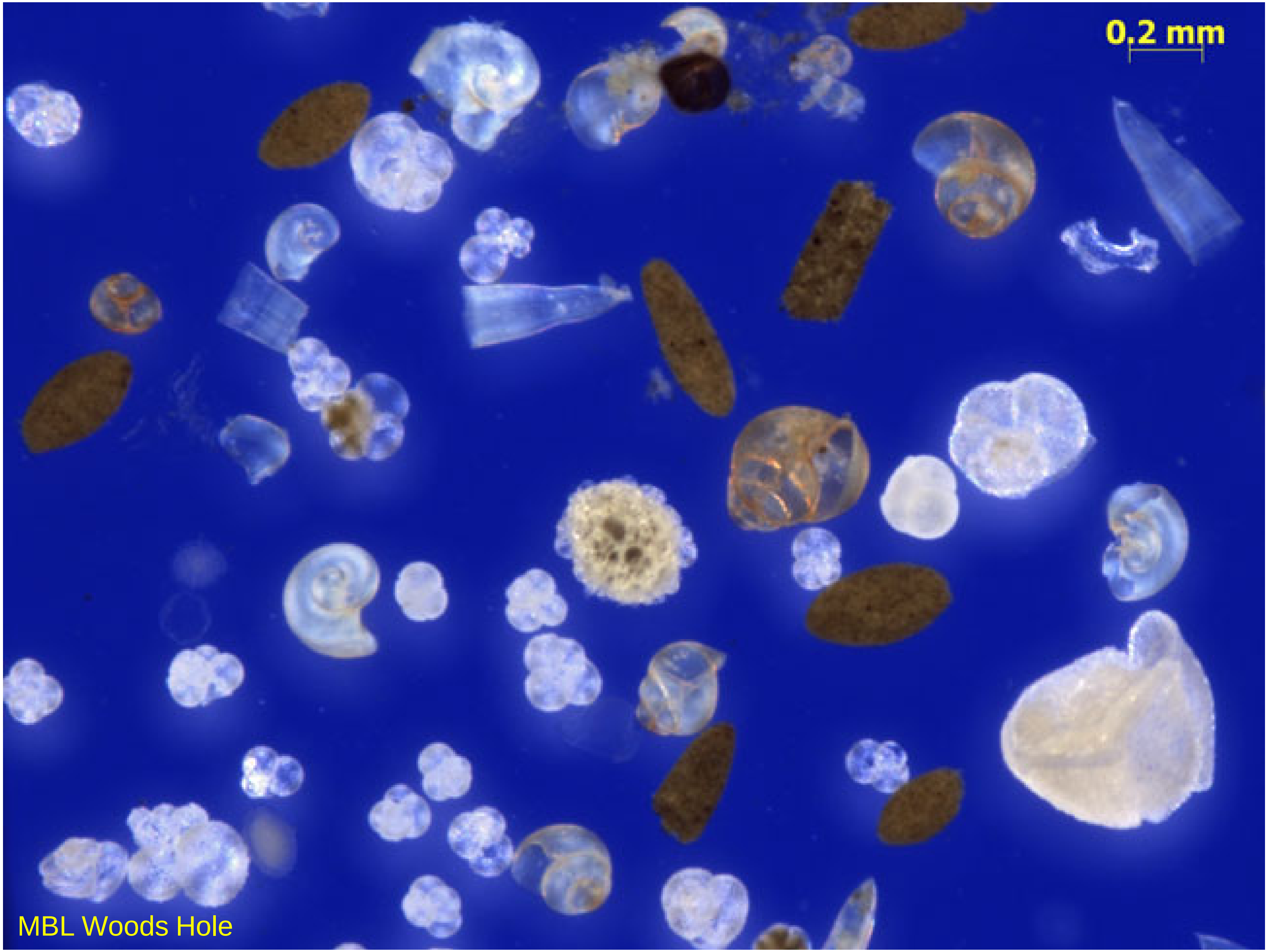
Particulate matter



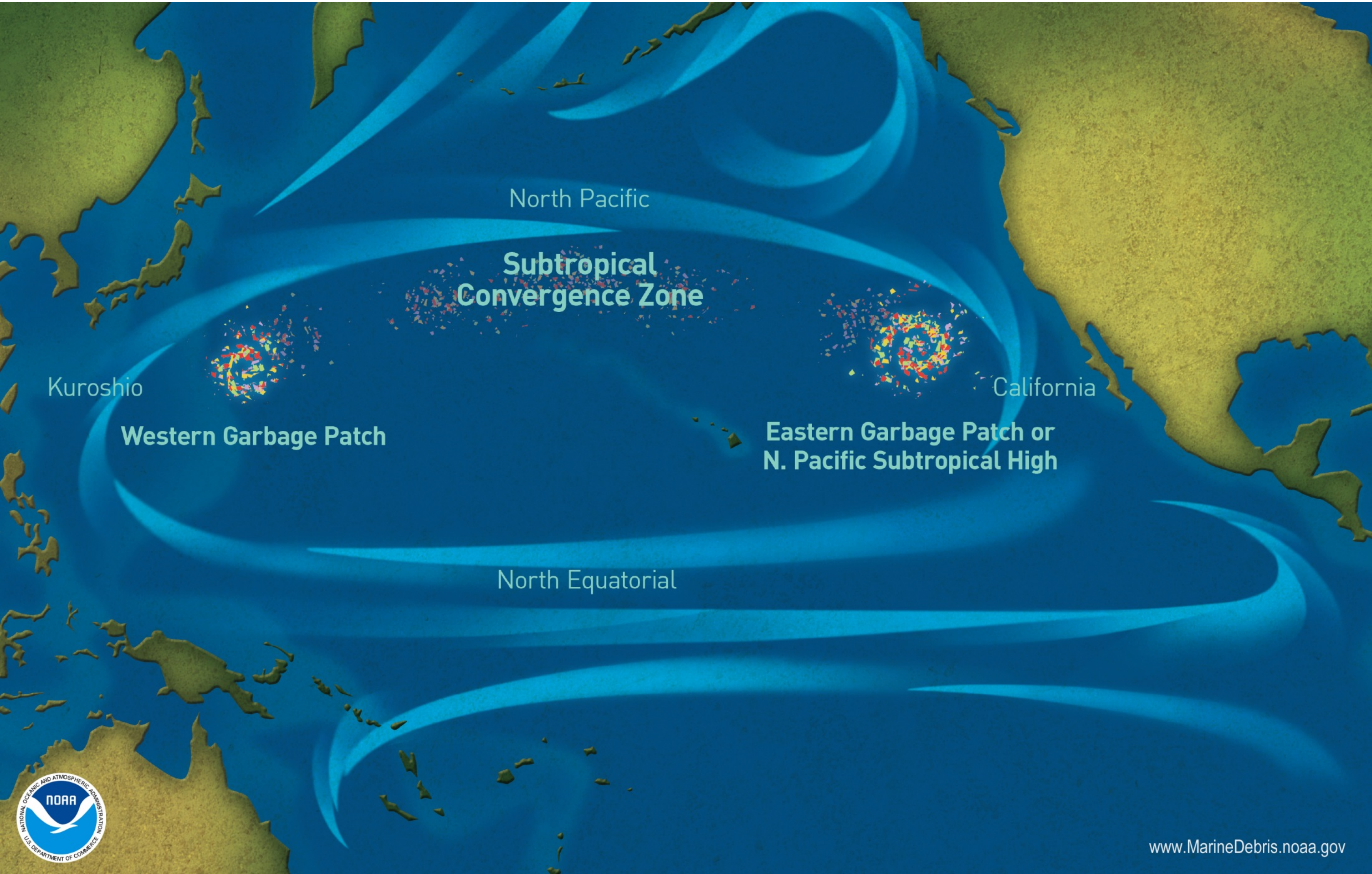
Total suspended material (TSM)

Source: USGS

FUNDAMENTALS OF ENVIRONMENTAL MEASUREMENTS

Anthropogenic TSM

North Pacific garbage patch




HOW LONG UNTIL IT'S GONE?
Estimated decomposition rates of common marine debris items
Waxed Carton
3 months
Cardboard Box
2 months
Apple Core
2 months
Foamed Buoy
50 years
Plastic Grocery Bag
10 – 20 years
Plywood
1 – 3 years
Disposable Diaper
450 years
Cigarette Butt
1 – 5 years
Newspaper
6 weeks
Paper Towel
2 – 4 weeks
Wool Socks
1 – 5 years
Plastic Bottle
450 years
Photo-degradable Beverage Holder
6 months
Aluminium Can
200 years
Fishing Line
600 years
Glass Bottle
undetermined
Styrofoam Cup
50 years
Tin Can
50 years
Plastic Beverage Holder
400 years
Cotton Shirt
2 – 5 months
Estimated individual item timelines depend on product composition and environmental conditions.
Source: NOAA (National Oceanic and Atmospheric Administration), US / Woods Hole Sea Grant, US
Graphics: Oliver Lüde / Museum für Gestaltung Zürich, ZHdK

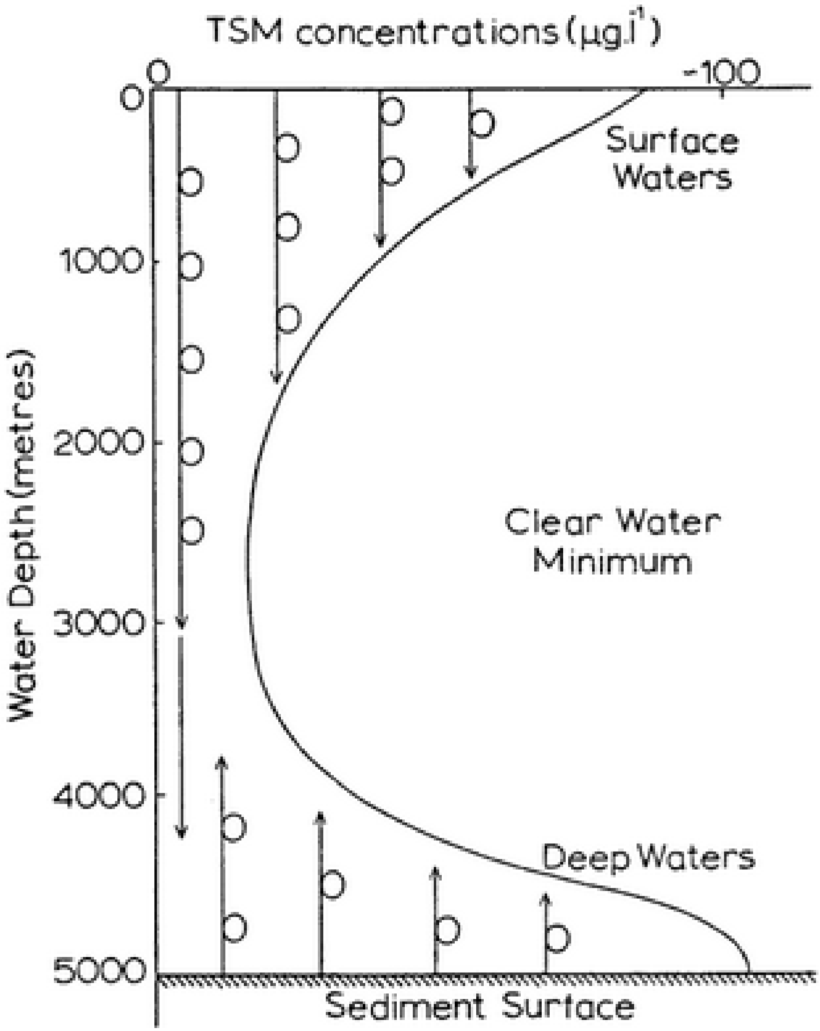
Three-layer distribution model of TSM

Devendra Lass *particle microcom*

or

Turekians *great particle conspiracy*

nepheloid layer or nepheloid zone

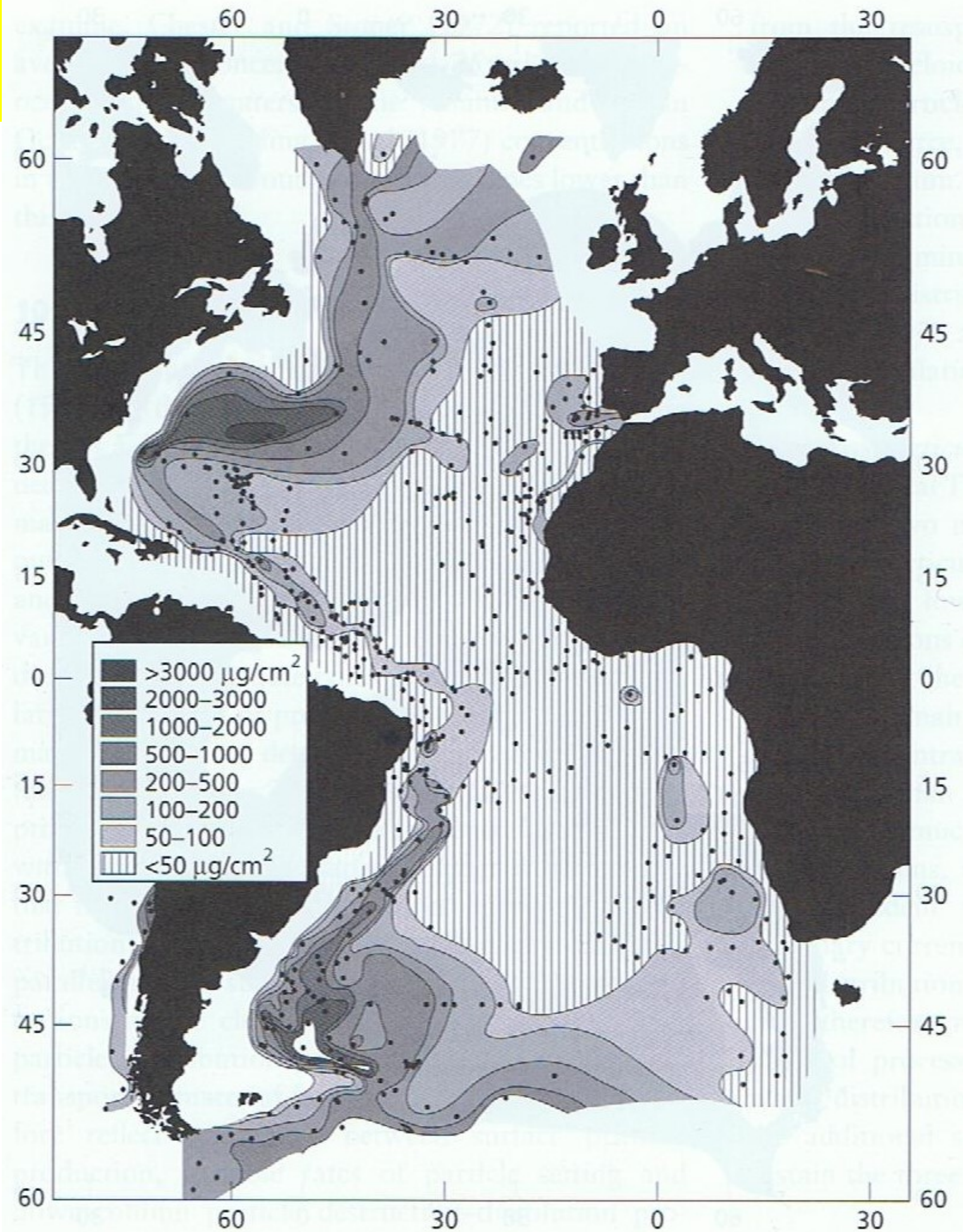


Chester: Marine Geochemistry

Distribution of TSM

TSM in the Atlantic Ocean in deep water (abyssal signal)

boundary currents on the western side of the ocean increase the TSM → *nepheloid layer*



Chester: Marine Geochemistry

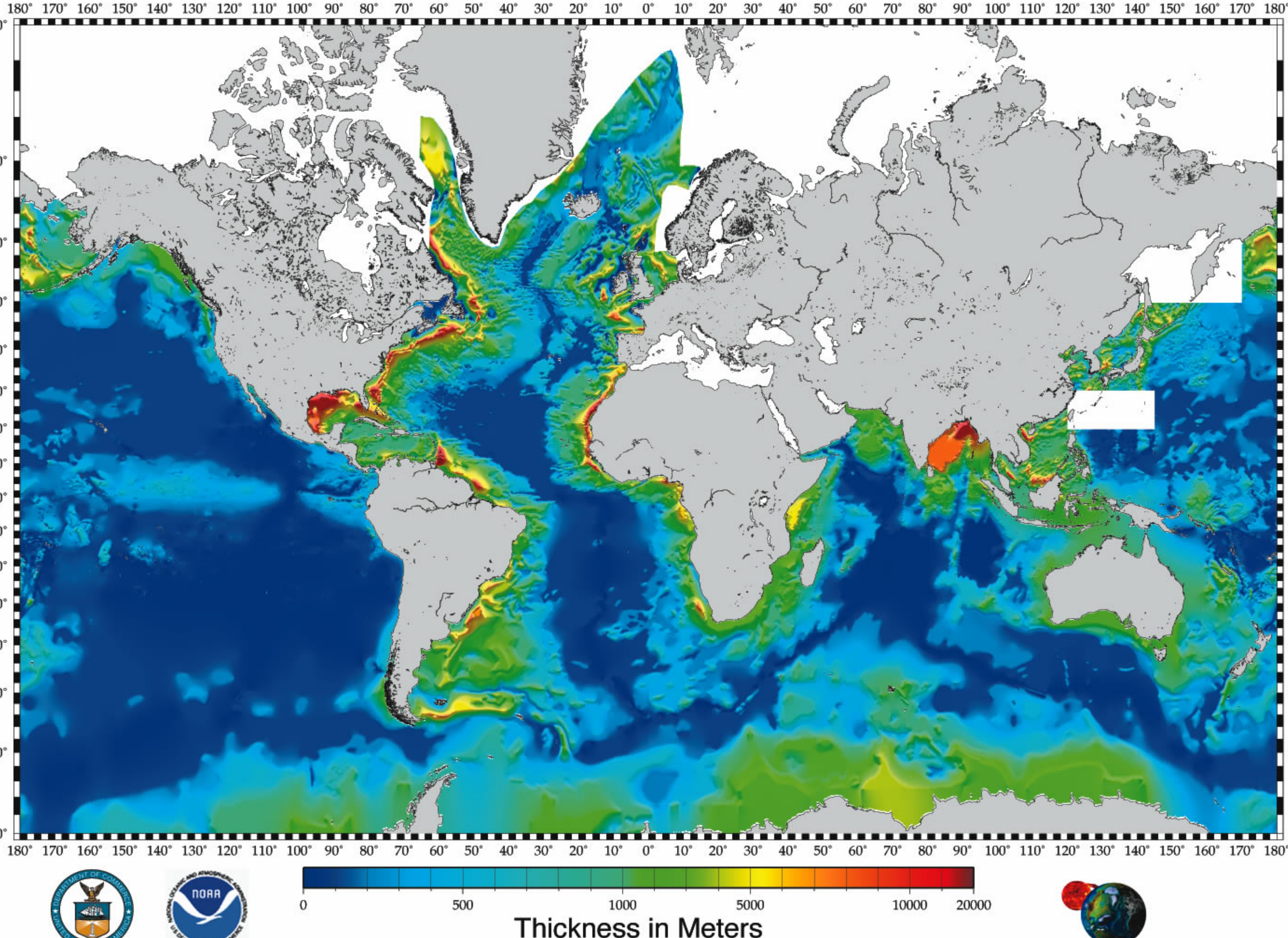
Down column changes in composition of TSM

Trap depth (m)	Mass flux ($mg\ m^{-2}\ day^{-1}$)	Flux composition (%)			
		$CaCO_3$	Opal	Organic matter	Lithogenic matter
890	139	8.7	41.0	34.3	16.0
1100	116	8.2	41.0	33.2	17.6
1870	50.4	9.6	36.8	23.8	29.8
2720	49.4	8.3	37.4	9.4	44.8
3420	60.0	9.8	27.2	6.0	57.0

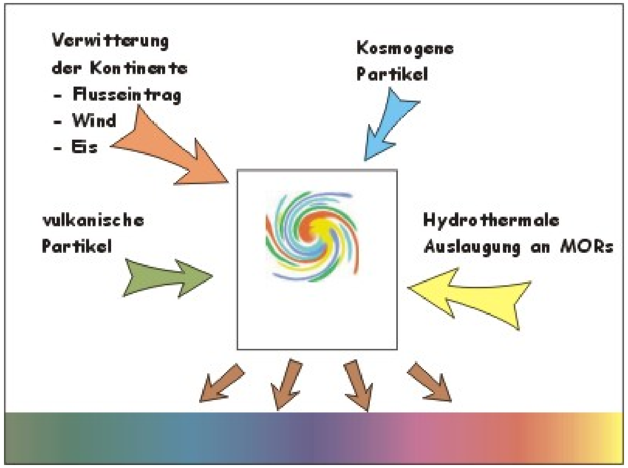
Chester: Marine Geochemistry

Marine sediments

Total Sediment Thickness of the World's Oceans & Marginal Seas



Marine sediments



source: http://www.meeresgeo-online.de/

Marine sediments:

provide records of

marine and terrestrial events,

volcanic activity,

past climate changes,

changes in ocean chemistry

Sediment formation depends on:

rock weathering, erosion and input flux from continents

transport way: estuaries, submarine canyons, glaciers, wind systems

with of schelf, continental marin (active, passive)

ocean productivity (nutrients, temperature)

volcanic activity

chemical stability of components

sediment-redistribution (turbidity currents, bottom currents, contourites)

Marine sediments

Terrigenous sediments

Accumulate slowly (5000 to 50,000 years to deposit 1 cm)

Biogenous sediments (primarily shells and skeletons of microscopic plankton)

Calcareous oozes

Remains of foraminifera  and coccolithophores 

May form chalk

Siliceous oozes  

Remains of radiolarians and diatoms

May form diatomite or chert

Phosphatic material

From bones, teeth and scales of fish

Hydrogenous sediments (authigenic or diagenetic minerals)

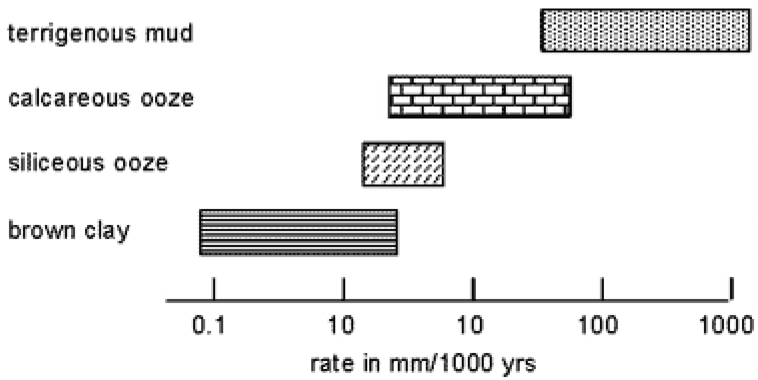
Minerals that precipitate from sea water by chemical reactions. Example: *manganese nodules* 

Marine sediments

Average thickness: ~500 m

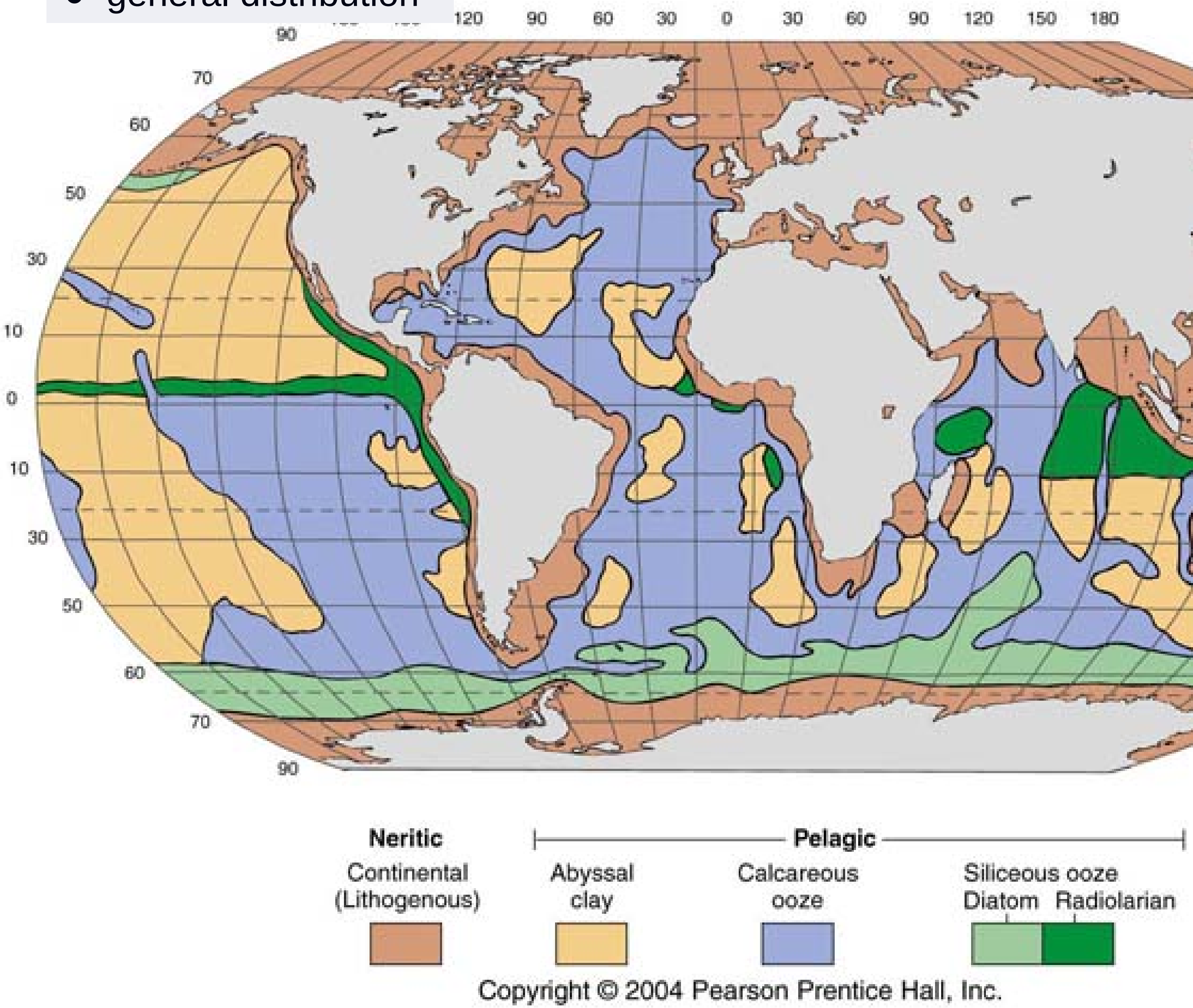
Average age of ocean basin: ~100 Ma

Average accumulation rate = ?



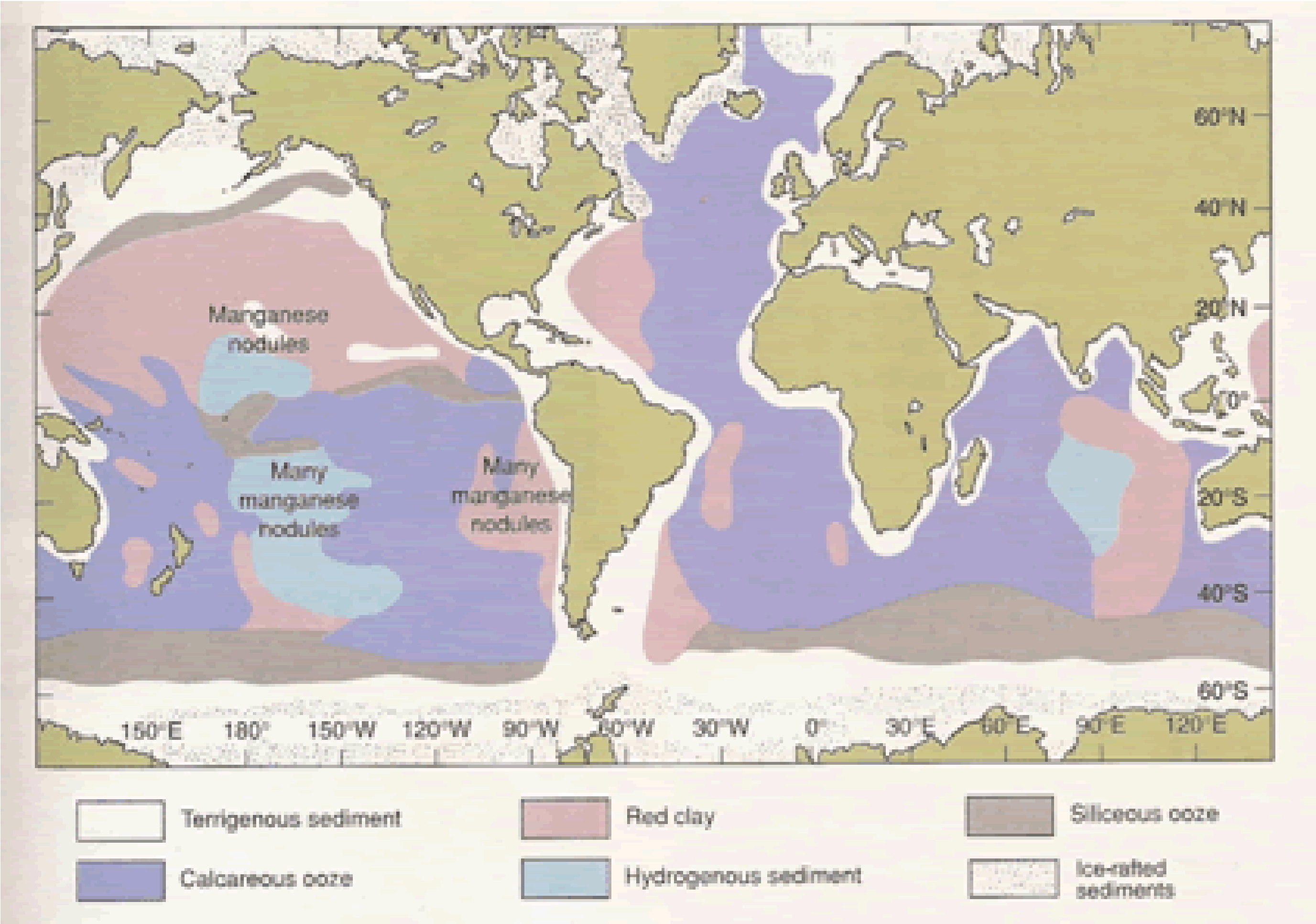
Marine sediments

- general distribution



Marine sediments

- distribution and component based classification



Marine sediments

inorganic components in marine sediments

Precipitates

- oxyhydroxides
- carbonates
- phosphates
- sulfides, sulfates
- evaporite minerals

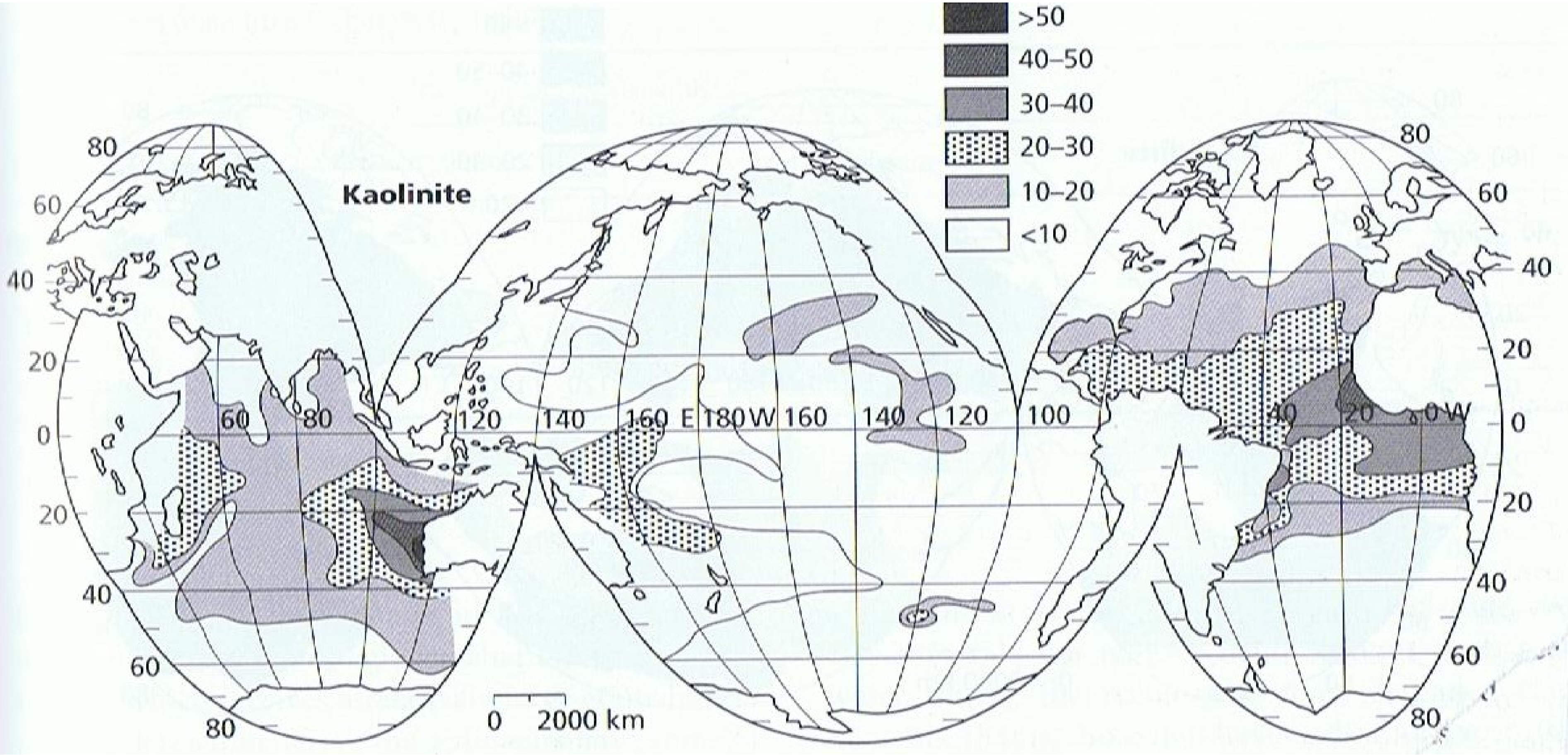
Halmyrolysates

- glauconite
- montmorillonite/smectite
- chamosite
- zeolithes

hydrogenous – hydrothermal – diagenetic

Marine sediments

- clay minerals

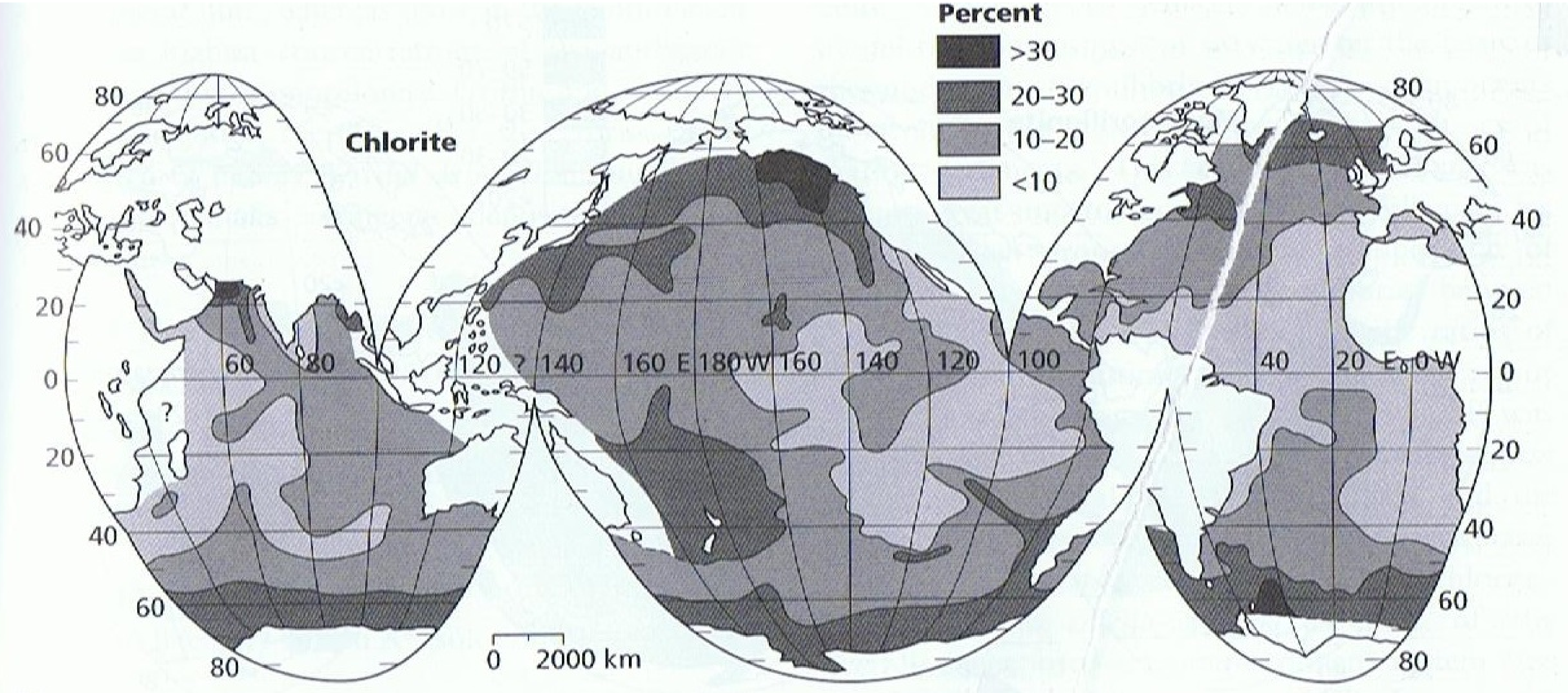


Kaolinite: from tropical and desert weathering

- low-latitude clay mineral

Marine sediments

- clay minerals

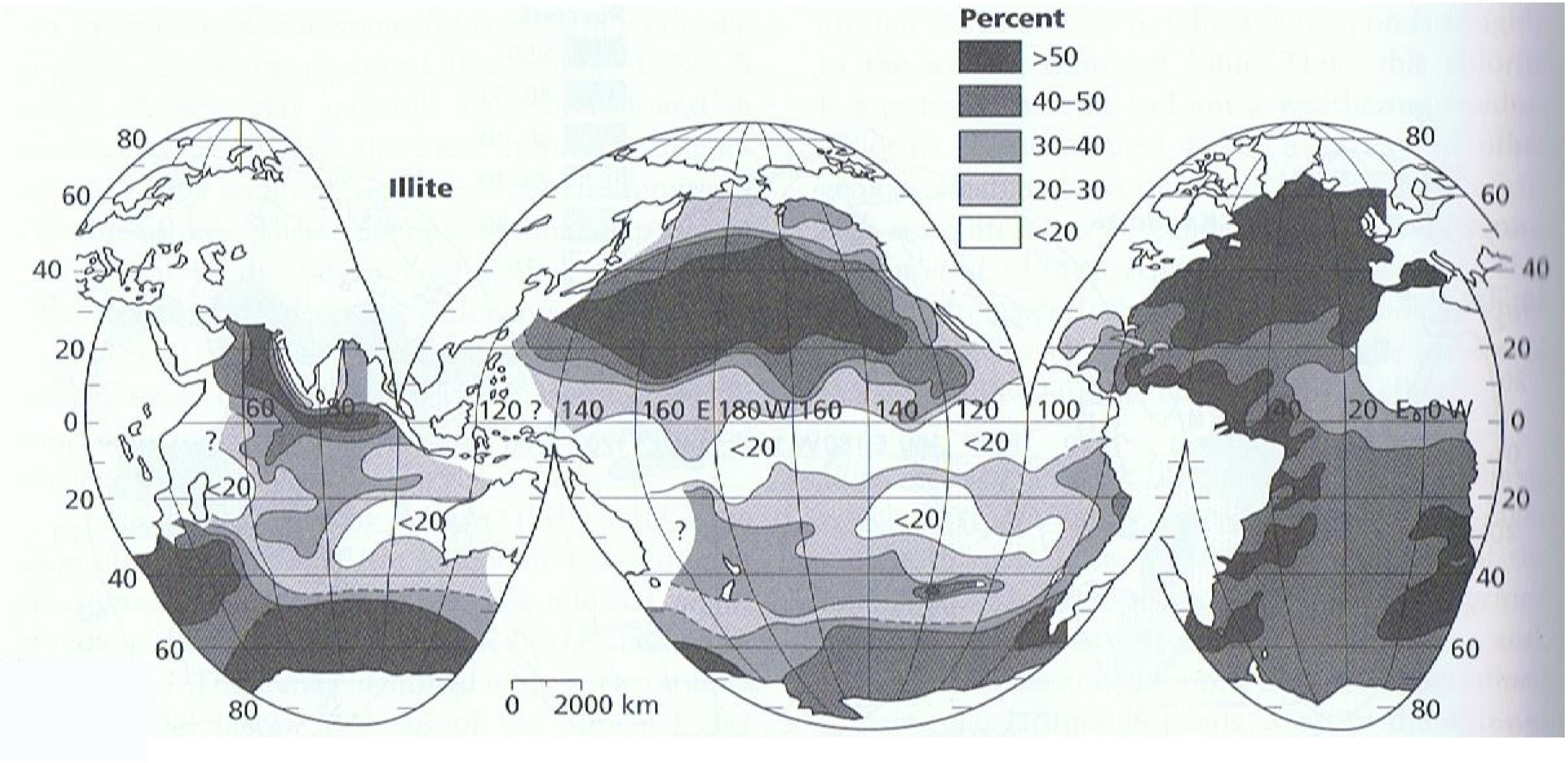


Chlotite: released from metamorphic and sedimentary rocks of the polar regions by mechanical processes (ice rafting)

- high-latitude clay mineral

Marine sediments

- clay minerals

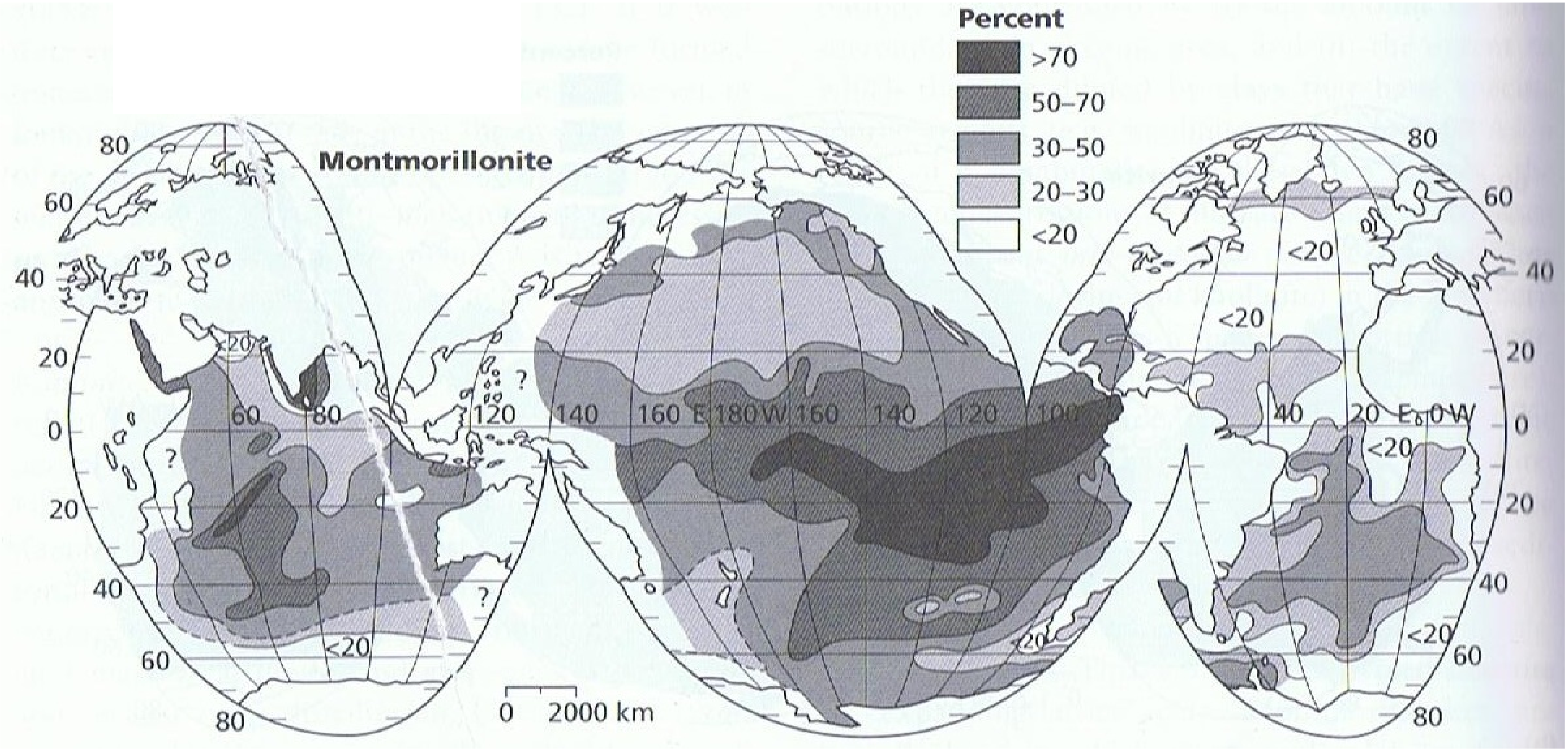


Illite: land-derived (i.e. amount of land surrounding the ocean)

- in areas where htere is less dilution from chlorite and kaolinite

Marine sediments

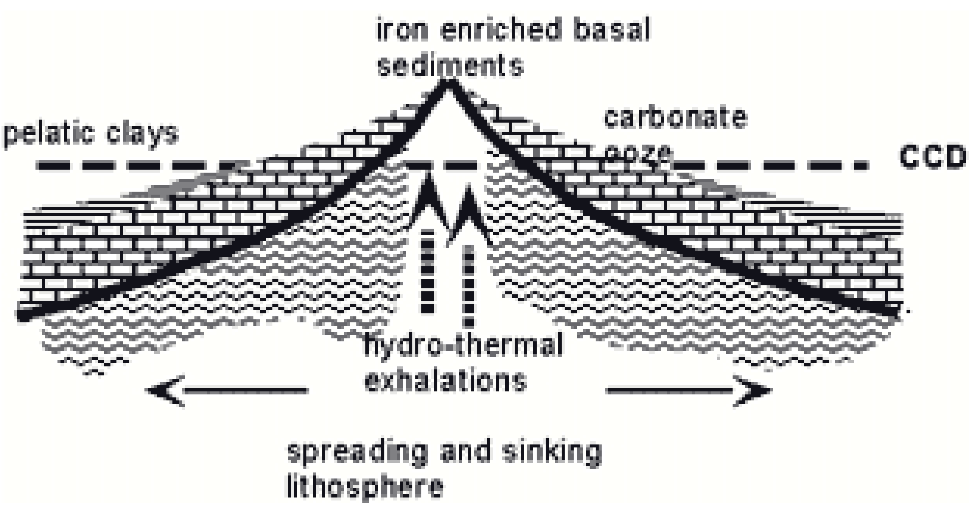
- clay minerals



Montmorillonite/smectite: in situ product of submarine weathering of volcanic material
- in areas with low sedimentation rate and prevalence of volcanic debris

Marine sediments

- progessive changes with time



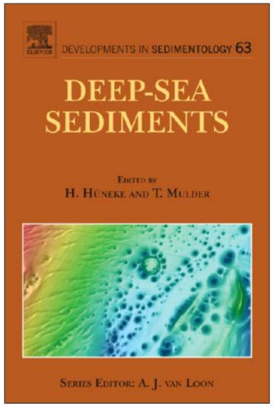
From bottom to top:

- basaltic crust
- hydrothermal deposit metal rich precipitates (umbers)
- carbonates (above CCD)
- clays

amount of biogenic material depends if plate moves through high- or low productivity zones

Marine sediments

- organic carbon and sedimentstion rates



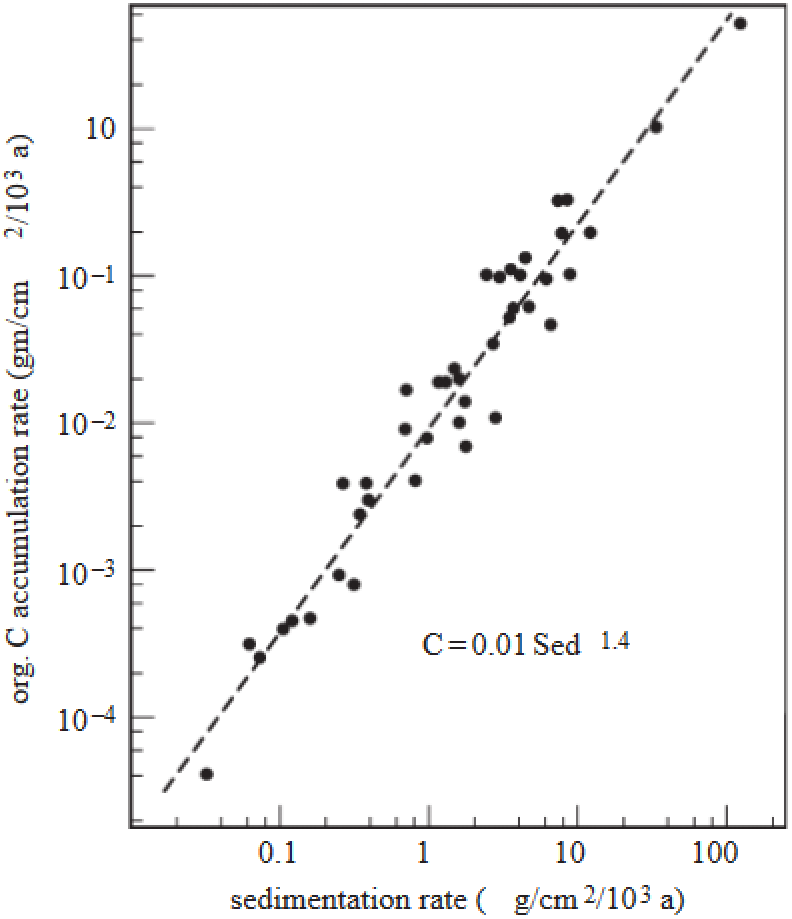
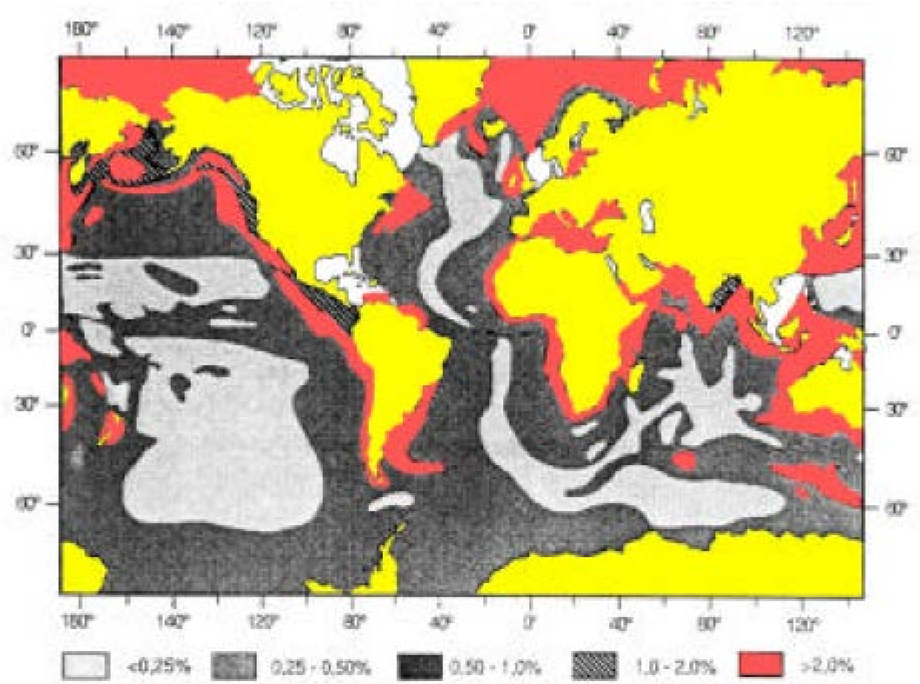


Figure 9.28 Correlation of the organic-carbon mass-accumulation rate and the sedimentation rate for open-marine pelagic and hemipelagic environments (redrawn and modified from Heath et al., 1977).

- hemi-pelagic sediments
  c. 1-5 % C_{org}
  reducing conditions
  grey-green clay
- pelagic sediments
  c. 0.1-0.2 % C_{org}
  ferric iron – red clays

Marine sediments

- organic carbon and sedimentstion rates



- hemi-pelagic sediments
  c. 1-5 % C_{org}
  reducing conditions
  grey-green clay
- pelagic sediments
  c. 0.1-0.2 % C_{org}
  ferric iron – red clays

Distribution of organic carbon in marine sediments

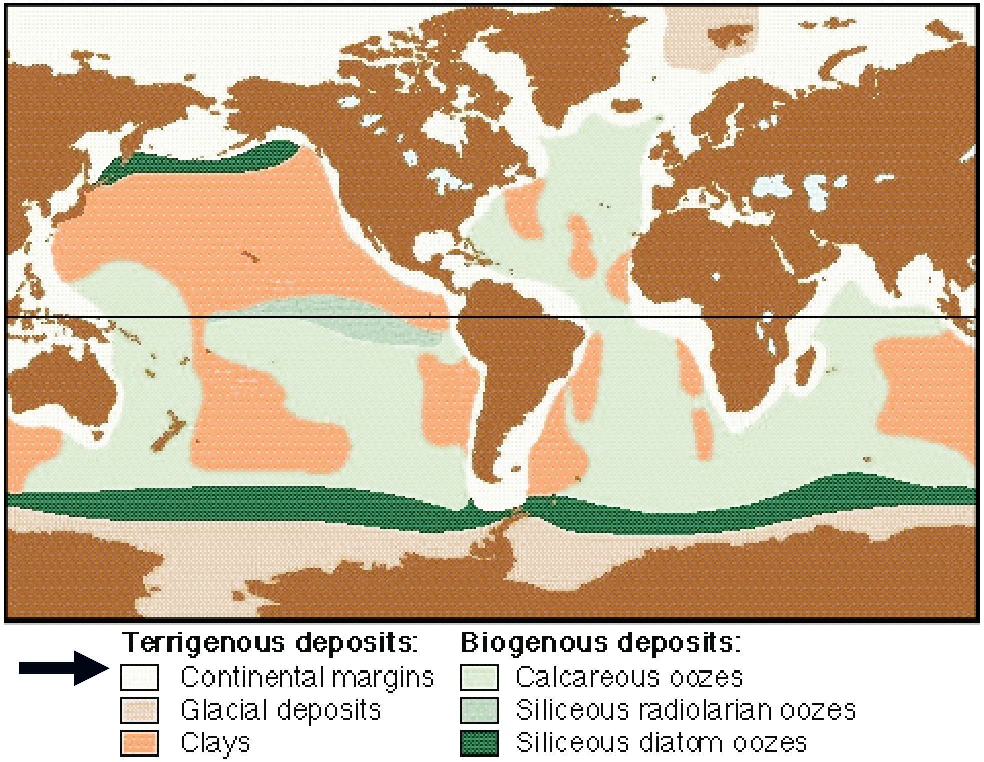
Marine sediments - composition

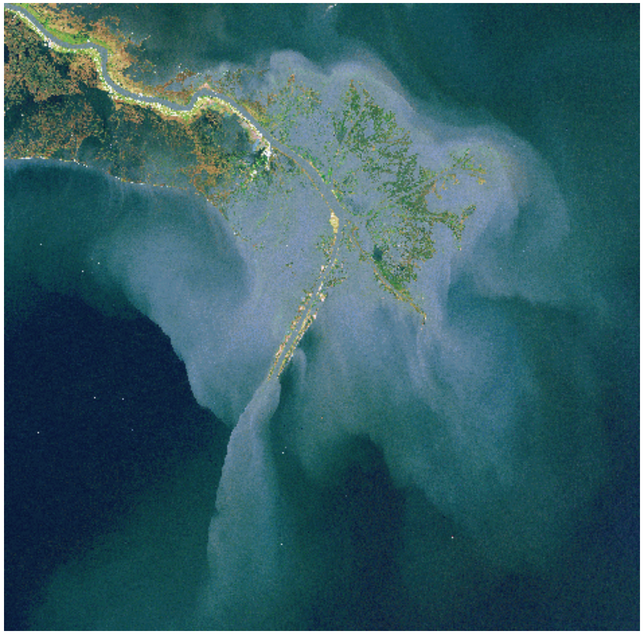
Table 13.4 The concentrations of some trace elements in deep-sea deposits* (units, $\mu g\,g^{-1}$).

Trace element	Nearshore muds	Deep-sea carbonate	Atlantic deep-sea clay	Pacific deep-sea clay	Active ridge sediment	Ferromanganese nodules
Cr	100	11	86	77	55	10
V	130	20	140	130	450	590
Ga	19	13	21	19	–	17
Cu	48	30	130	570	730	3300
Ni	55	30	79	293	430	5700
Co	13	7	38	116	105	3400
Pb	20	9	45	162	–	1500
Zn	95	35	130	–	380	3500
Mn	850	1000	4000	12500	60000	220000
Fe	69900	9000	82000	65000	180000	140580

*From Chester and Aston (1976).

Marine sediments - distribution



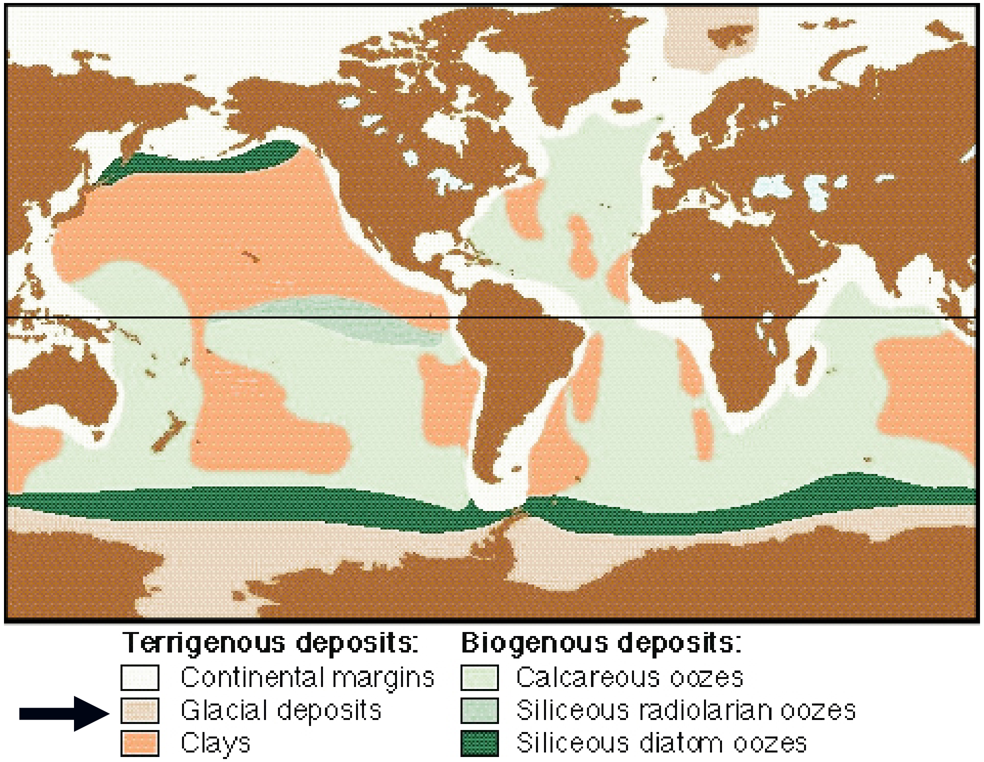


LANDSAT image of the Mississippi River Delta and accompanying sediment plume (from Geospace Images catalog)

Terrigenous sediments

- accumulated at continental margins
- highest input in tropical regions with high relief intensity and high chemical weathering rates
- channelized transport through submarine canyons (turbidity currents)
- Ganges & Brahmaputra: annual sedimentation load exceeds 1500 million tons

Marine sediments - distribution

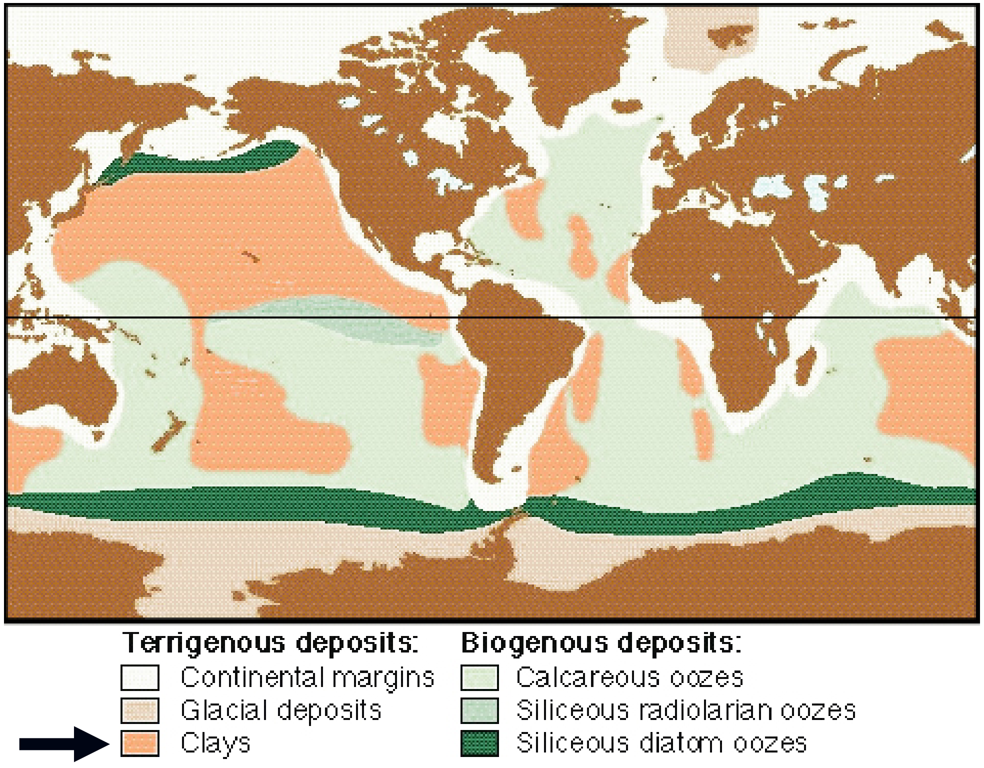


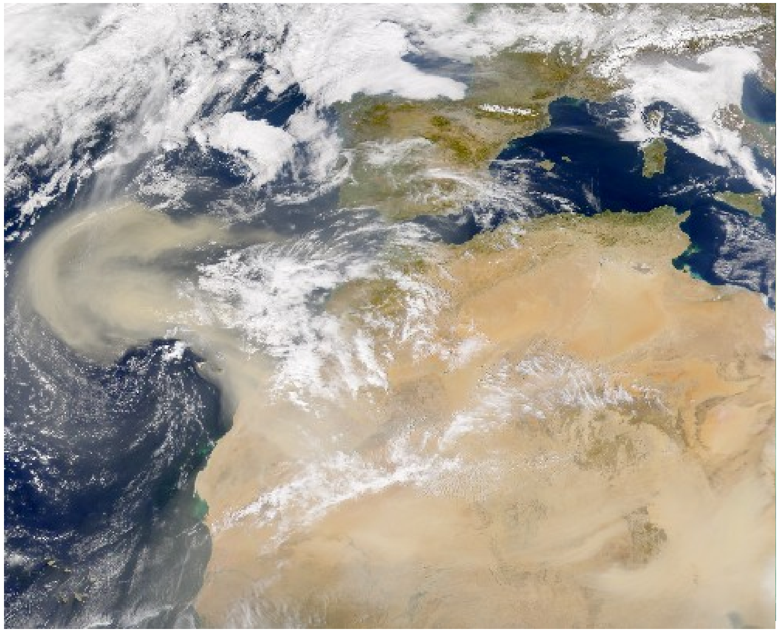
tillite, dropstone

glacier/icebergs

- glacial ice-rafted debris, iceberg discharge (ice-rafting)
- poorly-sorted material
- deposited at continental margins and deep sea!

Marine sediments - distribution





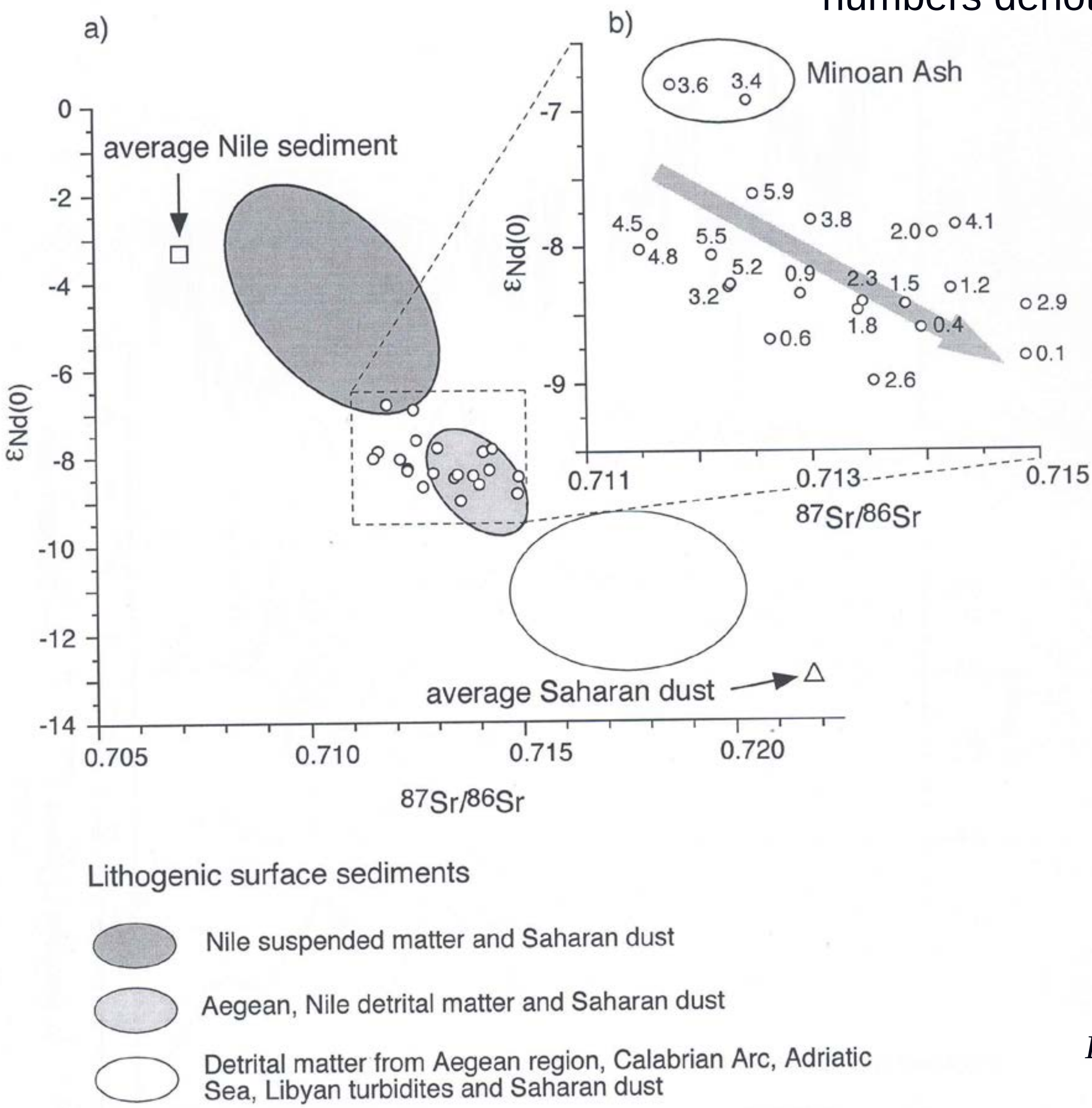
26/2/2000

Wind transport – aolian sediment (sand & dust)

- input from desserts (Saharan dust)
- usually very fine grained (< 20 μm)
- Example: red (or brown) abyssal clay in Pacific ocean
  very low sedimentation rates: ~1 mm/1000 a!

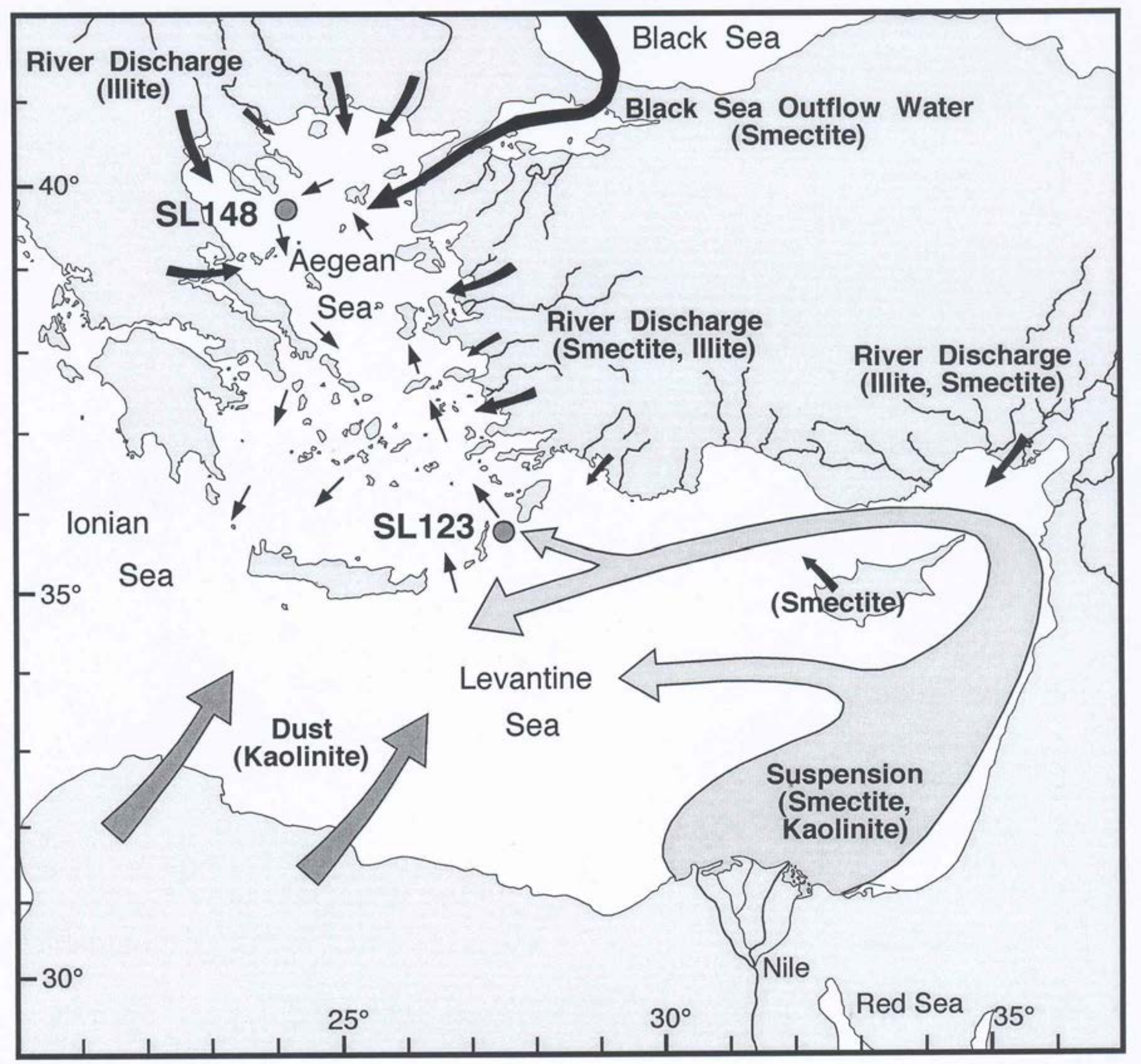
Marine sediments - distribution

numbers denote interpolated ages in ka



Ehrmann et al. (2007) P-cube

Marine sediments - distribution



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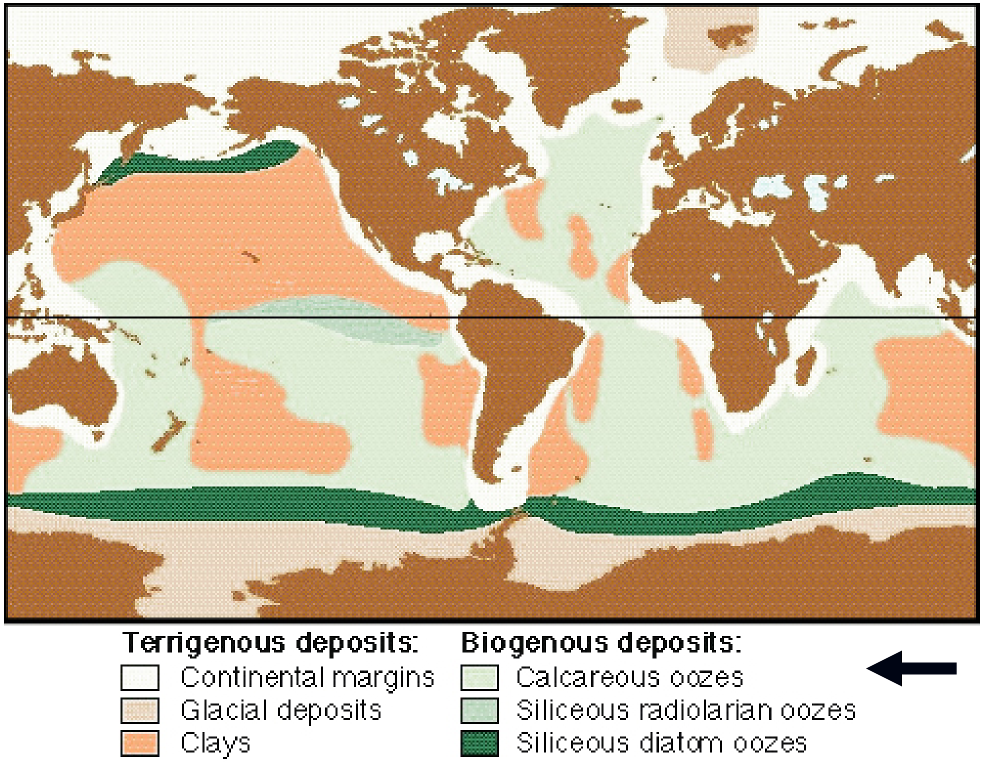
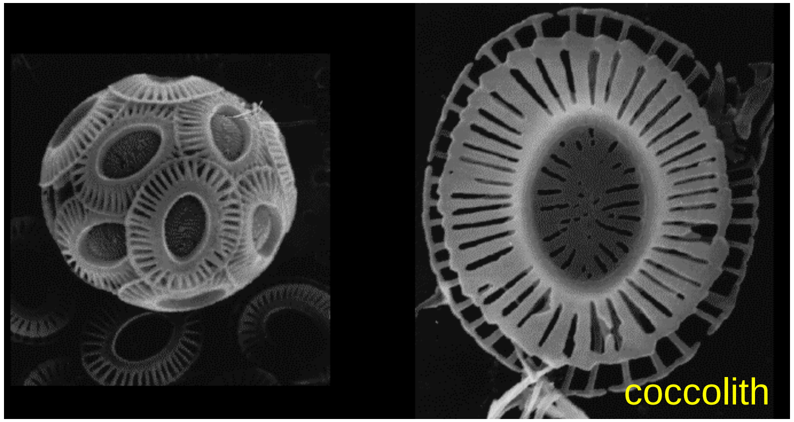
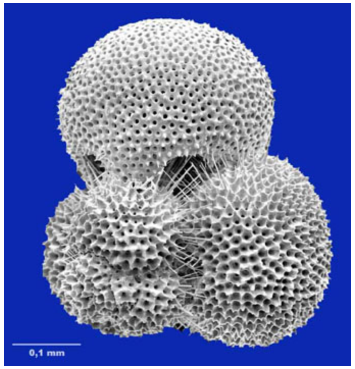
Marine sediments - distribution





Scanning electron microscope (SEM) image of the **coccolithophore** *Emiliani huxleyi*

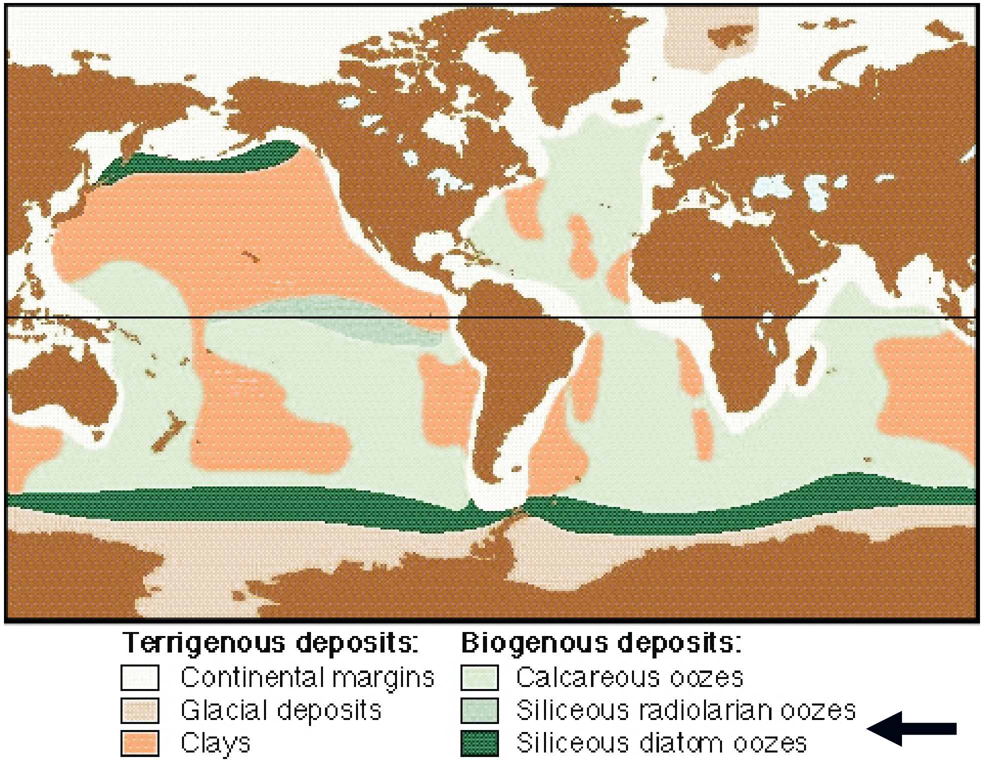


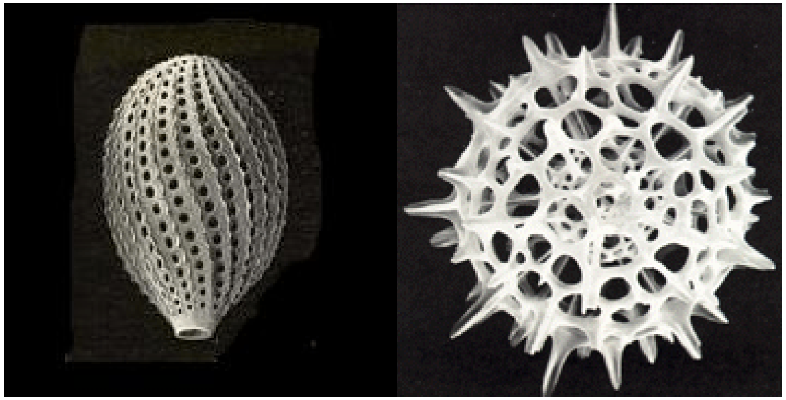
Globigerinoides, planktonische Foraminifere

Biogene sediments: calcareous ooze

- cover ~50% of the ocean floor
- widespread along mid-ocean ridges
- foraminiferas (protozoa, approximately 4.000 living species, 40,000 totally)
- coccolithophores (phytoplankton) – more than 1.5 million tons of calcite a year
- bottom of the Atlantic covered with calcareous ooze
- distribution depends on precipitation and dissolution processes

Marine sediments - distribution

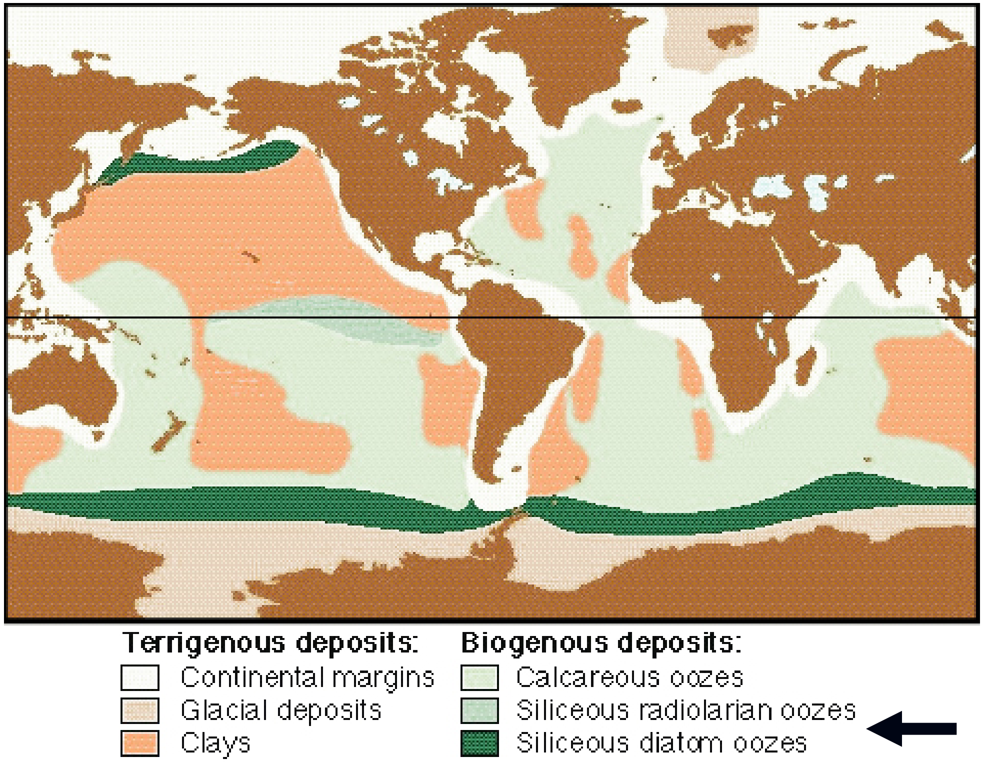


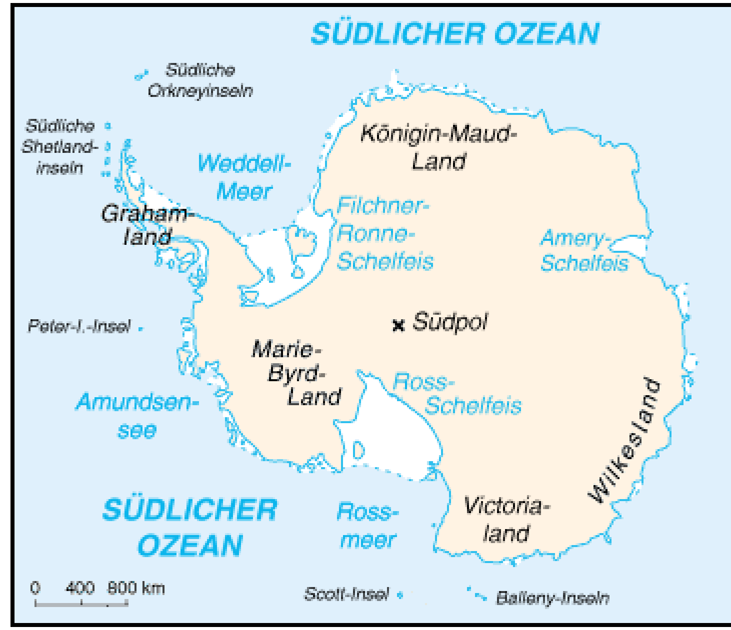


Biogene sediments: silicios ooze, $SiO_2.nH_2O$

- diatoms (algaes), radiolarians (protozoa), silicoflagellates (protozoa like radiolarians)
- Mineral: opal (colloidal silica)
- cover 15% of ocean floor (e.g. Ross sea)
- typical sediments in regions of high biological productivity in polar regions, circum antarctic region and in upwelling zones

Marine sediments - distribution





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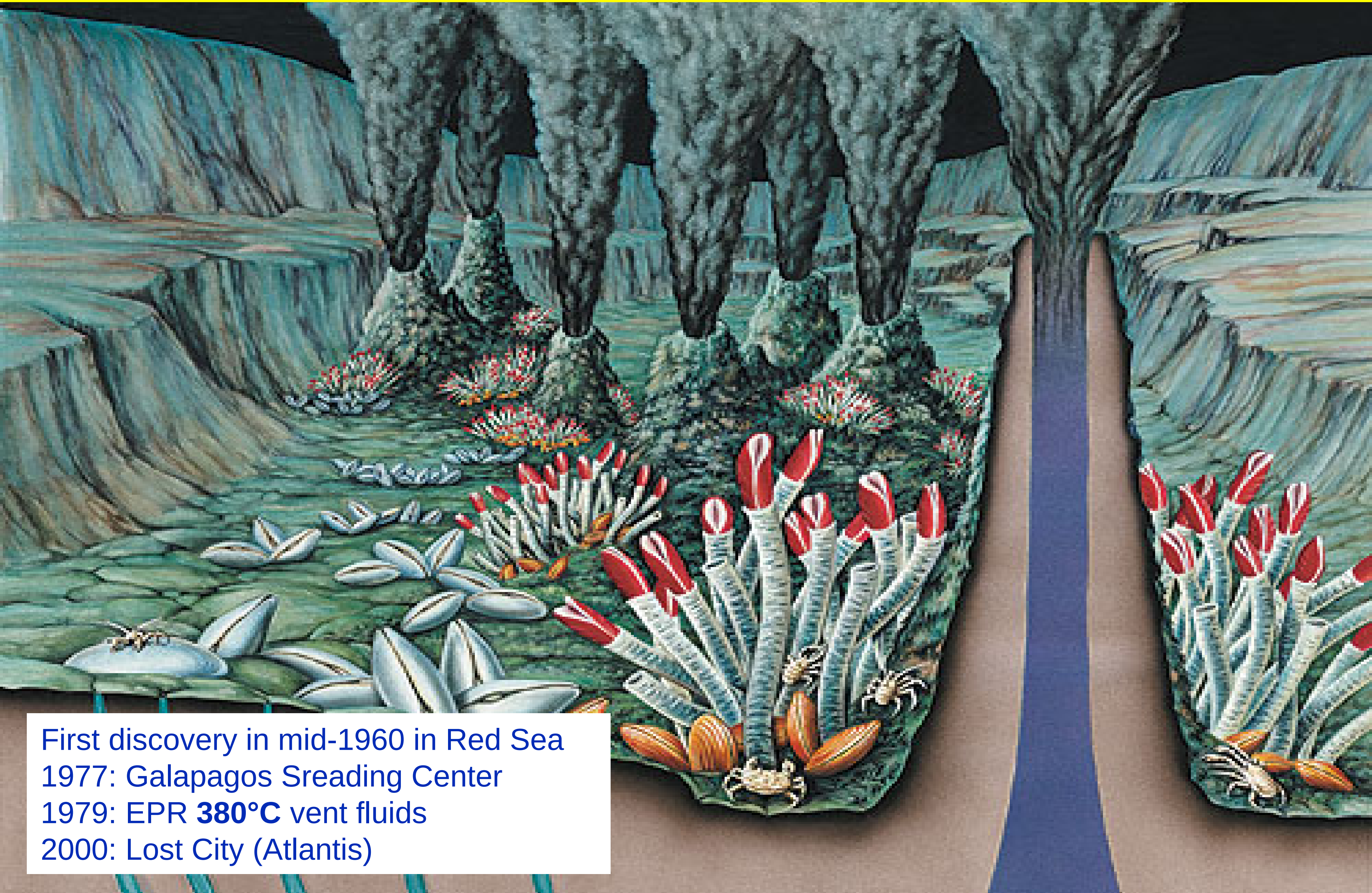
- cover 15% of ocean floor (e.g. Ross sea)
- typical sediments in regions of high biological productivity in polar regions, circum Antarctic region and in upwelling zones

Distribution of marine sediments

Dominant component	Composition	Atlantic	Pacific	Indian	Total %
Foraminiferal ooze and nannofossil ooze	Calcium carbonate	**65**	36	54	47
Pteropod ooze	Calcium carbonate	2	0.1	-	0.5
Diatom ooze	Silica (opal)	7	10	20	12
Radiolarian ooze	Silica (opal)	-	5	0.5	3
Red (actually brown) clay K, Fe	Al silicate	26	**49**	25	38

Source P.Pinet Invitation to Oceanography, 2000 2nd Edition, Jones and Barlett Publishers, Massachusetts

Hot vents



First discovery in mid-1960 in Red Sea
1977: Galapagos Sreading Center
1979: EPR **380°C** vent fluids
2000: Lost City (Atlantis)

Seafloor hydrothermal circulation

Mass exchange between ocean and the oceanic crust

Affects whole global ocean geochemistry

Accounts for ~10% of heat loss from the solid Earth

Chemosynthetically based animal and plant communities (implications for the origin of life)

Spectacular visual manifestation: Black smokers – fluid channels

- fluids enriched or depleted with respect to ambient seawater

Most dissolved chemicals released during venting precipitate immediately when in contact with cold sea water

- metal-sulfide and oxide mineral-rich smoke

Requirements for submarine hot springs

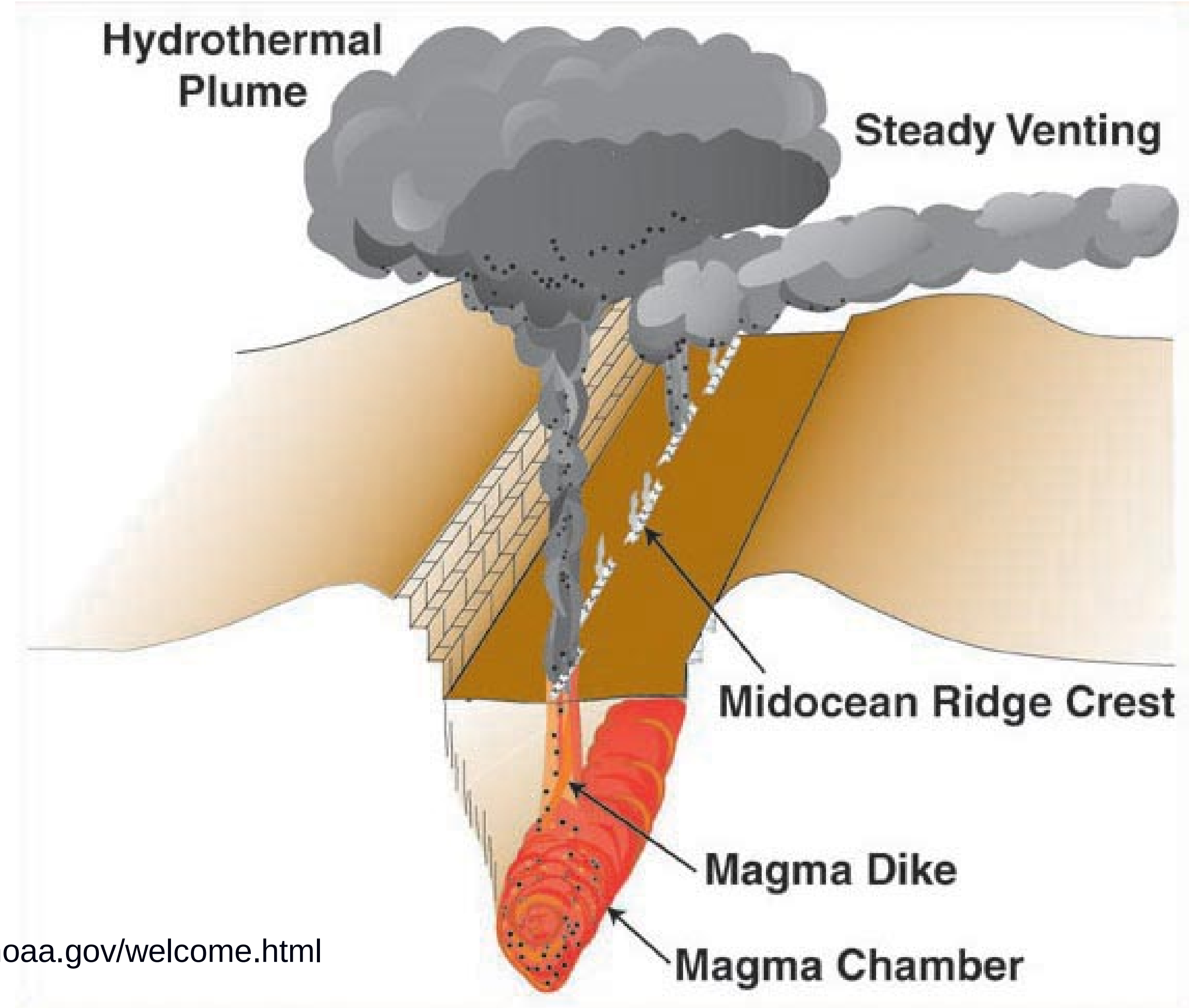
- Heat source (generally the magma chamber)
- Permeable medium (Layer 2 of oceanic crust, porous basaltic lava, faults)
- Fluid (seawater)

Temperature-based division:

- high-temperature solutions at the mid-ocean ridge centres
- intermediate on the ridge flanks
- low at the sea floor

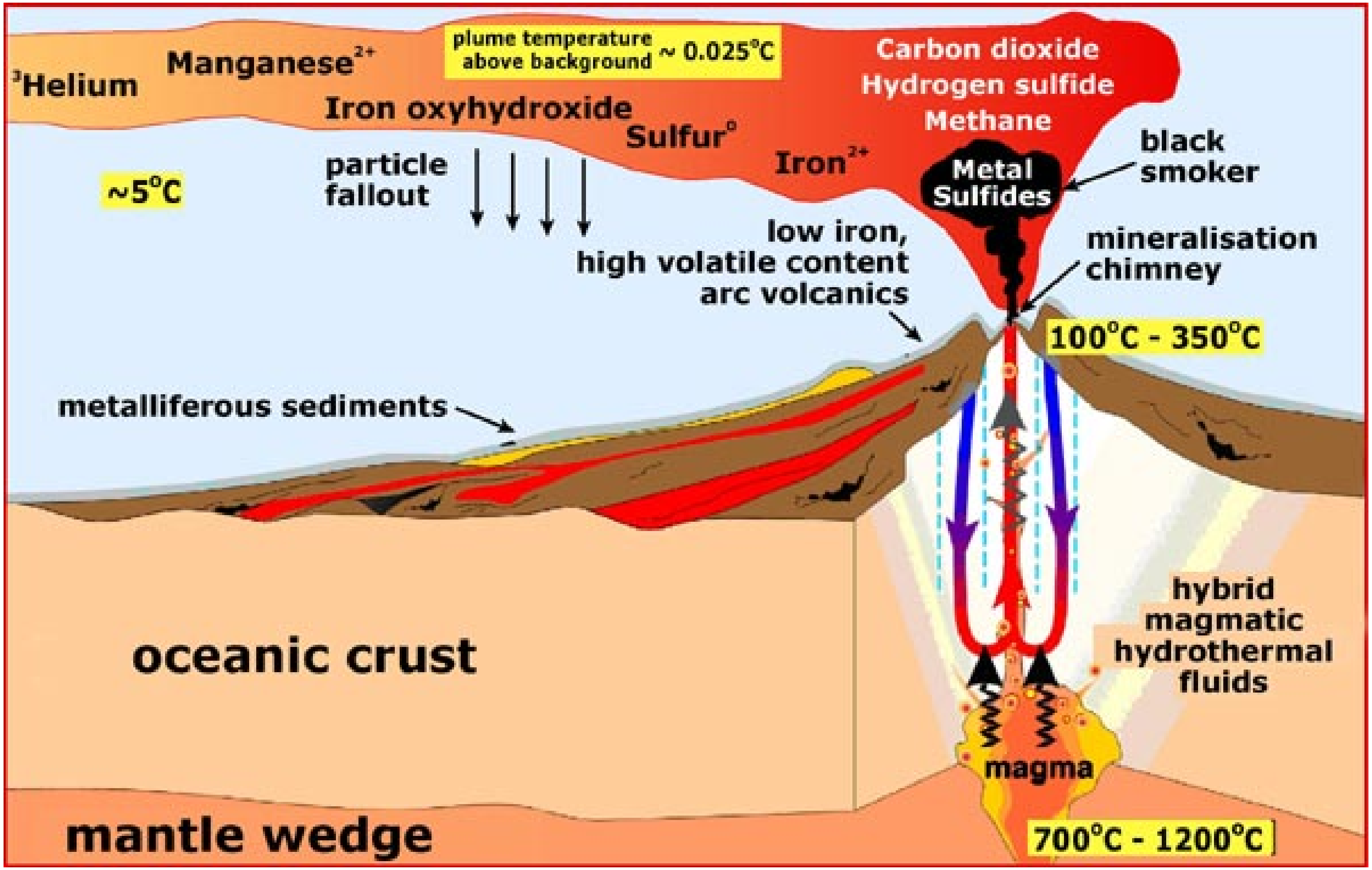
- geothermal solutions (thermal transfer)
- hydrothermal solutions (thermal and chemical transfer)

Hydrothermal plume



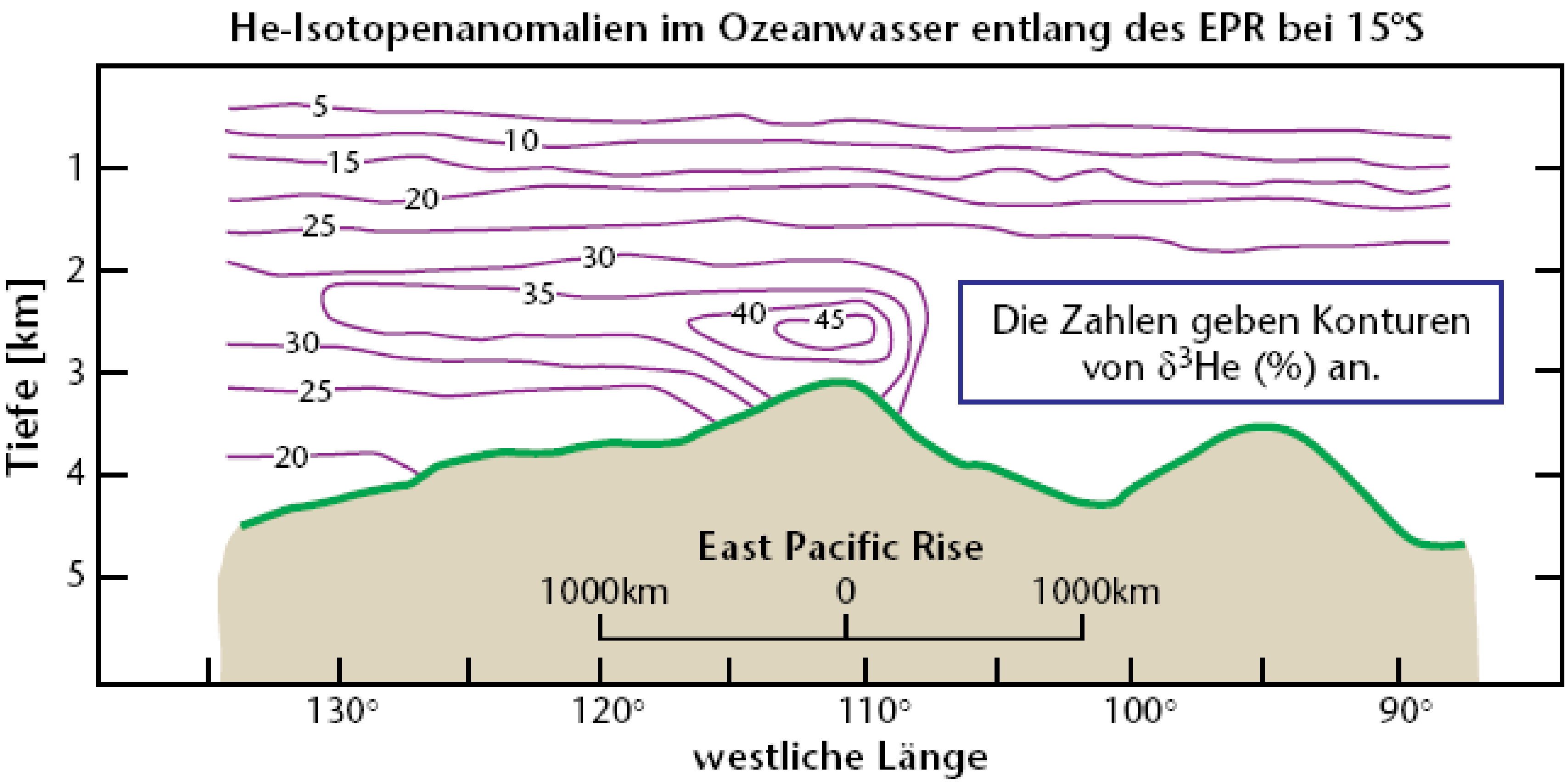
http://oceanexplorer.noaa.gov/welcome.html

Hydrothermal plumes

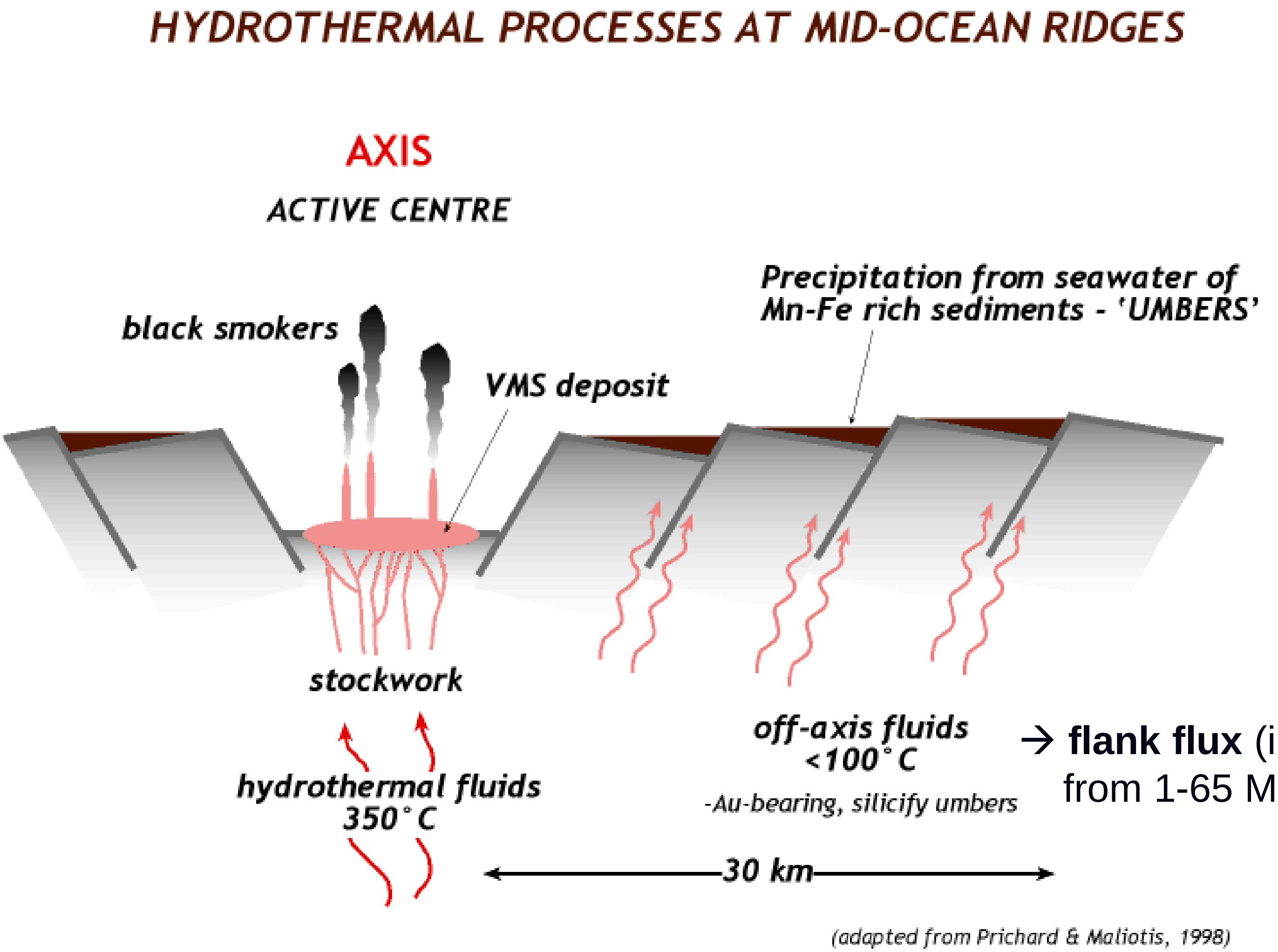


http://oceanexplorer.noaa.gov/welcome.html

“Plume hunting”

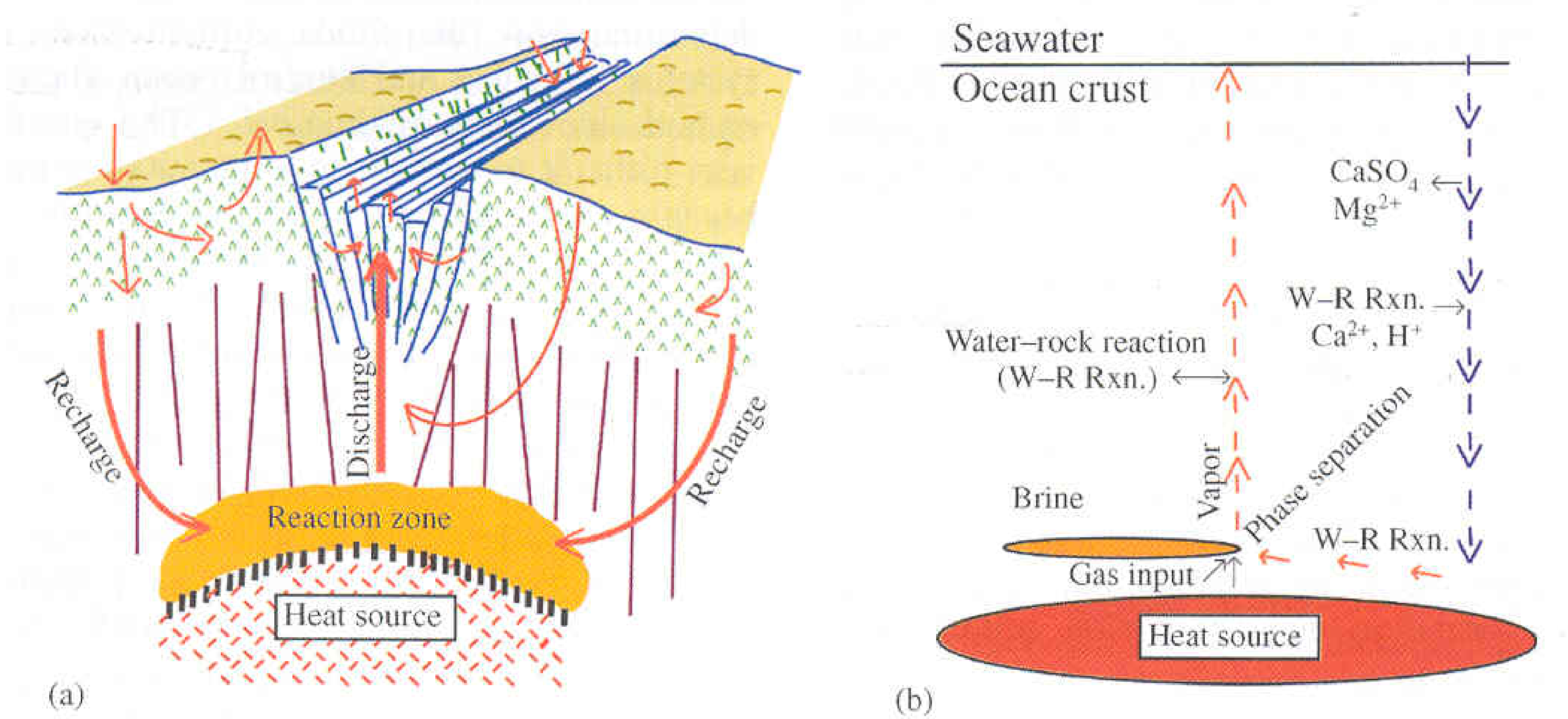


Seafloor hydrothermal circulation



→ **flank flux** (in crust from 1-65 Ma in age)

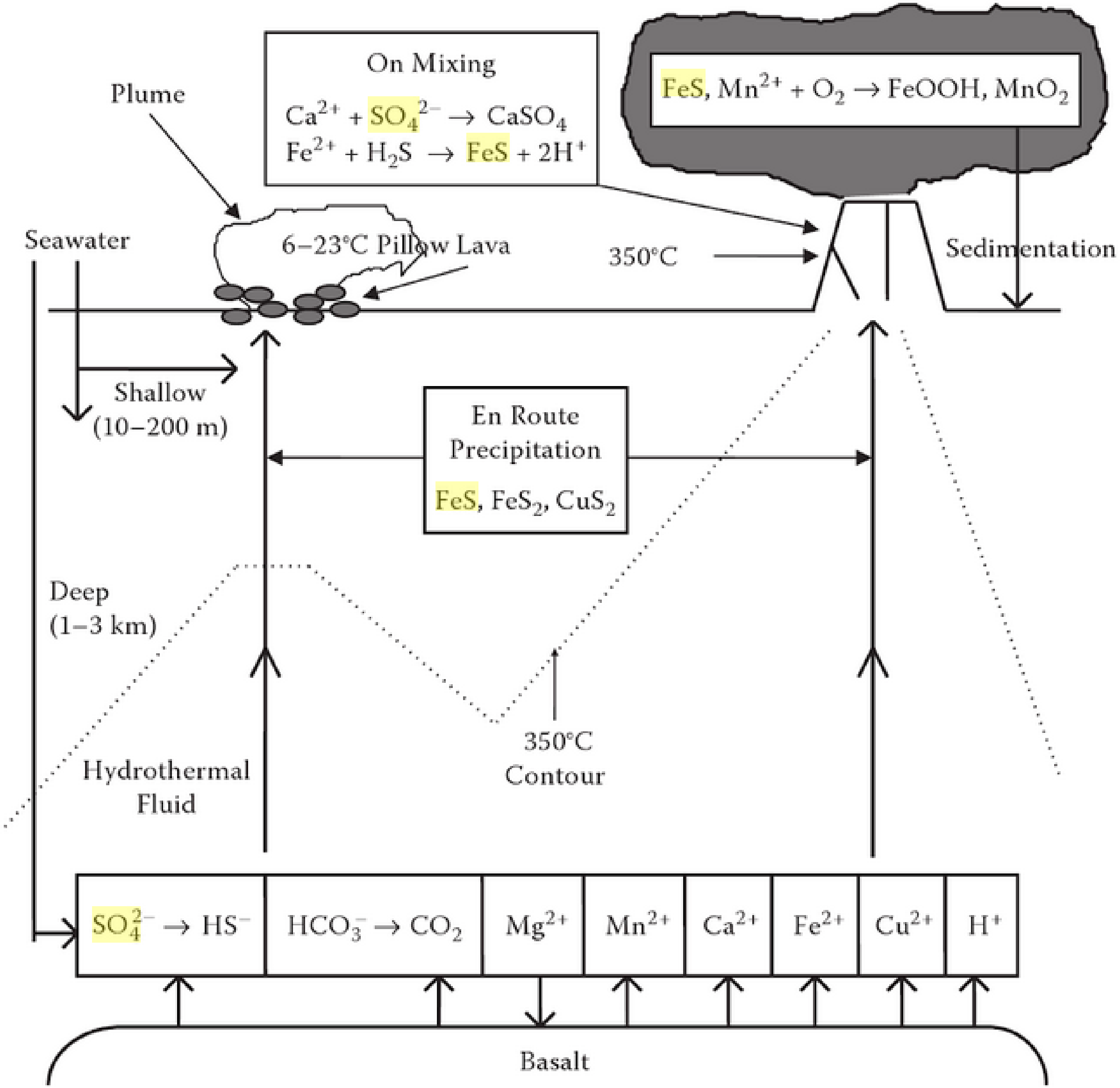
Hydrothermal circulation at mid-ocean ridges



- Seawater seeps into the crust. Ca^{2+}, sulfate (SO_4^{2-}) and **Mg^{2+}*** are removed from the water
- Water begins to heat up → Na^+, K^+, H^+ and Ca^{2+} dissolve from the crust.
- Magma superheats the water, dissolving metals like iron, zinc, copper.
- Water then rises back to the surface, where it mixes with the cold seawater → Formation of black metal-sulphide chimneys

***missing sink in Mg budget before vents were discovered**

Vents fluid reaction processes

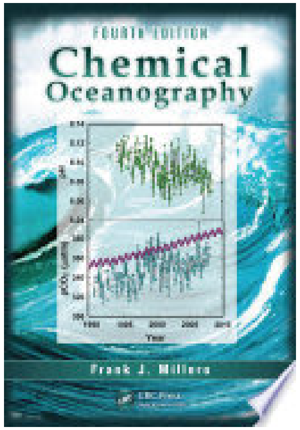


Basalt alteration reactions consume oxygen from the fluid (e.g. formation of ferric iron (Fe^{3+}) in magnetite or olivine leads to reducing conditions

As a consequence, reduced gas species, such as hydrogen gas (H_2), methane (CH_4) and hydrogen sulfide (H_2S), can be produced

These dissolved gas species provide important energy sources for **microbial activity**

Composition of vents fluid and sea water



Comparison of the Estimated Composition of the Galapagos and 21° N Vents and Seawater

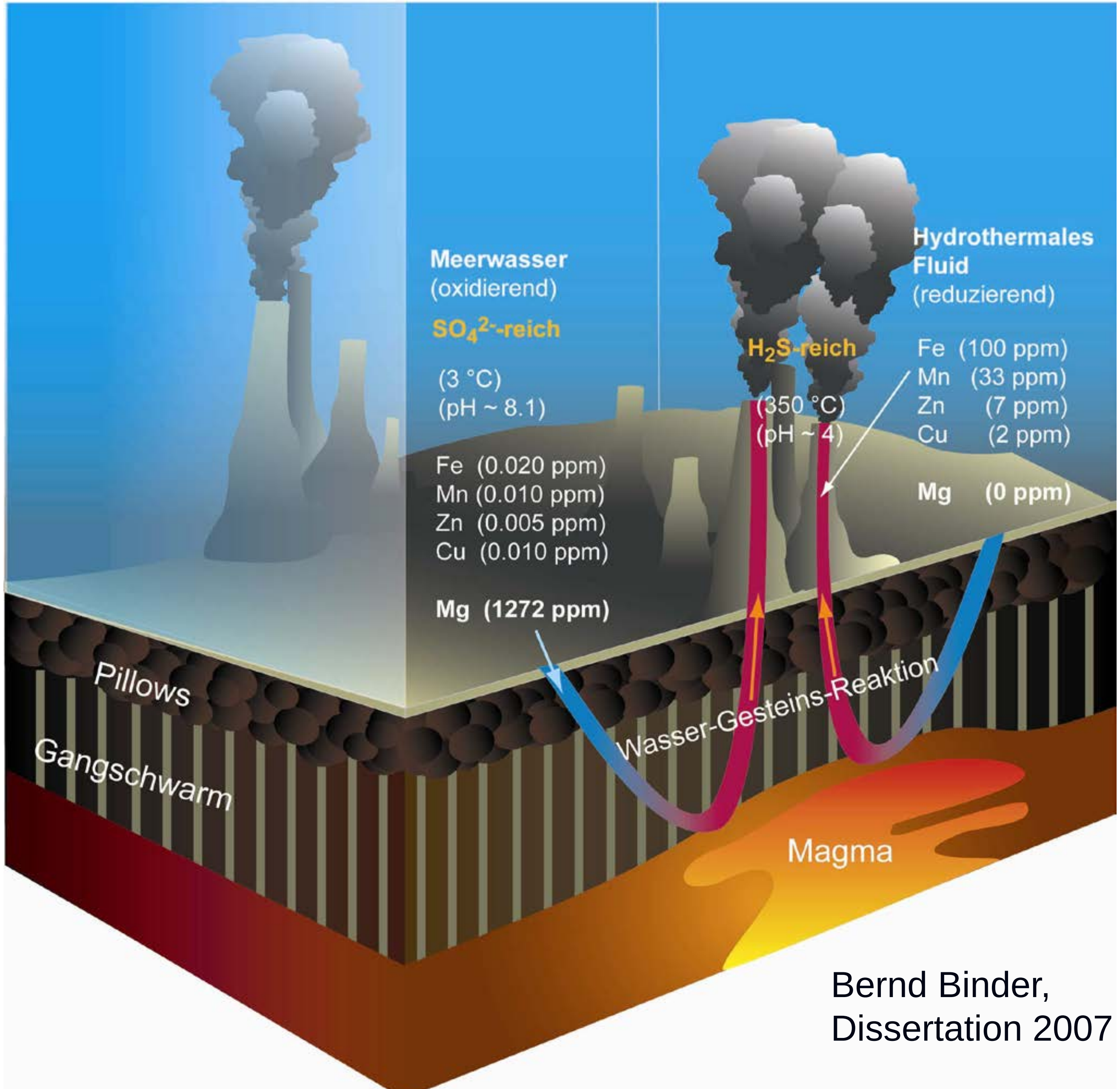
	Galapagos	21° N	Seawater
Li (μmol kg^{-1})	1142–689	820	28
K (mmol kg^{-1})	18.8	25.0	10.1
Rb (μmol kg^{-1})	20.3–13.4	26.0	1.32
Mg (mmol kg^{-1})	0	0	52.7
Ca (mmol kg^{-1})	40.2–24.6	21.5	10.3
Sr (μmol kg^{-1})	87	90	87
Ba (μmol kg^{-1})	42.6–17.2	95–35	0.145
Mn (μmol kg^{-1})	1140–360	610	0.002
Fe (μmol kg^{-1})	+ [a]	1800	– [a]
Si (mmol kg^{-1})	21.9	21.5	0.160
SO_4^{2-} (mmol kg^{-1})	0	0	28.6
H_2S (mmol kg^{-1})	+ [a]	6.5	0

Source: From Edmond et al. 1982.

[a] +, nonconservative to subsurface mixing; –, seawater concentration not accurately known.

Vent fluids are acidic, reducing, silica- iron-, manganese-rich and deficient in Mg^{2+} and SO_4^{2-} and alkalinity

Hydrothermal circulation at mid-ocean ridges

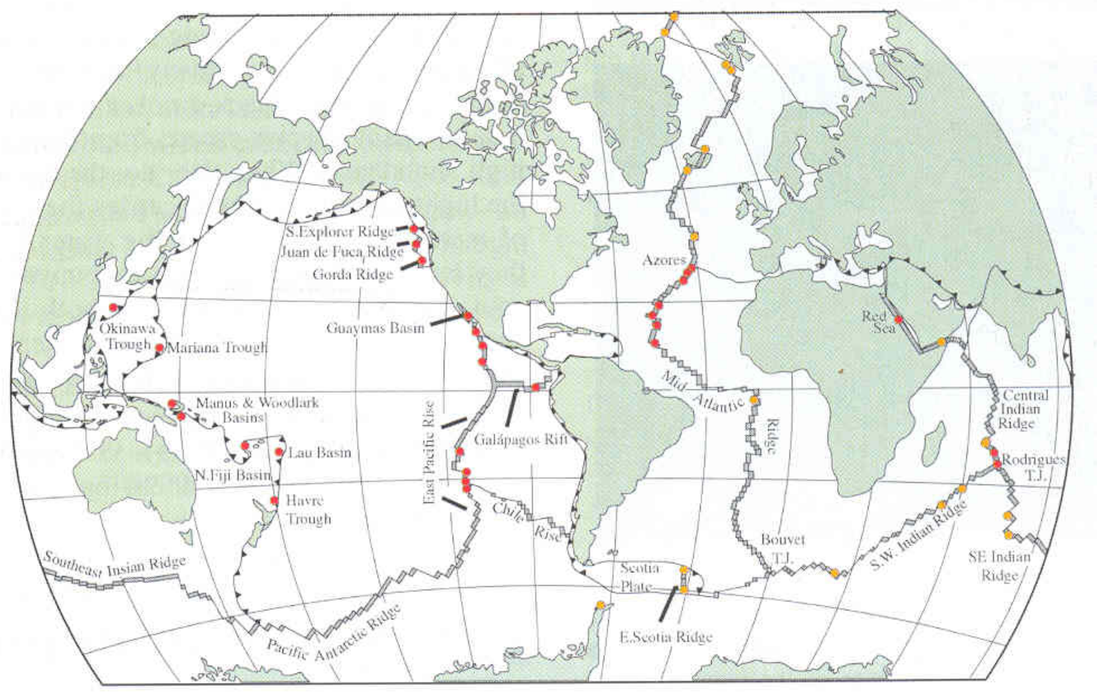


Bernd Binder,
Dissertation 2007

Distribution of active hydrothermal vents

Today: 70 known locations of hydrothermal activity in the world oceans

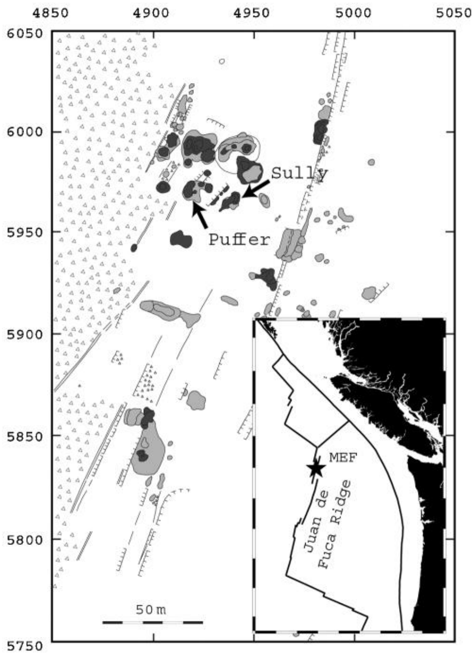
Most sites along MORs, some associated with island arcs, back-arc spreading centers and hot-spot related intraplate volcanism (e.g., Hawaii, Samoa...)



Locations of known hydrothermal activity along the global mid-ocean ridge system
• = known active sites • = active sites indicated by midwater chemical anomalies

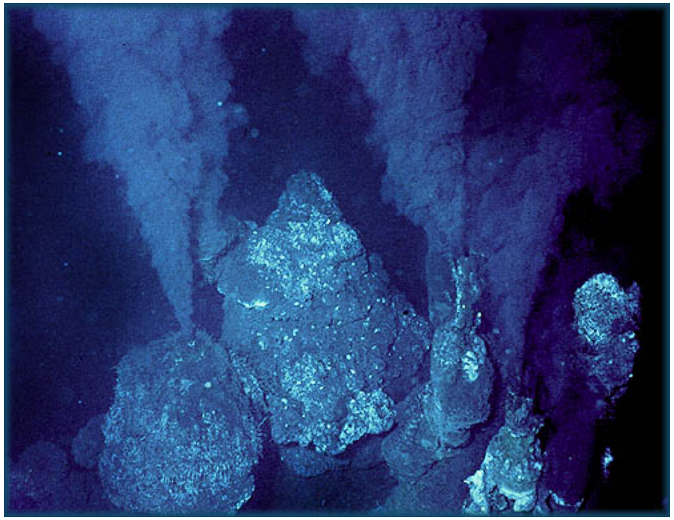
Details on active vent-sites:
http://interridge.org/

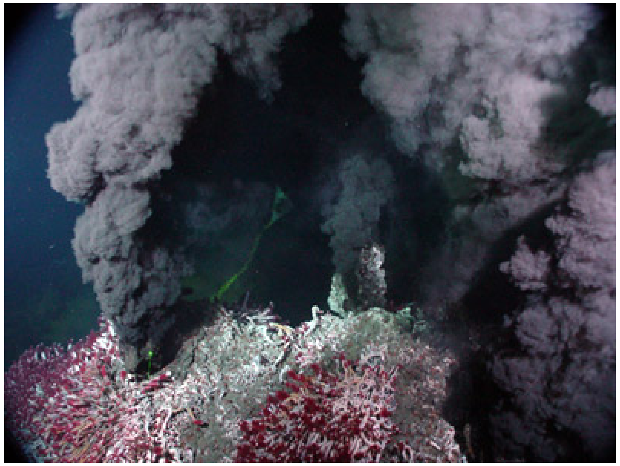
Vent sides



Lost city (Atlantis)

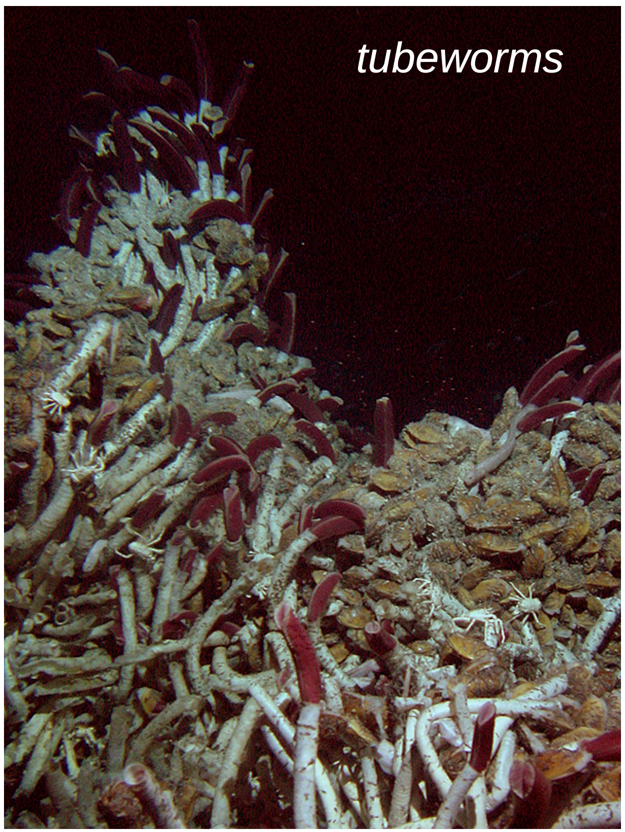
Monolith vent site

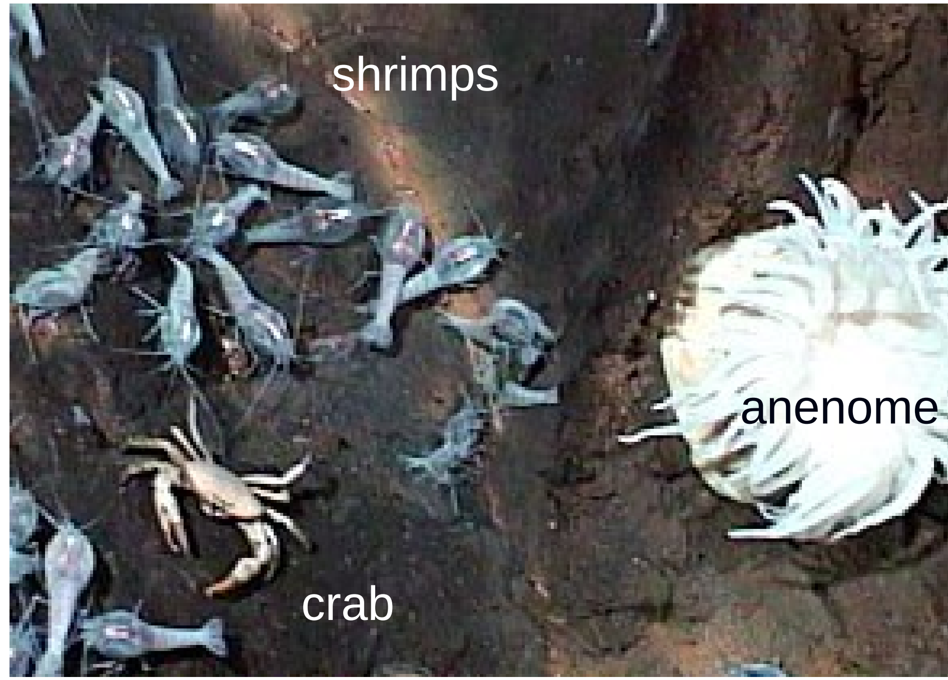




Sully

Vent side macrofauna





Chemosynthesis

Chemosynthetic bacteria:

$6CO_2 + 6H_2O + 3H_2S \rightarrow C_6H_{12}O_6 + 3H_2SO_4$

$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$

Methanogenic archaea or sulfate reducing bacteria:

$CH_4 + SO_4^{2-} \rightarrow HS^- + HCO_3^- + H_2O$

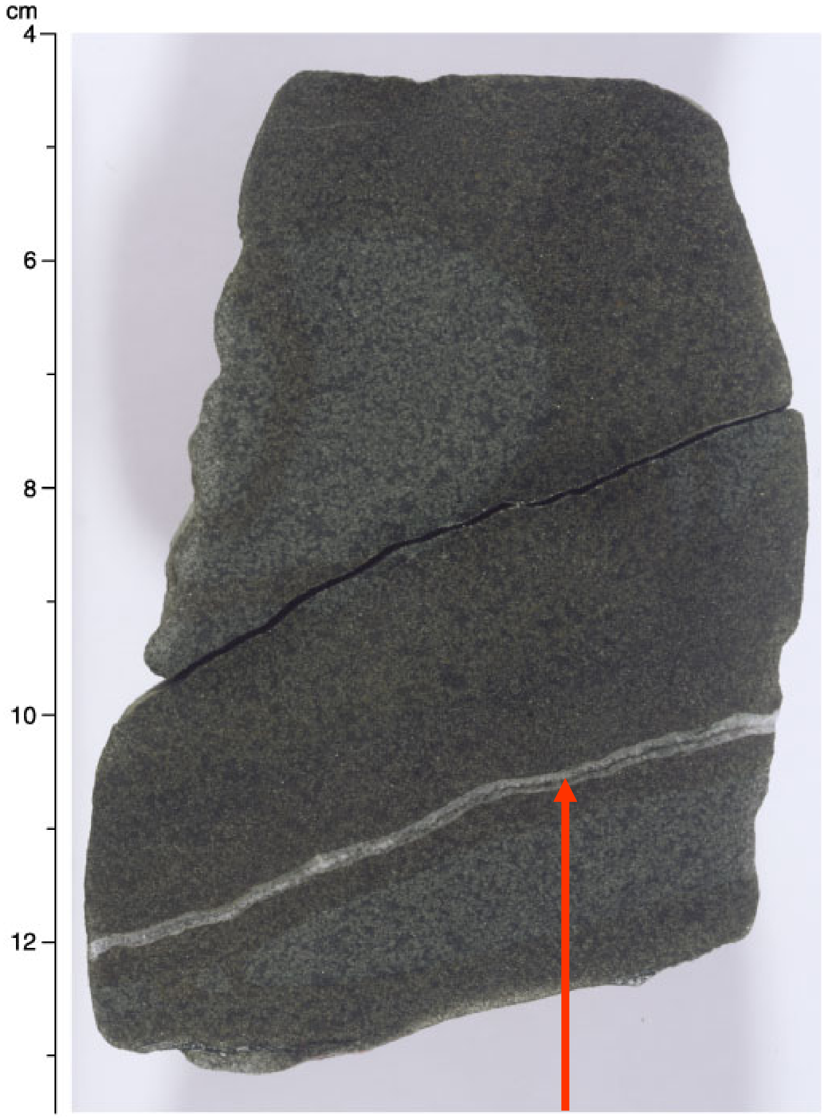
Why are vent fluids of interest?

- They influence and control ocean chemistry – warm (>20°C) and cold (<20°C) fluids → large and small changes in composition of circulating seawater

- Alteration of oceanic crust (next figures)

- Formation of hydrothermal mineral deposits – polymetallic sulfides and other minerals (`umbers´)

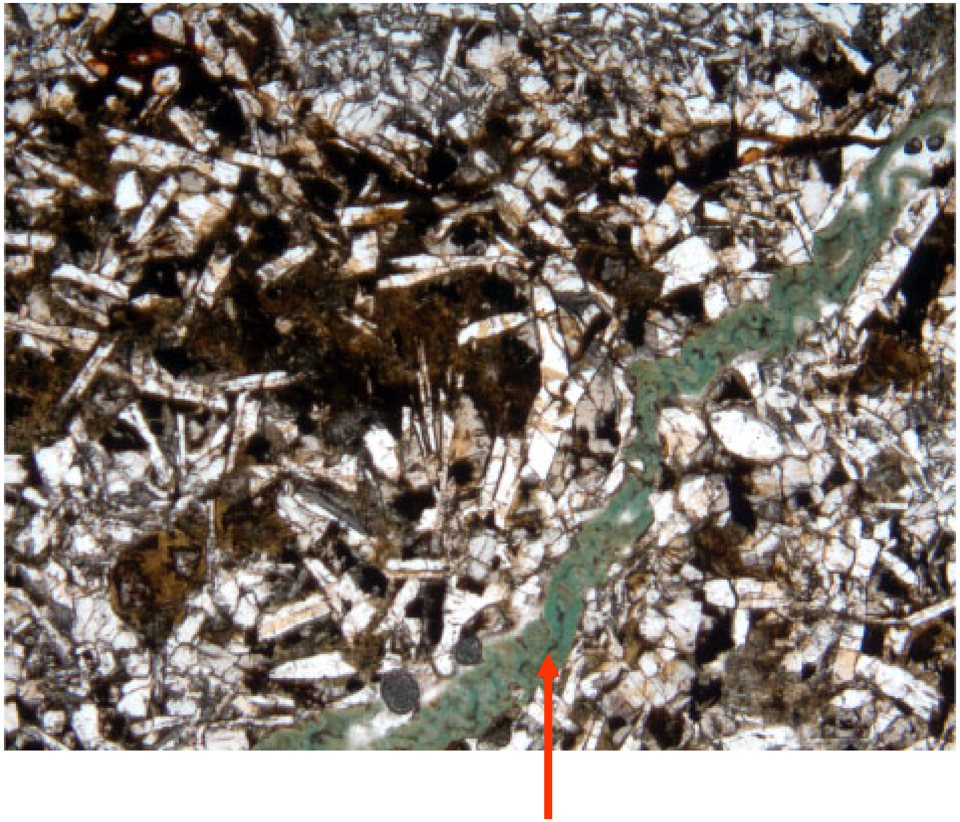
Impact of hydroth. circulation upon oceanic crust



calcite-smectite vein in basalt

MORB undergoes pervasive low-temperature interactions with seawater-derived fluids

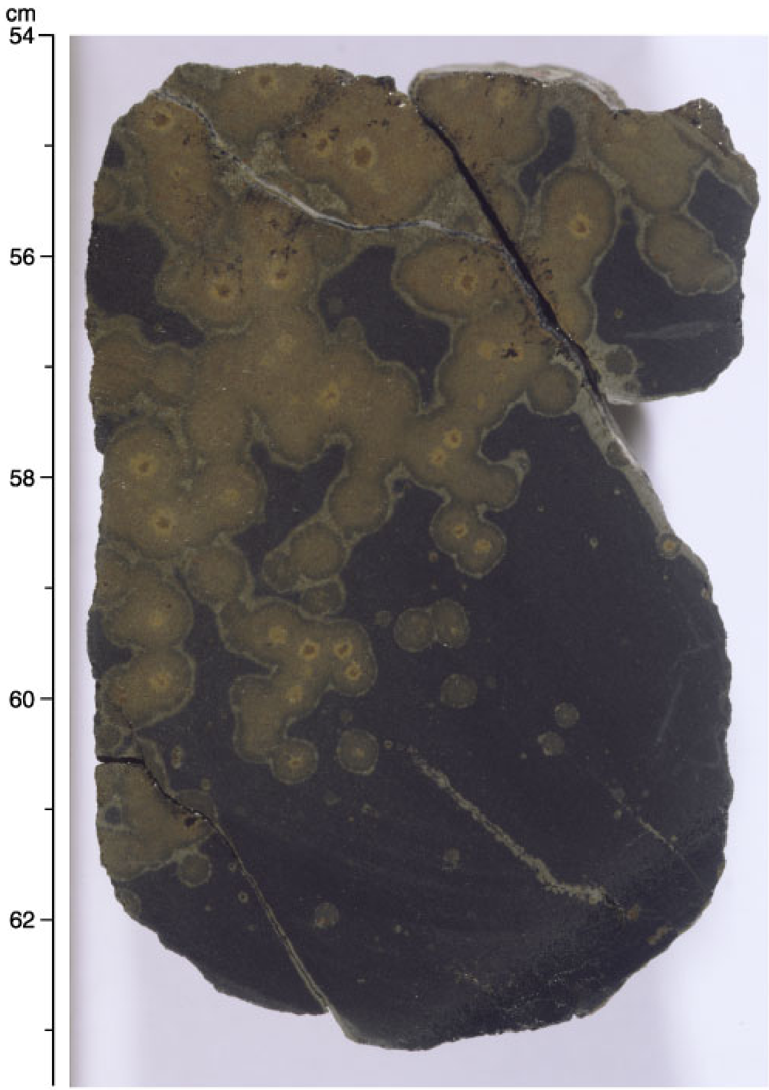
Source: ODP puplication (Leg 192, Site 1185, Java Plateau)



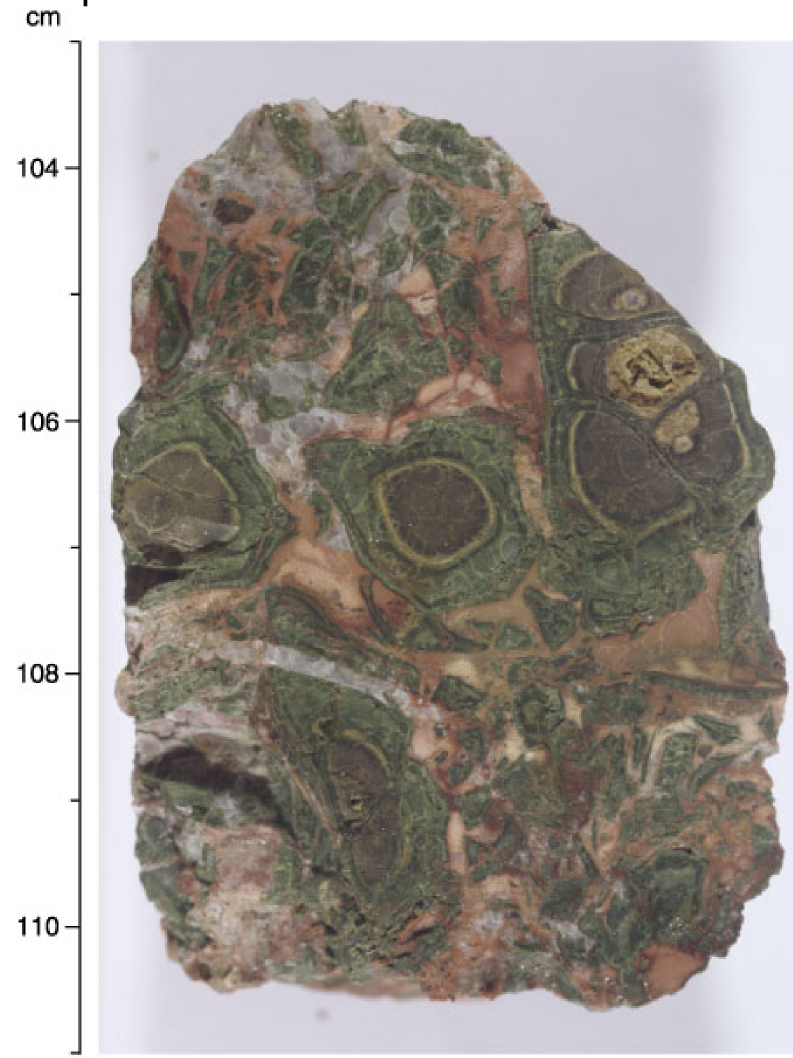
celadonite vein

Impact of hydroth.circulation upon oceanic crust

spherulites (Fe oxyhydroxide devitrification alteration)



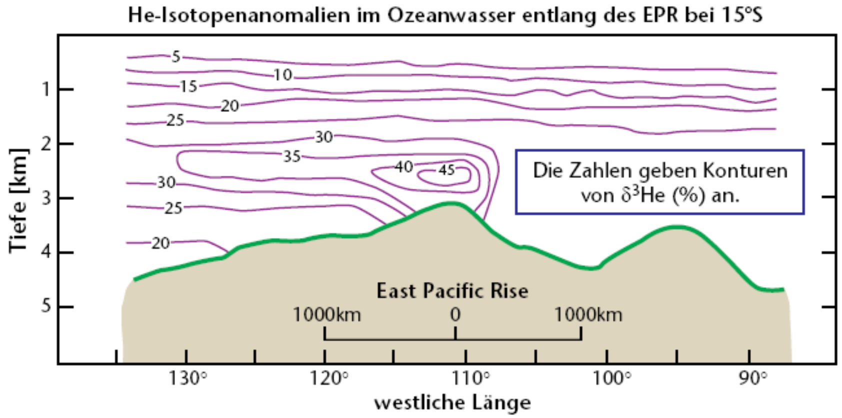
hyaloclastite – glass fragments replaced by smectite and cemented by white and pink carbonate



Source: ODP puplication (Leg 192, Site 1185, Java Plateau)

Processes affecting vent-fluid compositions

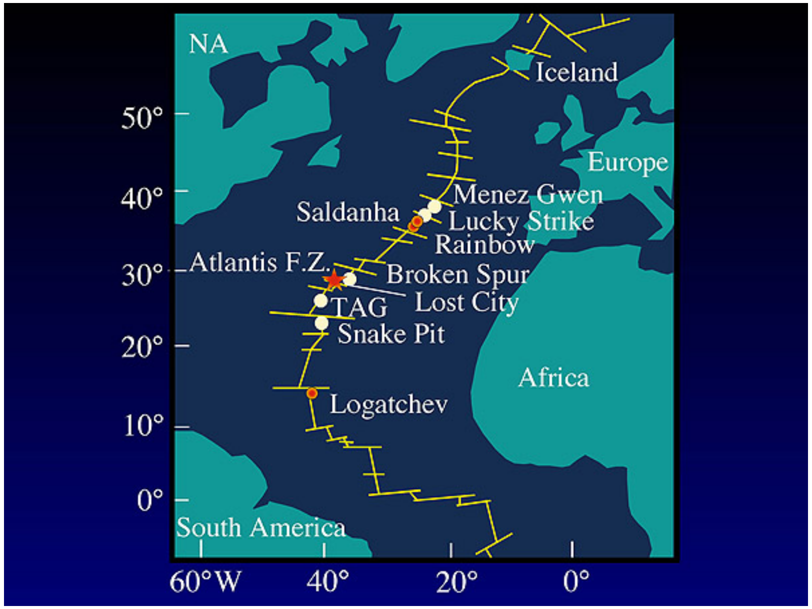
- Water-rock reaction
  - Seawater Mg, Ca and SO_4 are lost (formation of Mg-OH silicates, $CaSO_4$ precipitates at ~130°C)
  - Some SO_4 reduced to H_2S ($SO_4^{2-} + Fe^{2+} \rightarrow H_2S + Fe_2O_3$)
  - Si, Fe (Zn, Cu) and Mn are gained (i.e. leached out of the rock into the fluid)
  - pH is lowered
  - The anion **chloride** is a key component in hydrothermal fluids – cations are present in chloro-complexes
- Phase separation
  - Separation into two phases by boiling, condensation, vapor release; requires temperatures >350°C
- Magmatic degassing
  - High gas levels in the fluid (CO_2, He)
- Biological processes
  - Only in low-temperature vent-fluids



Recent discoveries

- **2000**: entirely new form of hydrothermal activity at the Atlantis fracture zone – calcite/aragonite and brucite chimneys (*Kelly et al. 2001 Nature **412***)

- **2003**: discovery of ultraslow-spreading Gakkel ridge in ice covered Arctic (*Edmonds et al. 2003 Nature **421***)



Summary

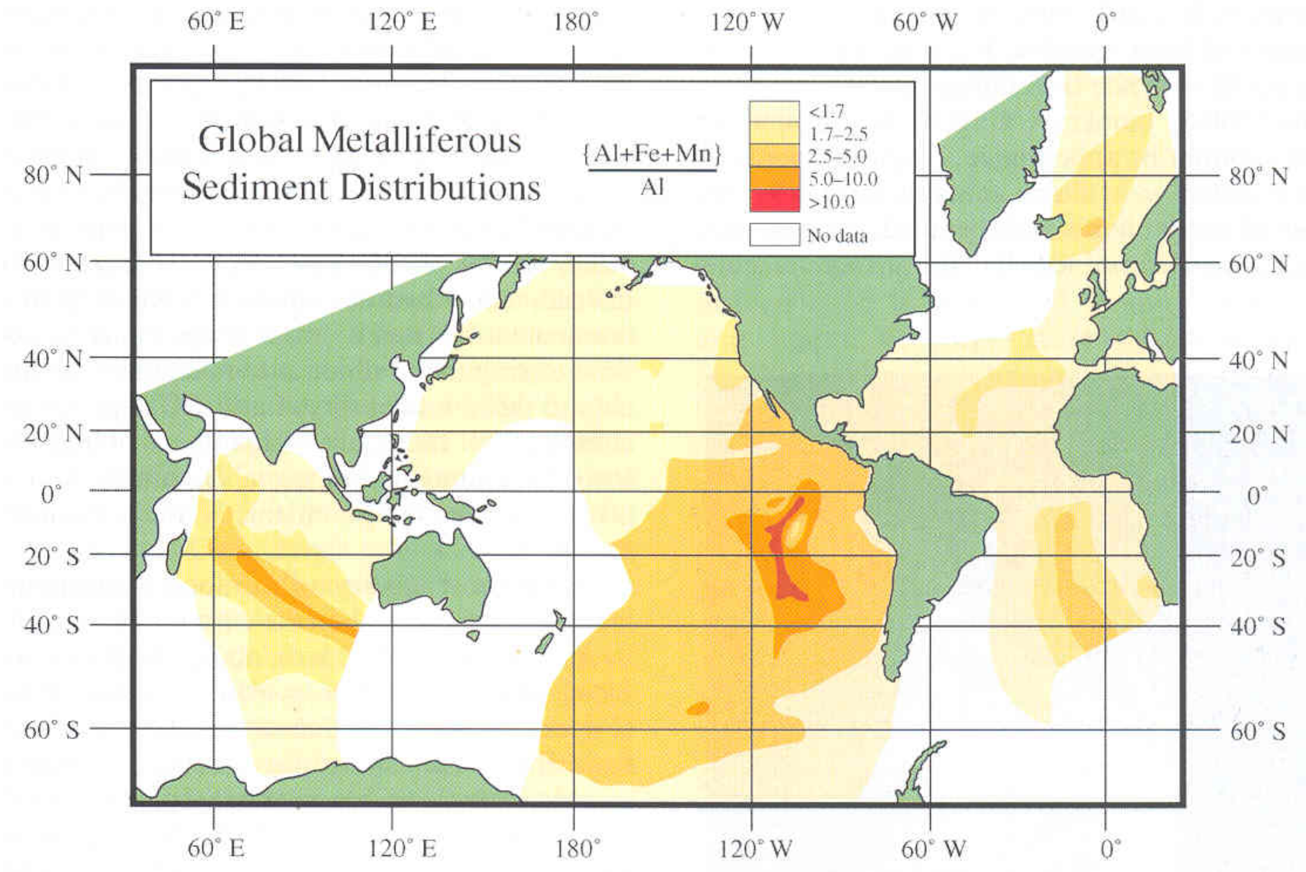
Vent-fluids are :

- (1) modified seawater characterized by the loss of Mg^{2+}, Ca^{2+} and SO_4^{2-} and the gain of many metals, especially on a chloride normalized basis

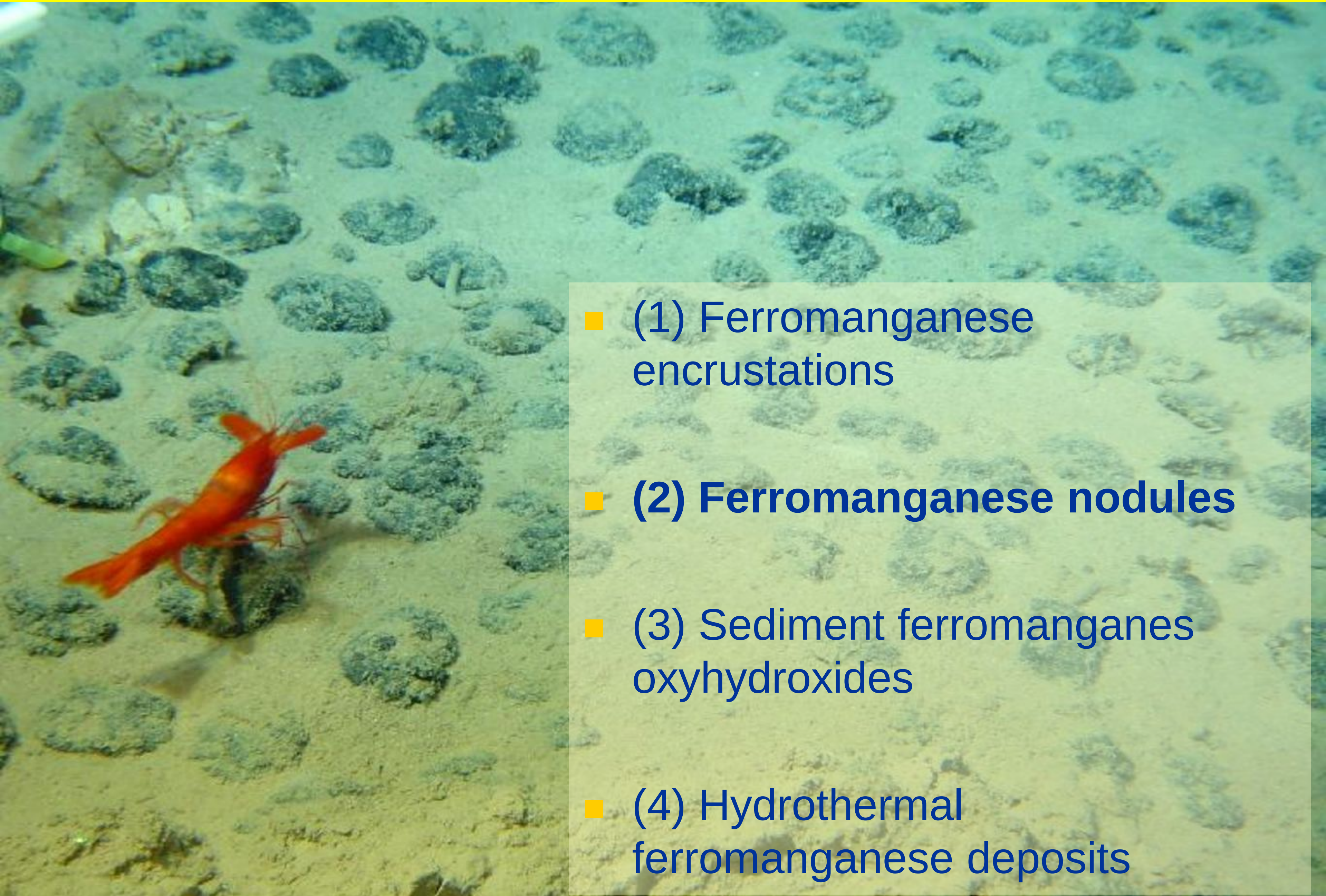
- (2) Acidic, reducing, metal-rich NaCl solutions

Lost city vent completely different!!!

Ferromanganese deposits in the oceans



Ferromanganese deposits in the oceans



- (1) Ferromanganese encrustations
- **(2) Ferromanganese nodules**
- (3) Sediment ferromanganes oxyhydroxides
- (4) Hydrothermal ferromanganese deposits

Ferromanganese nodules

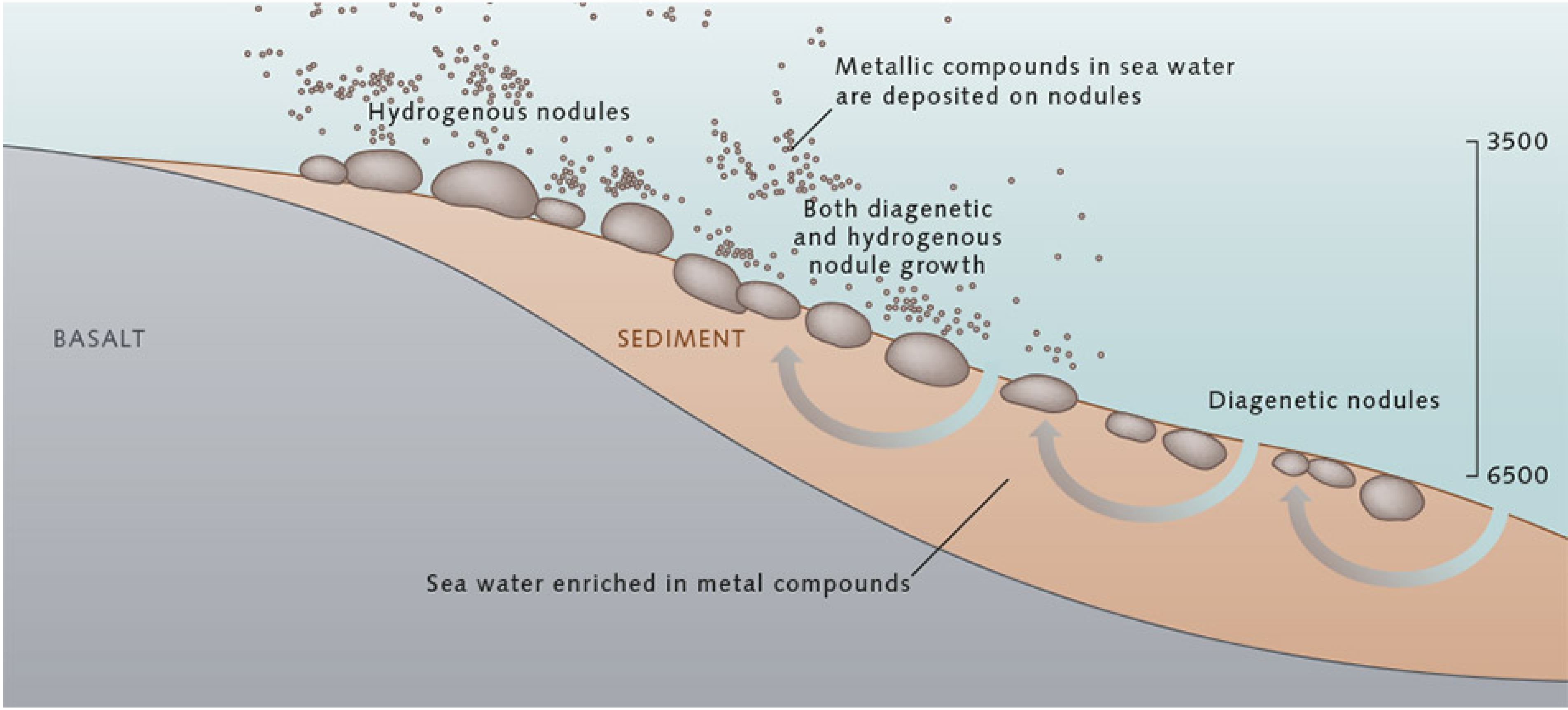
Discovered during Challenger expedition (1873-1876)

Occur between 4000 m und 6000 m depth on sea floor

Nodules are composed of Mn (20–30%), Fe (5–25%) and copper (Cu) (0.2–1.2%).
Minor but economically important components are Co (0.2–0.5%) and Ni (0.2–1.4%) and lanthanoids.

dominant minerals are hydrous manganese oxides todorokite (10Å manganite) and birnessite (7Å manganite or δMnO_2) and hydrous Fe ($FeOOH\mathit{n}H_2O$).

Ferromanganese deposits in the oceans



Source: http://worldoceanreview.com/en/wor-3-overview/mineral-resources/manganese-nodules/

Seawater source can be either hydrogenous or hydrothermal

Diagenetic sources can be either ocic or suboxic

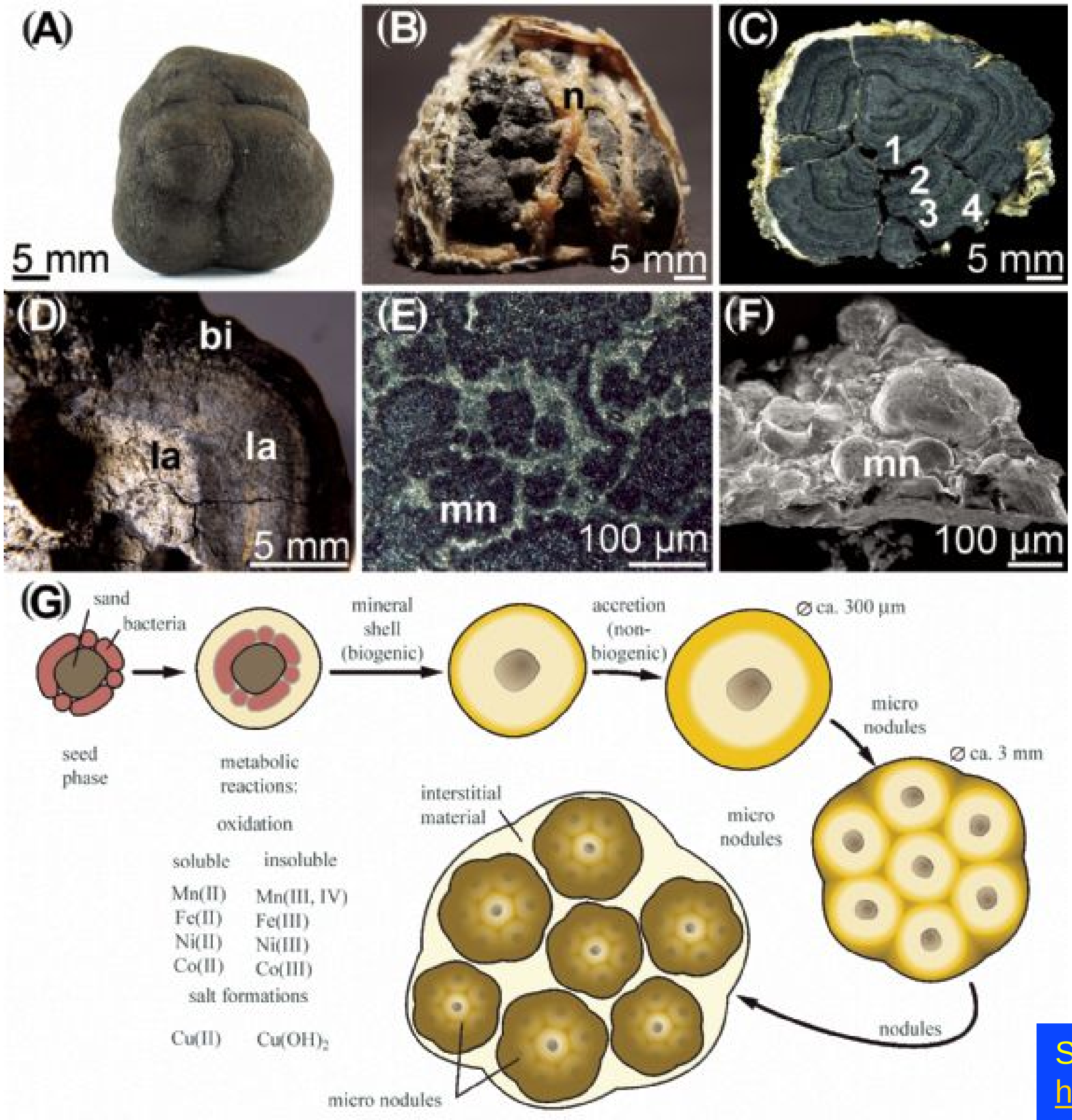
Hydrogenous vs. hydrothermal crust

Table 15.6 Some general characteristics of oceanic Fe–Mn deposits; units, μg g[-1].

	Chemical composition				
	A*	B*	C*	D†	E‡
	Hydrogenous crust	Oxic nodule	Suboxic nodule	Hydrothermal crust	Hydrothermal crust
Mn	222 000	316 500	480 000	410 000	550 000
Fe	190 000	44 500	4900	8 000	2 000
Co	1 300	280	35	33	39
Ni	5 500	10 100	4 400	310	180
Cu	1 480	4 400	2 000	120	50
Zn	750	2 500	2 200	400	2 020
Mn : Fe	1.2	7.1	98	51	275
Principal mineralogy of Fe–Mn phases	δMnO_2	δMnO_2, toderokite	Toderokite	Birnessite	Birnessite, toderokite
Approximate growth rates (mm $10^6 yr^{-1}$)	1–2	10–50	100–200	500	1000–2000

Source Chester & Jickells (2012): Marine Geochemistry

Ferromanganese nodules



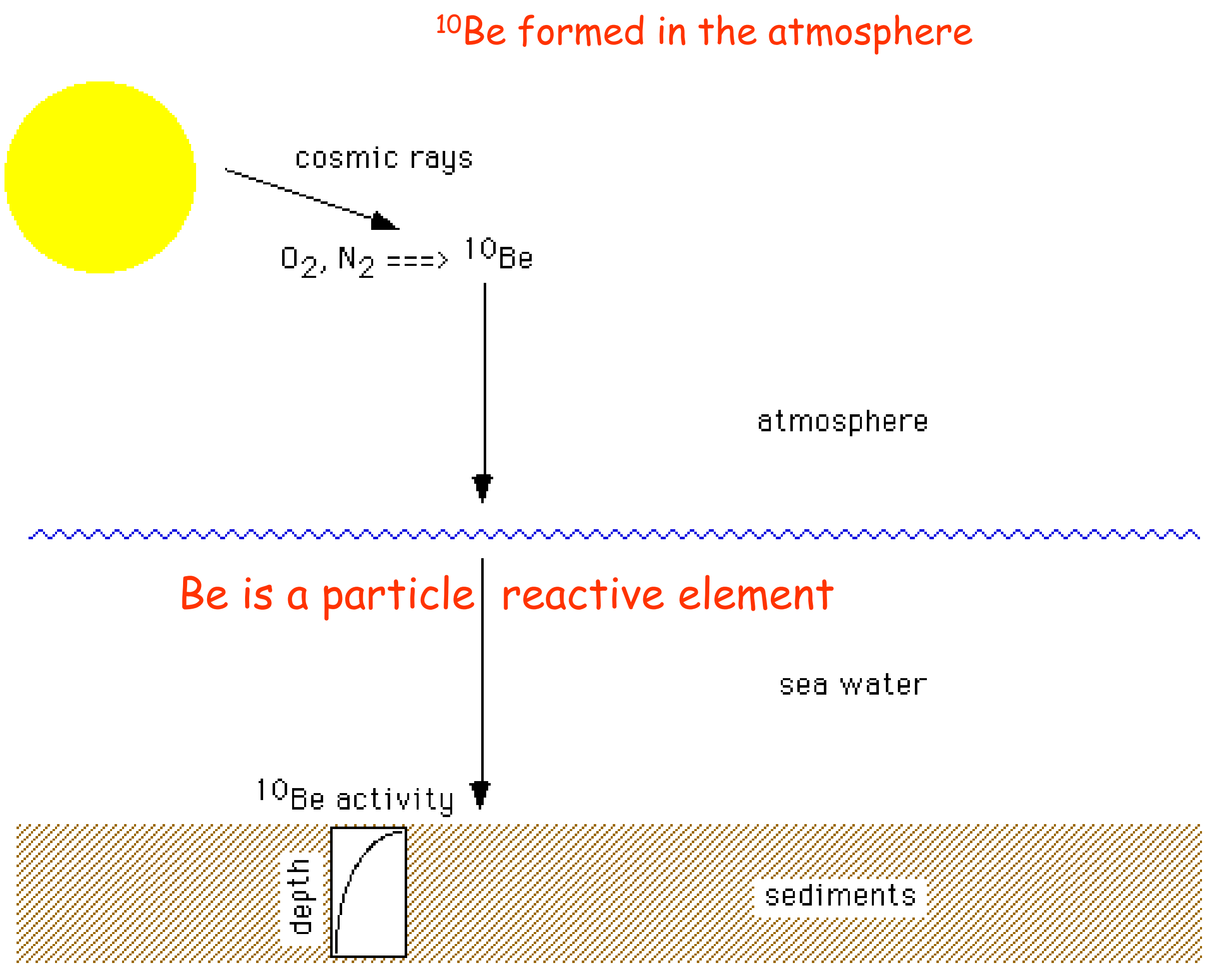
Source: Wang & Müller (2009)
http://dx.doi.org/10.1016/j.tibtech.2009.03.004

^{10}Be and growth rates of hydrogenous crust

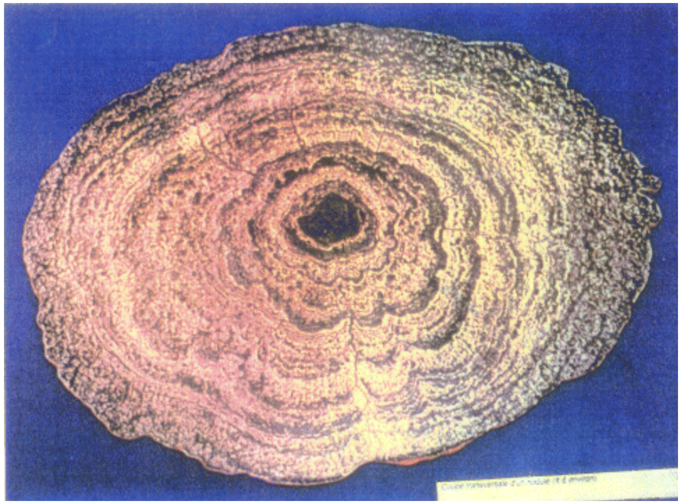
- ^{10}Be is produced by reactions of high energy cosmic ray protons with O_2 and N_2 in the atmosphere and at the surface of minerals exposed to atmosphere

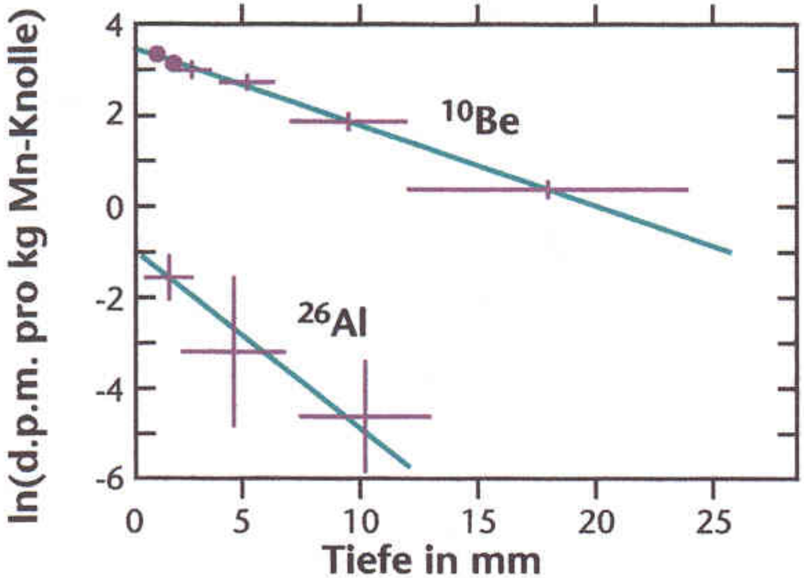
- ^{10}Be then undergoes decay to ^{10}B with a half-life of about 1.5 Ma

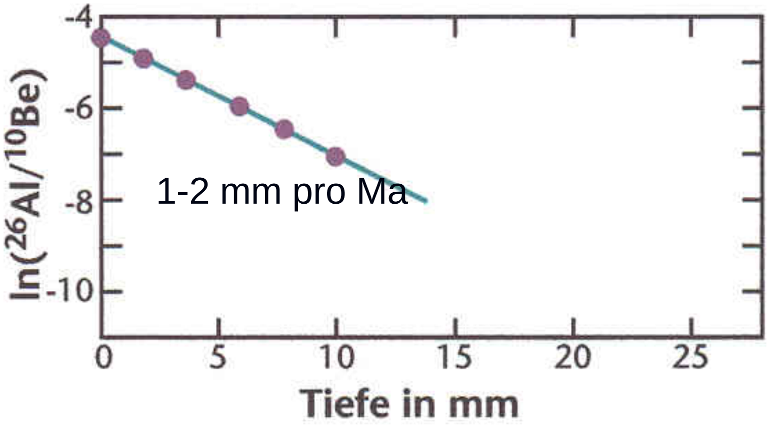
- ^{10}Be can be used to derive sedimentation rates



Growth rates of hydrogenous crust







Ferromanganese deposits

Press release 17.7.2006:

Deutschland (BGR) steckt Claim im Pazifik ab

„Manganknollen sollen Buntmetallversorgung der Zukunft sichern“

Location of the two areas covered by german liscence