HOW MANY BLUE WHALES ON MARS? OBTAINING A MAXIMUM EXTANT MARTIAN BIOMASS USING CO ANTIBIOSIGNATURES.

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Introduction: The modern martian atmosphere is characterized by a thermodynamic disequilibrium where substantial concentrations of CO and O_2 coexist. The chemical disequilibrium is maintained by photolysis of CO_2 and H_2O, coupled with hydrogen escape to space, in Mars' cold, dry, and thin atmosphere. Measured in terms of available Gibbs free energy, this disequilibrium amounts to ~140 J mol^{-1}, which is the largest in the Solar System aside from Earth's atmosphere-ocean system [1].

This untapped free energy constitutes a potential "free lunch" for life. Microbes in habitable environments in diffusive-contact with the atmosphere (e.g. deep subsurface aquifers) could, in principle, exploit this free energy and drive the atmosphere towards equilibrium. CO metabolisms are relatively simple, requiring only CO, water, and catalysis by enzymes possessing a variety of Ni-Fe or Mo active sites, which suggests multiple independent origins. Additionally, ~6% of sequenced microbial genomes contain at least one copy of the enzyme gene, which some argue suggests an ancient metabolism [2, 3].

This thermodynamic disequilibrium may represent an antibiosignature on Mars due to the availability of the simple-to-catalyze free energy from CO. Previous work used a photochemical code to account for biogenic sinks on CO and H_2 [4]. By calculating a maximum sink with plausible assumptions on minimum power requirements for survival, a maximum biomass was obtained of ~6×10^7 molecules cm^{-2} s^{-1} [4].

Here, we expand and improve on this work in 3 main ways: 1) we use updated present-day atmospheric compositions and uncertainties from MSL [5], 2) we account for ecosystems with multiple different metabolisms, and 3) we test over a broad range of tunable parameters (surface temperature, deposition velocity, and ionospheric fluxes). The results are rigorous constraints on the maximum biomass that could be on Mars today.

Methods: We use a validated 1-D photochemical model for modern Mars [6] and set a fixed downward flux for the reactants of each metabolism along with a corresponding upward flux of the products to simulate metabolizing microbes. We ramp up these fluxes monotonically until the resulting atmosphere conflicts with observations. CO_2 and H_2O are assumed to be replenished by indefinite (sub)surface reservoirs and thus are held at constant concentrations.

The following are the different net chemoautotrophic metabolism ecosystems we model in communication with the martian atmosphere:

1) CO-metabolism only:

$$CO + H_2O \rightarrow CO_2 + H_2$$

2) Methanogenesis only:

$$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$$

3) CO-metabolism & methanogenesis:

$$4CO + 2H_2O \rightarrow 3CO_2 + CH_4$$

4) CO-metabolism, methanogenesis, & methanotrophy:

$$4CO + 2O_2 \rightarrow 4CO_2$$

5) Methanogenesis & methanotrophy:

$$O_2 + 2H_2 \rightarrow 2H_2O$$

The nominal model is tuned to modern Mars, as such there are assumptions for unknown variables. To obtain a robust result, we optimize the code over a broad plausible parameter space for surface temperature, deposition velocity (a sink to account for surface reactions), and ionospheric flux (for reactions above the model grid height; representing a downward flux of NO, N, and CO). After incremental source/sink increases, we obtain a maximum possible biogenic flux, robust to uncertainties in tunable parameters.

Results and Discussion: Preliminary results suggest the maximum biogenic sink on CO is ~3×10^6 molecules cm^2 s^{-1}. Assuming that CO oxidation with water provides 50 kJ mol^{-1} of Gibbs free energy and a typical energy maintenance requirement of 10^{-7} kJ g^{-1} s^{-1} [7], a maximum metabolizing total biomass of ~4×10^6 kg is obtained. This is equivalent to approximately 35 blue whales, or, in terms of organic carbon, about 1 billionth of Earth's living biomass. If the biomass was evenly distributed in the upper 1 km of martian regolith, where the atmosphere can diffuse, there would be an abundance of ~0.3 cells cm^{-3}.

These updated results provide more robust constraints on the maximum size of an extant martian biosphere in contact with the atmosphere for a variety of metabolisms. Additionally, in the future, this CO-antibiosignature could be applied elsewhere, such as studying the atmospheres of exoplanets.

References: [1] Krissansen-Totton et al., *Astrobiology* 16, 2016. [2] Ragsdale, *Crit. Rev. Biochem. Mol. Biol.* 39, 2004. [3] Techtmann et al., *Environ. Microbiol.* 11, 2009. [4] Weiss et al., *PNAS* 97, 2000. [5] Franz et al., *Planet. Space Sci.* 109, 2015. [6] Sholes et al., *Icarus in review*, 2017. [7] Scholten and Conrad, *Appl. Environ. Microbiol.* 66, 2000.