Vorlesung 752-4001-00 Mikrobiologie
WS 04/05
Biochemische Diversität: C-Zyklus

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Topics

1. Overview: Photosynthesis, mineralization and storage
2. Energy turnover and biochemistry of photosynthesis
3. Energy turnover and biochemistry of mineralization
4. Storage of assimilated carbon (Humus, Oil, etc.)
5. Case study I: CO_2 cycle and global climate
6. Case study II: Methane oxidation in the subsurface
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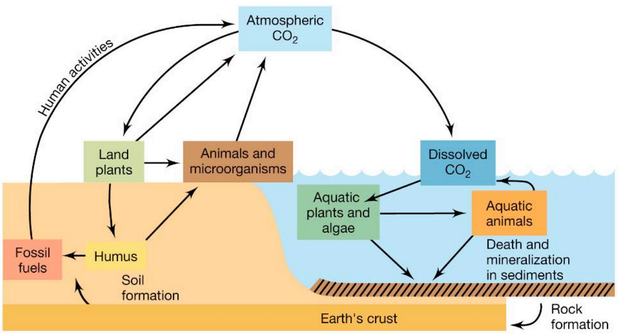
The carbon cycle in nature



Brock, 10th edit., 2003, Chapt. 19

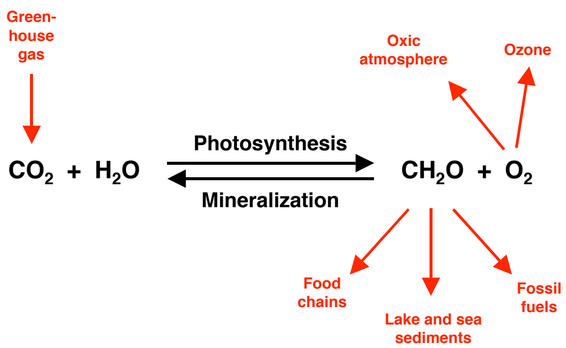
Photosynthesis, mineralization and carbon storage

$$CO_2 + H_2O \underset{\text{Mineralization}}{\overset{\text{Photosynthesis}}{\rightleftharpoons}} CH_2O + O_2$$

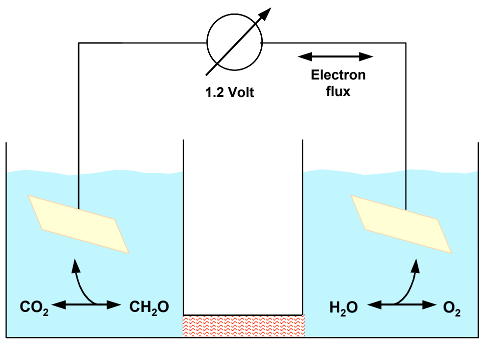
$\updownarrow$

Stored carbon
(e.g. humus, fuel)

Photosynthesis and mineralization: impact on ecology



Conceptual model to measure redox potential



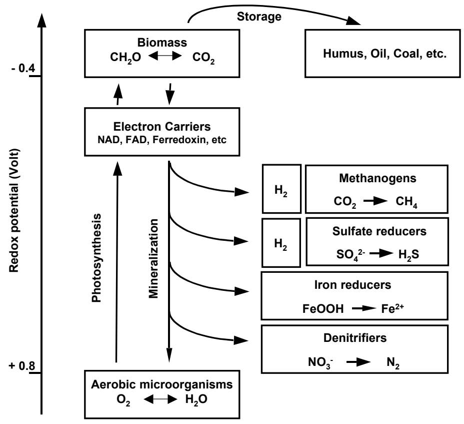
Redox values of microbiologically important reactions

Redox pair	E_0' (Volt)
CO_2/formate	-0.43
$2H^+/H_2$	-0.41
Ferredoxin ox/red	-0.39
NAD^+/NADH	-0.32
S^0/HS^-	-0.27
CO_2/CH_4	-0.24
$Fumarate^{2-}/succinate^{2-}$	+0.033
$Fe(OH)_3 + HCO_3^-/FeCO_3$	+0.20
NO_2^-/NO	+0.36
NO_3^-/NO_2^-	+0.43
Fe^{3+}/Fe^{2+}	+0.77
Mn^{4+}/Mn^{2+}	+0.798
O_2/H_2O	+0.82
NO/N_2O	+1.18
N_2O/N_2	+1.36

$\Delta G^{0\prime} = -nF * \Delta E_0'$ (F = Faraday constant, 96.48 kJ / Volt)

$\Delta G' = \Delta G^{0\prime} + RT * \ln([Products]/[Substrates])$

Biosynthesis and Mineralization of Biomass



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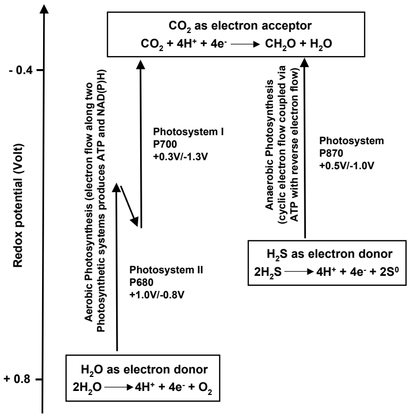
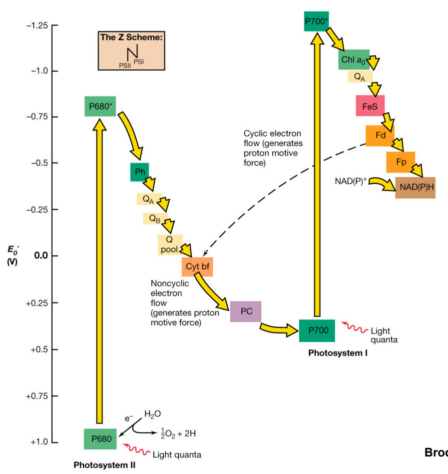
Aerobic and anaerobic photosynthesis

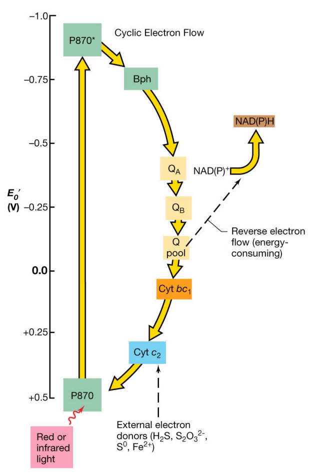




Electron flow in oxygenic photosynthesis

(green plants, cyanobacteria)

Brock, 10th edit., 2003, Chapt. 17



Electron flow in anoxygenic photosynthesis

(anaerobic purple bacteria)

Brock, 10th edit., 2003, Chapt. 17

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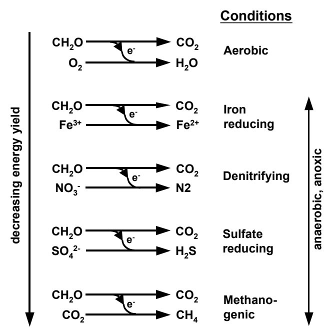
Mineralization of organic C-compounds

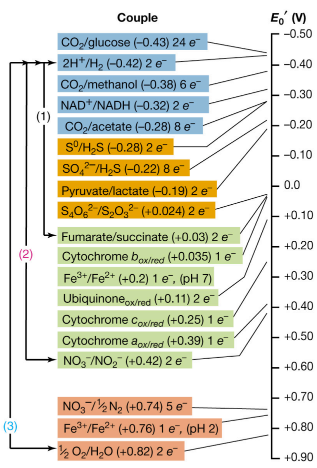


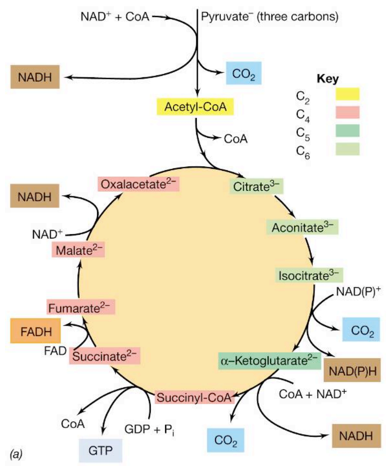
Examples of reactions with H_2 as e^- donor

(1) H_2 + fumarate^{2-} → succinate^{2-}
$\Delta G^{0\prime}$ = −86 kJ

(2) $H_2 + NO_3^- \rightarrow NO_2^- + H_2O$
$\Delta G^{0\prime}$ = −163 kJ

(3) $H_2 + \frac{1}{2} O_2 \rightarrow H_2O$
$\Delta G^{0\prime}$ = −237 kJ

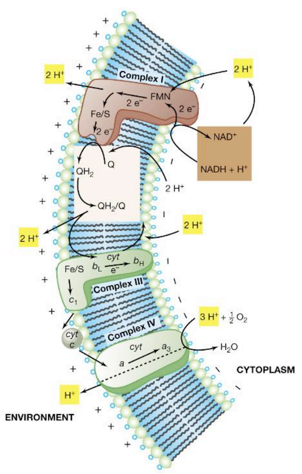




Citric Acid Cycle (CAC):

Carbon oxidation to CO_2 and generation of reducing equivalents

Brock, 10th edit., 2003, Chapt. 5



Respiratory chain:

Electron transfer to oxygen and generation of proton gradient

Brock, 10th edit., 2003, Chapt. 5

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Pools	Quantity (Gt)
Atmosphere	720
Oceans	38,400
Total inorganic	37,400
Surface layer	670
Deep layer	36,730
Total organic	1,000
Lithosphere	
Sedimentary carbonates	>60,000,000
Kerogens	15,000,000
Terrestrial biosphere (total)	2,000
Living biomass	600–1,000
Dead biomass	1,200
Aquatic biosphere	1–2
Fossil fuels	4,130
Coal	3,510
Oil	230
Gas	140
Other (peat)	250

Carbon pools in the major reservoirs on earth

Source: SCIENCE 290(13), 291 - 296, 2000

Estimated Turnover Time of Soil Carbon Based on Mean Carbon Pools and Mean Soil Respirations Rates

Vegetation type	Soil C ($t\ ha^{-1}$)	Soil respiration ($t\ ha^{-1}$)	Turnover[a] (years)
Tundra	204	0.6	490
Boreal forests	206	3.2	91
Temperate grasslands	189	4.4	61
Temperate forests	134	6.6	29
Woodlands	69	7.1	14
Cultivated lands	79	5.4	21
Desert scrub	58	2.2	37
Tropical grasslands	42	6.3	10
Tropical lowland forests	287	10.9	38
Swamps and marshes	723	2.0	520
Global total	15×10^8	5×10^7	32

a) Turnover time is estimated based on the assumption that 30 % of soil respiration is derived from root respiration.

Source: Soil Microbiology and Biochemistry, 2nd ed., by E.A. Paul and F.E. Clark, Academic Press, 1996

Siberian Peatlands a Net Carbon Sink and Global Methane Source Since the Early Holocene

L. C. Smith,[1,2*] G. M. MacDonald,[1,3*] A. A. Velichko,[4] D. W. Beilman,[1] O. K. Borisova,[4] K. E. Frey,[1] K. V. Kremenetski,[1,4] Y. Sheng[1]

Interpolar methane gradient (IPG) data from ice cores suggest the "switching on" of a major Northern Hemisphere methane source in the early Holocene. Extensive data from Russia's West Siberian Lowland show (i) explosive, widespread peatland establishment between 11.5 and 9 thousand years ago, predating comparable development in North America and synchronous with increased atmospheric methane concentrations and IPGs, (ii) larger carbon stocks than previously thought (70.2 Petagrams, up to ~26% of all terrestrial carbon accumulated since the Last Glacial Maximum), and (iii) little evidence for catastrophic oxidation, suggesting the region represents a long-term carbon dioxide sink and global methane source since the early Holocene.

Science, Vol. 303, 353 - 356, 2004

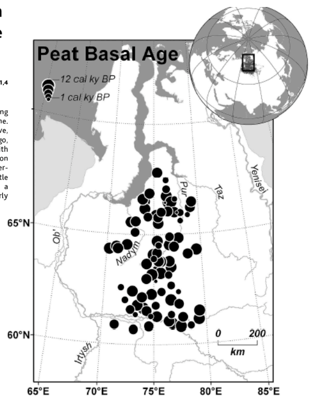

Fig. 1. Location of peat cores drilled in this study. Circle diameters are scaled by basal radiocarbon age. Broad spatial distribution of early Holocene ages [11,500 to 9000 calendar years before present (11.5 to 9 cal ky BP)] confirms that West Siberian peatlands were widely established during this time of high atmospheric methane concentration. Inset shows figure location and geographic extent of our GIS-based peatland inventory.

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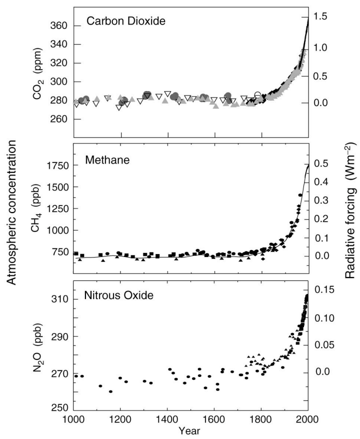
Global atmospheric concentration of three well mixed greenhouse gases



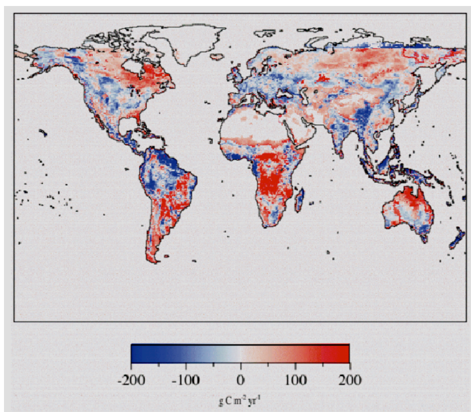


Fig. 1. Predicted global distribution of annual net ecosystem production fluxes in 2001. Net annual source areas are shown in blue, while net annual sink areas are shown in red.

EOS 84(46), 2003

Satellite data help predict terrestrial carbon sinks
Potter et al., EOS Vol. 84(46), 2003

MODIS: Moderate Resolution Imaging Spectroradiometer
Sensor aboard NASA's *TERRA* and *AQUA* satellites

Balance: Net primary production (NPP)
- Soil microbial CO_2 fluxes

Net ecosystem production (NEP)
============================

Observations 2001: Above average temp. was associated with positive NEP
Heavy rainfall was associated with negative NEP

Terrestrial NPP for the globe:
Around 50 Pg C / year
(Trend: increasing!)

Seasonal patterns:
Very pronounced for 30° – 60° North
In summer positive NEP
In winter negative NEP

Literature: Potter et al.

EOS 84(46), 2003

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Major microbial activities in soil involving gaseous species

Mineralization	CH_2O	+	O_2	->	CO_2		
Denitrification	NO_3^-			->	N_2	(N_2O)	
Nitrification	NH_4^+	+	O_2	->	NO_3^-	(N_2O)	
Methanogenesis	CO_2	+	H_2	->	CH_4		
	CH_3COOH			->	CH_4		+ CO_2
Methane oxidation	CH_4	+	O_2	->	CO_2		

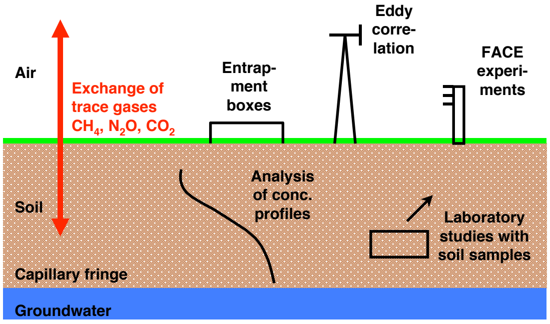
Rough estimates of CH_4 released into the atmosphere (units: 10^{12} g/year)

Total	350	-	820
Biogenic (81 - 86% of total)	302	-	665
Ruminants	80	-	100
Termites	25	-	150
Paddy fields	70	-	120
Natural wetlands	120	-	200
Landfills	5	-	70
Oceans and lakes	1	-	20
Tundra	1	-	5
Abiogenic (14 - 19% of total)	48	-	155
Coal mining	10	-	35
Natural gas flaring and venting	10	-	30
Industrial and pipeline losses	15	-	45
Biomass burning	10	-	40
Methane hydrates	2	-	4
Volcanoes		0.5	
Automobiles		0.5	

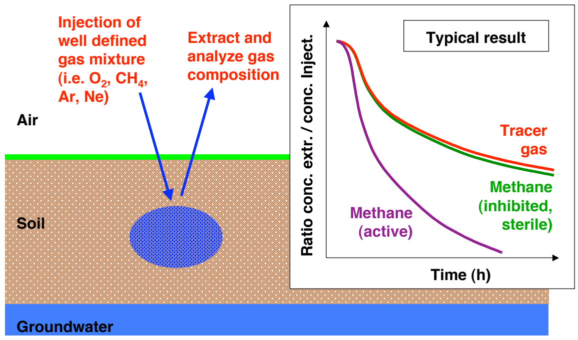
Microbial oxidation reduces flux!

Source: Brock's Biology of Microorganisms

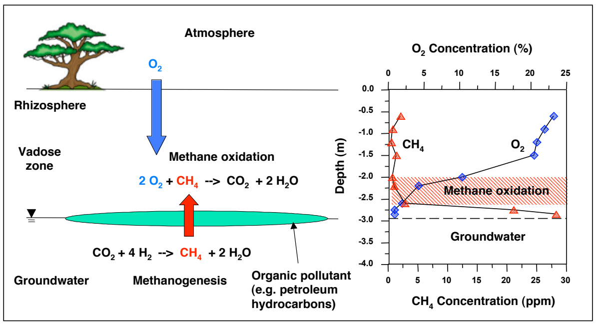
Experimental approaches to determine metabolism and fluxes of trace gases in soil

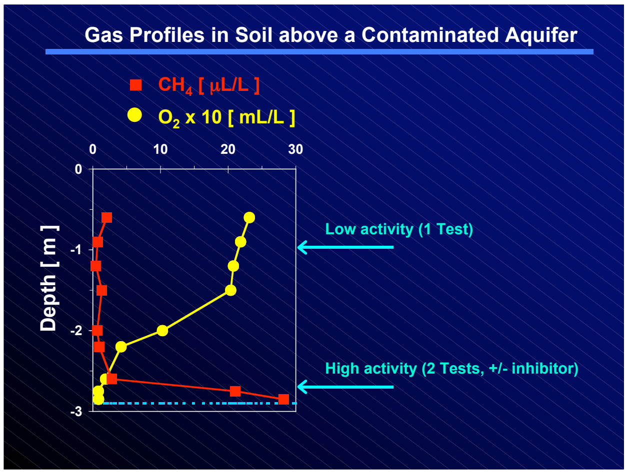


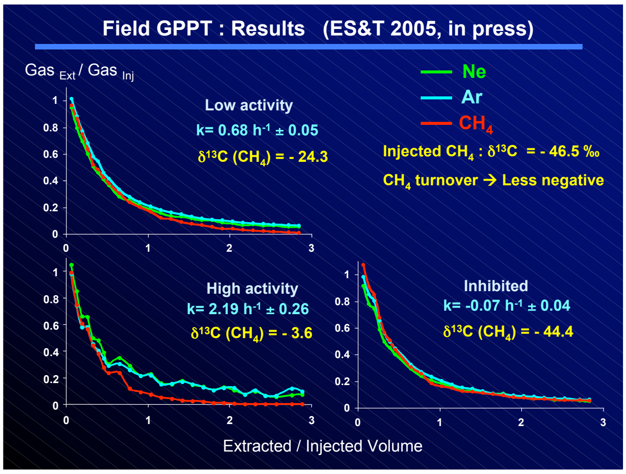
Basic concept of a gas push-pull test (GPPT)
(PPT successfully applied in groundwater!)



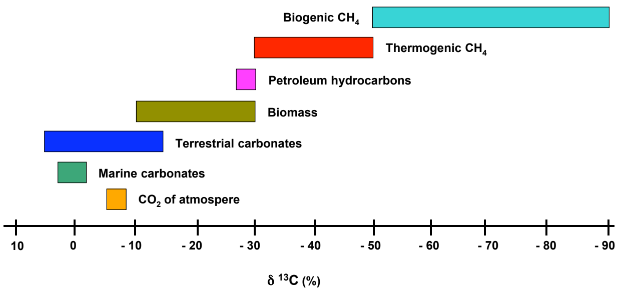
Fate of methane in vadose zone above oil contaminated aquifer (field site Studen)



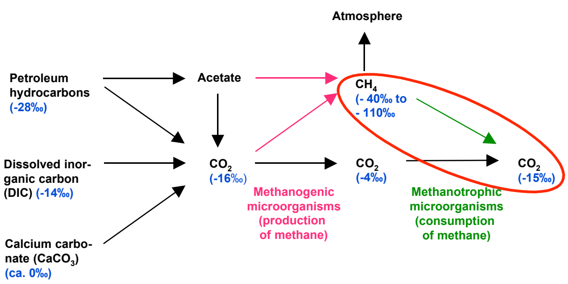




δ ^{13}C values of important carbon reservoirs



Biochemical pathways of methane
(δ^{13}C values in δ^{13}C notation)



Measurement of δ^{13}C in methane:
Rolf Siegwolf, PSI

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