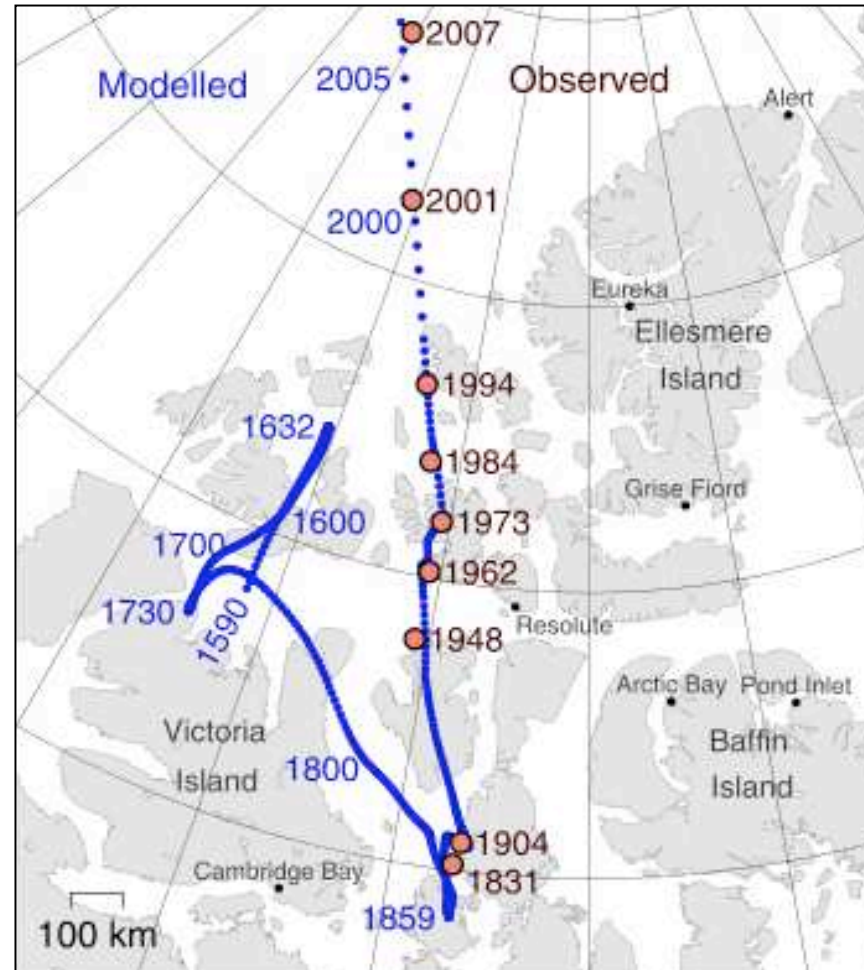


- | | | | |
|---|---|---|--|
| 1 | 2. November
Was ist Plattentektonik ?
Was sind Platten ?
Plattenrundgang | 4 | 23. November
Destruktive Plattengrenzen
Alles über Erdbeben ...
Magnituden - Intensitäten |
| 2 | 9. November
Entwicklung der Plattentektonik
Geosynklinale, Kontinentaldrift →
Sea floor Spreading - Subduktion | 5 | 30. November
Konservative Plattengrenzen
... noch mehr über Erdbeben
Berühmte Fälle |
| 3 | 16. November * Nachtrag
Geophysikalische Spurensicherung
Vom Rifting zur Subduktion
Mittelozeanische Rücken | 6 | 7. Dezember
Hotspots |

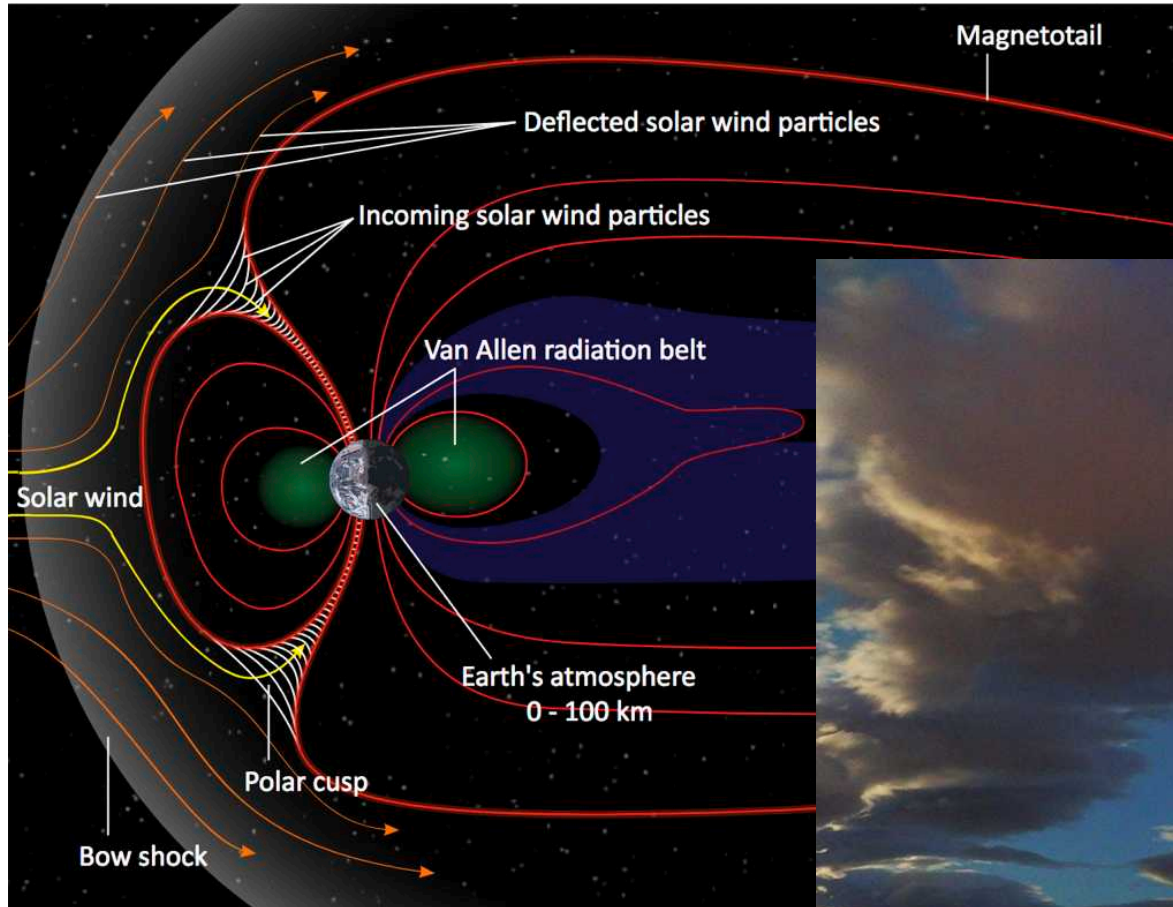
* im Bernoullianum Hörsaal 223

Nachtrag: Magnetfeld der Erde

Des arktische Magnetpols wandert mit variabler Geschwindigkeit. Derzeit etwa mit 90 m / Tag in Richtung NNE, entsprechend 30 km / Jahr.



Nachtrag: Magnetfeld der Erde

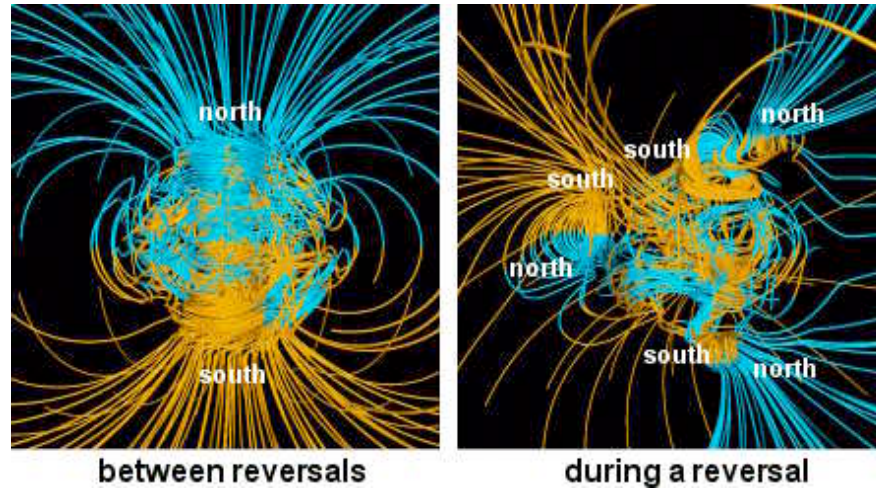
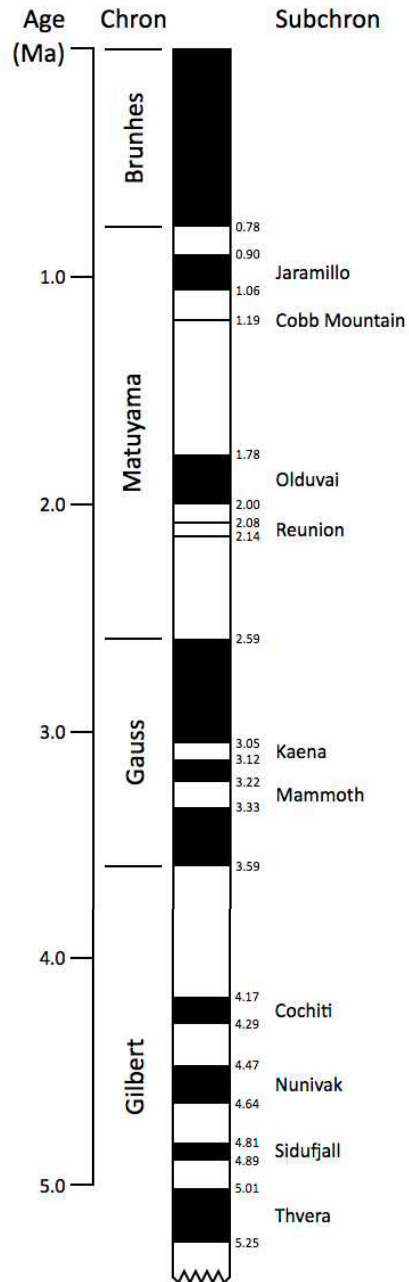


<https://de.wikipedia.org/wiki/Polarlicht>

Polarlicht (Nordlicht, Aurora borealis) = Leuchterscheinung durch Auftreffen beschleunigter geladener Teilchen aus der Erdmagnetosphäre auf Stickstoff- und Sauerstoffatome der Atmosphäre.

Tromsø, 30. August 2015, photo Yngvar Steinholt

Nachtrag: Polsprünge (Umkehrung des Erdfeldes)



Geomagnetische Exkursion

Laschamp-Ereignis (Laschamp-Exkursion) = kurzzeitige Umkehrung des Erdmagnetfeldes vor 41.000 ($\pm 2,000$) Jahren. Dauer ca. 440 Jahre - die Umkehrungen selbst ca. 250 Jahre. Das umgekehrte Feld $\approx 25\%$ der der normalen Feldstärke (vermehrte kosmische Strahlung).

1967 entdeckt, weltweit nachweisbar, liegt im Weichsel-Hochglazial (Wikipedia)

Magnetische Lineationen

Erstens: Feldumkehr ist eine Tatsache ...

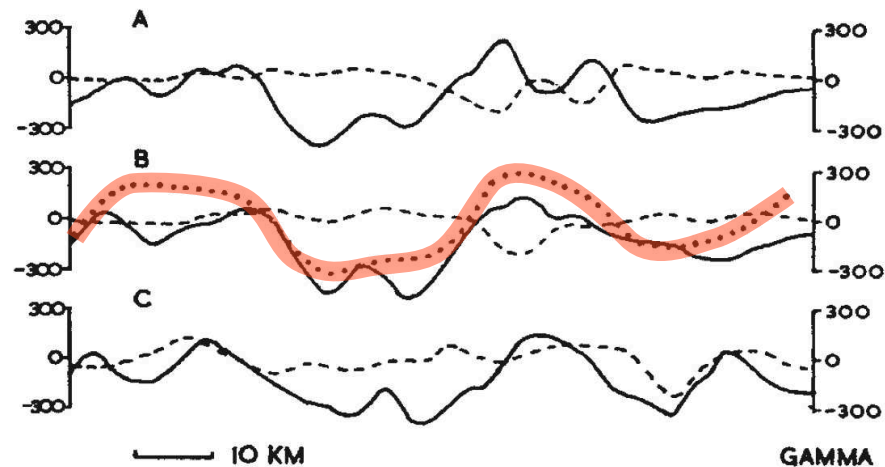
September 7, 1963

NATURE

MAGNETIC ANOMALIES OVER OCEANIC RIDGES

By F. J. VINE and DR. D. H. MATTHEWS

Department of Geodesy and Geophysics, University of Cambridge

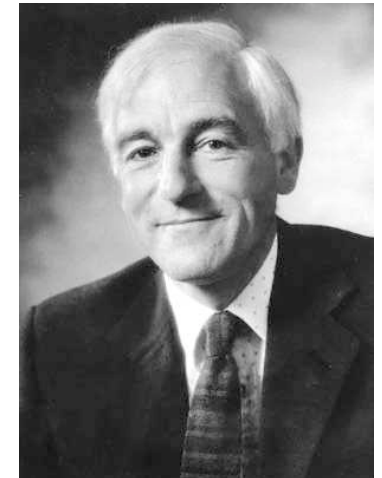


The theory is consistent with, in fact virtually a corollary of, current ideas on ocean floor spreading⁷ and periodic reversals in the Earth's magnetic field⁸.

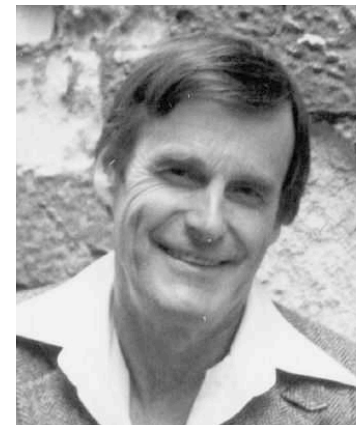
- beobachtet
- - - - berechnet - mit konstanter Magnetisierung
- berechnet - mit Annahme von Feldumkehr



Frederick John Vine
(* 1939)



Drummond Hoyle
Matthews
(1931 - 1997)



Lawrence W. Morley
(1920-2013)

Vine - Mathews - Morley
Hypothese

Zweitens: Seafloor Spreading ebenfalls...

16 December 1966, Volume 154, Number 3755

SCIENCE

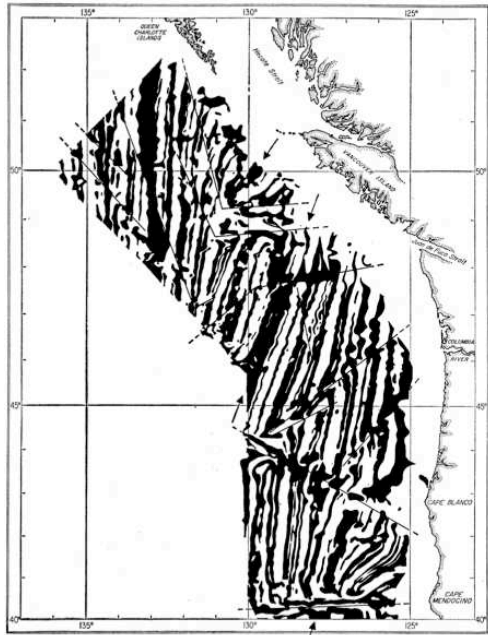
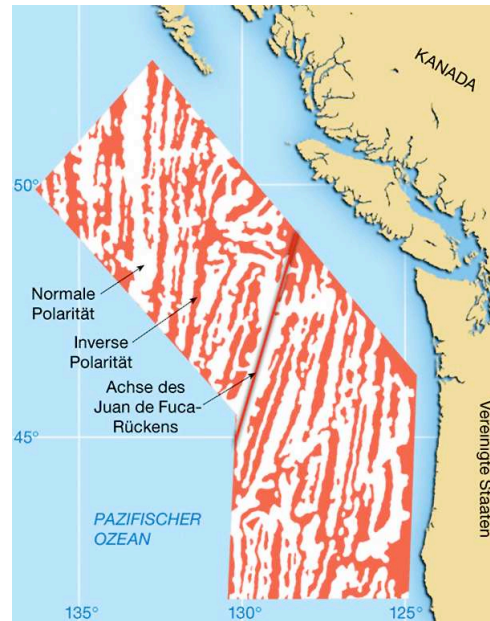


Fig. 1. Summary diagram of total magnetic-field anomalies southwest of Vancouver Island. Areas of positive anomaly are shown in black. Straight lines indicate faults offsetting the anomaly pattern; arrows, the axes of the three short ridge lengths within this area—from north to south, Explorer, Juan de Fuca, and Gorda ridges. See also Fig. 15. [Based on fig. 1 of Raff and Mason (27); courtesy Geol. Soc. Amer.]

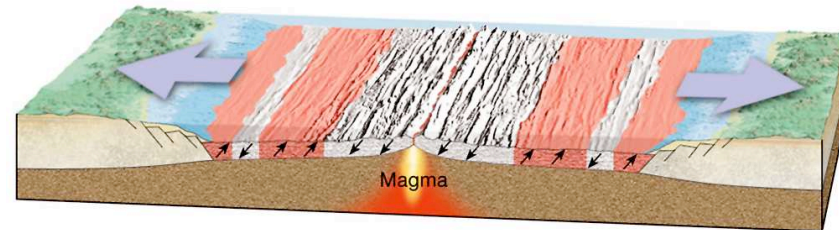
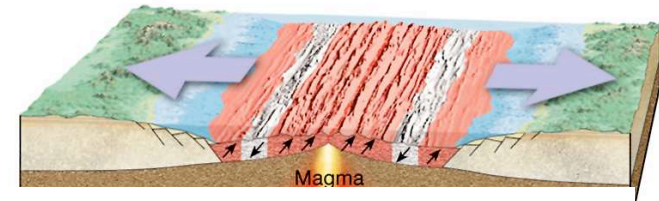
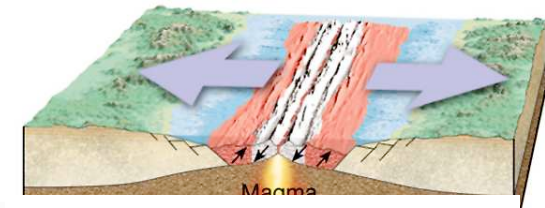
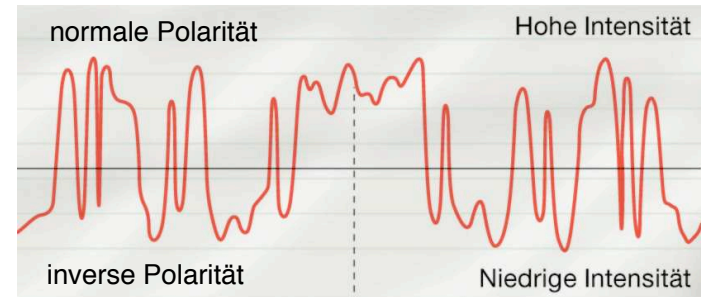


Spreading of the Ocean Floor:

New Evidence

Magnetic anomalies may record histories of the ocean basins and Earth's magnetic field for 2×10^8 years.

$$2 \cdot 10^8 = 200 \text{ Ma} \quad \text{F. J. Vine}$$



⇒ lineare Quelle für Erdoberfläche

Kinematische Feinheiten an Ozeanrücken

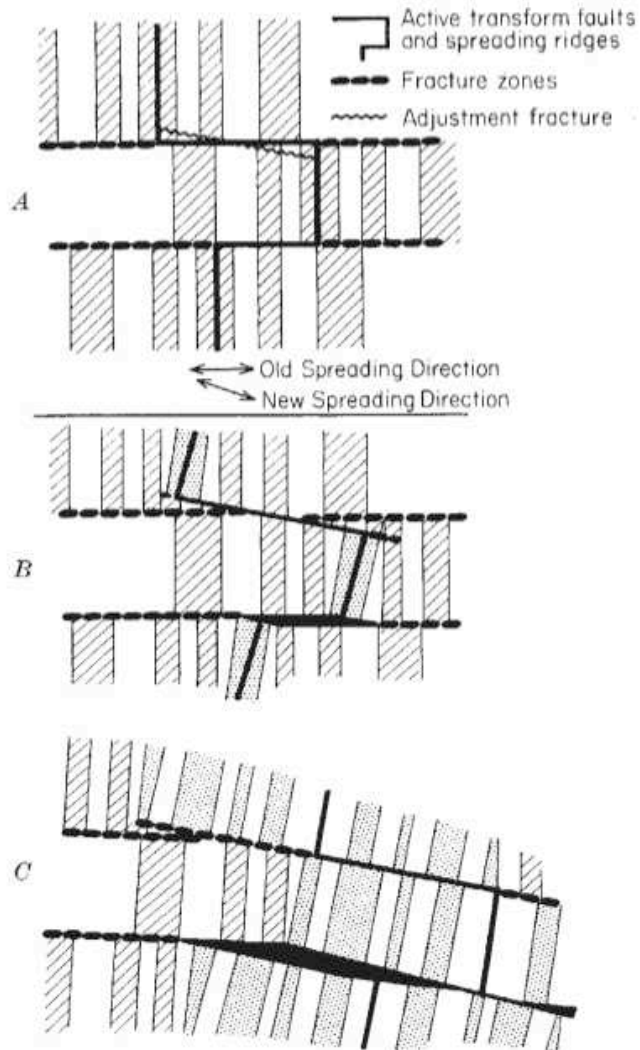
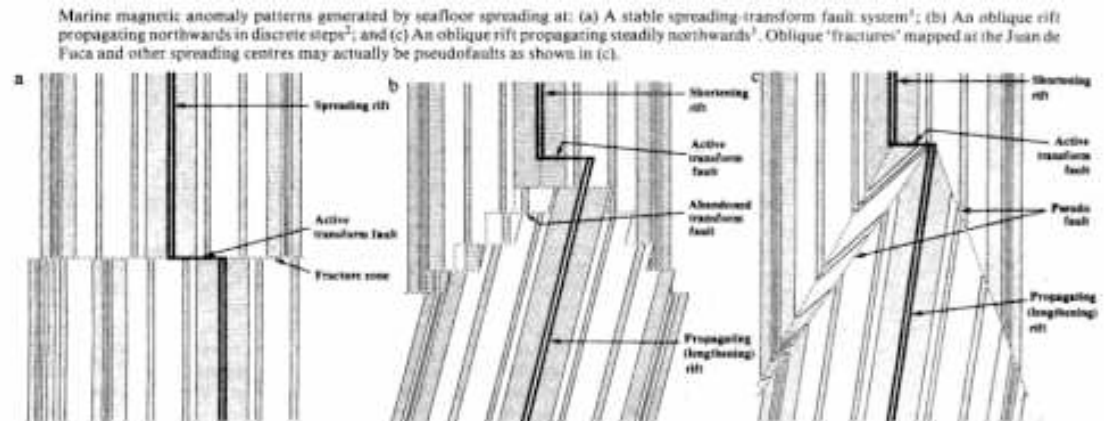


Fig. 4. Proposed modes of adjustment of transform faults to a change in spreading direction. *A*, A rise offset by two transform faults has been spreading in a direction perpendicular to itself. The spreading direction changes as shown. The block corners near the upper transform fault must fracture to adjust. The lower transform fault becomes a centre of slow spreading. *B*, Spreading occurs in the new direction. The ridge centre migrates around. At the upper offset the adjustment fractures take on the new transform fault motion. The lower transform fault opens, creating a zone of mixed spreading and shearing. *C*, Spreading continues in the new direction. The lower offset has become readjusted to pure transform fault motion. Note that the trends of the fracture zones and magnetic anomalies of the first episode are preserved.

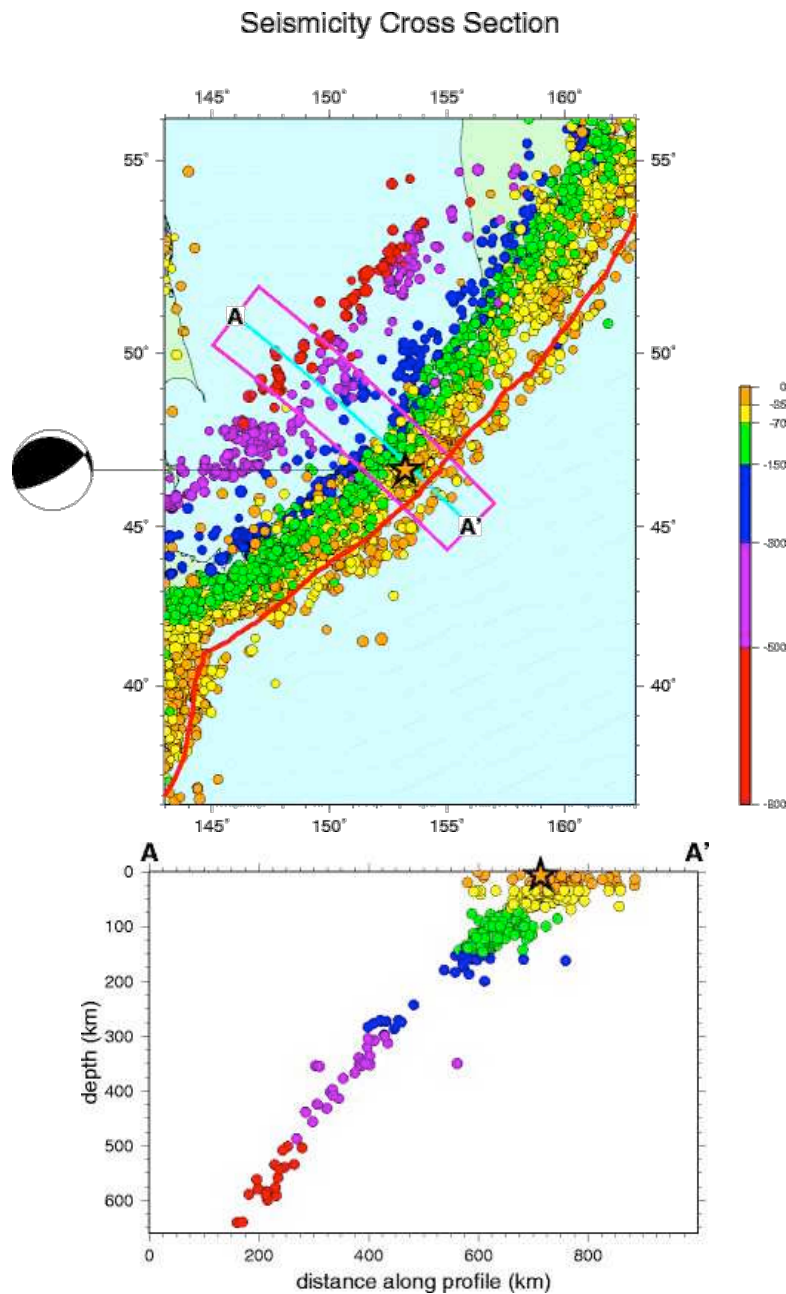


Tanya Atwater * 1942



Seismologie

Wadati-Benioff-Zone



Kiyoo Wadati
(1902 - 1995)



Victor Hugo Benioff
(1899 - 1968)

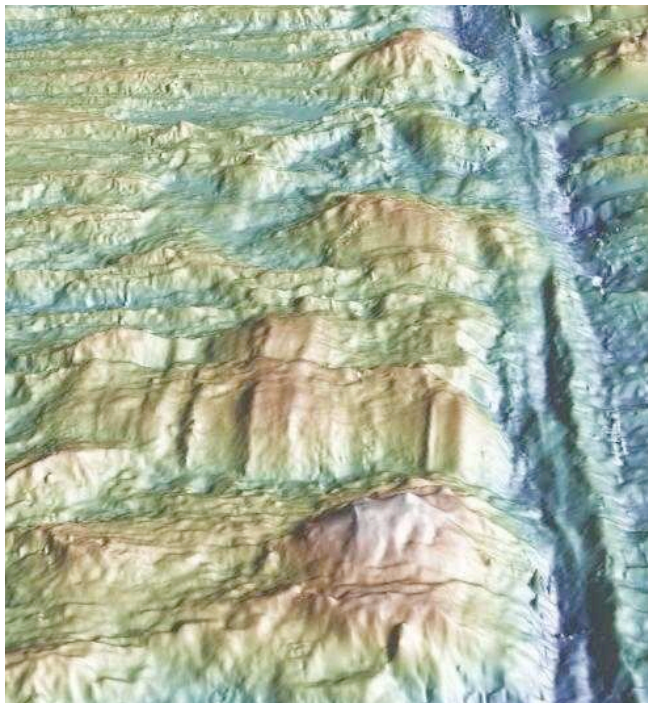
Wadati: deep earthquakes (>300km) are associated with oceanic trenches
Benioff: distribution of epicenters are evidence for fault origin of ocean deeps

⇒ lineare Senke für Erdoberfläche

Topographie der Transformbrüche

Bruchzonen und mittelatlantische Rücken haben erhöhte Ränder

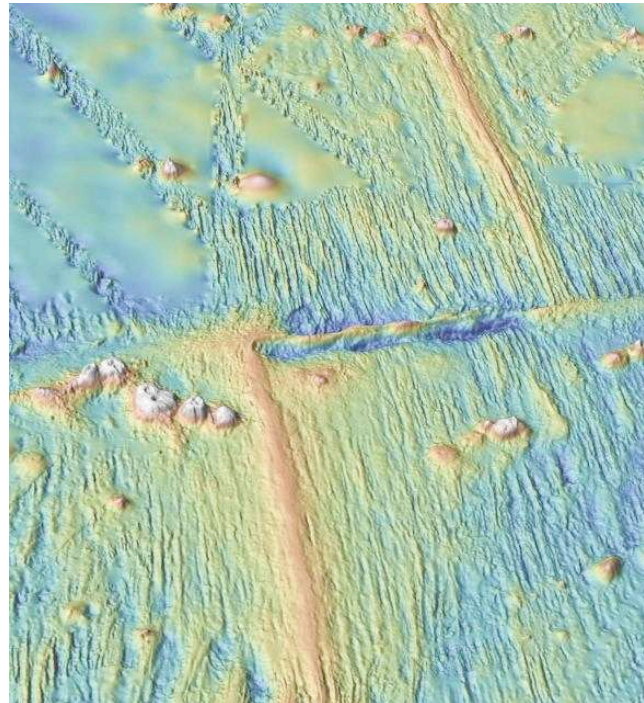
W-E Blickrichtung →
parallel zu Transformbruch



MAR Mid-Atlantic ridge

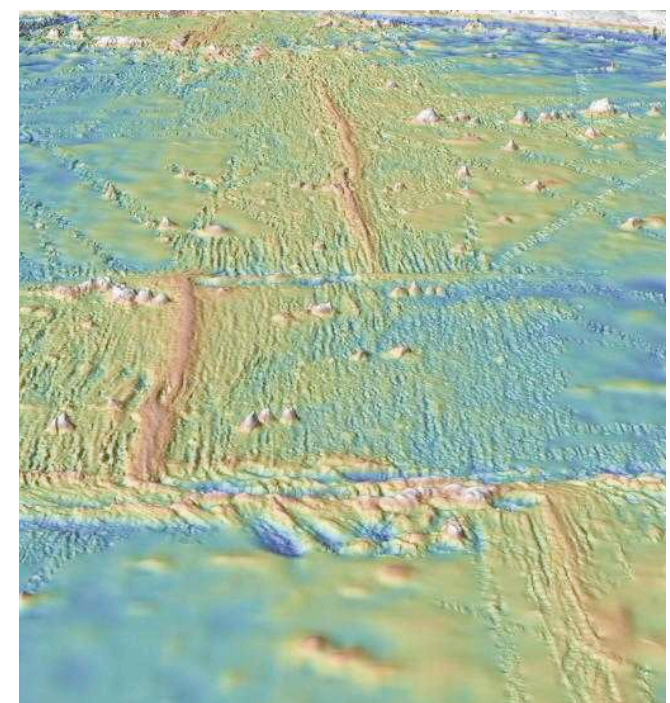
Kane Fracture zone

S-N Blickrichtung ↑
senkrecht auf Transformbruch



EPR East Pacific rise

S-N Blickrichtung ↑
senkrecht auf Transformbruch

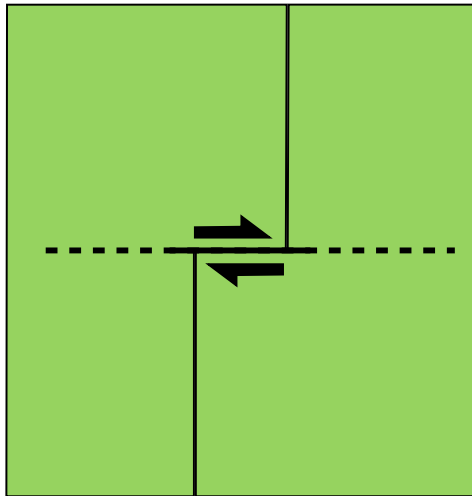


EPR East Pacific rise

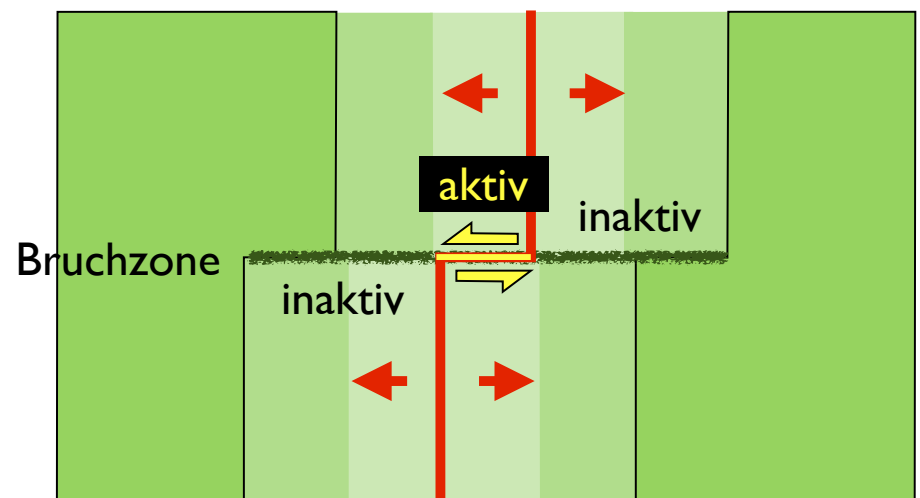
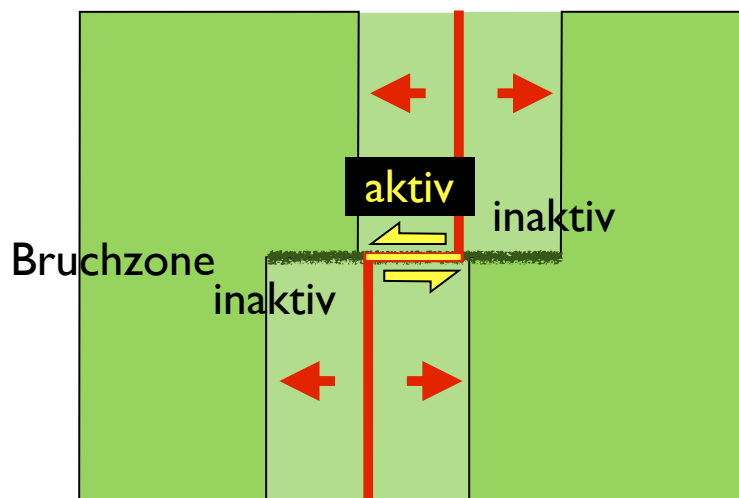
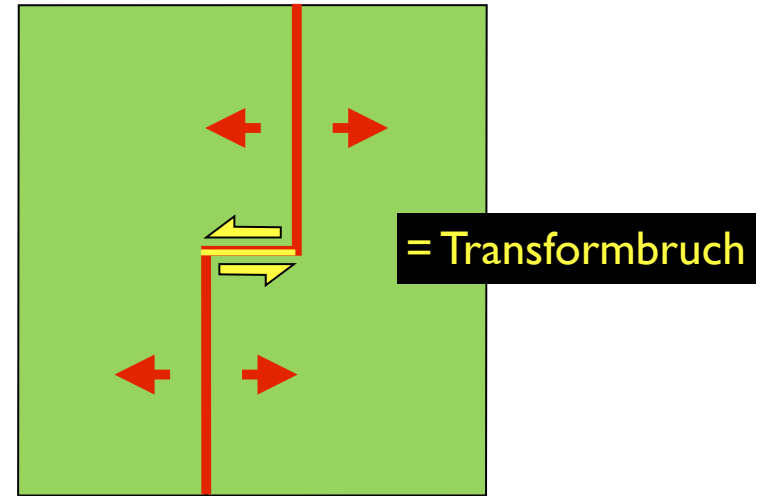
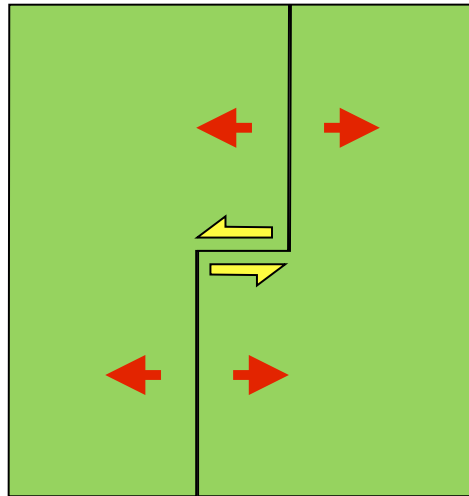
(Google Earth)

Bewegung an Transformstörungen

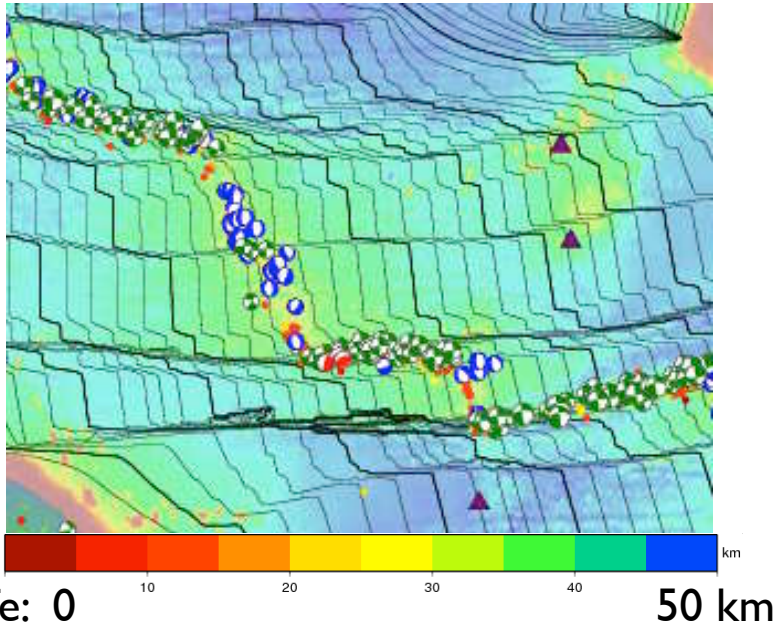
Standardinterpretation:
Versatz = dextral
Bewegungssinn = dextral



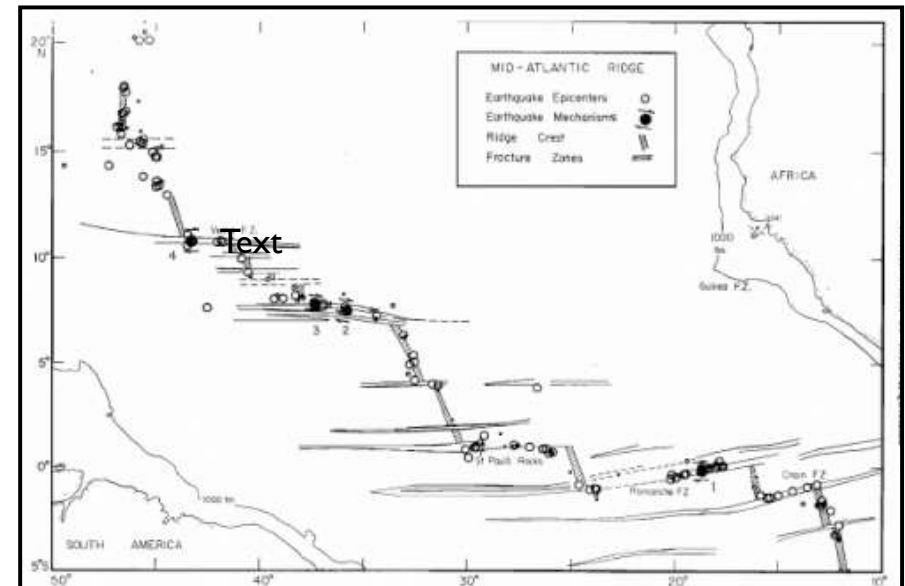
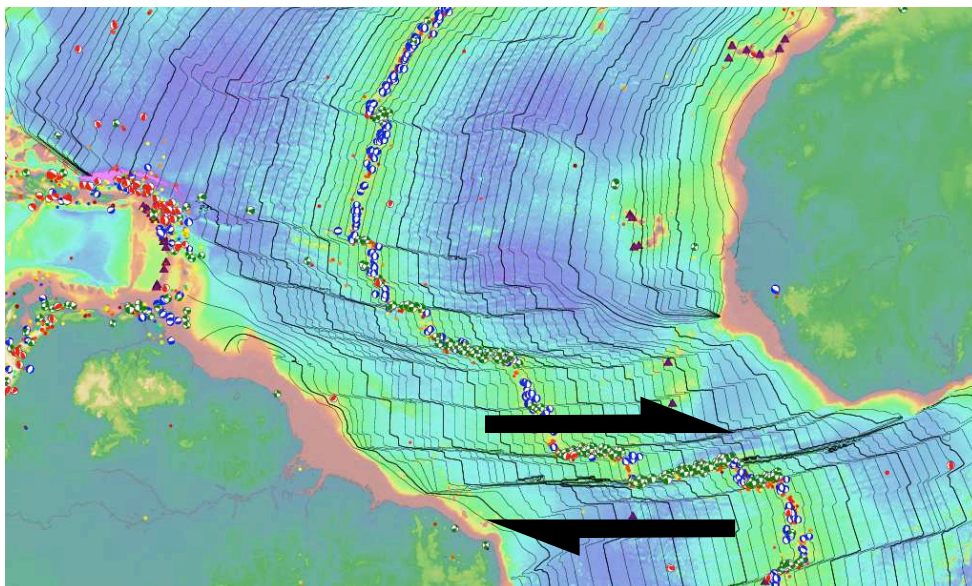
durch Seismik:
Bewegungssinn = sinistral
Bruch = Transformbruch



Transform est !

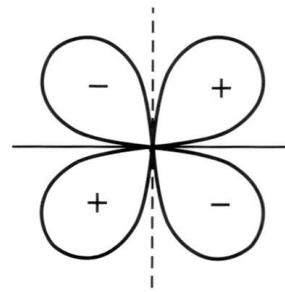
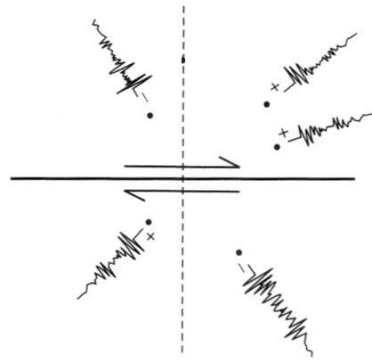
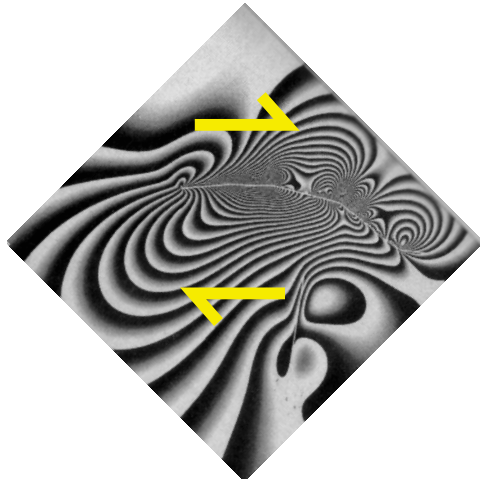


Lynn Ray Sykes
(* 16. April 1937)



Seismologie

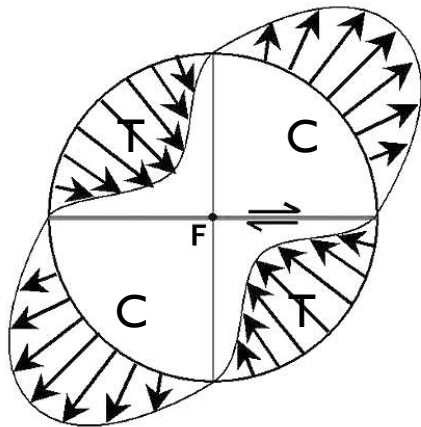
Herdflächenlösung



compressional wave
tensional wave

Stationen empfangen kompressiven Erstausschlag

Stationen empfangen tensilen Erstausschlag



Überschiebungsrichtung

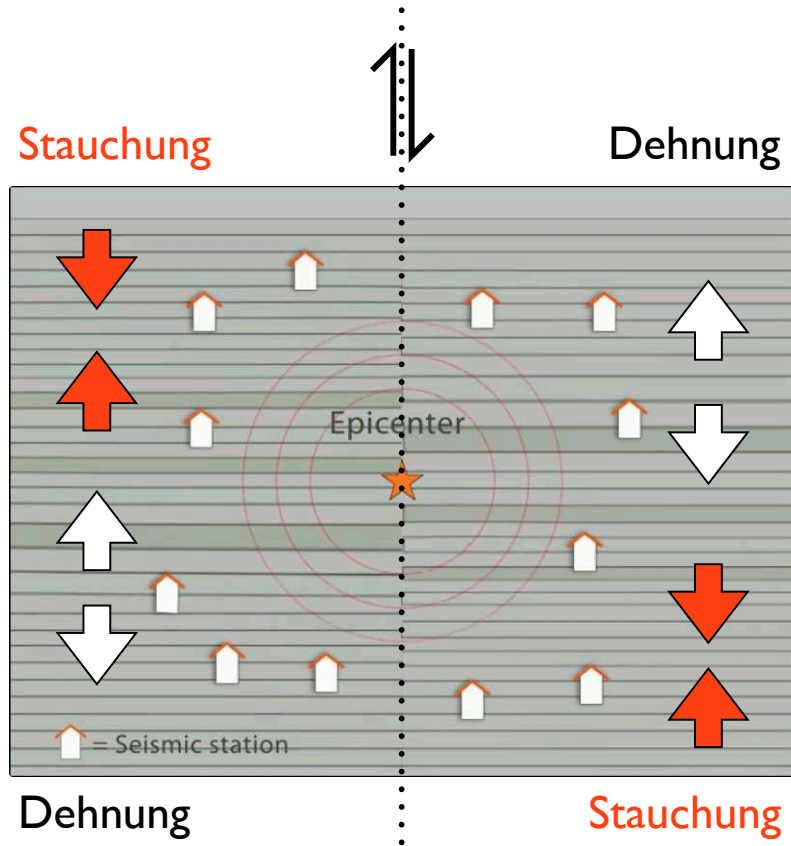
Abschiebungsrichtung

σ_3

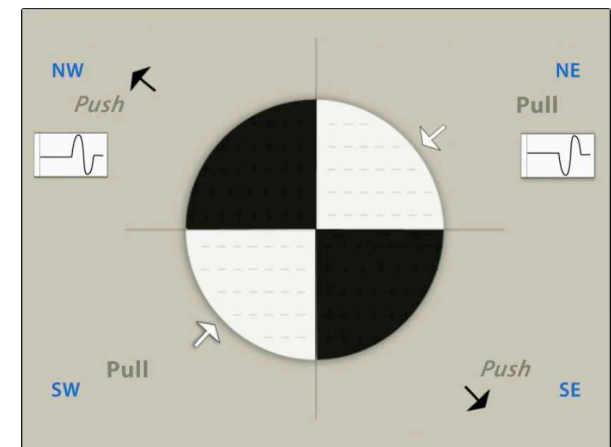
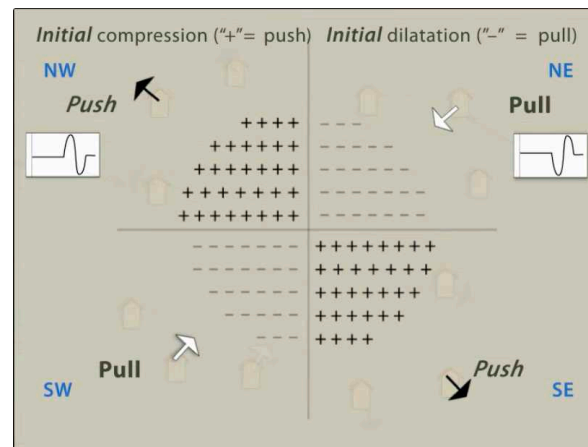
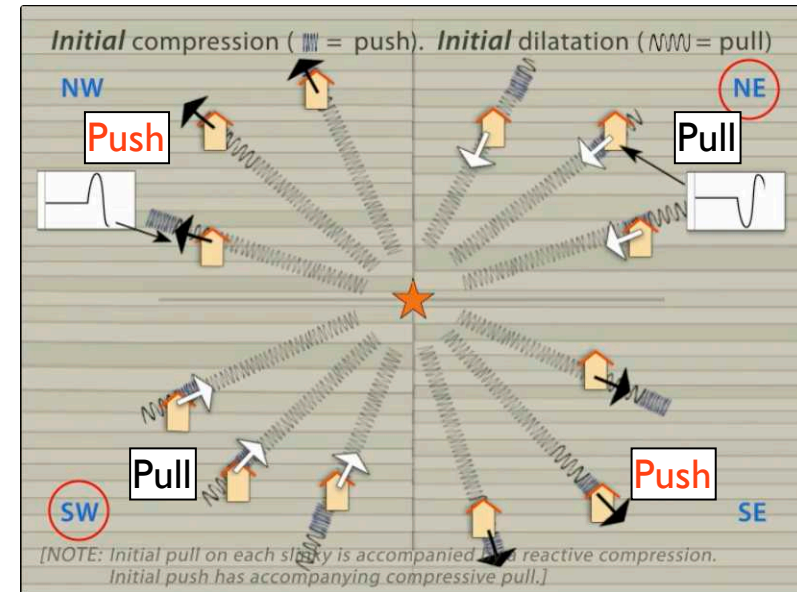
σ_1

aus allen Stationen zusammengesetzte Interpretation

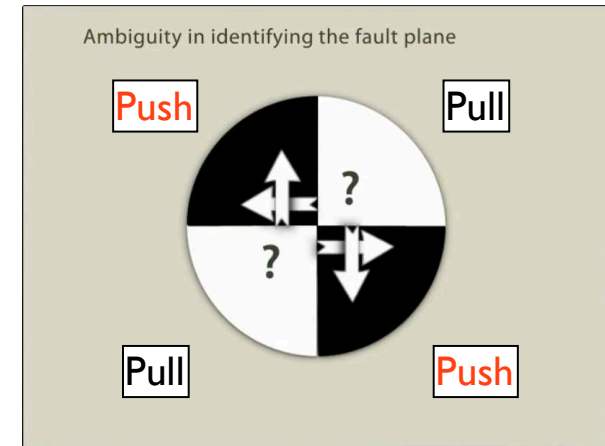
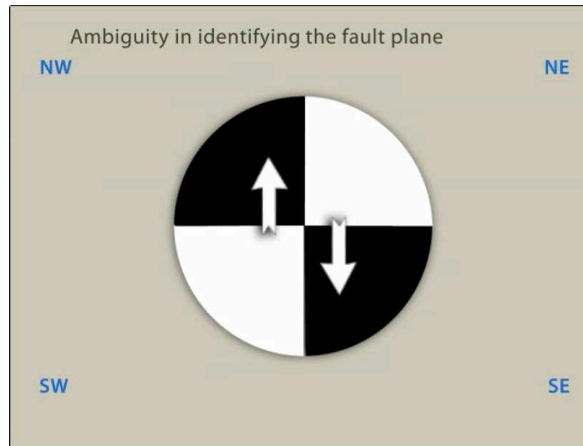
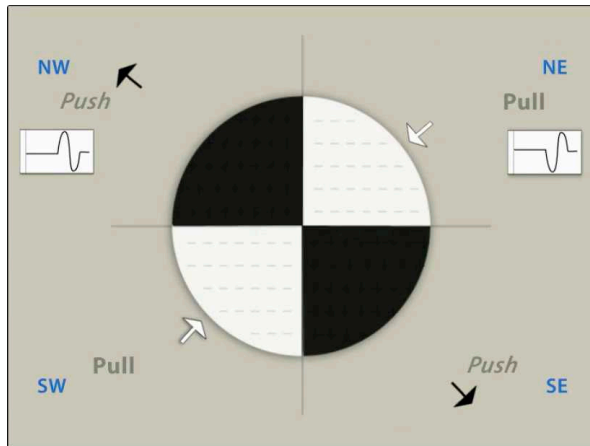
Seismologie



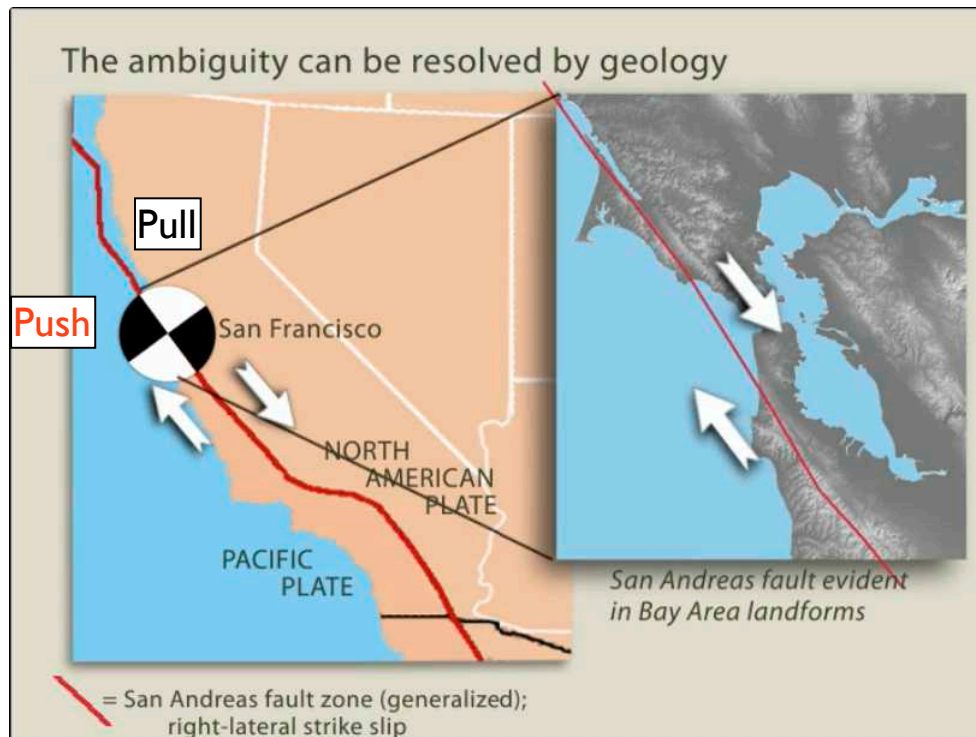
Herdflächenlösung



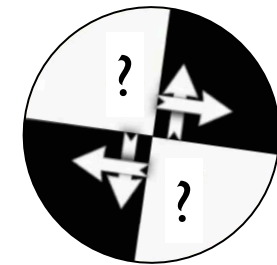
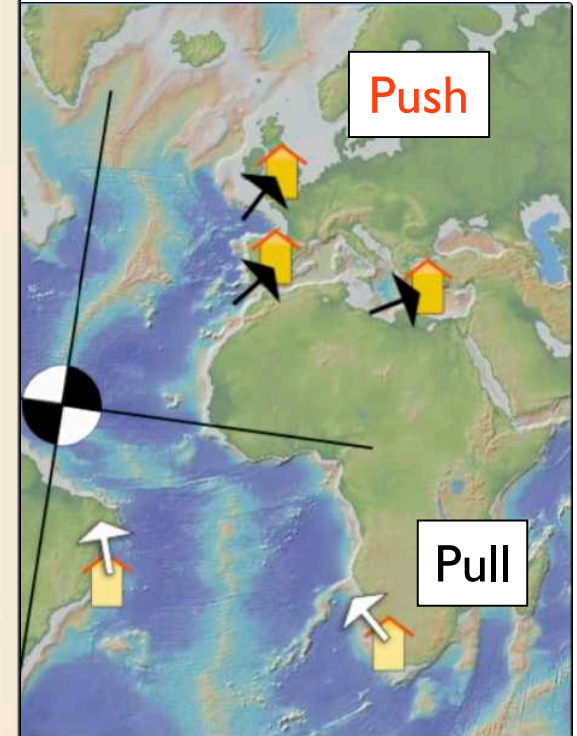
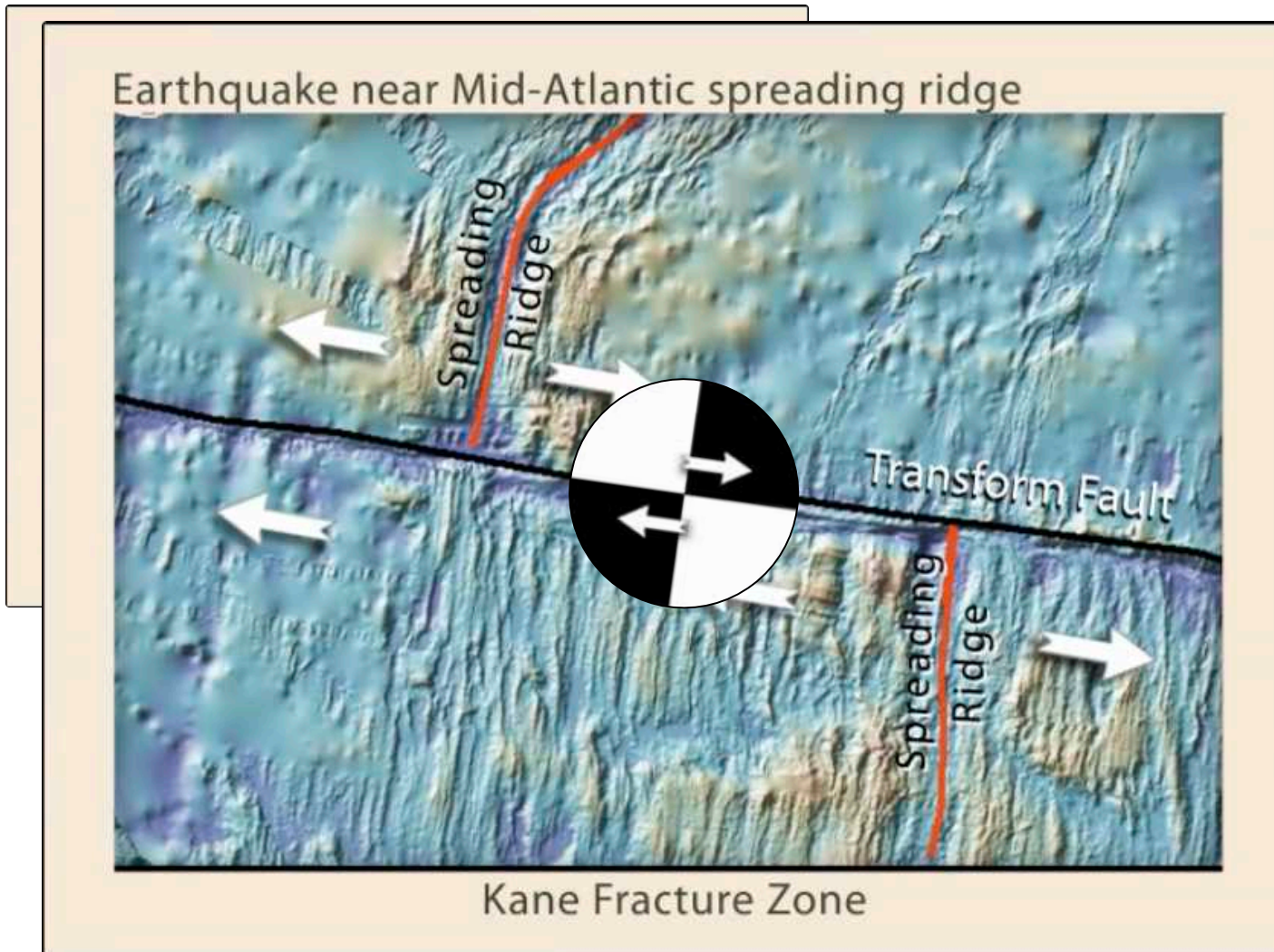
welches ist die Bruchfläche ?



geologische Einsicht:



Herdflächenlösung am Transformbruch



Transformbrüche - das letzte Puzzlestein

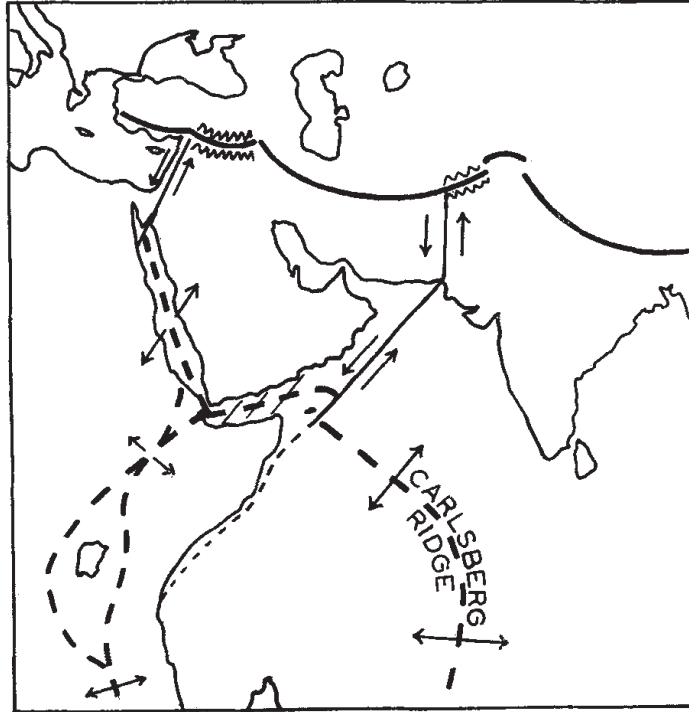


Fig. 8. Sketch illustrating the end of the Carlsberg mid-ocean ridge by a large transform fault (ridge-convex arc type) extending to the Hindu Kush, the end of the rift up the Red Sea by a similar transform fault extending into Turkey and the still younger East African rifts

Wilson, J. Tuzo (1965)
 "A new Class of Faults and their
 Bearing on Continental Drift"

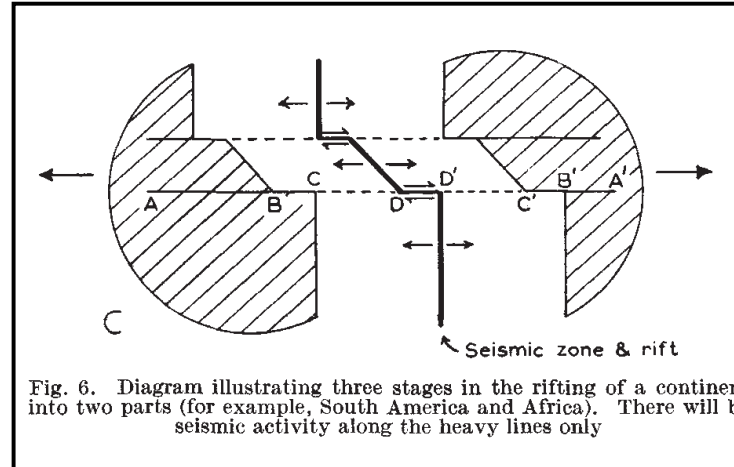
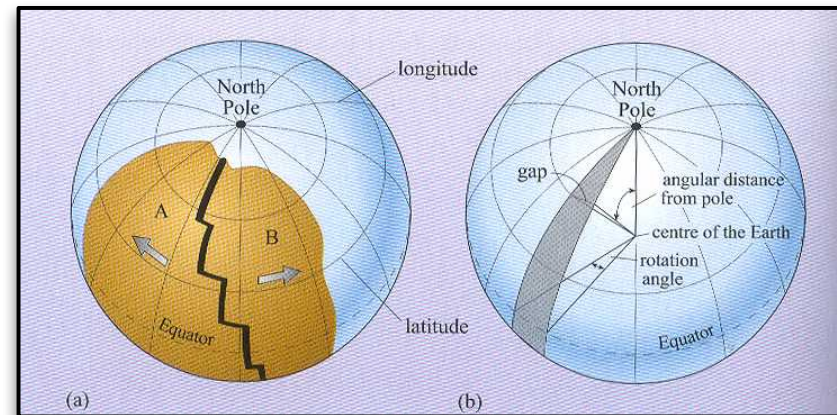
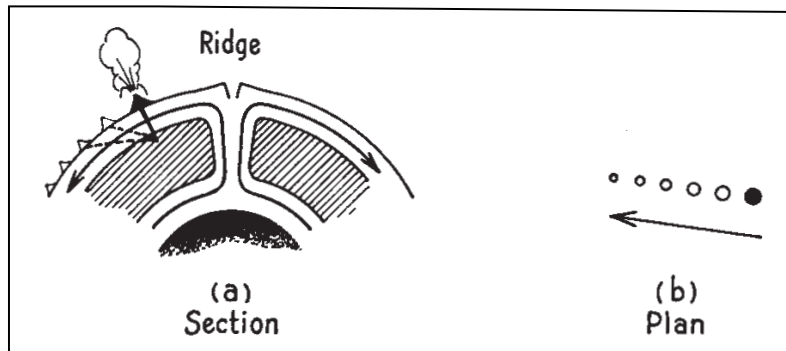


Fig. 6. Diagram illustrating three stages in the rifting of a continent into two parts (for example, South America and Africa). There will be seismic activity along the heavy lines only

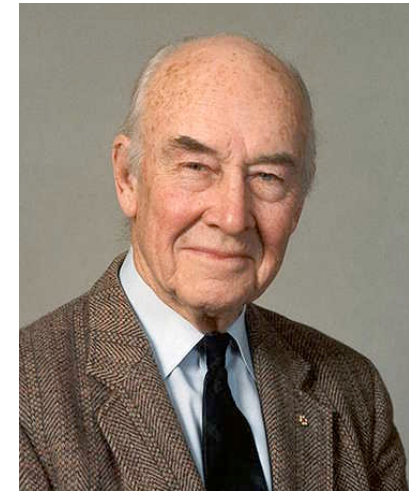


⇒ Verbindung von Quelle und Senke

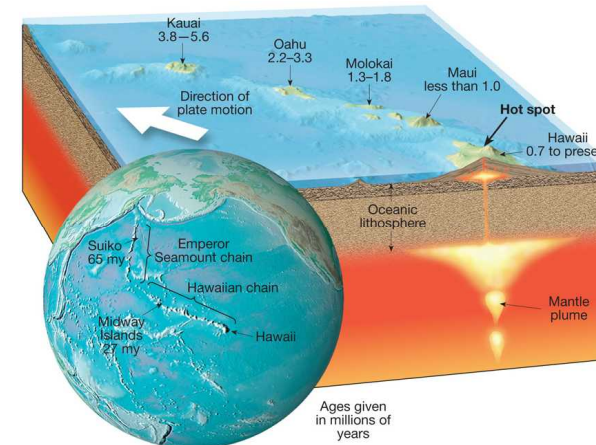
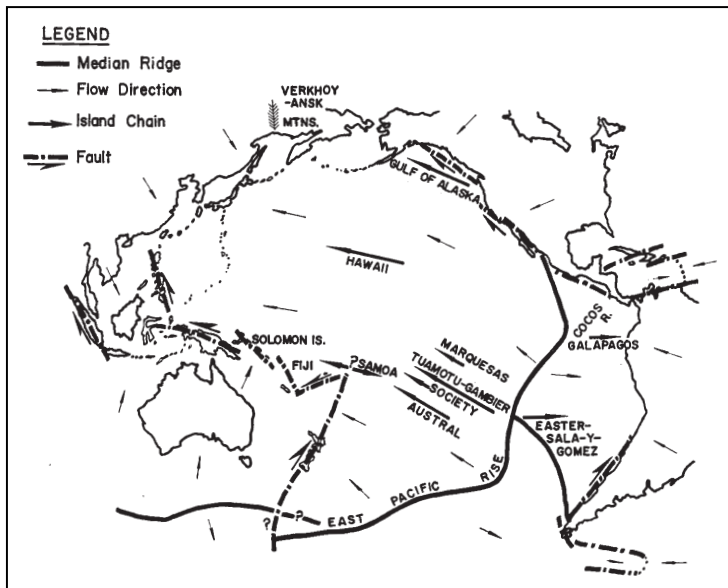
Hotspots - eine heiße Spur



(1) Hotspots (1963)
Platten bewegen sich über stationäre hotspots hinweg. Das bedeutet, dass die Platten relativ steif sind und sich über die weiche (schwache) Asthenosphäre hinwegbewegen, ohne sich intern zu verformen.



John Tuzo Wilson
(1908 - 1993)



(2) Transformbrüche (1965)

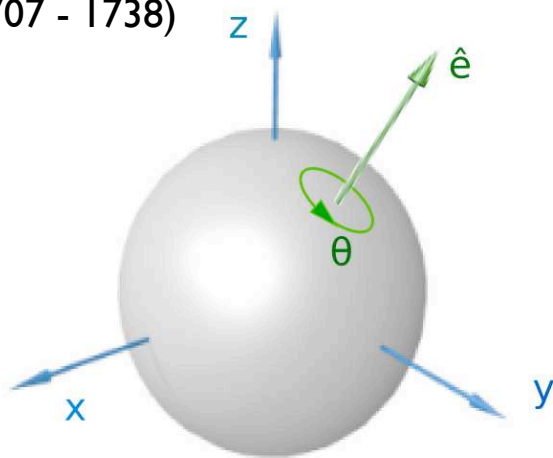
Die Erde expandiert nicht, deshalb muss es auch destruktive Plattengrenzen geben. Transformbrüche verbinden Seafloor Spreading und Subduktionszonen und bilden so eine zusammenhängende Plattengrenze.

⇒ steife Platten

Steife Platten ?



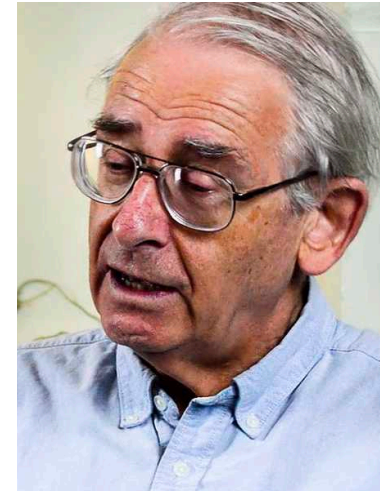
Leonhard Euler
(1707 - 1783)



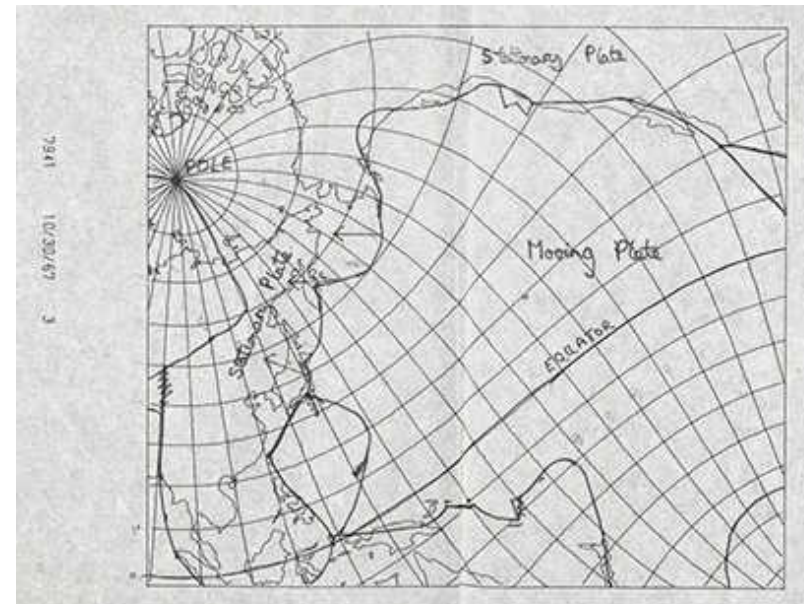
William Jason Morgan
* 1935



Xavier Le Pichon
* 1937

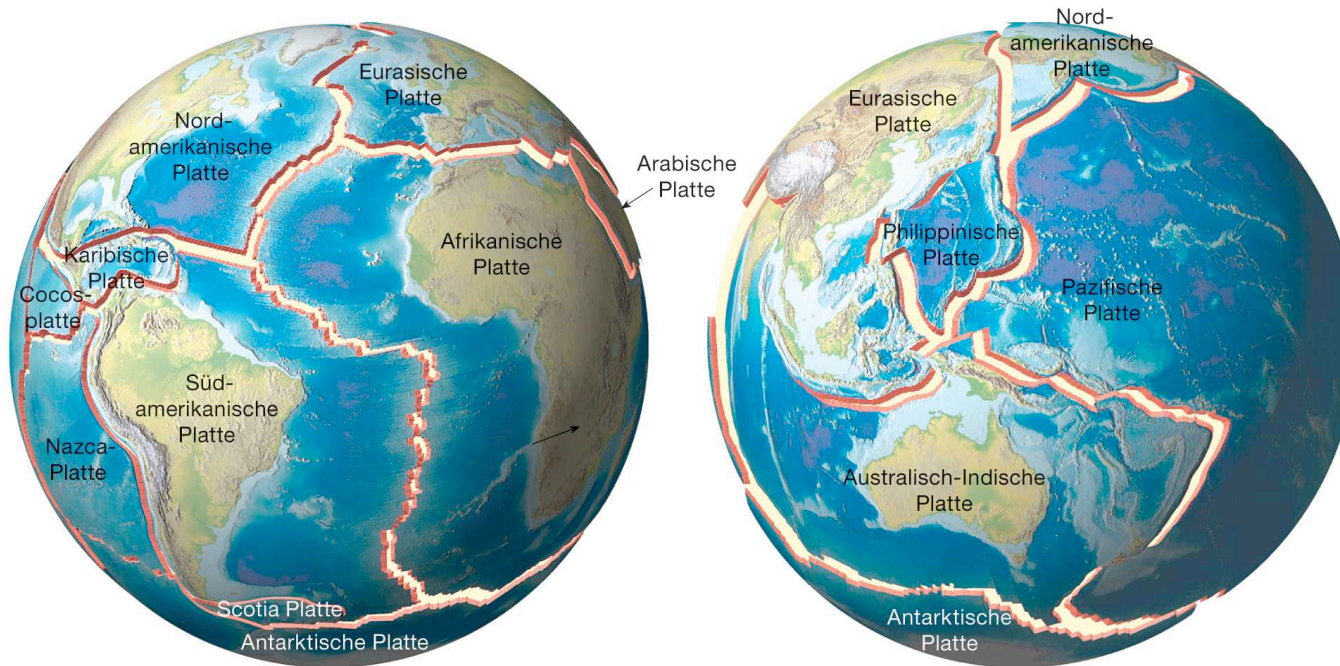


Dan Peter McKenzie
* 1942



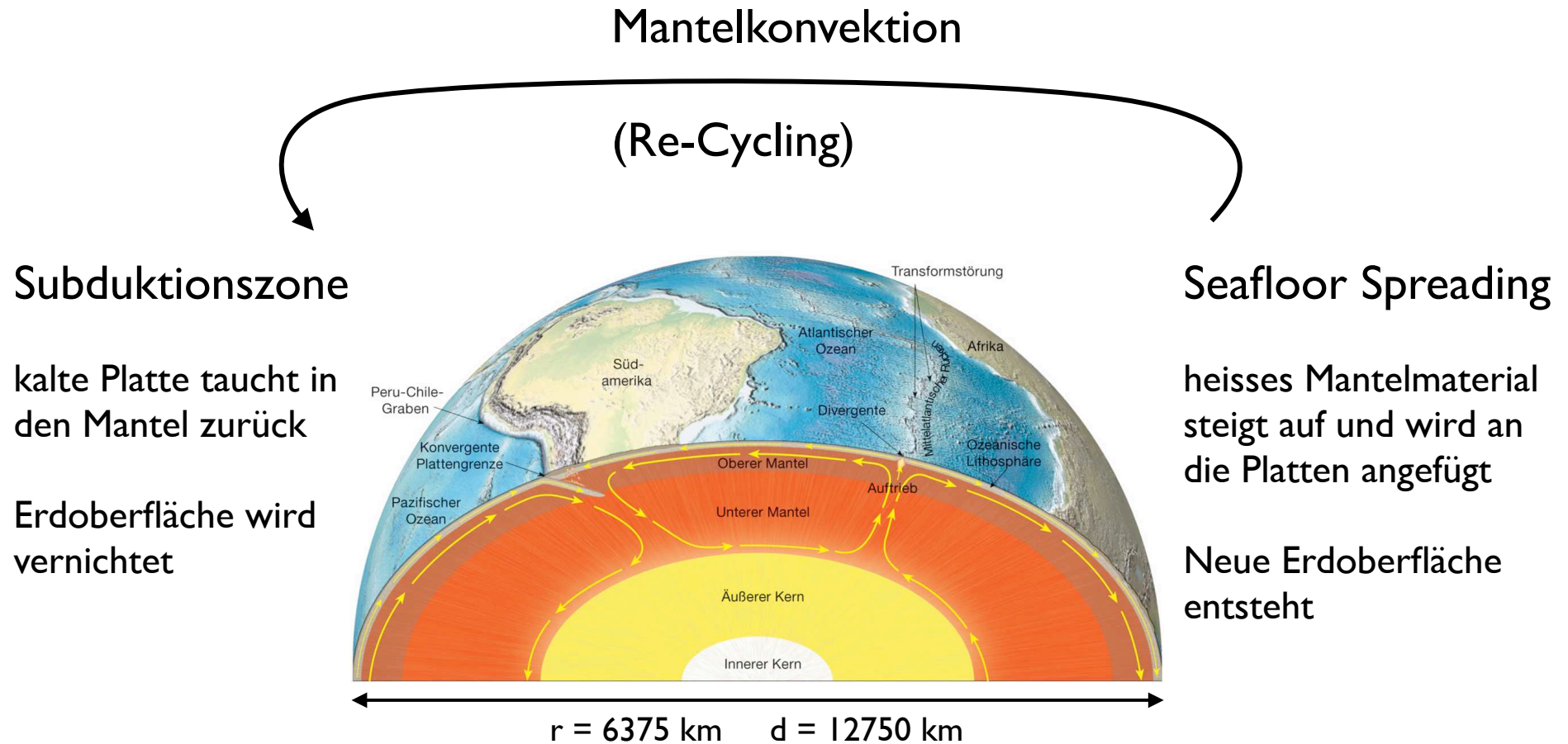
Formulierung des plattentektonischen Konzepts

Theorie der Plattentektonik



- Die Erdoberfläche ist in ca. 20 tektonische Platten unterteilt.
- Die Platten sind Lithosphärenplatten und bewegen sich \pm steif (ohne sich innerlich zu verformen) über die fließfähige Asthenosphäre hinweg.
 1. An den mittelozeanischen Rücken (= konstruktive Plattengrenze) wird aufsteigendes Mantelmaterial an die auseinander driftenden Platten angefügt (Seafloor Spreading)
 2. An den Subduktionszonen (= destruktive Plattengrenze) wird die Lithosphäre wieder in den Erdmantel zurück versenkt.
 3. Transformbrüche (= konservative Plattengrenzen) verbinden die Plattengrenzen, sodass jede Platte kinematisch vollkommen von ihren Nachbarinnen entkoppelt ist.

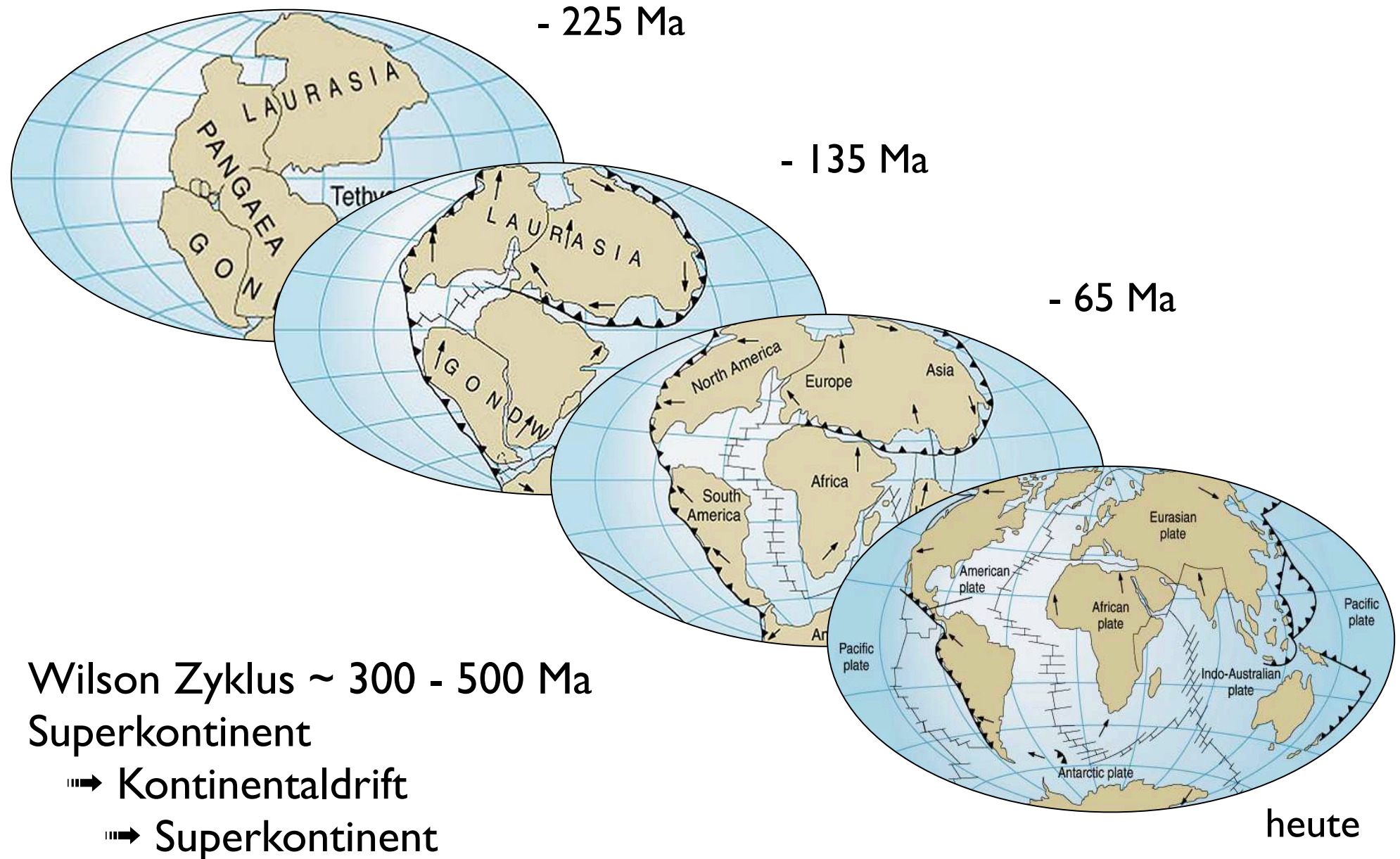
Motor der Plattentektonik



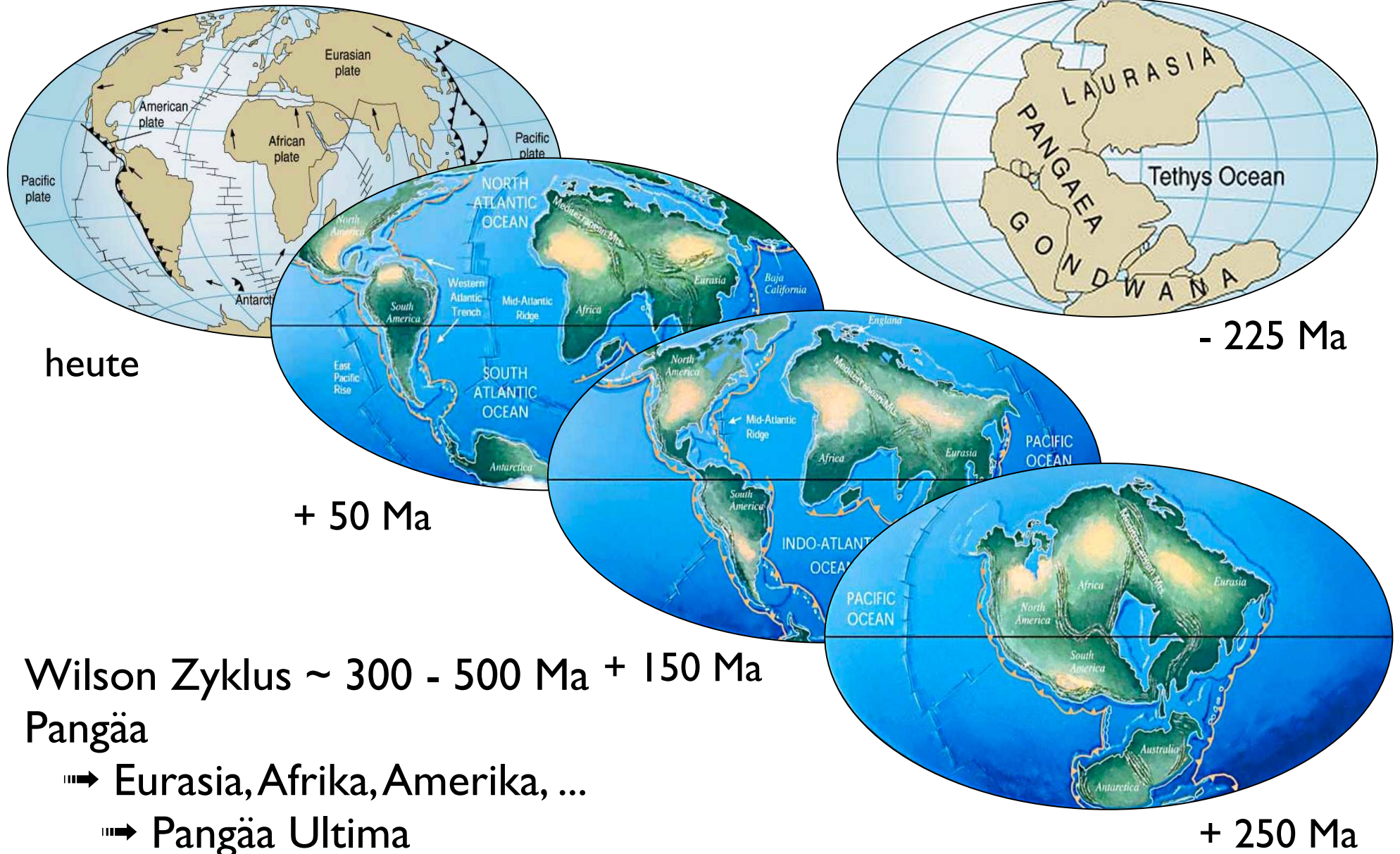
Lithosphärenplatten definiert durch Plattengrenzen:

- Seafloor Spreading
- Subduktionszonen
- Transformstörungen
- Untergrenze \neq Kruste/Mantel-Grenze (Moho)
- Untergrenze = Kontakt zu Asthenosphäre

Wilson Zyklus - von Pangäa bis heute

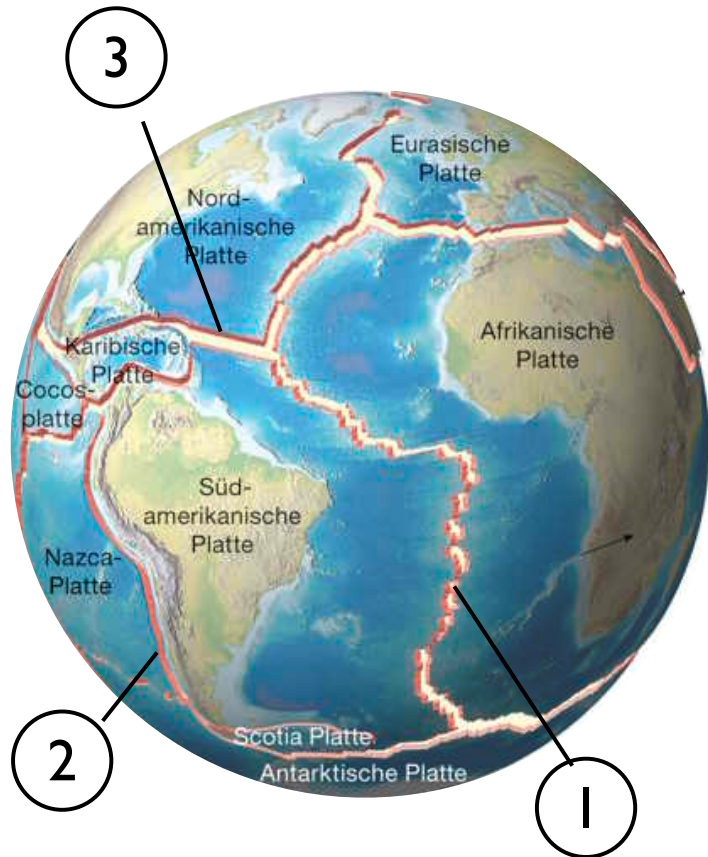


Wilson Zyklus - die nächsten 250 Ma



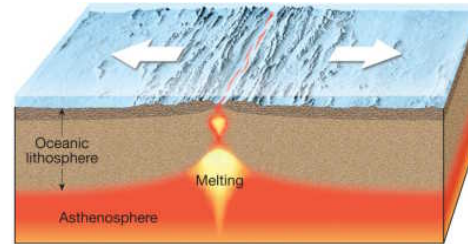
Spurensicherung an Plattengrenzen

pro memoria: Platten und Plattengrenzen

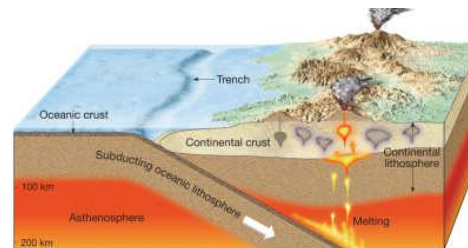


1. Seafloor Spreading
2. Subduktionszonen
3. Transformstörungen

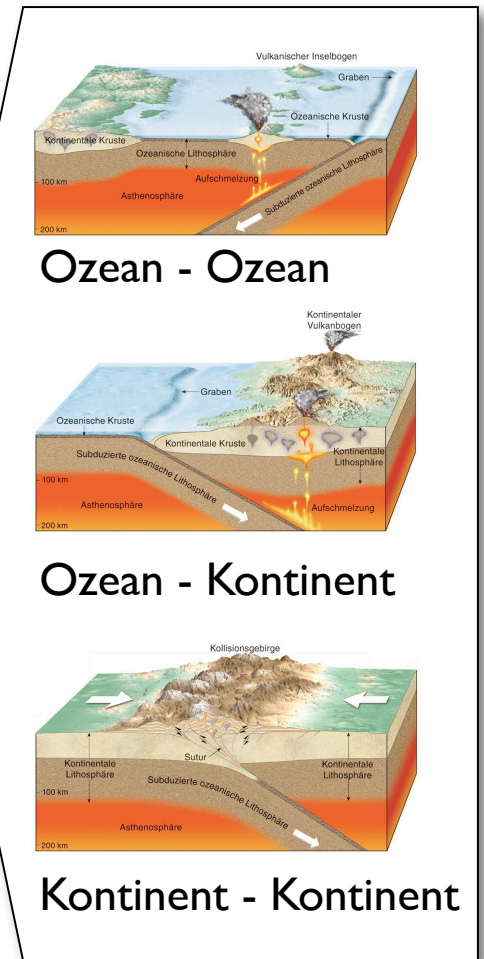
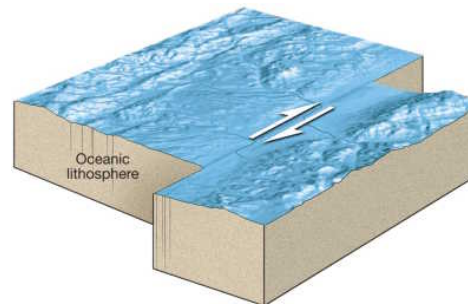
1 konstruktiv



2 destruktiv



3 konservativ



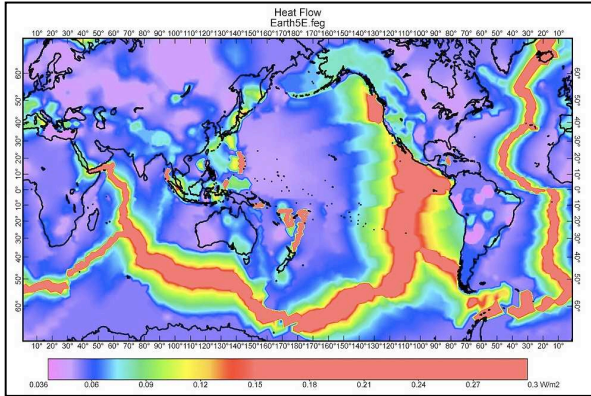
Ozean - Ozean

Ozean - Kontinent

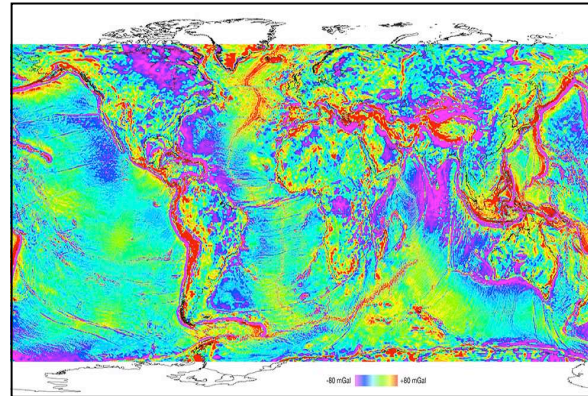
Kontinent - Kontinent

wie sich Plattengrenzen verraten

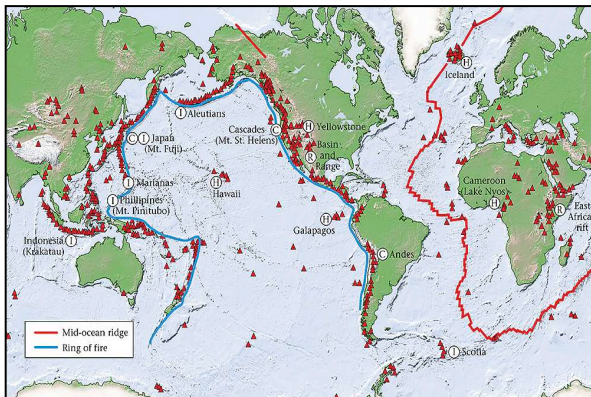
1- Wärmefluss → konstruktive



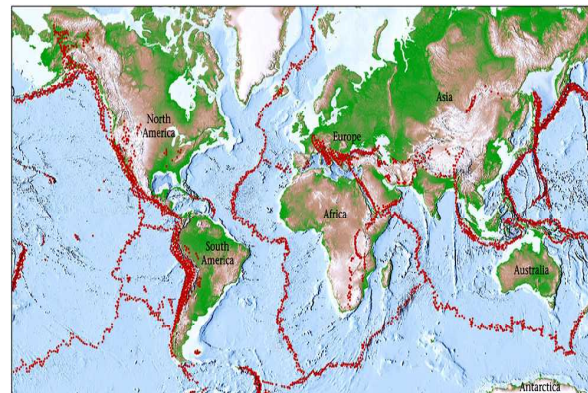
3- Schwereanomalien → destruktive



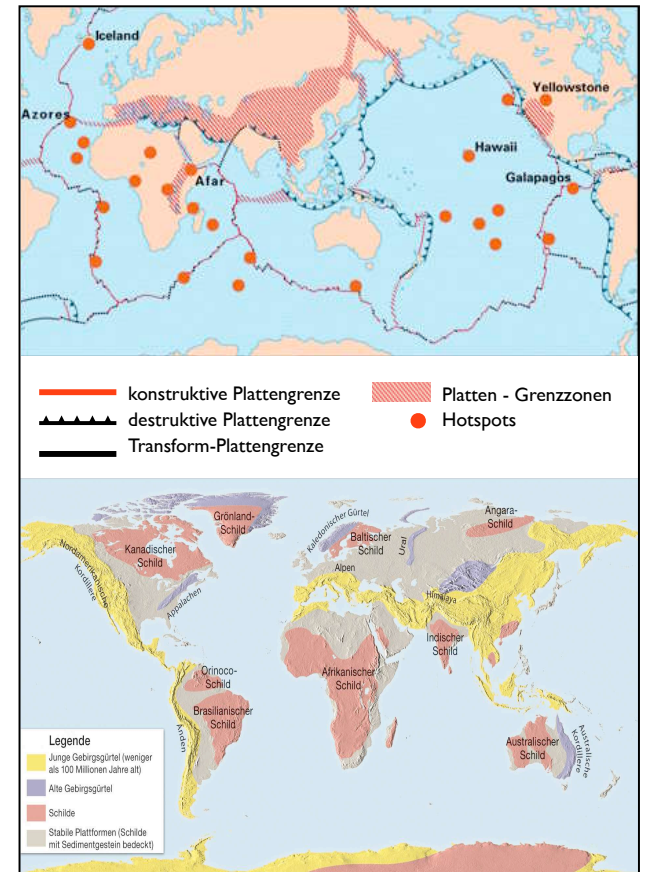
2- Vulkanismus → alle



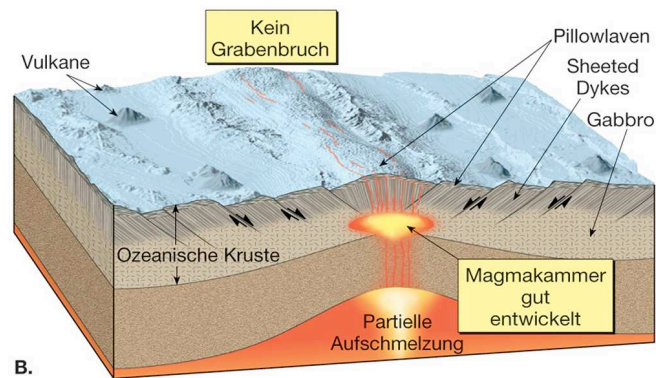
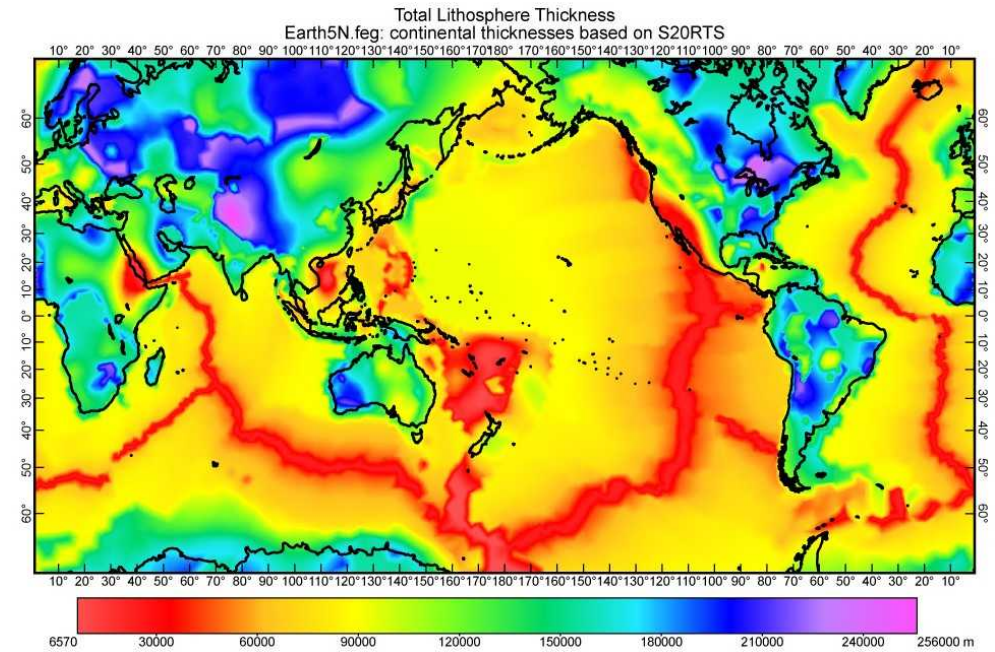
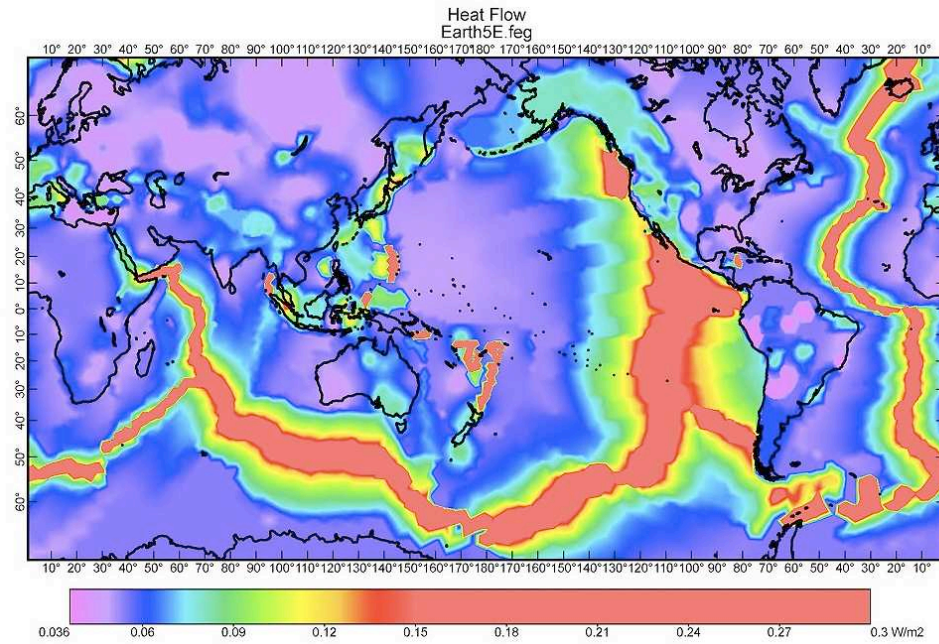
4- Erdbeben → alle



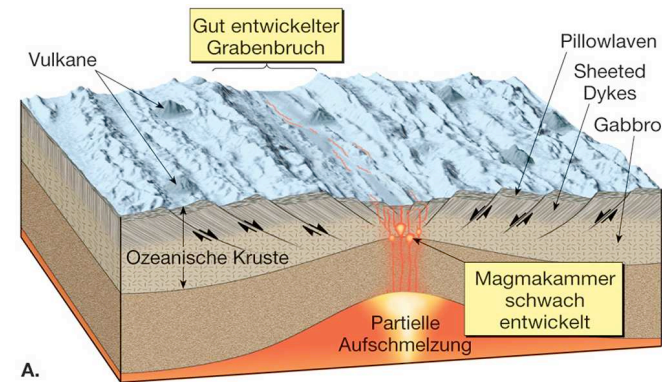
5- Deformation
Gebirgsbildung → destruktive



I - Wärmefluss: Seafloor Spreading

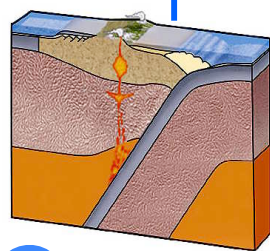
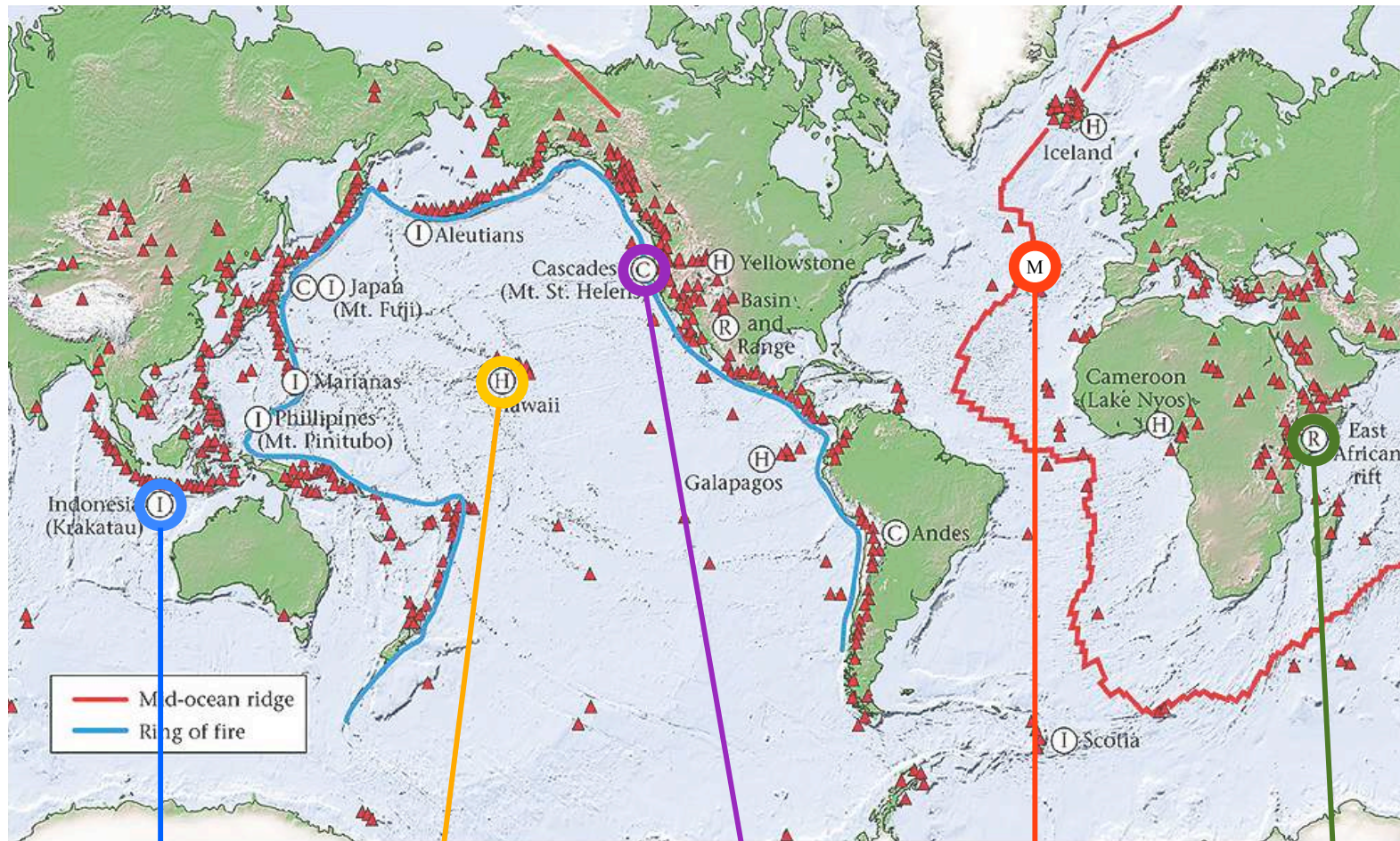


schnelle Öffnung
(Ostpazifischer Rücken)

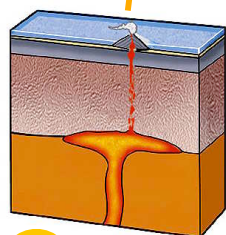


langsame Öffnung
(Mittelatlantischer Rücken)

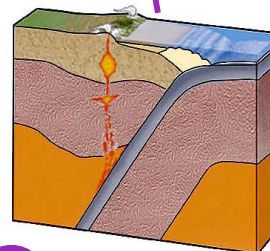
2- Vulkanismus an Plattengrenzen



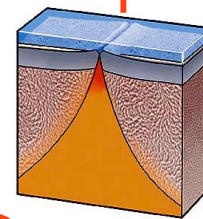
I = Island arc
destruktiv



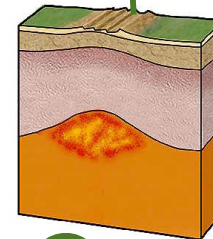
H = Hot spot
(-)



C = Continental arc
destruktiv



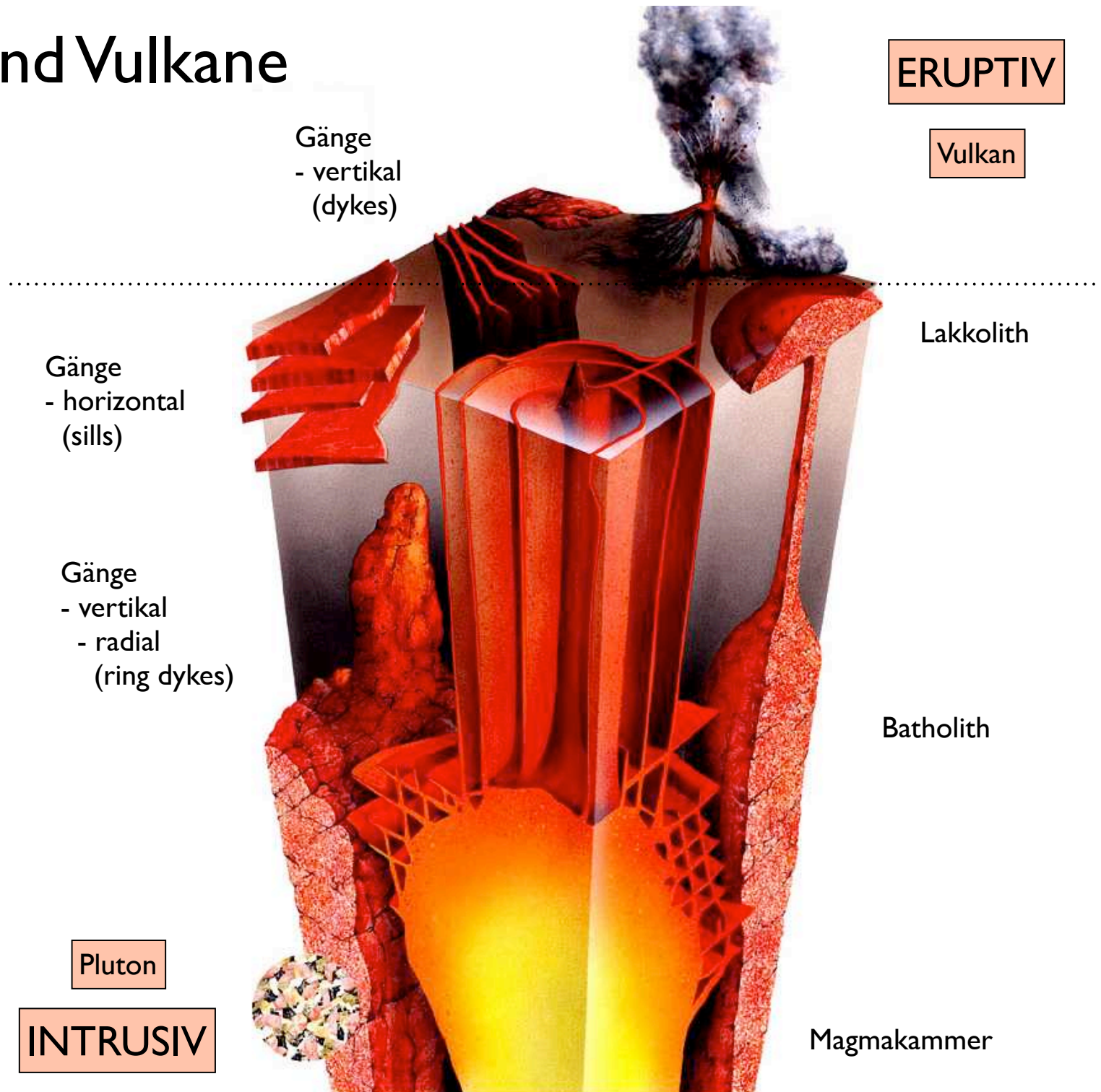
M = Mid-ocean ridge
konstruktiv



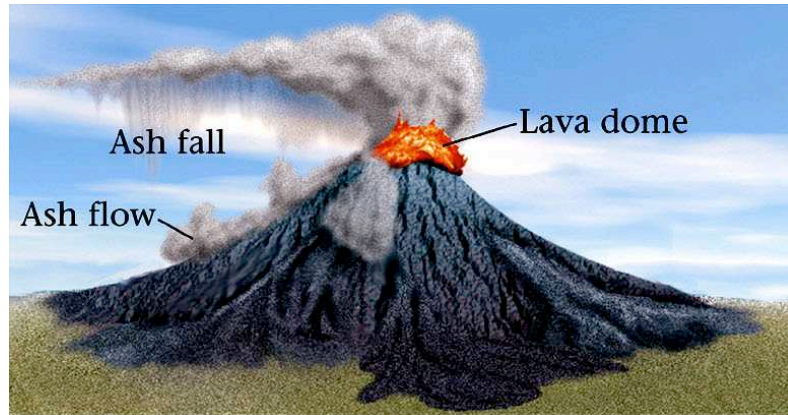
R = Rift
konstruktiv

2- Plutone und Vulkane

Erstarrungsgeschwindigkeit



2- will it flow or will it blow?



Felsisch = blow

Felsische Gesteinsschmelze (Magma)
→ Rhyolitische Lava

Zähflüssig, wenig fließfähig
(hochviskös)
→ Gefährliche Explosionen

Beispiel: Mount St Helens



Mafisch = flow

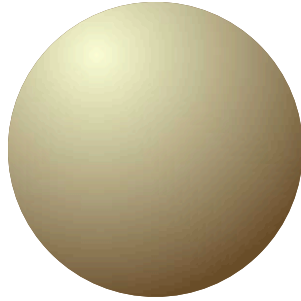
Mafische Gesteinsschmelze (Magma)
→ Basaltische Lava

Dünnflüssig, leicht fließfähig
(niederviskös)
→ Ungefährliches Ausfließen

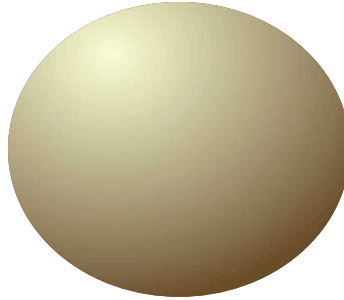
Beispiel: Hawaii

3- Schwerefeld der Erde - welche Form hat sie ?

Ist die Erde ...

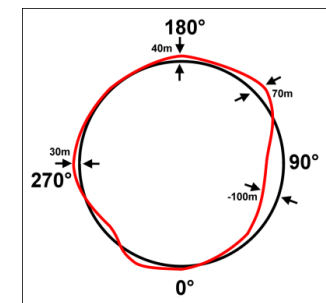
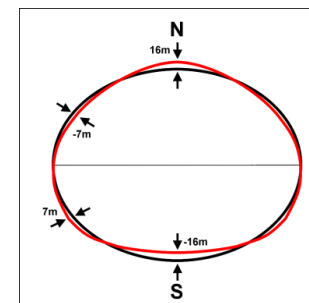
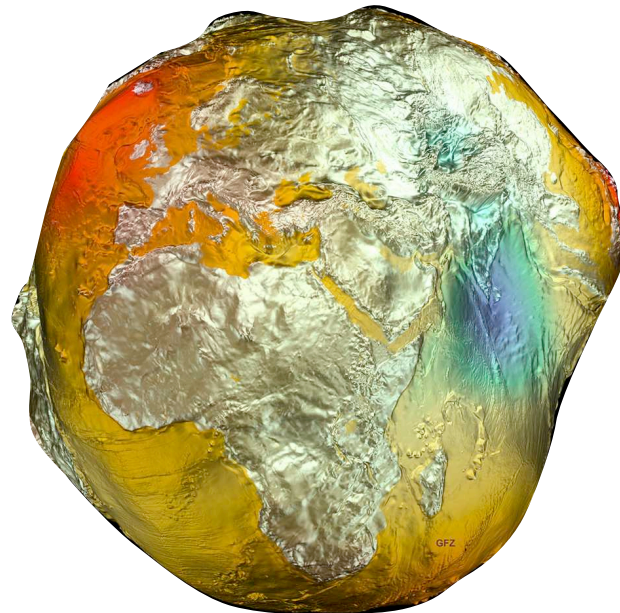
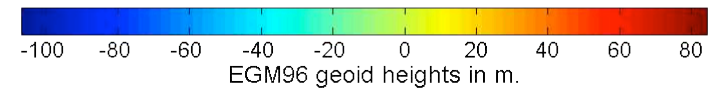
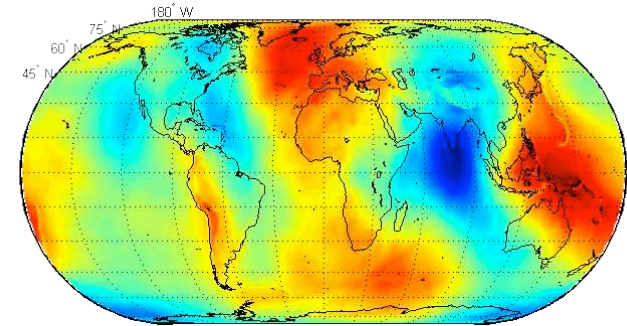


... eine Kugel ?



... ein Rotationsellipsoid ?

Seit 1828 (Carl Friedrich Gauss) ist die physikalische Form der Erde das sogenannte Geoid ...



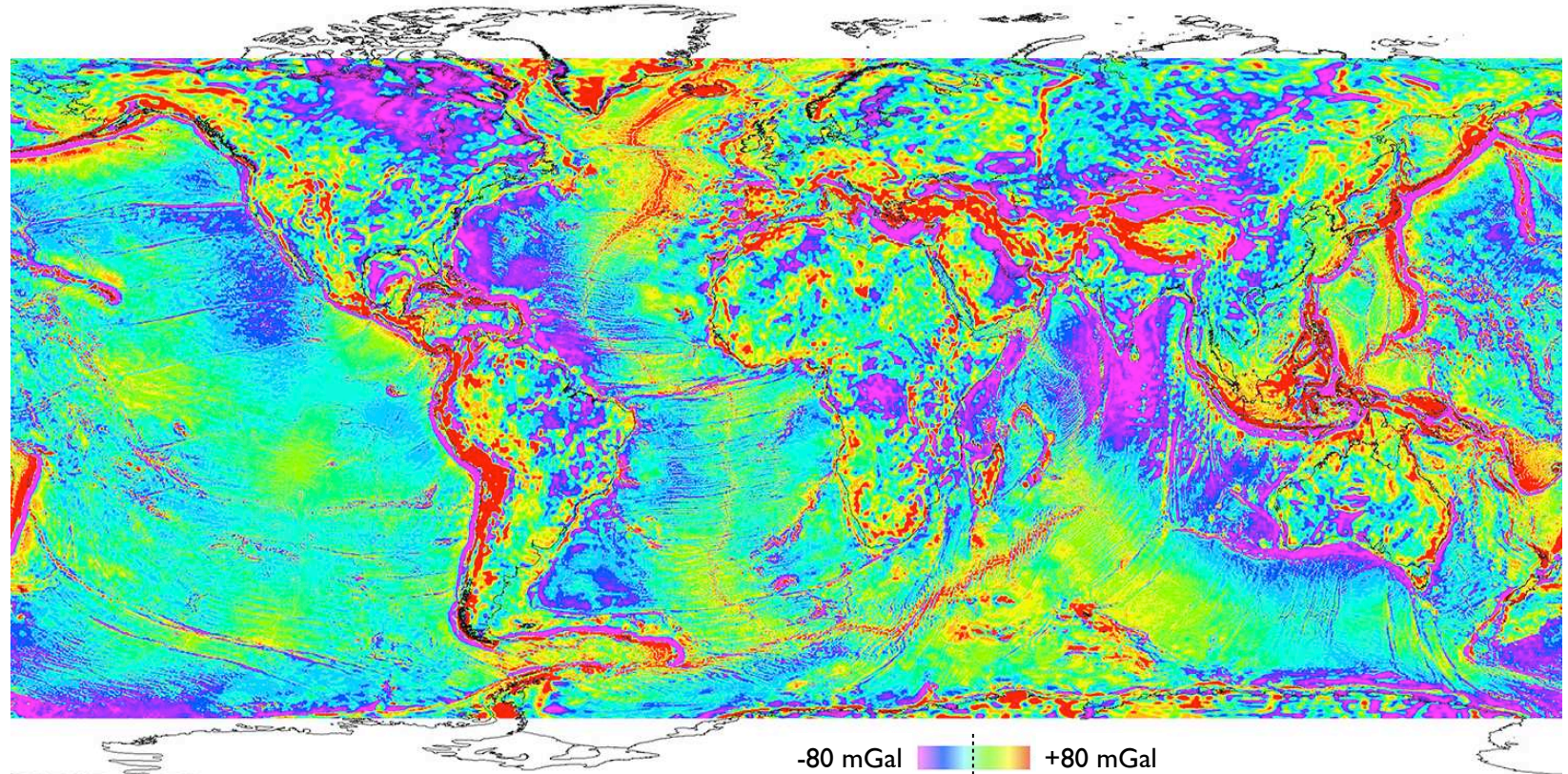
... seit 1996 ist ein Birne...

... und seit 2011 eine Kartoffel !

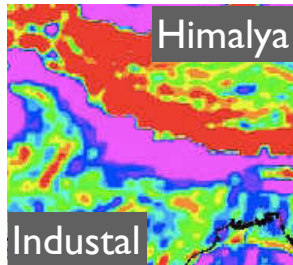
3- Welt - Schwerekarte

<http://www.ngu.no/geodynamics/gplates/>

--- Free Air Gravity Anomaly Map



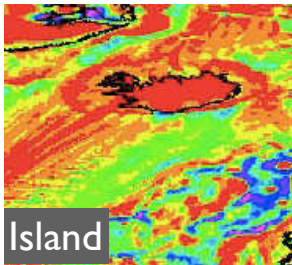
Kontinent



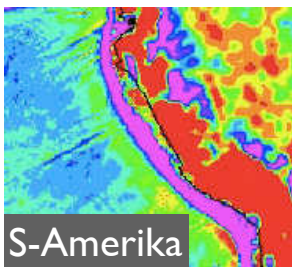
Himalaya

Industal


Ozean



Inland



S-Amerika

-80 mGal  +80 mGal

der Höhenlage entsprechende Erdanziehung: zu tief ← → zu hoch

Kontinentalbereich bedeutet:

$\Delta g_F > 0$ zusätzliche Gesteinsmasse

$\Delta g_F < 0$ sehr geringe Dichte - Sedimente

Im Ozeanbereich bedeutet

$\Delta g_F > 0$ dichtes (Mantel-) material - Ozeanrücken

$\Delta g_F < 0$ fehlende Anziehung - grosse Wassertiefe - Graben

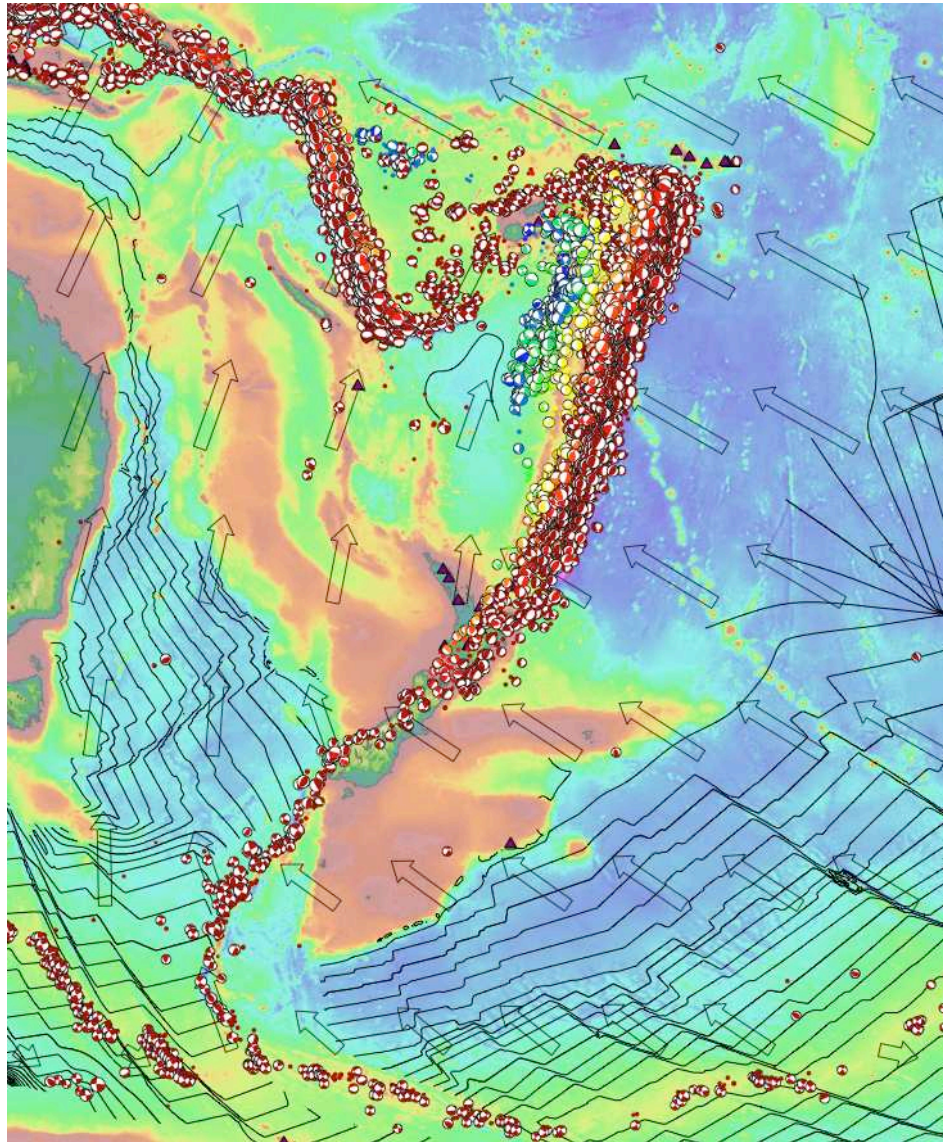
4- Erdbeben an Plattengrenzen



Epizentren definieren Plattengrenzen
Pro memoria: Plattengrenzen \neq Kontentalrand

Epizentrum:	Erdoberfläche
Hypozentrum:	Erdbebenherd (in der Tiefe)

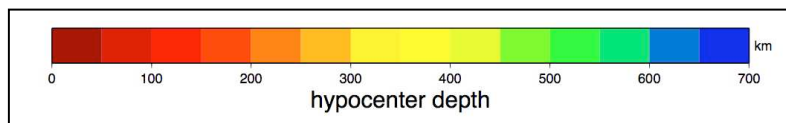
4- Erdbeben an Platten grenzen



Typ Plattengrenze	Tiefe der Erdbeben
konstruktiv	seicht
destruktiv	tief
Transform	seicht

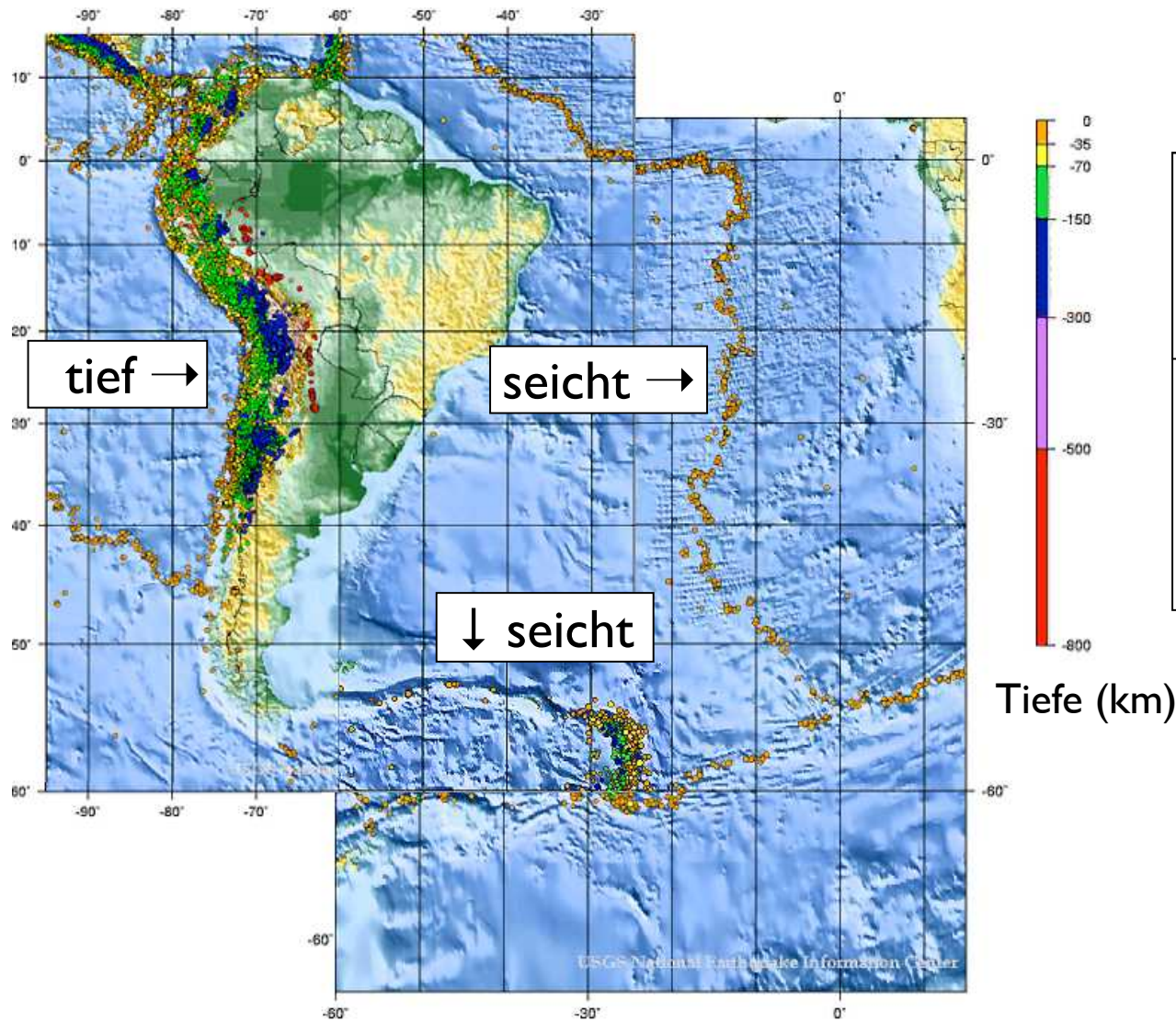
seicht: bis 50 km

tief: bis 700 km



⊙ ⊗ Erdbeben Hypozentren

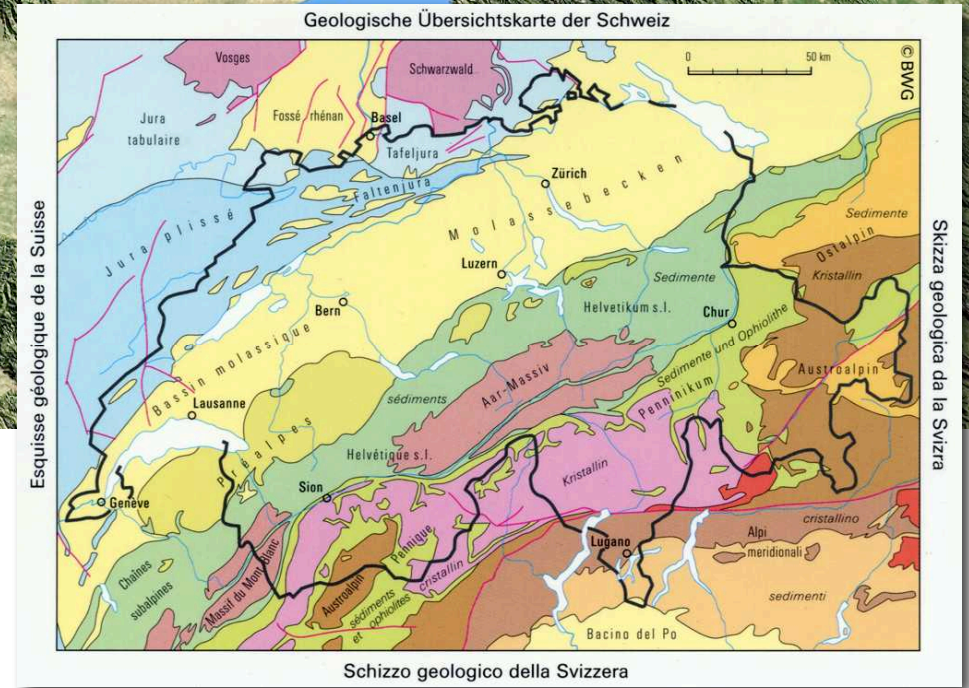
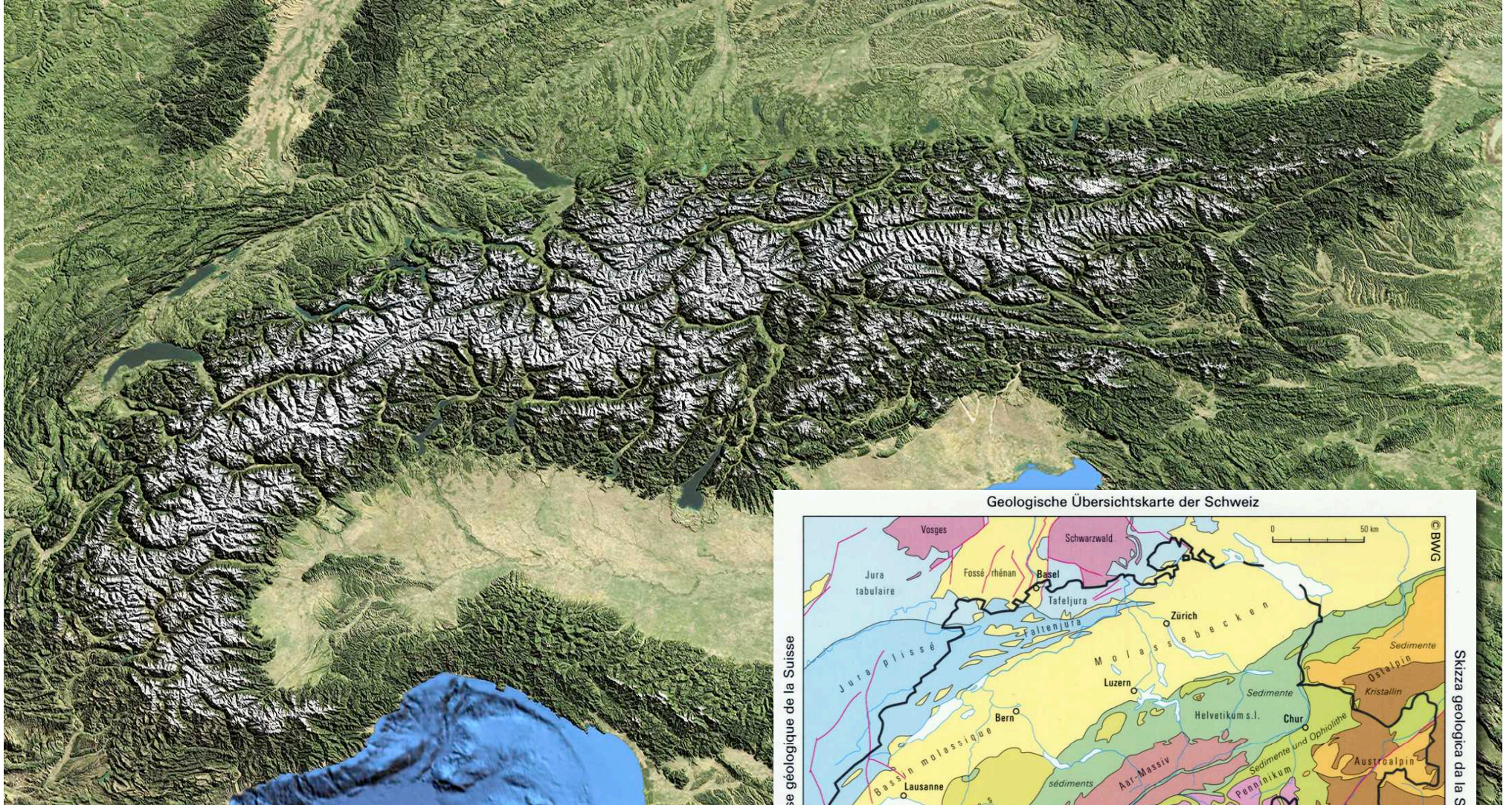
4- Charakteristische Tiefe der Erdbeben



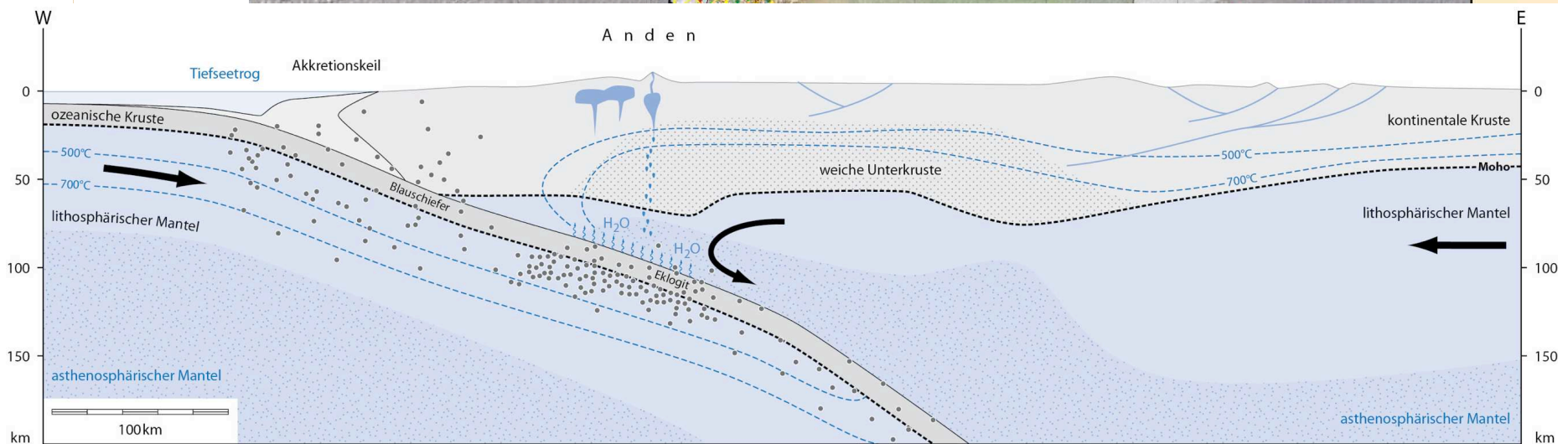
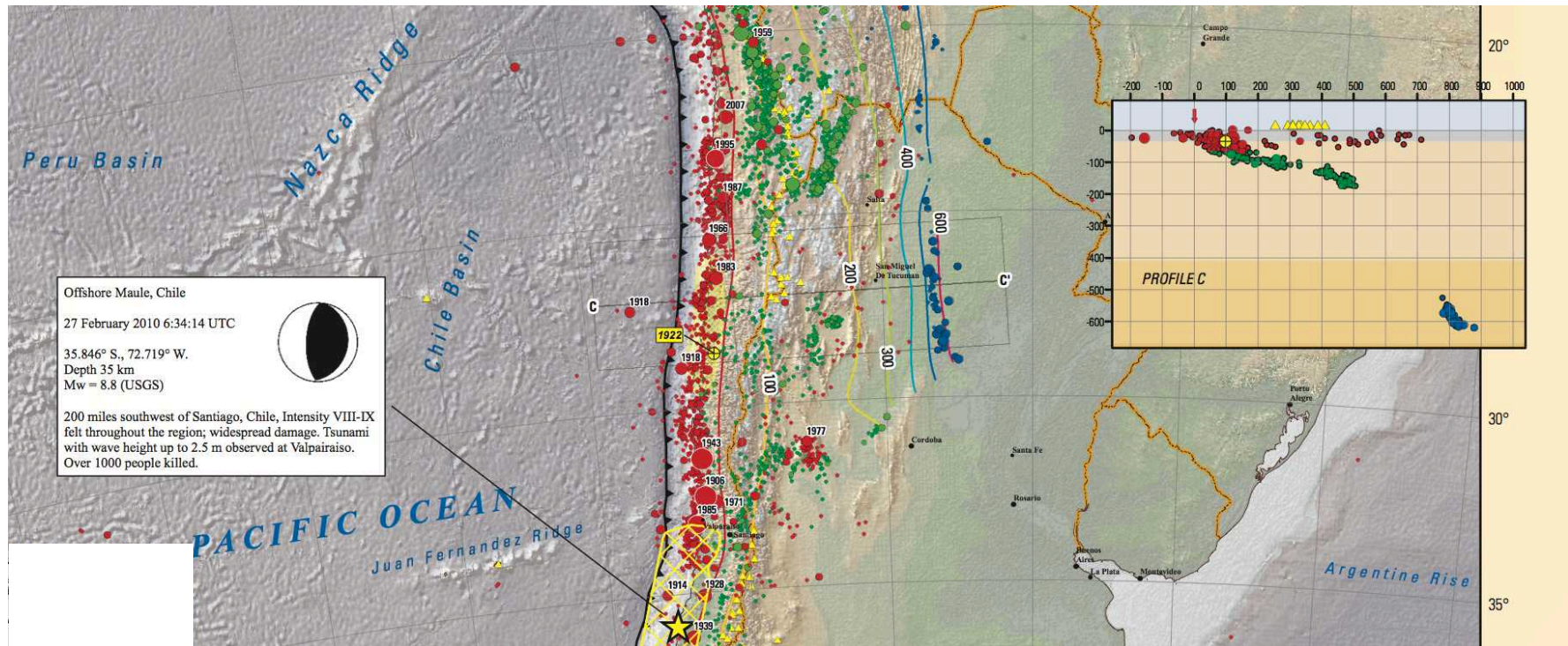
Typ Plattengrenze	Tiefe der Erdbeben
oz. Rücken	seicht
Subduktion	tief
Transform	seicht

seicht: bis ~50 km
 tief: bis 700 km

5- Deformation und Gebirgsbildung - Alpen

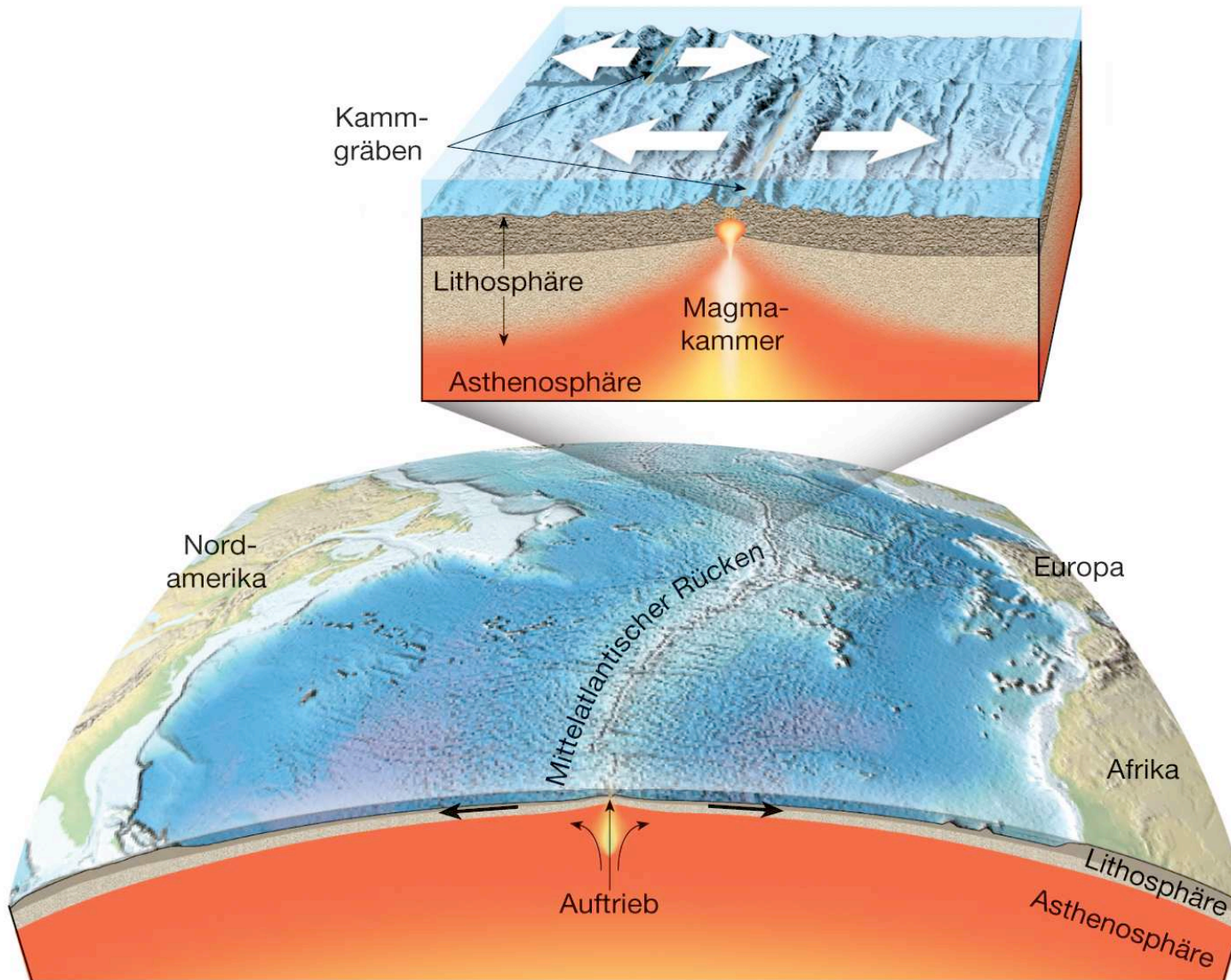


5- Deformation und Gebirgsbildung - Anden



**Steckbrief:
konstruktive
Plattengrenzen**

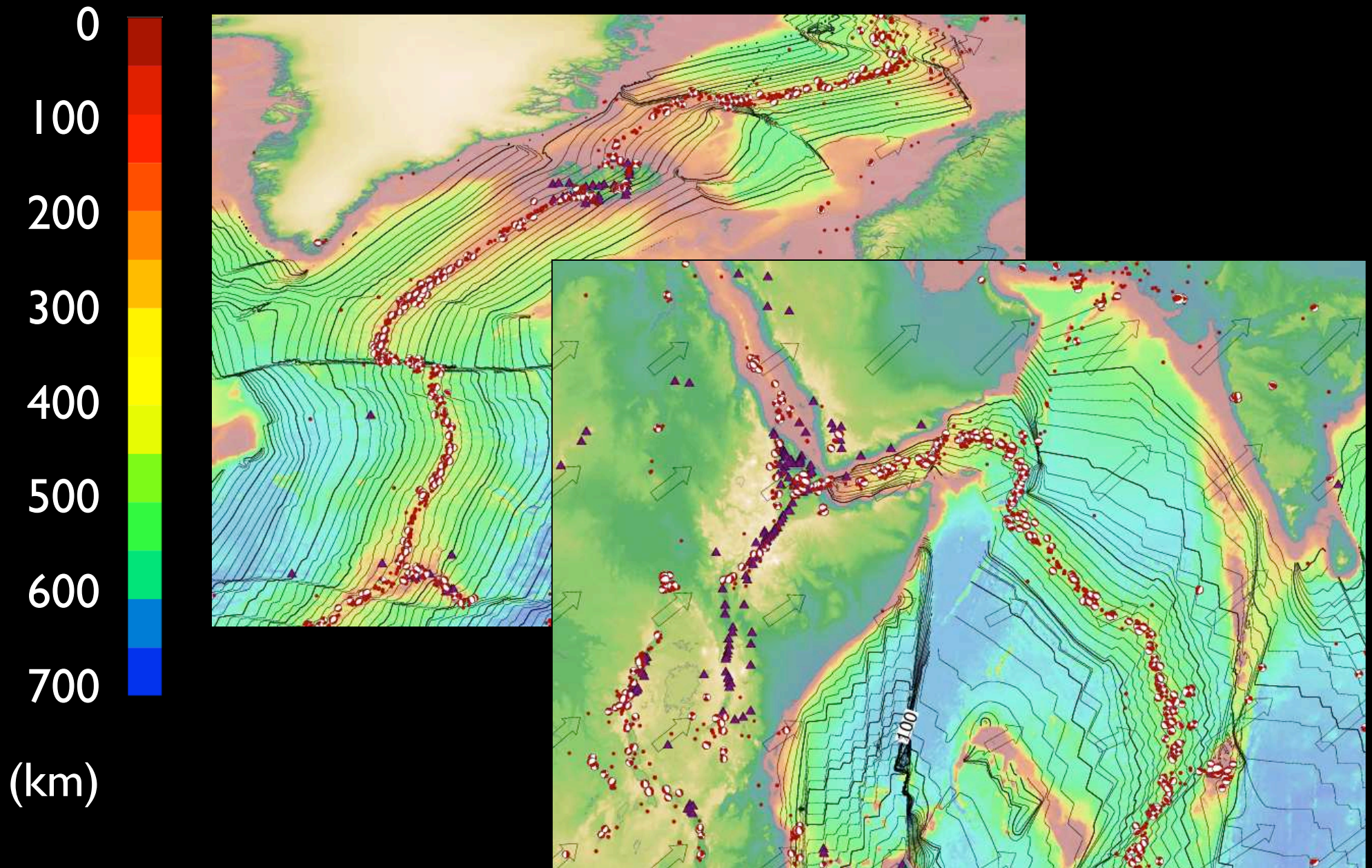
Konstruktive Plattengrenzen



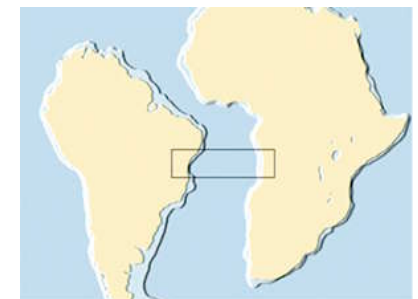
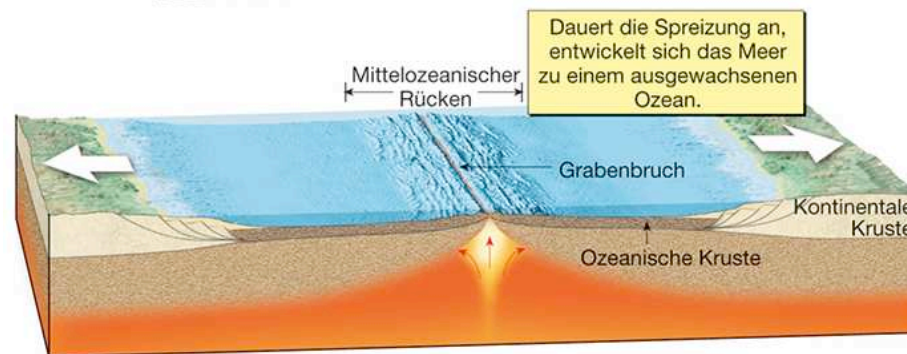
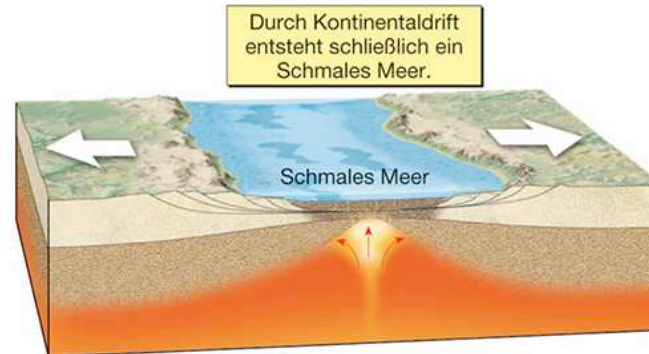
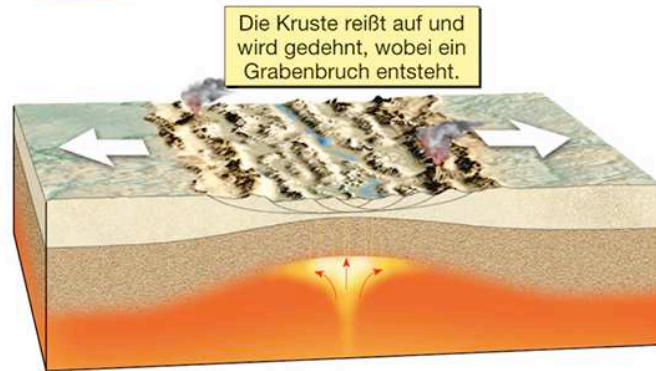
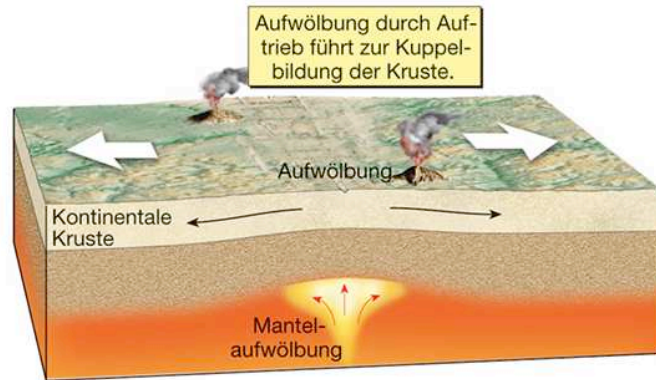
(physikalisch)
konstruktiv
=
(kinematisch)
divergent
=
(geometrisch)
distensiv

Abbildung 2.21: Die meisten divergenten Plattengrenzen befinden sich an den Kämmen der Ozeanischen Rücken.

Seichte Beben - Konstruktive Plattengrenzen

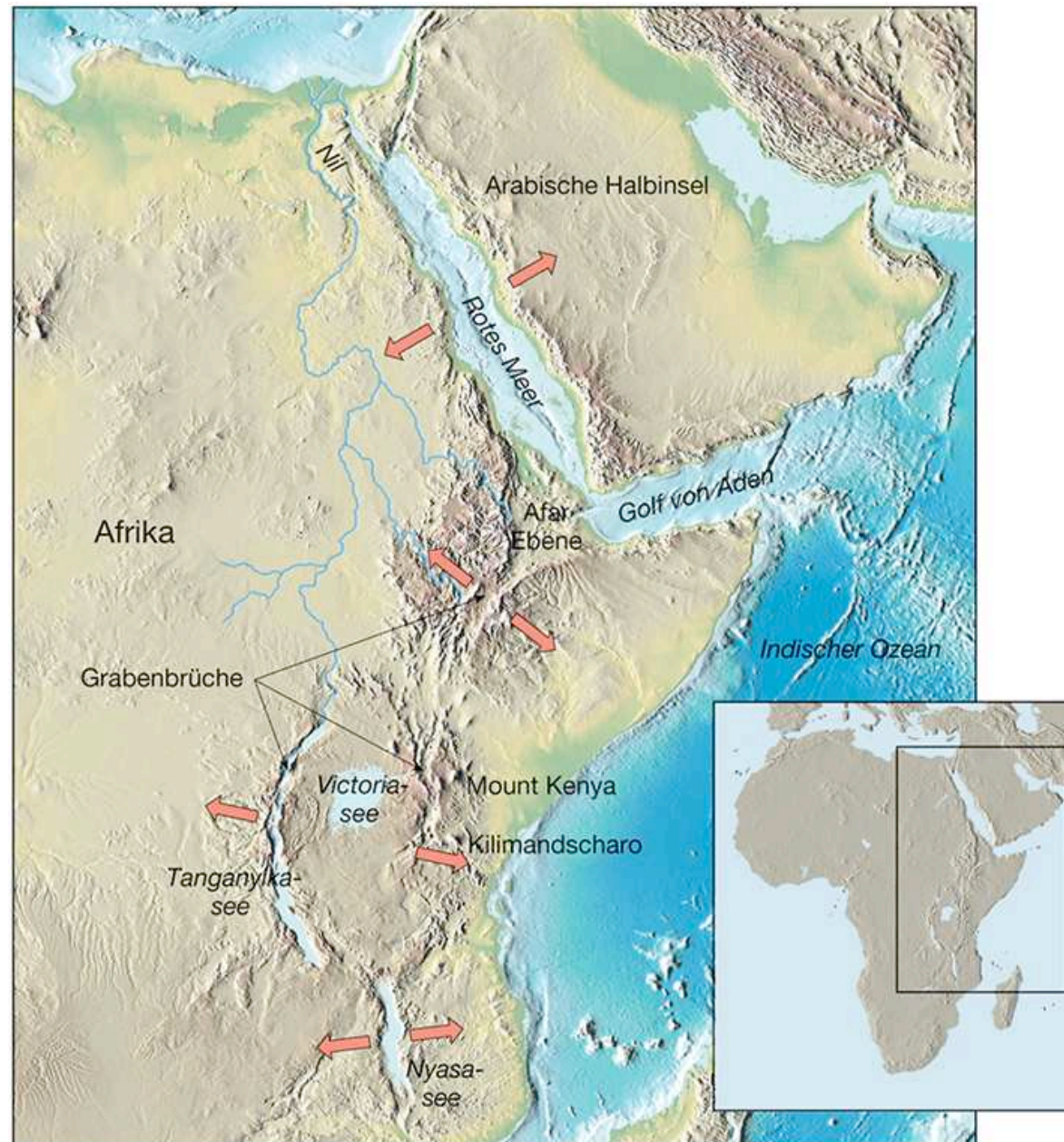


vom kontinentalen Grabenbruch zum Ozean



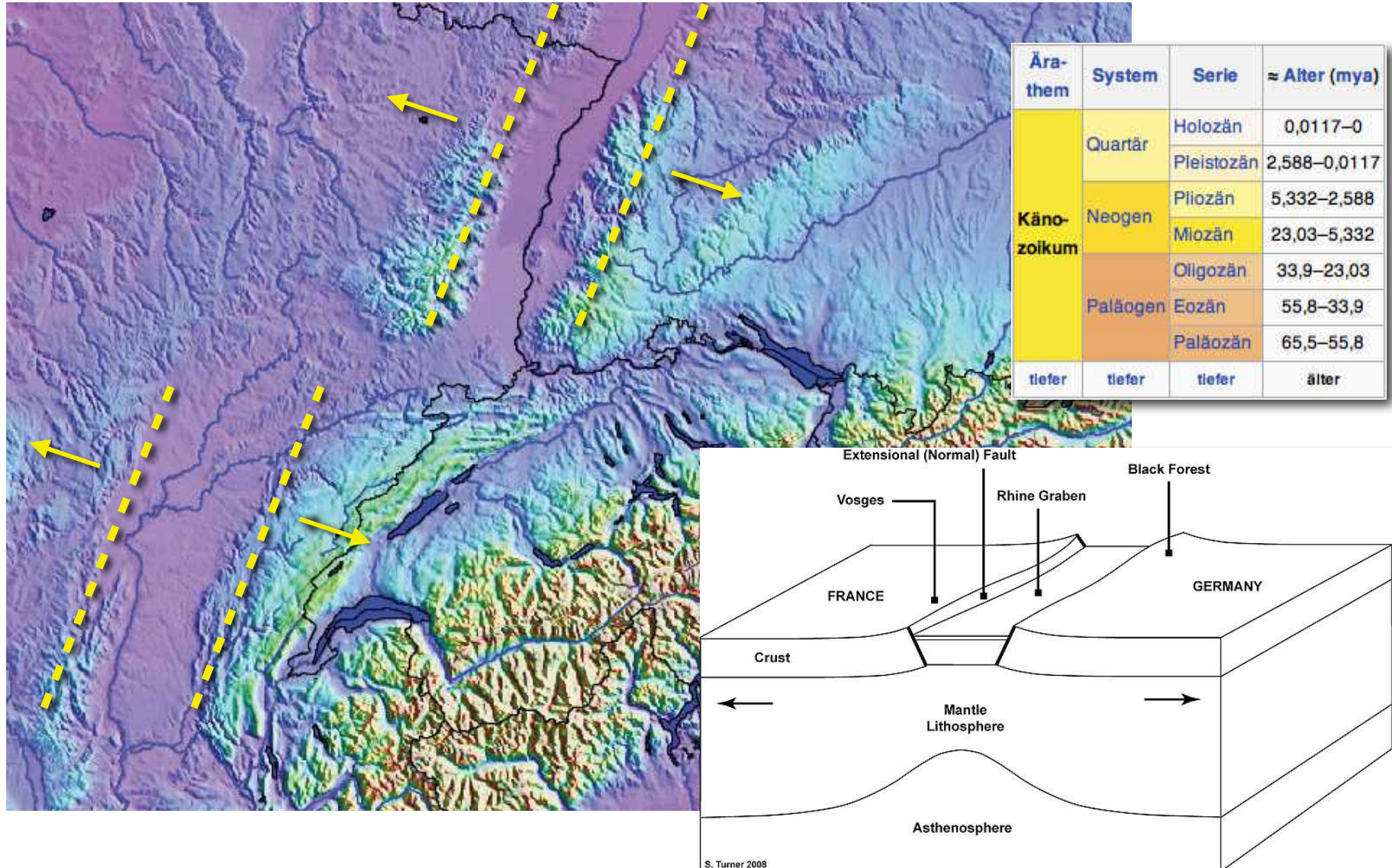
Beispiel: Ostafrikanischer Grabenbruch

aktuell
aktiv



Beispiel: Rheingraben Bressegraben

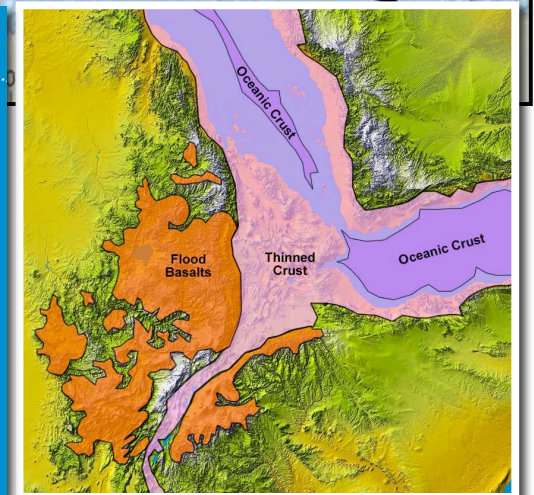
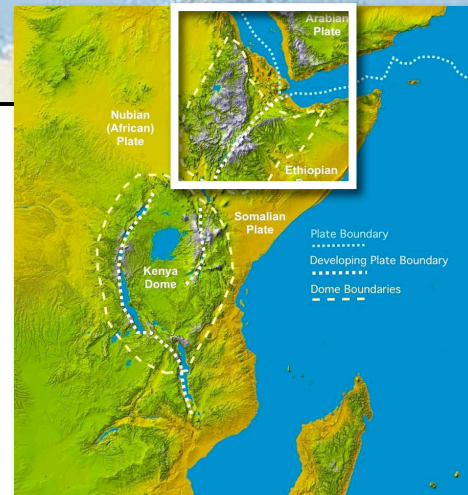
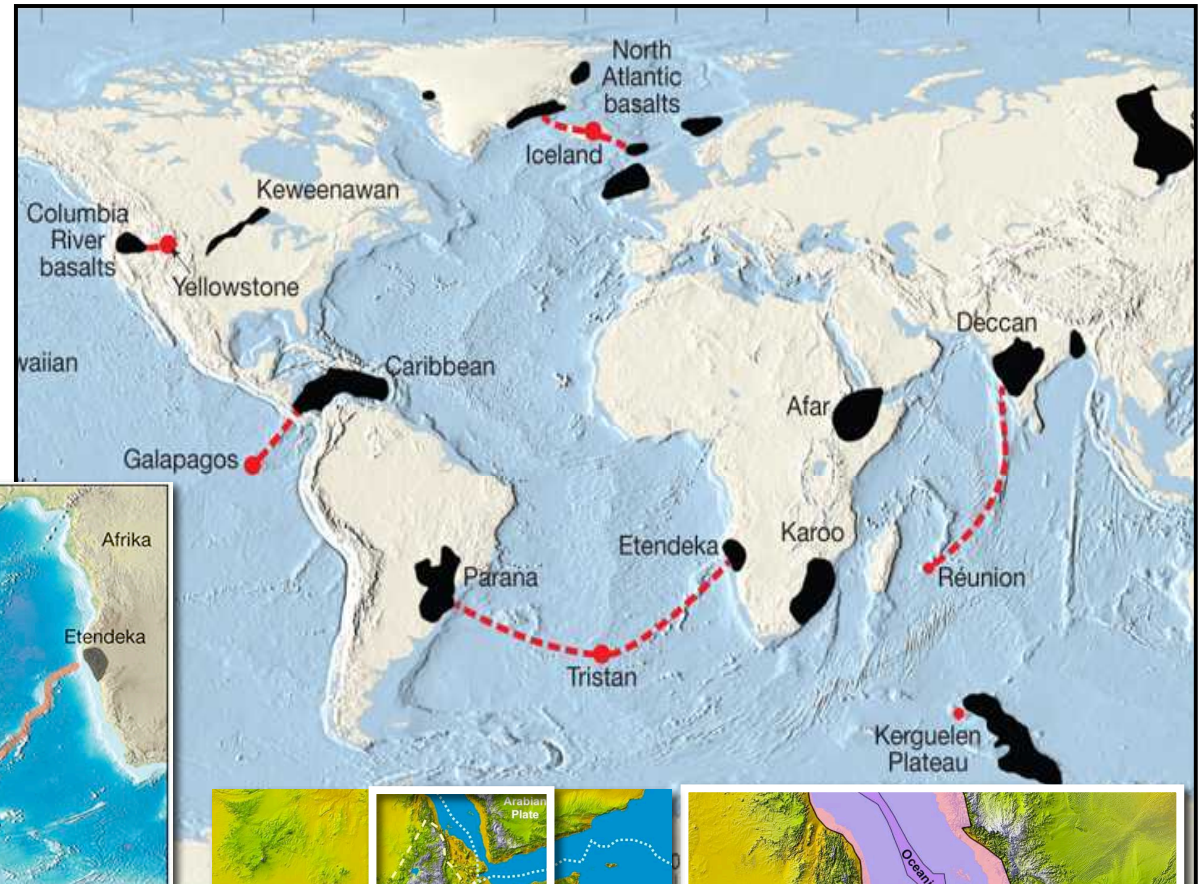
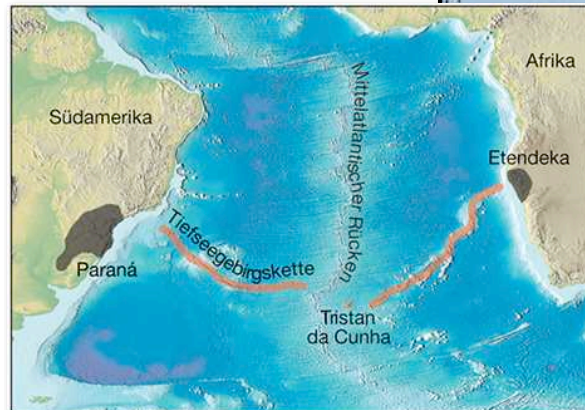
Eozän - Miozän



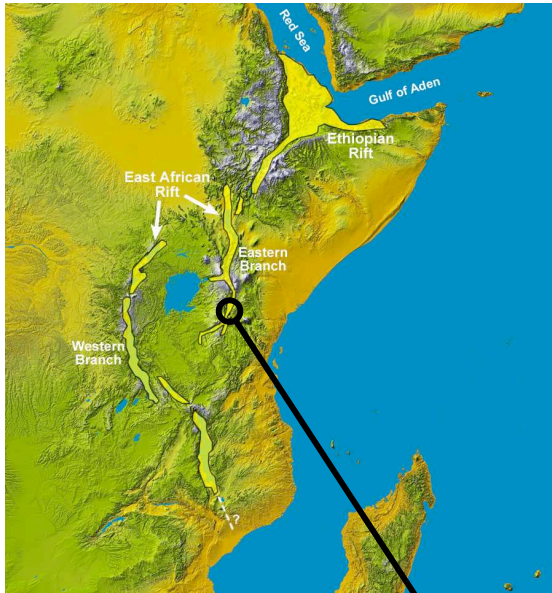
<http://en.wikipedia.org/wiki/File:Rhinegrabencross.jpg>

vom Hotspot zum Ozean

Plateaubasalte und Hotspot Trails



Ost-Afrikanisches Rift: Ein Kontinent zerbricht



Oldoinyo Lengai



Oldoinyo Lengai Lava, ca. 2 Tage alt

Einzigster aktiver Karbonatit Vulkan der Welt

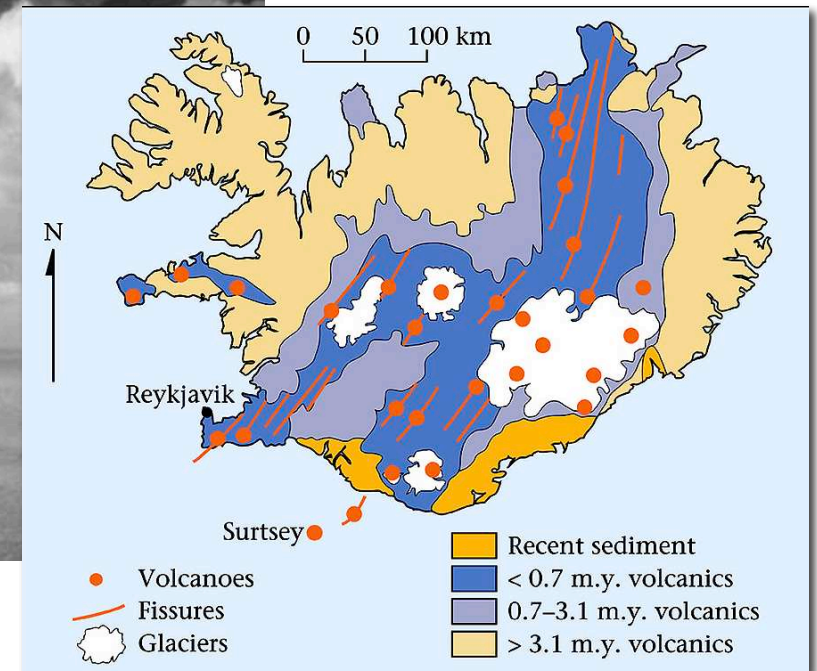
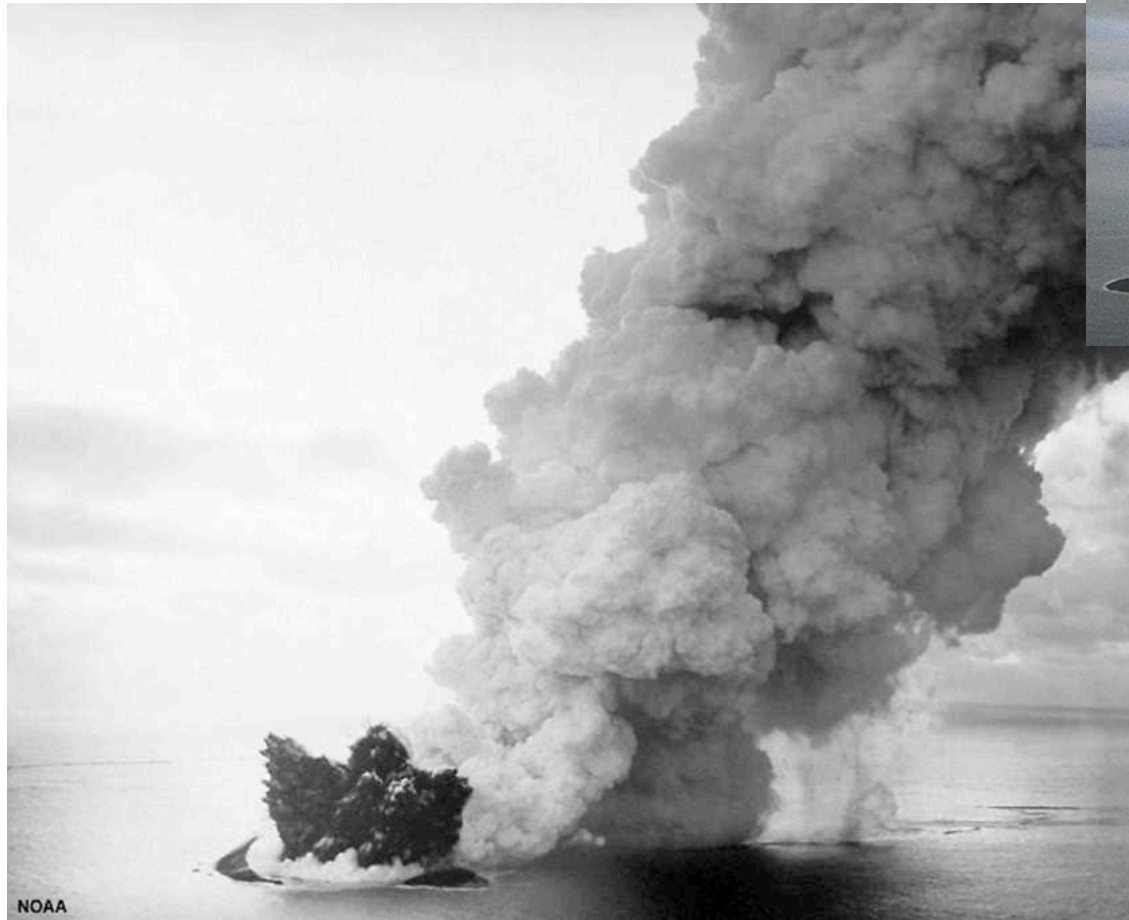
- Zusammensetzung:
typisch Ozeanrücken-Mantel mit $\geq 30\%$ CO_2
- Sehr niedrige Viskosität:
dünnflüssig, sprudelt fast wie Wasser
fließt aus bei $\sim 540^\circ\text{C}$
- An der Oberfläche wird das CO_2 - nach Erkalten - fest



Probennahme (B. Marty and T. Fischer)

Island: auf dem Mittelozeanischen Rücken

Surtsey Eruption 1963



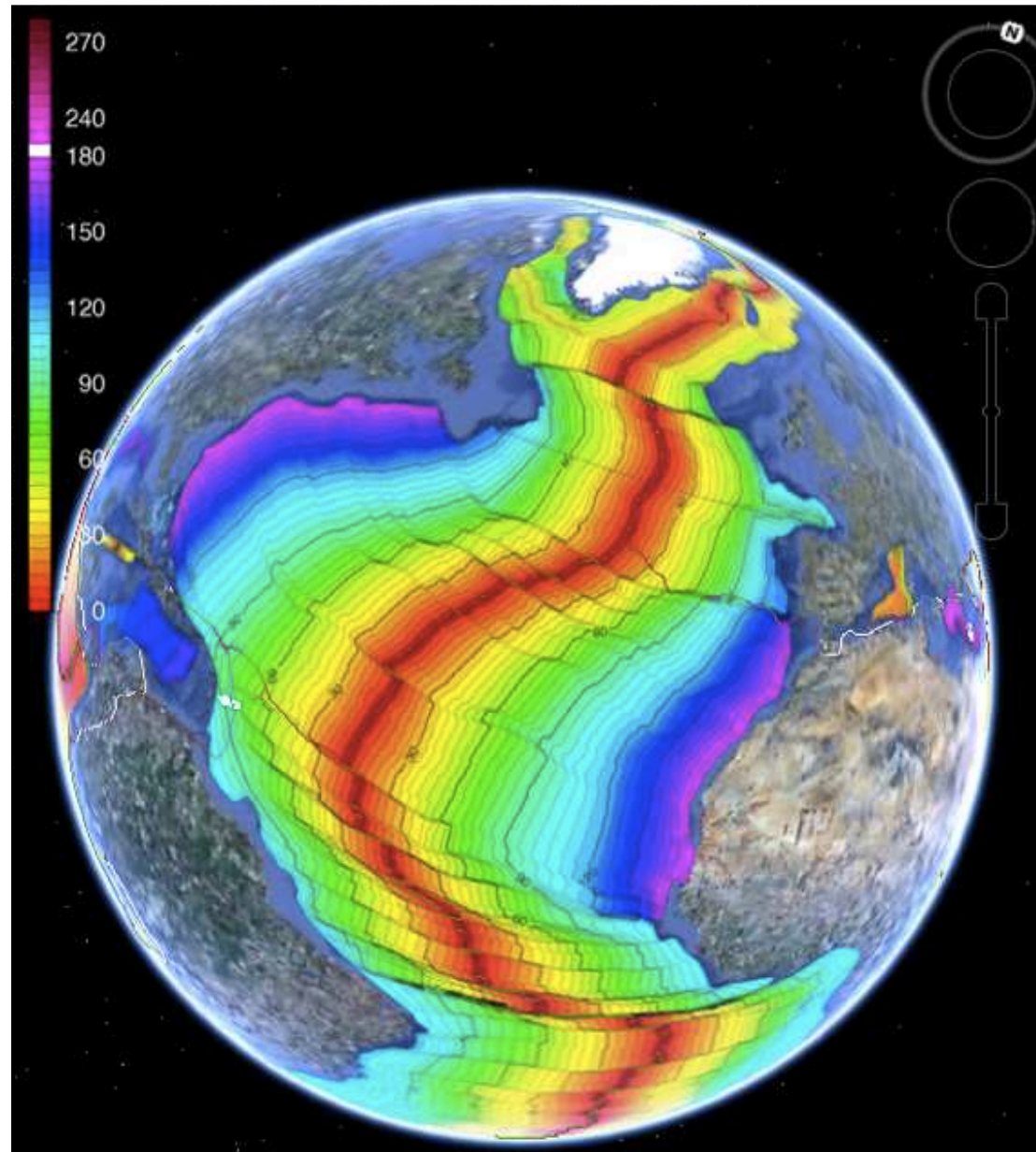
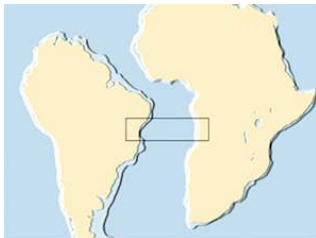
Der Mittelatlantische Rücken

Alter des Ozeanbodens

180 Ma

90 Ma

0 Ma

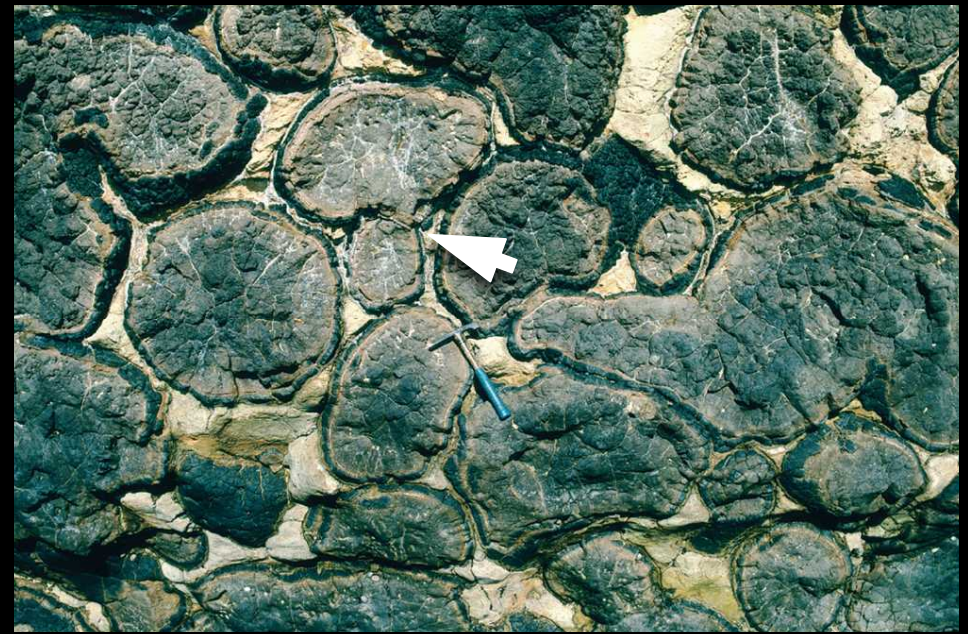
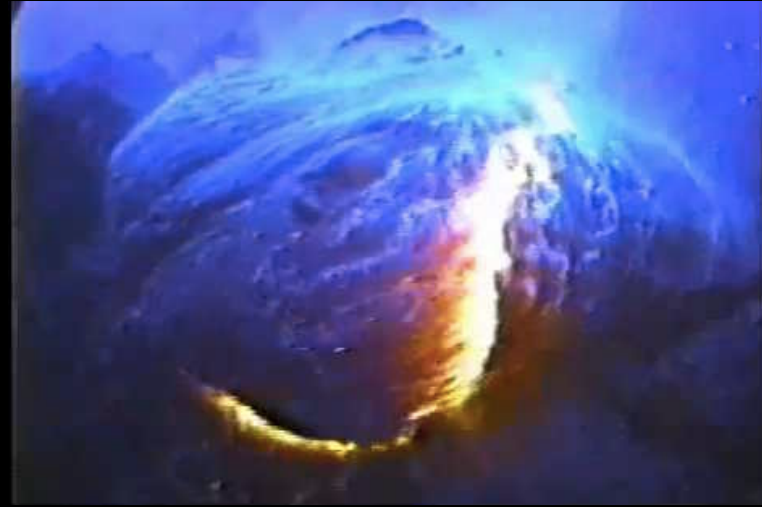


Leben am mittelozeanischen Rücken

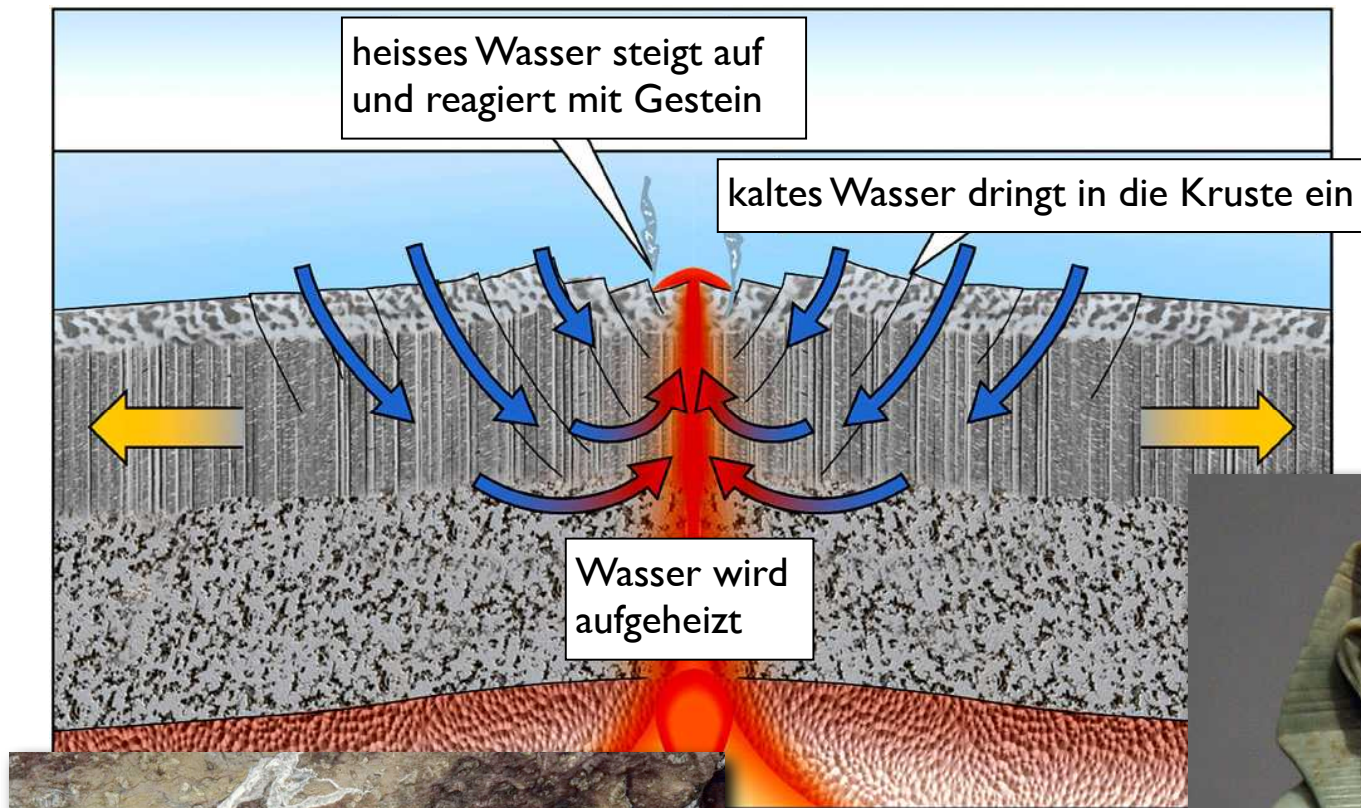
Bildung von Kissenlava (pillow lava)



<https://www.youtube.com/watch?v=DdlUuUY0L9c>



Interaktion Meerwasser - Kruste

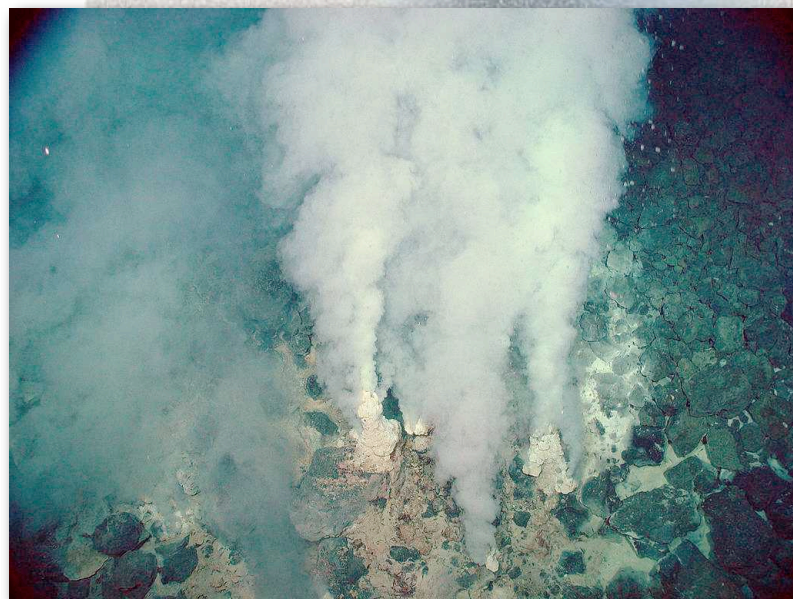
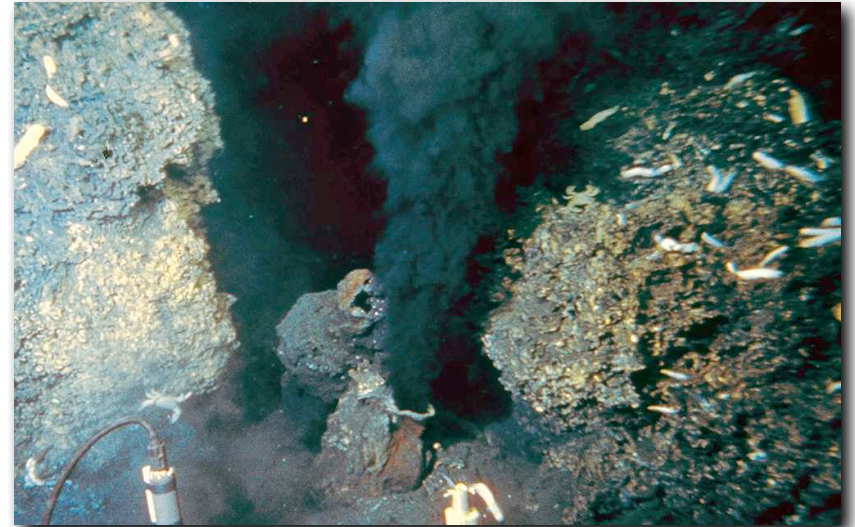
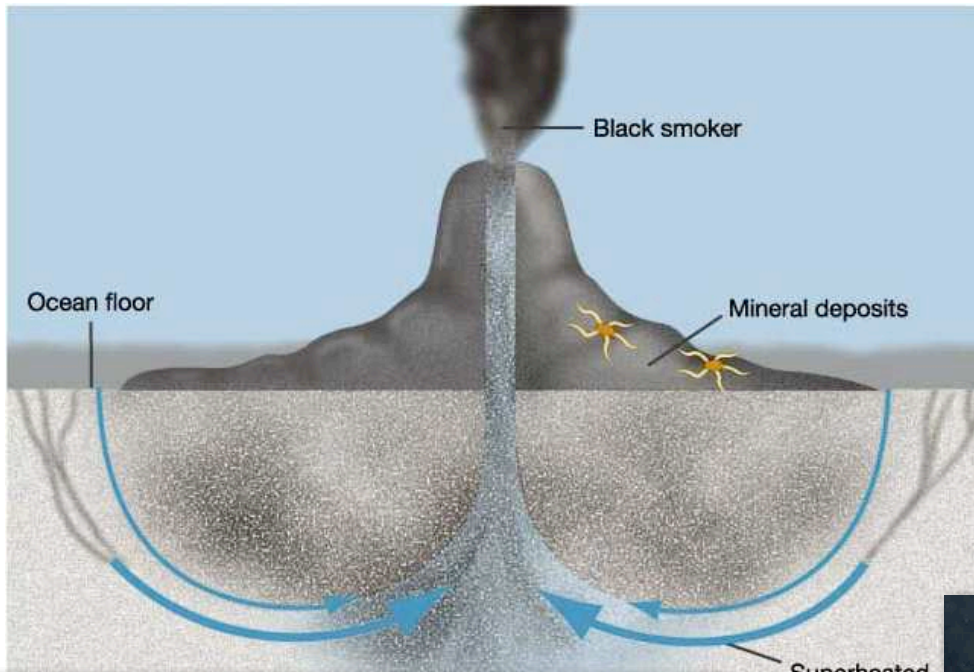


Ophikalzitbildung
Totalp Peridotit, Davos
D. Bernoulli

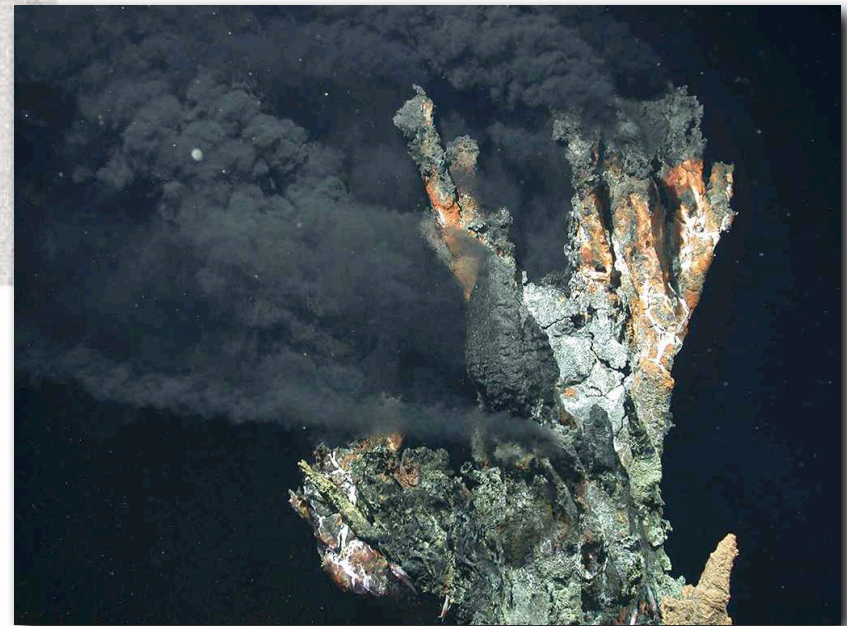


Amenemhet III.

Schwarze und weisse Raucher

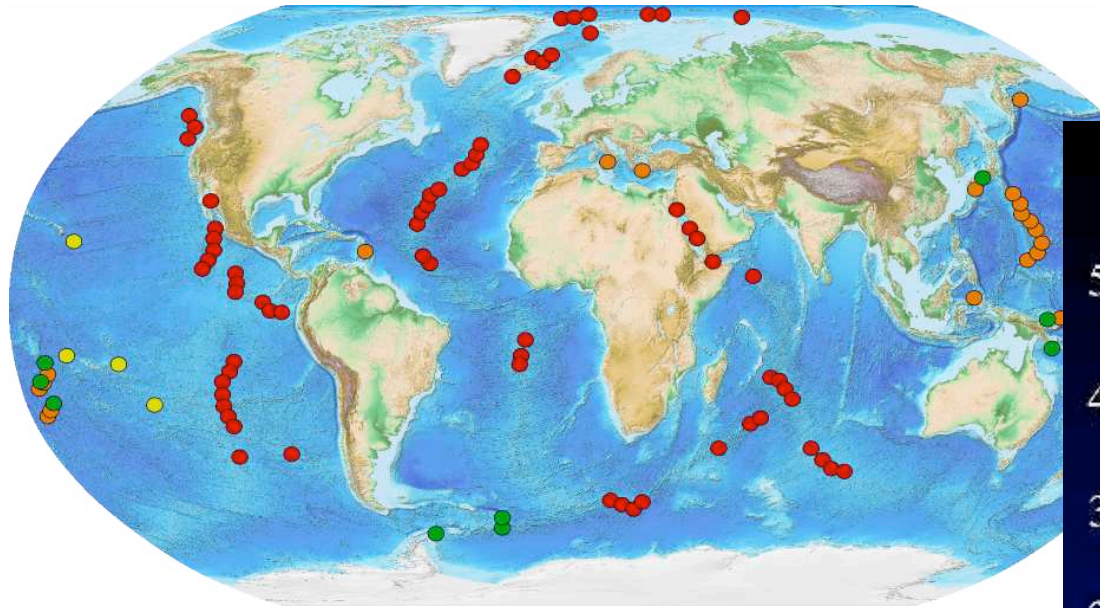


Superheated
water

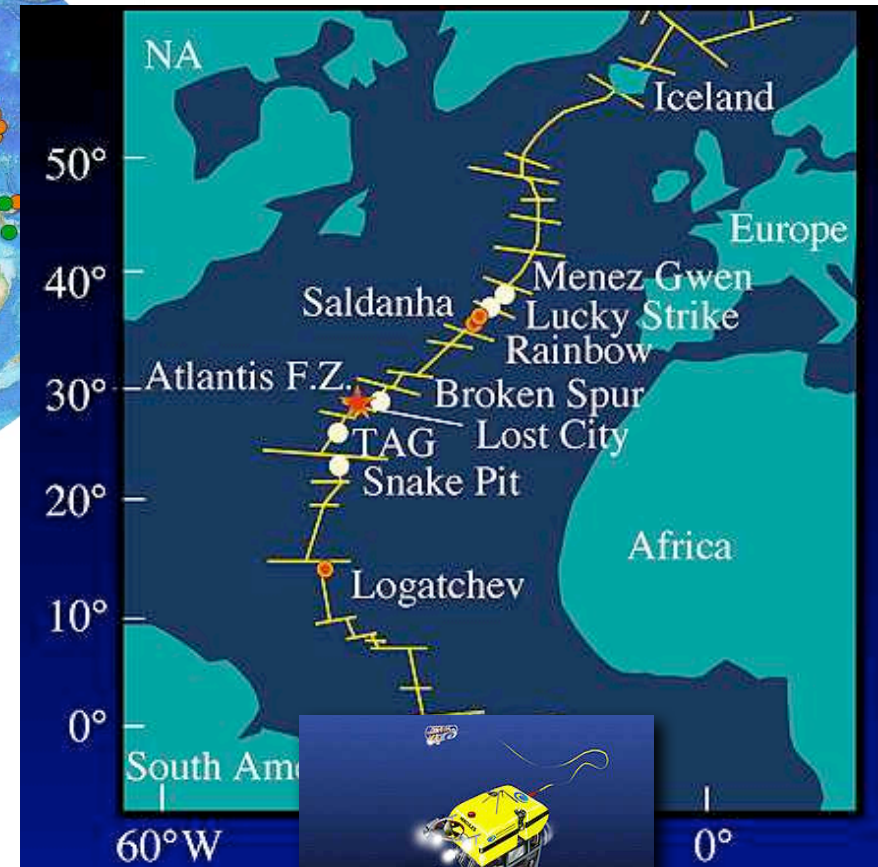


Hydrothermalfelder

<http://www.lostcity.washington.edu/>



gelb = Hotspot
rot = Mittelozeanische Rücken
grün = Back-arc Spreizungsrücken
orange = Vulkanbögen



Gretchen L. Früh-Green
Petrologist and Geochemist
Department of Earth Sciences
ETH-Zurich, Switzerland
shore-based

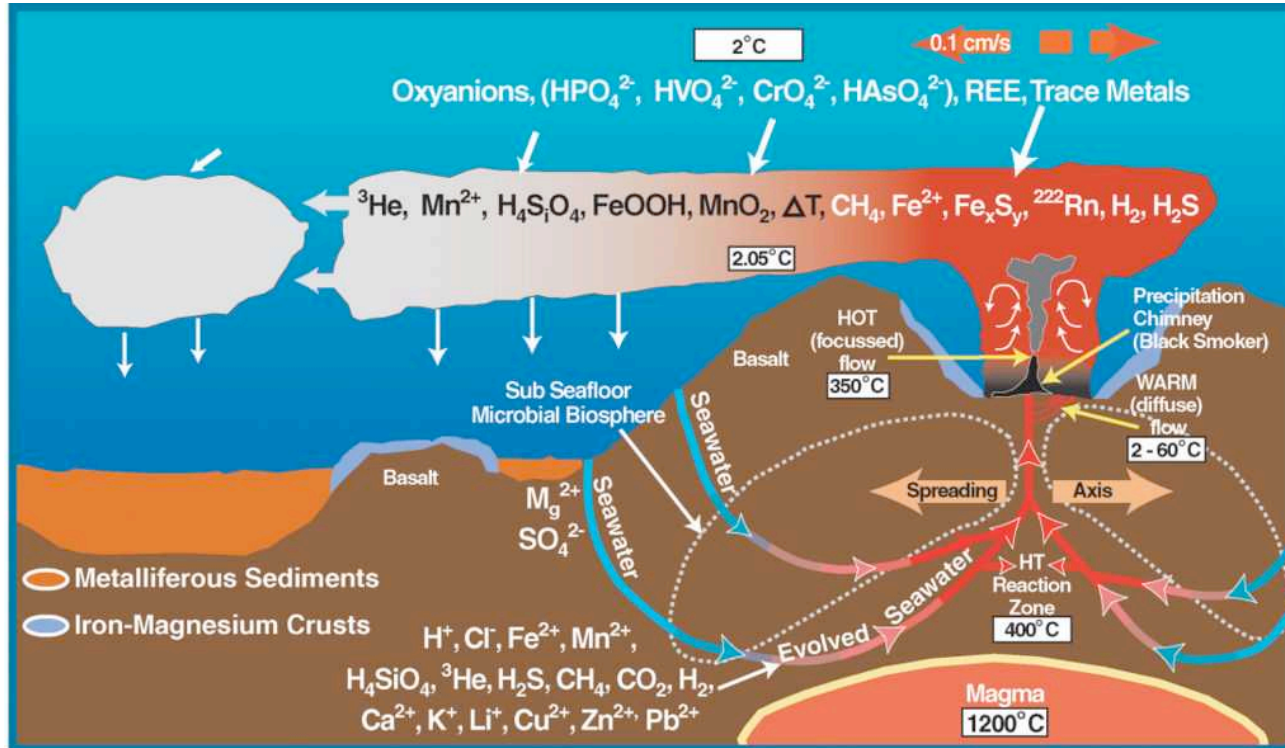


ROV Kiel nach Twin Sisters



<http://www.geomar.de/entdecken/videos/schwarze-raucher-erzfabriken-der-tiefsee/>

Chemosynthese versus Photosynthese



Riftia pachyptila (Bartwurm)
bis zu 3m lang (nur im Pazifik)
Symbiose mit Schwefelbakterium
Filamente (rot=Hämoglobin)

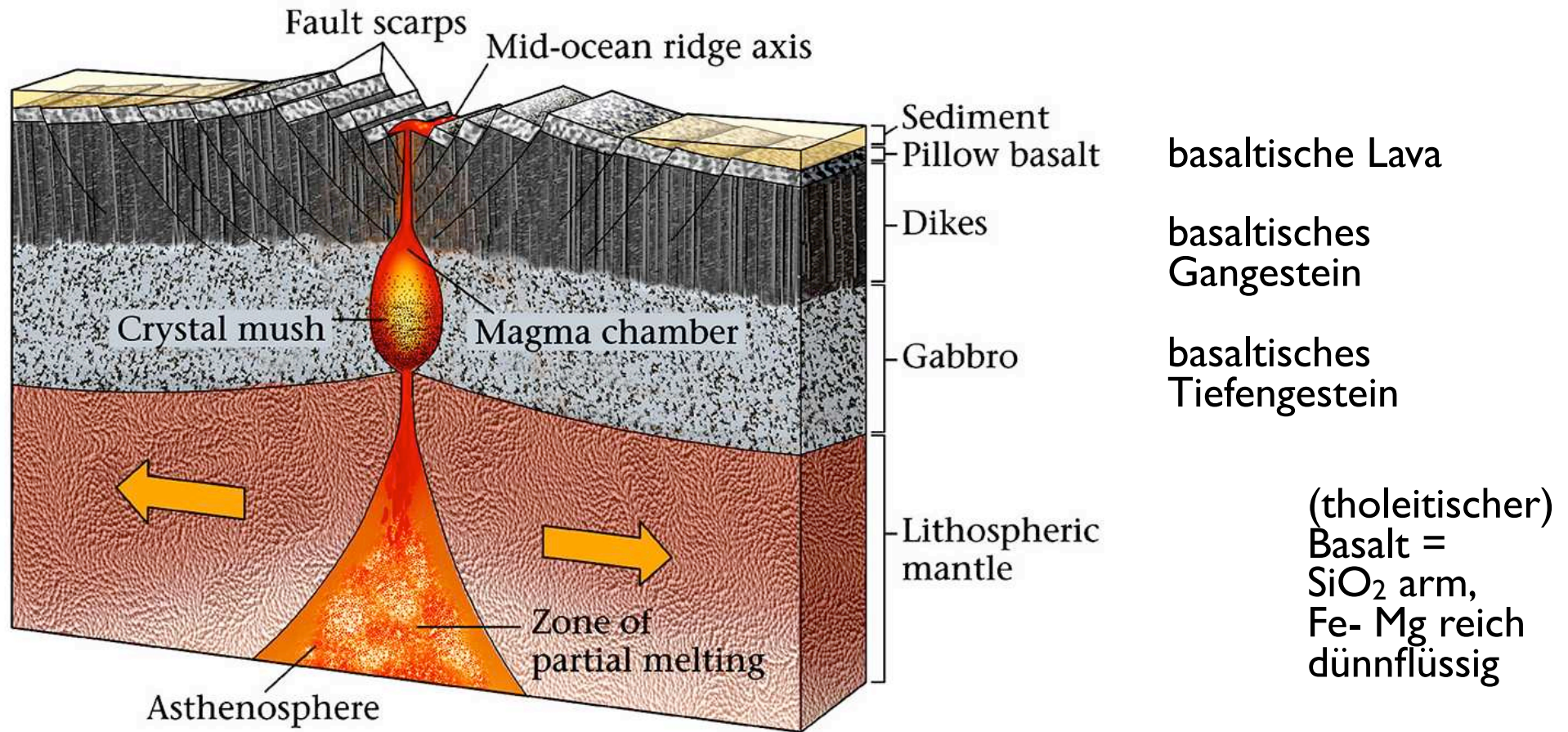
Lebensbasis für Tiere =
chemosynthetisch aktive Bakterien und Archäen

Bartwürmer, Venus-/Miesmuscheln, Spinnenkrabben,...etc.
haben kein Verdauungssystem sondern Symbionten



**vom Ozeanrücken zum
Tiefseegraben**

Entstehung von Ozeanboden

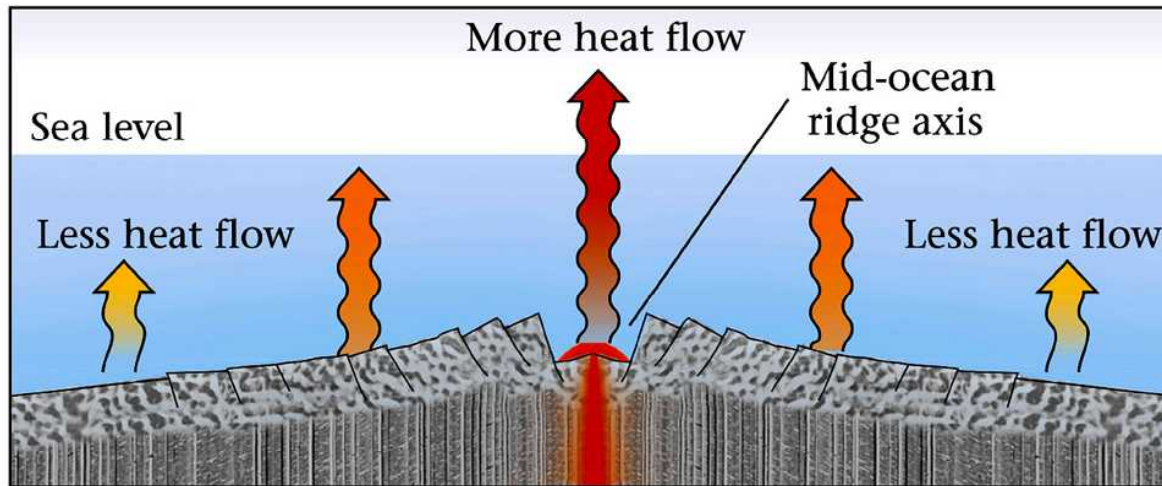


Basaltische Magmen aus partiell geschmolzenem Mantelperidotit

Injektion in Brüche → sheeted dyke complex

Submarine Laven werden abgeschreckt → Kissenlava (pillow basalt)

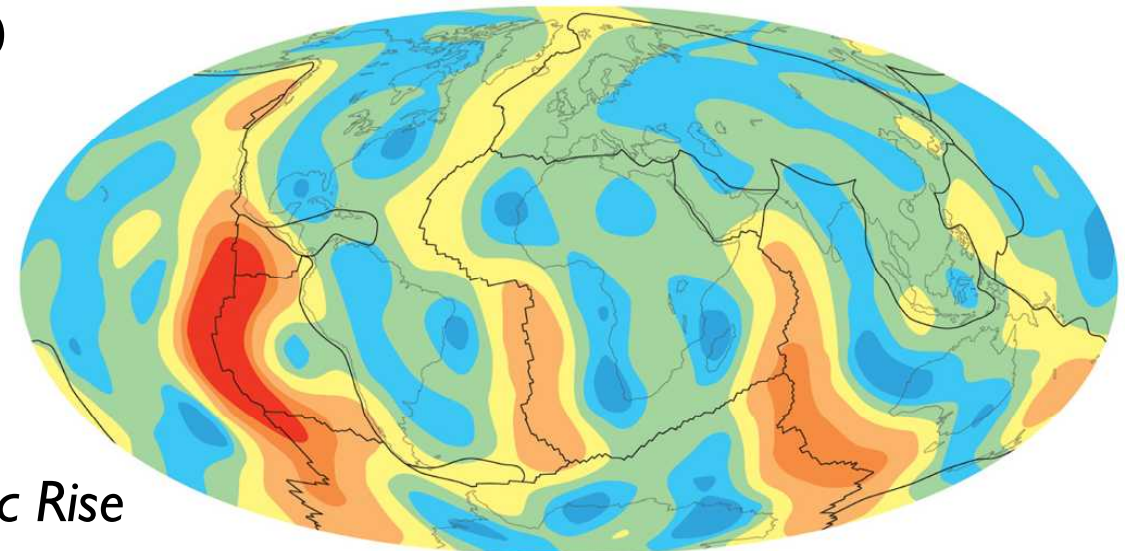
Wärmefluss



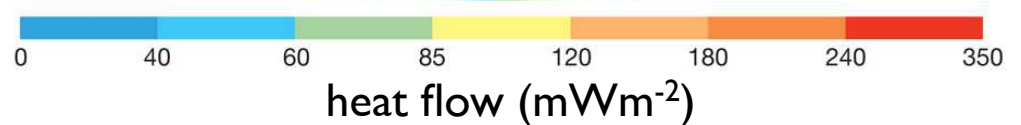
typische Werte (10^{-3} Wm^{-2})

Mittelozeanische Rücken	100-200
Alte ozeanische Kruste	~ 50
Junge Gebirge	60-75
Alte Kratone	< 40

*Mittelatlantischer Rücken
langsam*



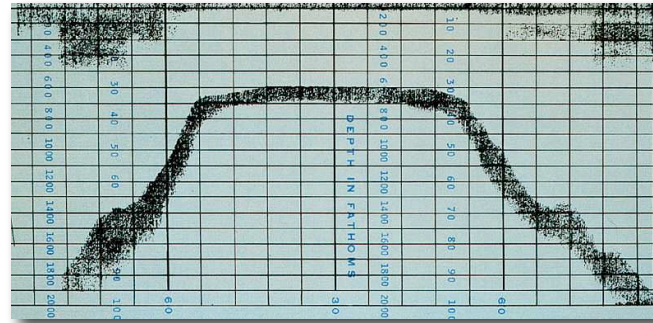
*East Pacific Rise
schnell*



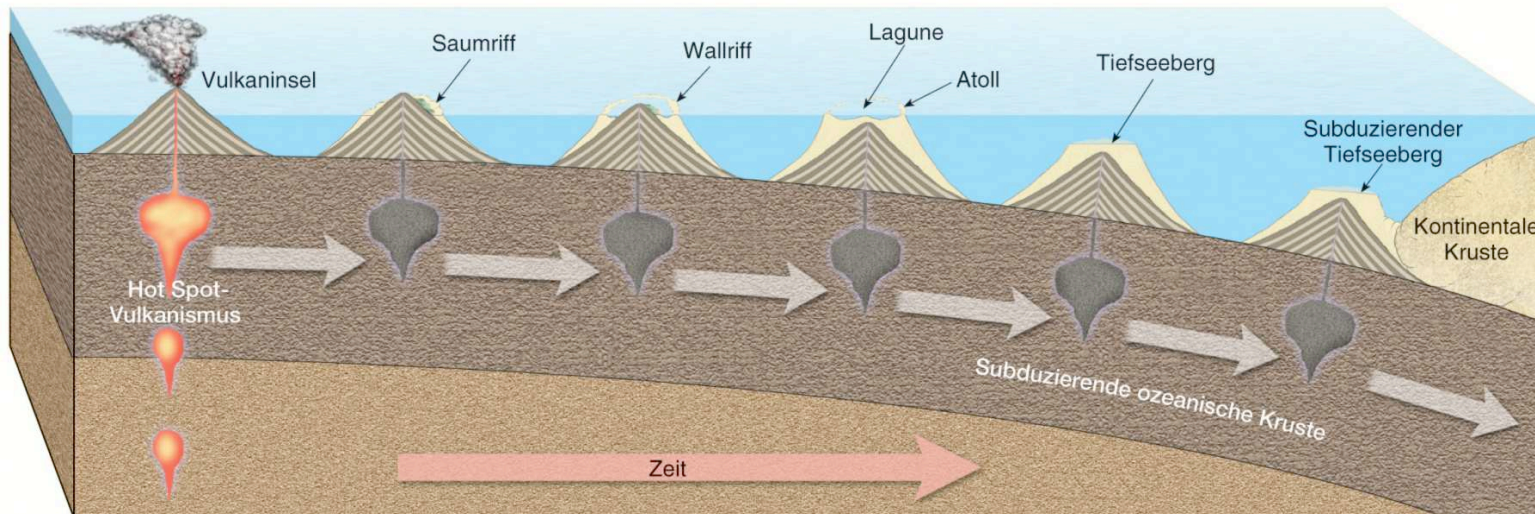
Tiefseeberge auf dem Weg in die Subduktion



Harry Hammond Hess
(1906 - 1969)

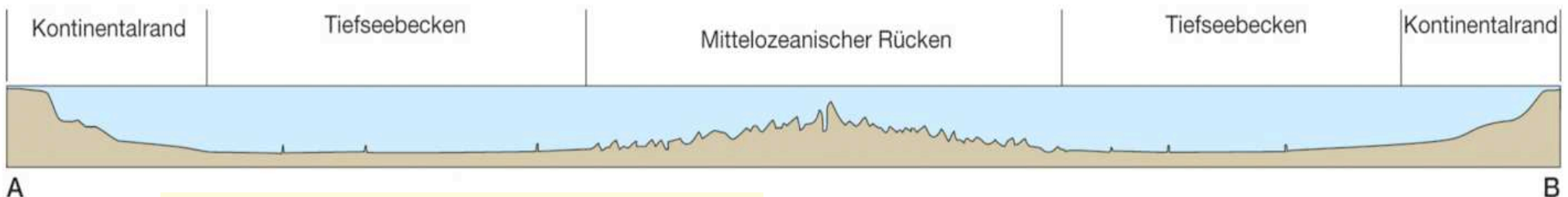
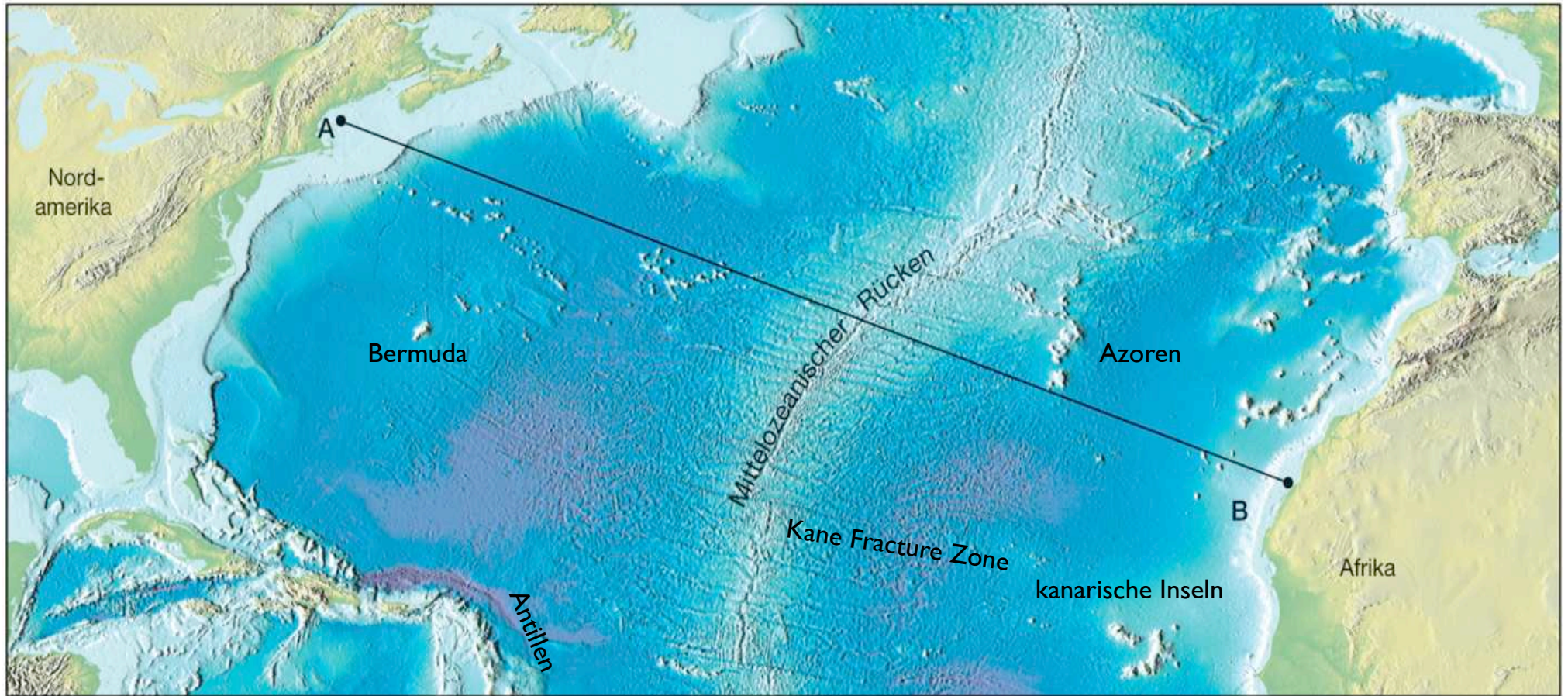


Echlot-Aufzeichnung des "ersten Guyots",
entdeckt von Harry Hess, Universität Princeton



Plattentektonische Domänen des Ozeanbodens

Ozeanböden



Grenze Kontinent-Ozean \neq Küstenlinie

passiver Kontinentalrand

Kontinentalschelf

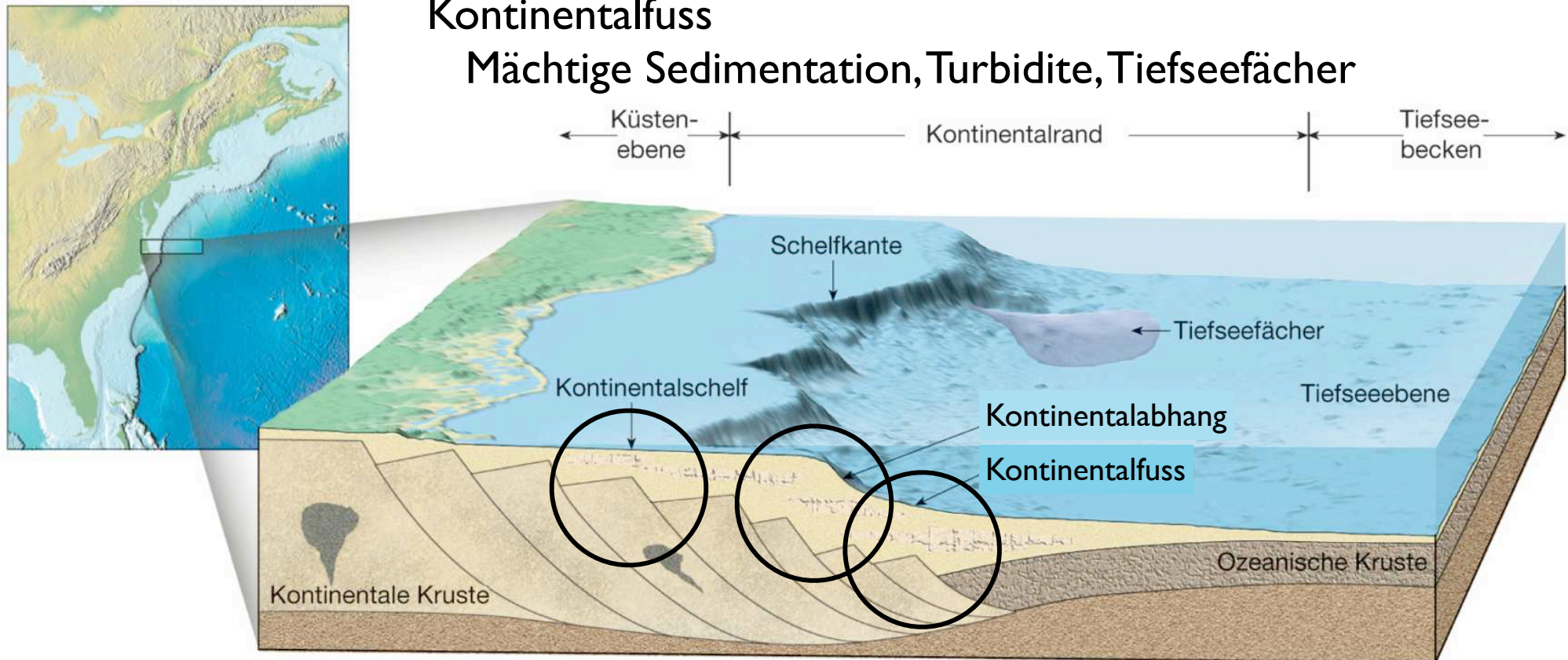
Langsame Absenkung, mächtige Ablagerung,
Mineral-, Erdöl-, Erdgas- Lagerstätten

Kontinentalabhang

Submarine Schluchten (Canyons), Erosion

Kontinentalfuss

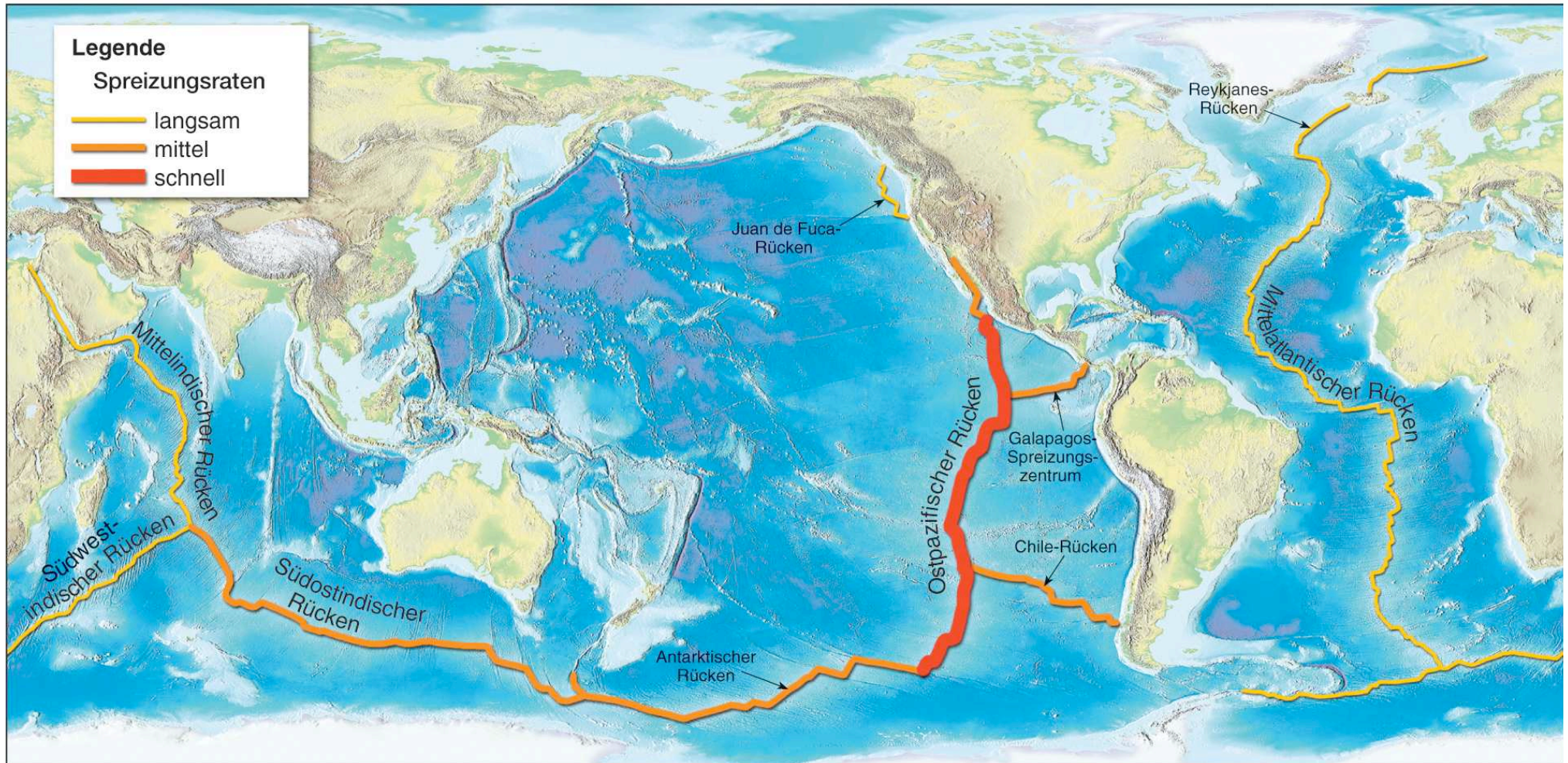
Mächtige Sedimentation, Turbidite, Tiefseefächer



Ozeanrücken

Ozeanrücken = aktiver Plattenrand
≠ aktiver Kontinentalrand

konstruktiv



Gesamtlänge mittelozeanischer Rücken: 70'000 km

Tiefseeergräben

= aktiver Plattenrand

= aktiver Kontinentalrand

destruktiv

Graben	Tiefe (Kilometer)	Durchschnittliche Breite (Kilometer)	Länge (Kilometer)
Aleuten	7,7	50	3.700
Japan	8,4	100	800
Java	7,5	80	4.500
Kurile-Kamchatka	10,5	120	2.200
Marianen	11,0	70	2.550
Zentralamerika	6,7	40	2.800
Peru-Chile	8,1	100	5.900
Philippinen	10,5	60	1.400
Puerto Rico	8,4	120	1.550
Süd Sandwich	8,4	90	1.450
Tonga	10,8	55	1.400

