Particle-Associated Biogeochemical Processes in Fayetteville Green Lake, a high sulfur, permanently anoxic lake

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Field Site

Fayetteville Green Lake, Fayetteville, NY is a glacially-sculpted, sulfidic, and permanently anoxic, meromictic (stratified) lake (Fig. 1). Because FGL has DIC and sulfate concentrations comparable to marine anoxic basins and the mid-Proterozoic ocean, it serves as an easily accessible "snow globe" model to study their biogeochemistry.

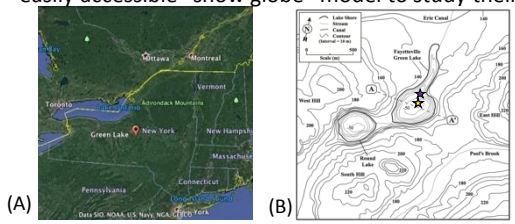

Figure 1: (A) Location of Fayetteville Green Lake in New York State. Image source: maps.google.com (B) Topographic Map indicating the location of water sample state (yellow star) and sediment trap mooring station (purple star). Image modified from[1]

Key water column biogeochemical features

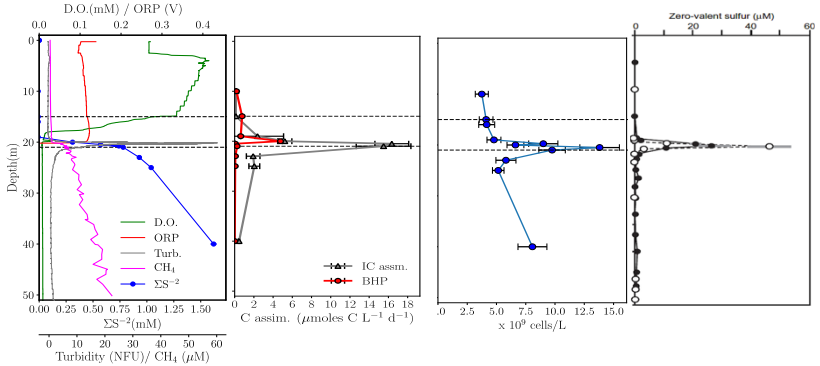

Figure 3: All data are from field experiments conducted during July 2017 other than zero-valent sulfur data [2] and CH_4 data (courtesy of M. McCormick, Hamilton U). IC assm=inorganic carbon assimilation. BHP=Bacterial Heterotrophic Production. D.O.=dissolved oxygen. Dashed lines indicate upper and lower redoxcline boundaries. The peak in biomass corresponds to the maxima of autotrophic carbon fixation rate and elemental sulfur concentration in the lower redoxcline. Dashed lines are upper and lower redoxcline boundaries

The autotrophic side of the sulfur cycle

In modern low O_2 environments, and thus probably the early world ocean during periods of anoxia, distinct communities of dark and photoautotrophic sulfur oxidizing and disproportionating autotrophs are abundant. Unlike phytoplankton in oxic environments, the maximum abundance of these primary producers is in deeper and nearly anoxic water where grazing is minimal and in close proximity to ballast minerals, so they have a higher likelihood of sinking to the sediment-water interface (Fig 2-3). Their spatial distribution and biogeochemical function is organized by the tolerance of their carbon fixation enzymes to oxygen, and thus vertical gradients in ambient dissolved oxygen concentration. Dark sulfur oxidizers' carbon fixation pathways fractionate carbon to differing extents while also fractionating sulfur by dark sulfur oxidation/disproportionation (Fig 6) [5,6]. Thus, the C and S cycles are intimately intertwined by autotrophic processes. This side of the sulfur cycle is often ignored when interpreting stable isotope data

Sampling: tracing the biological pump

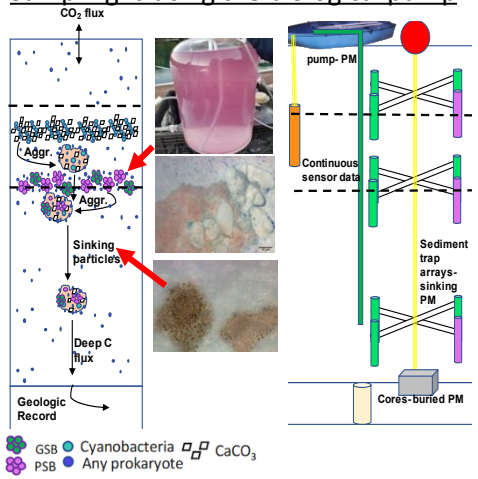

Figure 2: Unlike like biological pump in oxic systems, the main primary producers in Fayetteville Green Lake are cyanobacteria, anoxygenic photoautotrophic purple and green sulfur bacteria, and chemoautotrophs, all of who live within one meter of the lower redoxcline boundary [3]. The biological material forms aggregates. The cyanobacteria cause precipitation of $CaCO_3$, which can make the aggregates more dense and enhance their settling velocity.

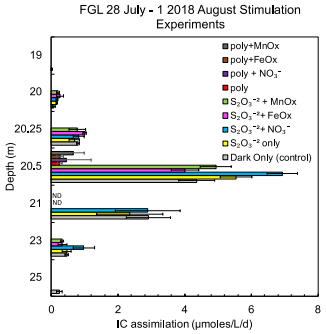

Figure 4: Dark IC assim. rates with combinations of potential terminal electron acceptors with thiosulfate ($S_2O_3^{-2}$) or polysulfide (poly.), which were the most stimulatory sulfur species according to prior experiments. $S_2O_3^{-2}$ + NO_3^- was the most stimulatory, suggesting this is how dark sulfur oxidizing bacteria make a living near the lower redoxcline boundary.

The Big Idea: C and S stable isotope signatures delivered to sediment mostly reflect the biogeochemical transition zone near the lower redoxcline boundary rather than the majority of the water column and reflect **particle-associated autotrophic carbon fixation by sulfur oxidizers** from the lower redoxcline-upper monimolimnion.

Research Approach

- "Particle-associated" (> 2.7 μ) and "free-living" (0.2-2.7 μ), sinking, and buried particulate matter collection:
  - **How?** quantitative polymerase chain reaction assays of carbon fixation pathway and sulfur oxidation genes and stable isotopes
  - **Who?** 16S rRNA libraries
- In-situ incubation experiments: **who**
- (sulfur oxidizer) and **how** do they make a living: ^{14}C-HCO_3 stimulation(Fig. 4) experiments, Stable Isotope Probing-Raman-Fluorescence in situ hybridization
- Raman microspectroscopy: quantify flux of elemental sulfur in PSB aggregates (Fig. 5)

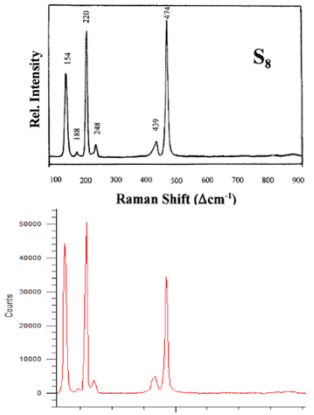

Figure 5: Raman shift spectrum of PSB aggregates collected sediment traps deployed at 40m depth match those of S8 elemental sulfur, showing S0 is being exported to the deep lake in biogenic aggregates. Reference spectrum from [4]

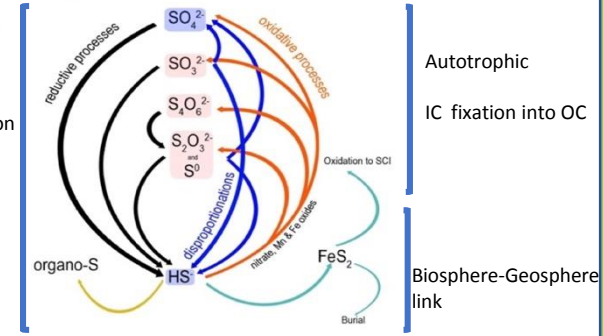

Figure 6: Autotrophs oxidize sulfide and oxidize or disproportionate sulfur cycle intermediate species into sulfide and sulfate. Dark sulfur oxidation and disproportionation can significantly enrich the sulfur isotopes in reaction products. Image modified from: http://www.microbial-ecology.net

Acknowledgements

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References

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