

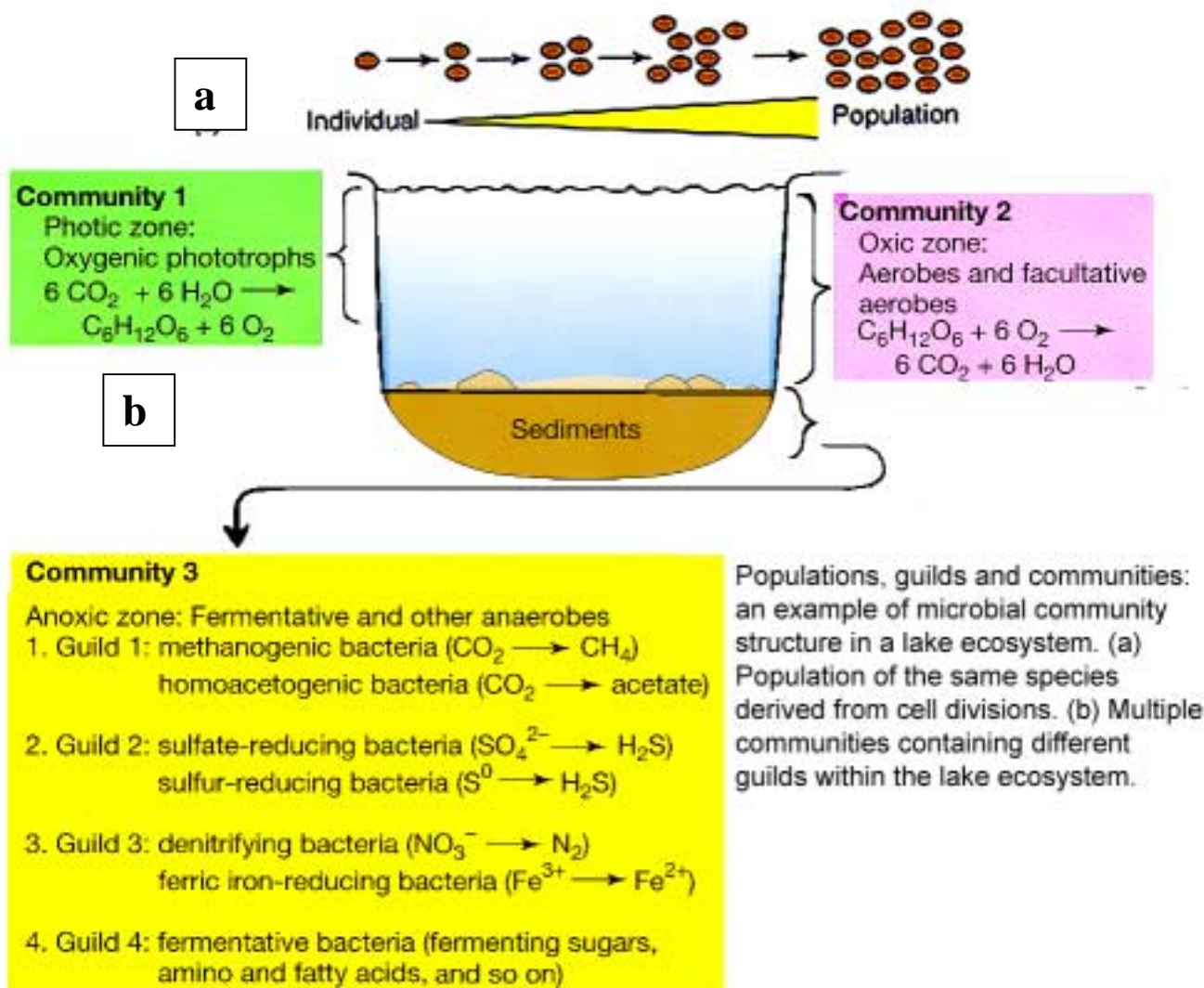
MMG 301 Dr. Frank Dazzo

Microbial Ecology I: General Concepts & Biogeochemistry

Ecology: study of organisms in their natural and managed environments

Hierarchy of ecological order for microorganisms:

- Individual cells of the same type multiply to form populations
- Metabolically related populations constitute groups called guilds
- Mixtures of different guilds conducting complementary physiological processes interact to form microbial communities
- Microbial communities then interact with communities of macroorganisms and the physicochemical environment to define the entire ecosystem



The science of Microbial Ecology has 2 broad objectives:

- 1. To understand the biodiversity of microorganisms in nature and how different guilds interact in microbial communities**
- 2. To measure the behavior and activities of microorganisms in natural environments and monitor their effects on ecosystems**

A few important concepts:

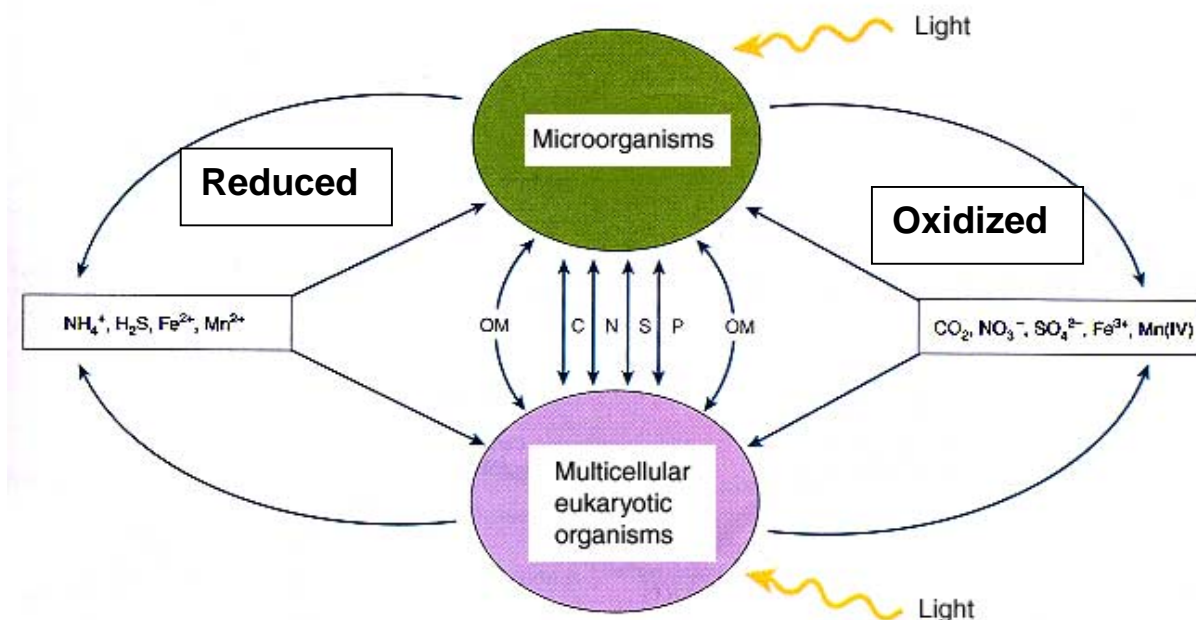
- 1. Much is known about the activities of only a small proportion of the microbial world: there are many microorganisms left to be discovered and this is a major goal of microbial ecology.**
- 2. Each type of microorganism has at least one ecological niche, *i.e.*, a function that it can successfully compete for in a habitat.**
- 3. Countless microbial niches exist in the biosphere and are in large part responsible for the great metabolic diversity and biodiversity of microorganisms on Earth.**
- 4. Since microbes are small, their habitats are small, and their ecological niches can also cover small spatial scales. Despite their small size, microbes nevertheless affect ecosystems on greater scales, including global-level effects, e.g., biogeochemical cycling of C, N, S needed to sustain life on Earth.**
- 5. The concept of microenvironment becomes important in understanding how microbes actually live and metabolize within their natural habitats.**
- 6. Such microenvironments commonly undergo profound changes in physicochemical characteristics, resulting in gradients.**
- 7. Example: respiratory consumption of oxygen by large populations of aerobic microbes on biofilms within the human mouth creates anoxic microenvironments that allow anaerobic microbes to produce various volatile fermentation waste products that cause “bad breath” odor.**

**Microbes participate in both positive (+) and negative (-) interactions:
Description and microbial example:**

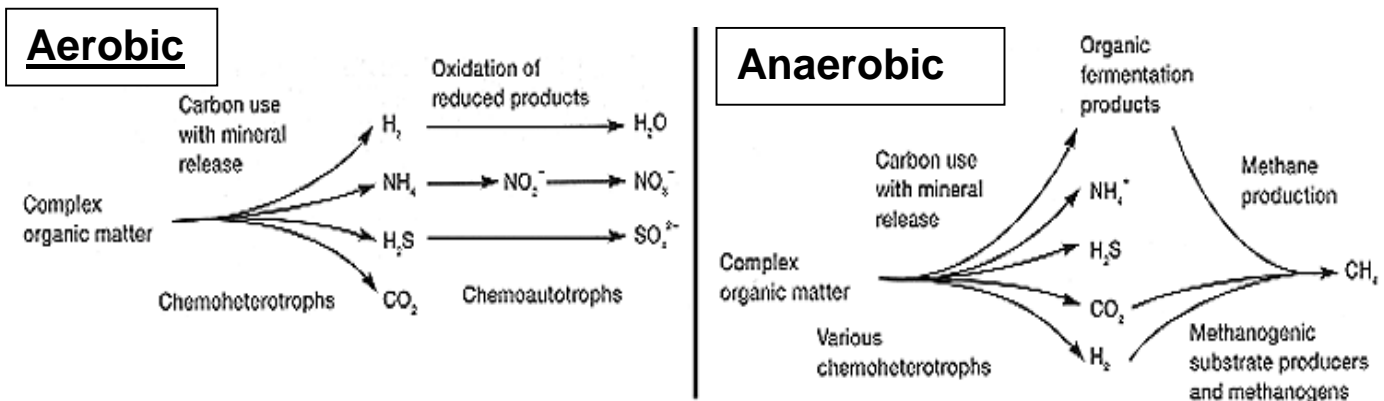
Interaction type	Interaction example	Description and microbial example
Mutualism		<p>Bidirectional; some reciprocal benefit accrues to both partners. Examples: lichen symbiosis: fungus (mycobiont) and algae or cyanobacteria phycobiont); rumen-microbe symbiosis (cow and anaerobic bacteria), nitrogen-fixing <i>Rhizobium</i>-legume root nodule symbiosis</p>
Protocooperation		<p>Unidirectional: one partner benefits while the other is neither benefited nor harmed. Examples: many interactions in microbial biofilms and indigenous normal microflora of the intact human body</p>
Commensalism		<p>Predator engulfs, attacks and kills the prey. Examples: density-dependent predation of bacteria by protozoans in aquatic and soil habitats.</p>
Predation		<p>Parasite infects host, who is harmed. Examples; bacteriophage infecting bacteria, human infectious diseases.</p>
Parasitism		<p>Unidirectional release of an inhibitory compound by one organisms that harms a susceptible microorganism. Example: production of antibiotics or bacteriocins.</p>
Amensalism		<p>The demand for a food resource exceeds the supply: a major cause of restricted microbial productivity in soil and marine ecosystems (limitation of energy-yielding organic carbon).</p>
Competition		

Biogeochemical Cycles

- **Biogeochemical cycling** involves both biological and chemical processes that result in the cyclic interconversion of certain key elements (e.g., C, N, S, others) needed to sustain productive life processes in the biosphere.
- The most important role of microorganisms in the biosphere is their participation in the biogeochemical cycling of nutrients.
- Life as we know it would ultimately cease to exist without this contribution of microorganisms to biogeochemical cycling.
Bacteria are essential for life on Earth
- These cycles are driven by microbial metabolism that transforms nutrients, often by oxidation-reduction reactions, thereby changing their physical and chemical characteristics.
- All biogeochemical cycles are interlinked and these nutrient transformations have global-level impacts.

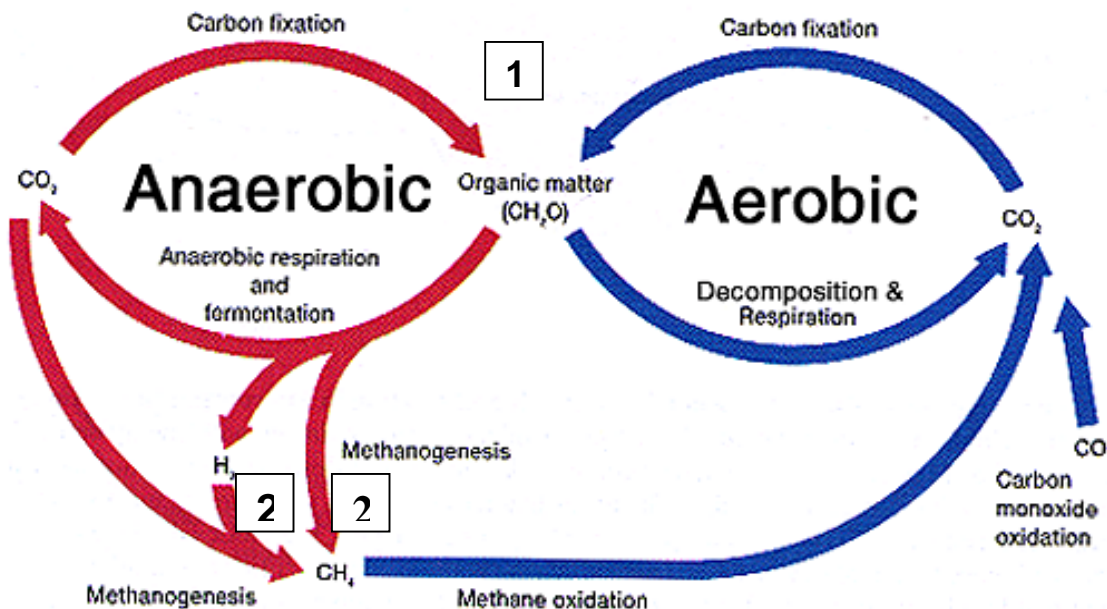


Presence of O₂ significantly influences biogeochemical cycling, as illustrated by its influence on organic matter decomposition:



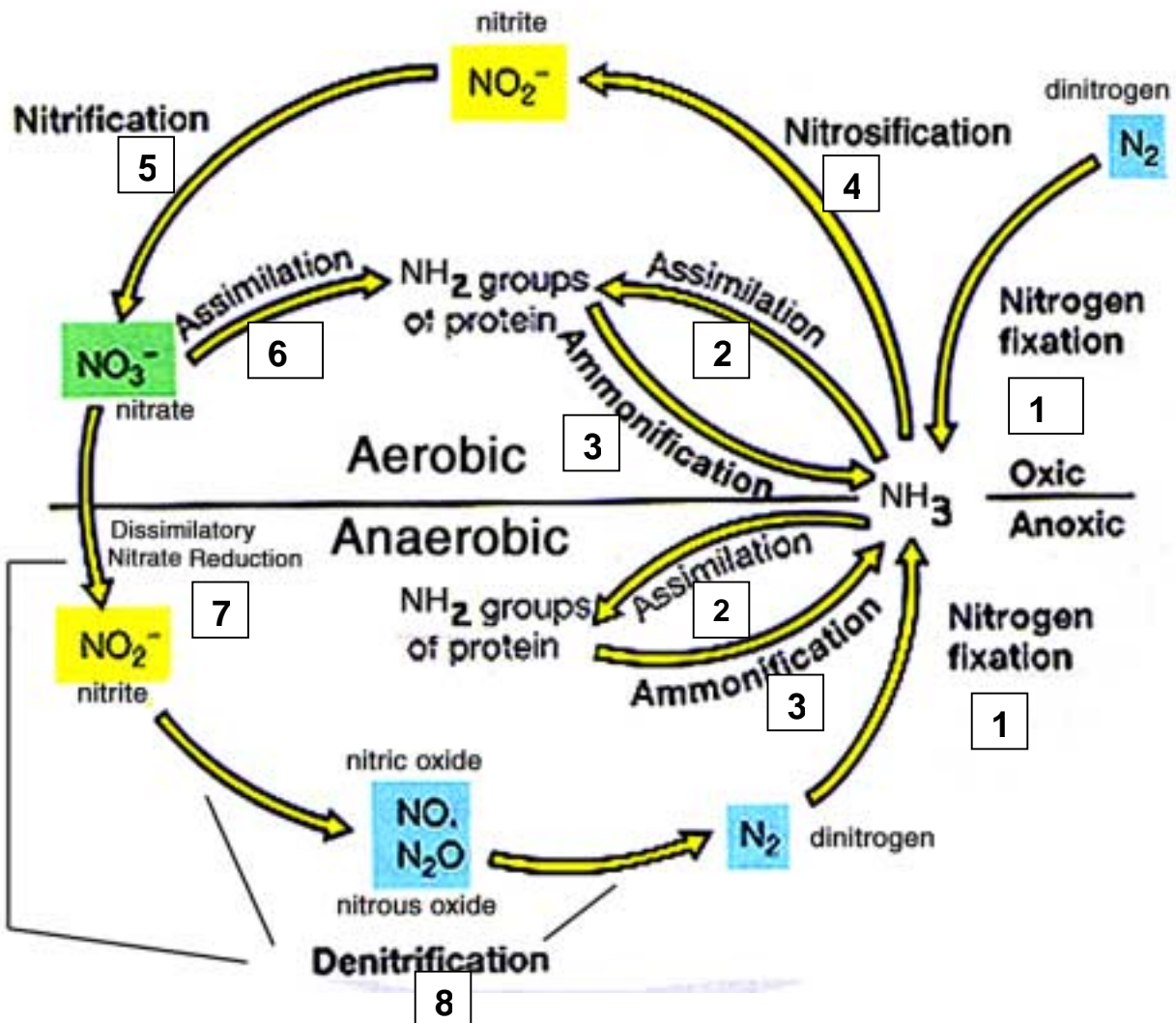
- Microorganisms form different products when decomposing complex organic matter. Oxidized products accumulate aerobically, while reduced products accumulate anaerobically.
- These reactions also illustrate commensalistic transformations, where the waste products from one microbial group are used as substrates by other microbial groups (*syntrophy*).

Biogeochemical Carbon Cycle:



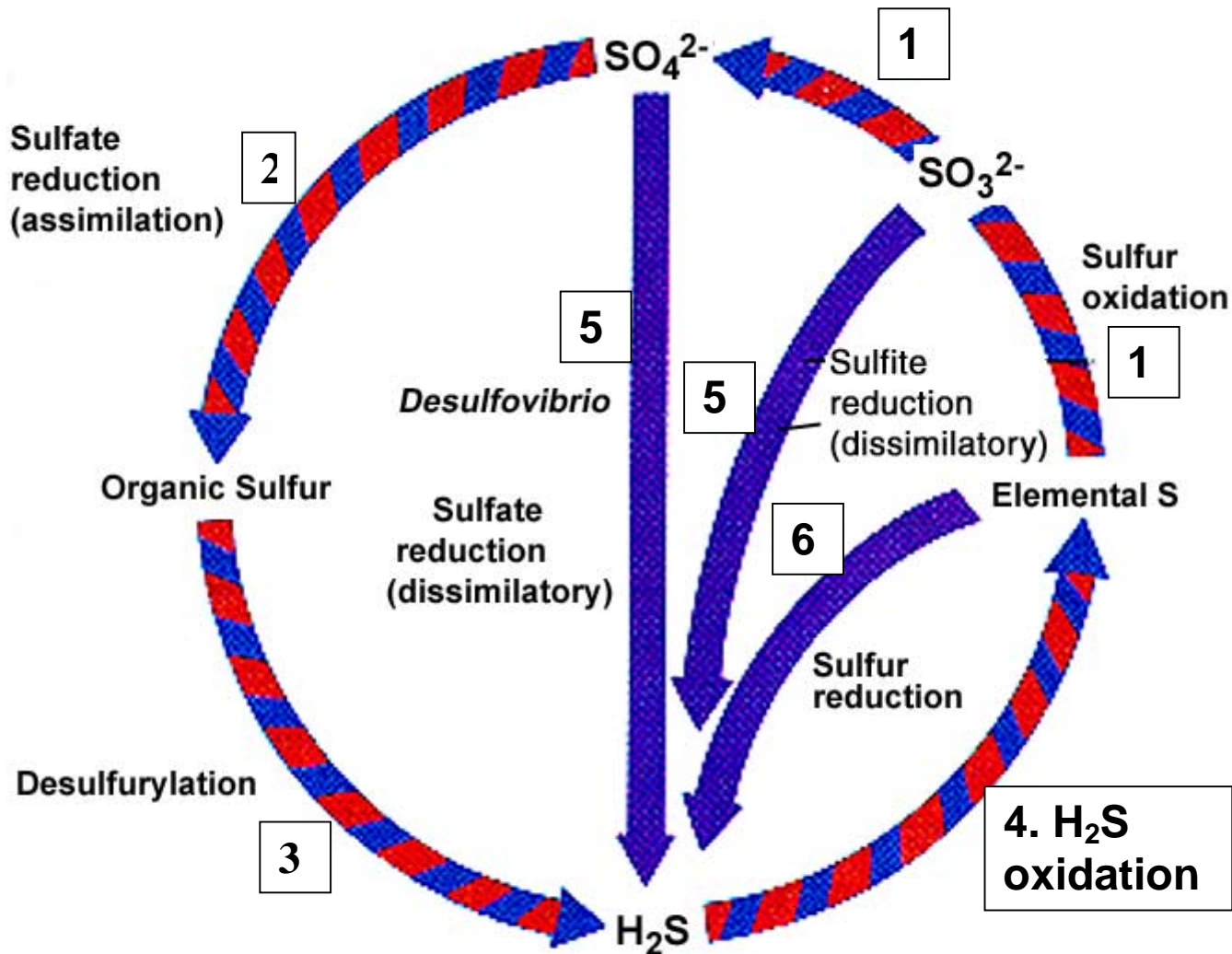
1. CO₂ fixation by photoautotrophs and chemoautotrophs.
2. Methanogenesis from inorganic (CO₂ + H₂) or organic matter, involves various archaea methanogens (*Methanobacterium*, others). Global CH₄ production ~10¹¹ kg / yr (~ 85% biogenic)

Biogeochemical Nitrogen cycle:



Examples of bacteria involved in box numbered steps:

1. **Nitrogen fixation** $N_2 \rightarrow NH_3$ (aerobic) **free-living**: *Azotobacter*, cyanobacteria; **symbiotic**: *Rhizobium*, *Frankia*. (anaerobic): *Clostridium perfringens*, purple & green sulfur phototrophs.
2. **NH_3 assimilation** (aerobic & anaerobic) many organisms
3. **Ammonification** (organic N $\rightarrow NH_3$) many organisms
4. **Nitrosification** (aerobic), *Nitrosomonas*
5. **Nitrification** (aerobic), *Nitrobacter*
6. **Nitrate assimilation** ($NO_3^- \rightarrow NH_3 \rightarrow$ amino acids) many organisms
7. **Dissimilatory nitrate reduction** ($NO_3^- \rightarrow NO_2^-$) many organisms
8. **Denitrification** ($NO_3^- \rightarrow \rightarrow \rightarrow N_2$) *Bacillus*, *Pseudomonas*, others



Biogeochemical Sulfur Cycle:

1. Sulfur oxidation ($\text{S}^0 \rightarrow \text{SO}_3^{-2} \rightarrow \text{SO}_4^{-2}$): (aerobic) many chemolithotrophs; (anaerobic) purple & green photoautotrophs
2. Assimilatory sulfate reduction ($\text{SO}_4^{-2} \rightarrow$ organic S) many microbes
3. Desulfurylation (organic S decomposition $\rightarrow \text{H}_2\text{S}$) many microbes
4. H_2S oxidation ($\text{H}_2\text{S} \rightarrow \text{S}^0$) Aerobic: *Thiobacillus*, *Beggiotoa* (chemolithotrophs). Anaerobic: *Chlorobium*, *Chromatium* (anoxygenic photoautotrophs)
5. Dissimilatory sulfate and sulfite reduction (solid purple arrows) SO_4^{-2} or $\text{SO}_3^{-2} \rightarrow \text{H}_2\text{S}$: *Desulfovibrio* and related organisms
6. Elemental sulfur reduction ($\text{S}^0 \rightarrow \text{H}_2\text{S}$) *Desulfuromonas*, thermophilic archaea, cyanobacteria in hypersaline sediments.