Ecophysiology of Heterotrophy in Subglacial Lake Whillans, Antarctica

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Introduction

Subglacial Lake Whillans (SLW) is one of more than 400 subglacial lakes that have been discovered beneath the Antarctic ice sheet over the past two decades. Taken together, Antarctic subglacial environments comprise an estimated 10^4 km^3 of liquid water, making them one of the largest unexplored habitats on Earth. The lakes and water saturated sediments beneath the East and West Antarctic ice sheets have been isolated from the atmosphere and from sunlight for many thousands of years. Organisms living in these environments must rely on inorganic substrates or relict organic matter as energy sources. SLW lies beneath the West Antarctic Ice Sheet, in a region that has been inundated with seawater during past periods of ice sheet retreat, depositing organic matter and nutrients.

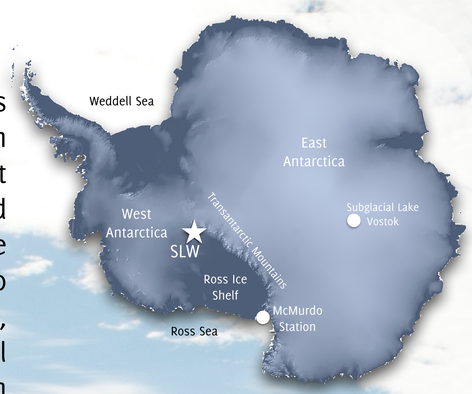


Figure 1. Map. **Subglacial Lake Whillans (SLW)** lies beneath 801 m of ice in West Antarctica in a relict marine embayment.

Table 1. Water Column Physicochemical Characteristics

Cond (µS cm^{-1})	Water depth (m)	Temp (°C)	DO (µM)	DIN (µM)	SRP (µM)	DIC (mM)	DON (µM)	DOP (µM)	DOC (µM)
720	2.2	-0.5	71.9	3.3	3.1	2.1	2.4	6.1	221

SLW is a freshwater lake, with water temperature at the pressure freezing point. Oxygen concentrations are ~16% saturation, indicating a biological sink for oxygen liberated from ice-melt. Nutrient concentrations are three orders of magnitude higher than the oligotrophic ocean. *Data from ref (1) and this study.*

Coccoid	Rod	Curved Rod	Filament	Size (µm^2)	Cells mL^{-1} (x10^5)
58%	28%	12%	1.6%	0.31	1.3

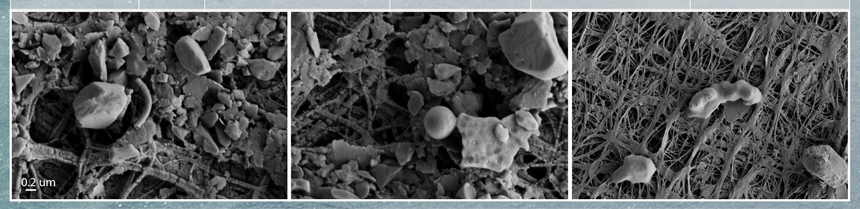
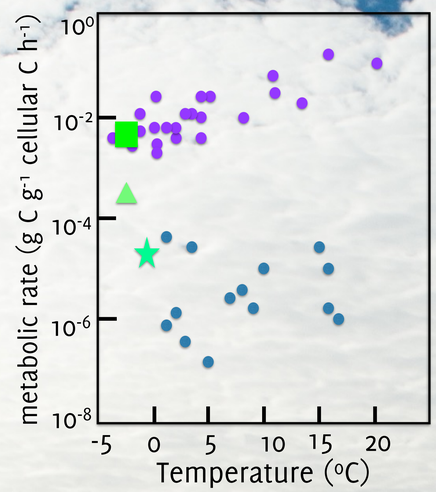


Figure 1. Cells in the SLW water column are relatively small and morphologically diverse, but are dominated by coccoid-shapes. *Data from ref (1) and this study.*



Heterotrophic Production (nmol C L^{-1} h^{-1})	0.03
Growth efficiency	8%
Growth rate (h^{-1})	0.0002
Doubling time (days)	118
Respiration (nmol O_2 L^{-1} h^{-1})	0.68
Chemoautotrophic Production (nmol C L^{-1} h^{-1})	0.11

Figure 2. Low growth efficiency and metabolic rates place SLW in the maintenance range typical of low energy environments. Heterotrophic rates are averaged from thymidine and leucine incubations from three samples. Star=SLW, square=sub-McMurdo Ice Shelf, triangle=Antarctic ice-covered surface lakes in autumn, blue=subsurface/low energy, purple=high productivity environments. *Figure modified from ref (2) and (3), table from this study and (1).*

Questions

- **Given plentiful carbon and nutrients, why are rates of heterotrophic production low?**
- **Is heterotrophic production limited by nutrients and/or nutrient stoichiometry?**
- **Is heterotrophic production limited by temperature?**
- **Is heterotrophic production limited by the availability or quality of organic matter?**

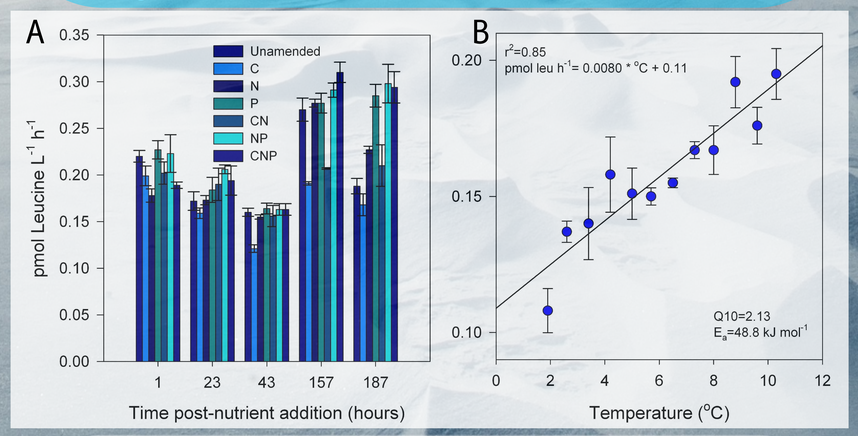


Figure 3. Response of leucine uptake to (A) nutrient enrichment and (B) temperature. Uptake increased in response to N +P treatment after 23 hours. A metabolic upshift took place after 157 hours. Rates increased by 0.0080 pmol leu L^{-1} h^{-1} °C with Q10 similar to other microbial communities.

Table 2. Molar Ratios of Particulate and Dissolved Organic Matter

Molar ratio	Water column	Surface Sediment
POC:PN	65	19
DOC:DON	95	14
PN:PP	0.78	n/a
DON:DOP	0.38	n/a

In spite of the apparent response to P-containing nutrient treatments, organic matter in SLW is N-poor, and N is quickly scavenged from organic matter entering the water column from the surface sediments.

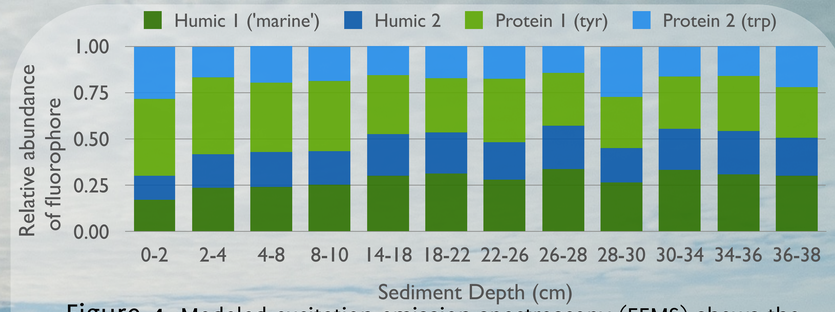


Figure 4. Modeled excitation-emission spectroscopy (EEMS) shows the presence of putatively bioavailable DOM in sediment porewaters. Water column EEMS (not shown) reveal the presence of protein-like DOM.

Discussion

Small cell size and low metabolic rates suggest that heterotrophic prokaryotes in SLW are energy-limited. Variable response to nutrient amendment and low rate of increase with temperature suggest that nutrients and temperature are not solely responsible for low efficiency and heterotrophic growth rates. While bioavailable organic matter is present in SLW, N-poor organic matter may put energetic constraints on heterotrophic activity. Competition for oxygen may also limit heterotrophic production, given some key metabolisms (e.g. methanotrophy and nitrification[1]) in SLW. Finally, freshly produced carbon resulting from chemoautotrophy may not be available on the same timescale that heterotrophic production occurs (production-demand mismatch[4]).

Methods

We used clean hot water drilling to penetrate 800 m of ice overlying SLW in 2013, and retrieved water and sediment samples using Niskin bottles and a Uwitec multicorer. Incubations were carried out in a lake-side lab with ^{3}H-thymidine and leucine, ^{14}C-leucine and ^{14}C-bicarbonate to determine heterotrophic growth rates, growth efficiency, and chemoautotrophy. O_2-respiration was determined via potential electron transport system activity. EEMS were collected on a Horiba Fluoromax 4 and modeled using PARAFAC (drEEM toolbox in MATLAB; Murphy et al 2013). Water column data are averages of n=3.

References

1. Christner et al., 2014. Nature. 512:310-313. 2. Jørgensen, 2011. PNAS 108:18193-18194. 3. Price and Sowers, 2004. PNAS 101:4631-4636. 4. Carlson et al., 2007. Oceanography. 20:89-100.

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