

conditions with ~7 mbar in the atmosphere, <300 mbar in the regolith, and <5 mbar in the caps.

Such scenarios only exist if the early Sun was brighter than standard solar models suggest, if greenhouse gases other than CO₂ were present in the early atmosphere, or if the polar albedo is significantly lower than 0.75. However, these scenarios generally require the storage of large amounts of CO₂ (>1 bar) in the carbonate reservoir. If the warm and wet early Mars constraint is relaxed, then we find best overall agreement with present-day reservoirs for initial CO₂ inventories of 0.5–1.0 bar. We also find that the polar caps can have a profound effect on how the system evolves. If the initial amount of CO₂ is less than some critical value, then there is not enough heating of the poles to prevent permanent caps from forming.

Once formed, these caps control how the system evolves because they set the surface pressure and hence the thermal environment. If the initial amount of CO₂ is greater than this critical value, then caps do not form initially, but can form later on when weathering and escape lower the surface pressure to a point where polar heating is no longer sufficient to prevent cap formation and the collapse of the climate system. Our modeling suggests this critical initial amount of CO₂ is between 1 and 2 bar, but its true value will depend on all factors affecting the polar heat budget.

References: [1] Gierasch P. J. and Toon O. B. (1973) *J. Atmos. Sci.*, 30, 1502–1508.

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POSSIBLE TEST OF ANCIENT DENSE MARTIAN ATMOSPHERE. W. K. Hartmann¹ and S. Engel², ¹Planetary Science Institute, Tucson AZ 85705, USA, ²Lunar and Planetary Lab, University of Arizona, Tucson AZ 85721, USA.

We have completed preliminary calculations of the minimum sizes of bolides that would penetrate various hypothetical martian atmospheres with surface pressures ranging from 6 to 1000 mbar for projectiles of various strengths (weak icy comet, carbonaceous bodies, coherent chondrite, iron). The calculations are based on a program kindly provided by C. Chyba [1]. These numbers are used to estimate the diameter corresponding to the turnaround in the crater diameter distribution due to the loss of these bodies, analogous to the dramatic turnaround at larger size already discovered on Venus due to this effect.

We conclude that for an atmosphere greater than a few hundred millibars, a unique downward displacement in the diameter distribution would develop in the crater diameter distribution at $D \sim 0.5\text{--}4$ km, due to loss of all but Fe bolides.

Careful search for this displacement globally, as outlined here, would allow us to place upper limits on the pressure of the atmosphere contemporaneous with the oldest surfaces, and possibly to get direct confirmation of dense ancient atmospheres.

We are currently searching for support to refine the calculations and conduct the necessary careful search in the cratering records.

References: [1] Chyba C. (1993) *Nature*, 361, 40.

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The amount of dust in the martian atmosphere is variable in both space and time [1,2]. The presence of aerosols in Mars' atmosphere complicates quantitative analysis of martian surface properties [3–7]. Dust storms have been observed telescopically for almost 200 yr and are known to have major effects upon the structure and circulation of the martian atmosphere [8,9]. Great dust storms tend to occur during the southern spring and summer [2] and may be an important mechanism by which dust is transported into the polar regions [10]. It is widely believed that the martian polar layered deposits record climate variations over at least the last 10–100 m.y. [11–18], but the details of the processes involved and their relative roles in layer formation and evolution remain obscure [19]. The layered deposits are widely believed to be the result of variations in the proportions of dust and water ice deposited over many climate cycles [13–15]. However, the amount of dust currently transported into the polar regions is unknown, as are the effects of global climate changes on dust transport. In order to infer the climate history of Mars from geologic evidence including the polar layered deposits, the current cycling of dust through the martian atmosphere must be understood. In addition, future missions to Mars (including possible human exploration) will require better knowledge of the likelihood and severity of martian dust storms.

Zurek and Martin [2] found that "planet-encircling dust storms do not occur every Mars year, and . . . that there may have been periods of several successive years without such storms." The clarity of Mars images taken during recent oppositions suggests that the martian atmosphere has been less dusty recently than in previous years [20]. Hubble Space Telescope images of Mars show that the dust opacity was less than 0.06 in December 1990 [21]. Ingersoll and Lyons [22] proposed that martian great dust storms are chaotic phenomena, influenced by the amount of "background" dust in the atmosphere. However, their analysis was hindered by gaps in the historical record of martian dust opacity. Martian dust storms can be detected only when Mars is relatively close to Earth, so a complete seasonal or interannual history of dust storms is impossible to obtain from groundbased data alone. The optical depth of aerosols in the martian atmosphere between dust storms has been determined primarily from spacecraft data [23,24], but can also be inferred from groundbased observations [5]. Groundbased images of Mars show that atmospheric dust opacity significantly affects the photometric behavior of the planet. Lumme [5] modeled martian limb brightening using high-quality visible-light photographs taken on September 3, 1973. The optical thickness (0.16) and single-scattering albedo (0.55) at 435 nm that he derived are consistent with more recent results using Viking Orbiter violet-filter television data [4,6,25,26], indicating that groundbased data may be used to determine the scattering properties of the martian atmosphere. As shown below, Mars limb brightening data can be used to determine the opacity of aerosols in the martian atmosphere between dust storms.

We have developed a model for Mars surface and atmospheric scattering based on equations (1)–(6) in Hillier et al. [27]. This formulation was chosen for its speed of computation and because it accounts for the spherical geometry of atmospheric scattering at