escape would produce a fractionation of $^{15}N/^{14}N$ larger that observed; an early, thicker CO_2 atmosphere could mitigate the N loss and produce the observed fractionation. The total amount of CO_2 lost over geologic time is probably of the order of tens of millibars rather than a substantial fraction of a bar. The total loss from solar-wind-induced sputtering and photochemical escape, therefore, does not seem to be able to explain the loss of a putative thick, early atmosphere without requiring formation of extensive surface carbonate deposits.

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POSSIBLE SOLUTIONS TO THE PROBLEM OF CHANNEL FORMATION ON EARLY MARS. J. F. Kasting, Department of Geosciences, 211 Deike, Pennsylvania State University, University Park PA 16802, USA.

A warm climate on early Mars would provide a natural, although not unique, explanation for the presence of fluvial networks on the ancient, heavily cratered terrains. Explaining how the climate could have been kept warm, however, is not easy. The idea that the global average surface temperature, T_s, could have been kept warm by a dense, CO_2 atmosphere supplied by volcanism or impacts [1,2] is no longer viable. It has been shown that CO_2 cloud formation should have kept T_s well below freezing until ~2 b.y. ago, when the Sun had brightened to at least 86% of its present value [3] (Fig. 1). Warm equatorial regions on an otherwise cold planet seem unlikely because atmospheric CO_2 would probably condense out at the poles. Warming by impact-produced dust in the atmosphere seems unlikely because the amount of warming expected for silicate dust particles is relatively small [4]. Greenhouse warming by high-altitude CO_2 ice clouds seems unlikely because such clouds are poor absorbers of infrared radiation at most wavelengths [5]. Warming by atmospheric NH_3 [6] seems unlikely because NH_3 is readily photodissociated [7] and because N may have been in short supply as a consequence of impact erosion [8] and the high solubility of NH_3. A brighter, mass-losing young Sun [9] seems unlikely because stellar winds of the required strength have not been observed on other solar-type stars. In short, most of the explanations for a warm martian paleoclimate that have been proposed in the past seem unlikely.

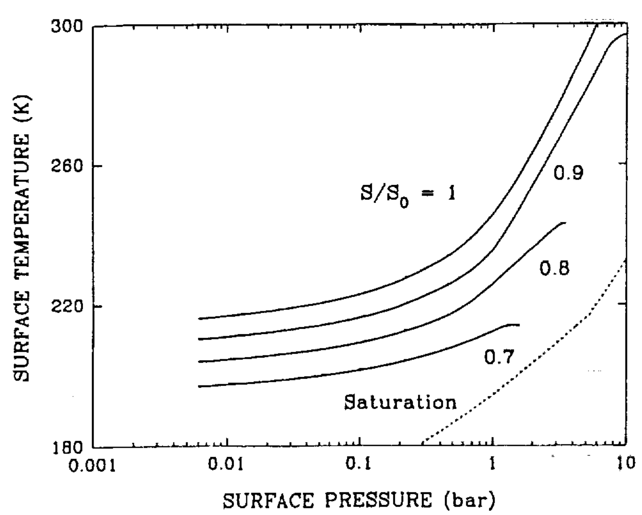

Fig. 1. Mean global surface temperature on Mars as a function of atmospheric CO_2 partial pressure. S/S_0 represents the magnitude of the solar luminosity compared to its present value. Solutions with mean surface temperature >273 K are found only for S/S_0 > 0.86. The dashed curve is the saturation vapor pressure curve for CO_2. (From [3].)

One possibility that seems feasible from a radiative/photochemical standpoint is that CH_4 and associated hydrocarbon gases and particles contributed substantially to the greenhouse effect on early Mars. Methane is photochemically more stable than NH_3 and the gases and particles that can be formed from it are all good absorbers of infrared radiation. The idea of a CH_4-rich martian paleoatmosphere was suggested a long time ago [10] but has fallen out of favor because of perceived difficulties in maintaining a CH_4-rich atmosphere. In particular, it is not obvious where the CH_4 might come from, since volcanic gases (on Earth, at least) contain very little CH_4. This difficulty could be largely overcome if early Mars was inhabited by microorganisms. Then, methanogenic bacteria living in sediments could presumably have supplied CH_4 to the atmosphere in copious quantities.

Thus, if I were a betting scientist, I would wager that either early Mars was inhabited, or the martian channels were formed by recycling of subsurface water under a cold climate, as proposed by Clifford [11] and others.

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CORE FORMATION, WET EARLY MANTLE, AND H_2O DEGASSING ON EARLY MARS. K. Kuramoto and T. Matsui, Department of Earth and Planetary Physics, University of Tokyo, Bunkyo-ku, Tokyo 113, Japan.

Introduction: Geophysical and geochemical observations strongly suggest a "hot origin of Mars," i.e., the early formation of both the core and the crust-mantle system either during or just after planetary accretion [1]. To consider the behavior of H_2O in the planetary interior it is specifically important to determine by what mechanism the planet is heated enough to cause melting. For Mars, the main heat source is probably accretional heating. Because Mars is small, the accretion energy needs to be effectively retained in its interior. Therefore, we first discuss the three candidates of heat retention mechanism: (1) the blanketing effect of the primordial H_2-He atmosphere, (2) the blanketing effect of the impact-induced H_2O-CO_2 atmosphere, and (3) the higher deposition efficiency of impact energy due to larger impacts. We conclude that (3) the is the most plausible mechanism for Mars. Then, we discuss its possible consequence on how wet the early martian mantle was.