spheric lifetimes, will need to take into account the rate at which they may have been supplied to the atmosphere. Schemes analogous to that presented for CO_2 will have to be explored in order to assess the absolute contribution of any potential greenhouse gas on early Mars.

References: [1] Wänke H. et al. (1992) *LPS XXIII*, 1489–1490. [2] Pien D. C. (1980) *Science, 210,* 895–897. [3] Gulick V. C. and Baker V. R. (1993) *LPS XIV*, 587–588. [4] Squyres S. W. (1989) *Fourth Intl. Conf. on Mars.* [5] Sagan C. and Mullen G. (1972) *Science, 177,* 52–56. [6] Toon O. B. et al. (1980) *Icarus, 44,* 552–607. [7] Pollack J. B. et al. (1987) *Icarus, 71,* 203–224. [8] Kasting J. (1991) *Icarus, 94,* 1–13. [9] Kasting J. F. (1992) *Workshop on the Evolution of the Martian Atmosphere.* [10] Postawko S. E. and Fanale F. P. (1992) *Workshop on the Evolution of the Martian Atmosphere.*

N94-21682
S23-91 ABS ONLY 6L3

THE MARTIAN VALLEY NETWORKS: ORIGIN BY NIVEO-FLUVIAL PROCESSES. J. W. Rice Jr., Department of Geography, Arizona State University, Tempe AZ 85287, USA.

The valley networks may hold the key to unlocking the paleoclimatic history of Mars. These enigmatic landforms may be regarded as the martian equivalent of the Rosetta Stone. Therefore, a more thorough understanding of their origin and evolution is required. However, there is still no consensus among investigators regarding the formation (runoff vs. sapping) of these features.

Recent climatic modeling [1] precludes warm (0°C) globally averaged surface temperatures prior to 2 b.y. when solar luminosity was 25–30% less than present levels. This paper advocates snowmelt as the dominant process responsible for the formation of the dendritic valley networks. Evidence for martian snowfall and subsequent melt has been discussed in previous studies. It has been suggested [2] that Mars has undergone periods of very high obliquities, up to 45°, thus allowing snow accumulations, several tens of meters thick, at low latitudes as a result of sublimation from the poles. Clow investigated the conditions under which snow could have melted by solar radiation by using an optical-thermal model developed for dusty snowpacks [3]. It was found that the low thermal conductivity of snow and its partial transparency to solar radiation can result in subsurface melting despite surface temperatures well below freezing. Melting and subsequent runoff can occur at atmospheric pressures as low as 30–100 mbar [3]. Carr showed that if streams 2 m deep or larger can be initiated and sustained, then flows up to a few hundred kilometers long can be established, even under present-day climatic conditions [4]. Therefore, based on the above-mentioned work, it seems logical to the author that snowfall and subsequent snowmelt has many advantages to other explanations for the formation of the valley networks.

It has been argued that the valley networks were formed primarily by groundwater seepage. This is based on the measurement of junction angles between intersecting tributaries and on morphologic characteristics that appear to suggest headward extension through basal sapping [5]. The evidence for sapping is in some cases convincing (i.e., Nirgal Vallis), but it does not explain many of the dendritic valley systems, e.g., those located in the Margaritifer Sinus region.

Some problems with the sapping model will be discussed below. First, the measurement of junction angles between individual intersecting tributaries of the valley networks does not provide evidence to refute the view that the networks were formed by rainfall/snowmelt-fed erosion. Stream junction angles are controlled by slope, structure, lithology, and basin development stage, not precipitation [6]. Sapping requires that zones of low hydraulic head somehow be established to support the gradients needed to allow groundwater flow, and that zones of high hydraulic head be recharged, presumably by precipitation. Additionally, some of the valley networks whose channels originate on crater-rim crests indicate that the local water table must have intersected the surface high on the crater wall if sapping was involved [3]. This would mean that the crater was once filled with water, but there is no evidence, such as inflowing channels, to support this condition. It should also be noted that all the valley networks have been modified by mass wasting processes such as gelifluction and thermal erosion.

In order to more fully understand niveo-fluvial systems on Mars one should study terrestrial periglacial regions such as the Northwest Territories in the Canadian High Arctic. It is proposed that the following geomorphic processes and resulting landforms of snowmelt-fed rivers be used to explain the dendritic valley networks on Mars.

The Mecham River near Resolute, Northwest Territories, provides an excellent example of stream action and valley development in the periglacial realm. The area is underlain by continuous permafrost and mean monthly air temperatures are below zero for 9–10 months a year. The Mecham River has 80–90% of its annual flow concentrated in a 10-day period. This is typical for periglacial rivers in the High Arctic. During this brief period of concentrated flow extensive movement of bedload occurs, sometimes with peak velocities up to 4 m/s, causing the whole bed to be in motion [7]. This pattern of intense activity has far greater erosive and transporting potential than a regime in which river flow is evenly distributed throughout the year. The dominance of bedload movement in Arctic streams helps explain the distinctive flat-bottomed form of many periglacial stream valleys [8]. Thermal erosion and the subsequent collapse of river banks provides material for bedload transport and deposition downstream. This process also aids in the development of the broad flat-floored valleys. The permafrost also favors the flat-floored valley profiles because it provides a near-surface limit to downward percolation of water, thereby promoting runoff [9]. Another interesting feature of these periglacial rivers is that they lack a pronounced channel on their floors. This holds true for valleys eroded into either bedrock or unconsolidated debris.

Other work [10] indicates that fluvial processes have often been underestimated in periglacial regions. Budel illustrates this point in Spitsbergen, where he pointed out that ground ice breaks apart the rocks and prepares them for fluvial action. Periglacial rivers do not need to carry out new erosive action but need only melt the eisrinde and transport the shattered debris. The eisrinde is composed of the upper frozen and highly shattered layer of the permafrost. Rivers operating under this regime can deepen their beds rapidly; downcutting rates on the order of 1–3 m/1000 yr over the last 10,000 yr have been estimated for Spitsbergen [10].

References: [1] Kasting J. F. (1991) *Icarus, 94,* 1–13. [2] Jakosky B. M. and Carr M. H. (1985) *Nature, 315,* 559–561. [3] Clow G. D. (1987) *Icarus, 72,* 95–127. [4] Carr M. H. (1983)

Icarus, 56, 476–495. [5] Pieri D. C. (1980) *Science, 210,* 895–897. [6] Schumm S. A. (1956) *GSA, 67,* 597–646. [7] Cook F. A. (1967) *Geo. Bull., 9,* 262–268. [8] French H. M. (1976) *The Periglacial Environment,* 309. [9] Washburn A. L. (1980) *Geocryology,* 406. [10] Budel J. (1977) *Climatic Geomorphology,* 304.

N94-21683

S24-91 ABS. ONLY 197614

MARS AND THE EARLY SUN. D. P. Whitmire[1], L. R. Doyle[2], R. T. Reynolds[3], and P. G. Whitman[1], [1]University of Southwestern Louisiana, Lafayette LA 70504-4210, USA, [2]SETI Institute, NASA Ames Research Center, Moffett Field CA 94035, USA, [3]Theoretical Studies, NASA Ames Research Center, Moffett Field CA 94035, USA.

P.1

Global mean temperatures near 273 K on early Mars are difficult to explain in the context of standard solar evolution models. Even assuming maximum CO_2 greenhouse warming, the required flux is ~15% too low [1]. Here we consider two astrophysical models that could increase the flux by this amount. The first model is a nonstandard solar model in which the early Sun had a mass somewhat greater than today's mass (1.02–1.06 $M_\odot$). The second model is based on a standard evolutionary solar model, but the ecliptic flux is increased due to focusing by an (expected) heavily spotted early Sun.

The relation between stellar mass M and luminosity L for stars near 1 $M_\odot$ is $L \sim M^{4.75}$ [2]. If the Sun's original mass were larger than at present, the early planetary flux would be further increased due to migration of orbits. Isotropic mass loss does not produce a torque on a planet and so angular momentum is conserved. Consequently, semimajor axes increase inversely with mass loss and the flux is proportional to $M^{6.75}$. To increase the flux at Mars by 15% requires that the Sun's mass be ≥1.02 $M_\odot$. On the other hand, the flux cannot be so large (1.1× that of the flux at 1 AU today) that Earth would have lost its water [3]. This imposes an upper mass limit of 1.06 $M_\odot$.

Nonclimatic evidence for mass loss of this magnitude might be found in the ion implantation record of meteorites and Moon rocks. Such evidence does exist, but is inconclusive due to uncertainties in exposure times and dating [4,5]. The dynamical record of adiabatic mass loss is also inconclusive. The adiabatic invariance of the action variables implies that the eccentricities and inclinations of planetary orbits remain constant as the semimajor axes increase. The dynamical drag of the wind would have no effect on planets, but would cause a net inward migration of bodies of sizes less than about 1 km [6]. Whether the cratering record is consistent with this dynamical consequence is unclear. Mass loss could also be an additional process contributing to bringing organics into the inner solar system.

A mass loss of 0.1 $M_\odot$ has been suggested as an explanation for the depletion of Li in the Sun by 2 orders of magnitude over primordial values [7]. However, this explanation has been reconsidered by [8], who find that mass loss cannot explain the depletion of Li in Hyades G dwarfs. Although it is generally believed that young G stars are spun down by mass loss, most models are insensitive to the total mass loss required [e.g., 9]: An exception is the model by [10] which predicts a mass loss comparable to our lower limit.

The most promising nonclimatic evidence for main sequence mass loss from the early Sun is the direct observation of similar mass loss from young main-sequence G stars. Detection of stellar mass loss from late dwarfs at the predicted rate (less than $\sim 10^{-10} M_\odot\, yr^{-1}$) by optical techniques is generally not possible. However, in one unique case where it could be measured, an outflow 1000× that of the present Sun was found in a K2V dwarf [11]. Recently, huge winds have been reported from several M dwarfs [12]. This technique involves detections over a wide range of radio and millimeter wavelengths and the fact that free-free emission from an optically thick wind has a characteristic spectrum in which the flux is proportional to the 2/3 power of the frequency. As a first step in extending this technique to solar-type stars we have recently used the VLA to obtain the radio emission at 2 and 6 cm in four nearby young G-type stars.

In the second model (ecliptic focusing) we assume standard solar evolution. Young G stars are often observed to be heavily spotted (10–50%). In contrast to mature G stars like the Sun, which typically have only a maximum coverage of ~0.1%, the net effect of star spots on young G stars is to reduce the radiated flux at the location of the spot. Since the total stellar luminosity is determined by nuclear reactions in the core, the flux must increase in regions without spots. Such variations in flux are observed on short (days) and long (years) timescales [13]. These observations measure the anisotropy in the distribution of spots. A more significant effect would be the average increase in the equatorial flux if the time-averaged location of the spotted regions was nearer to the stellar poles than to the equator. This is not the case in today's Sun, but is observed to occur in young stars such as the G2V star SV Camelopardalis, in which there is a ~10% coverage, localized in latitude and longitude, toward one of the poles.

We have investigated a simple model in which polar cap blocking focuses the stellar flux in the equatorial plane. The equatorial flux can be enhanced a maximum of a factor of 2 over the uncapped case. For a time-averaged polar coverage of 10% the equatorial flux enhancement factor is 1.17. Refinements in this model and a review of the relevant observational data will be presented.

Acknowledgments: D.P.W. and P.G.W. thank the Louisiana Educational Quality Support Fund for partial support of this work. D.P.W. also acknowledges a NASA Ames/Stanford ASEE summer research fellowship.

References: [1] Kasting J. (1991) *Icarus, 94,* 1–13. [2] Iben I. (1967) *Annu. Rev. Astron. Astrophys., 5,* 571–626. [3] Kasting J. (1988) *Icarus, 74,* 472–494. [4] Caffee M. et al. (1987) *Astrophys. J., 313,* L31–L35. [5] Geiss J. and Bochsler P. (1991) *The Sun in Time* (C. Sonett et al., eds.), 99–117, Univ. of Arizona. [6] Whitmire D. et al. (1991) *Intl. Conf. on Asteroids, Comets, Meteors, 238,* Flagstaff, Arizona. [7] Graedel T. et al. (1991) *GRL, 18,* 1881–1884. [8] Swenson F. and Faulkner J. (1992) *Astrphys. J., 395,* 654–674. [9] Pinsonneault M. et al. (1989) *Astrophys. J., 338,* 424–452. [10] Bohigas J. et al. (1986) *AAS, 157,* 278–296. [11] Mullan D. et al. (1989) *Astrophys. J., 339,* L33–L36. [12] Mullan D. et al. (1992) *Astrophys. J.* [13] Radick R. (1991) *The Sun in Time* (C. Sonett et al., eds.), 787–808, Univ. of Arizona.