Supplementary Information

Fluid Composition

The concentrations of chemical species for the 7 fluids considered in this study are listed in Table 2. In cases where AOM-relevant species were not given in the literature, concentrations from similar environments were used to approximate these values for the fluid in question. Specific instances include the following.

Reduced Sulfur

Sulfide concentrations for Fluids 1 and 4 were determined by calculating the ratios of the five most abundant ions (Na^+, K^+, Mg^{2+}, SO_4^{2-}, and Cl^-) to sulfide in Fluid 2, which has a similar acid-sulfate geochemistry. The mean of these analogous ratios was used to back-calculate a sulfide concentration from the fluid's other ions. The sulfide concentration in Fluid 2 was also used for Fluid 3, due to the solutions' chemical similarities. The sulfide value for Fluid 5 was obtained from the work of Seyfried and Bischoff (1981), whose data come from similarly sourced Icelandic groundwater. An upper limit for sulfide in Fluid 7 is derived from the work of Alt and Shanks (2006), who characterize a serpentinization system in the Mariana forearc.

Oxidized Carbon

Dissolved inorganic carbon (DIC, including CO_2 (aq), HCO_3^-, or CO_3^{2-}, depending on the pH) concentrations were only provided in primary sources for Fluids 1, 4, 5, 6, and 7. The inclusion of specific CO_2 concentrations from atmospheric approximations (see main text) provided DIC for all fluids. For Fluids 1, 4, 5, 6, and 7, the higher of the reported and atmospheric values was used.

RTM Parameters

Specific values for boundary conditions and reaction parameters were taken from similar studies reported in the literature. The Matlab file of the model is available upon request.

Porosity

Martian crust porosity was approximated by the mean value of porosities measured in 14 martian meteorites. In a compilation of data that uses 100× magnification images to quantify pore space, Coulson *et al.* (2007) reported a mean porosity of 0.049 (and a standard deviation of 0.03). This value is on the lower range of those given for terrestrial fractured basalts (0.05–0.5) as tabulated by Freeze and Cherry (1979) and may represent a conservative treatment of porosity, nutrient flow, and the spatial extent of exergonic conditions.

Concentrations

Dirichlet boundary conditions were used for all chemical species. Initial molal concentrations of dissolved chemical species were obtained from relevant published reports and supplemented as described above. Dissolved methane was kept constant at the lower boundary of the simulated rock column at 2 mM. This value is commonly observed at sites of AOM on Earth (*e.g.*, Joye *et al.*, 2004; Alperin *et al.*, 1988), is producible through serpentinization (Bradley & Summons 2010; Brazelton *et al.*, 2006), but represents a conservative concentration given analogous studies (Boetius *et al.*, 2000; Gibson *et al.*, 2005). Maintaining up to 2 mM dissolved methane in aqueous solution is possible at shallow depths due to lithostatic pressure (Zatsepina & Buffett, 1997). The top-of-column methane concentration remained at 0 mM throughout each model run.

Diffusion Coefficients

Temperature dependent molecular diffusion coefficients for CO_2, H_2S, HS^-, HCO_3^-, and SO_4^{2-} were obtained from the work of Tivey and McDuff (1990), who modified the Einstein-Stokes equation to better fit experimental data. Values for CH_4 were obtained from a second degree polynomial fit to data from a study by Oelkers (1991).

Advection Velocity

Any estimates of groundwater advection rates on ancient Mars would be largely speculative given the uncertainties of flow paths, water sources, heat sources, and the localized plumbing configuration. Advection may derive from buoyant flow due to hotter fluids at depth and/or other gravity- or pressure-driven mixing dictated by local geological circumstances. This study uses four different advection rates: 0, 1, 2, and 3 m/day, offering a range of values sufficient for demonstrating the effect of advection rate on the modeled AOM system.

V_{max} *for AOM*

The maximum rate of AOM is an important parameter that determines the speed of the reaction when methane is not limiting. The value of 1.89 mol / m^3 day is obtained from the work of Dale *et al.* (2008), who used *in situ* data and a kinetic-bioenergetic model (Dale *et al.*, 2006) to estimate reaction rates in the Skagerrak, Denmark.

Temperature

Temperatures used in the model are as shown in Table 2; these parameters allow for the geochemical speciation used as thermodynamic input and are all feasible values for putative microbial niches on ancient Mars.

Half Saturation Constants

The K_m for CH_4 in AOM is relatively high, possibly because the first step in reverse methanogenesis would generate a destabilizing methyl radical (Krüger *et al.*, 2003; Hallam *et al.*, 2004; Shima & Thauer, 2005). The model uses 5 mM, a value obtained from an experimental treatment of seep sediment from multiple field sites (Wegener & Boetius, 2009) and one that is in keeping with other findings (Nauhaus *et al.*, 2007; Orcutt and Meile, 2008). For SO_4^{2-}, a K_m of 500 μM was used (Pallud & Van Cappellen, 2006; Wegener & Boetius, 2009).

Membrane Potential

A $\Delta\Psi$ value of 120 mV was selected because it has been shown to be the optimal physiological potential for ATP production in multiple species (Dimroth *et al.*, 2003; Kadenbach, 2003; Toei *et al.*, 2007). The standing membrane potential of three methanogenic organisms was found to be 118 mV (Daniels *et al.*, 1984), and LaRowe *et al.* (2012) reported that experimental data are best approximated in model thermodynamic calculations when 120 mV is used.

Growth Yield and Maximum Biomass

A microbial growth yield of 600 mg cell dry weight per mol of CH_4 consumption was measured by Nauhaus *et al.* (2007) in their 24-month incubation of Hydrate Ridge seep sediment. This value corresponds to a 1% contribution of catabolic AOM throughput to anabolism. The upper biomass limit of 3×10^6 mg/m^3 was calculated from the maximum cell count value of 3×10^9 cells/ml, measured by Orcutt *et al.* (2005) at a Gulf of Mexico seep, and an average microbial cell mass of 1×10^{-12} g (Kubitschek, 1986). This value is similar to other maximum biomass estimates, such as investigations at Hydrate Ridge by Boetius *et al.* (2000), which revealed a maximum of 7×10^7 300-cell aggregates per cm^3, corresponding to 2.1×10^6 mg/m^3.

Decay Constant

The environmental destruction rate of AOM organisms is a poorly constrained parameter, as long term *in situ* studies on standing stocks of biomass have not been conducted, and predation (which is not included in our model) is an important component in terrestrial systems (Thurber *et al.*, 2012). Our model uses an estimate of a predation-independent decay term in a sulfate-reducing, hydrocarbon-oxidizing system of 10^{-9} s^{-1} (Bethke, 2008). This is a low value relative to the rate of production; thus, biomass decay does not strongly influence RTM output.