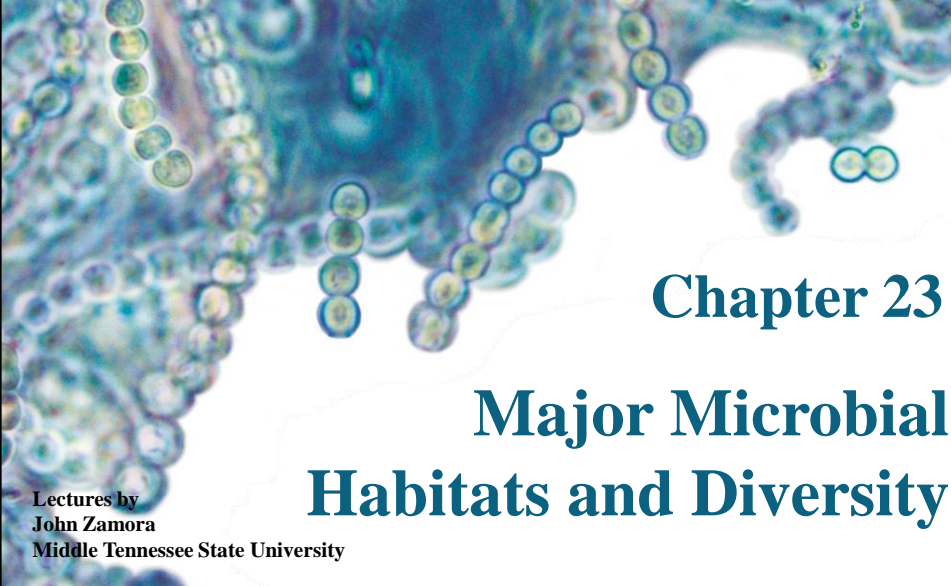


LECTURE PRESENTATIONS
For BROCK BIOLOGY OF MICROORGANISMS, THIRTEENTH EDITION
Michael T. Madigan, John M. Martinko, David A. Stahl, David P. Clark



Chapter 23

**Major Microbial
Habitats and Diversity**

Lectures by
John Zamora
Middle Tennessee State University

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I. Microbial Ecology

- 23.1 General Ecological Concepts
- 23.2 Ecosystem Service: Biogeochemistry and Nutrient Cycles

23.1 General Ecological Concepts

- Ecosystem
 - The sum total of all organisms and abiotic factors in a particular environment
- Habitat
 - Portion of an ecosystem where a community could reside
- An ecosystem contains many different habitats

23.1 General Ecological Concepts

- Microbes account for ~50% of all biomass on Earth
 - They are ubiquitous on the surface and deep within the earth

23.1 General Ecological Concepts

- Many microbes establish relationships with other organisms (symbioses)
 - Parasitism
 - One member in the relationship is harmed and the other benefits
 - Mutualism
 - Both species benefit
 - Commensalism
 - One species benefits and the other is neither harmed nor helped

23.1 General Ecological Concepts

- Diversity of microbial species in an ecosystem is expressed in two ways:
 - Species richness: the total number of different species present
 - Species abundance: the proportion of each species in an ecosystem
- Microbial species richness and abundance is a function of the kinds and amounts of nutrients available in a given habitat

23.1 General Ecological Concepts

Table 23.1 Resources and conditions that determine microbial growth in nature

Resources

Carbon (organic, CO₂)
 Nitrogen (organic, inorganic)
 Other macronutrients (S, P, K, Mg)
 Micronutrients (Fe, Mn, Co, Cu, Zn, Mn, Ni)
 O₂ and other electron acceptors (NO₃⁻, SO₄²⁻, Fe³⁺)
 Inorganic electron donors (H₂, H₂S, Fe²⁺, NH₄⁺, NO₂⁻)

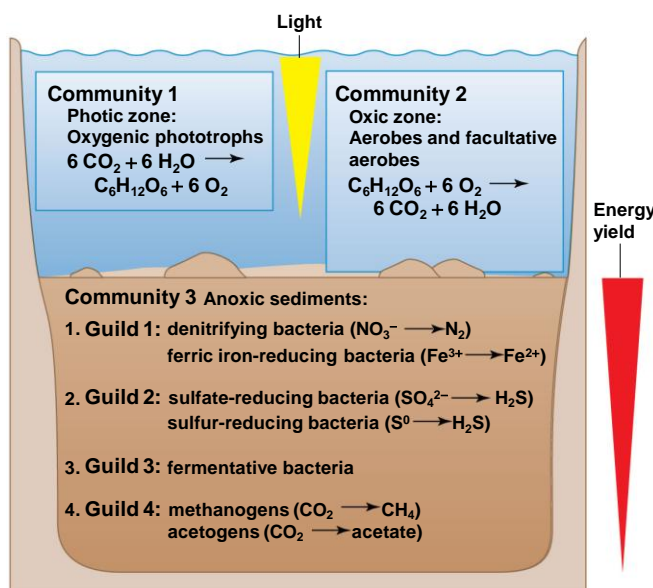
Conditions

Temperature: cold → warm → hot
 Water potential: dry → moist → wet
 pH: 0 → 7 → 14
 O₂: oxic → microoxic → anoxic
 Light: bright light → dim light → dark
 Osmotic conditions: freshwater → marine → hypersaline

23.2 Ecosystem Service: Biogeochemistry and Nutrient Cycles

- Guilds
 - Metabolically related microbial populations (Figure 23.2)
- Sets of guilds form microbial communities that interact with macroorganisms and abiotic factors in the ecosystem
- Niche
 - Habitat shared by a guild
 - Supplies nutrients as well as conditions for growth

Figure 23.2 Populations, guilds, and communities



- Microbial communities consist of populations of cells of different species.
- The region of greatest activity for each of the different respiratory processes would differ with depth in the sediment.
- As more energetically favorable electron acceptors are depleted by microbial activity near the surface, less favorable reactions occur deeper in the sediment.

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23.2 Ecosystem Service: Biogeochemistry and Nutrient Cycles

- *Biogeochemistry*: the study of biologically mediated chemical transformations
- A biogeochemical cycle defines the transformations of a key element by biological or chemical agents
 - Typically proceed by oxidation–reduction reactions
- Microbes play critical roles in energy transformations and biogeochemical processes that result in the recycling of elements to living systems

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II. The Microbial Environment

- 23.3 Environments and Microenvironments
- 23.4 Surfaces and Biofilms
- 23.5 Microbial Mats

23.3 Environments and Microenvironments

- The growth of microbes depends on resources and growth conditions
- Difference in the type and quantity of resources and the physiochemical conditions of a habitat define the niche for each microbe
- For each organism there exists at least one niche in which that organism is most successful (*prime niche*)

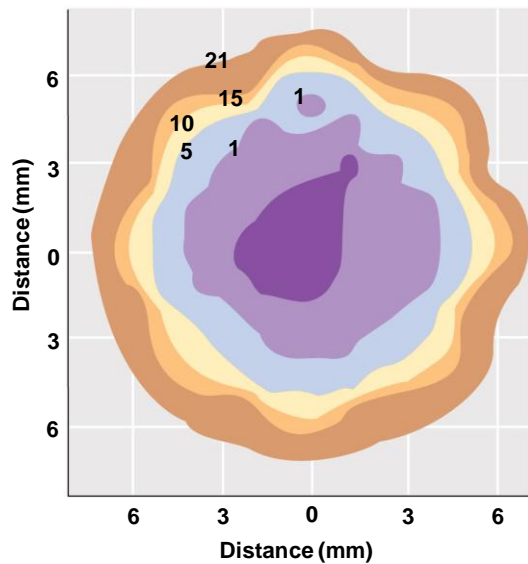
23.3 Environments and Microenvironments

- Microenvironment
 - The immediate environmental surroundings of a microbial cell or group of cells (Figure 23.3)
 - Soil particles contain many microenvironments

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Figure 23.3 Oxygen microenvironments



- Contour map of O_2 concentrations in a small soil particle as determined by a microelectrode.
- The axes show the dimensions of the particle.
- The numbers on the contours are percentages of O_2 concentration (air is 21% O_2).
- Each zone can be considered a different microenvironment.

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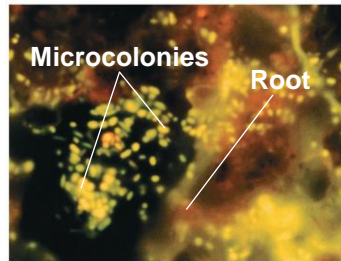
23.3 Environments and Microenvironments

- Physiochemical conditions in a microenvironment are subject to rapid change, both spatially and temporally
- Resources in natural environments are highly variable and many microbes in nature face a *feast-or-famine* existence
- Growth rates of microbes in nature are usually well below maximum growth rates defined in the laboratory
- Competition and cooperation occur between microbes in natural systems

23.4 Surfaces and Biofilms

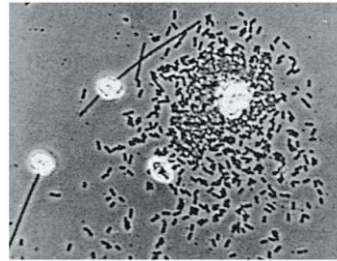
- Surfaces are important microbial habitats because
 - Nutrients adsorb to surfaces
 - Microbial cells can attach to surfaces (Figure 23.4)

Figure 23.4 Microorganisms on surfaces



Frank Dazzo

(a) Fluorescence photomicrograph of a natural microbial community living on plant roots in soil. The preparation has been stained with acridine orange.



T. D. Brock

(b) Bacterial microcolonies developing on a microscope slide that was immersed in a river. The bright particles are mineral matter.

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23.4 Surfaces and Biofilms

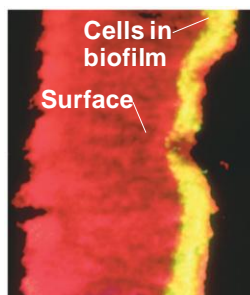
- Biofilms

- Assemblages of bacterial cells adhered to a surface and enclosed in an adhesive matrix excreted by the cells (Figure 23.5)
- The matrix is typically a mixture of polysaccharides
- Biofilms trap nutrients for microbial growth and help prevent detachment of cells in flowing systems

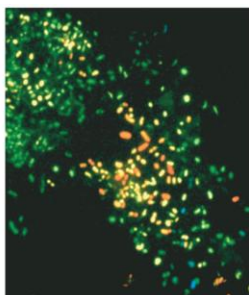
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Figure 23.5 Examples of microbial biofilms



C.-T. Huang, Karen Xu, Gordon McFeters, and Philip S. Stewart



Cindy E. Morris

(a)

(b)

a) A cross-sectional view of an experimental biofilm made up of cells of *Pseudomonas aeruginosa*. The yellow layer (about 15 μm in depth) contains cells

b) Confocal laser scanning microscopy of a natural biofilm on a leaf surface. The color of the cells indicates their depth in the biofilm:



J.M. Sánchez, J.J. deLope, and Ricardo Amils

(c)

c) A biofilm of iron-oxidizing bacteria attached to rocks. As Fe^{2+} -rich water passes over and through the biofilm, the organisms oxidize Fe^{2+} to Fe^{3+} .

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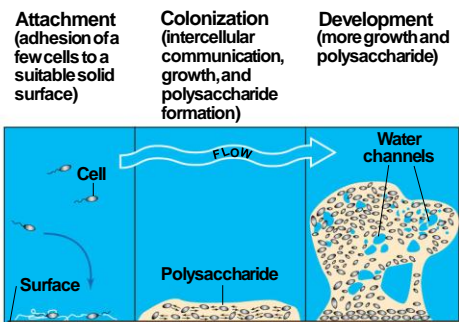
23.4 Surfaces and Biofilms

- Biofilm formation is initiated by attachment of a cell to a surface followed by expression of biofilm-specific genes (Figure 23.6)
- Genes encode proteins that synthesize intercellular signaling molecules and initiate matrix formation

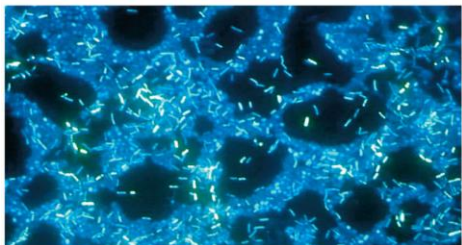
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Figure 23.6 Biofilm formation



(a)



(b)

Rodney M. Donlan and Emerging Infectious Diseases

Biofilms begin with the attachment of a few cells that then grow and communicate with other cells. The matrix is formed and becomes more extensive as biofilm grows.

Photomicrograph of a DAPI-stained biofilm that developed on a stainless steel pipe. Note the water channels

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23.4 Surfaces and Biofilms

- Bacteria form biofilms for several reasons
 - Self-defense
 - Biofilms resist physical forces that sweep away unattached cells, phagocytosis by immune system cells, and penetration of toxins (e.g., antibiotics)
 - Allows cells to remain in a favorable niche
 - Allows bacterial cells to live in close association with one another

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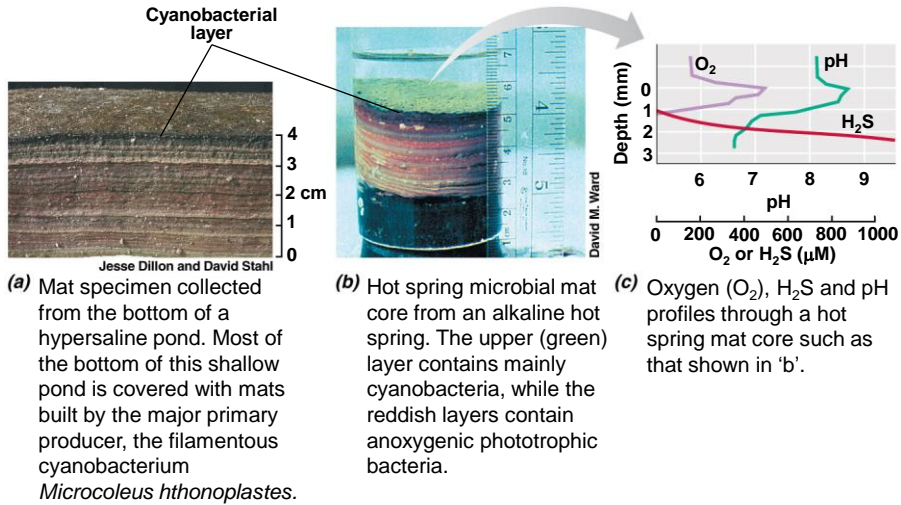
23.4 Surfaces and Biofilms

- Biofilms have been implicated in several medical and dental conditions
- In industrial settings, biofilms can slow the flow of liquids through pipelines and can accelerate corrosion of inert surfaces
- Few highly effective antibiofilm agents are available

23.5 Microbial Mats

- Microbial mats are very thick biofilms (Figure 23.9)
 - Built by phototrophic and/or chemolithotrophic bacteria
 - Phototrophic mats contain filamentous cyanobacteria
 - Cyanobacterial mats are complete ecosystem
 - Have existed for over 3.5 billion years
 - Chemolithotrophic mats contain filamentous sulfur-oxidizing bacteria

Figure 23.9 Microbial mats



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III. Terrestrial Environments

- 23.6 Soils
- 23.7 The Subsurface

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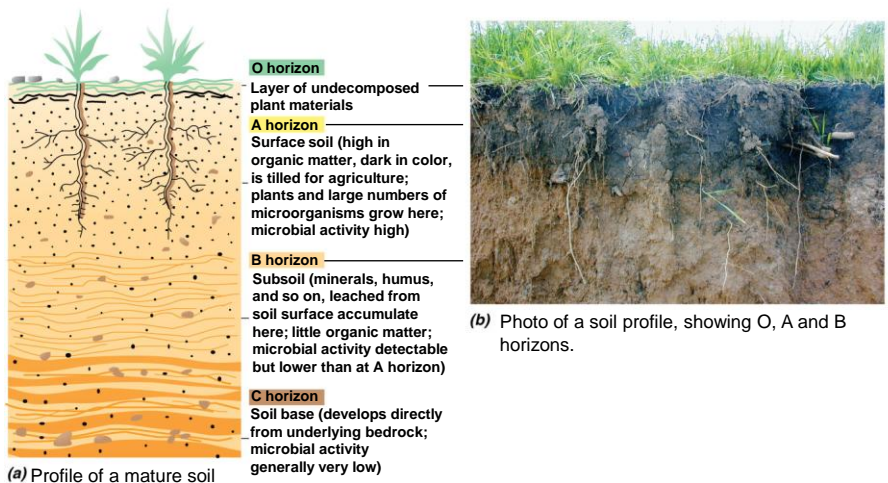
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23.6 Soil

- Soil

- The loose outer material of Earth's surface (Figure 23.10)
- Distinct from bedrock
- Soil can be divided into two broad groups:
 - Mineral soils
 - Derived from rock weathering and other inorganic materials
 - Organic soils
 - Derived from sedimentation in bogs and marshes

Figure 23.10 Soil



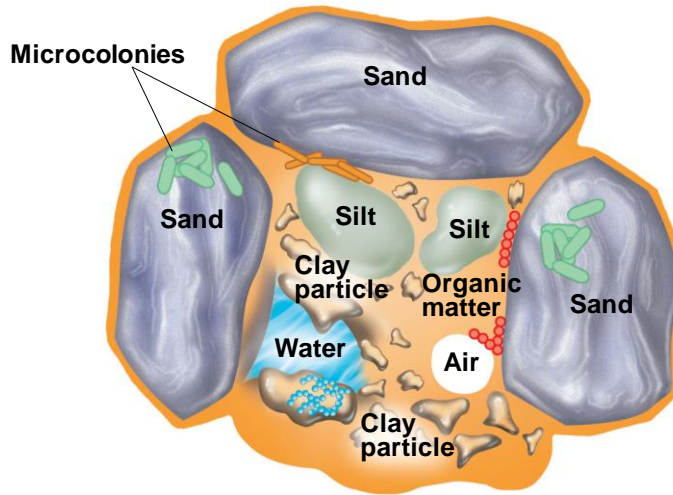
23.6 Soil

- Soils are composed of
 - Inorganic mineral matter (~40% of soil volume)
 - Organic matter (~5%)
 - Air and water (~50%)
 - Living organisms

23.6 Soil

- Most microbial growth takes place on the surfaces of soil particles (Figure 23.11)
- Soil aggregates can contain many different microenvironments supporting the growth of several types of microbes

Figure 23.11 A soil microbial habitat



Very few microorganisms are free in the soil solution; most of them reside in microcolonies attached to the soil particles. Note the relative size differences among sand, clay and silt particles.

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23.6 Soil

- The availability of water is the most important factor influencing microbial activity in surface soils
- Nutrient availability is the most important factor in subsurface environments

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23.6 Soil

- Phylogenetic sampling
 - Molecular sampling indicates thousands of different microbial species
 - *Phylotype*: a “species” defined by a 16S rRNA sequence that differs from all other sequences by 3%
 - Microbial diversity varies with soil type and geographical location

23.7 The Subsurface

- The deep soil subsurface can extend for several hundred meters below the soil surface
- *Archaea* and *Bacteria* believed to exist in deep subsurface
- Microorganisms in the deep subsurface have access to nutrients because groundwater flows through their habitats

IV. Aquatic Environments

- 23.8 Freshwaters
- 23.9 Coastal and Ocean Waters: Phototrophic Microorganisms
- 23.10 Pelagic *Bacteria*, *Archaea* and Viruses
- 23.11 The Deep Sea and Deep-Sea Sediments
- 23.12 Hydrothermal Vents

23.8 Freshwaters

- Freshwater environments are highly variable in the resources and conditions available for microbial growth
- The balance between photosynthesis and respiration controls the oxygen and carbon cycles
- *Phytoplankton*: oxygenic phototrophs suspended freely in water; include algae and cyanobacteria
- *Benthic species* are attached to the bottom or sides of a lake or stream

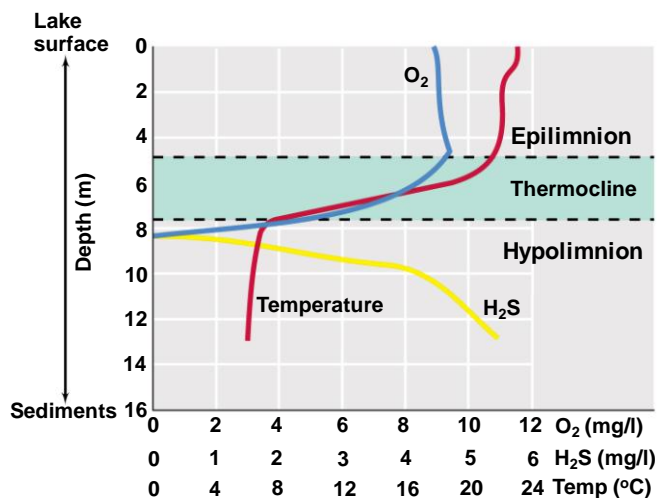
23.8 Freshwaters

- The activity of heterotrophic microbes in aquatic systems is highly dependent upon activity of primary producers; oxygenic phototrophs produce organic material and oxygen
- Oxygen has limited solubility in water; the deep layers of freshwater lakes can become anoxic once the oxygen is consumed
- Oxygen concentrations in aquatic systems are dependent on the amount of organic matter present and the physical mixing of the system

23.8 Freshwaters

- In many temperate lakes the water column becomes stratified during the summer (Figure 23.15)
 - Stratification: the formation of water layers based on temperature

Figure 23.15 Development of anoxic conditions in a temperate lake due to summer stratification



The colder bottom waters are more dense and contain H₂S from bacterial sulfate reduction. The thermocline is the zone of rapid temperature change. As surface waters cool in the fall and early winter, they reach the temperature and density of hypolimnetic waters and sink, displacing bottom waters and effecting lake turnover.

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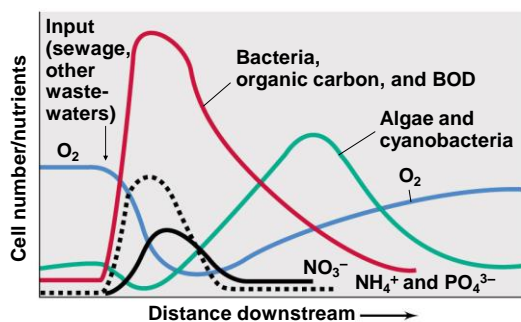
23.8 Freshwaters

- Rivers
 - May be well mixed because of rapid water flow
 - Can still suffer from oxygen deficiencies due to high inputs of
 - Organic matter from sewage (Figure 23.16)
 - Agricultural and industrial pollution
- Biochemical oxygen demand (BOD)
 - The microbial oxygen-consuming capacity of a body of water

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Figure 23.16 Effect of the input of organic-rich wastewaters into aquatic systems



In a river, bacterial numbers increase and O_2 levels decrease with a spike of organic matter. The rise in numbers of algae and cyanobacteria is primarily a response to inorganic nutrients, especially phosphate (PO_4^{3-}).

(a)



Photo of a eutrophic (nutrient-rich) lake, showing algae, cyanobacteria and aquatic plants that bloom in response to nutrient pollution from agricultural runoff.

T. D. Brock

(b)

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23.9 Coastal and Ocean Waters: Phototrophic Microorganisms

- Compared with most freshwater environments, the open ocean environment is
 - Saline
 - Low in nutrients, especially with respect to nitrogen, phosphorus and iron
 - Cooler
- Due to the size of the oceans, the microbial activities taking place in them are major factors in Earth's carbon balance

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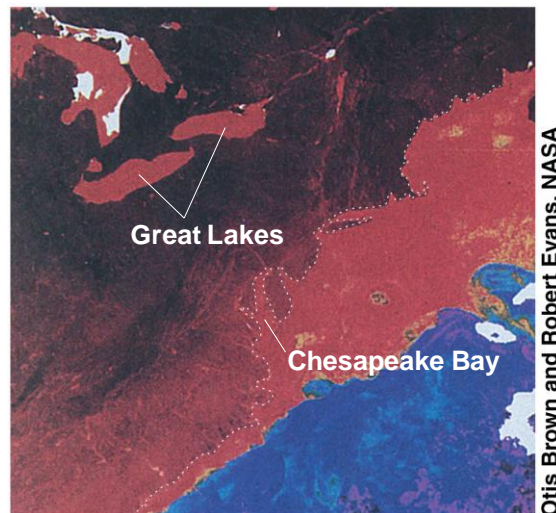
23.9 Coastal and Ocean Waters: Phototrophic Microorganisms

- Near-shore marine waters typically contain higher microbial numbers than the open ocean because of higher nutrient levels (Figure 23.17)

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Figure 23.17 Distribution of chlorophyll in the western North Atlantic Ocean as recorded by satellite



The northeast coast of the United States is shown in dotted outline. Areas rich in phototrophic plankton are shown in red ($1 \text{ mg chlorophyll/m}^3$); blue and purple areas have lower chlorophyll concentrations (0.01 mg/m^3). Note the high primary productivity of coastal areas and the Great Lakes.

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23.9 Coastal and Ocean Waters: Phototrophic Microorganisms

- Most of the primary productivity in the open oceans is due to photosynthesis by prochlorophytes
- *Prochlorococcus* is the most abundant oxygenic phototroph in the oceans and accounts for
 - >40% of the biomass of marine phototrophs
 - ~50% of the net primary production

23.9 Coastal and Ocean Waters: Phototrophic Microorganisms

- The planktonic filamentous cyanobacterium *Trichodesmium* is an abundant phototroph in tropical and subtropical oceans
- Small phototrophic eukaryotes, such as *Ostreococcus*, inhabit coastal and marine waters and are likely important primary producers.

23.9 Coastal and Ocean Waters: Phototrophic Microorganisms

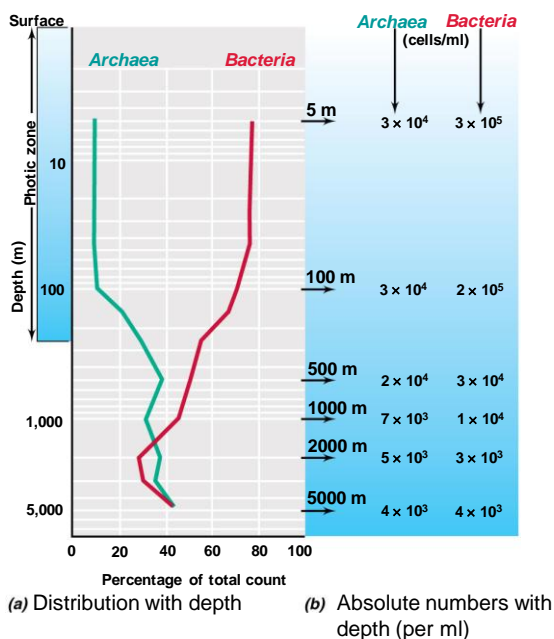
- *Aerobic anoxygenic phototrophs*
 - Another class of marine microbes that use light energy but do not fix carbon dioxide
 - Light is used for ATP synthesis via photophosphorylation

23.10 Pelagic* *Bacteria, Archaea,* and Viruses

- Small planktonic heterotrophic prokaryotes are abundant (10^5 - 10^6 cells/ml) in pelagic marine waters
- Prokaryote densities in the open ocean decrease with depth
- Surface waters contain $\sim 10^6$ cells/ml; cell numbers drop to 10^3 - 10^5 /ml below 1,000 m in depth
- Bacterial species tend to dominate in surface waters, and archaeal species dominate in deeper waters (Figure 23.21)

* living or growing at or near the surface of the ocean, far from land.

Figure 23.21 Percentage of total prokaryotes belonging to *Archaea* and *Bacteria* in North Pacific Ocean water



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23.10 Pelagic *Bacteria*, *Archaea*, and Viruses

- The most abundant marine heterotroph is *Pelagibacter*, an oligotroph
- Oligotroph: an organism that grows best at very low nutrient concentrations
- *Pelagibacter* and other marine heterotrophs contain proteorhodopsin, a form of rhodopsin that allows cells to use light energy to drive ATP synthesis

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23.10 Pelagic *Bacteria*, *Archaea*, and Viruses

- Viruses are the most abundant microorganisms in the oceans
- Viral concentration believed to be as high as 10^8 virion particles/ml
- Viruses affect prokaryotic populations and are highly diverse

23.11 The Deep Sea and Deep-Sea Sediments

- >75% of all ocean water is deep sea, lying primarily between 1,000 and 6,000 m
- Organisms that inhabit the deep sea must deal with
 - Low temperature
 - High pressure
 - Low nutrient levels
 - Absence of light energy

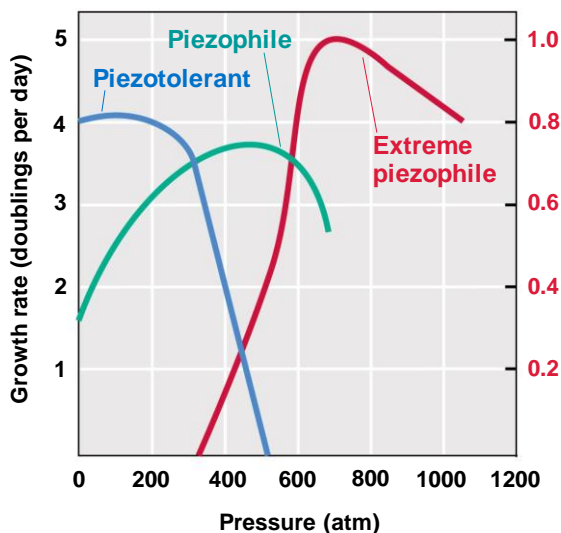
23.11 The Deep Sea and Deep-Sea Sediments

- Deep-sea microbes are
 - *Psychrophilic* (cold-loving) or *psychrotolerant*
 - *Piezophilic* (pressure-loving) or *piezotolerant* (Figure 23.25)
- Adaptations for growth under high pressure are likely only seen for a few key proteins

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Figure 23.25 Growth of piezotolerant, piezophilic, and extremely piezophilic bacteria



Compare the slower growth rate of the extreme piezophile (right ordinate) with the growth rate of the piezotolerant and piezophilic bacteria (left ordinate), and note the inability of the extreme piezophile to grow at low pressures.

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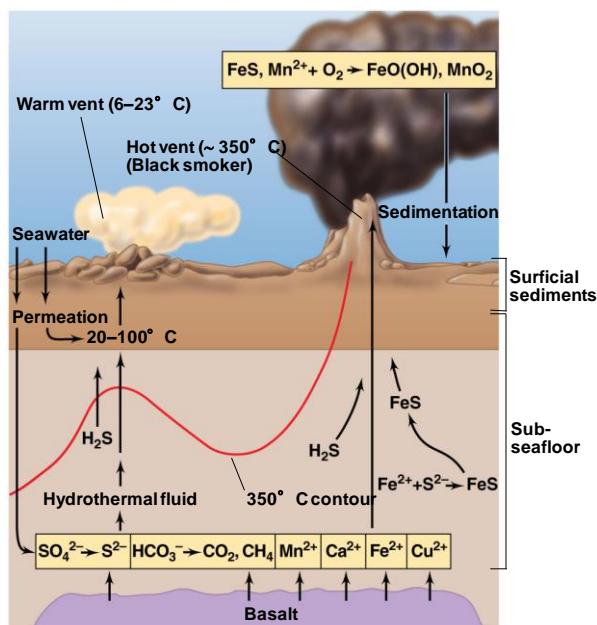
23.12 Hydrothermal Vents

- Thriving animal and microbial communities associated with deep-sea hydrothermal vents (Figure 23.30)
- Two types of vents:
 - Warm diffuse or very hot (Figure 23.31)
- Chemolithotrophic bacteria predominate at vent
 - Thermophiles and hyperthermophiles present
 - Chemolithotrophic prokaryotes utilize inorganic materials from the vents

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Figure 23.30 Hydrothermal vents



Schematic showing geological formations and major chemical species at warm vents and black smokers.

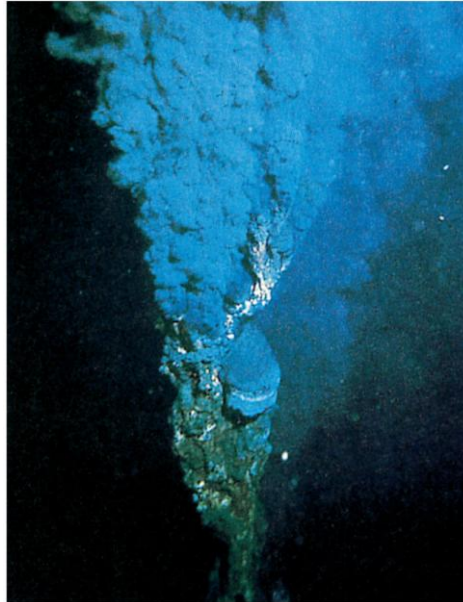
In warm vents, the hot hydrothermal fluid is cooled by cold 2–3 °C seawater permeating the sediments.

In black smokers, hot hydrothermal fluid near 350 °C reaches the seafloor directly.

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Figure 23.31 A hydrothermal vent black smoker emitting sulfide- and mineral-rich water at 350 °C



The walls of the black smoker chimneys display a steep temperature gradient and contain several types of prokaryotes.

Robert D. Ballard