Geodynamik
und
Tektonik

Prof. Romain Bousquet,
Prof. Manfred Strecker
und PD. Mike Riedel

Winter Semester 2009-2010

01- Die Tektonik vor der Plattentektonik

Das Oberflächenrelief

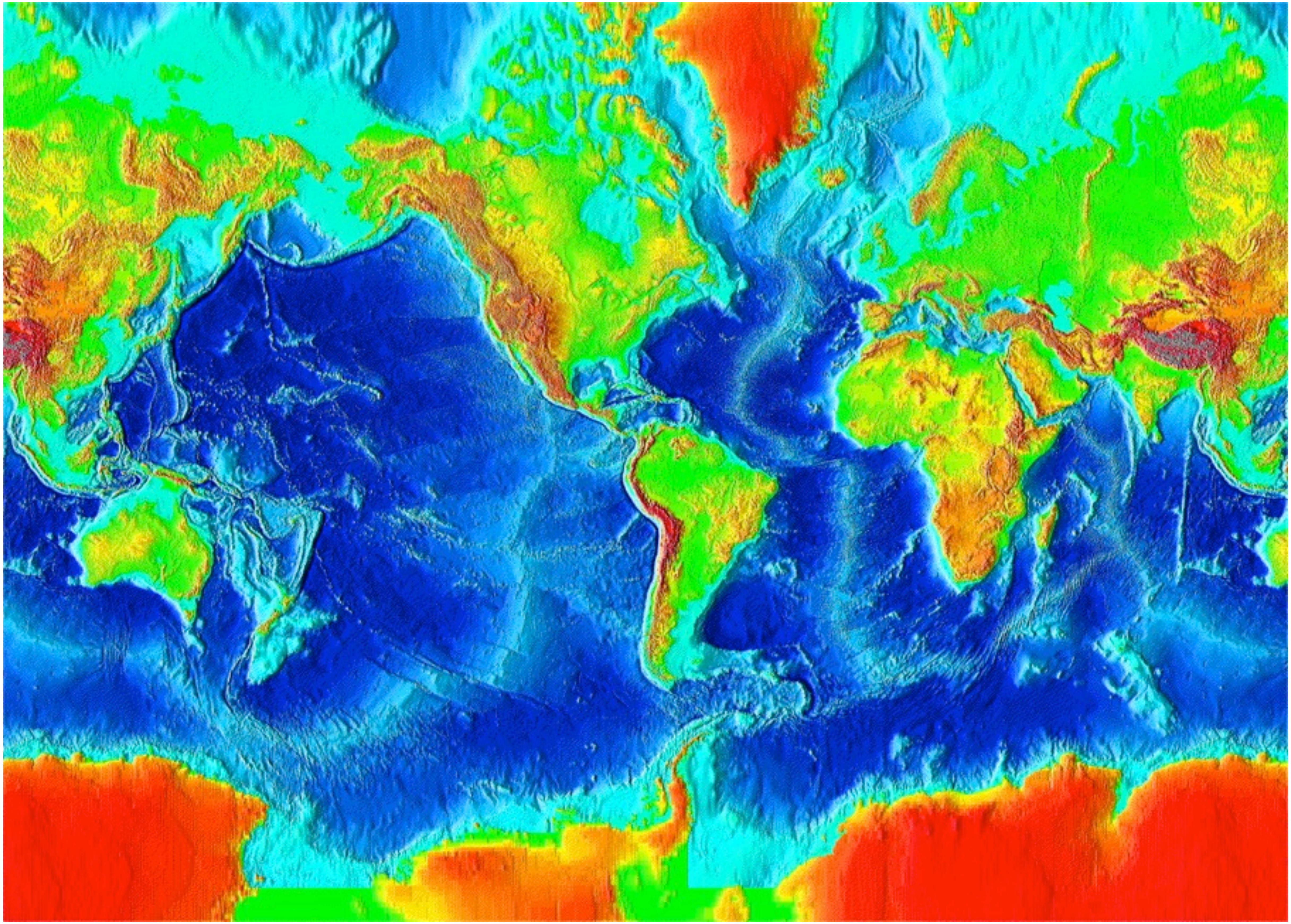
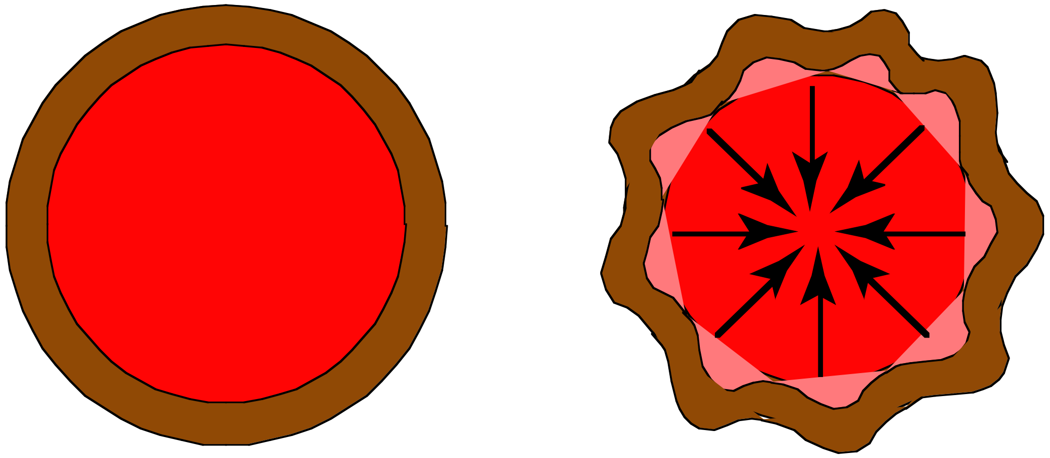
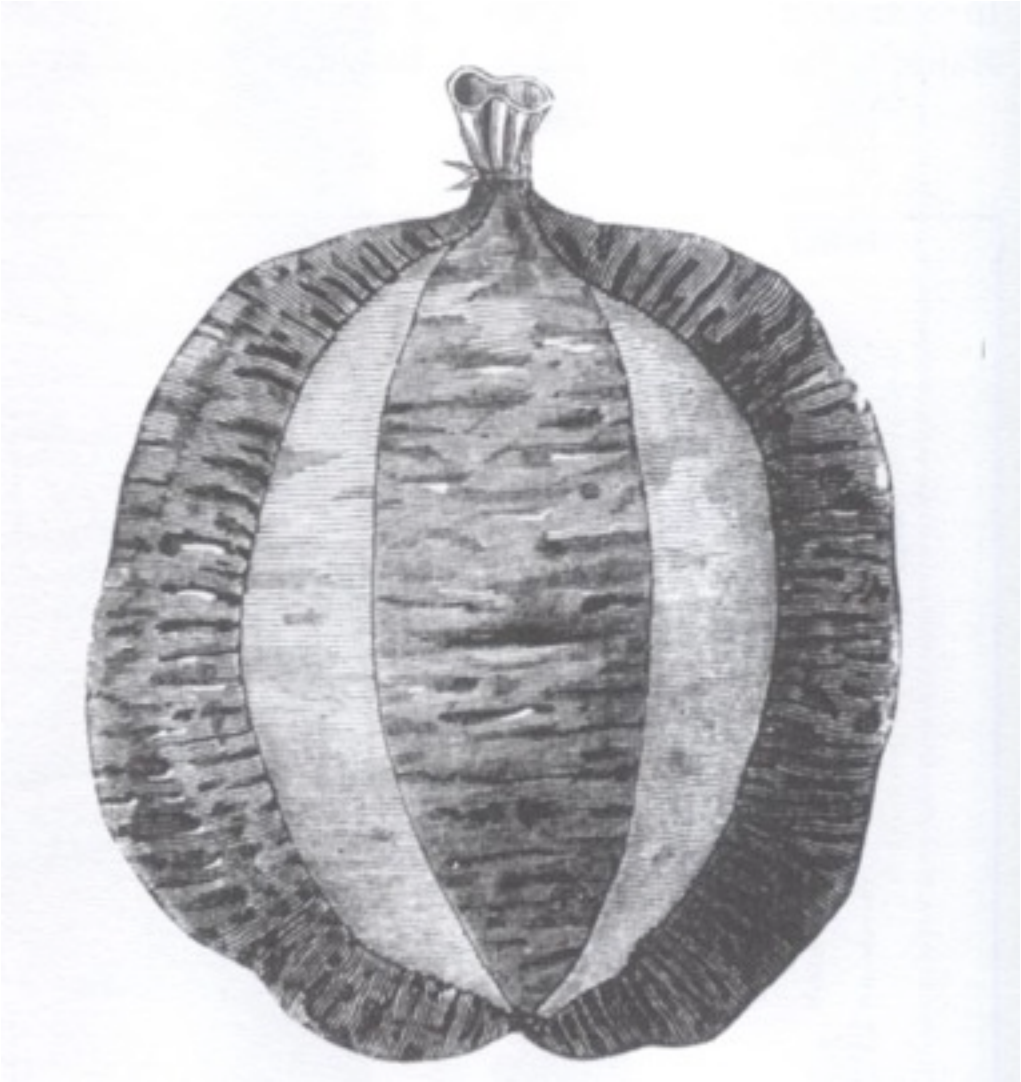


Figure 1.1 *Snider's reconstruction of the continents (Snider, 1858).*

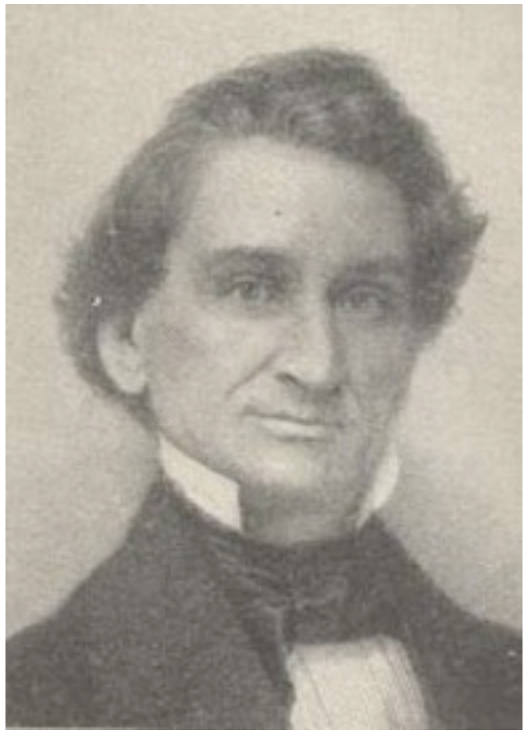
Die Einschnürung der Erde





Daubrée 1879

Die Einschnürung der Erde



Dana 1847

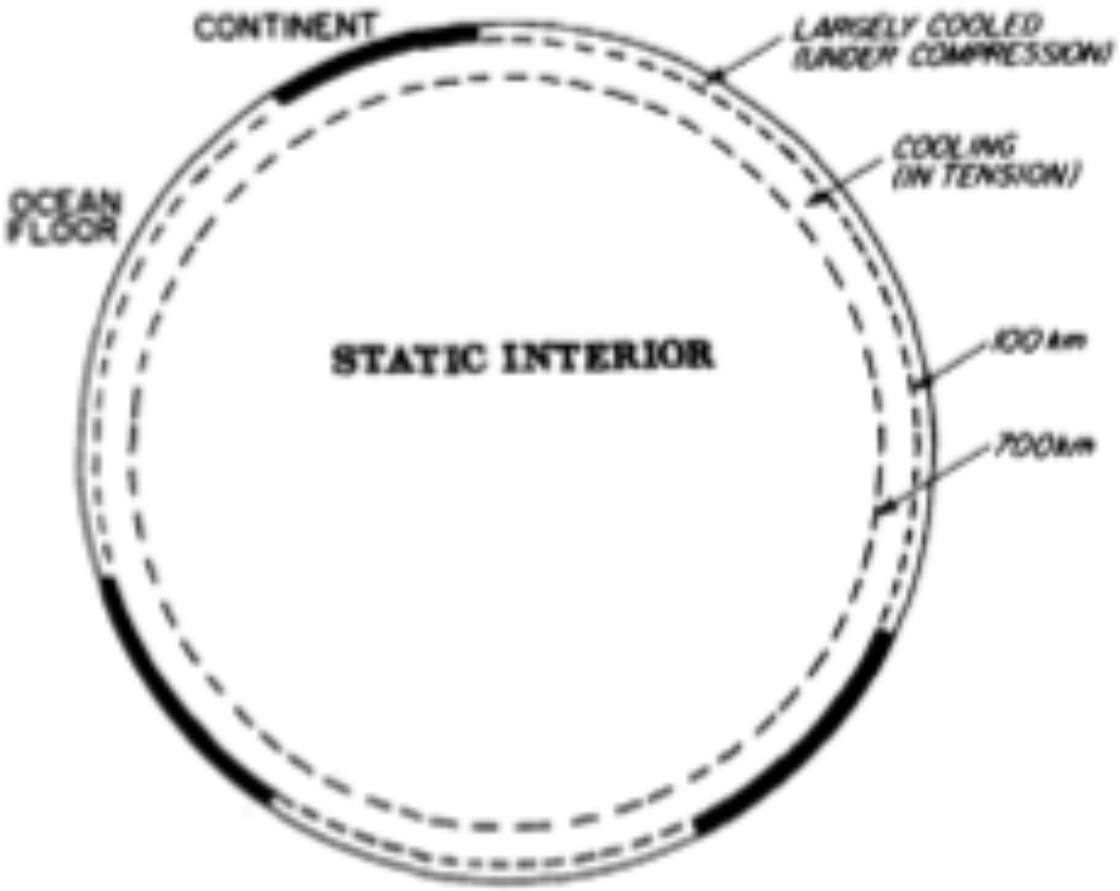


Fig. 1.

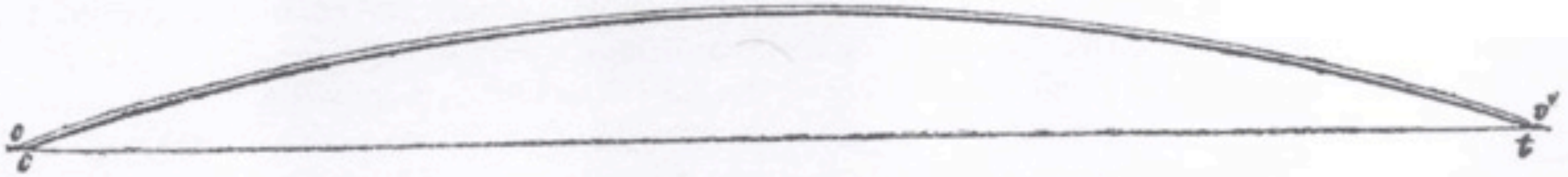


Fig. 2.

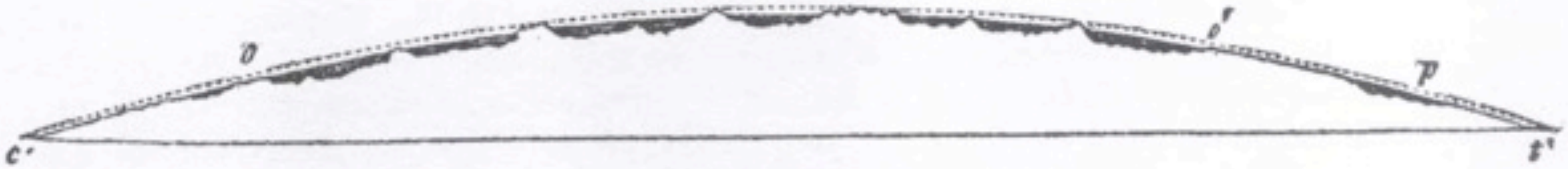
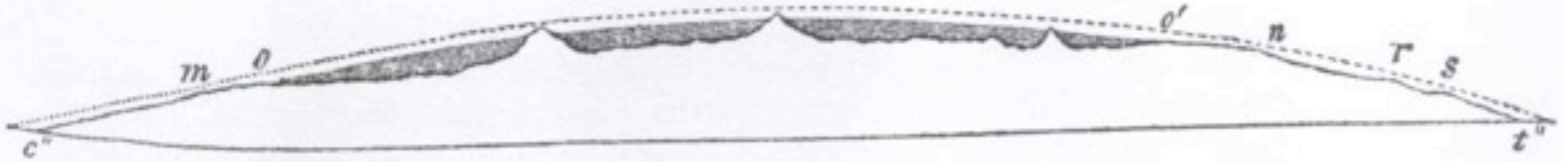
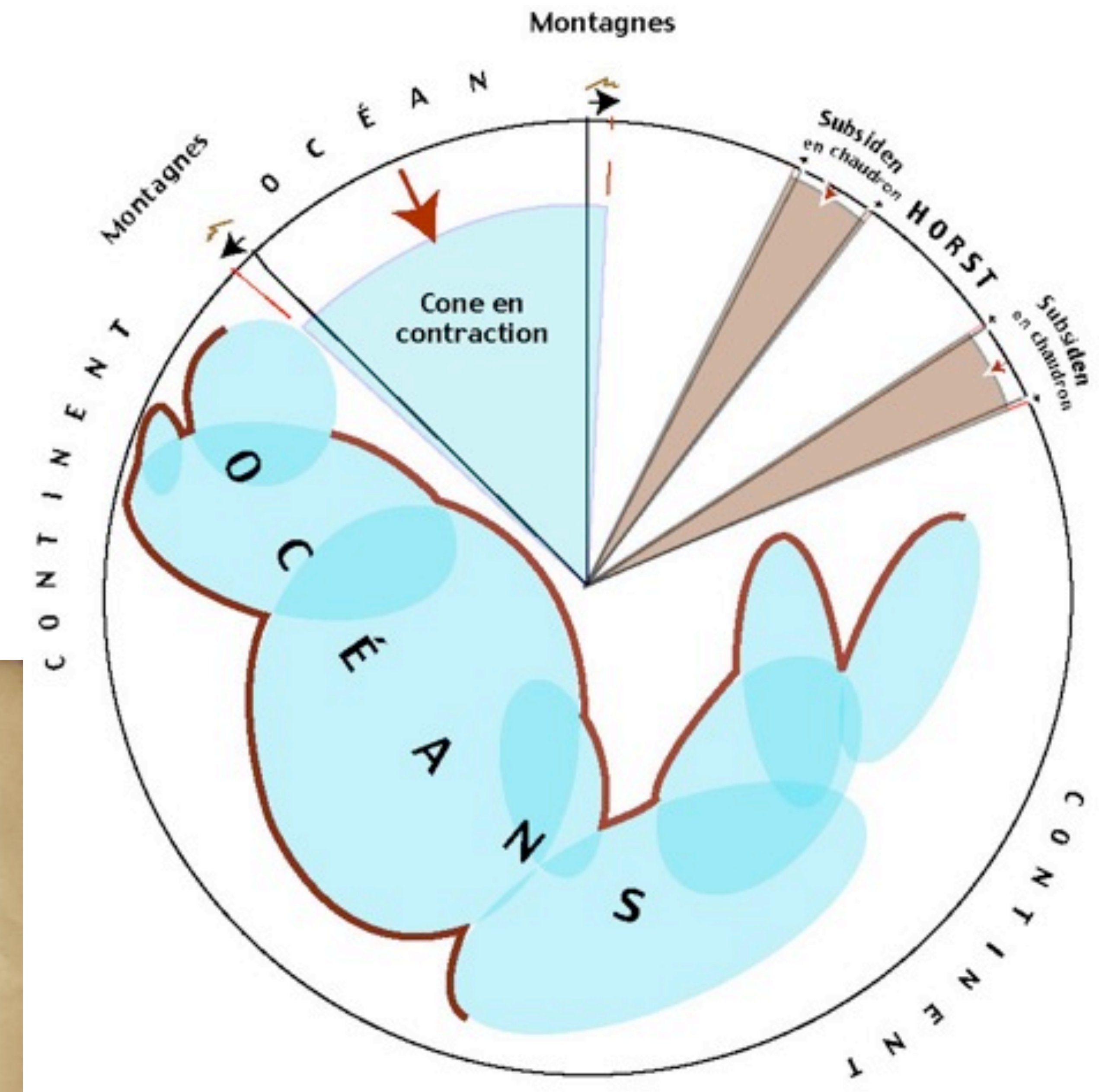


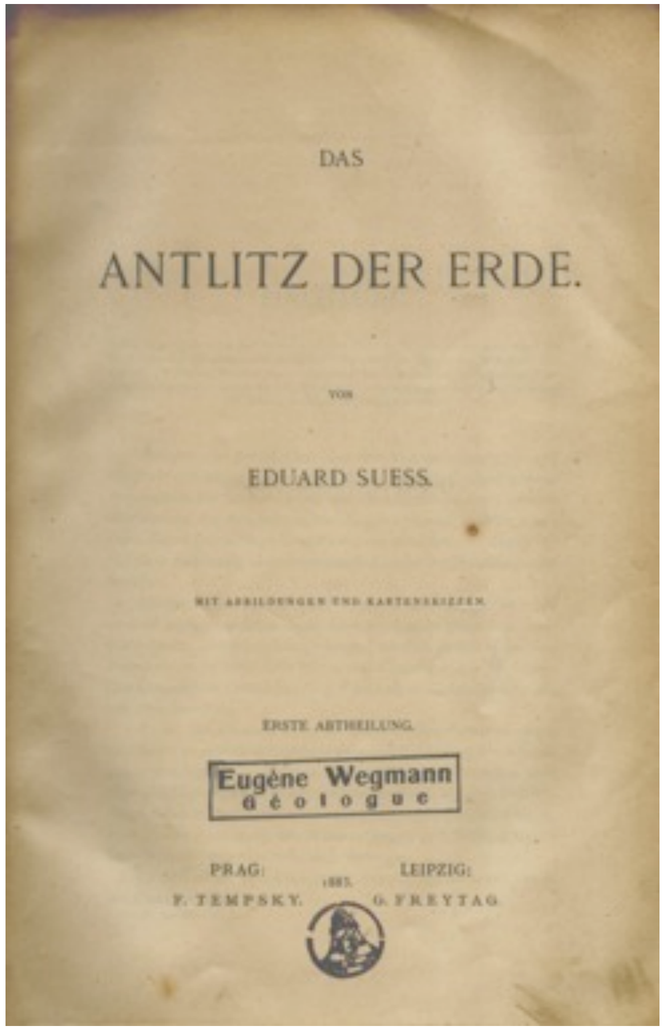
Fig. 3.



Die Einschnürung der Erde



Eduard Suess
(1831-1914)



DAS

ANTLITZ DER ERDE.

VON

EDUARD SUESS.

MIT ABBILDUNGEN UND KARTENSKIZZEN.

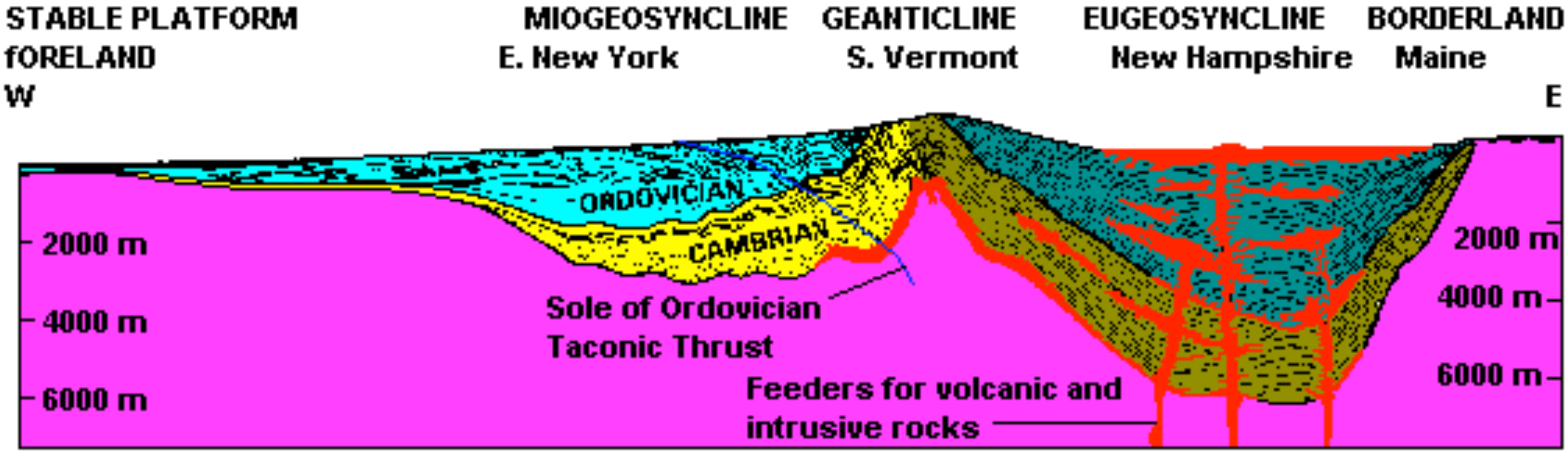
ERSTE ABTHEILUNG.

Eugène Wegmann
Géologue

PRAG: 1883. LEIPZIG:
F. TEMPSKY. G. FREYTAG.

Das Antlitz der Erde, 1883

Geosynclines



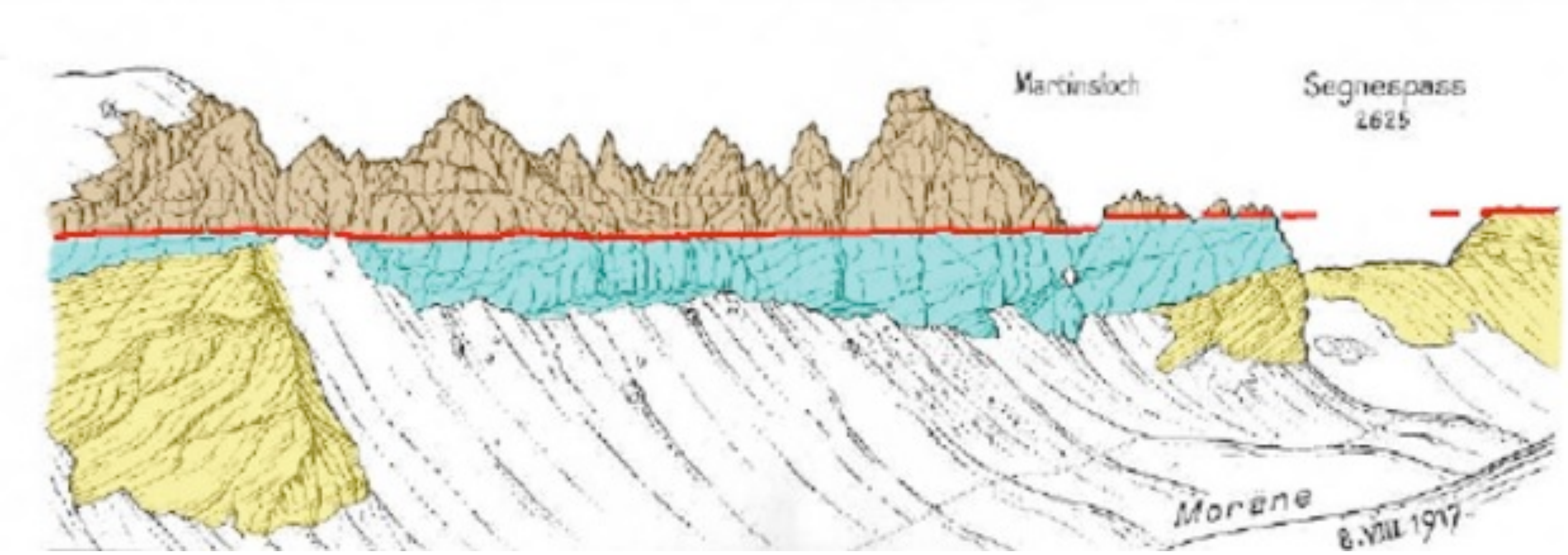
James Hall
(1811-1889)

Ende der Einschnürung Theorie

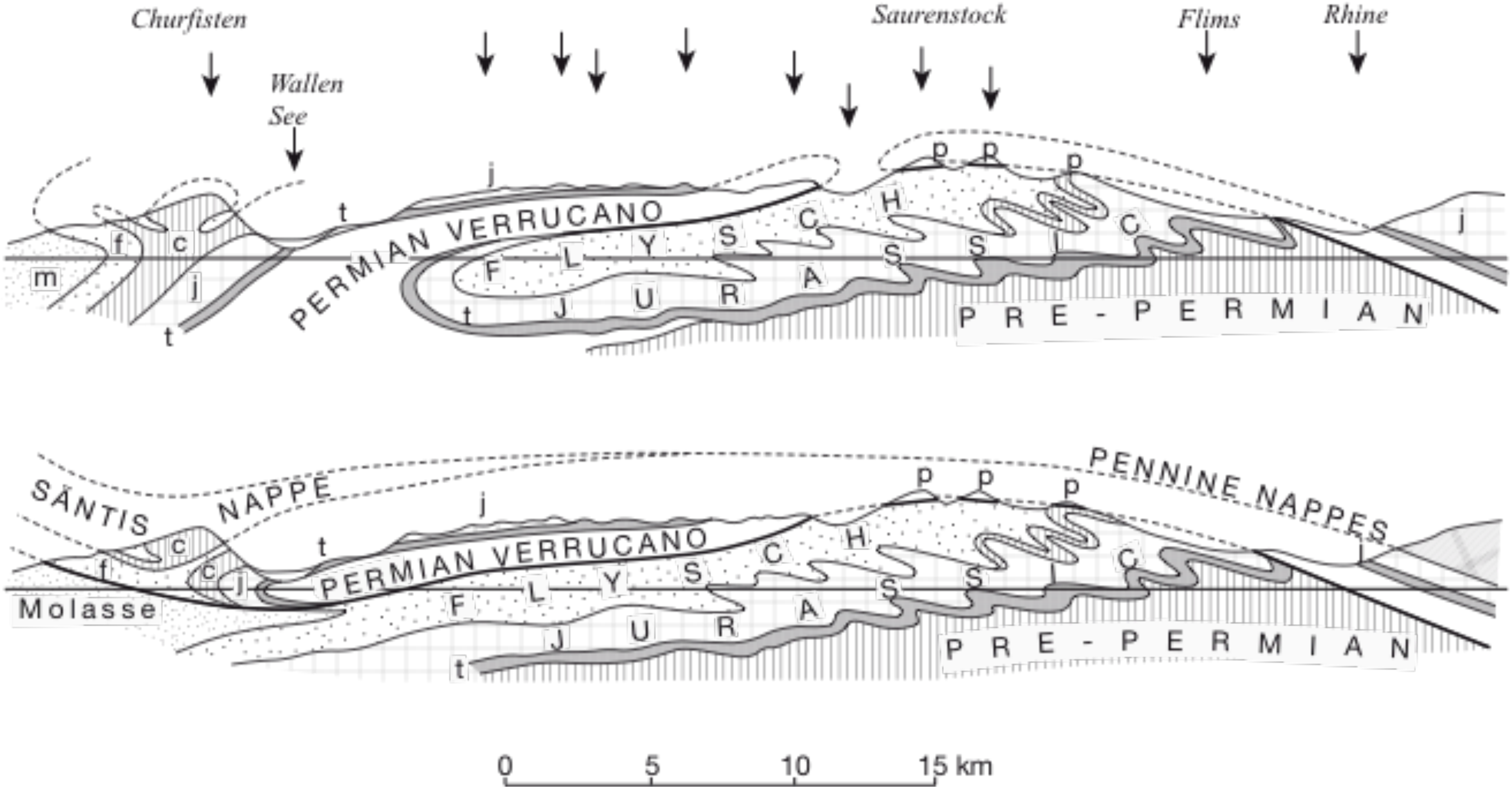
Drei unabhängig Beweise gegende Abkülung der Erde

- Strukturgeologie mit Feldkartierung
- Geodäsie
- Physik

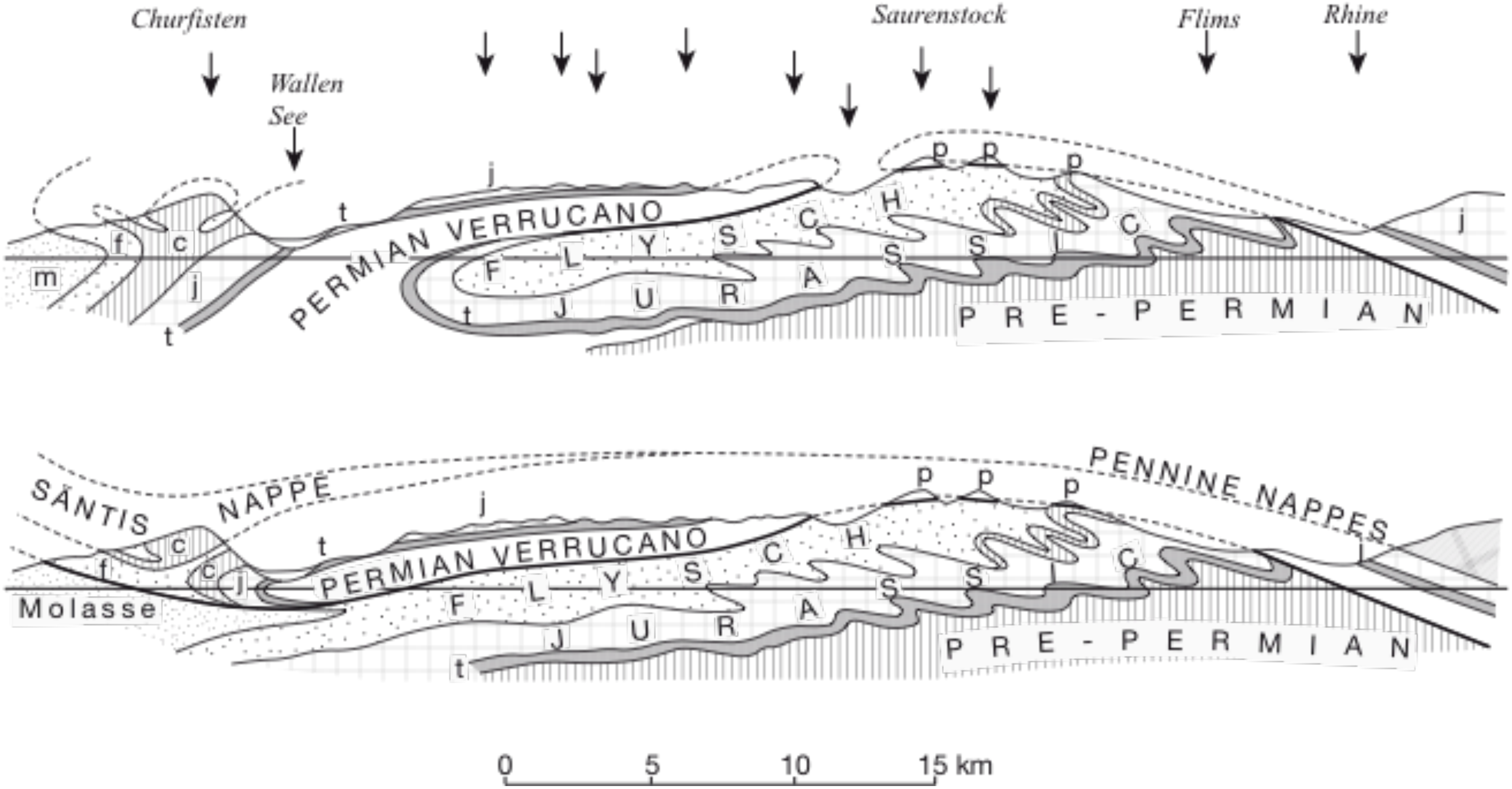
Feldgeologie



Feldgeologie



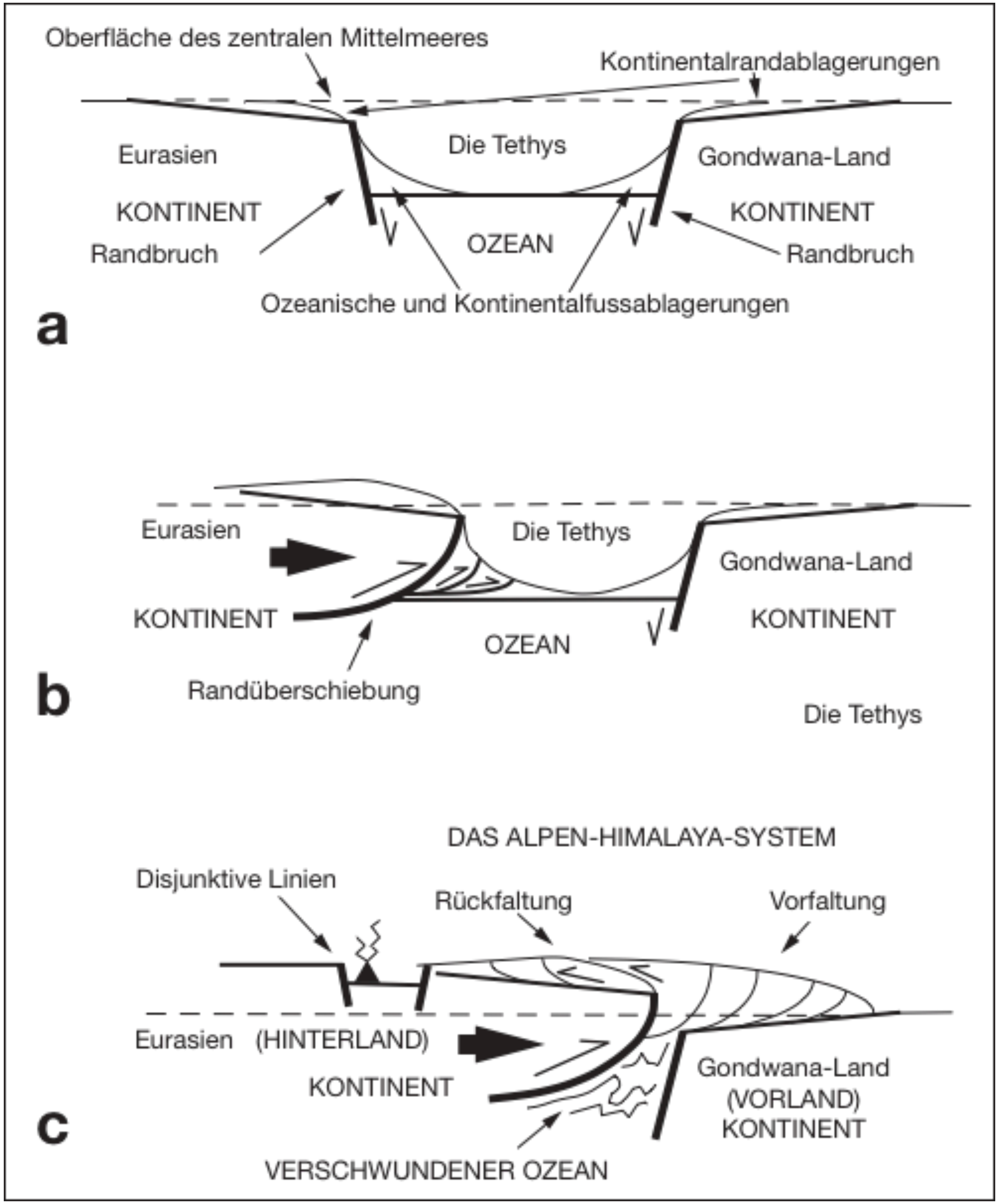
Feldgeologie



Die Glarner Überschiebung:

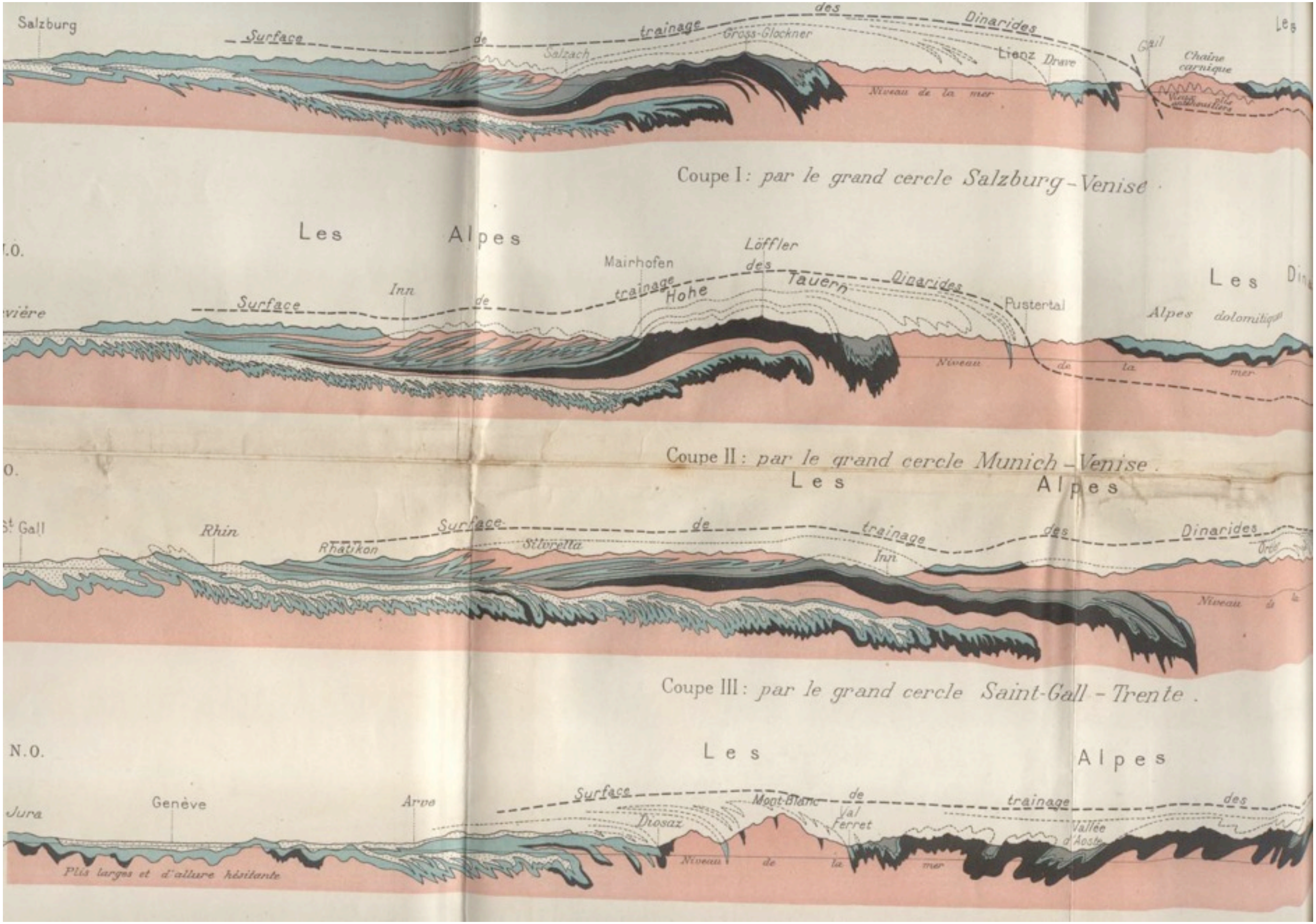
In 1884, hat Marcel Bertrand eine Überschiebung nach Nord behauptet. Die Bewegung war mindestens 30 km.

Feldgeologie



Bassins, mother of the mountain Suess (1885-1909)

Feldgeologie: Tektonik in den Alpen



Coupe I: par le grand cercle Salzburg-Venise.

Coupe II: par le grand cercle Munich-Venise.

Coupe III: par le grand cercle Saint-Gall-Trente.

Pierre Termier, 1903

Geodäsie

Pierre Bouguer
1698-1758

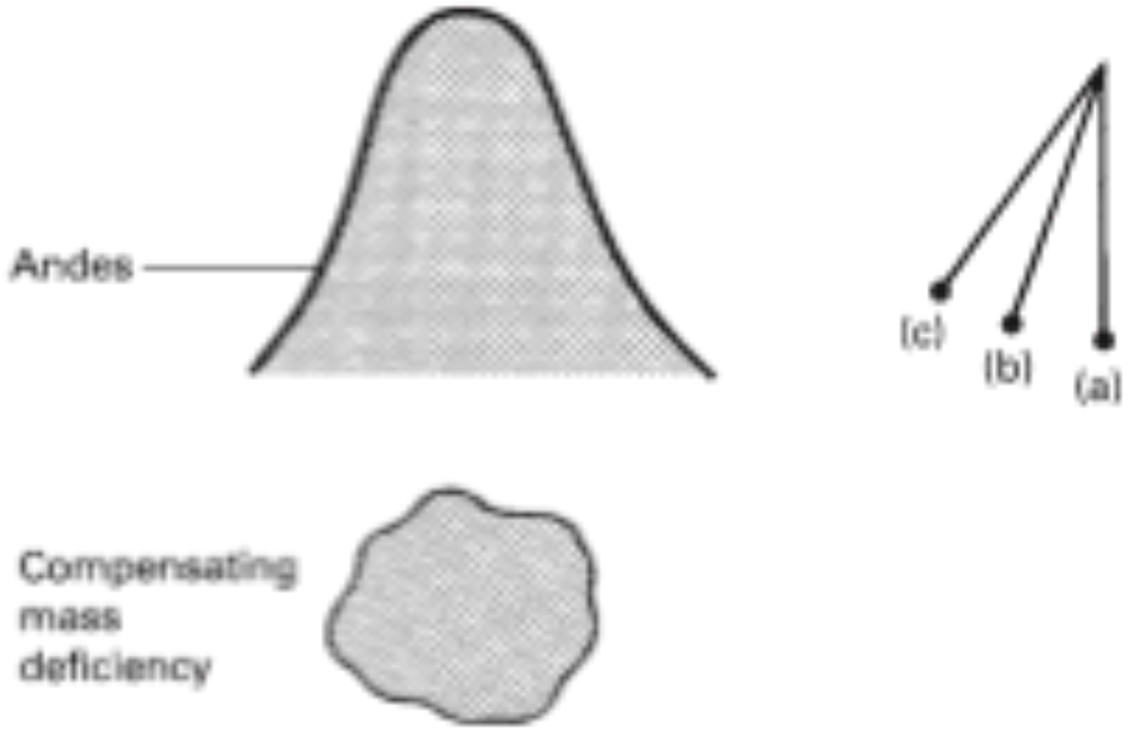
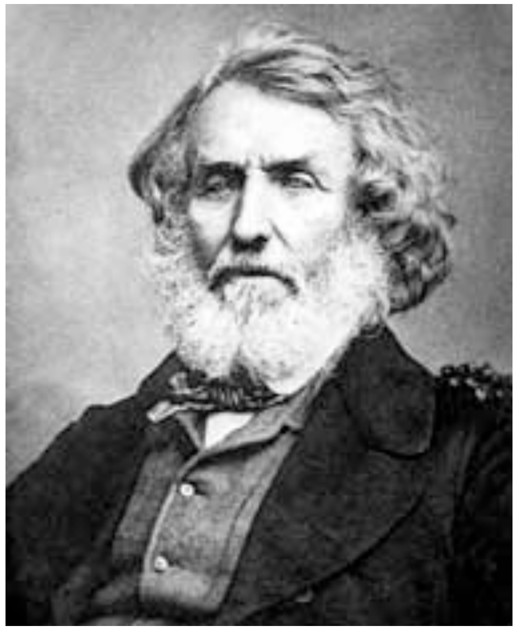


Figure 2.27 *Horizontal gravitational attraction of the mass of the Andes above sea level would cause the deflection (c) of a plumb bob from the vertical (a). The observed deflection (b) is smaller, indicating the presence of a compensating mass deficiency beneath the Andes (angles of deflection and mass distribution are schematic only).*

Georg Everest
1790-1866



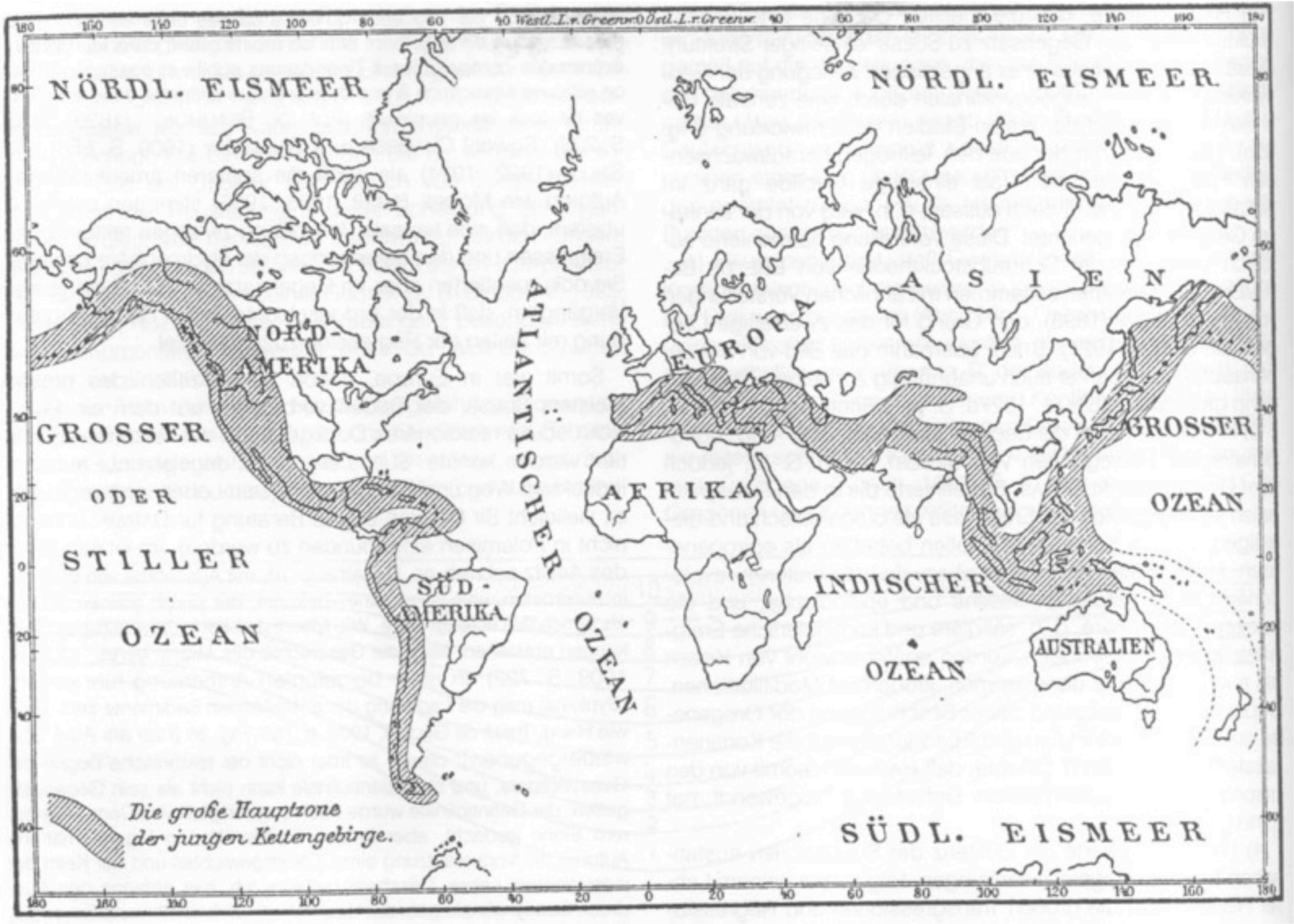
Der Begriff der Isostasie

Die Entdeckung der Radioaktivität:

1902- Marie Curie Radioactivität des Thorium.
Mit Albert Laborde, sie hat gezeigt, dass der radioaktiv Abfall exothermisch ist

Marie Sklodowska Curie
(1867-1934)

Dies widerspricht die essentielle Vermutung der Einschnürungstheorie



Young mountain belts after Neumayr (*Erdgeschichte*, t. 2, 1887)

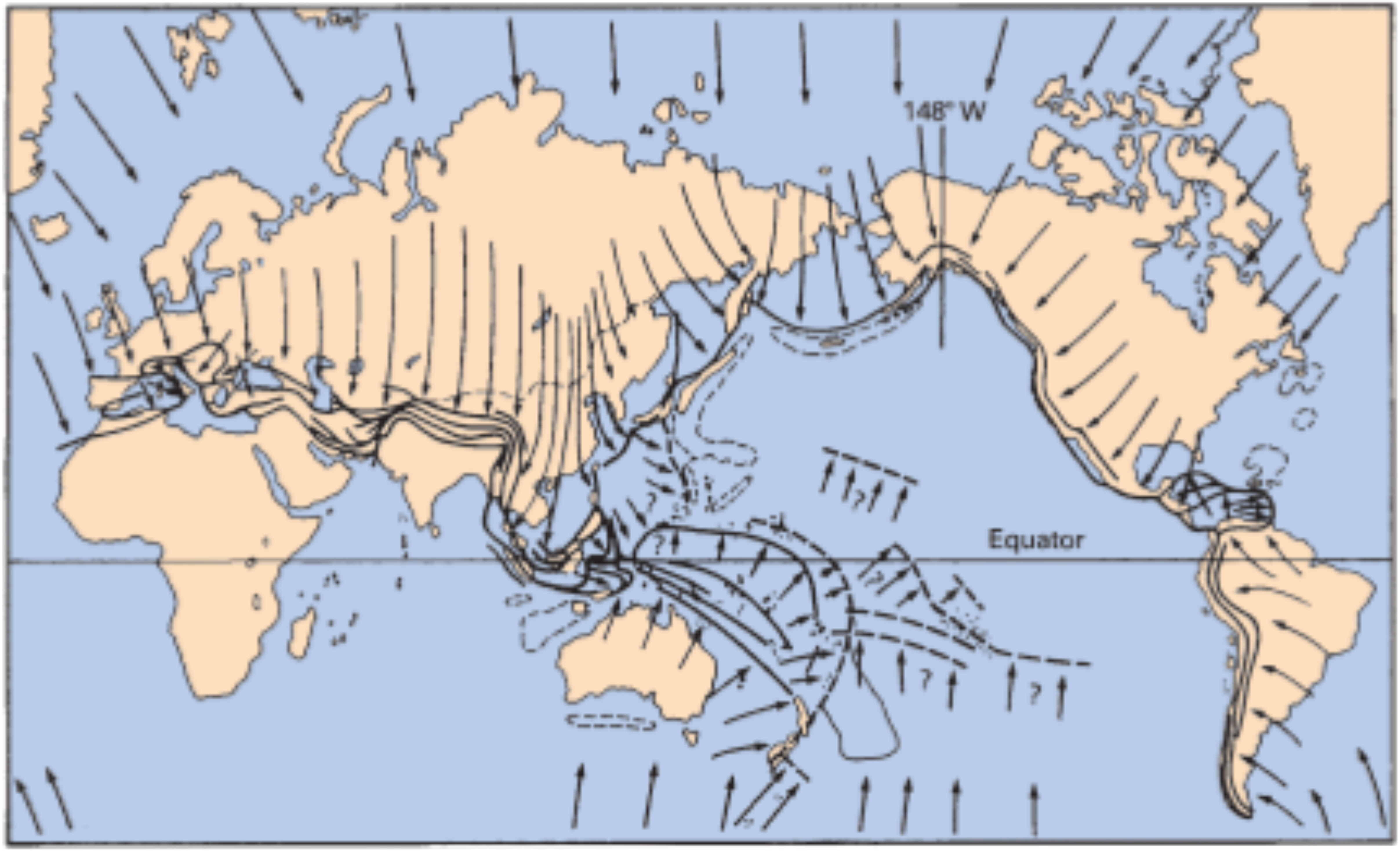
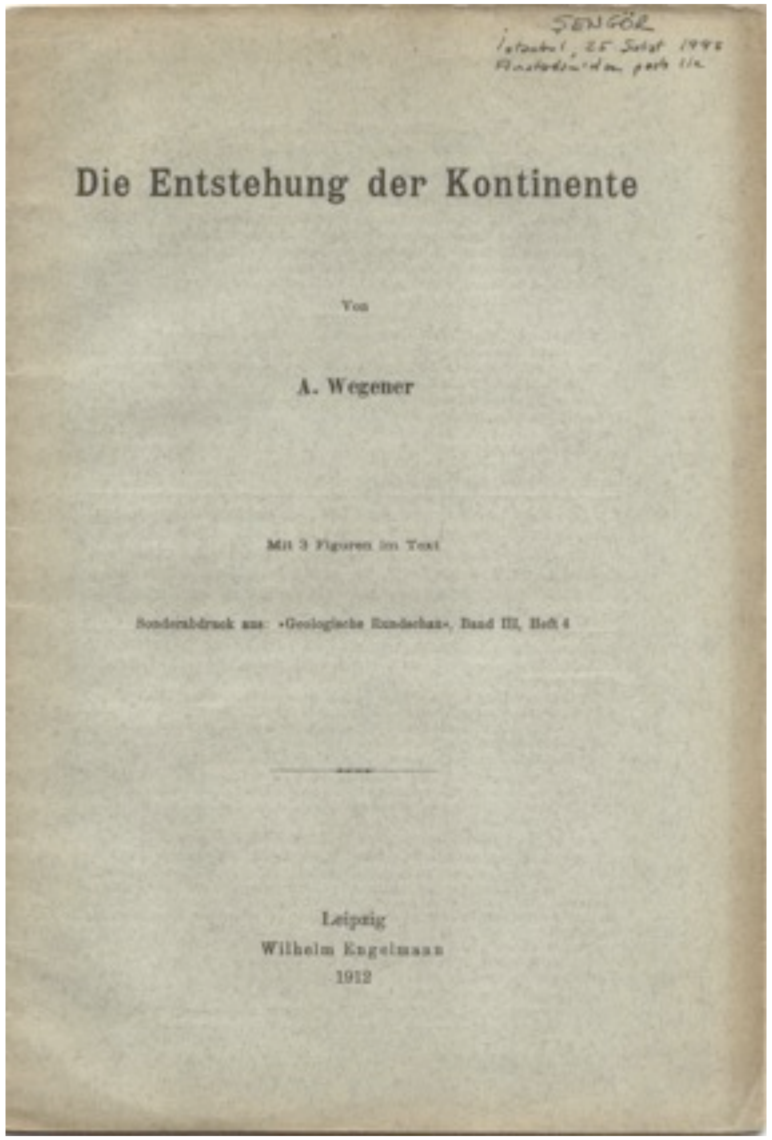


Figure 1.2 *Taylor's mechanism for the formation of Cenozoic mountain belts by continental drift (after Taylor, 1910).*

Die kontinentale Drift



ŞENGÖR
İstanbul, 25 Şubat 1995
Amsterdam'dan posta ile

Die Entstehung der Kontinente

Von

A. Wegener

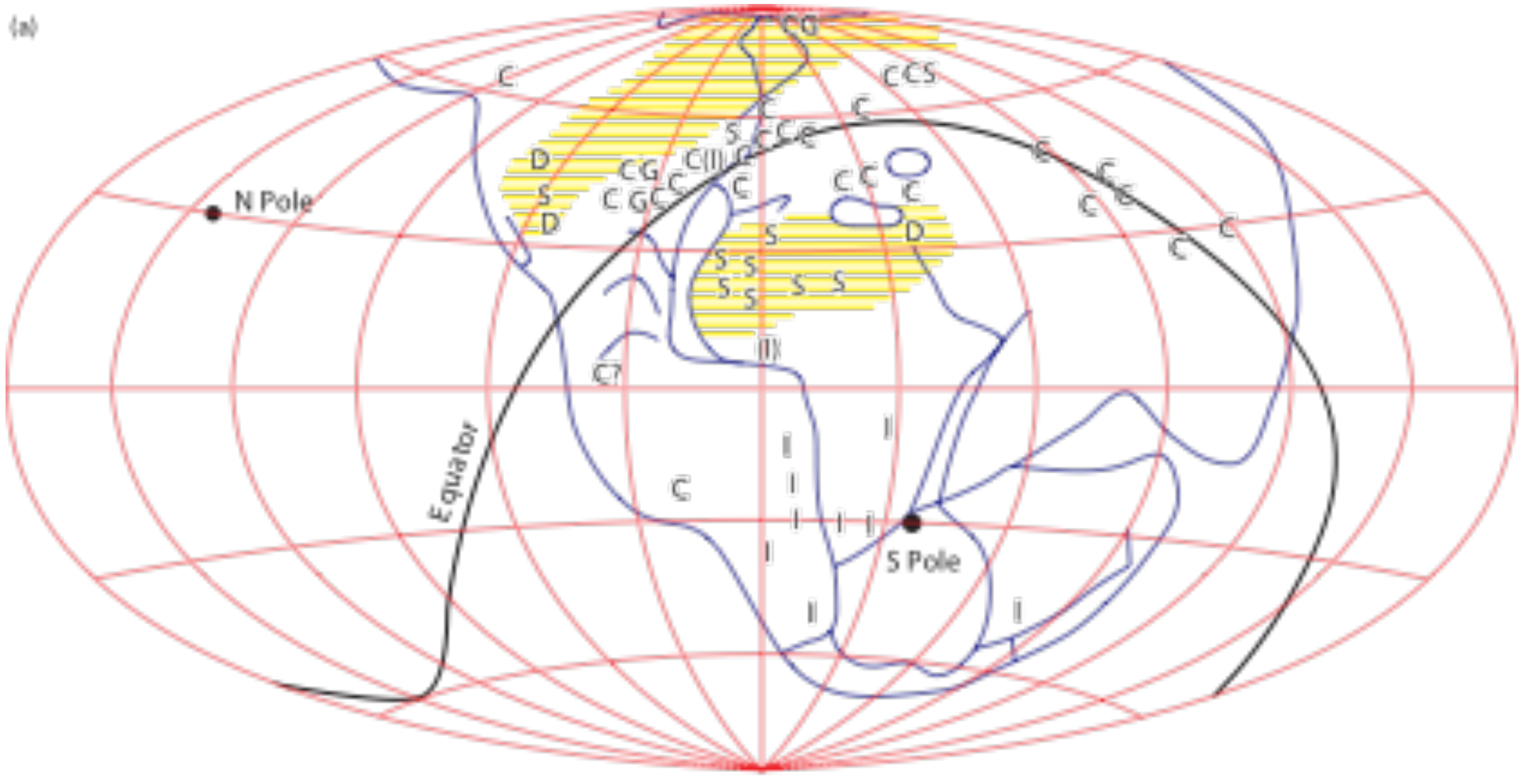
Mit 3 Figuren im Text

Sonderabdruck aus: »Geologische Rundschau«, Band III, Heft 4

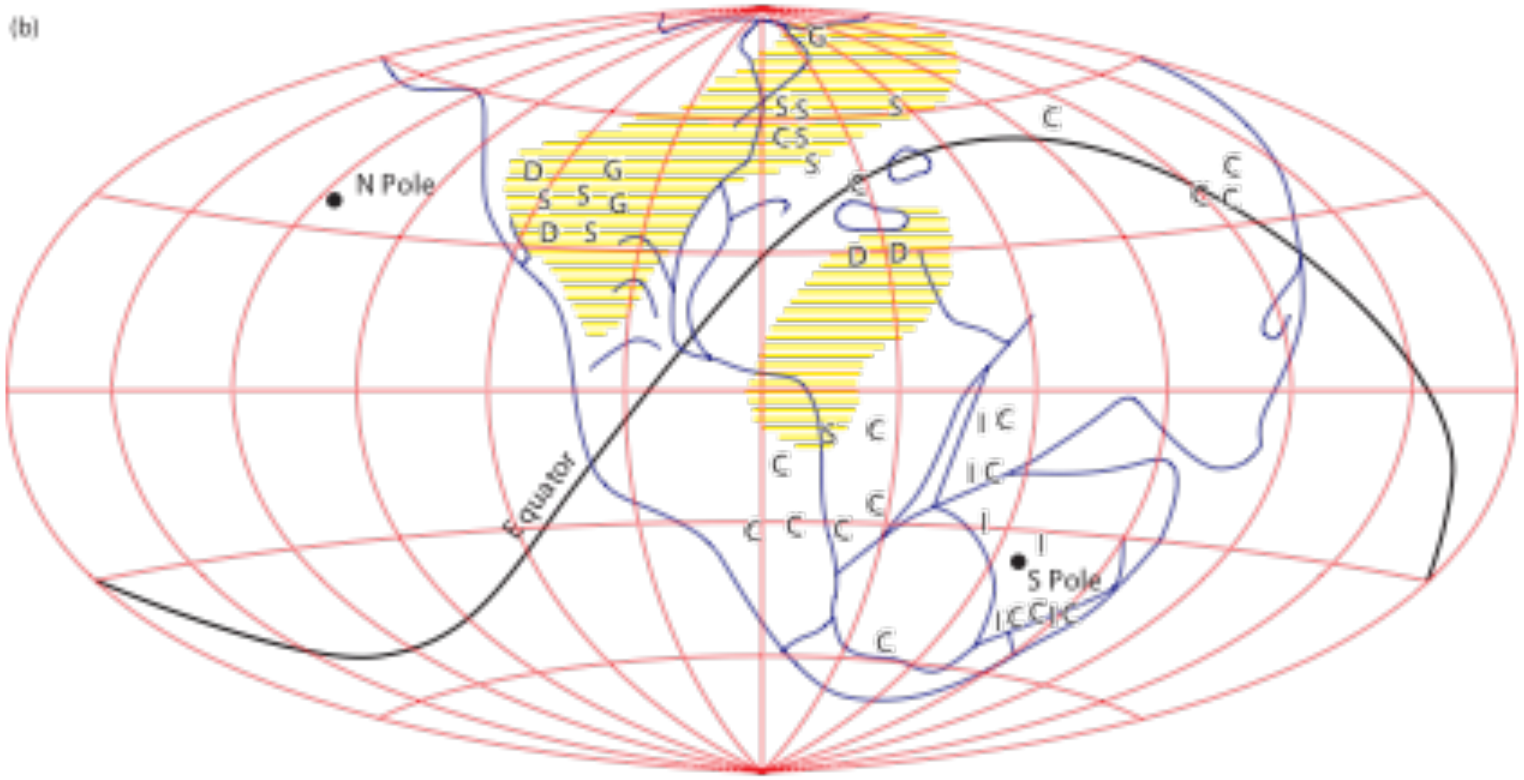
Leipzig
Wilhelm Engelmann
1912

Alfred Lothar Wegener (1880-1930)

Die kontinentale Drift



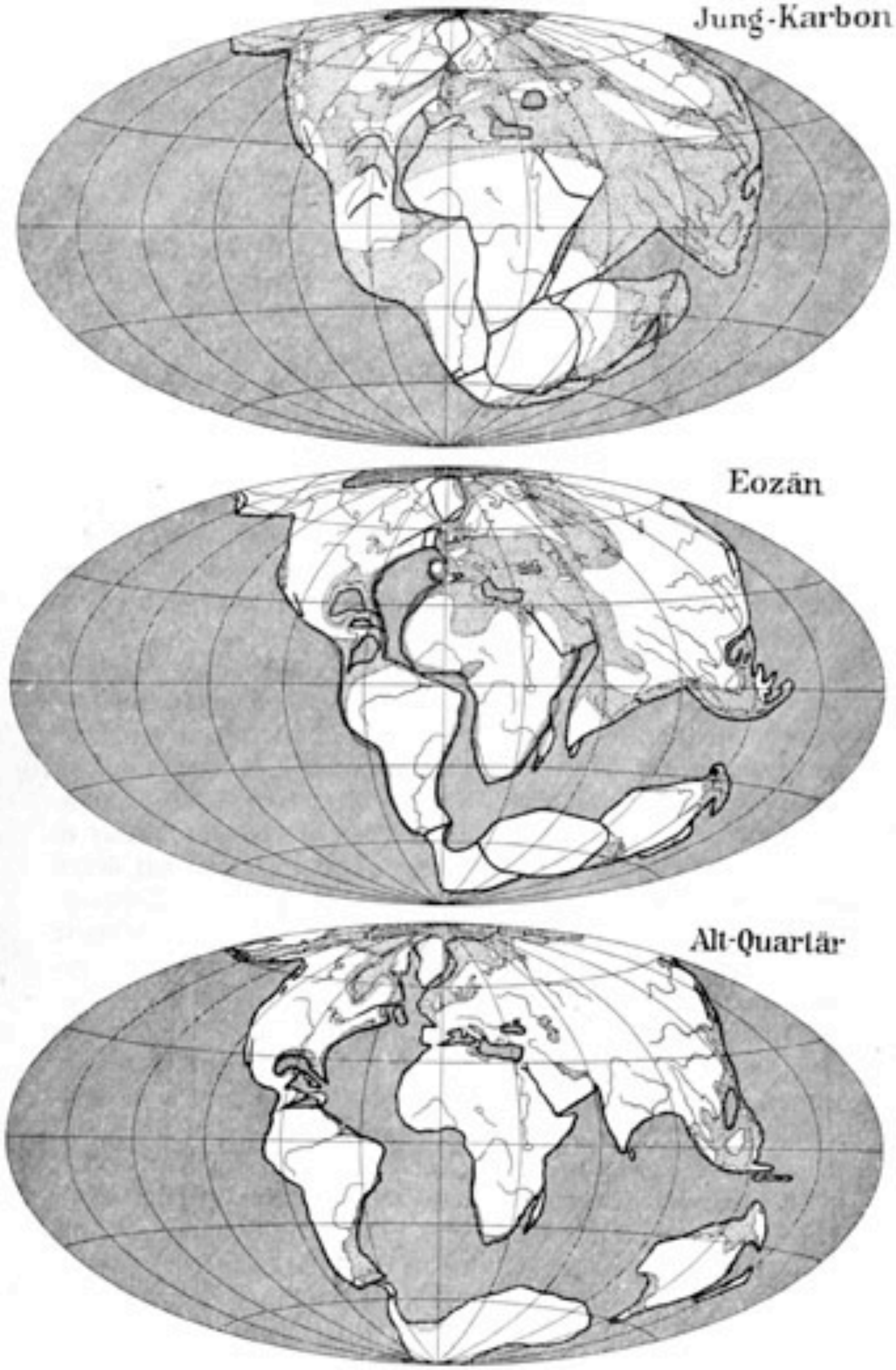
Carboniferous



Permian

Die kontinentale Drift

Abb. 4.



Jung-Karbon

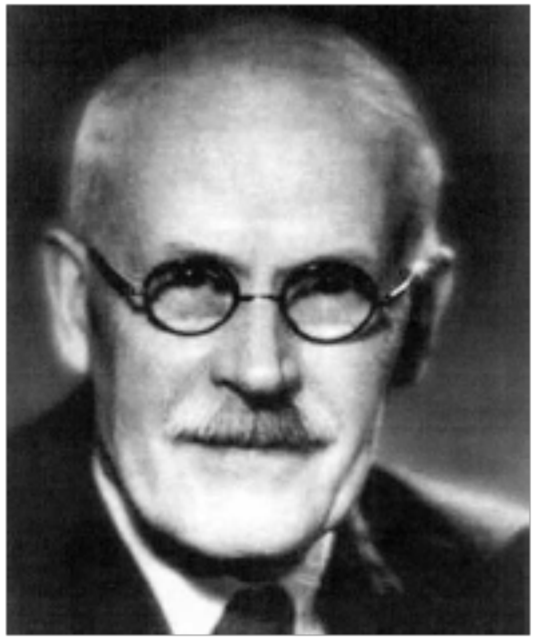
Eozän

Alt-Quartär

Rekonstruktionen der Erdkarte nach der Verschiebungstheorie
für drei Zeiten.

Schraffiert: Tiefsee; punktiert: Flachsee; heutige Konturen und Flüsse nur zum Erkennen.
Gradnetz willkürlich (das heutige von Afrika).

Gegen die kontinentale Drift



Die Geophysiker:

- Welcher Mechanismus? Die seismische Wellen propagieren sich in der Erde, denn ist sie fest.

Viele amerikanische Geowissenchafler

- Passt nicht mit dem Geosyncline Modell
- Isostasie
- Uniformitarismus

Uniformitarismus

1830 Charles Lyell published Principles of Geology

Concept of **Uniformitarianism** contrasted with prevailing concept of **Catastrosphism**

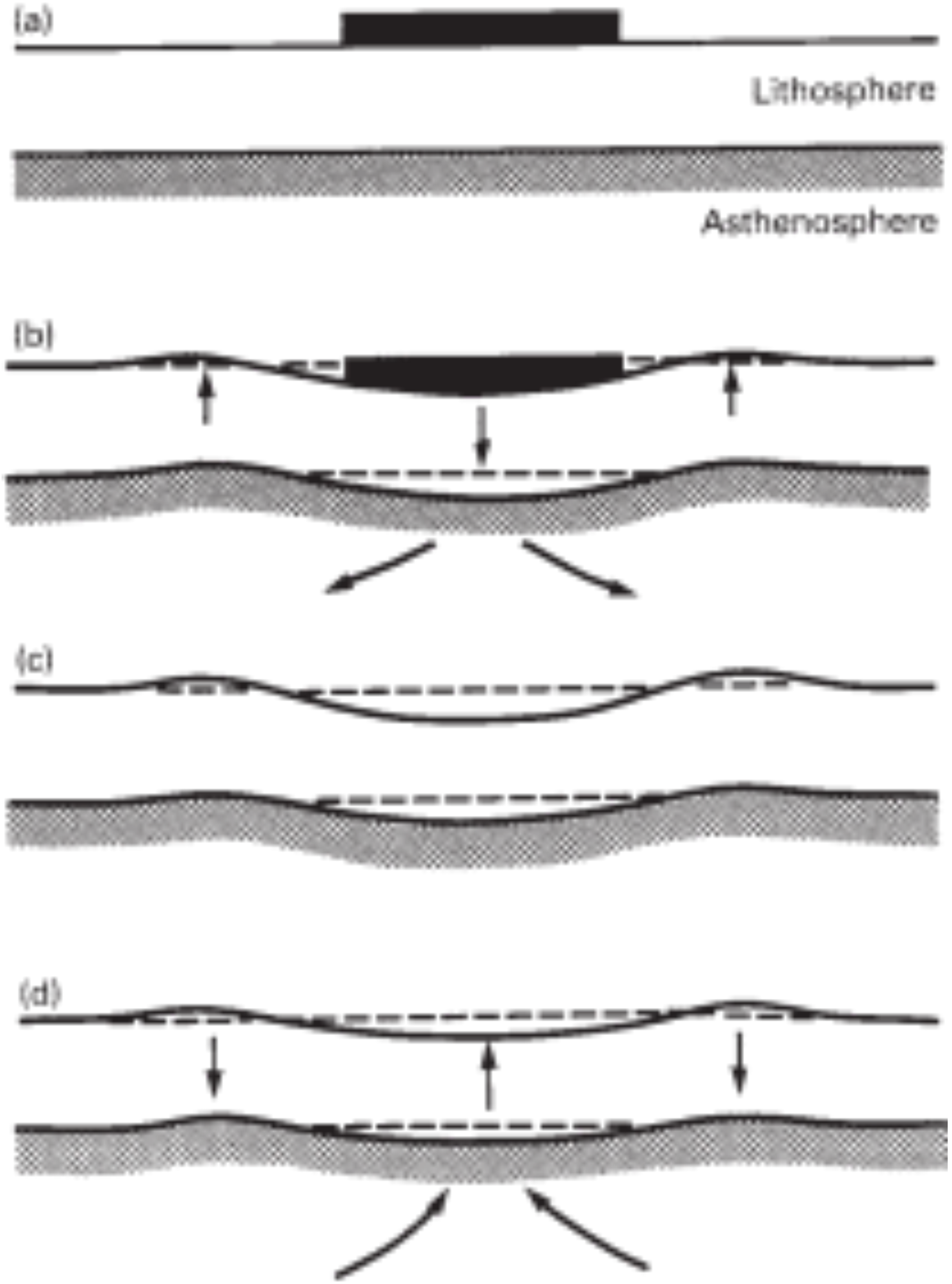
- ✓ Natural Laws are constant in space and time
- ✓ Present processes can explain the past (uniformity of process through time)
- ✓ Geologic change is slow, steady, gradual
- ✓ The Earth has been fundamentally the same since its formation (uniformity of configuration)

Sir Charles Lyell
(1797-1875)

"Uniformity and Catastrophy" in *Ever Since Darwin*, by Stephen J. Gould, New York: Norton, 1977

Bewegung im Mantel

Theorie of isostatiche Rückprall (rebound)



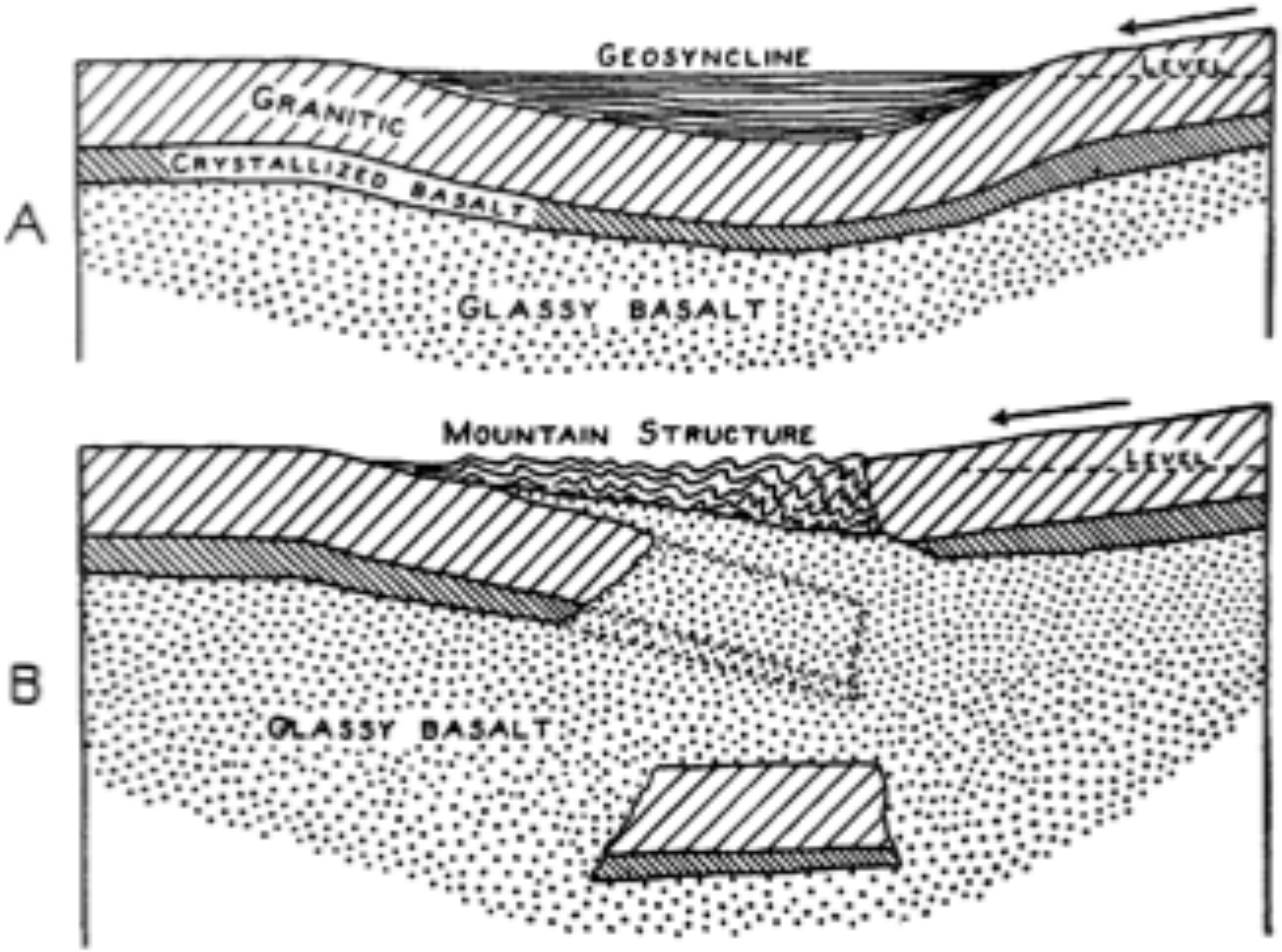
(a) The load of an icecap on the lithosphere causes downbending accompanied by the elevation of the peripheral lithosphere and lateral flow in the asthenosphere

(b). When the icecap melts

(c), isostatic equilibrium is regained by reversed flow in the asthenosphere,

sinking of the peripheral bulges and elevation of the central region (d).

Bewegung im Mantel



Reginald Daly's mechanism of continental drift by gravity sliding. Reprinted with

Reginald Daly
1926

Bewegung im Mantel

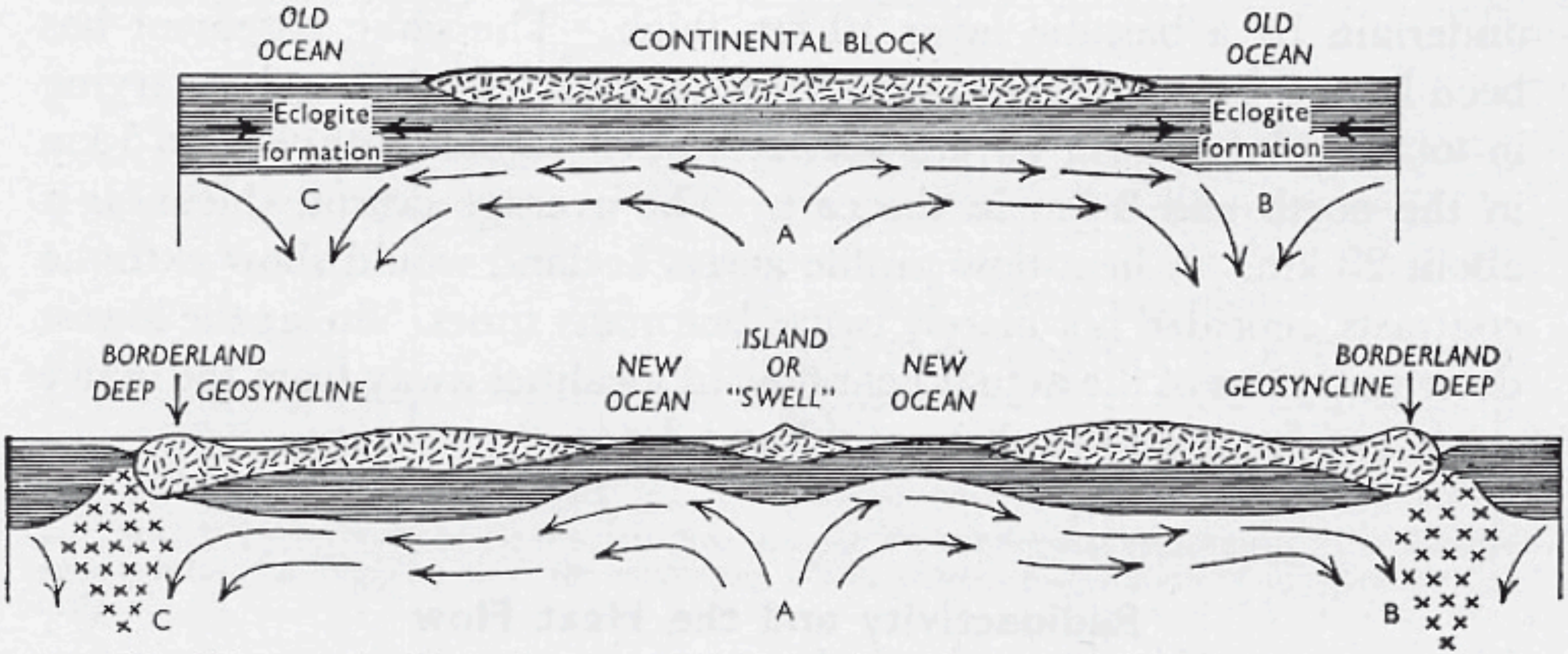


FIG. 734 Diagrams to illustrate a convective-current mechanism for ‘engineering’ continental drift and the development of new ocean basins, proposed by the author in 1928, when it was thought that the oceanic crust was a thick continuation of the continental basaltic layer (horizontal line shading).

(a) A current ascending at A spreads out laterally, extends the continental block and drags the two main parts aside, provided that the obstruction of the old ocean floor can be overcome. This is accomplished by the formation of eclogite at B and C, where sub-continental currents meet sub-oceanic currents and turn downwards. Being heavy, the eclogite is carried down, so making room for the continents to advance.

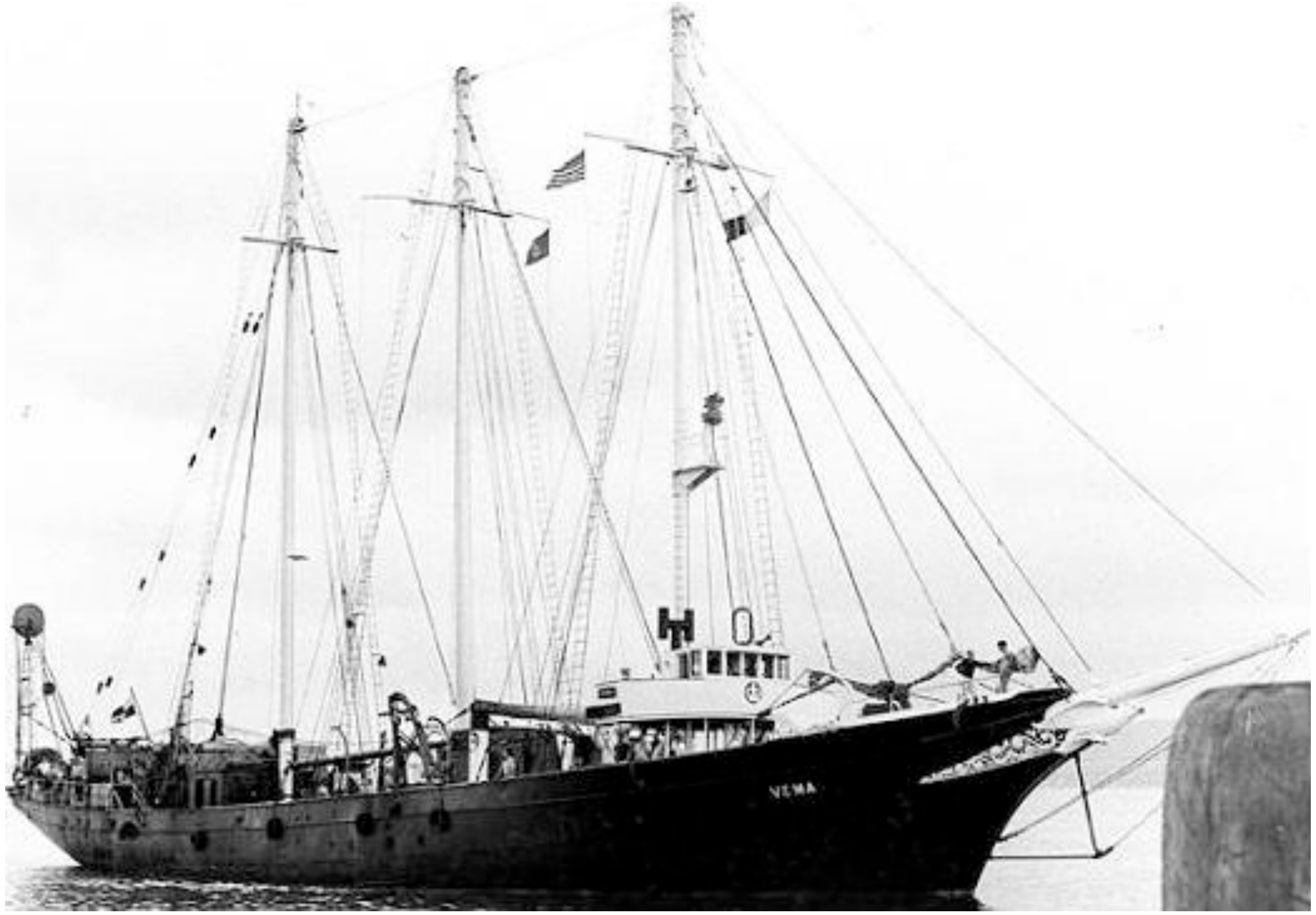
(b) The foundering masses of eclogite at B and C share in the main convective circulation and, melting at depth to form basaltic magma, the material rises in ascending currents: e.g. at A, healing the gaps in the disrupted continent and forming new ocean floors (locally with a swell of old sial left behind, such as Iceland). Other smaller current systems, set going by the buoyancy of basaltic magma, ascend beneath the continents and feed great floods of plateau basalts, or beneath the ‘old’ (Pacific) ocean floor to feed the outpourings responsible for the volcanic islands and seamounts. (*Arthur Holmes, Transactions of the Geological Society of Glasgow*, 1928–1929, *vol.* 18, *p.* 579)

Arthur Holmes

Vom Land nach Meer

Drei geophysikalische Untersuchungen der Ozean:

- Gravimetrie
- Topographie des Ozeans
- Paleomagnetismus



Vema

Gravimetrie

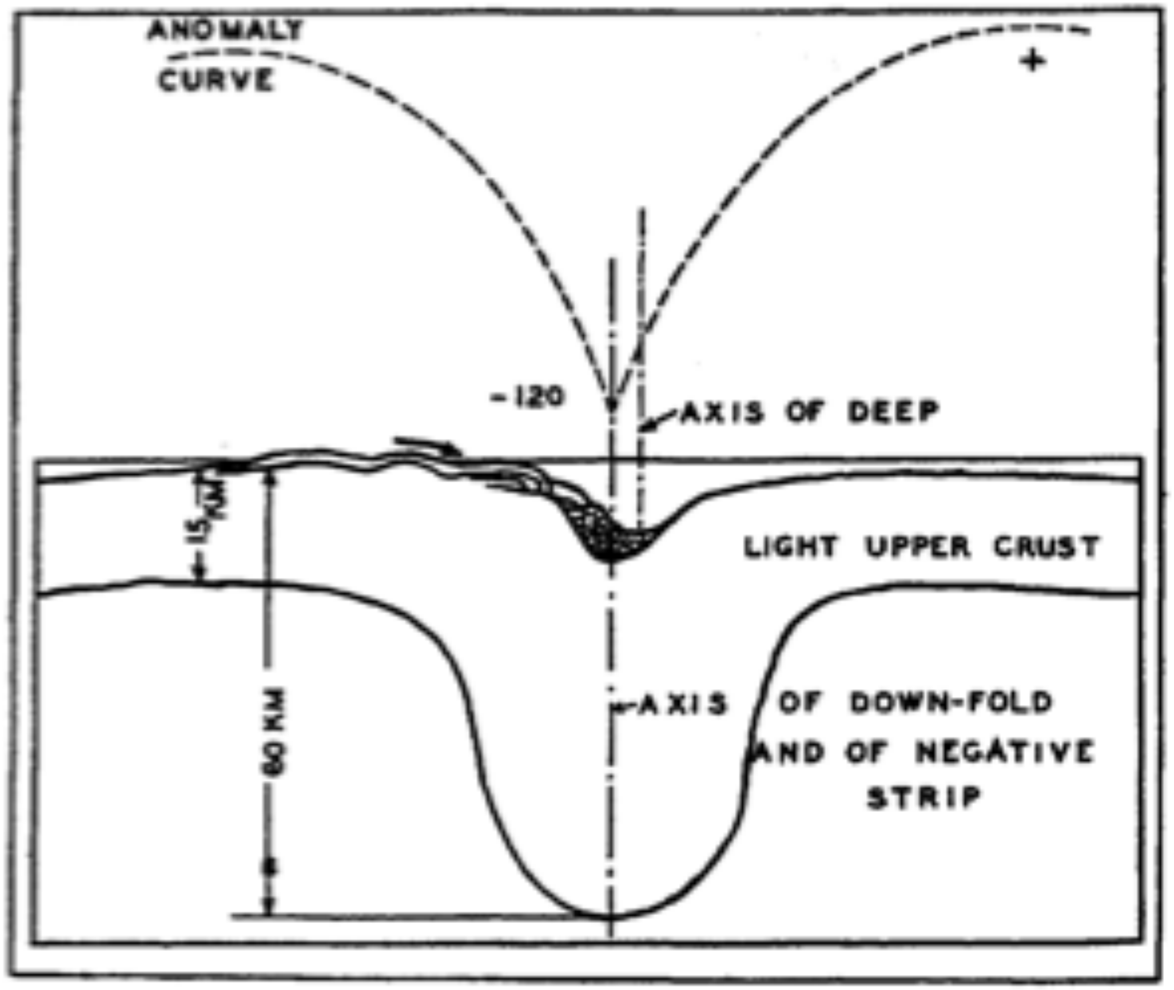
In 1923 in Indonesia, hat Felix Vening Meinesz (1887-1966) eine grosse gravimetrische Abweichung assoziiert mit dem Java Graben

In 1928, haben Vening Meinesz mit den amerikanischen Harry Hess und Maurice Ewing und dem britischen Ted Bullard Geophysiker in der Karibik die Beobachtung bestätigen

Vening Meinesz schlaget vor, dass die Konvektionsströmungen verantwortlich sein könnten.

In 1933, Hess stellt ein neues Modell, *the tectogene*: eine verticale Beule in der Kruste

Gleichseitig haben Beno Gutenberg und Charles Richter gezeigt, dass die Erdbeben um das pazifische Becke nur im bestimmten Gebieten mit Abhang von 45° Richtung des Kontinents lokalisiert werden



Harry Hess' tectogene concept explaining the origins of ocean deeps associated with negative gravity anomalies, from Hess (1933), Interpretation of geological and geophysical observations, in *The Navy–Princeton Gravity Expedition*

Konvektion

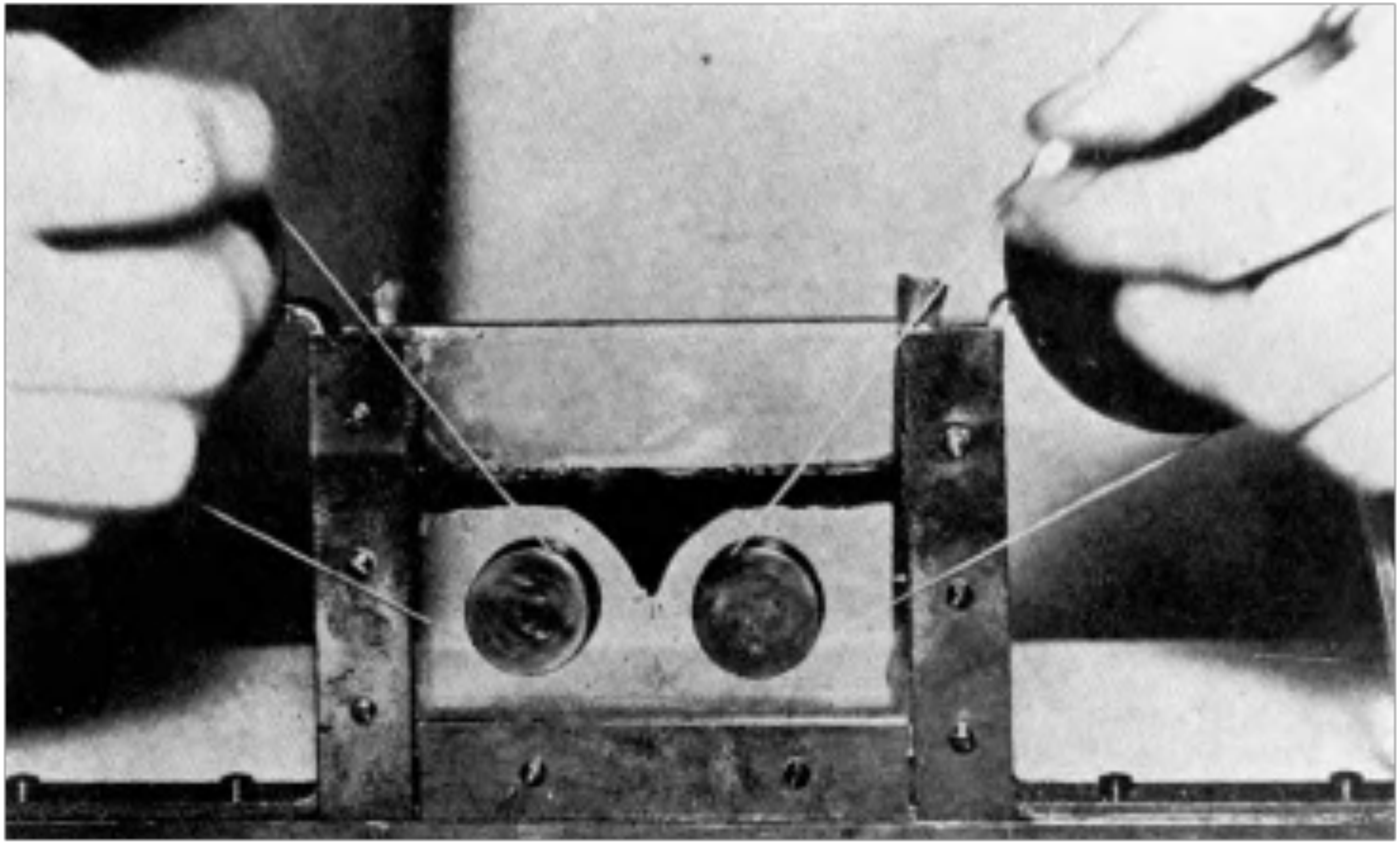
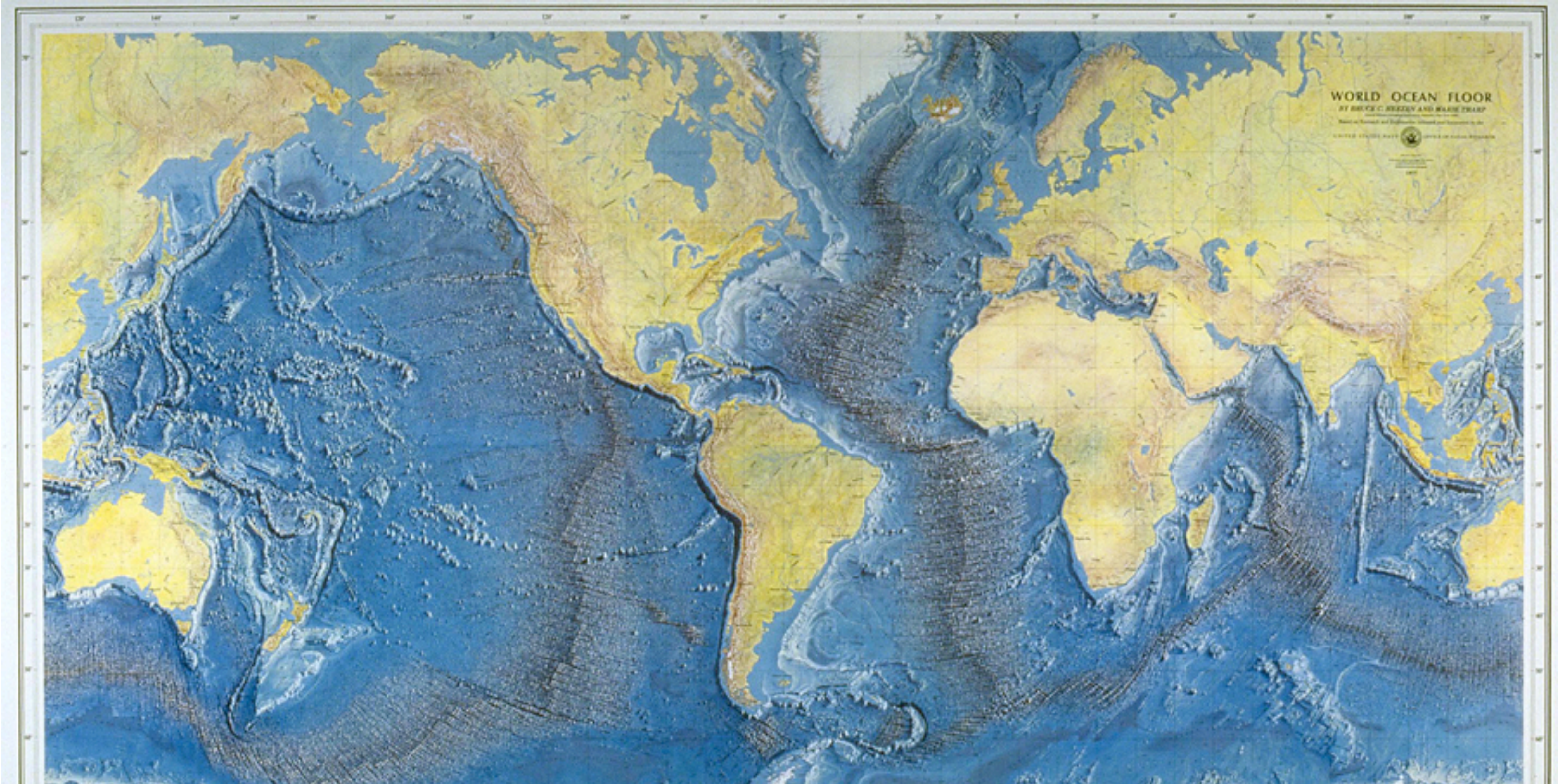


Figure 1.11. Early experiment on mantle convection by David Griggs (1939), showing styles of deformation of a brittle crustal layer overlying a viscous mantle. The cellular flow was driven mechanically by rotating cylinders.

David Griggs Experiment
(1939)

Topographie der Ozean



Heezen & Tharp, 1960s

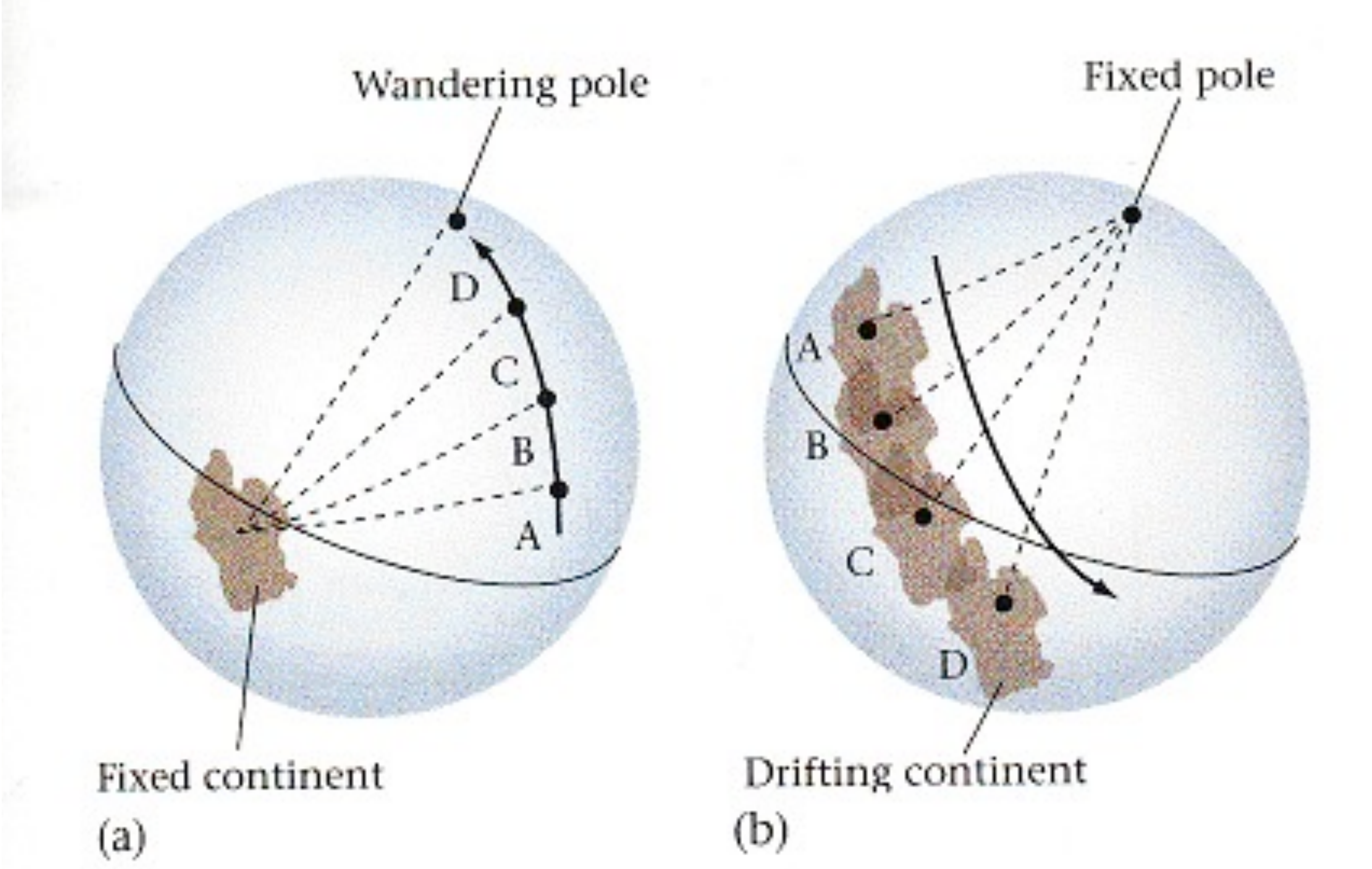
Paleomagnetismus

- In the early 20th century, Pierre Curie had discovered that rocks cooled in a magnetic field take on the polarity of that field (the temperature: Curie point).
- Mid-1950s discovery of the fact that rocks of different age are displaying different magnetic orientation

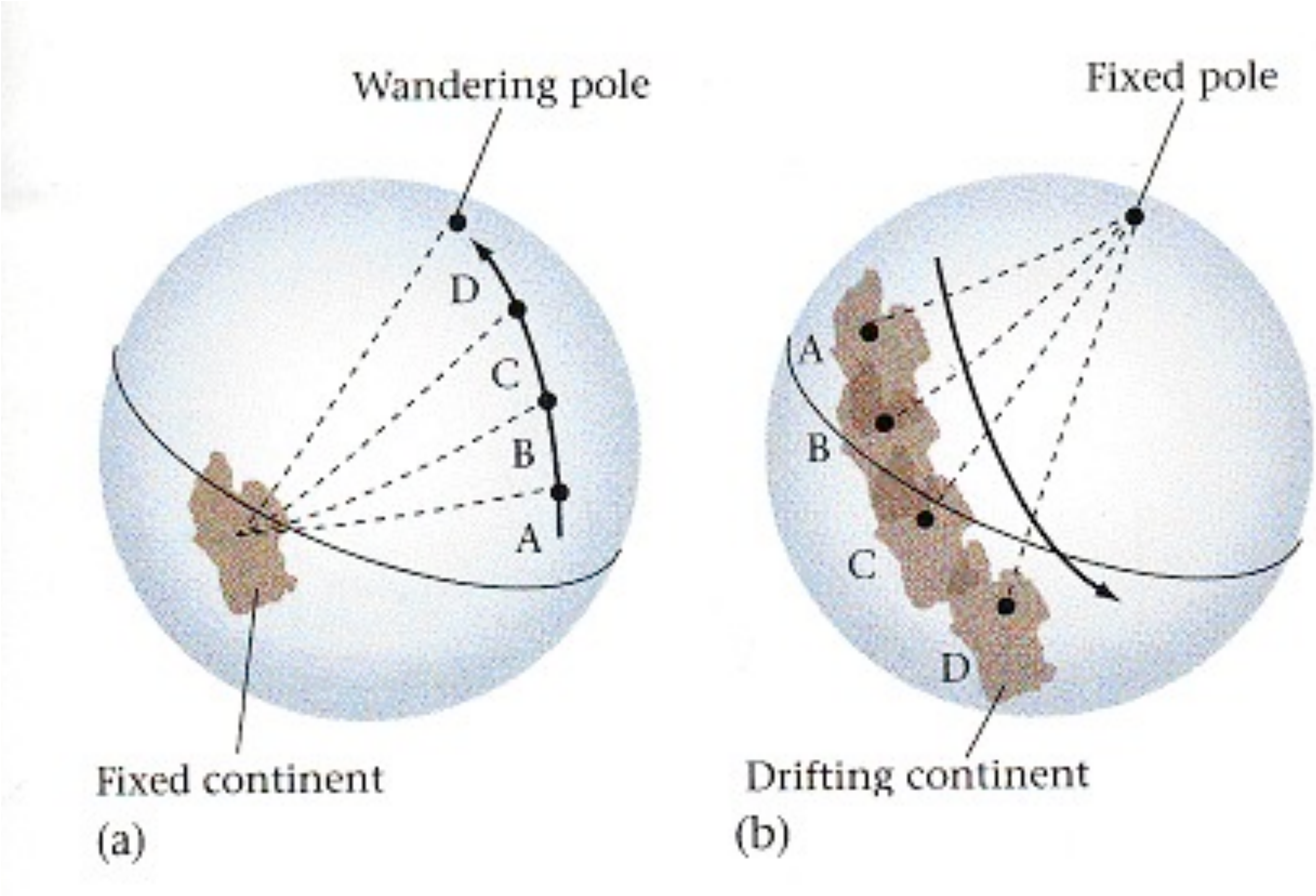
Two possible interpretations:

either the earth's poles had moved relative to the land masses (true polarwander),

or the land masses had moved relative to the poles (continental drift).

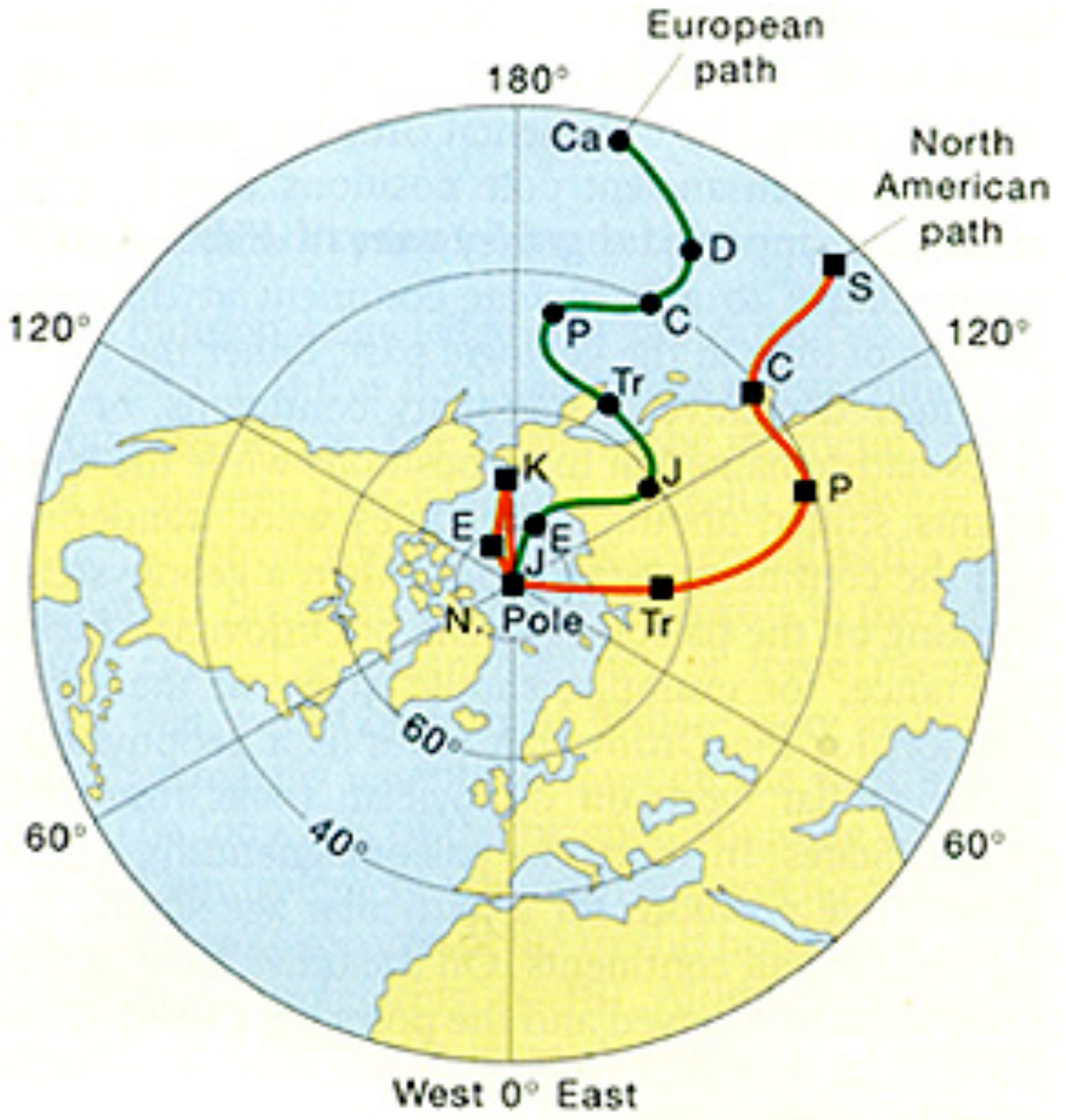


Paleomagnetismus

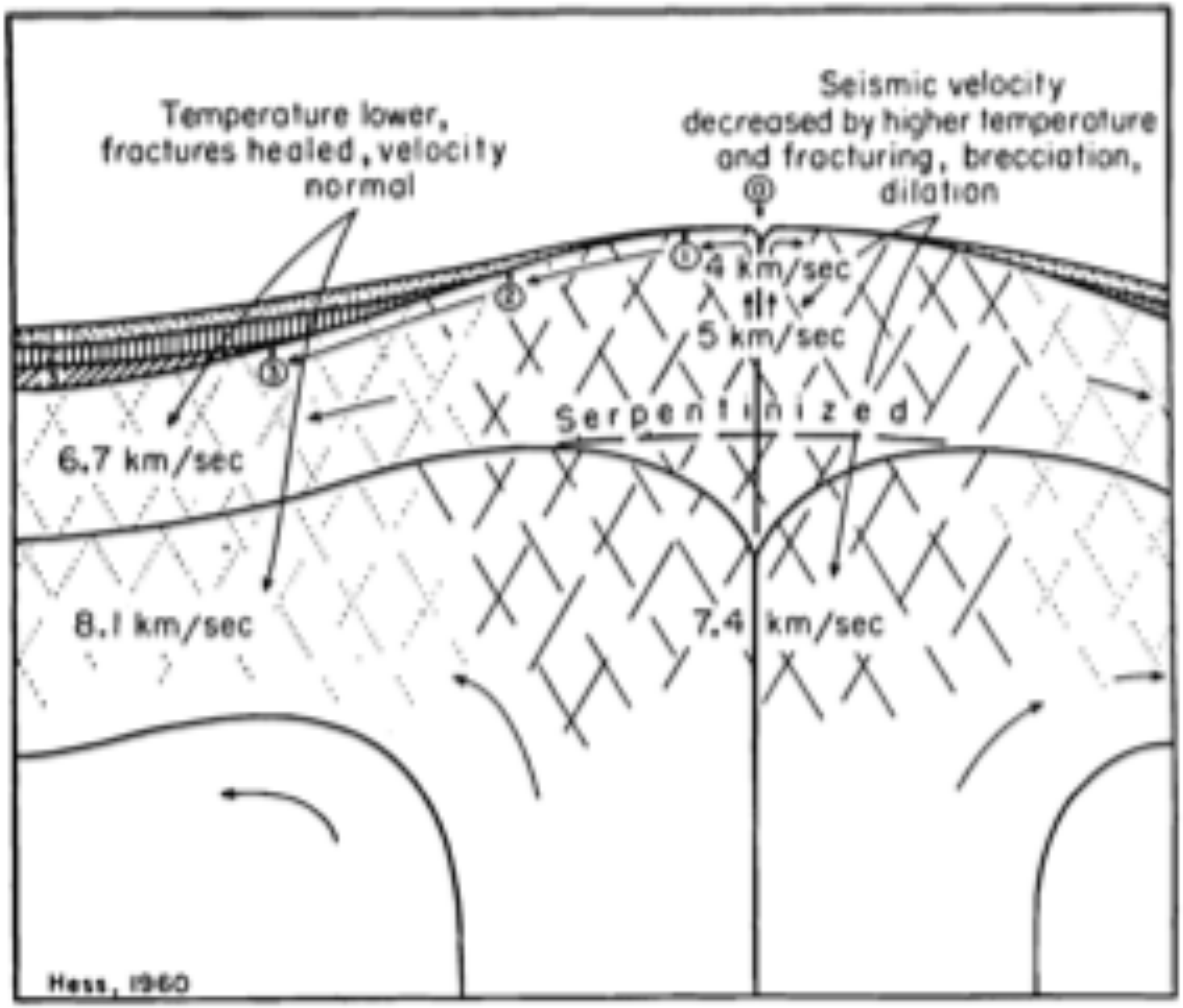


Paleomagnetismus

By compiling remanent magnetism of rocks of varying ages, one could construct a record of how the poles had seemed to move over time, an **"apparent polar-wandering path."**



Sea-floor spreading



Hess, 1962

Sea-floor spreading

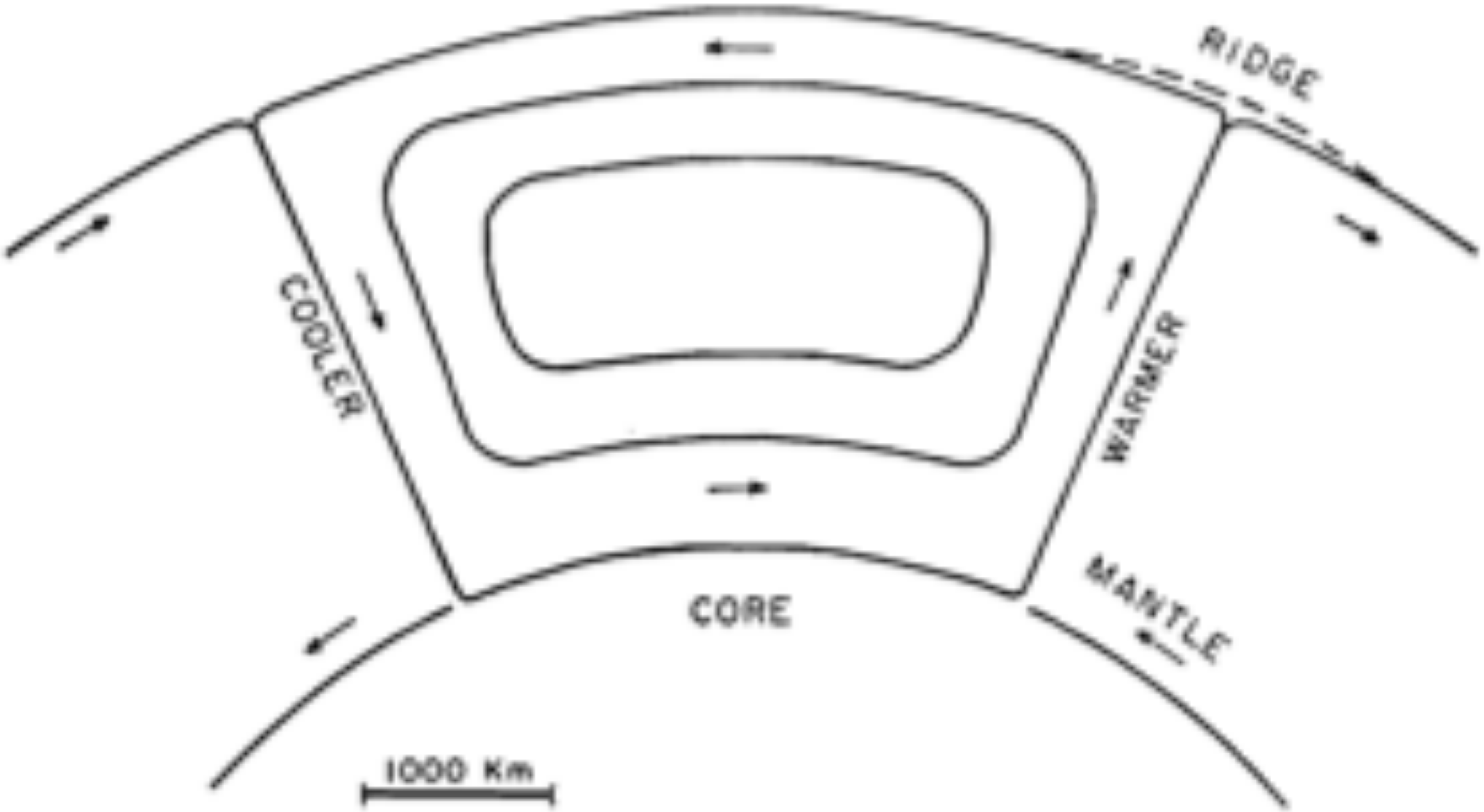


Figure 8. Possible geometry of a mantle convection cell

Hess, 1962

Sea-floor spreading

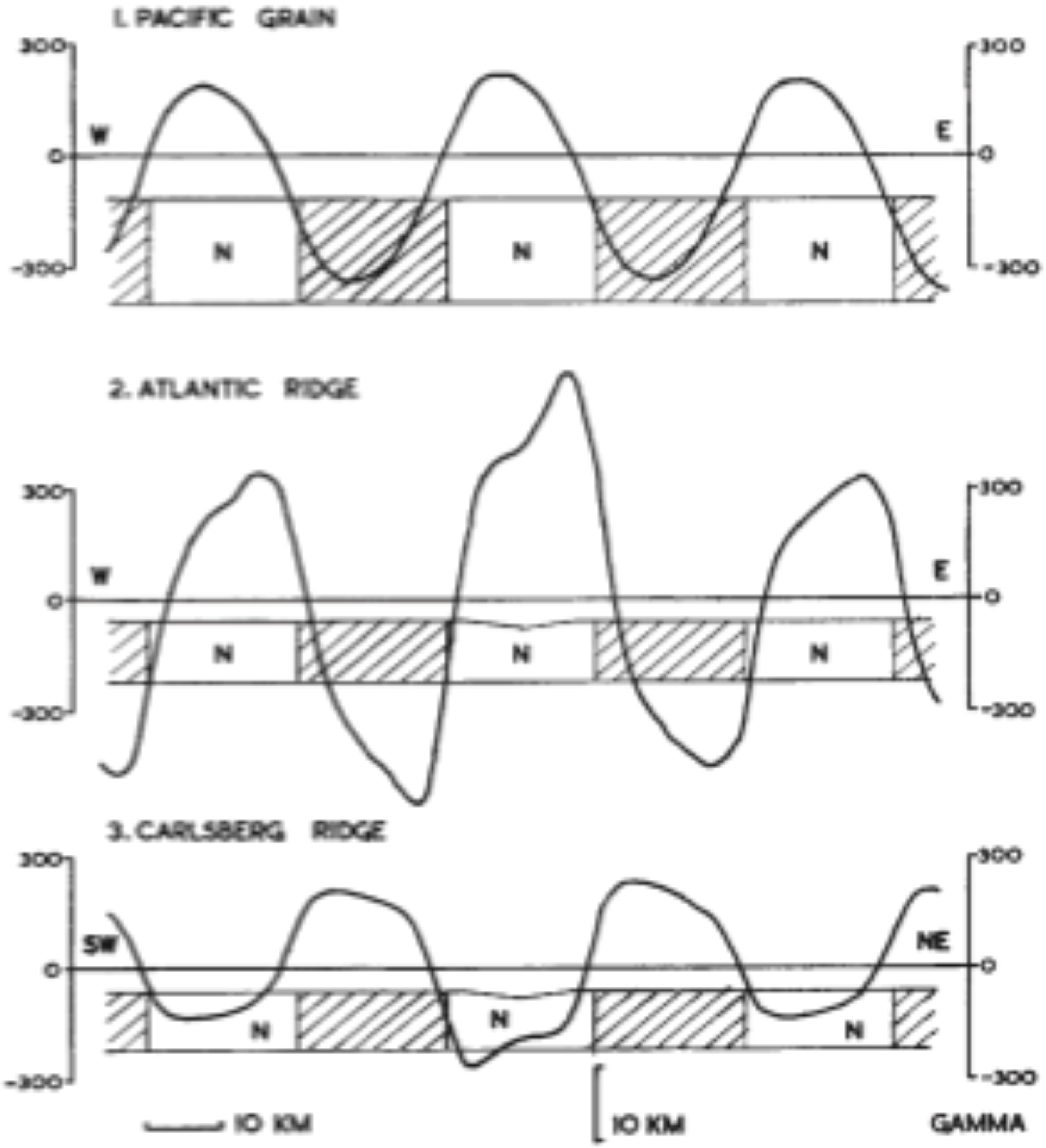


Fig. 4. Magnetic profiles computed for various crustal models. Crustal blocks marked *N*, normally magnetized; diagonally shaded blocks, reversely magnetized. Effective susceptibility of blocks, 0·0027, except for the block under the median valley in profiles 2 and 3, 0·0053

(1) Pacific Grain. Total field strength, T = 0·5 oersted; inclination, $I = 60°$; magnetic bearing of profile, θ = 078°. (2) Mid-Atlantic Ridge, T = 0·48 oersted; $I = 65°$; θ = 120°. (3) Carlsberg Ridge, T = 0·376 oersted; $I = -6°$; θ = 044°

Vine & Mattews, 1963

Sea-floor spreading

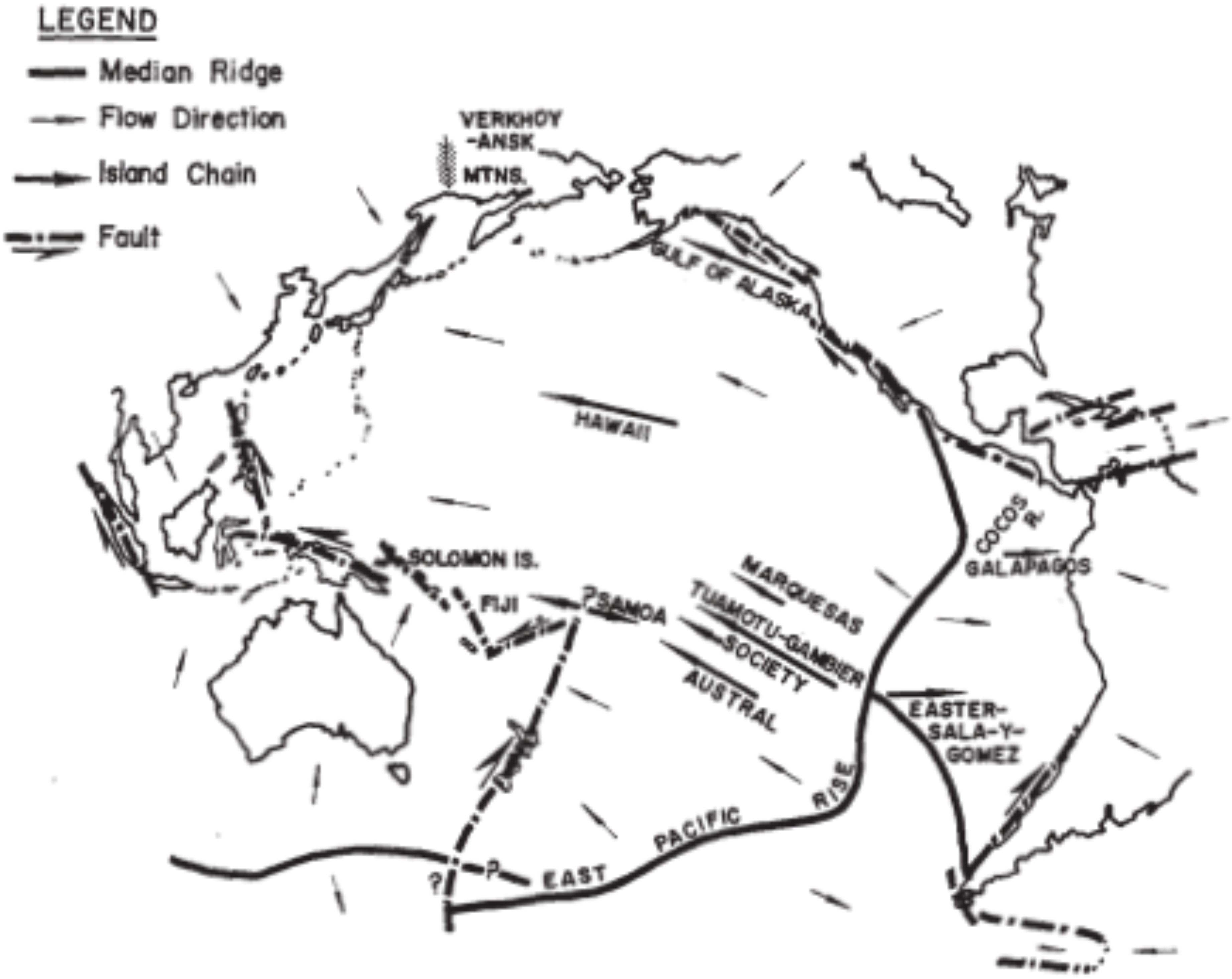


FIG. 1. Sketch of Pacific Ocean. Heavy arrows show nine linear chains of islands and seamounts which increase in age in direction of arrow. Single-headed arrows show direction of motion, where known, along large transcurrent faults. Small arrows show postulated direction of flow away from median ridges.

Wilson, 1962

Sea-floor spreading

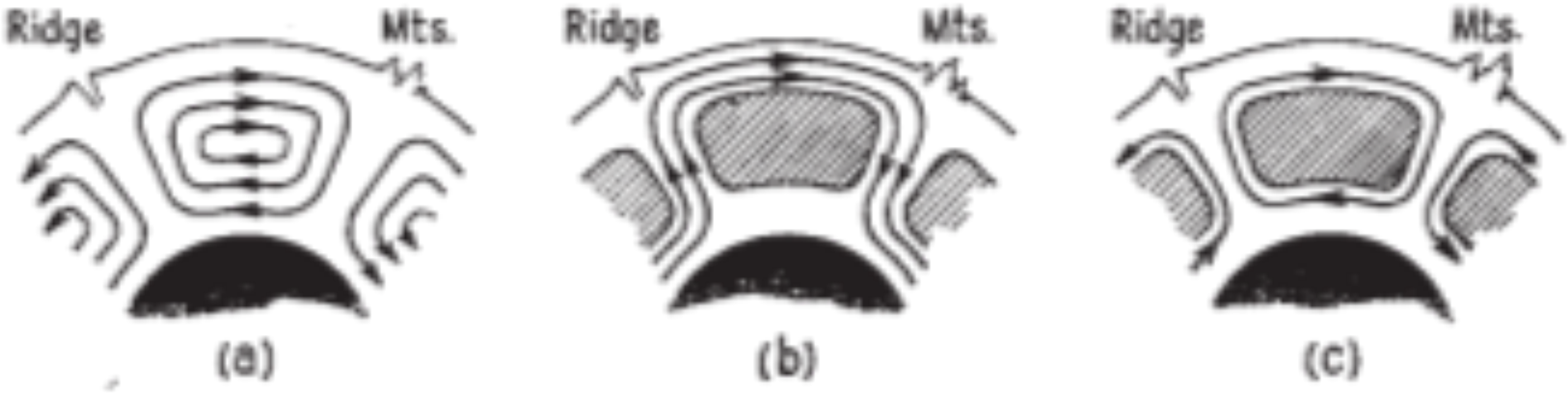


FIG. 2. Three possible modes of convection in the Earth's mantle.

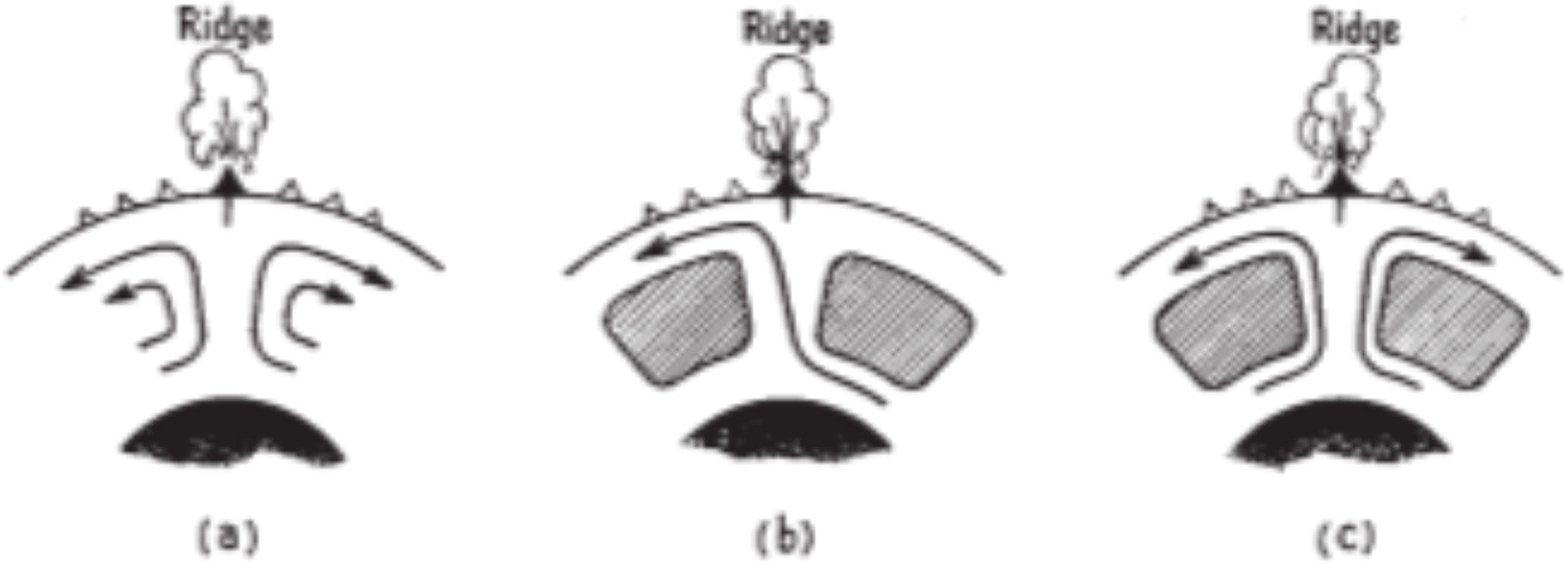


FIG. 3. Some possible patterns of convection, showing that, if active volcanoes form over rising vertical currents, chains of extinct volcanoes might be formed by the horizontal flow of the currents. The shaded areas represent stable cores of cells.

Wilson, 1962

Sea-floor spreading

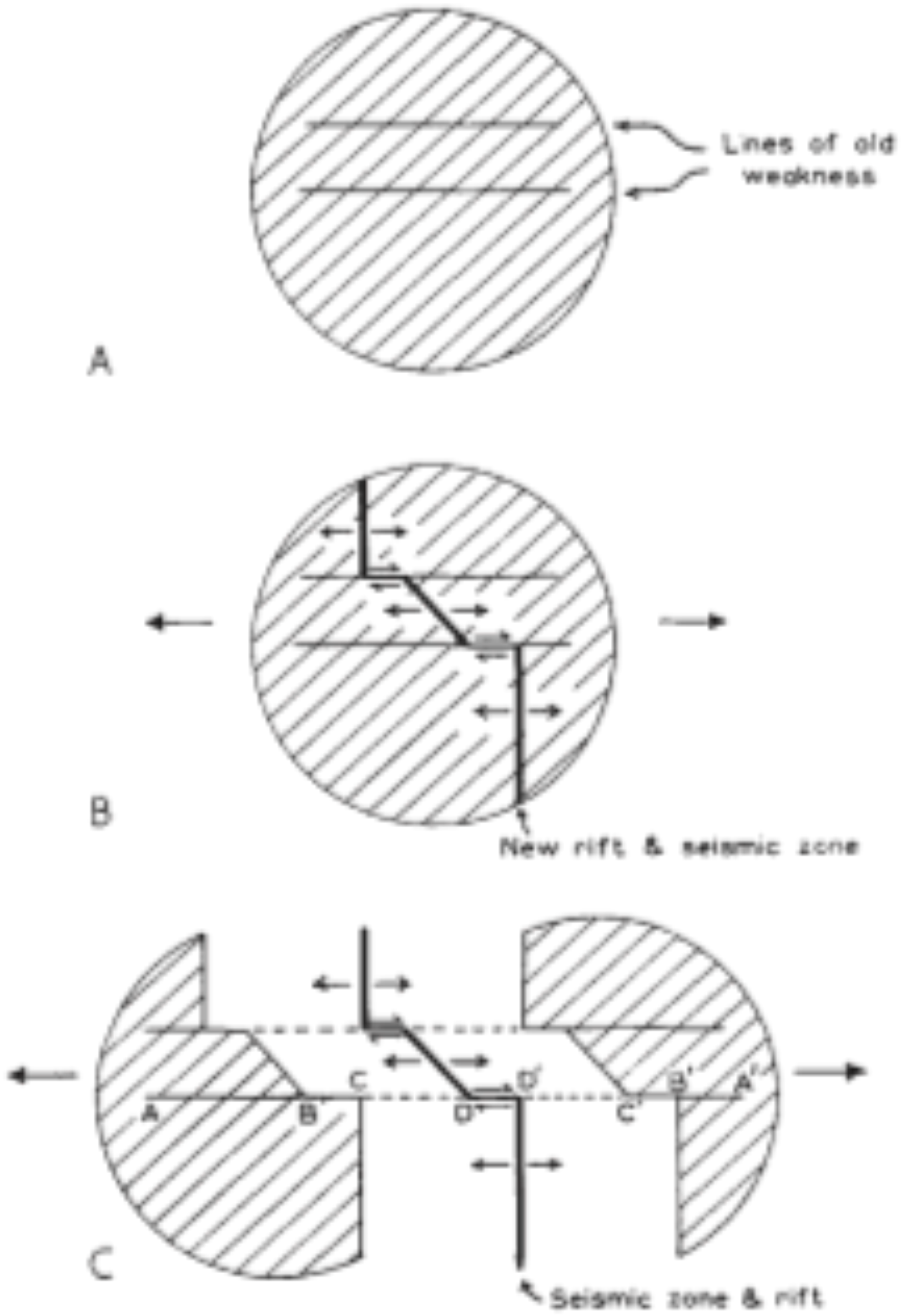
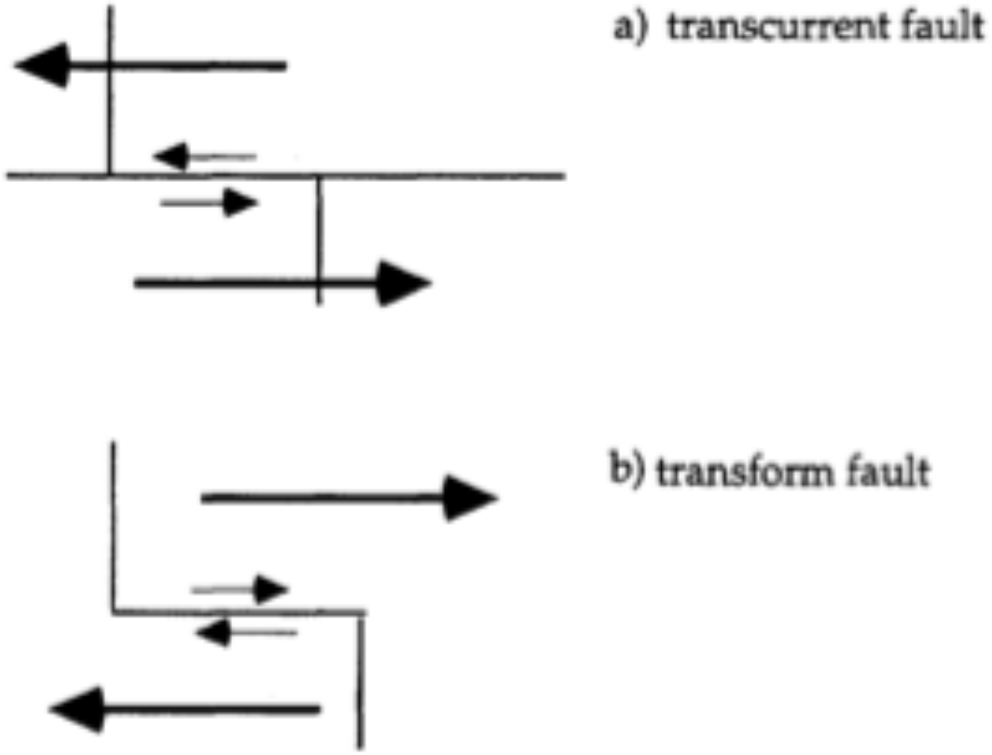


Fig. 6. Diagram illustrating three stages in the rifting of a continent into two parts (for example, South America and Africa). There will be seismic activity along the heavy lines only



The difference between transcurrent and transform faults. (a) In a transcurrent (or strike-slip) fault, the direction of movement can be determined from the offset of a feature intersecting the fault. If the feature is moved to the left, it is a left-lateral fault, as shown here. The north side of the fault has moved to the left (west), the south side of the fault has moved to the right (east), and the fault may continue indefinitely. (b) In a ridge-to-ridge transform fault, a section of the mid-ocean ridge is fractured perpendicular to its length. In this case, the right side of the ridge is moving to the right (east), the left side is moving to the left (west), and the sense of motion is opposite of that illustrated in (a). Note also that the fault does not extend indefinitely, but terminates against the north-south running ridge segments.

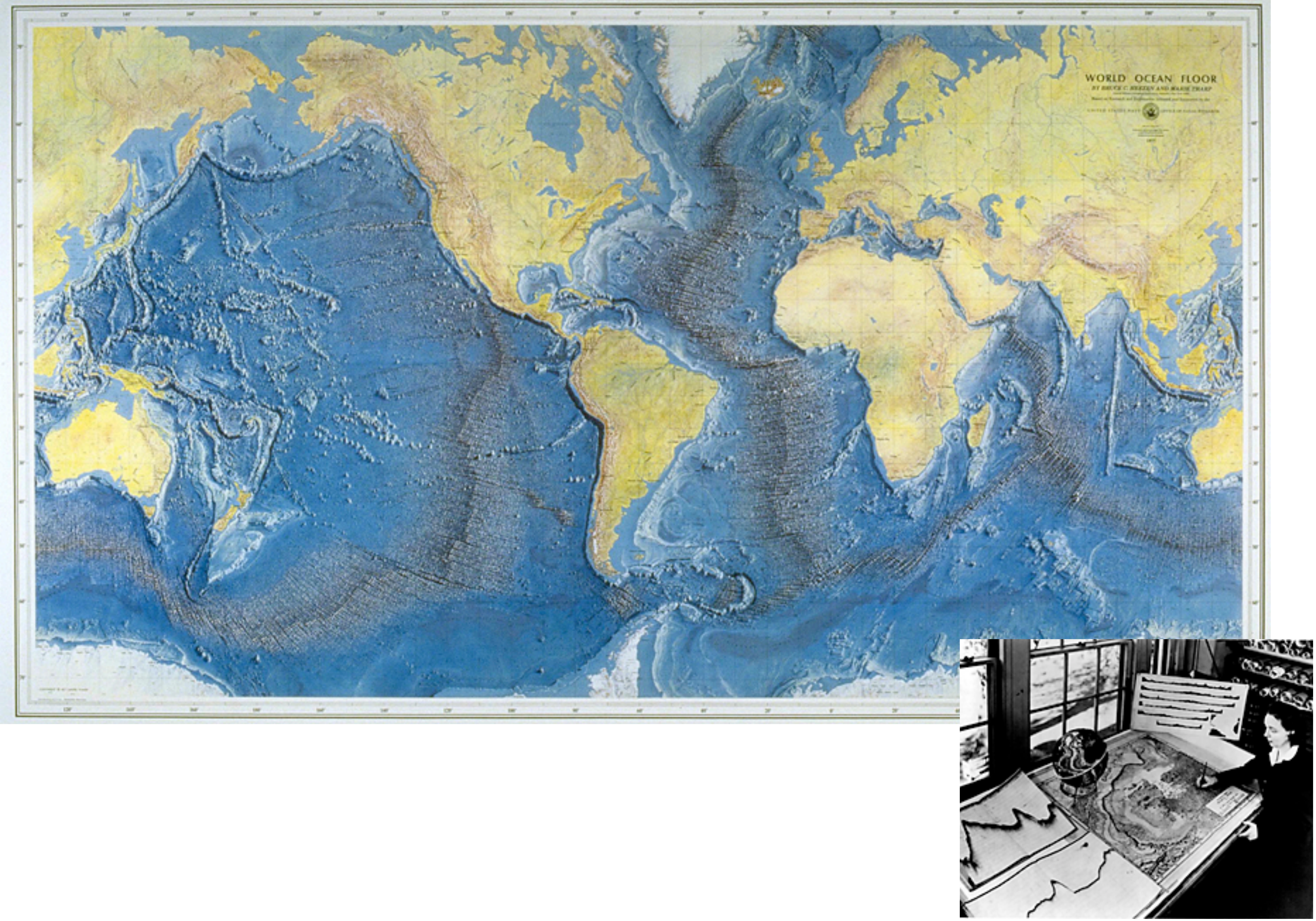
Wilson, 1965

Geometry on a sphere

Morgan, 1967

Fig. 4. On a sphere, the motion of block 2 elative to block 1 must be a rotation about some ole. All faults on the boundary between 1 and 2 ust be small circles concentric about the pole A.

Topographie



Die Plattentektonik, erst Model

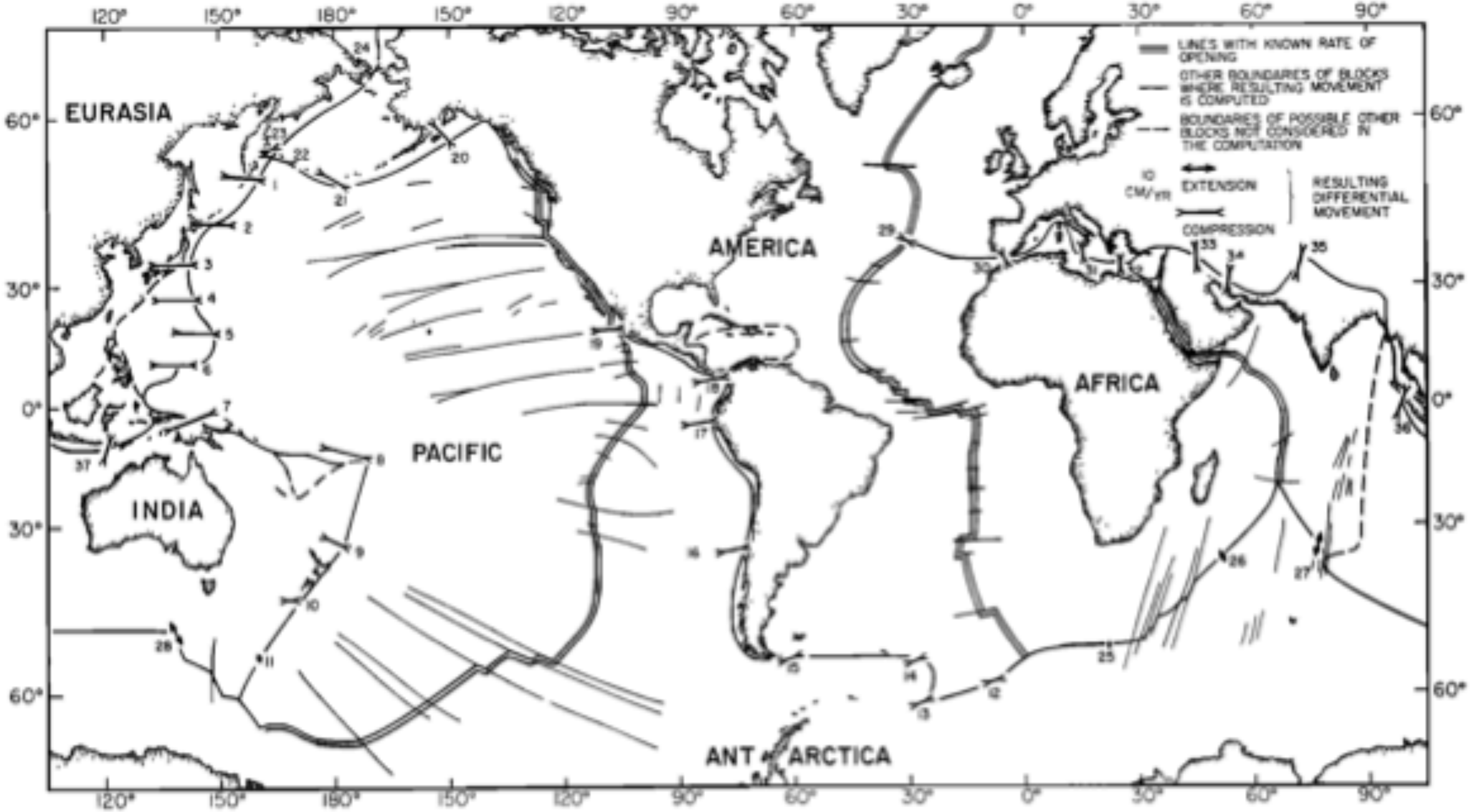
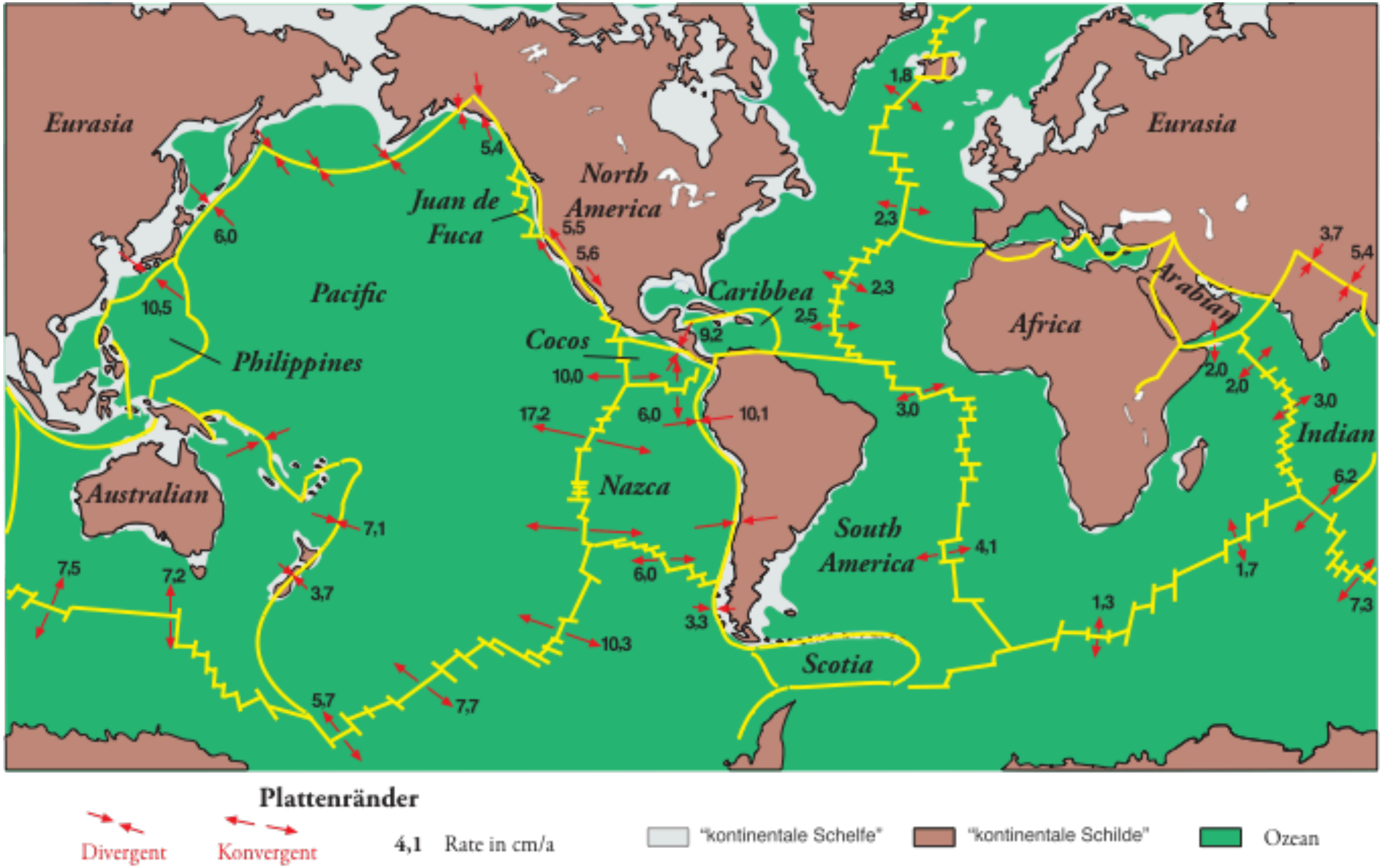


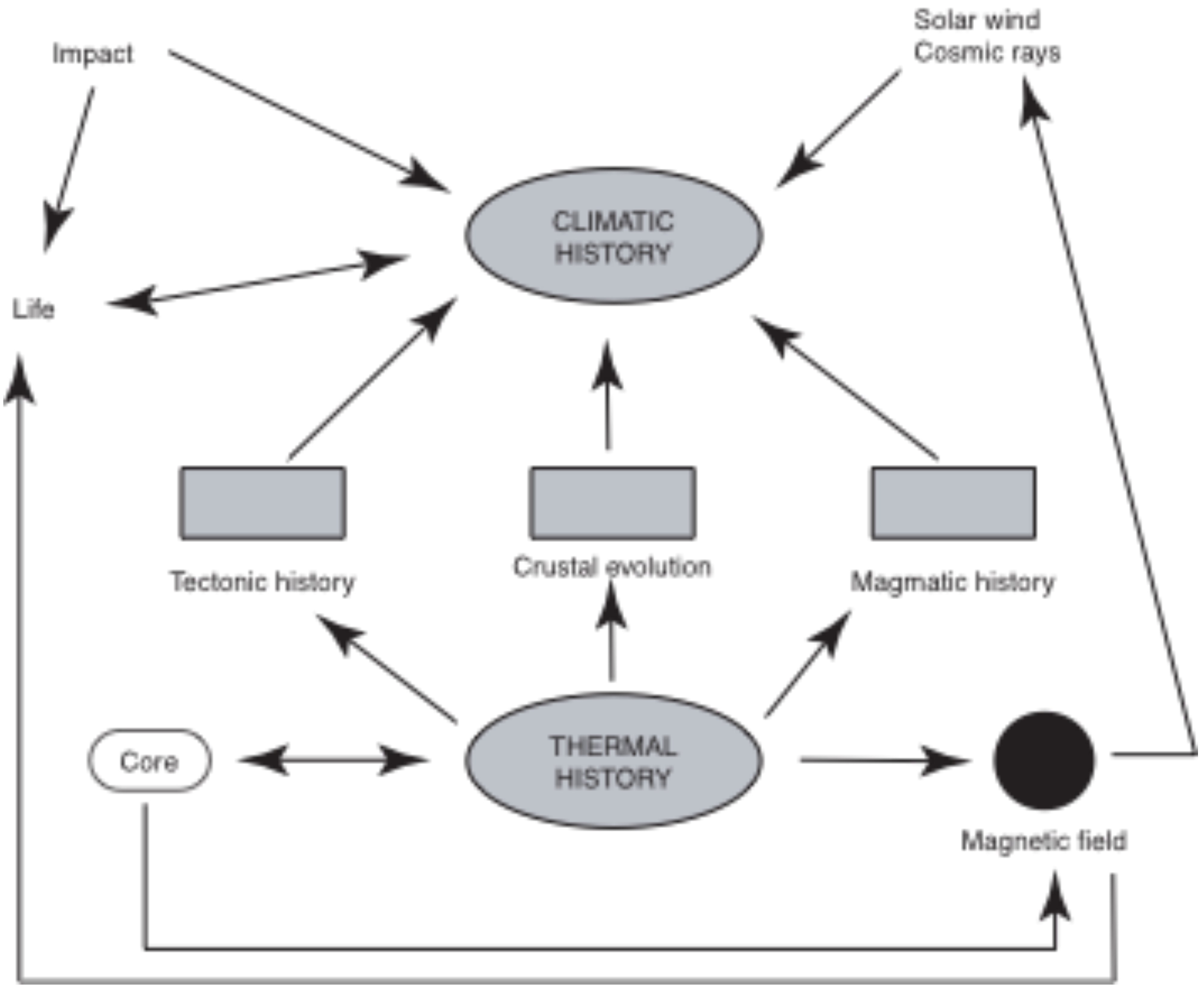
Fig. 6. The locations of the boundaries of the six blocks used in the computations. The numbers next to the vectors of differential movement refer to Table 5. Note that the boundaries where the rate of shortening or slippage exceeds about 2 cm/yr account for most of the world earthquake activity.

Le Pichon, 1968

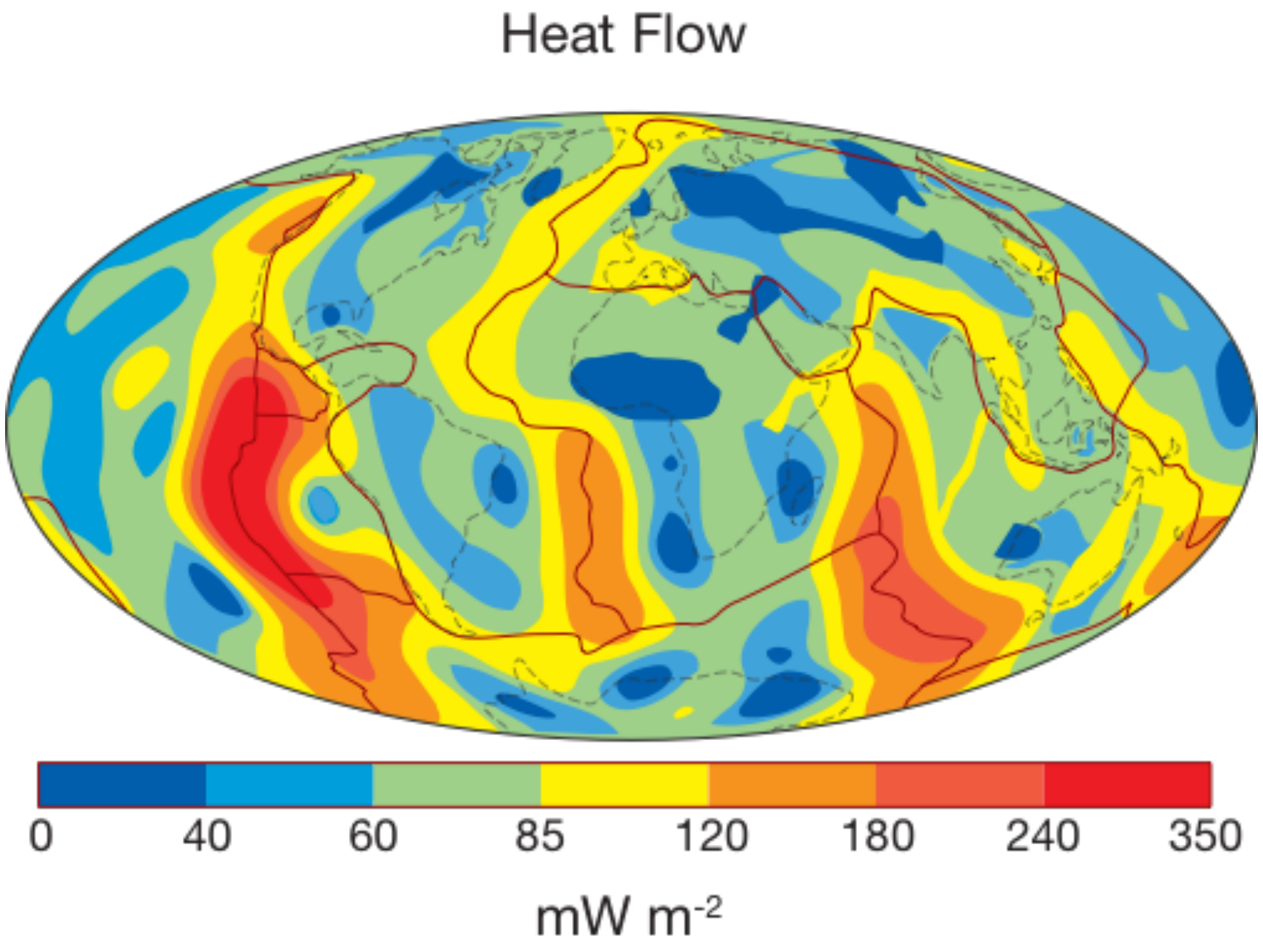
Die Plattentektonik, heutige Model



Die Geodynamik, eine Menge der Interaktionen

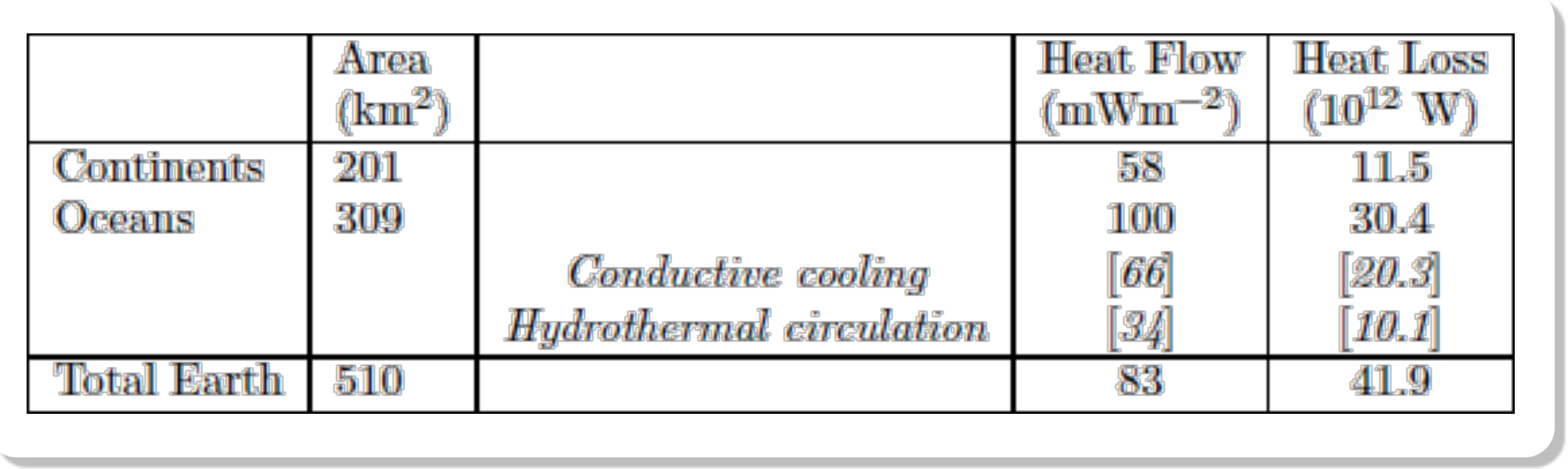


Wärmefluss auf der Erde



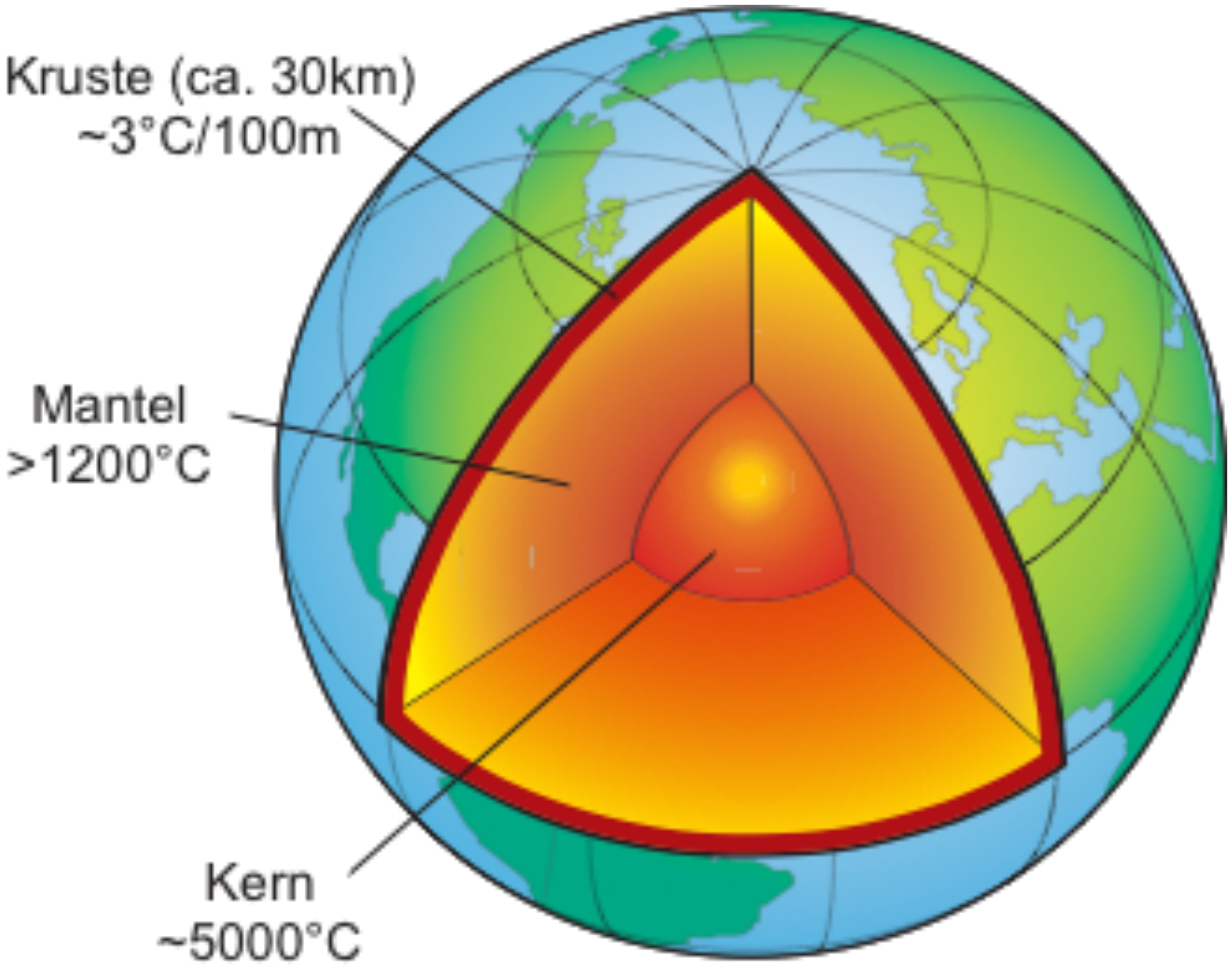
The amount of heat lost through the ocean is up to 73%!

The oceans cover about 60% of the Earth's surface.



	Area (km^2)		Heat Flow (mWm^{-2})	Heat Loss (10^{12} W)
Continents	201		58	11.5
Oceans	309		100	30.4
		Conductive cooling	*[66]*	*[20.3]*
		Hydrothermal circulation	*[34]*	*[10.1]*
Total Earth	510		83	41.9

Wärmequellen



Drei Hauptwärmequelle in der Erde

Die originelle Wärme

Die Gravitationswärme (potential energy)

Die Radioactivität

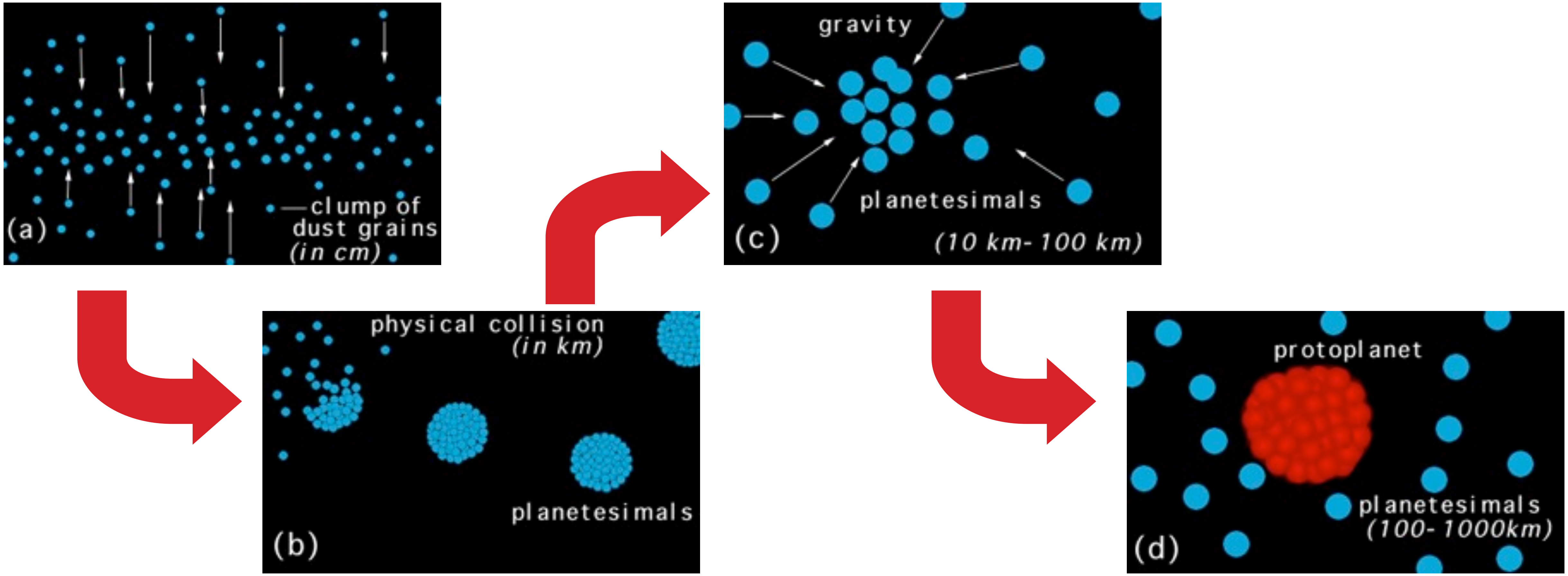
Wärmequellen: *1."Originelle" Wärme*

✓**This is the release of heat due to the cooling of the Earth. This heat was created during the accretion of interstellar dust to form planets.**

This energy is a kinetic energy. Steps in the accretion process:

1. Accretion of cm sized particles

3. Gravitational accretion on 10-100 km scale



2. Physical Collision on km scale

4. Molten protoplanet from the heat of accretion

Wärmequellen: *2- Gravitation (potential energy)*

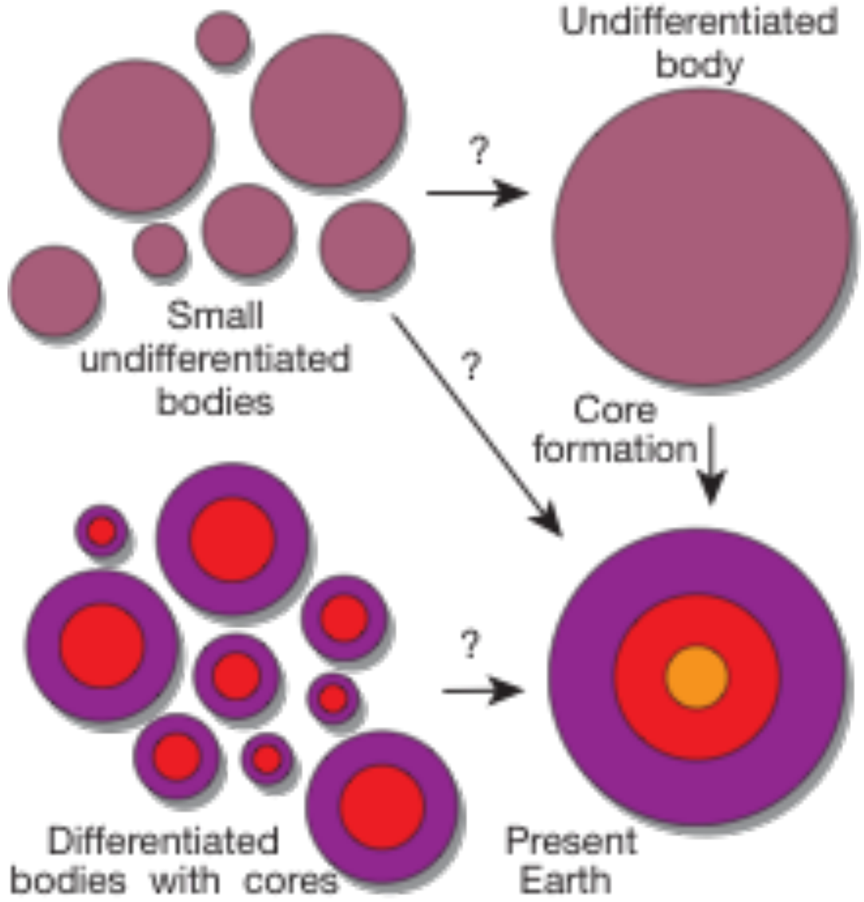
✓**Gravitational potential energy released by the transfer of material from the surface to depths.** Final step is differentiation of the earth: Light objects float; heavy objects sink.

The gravitational potential energy released would be:

$$\mathbf{\Delta E = \Delta\rho g h} \quad \Rightarrow \Delta E \approx 1.2 \bullet 10^{11} J.m^{-3}.$$

with $g \approx 10\ ms^{-2}$ $h = 3 \bullet 10^{6}$ m (diameter of the mantle)

$\rho_{silicates} \approx 3 \bullet 10^{3}\ kg.m^{-3} \rho_{iron} 7 \approx 7 \bullet 10^{3} kg.m^{-3}$ so that $\Delta\rho = 4 \bullet 10^{3}\ kg.m^{-3}$

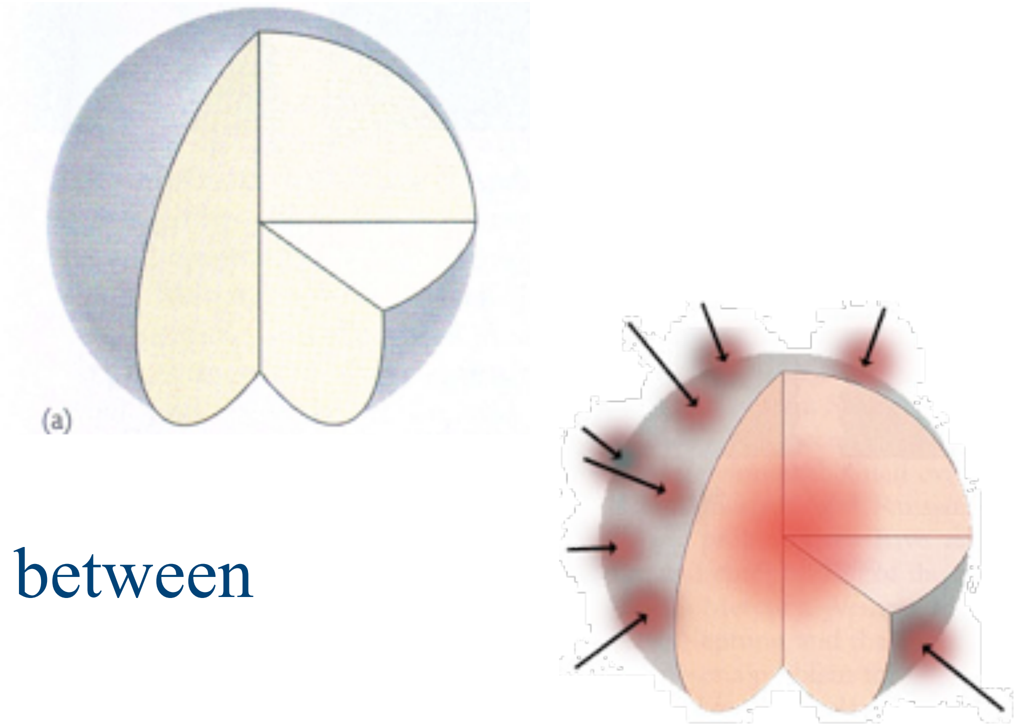


(from Minarik, 2003)

This heat is related to the differentiation within the Earth

Iron-Nickel Core (magnetic field) and oxygen-silicon crust

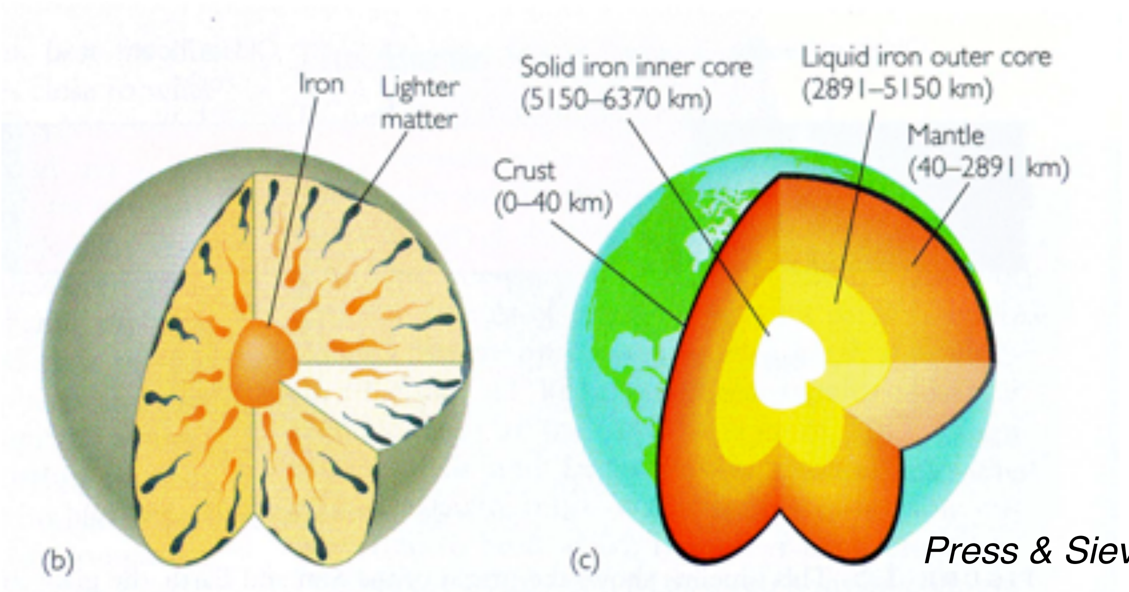
Wärmequellen



Early Earth uniform (Homogeneous)

Planets heats up due to the accretion's heat

Dense Iron core sink, leaving layered planet:
light crust on top, core below, and mantle in between



Press & Siever

Differentiation continues today as planet cools by thermal convection – plate tectonics

Hence **Earth's evolution is controlled by its thermal history**
temperature as function of depth and time

Wärmequellen: *3. Radioaktive Abfall*

Rates of Heat Production and Half-lives

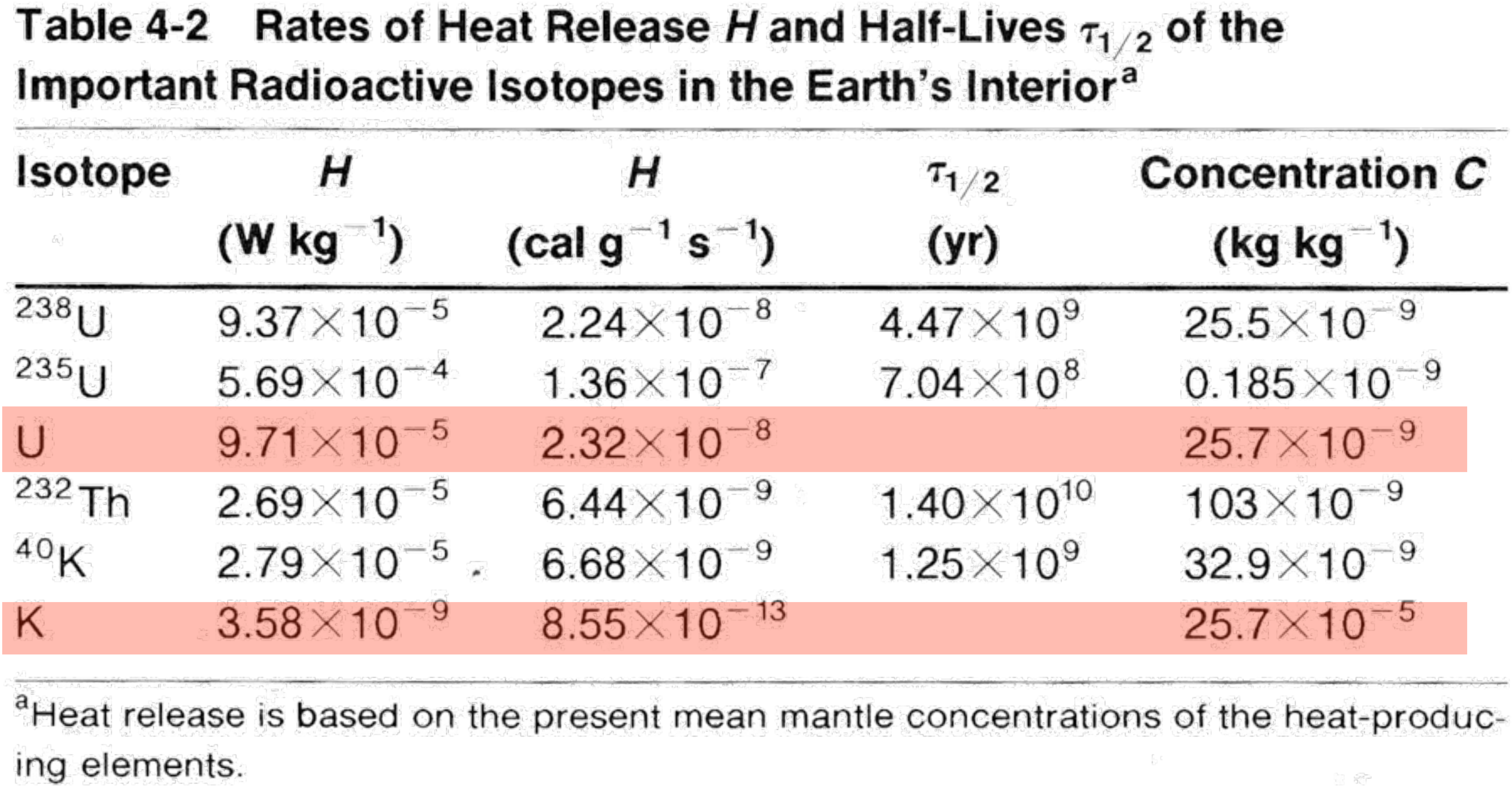


Table 4-2 Rates of Heat Release *H* and Half-Lives $\tau_{1/2}$ of the Important Radioactive Isotopes in the Earth's Interior[a]

Isotope	*H* (W kg^{-1})	*H* (cal g^{-1} s^{-1})	$\tau_{1/2}$ (yr)	Concentration *C* (kg kg^{-1})
^{238}U	9.37×10^{-5}	2.24×10^{-8}	4.47×10^{9}	25.5×10^{-9}
^{235}U	5.69×10^{-4}	1.36×10^{-7}	7.04×10^{8}	0.185×10^{-9}
U	9.71×10^{-5}	2.32×10^{-8}		25.7×10^{-9}
^{232}Th	2.69×10^{-5}	6.44×10^{-9}	1.40×10^{10}	103×10^{-9}
^{40}K	2.79×10^{-5}	6.68×10^{-9}	1.25×10^{9}	32.9×10^{-9}
K	3.58×10^{-9}	8.55×10^{-13}		25.7×10^{-5}

---

[a] Heat release is based on the present mean mantle concentrations of the heat-producing elements.

Wärmequellen: *3. Radioaktive Abfall*

Heat generation within rocks by radioactive decay

	Granite	Average continental upper crust	Tholeitic basalt	Alkali basalt	Oceanic crust	Peridotite	Undepleted mantle
Concentration by weight							
U (ppm)	4.0	1.6	0.1	0.8	0.9	0.006	0.020
Th (ppm)	15.0	5.8	0.4	2.5	2.7	0.040	0.100
K (%)	3.5	2.0	0.2	1.2	0.4	0.010	0.020
Heat generation (10^{-10} W.kg^{-1})							
U	3.9	1.6	0.1	0.8	0.9	0.006	0.020
Th	4.1	1.6	0.1	0.7	0.7	0.010	0.030
K	1.3	0.7	0.1	0.4	0.1	0.004	0.007
Total	9.3	3.9	0.3	1.9	1.7	0.020	0.057
Density (10^3kg.m^{-3})	2.7	2.7	2.8	2.7	2.9	3.2	3.2
Heat generation (µWm^{-3})	**2.5**	**1.0**	**0.08**	**0.5**	**0.5**	**0.006**	**0.02**
Thermal conductivity (W.m^{-1}.K^{-1})	3.5	2.5			2.0	4.0	

Wärmequellen: *3. Radioaktive Abfall*

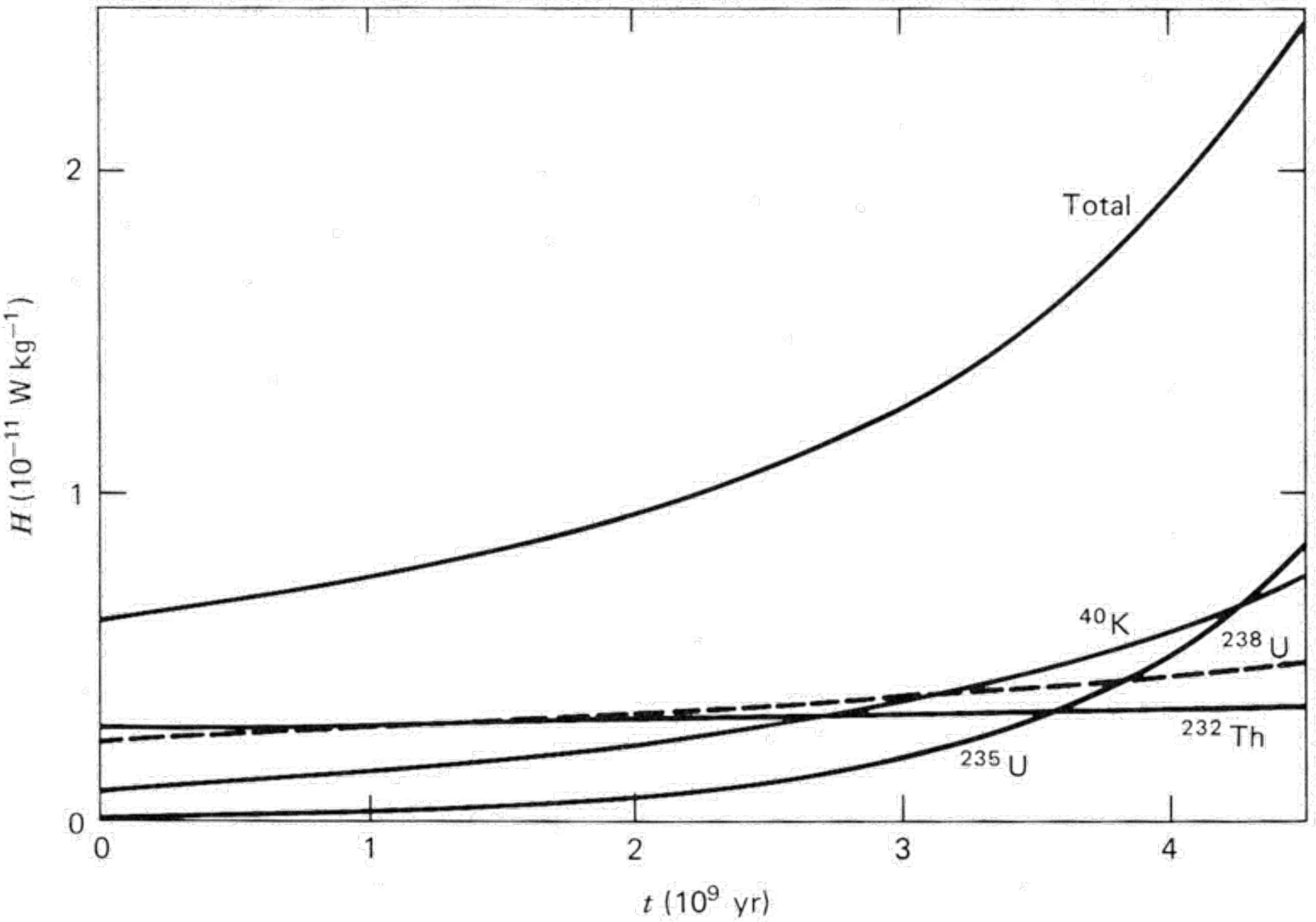
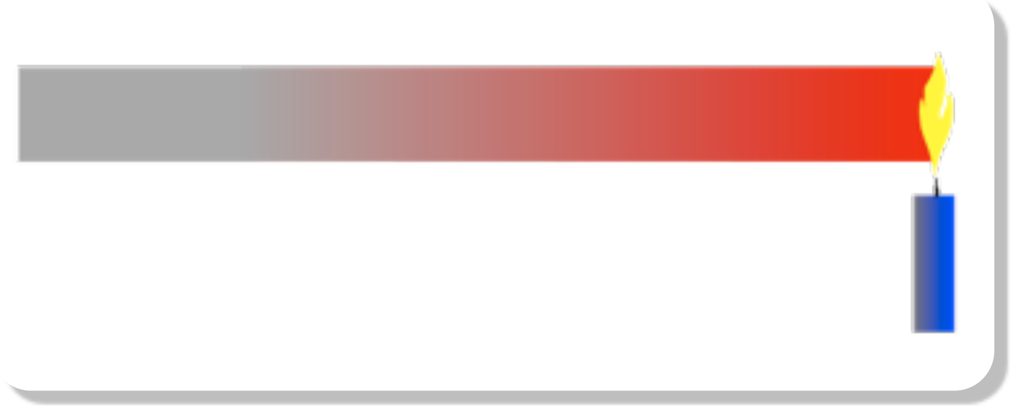


Figure 4-4 Mean mantle heat production rates due to the decay of the radioactive isotopes ^{238}U, ^{235}U, ^{232}Th, and ^{40}K as functions of time measured back from the present.

Der Transport der Wärme

Conduction

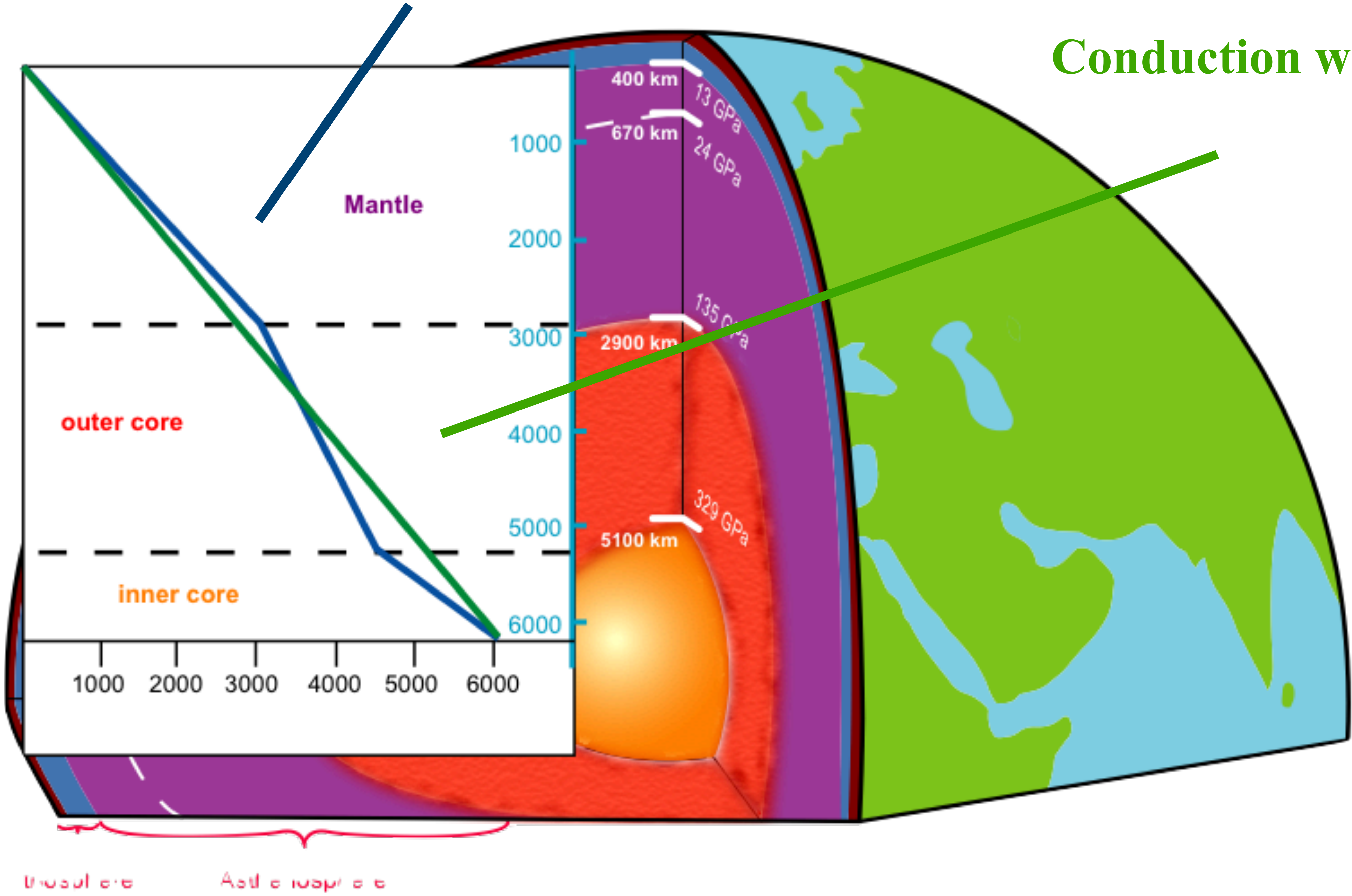
Crystal lattice interaction:
Heat ↑ => Vibrations of atoms ↑
Transfer of kinetic Energy



Convection

Radiation

Conduction



Conduction with different layers

Conduction with one layer

Der Transport der Wärme

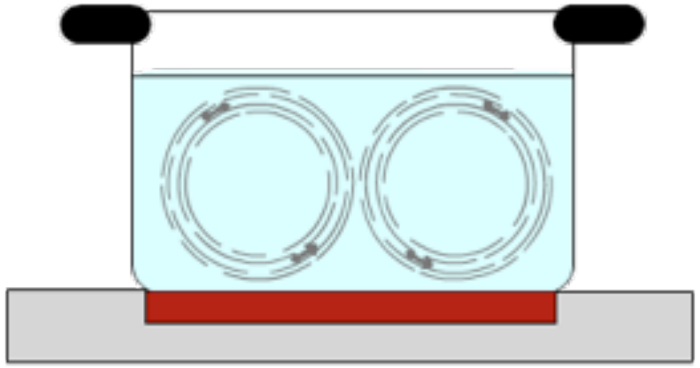
Conduction

Crystal lattice interaction:

Heat ↑ => Vibrations of atoms ↑

Transfer of kinetic Energy

Convection



The heat is transferred by relative motion of portions of the heated body. (Fluids, Ice, Mantle rocks...)

Radiation

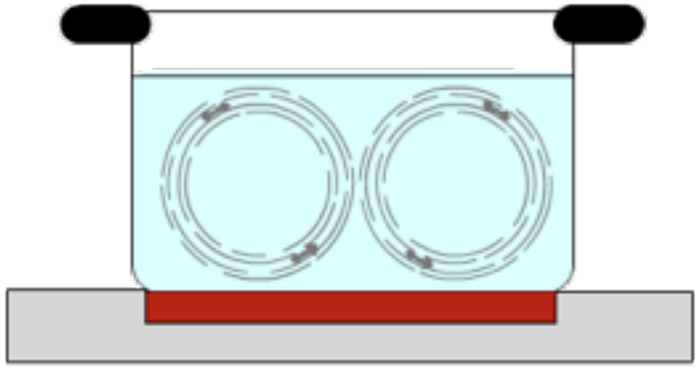
Der Transport der Wärme

Conduction

Crystal lattice interaction:
Heat ↑ => Vibrations of atoms
↑
Transfer of kinetic Energy

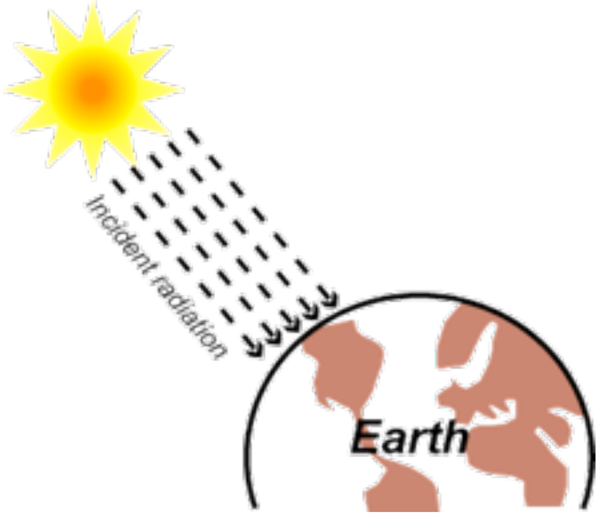
Convection

The heat is transferred by relative motion of portions of the heated body. (Fluids, Ice, Mantle rocks...)



Radiation

The heat is transferred directly between the distant portions of the body by the electromagnetic radiation (Sun,...)



Der Transport der Wärme

1-Conduction: transfer of kinetic energy by atomic vibration. Cannot occur in a vacuum. For a given volume, heat is conducted away faster if the enclosing surface area is larger.

2-Advection: involves flow of a liquid through openings in a rock whose T is different from the fluid (mass flux). Important near Earth's surface due to fractured nature of crust.

Convection: movement of material having contrasting T's from one place to another. T differences give rise to density differences. In a gravitational field, higher density (generally colder) materials sink.

3-Radiation: involves emission of EM energy from the surface of hot body into the transparent cooler surroundings. Not important in cool rocks, but increasingly important at T's >1200°C

Isothermen in der Erde