Evolution and how microbes see it

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- Bremen Institute for Materials Testing
- A Division of the Foundation Institute of Materials Science
- SV Werder Bremen
- The town musicians
- Schnoor-Quarter
- The town-hall
- Drop tower
- Universum Science Center
Bremen Institute for Materials Testing

Metallic Materials and Components - Dept. 1
- Analysis of material data
- Examination and testing of metallic parts
- Damage analysis
- Investigation of synergistic effects of matrices for material characteristics

Civil Engineering - Dept. 2
- Testing of building materials
- Surveillance and certification
- Research and development of building materials
- Damage analysis at buildings

Accreditation
acc. to DIN EN ISO/IEC 17025 since 2001

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Analytic Microscopy for Constructional Materials - Dept. 3

- Microscopic damage research
- Development of new matrices for concrete
- Research in the conservation of historical objects
- Analysis of asbestos

Microbiology - Dept. 4

- Microbiological damage analysis
- Identification of damage-relevant microorganisms
- Development of conservation concepts
- Research and development in material resistance
- also tests acc. to ISO, ASTM, AITM, VdL etc.
- Investigations and research in microbial contamination of technical fluids

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Service and Research Topics

- Testing of materials and coatings
- Developments of testing methods
- Isolation, cultivation and identification of microorganisms (fungi, bacteria, archaea, algae)
- Development of biocidic coatings (together with partners)
- Molecular identification and detection
- Rapid identification of microorganisms using MALDI BioTyper™ system
- Systematic of bacteria and fungi
- Functional gene analysis
Microorganisms (MO)

- Prokaryotes: bacteria and archaea
- Eukaryotes: fungi (yeasts), algae
Phylogenetic Tree of Life

Bacteria
- Spirochetes
- Cyanobacteria
- Planctomyces
- Bacteroides
- Cytophaga
- Thermotoga
- Aquifex
- Proteobacteria
- Gram positives
- Green filamentous bacteria

Archaea
- Methanosarcina
- Methanobacterium
- Methanococcus
- T. celer
- Thermoproteus
- Pyrodictium

Eucarya
- Entamoeba
- Slime molds
- Animals
- Fungi
- Plants
- Ciliates
- Flagellates
- Trichomonads
- Microsporidia
- Diplomonads

Not a single cell
Early earth conditions

- High temperature (cold-hot changes?)
- Nearly no organic material present
- High UV-light (no ozone layer present)
- Reduced atmosphere (H₂, H₂S, CO, NH₄⁺, N₂, CO₂, CH₄, H₂O)
Early pathways

- Carbon fixation pathways for cell synthesis (Assimilation)
  - Actetyl-CoA pathway (Wood-Ljungdahl pathway) or
  - Reverse TCA cycle

- ATP synthesis, energy production (Dissimilation)
  - Sulfur (sulfite) reduction: $\text{H}_2 + \text{S} \rightarrow \text{H}_2\text{S}$
  - Methanogenesis: $4\text{H}_2 + \text{HCO}_3^- \rightarrow \text{CH}_4 + \text{H}_2\text{O}$
  - Homoacteogenesis: $4\text{H}_2 + 2\text{HCO}_3^- \rightarrow \text{H}_3\text{CCOO}^- + \text{OH}^- + 3\text{H}_2\text{O}$
Problems

- Purely chemosynthesis
- Low amount of energy generation
- Limited to energy efficient carbon fixation pathways
- Probably dependent on hydrogen
From Nisbet & Sleep, 2001, Nature vol 409
Locations of known hydrothermal activity along the global mid-ocean ridge system

- known active sites
- active sites indicated by midwater chemical anomalies

aus: German and von Damm (2004)
Fig. 4: Schematic model of fluid flow based on geochemical, petrological, and isotopic investigations of altered rocks, sulfides and hydrothermal fluids. Low-T serpentinization of ultramafic rocks takes place well away from the high-T vent sites. Close to the vent sites already serenitized rocks are overprinted by either high-T hydrothermal fluids or by convectively heated, seawater-derived fluids to form late stage and talc alteration.

What still needs to be done. how and when?
Next steps I:

- Use of light as energy source (anoxygenic photosynthesis)
- Formation of syntrophic interactions (cooperation between different physiological types)
- Establishment of primitive element cycling
- Energy was not limited for phototrophs (blooms?)
- First filamentous cyanobacteria-like organisms
From Nisbet & Sleep, 2001, Nature vol 409
Microorganisms of the sulfur cycle: sulfate-reducing prokaryotes (SRP) and sulfur-oxidizing prokaryotes (SOP)

**Organic S-compounds**
- Desulfurylation

**Dissimilatory sulfate-reducing prokaryotes**
- Desulfovibrio, Thermodesulfobacterium, Archaeoglobus

**S_0**
- **S_2O_3^{2-}**
- Assimilatory sulfate-reduction
  - Plants
  - Fungi
  - Prokaryotes

- **HS^-**

**Anoxygenic phototrophic sulfur bacteria**
- Allochromatium
- Chlorobium
- Chloroflexus
- Rhodovulum

**„Colourless“, chemotrophic sulfur bacteria**
- Thiobacillus
- Beggiatoa
- Thiomicrospira

**Organic S-compounds**
- **SO_3^{2-}**
- **SO_4^{2-}**
- **H_2O, N_2, NH_4^+**
- **O_2, NO_3^{-}**

[Brock. © Pearson education international]
Next steps II:

- Invention of oxygenic photosynthesis
- Reduced atmosphere changed into today's atmosphere
- Oxygen became an important electron acceptor
- Due to the use of oxygen, no energy limitation, development of multicellular life forms, and eukaryotes
From Nisbet & Sleep, 2001, Nature vol 409
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What you should know about MO part I

- Growth at:
  - -12 to ca. 120°C
  - pH 0 bis 13
  - Hydrostatic pressure 0 to 1000 bar
  - Salinity: 0 to saturated
  - Redox potential: -450 to 850 mV
What you should know about MO part II

- Growth on inorganic materials alone
- High tolerance against UV light and radioactive radiation
- High resistance against chlorine and biocides, especially in biofilms
- Surfaces are favored substrates to settle and to develop
- Molecules can be transported against chemical gradients
- MO are working together
Where can you find microorganisms (MO) and why are they so successful?

- Nearly everywhere
- They have a large diversity of physiological pathways
- They can adapt to new situations, new food sources, new chemicals
- Rapid growth
- They can take up DNA (genes) from other cells (lateral gene transfer) or from the environment
Why are surfaces attractive for MO?

- Surface material itself can be used as food source or provides important nutrients
- Build up of colonies is much easier
- Interaction between cells is possible (cooperation)
- Protection against enemies
- Modification of the surrounding area is possible
MO in space station
MIC by sulfate-reducing bacteria (SRB)

- No oxygen present, in general oxygen is toxic
- Reduction of sulfate (or other oxidized sulfur compounds) to sulfide
- Most important MIC process
Traditional model: corrosion in the absence of oxygen
Traditional model

- cathodic depolarization
- Formation of $\text{H}_2$ which is then removed by SRB
Direct mechanism: removal of hydrogen

classical depolarization theory:

\[ 4\text{Fe} + \text{SO}_4^{2-} + 4\text{H}_2\text{O} \rightarrow \text{FeS} + 3\text{Fe}^{2+} + 8\text{HO}^- \]

Dissolution of Fe:

\[ 2\text{Fe} \leftrightarrow 2\text{Fe}^{2+} + 4\text{e}^- \]

Cleavage of water:

\[ 2\text{H}_2\text{O} \leftrightarrow 4\text{H}^+ + 2\text{HO}^- \]
Indirect mechanism: attack by sulfide produced by SRB

Overall reaction:

\[ 2\text{Fe} + 2\text{H}_2\text{S} \rightarrow 2\text{FeS} + 2\text{H}_2 \]

- \[ 2\text{e}^- + 2\text{H}_2\text{S} \rightarrow \text{H}_2 + 2\text{HS}^- \]
- \[ 2\text{e}^- + 2\text{HS}^- \rightarrow \text{H}_2 + 2\text{S}^{2-} \]
- \[ 2\text{Fe}^{2+} + 2\text{S}^{2-} \rightarrow 2\text{FeS} \]
- Sulfide produces more hydrogen
- Massive hydrogen embrittlement
New corrosive sulfate-reducing bacterium
„Desulfobacterium corrodens“

e-donor: Fe
carbon source: CO$_2$
New results

- Widespread at marine habitats
- Growth faster on Fe than on H₂
- Growth only on inorganic compounds
- Produced additional H₂
- Direct contact to metal surface needed
- Cathodic depolarization only side reaction?
Fluorescence-labeled bacteria cells on metal surfaces
Fungi in an anodizing bath
Fungi in a metalworking fluid system
Important:

- MO are extremely important for our world
- Most of them are not at all dangerous for human beings
- You should never underestimate MO
- They can adapt very fast to new situations
- Even modern genome analysis data are only snapshots not more!!!!!!
- One gene ---- encodes one protein is much to simple
- Heterotrophs have advantages in taking up genes
- Often a complete gene cluster has to be taken up, otherwise it would be useless
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Thank you very much for your attention!