Introducction in die Mineralogi, geology and sedimentology

Environmental archives
and
ore deposits

Rolf Kilian

1.1 Overview of climate and environmentmtal archives

Archive	Time period	Possible age determinations	Time resolution	Important proxies	Besonderheiten
Continen-tal sedi-ments	>600 Myr until the present	Lithology, Paleontology and Tephra chronology	Million years	Fossils, sediment lithologies	Influences of plate tectonics, impacts, formation of flood basalts, evolution of the biosphere
Deep sea sediments	60 Myr until the present	O and C isotope, Paleontology	Decades to millenia	0 isotopes, sedimentology, micropaleontology	Sea water composition, sea surface tempertures, paleoocean currents
Schelf sediments	4 Myr until present	O and C isotope	Decades to centuries	0-Isotope, Sedimentology, micropaleontology	Ocean currents and denudation of mountain ranges
Terrestrial sediments and soils	2 Myr until present	Tephra chronology	Decades to centuries	Soil types and glacial deposits (Morains, Loess)	Glaciation and fluvial prozesses
Lacustrine Lake sedi-ments	200 000 years until the present	C and U/Th isotopes	Up to yearly resolution, warves	Palynology, Isotopes, sedimentation rates	Paleotemperature, precipitation, vegetation, population history
Ice cores	200 000 years until the present	Yearly variations in dust and O-Isotopes	yearly	Accumulation, chemistry and isotopes from ice and air inclusions	Paleoatmospheric composition
Stalagmite& Speleothems	40 000 years until present	^{14}C and U/Th determinations	Until yearly	$\delta^{18}O$ and $\delta^{13}C$ isotope hydrochemistry (Mg/Ca), Detritus-Chemistry	Paleotemperature, Paleoprecipitation
Peat	14 000 years until present	^{14}C determinations	Decades	Growing and humifiation rates, chemical characteristics	Atmospheric dust and anthropogene pollutions
Tree-ring chronologies	10 000 years until present	Tree ring chronologies	Yearly and saisonal	Tree ring width	Paleotemperature maps for certain calender years
Weather stations	The last 200-300 Years	Calender years and short time periods	Minutes to years	Weather station, historical archives	Kalibrierung von Proxies

Important age determination for climate archives:

1) **^{40}K ➔ ^{40}Ar or Ar-Ar methods** (>5 000 years) of potassium-bearing minerals of volcanic rocks or volcanic glass (tephra)

2) **U-Th methods ➔** Dating of bones, carbonates, teaths and volacnic rocks, eg. with $^{230}Th/^{234}U$ (10 kyr – 550 kyr)

3) **Radiocarbon method and other cosmogenic nuclides:** ^{14}C, ^{81}Kr, ^{3}H, ^{10}Be, ^{26}Al

4) **Radiation dosimetry** (100 yr bis 1 Myr): radiation damages in latices of minerals in rocks and soils
   ➔ Thermoluminecens (TL)
   ➔ Optical stimulated Luminescens (OSL)

1.3 Climate forcings

Extraterrestrial and terrestrial climate forcings

Factors which influence the radiation intensity (insolation)

Sun activity

Orbital parameters

Composition of the Earth‘s atmophere (green house gases)

Albedo (rejection of radiation at the Earths‘s surface)

Factors which control the temperature distribution on Earth:

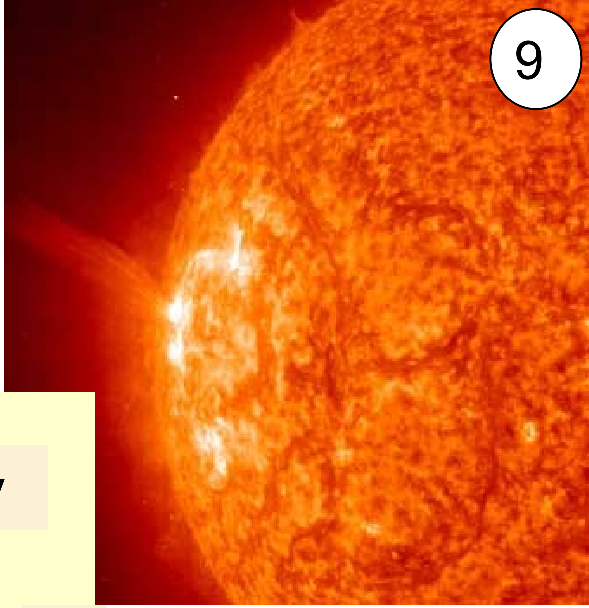
Atmospheric circulation

Ocean currents

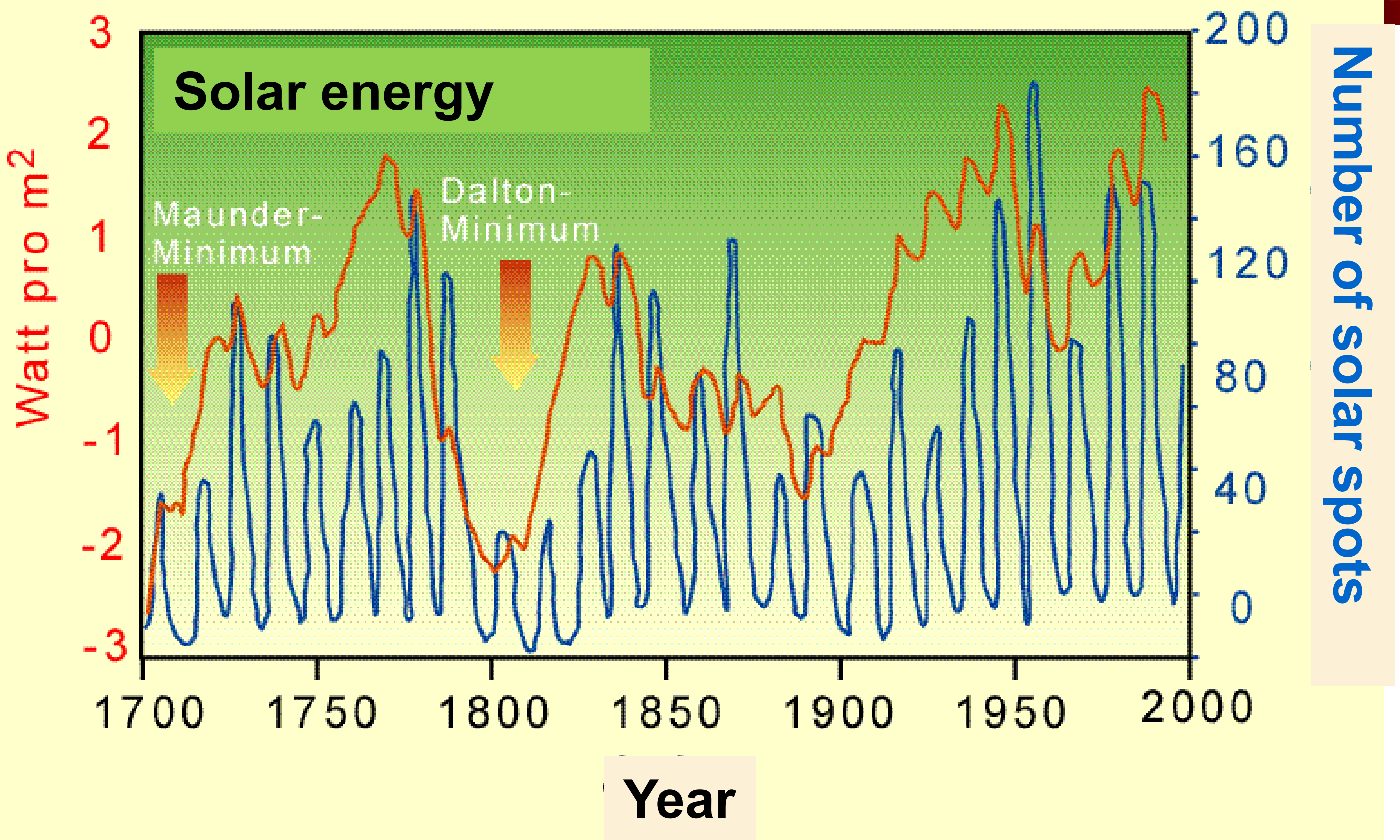
Global distribution of ocean basins and mountain belts

Klima forcing: Sun activity

Solar eruption in April 2002 =>



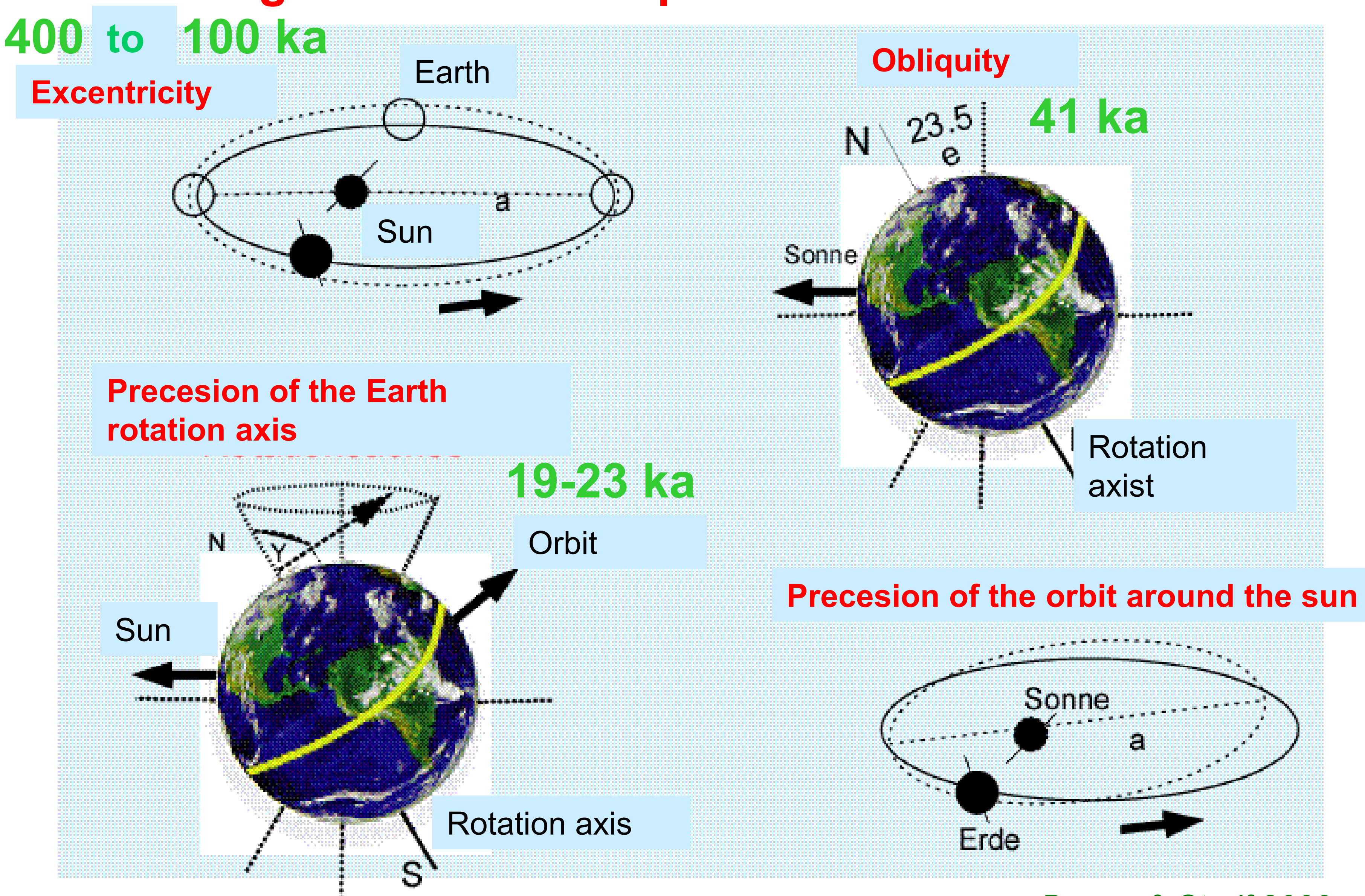
Relationship between sun spots and solar activity



Berner & Streif 2000

Climate forcings:

Changes in the orbital parameters of the Earth

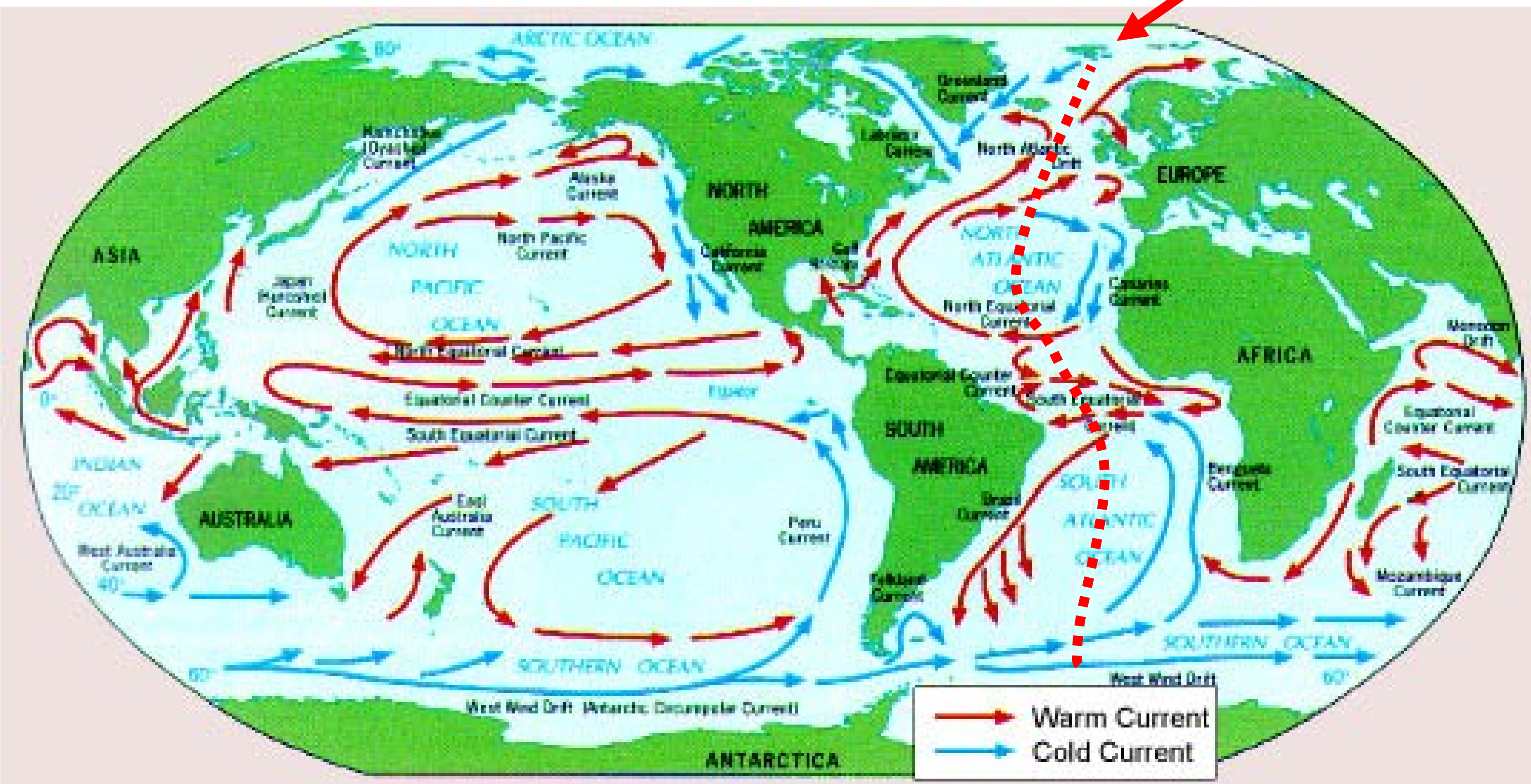


Berner & Streif 2000

Climate forcings

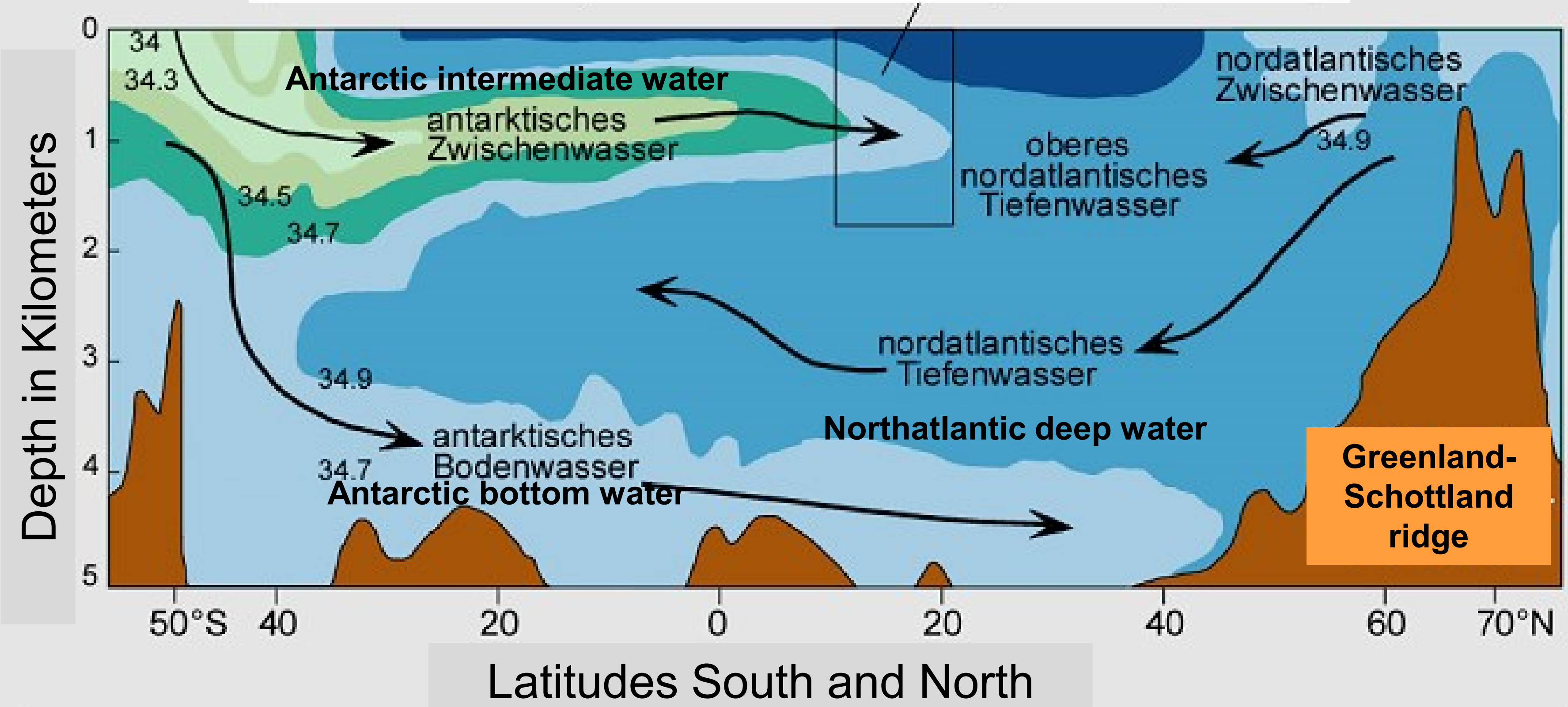
Temperature distribution on Earth
➔ ocean-continent distribution
and ocean currents

North-South profile
See next side



www.indiana.edu/geol105/gaia_chapter_4/oceancirculation.jpg

Currents and salinity distribution in a South-north profile of the Atlantic ocean



- Salinity between 34 and 34.3
- Salinity between 34.3 and 34.5
- Salinity between 34.5 and 34.7
- Salinity between 34.7 and 34.9
- Salinity between 34.9 and 35.1
- Salinity between 35.1 and 35.3

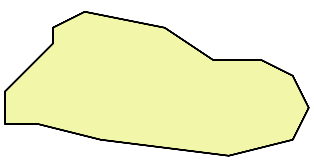
Atmospheric and ocean circulation

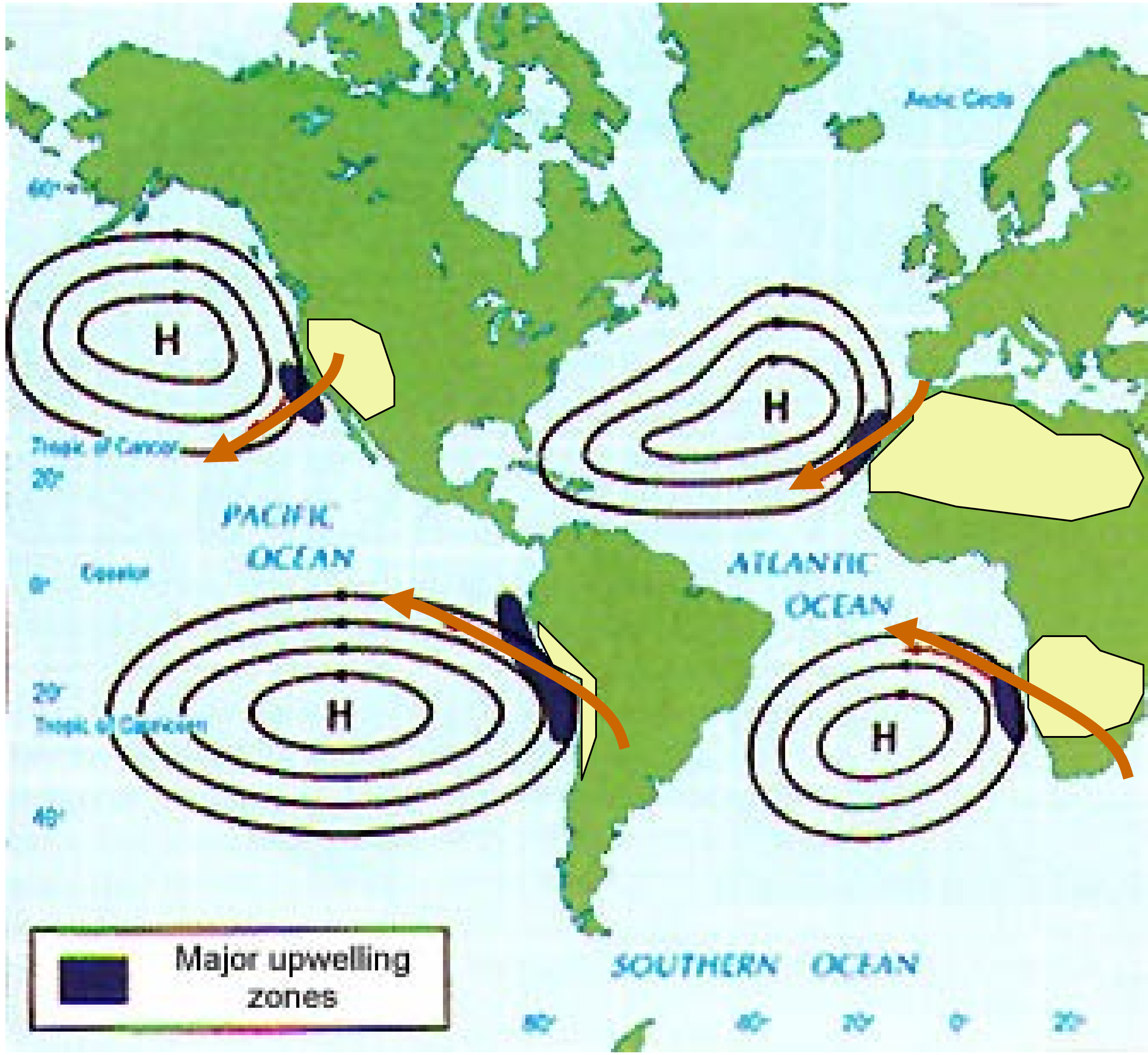
Areas with upwelling of

deeper ocean water

(De Blij, 1996)

Dessert areas





Climate proxies (Examples)

Gas bubbles in ice cores
➔ Paleoatmosphere

Alkenones from marine Sediments
➔Paleotemperature

Emiliania huxleyi

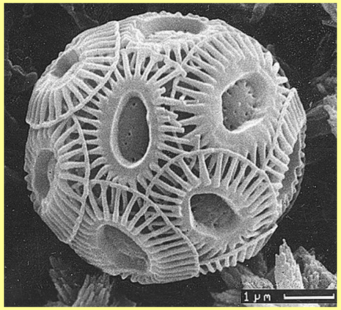
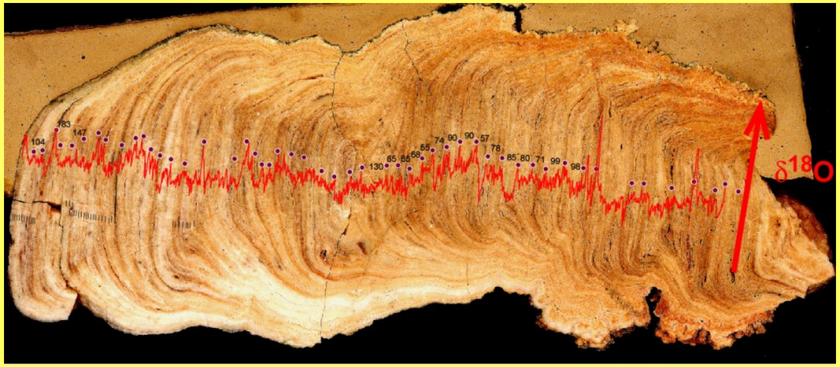
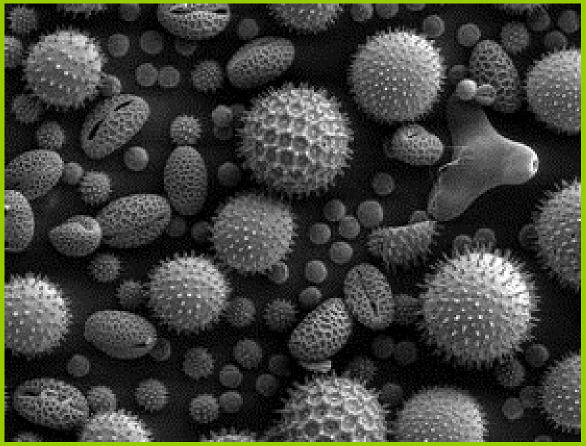


Foto: M. Čepek

O-isotopes of Stalagmites
➔ Paleoprecipitation



Pollen of lake sediments
➔ Paleovegetation



Long chains of C_{37}-alkenones

Organic components of Coccolithophoridae are preserved in sediments

Emiliania huxleyi

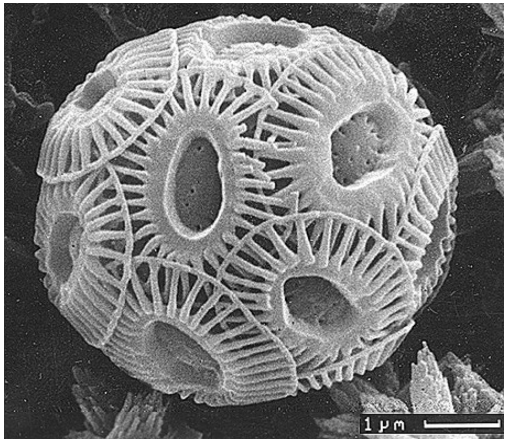
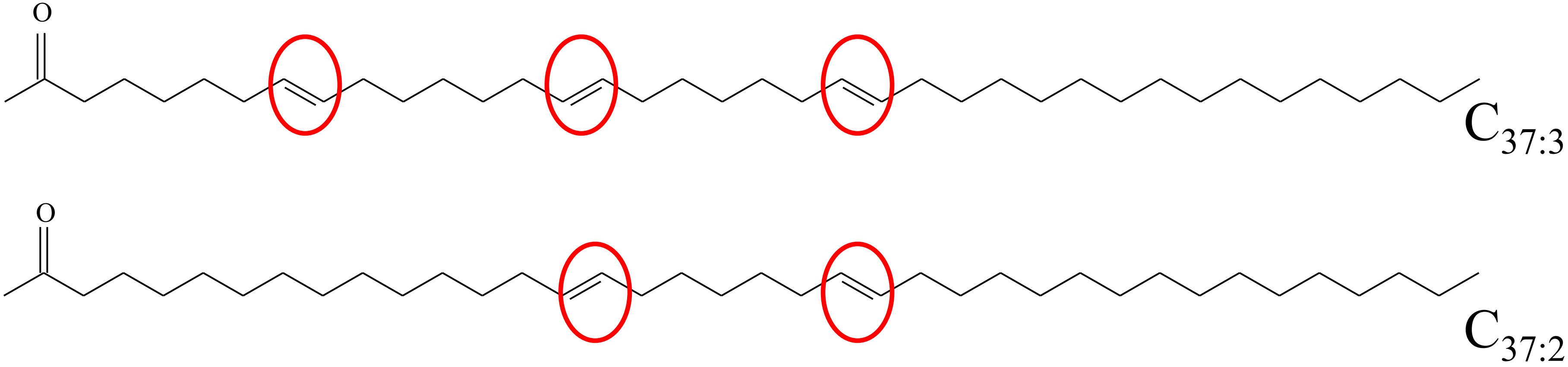


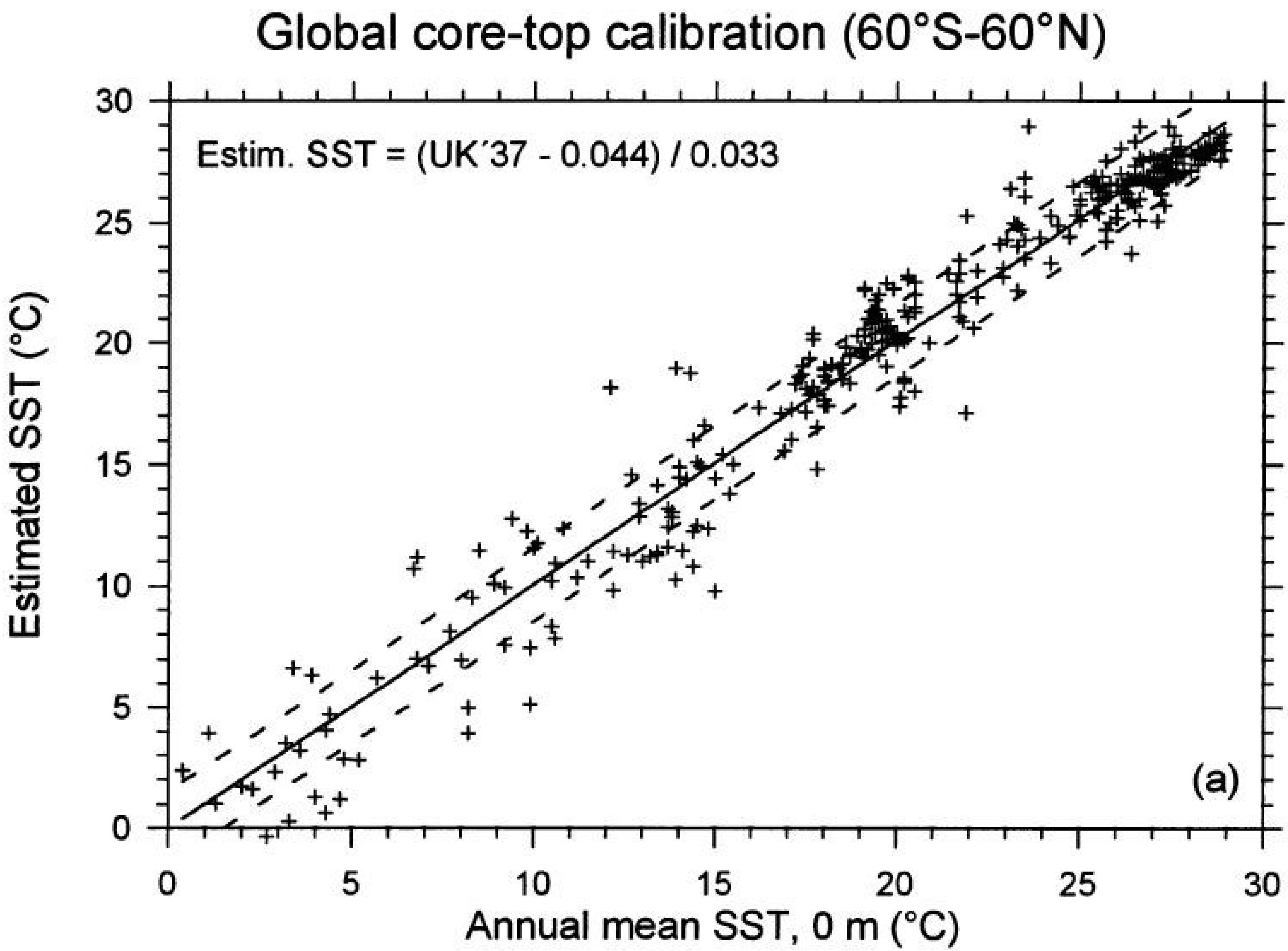
Foto: M. Čepek

Alkenone saturation index after Brasell et al. (1984):

$$U_{37}^{K'} = \frac{[C37:2]}{[C37:2 + C37:3]}$$

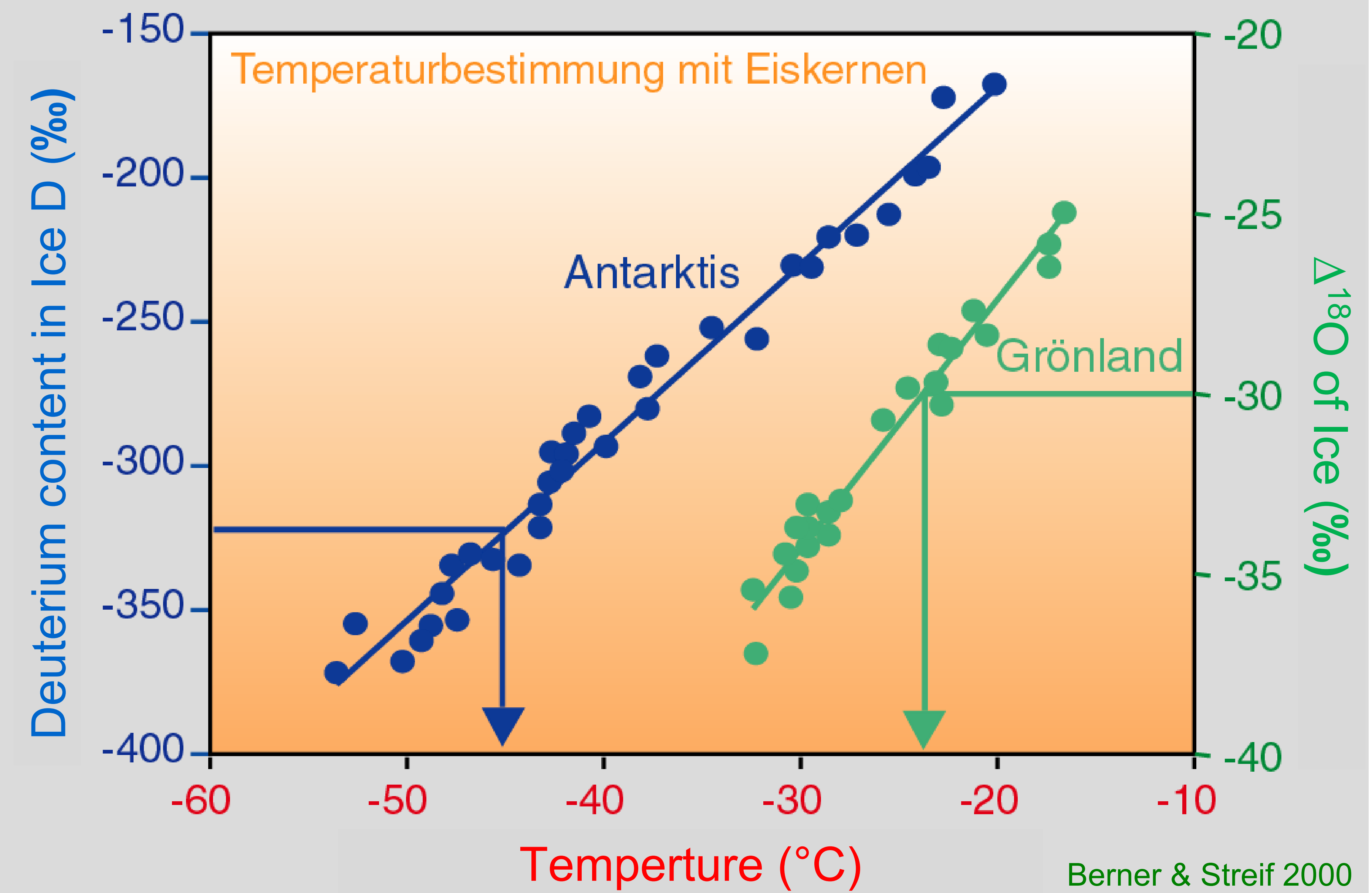


Calibration of the alkenones UK'37 index



Tom Curtis Writes

Calibration of Greenland and Antarctic Ice Cores

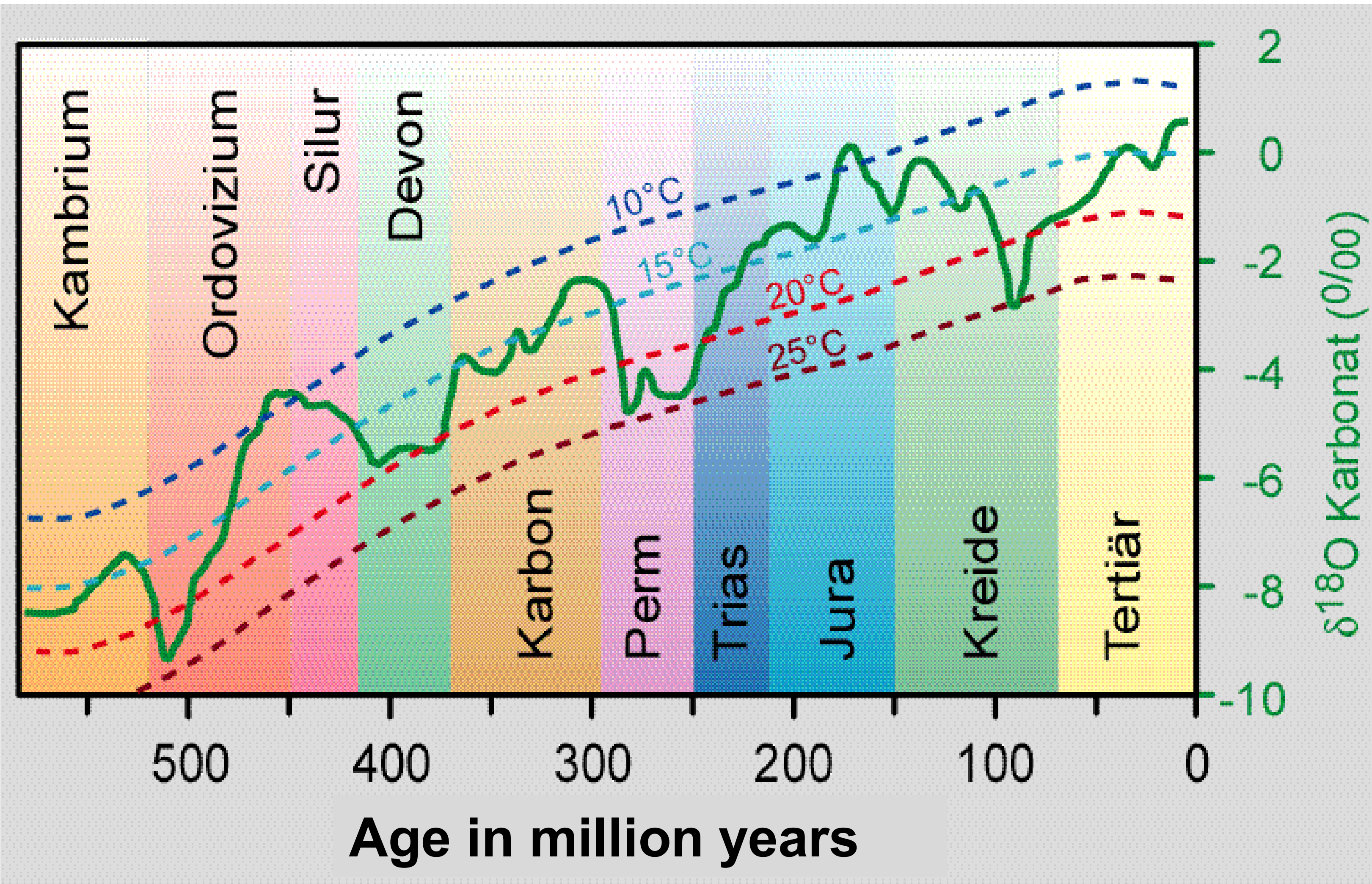


Berner & Streif 2000

2. Climate Variations during the Earth's history

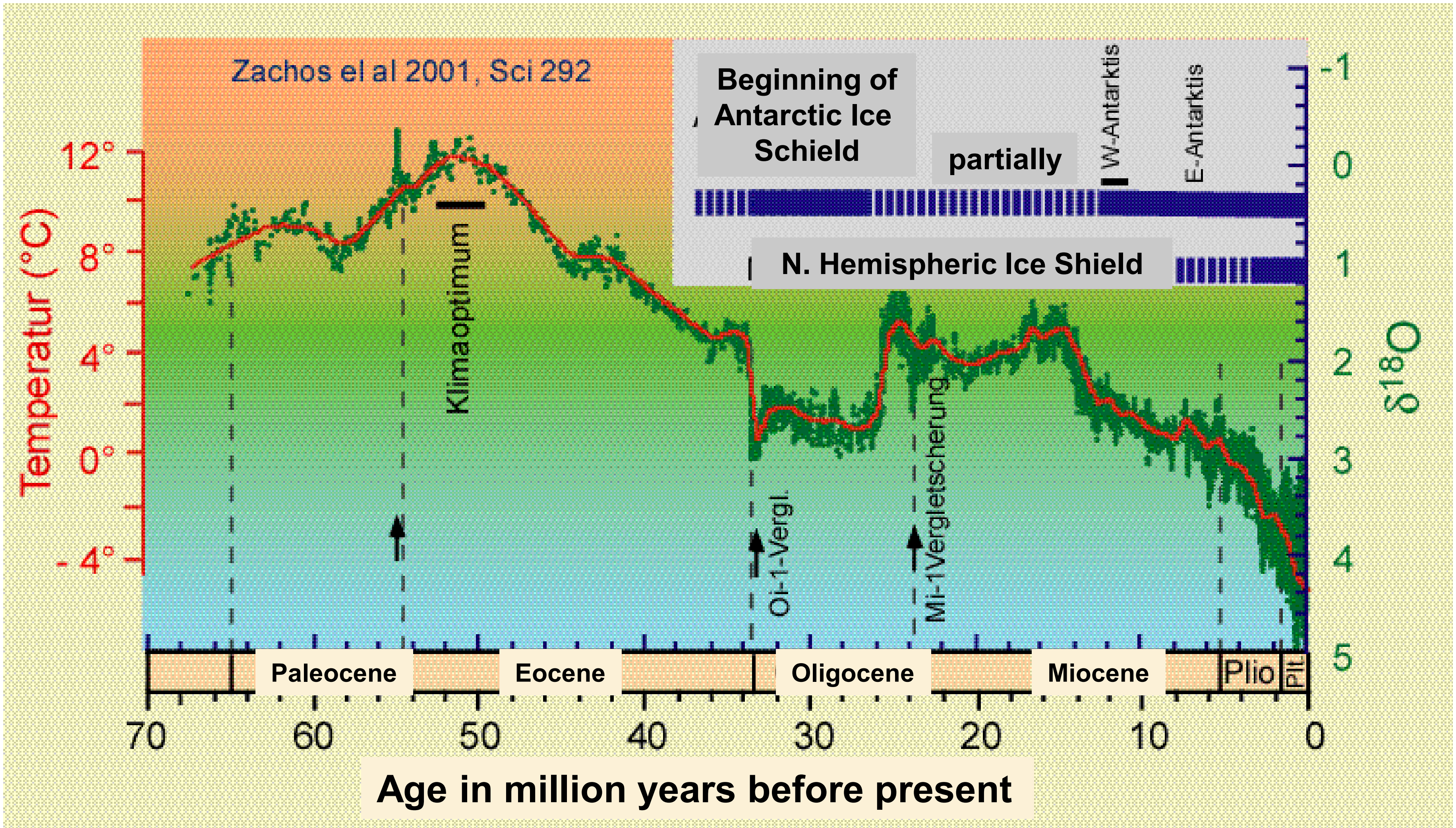
Global temperature development during the last 500 Myr, reconstructed based on $\delta^{18}O$ from carbonate microfossils

(Berner 2000 und Veizer et al. 1999).

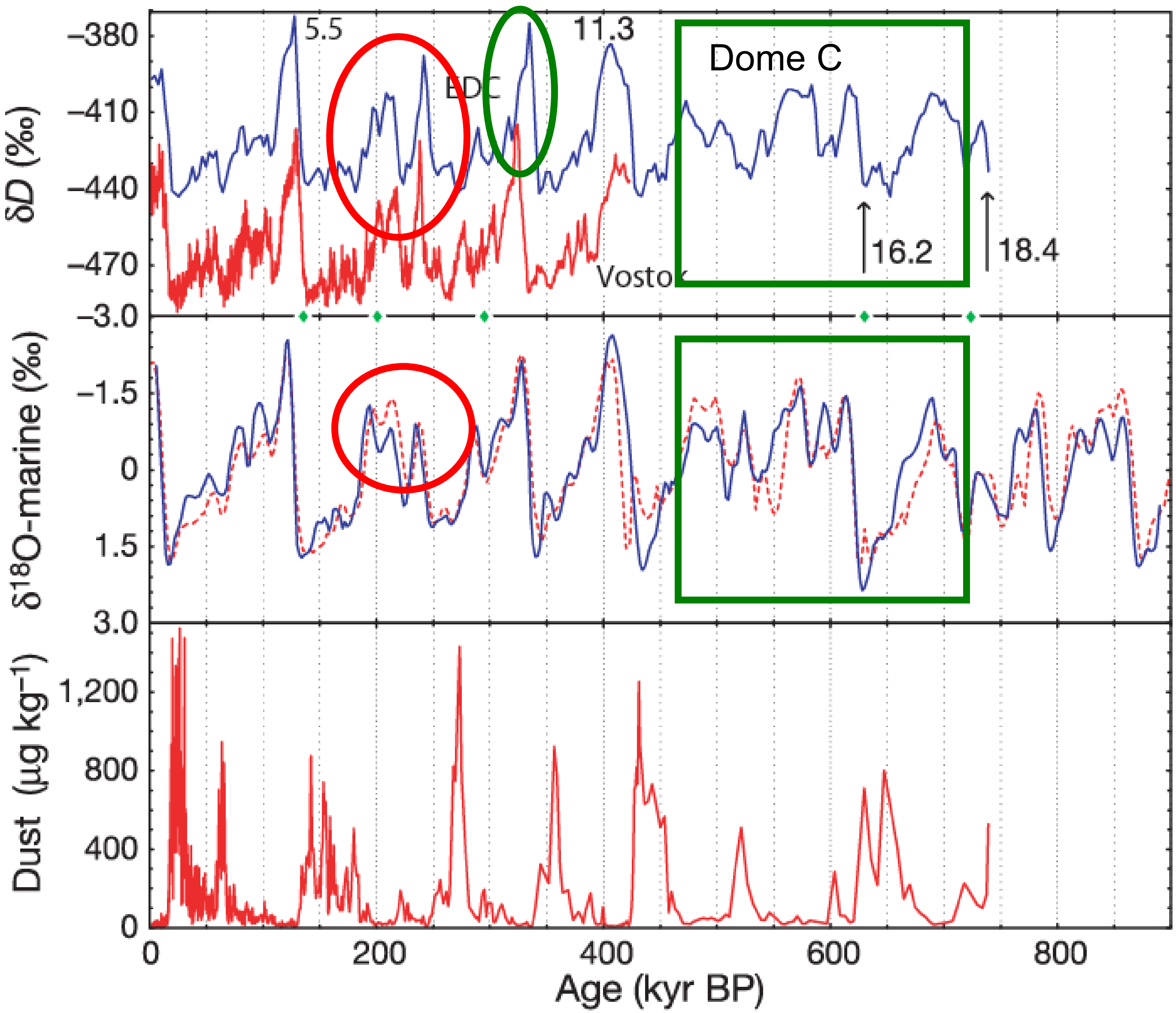


2. Climate Variations during the Earth‘s history

Long-term cooling during the last 50 Myr and its relationship to the formation of the Antarctic and Northern Hemisphercs Ice Schields

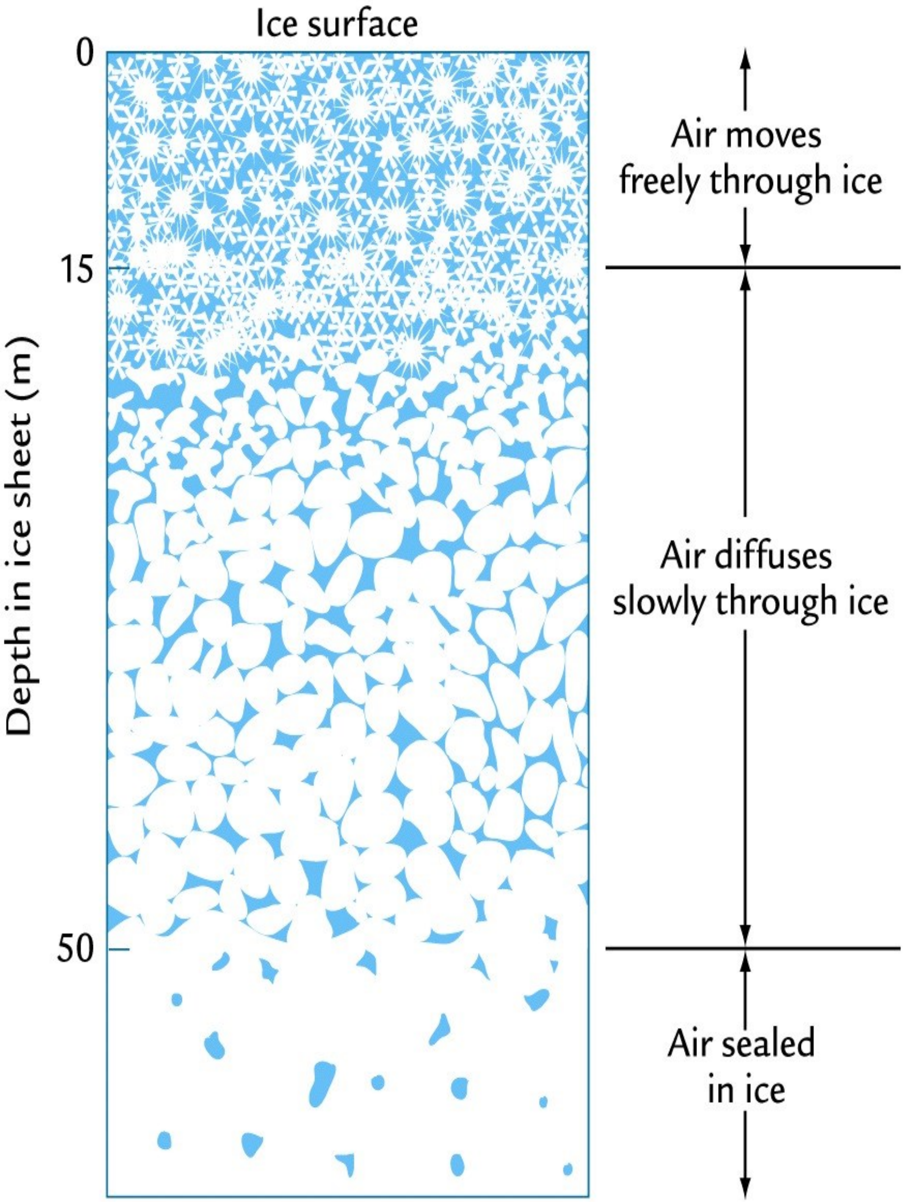


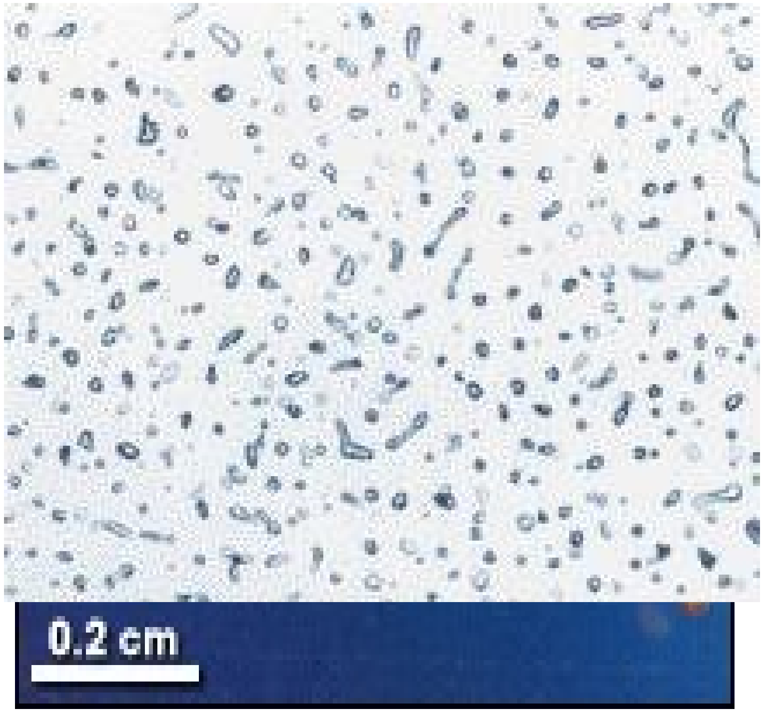
European Project of Ice Coring in the Antarctica (EPICA)



EPICA 2004, *Nature*

Gas bubbles in ice cores (CO_2, methan) and compaction





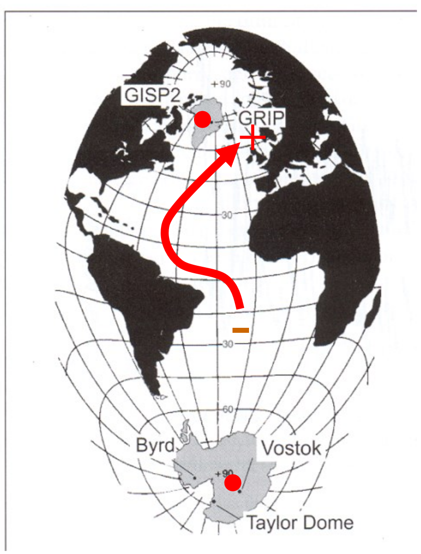
Accumulation rates:

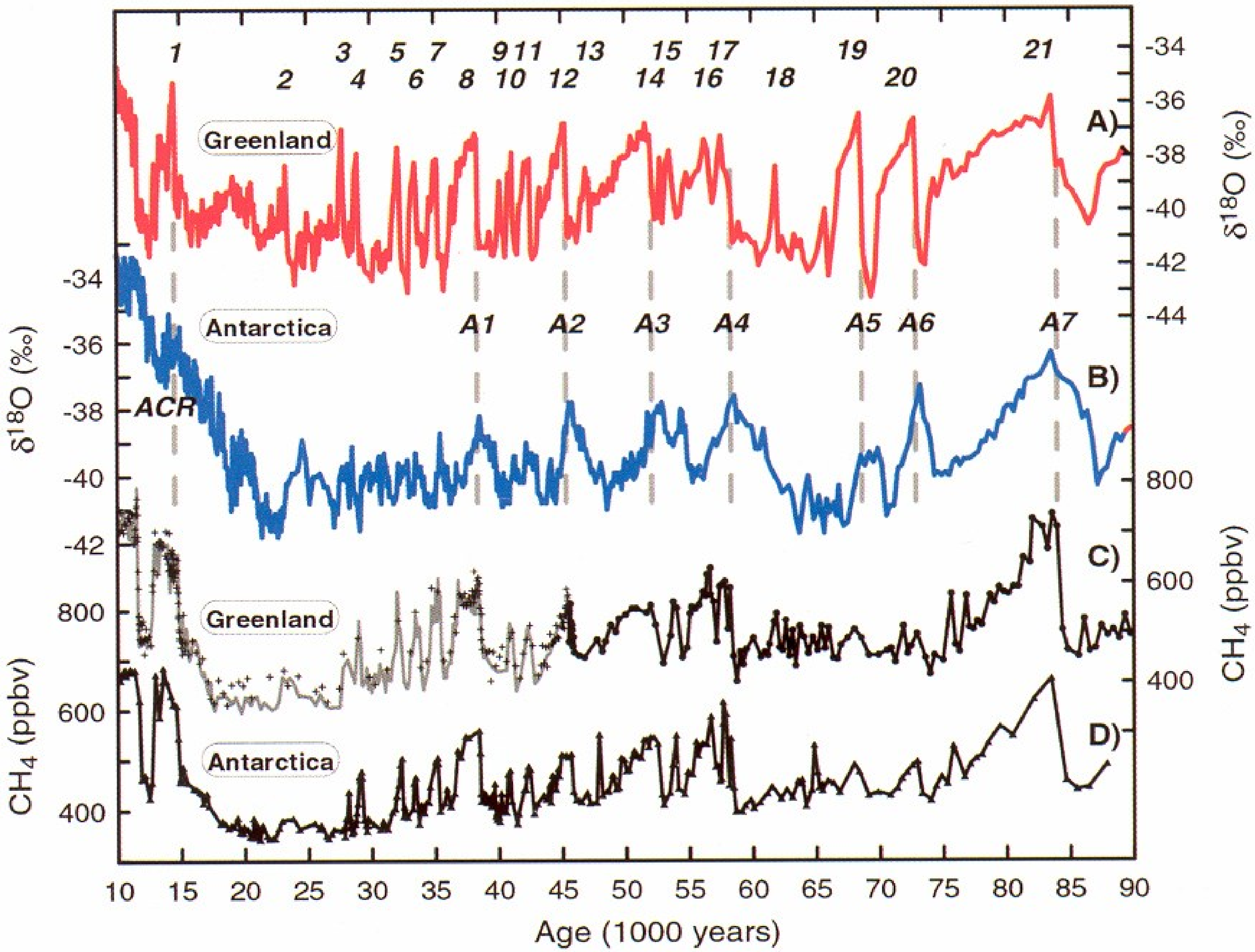
Greenland = 0.5 m/year

Antarctic = 0.05 m/year

Synchronisation of ice cores from the northern (Greenland) southern hemisphere (Antarctica)
➔ Partly antiphasing of temperatures due to sea saw effect

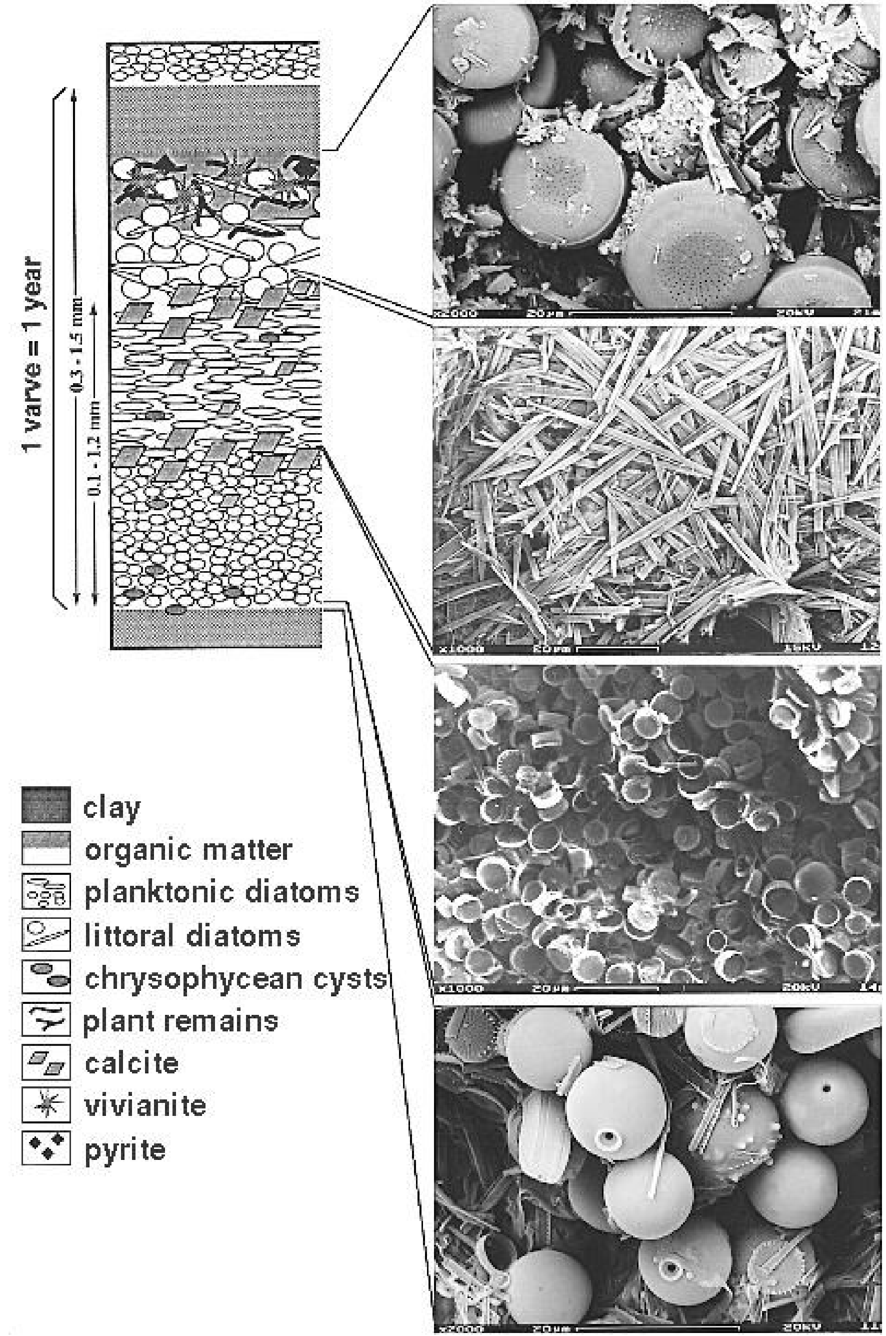
Localities of the Ice Cores





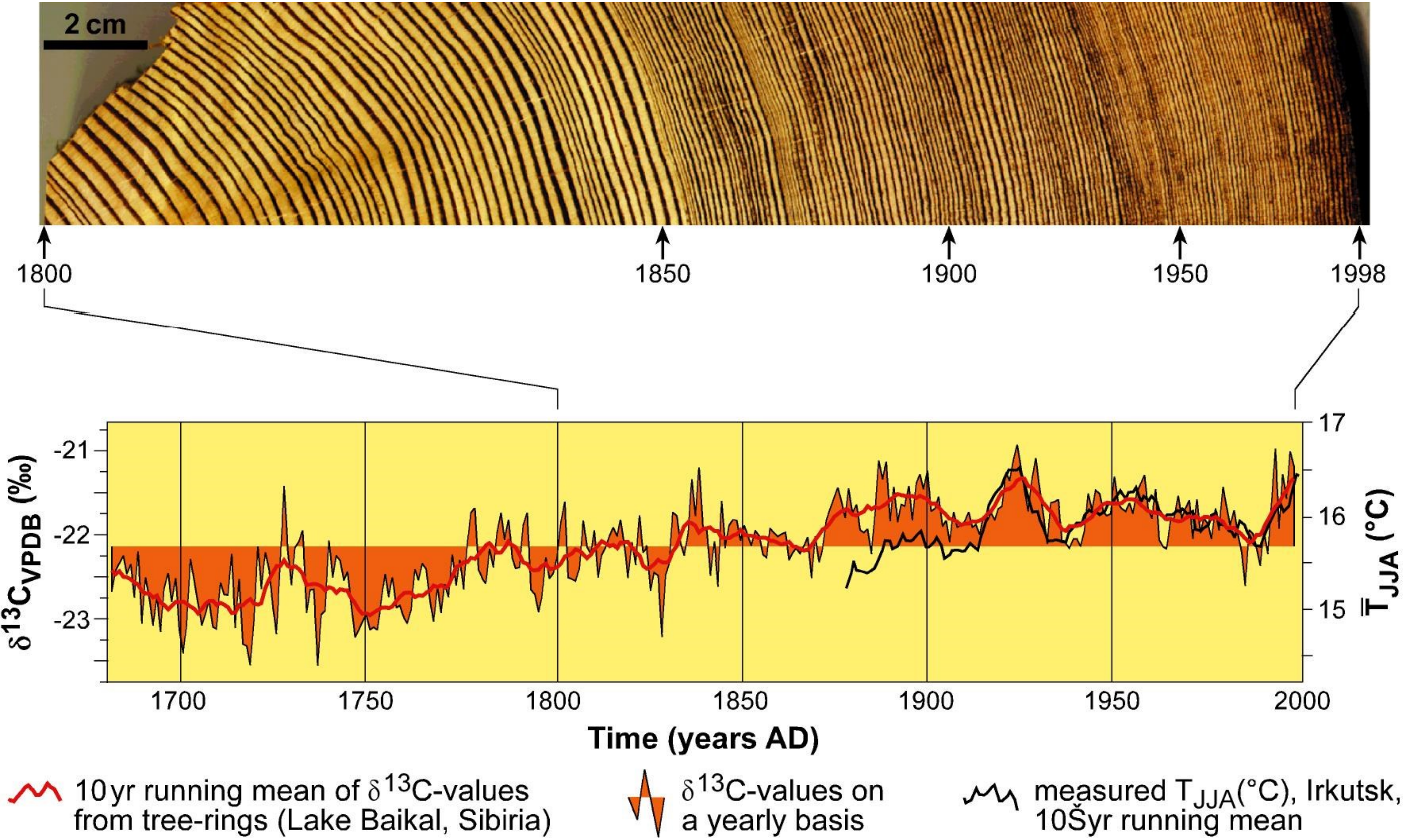
Blunier & Broock 2001; Stocker 2001 Nova Acta Leopoldina 88

Warves from Lake Holzmaar



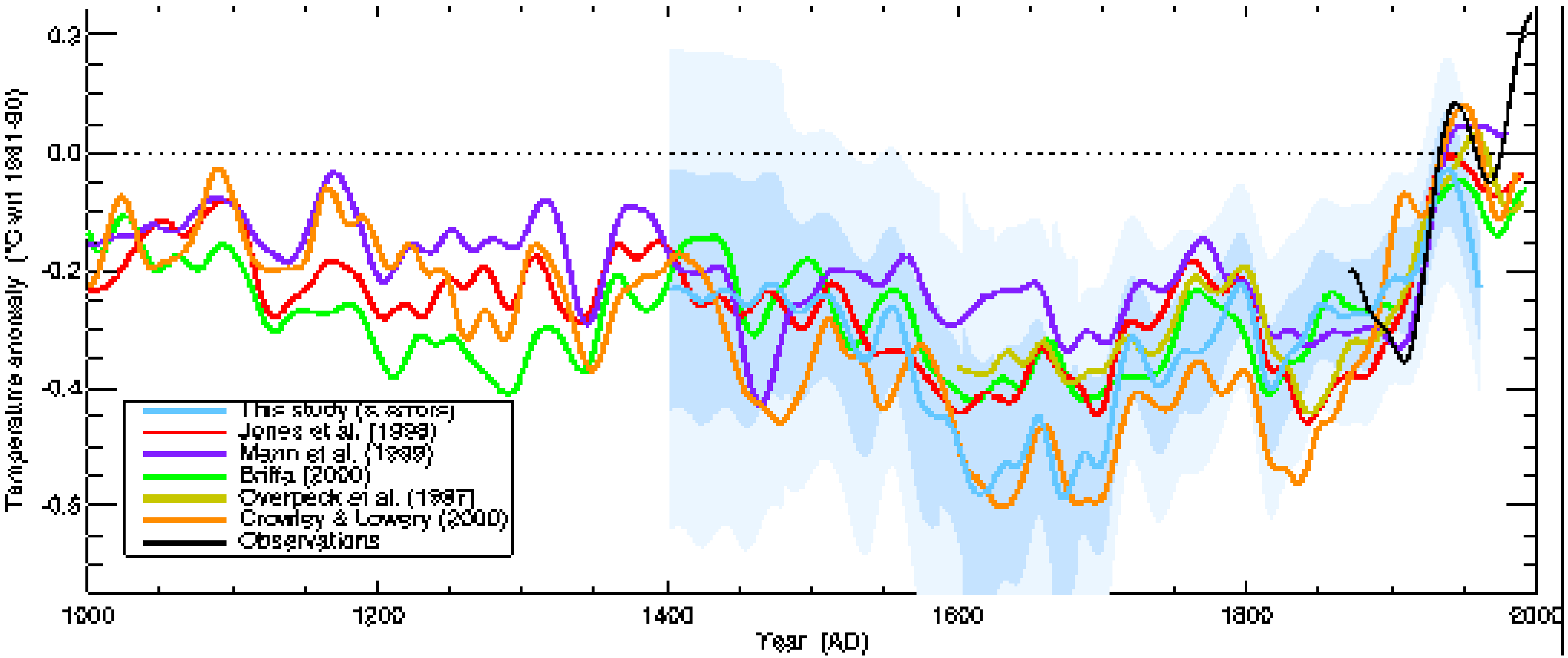
http://www.gfz-potsdam.de/pb3/pb33/wiav.html

8. Tree rings: Annual curves with δ^{13}C temperature calibration

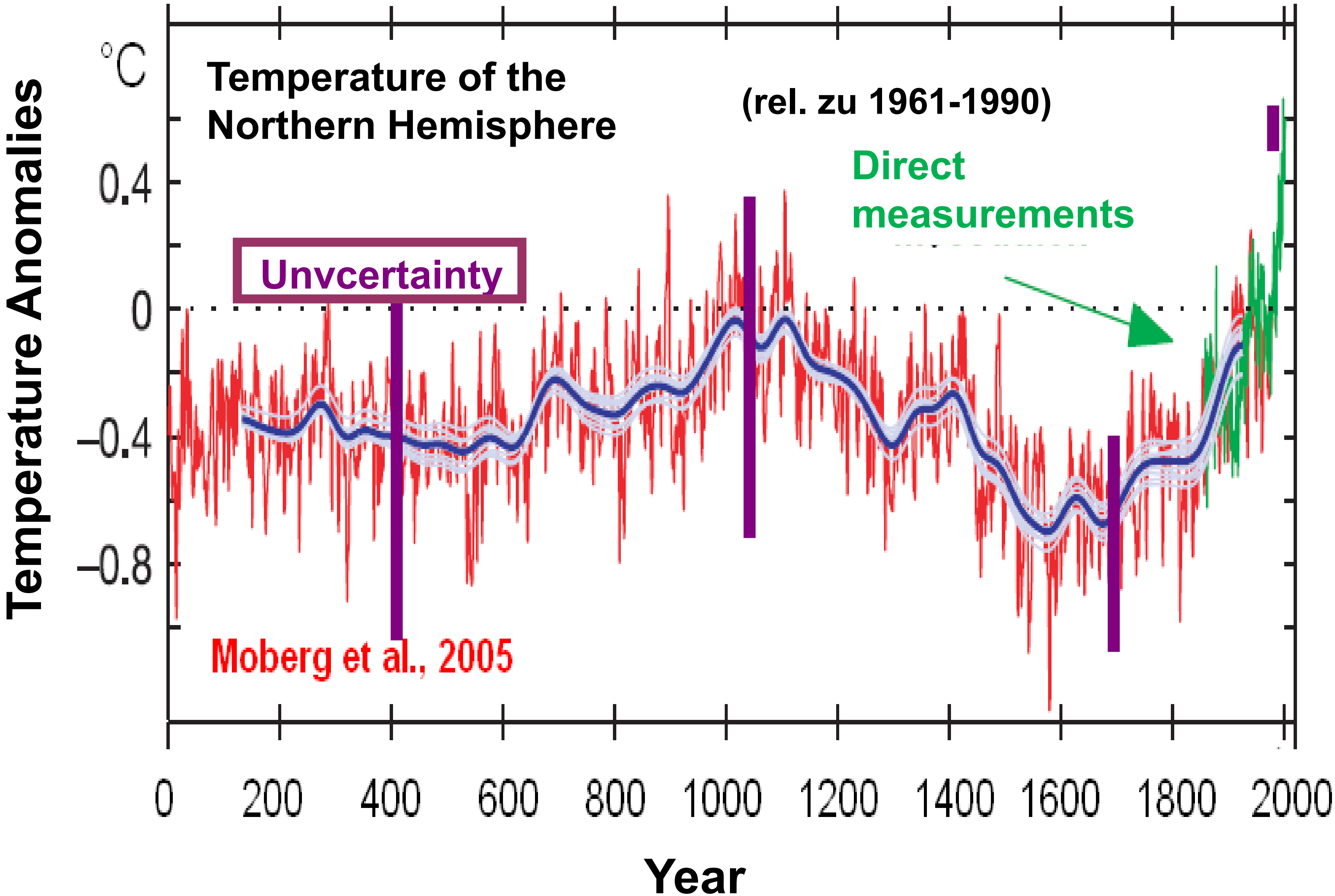


http://www.gfz-potsdam.de/pb3/pb33/kihzhome/kihz02/02baumringe_de.html

Northern hemispheric tree-ring curves from which temperatures of the last 1000 years have been reconstructed

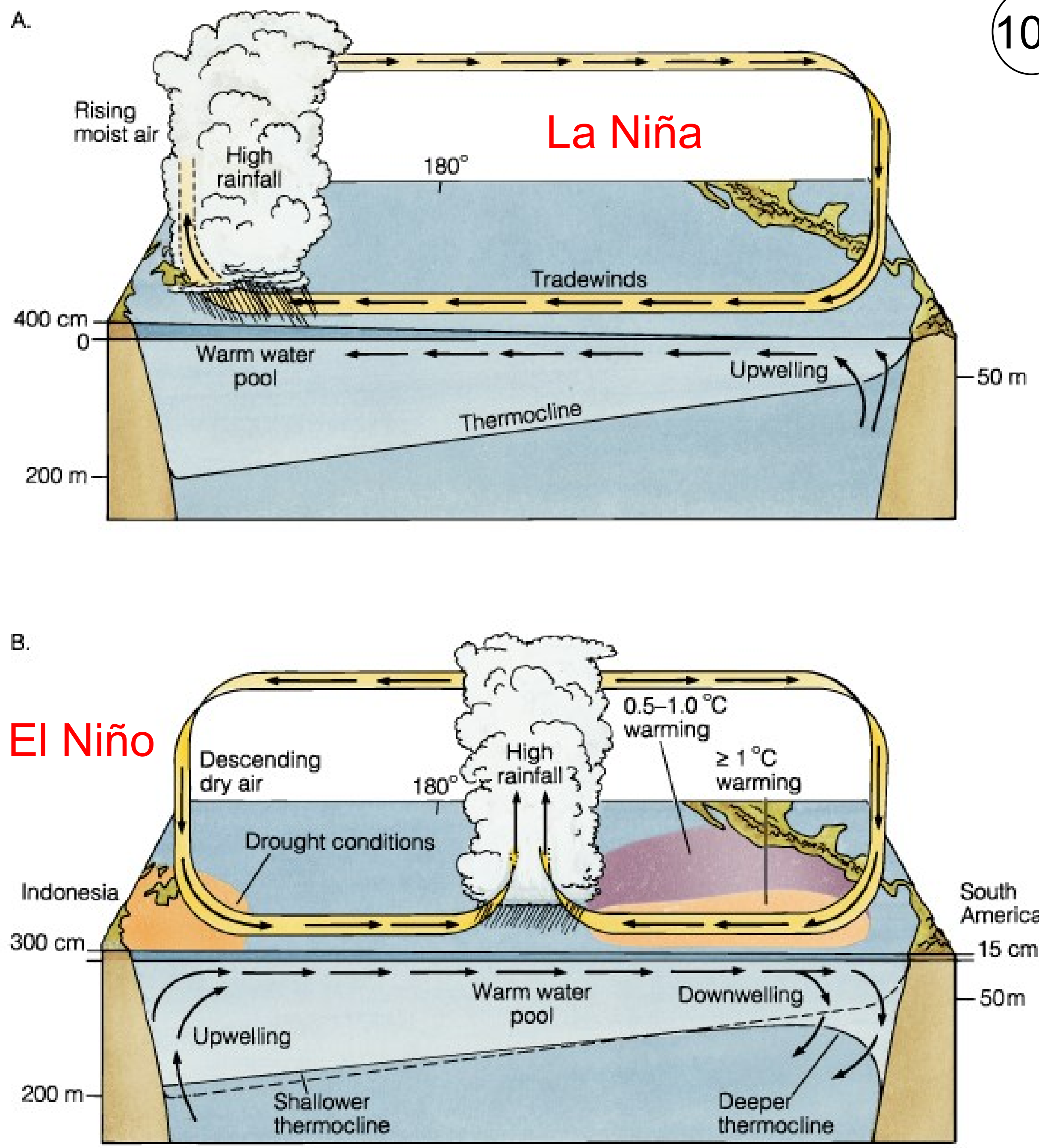


Climate development during the last 2000 years

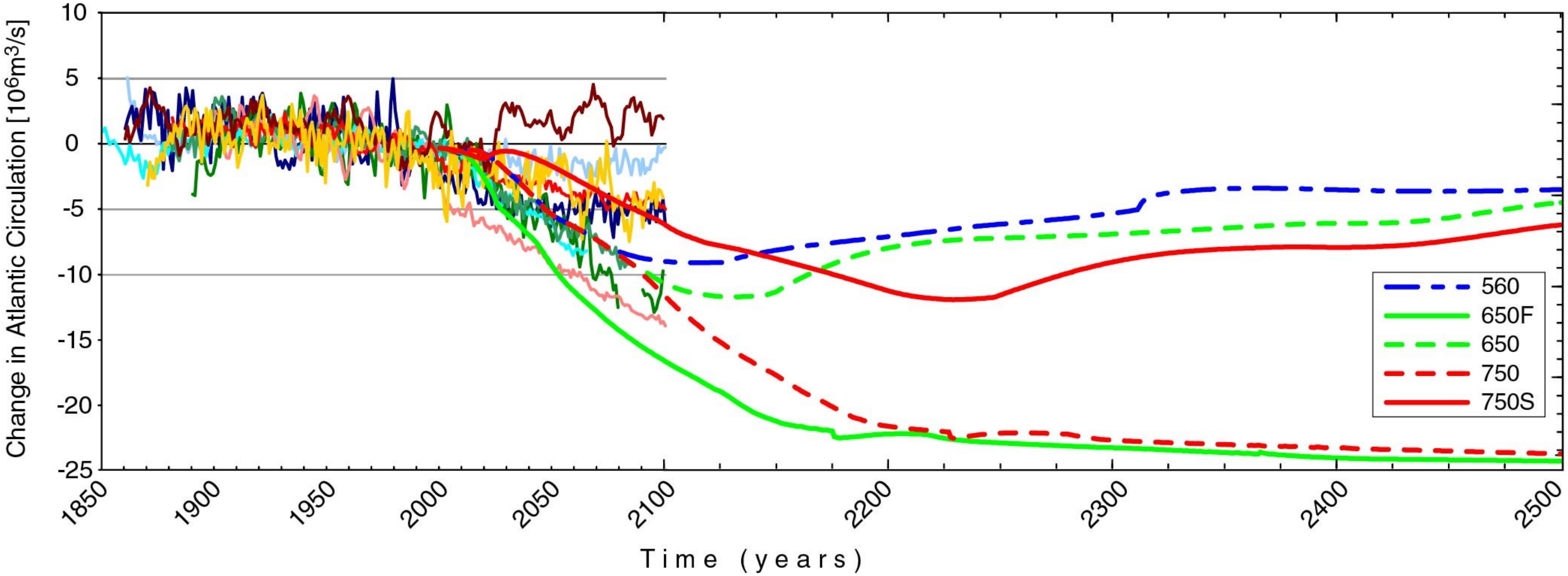


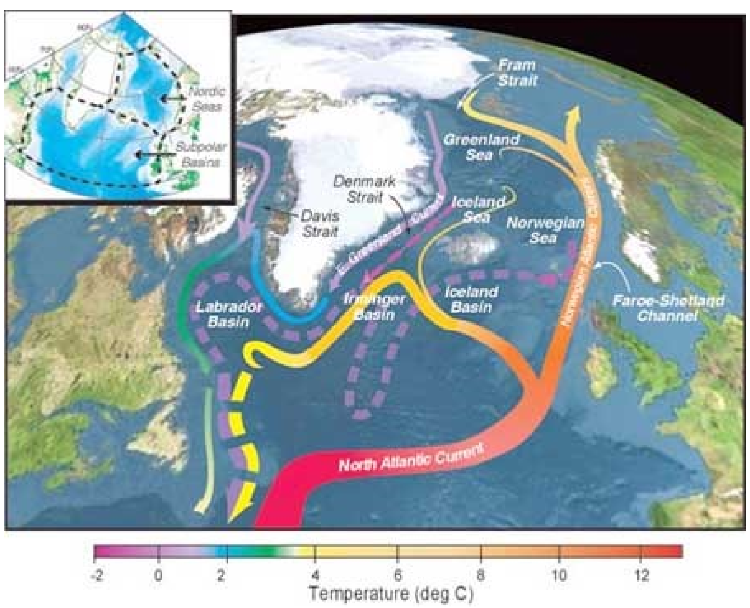
BQuelle: C.D.Schönwiese (2207):"Der neue wissenschaftliche Sachstandsbereicht des IPCC"; **AKE2007F-Vortrag** , Folie 15

Variations of El Niño Southern Oscillation (ENSO)

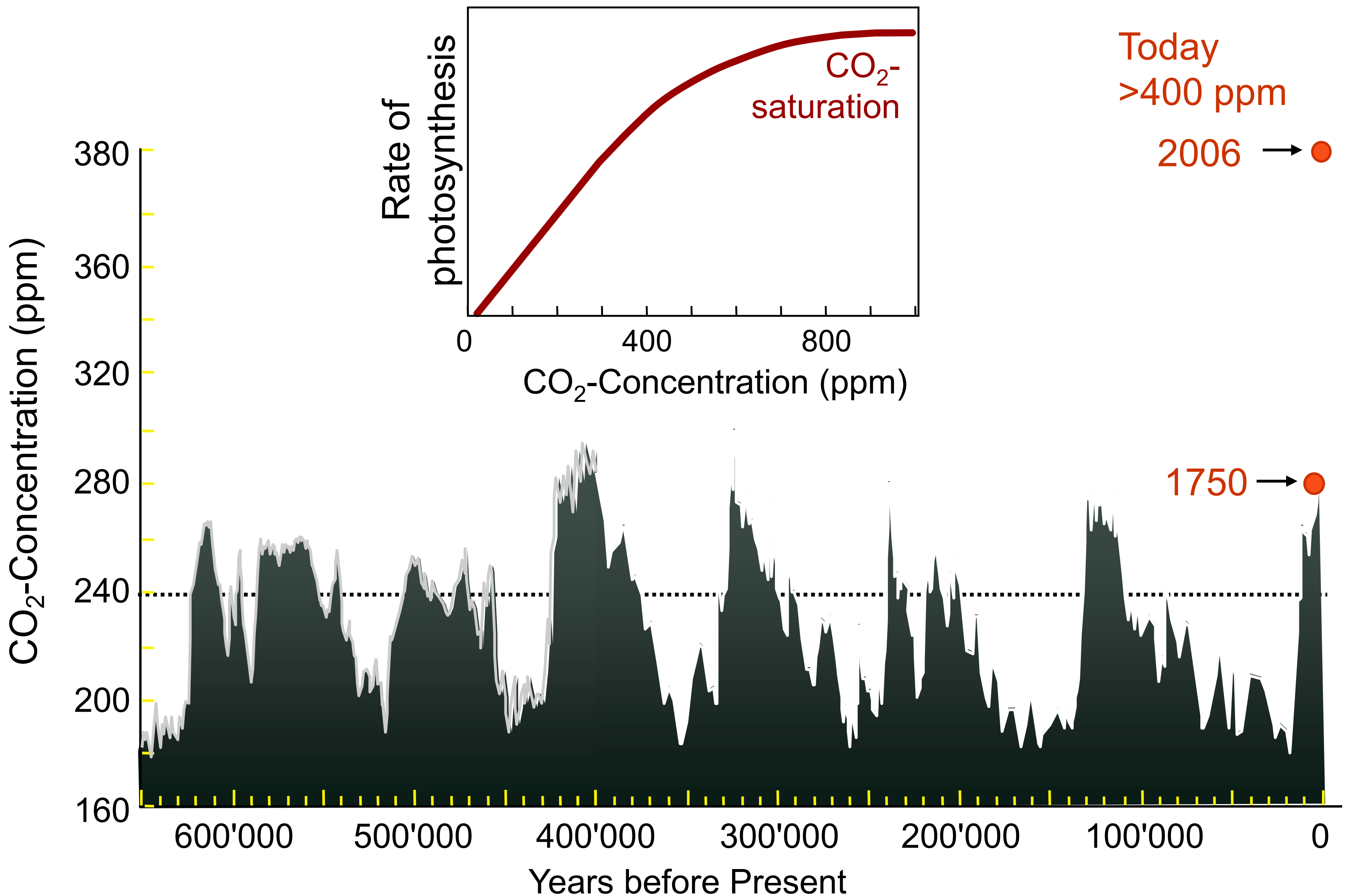


Possible changes of future Northatlantic Circulations (Stocker T.)





IGBP Synthesis
(2003)



BQuelle: C.Körner :"Wälder als Kohlenstoffspeicher.." http://www.uni-saarland.de/fak7/fze/AKE_Archiv/AKE2006F/Links_AKE2006F.htm#AKE2006F_05

Physical weathering

→ mechanical grinding without chemical changes in the minerals and rocks

→ Volume expansion

- **Decompression** (Exfoliation in particular of magmatic rocks)
  Desquamation starts near the surfce rocks along tiny capillary cracks
- **Temperature changes** (Insolation)
- **Frostsprengung** (9% Volume expansion durcing Crystallisation of Ice)
- **Blasting of rocks due to increased cryostatic pressure**
- **Blasting due to salt crystallisation** from salty water which has
  penetrated cleavages and capillarty systems of rocks

Faktors which control chemical weathering

- Rock composition and structure
- Climate: Precipitation / temperature and its variations
- Biosphere (Animals/ plants)
- Morphology
- Time

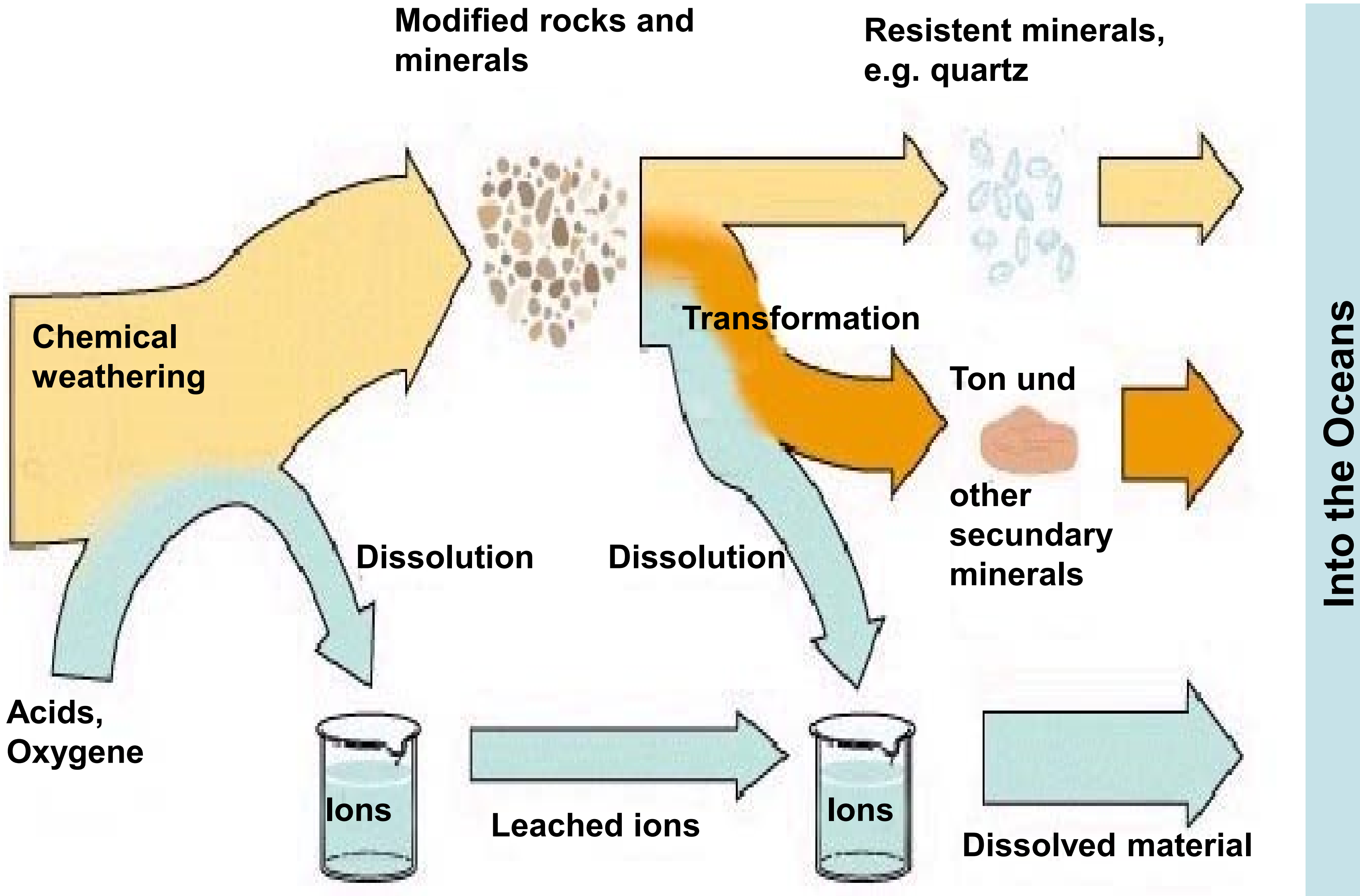
Factors which influence the weathering veolcity:

Chemical weathering

	low ⟷ high		
Solubility	low (e.g. quartz)	mäßig z.B. pyroxene, feldspar	high Calcite
Precipitation	low	middle	high
Temperature	low	moderate	warm
Vegetation and soil microorgansimen	little	medium	strong
Rock cover	bare rocks	low to medium soil	very thick soil

Press & Siever (2001)

Combined physical and chemical weathering of minerals and rocks



Hydratisation (Hydration)

→ Adsorption of water molecules in the crystal lattice or crystall surfaces of minerals

Hematite + *Water* → *Goethit e* · *Water*

Fe_2O_3 + H_20 → $Fe_2O_3 \cdot H_2O$

Anhydrite + *Water* → *Gipsum* · *Water*

$CaSO_4$ + $2\ H_2O$ → $CaSO_4 \cdot 2\ H_2O$

→ ca. 60 %i volume increase → blasting effect

Oxidation

Ironpyroxene + Oxygene → Hematite + disolved silicadioxide

$$4\,FeSiO_3 + O_2 \xrightarrow[H_2O]{} 2Fe_2O_3 + 4SiO_2$$

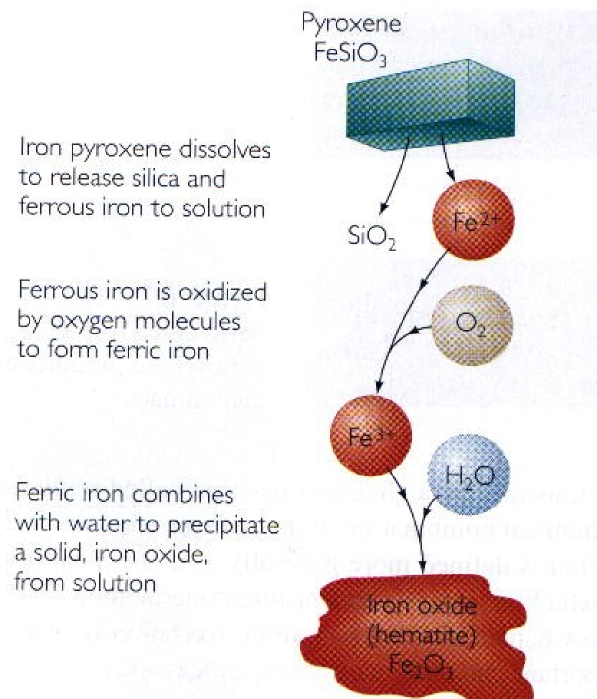


Figure 6.8 The general course of chemical reactions by which an iron-rich mineral, such as pyroxene, weathers in the presence of oxygen and water.

Press & Siever (2001)

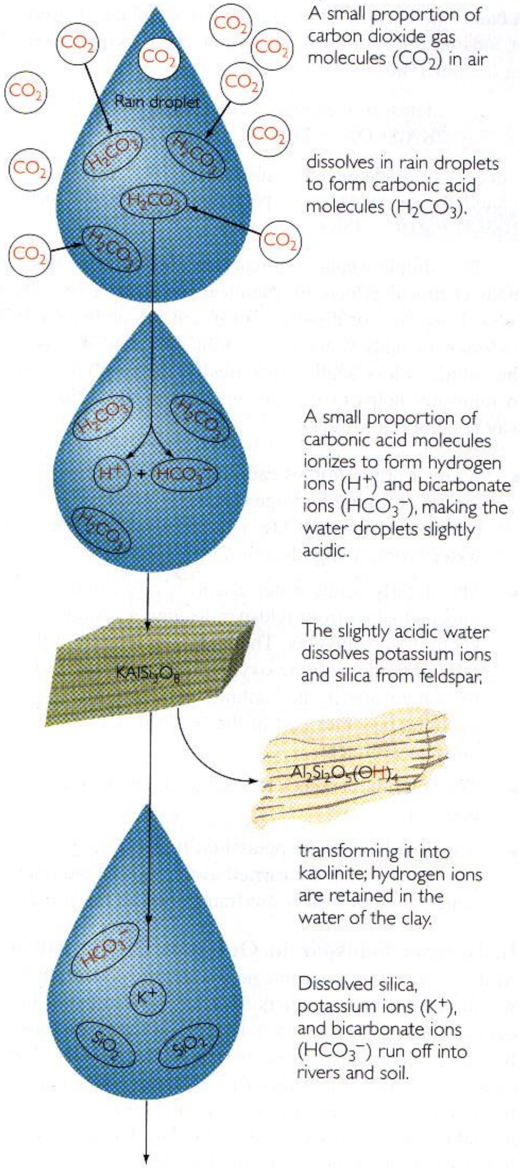


Figure 6.6 Feldspar weathering when it is in contact with carbonic acid from rainwater containing carbon dioxide. Two products are formed: kaolinite clay and a solution containing dissolved silica, potassium ions, and bicarbonate ions.

Hydrolysis

K-Feldspar + water + carbondioxide →
Kaolinite + dissolved hydrogen carbonate +
dissolved potassium + dissolved SiO_2

$$2\,KAlSi_3O_8 \;+\; H_2O \;+\; 2\,H_2CO_3 \;\rightarrow$$
$$Al_2Si_2O_5(OH)_4 \;+\; 2\,HCO_3^- \;+\; 2K^+ \;+\; 4\,SiO_2$$

Press & Siever (2001)

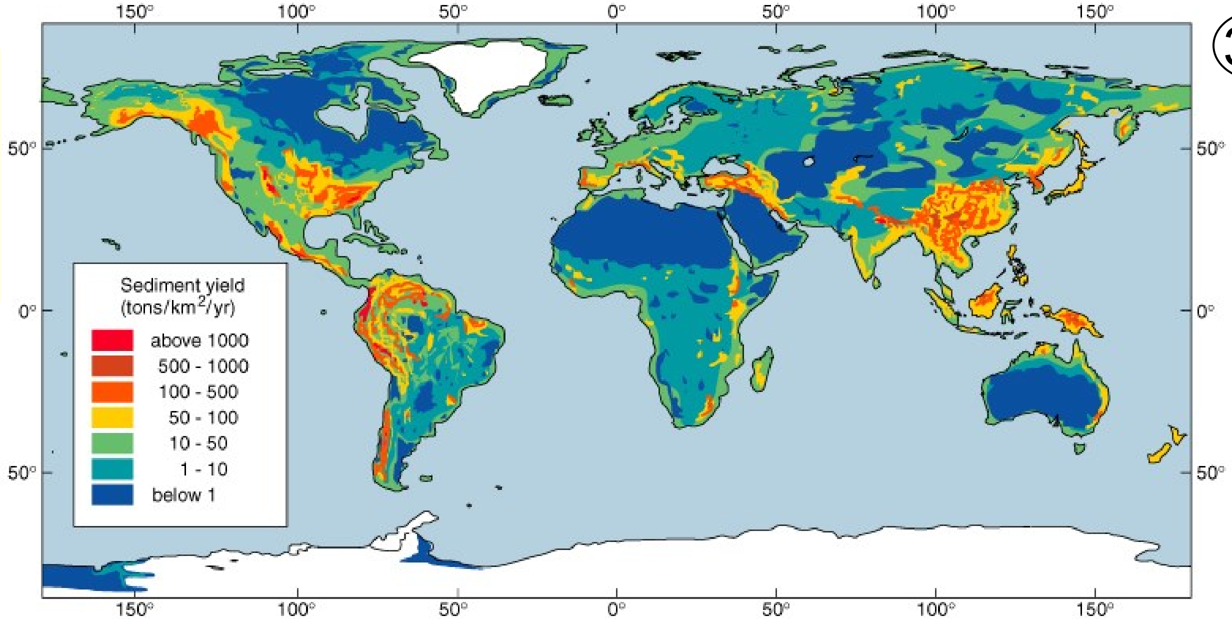
Erosion/Denudation

Exogene forces, which causes erosion/denudation processes:

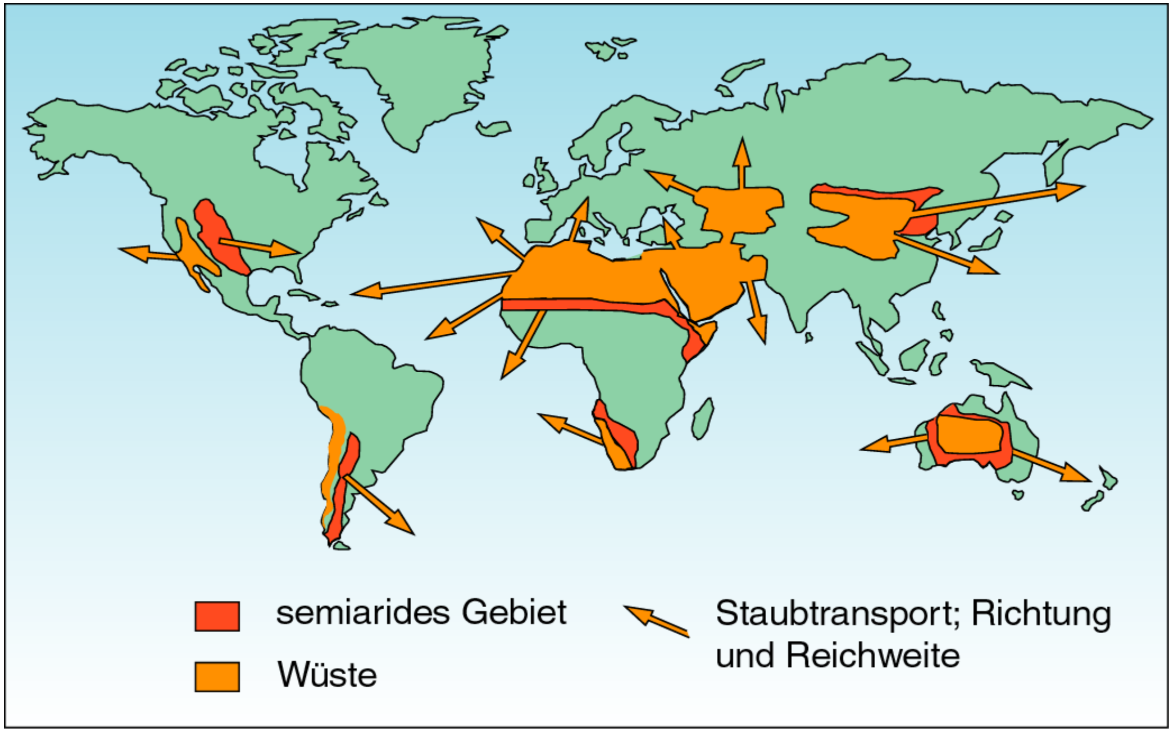
- Water
- Ice
- Wind
- Gravitation

Fluvial erosion and wind denudation

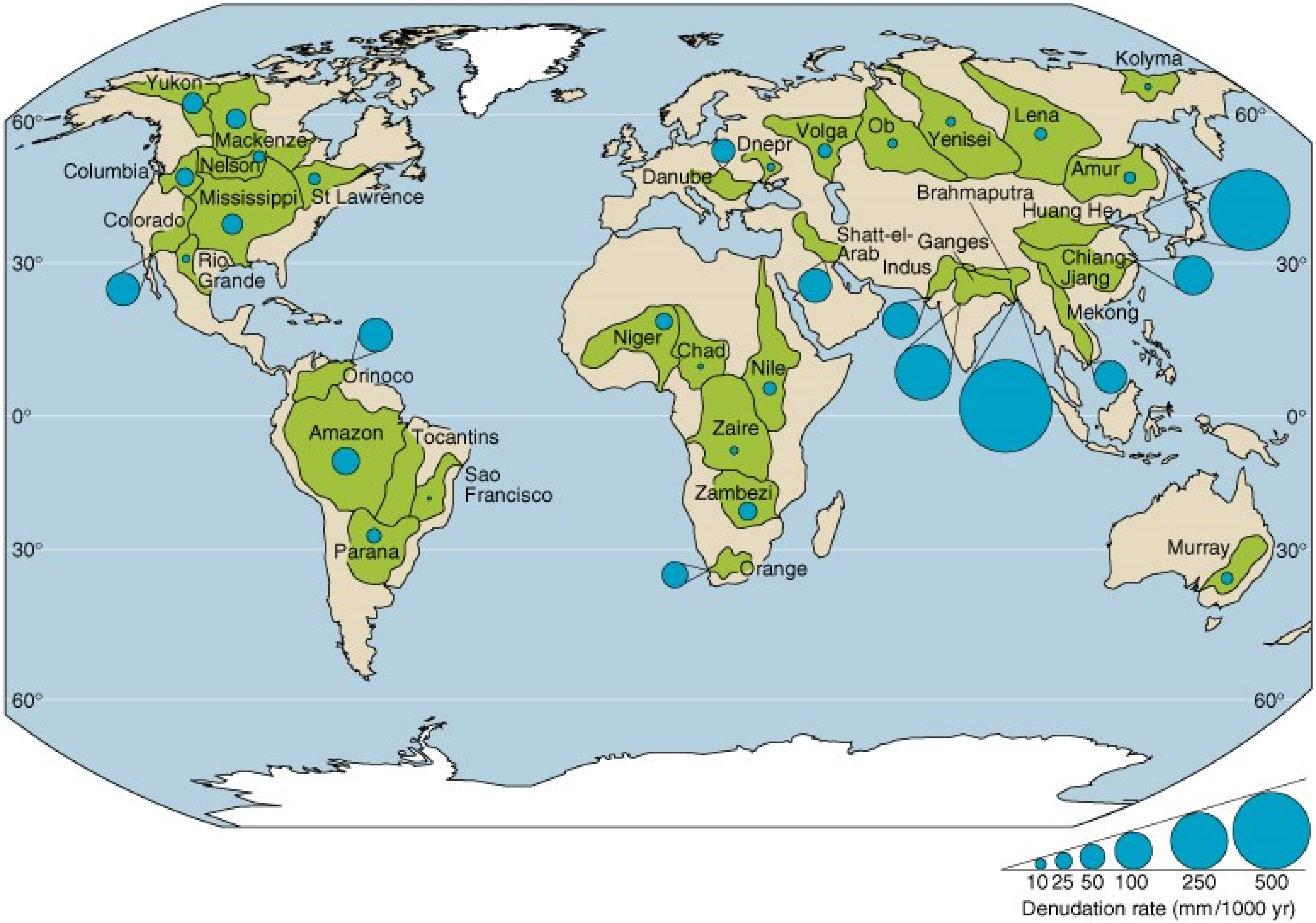
Sediment denudation rates on continents



Sources and transport directions of eolian sediments

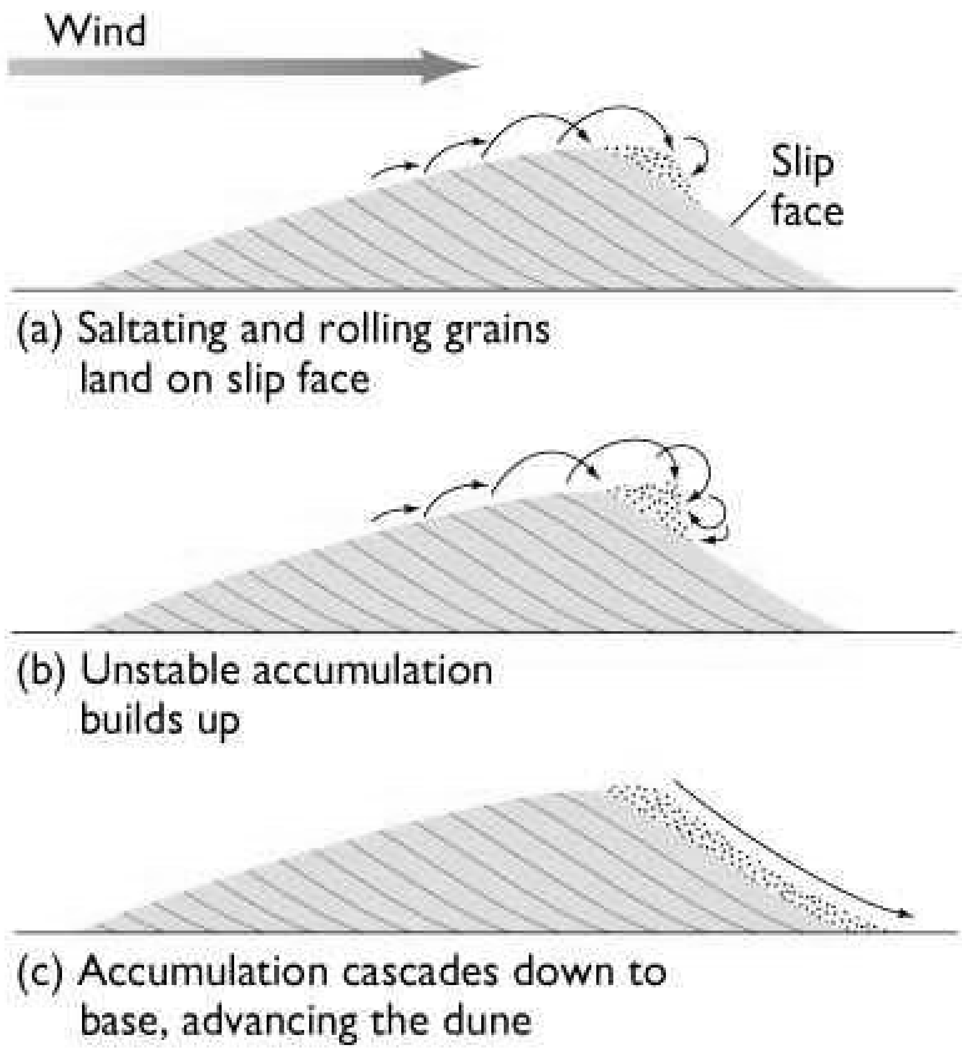


Denudation rates:



Denudation rates calculated for large river catchments: In the Missisippi and Amazonas catchment (< 0.1 mm/year) it amounts only 10 to 20% of that from the east-asiatic areas (>0.5 mm/year).

Formation and development of sand dunes



Mighty loess deposits near Hunyuan, Shanxi Province, China
(Foto :T. Niermann)

Typical ore deposits

Magmatic

- Pt, Cr, Fe, Ni, Ti, Diamand

Pegmatites

- Li, Be, U, Rare Earth Elements, Feldspar, Mica, Jewelry

Hydrothermal

- 600 °C: W, Sn
- 400 °C: Au, U, Ag, Co, Mo
- 200 °C: Cu, Zn, Cd, Pb
- Cold: Hg, As

Sediments

- Fe, Cu, U, Mn, Mg

Weathering

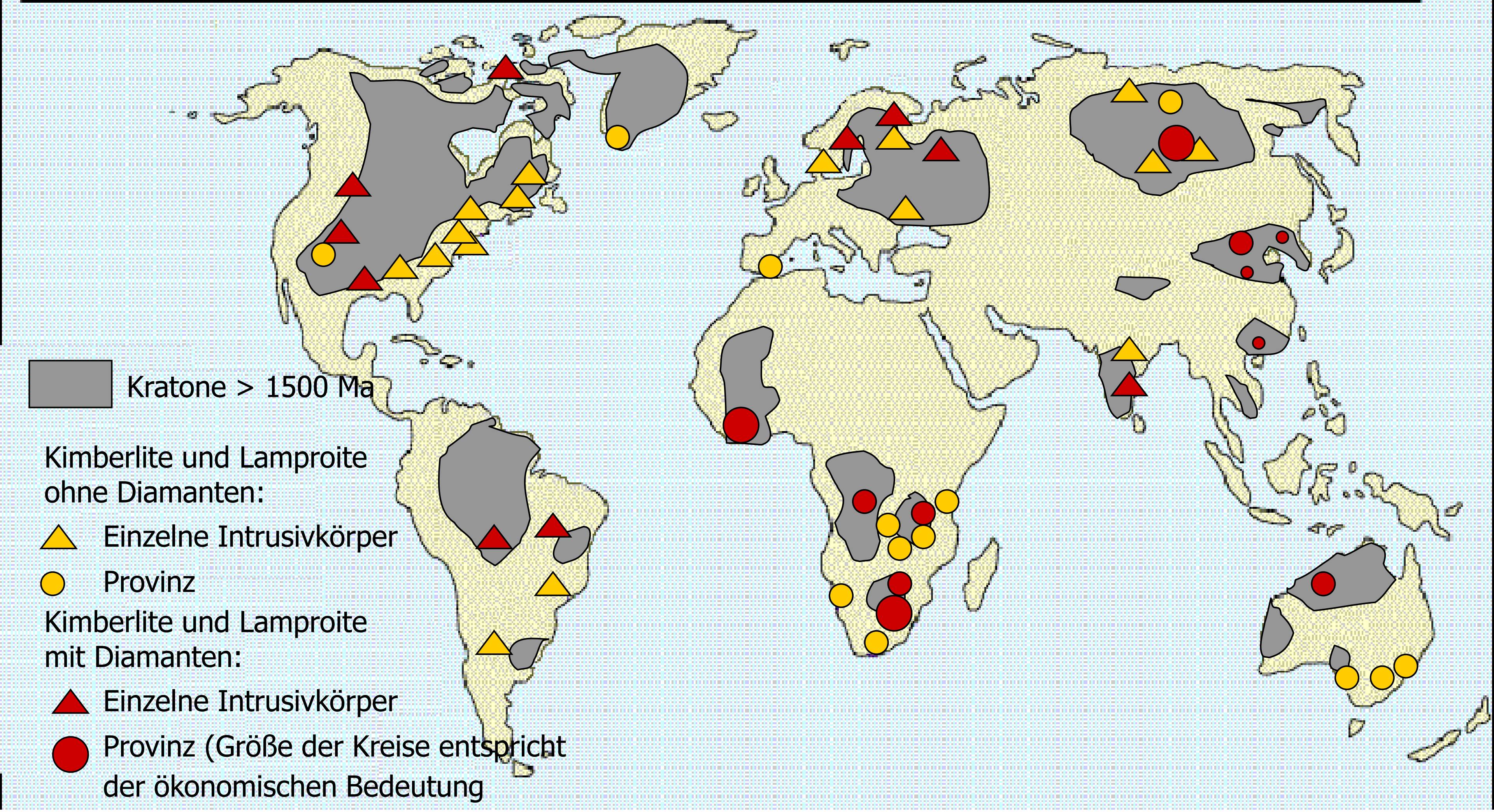
- Secundary enrichment:
  - Cu, Ni
- Soils
  - Al, Ni

Replacement

- Pt, Au, Sn, Ti, W, Th, Rare Earth Element, U (Fossil), Jewelry

Diamands form in the comparatively low mantle in mor than 300 km depth and are extracted within mantle xenoliths during explosive magmatic activity (Volcanic pipes) Where they were exploited or redistributed to placer deposits

Global distribution of diamand-bearing kimberites and lamproites



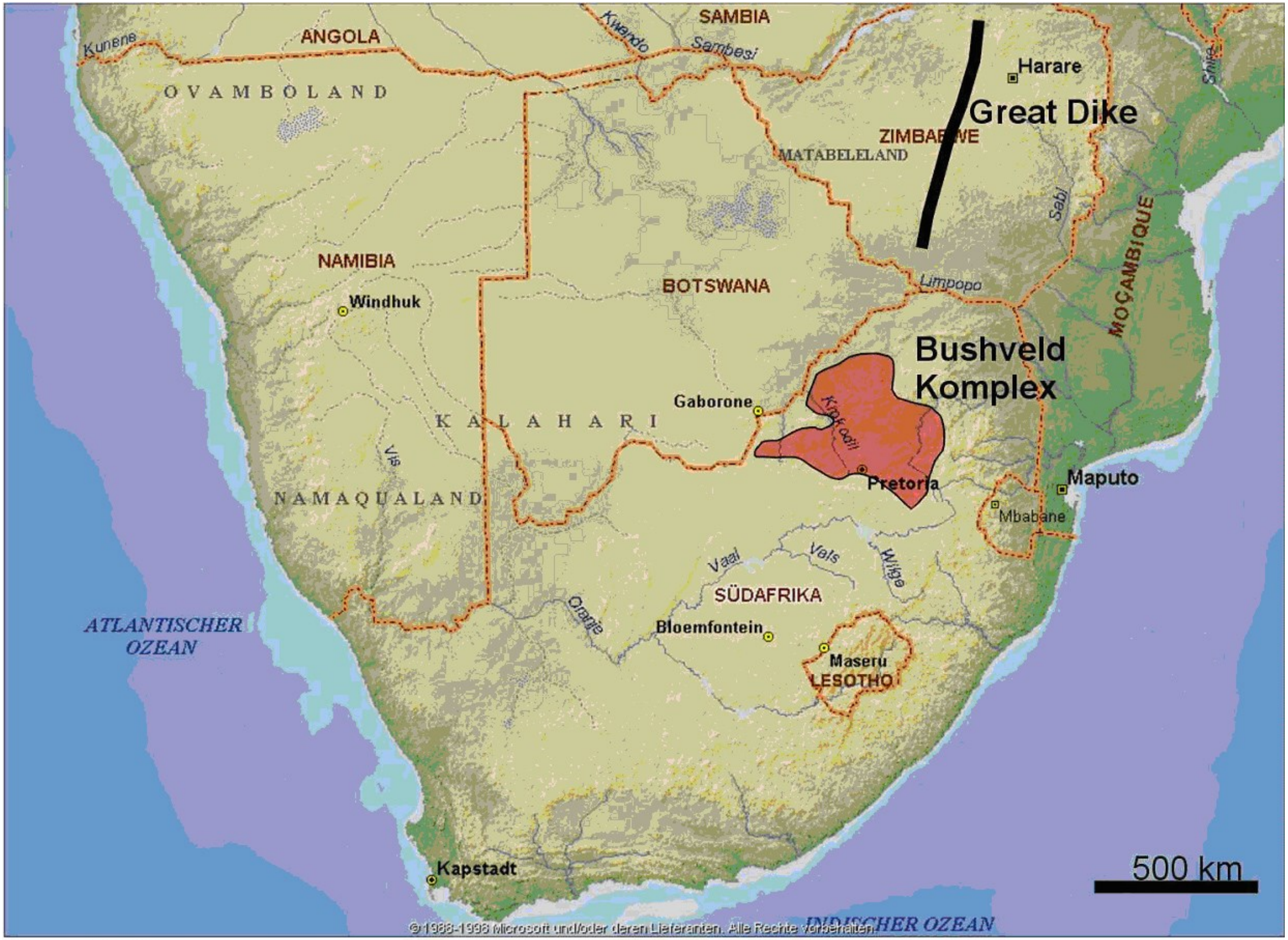
2.1.2 Early crystallization

Minerals which form early (like chromite) during crystallization can settle down in magma chambers and fotm cummulate ores.

Chromite deposits which formed during crystallization of the Bushveld Intrusive Magmatic complex in South Africa represent an important example.

In other cases a segregation of silicate melt and sulfid liquid can be formed during an early crystallization stage. During this process the elements copper, nickel and elements from the platin group become enriched in the sulfide liquid. Sudbury in Canada represents such an example.

2Early crystallization: Bushveld Intrusion



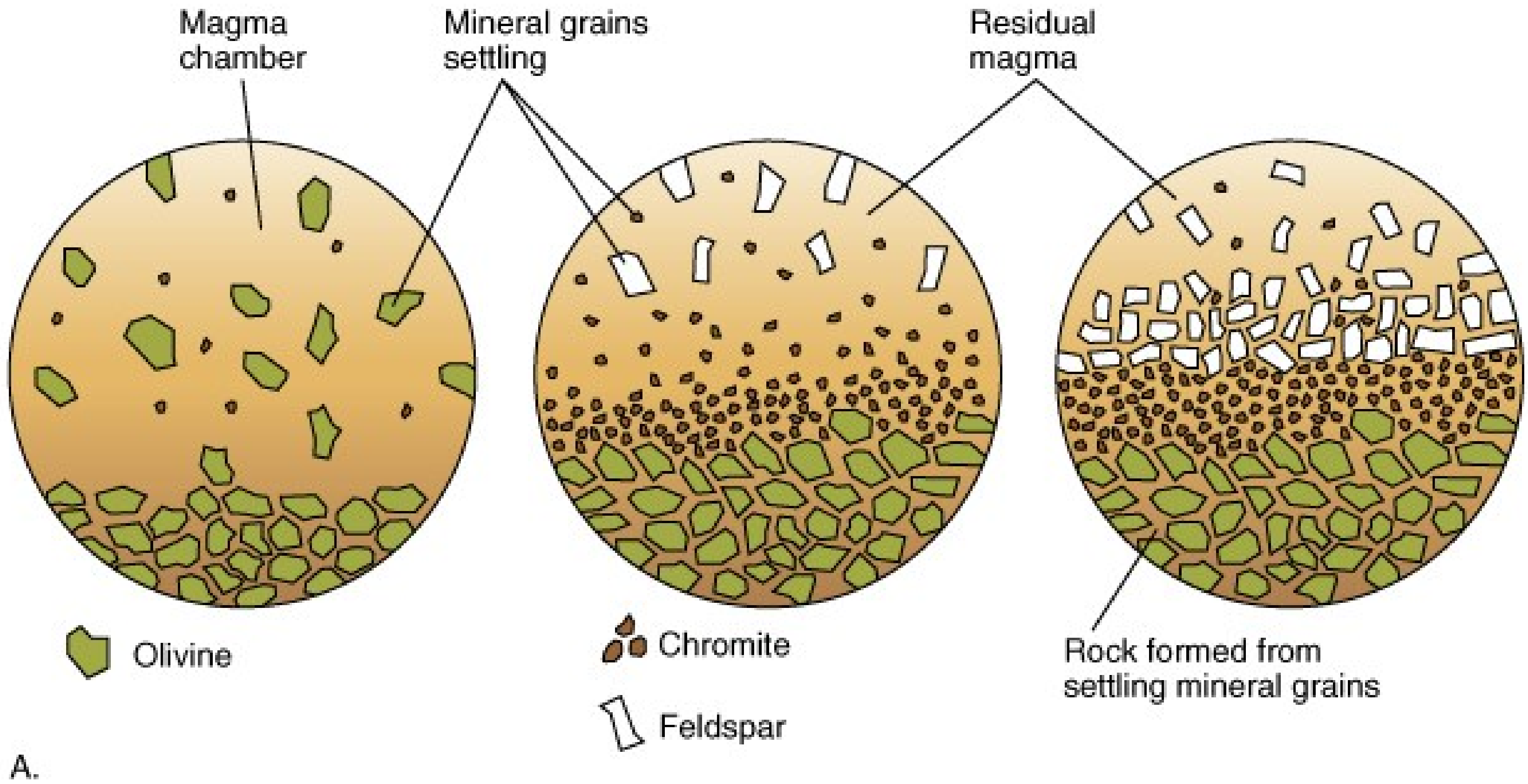
(Borg, 2000)

Bushveld crystallization (cumulate) layers

Layers of light-grey plagioclase and black chromite during fractional crystallisation in the Bushveld Intrusion

Cristallization and cumulate bformation in a magma chamber of the Bushveld intrusion

The example shows fractional crystallization in the magma forming layers of olivine, chromite and plagioklase controlle by the distinct physical properties (density contrast, diameter, viscosity) described in the Lev of Stokes



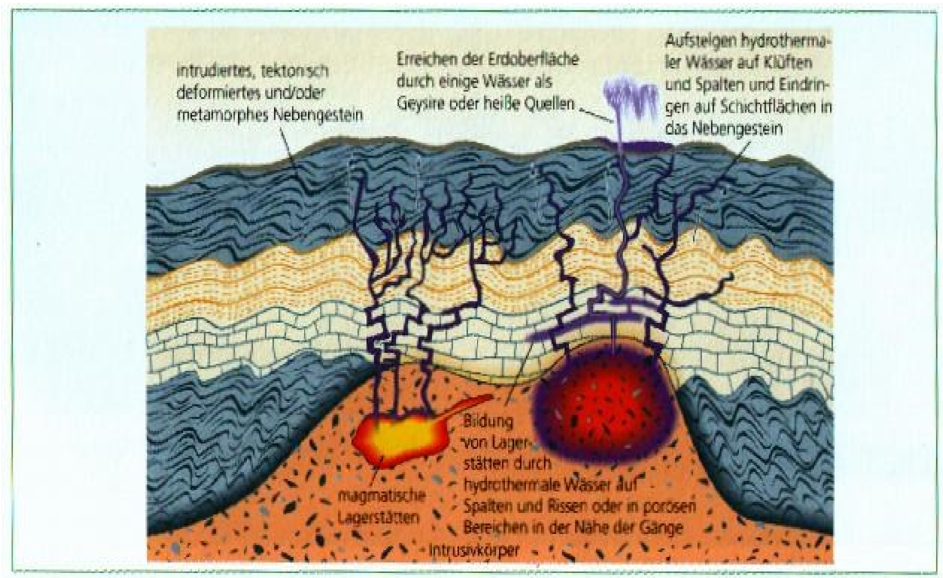
Main and Late crystallisation

The hydrothermal mineralization starts first when 90 Vol.% of a differentiated granitic magma was crystallised and a water-rich rest melt remains ➔Pegmatitic mineralization

- Remaining granitic melt
- Enrichment of incompatible elements
- Common pegmatites contain typical minerals of granites and black tourmaline
- Lepidolite (mica) is a typical indicator for complex pegmatite formation
- Häufig Edelsteine, micas, feldspar, rare earth elements, Lithium

2.2 Hydrothermal ore deposits

After crystallisation of more that 95 vol. % of the magma a very water-rich fluid remain in which many elements are enriched which have not been incorperated in previously crystallized major magmatic mineral phases. This hot liquid penetrates the continental crust, in particular along fracture zones, but also in disseminated form. During further cooling of the hydrothermal fluids gold, silver, copper, tin, lead and other metals starts to crystallize. During this process most metals are incorporated in sulfides.



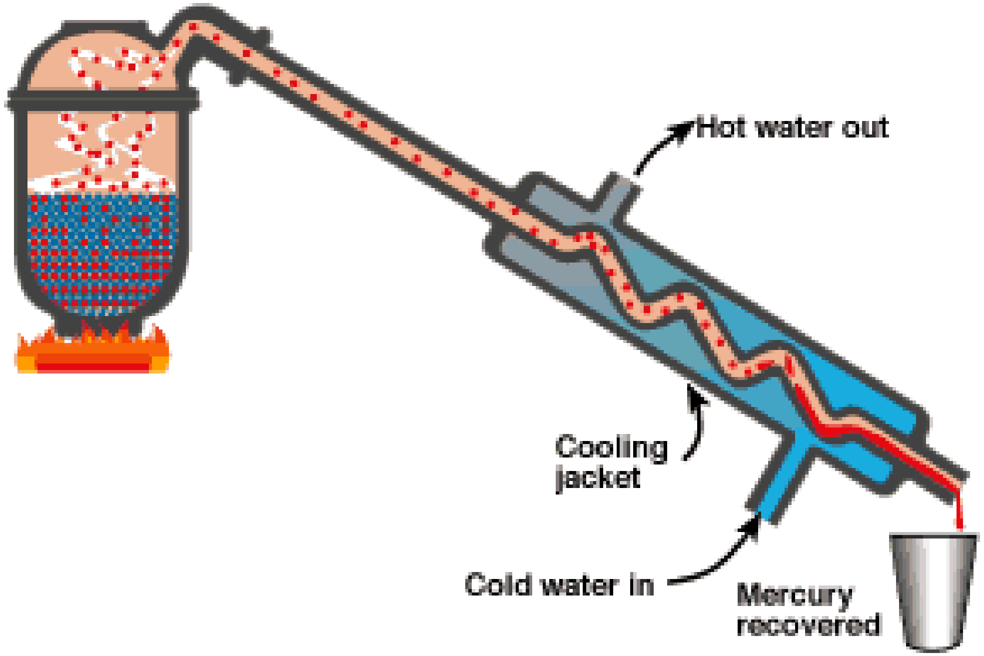
http://www.geophysik.uni-frankfurt.de/~nickbagd/Lagerstaetten-3.ppt

Hydrothermal mineralization

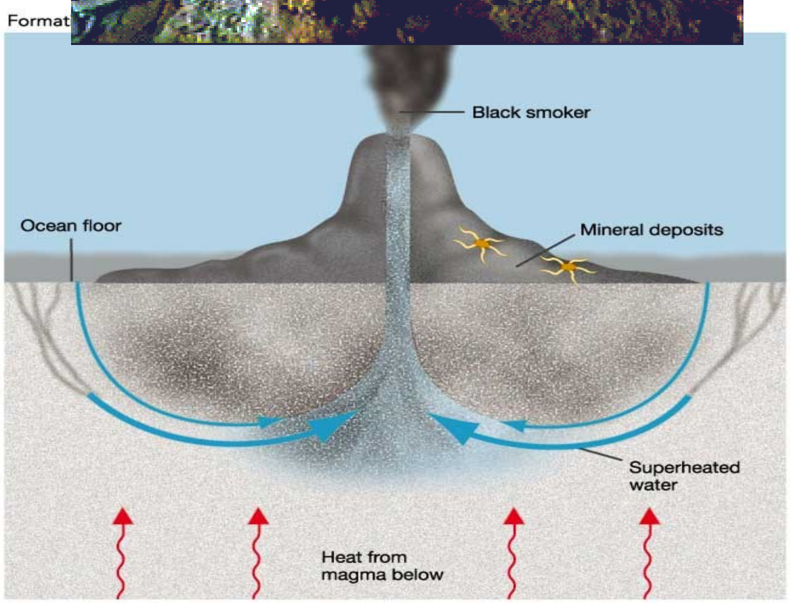
- 600 °C: W, Sn in granites
- 400 °C: Au, U, Ag, Co, Mo, Cu
  - Gold-quartz enrichment in metavolcanic rocks
  - “Porphyry Copper”
  - Mineralization at margins of intrusiva
- 200 °C: Cu, Zn, Cd, Pb
  - Outermost contact zones of intrusiva
  - Mineralization along the Mississippi
- Cold: Hg, As
  - Warme Quellen, Störungszonen

Mecury has an affinity to gold

- Gold and mercury bearing rocks are crushed and heated so much that Gold and mercury became evaporated. Than the vapor is cooled down until first gold and than mercury became condensed.



Recent hydrothermal ore fomation in the deeper ocean around Black Smokers



- Hydrothermal fluids appear frequently around Mid-Ocean Ridges and have temperatures of 350-400° C. These acid hot water penetrate the oceanic crustthrough fracture zones where they disolve many metals. They become precipitated as sulfides and hydroxides when the hydrothermal water reach the alkaline sea water forming black and White Smokers.

  Black smoker are characterized by emission of tinny black particles which are in particular pyrrhotin, pyrite and sphalerite.

  White smoker are characterized by emission of tiny particles of baryt and amorphous silicon dioxide.

http://www.geophysik.uni-frankfurt.de/~nickbagd/Lagerstaetten-3.ppt

Sedimentary ores

The most important ore deposits are:

➔Ooidic often phanerozoic iron deposits (e.g.Minette Iron Ores).

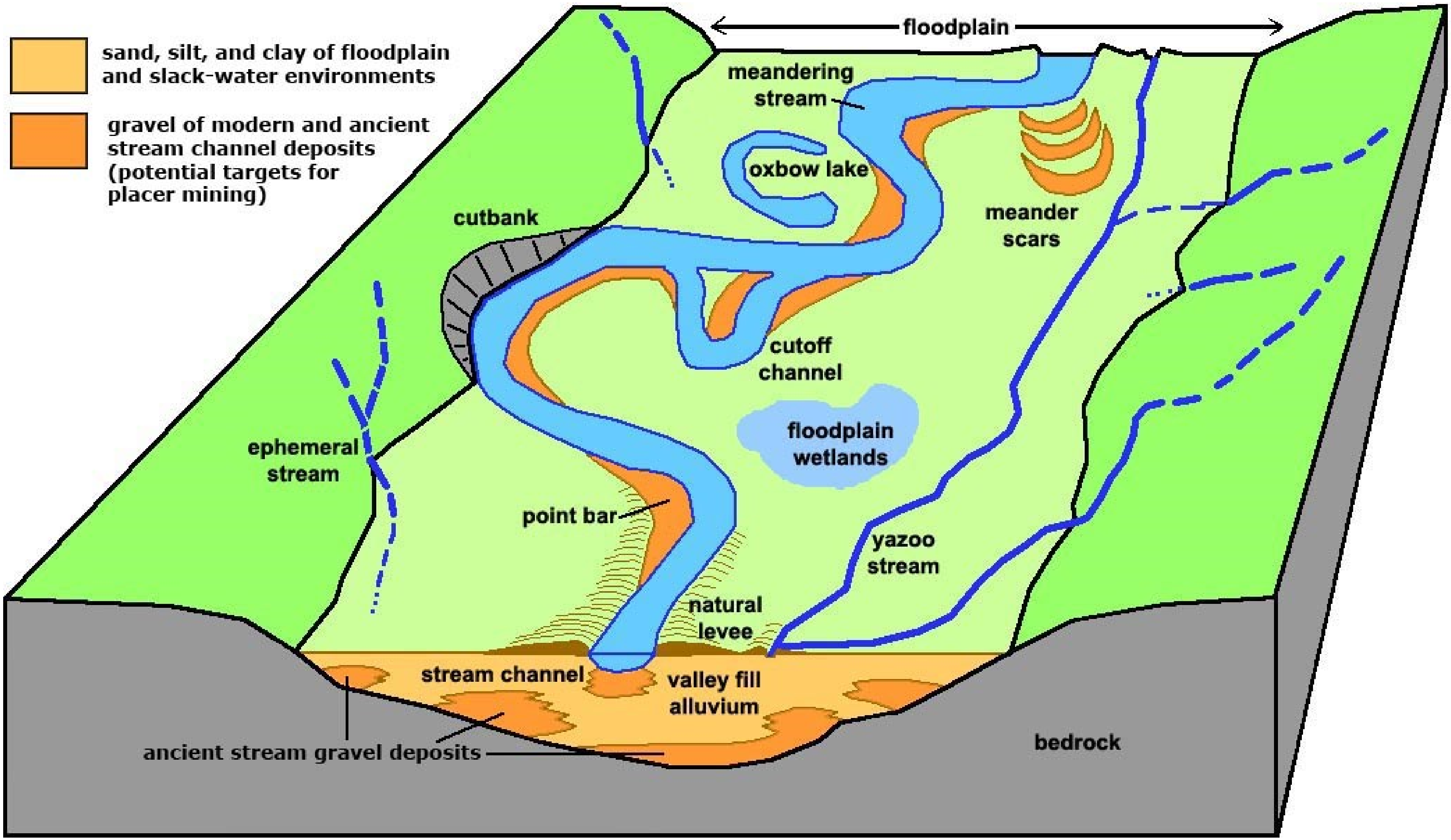
➔Oceanic and continental evaporites (Salts with e.g. lithium)

➔ Biogenic carbonates as building material and for cement industry

➔Carbon-bearing organic deposits (e.g. coal, oil)

Placer deposite

Weathering-resistent heavy minerals are enriched in Placer Deposits: e.g. Gold, Diamand, Korundium (Sapphire, Ruby)



Heavy mineral s a n d s

which Minerals ?	*Resource*
• Ilmenite $FeTiO_3$	Titanium, Titaniumdioxide
• Rutil TiO_2	Titanium, Titaniumdioxide
• Magnetite Fe $(FeO_2)_2$	Iron
• Zircon $ZrSiO_4$	Zircon
• Monazite (Ce, La, Y, Th) PO_4	Rare Erth Elements
• Diamand C	

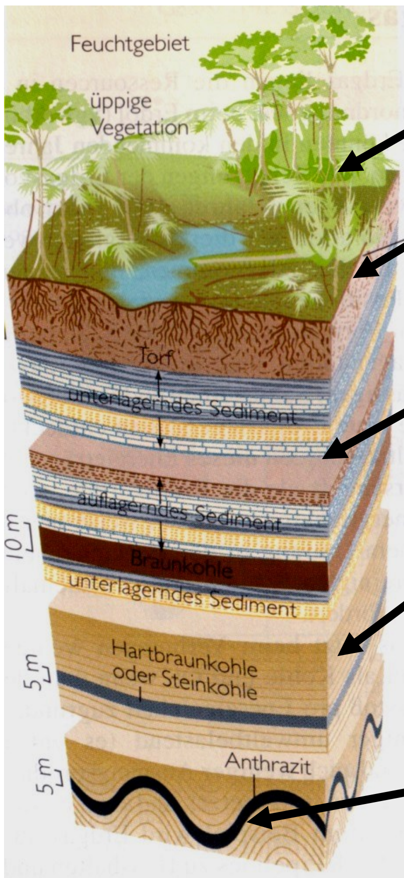
• Gold	
• Platin metals	
• Cassiterite (SnO_2)	tin

2.3.1 Carbon-bearing biogenic sediments

Formation of Coal

Requierment: Anoxic conditions, Sinking, Temperature increase → Enrichment of pure carbon

Carbonatization



Verändert nach Press und Siever, 1995

Source material: Remnants from plants

Peat

Transformation of peat to brown coal

Transformation of brown to black coal

Anthracite (Metamorphosis)

Weathering-related ore deposits

- Bauxite: an oxidative Aluminium-rich weathering product very humid-warm regions
- Nickel-laterites in tropical areas
  - Ni replaces Mg
  - Strongly enriched in ultramafic rocks
  - Enrichment within he groundwater level
- Near-surface enrichments
  - Cu leaching from rocks and near-surface Enrichment next to the ground water level