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Trace Gas Consumption as a Metabolic Strategy for Life Beneath the Martian Surface and the Means to Detect It

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Whether searching for extant life or for biomarkers of extinct life, one of the fundamental questions driving astrobiological studies of Mars is how putative Martian microorganisms could derive energy for maintenance and growth. Direct comparison of the theoretical development of Martian life with the evolution of life on Earth may be misleading due to the contrasting geological and atmospheric histories of the planets. The early collapse of the Martian magnetic dynamo and significant loss of its atmosphere likely transformed Mars into a cold hyper-arid desert before a metabolism resembling oxygenic photosynthesis was able to emerge. However, Mars may have still supported habitable surface environments from the late Noachian to early Hesperian in locations where impacts and/or volcanic activity allowed for water to reach the surface and form geothermal springs[1]. Such environments could have provided a source of energy for microbes through emission of reduced trace gases (e.g., CH_4, H_2, and CO), which represent a valuable chemical source for autotrophy due to their high redox potential.

Microbial trace gas oxidation via high-affinity enzymes has become increasingly recognized as a significant metabolic tactic in a variety of oligotrophic terrestrial environments, including past and present Mars analogue sites such as Atacama Desert volcanic fumaroles[2], Canadian High Arctic cryosols[3], Antarctic Dry Valley soils[4], and Andean Altiplano arid saltpans[5]. Atmospheric CH_4 consumption has also been reported in cavern soils[6]. Chemolithotrophs in these soil environments are capable of obtaining and utilizing these reduced gases directly from the atmosphere at trace levels of abundance (ppb scale). On Mars, similar metabolic strategies could have evolved over time as water diminished on the Martian surface, introducing selective pressure to adapt to lower, ambient concentrations of atmospheric gas substrates. This scenario implies that **trace gas consumption could remain a prevalent tactic for modern extant life on Mars despite the low abundances of reduced gas species in the atmosphere. Hot spots of such activity could be detected by measuring soil gas fluxes.**

Defining local and global trace gas concentrations are a prominent focus of modern atmospheric studies on Mars, serving as a primary science goal for currently active missions including ExoMars Trace Gas Orbiter (TGO) and the Sample Analysis at Mars (SAM) instrument suite onboard MSL. While CH_4 has remained undetected by TGO, recent observations by SAM indicate that CH_4 concentrations fluctuate significantly at the local scale on a seemingly seasonal cycle[7]. Measurements of other biologically relevant trace gases, including O_2 and CO, also exhibit local oscillations driven by undefined processes[8]. To gain further insight into the mechanisms controlling the cycles of these gases in the Martian atmosphere, it will be vital to prioritize measurements of surface fluxes to capture atmosphere-regolith interactions and improve understanding of the gas reservoirs, sources, and sinks. It is at this scale that specific processes, both physical and biological, would be detectable. Understanding fluxes within the context of the global and local data collected from current missions would permit the characterization of cycling pathway(s) and specific rate quantification for the planet. The measurement of reactive gas and helium surface fluxes provides another tool for characterizing the Martian subsurface. Most importantly, surface gas fluxes would provide the opportunity to determine the potential and likelihood for biology to be an active participant in gas cycling and for trace gases to support chemolithotrophic life in the shallow subsurface of Mars.

Accurate measurement of trace gas flux will require the development of gas sensors different from those currently used on MSL in addition to other technologies to aid in trace gas detection (e.g., the ability to place chambers on the Martian surface or probes into the shallow subsurface). The sensitivity and efficacy of these technologies need to be tested at Mars analogue sites where the ability of the measured trace gas fluxes to detect subsurface microbial life can be ground tested by characterization of the shallow subsurface through coring. An example of such an approach has been published for Axel Heiberg Island[3].

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Current status of the white paper and community collaboration:

Currently in early stages of development by recruiting coauthors with expertise in the fields of microbiology and trace gases of extreme environments, gas sensor technology, subsurface characterization, and Martian geology. Looking for contributors to expand and develop this important topic as a white paper that would provide a basis for developing a proposal to fund technology development and field testing.