Lecture 5

18. Global biogeochemical cycling of elements

18.1 Biogeochemistry

- Time scales: Precambrian chemistry begins about at 4.6 eons (Gigayears ago); precambrian biology begins about 3.8 Gy ago; stromatolites (most common precambrian fossils) 2.2-3.4 eons; first 2-dimensional animal 1.2 eons.
- Interactions between global cycles of carbon, sulfur, nitrogen, phosphorus, iron and manganese.
- Evolution of oxic photosynthesis.
- The role of microbes in Hadean to Proterozoic atmosphere and hydrosphere evolution.

18.2 Atmosphere/biosphere interactions

- The role of climate oscillations on biological evolution: how was prokaryotic evolution affected ?
- How oxygenic phototrophs changed atmospheric chemistry globally.
- Microbial regulation of atmospheric gases (O_2, CO_2, CH_4, N_2, N_2O, NOx, DMSO).
- The contribution of aerobic C-1 oxidizers to global budgets of atmospheric trace gases.

18.3 Solid-state microbiology

- How microbes interact with mineral surfaces: weathering, corrosion, leaching.
- Natural weathering agents of microbial origin. Disturbance of weathering processes by anthropogenic pollutants.
- Active and passive formation of biominerals: intracellular and extracellular magnetite, nucleation of crystal formation on cell surfaces and inside cells.
- Biologically mediated mineral dissolution: acid-base reactions, redox processes, ligand mediated reactions.
- Microbially mediated formation of hydroxyapatite in sediments: a thermodynamic case study.
- Geomicrobiology and crustal evolution, effects of volcanism, plate tectonics, eustatic sea-level change, glaciation (snowball earth).
- Clay surfaces as early bio-informatic templates.
- Ironsulfide crystals as templates and energy sources.

18.4 Carbon sinks and sources

- The microbe's role in "fossil fuel" formation, accumulation and cycling
- Tar pits as ecosystems
- The mobilization of methane clathrates

18.5 Prokaryotic extremophiles

- Microbes which make use of redox-labile heavy elements (As, Se, Cr, Cu, Mo, Sb, U, etc.)
- Microbes which thrive under extremes of pH, salinity and temperature
- Strategies to overcome nutrient deprivation: transport efficiency, remaining very small (nanobes)
- Not growth, but maintenance as survival strategy

18.6 Metal-microbe interactions

- Biosorption of metals
- Bioaccumulation
- Metal alkylation
- Metal solubilization mechanisms
- Industrial applications

Lecture 6

4. Microbial paleontology

4.1 Origin of life-molecules and life-styles

- Theories about the chemolithoautotrophic origin of life and possible lifestyles of ancient microbes.
- Theories about the chemoorganotrophic origin of life: organic molecules in the "primordial soup" and remineralization of organics from early biomass.
- Possible syntheses of sugars, purines, pyrimidines and amino acids.
- Initial reaction mechanisms: a) "warm (hot) soup metabolism" in the cytoplasm.
- Initial reaction mechanisms: b) in the cold on chemically reactive solid surfaces.
- The role of mineral surfaces in the evolution of biochemistry: e.g. ironsulfides, clays.
- Nutrient scavenging and retention in dilute environments.
- Initial topologies needed for metabolism: membrane associated electron transport and charge (proton) translocation.
- Initial physiologies: fermentation, CO_2-reduction to CH_4, Fe(II+)-oxidation by photosynthesis, mechanisms for assimilative CO_2-fixation.

4.2 From RNA to RNA/protein to DNA/RNA/protein worlds.

- Early catalytic molecules, catalytic RNA.
- Evolution of bio-cryptography.
- Life was originally prokaryotic and anaerobic.
- How "primitive" prokaryotes shaped 3.5 billion years of evolution.
- Enzyme evolution: metabolism(s) in non-compartmentalized prokaryotic cells.
- Evolutionarily missing microbial ecosystem processes.

4.3 Evolution of communities

- Evolution in the absence of other organisms: exploitation of energy and chemicals.
- The necessity for redox cycling of the nutritive elements: development of specialist microbes.
- Exploitable sources of electrons, oxidants and energy.
- The emergence of communities able to do very different things.
- The missing prokaryote that can do everything.
- Ancestral communities were nearly omnipotent: sulfur-, ferric-iron-, sulfate-respiration preceeding fermentation, methanogenesis and photosynthesis.
- Initially abundant electron acceptors: CO_2, Fe(III+), S^0 (present in traces SO_4^{2-}, NO_3^-, O_2).
- Initially abundant electron donors: reduced inorganic (and organic ?) compounds in hydrothermal fluids: H_2, H_2S, Fe(II+), Corg. favouring thermophilic chemolithotrophs.

4.4 Evolution from chemotrophic to phototrophic ways of life

- Methanogenesis might have preceeded photosynthesis. Was early photoynthesis recycling methane ?
- Prerequisites for using the energy of sunlight: pigment and protein complexes (light harvesting, reaction centers for near IR-radiation, 700nm to 1100nm); exploitation of electron sources and aquisition of C-assimilation mechanism.
- How old are the photosystems and when and from where did photosystem II emerge ?
- Possible evolutionary sequence among the phototrophs: Heliobacterium spp. (gram+, low G+C); Chloroflexus spp. (diderm, but actually gram+); Cyanobacteria (some are gram +); Chlorobium spp.; phototrophic Proteobacteria.
- Did ferrotrophic photosynthesis emerge before or after organotrophic photosynthesis ?
- Energetic prerequisites and advantages of chlorophyll-a-based oxic photosynthesis and of using H_2O-electrons.

- Developing UV-radiation protection; "sunscreen pigments".
- Developing protection against oxygen poisoning: superoxide dismutases.
- Coping with the chemistry of iron in an oxic world: iron aquisition, siderophores, iron-containing proteins.
- Fundamental metabolic adaptations during the anoxic to oxic transition.

4.5 Sedimentary records of biogeochemical processes

- Microbial metabolites (activities) which are preserved in rocks.
- Life's geochemical and geophysical signatures: molecular fossils, biomarkers, hopanoids (bacteria), sterenes (eukarya), polyisokenoates (Archaea), kerogens, black shales, bio-minerals, BIF, sedimentary deposits, precambrian stromatolites, isotope fractionation.

4.6 The rock record vs. the genome record of microbial evolution

- Evolutionary theory with microbial genomes: molecular history with genome sequence information.
- How old is the prokaryotic genome ?
- Genetic approaches to reconstruct geochemical processes.

Exercises V: To topics from

10. Biochemistry of energy metabolism

- Basic principles of metabolic energetics.
- Membrane separated compartments for the maintenance of electrochemical potentials.
- Electron and proton translocating compounds.
- Creation of membrane-separated potential differences through electron and proton transport.
- Transformation of oxidation energy into chemiosmotic energy.
- Transformation of chemiosmotic and oxidation energy into energy-rich compounds.

Exercises VI: To topics from

13. From environmental thermodynamics to bacterial lifestyles

- Microbial diversity emerges from the different ways microorganisms exploit environmental conditions.
- Major metabolic types: respiration, photosynthesis, fermentation.
- Diversity of life styles determined by electron acceptors.
- Life styles determined by electron donors.
- Life styles deduced from ways of carbon-assimilation.
- Life styles based on energy conversion mechanisms.
- Metabolic versatility and flexibility.