Adaptation to environmental conditions

Adaptation

• What environmental factors affect growth?
• Cell structure and growth
• Adaptations to environmental factors
• Cold adaptation in SRB
• Growth above 100 °C
What environmental factors affect growth?

- Temperature
- pH
- Water availability
- Oxygen
- Pressure
- Light and radiation
- (Energy & carbon source)

Extreme <-> Normal

Specialist <-> Generalist

Growth <-> Survival

Permanent <-> Transient

Obligate <-> Tolerant
Growth

Transport
Biosynthesis
Maintenence of highly organized structure
Regulation
Reproduction
Detoxification

Macromolecules in the cell
Fluid-mosaic structure of the membrane

What environmental factors affect growth?

- Temperature
- pH
- Water availability
- Oxygen
- Pressure
Temperature limits for life

- Freezing point in seawater around -2 °C
- Partially liquid in antarctic sea ice at -15 °C
- Liquid up to 300 °C at high pressure
- Only Prokaryotes grow above 65 °C
- Upper limit: strain 121 grows at 121 °C
Upper limit: strain 121 grows at 121 °C

Quelle: Brock Biology of Microorganisms

Kashefi and Lovley 2003
What environmental factors affect growth?

- Temperature
- pH
- Water availability
- Oxygen
- Pressure

Quelle: Brock Biology of Microorganisms
pH and microbial growth

- pH range for growth limited to 2 units
- How can they generate proton motive force?
- *Picrophilus oshimae* (pH 0.7 - 2)
- Sea water in general well buffered around pH 8

What environmental factors affect growth?

- Temperature
- pH
- **Water availability**
- Oxygen
- Energy & carbon source
Water activity, osmosis, and halophiles

- All organisms require water
- Water content and substances dissolved in water
- Sea water contains about 3% NaCl
- Halophiles: salt-loving organisms
Water activity, osmosis, and halophiles

- All organisms require water
- Water content and substances dissolved in water
- Sea water contains about 3% NaCl
- Halophiles
  - Osmophiles: live in environments high in sugars
  - Xerophiles: live in very dry environments
Water content

Measure for the water content is the water activity $a_w$.

<table>
<thead>
<tr>
<th>Environment</th>
<th>$a_w$</th>
<th>Organism Type</th>
<th>$a_w$</th>
</tr>
</thead>
<tbody>
<tr>
<td>dest. water</td>
<td>1</td>
<td>“normal” microorganisms</td>
<td>0.9</td>
</tr>
<tr>
<td>Seawater</td>
<td>0.98</td>
<td>halophilic microorganisms</td>
<td>0.75</td>
</tr>
<tr>
<td>Salt lakes</td>
<td>0.75</td>
<td>xerophilic fungi</td>
<td>0.7</td>
</tr>
</tbody>
</table>

**Problem:** Osmolarity

**Solution:** Compatible Solutes (Osmolytica) in high concentration

Compatible solutes allow growth under conditions of low water activity.

1. Amino acid-type solutes:
   - Glycine betaine
   - Ectoine

2. Carbohydrate-type solutes:
   - Sucrose
   - Trehalose

[Quelle: Brock Biology of Microorganisms]
Compatible solutes increase the internal solute concentration.

3. Alcohol-type solutes:

<table>
<thead>
<tr>
<th>Glycerol</th>
<th>Mannitol</th>
</tr>
</thead>
<tbody>
<tr>
<td>CH₂OH</td>
<td>CH₂OH</td>
</tr>
<tr>
<td>CH₂OH</td>
<td>HO─C─H</td>
</tr>
<tr>
<td>CH₂OH</td>
<td>HO─C─H</td>
</tr>
<tr>
<td></td>
<td>H─C─OH</td>
</tr>
<tr>
<td></td>
<td>H─C─OH</td>
</tr>
<tr>
<td></td>
<td>CH₂OH</td>
</tr>
</tbody>
</table>

4. Other:

Dimethylsulfiniopropionate:

\[
\text{CH}_3\text{O}^-
\]

\[
\text{CH}_3\text{S}—\text{CH}_2\text{CH}_2\text{C}—\text{O}^-
\]

What environmental factors affect growth?

- Temperature
- pH
- Water availability
- Oxygen
- Pressure
Toxic forms of oxygen
(By-products during O_2 reduction)

\[ O_2 + e^- \rightarrow O_2^- \quad \text{Superoxide} \]
\[ O_2^- + e^- + 2 H^+ \rightarrow H_2O_2 \quad \text{Hydrogen peroxide} \]
\[ H_2O_2 + e^- + H^+ \rightarrow H_2O + OH^- \quad \text{Hydroxyl radical} \]
\[ OH^- + e^- + H^+ \rightarrow H_2O \quad \text{Water} \]

Overall: \[ O_2 + 4 e^- + 4 H^+ \rightarrow 2 H_2O \]

(a) Catalase:
\[ H_2O_2 \ + \ H_2O_2 \rightarrow 2 \ H_2O \ + \ O_2 \]

(b) Peroxidase:
\[ H_2O_2 \ + \ NADH \ + \ H^+ \rightarrow 2 \ H_2O \ + \ NAD^+ \]

(c) Superoxide dismutase:
\[ O_2^- \ + \ O_2^- \ + \ 2 H^+ \rightarrow H_2O_2 \ + \ O_2 \]

(d) Superoxide dismutase/catalase in combination:
\[ 4 \ O_2^- \ + \ 4 \ H^+ \rightarrow 2 \ H_2O \ + \ 3 \ O_2 \]

(e) Superoxide reductase:
\[ O_2^- \ + \ 2 \ H^+ \ + \ cyt \ c_{\text{reduced}} \rightarrow H_2O_2 \ + \ cyt \ c_{\text{oxidized}} \]
Temperature adaptation in SRB

Dissimilatory sulfate-reduction occurs between -1.8 °C (arctic sediment) and above 100 °C (Guaymas basin sediment)

High phylogenetic and physiological diversity
So-called "black smokers" are the hottest of the vents. They spew mostly iron and sulfide, which combine to form iron monosulfide. This compound gives the smoker its black color.

More than 90% of the ocean biosphere is permanently cold!
Cold adaptations of microorganisms

- Effects on growth rate and growth yield
- Metabolic activity
- Protein flexibility and cold-adapted enzymes
- Protein synthesis and cold-induced proteins
- Effects on membrane and lipid structure

### Temperature range

- **Mesophilic**: Most isolated SRB (since Beijerinck, 1895)

  - 0°C - 40°C

- **psychrotolerant**: e.g. *Desulfo bacter hydrogenophilus* (Widdel, 1987)

  - 0°C - 20°C

- **psychrophilic**: Isolates from Arctic sediments (Knoblauch et al., 1999)

  - 0°C - 10°C

- **Ice**
Fluid-mosaic structure of the membrane

Quelle: Brock Biology of Microorganisms
Fatty acids, that were found in membrane lipids

Rule of thumb: The higher the temperature, the more stable is the membrane. High content of saturated fatty acids.

Lipid bonds in Bacteria, Eukarya and Archaea

Ester

\[
\text{CH}_2\text{OH} \quad \text{O} \\
\text{CH}_3 \quad \text{C} \quad \text{CH}_2 \quad \text{-(CH}_2)_3 \quad \text{CH}_3
\]

Bacteria, Eukarya

Ether

\[
\text{CH}_2\text{OH} \\
\text{CH}_2\text{OH} \\
\text{CH}_3 \quad \text{CH}_3 \quad \text{CH}_3 \quad \text{CH}_3 \quad \text{CH}_3
\]

Archaea

Quelle: Brock Biology of Microorganisms
Etherlipids in Archaea

Side chains consist of repeating isoprene units!

Structure of archaeal membranes

Quelle: Brock Biology of Microorganisms
Temperature adaptation of bacterial membrane fatty acids

Low temperature                      High temperature

cis-unsaturated fatty acids

Desaturase De novo-synthesis           saturated fatty acids

branched fatty acids

De novo-synthesis                   saturated fatty acids

short-chain fatty acids

De novo-synthesis                   long chain fatty acids

Effect of temperature on unsaturated fatty acids in psychrophilic SRB

<table>
<thead>
<tr>
<th></th>
<th>4 °C</th>
<th>12 °C</th>
<th>20 °C</th>
<th>28 °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Desulfobacula gelida</td>
<td>40%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Desulfrofrigus oceanense</td>
<td>73%</td>
<td>70%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Desulfotalea psychrophila</td>
<td>82%</td>
<td>78%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Desulfotalea arctica</td>
<td>85%</td>
<td></td>
<td>83%</td>
<td></td>
</tr>
<tr>
<td>Desulfophalus vacuolatus</td>
<td>85%</td>
<td></td>
<td></td>
<td>81%</td>
</tr>
</tbody>
</table>

contains high amounts (>70%) of short chain fatty acids

Total amount of unsaturated fatty acids
### Effect of temperature on unsaturated fatty acids in mesophilic SRB

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>Desulfovibrio desulfuricans</th>
<th>Desulfococcus multivorans</th>
<th>Desulfosarcina variabilis</th>
<th>Desulfobacter postgatei</th>
<th>Desulfobacter hydrogenophilus</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>49%</td>
<td>25%</td>
<td>23%</td>
<td>43%</td>
<td>65%</td>
</tr>
<tr>
<td>12</td>
<td>50%</td>
<td>23%</td>
<td>22%</td>
<td>24%</td>
<td>61%</td>
</tr>
<tr>
<td>20</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>28</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **Total amount of unsaturated fatty acids**

### Psychrophiles (permanently cold sediments)
- exhibited constant fatty acid composition with high amounts of unsaturated or short-chain fatty acids.
- are "specialists" in a small temperature range, in which they probably outcompete mesophilic/psychrotolerant species.

### Psychrotolerants (moderate climate)
- change the ratio of saturated, unsaturated and cyclopropane containing fatty acids with changing temperature via *de novo* synthesis.
- are "generalists", which probably outcompete psychrophiles in environments with changing temperatures.
What environmental factors affect growth?

- Temperature
- pH
- Water availability
- Oxygen
- Pressure

High pressures have an influence on:
- Boiling point and viscosity of water
- Membrane fluidity
- Stability of certain biomolecules

Barophilic microorganisms are adapted to high pressures e.g. higher amount of unsaturated fatty acids within their membrane, or modified enzymes
Pressure Are bacteria pressure sensitive?

Experiment: Bring a balloon to a water depth of 1000 m
... 1 bar pressure rise per 10 m; at 1000 m, pressure is a 100 times higher

?... filled with air $O \rightarrow \circ$ (1 %)

? ... or with water $O \rightarrow O$ (almost 100 %)

Bacteria do not have a swim bladder (Schwimmblase).

Observations on our moderate thermophilic sulfate-reducing isolates

Isolation conditions: $20^{\circ}$ C, 0.1 MPa

Growth range: 10 - 48 $^{\circ}$ C

In-situ conditions: $56-61^{\circ}$ C, ~30 MPa

Question?

Will our strains grow at in-situ temperatures when we let them grow under in-situ pressure?
Adaptation experiments: Pressure experiments with moderate thermophilic sulfate-reducing JdFR-isolates

(With cooperation with MPI Bremen & ICBM-AG Organic Chemistry)

Pressure and temperature effect on growth of *D. indonesiensis* strains

→ At 20°C: piezotolerant behaviour
→ Pressure: Decelerates growth (stress!)

→ At 45°C: piezophilic behaviour
→ Pressure: Stimulates growth

Shift in temperature range:
0.1 MPa = 10 - 48°C
20 MPa = 15 - 52°C
Adaptation of membrane lipids: Pressurised cultures show higher percentage of unsaturated fatty acids.

Measuring of growth?

D. indonesiensis 250-260 mbsf, lactate medium 45°C