Biological Soil Crusts and the Great Oxidation Event: Results from Laboratory Experiments.

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Introduction: There are few, if any, uninhabited environments on Earth today. Even the driest environments host organisms that survive where liquid water is is scarce and ephemeral. Biological Soil Crusts (BSCs) are terrestrial microbial consortia consisting of cyanobacteria, algae, and fungi; BSCs are the well-adapted, primary-colonizers of arid and semi-arid environments[1]. These arid environments are characterized by carbon-, nitrogen-, and water-limitation, and often high UV flux. Eukaryotic and vascular plants are often unable to colonize these environments, making BSCs the first and final stage of ecological succession[1]. The earliest successional stages of the BSC community are primarily cyanobacterial and they survive in these environments due to their ability to fix carbon and nitrogen between protracted periods of dessication, alleviating the pressures of the environment[1].

Prior to the great oxidation event (GOE) at ~2.4 Ga the Earth's atmosphere and oceans were anoxic, and there was no ozone layer to protect the surface from UV radiation[2]. Despite the inhospitable conditions, life persisted and photosynthesis evolved into a significant process during this period[3]. By 2.4 Ga enough photosynthesis had occurred to allow a significant increase in atmospheric oxygen[4].

Lalonde and Konhouser proposed a mechanism for the GOE that invoked BSCs and other terrestrial phototrophs as the organisms which ultimately oxygenated Earth's atmosphere[5]. It is argued that terrestrial microbes would have advantages over their marine or lacustrine counterparts. The solid substrate provides direct contact for nutrients as well as protection from UV radiation. Additionally, the substrate limits the diffusion of gasses which allows oxygen to accumulate in the soil at high concentrations. This oxygen has the potential to be consumed locally without significant oxidation of the overlying atmosphere. Therefore, a better understanding of terrestrial microbial systems that could have been present during Earth's anaerobic period may provide insight that can inform the potential for detectable life on other dry, anaerobic worlds. However, little experimental work has been done to explore the biogeochemistry of early cyanobacterial communities during the pre-GOE period of Earth's history.

Work to be Presented: This work presents laboratory experiments investigating the biogeochemical activity of modern BSC microorganisms under low-oxygen conditions that simulate the pre-GOE Archean atmosphere. BSC samples were collected from the Sonoran desert near Phoenix AZ. Replicates of six crusts were wetted with a nutrient solution containing 100 micromolar NH_4^+, NO_3^-, and PO_4^{3-} – to alleviate N and P limiatation – and incubated in air-tight chambers for 5 hr of light and 17 hr of dark.

We measured changes in headspace CO_2 and O_2 concentrations in the chambers containing BSCs over the course of the experiment. Photographs were taken and the images processed to quantify each crust's "greenness" which is a proxy for CO_2 uptake or photosynthetic potential[6].

The average CO_2 uptake rate was 276 nmol hr^{-1} and the average O_2 production rate was 169 nmol hr^{-1}. The CO_2 flux is 3 times greater than the O_2 flux. This imbalance suggests that oxygen is either restricted from diffusion by the substrate or consumed locally. Local consumption of oxygen could be microbial or oxidative weathering of minerals.

We compared results for BSC communities on substrates with and without pyrite in order to elucidate differences in carbon and oxygen cycling, as well as photosynthetic potential. This study also measures the potential for the O_2 produced locally by BSC phototrophs to oxidize reduced minerals, such as pyrite, under an anaerobic atmosphere.

References:

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