

Biosignatures from the Metabolic Model of a Methanogen-Acetogen Microbial Community

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Introduction

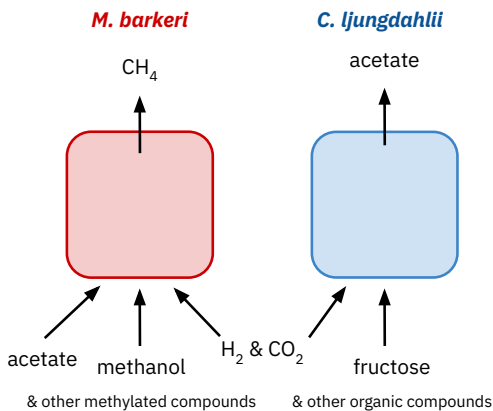
- **Biosignatures:** phenomena that specifically require a biological process
 - Local (e.g. stromatolites) vs. global (e.g. atmospheric gases)
- **Planetary changes:** life has transformed the conditions on Earth
 - Methanogens linked to the largest mass extinction, Permian–Triassic [1]
- **Microbial communities:** present in all natural environments
 - Communities in anoxic sediments include methanogens and acetogens [2]
- **Metabolic models:** connect networks of reactions with genes and proteins
 - Solved with optimization software for a specific goal (e.g. maximum biomass growth)



Modern stromatolites in Western Australia
(adapted from [3])

Materials and methods

- **Metabolic models:** *Methanosarcina barkeri* (a methanogen that can grow on acetate), *Clostridium ljungdahlii* (an acetogen)
- **Community analysis:** with SteadyCom from the COBREXA.jl software [4]
 - Biomass growth, community composition, fluxes of potential biosignatures
 - Tested different organic substrates for *C. ljungdahlii*
- **Simulating external changes:** similar to the Permian–Triassic extinction
 - Linear increase in fluxes of available nickel ions (Ni^{2+}) and organic substrates
 - Three scenarios representing increase in only one or both fluxes

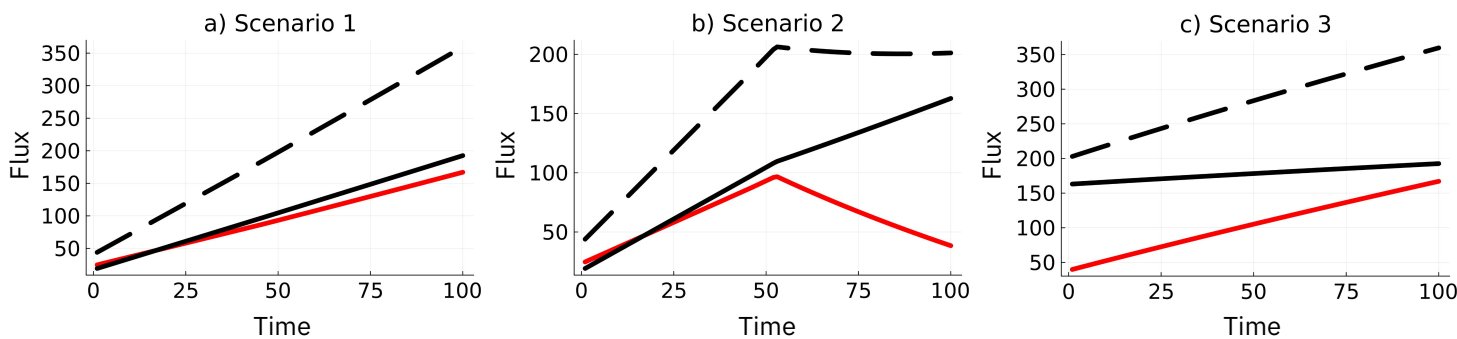


Acknowledgements

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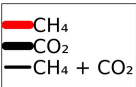
Results

- Fructose: largest biomass growth and **methane** flux, smallest variability in the community composition
- Biomass growth similar in all scenarios, while community composition follows the changes in nickel
- Potential biosignatures: **methane**, **carbon dioxide** with **methane** (high fluxes), **methanethiol** (low flux)



Fluxes of **methane** and **carbon dioxide** produced by the community in three scenarios:

a) increase in nickel and organic substrates, b) increase in organic substrates, c) increase in nickel.



Discussion and conclusions

- **Methane** production depends primarily on the available nickel as the limiting factor
- Major changes observed in fluxes of all potential biosignatures
- Future work could connect metabolic models to the models of geochemical cycles
- Applications to the role of methanogens on other planetary bodies (e.g. Mars, Titan, Enceladus)

References

- [1] Rothman et al (2014). *PNAS*, 111(15), 5462–5467. <https://doi.org/10.1073/pnas.1318106111>
- [2] Orsi (2018). *Nature Reviews Microbiology*, 16(11), 671–683. <https://doi.org/10.1038/s41579-018-0046-8>
- [3] Harrison (2005). *Wikimedia Commons*. https://commons.wikimedia.org/wiki/File:Stromatolites_in_Sharkbay.jpg
- [4] Kratochvíl et al (2025). *Bioinformatics*, 41(2). <https://doi.org/10.1093/bioinformatics/btaf056>