Response of chemotrophic processes to dynamic redox conditions in a cyanobacterial mat

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The benthic cyanobacterial mats in Middle Island Sinkhole (MIS) in Lake Huron, Michigan, USA, are driven by both oxygenic and sulfide-driven anoxygenic photosynthesis (PS). Dependent on the availability of light and sulfide, cyanobacterial activity transitions between these photosynthetic modes within a diel cycle. The resultant profound fluctuations in the availability of electron donors and acceptors implies that non-phototrophic inhabitants are likely highly adapted to be metabolically versatile and/or to transient exposure to potentially toxic compounds, such as oxygen and sulfide. We found that aerobic processes, reduction of sulfate and zero-valent sulfur, methane oxidation and dissimilatory reduction of nitrate to ammonium co-occur in the mats throughout day and night at variable proportions. Aerobic respiration, aerobic chemosynthesis and sulfur reduction rates were tightly coupled to PS, with the process rates proportional to PS irrespective of the O_2 concentration. Non-photosynthetic processes in turn exerted feedback effects on the mode and magnitude of PS. Most prominently, the local production of sulfide during sulfur reduction supported anoxygenic PS. Intriguingly, the methane cycle affected PS by engineering mat morphology. When methane oxidation in the mats was limited, bubbles of methane gas extruded the mat surface into columnar finger-like structures. As this process separated the mats from the sedimentary sulfide fluxes, oxygenic PS dominated over anoxygenic PS. These mat fingers therefore turned into O_2 production hotspots.

Overall, the dynamic conditions in the MIS mats give rise to a system in which processes are not only separated in space but also in time, and where metabolic flexibility matters more than energetics. This shapes not only the spatial and temporal sequence of respiratory processes but also fundamentally affects rates of primary production.