Part 2. The Hydrosphere

Chapter 15.
Microbiological Processes

Chapter 15. Microbiological Processes

15.1 Classification of microorganisms: based on phylum of microbe

- Basic terminology
- Abiotic and biotic reactions:

  -Abiotic reactions: occur through purely physical and/or chemical means

  -Biotic reactions: involve biological component, e.g. microorganisms

- Plankton: free-floating organisms in water

  -phytoplankton: plant component of plankton

  -zooplankton: animal component of plankton

- Phylum: 생물학상의 분류 순서 중 하나
  kingdom(계(界)) 【동물】 phylum, 【식물】 division(문(門)) class(강(綱)) order(목(目)) family(과(科)) genus(속(屬)) species(종(種)) variety(변종(變種))

Chapter 15. Microbiological Processes

15.1 Classification of microorganisms: based on phylum of microbe (cont'd)

- Microorganisms- Bacteria, Fungi, Actinomycetes,
- Bacteria:

-most abundant microorganism in both aqueous and terrestrial environments

-diameters ranging

-high surface/volume ratio

-negative surface charge due to the deprotonated acidic groups

-various morphologies ranging from spherical through ellipsoidal to rod-like

-found in both aerobic and anaerobic conditions, population depends on T, pH, electrolyte conc., nutrient supply, and in the case of soils, the moisture content

-requires a variety of chemical species as nutrients such as N, P, and K

-In sediments and soils, population is a positive fct. with organic matter content. Less than 0.1% of the total mass of the solid material

-In water column itself, population is 5×10^4 mL^{-1} ~ 5×10^7 mL^{-1} , depending on the location, season, position in the water column, and the tropic status of the water

Chapter 15. Microbiological Processes

15.1 Classification of microorganisms: based on phylum of microbe (cont'd)

- Fungi:

  -ubiquitous and diverse category of microorganism

  -always require presynthesized comp'ds as carbon source

  -play a key role in the degradation of litter in soil, i.e. in the reaction chains resulting in formation of humic materials

  -prefer acidic conditions. C.F. bacteria prefer neutral to slightly alkaline environments

  -fibrous morphology, and hence high surface/volume ratio

- Actinomycetes (방선균):

  -a class of unicellular organisms

  -found in both aquatic, and aerobic and dry terrestrial situations

  -more abundant in warm climates and are particularly numerous in tropical grasslands

  -sensitive to acidity but are able to tolerate higher salt conc. than many bacteria

  -involved in degradation processes in both water and soil, and also produce natural antibiotics that control the populations of coexisting microorganisms

Chapter 15. Microbiological Processes

15.1 Classification of microorganisms: based on phylum of microbe (cont'd)

- Algae:

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  -size ranges from microscopic to large plant-like structures

  -abundant in the upper epilimnion (표수층(表水層)) of eutrophic (부영양[富營養]) water bodies as well as in the moist surface layer of soil

  -produce new organic matter, i.e play an important role in converting inorganic carbonate into organic forms. C.F. bacteria and actinomycete are essentially degraders of pre-existing organic structures

  -can cope with great temperature extremes and are present in lakes and rivers in all parts, even in polar ice as well as in hot springs

- Protozoa (원생동물문):

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  -commonly 5~50 μm in size and found in both water and in ground

  -prefer warm (18~30 ^{0}C), well oxygenated, and with

  -Being consumers of bacteria and other microorganisms, protozoa regulate the total microbial population

Chapter 15. Microbiological Processes

15.1 Classification of microorganisms: based on ecological characteristics

- Autochthonous microorganisms:

- Allochthonous microorganisms:

15.1 Classification of microorganisms: by carbon source

- Autotrophs: microorganisms that are capable of growing in a completely inorganic medium using carbonate species as their sole source of carbon

-photoautotrophs: e.g. most , - use solar radiation as an energy source for their synthetic processes

-chemoautotrophs: e.g. most , - derive energy from chemical oxidation reaction

$$2NH_4^+(aq) + 3O_2 + H_2O \rightarrow 2NO_2^-(aq) + 4H_3O^+(aq)$$

- Heterotrophs: microorganisms that make use of presynthesized organic compounds as a carbon source, i.e. plant and animal residues in water and soil. E.g. Fungi, actinomycetes, protozoa and most bacteria

Chapter 15. Microbiological Processes

15.1 Classification of microorganisms: by source of electron acceptor

- : a large category of microorganisms that use molecular oxygen, either in gaseous form or dissolved in water, as the electron acceptor for their oxidation reactions. i.e. $O_2 + 4H_3O^+ (aq) + 4e^- \rightarrow 6H_2O$
- : have the capability of effecting oxidation without molecular oxygen. Instead, they use other electron poor species, e.g. sulfate, to accept electrons from the reduced substrate. The electron acceptor species is converted into a more reduced form: $SO_4^{2-} (aq) + 9H_3O^+(aq) + 8e^- \rightarrow HS^-(aq) + 13H_2O$

15.1 Classification of microorganisms: by temperature preference

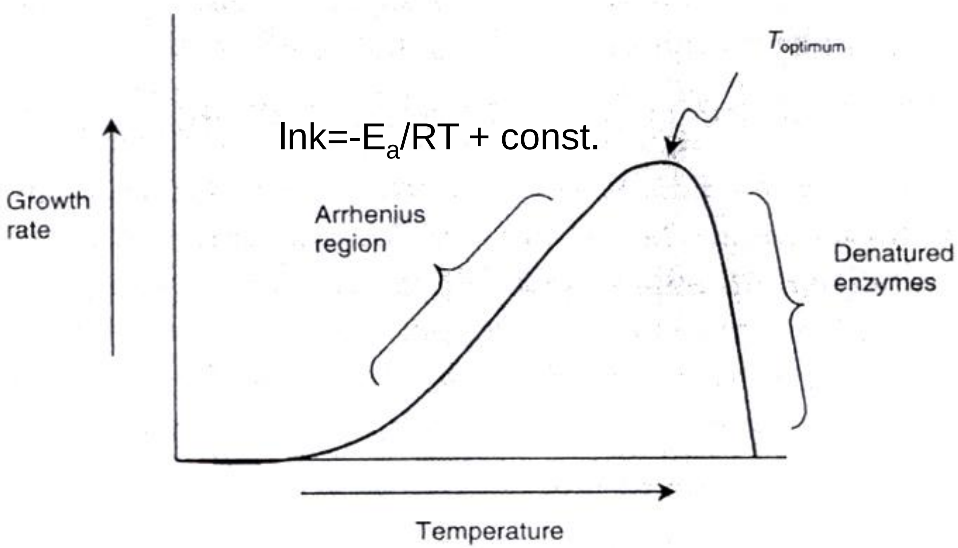

Fig. 15.1 Growth rate vs. temperature for micro-organisms.

- Psychrophiles: $T_{opt} < 20\ ^0C$
- Mesophiles: T_{opt} 20~45 ^0C (most common)
- Thermophiles: $T_{opt} > 45\ ^0C$

Chapter 15. Microbiological Processes

15.2 Microbiological processes – the carbon cycle

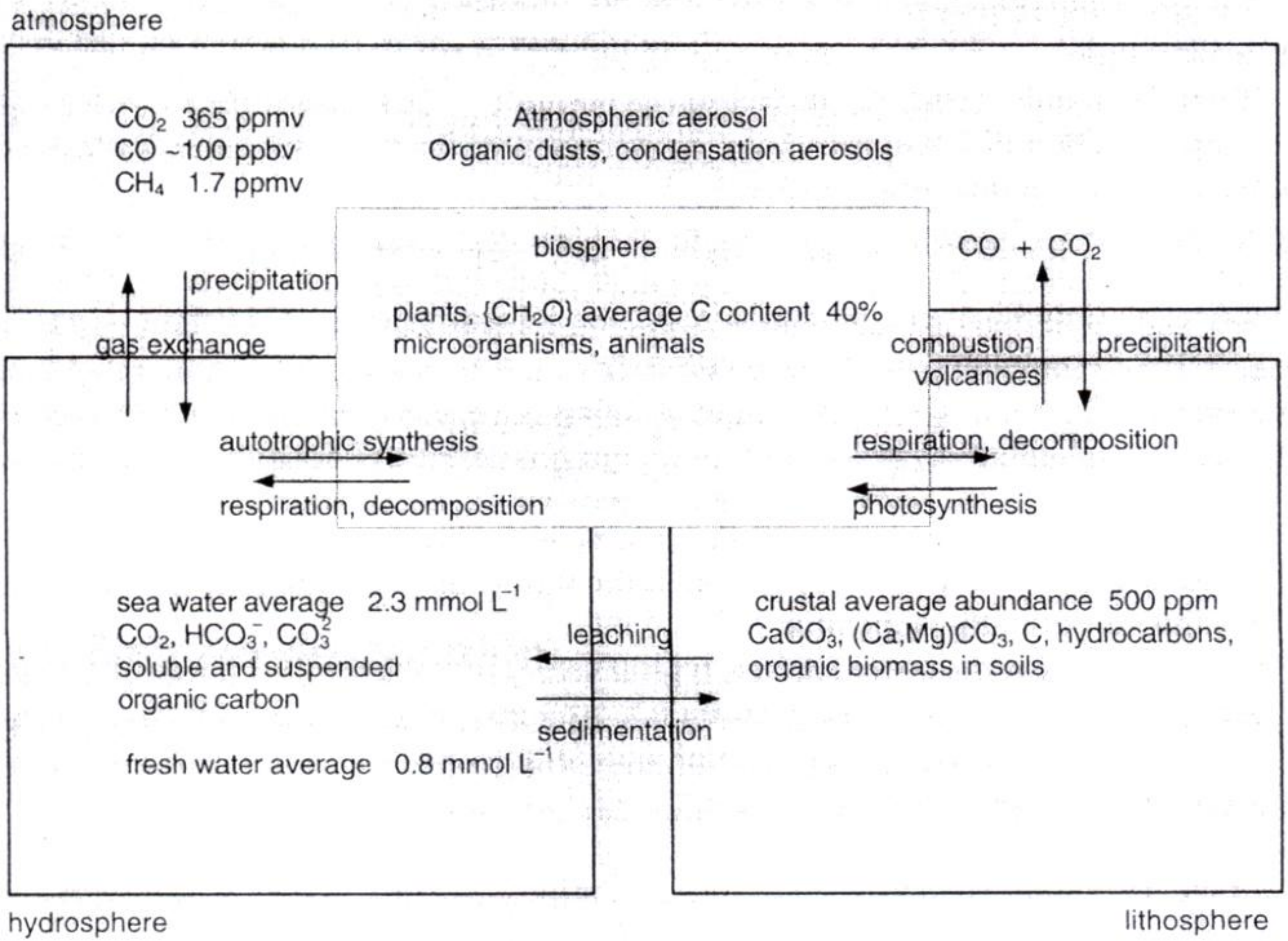

Fig. 15.2 The carbon cycle—a summary of principal processes in the environment.

Chapter 15. Microbiological Processes

15.2 Microbiological processes – the carbon cycle

15.2.1 Carbon species in water and on land

- Three major reservoirs of carbon on land: carbonate rocks, limestone ($CaCO_3$), and dolomite ($(Ca,Mg)CO_3$)
- The second major carbon reservoir in the Earth: fossil fuels of the types of solid coal, liquid petroleum, and natural gas
- The third large terrestrial reservoir of carbon: organic material in various stages of chemical modification, on or in the soil.
- In the surface of the oceans which plays a major role in establishing and maintaining the global carbon balance,

  $$CaCO_3 + CO_2(aq) + H_2O \leftrightarrow Ca^{2+}(aq) + 2HCO_3^-(aq) \quad (15.6)$$

  the surface water is highly supersaturated w.r.t $CaCO_3$ and a colloidal precipitate is formed.
- In the deep water situation, the water is under saturated.

Chapter 15. Microbiological Processes

15.2 Microbiological processes – the carbon cycle

15.2.2 Oxygen

- Molecular Oxygen is reduced

$O_2 + 4H_3O^+ (aq) + 4e^- \rightarrow 6H_2O \quad pE^0(w) = +13.80 \quad (15.8)$

- Overall reaction for oxidation of biomass by oxygen

$\{CH_2O\} + O_2 \rightarrow CO_2 + H_2O$ (from eqn (15.7) + eqn (15.8))

(because $\{CH_2O\} + 5H_2O \rightarrow CO_2 (g) + 4H_3O^+(aq) + 4e^-$ (15.7) for the decomposition of biomass)

$pE^0(w)_1 = pE^0(w)_{O2} - pE^0(w)_{CH2O} = +22.00$

Gibb's free energy for the oxidation at 298K is a 4 electron process, and

$\Delta G_0(w)_1 = -2.303nRTpE_0(w)_1 = -500\ kJ$

Chapter 15. Microbiological Processes

15.2 Microbiological processes – the carbon cycle

15.2.3 Nitrate

- Nitrate can serve as an electron acceptor, being reduced to nitrate, ammonium ion, nitrous oxide, or dinitrogen gas depending on environmental circumstances. The reduction reaction producing dinitrogen gas is important as a link in the global nitrogen cycle and the equation for it is

$$2NO_3^- + 12H_3O^+ (aq) + 10e^- \rightarrow N_2 + 18H_2O \quad pE^0(w) = +12.65 \qquad (15.10)$$

- When coupled with oxidation of carbohydrate, the overall reaction is

$$4NO_3^- + 5\{CH_2O\} + 4H_3O^+ (aq) \rightarrow 2N_2 + 5CO_2 + 11H_2O \text{ (denitrification rxn)}$$

$$pE^0(w)_2 = pE^0(w)_{NO3-} - pE^0(w)_{CH2O} = +20.85$$

Gibb's free energy for the reaction at 298K is a 20 electron process is

$$\Delta G_0(w)_2 = -2.303nRTpE_0(w)_2 = -2380 \text{ kJ}$$

In terms of 1 mol of $\{CH_2O\}$ = -480 kJ (this value indicates that nitrate is capable of oxidizing OM in the absence of oxygen)

Chapter 15. Microbiological Processes

15.2 Microbiological processes – the carbon cycle

15.2.4 Sulfate

Where oxygen and nitrate are both absent and sulfate is present, the latter species may serve as an electron accptor for the oxidation of organic matter :

$$SO_4^{2-}(aq) + 9H_3O^+(aq) + 8e^- \rightarrow HS^-(aq) + 13H_2O \qquad \text{pE°(w)} = \text{-3.68} \qquad (15.12)$$

The overall reaction is obtained by combining reactions 15.7 and 15.12 :

$$2\{\mathrm{CH}_2O\} + H_3O^+(aq) + SO_4^{2-}(aq) \rightarrow HS^-(aq) + 2CO_2 + 3H_2O \qquad (15.13)$$

The pE°(w) and Gibb's free energy are calculated as before :

$$pE°(w)_3 = pE°(w)_{SO_4^{2-}} - pE°(w)_{CH_2O}$$

$$= -3.68 - (-8.20)$$

$$= +4.52$$

$$\Delta G° = (w, 1\,\mathrm{mol})_3 = -103 kJ$$

Again, the $\Delta G°$ calculated here is for one mole of $\{\mathrm{CH}_2O\}$. The negative value indicates that oxidation by sulfate is also thermodyn amically favourable . This reaction is important, in marine sediments where there is abundance of sulfate available in the sea water.

Chapter 15. Microbiological Processes

15.2 Microbiological processes – the carbon cycle

15.2.5 No Oxidants present

In an environmen t in which no oxygen, nitrate, or sulfate is present, organic matter may still undergo oxidation by means of anaerobic reactions leading to a variety of products. The ultimate products of anaerobic decomposit ion include methane and are via internal redox processes, or redox disproport ion reactions. The overall reduction half reaction is

$$CO_2 + 8H_3O^+(aq) + 8e^- \rightarrow CH_4 + 10H_2O \qquad \mathrm{pE°}(w) = -4.13 \qquad (15.14)$$

Combining 15.14 with the half reaction for the oxidation of carbohydra te (15.7) gives the followin goverall redox process :

$$2\{\mathrm{CH_2}O\} \rightarrow CH_4 + CO_2 \qquad (15.15)$$

The pE°(w) and Gibb' s free energy are

$$\mathrm{pE°(w)} = \mathrm{pE°(w)}_{\mathrm{CO_2}} - \mathrm{pE°(w)}_{\mathrm{CH_2O}}$$

$$= -4.13 - (-8.20)$$

$$= +4.07$$

$$\Delta\mathrm{G°(w, 1\,mol)}_4 = -93kJ$$

Thermodyna mically th e least favored rxn of the four abovementi oned rxns.