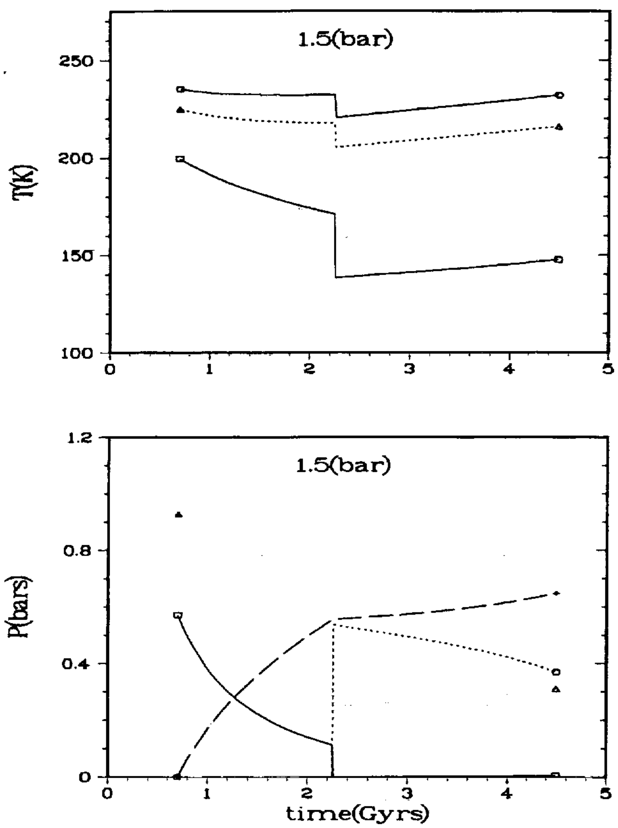

Fig. 1. Temperature (top) and pressure evolution (bottom) for total initial abundance of 1.5 bar. The temperatures shown are for the surface at equator (solid line with circles), pole (solid line with squares), global mean (dashed line with triangles), and frost point (dotted). The CO_2 reservoir pressures are atmosphere (solid line with squares), caps (dashed line with circles), regolith (dotted line with triangles), and carbonate (chain dotted line with plus sign).

difficulty is making Mars warm early on. As Kasting has pointed out, only a stronger greenhouse or a brighter early Sun can help in this regard. However, we have found that if the greenhouse were stronger or if the Sun were brighter, then massive permanent caps would form as a result of a collapse in the climate system sometime between 1.5 and 3.5 b.y. ago. An example of this collapse and the thermal history associated with it is shown in Fig. 1.

The collapse is a result of an unstable feedback between the poleward transport of heat by the atmosphere, the greenhouse effect, and surface pressure. As surface pressure falls, heat transport and the greenhouse effect are reduced, the polar caps cool, surface pressure falls further, and so on. Gierasch and Toon [4] discuss this instability in detail. In our model, the instability is set off by weathering that removes CO_2 from the atmosphere at a rate that is exponentially proportional to temperature. Thus, the warmer early Mars is, the more likely collapse will occur. As much as 600 mbar goes into the caps when collapse occurs with the CO_2 coming from the atmosphere and the regolith. More importantly, at least 300 mbar survives to the present epoch—much more than appears to reside in the south residual cap.

Collapse can be avoided if the polar albedo is significantly lower than the value we have assumed (0.75), or if the actual poleward heat flux is greater than that given by our simple parameterization. However, in either case, the implication is that if global mean surface temperatures were at or above 240 K on early Mars, then a minimum total inventory of 2 bar of CO_2 is required, and at least 70% of it has been sequestered as carbonate in near-surface materials. On the other hand, if the fluvial features in the ancient terrains do not require global mean temperatures near 240 K and can be explained by phenomena that are not climate related, such as an elevated geothermal heat flux, then our model favors an initial CO_2 inventory near 600 mbar. Of this initial CO_2, most has gone into the regolith (300 mbar), modest amounts into carbonates (130 mbar), even smaller amounts into the atmosphere (7 mbar) and caps (3 mbar), with the remainder having escaped into space (160 mbar). Thus, it is crucial that we obtain better constraints on the thermal regime required to form the fluvial features on early Mars.

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N94-21672

S13-91 ABS. ONLY 177603

MARS ATMOSPHERIC LOSS AND ISOTOPIC FRACTIONATION BY SOLAR-WIND-INDUCED SPUTTERING AND PHOTOCHEMICAL ESCAPE. B. M. Jakosky[1], R. O. Pepin[2], R. E. Johnson[3], and J. L. Fox[4], [1]Laboratory for Atmospheric and Space Physics, University of Colorado, Boulder CO 80309-0392, USA, [2]School of Physics and Astronomy, University of Minnesota, Minneapolis MN 55455, USA, [3]Department of Nuclear Engineering and Engineering Physics, University of Virginia, Charlottesville VA 22903, USA, [4]Department of Mechanical Engineering, State University of New York–Stony Brook, Stony Brook NY 11794, USA.

We examine the effects of loss of Mars atmospheric constituents by solar-wind-induced sputtering and by photochemical escape during the last 3.8 b.y. Sputtering is capable of efficiently removing all species from the upper atmosphere, including the light noble gases; N also is removed by photochemical processes. Due to the diffusive separation by mass above the homopause, removal from the top of the atmosphere will fractionate the isotopes of each species, with the lighter mass being preferentially lost. For C and O, this allows us to determine the size of nonatmospheric reservoirs that mix with the atmosphere; these reservoirs can be accounted for by exchange with CO_2 adsorbed in the regolith and with H_2O in the polar ice deposits. We have constructed both simple analytical models and time-dependent models of the loss of volatiles from and supply to the martian atmosphere. Both Ar and Ne require continued replenishment from outgassing over geologic time.

For Ar, sputtering loss then explains the fractionation of $^{36}Ar/^{38}Ar$ without requiring a distinct epoch of hydrodynamic escape (although fractionation of Xe isotopes still requires a very early hydrodynamic escape). For Ne, the current ratio of $^{22}Ne/^{20}Ne$ represents a balance between loss to space and continued resupply from the interior; the similarity of the ratio to the terrestrial value is coincidental. For N, the loss by both sputtering and photochemical 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.

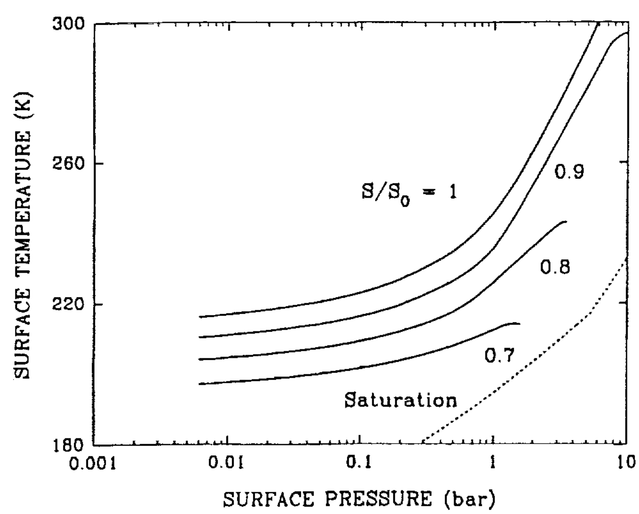

Fig. 1. Mean global surface temperature on Mars as a function of atmospheric CO_2 partial pressure. S/S_0 represents the magnitude of the solar luminosity compared to its present value. Solutions with mean surface temperature >273 K are found only for S/S_0 > 0.86. The dashed curve is the saturation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