

Tatort

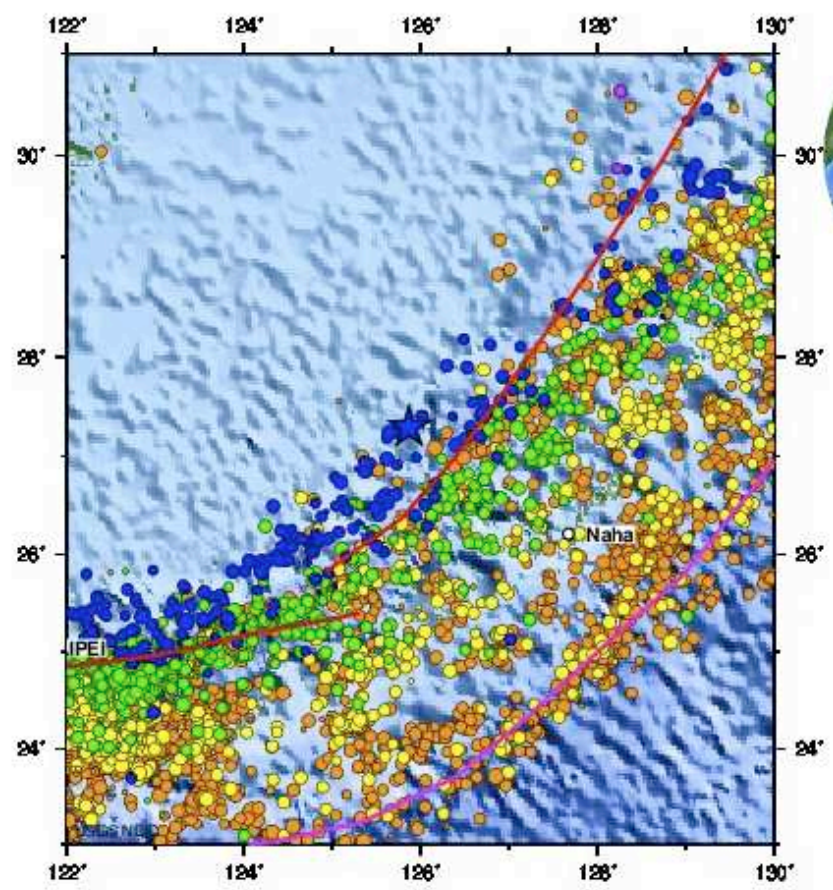
Plattengrenze

Fokus Erdbeben (3)

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Magnitude 6.9 NORTHEAST OF TAIWAN
 Tuesday, November 08, 2011 at 02:59:06 UTC



NORTHEAST OF TAIWAN
 2011 11 08 02:59:06 UTC 27.29N 125.87E Depth: 209.5 km

Seismicity 1990 to Present
 ● ● ● ● ● ● ● ● ● ●
 <=3 4 5 6 7 8 9
 Magnitude (size)

-800 -500 -300 -150 -70 -35 0
 Depth in km (color)

Major Tectonic Boundaries: Subduction Zones -purple, Ridges -red and Transform Faults -green

© 2011 Mapabc.com



Google

27°08'27.85" N 121°58'31.78" E elev -61 m

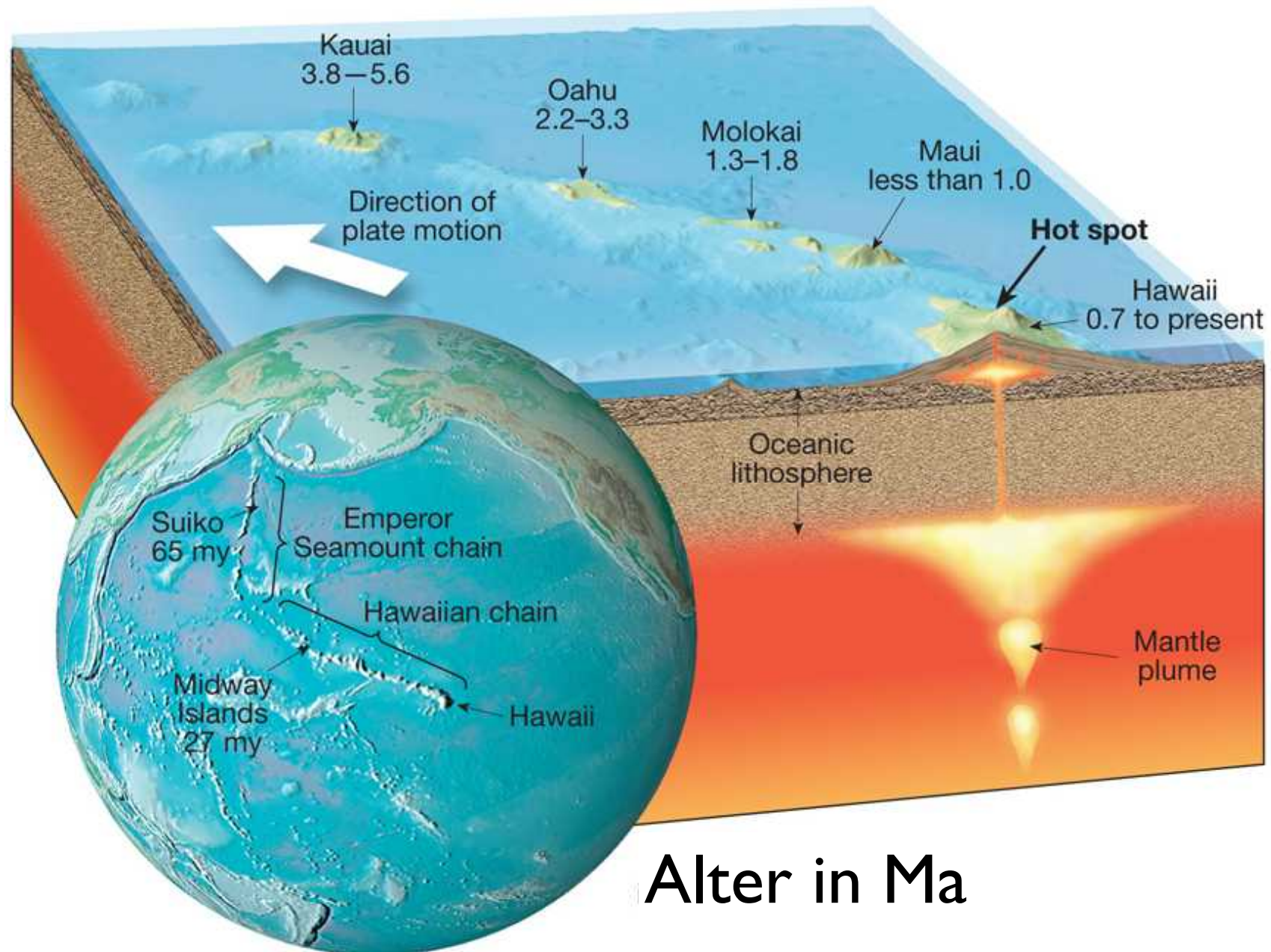
Eye alt 1092.52 km

Aufbau und Dynamik der Erde

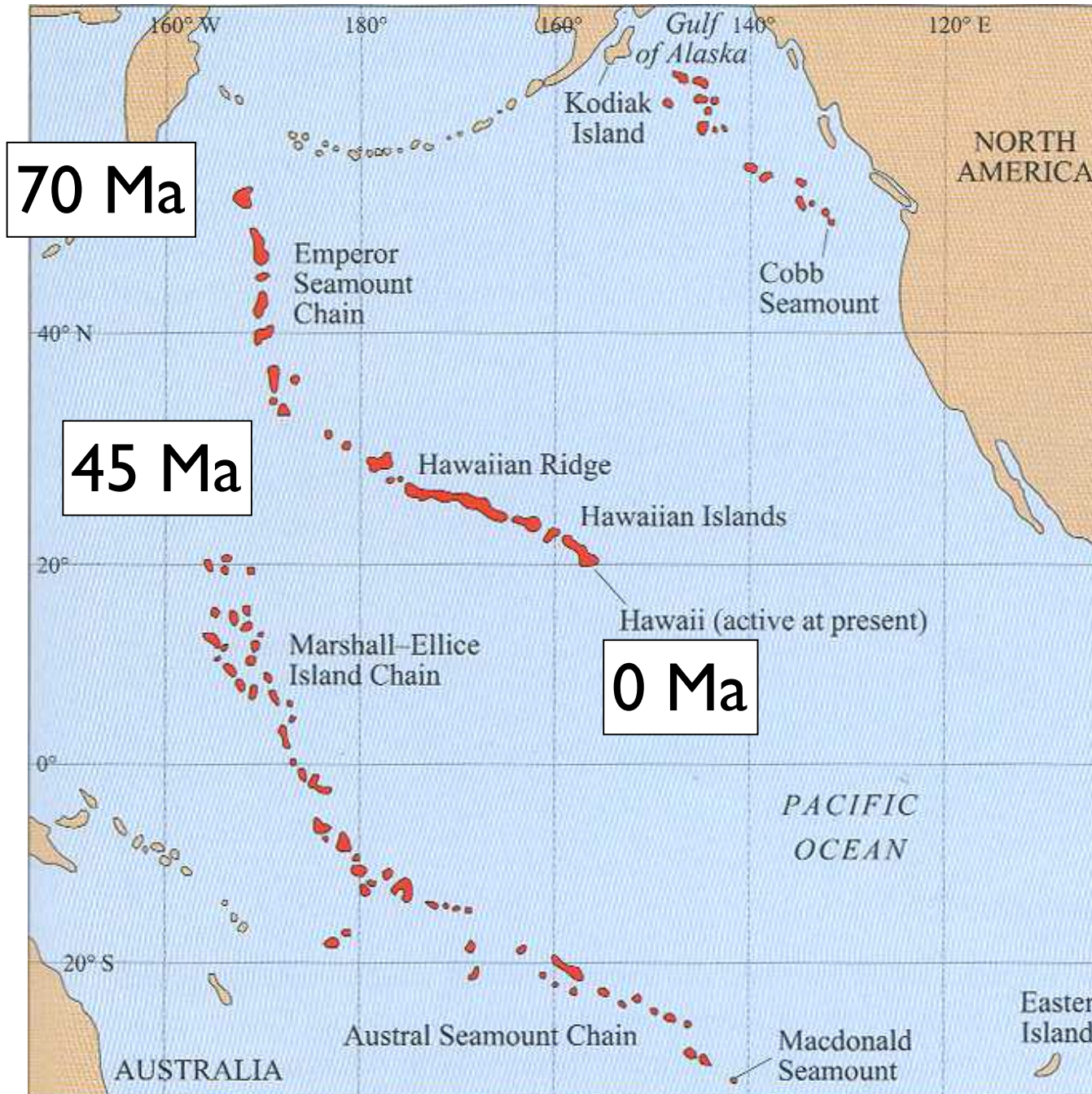
- Plattenbewegungen und geologische Geschwindigkeiten
- Entstehung der Erde
- geologische Zeiträume
- Schalenbau der Erde - Plattenuntergrenze
- wie sich die Erde verformt (spröd - duktil)
- (Bruch-)Tektonik an Plattengrenzen
- Erdbeben - Herdflächen

Platten- bewegung

The Hawaiian Islands



Absolute Plattenbewegung



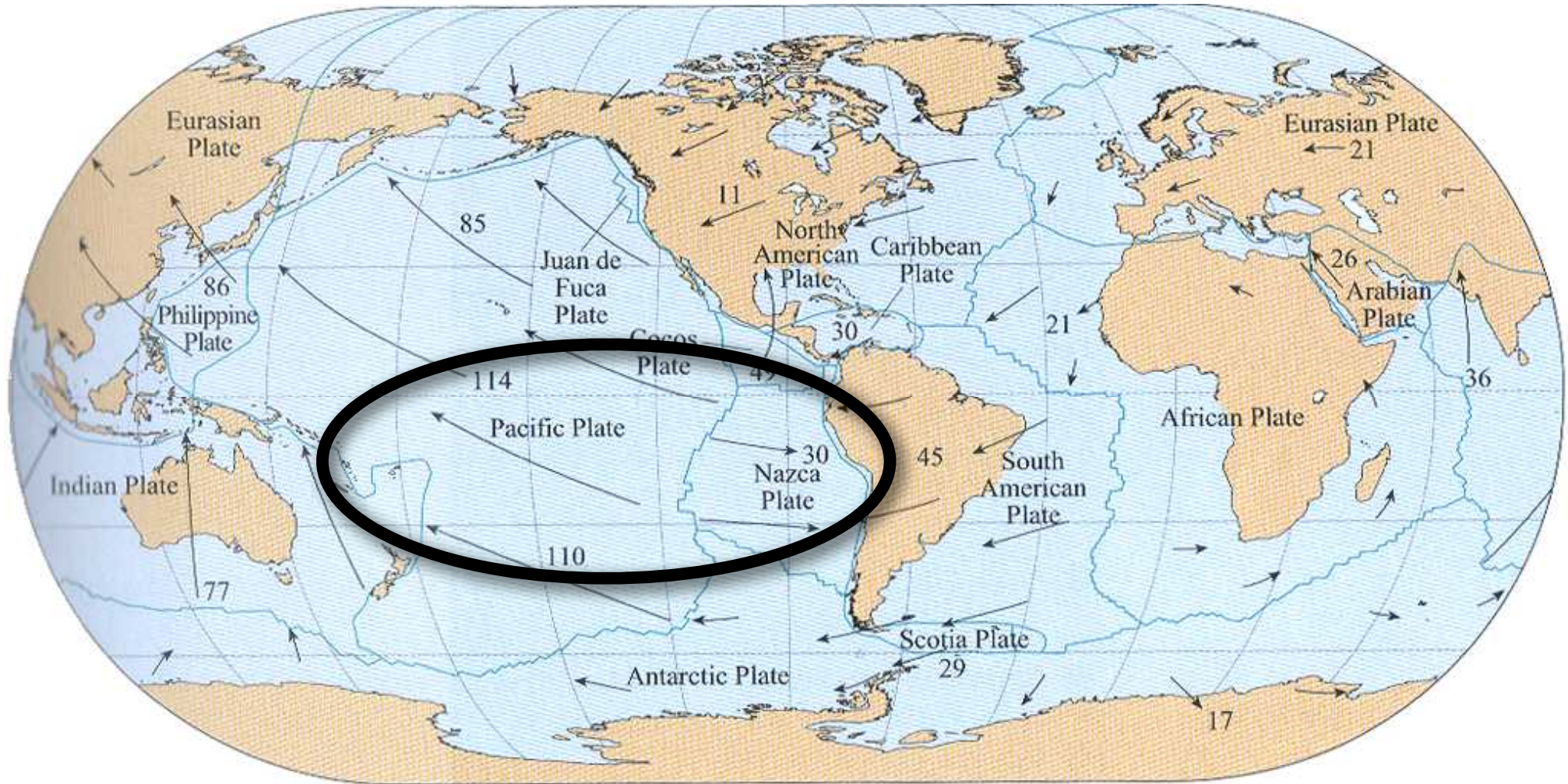
Hawaii -
Emperor
Seamount
Chain

Länge 6000km

Zeit: 70 Ma

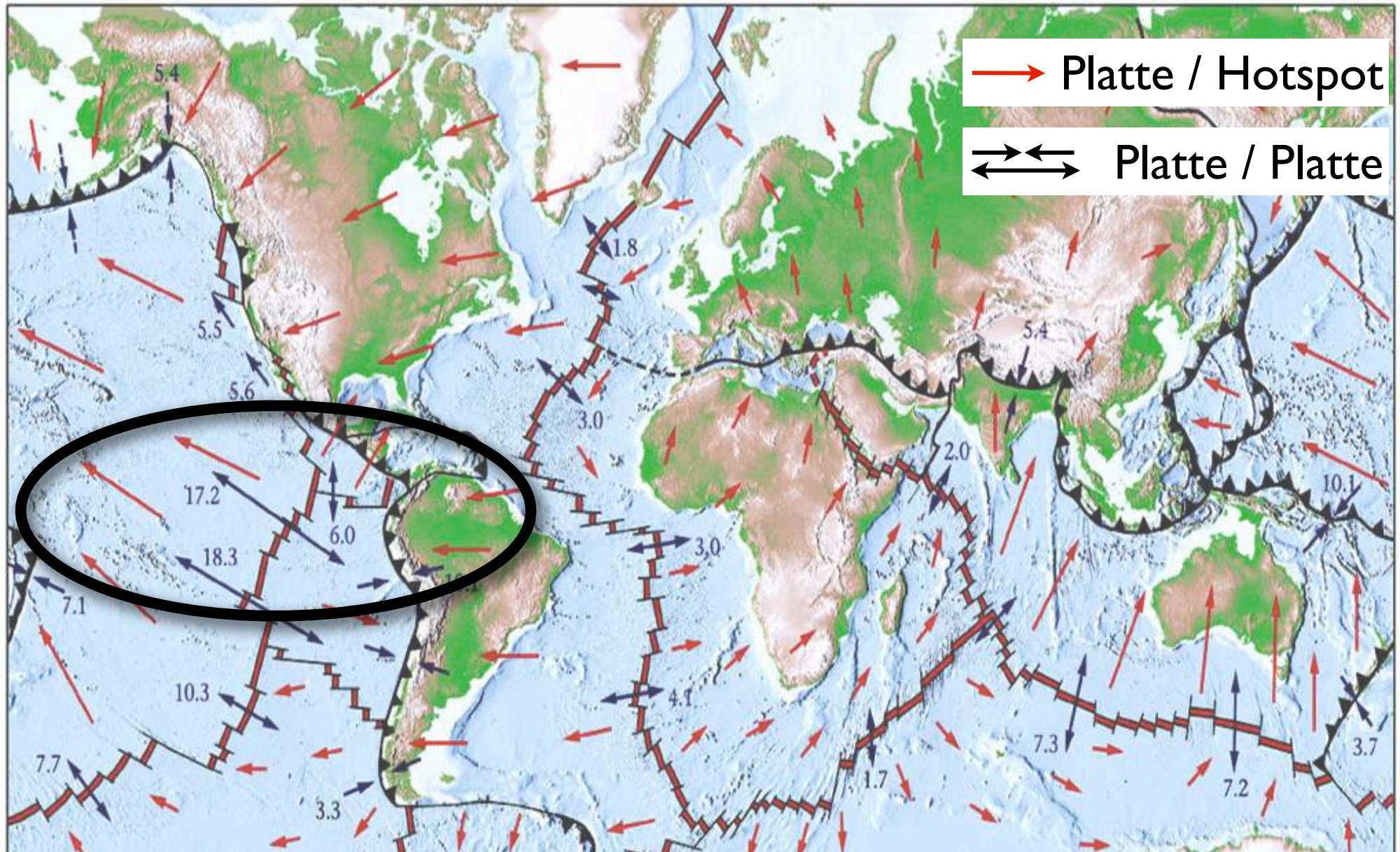
$\approx 9 \text{ cm / Jahr}$

Absolute Plattenbewegung



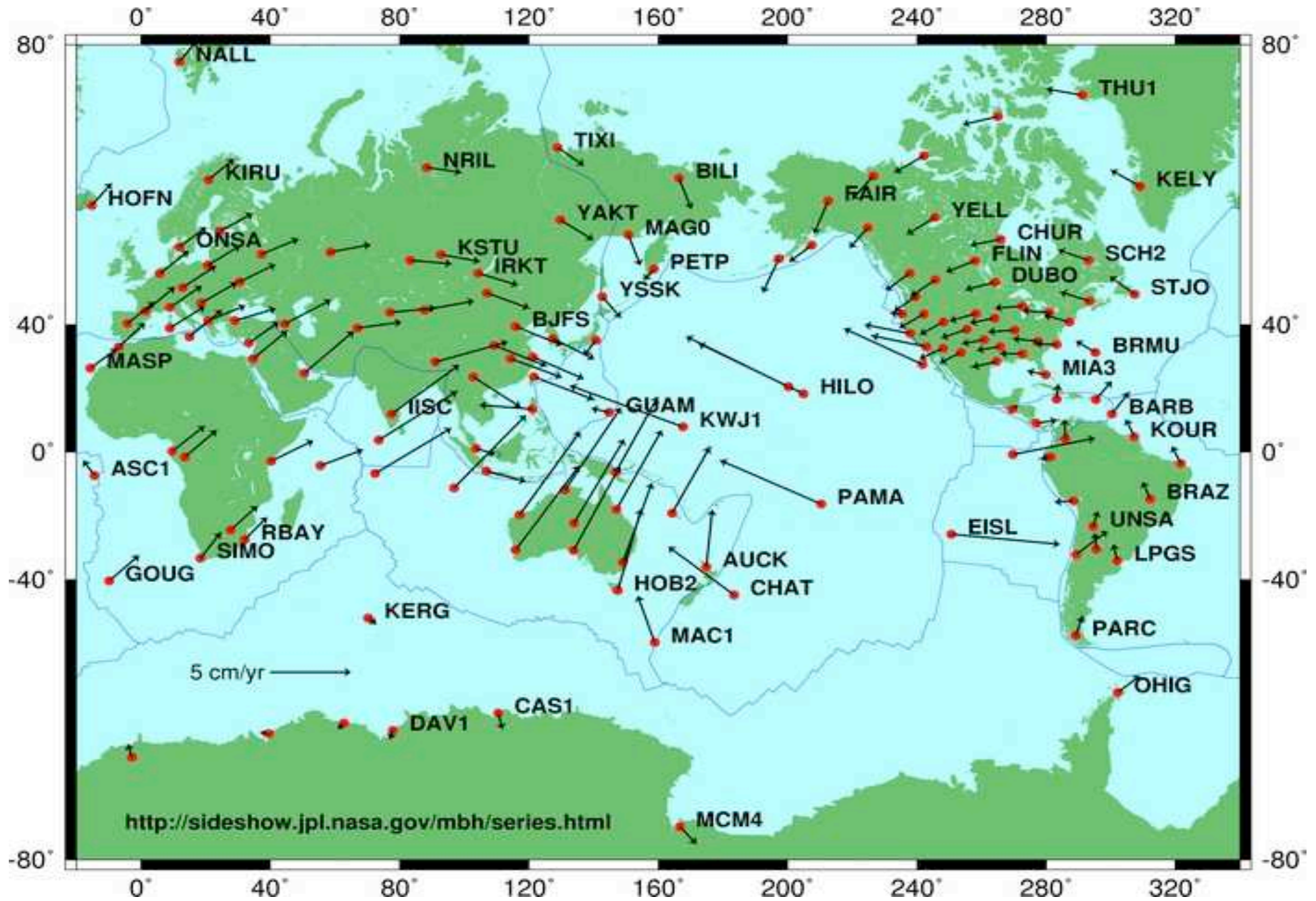
bezüglich Hot Spots (mm a⁻¹)

Spreading rates



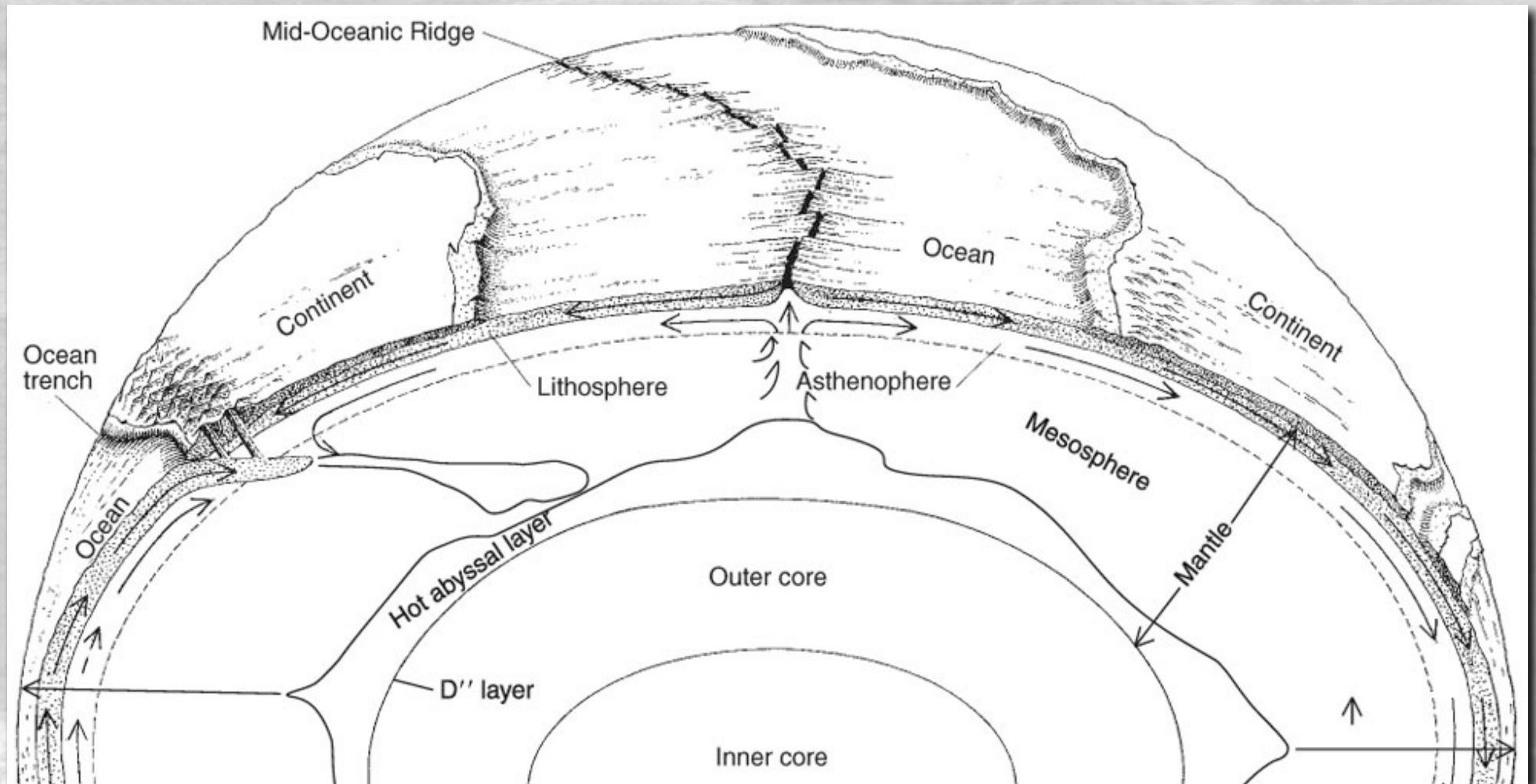
▲▲▲ destruktive — konstruktive — Transform

Plattenbewegungen GPS



geologische
Deformations-
raten

Plattenbewegung



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 ms^{-1}
tektonische Platten:	3 cm / Jahr	$\sim 10^{-8} \text{ ms}^{-1}$
	$= 0.003 \text{ mm / a}$	

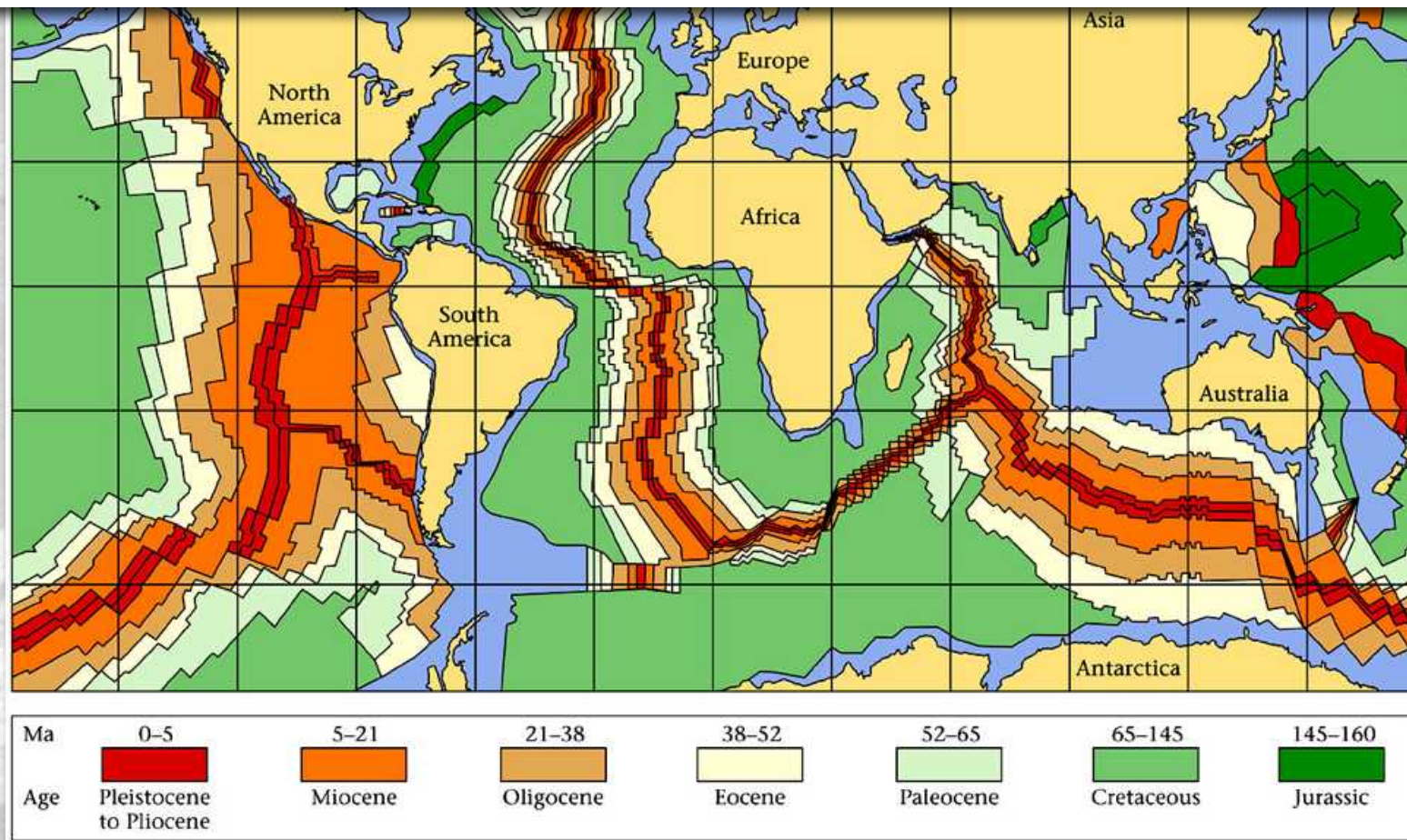
1 Jahr	$= 365 \cdot 24 \text{ h}$	$= 8760 \text{ h}$
	$= 31'536'000 \text{ s}$	$\approx 3 \cdot 10^7 \text{ s}$

was ist langsam - was ist schnell ?

im Durchschnitt : **3000 km / 150 Ma**

$$= 3 \cdot 10^3 \cdot 10^3 \text{ m} / 150 \cdot 10^6 \cdot 3 \cdot 10^7 \text{ s}$$

$$= 3 \cdot 10^6 / 4.5 \cdot 10^2 \cdot 10^{13} \quad \approx 10^{-9} \text{ ms}^{-1}$$

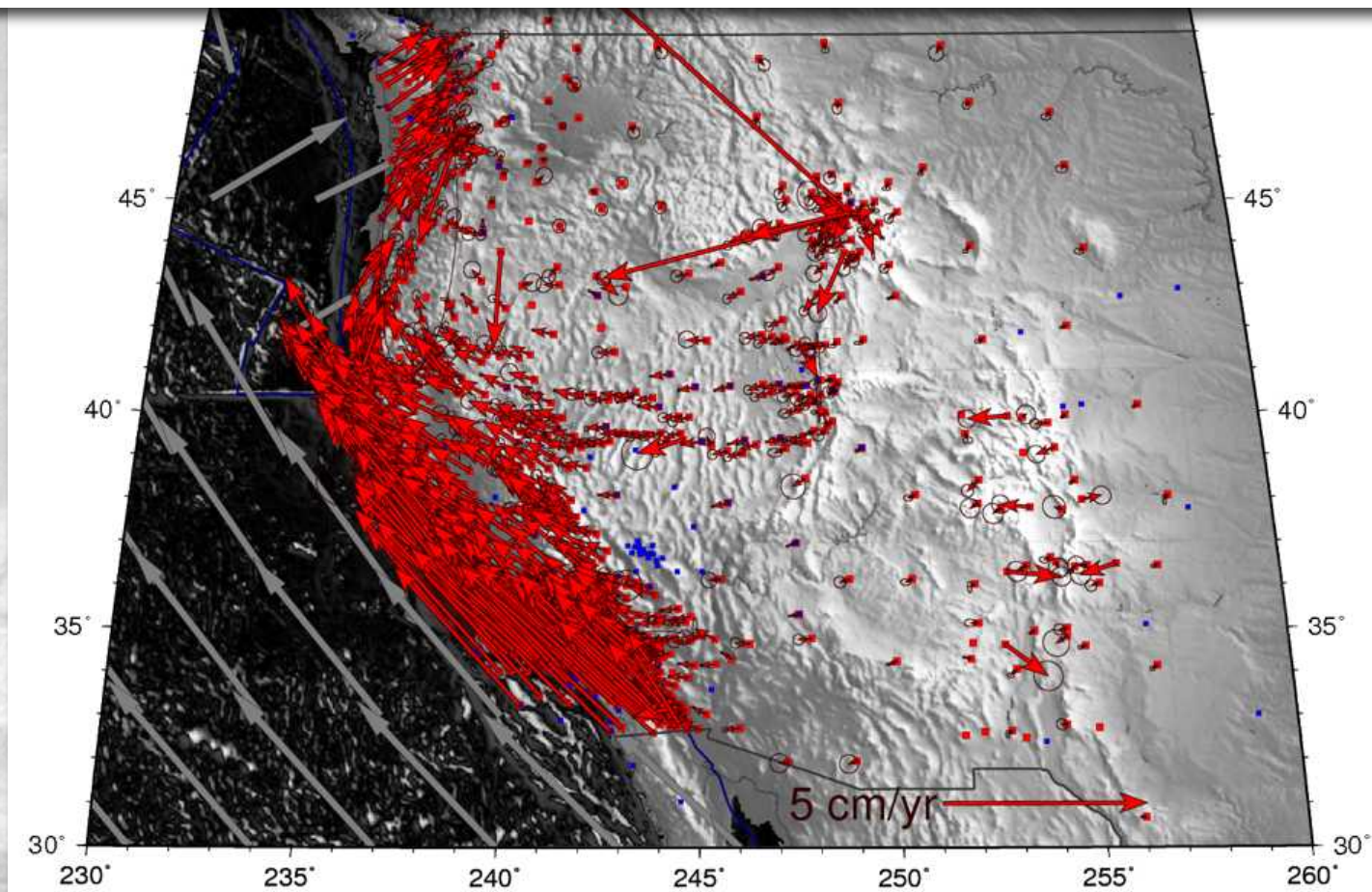


was ist langsam - was ist schnell ?

Momentane Geschwindigkeiten:

1 bis 10 cm / Jahr

$= 10^{-2} - 10^{-1} \text{ m} / 31'536'000 \text{ s} \approx 10^{-9} \text{ ms}^{-1}$



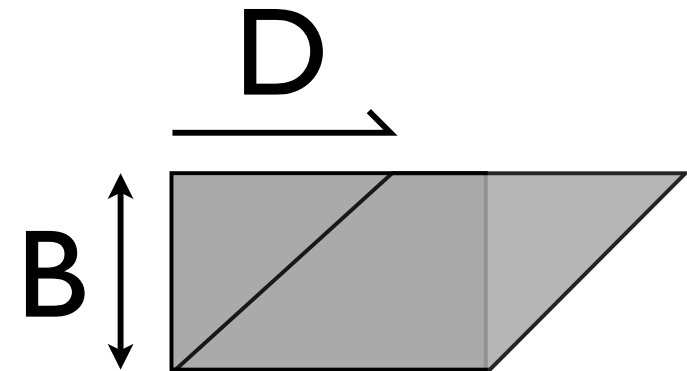
Relativbewegung an Plattengrenzen...

... führt zu Deformation



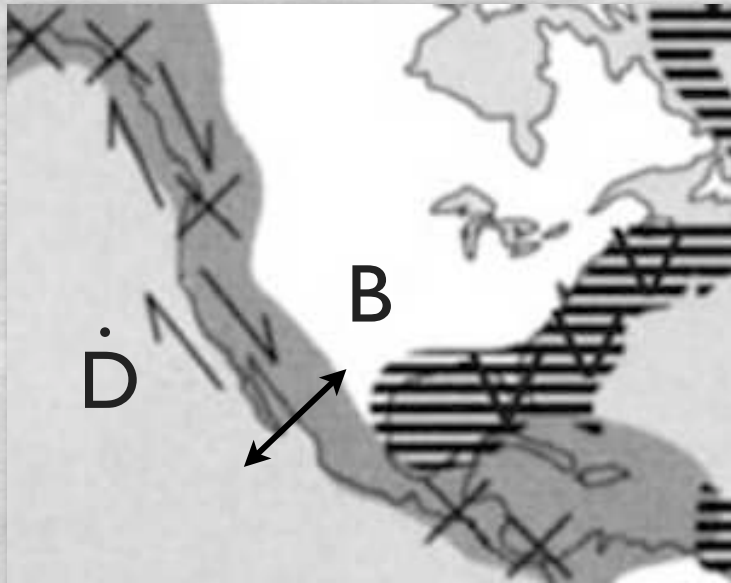
Scherverformung

$$\gamma = \frac{\text{Scherbetrag}}{\text{Breite}}$$

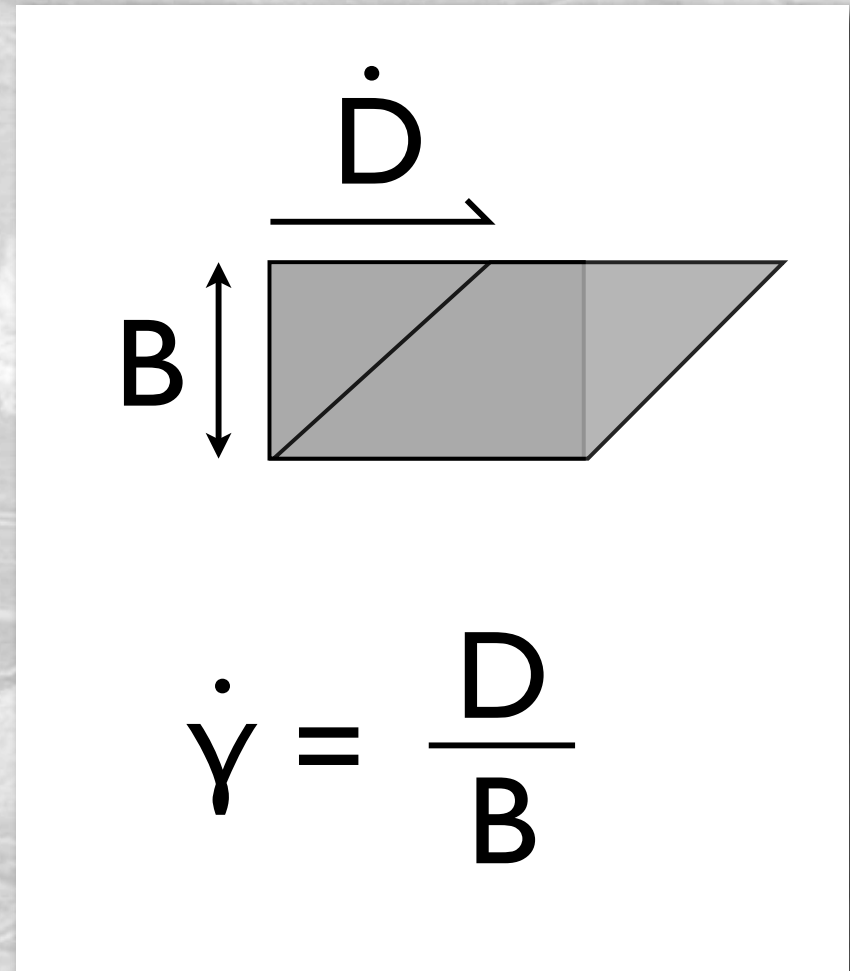


$$\gamma = \frac{D}{B}$$

Deformationsraten an Plattengrenzen



Deformationsraten
(strain rates)



Verformungsrate

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

$$\dot{\gamma} = \frac{D}{B}$$

geologische Deformationsraten

Plattenbewegung pro Jahr $D = 10 \text{ cm}$

Verformter Bereich $B = 100 \text{ km}$

Plattengeschwindigkeit:

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

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

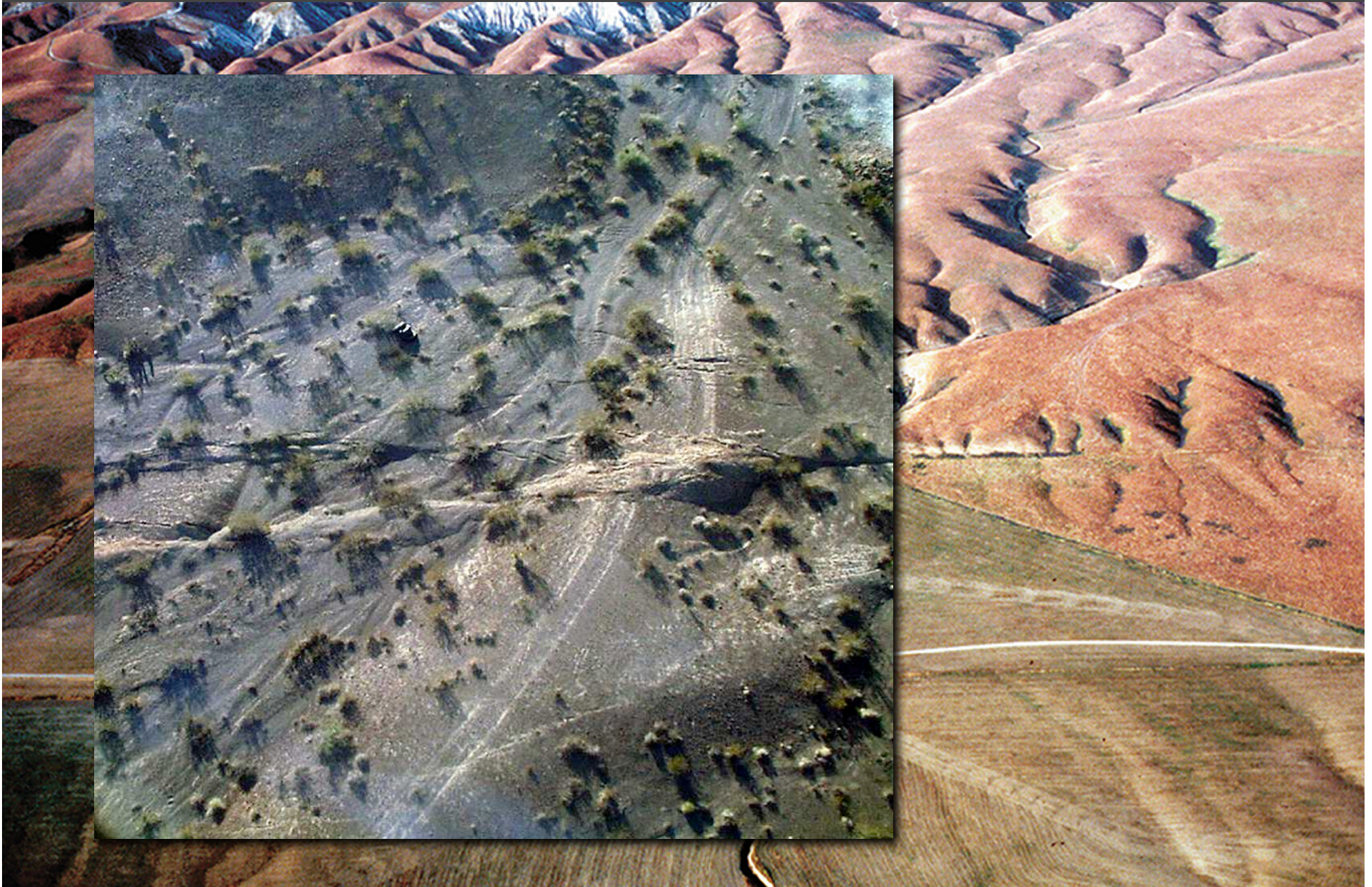
$$\dot{\gamma} = \dot{D} / B = 3 \cdot 10^{-9} / 10^5 \text{ m} = 3 \cdot 10^{-14} \text{ s}^{-1}$$

$$\dot{\gamma} \approx 10^{-14} \text{ s}^{-1}$$

Lokalisierung der Deformation



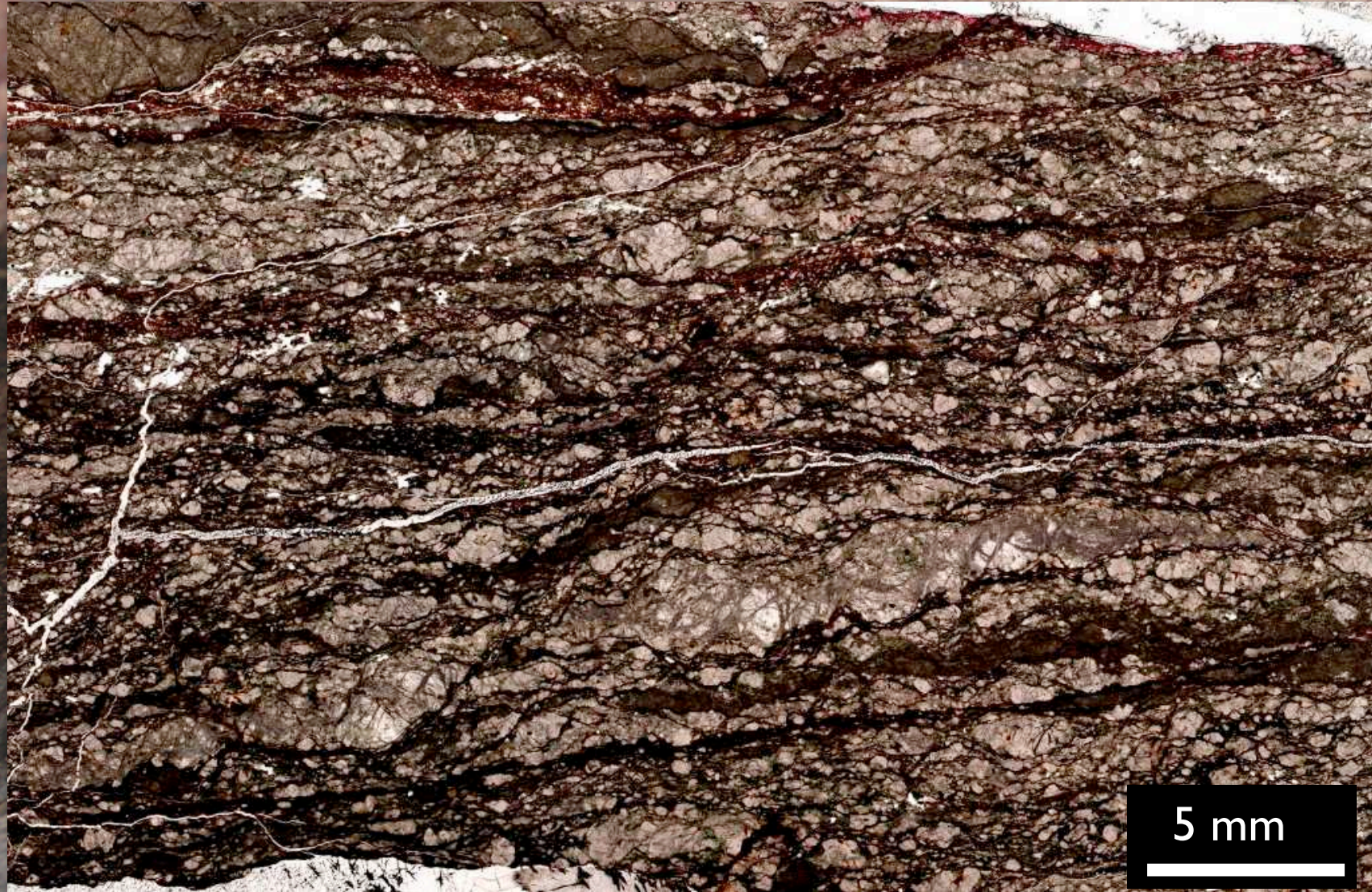
Lokalisierung der Deformation



vom grossen ins kleine

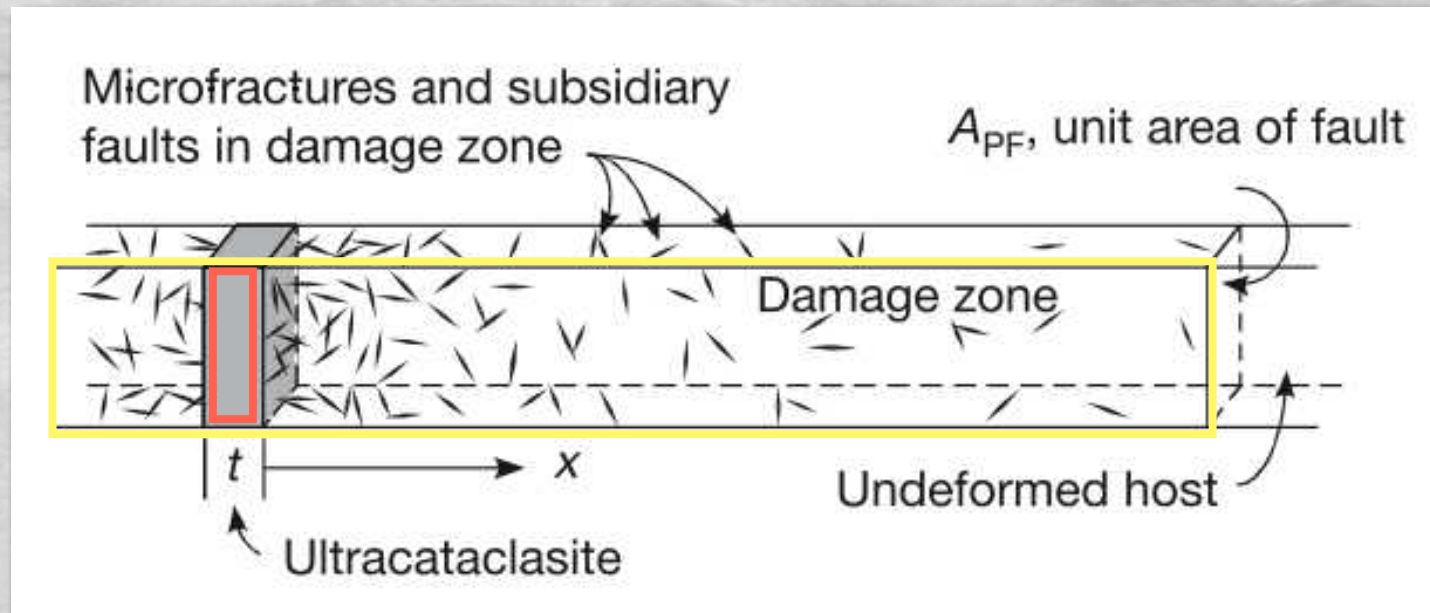


vom grossen ins kleine



örtlich lokalisiert...

$$\dot{\gamma} \approx 10^{-14} \text{ s}^{-1}$$



100km → 100m
(Faktor 10³)

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

100km → 1mm
(Faktor 10⁸)

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

... und zeitlich lokalisiert

bei konstanter Plattengeschwindigkeit:

$$\dot{D} = D / t = 3 \text{ cm / Jahr}$$

Erdbeben (stick-slip):

in 700 Jahren

$$700 \cdot 3 \text{ cm} = 21 \text{ m Versatz}$$

\approx Magnitude 7-8 Erdbeben

Entstehung der Erde

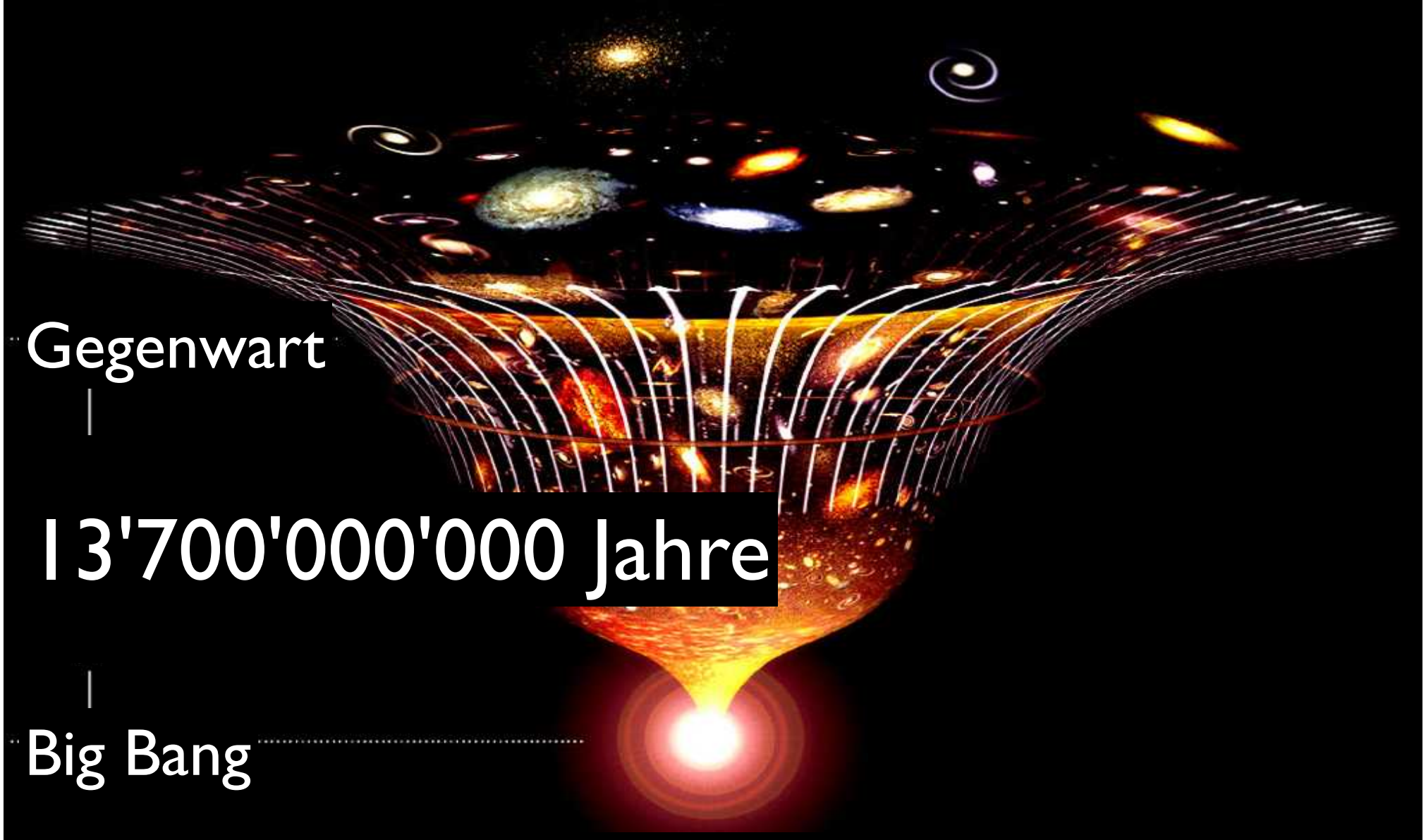
... vom big bang bis heute

Gegenwart



13'700'000'000 Jahre

Big Bang



Zeitliche Dimensionen

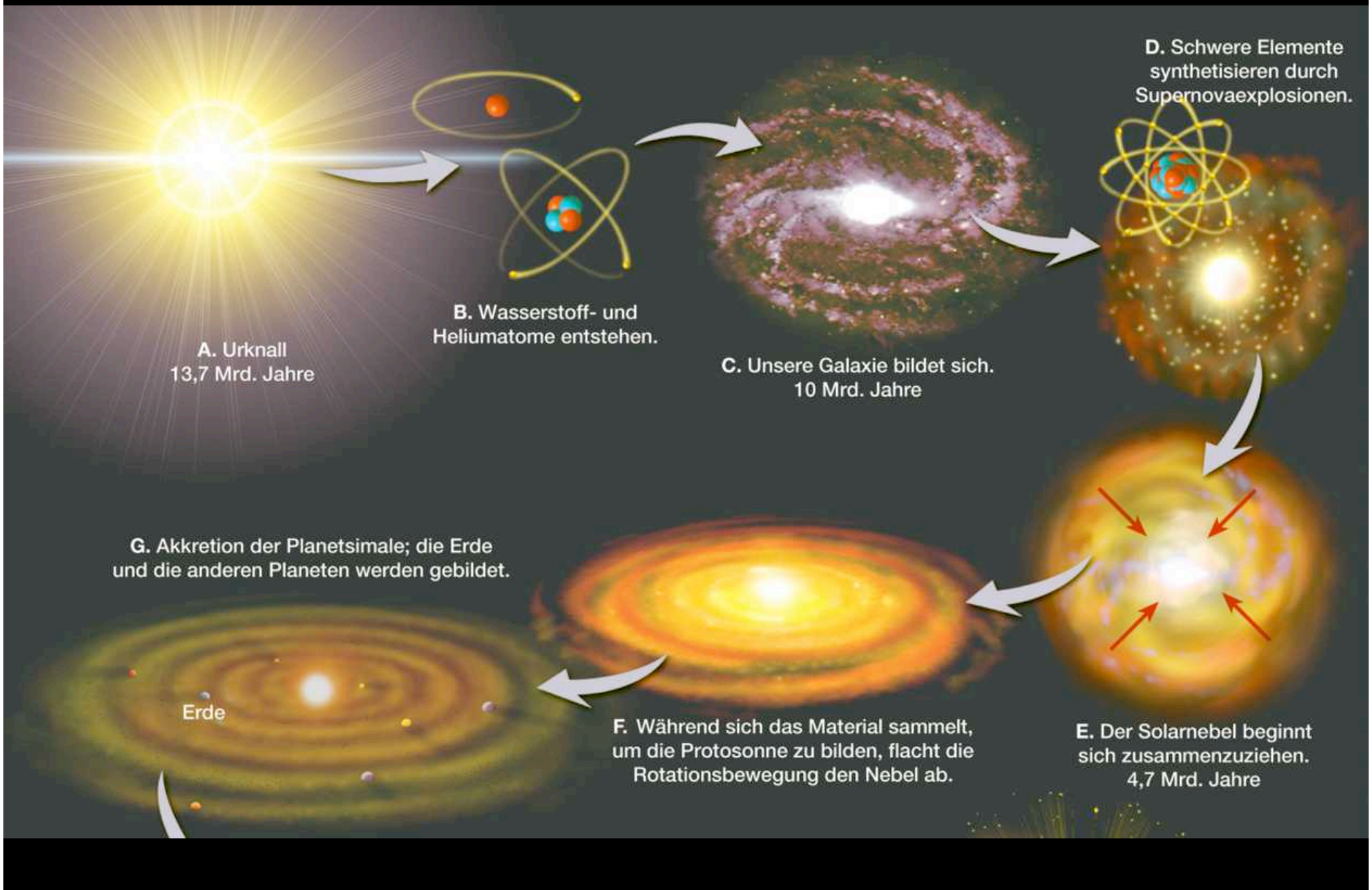
Gegenwart

13.7 Ga

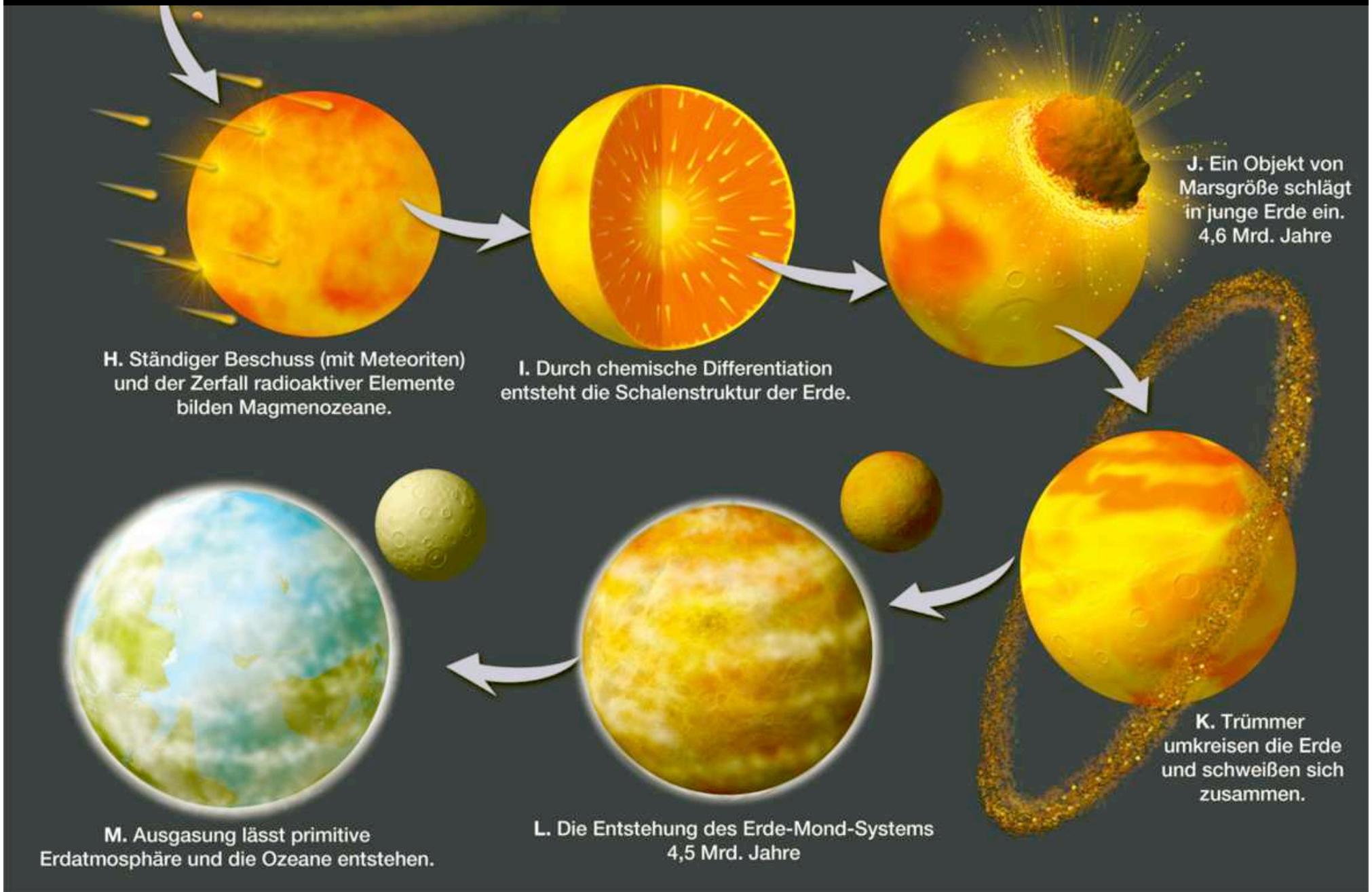
Big Bang

			Jahr
			a
kilo	1'000	$1 \cdot 10^3$	
mega	1'000'000	$1 \cdot 10^6$	Ma
giga	1'000'000'000	$1 \cdot 10^9$	Ga

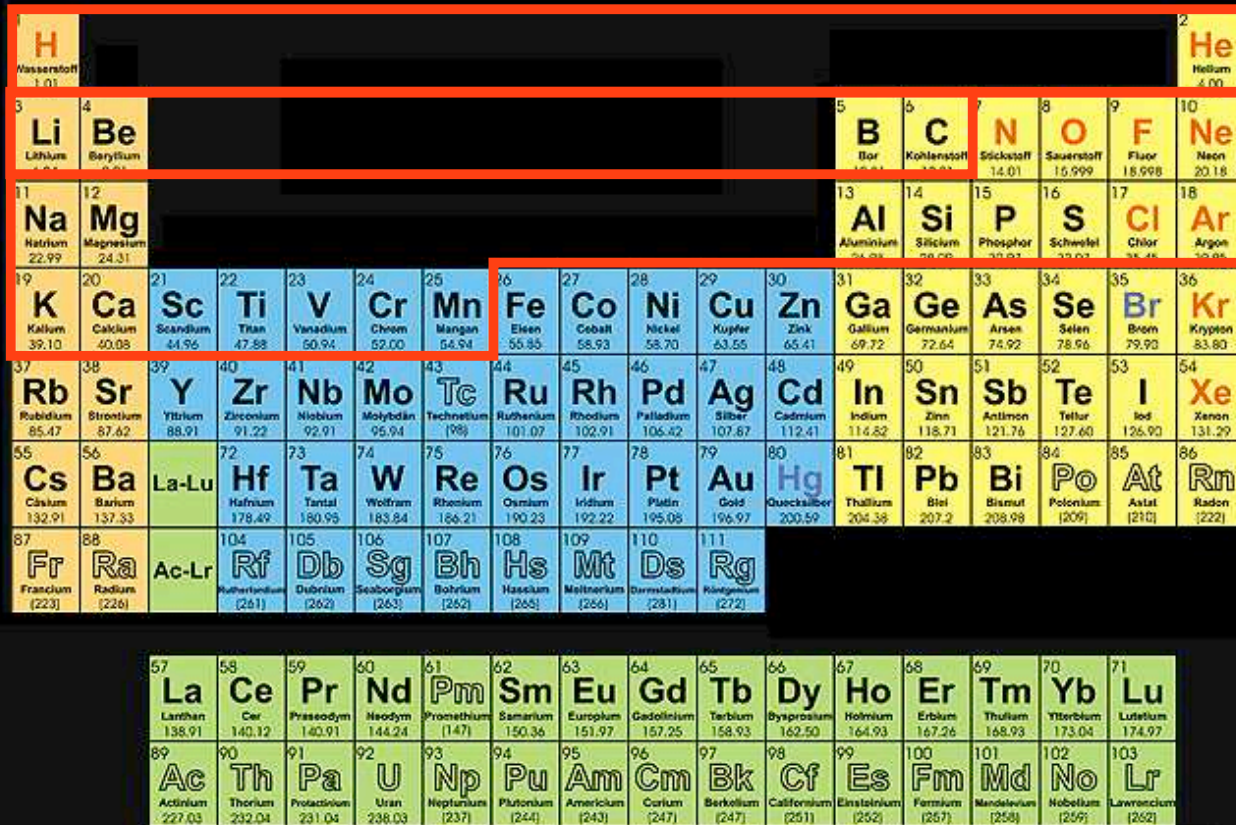
Entstehung des Sonnensystems



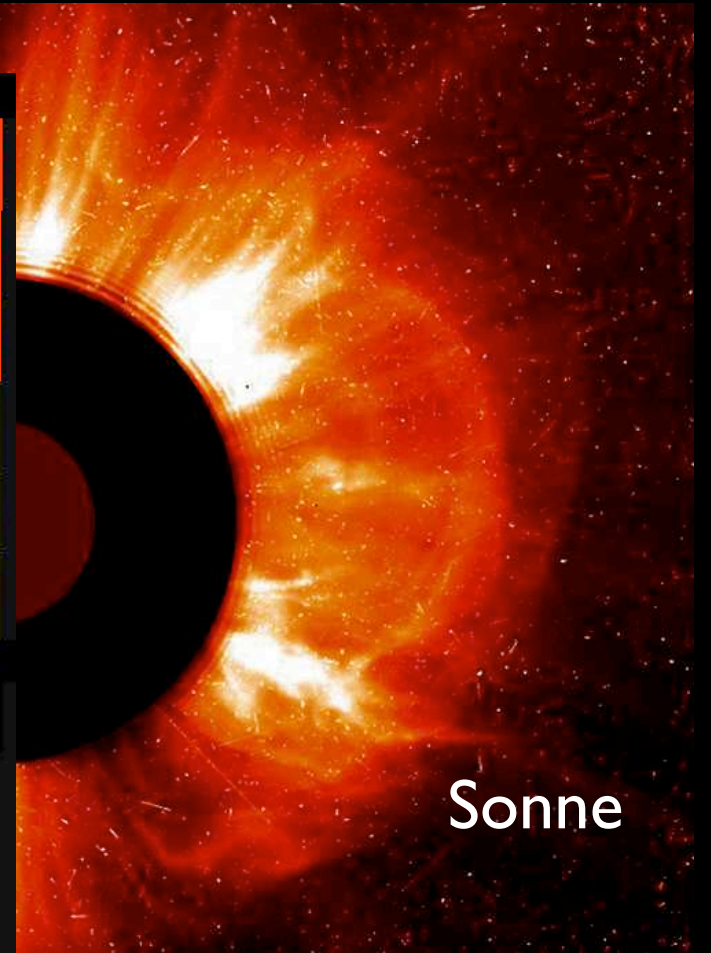
Entstehung der Erde



Entstehung des Universums

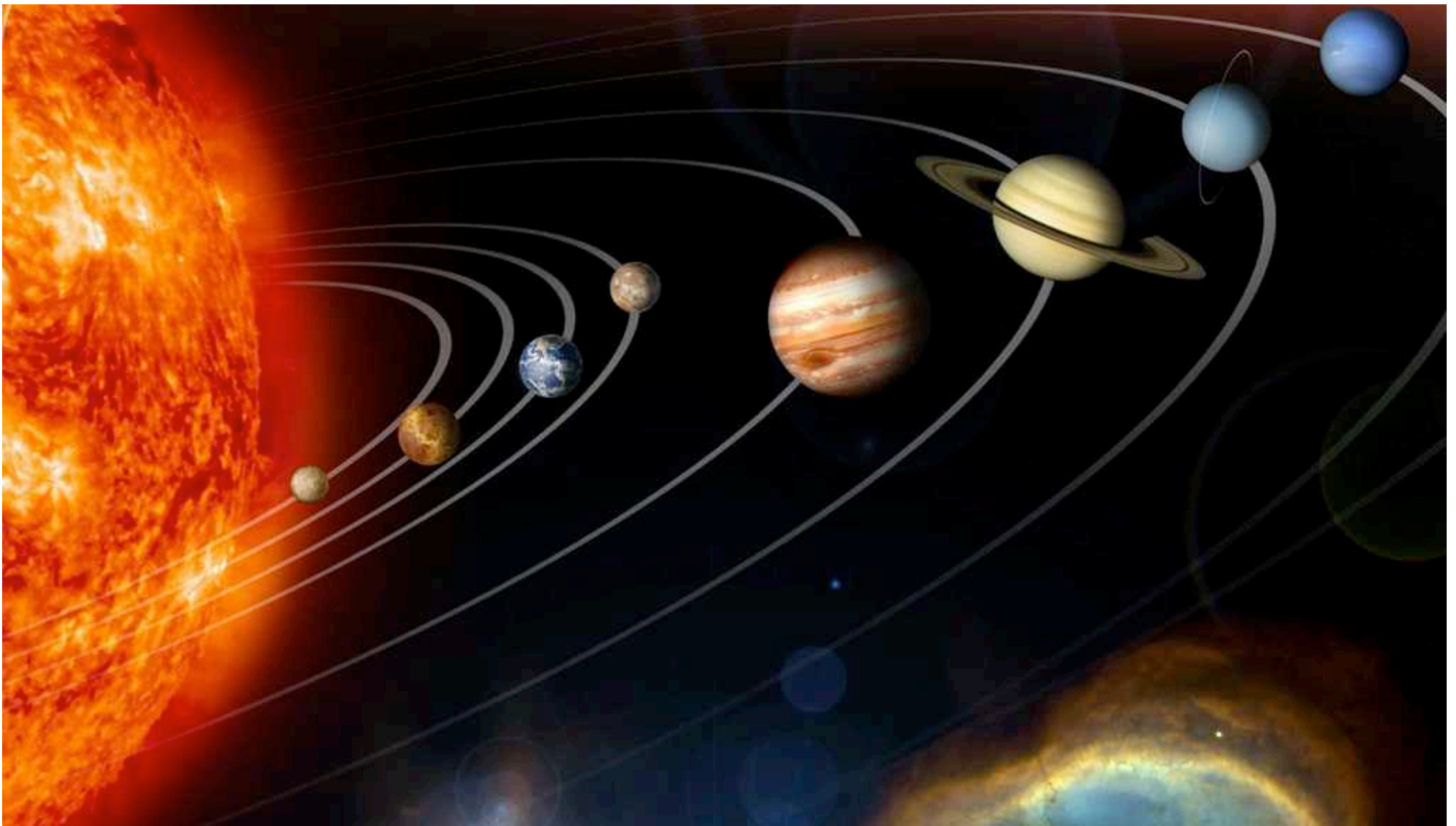


1 H Wasserstoff 1.01																	2 He Helium 4.00															
3 Li Lithium 6.94	4 Be Beryllium 9.01											5 B Bor 10.81	6 C Kohlenstoff 12.01	7 N Stickstoff 14.01	8 O Sauerstoff 15.999	9 F Fluor 18.998	10 Ne Neon 20.18															
11 Na Natrium 22.99	12 Mg Magnesium 24.31											13 Al Aluminium 26.98	14 Si Silicium 28.09	15 P Phosphor 30.97	16 S Schwefel 32.06	17 Cl Chlor 35.45	18 Ar Argon 39.95															
19 K Kalium 39.10	20 Ca Calcium 40.08	21 Sc Scandium 44.96	22 Ti Titan 47.88	23 V Vanadium 50.94	24 Cr Chrom 52.00	25 Mn Mangan 54.94	26 Fe Eisen 55.85	27 Co Cobalt 58.93	28 Ni Nickel 58.70	29 Cu Kupfer 63.55	30 Zn Zink 65.41	31 Ga Gallium 69.72	32 Ge Germanium 72.64	33 As Arsen 74.92	34 Se Selen 78.96	35 Br Brom 79.90	36 Kr Krypton 83.80															
37 Rb Rubidium 85.47	38 Sr Strontium 87.62	39 Y Yttrium 88.91	40 Zr Zirkon 91.22	41 Nb Niobium 92.91	42 Mo Molybdän 95.94	43 Tc Technetium (98)	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.91	46 Pd Palladium 106.42	47 Ag Silber 107.87	48 Cd Cadmium 112.41	49 In Indium 114.82	50 Sn Zinn 118.71	51 Sb Antimon 121.76	52 Te Tellur 127.60	53 I Jod 126.90	54 Xe Xenon 131.29															
55 Cs Cäsium 132.91	56 Ba Barium 137.33	La-Lu		72 Hf Hafnium 178.49	73 Ta Tantal 180.95	74 W Wolfram 183.84	75 Re Rhenium 186.21	76 Os Osmium 190.23	77 Ir Iridium 192.22	78 Pt Platin 195.08	79 Au Gold 196.97	80 Hg Quecksilber 200.59	81 Tl Thallium 204.38	82 Pb Blei 207.2	83 Bi Bismut 208.98	84 Po Polonium (209)	85 At Astat (211)	86 Rn Radon (222)														
87 Fr Francium (223)	88 Ra Radium (226)	Ac-Lr		104 Rf Rutherfordium (261)	105 Db Dubnium (262)	106 Sg Seaborgium (263)	107 Bh Bohrium (264)	108 Hs Hassium (265)	109 Mt Meitnerium (266)	110 Ds Darmstadtium (281)	111 Rg Roentgenium (272)																					
																		57 La Lanthan 138.91	58 Ce Cer 140.12	59 Pr Praseodym 140.91	60 Nd Neodym 144.24	61 Pm Promethium (147)	62 Sm Samarium 150.36	63 Eu Europium 151.97	64 Gd Gadolinium 157.25	65 Tb Terbium 158.93	66 Dy Dysprosium 162.50	67 Ho Holmium 164.93	68 Er Erbium 167.26	69 Tm Thulium 168.93	70 Yb Ytterbium 173.04	71 Lu Lutetium 174.97
																		89 Ac Actinium 227.03	90 Th Thorium 232.04	91 Pa Protactinium 231.04	92 U Uran 238.03	93 Np Neptunium (237)	94 Pu Plutonium (244)	95 Am Americium (243)	96 Cm Curium (247)	97 Bk Berkelium (247)	98 Cf Californium (251)	99 Es Einsteinium (252)	100 Fm Fermium (257)	101 Md Mendelevium (258)	102 No Nobelium (259)	103 Lr Lawrencium (262)



Sonne

Sterne wirken als "Element-Fabriken"
kleine Sterne (10 Ga): Elemente mit $N \leq 6$
grosse Sterne (20 Ma): Elemente mit $N < 26$



Merkur, Venus, Erde, Mars, Jupiter, Saturn, Uranus, Neptun, Pluto

"Mein Vater erklärt mir jeden Sonntag unsere neun Planeten"

Differenzierung

nach oben \Rightarrow Kruste:

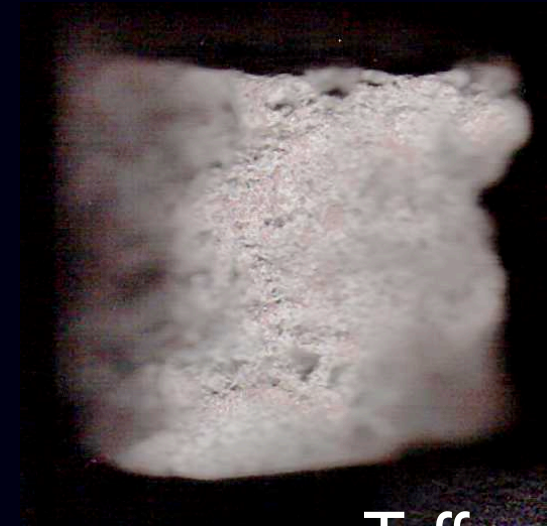
Si Al



Granodiorit



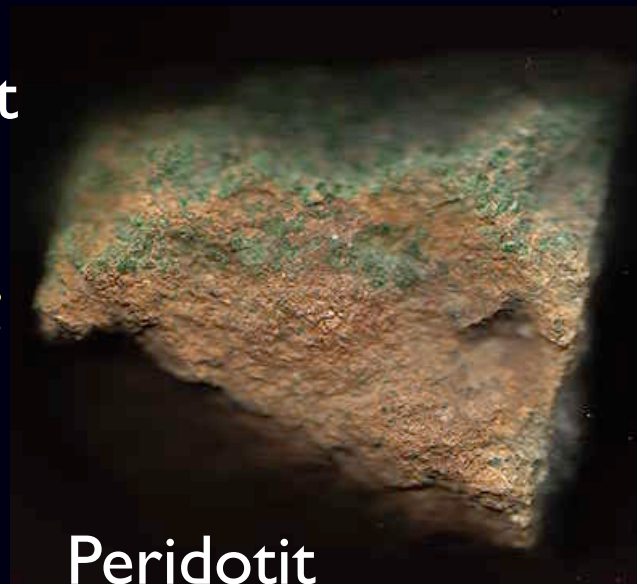
Granit



Tuff

nach unten \Rightarrow Mantel:

Fe Mg



Peridotit



Basalt

die Erde - ein spezieller Planet

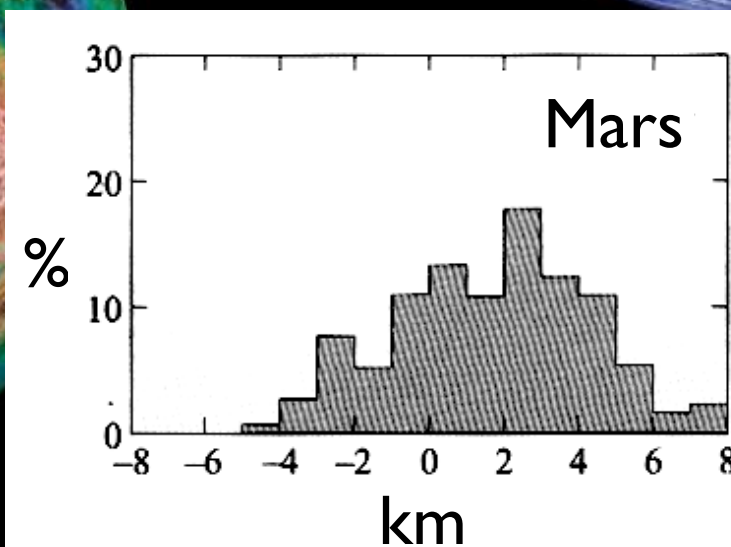
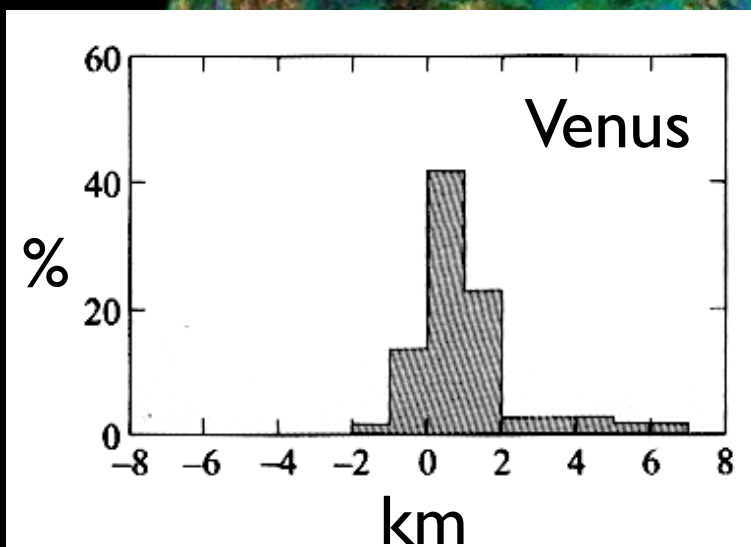
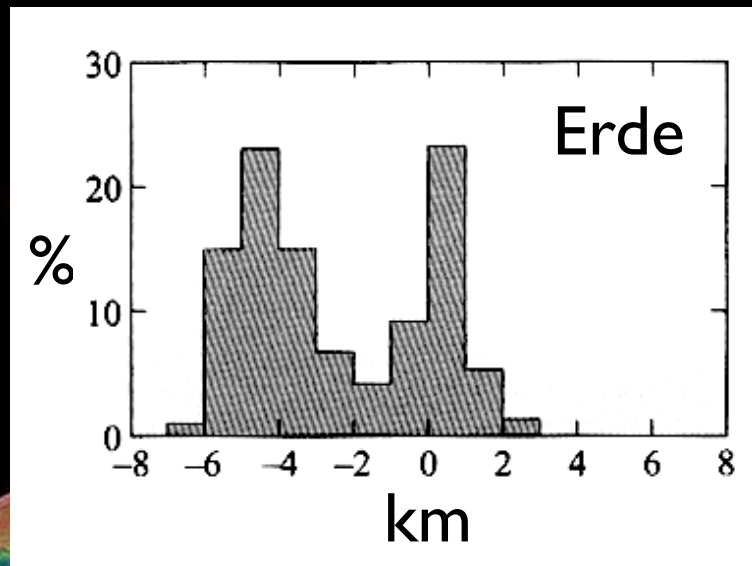


Mond



Erde

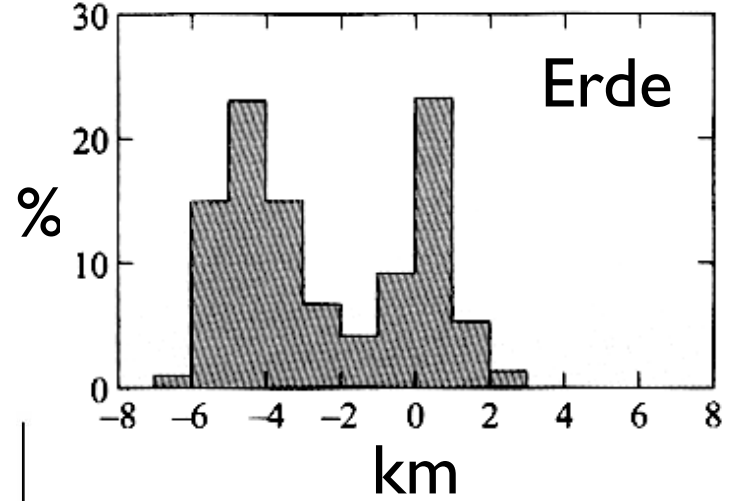
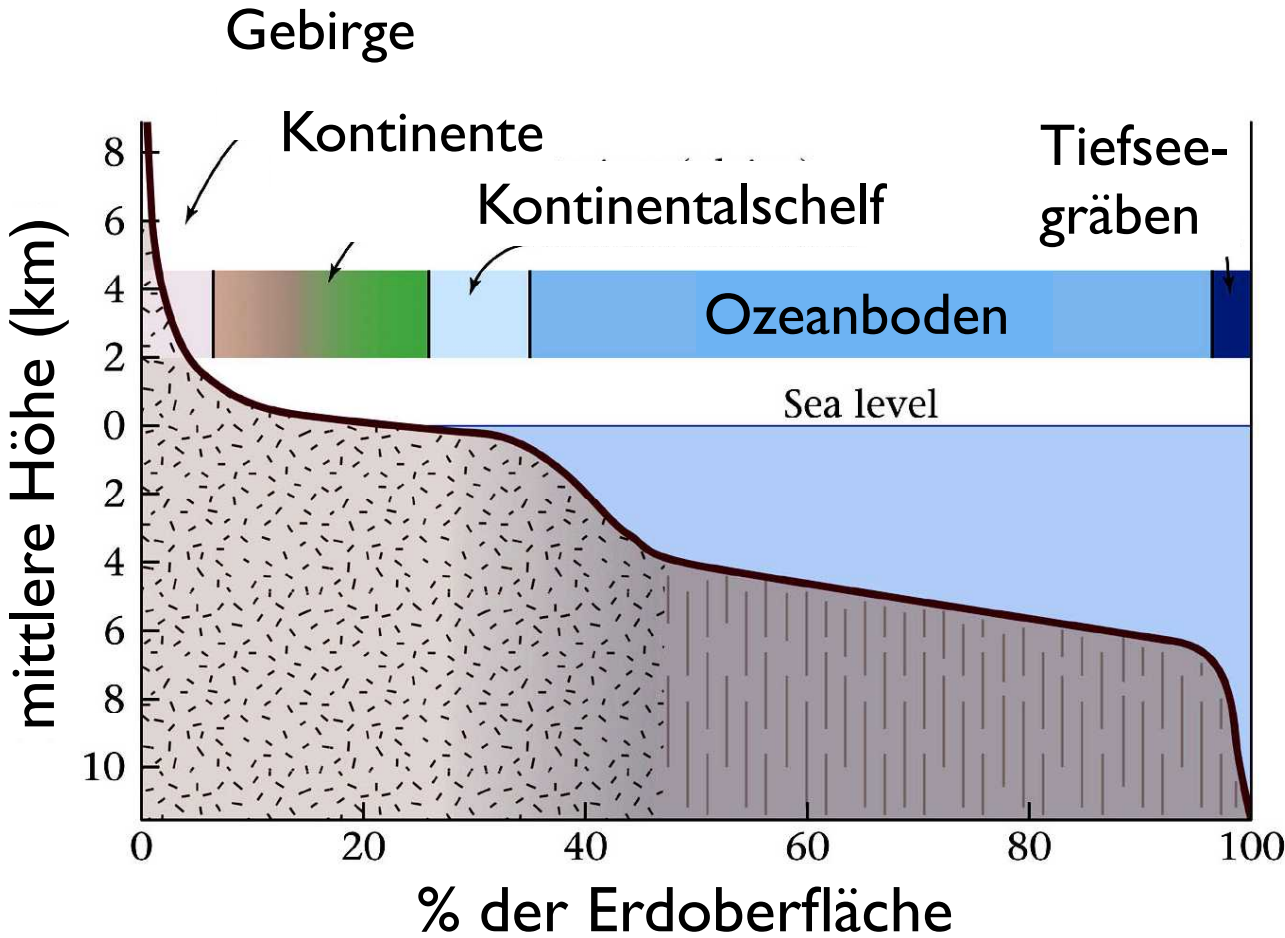
Merkur Venus Erde Mars



th

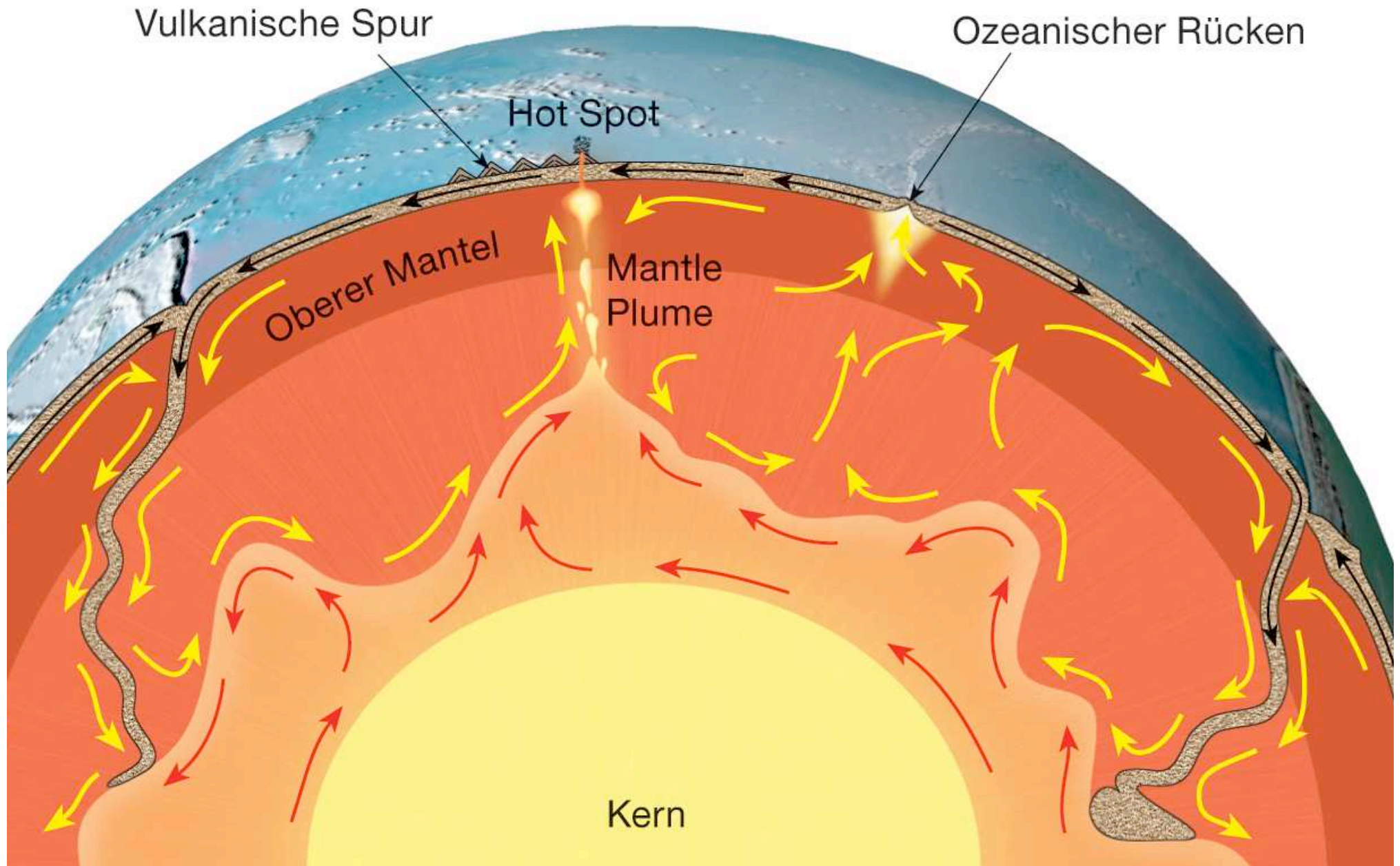
rs

Hypsometrisches Histogramm



2 Typen von Oberflächen:
- ozeanisch
- kontinental

Schalenbau der Erde

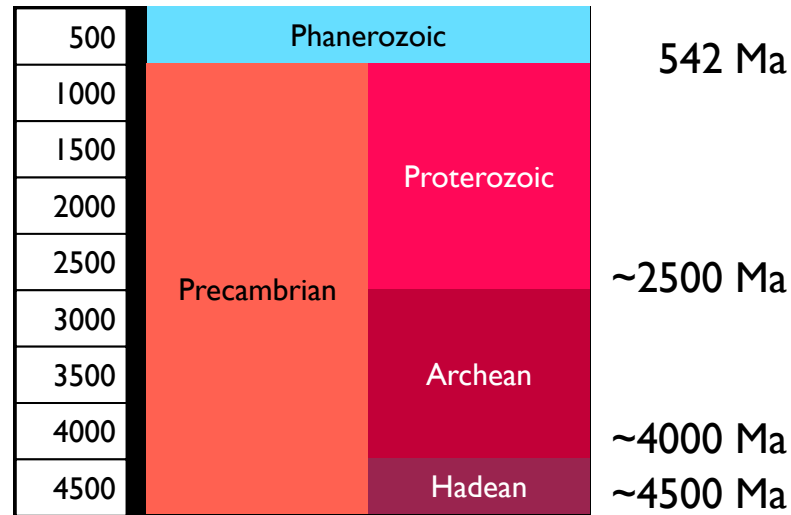


geologische Zeiträume

Geologische Zeiträume

Entstehung ...

... der Erde
~ 4.5 Ga



supernova

... des Universums
~ 13.7 Ga

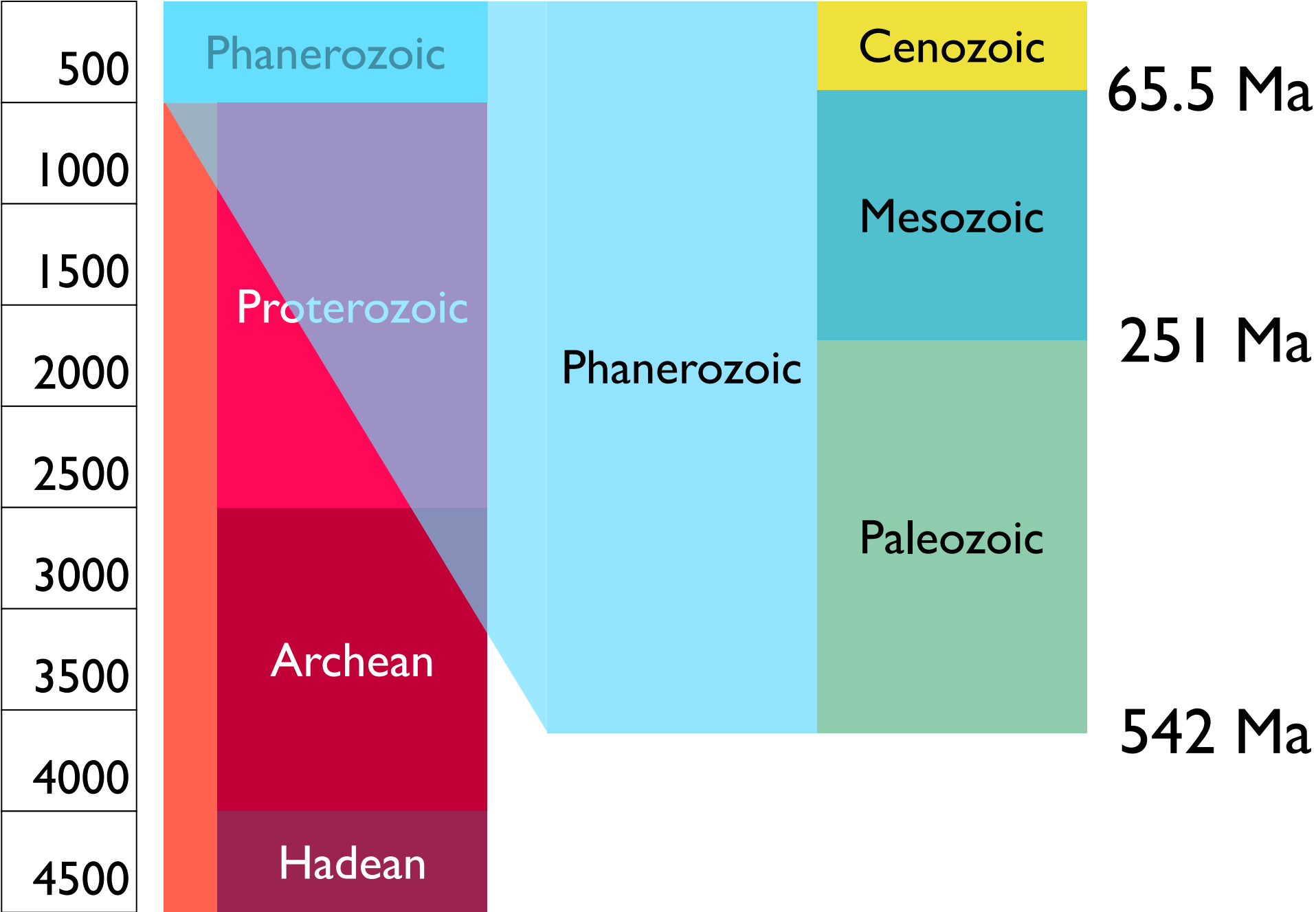
big bang

1 a 1 Jahr
1 Ma 10^6 Jahre
1 Ga 10^9 Jahre

1 a ~ $3 \cdot 10^7$ s

Äon

Ära (Zeitalter)



Stratigraphische Tabelle

Eonothem Era	Erathem Era	System Period	Series Epoch	Stage Age	Age Ma	GSSP
Phanerozoic	Cenozoic	Quaternary *	Holocene			
				Upper	0.0117	👉
			Pleistocene	"Ionian"	0.126	
				Calabrian	0.781	👉
		Pliocene	Gelasian	1.806	👉	
			Piacenzian	2.588	👉	
			Zanclean	3.600	👉	
		Neogene	Miocene	Messinian	5.332	👉
				Tortonian	7.246	👉
				Serravallian	11.608	👉
				Langhian	13.82	👉
				Burdigalian	15.97	👉
			Aquitanian	20.43	👉	
			Oligocene	Chattian	23.03	👉
	Rupelian			28.4 ± 0.1	👉	
	Priabonian			33.9 ± 0.1	👉	
	Bartonian			37.2 ± 0.1	👉	
	Lutetian	40.4 ± 0.2		👉		
	Paleogene	Eocene	Ypresian	48.6 ± 0.2	👉	
			Thanetian	55.8 ± 0.2	👉	
			Selandian	58.7 ± 0.2	👉	
			Danian	~ 61.1	👉	
		Paleocene	Maastrichtian	65.5 ± 0.3	👉	
			Campanian	70.6 ± 0.6	👉	
			Santonian	83.5 ± 0.7	👉	
			Coniacian	85.8 ± 0.7	👉	
	Mesozoic	Cretaceous	Turonian	~ 88.6	👉	
			Cenomanian	93.6 ± 0.8	👉	
			Albian	99.6 ± 0.9	👉	
			Aptian	112.0 ± 1.0	👉	
			Barremian	125.0 ± 1.0	👉	
		Upper	Hauterivian	130.0 ± 1.5	👉	
Valanginian			~ 133.9	👉		
Berriasian			140.2 ± 3.0	👉		
			145.5 ± 4.0	👉		

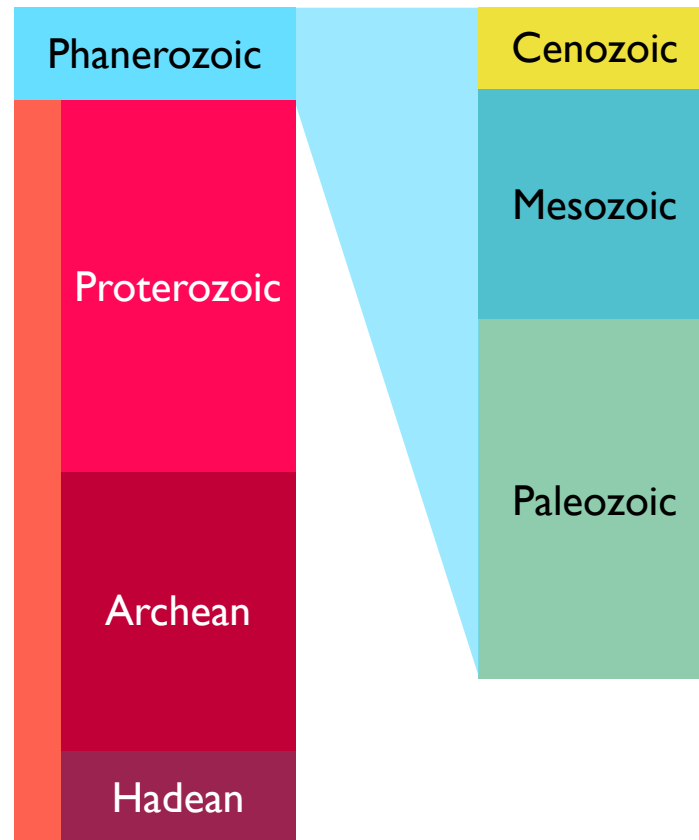
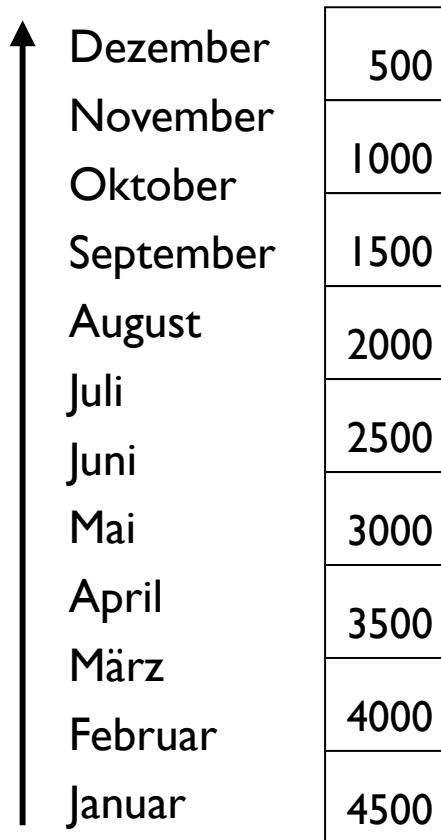
Eonothem Era	Erathem Era	System Period	Series Epoch	Stage Age	Age Ma	GSSP	
Phanerozoic	Mesozoic	Jurassic	Upper	Tithonian	145.5 ± 4.0	👉	
				Kimmeridgian	150.8 ± 4.0	👉	
				Oxfordian	~ 155.6	👉	
			Middle	Callovian	161.2 ± 4.0	👉	
				Bathonian	164.7 ± 4.0	👉	
				Bajocian	167.7 ± 3.5	👉	
		Lower	Aalenian	171.6 ± 3.0	👉		
			Toarcian	175.6 ± 2.0	👉		
			Pliensbachian	183.0 ± 1.5	👉		
			Sinemurian	189.6 ± 1.5	👉		
			Hettangian	196.5 ± 1.0	👉		
		Triassic	Upper	Rhaetian	199.6 ± 0.6	👉	
				Norian	203.6 ± 1.5	👉	
				Carian	216.5 ± 2.0	👉	
	Middle		Ladinian	~ 228.7	👉		
			Anisian	237.0 ± 2.0	👉		
	Lower		Olenekian	~ 245.9	👉		
	Induan	Induan	~ 249.5	👉			
	Paleozoic	Permian	Lopingian	Changhsingian	251.0 ± 0.4	👉	
				Wuchiapingian	253.8 ± 0.7	👉	
				Capitanian	260.4 ± 0.7	👉	
			Guadalupian	Wordian	265.8 ± 0.7	👉	
				Roadian	268.0 ± 0.7	👉	
				Kungurian	270.6 ± 0.7	👉	
		Cisuralian	Artinskian	275.6 ± 0.7	👉		
			Sakmarian	284.4 ± 0.7	👉		
			Sakmarian	294.6 ± 0.8	👉		
			Asselian	299.0 ± 0.8	👉		
			Gzhelian	299.0 ± 0.8	👉		
		Carboniferous	Pennsylvanian	Upper	Kasimovian	303.4 ± 0.9	👉
					Moscovian	307.2 ± 1.0	👉
				Lower	Bashkirian	311.7 ± 1.1	👉
Serpukhovian	318.1 ± 1.3				👉		
Mississippian	Upper		Visean	328.3 ± 1.6	👉		
			Tournaisian	345.3 ± 2.1	👉		
	Lower		Tournaisian	359.2 ± 2.5	👉		

Eonothem Era	Erathem Era	System Period	Series Epoch	Stage Age	Age Ma	GSSP
Phanerozoic	Paleozoic	Devonian	Upper	Famennian	359.2 ± 2.5	👉
				Frasnian	374.5 ± 2.6	👉
			Middle	Givetian	385.3 ± 2.6	👉
				Eifelian	391.8 ± 2.7	👉
			Lower	Emsian	397.5 ± 2.7	👉
				Pragian	407.0 ± 2.8	👉
		Silurian	Pridoli	Lochkovian	411.2 ± 2.8	👉
				Ludlow	416.0 ± 2.8	👉
			Ludlow	Ludfordian	418.7 ± 2.7	👉
				Gorstian	421.3 ± 2.6	👉
			Wenlock	Homerian	422.9 ± 2.5	👉
				Sheinwoodian	426.2 ± 2.4	👉
			Llandovery	Telychian	428.2 ± 2.3	👉
				Aeronian	436.0 ± 1.9	👉
	Ordovician		Upper	Rhuddanian	439.0 ± 1.8	👉
				Hirnantian	443.7 ± 1.5	👉
		Middle	Katian	445.6 ± 1.5	👉	
			Sandbian	455.8 ± 1.6	👉	
		Lower	Darriwilian	460.9 ± 1.6	👉	
			Dapingian	468.1 ± 1.6	👉	
		Floian	Floian	471.8 ± 1.6	👉	
		Tremadocian	Tremadocian	478.6 ± 1.7	👉	
	Cambrian	Furongian	Stage 10	488.3 ± 1.7	👉	
			Stage 9	~ 492 *	👉	
			Paibian	~ 496 *	👉	
			Stage 8	~ 499	👉	
			Guzhangian	~ 503	👉	
			Drumian	~ 506.5	👉	
			Stage 5	~ 510 *	👉	
			Stage 4	~ 515 *	👉	
			Stage 3	~ 521 *	👉	
			Stage 2	~ 528 *	👉	
Terreneuvian		Fortunian	542.0 ± 1.0	👉		

Eonothem Era	Erathem Era	System Period	Age Ma	GSSP		
Precambrian	Proterozoic	Ediacaran	542	👉		
			Neo-proterozoic	Cryogenian	~ 635	👉
				Tonian	850	👉
		Meso-proterozoic	Stenian	1000	👉	
			Ectasian	1200	👉	
			Calymnian	1400	👉	
	Paleo-proterozoic	Statherian	Orosirian	1600	👉	
			Rhyacian	1800	👉	
			Siderian	2050	👉	
	Archean	Neoarchean	2300	👉		
			2500	👉		
		Mesoarchean	2800	👉		
			3200	👉		
		Paleoarchean	3600	👉		
			4000	👉		
	Hadean (informal)	~ 4600	👉			

← Phanerozoikum ~ 500 Ma →

Präkambrium ~ 4000 Ma

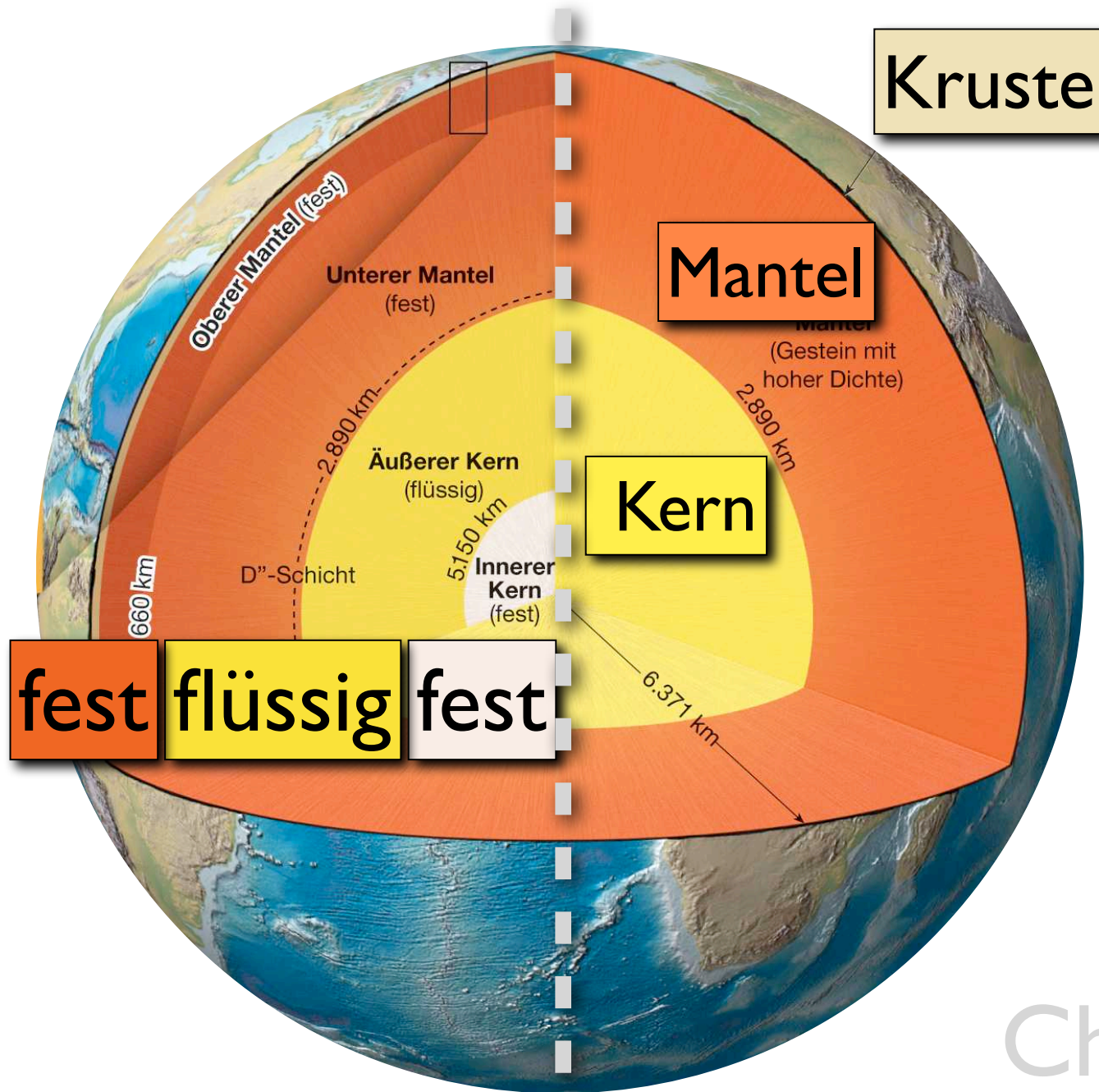


1 Jahr = 4.5 Ga

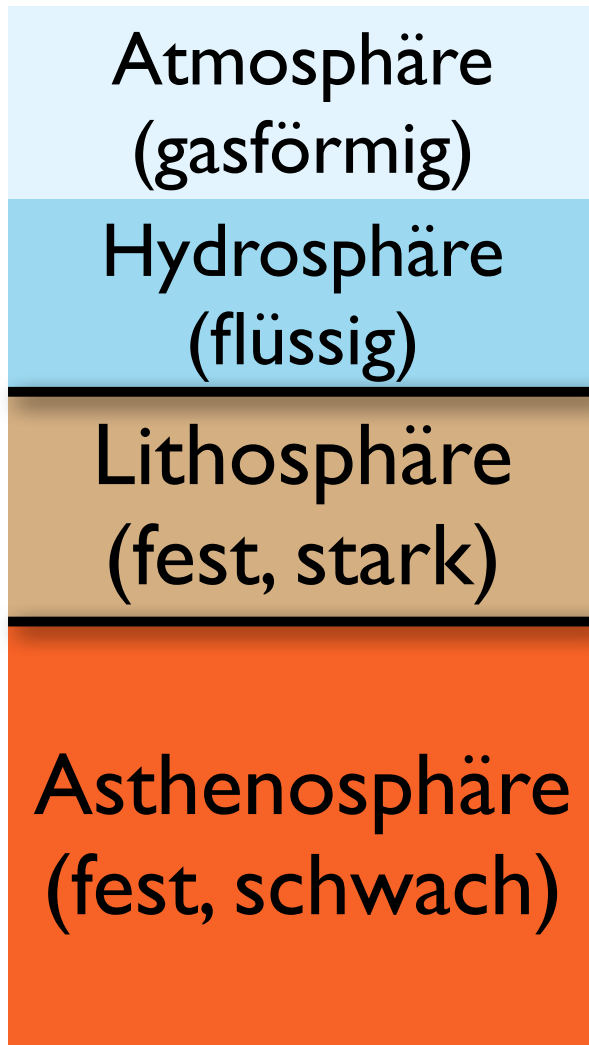
-
- 31.12. 23:59:59 James Hutton - moderne Geologie
 - 31.12. 23:59:57 Kolumbus entdeckt Amerika
 - 31.12. 23:59:45 Römisches Reich (dauert 5 s ...)
 - 31.12. abend: Menschen-ähnliche Wesen
 - Mitte Dezember: Dinosauriere
 - Ende November: Landpflanzen, -tiere
 - Anfang Mai: Leben im Wasser
 - Mitte März: ältestes Gestein

Schalenbau

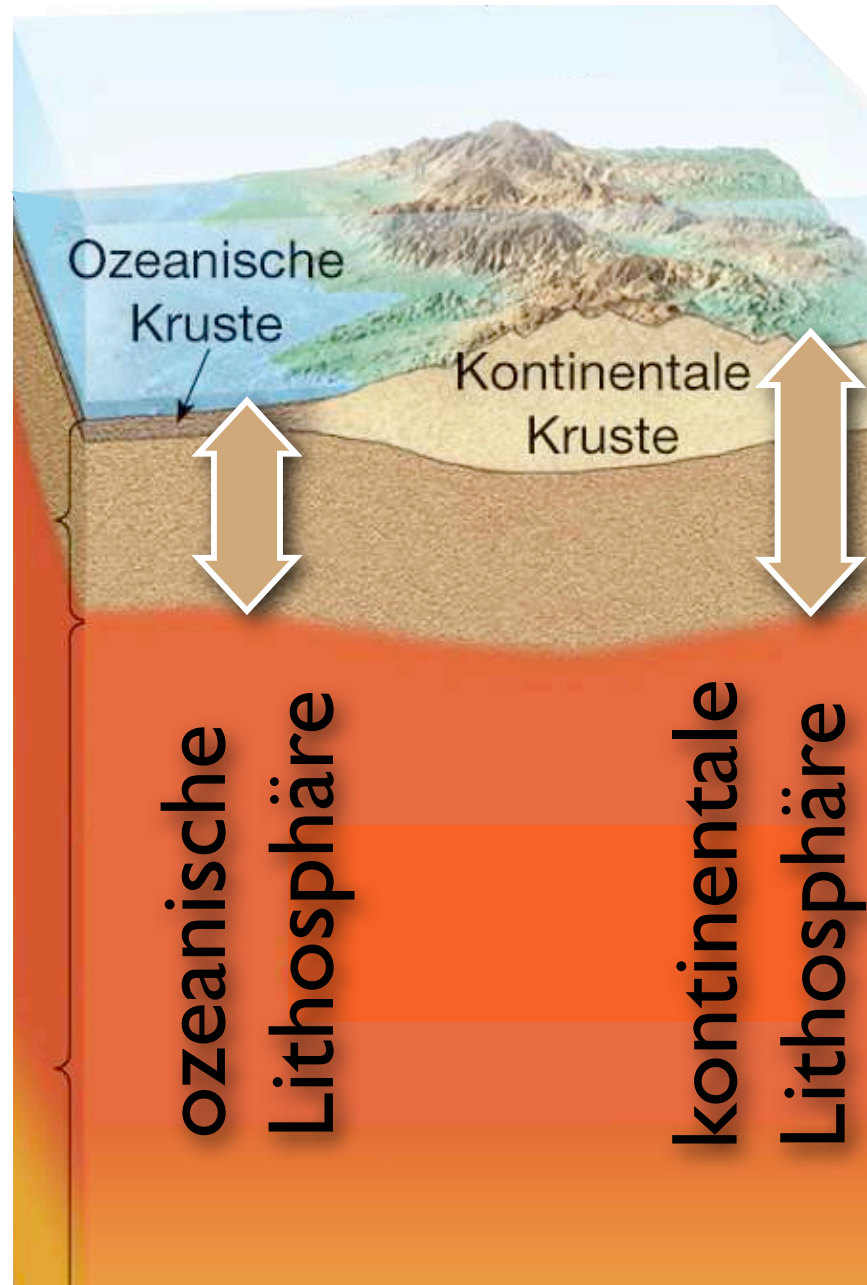
Schalenbau der Erde



Schalenbau der Erde



Physik

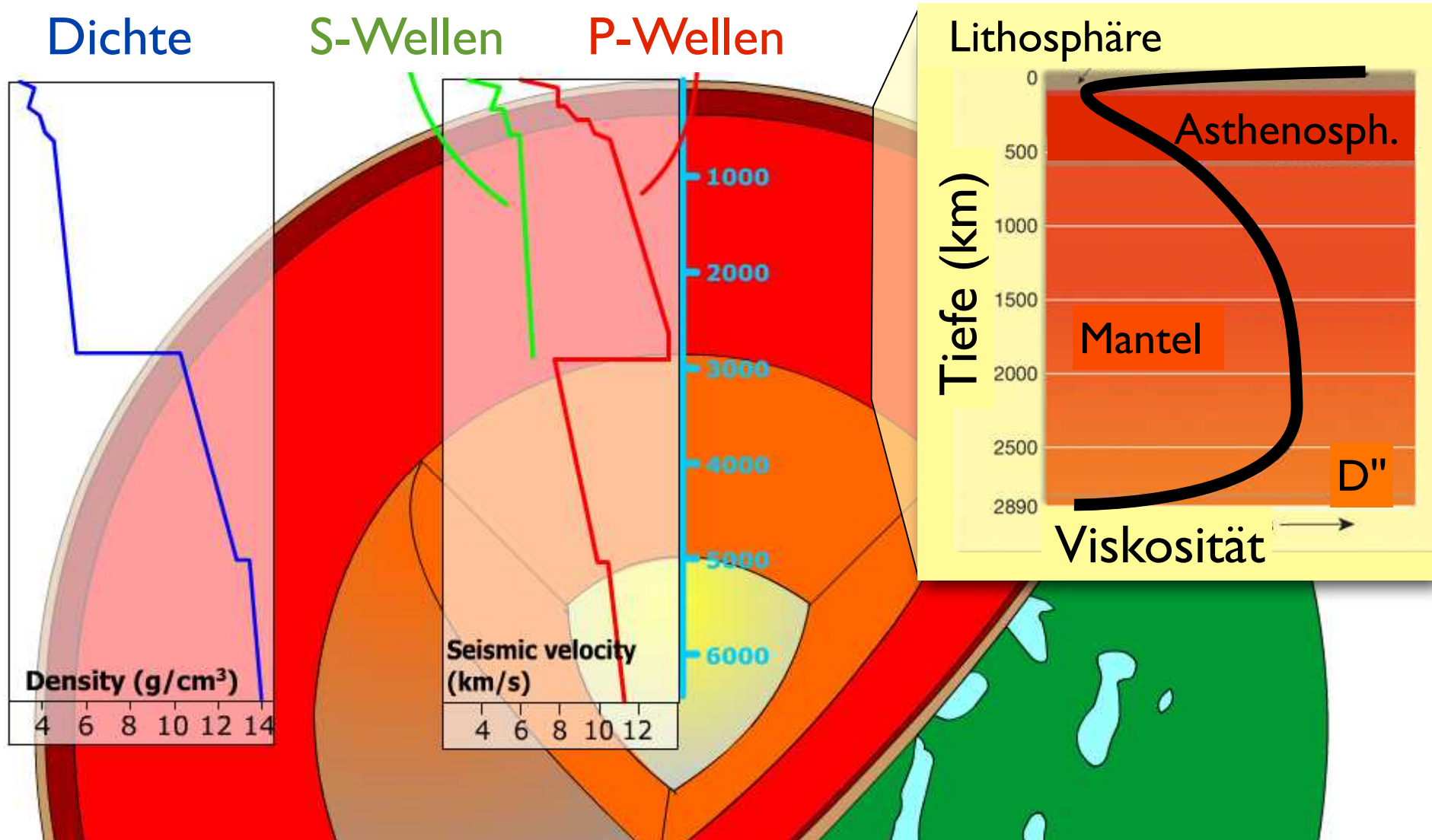


Chemie

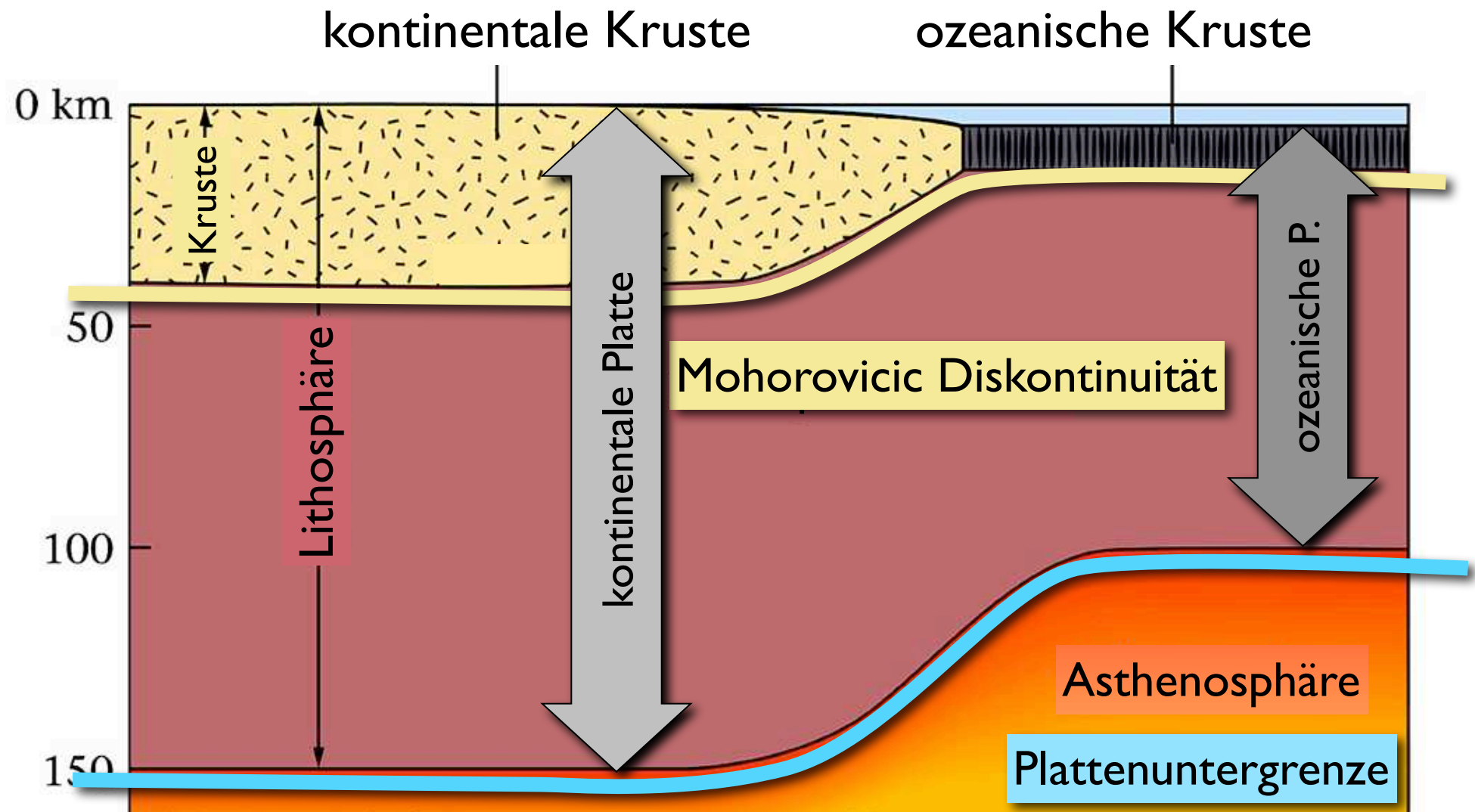
Schalenbau - Zusammensetzung

	Zusammen- setzung	Dicke	Dichte (kgm ⁻³)	Alter
Kruste				
- kontinental	Granodiorit	35 - 40 km (up to 70 km)	2700	≤ 4 Ga
- ozeanisch	Basalt	~7 km	3000	≤ 180 Ma
Mantel	Peridotit (Fe-Mg-Silikat)	82 % (Erdvolumen)	3000-5000	± Erde (4.5 Ga)
Kern	Fe-Ni Legierung		11'000	± Erde (4.5 Ga)

Physikalische Eigenschaften



das plattentektonische Modell



Platten sind Lithosphärenplatten:
bestehen aus Kruste und Mantel - haben Festigkeit

Spröd - duktil

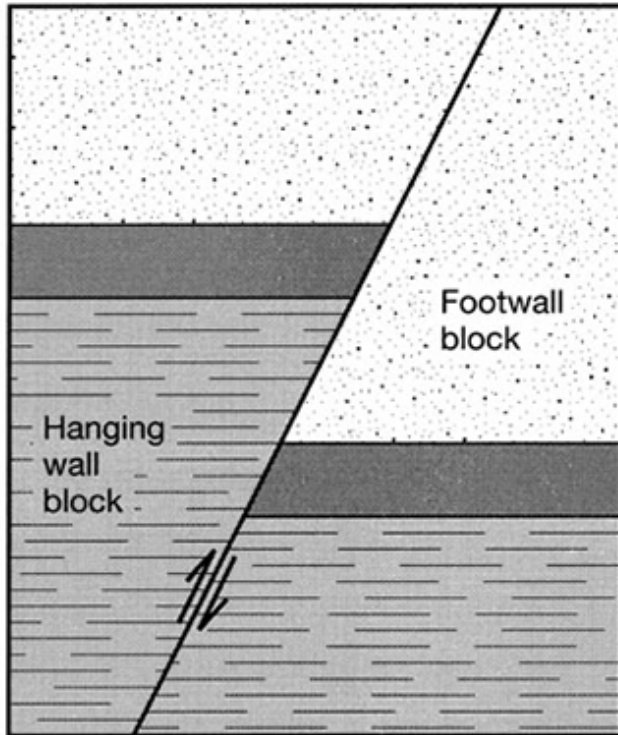
Spröd:
Bruch

Duktil:
Fließen

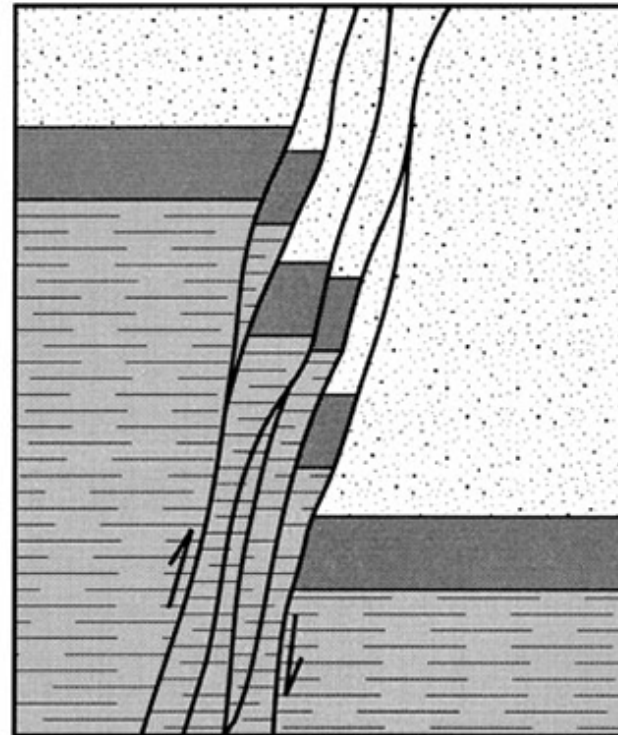
geflossene Kalkplatte
(Geologisches Institut
Universität Toulouse)



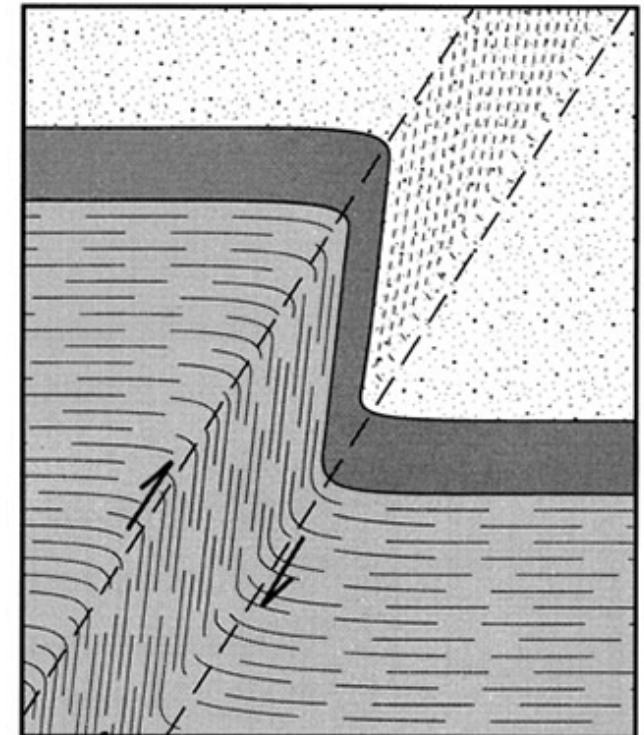
Spröd - Duktil Übergang



Bruch

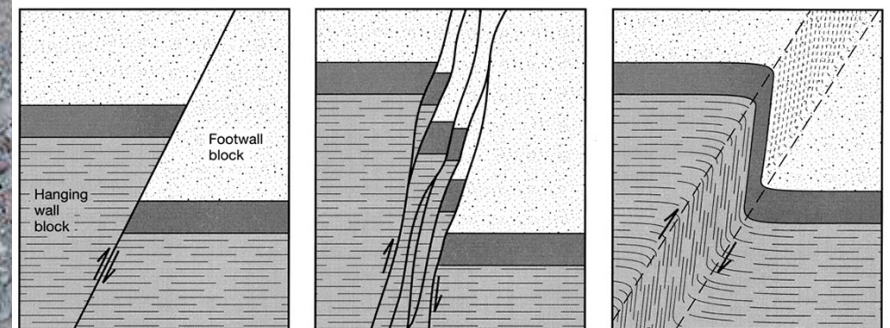
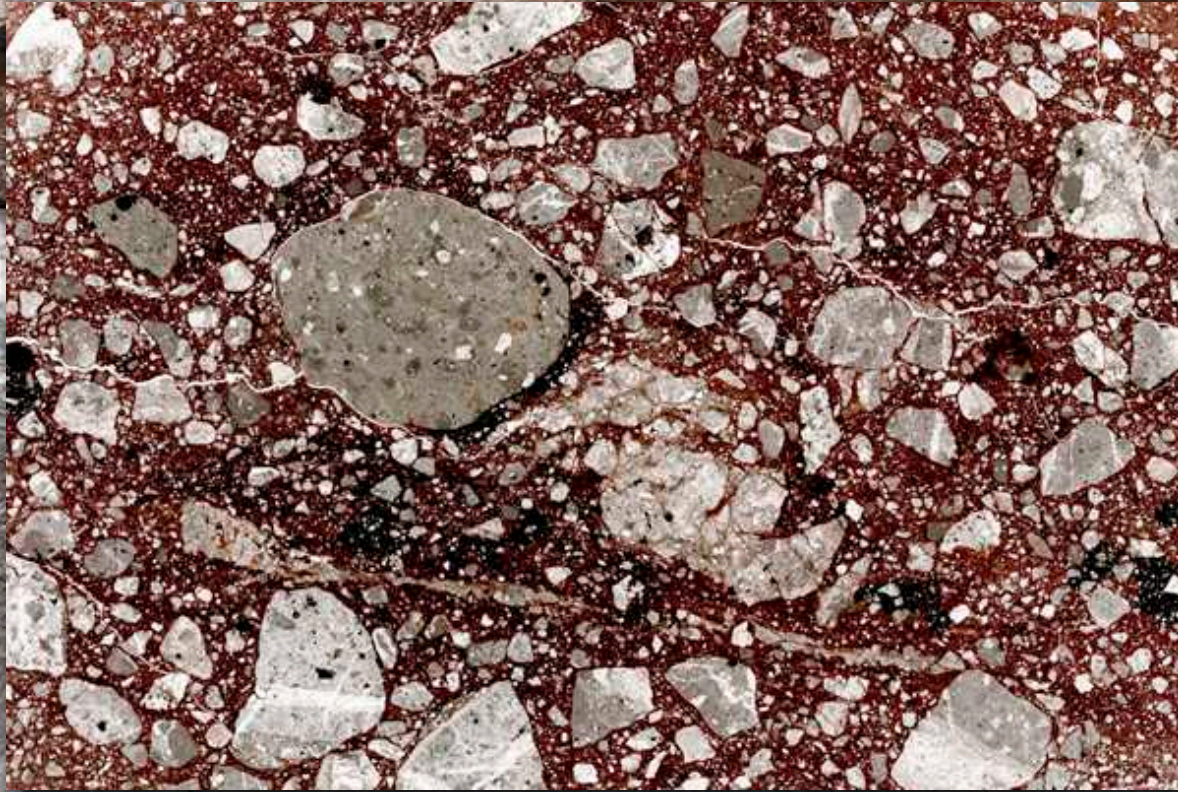


Bruchzone



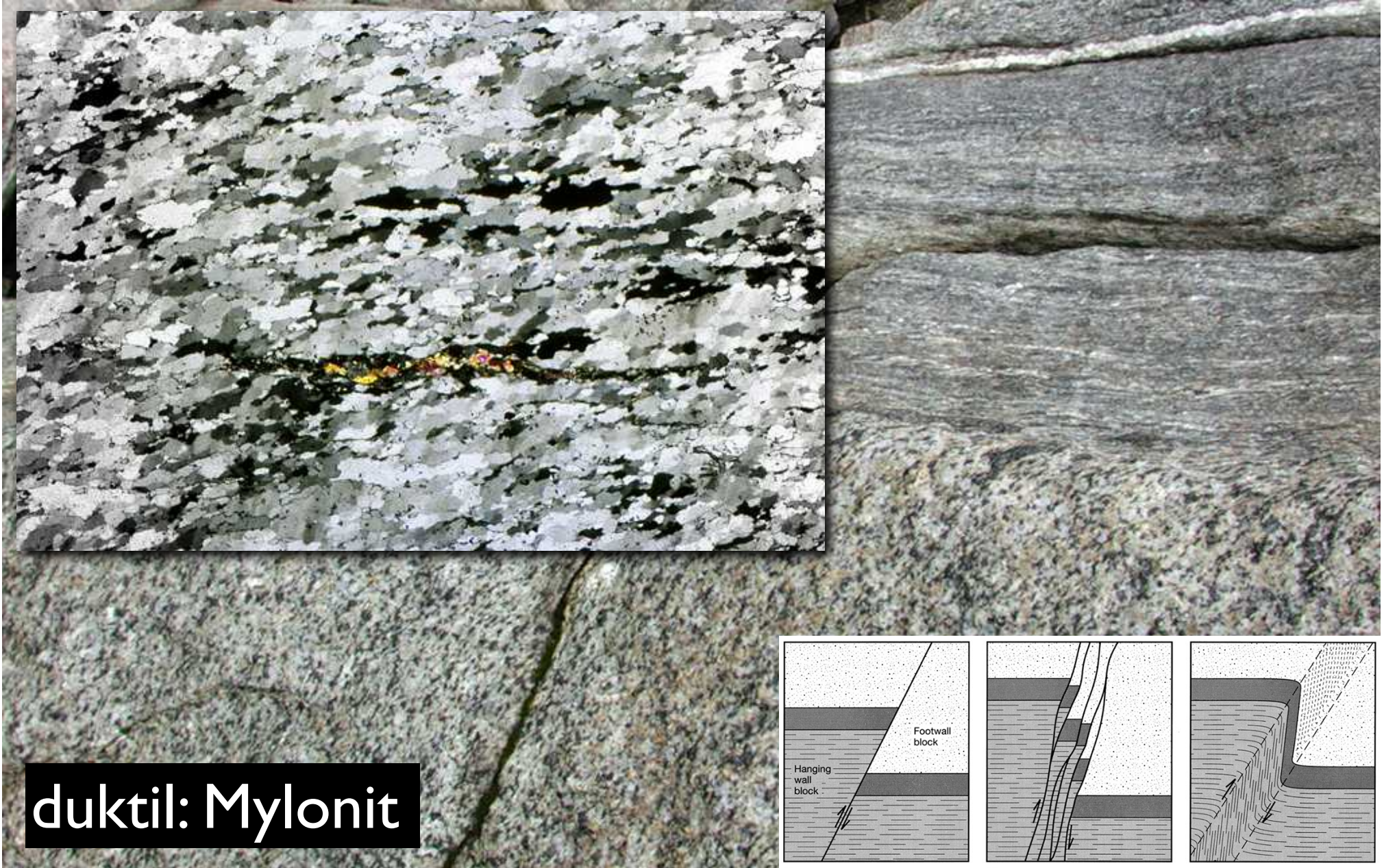
Duktile Scherzone

brittle - ductile transition

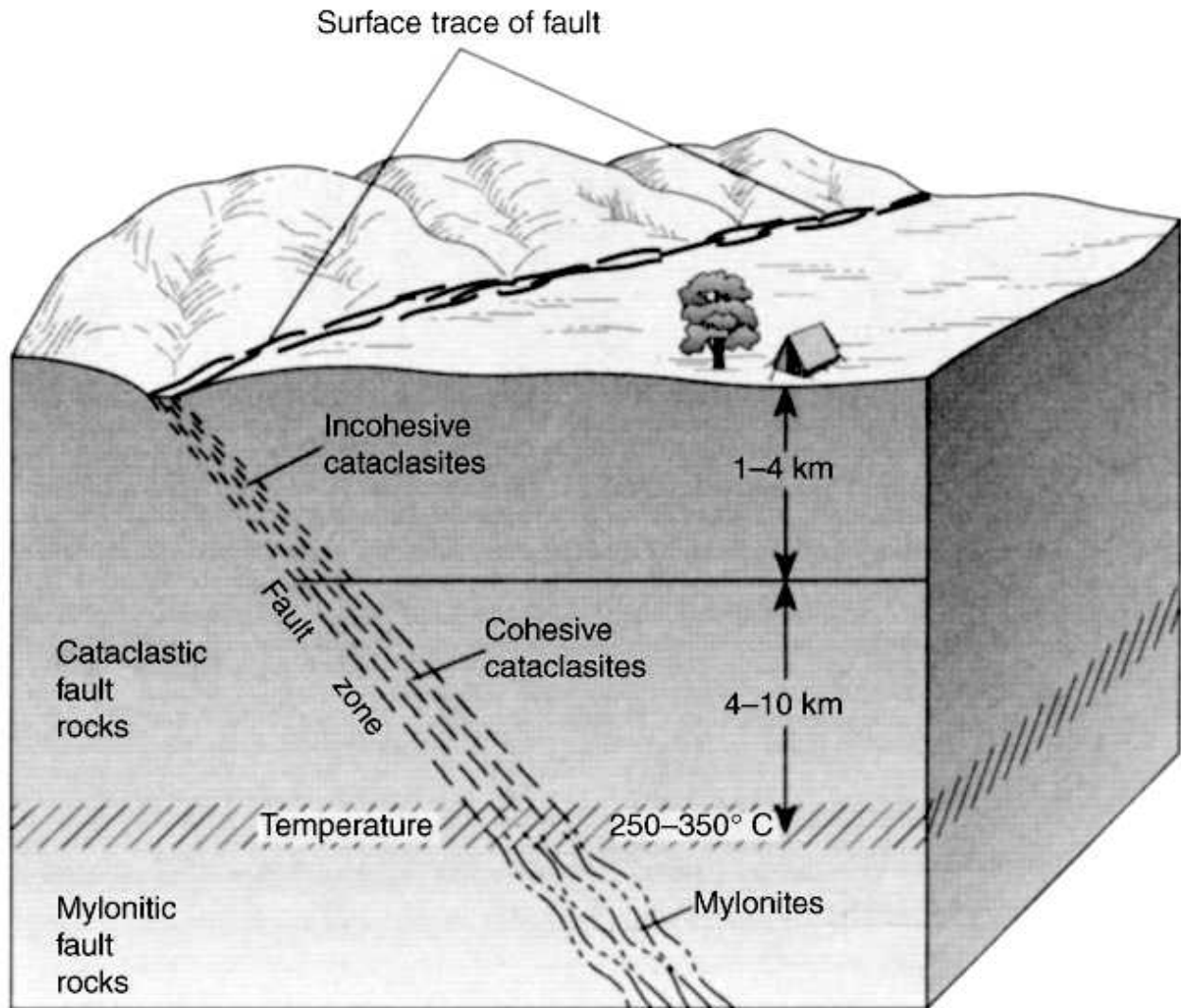


spröd: Kataklasit

brittle - ductile transition



Spröd - Duktil Übergang



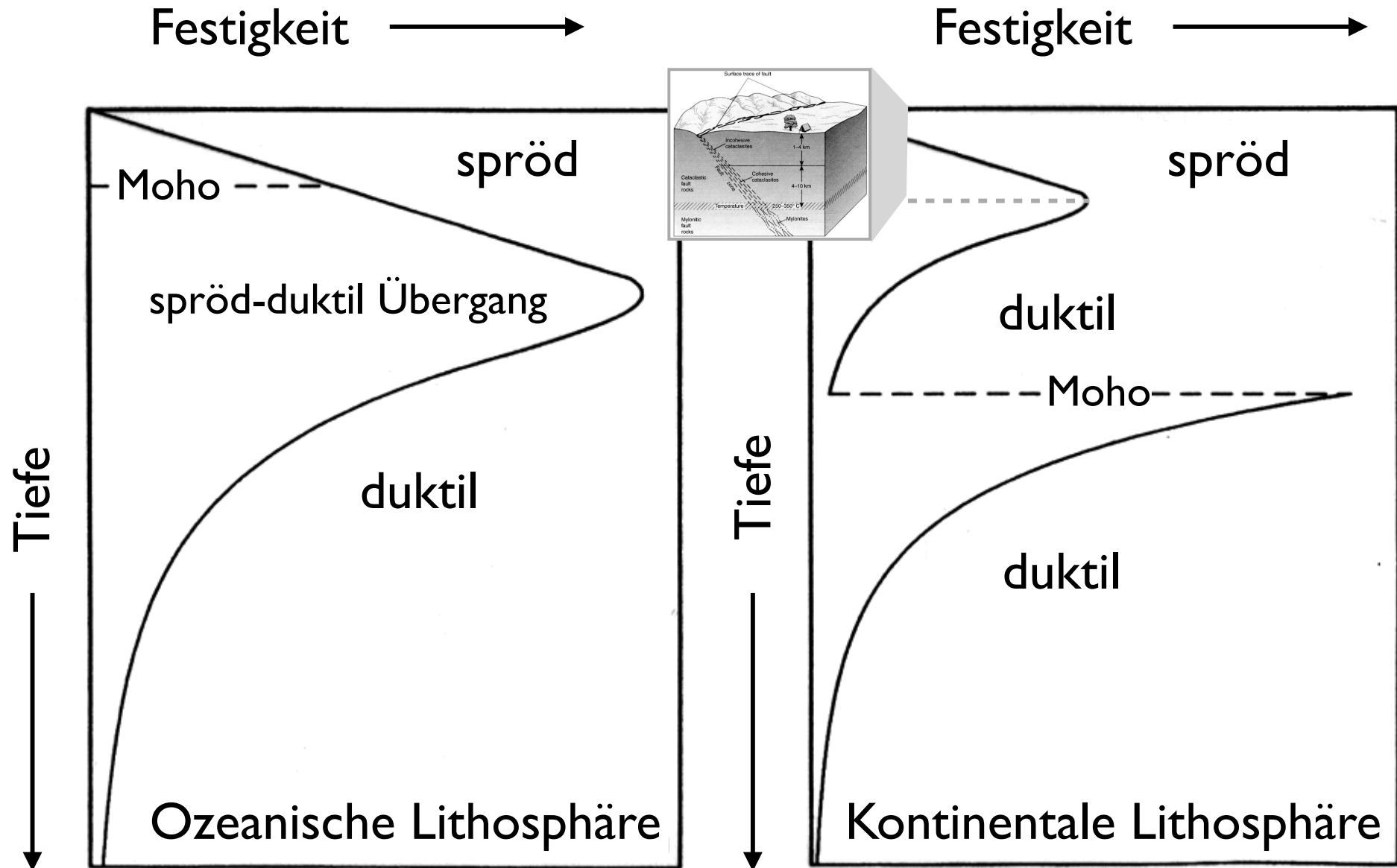
Brekkzien

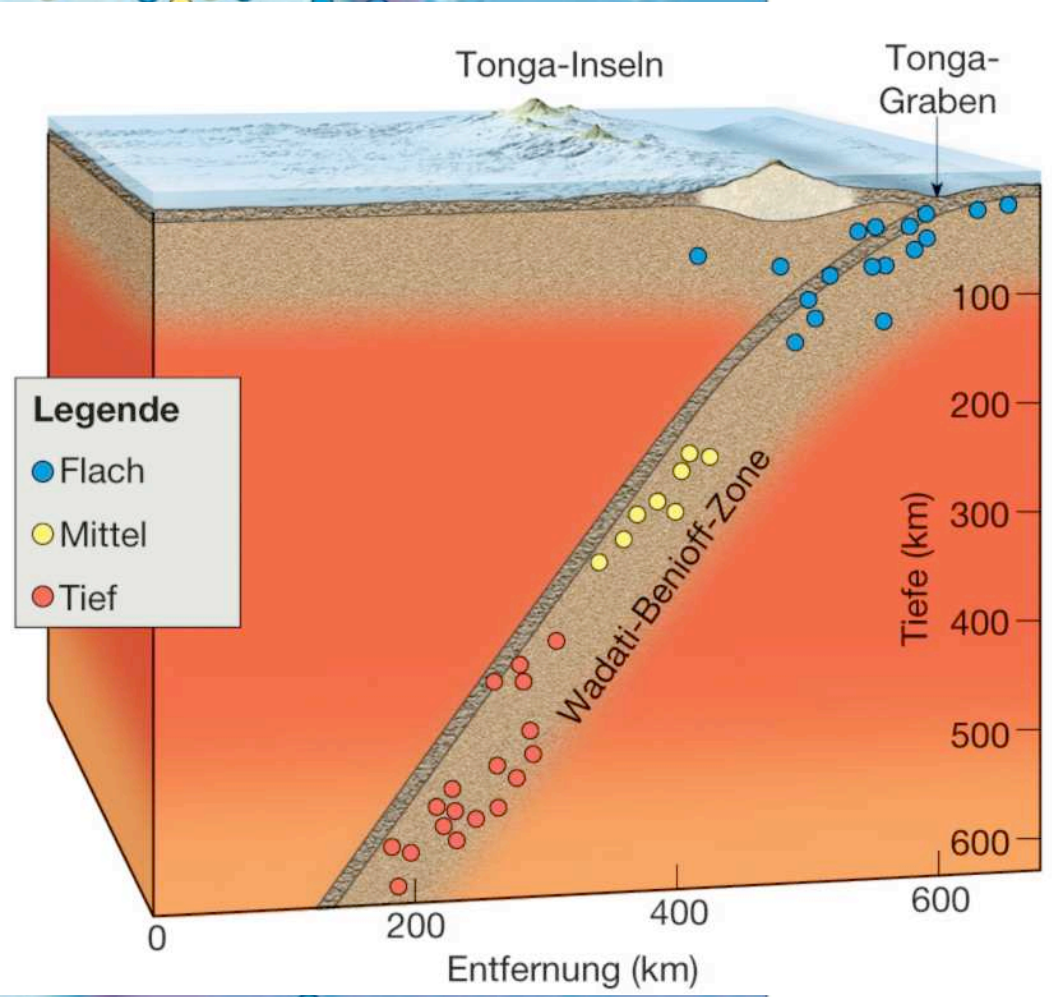
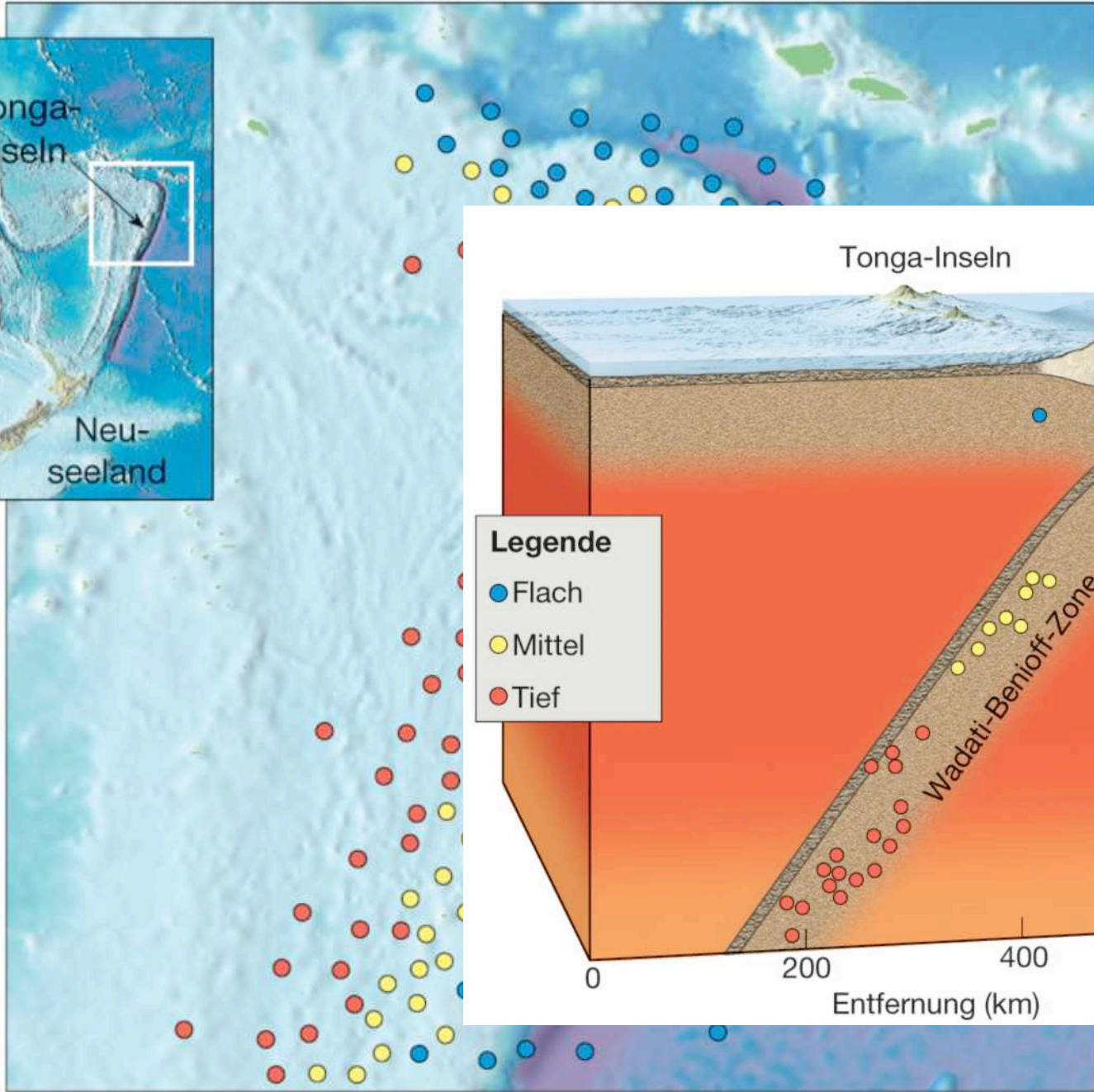
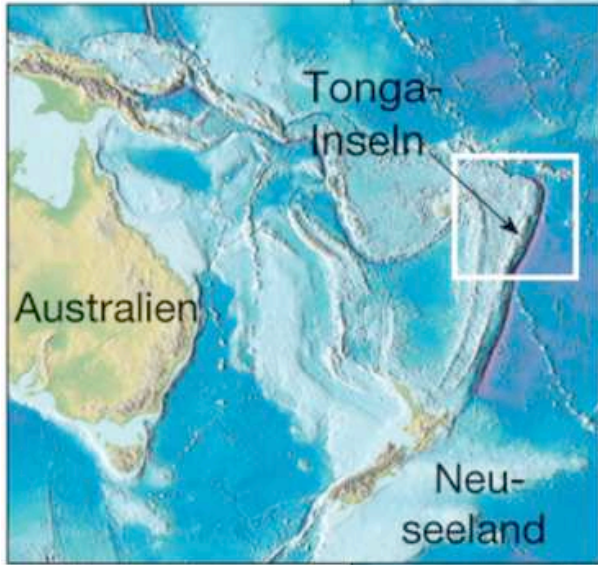
Kataklasite

Mylonite

Tiefe, Druck, Temperatur

Rheologisches Profil





Legende

- Flach
- Mittel
- Tief

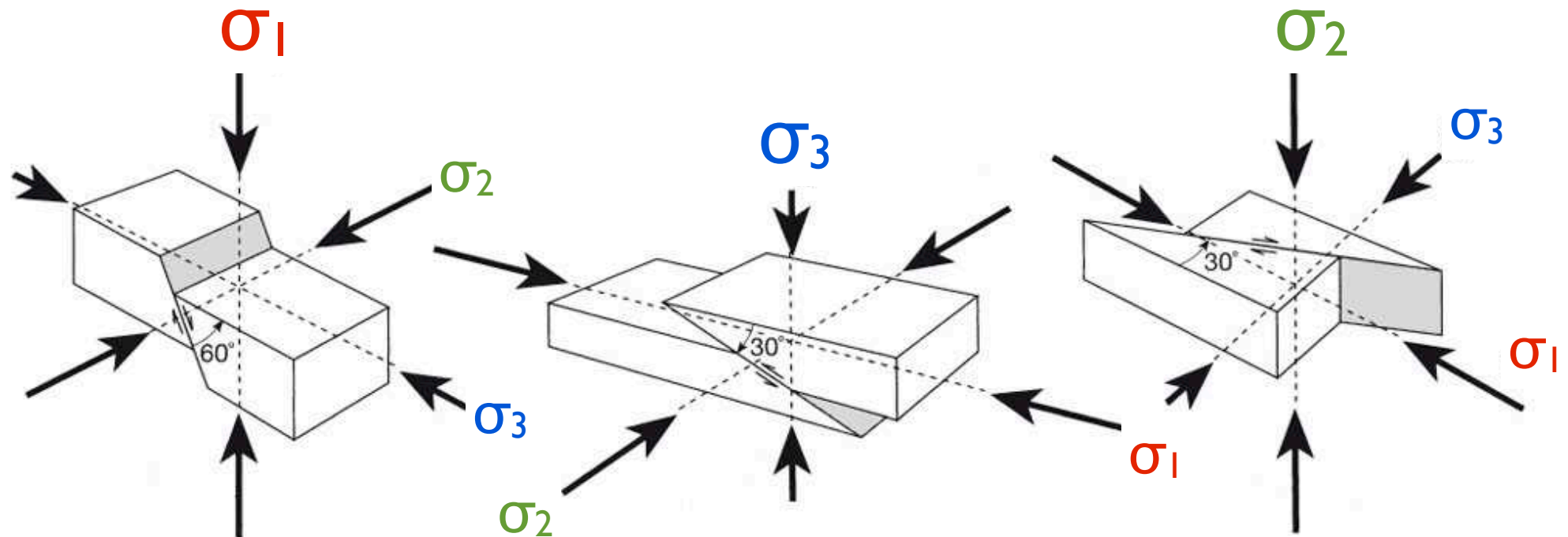
Tektonik an Plattengrenzen

Andersons Bruchtheorie

σ_1 grösste kompressive Hauptspannung

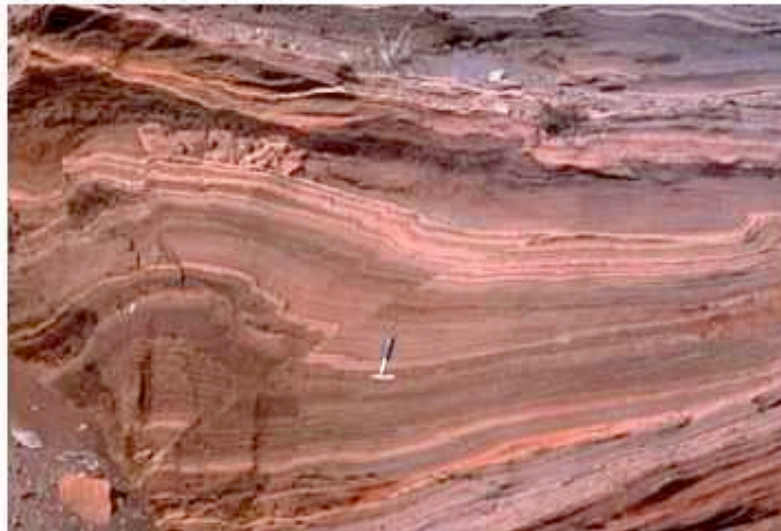
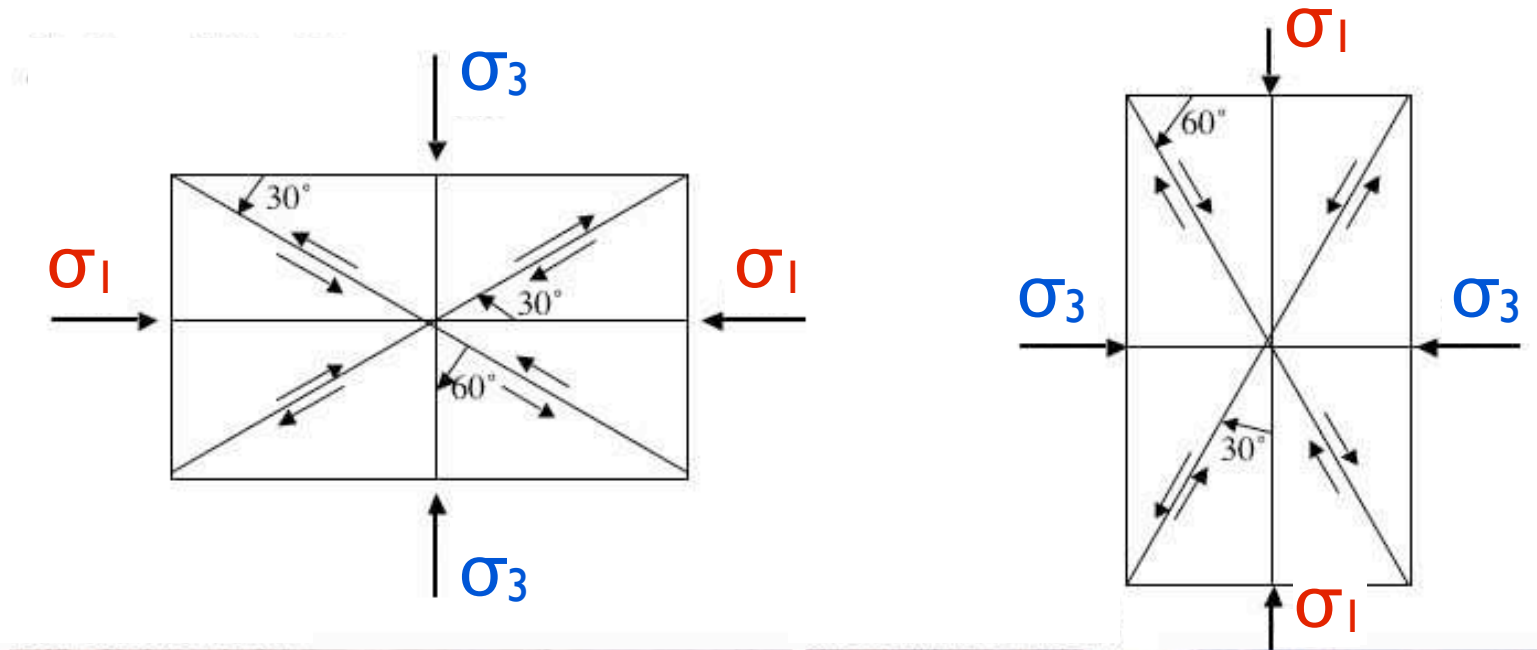
σ_3 kleinste kompressive Hauptspannung

σ_2 intermediäre kompressive Hauptspannung

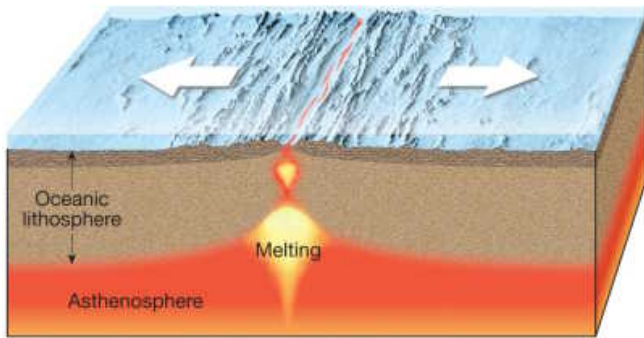
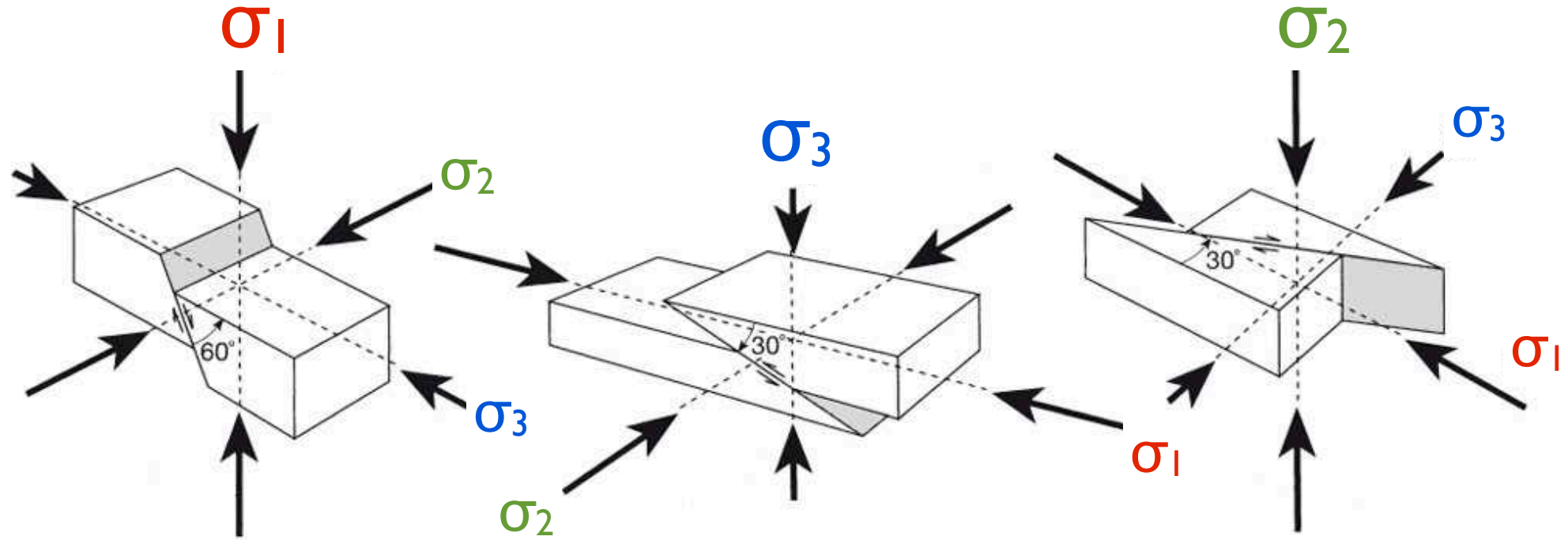


in der Regel: Winkel zwischen σ_1 und Bruchfläche $\approx 30^\circ$

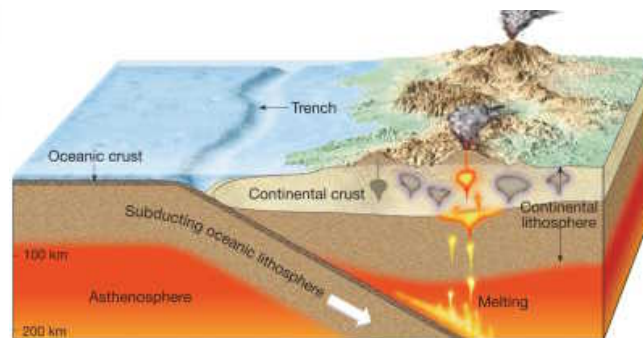
Überschiebung - Abschiebung



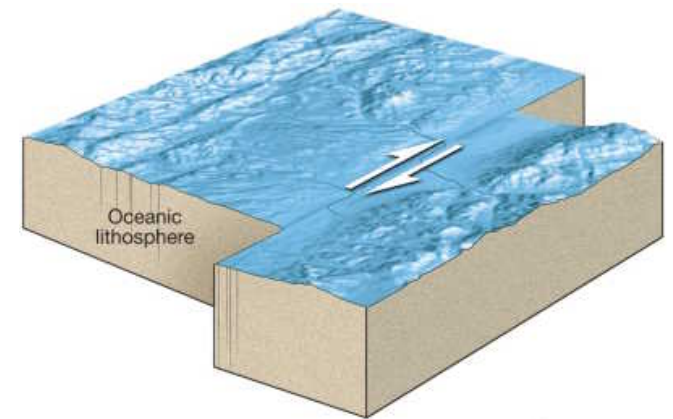
3 Typen Plattengrenzen



konstruktiv

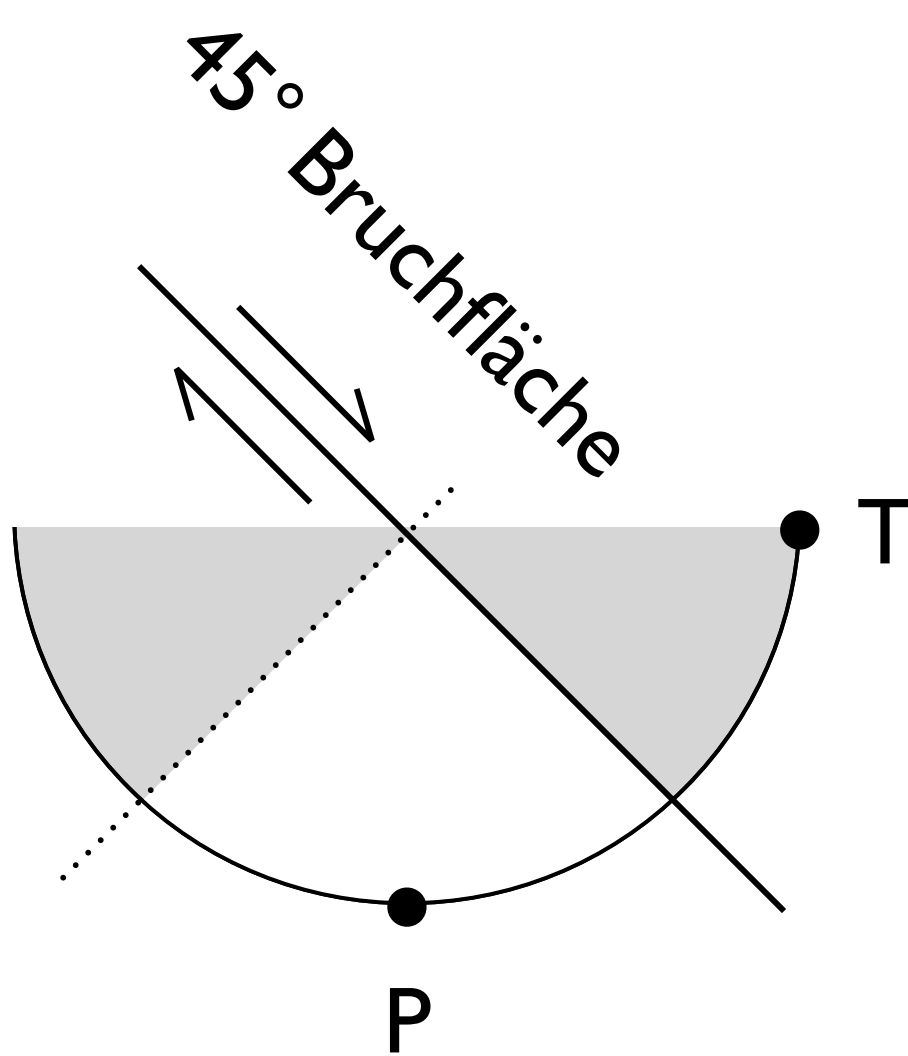


destruktiv

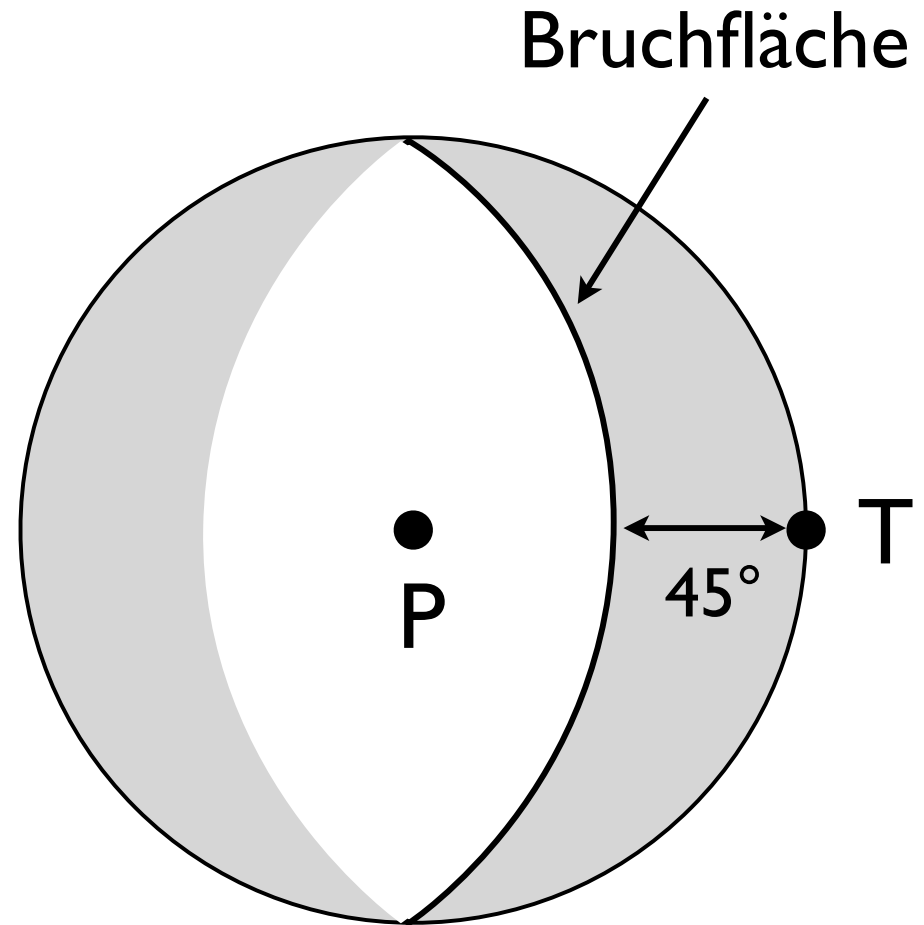


konservativ

Erdbeben - Bruchfläche



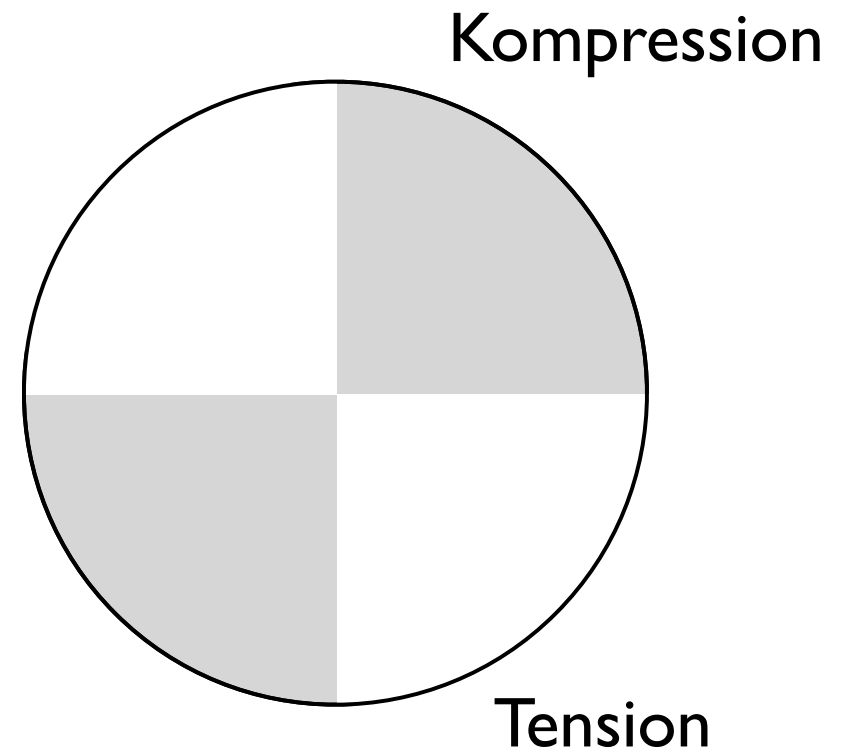
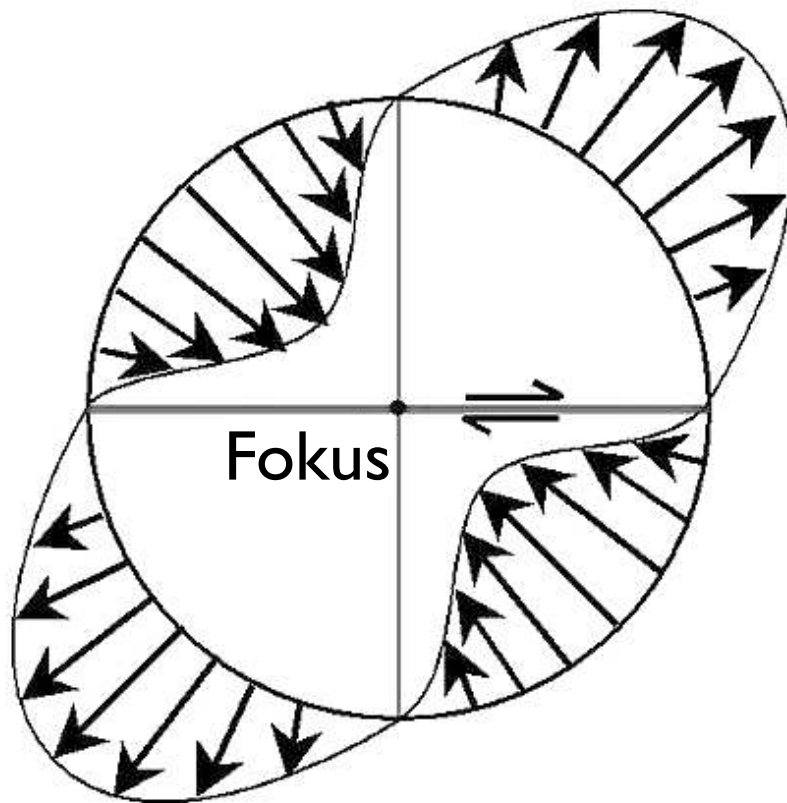
von der Seite



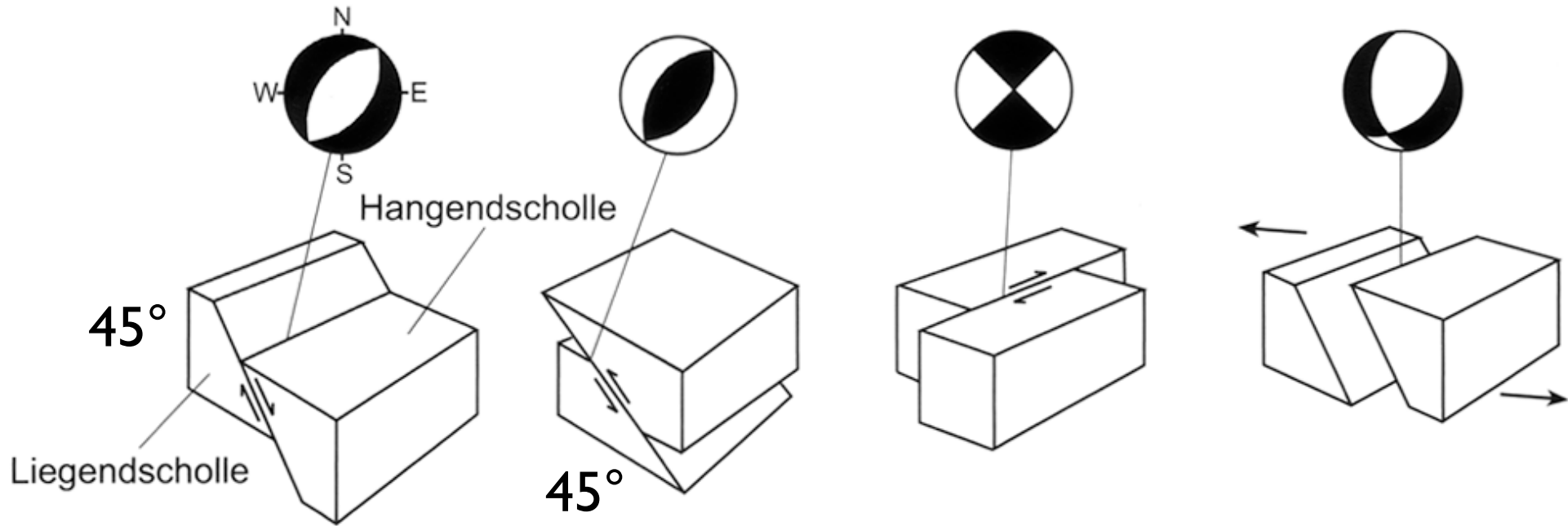
von oben

Erdbeben - Bruchfläche

Bewegungssinn der
abgestrahlten Welle:



Erdbeben - Herdflächenlösung



Abschiebung

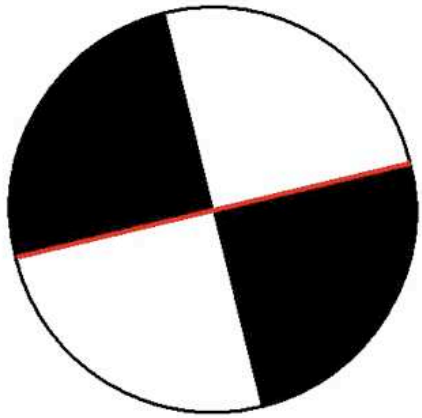
Aufschiebung
Überschiebung

Blattverschiebung
Seitenverschiebung

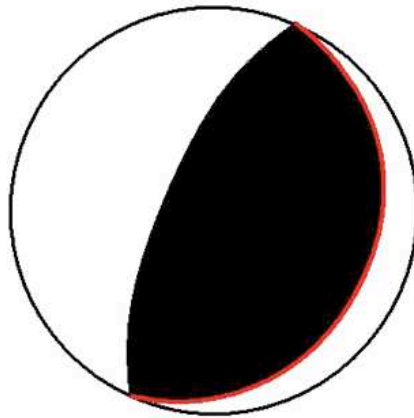
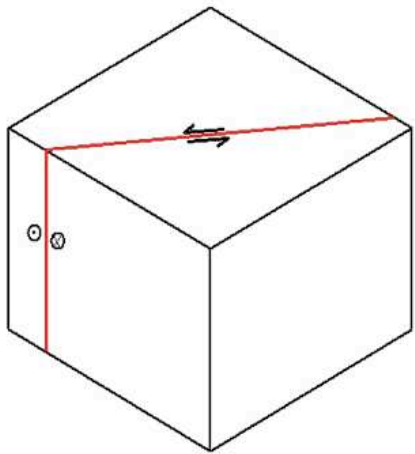
Transtension

45° ≠ richtig

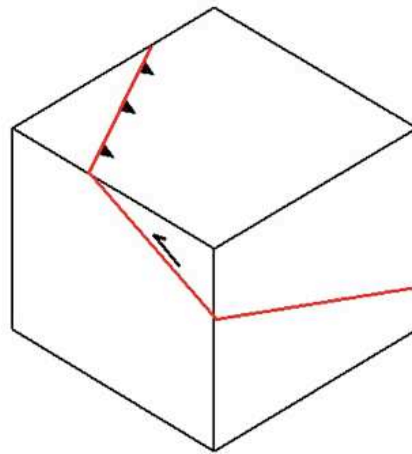
Erdbeben - Herdflächenlösung



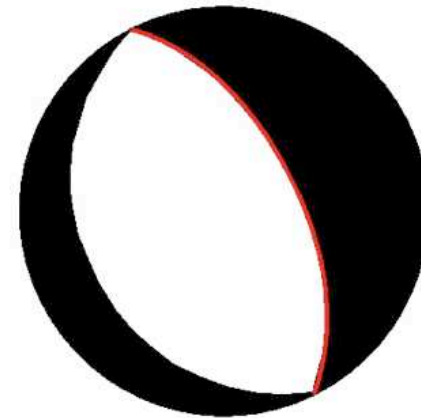
Transformbruch



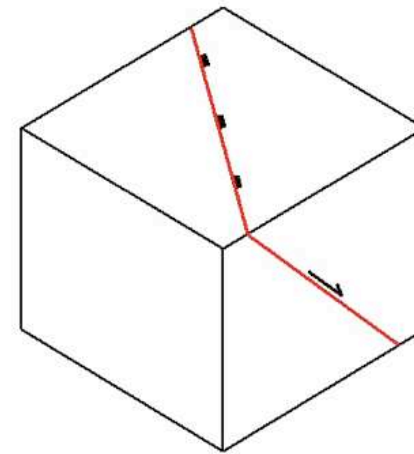
Überschiebung



(richtig 30°)



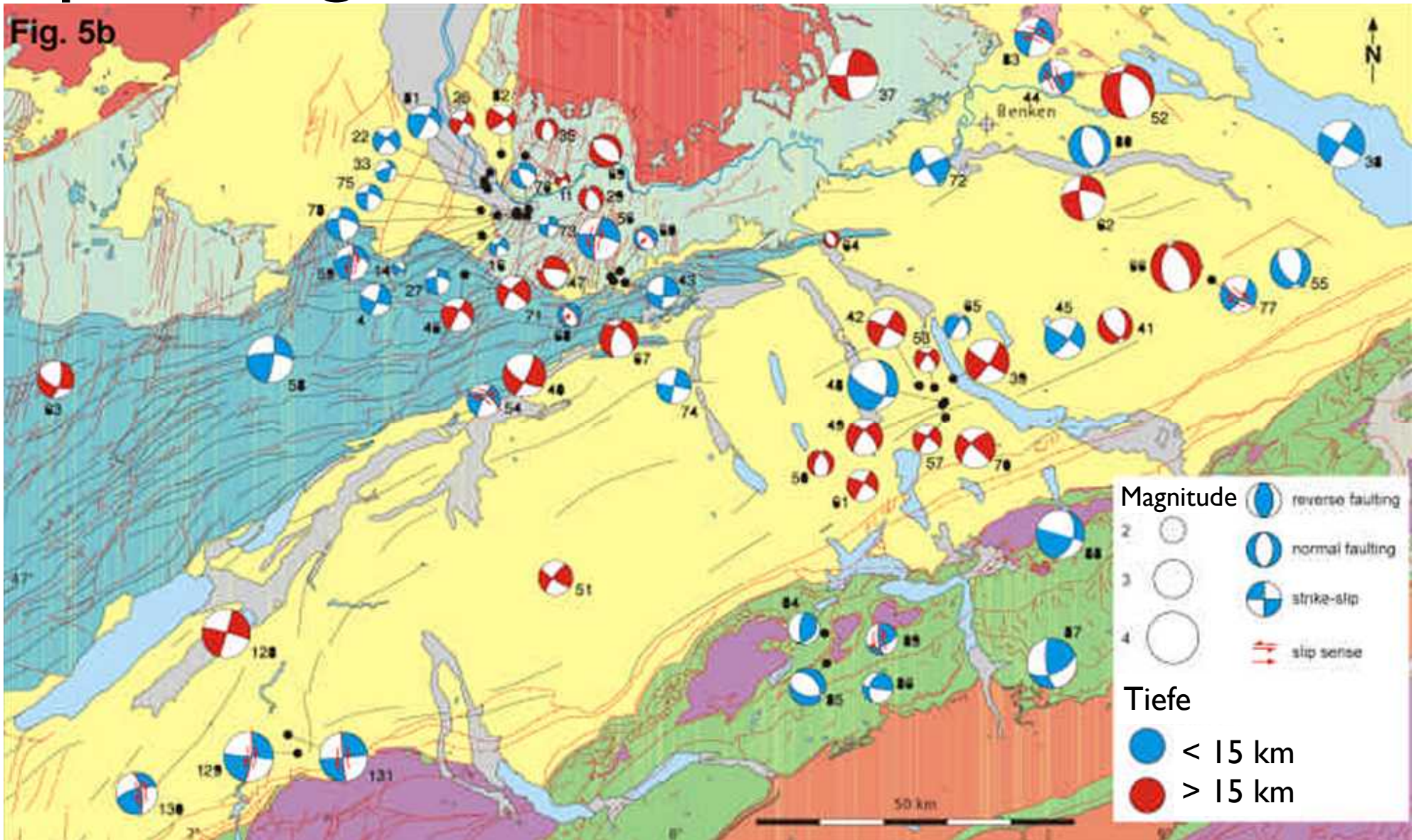
Abschiebung



(richtig 60°)

Spannungsfeld

fault plane solutions

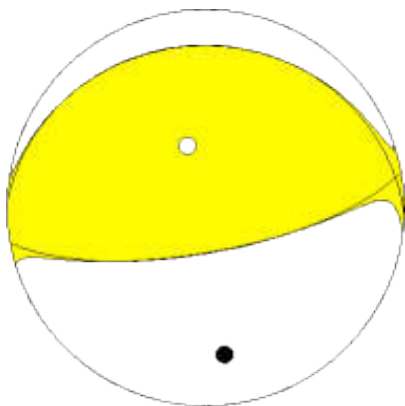


<http://pages.unibas.ch/earth/tecto/images/Hazard.pdf>

S.M. Schmid¹), K. Ustaszewski¹), N. Deichmann²), W.H. Müller³), D. Slejko⁴)

This earthquake was in a broad region of convergence east of the Anatolian strike-slip faults.

P-wave first-motion solution indicates oblique-thrust faulting.



USGS WPhase Centroid Moment Tensor Solution

Reverse (or Thrust) Fault

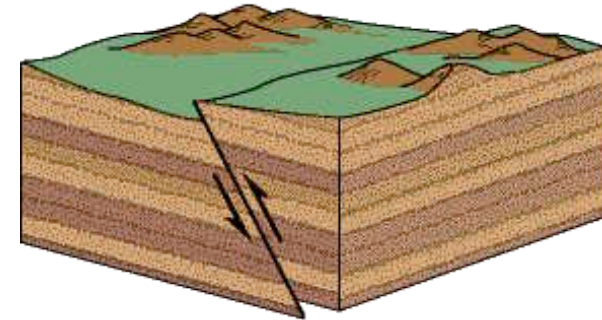


Image courtesy of the US Geological Survey

