Exploring Chemical Disequilibrium Biosignatures in Icy Moon Oceans with Antarctic Subglacial Lake Analogs

Nicholas Wogan, and Dale Winebrenner
University of Washington
Email: wogan@uw.edu

1. INTRODUCTION

Chemical disequilibrium is the long-term coexistence of two or more incompatible molecules or atoms.

- **Example** of chemical disequilibrium: coexistence of CH_4 and O_2 in Earth's atmosphere. They should react out of the atmosphere, but instead persist because of biological fluxes.

In dark environments (e.g. icy moon oceans) all life, as we know it, must get energy by consuming chemical disequilibria.

Chemical Disequilibrium = Microbial food = Chemical Energy

Relatively low chemical disequilibrium should be a biosignature for icy moon oceans because it is a sign that life is consuming the microbial food generated by abiotic processes (e.g. hydrothermal vents).

We explore this biosignature by calculating the chemical disequilibrium in

1. an environment analogous to icy moons: **Antarctic Subglacial Lake Whillans** (Figure 1).
2. **Enceladus' ocean**.

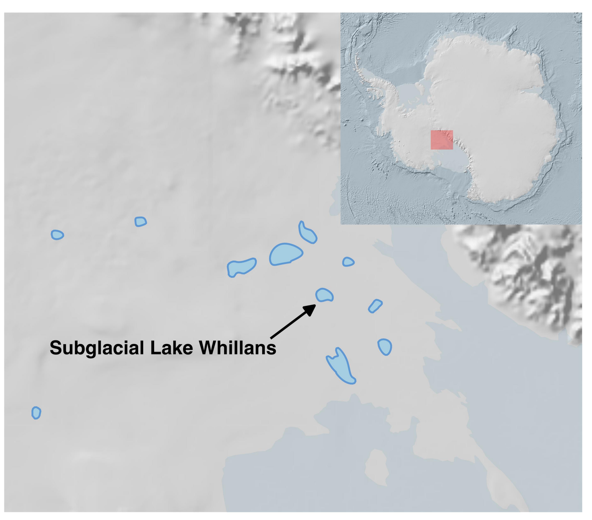


Figure 1: A map showing the location of Subglacial Lake Whillans.

2. METHODS

Chemical disequilibrium quantification: The available work, or Gibbs free energy, that is produced from reacting all chemical species to an equilibrium state. We do this calculation with a Gibbs minimization code. [1]

Disequilibrium = Available Gibbs energy = ΔG

Subglacial Lake Whillans: **3 ΔG calculations**

1. Observed lake composition which is influenced by the life found in the lake. [2]
2. Modeled "dead" lake chemistry (i.e. lake composition if life was not influencing lake chemistry). See Figure 2.
3. Modeled lake composition if an aerobic heterotrophic ecosystem was energy limited (similar to Figure 3).

Enceladus' Ocean: **2 ΔG calculations**

1. Observed ocean composition from Cassini measurements and Fifer et al. modeling (see poster 127-064).
2. Modeled ocean composition if a methanogenic ecosystem was present and was energy limited. See Figure 3.

Relatively small amounts of chemical energy in icy moon oceans might be a biosignature because it is a sign that life is consuming the microbial food generated by geologic processes.

Enceladus' ocean likely has a lot of chemical energy which would indicate low biomass, if life exists, because life should consume this free lunch.

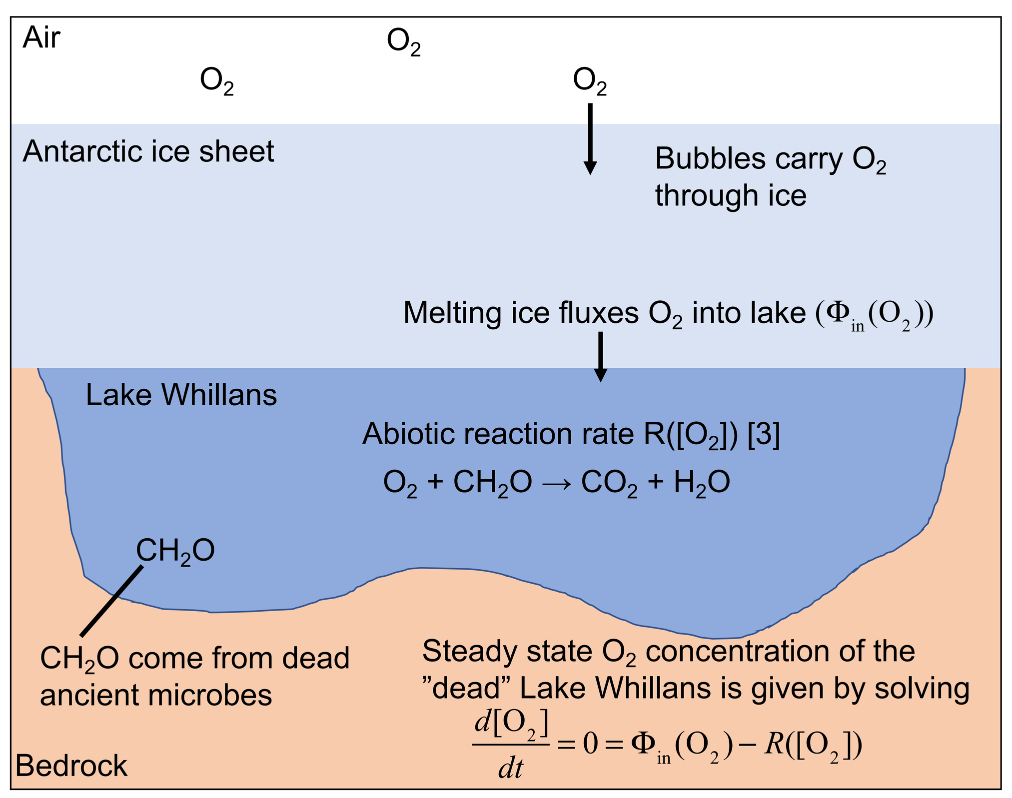


Figure 2: Method for modeling the "Dead" Subglacial Lake Whillans.

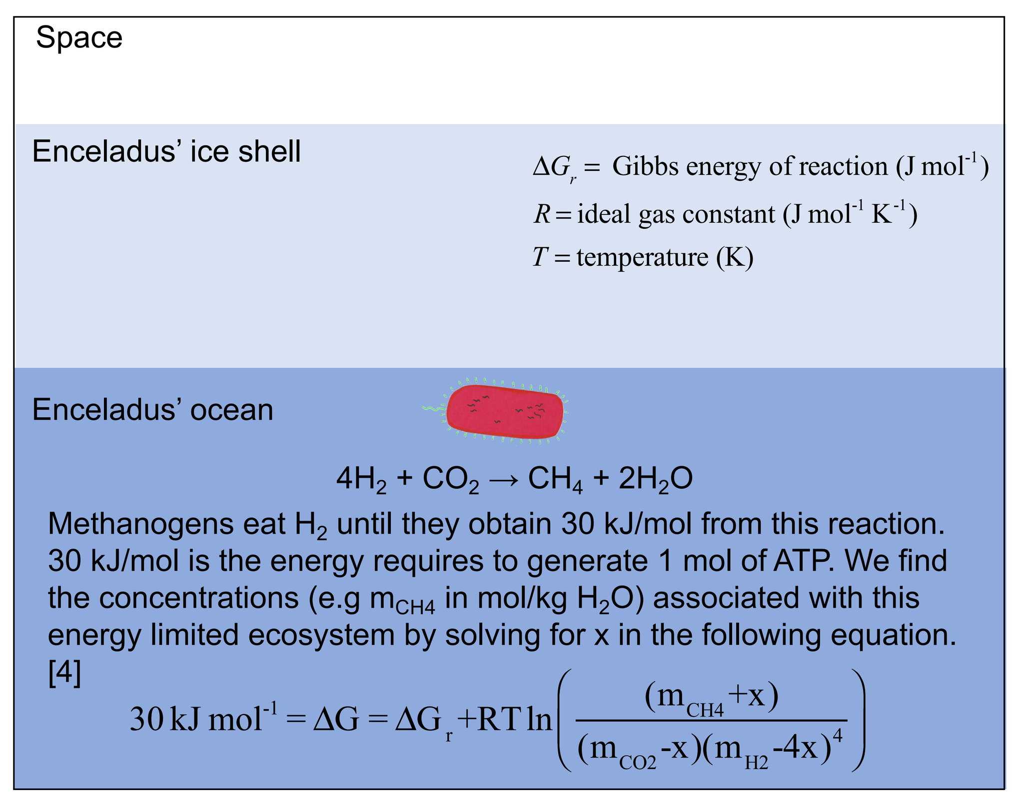
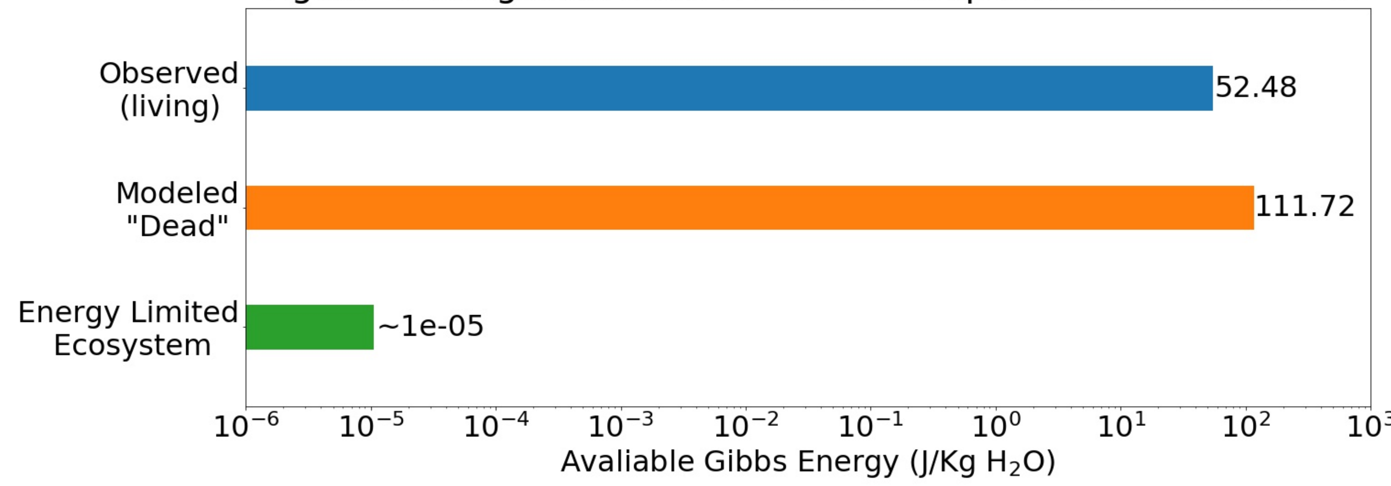


Figure 3: Method for modeling an energy limited methanogenic ecosystem in Enceladus' ocean.

3. RESULTS AND DISCUSSION

Figure 4: Subglacial Lake Whillans Disequilibrium Calculations

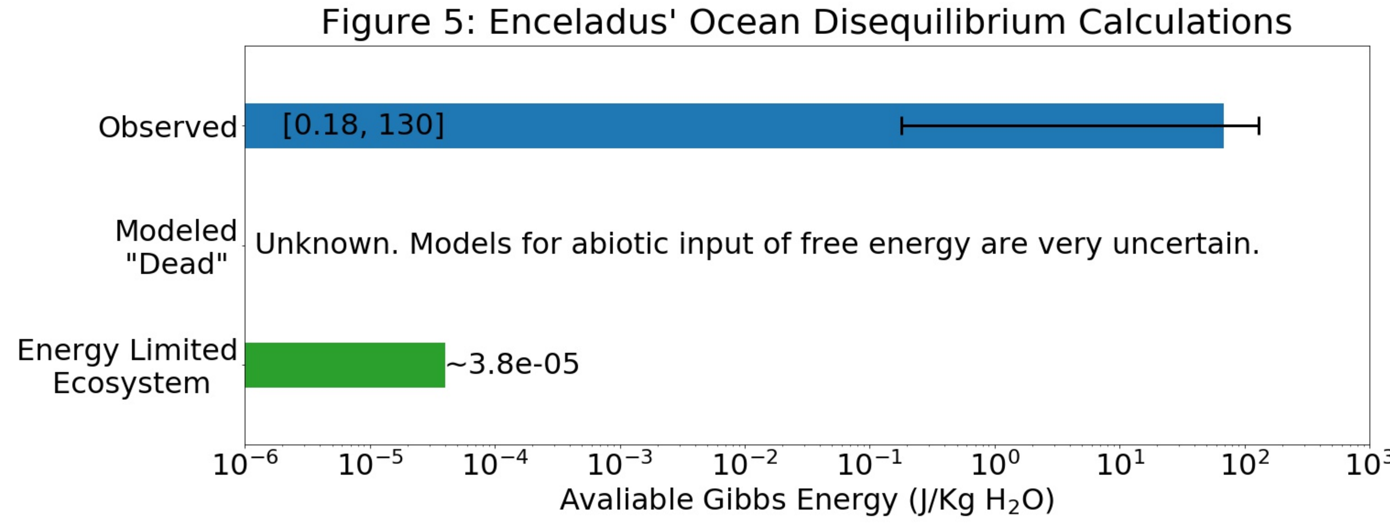


Lake Whillans' observed disequilibrium, which is influenced by bacteria and archaea, is **lower** than the modeled "dead" lake's, and **higher** than the energy limited ecosystem's. [5] Life lowers the abiotically generated disequilibrium by eating O_2 that enters the lake from the ice-lake interface:

$$O_2 + CH_2O \rightarrow CO_2 + H_2O$$

Lake Whillans' illustrates that we can look for life by observing life's consumption of free energy in an environment.

Figure 5: Enceladus' Ocean Disequilibrium Calculations



Enceladus likely has a lot of microbial food from the coexistence of H_2 and CO_2. The H_2-CO_2 disequilibrium would nearly vanish if a energy limited methanogenic ecosystem was present in Enceladus' ocean. Why isn't life consuming this free lunch? Perhaps there isn't any life around to eat it.

To use the disequilibrium biosignature on Enceladus, you must accurately model the abiotic inputs of free energy into Enceladus' ocean (e.g. hydrothermal production of H_2, or H_2 lost from plume eruptions). If the chemical disequilibrium of this modeled "dead" world is larger than the observed disequilibrium, then life might be responsible for the discrepancy. Unfortunately, modeling abiotic inputs of energy are currently very uncertain. [6]

4. SUMMARY

- Relatively **low** chemical disequilibrium might be a **biosignature** for icy moon oceans because it a sign that life is consuming the microbial food generated by abiotic processes.
- Relatively **high** chemical disequilibrium might be an **antibiosignature** for icy moons because it might be a sign that life isn't around to consume the available microbial food.

References: **[1]** J. Krissansen-Totton et al., *Astrobiology*, vol. 16, no. 1, pp. 39–67, 2016. **[2]** B. C. Christner et al., *Nature*, vol. 512, no. 7514, pp. 310–313, 2014. **[3]** S. Chang et al., *Geochimica et Cosmochimica Acta*, vol. 63, no.19, pp. 3301-3310, 1999. **[4]** J. Kasting et al., *Orig. of Life and Evo. Biosph.*, vol. 31, no. 3, pp. 271-285, 2001. **[5]** J. A. Mikucki et al., *Philos. Trans. R. Soc. A Math. Phys. Eng. Sci*., vol. 374, no. 2059, pp. 1-22, 2016. **[6]** J. H. Waite et al., *Science*, vol. 356, no. 6334, pp. 155–159, 2017.