Methanogenesis under Extreme Environmental Conditions in Permafrost Soils: A Model for Exobiological Processes?

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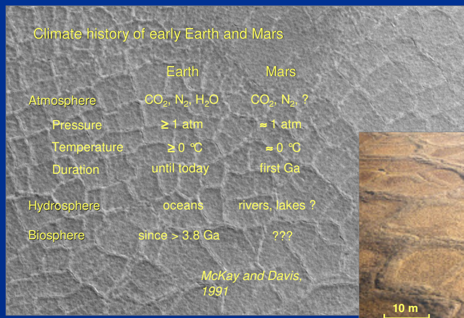
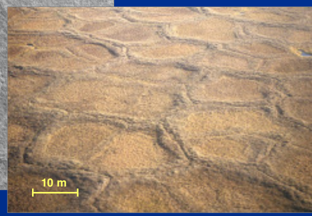
Introduction

The evolution of life on Earth had already started 3.8 Ga ago, when living conditions on Mars were similar to those on early Earth. Assuming that first life on both planets was determined by complex microbial communities, the Martian life must have adapted to drastically changing environmental conditions or become extinct again. One possibility for survival of Martian primitive life might be subsurface lithoautotrophic ecosystems. Comparable environments exist in permafrost regions on Earth. Therefore, terrestrial permafrost, in which microorg-anisms have survived for several million years, is considered to be a model for extraterrestrial analogues.

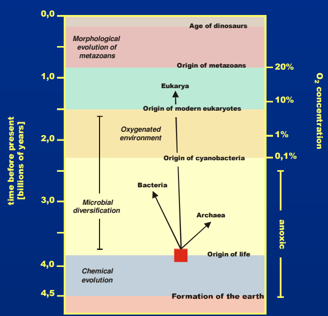


Northern Martian hemisphere (NASA)

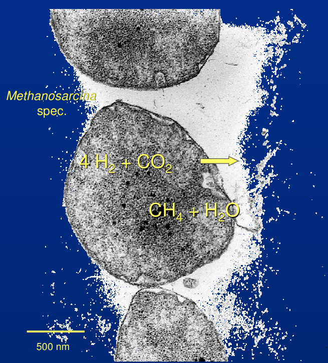
Martian surface and terrestrial permafrost areas show similar mor-phological structures.



Lena Delta, Siberia (AWI)



Major landmarks of bio-logical evolution on Earth



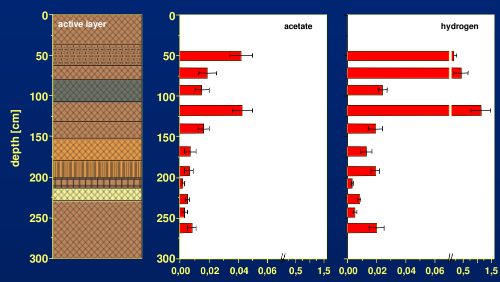
Methanogenic Archaea

Responsible for the microbial methane production (methanogenesis) is a small group of highly specialised microorganisms, called methanogenic archaea. They are regarded as strictly anaerobic microbes, which can grow and survive only under anoxic conditions. They are characterised by lithoautotrophic growth, whereby energy is gained by the oxidation of hydrogen and carbon dioxide can be used as the only carbon source. Because of the specific adaptations of methanogenic archaea to conditions like those on early Earth (e.g. no oxygen, no or little organic substrates) and their phylogenetic origin, they are considered as *key-organisms* in astrobiological research .

Methanogenesis

Studies of CH_4 production in the active layer showed methanogenesis at *in situ* temperatures between 0.6 and 1.2 °C as well as at –3 °C (0.1 – 11.4 nmol CH_4 h^{-1} g^{-1}) and –6 °C (0.08 – 4.3 nmol CH_4 h^{-1} g^{-1}). In Holocene permafrost deposits high CH_4 concentrations were proven and methanogenesis could be initiated after thawing of the sediments. The results indicated the existence of a methanogenic community, which has well adapted to the low *in situ* temperature of permafrost.

CH_4 production potential at 5 °C with acetate or hydrogen as substrate after thawing of the Holocene sediments



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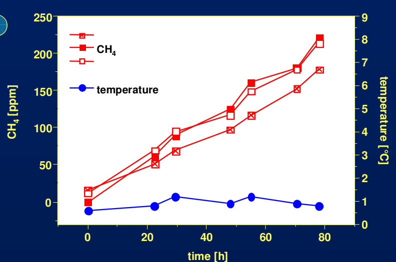
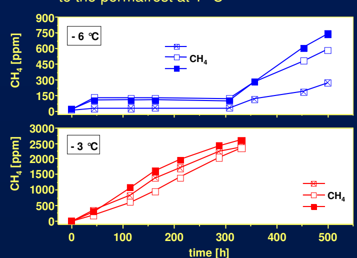
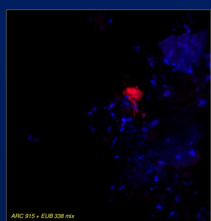


In situ CH_4 production in the boundary layer to the permafrost at 1 °C



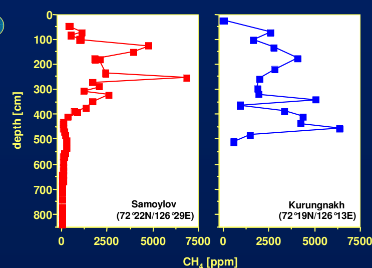
CH_4 production at subzero temperatures with H_2/CO_2 as a substrate

3



Aggregates of methanogenic archaea in permafrost soils detected by fluorescence *in situ* hybridisation. The aggregate formation could serve as protection against extreme habitate conditions.

2



CH_4 concentration in Holocene permafrost deposits of the Lena Delta

Conclusion

The presented results show that methanogenic archaea are suitable *key-organisms* for further studies about adaptation strategies and long-term survival in extreme environments. Microbiological studies in combination with geochemical and physical analysis can give insights into early stages of life in terrestrial permafrost, which can be used as a model for exobiological processes.

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