu 2004



Christchurch 2011



Kobe 1995



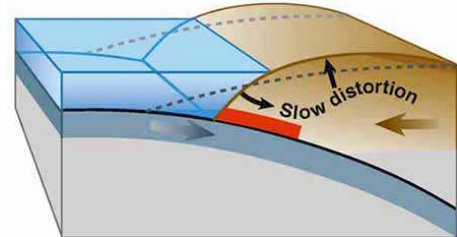
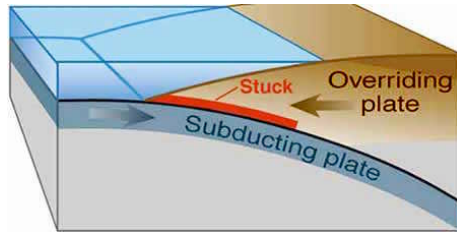
Kobe 1995



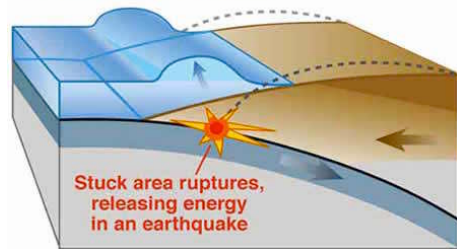
Loma Prieta 1989



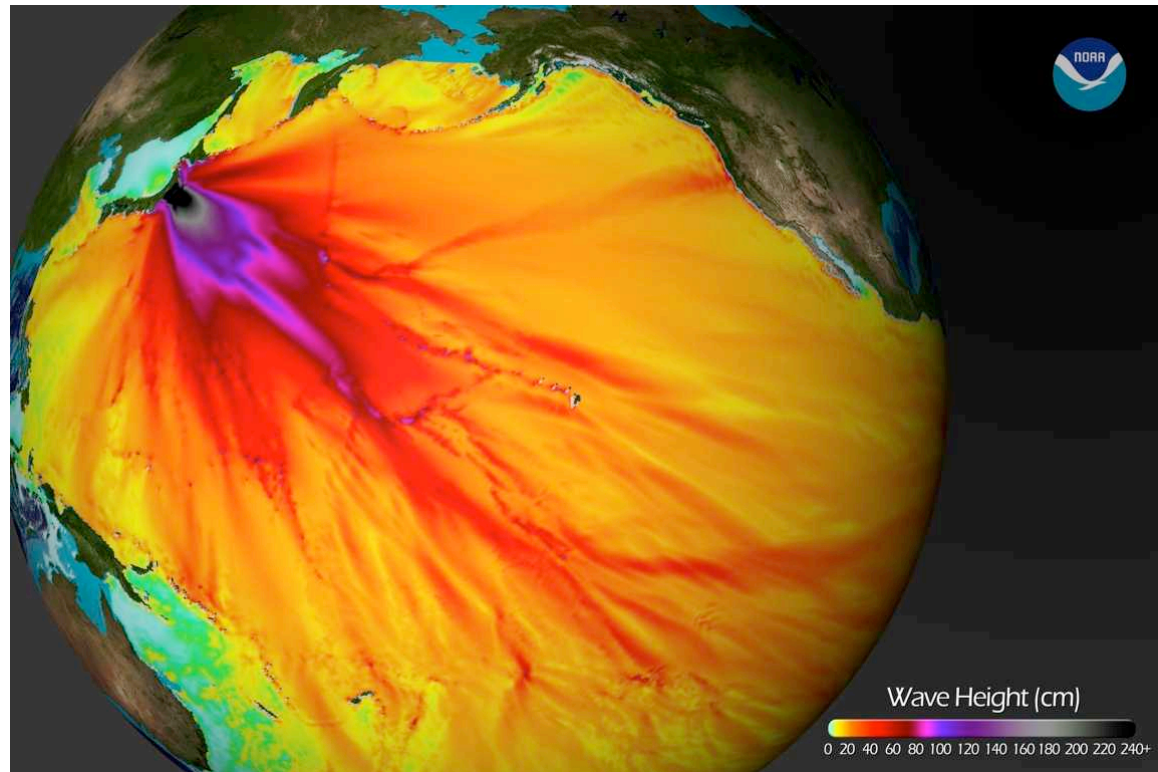
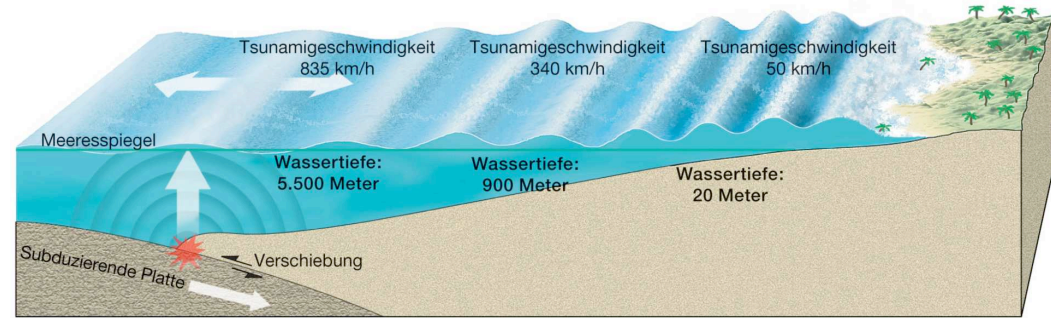
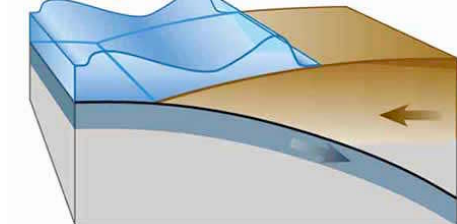
# Tsunami



Earthquake starts tsunami



Tsunami waves spread

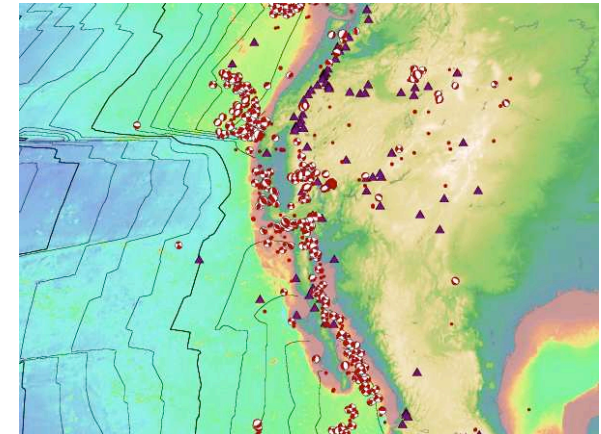
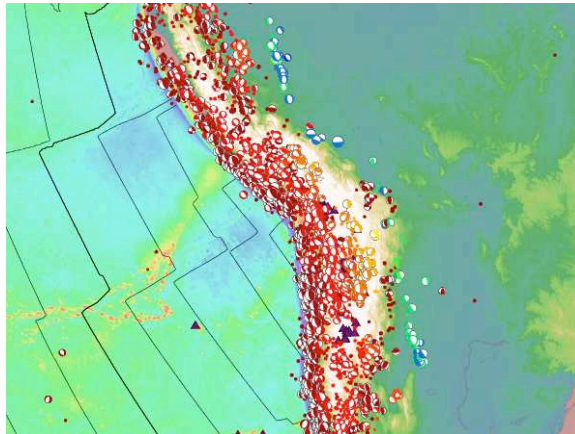
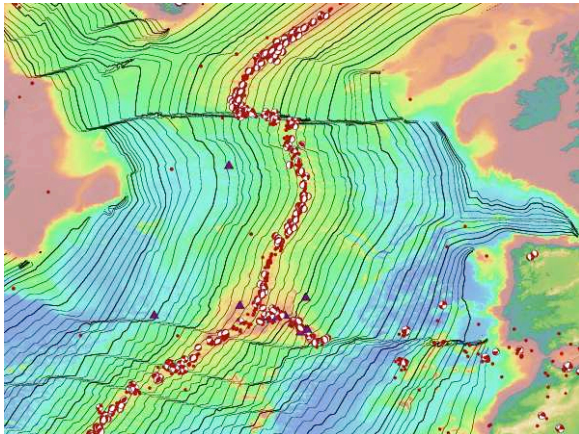
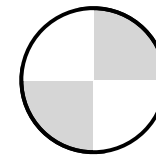
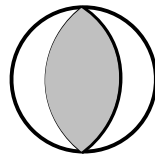
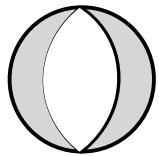
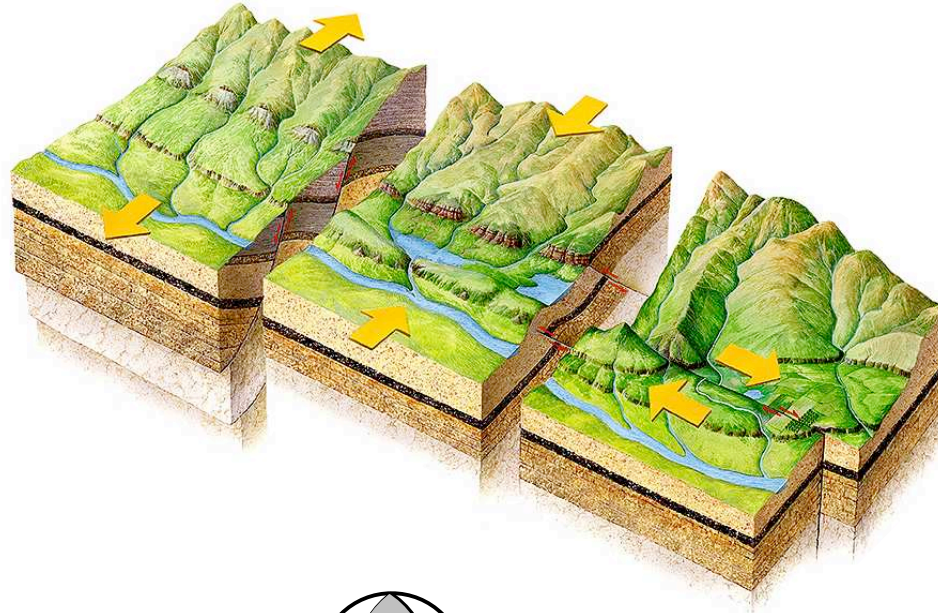


Tohoku 2011

# Spuren von Erdbeben

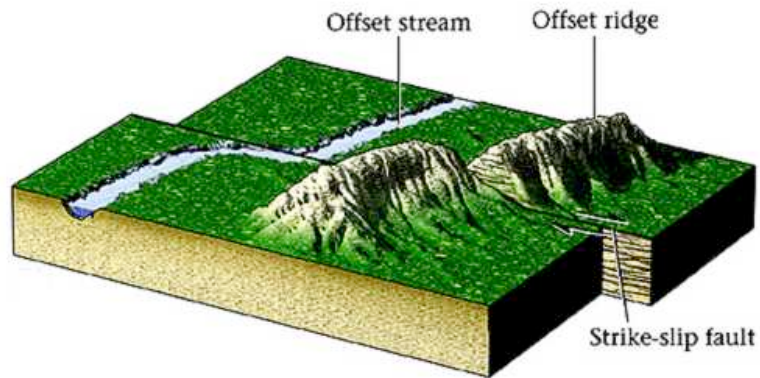


# Verschiedene Typen von Erdbeben

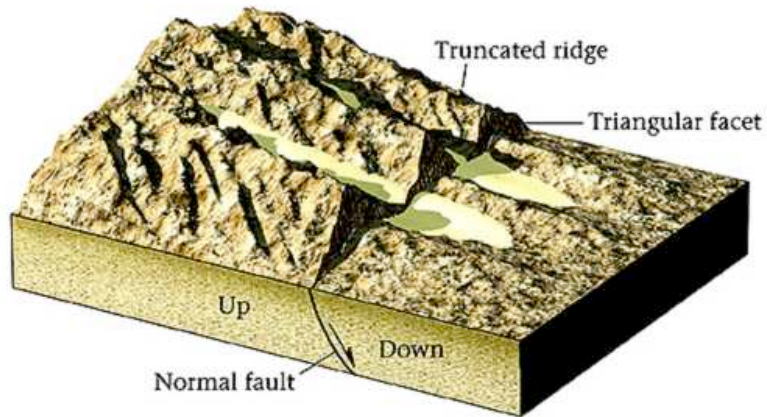
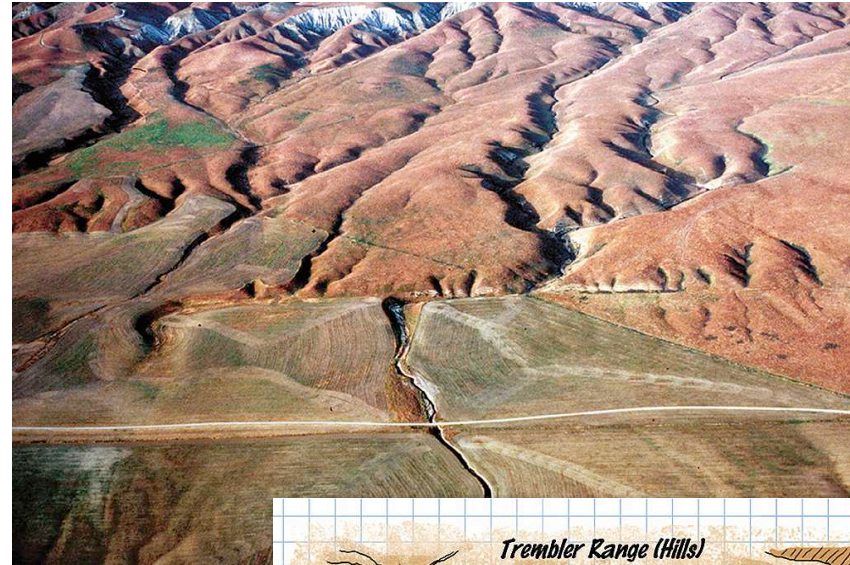




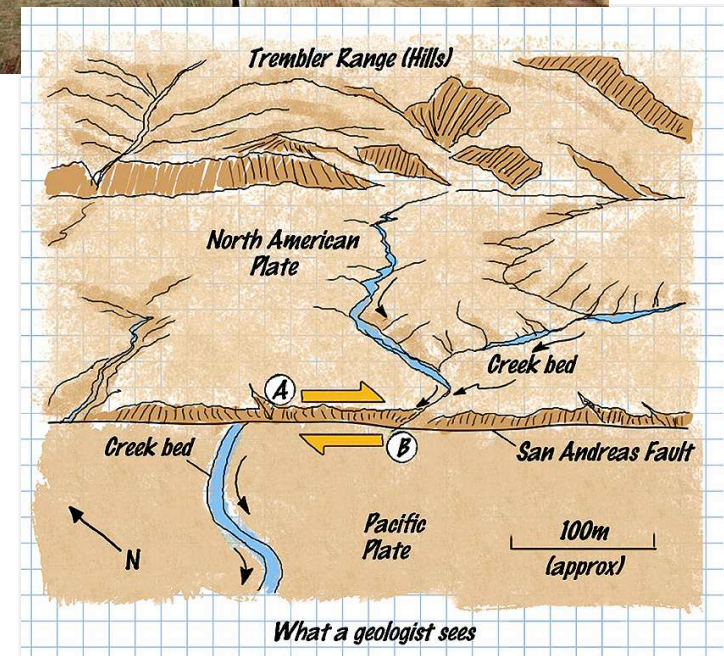
# Topographische Ausprägung



Blattverschiebung



Abschiebung



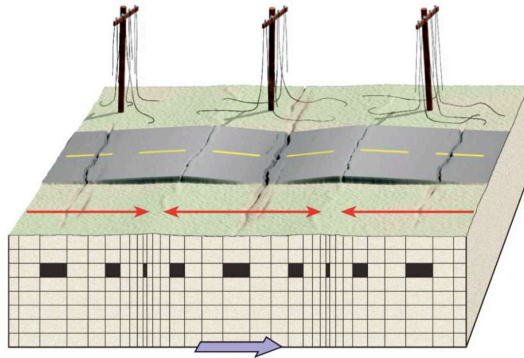


**wie gross ist ein  
Erdbeben?**

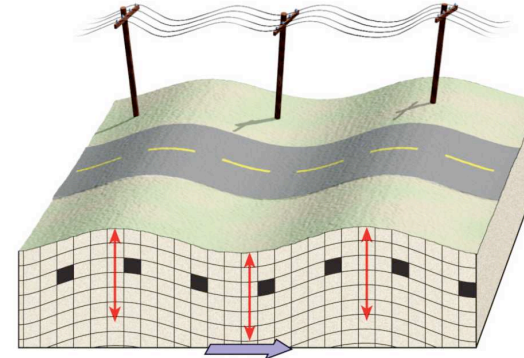
# Seismische Wellen

## Körperwellen

P-Wellen



S-Wellen

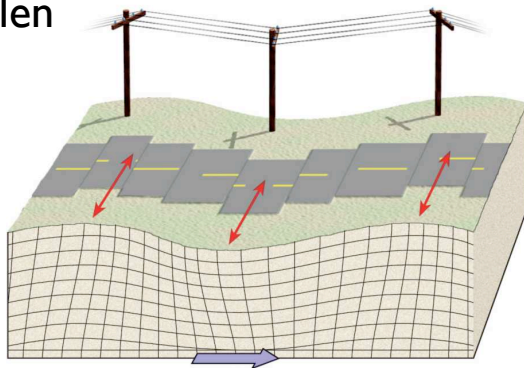


Bewegungsrichtung  
der Teilchen im Körper

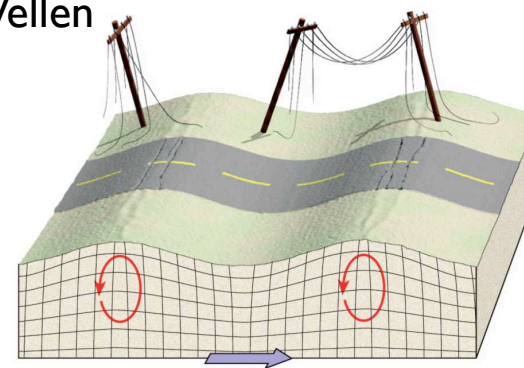
Fortpflanzungsrichtung der Welle

## Oberflächenwellen

Love-Wellen



Raleigh-Wellen





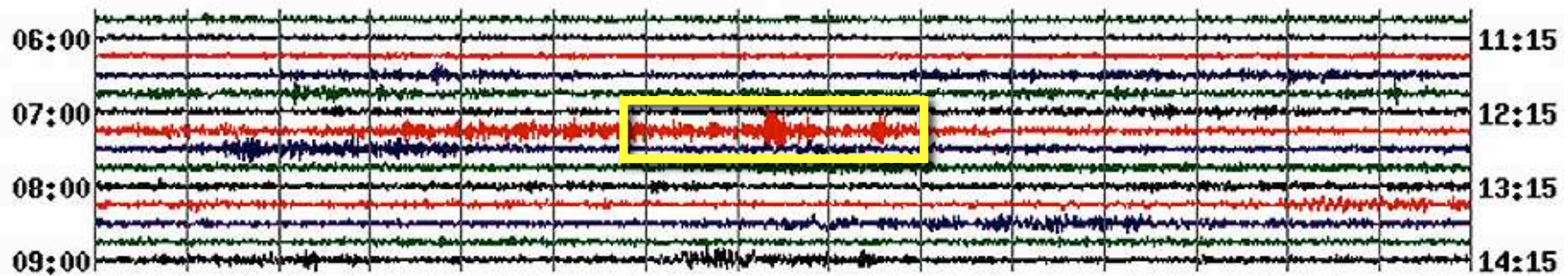
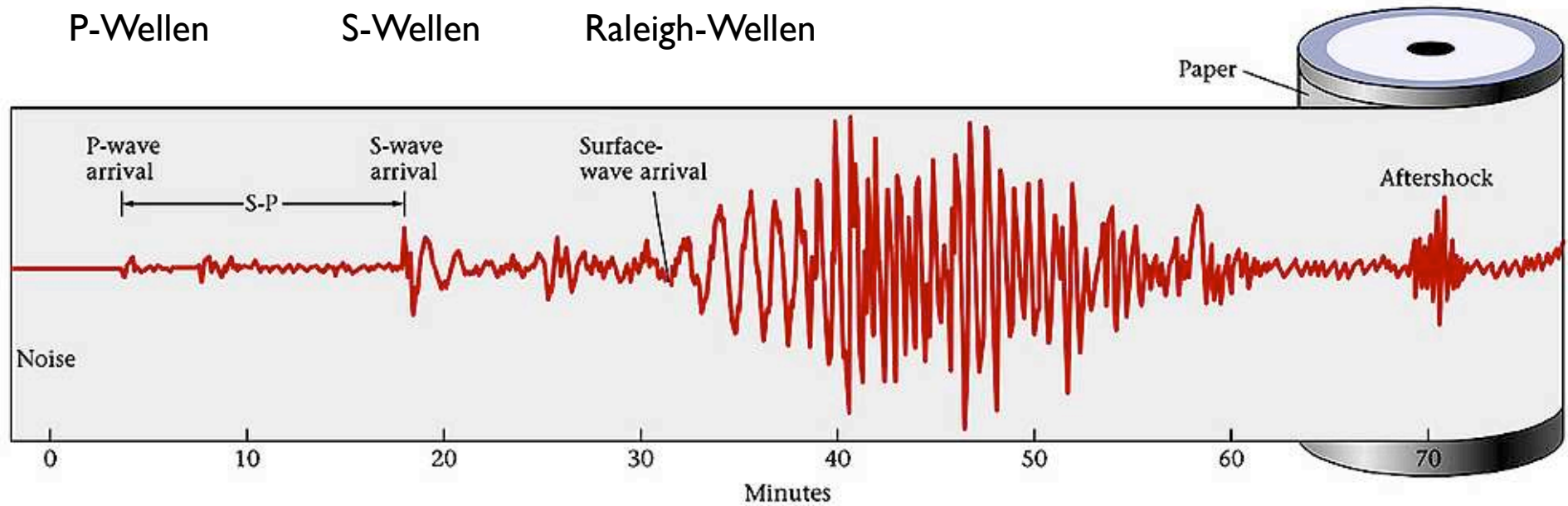
# Amplituden

P-Wellen

S-Wellen

Love-Wellen

Raleigh-Wellen

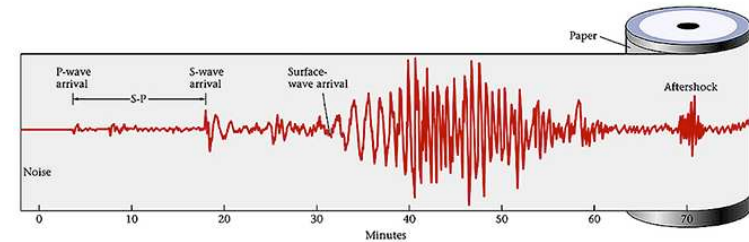


# Magnitude

Allgemeine Formulierung

$$M = \log_{10}(A/T) + q(\Delta, h) + a$$

M	Magnitude
A	maximale Amplitude ( $\mu\text{m}$ )
T	Periode (s)
q	Korrekturfunktion
$\Delta$	Winkelabstand Seismograph - Herd ( $^\circ$ )
h	Herdtiefe (km)
a	empirische Konstante für Seismograph



Bemerkung:

Logarithmisches Mass, Zehnerlogarithmus (Basis 10),  
setzt Amplitude und Frequenz ( $1/T$ ) ins Verhältnis,  
Messung ist frequenz-abhängig,  
a und q müssen entsprechend kalibriert werden



# Magnituden

## Oberflächenwellen

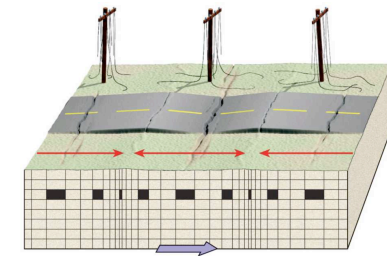
$$M_s = \log_{10}(A/T)_{\max} + \log(\Delta) + 3.3$$

$M_s$	Magnitude (surface magnitude)
$A$	maximale Amplitude ( $\mu\text{m}$ )
$T$	Periode (s)
$\Delta$	Winkelabstand Seismograph - Herd ( $^\circ$ )

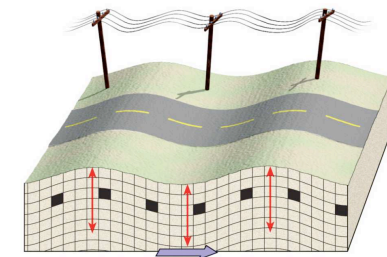
## Raumwellen

$$m_b = \log_{10}(A/12) + 0.01\Delta + 5.9$$

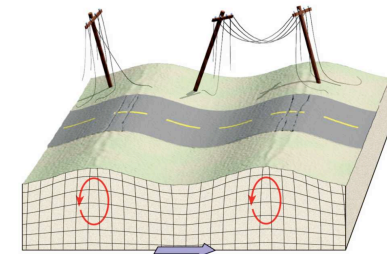
$m_b$	Magnitude (body wave magnitude)
$A$	maximale Amplitude ( $\mu\text{m}$ )
12	Wellen mit Periode $T=12$ s
0.01	Korrekturfaktor ( $\sim q$ )
$\Delta$	Winkelabstand Seismograph - Herd ( $^\circ$ )
5.9	empirische Konstante für Seismograph



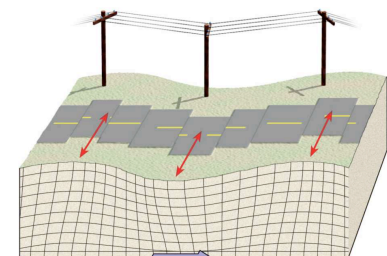
P-Wellen



S-Wellen



Love-Wellen



Raleigh-Wellen

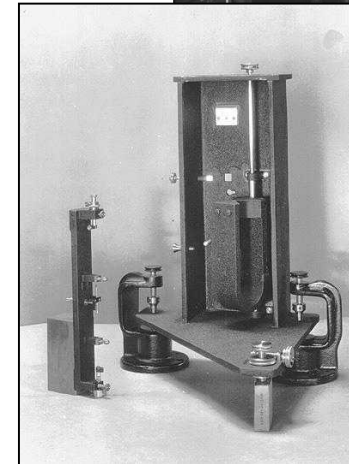
# Gutenberg-Richter - Skala

$$M_L = \log_{10}(A/T)_{\max} + q(\Delta, h)$$

- $M_L$  Magnitude (body wave magnitude)  
 $A$  maximale Amplitude ( $\mu\text{m}$ )  
 $T$  Periode (s)  
 $q$  Korrekturfunktion  
 $\Delta$  Winkelabstand Seismograph - Herd ( $^\circ$ )  
 $h$  Herdtiefe (km)



Gutenberg  
in seinem  
Wohnzimmer



Anderson-Wood Seismograf

Die Gutenberg-Richter Magnitude ( $M_L$ ) und die Oberflächenwellen-Magnitude ( $M_S$ ) stimmen beim Wert  $M_L = M_S = 6.5$  überein. Für Magnituden  $< 6.5$  ist  $M_L > M_S$ , darüber ist  $M_S > M_L$



# grösste Erdbeben

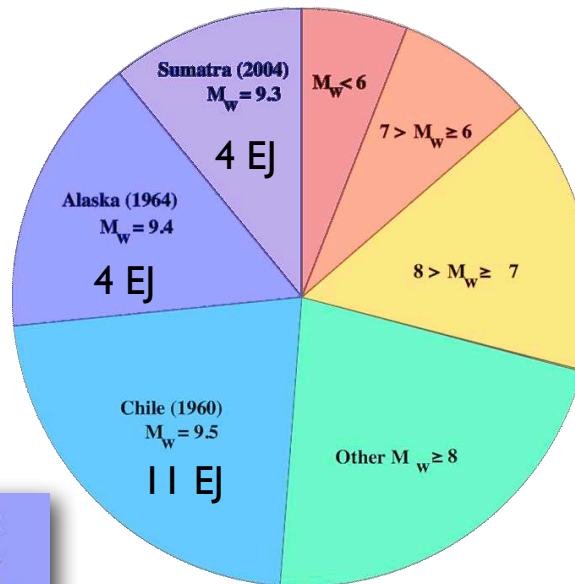
Januar 1906 - December 2005

Totale seismische Energie  $E_S \approx 50 \cdot 10^{18} \text{ Nm} = 50 \text{ EJ}$  ( $10^{18} \text{ J} = 1 \text{ Exa-Joule}$ )

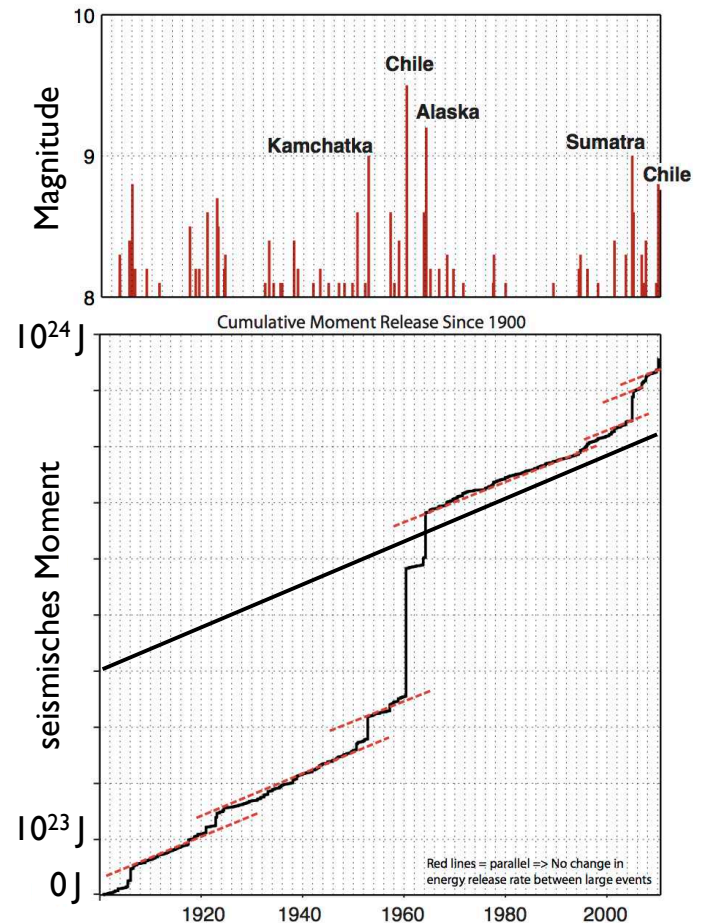
Globales seismisches Moment  $M_0 \approx 10^{24} \text{ Nm} = 1 \text{ YJ}$  ( $10^{24} \text{ J} = 1 \text{ Yotta-Joule}$ )

Beachte:

fast 50% des Gesamtmomentes durch die 3 grössten Erdbeben aufgebracht



$M_w$	$E_S$ in Joule	Menge TNT in Tonnen	Äquivalenz Hiroshima-Atombomben (12,5 kT TNT)
4	$6,3 \cdot 10^{10}$	15	0,0012
5	$2,0 \cdot 10^{12}$	475	0,038
6	$6,3 \cdot 10^{13}$	15.000	1,2
7	$2,0 \cdot 10^{15}$	475.000	38
8	$6,3 \cdot 10^{16}$	15.000.000	1.200
9	$2,0 \cdot 10^{18}$	475.000.000	38.000





A photomicrograph showing a dark brown, fibrous matrix containing numerous angular clasts of various sizes and colors, including light blue, yellow, and white. The clasts are embedded in a dense, interlocking network of fibers.

Ende 5. Stunde

Kataklasit, Mohave Desert