Geologic and Energetic Constraints of Anaerobic Methane Oxidation on Mars

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The discovery of atmospheric methane on Mars – out of equilibrium with photochemical destructive processes – has prompted widespread discussion of the potential significance of the molecule in a biological context. Multiple studies have yielded atmospheric methane concentrations in the range of tens of parts per billion (ppb)¹⁻⁴, though early results from the Mars Science Laboratory mission provide scant evidence for atmospheric methane at Gale Crater. Nonetheless, because of its incongruity in the geochemical dynamics of Mars and frequent associations with life in the terrestrial context, atmospheric methane and its significance warrant further investigation.

Much of the martian methane-related microbial speculation has focused on methanogenesis; this study examines methanotrophy. On Earth, the anaerobic oxidation of methane (AOM) is a microbially mediated process found at high-methane environments including marine cold seeps and terrestrial mud volcanoes⁵. The metabolism operates near the limits of energetic feasibility, and is believed to require a syntrophic link between methane oxidizing archaea and sulfate reducing bacteria. Metal based reductions, involving oxidized iron or manganese minerals, are likely energetically feasible as well⁶, though definitive evidence of these metabolisms is still lacking.

Using published methane measurements⁴, predictions of martian aqueous chemistry⁷, mineralogical data⁸, and a geochemical model tailored to low-temperature brines⁹, we constrain the conditions under which AOM could be energetically viable. By considering brines across a range of low temperatures, our energetic calculations are extremely sensitive to activity coefficients, and multiple types of calculations are employed to survey the range of responses. If martian atmospheric methane is derived from focused point sources, similar to those observed at convergent margins on Earth, energetic yield could exceed the minimum biological energy quantum.

Using this “follow the energy” approach in an astrobiological context, we identify particular areas within Terra Sabae and Nili Fossae that could be most promising for modern or ancient biological AOM. We also highlight particular biomarkers that would point strongly to AOM metabolic activity and discuss their potential for preservation throughout the planet’s history.