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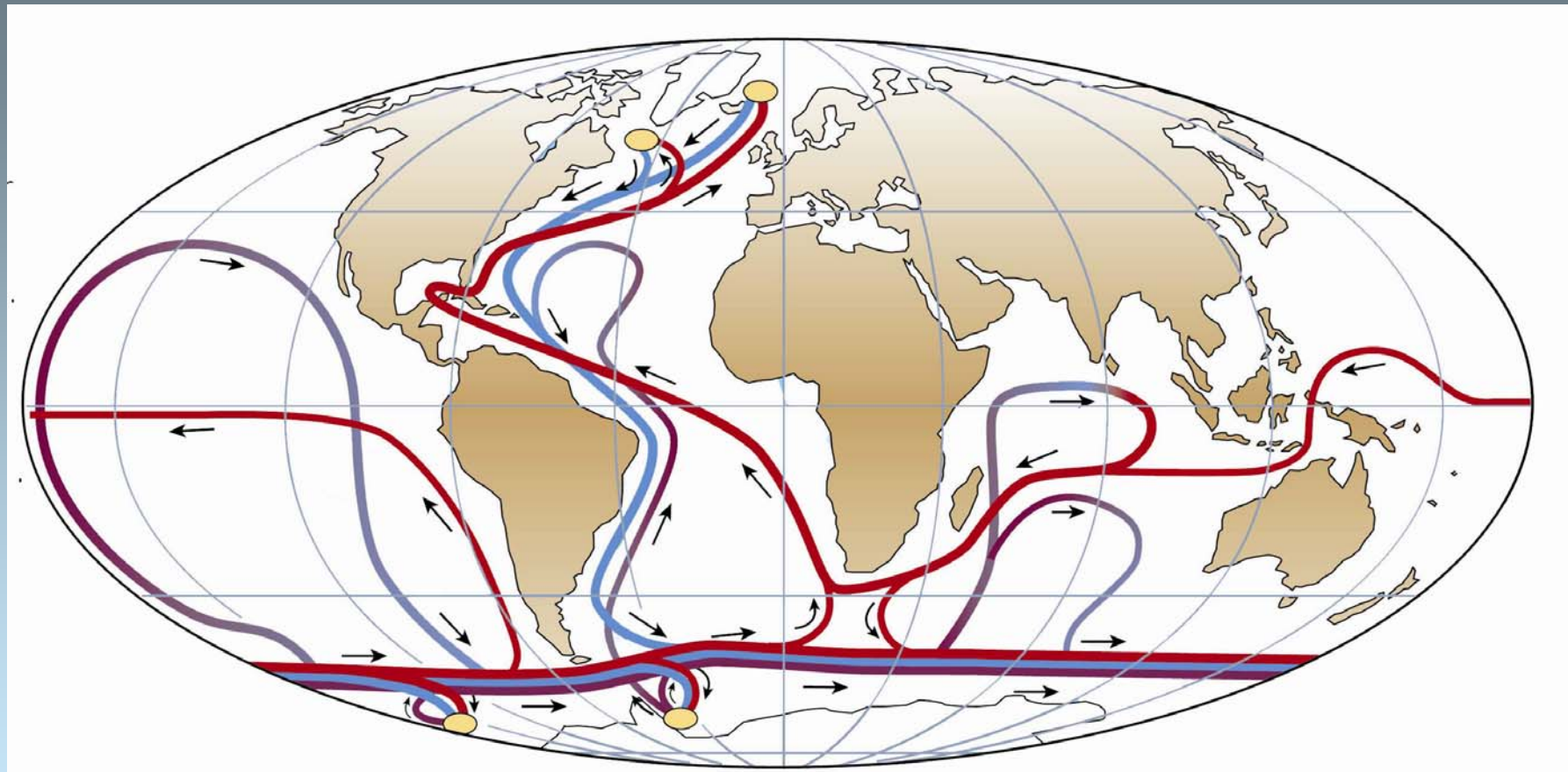
„Going down in the Weddell Sea" – why deep water formation is of vital importance

Outline

1. Modern ocean circulation
2. Motors of ocean circulation
3. How long since the motors exist?
4. What can stop the motor?
5. *Film sequence and classroom experiments*

1. Modern Ocean Circulation



red: near-surface currents
blue: deep currents
purple: bottom currents

Rahmstorf et al. 2002 (#1)

2. Motors of ocean circulation?

- **surface currents**

  set in motion by major windbelts of the earth

Atmospheric circulation

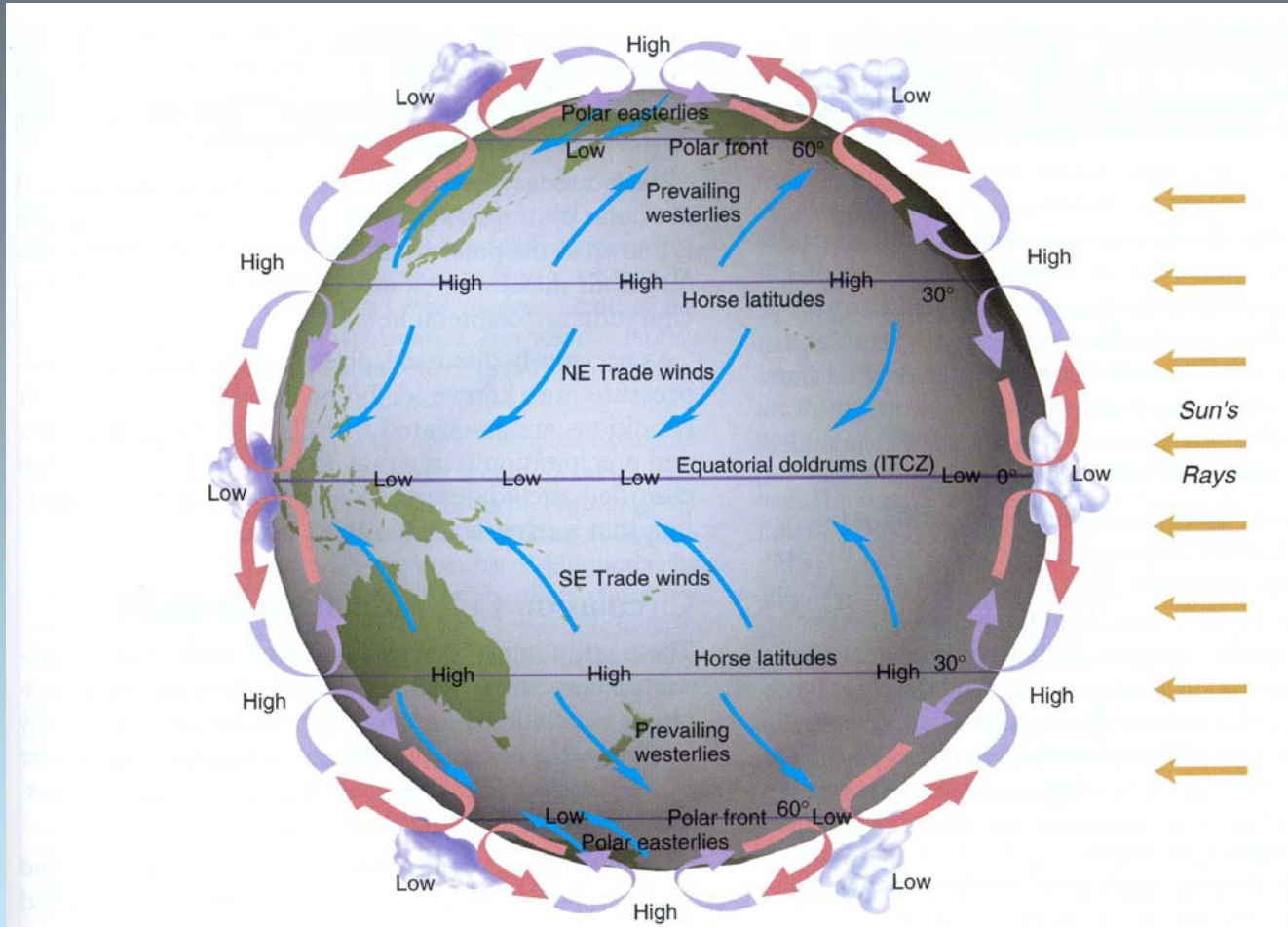
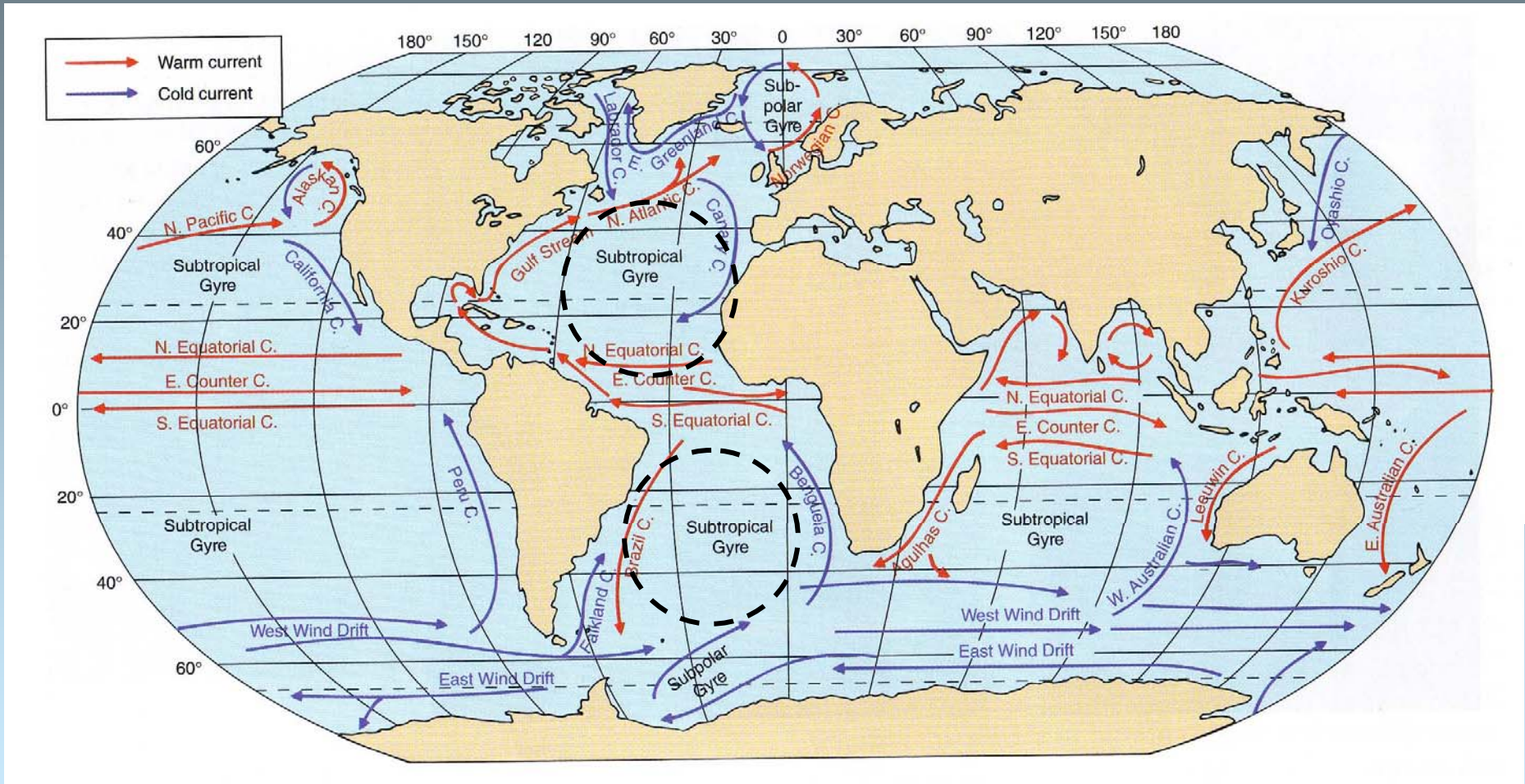


Figure 6–11 Atmospheric circulation and wind belts of the world.
The wind belts of the world are formed by atmospheric circulation cells. The general pattern shown here is modified by seasonal changes and the distribution of continents.

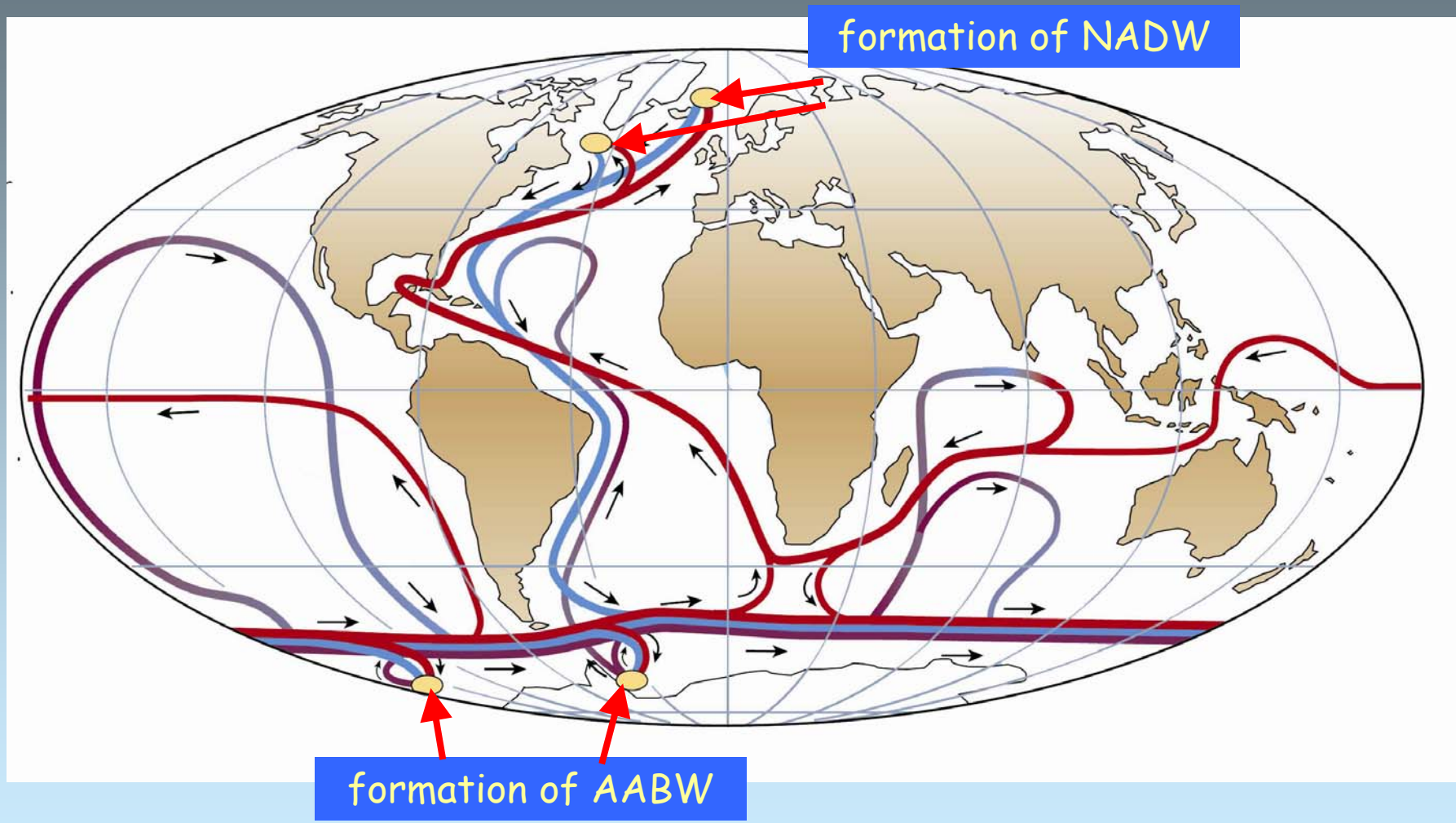
Thurman & Trujillo, 1999 (#2)

Wind-driven surface currents



Thurman & Trujillo, 1999 (#2)

Formation of deepwater



Rahmstorf et al. 2002 (#1)

2. Motors of ocean circulation?

- **surface currents**
  set in motion by major windbelts of the earth

- **deepwater currents / sinking of water masses**
  driven by density differences of water masses

- **tides** (turbulent engergy to mix all water masses)
  driven by gravitational pull of moon and sun
  (here: neglected)

Locations of deepwater formation

In northern North Atlantic: NADW

- Norwegian-Greenland Sea
- Labrador-Sea

In the South, along margins of Antarctica: AABW

- Weddell-Sea
- Ross-Sea

Formation of deepwater = driving force of worldwide „thermohaline circulation“

(thermo = heat, haline = salt)

Rate of deepwater-formation (recent estimate, Rahmstorf, 2002)

In northern North Atlantic

salinity: 35 g/l

rate: 15 +/- 2 Sv (1 Sv = 10^6 m^3 s^{-1})

In the Southern Ocean

salinity: 34 g/l

rate: 21 +/- 6 Sv

In the Northern Pacific

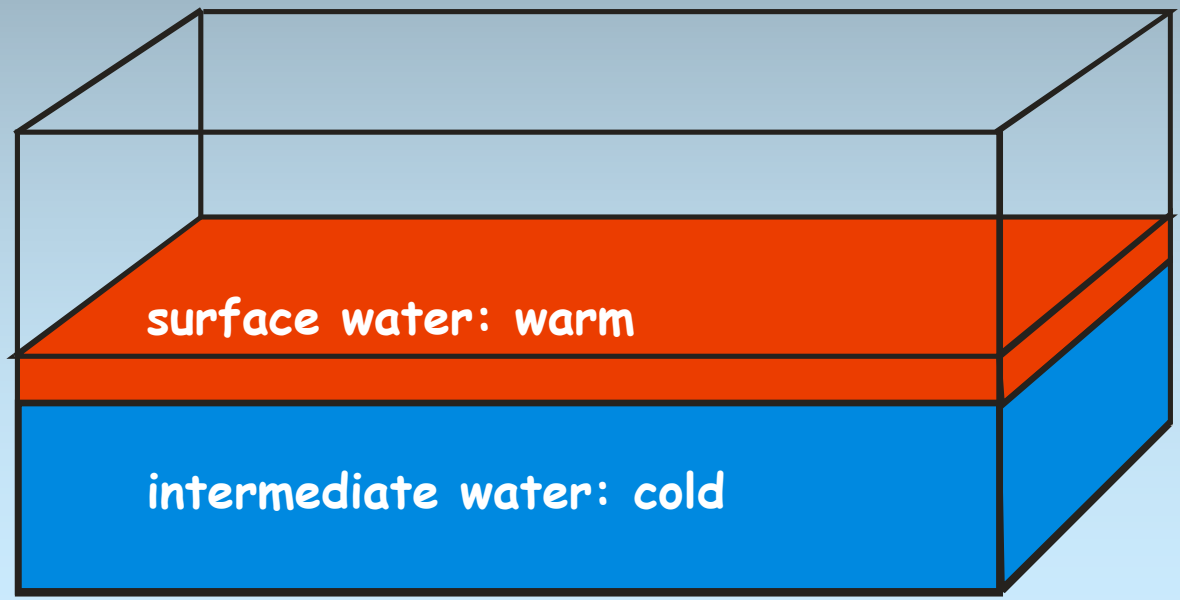
salinity: 32 g/l

rate: 0 Sv

Thermohaline stratification of the ocean

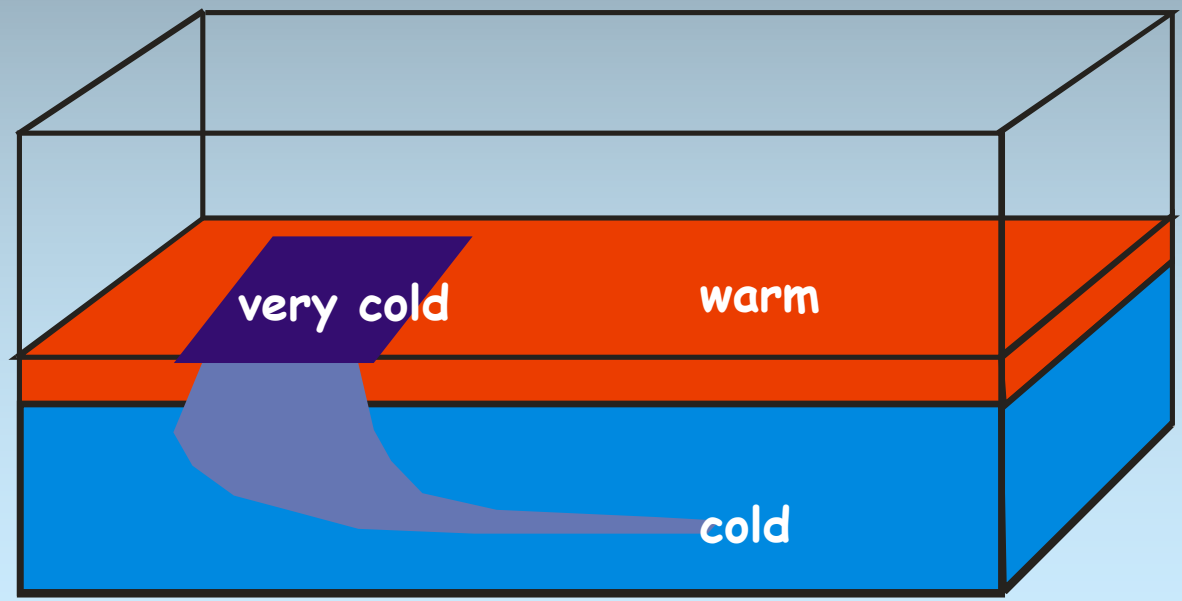
water density is determined by both temperature and salinity:
the higher the density, the heavier the water

- a warm (low saline) waterlayer rests on a cold (high saline) one
- exchange of substances between both layers is difficult



The physical pump: formation of deepwater

- thermohaline stratification is abrogated
- substances (nutrients, O_2, CO_2) can be transported into the deep ocean



Most amazing is…

… that slightest, irrelevant seeming properties like density of ocean water are of **vital importance** for vertical stratification and circulation of water masses and life in the worlds' oceans.

… normally **temperature** is the dominant factor, salinity is second-order, but **in high latitudes: salinity dominates**

Deepwater formation in the NORTH

NADW = North Atlantic Deep Water

originates in **cooling** and evaporation of warm saline surface water transported by the Gulf Stream & the North Atlantic Current into the Greenland Sea

Deepwater formation in the SOUTH

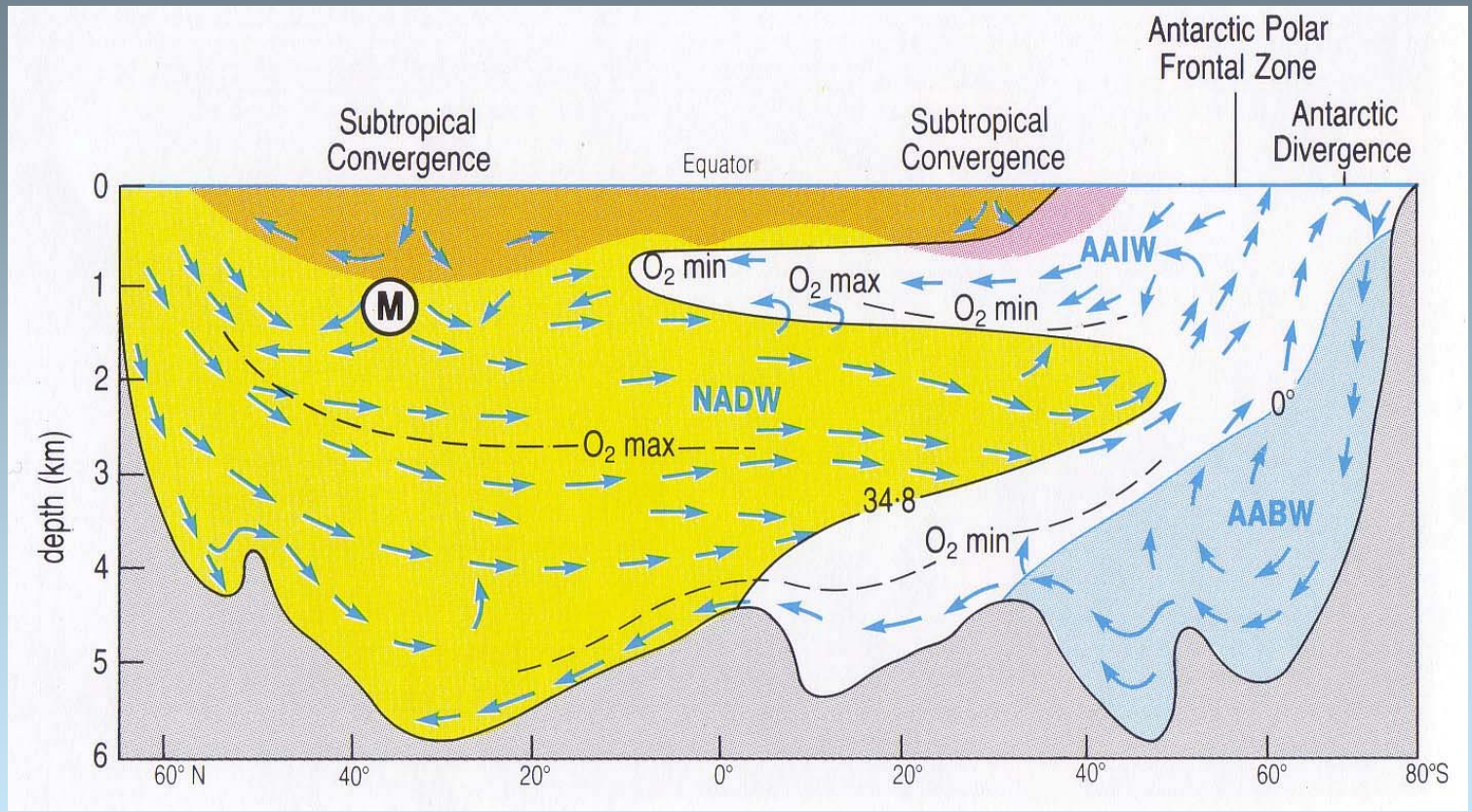
AABW = Antarctic Bottom Water

develops by **cooling** and salt precipitation below the sea ice and shelf ice regions

densest water in world oceans

spreads across bottom layers of all ocean basins

Cross section of the Atlantic Ocean: movement of the major water masses



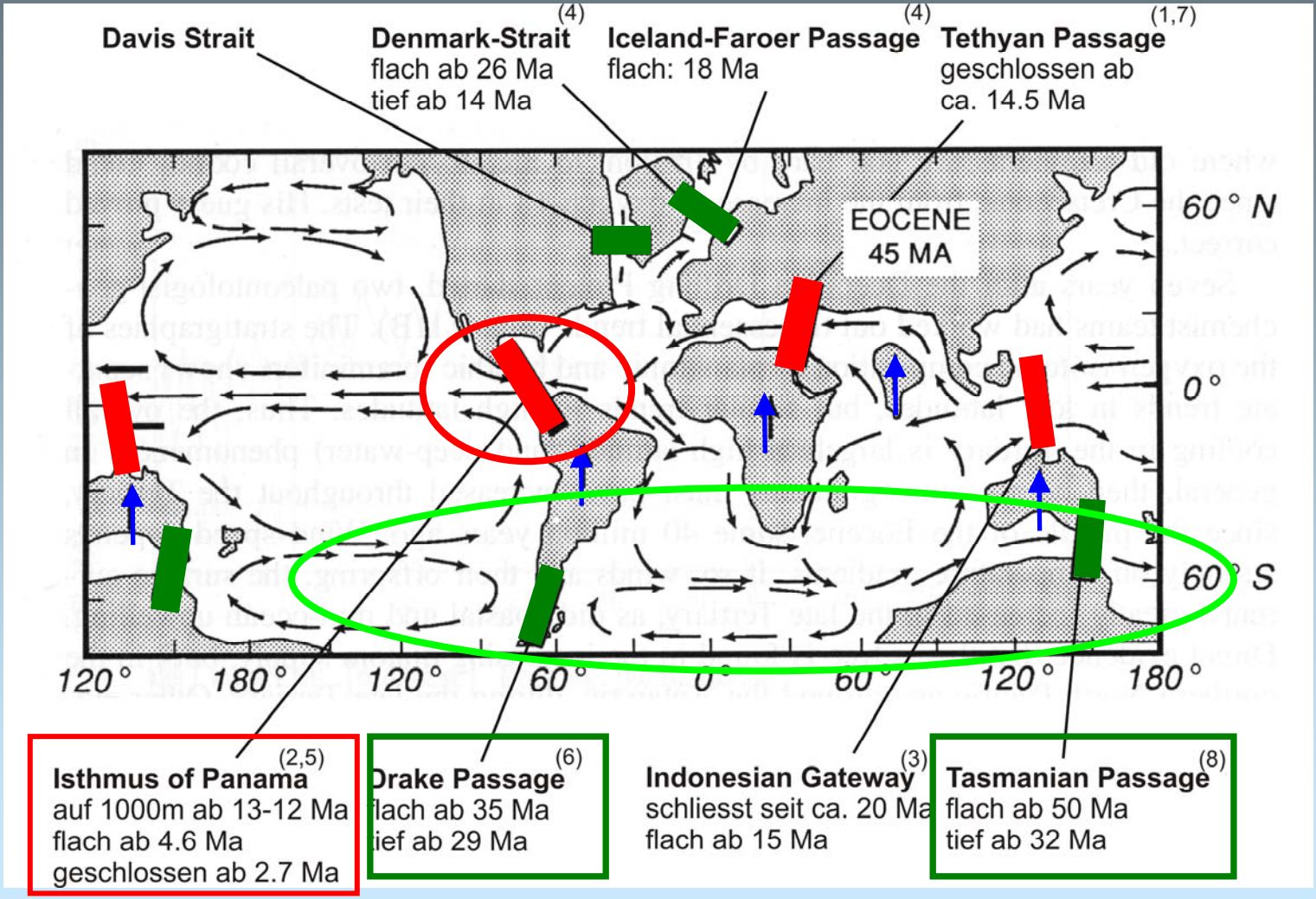
The Open University, 1998 (#3)

3. How long since the motors, i.e.

- deepwater formation
- modern thermohaline circulation

exist?

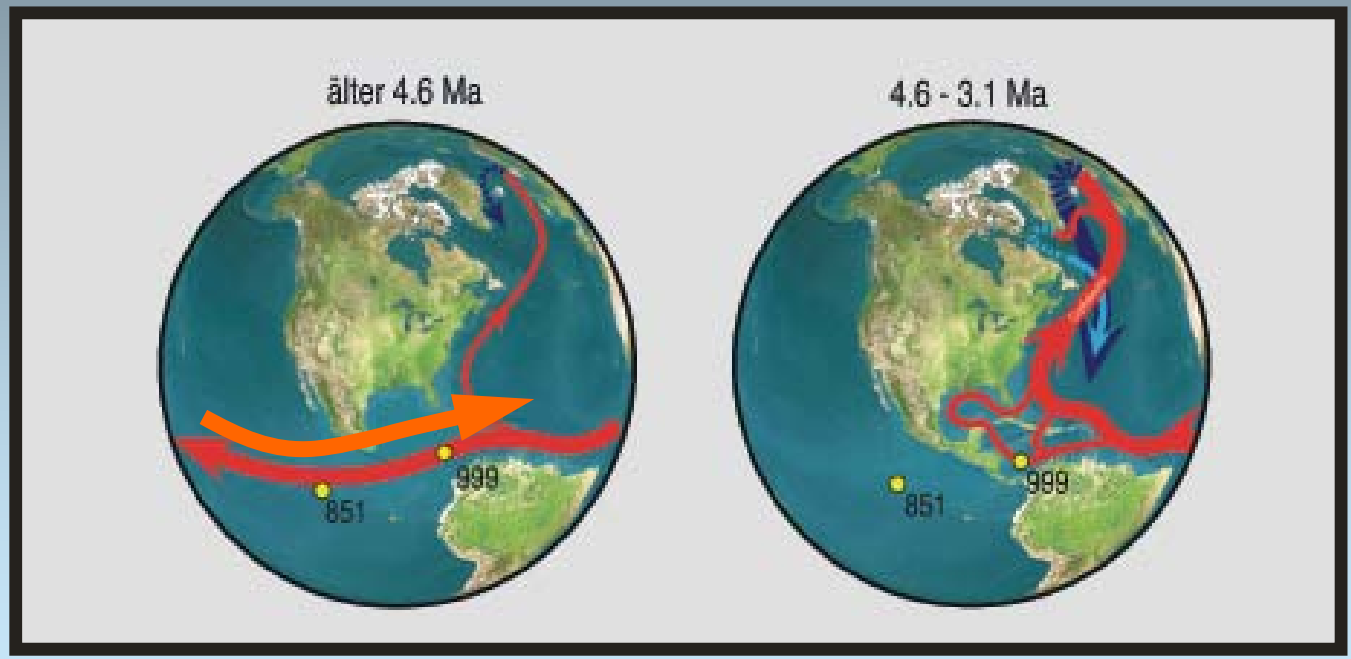
Circulation in paleogene: eocene, 45 Ma b.p.



(1) Woodruff and Savin 1989, (2) Duque-Caro 1990, (3) Lee and Lawver 1995, (4) Hay 1996, (5) Haug and Tiedemann 1998, (6) Lawver and Gahagan 1998, (7) Ramsay et al. 1998, (8) Lawver and Gahagan 2003.

Effects of plate tectonics: in NORTHERN hemisphere

1. closure of the seaway between the North and South American continents in late Neogene



after Haug & Tiedemann, 1998 (#4)

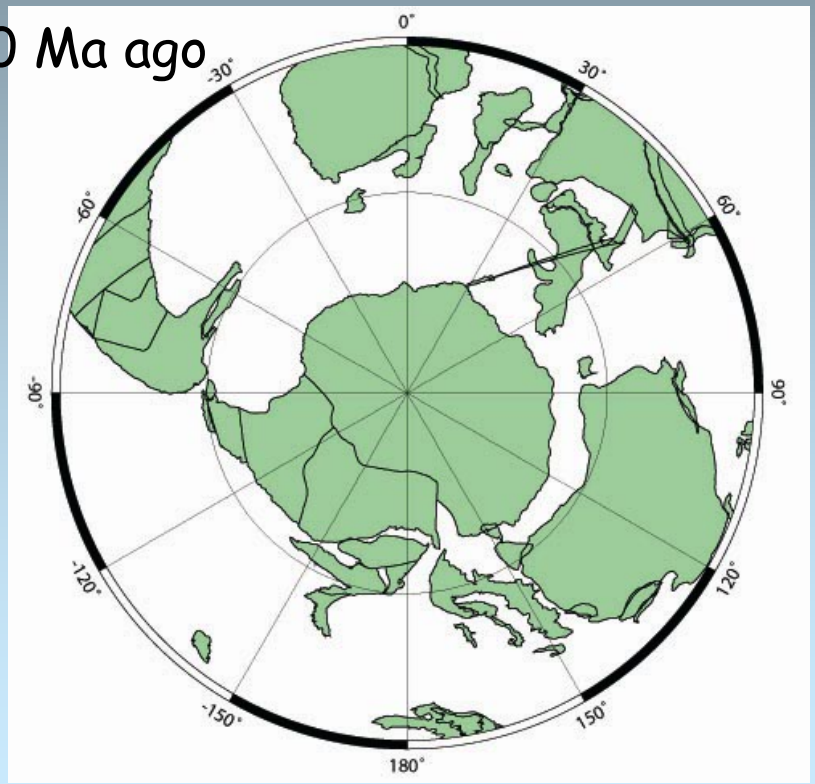
2. **marked reorganization of surface & deep water circulation 4.6 Ma ago:**
   - **intensification of Gulf stream**
   - **initiation of deep water formation**

3. extensive changes in northern hemisphere climate

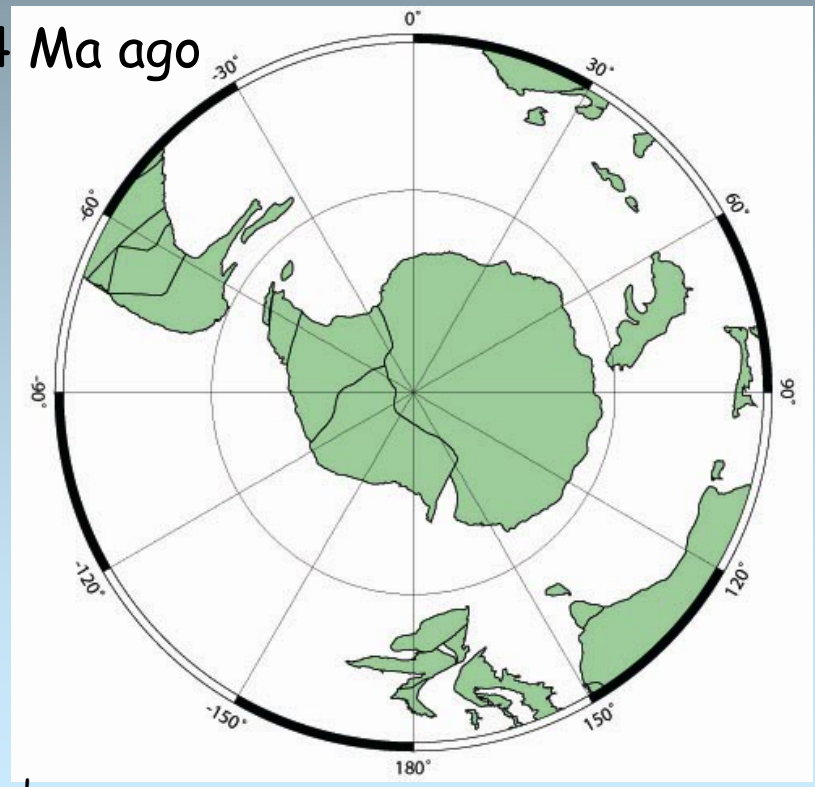
Effects of plate tectonics: in SOUTHERN hemisphere

- Fragmenting of Gondwana, drift of Australia away from Antarctica
- Opening of southern gateways, initiation of circumpolar current

80 Ma ago

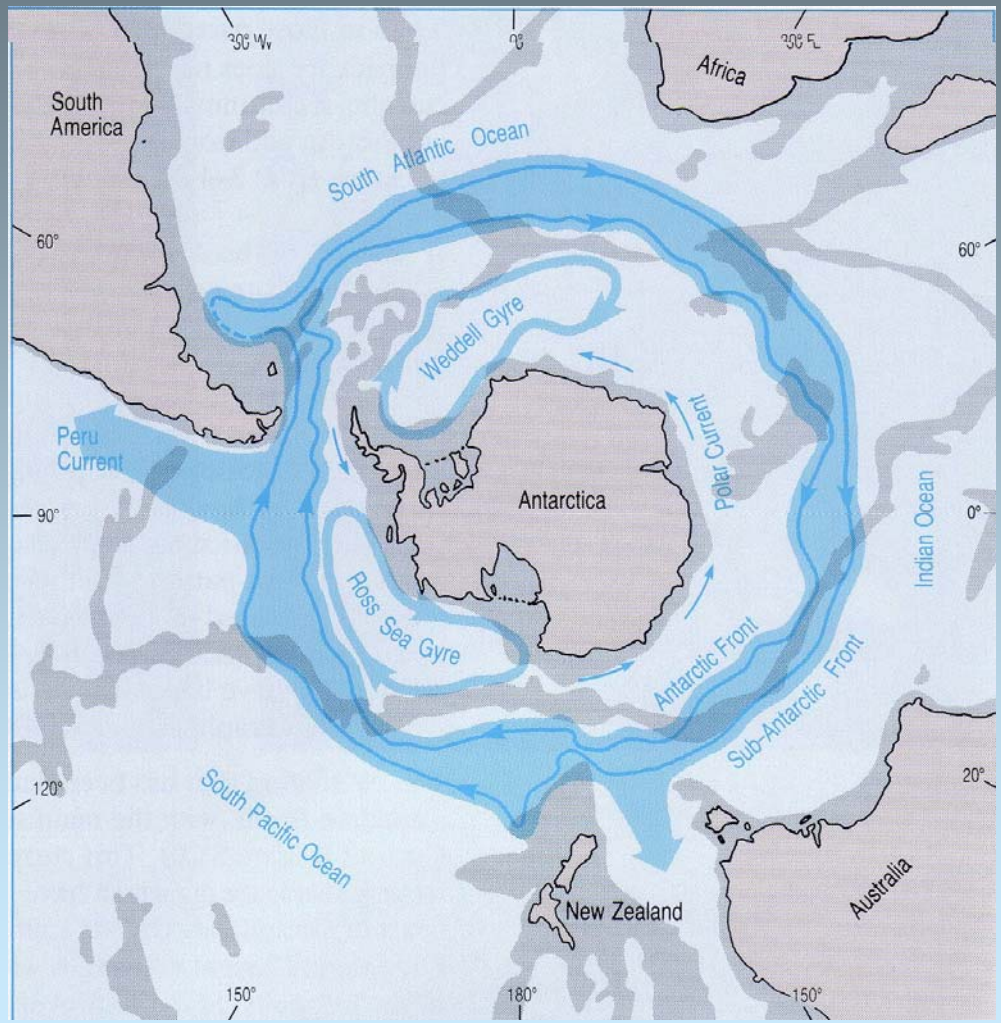


14 Ma ago



www.odsn.de

Plates' constellation today: Antarctic Circumpolar Current



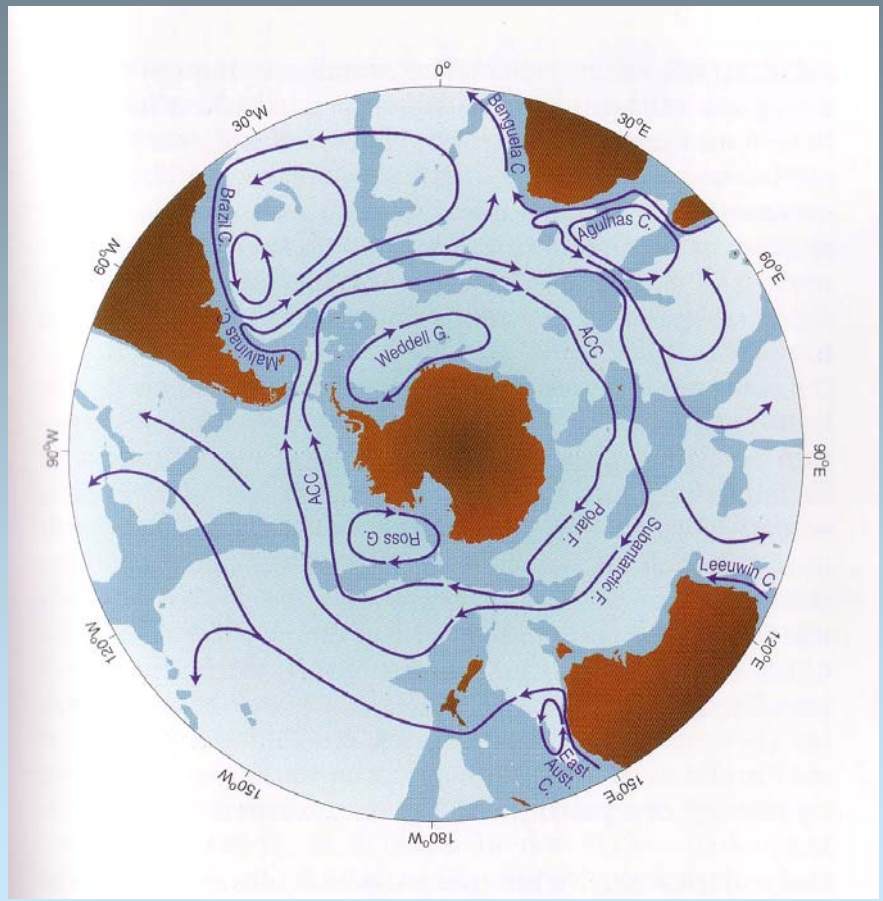
after Rintoul, Hughes and Olbers, 2001 (#5)

- isolated the Antarctic continent
- caused cooling of the region
- supported inland glaciation
- facilitated deep water formation

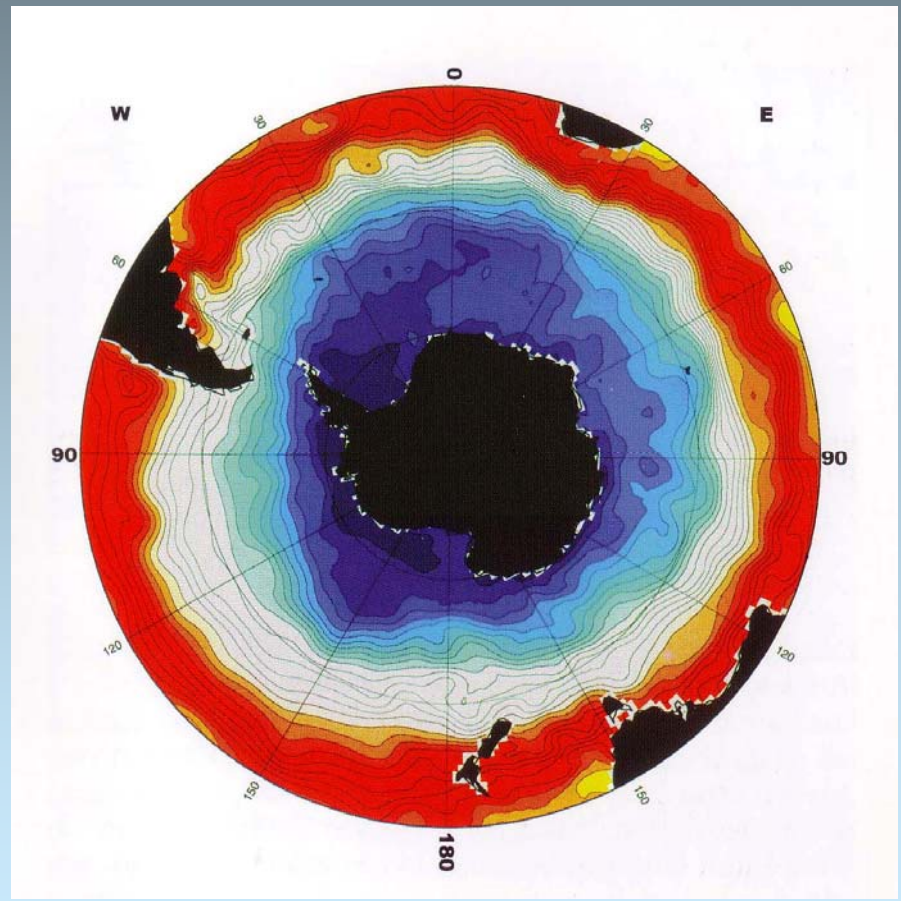
- **modern situation since about 8 Ma**

Southern Ocean

Ocean currents, frontal systems and topography

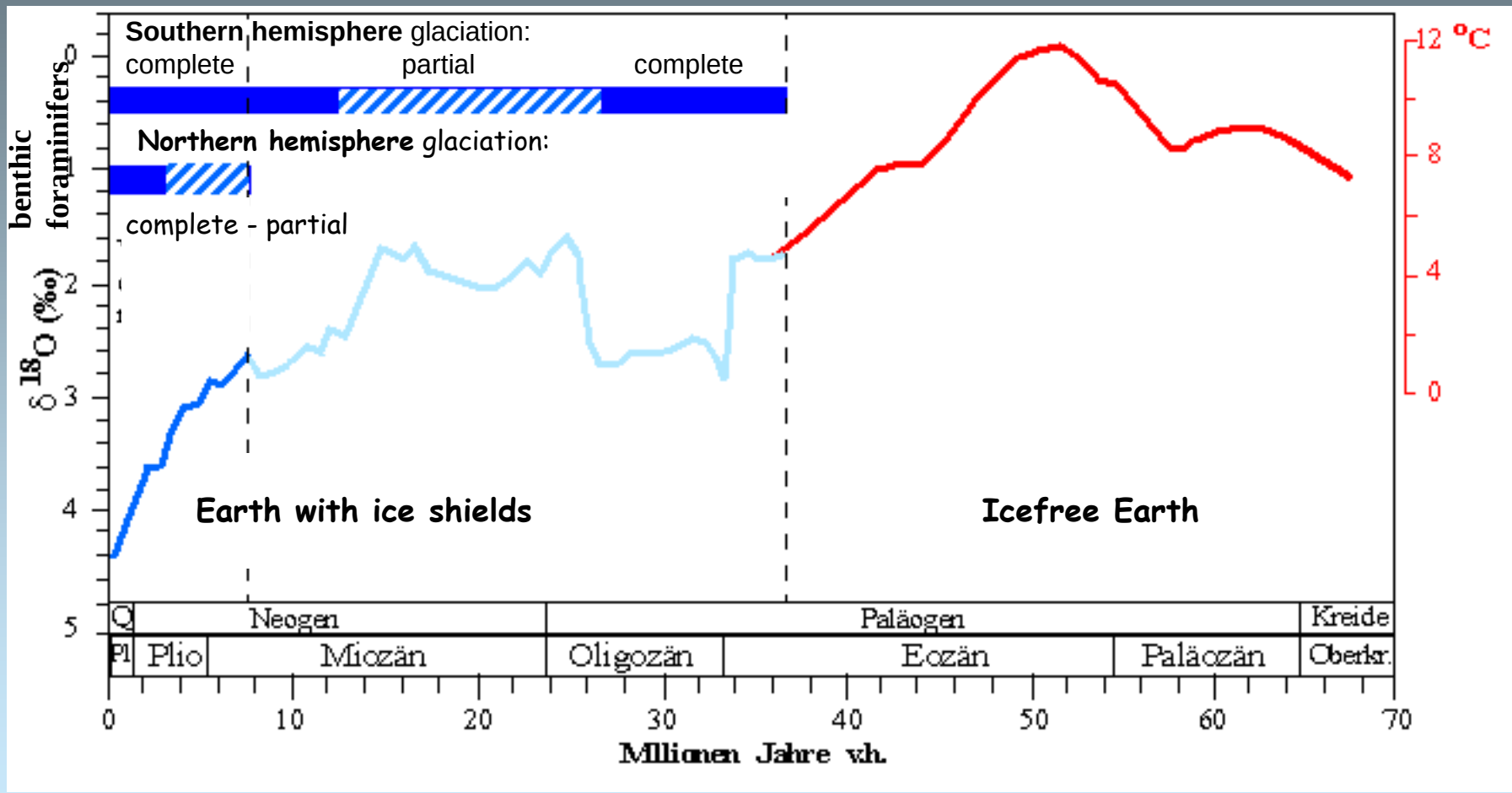


Temperature in 10 m water depth: 20°C (red) to -2°C (dark blue)



after Rintoul, Hughes and Olbers, 2001 (#5)

Formation of inland ice shield



after Zachos et al., Science, 2001 (#6)

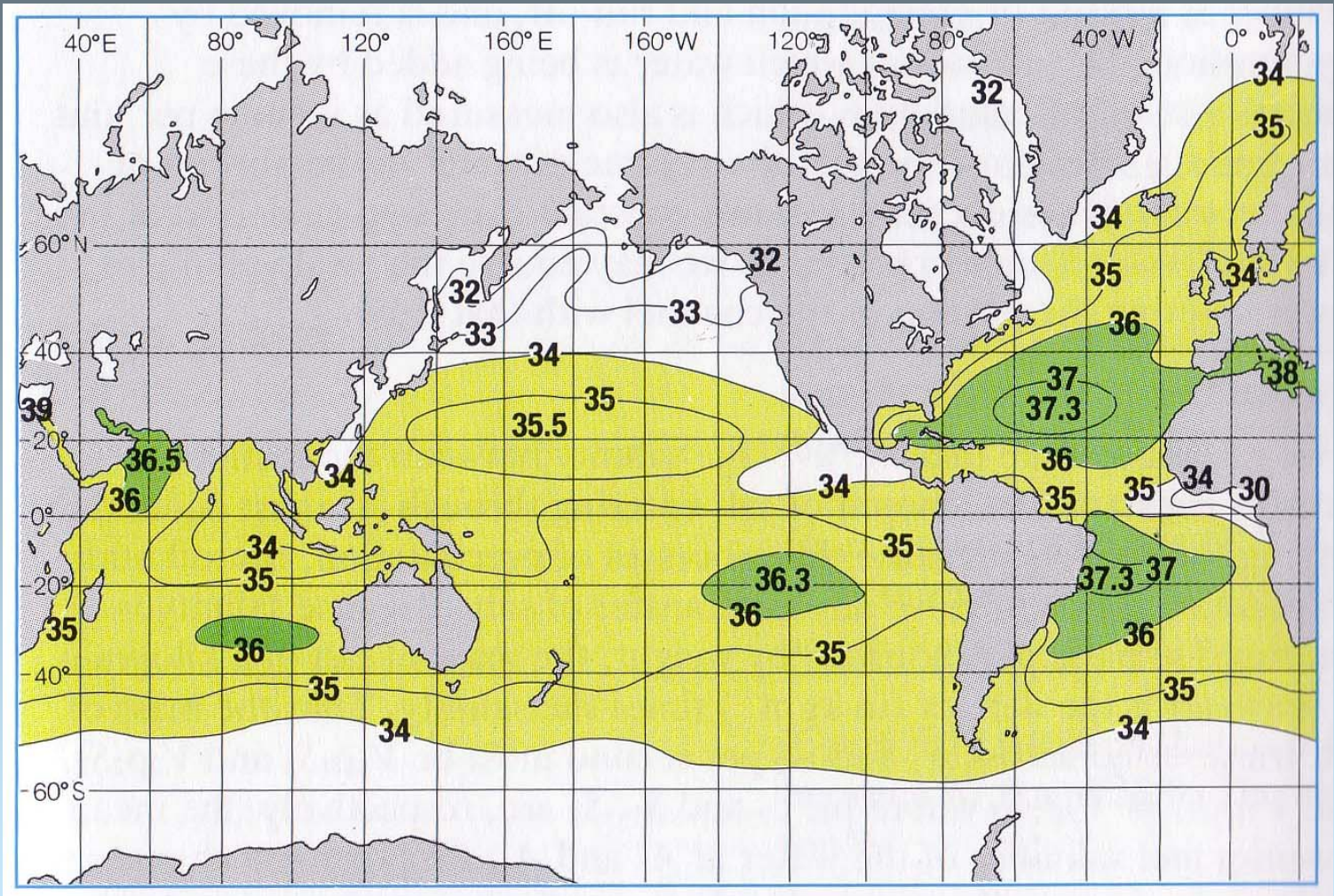
4. What can stop the motor?

… changes in density, i.e. in salinity or temperature

Global warming accompanied by an increased freshwater input into the North Atlantic could result in major changes in THC strength

A weakening or even a temporary or permanent cessation of NADW formation is within the range of possibilities

The mean annual distribution of surface salinity



The Open University, 1998 (#3)

References

Articles

Broecker, W.S. (1995): Chaotic Climate, Scientific American, November, 62-68.

Haug, G.H. & R. Tiedemann (1998): Effect of the formation of the Isthmus of Panama on Atlantic Ocean thermohaline circulation. Nature 393, 673-676.

Rahmstorf, S. (2002): Ocean circulation and climate during the past 120,000 years. Nature 419, 207-214.

The Open University (2002): Ocean Circulation. Butterworth Heinemann.

Thurman H.V. & A.P. Trujillo (2002): Essentials of Oceanography. Prentice Hall.

Movie

Planet Ozean (2 DVD or 7 VHS, only in German)
Komplett-media GmbH, 82 031 Grünwald, Germany
www.komplett-media.de

References:

Figures

(#1) Rahmstorf, S. (2002): Ocean circulation and climate during the past 120,000 years. Nature 419, 207-214.

(#2) Thurman, H.V. & A.P. Trujillo (2002): Essentials of Oceanography. Prentice Hall.

(3#) The Open University (2002): Ocean Circulation. Butterworth Heinemann.

(4#) Haug, G.H. & R. Tiedemann (1998): Effect of the formation of the Isthmus of Panama on Atlantic Ocean thermohaline circulation. Nature 393, 673-676.

(5#) Rintoul, S.R., Hughes, C.W. & D. Olbers (2001): The Antarctic circumpolar current system. In: Ocean Circulation and Climate: Observing and Modelling the Global Ocean, pp. 271-302, Academic Press, San Diego, CA.

(6#) Zachos, J.C., M. Pagani, L. Sloan, E. Thomas & K. Billups (2002): Trends, Rhythms, and Aberrations in Global Climate 65 Ma to Present. Science 292, 686-693.