A METHANE-RICH EARLY MARS: IMPLICATIONS FOR HABITABILITY AND THE EMERGENCE OF LIFE. M. L. Wong[1], P. Gao[2], A. J. Friedson[3], Y. L. Yung[1,3], M. J. Russell[3] [1]California Institute of Technology, Division of Geological and Planetary Sciences (mlwong@caltech.edu), [2]NASA Ames Research Center, [3]NASA Jet Propulsion Laboratory

We present radiative transfer and photochemical models for the atmosphere of a young Mars-like planet that outgasses carbon primarily in the form of CH_4 rather than CO_2. While volcanic emissions on Earth have always been high in CO_2 and low in CH_4, this may not be the case for smaller terrestrial planets. All rocky bodies in the Solar System formed from planetesimals that, based on meteoritic studies, are generally at or below the iron–wüstite buffer and contain reduced organic compounds [1]. In spite of this, Earth's mantle has existed in a high oxidation state throughout geologic history thanks to ferrous iron's tendency to disproportionate to ferric and native iron in the presence of silicate perovskite [2,3]. The spinel-to-perovskite transition occurs at 24 GPa and 1900 K; on Earth, this creates the 660 km discontinuity [4]. Mantles of smaller terrestrial bodies may never reach the requisite pressure and temperature for this phase change. If a Mars-sized planet had a lower oxygen fugacity mantle, magmatic outgassing would have produced a CH_4-rich atmosphere [5]. In addition, impact degassing would have contributed a sizeable amount of CH_4 to the atmosphere [6]. These processes would be expected for any Mars-sized exoplanet.

A CH_4 atmosphere has profound implications for the emergence of life on a wet, rocky world. According to the alkaline hydrothermal vent theory, nascent life gained its carbon and energy by burning CO_2 with hydrothermal H_2 and perhaps CH_4 [7,8,9]. A terrestrial world whose atmosphere is laden with CH_4 would not drive the emergence of metabolism in such a manner; instead, it may exhibit prebiotic chemistry similar to that of Titan. However, the presence of H_2O may oxidize the outgassed CH_4 to CO_2; if this process is efficient enough, there will be CO_2 aplenty for life.

On the other hand, if CH_4 is destroyed too efficiently, then a young Mars-sized planet may lose the greenhouse warming necessary to maintain liquid water at the surface. Atmospheric models have demonstrated that a purely CO_2 atmosphere, even one as massive as 7 bars, is incapable of heating Mars above an annual-mean surface temperature of 273 K [10], although recent studies show that recurring wet states could have been induced in an H_2-rich atmosphere [11,12]. While CH_4 alone is probably insufficient to warm the planet above freezing, it would raise middle atmosphere temperatures and prolong the photochemical lifetime of SO_2, another potent greenhouse gas.

Using the non-gray 1-D radiative-convective equilibrium model "RC1D" and the Caltech/JPL 1-D chemistry transport model "KINETICS" [11] , we investigate the chemistry of a C-H-N-O atmosphere blanketing a ~0.5 Gyr-old Mars-like world orbiting a Sun-like star at 1.52 AU. The atmosphere is sourced from CH_4–N_2 outgassing, in vapor pressure equilibrium with an H_2O ocean [14] or massive glaciation [15], losing hydrogen to space via hydrodynamic escape, and irradiated by the spectrum of the faint-young Sun. RC1D is be used to calculate the atmospheric thermal structure consistent with the radiative heating and cooling associated with the composition computed at each chemical model time step, the Sun's luminosity at that time, and global average insolation conditions. KINETICS will determine how effectively the CH_4 can be oxidized to CO_2 and evaluate the synthesis of organic molecules in the atmosphere. This study is a step towards a grander, more realistic model of Mars-like terrestrial planets that includes sulfur chemistry, atmospheric dust and haze, and aqueous chemistry.

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