POTENTIAL FOR LIFE ON MARS FROM LOW-TEMPERATURE AQUEOUS WEATHERING.

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Introduction: We have explored the chemical weathering at low temperatures on Mars based on the increasing evidence for non-hydrothermal water at or near the martian surface. Simple reactions involving water and rock at low temperatures (as low as 0°C) are sources of geochemical energy that are able to support metabolism for potential martian microbes. Quantifying the amount of energy produced from these low temperature water-rock reactions on Mars allows us to determine how much biomass potentially could have existed and what environments might have been most conducive to the existence of an ecosystem.

The most plausible source of energy to support early organisms is geochemical energy obtained from water-rock reactions [1]. On Earth, there are chemolithotrophic organisms that take advantage of these types of reactions today. The weathering of different primary minerals produces different secondary products and thus different available free energies. In order to have low-temperature water-rock reactions on Mars, there would need to be water at the surface or very near the surface. There is a growing body of morphological and geochemical evidence that suggests that liquid water has been present within the martian crust up to the present (see review by [2]). Recent results from Eagle crater in Meridiani Planum, for example, show that the rocks have been exposed to surface water at shallow depths [3].

Methodology: Based on the martian mineralogy and geochemistry, a suite of possible reactants and products was created (Table 1). In order to determine which primary and secondary minerals are found on the surface of Mars, we reviewed global martian mineralogy data from the Thermal Emission Spectrometer (TES) [4], martian meteorites [5,6] and terrestrial analogues. Because the surface of Mars is mainly basalt [7], we focused on weathering reactions involving minerals specifically found in basalt, such as fayalite, forsterite, diopside, hedenbergite, enstatite, ferrosillite, and anorthite.

We then chose reactions that were energetically favorable and most plausible. We assumed a maximum pressure of the martian atmosphere in the past of 1.5 bar [8]. We varied the fugacities of CO_2, H_2 and O_2 and modeled weathering reactions in both the present atmosphere and a likely past atmosphere.

To calculate the energy available from each reaction, *Geochemist's Workbench 5.0©* and the Gibbs free energy equation were used. *Geochemist's Workbench* was used to balance the reactions and calculate the log K. The log K can then be used to calculate ΔG^o, the change in Gibbs free energy in the standard state

$$\text{Log K} = -\Delta G^o/RT \qquad (1)$$

The change in Gibbs free energy at a non-standard state then is written as:

$$\Delta G = \Delta G^o + RT\ln Q \qquad (2)$$

where ΔG is the change that occurs during the reaction at specific conditions, R is the universal gas constant (1.987cal mol^{-1} K^{-1}), T is the temperature in Kelvin, Q is the ratio of the activities of the products to those of the reactants, and K is the equilibrium constant. If the reaction is exergonic (change in Gibbs free energy is negative), then the reaction will give off energy as it proceeds and is favorable for providing energy for microbial metabolism [9].

Table 1: The reactants and their possible products.

REACTANTS	PRODUCTS
Fayalite (Fe_2SiO_4)	**Hematite** (Fe_2O_3) **Goethite** (FeO(OH)) **Quartz** (SiO_2)
Forsterite (Mg_2SiO_4)	**Magnesite** (MgCO3) **Talc** ($Mg_3Si_4O_{10}(OH)_2$)
Diopside ($CaMgSi_2O_6$)	**Talc** ($Mg_3Si_4O_{10}(OH)_2$) **Antigorite** ($Mg_{24}Si_{17}O_{42.5}(OH)_{31}$) **Calcite** ($CaCO_3$) **Quartz** ($SiO_2$)
Hedenbergite ($CaFeSi_2O_6$)	**Greenalite** ($Fe_3Si_2O_5(OH)_4$) **Calcite** ($CaCO_3$) **Quartz** (SiO_2)
Enstatite ($MgSiO_3$)	**Talc** ($Mg_3Si_4O_{10}(OH)_2$) **Magnesite** (MgCO3)
Ferrosillite ($FeSi_2O_3$)	**Hematite** (Fe_2O_3) **Goethite** (FeO(OH)) **Quartz** (SiO_2)
Anorthite ($CaAl_2Si_2O_8$)	**Kaolinite** ($Al_2Si_2O_5(OH_4)$) **Calcite** ($CaCO_3$)
Magnetite (Fe_3O_4)	**Hematite** (Fe_2O_3) **Goethite** (FeO(OH))
Pyrrhotite (FeS)	**Goethite** (FeO(OH)) **Sulfur** (S)

We varied T and Q (fugacities of the gases) to determine under what conditions the reaction is most favorable, and thus most favorable to the microbes.

We varied the temperatures from 0-100°C. From experimental studies, it is known that some microbes can grow at temperatures as low as -10°C and metabolize at -20°C [10], but we did not calculate energies for temperatures this low. For the reactions of interest, we found that the value of Q depends on the fugacity of the atmosphere, assuming all mineral activities are 1. We then calculated the amount of biota that could be constructed by weathering one mole of the primary mineral (see [11] for calculations and assumptions).

Results: We calculated Gibbs free energy for 13 different weathering reactions. Eight out of the 13 reactions are more favorable at lower temperatures. This is because these 8 reactions are exothermic whereas the others are endothermic. All reactions are more favorable with a higher fugacity of CO_2, and O_2, or a lower fugacity of H_2.

An example of one of these reactions is the aqueous weathering of forsterite (Mg endmember of olivine) to magnesite and talc. The ΔG of this reaction at present atmospheric conditions and at 0°C is -12,140 cal/mol. Weathering one mole of forsterite would allow for the construction of 6 grams of biomass (see Figures 1 and 2). This means that the aqueous weathering of 1 kg of an ultramafic rock like Chassigny meteorite (which has a high abundance of olivine) at present martian conditions can support the construction for ~30 grams of microbes. The aqueous weathering of 1 kg of a basaltic rock (SiO_2 weight % =49.97, Na_2O+K_2O weight % = 4.08, and Mg# = 55) on Mars can support metabolism for ~ 26 grams of biomass at present martian conditions and ~32 grams for conditions likely in the past. If the entire surface of Mars were weathered down to a depth of 1m, there would be enough energy to support 1.3×10^{19} g of biomass globally, equivalent to 0.09 g/cm^3.

Figure 1: Delta G calculated from weathering one mole of forsterite.

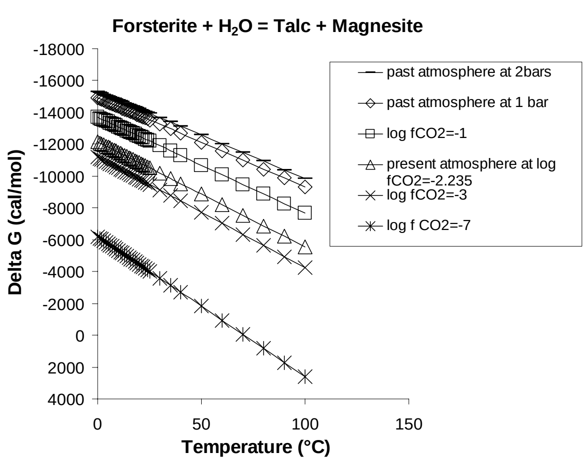
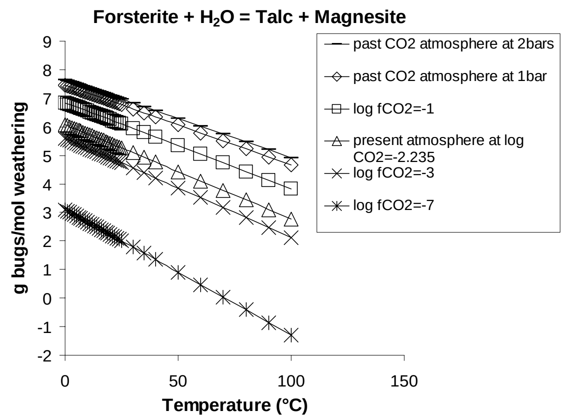


Figure 2: Grams of biomass calculated from weathering one mole of forsterite.



Discussion/Conclusion: These results indicate that chemical weathering of minerals at low temperatures (down to 0°C) in aqueous environments on Mars can produce enough geochemical energy to support metabolism for potential martian organisms. Therefore, low-temperature environments on Mars where there are/were water-rock reactions taking place, are good places to search for extant or extinct life on Mars. Terrestrial chemolithotrophs that oxidize ferrous Fe or H_2, or psychrophiles that thrive in low temperatures (0-12° C), could be useful analogs when formulating critieria for the biological indicators of martian life.

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