ASSESSING THE HABITABILITY OF MERIDIANI PLANUM, MARS, BASED ON THERMODYNAMIC ENERGY REQUIREMENTS. L. L. Tierney[1] and B. M. Jakosky[1], [1]Laboratory for Atmospheric and Space Physics and Department of Geological Science, University of Colorado, Boulder, CO 80309, email: Lindsey.Tierney@lasp.colorado.edu.

Introduction: A source of metabolic energy is a requirement for life, and one likely source of energy that may have supported potential organisms on Mars was geochemical energy from chemical disequilibrium. We evaluate the habitability of Meridiani Planum by calculating the amount of geochemical energy that would have been available from low-temperature (0°C) redox reactions that likely occurred near the surface. Meridiani Planum was selected as a Mars Exploration Rover landing site because hematite was detected spectroscopically from orbit by the Thermal Emission Spectrometer (TES) on board Mars Global Surveyor (MGS) [1]. Hematite is interesting astrobiologically because it typically forms in the presence of liquid water, which is a requirement for life. However, not only is water a requirement for life as we know it, but so is a source of energy from chemical disequilibrium.

Chemical disequilibrium can occur when there is a contrast in oxidation states between strongly reduced basaltic rocks and relatively oxidized water, for example [2,3]. Additionally, the weathering of primary minerals to form secondary minerals can be used by microorganisms to sustain metabolic activity [4]. The occurrence of weathering products and various oxidation states of elements today at Meridiani indicates that redox reactions have gone forward in the past and would have released energy for potential organisms to take advantage of for growth.

Background: Previous analyses have used thermodynamics to calculate the amount of geochemical energy that may be available in various environments. For instance, [5] and [6] estimated the amount of metabolic energy from terrestrial hydrothermal systems; [7] estimated the amount of metabolic energy available from a martian hydrothermal system; and [8] and [9] calculated the amount of geochemical energy released from low-temperature weathering reactions on Mars. Like these previous studies, we also use a thermodynamic approach in order to assess the habitability of Meridiani. Specifically, we quantify the amount of available geochemical energy supplied in the past for potential microorganisms at Meridiani Planum and estimate the amount of biomass that may have been supported. When assessing the habitability of Meridiani, we need not only to "follow the water", but we must also "follow the energy".

Methods: We calculate the energy that was available from each reaction using Gibbs free energy equation. Thirteen chemolithoautotrophic reactions involving dissolved compounds and eight weathering reactions were evaluated. The weathering reactions were chosen based on likely reactions that produced the observed mineralogy at Meridiani.

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

$$\Delta G = \Delta G^o + RT\ln Q \qquad (1)$$

where ΔG is the change that occurs during the reaction at specific conditions, $\Delta G°$ is Gibbs free energy in a standard state, R is the universal gas constant (8.314 J K^{-1} mol^{-1}), T is the temperature in Kelvin, and Q is the ratio of the activities of the products to those of the reactants. We assume that 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 [6]. All calculations were performed at 0°C and the assumed activities are listed in Table 1. The assumed activities were selected based on a thermodynamic program called REACT, which is a program within *Geochemist's Workbench 6.0©* that allows the user to react a specific water composition with a specific rock composition. The resulting fluid and mineralogy is then produced as the output.

Table 1: Assumed activities (in mol/kg). All mineral and H_2O activities are assumed to be 1.

Species	Activity	Species	Activity
HCO_3^-	6×10^{-3}	Fe^{2+}	10^{-2}
H^+	10^{-3}	SO_4^{2-}	6×10^{-2}
$H_{2(aq)}$	10^{-6}	HS^-	10^{-5}
$CH_{4(aq)}$	10^{-9}	S°	10^{-8}
$O_{2(aq)}$	10^{-5}	Mn^{2+}	10^{-3}
Fe^{3+}	10^{-8}	Mg^{2+}	10^{-2}

Interestingly enough, varying the activities by orders of magnitudes, does not affect the gibbs free energy significantly (Figure 1). Figure 1 shows how the gibbs free energy is affected when the pH is varied from 1-12. The free energy stays fairly constant as pH changes with the exception of the anaerobic sulfide oxidation (ASO) reaction.

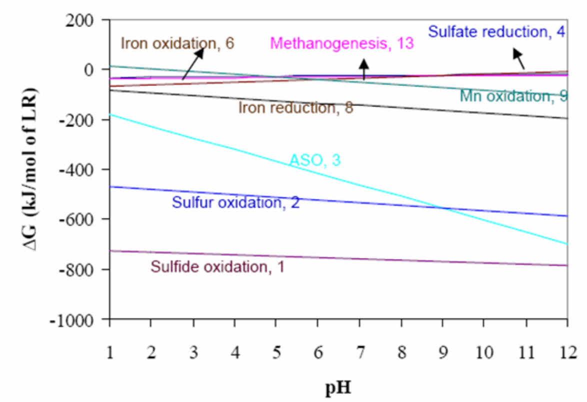

Figure 1: Gibbs free enegy vs. pH for different chemolithoautotrophic reactions.

We estimate the amount of biomass that could be produced by assuming that autotrophic microbes that use H_2 as an electron donor require the dissipation of ~83 kJ to synthesize each g of C in cellular biomass, while microbes that use O_2 as an electron acceptor require ~292 kJ/g C cellular biomass with a 40% uncertainty [10, 6, 2]. We then assume that one g of C cellular biomass is equivalent to 2.2 g dry weight of cells [11].

Results: The weathering reactions each provided enough energy to support ~10^9-10^{11} cells/cm^3 rock weathered. The weathering of epsomite ($MgSO_4 \cdot 7H_2O$) and pyrite (FeS_2) can support the most amount of biomass, ~10^{11} cells cm^{-3} and ~$6x10^{10}$ cells cm^{-3}, respectively. These reactions depend not only on how much energy is available, but the resulting biomass estimate will depend on how much of the primary mineral is present. We used values from [12] and [13] to estimate the relative abundance of each mineral at Meridiani.

Iron-oxidation and sulfide-oxidation reactions would produce the most biomass (~10^5-10^8 cells/cm^3 rock) if we assume a water/rock = 1. A wide variety of terrestrial organisms oxidize sulfide or intermediate states of sulfur in nature using O_2 as an electron acceptor [14]. Sulfate-reducing organisms are also found in a wide range of environments on Earth using H_2 as an electron donor. Fe-redox reactions may have also played a major role at Meridiani because we see evidence for both ferrous (i.e., olivine, pyroxene) and ferric (i.e., hematite, magnetite, goethite, jarosite, etc.) minerals [15, 16]. Combined iron-redox reactions at Meridiani are estimated to release enough energy to support ~$8x10^7$cells cm^{-3}. This is about the same density of biomass that [17] counted from samples taken from sediment at Earth's seafloor.

Our results demonstrate that there are a number of reactions that may have provided sufficient metabolic energy for potential microorganisms at Meridiani.

Conclusions: Based on thermodynamics alone, it appears that Meridiani was an environment that had enough energy sources to allow for a habitable environment. We suggest that there were sufficient electron acceptors and donors available at Meridiani, and there is a possibility that the reactions may have gone forward at sluggish rates because of the low temperatures on Mars. Biology may have been able to take advantage of the slow reactions by catalyzing them and in return gain metabolic energy and reproduce. Meridiani Planum appears to be a viable location for a search for past life.

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