



Applied Microbial Ecology

“Microorganisms are Earth’s greatest chemists”

The activities of these tiny biochemical factories have been exploited in many ways.

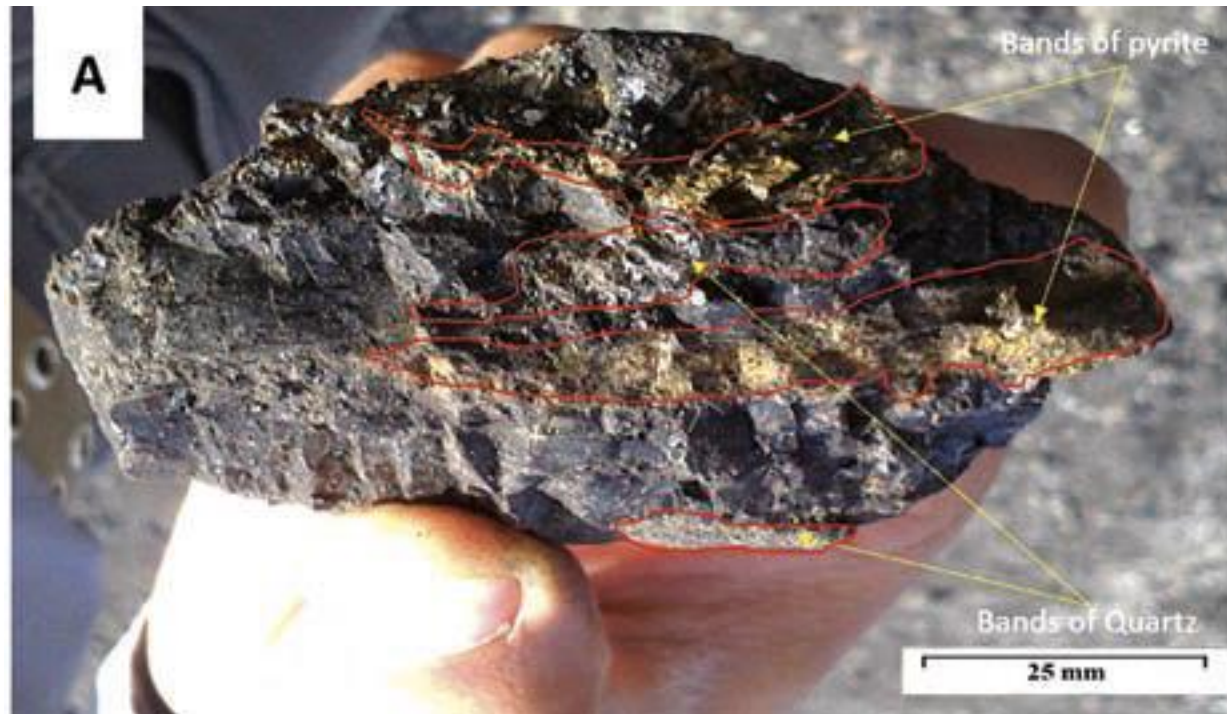
Mining with Microorganisms

- Pyrite (FeS₂)
 - one of the most common forms of iron in nature
 - Formed in low-oxygen conditions where sulfur is in the form of sulfide (S²⁻ or HS⁻) and not sulfate (SO₄²⁻).
 - found in coals and in metal ores

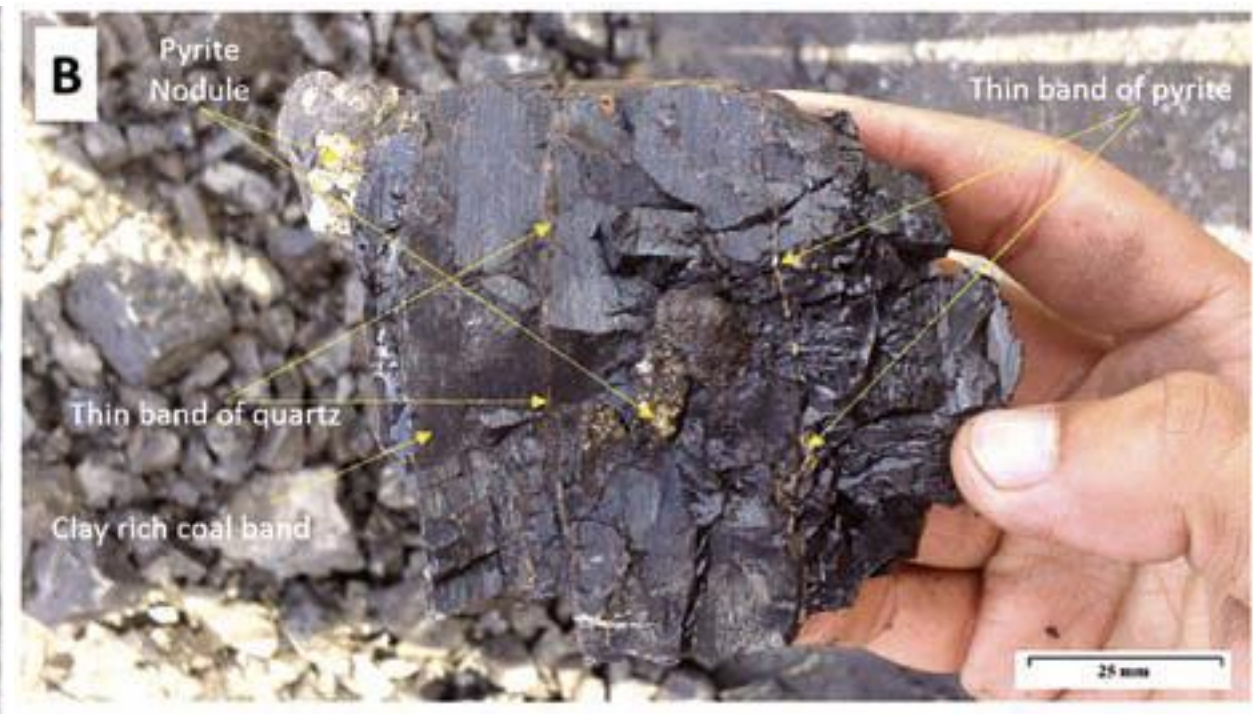


fool's gold

Pyrite and quartz bands of medium thickness in the coal.



Pyrite nodules and thin bands in the coal lump.



Mining with Microorganisms

- Pyrite (FeS_2)
 - one of the most common forms of iron in nature
 - found in coals and in metal ores
- Sulfides (HS^-) also form insoluble minerals with metals
- Economically feasible to mine low-grade ores only if the metal can be concentrated



Mining with Microorganisms

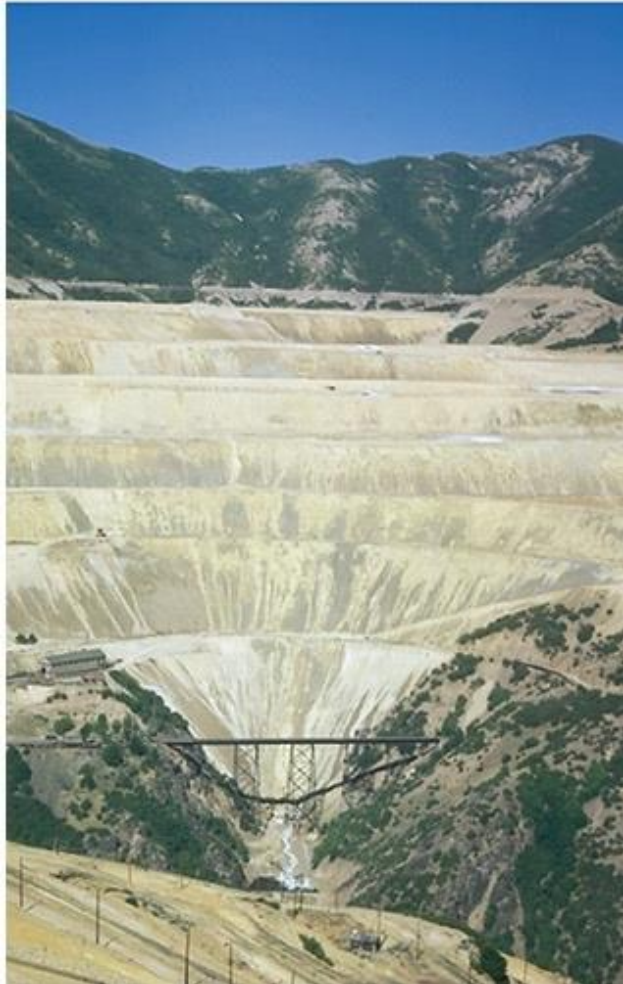
- Microbial leaching
 - the removal of valuable metals, such as copper, from sulfide ores by microbial activities
 - particularly useful for copper ores
 - copper sulfate (CuSO_4), formed during the oxidation of copper sulfide ores, is very water-soluble
 - approximately a quarter of all copper mined worldwide is obtained by microbial leaching



CuS : Covellite

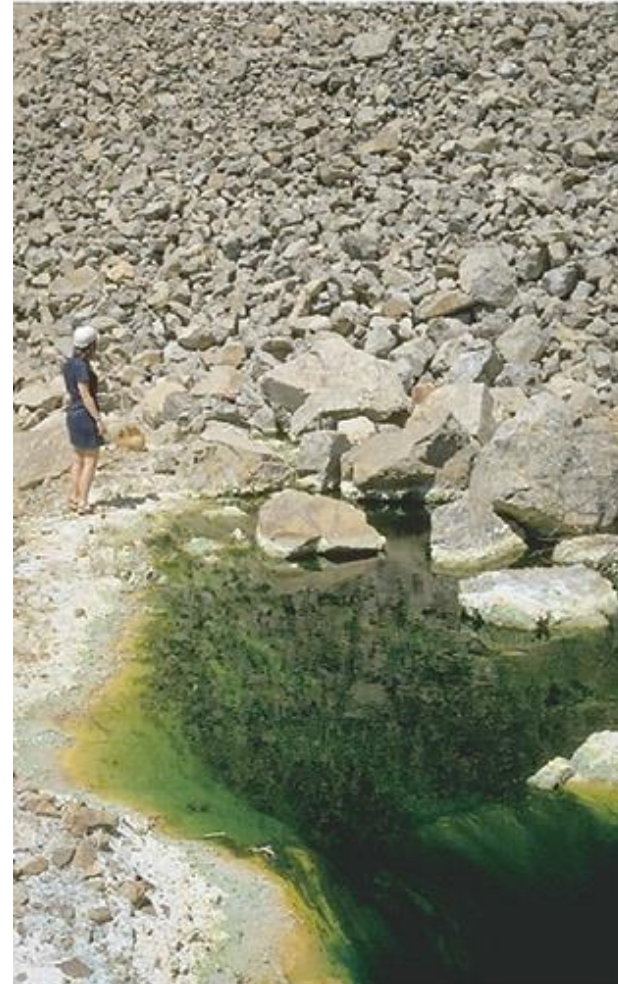
The Leaching of Low-Grade Copper Ores Using Iron-Oxidizing Bacteria

A typical leaching dump



- low-grade ore is crushed and dumped with high surface area exposed
- pipes distribute the acidic leach water over the surface of the pile
- acidic water slowly percolates through the pile and exits at the bottom

Effluent

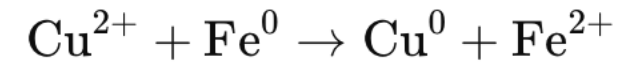


- acidic water is very rich in Cu^2

The Leaching of Low-Grade Copper Ores Using Iron-Oxidizing Bacteria



Recovery of copper as metallic copper (Cu^0) by passage of the Cu^{2+} -rich water over metallic iron (Fe^0) in a long flume



Reduction of copper

(c)

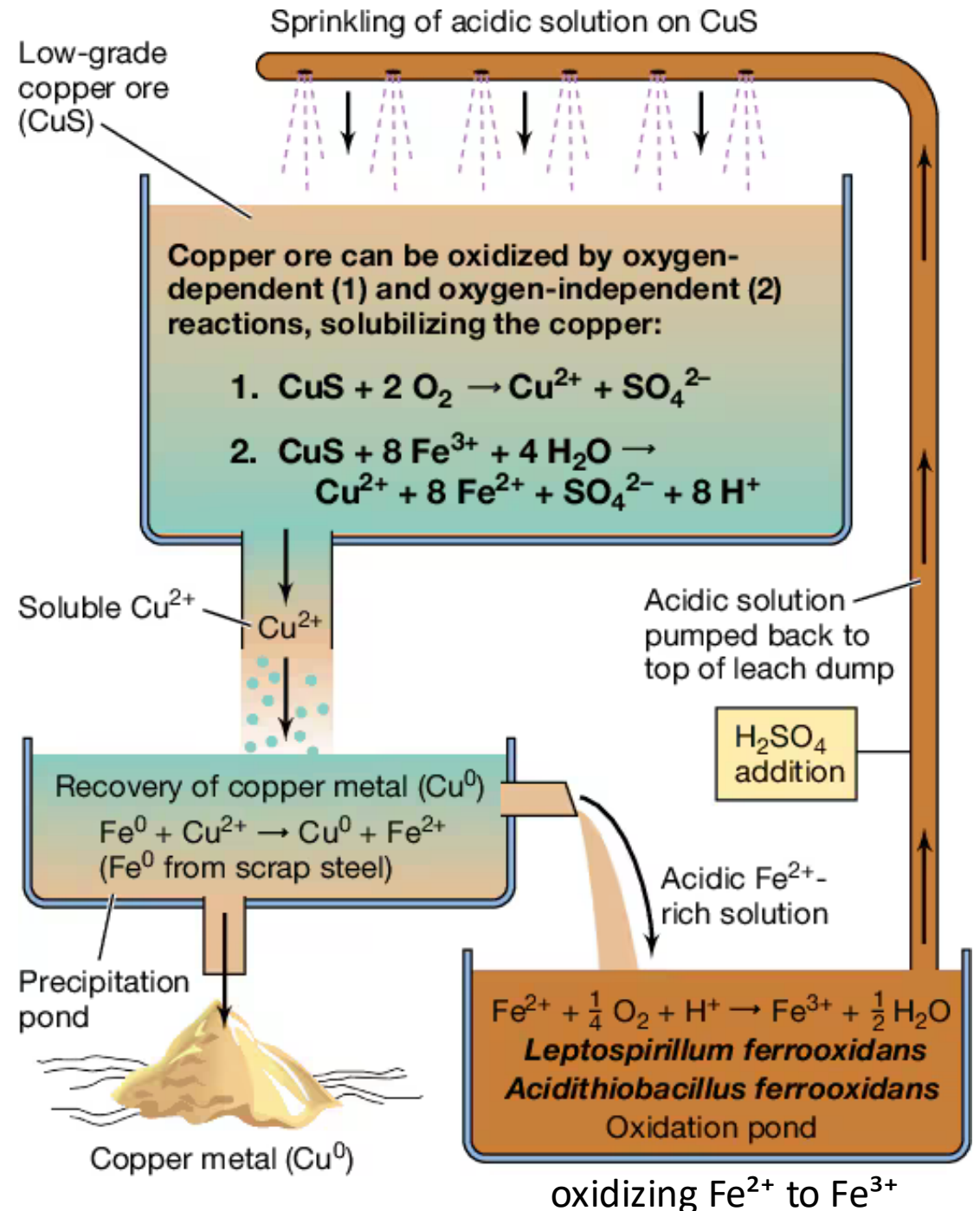


A small pile of metallic copper removed from the flume, ready for further purification

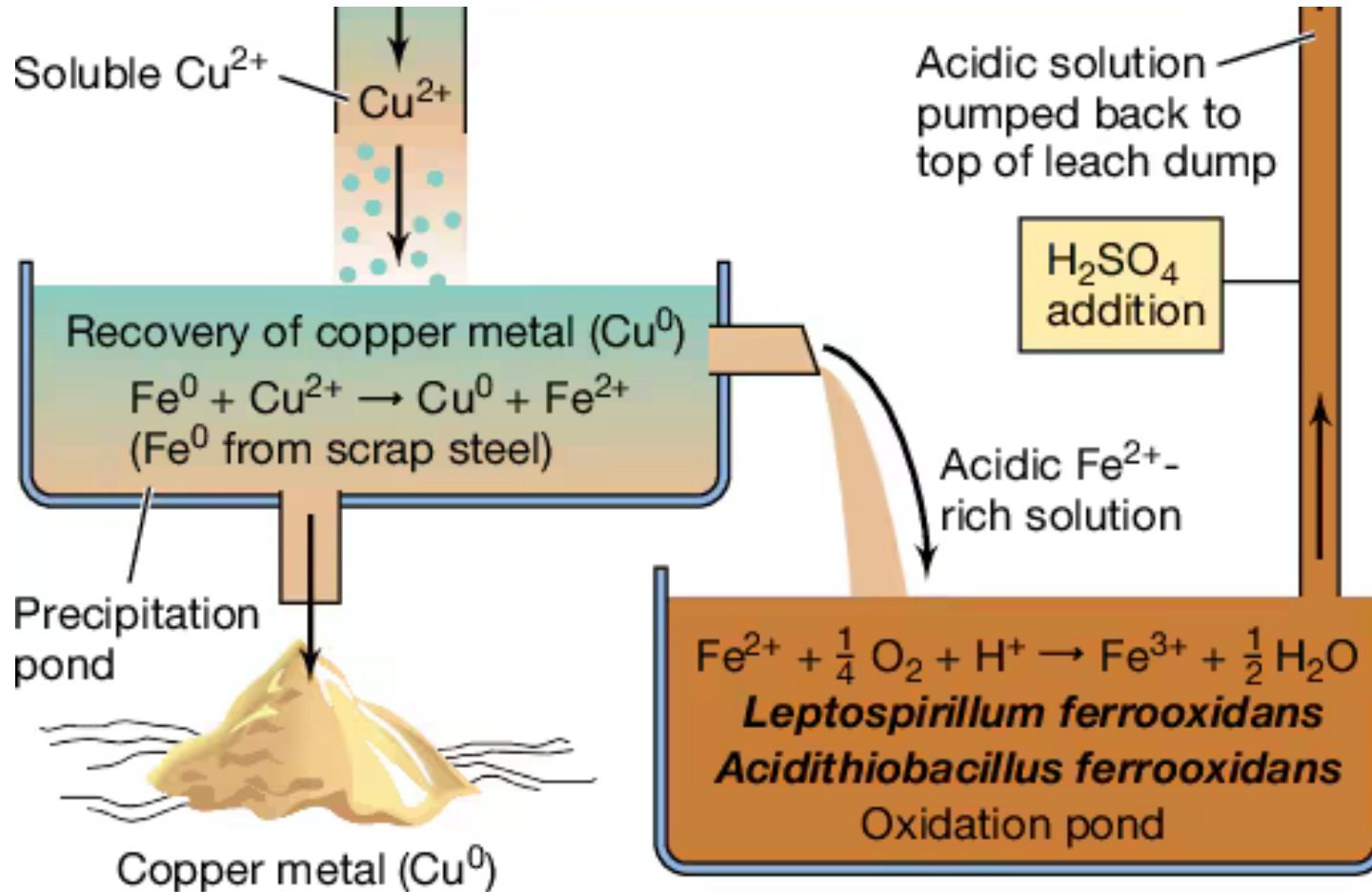
(d)

The Leaching Process

- In microbial leaching, low-grade ore is dumped in a large pile (the **leach dump**) and dilute sulfuric acid (**pH 2**) is added
- The liquid emerging from the bottom of the pile is enriched in dissolved metals and transported to a precipitation plant
- Bacterial oxidation of Fe^{2+} is critical in microbial leaching, as Fe^{3+} itself can oxidize metals in the ores



Metal Recovery



(c)

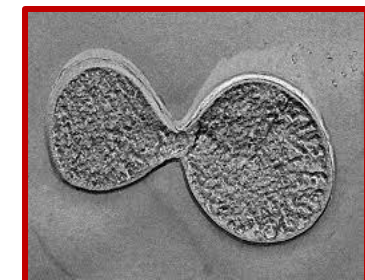
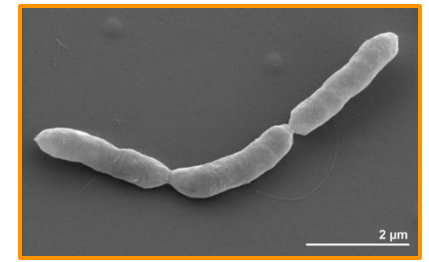
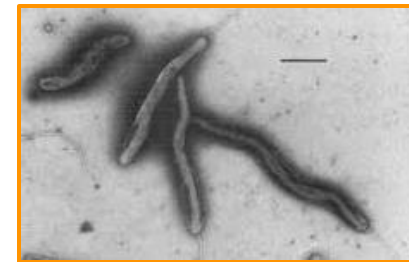
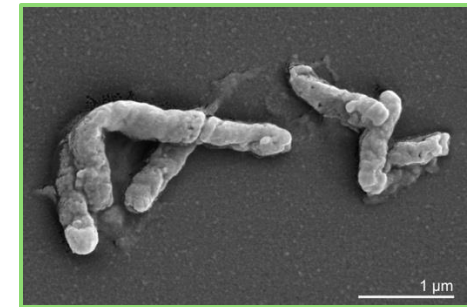


(d)

The entire CuS leaching operation is driven by the oxidation of Fe^{+2} to Fe^{+3} by iron-oxidizing chemotrophic bacteria.

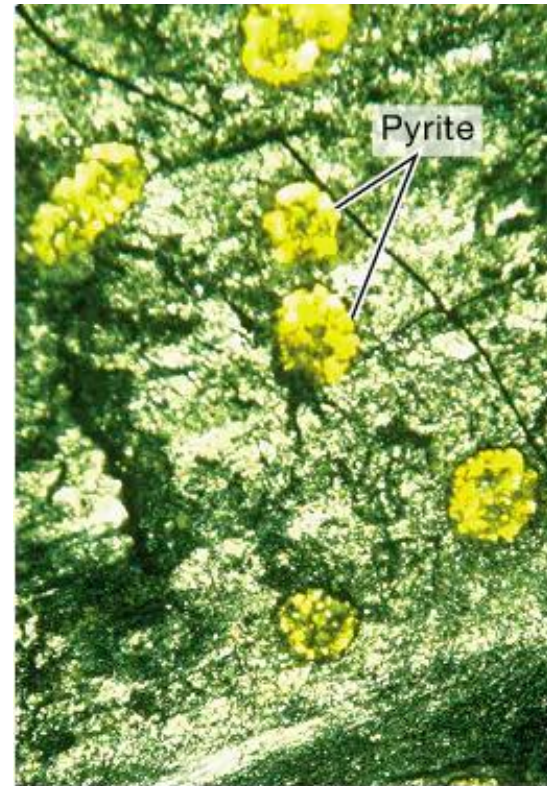
Leaching Dump Microbiome

- Temperatures rise in a leaching dump
- Shifts in the iron-oxidizing microbial community:
 - *A. ferrooxidans* is a mesophile and first dominates the community
 - Heat generated by microbial activities raises temperatures
 - *A. ferrooxidans* is outcompeted by mildly thermophilic, iron-oxidizing chemolithotrophic *Bacteria*, *Leptospirillum ferrooxidans* and *Sulfobacillus*
 - At even higher temperatures hyperthermophilic Archaea such as *Sulfolobus* predominate in the leach dump



Acid Mine Drainage

- Microbial leaching is also responsible for environmental damage
- Improperly handling or disposal of pyrite-containing coal and mineral deposits
 - Rich in sulfides
 - oxygen and water start to oxidize pyrite slowly
 - Oxidation of metal sulfides by bacteria can result in acidic conditions



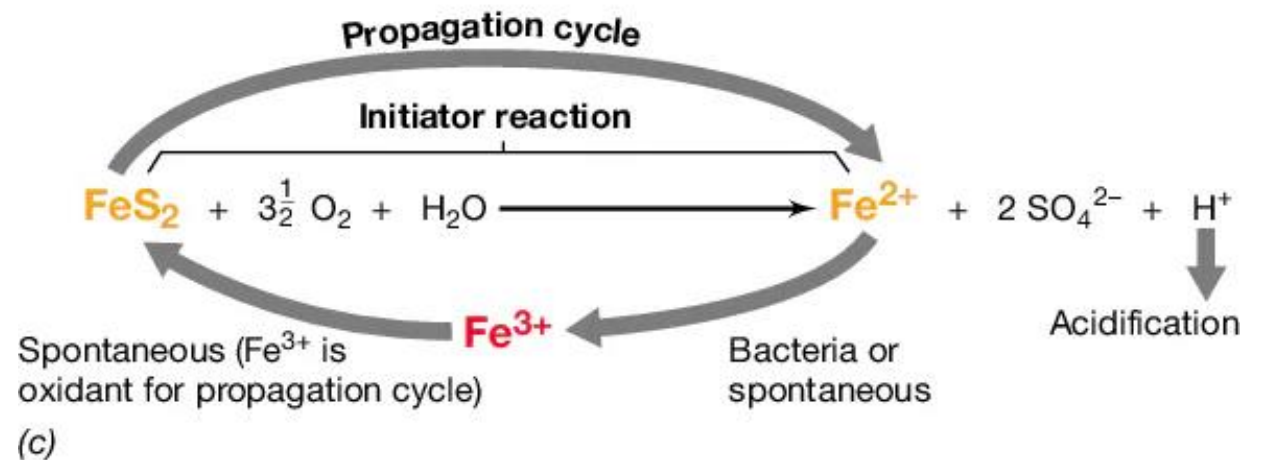
Rawin Donald

(a)



T.D. Brock

(b)



Acid Mine Drainage



T.D. Brock

The yellowish-red colour is due to the precipitated iron oxides in the drainage.

Bioremediation

- Bioremediation is the microbial cleanup of oil, toxic chemicals, or other environmental pollutants by microbes.
- Stimulating the degradative activities of indigenous microbes.
- Addition of microbes having the needed degradative capacity.
- Pollutants can include both natural materials, such as petroleum products, and synthetic chemicals new to nature.

Bioremediation of Uranium-Contaminated Environments

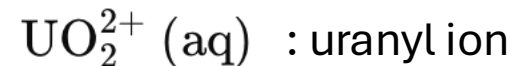
- Uranium contamination of groundwater has occurred where uranium has been processed or stored improperly
- Because the contamination is often widespread, making mechanical methods of recovery very expensive, microbiologists have joined forces with engineers to develop biological treatments.



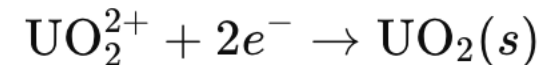
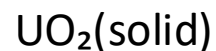
Bioremediation of Uranium-Contaminated Environments

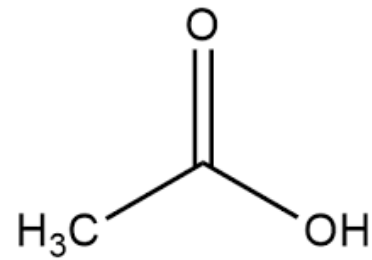
- Groundwater can become contaminated with uranium U^{6+} as a consequence of nuclear energy and weapons production
- Biological treatments exploit the $UO_2^{2+} + 2e^- \rightarrow UO_2(s)$ via to reduce U^{6+} to U^{4+}

- U^{6+} is water soluble, mobile, and toxic



- U^{4+} is NOT water soluble
 - forms an immobile uranium mineral called uraninite

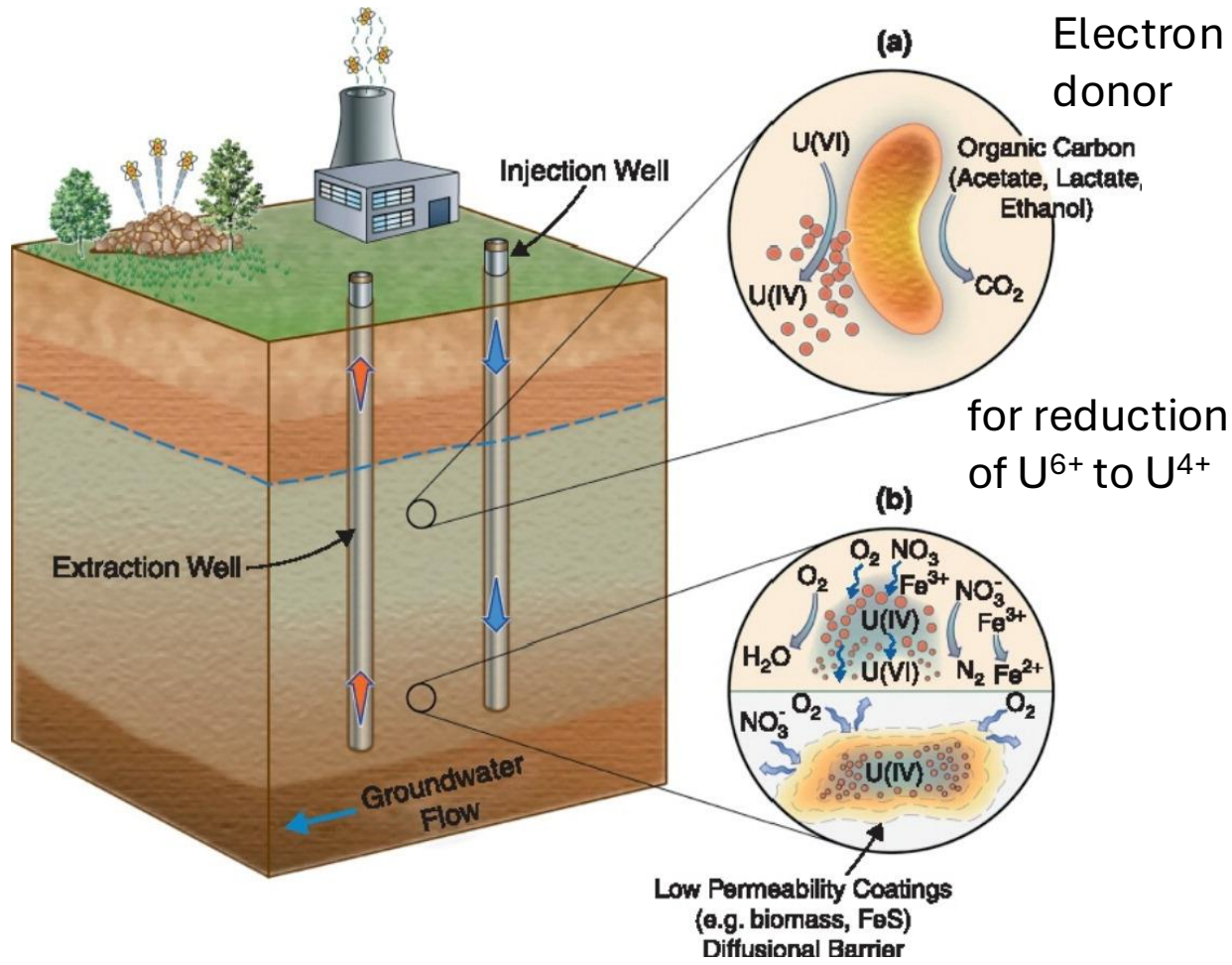




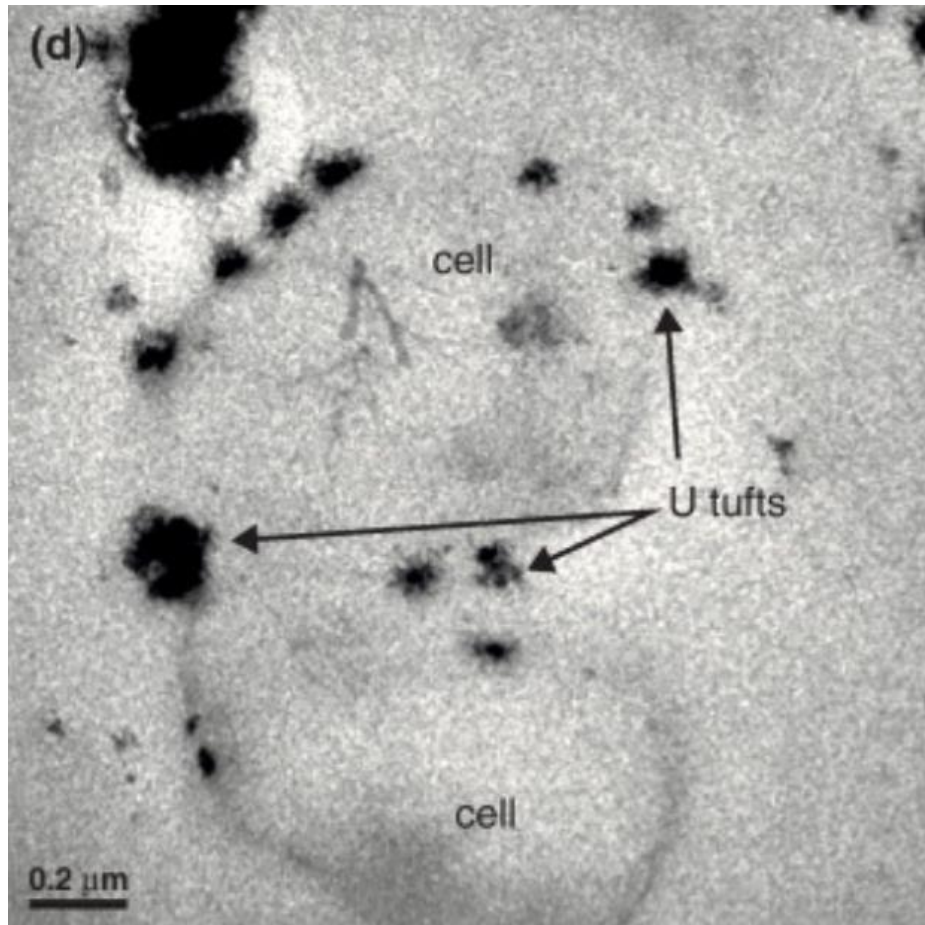
Acetate



An experimental plot at a uranium-contaminated site



- Uranium is contained, not removed
 - limiting movement of Uranium into groundwater
 - Reducing contact with humans and other animals

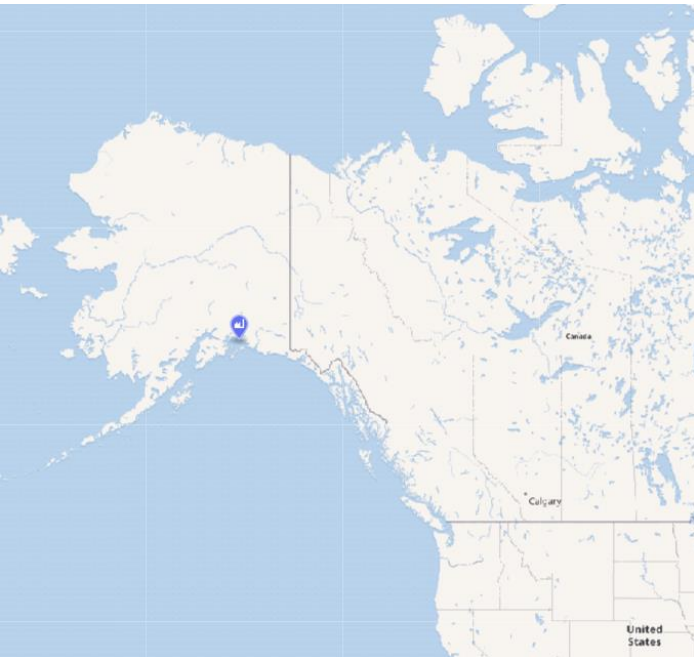


Bioremediation of Organic Pollutants: Hydrocarbons

- Organic pollutants can eventually be completely degraded to CO_2 by microbes
- Prokaryotes have been used in bioremediation of several major crude oil spills



Exxon Valdez Oil Spill

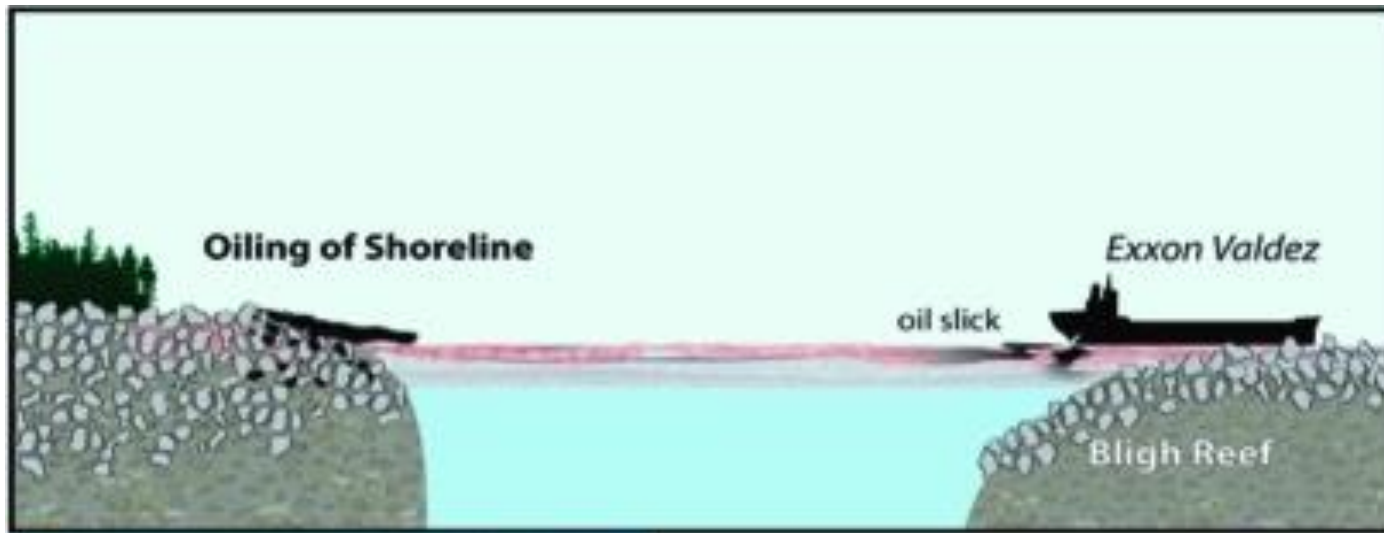


Environmental Consequences of Large Oil Spills and the Effect of Bioremediation



Environmental Consequences of Large Oil Spills and the Effect of Bioremediation





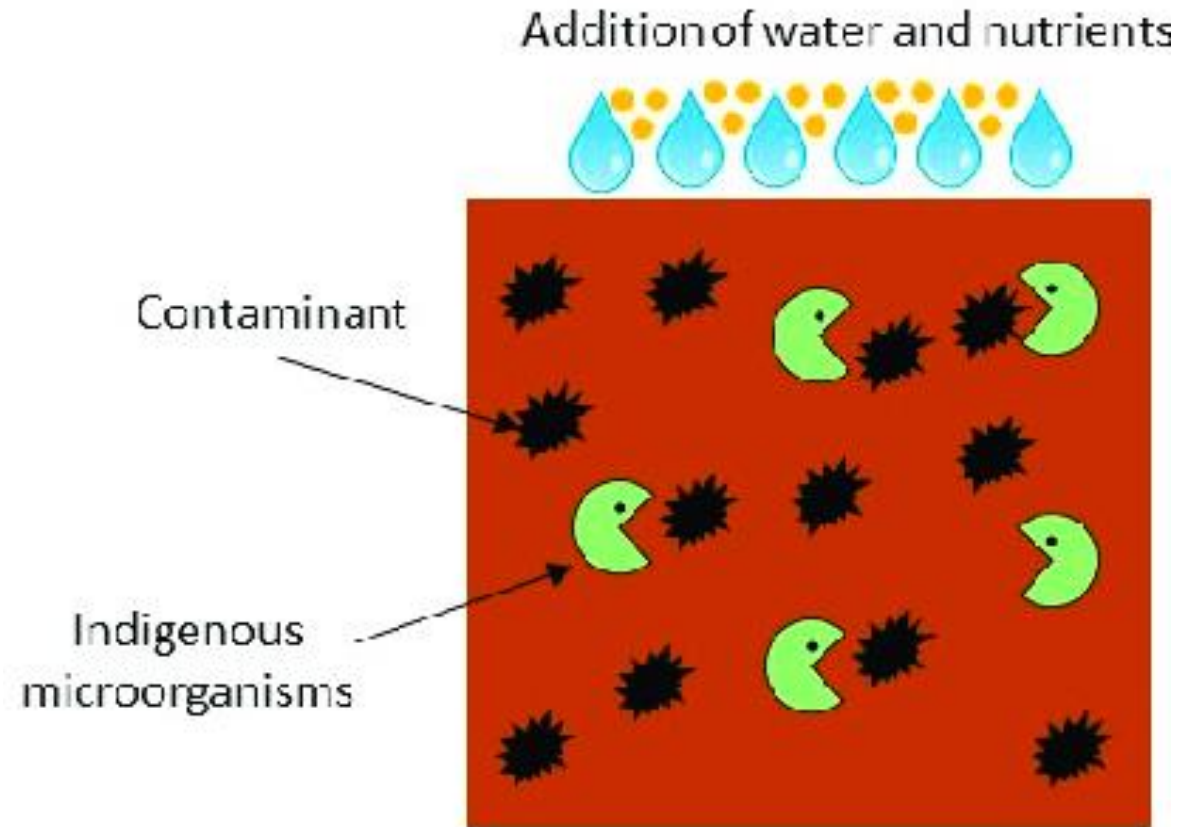
Physical washing of shorelines with high pressure water



Application of fertilizer for bioremediation

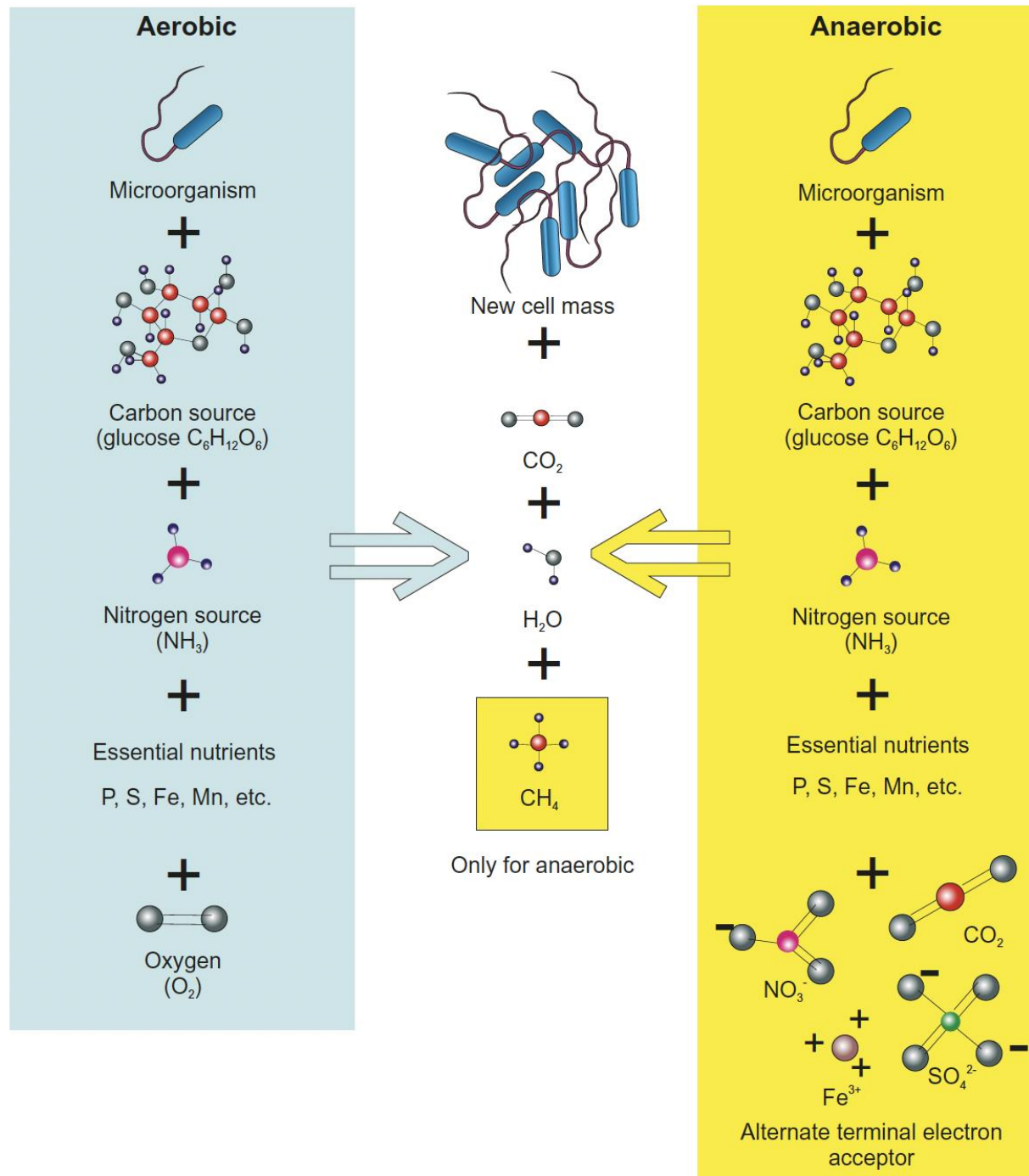
Biostimulation

- The modification of environmental conditions to enhance the biodegradation activity of indigenous microorganisms.
 - e.g., addition of oxygen, N, P
- Used to increase the speed and effectiveness of bioremediation

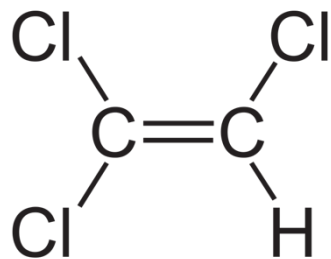


Biostimulation

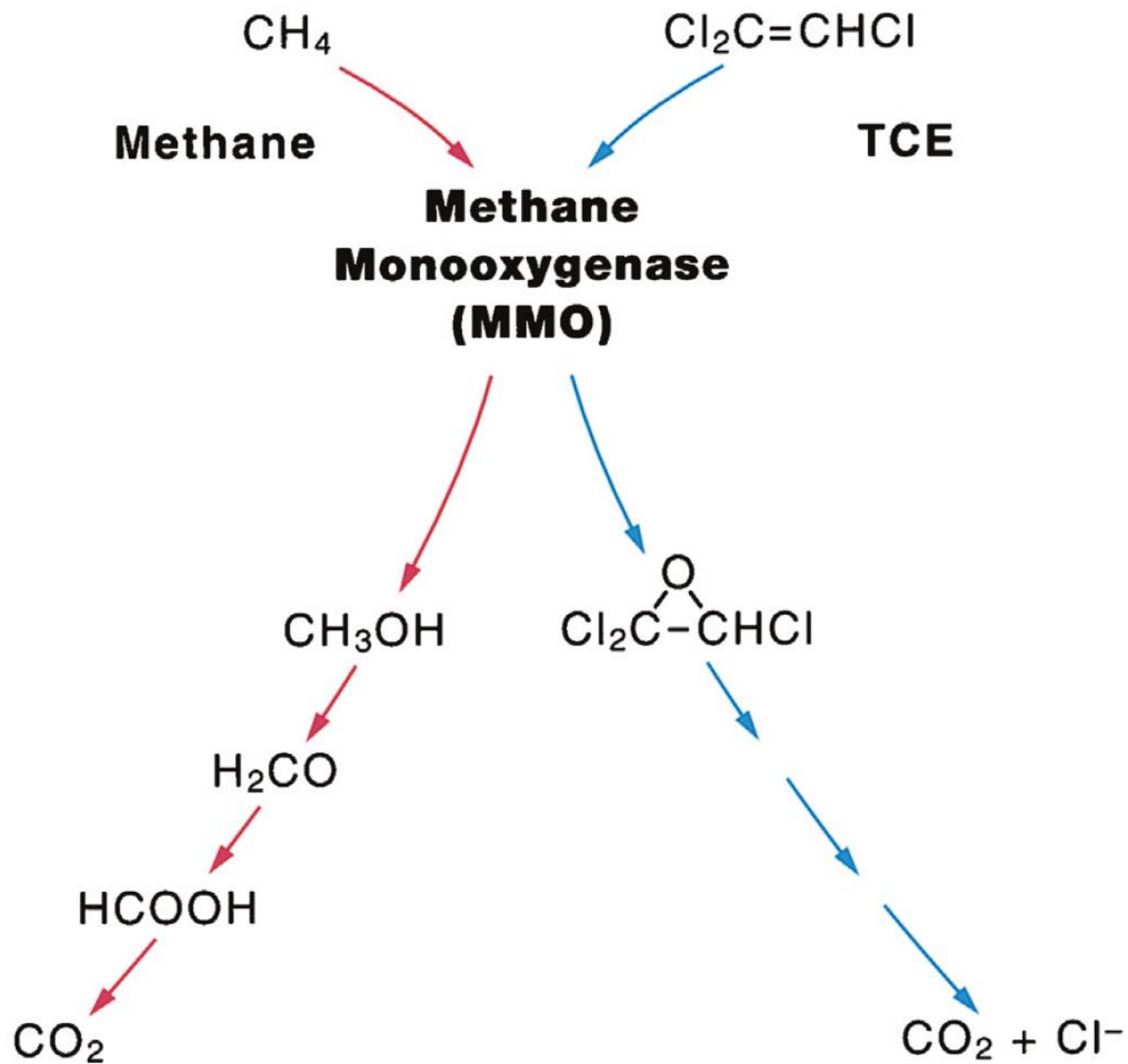




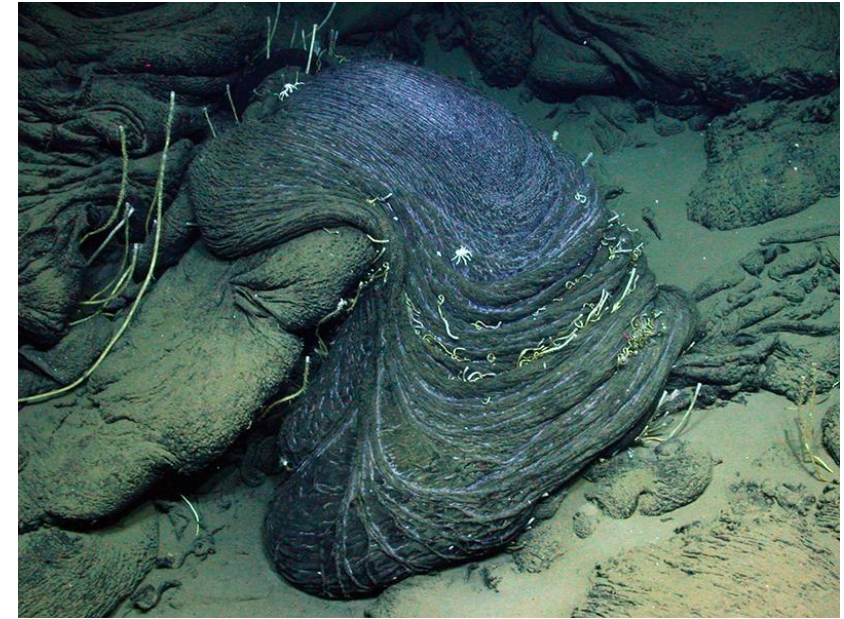
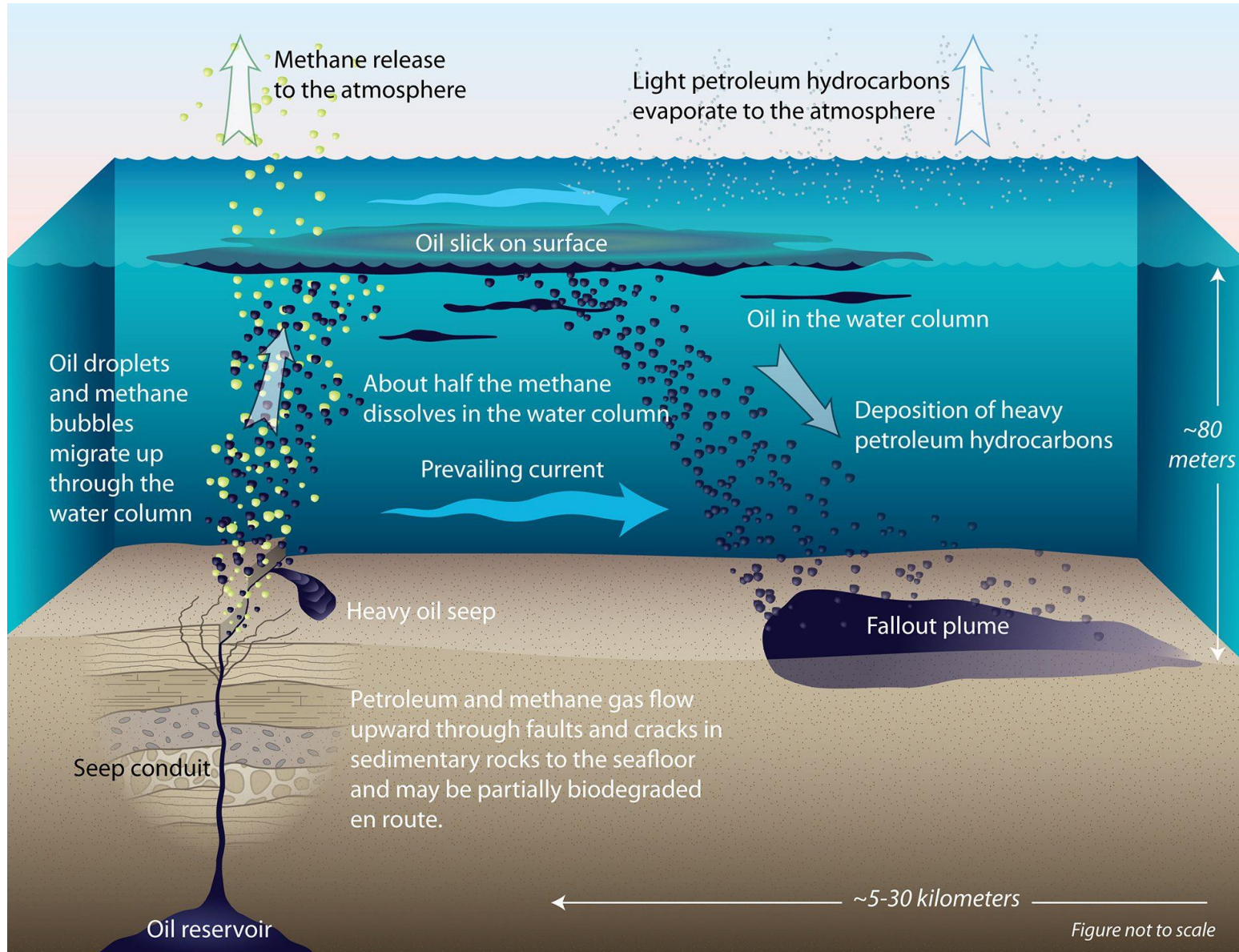
*mineralization
of an organic compound*



TCE: trichloroethylene



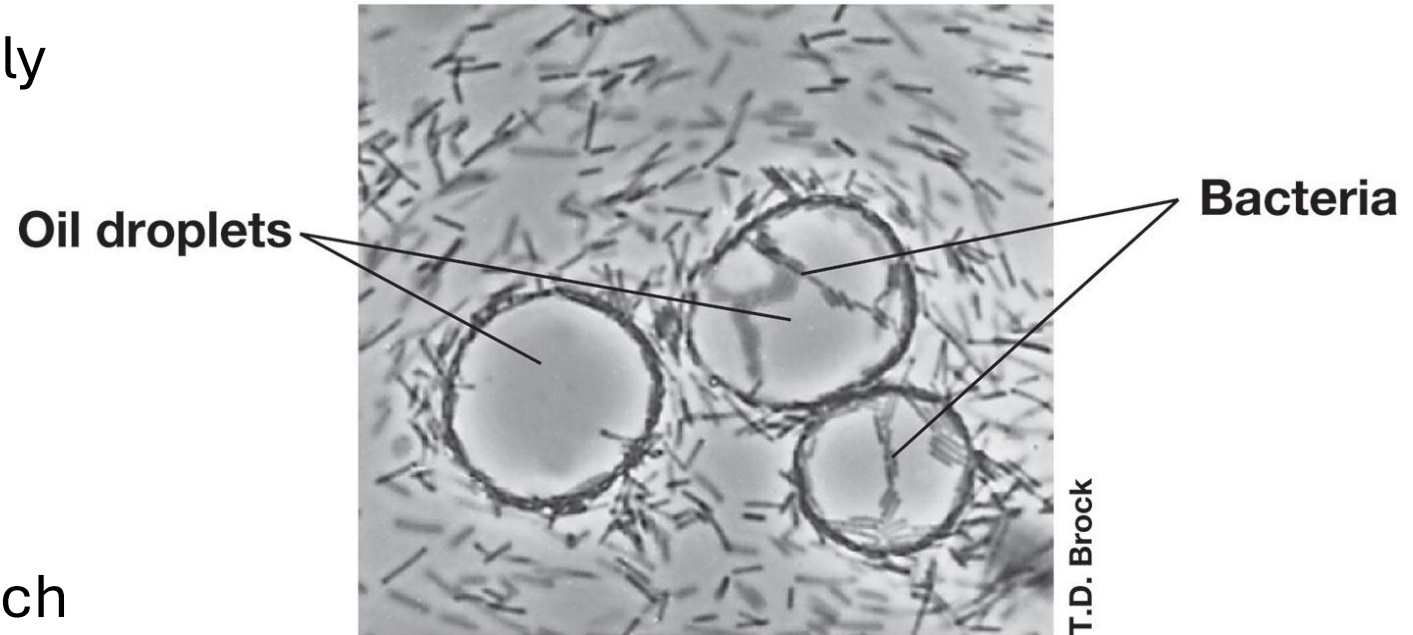
Natural Oil Seeps



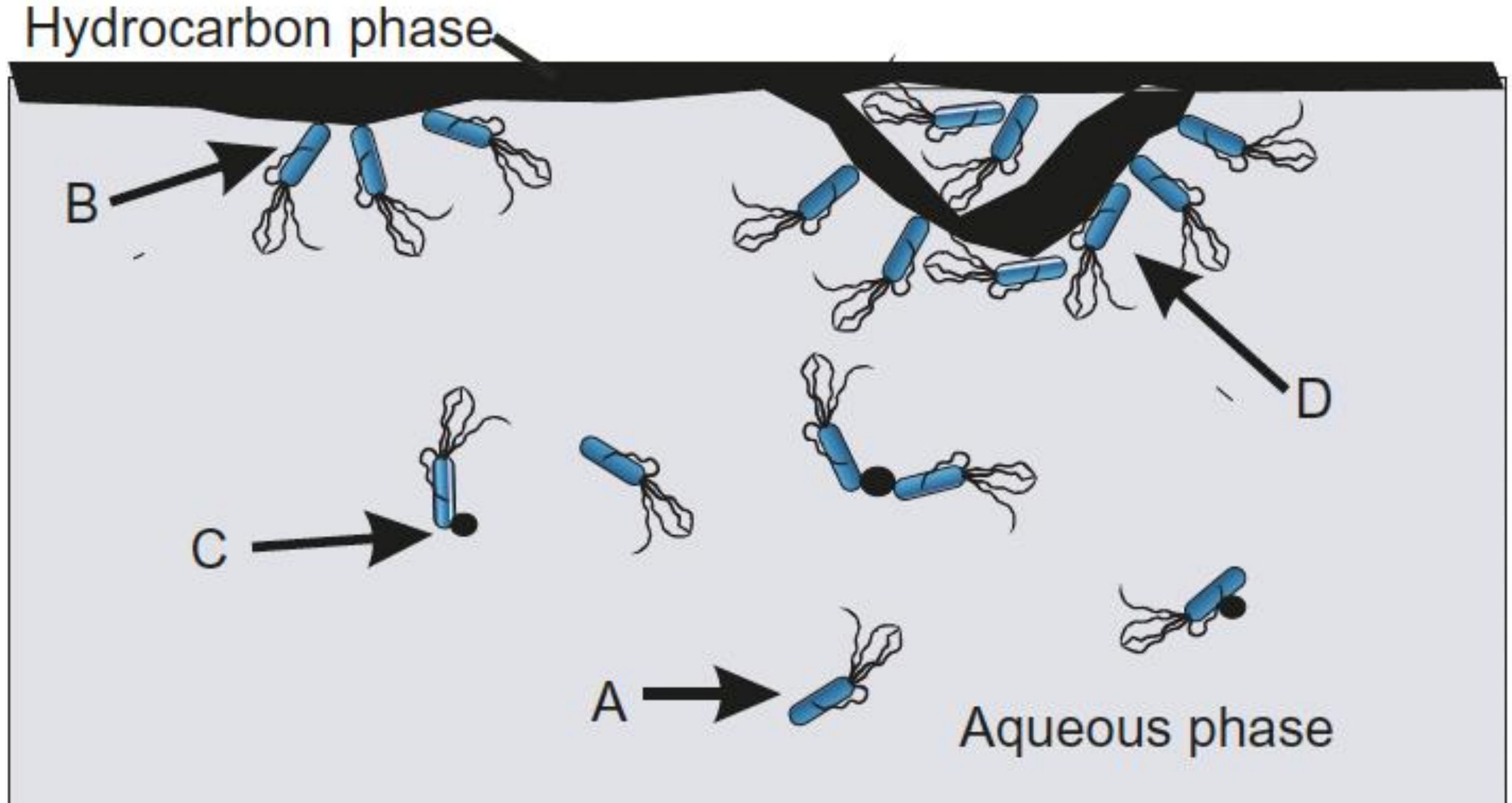
- petroleum hydrocarbons occur naturally in all marine environments
- occur in clusters around the world
- oil flows slowly up through networks of cracks

Bioremediation of Organic Pollutants: Hydrocarbons

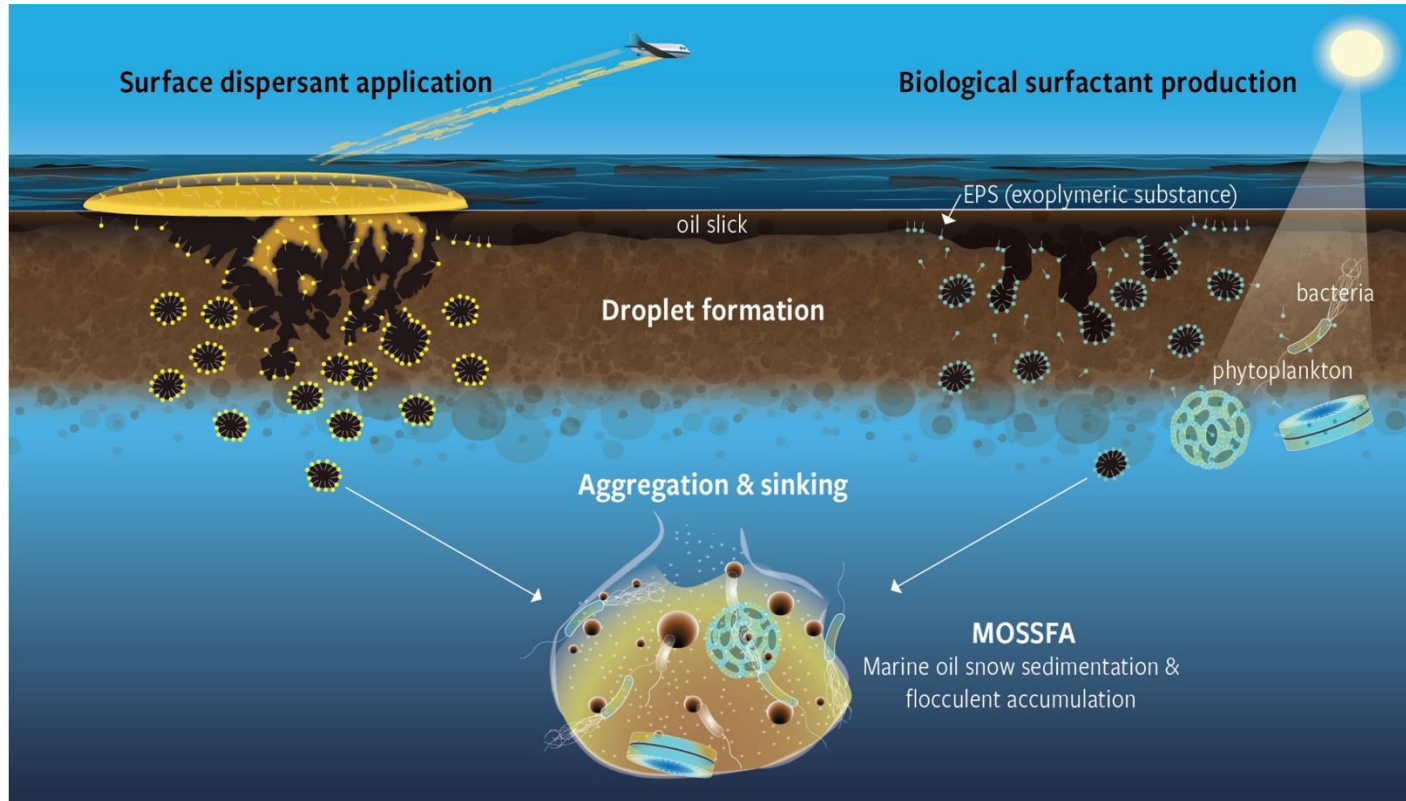
- Diverse bacteria, fungi, and some cyanobacteria and green algae can oxidize petroleum products aerobically
- Oil-oxidizing activity is best if temperature and inorganic nutrient concentrations are optimal, so these nutrients are often added
- Hydrocarbon-degrading bacteria attach to oil droplets, decompose the oil, and disperse the slick



water environment with a petroleum oil phase floating on the surface



Dispersants



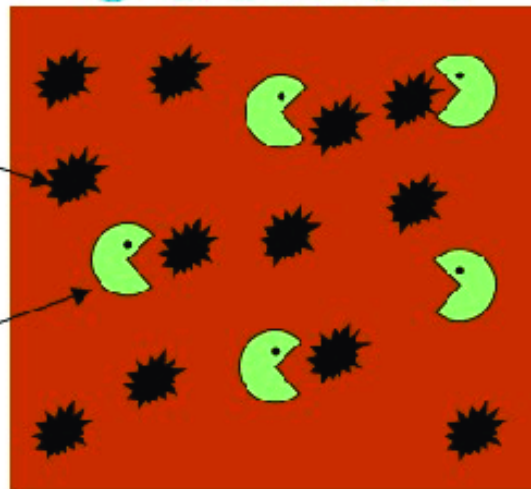
Biostimulation

Addition of water and nutrients



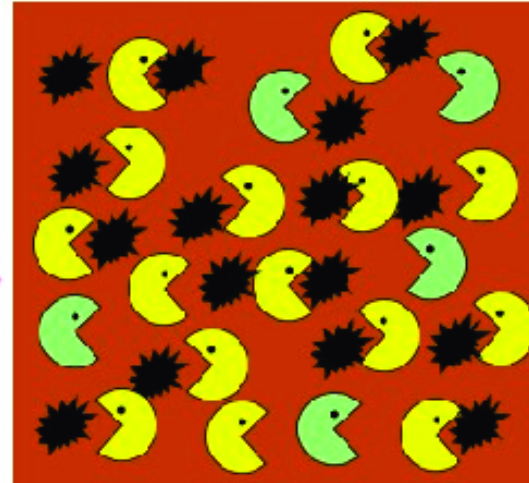
Contaminant

Indigenous microorganisms

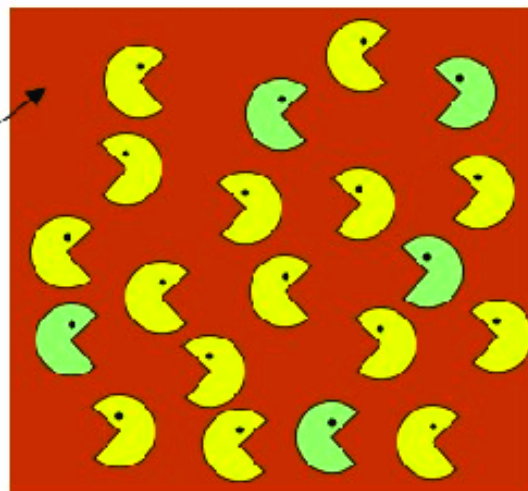


Bioaugmentation

Addition of microorganisms



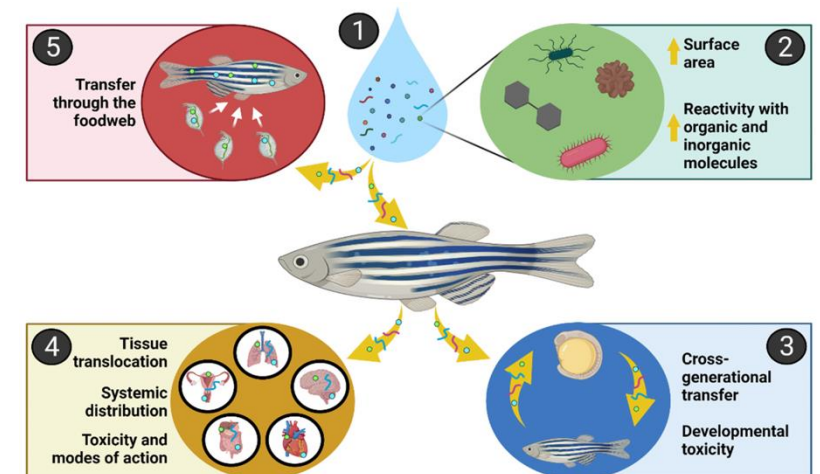
Contaminant free environment



Successful bioremediation

Bioplastics

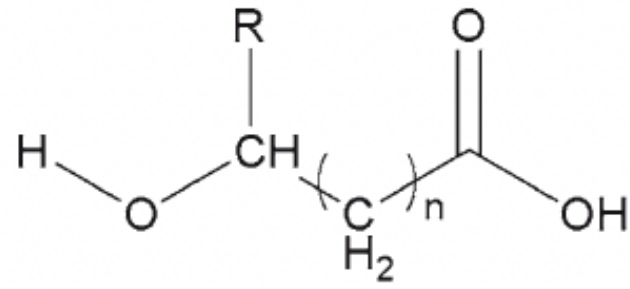
- Plastics industry worldwide produces over 300 million tons of plastic per year
- Most plastics are produced from fossil-fuels derived from petroleum or natural gas
 - Non-renewable fossilized biomass
 - Low biodegradation ability
 - Production of nanoplastics



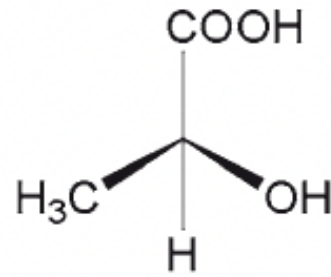
Bioplastics

- Production of bacterial plastics
 - polyhydroxyalkanoates (PHA)
 - polylactic acid (PLA)
 - poly(butylene succinate) (PBS)
- monomers synthesized via bacterial transformation
- well known for their biodegradability

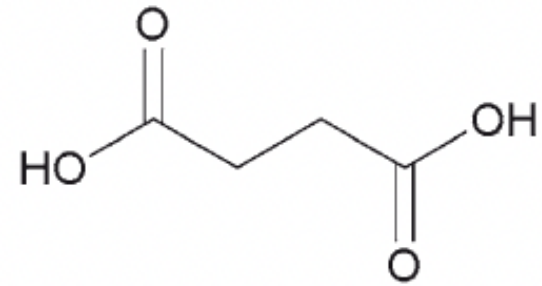




Hydroxyalkanoates



D, L-lactic acids



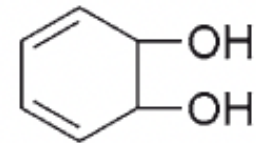
Succinic acid



Bio-ethylene



1,3-Propanediol



cis-3,5-cyclohexadien-1,2-diols

Fig. 1 Most common bio-based polymer building blocks for bacterial plastics

PHA is the only bioplastic completely synthesized by biological means.

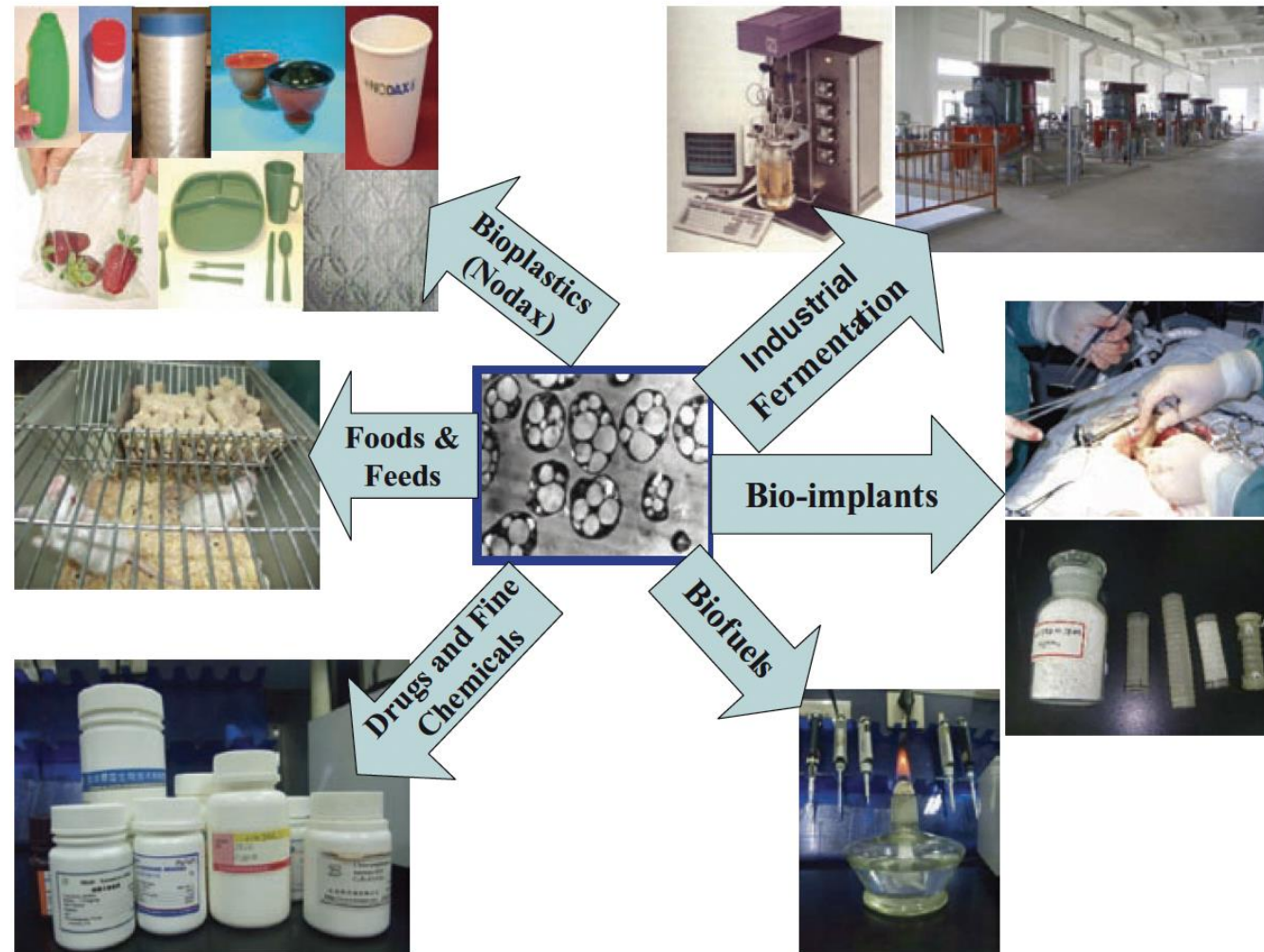
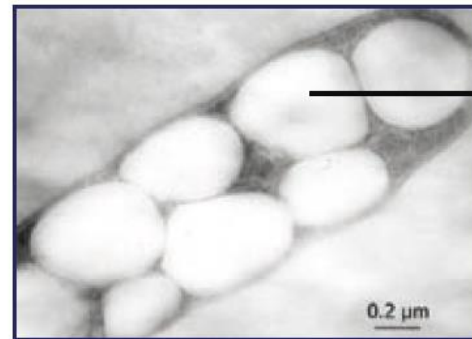


Fig. 1 Applications of polyhydroxyalkanoates (PHA) in various fields (Chen 2009a)

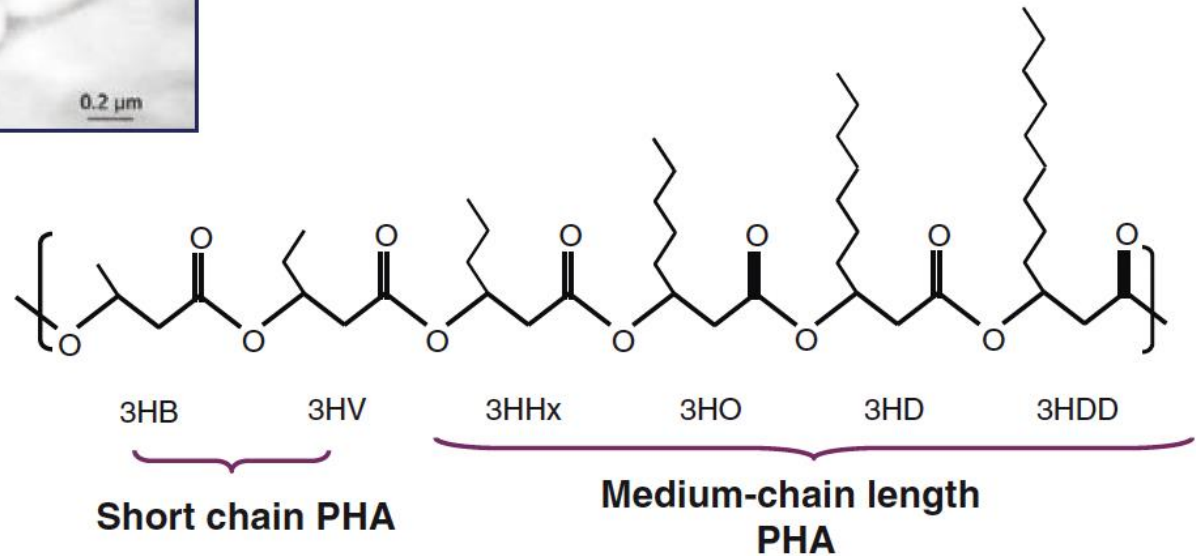
PHA is the only bioplastic completely synthesized by biological means.

- Synthesized by soil-inhabiting bacteria
- Plastic properties can be controlled by growth conditions



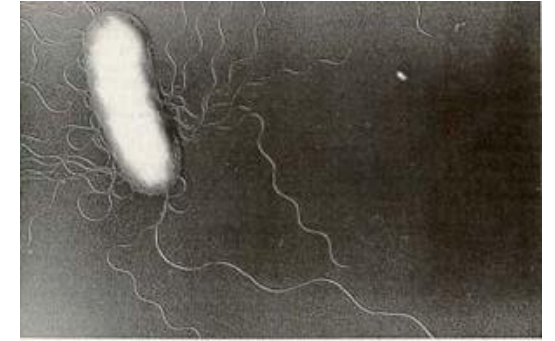
PHA Granules

PHA has 150 monomers reported

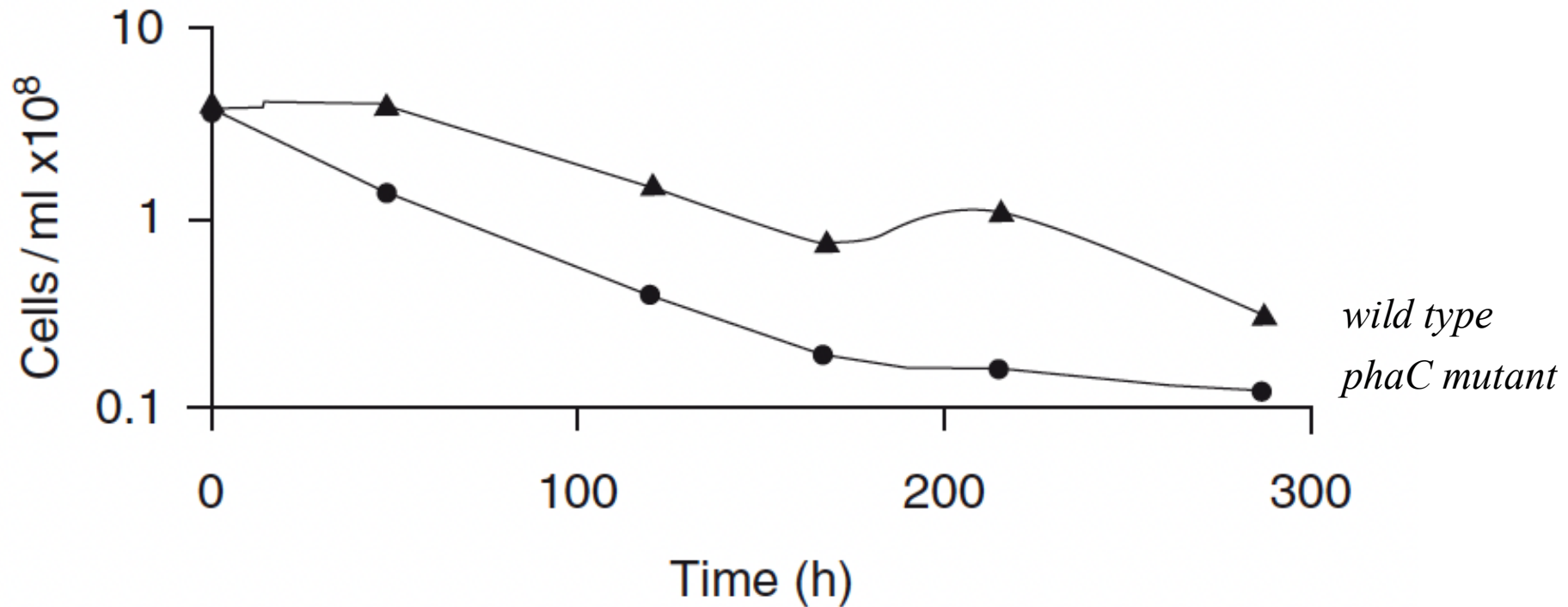


Why microorganism produce PAHs

- Intracellular carbon storage compounds
 - during carbon limitation



Azospirillum brasilense



Why microorganism produce PAHs

- Enhances the survival of several bacterial species under environmental stress conditions imposed in water and soil,
 - such as UV-irradiation
 - salinity
 - thermal and oxidative stress
 - desiccation

