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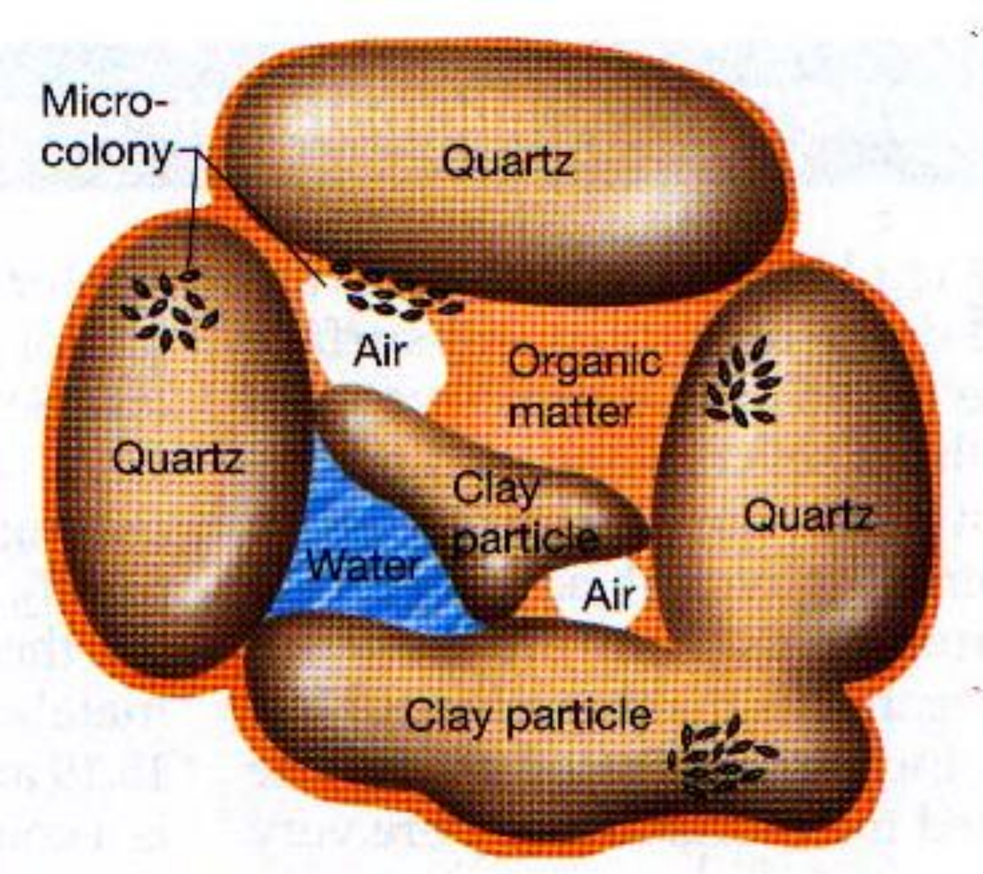
Microbial Ecology



Chapter outline

9.1 Microorganisms in nature ecosystem

9.2 Microbial population interactions

9.3 Biogeochemical cycles

9.4 Plant-microbe interactions

9.5 Bioremediation

Concepts

- Microbial ecology is the study of microbial relationship with other organisms and also with nonliving environments. These relationships, based on interactive uses of resources, have effects extending to the global scale.
- Methods used to study microbial interaction and microbial ecology provide information on environmental characteristics; microbial biomass. Numbers, types and activity, and community structure. Microscopic, chemical, enzymatic and molecular techniques are used in these studies.

Microbial ecology = ? Environmental microbiology

Microbial ecology

- The term microbial ecology is now used in a general way to describe the presence and distributions of microorganisms.

- Microbial ecology is the the study of the behavior and activities of microorganisms in their natural environments.

Environmental microbiology

- Environmental microbiology is relates primarily to all over microbial processes that occur in a soil, water or food, as examples.
- It is not concerned with the particular micro-environment where the microorganisms actual ly are functioning, but with the broader-scale e ffects of micro-bial presence and activities.

9.1 Microorganisms in Nature Ecosystem

1. Microorganisms and Microenvironment
2. Terrestrial Environments
3. Freshwater Environments
4. Marine Environments

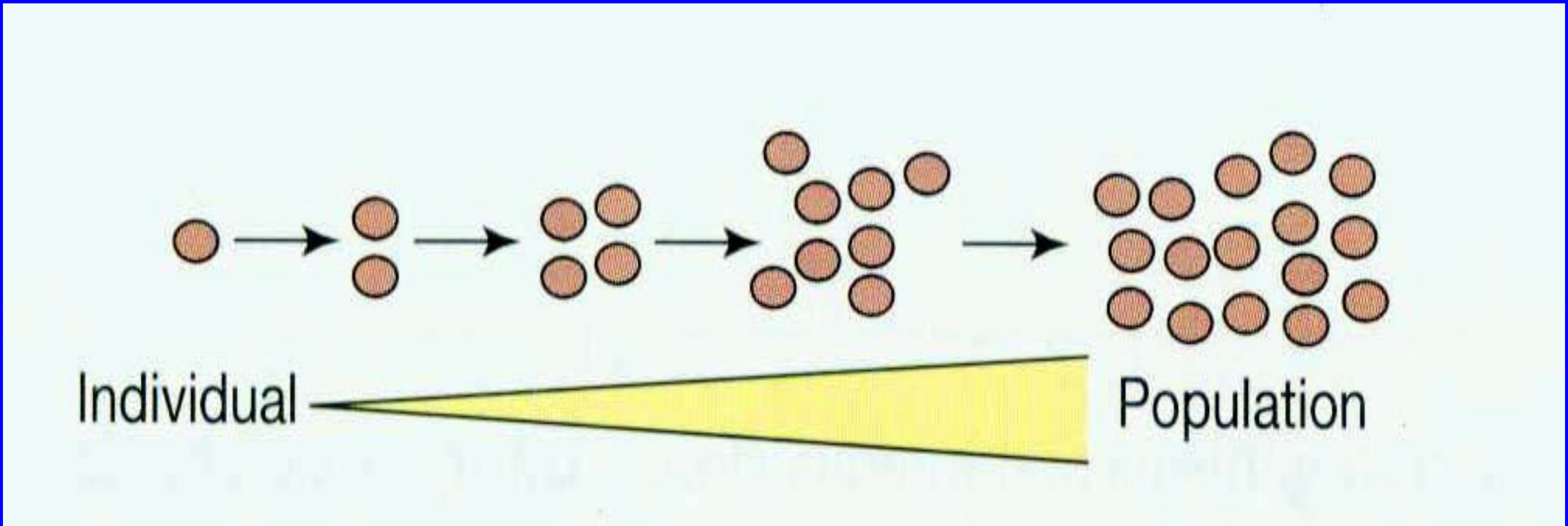
Microorganisms and Microenvironment

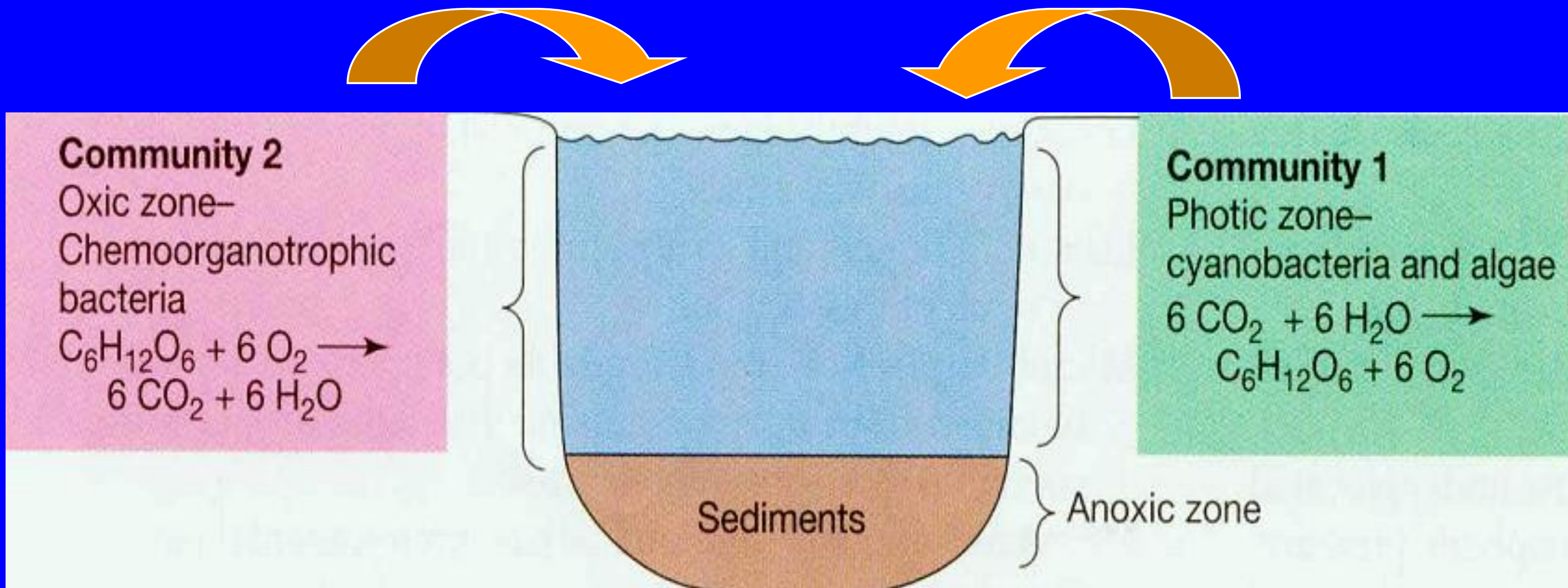
- **Populations**
- **Guilds**
- **Communities**
- **Ecosystem**

In a microbial ecosystem individual cells grow to form **populations**.

Metabolically related populations constitute groupings called **guilds**.

Sets of guilds conducting complementary physiological processes interact to form microbial **communities**.


Individual
Population



Community 2
Oxic zone–
Chemoorganotrophic
bacteria
$C_6H_{12}O_6 + 6\ O_2 \longrightarrow 6\ CO_2 + 6\ H_2O$
Community 1
Photic zone–
cyanobacteria and algae
$6\ CO_2 + 6\ H_2O \longrightarrow C_6H_{12}O_6 + 6\ O_2$
Sediments
Anoxic zone

Community 3

1. Guild 1: methanogenic bacteria ($CO_2 \longrightarrow CH_4$)
   homoacetogenic bacteria ($CO_2 \longrightarrow$ acetate)

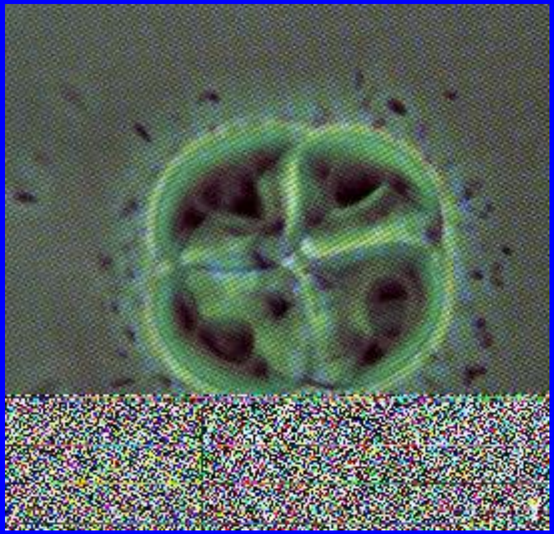
2. Guild 2: sulfate-reducing bacteria ($SO_4^{2-} \longrightarrow H_2S$)
   sulfur-reducing bacteria ($S^0 \longrightarrow H_2S$)

3. Guild 3: denitrifying bacteria ($NO_3^- \longrightarrow N_2$)
   ferric iron-reducing bacteria ($Fe^{3+} \longrightarrow Fe^{2+}$)

4. Guild 4: fermentative bacteria (fermenting sugars, amino and fatty acids, and so on)

Ecosystem

Microbial communities then interact with communities of microorganisms to define the entire ecosystem.



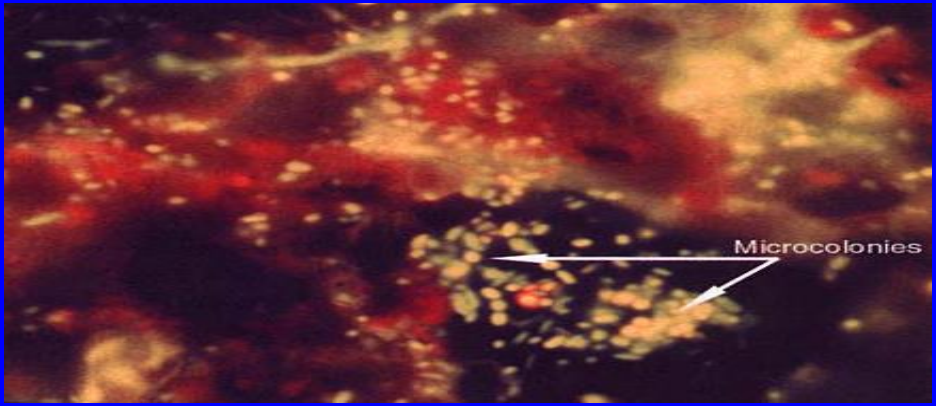
A Simple Ecosystem. An alga,which releases photosynthetically generated oxygen and organic matter to its enviroment ,is surrounded by chemoheterotrophs that are using these products of primary production.

Microorganisms in Nature

Distribution of microorganisms In:

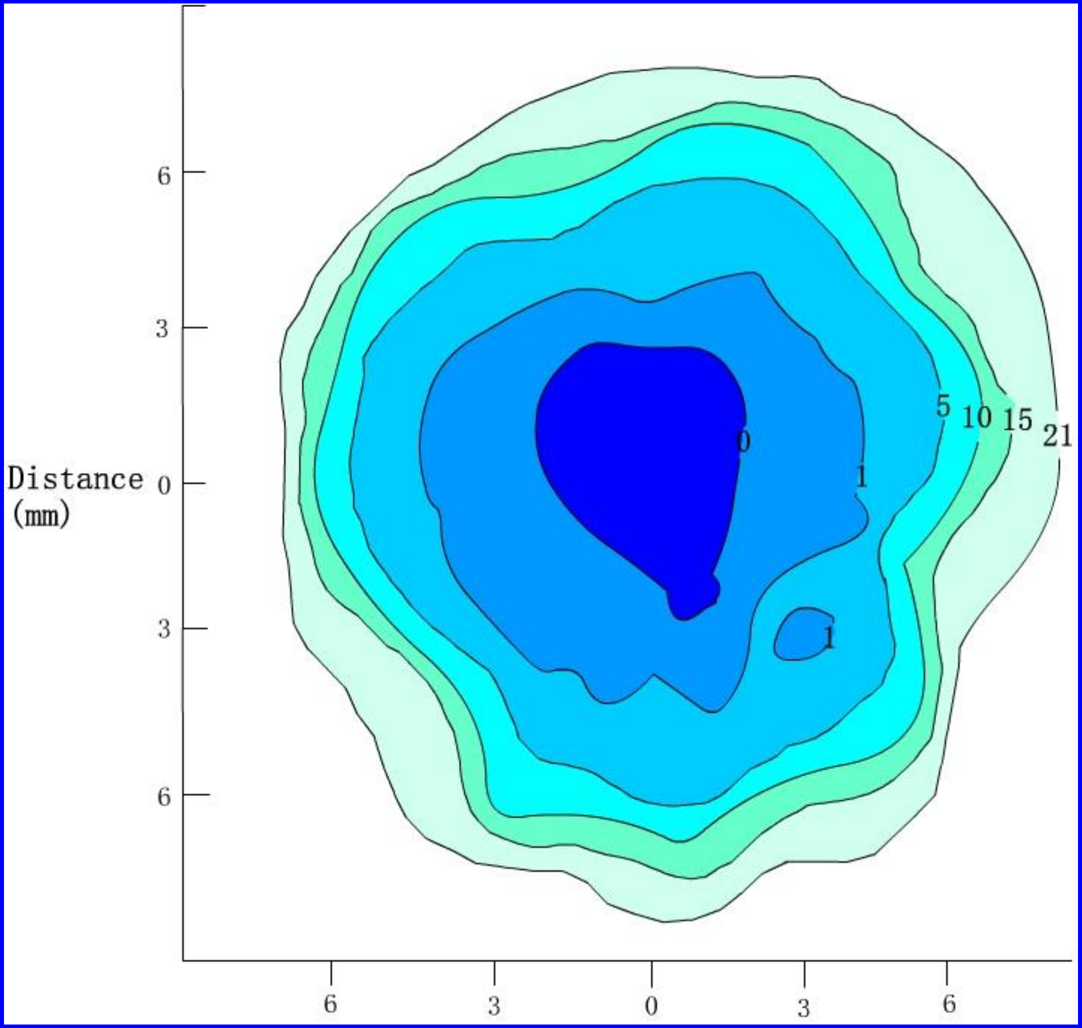
- Soil
- Water
- Air
- Food
- With plants and animals

Terrestrial Environments



1. The distribution of microorganisms in nature ecosystem depends on the resources (nutrients) available and on the growth conditions.

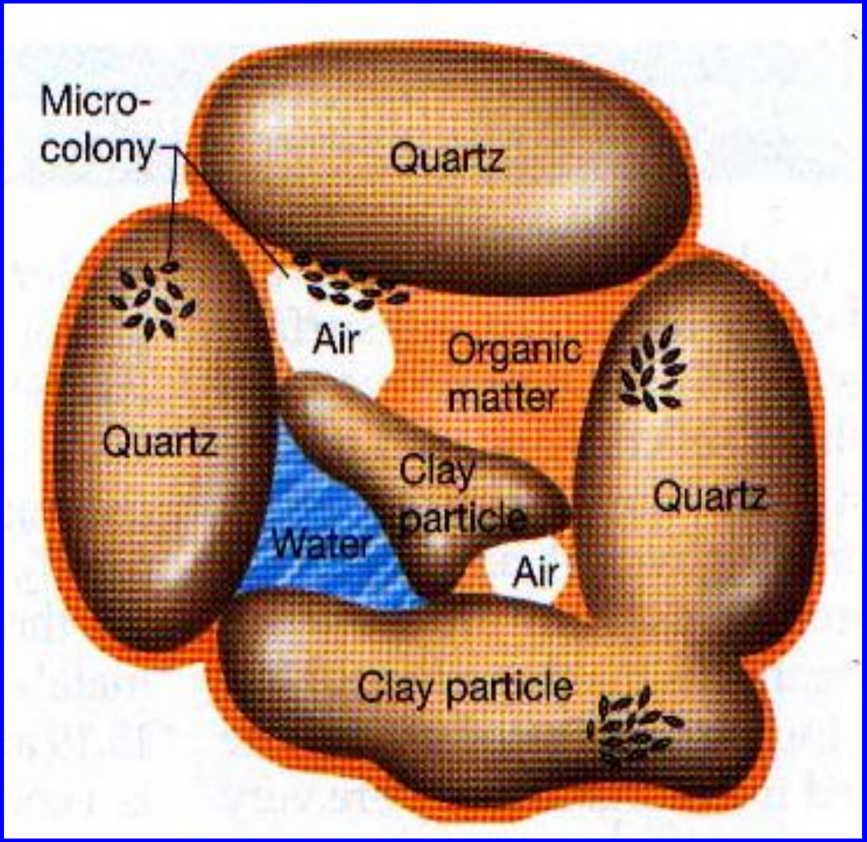
2. Temperature, pH, water availability, light, oxygen of a habitat define the niche for each particular microorganism.



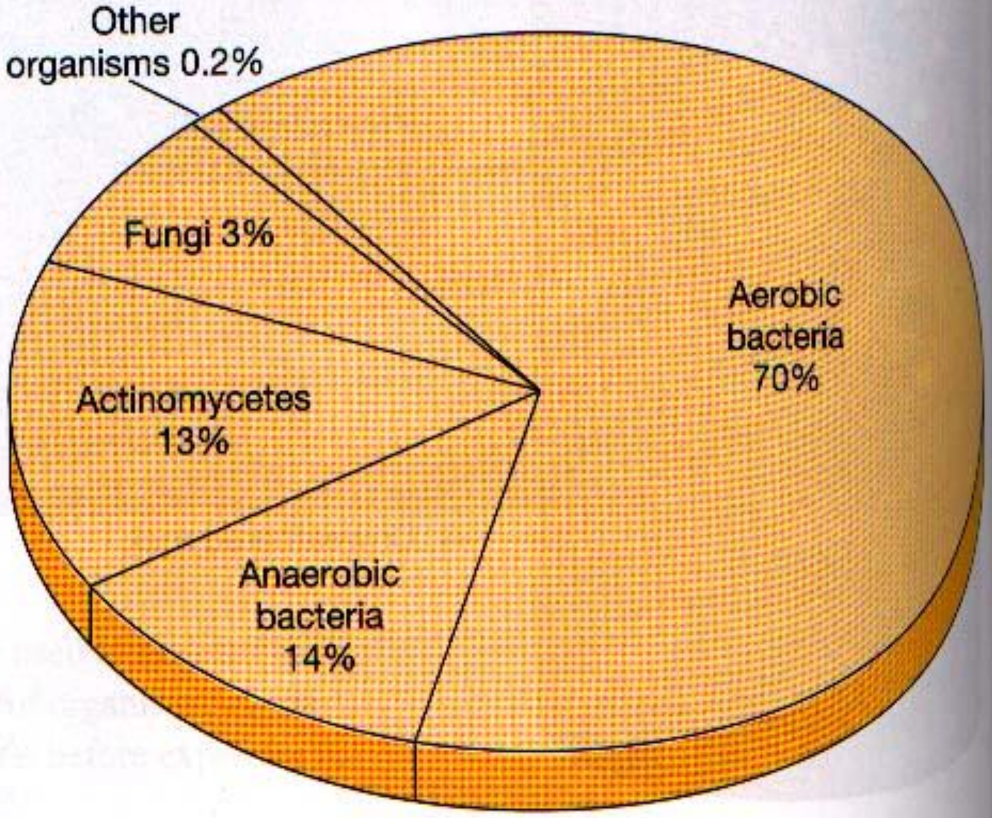
Soil particles are not homogeneous in terms of their oxygen content. The outer zones of a small soil particle may be fully oxic, whereas the center, only a very short distance away, can remain completely anoxic.

A soil aggregate composed of mineral and organic components, showing that localization of soil microbes.

Very few microorganisms are found free in the soil solution; most of them occur as microcolonies attached to the soil particles.



Proportion of different soil microorganisms in soil



➤ Figure 25.12 **The relative proportions of various kinds of organisms found in soil.** "Other organisms" include such things as algae, protists, and viruses.

Microbial number and biomass in cultivated field soil（15 cm）

Microbos	Number /g	Biomass(g/m^3)
Bacteria	10^8	160
Fungi	10^5	200
Actinomycets	10^5 - 10^6	160
Algae	10^4 - 10^5	32
Protozoa	10^4	38

Main types of soil microorganisms

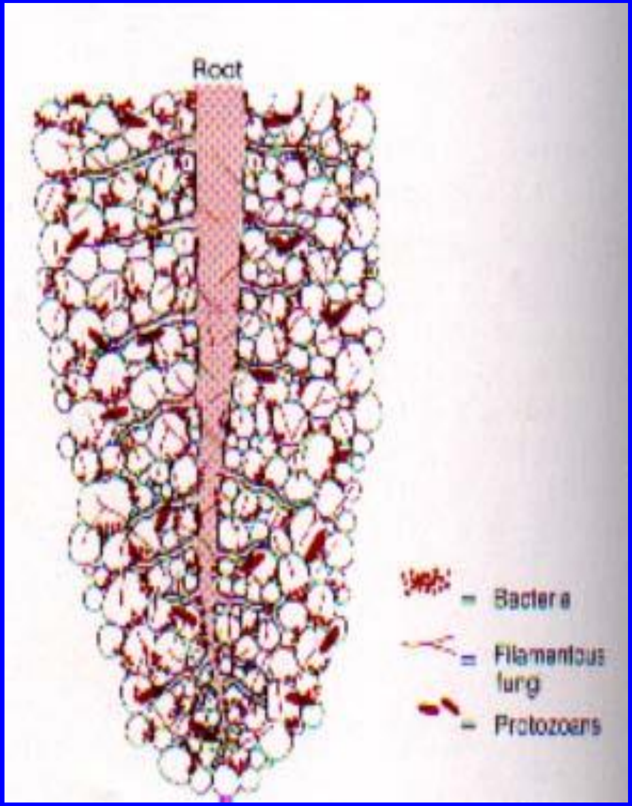
Agrobacterium	*Alcaligenes*
Arthrobacter	*Bacillus*
Caulobacter	*Cellulomonas*
Clostridium	*Corynebacterium*
Flavobacterium	*Micrococcus*
Mycobacterium	*Pseudomonas*
Staphylcoccus	

Rhizosphere Effect

(R/S ratio)

The rhizosphere is the soil region in close contact with plant roots.

Within the rhizosphere, the plant roots exert a direct influence on the soil bacteria. This influence is known as the rhizosphere effect.



In the rhizosphere, microbial populations reach much higher densities in the rhizosphere than in the free soil.

Microbial populations in the rhizosphere may benefit the plant by:

(1) removing hydrogen sulfide, which is toxic to the plant roots

(2) increasing solubilization of mineral nutrients needed by the plant for growth

(3) synthesizing vitamins, amino acids, auxins, gibberellins that stimulate plant growth

(4) antagonizing potential plant pathogens through competition and the production of antibiotics

9.2 Microbial population interactions

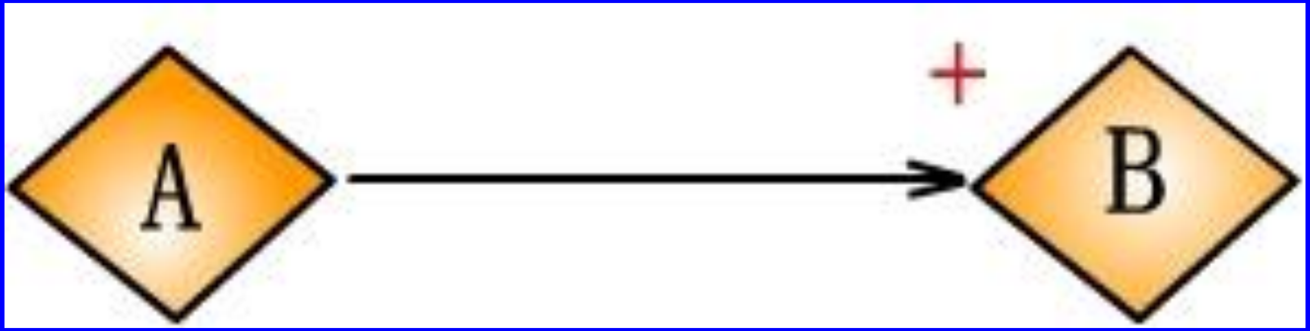
1. neutralism
2. commensalism
3. synergism
4. mutualism
5. competition
6. antagonism
7. parasitism
8. predation

- **Neutralism**

  there is no any physiological effect between the populations.

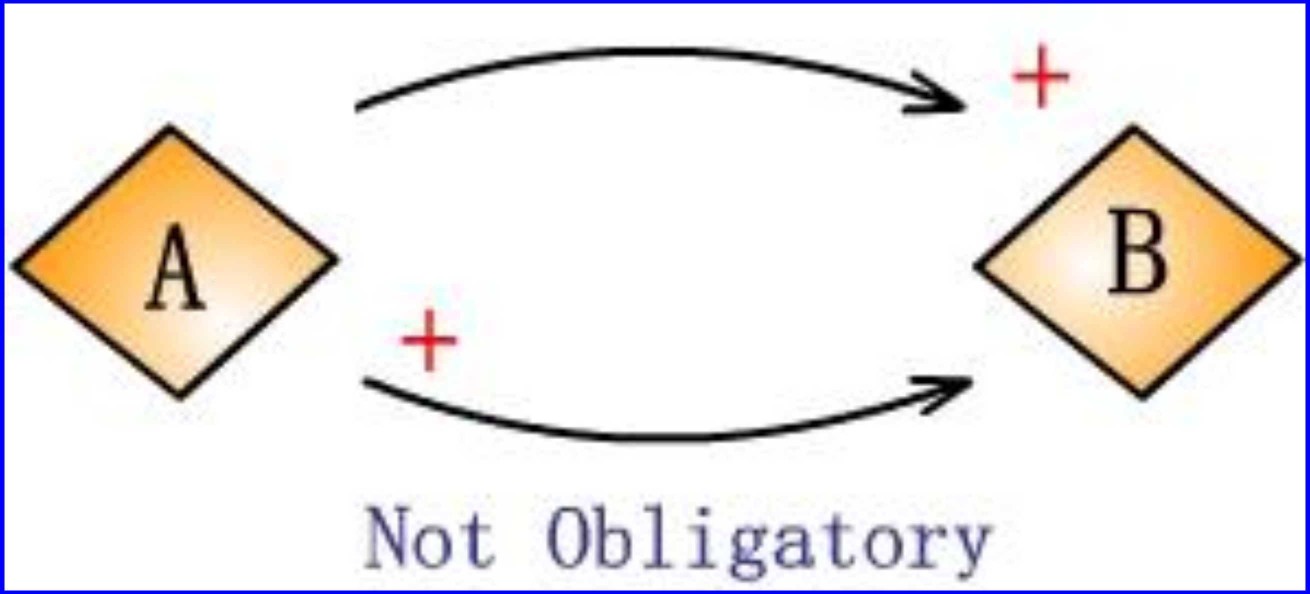
- **Commensalism**

  Commensalism is a unidirectional relationship betwen populations in which one population benefits and the other one isunaffected.



❖ Synergism

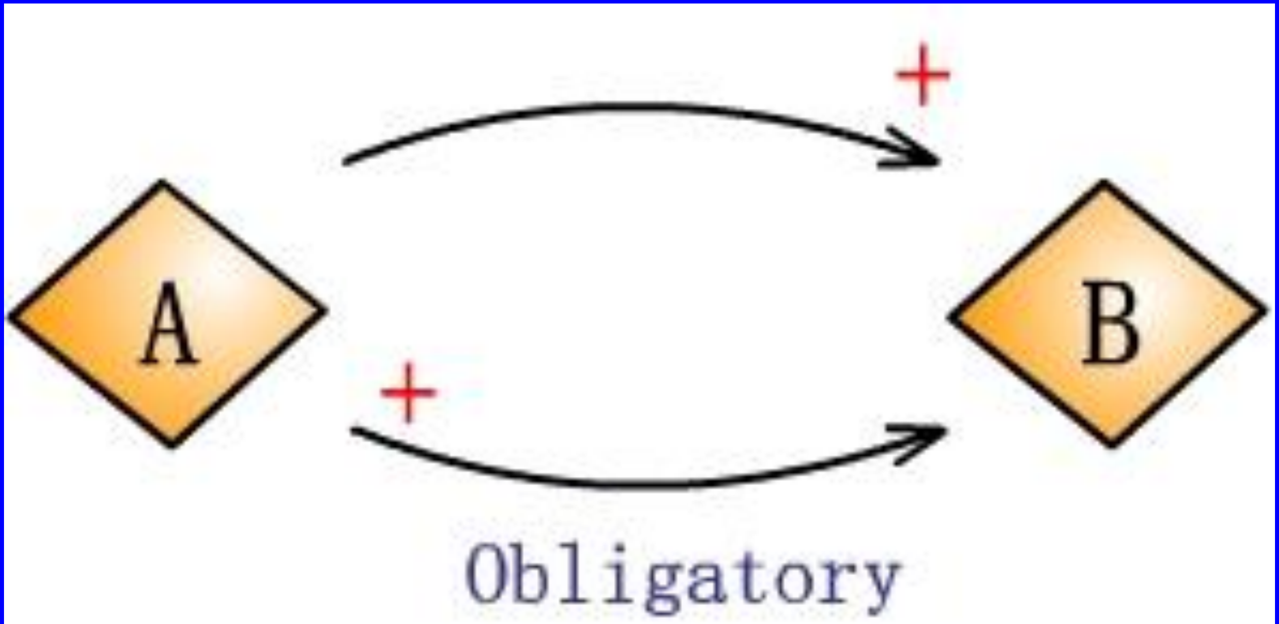
Synergism indicates that both populations benefit from the relationship but the association is not obligatory. Both populations are capable of surviving independently.



❖ Mutualism Symbiosis

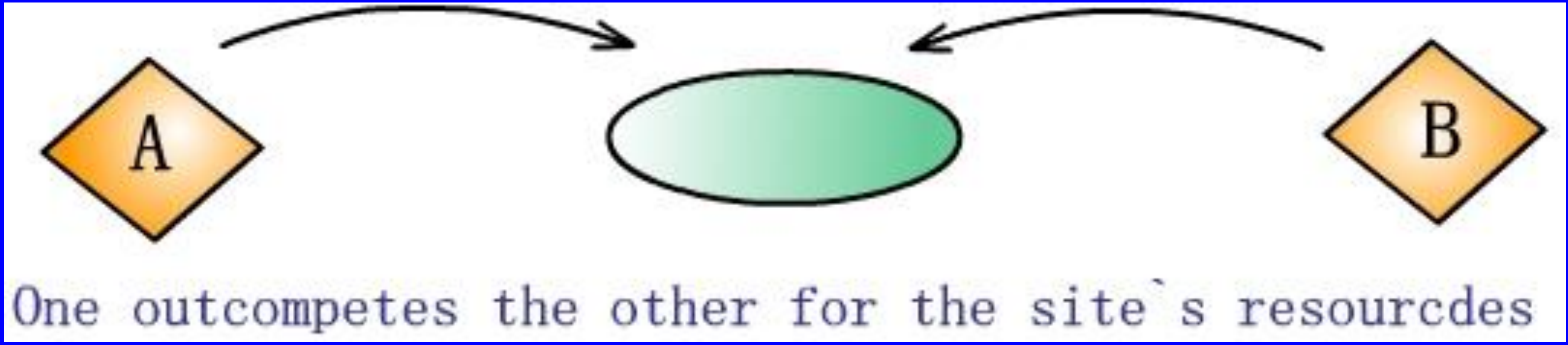
Mutualism Symbiosis is an obligatory inter-relationship between two populations that benefits both of them.

Lichens is composed of a fungus and an alga.



❖ Competition

Competition occurs when two populations are striving for the same resource of nutrients or the habitat.



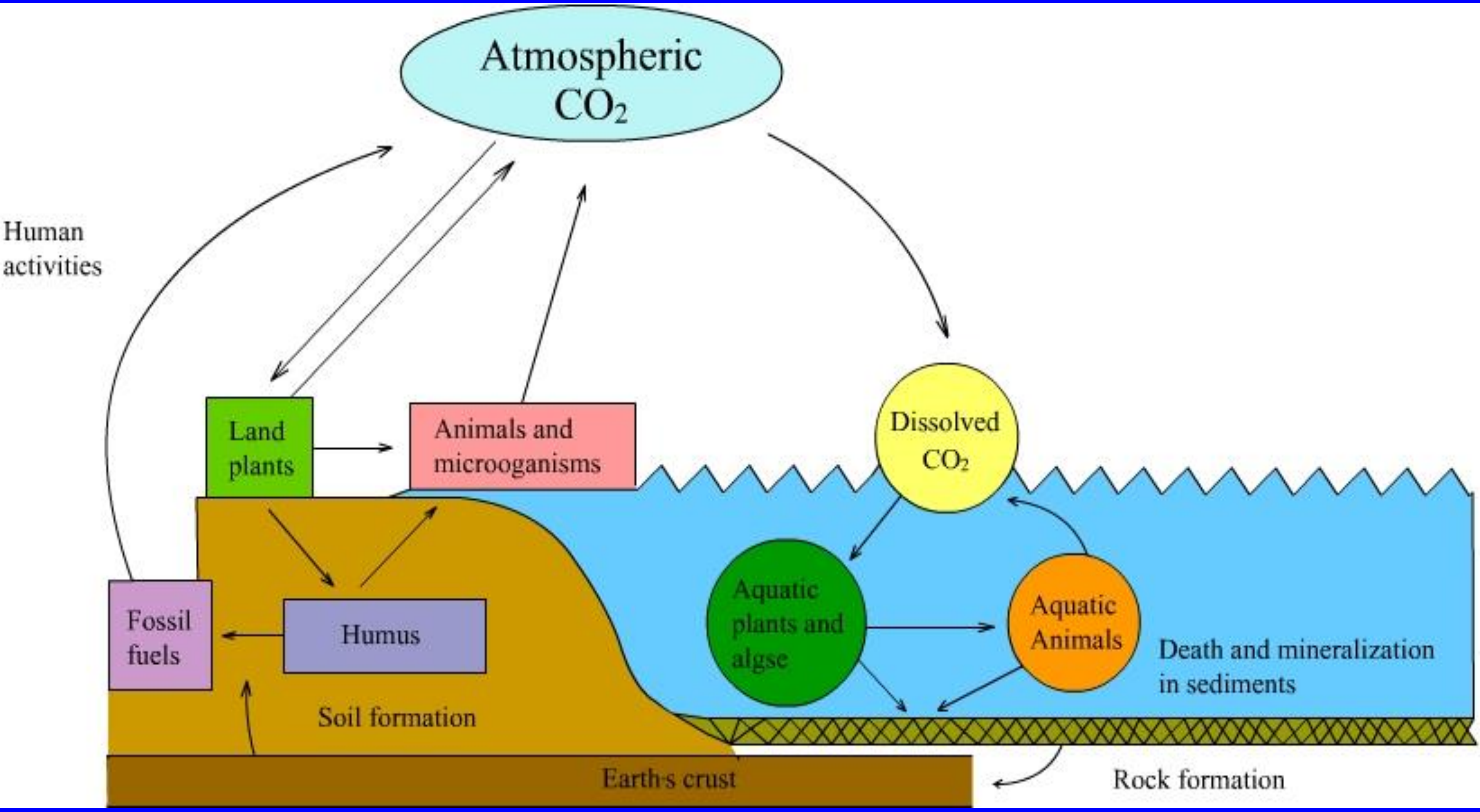
❖ Antagonism

Antagonism occurs when one population produces a substrate inhibitory to another population.

9.3 Biogeochemical Cycles

1. Carbon cycle
2. Nitrogen cycle
3. Sulfur cycle
4. Iron cycle

Carbon cycle

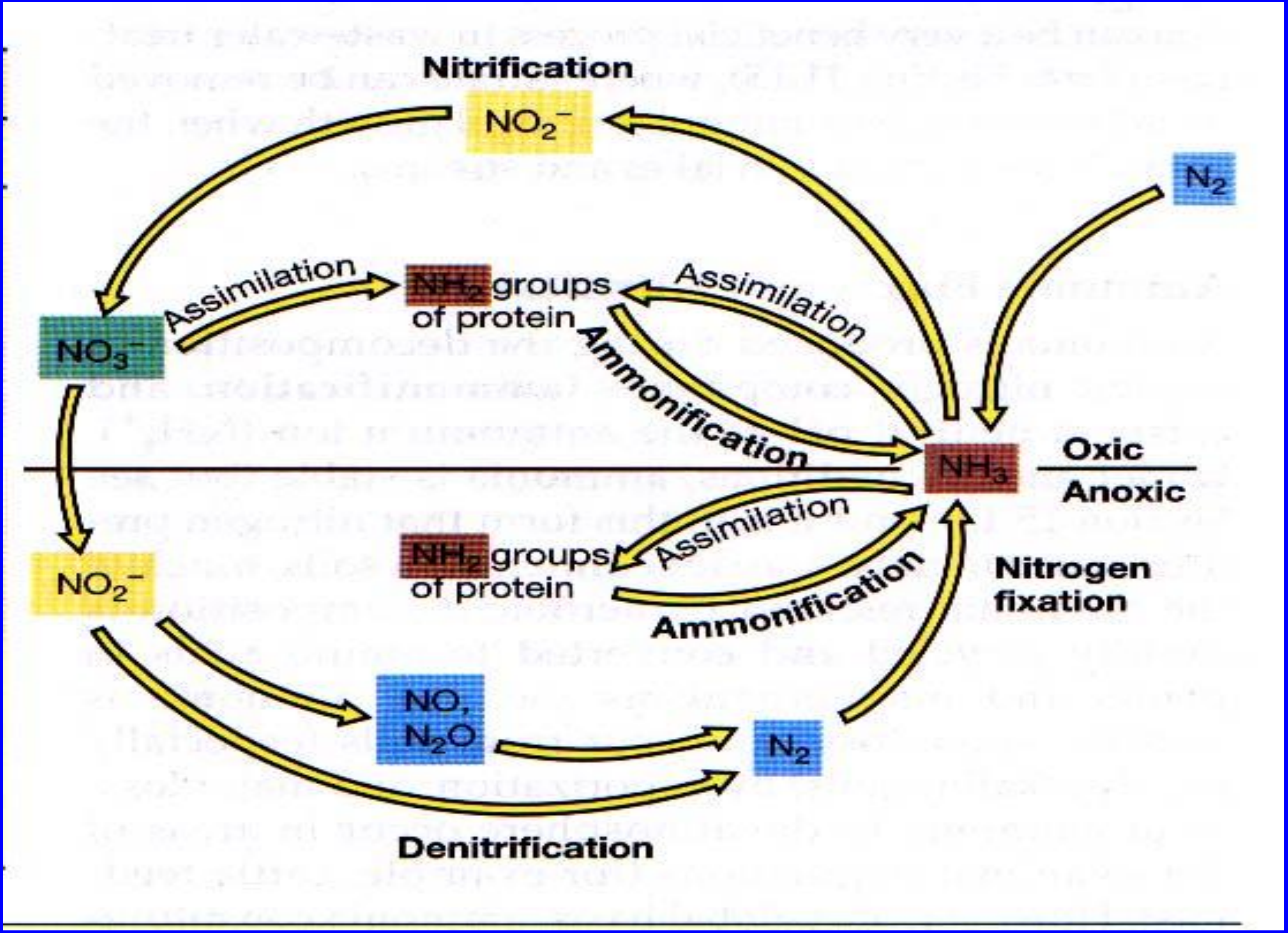


Carbon dioxide is incorporated, or fixed, into organic compounds by such photoautotrophs as cyanobacteria, green plants, algae, and green and purple sulfur bacteria.

Chemoheterotrophs consume the organic compounds, animals eat photoautotrophs, especially green plants, and may in turn be eaten by other animals.

When the organisms die, the organic compounds of their bodies are deposited in the soil and are decomposed by microorganisms, principally by bacteria and fungi. During this decomposition, carbon dioxide is returned to the atmosphere.

Nitrogen cycle



Proteins from dead cells and waste products $\xrightarrow{\text{Microbial decomposition}}$ Amino acids

Almost all the nitrogen in the soil exists in organic molecules, primarily in proteins. When an organism dies, the process of microbial decomposition results in the hydrolytic breakdown of proteins into amino acids.

Amino acids $\xrightarrow{\text{ammonification}}$ Ammonia (NH_3)

The amino groups of amino acids are removed and converted into ammonia (NH_3). Ammonification is brought about by numerous bacteria and fungi.

Nitrification involves the oxidation of the ammonium ion to nitrate

$$NH_4^+ \xrightarrow{\textit{Nitrosomonas}} NO_2^-$$

Ammonium ion → Nitrite ion

$$NO_2^- \xrightarrow{\textit{Nitrobacter}} NO_3^-$$

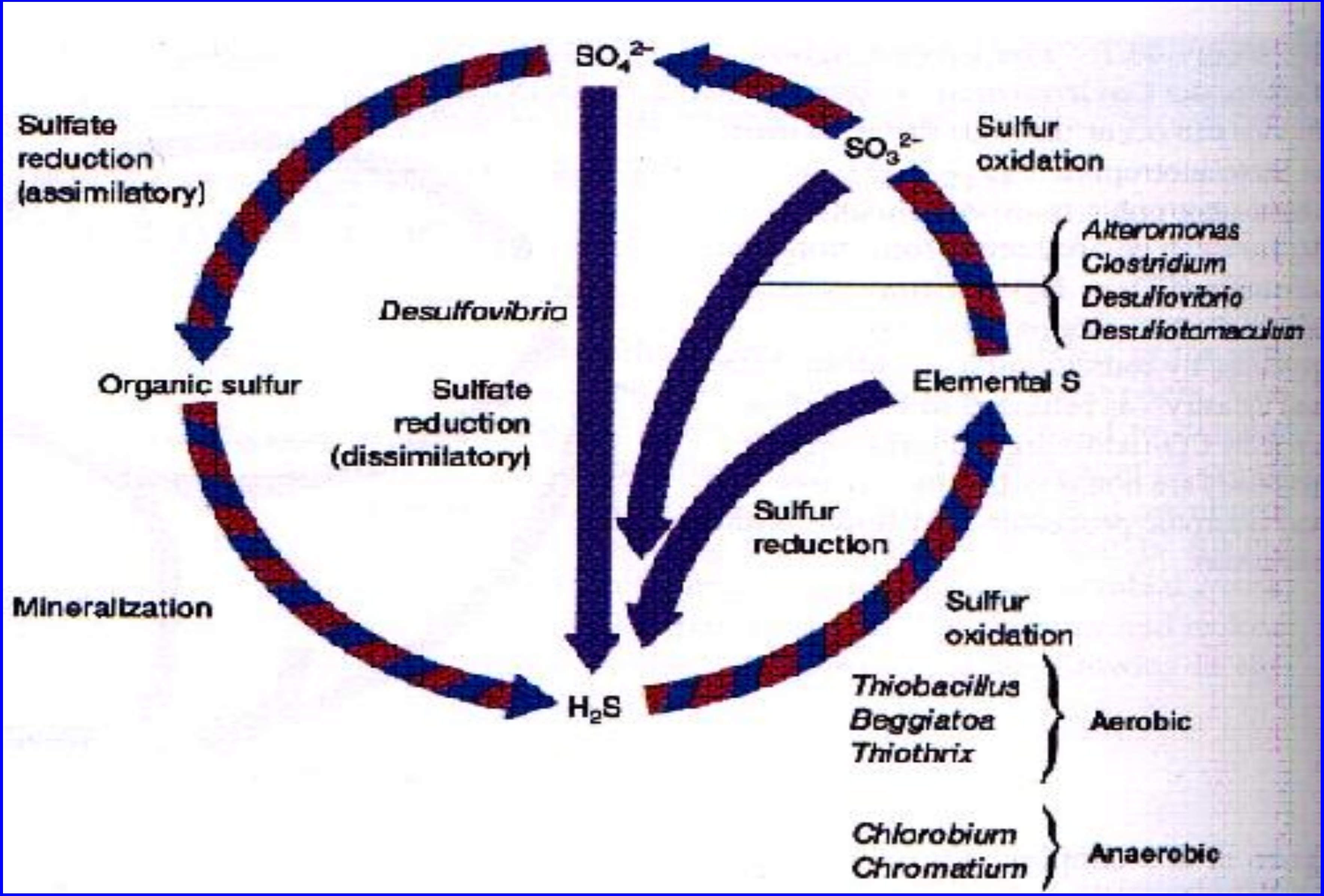
Nitrite ion → Nitrate ion

The ge*nera Nitrosomonas and Nitrobacter* are autotrophic nitrifying bacteria. These organisms obtain energy by oxidizing ammonia or nitrite. In the first stage, *Nitrosomonas* oxidizes ammonium to nitrites. In the second stage, such organisms as *Nitrobacter oxi*dize nitrites to nitrates

Key processes and prokaryotes in the nitrogen cycle

Processes	Example organisms
Nitrification($NH_4^+ \rightarrow NO_3^-$)	
$NH_4^+ \rightarrow NO_2^-$	*Nitrosomonas*
$NO_2^- \rightarrow NO_3^-$	*Nitrobacter*
Denitrification($NO_3^- \rightarrow N_2$)	*Bacillus, Pseudomonas*
N_2 Fixation($N_2 + 8H \rightarrow NH_3 + H_2$)	
Free-living	
Aerobic	*Azotobacter*
	Cyanobacteria
Anaerobic	*Clostridium,purple green bacteria*
Symbiotic	*Rhizobium Bradyrhizobium. Frankia*
Ammonification(organic-N $\rightarrow NH_4^+$)	
	Many organisms can do this

Sulfur cycle



Key processes and prokaryotes in the sulfur cycle

Processes	Organisms
Sulfide/sulfur oxidation($H_2S \rightarrow S^0 \rightarrow SO_4^{2-}$)	
Aerobic	Sulfur chemolithotrophs (*Thiobacillus*, *Beggiatoa*, many others)
Anaerobic	Purple and green phototrophic bacteria, some chemolithotrophs
Sulfate reduction(anaerobic)($SO_4^{2-} \rightarrow H_2S$)	
	Desulfovibrio, *Desulfobacter*
Sulfur reduction(anaerobic) ($S^0 \rightarrow H_2S$)	
	Desulfuromonas, many hyperthermophilic Archaea
Sulfur disproportionation($S_2O_3^{2-} \rightarrow H_2S + SO_4^{2-}$)	
	Desulfovibrio and others
Organic sulfur compound oxidation or reduction($CH_3SH \rightarrow CO_2 + H_2S$)	
	(DMSO→DMS)
Desulfurylation(organic-S $\rightarrow H_2S$)	
	Many organisms can do this

The Iron Cycle

- Iron is one of the most abundant elements in Earth's crust.

- In nature then, iron cycles primarily between the ferrous and ferric forms, the reduction of Fe^{3+} occurring both chemically and as a form of anaerobic respiration, and the oxidation of Fe^{2+} occurring both chemically and as a form of chemolithotrophic metabolism.

9.4 Plant-microbe Interactions

1. Lichens and Mycorrhizas

2. Root nodule bacteria and symbiosis with legumes

Lichens

Lichens are leafy or encrusting growths that are widespread in nature and are often found growing on bare rocks, tree trunks, house roofs, and surfaces of bare soils .

The lichen plant consists of a symbiosis of two organisms, a fungus and an alga. Lichens consist of a tight association of many fungal cells within which the algal cells are embedded .

Mycorrhizas

Mycorrhiza literally means "root fungus" and refers to the symbiotic association that exists between plant roots and fungi. Probably the roots of the majority of terrestrial plants are mycorrhizal.

There are two classes of mycorrhizae: ectomycorrhizae, in which fungal cells form an extensive sheath around the outside of the root with only little penetration into the root tissue itself, and endomycorrhizae, in which the fungal mycelium is embedded within the root tissue.

Mycorrhizas

- Type of Mycorrhizas: Ectomycorrhiza and Endomycorrhiza
- Morphology and Function of Mycorrhizal Infection
- Mycorrhiza and Plant Nutrition
- Application Potential of VAM in Agricultural practice and Ecosystem
- Development and Application of Molecular Probes
- Construction and Analysis of Genomic Library

Mycorrihizas

- Ectomycorrhiza
- Endomycorrhiza
  - Ericacious Mycorrihiza
  - VA Mycorrhiza
  - Orichidacious Mycorrhiza

Functions of mycorrhiza

Increase in P and nutrient uptake

Protection of plant against soil stresses

VA Mycorrhiza

Production of plant growth hormones

Increase solubility of soil minerals

Root Nodule Bacteria and Symbiosis with Legumes

- Stages in Nodule Formation
- Biochemistry of Nitrogen Fixation in Nodules
- Genetics of Nodule Formation: nod Genes
- Genetic Cooperativity in the Rhizobium-legume Symbiosis
- Construction and Application of Genetic-engineered Rhizobium

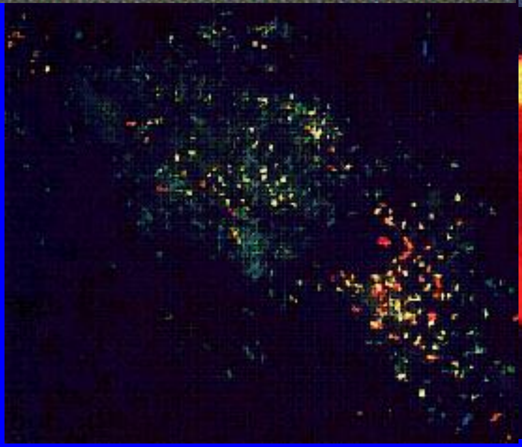
Symbiosis of Frankia and Nonleguminous Plant

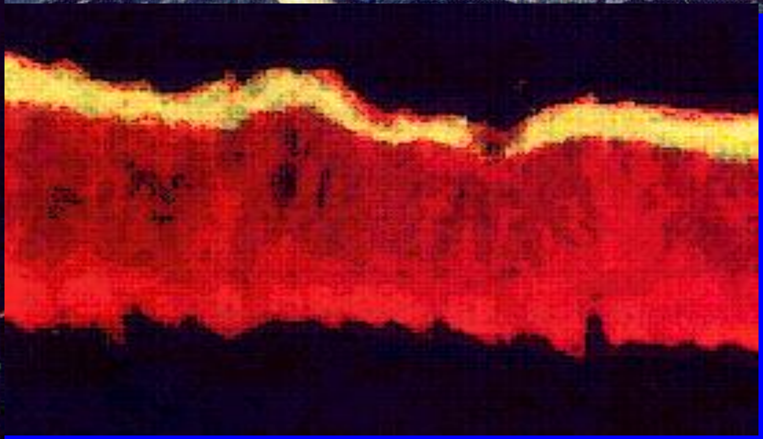
- Morphology and Physiological Characteristic of Frankia

- Hosts

- Application Potential

9.5 Bioremediation

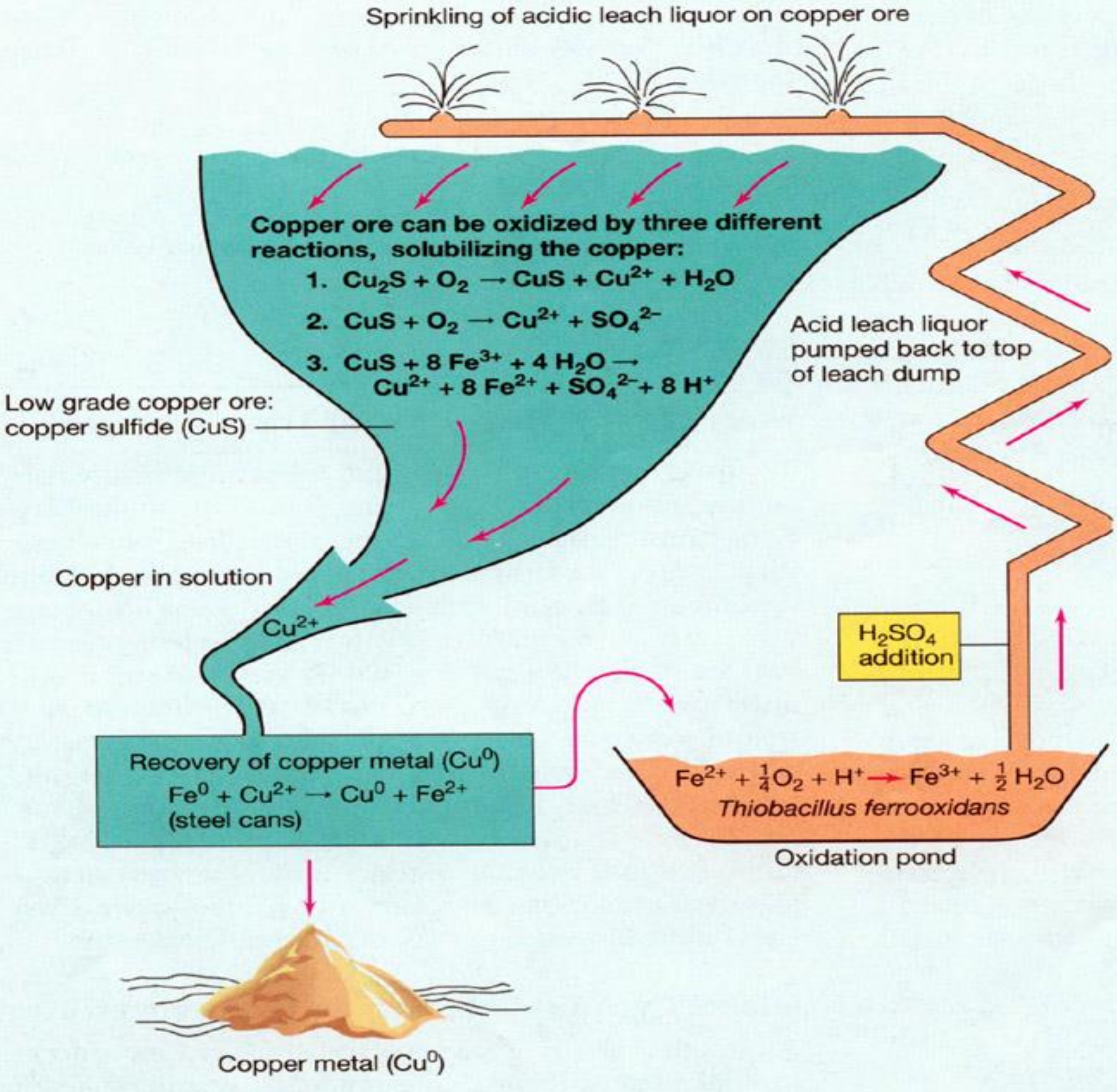




Microbial Leaching of Ores

- benefit: the process of acid production and metal solubility by acidophilic bacteria play a role in mining
- iron and copper sulfide are readily leached
- In the oceans primary productivity is rather low
- Much of the primary productivity occur in the open oceans
- Inshore ocean areas are typically more nutritionally fertile and therefore support more dense populations of phytoplankton

The Leaching Process

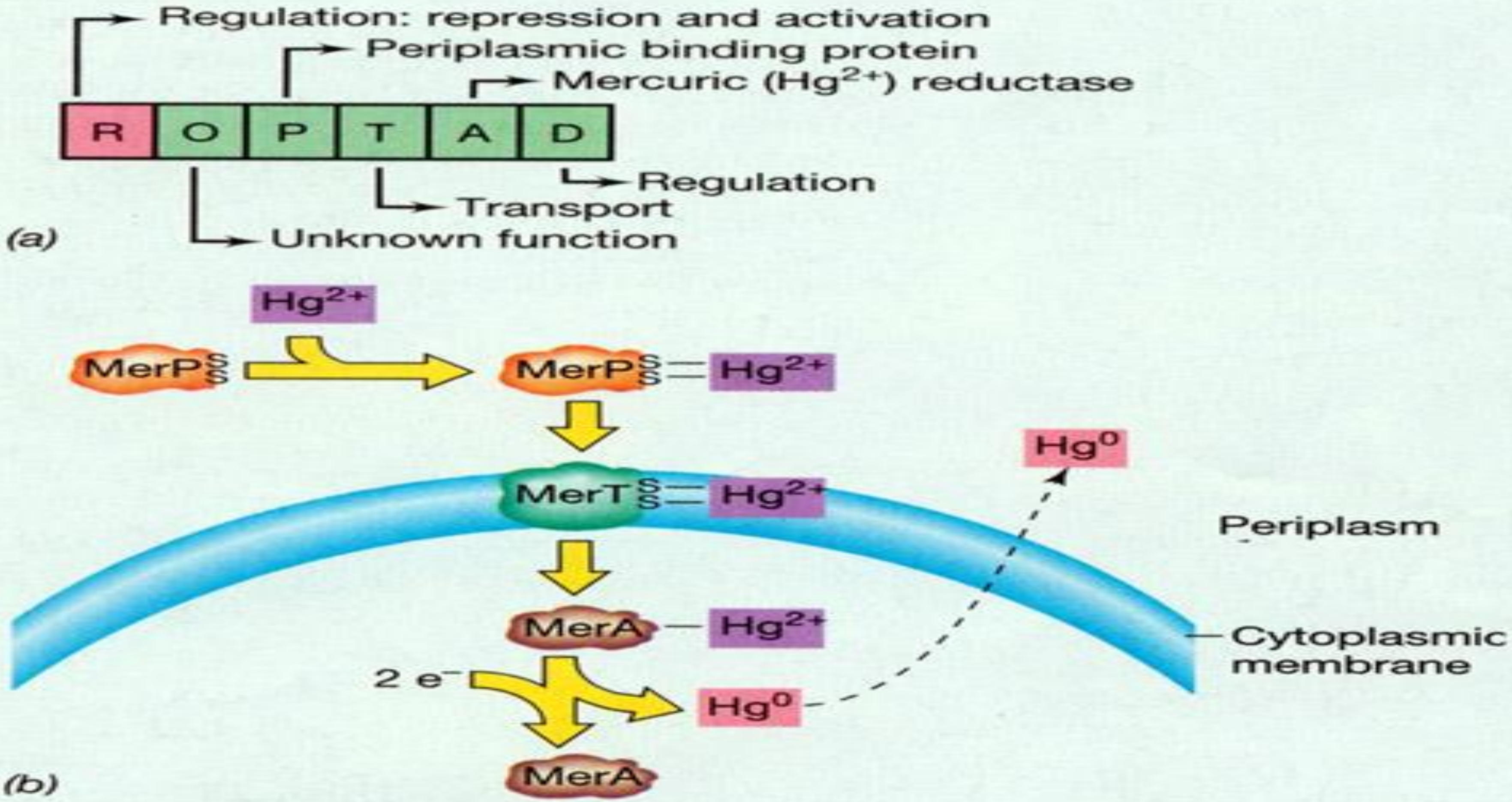


Arrangement of a leaching pile and reactions involved in the microbial leaching of copper sulfide minerals to yield Cu^0 (copper metal). Reaction 1 is primarily bacterial while Reaction 2 occurs both biologically and chemically. Reaction 3 is strictly chemical, but is probably the most important reaction in copper-leaching processes. Note how it is essential for Reaction 3 to proceed that the Fe^{2+} produced (from the oxidation of sulfide in CuS to sulfate) be oxidized back to Fe^{3+} by *Thiobacillus ferrooxidans*.

The Problem Caused by Mercury and Methylmercury

- Both methylmercury and dimethylmercury bond to proteins and tend to accumulate in animal tissues, especially muscle.
- Methylmercury can be concentrated in fish, where it is a potent neurotoxin, eventually causing death.
- Mercury can also cause liver and kidney damage in humans and other animals.

Mercuric Resistance



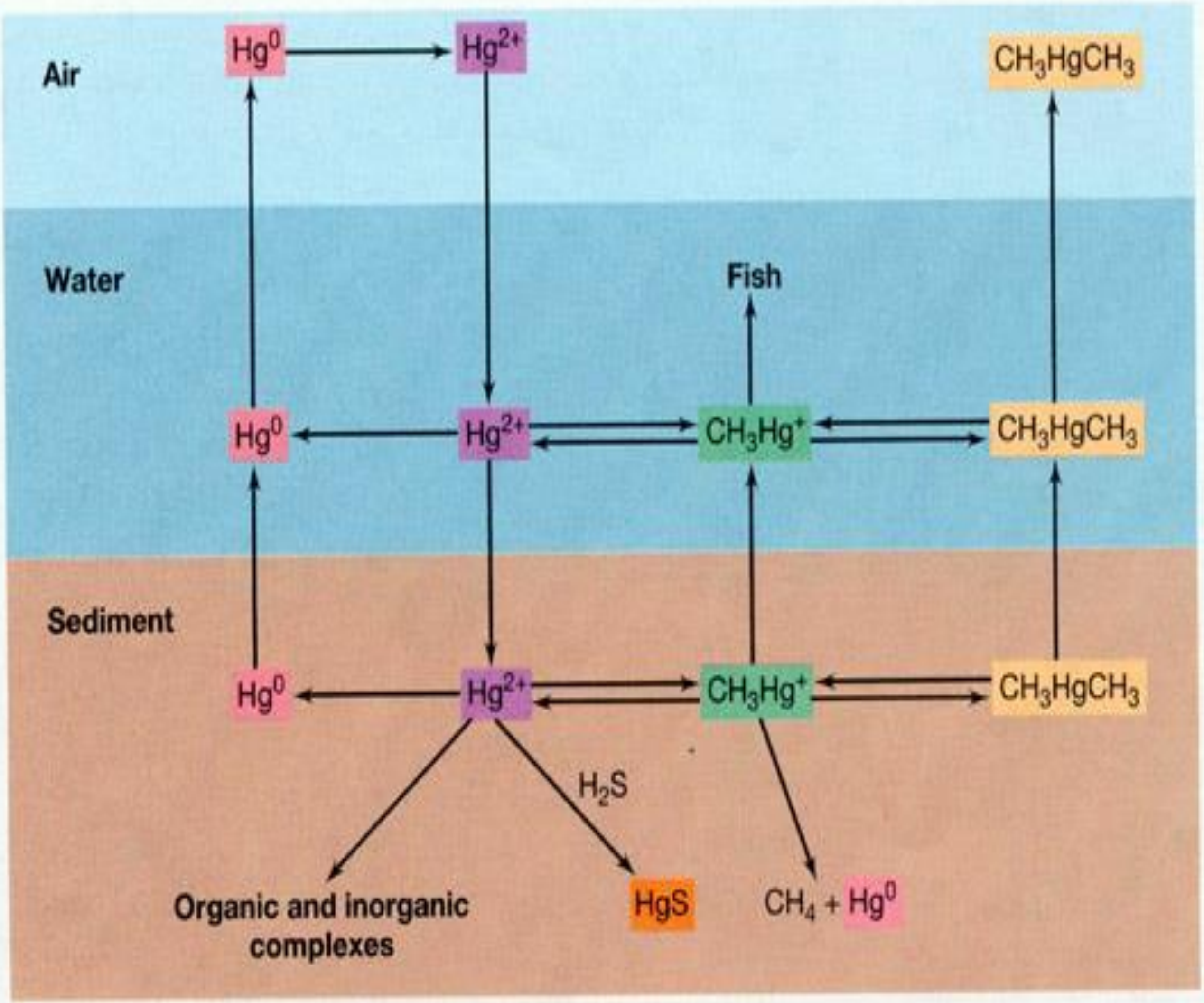
Mechanism of Hg^{2+} reduction to Hg^0 in *Pseudomonas aeruginosa*. (a) The *mer* operon. MerR can function as either a repressor (absence of Hg^{2+}) or transcriptional activator (presence of Hg^{2+}). (b) Transport and reduction of Hg^{2+}. Hg^{2+} is bound by cysteine residues in both proteins MerP and MerT.

Mercury and Heavy Metal Transformations

- Problem: a number of trace elements in high concentrations are toxic to organisms

- Include: mercury, lead, arsenic, cadmium, and selenium.

Global Cycling of Mercury and Methylmercury



Biogeochemical cycling of mercury. The major reservoirs of mercury are in water and in sediments where it can be concentrated in animal tissues or precipitated out as HgS. The various forms of mercury commonly found in aquatic environments are each shown in a different color.

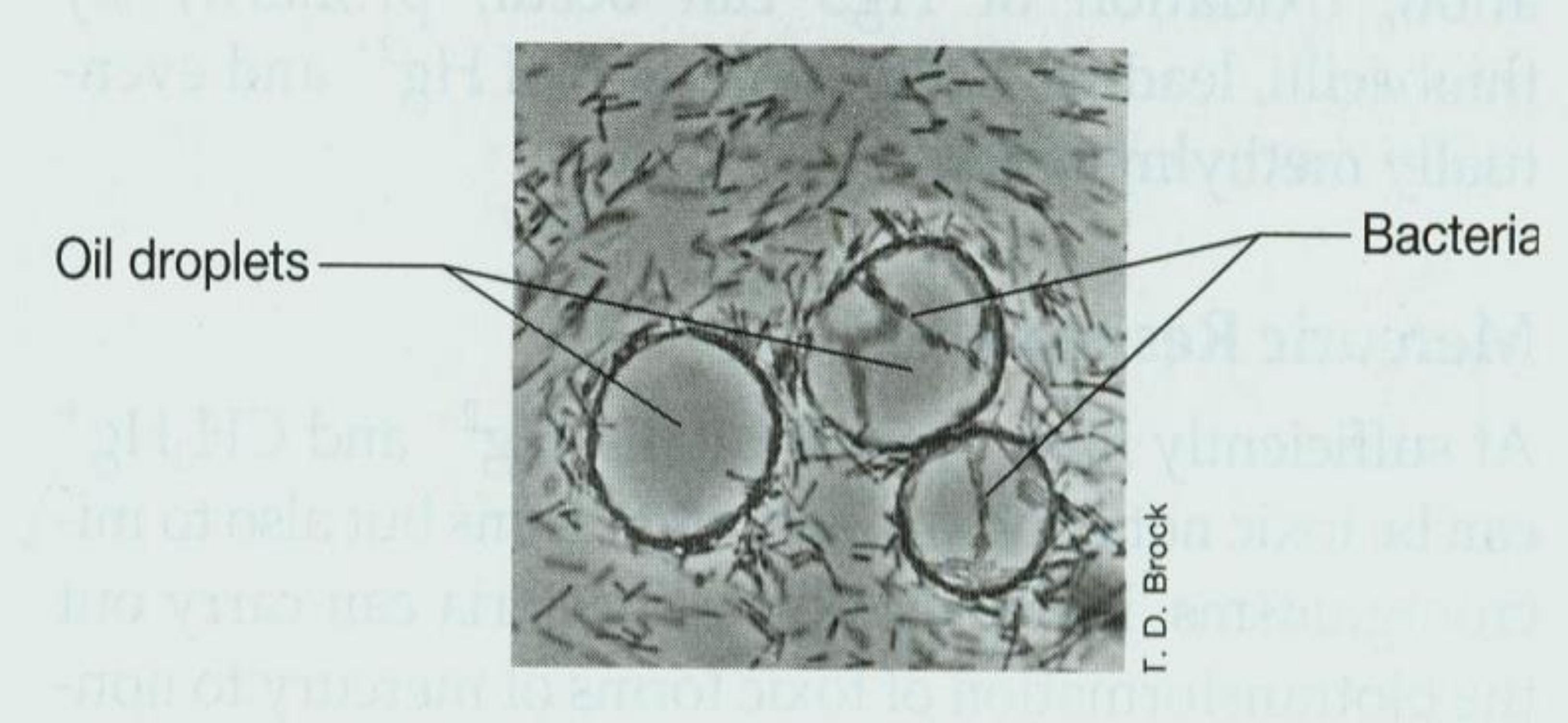
Resistance to Other Heavy Metals

- Bacteria have been found to encode resistance to the effects of heavy metals.
- The mechanism of resistance to any specific metal varies.

Petroleum Biodegradation

Microbial decomposition of petroleum and petroleum products is of considerable economic and environmental importance

Hydrocarbon Decomposition



Hydrocarbon-oxidizing bacteria in association with oil droplet .The bacteria are concentrated in large numbers at the oil-water interface but are not within the droplet itself.

Biodegradation of Xenobiotics

- Xenobiotics are chemically synthesized compounds that are not naturally occurring
- Xenobiotics include pesticides, polychlorinated biphenyls, munitions, dyes, and chlorinated solvents

Pesticides

Persistence of herbicides and insecticides in soil

Substance	Time for 75–100% disappearance
Chlorinated insecticides	
DDT [1,1,1-trichloro-2,2-bis-(ρ-chlorophenyl)ethane]	4 years
Aldrin	3 years
Chlordane	5 years
Heptachlor	2 years
Lindane (hexachlorocyclohexane)	3 years
Organophosphate insecticides	
Diazinon	12 weeks
Malathion	1 week
Parathion	1 week
Herbicides	
2,4-D (2,4-dichlorophenoxyacetic acid)	4 weeks
2,4,5-T (2,4,5-trichlorophenoxyacetic acid)	20 weeks
Dalapin	8 weeks
Atrazine	40 weeks
Simazine	48 weeks
Propazine	1.5 years

Characteristics of Major Genera of Bacteria Capable of Reductive Dechlorination

Property	Genus		
	Dehalospirillum	*Dehalococcoides*	*Dehalobacterium*
Electron donors	H_2, formate, pyruvate, lactate, benzoate	H_2 lactate	CH_2Cl_2 lactate, ethanol, glycerol
Electron acceptors	Trichloroethylene, tetrachloroethylene, NO_3^-, fumarate	Trichloroethylene, tetrachloroethylene	CO_2
Product of reduction of tetrachloroethylene	Dichloroethylene	Ethene	—
Other properties[a]	Contains *b*- and *c*-type cytochromes	Lacks peptidoglycan	Makes acetate and formate from CH_2Cl_2 plus CO_2. Can grow only on CH_2Cl_2 plus CO_2
Phylogeny[b]	Related to epsilon Proteobacteria	Unique lineage (kingdom?) of Bacteria	Related to low GC gram-positive bacteria

Review Questions

1. why is predation such a very important part of microbial ecology?can a predator ever completely eliminate all of its prey?

2. why might microorganism prefer to grow in association with other microorganism ,as in biofilms ,when they can have better access to nutrients are single cells?

3. Compare and contrast the processes of nitrificatio.and denitrification in terms of the organism involved, the envirolmlental conditions that favor each process, and the change in nutrient availability that accompany each process.

4. Why is sulfate reduction the main form of anarobic respiration in marine enviroments, Whereas methanogenesis dominates in fresh waters? Does any methanogenesis occur in the marine enviroment?If so , how?

5. What physical and chemical conditions are necessary for the rapid microbial degradation of oil in aquatic environments? Design an experiment that would allow you to test what conditions optimized the oil oxidation process.