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EARLY MARS: A REGIONAL ASSESSMENT OF DENUDATION CHRONOLOGY. T. A. Maxwell and R. A. Craddock, Center for Earth and Planetary Studies, National Air and Space Museum, Smithsonian Institution, Washington DC 20560, USA.

Within the oldest highland units on Mars, the record of crater degradation indicates that fluvial resurfacing was responsible for modifying the Noachian through middle-Hesperian crater population [1]. Based on crater frequency in the Noachian cratered terrain, age/elevation relations suggest that the highest exposures of Noachian dissected and plateau units became stabilized first, followed by successively lower units [2]. In addition, studies of drainage networks indicate that the frequency of Noachian channels is greatest at high elevations [3]. Together, these observations provide strong evidence of atmospheric involvement in volatile recycling. The long time period of crater modification also suggests that dendritic highland drainage was not simply the result of sapping by release of juvenile water, because the varied geologic units as well as the elevation dependence of stability ages makes it unlikely that subsurface recycling could provide a continuous supply of water for channel formation by sapping. While such geomorphic constraints on volatile history have been established by crater counts and stratigraphic relations using the 1:2M photomosaic series, photo-geologic age relationships at the detailed level are needed to establish a specific chronology of erosion and sedimentation. Age relations for discrete erosional slopes and depositional basins will help refine ages of fluvial degradation, assess effectiveness of aeolian processes, and provide a regional chronology of fluvial events. In particular, are stratigraphic relations between dissected plateau units and neighboring plains (usually lumped on small-scale mapping) consistent with a local source/sink scenario for fluvial deposits? Can age relations be determined for discrete depositional basins [e.g., 4] and their neighboring eroded highlands? Did individual degradation events last long enough to be resolved by the cratering record?

One of the long-standing problems in martian geomorphology has been the unique identification of fluvial deposits either within the northern plains [5,6] or elsewhere in the debouchment regions of channels. However, in the low-latitude highlands, sedimentary deposits occur within enclosed basins [4], at areas of channel constriction, and within impact craters. These materials typically consist of subdued, polygonal mesas 2–10 km across, are morphologically similar to the fretted terrain of the Nilosyrtris Mensae region [7], and are laterally confined. Where these deposits are present within degraded craters, the host crater is typically breached by either a through-going or terminating channel. Unfortunately, these units are not extensive enough to allow crater age determinations, so their ages must be inferred by stratigraphy and the age of the superposed surface. Later periods of volcanism and airfall deposition [8] have probably buried many of these deposits, but their distribution suggests that the original sedimentary cover of the martian highlands was once more extensive than is now represented by the few scattered outliers.

In contrast to depositional surfaces, erosional surfaces in the highlands are much more easy to date. There the record of degraded craters indicates the combined effects of erosion from the Noachian through mid Hesperian. The fresh crater population can be used to tell when such surfaces were no longer subject to earlier intense

erosion. In the absence of discrete, datable deposits, such erosion surfaces are being used to determine the timing of Mars denudation.

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EARLY MARS WAS WET BUT NOT WARM: EROSION, FLUVIAL FEATURES, LIQUID WATER HABITATS, AND LIFE BELOW FREEZING. C. P. McKay and W. L. Davis, NASA Ames Research Center, Moffett Field CA 94035, USA.

There is considerable evidence that Mars had liquid water early in its history and possibly at recurrent intervals. It has generally been assumed that this implied that the climate was warmer as a result of a thicker CO₂ atmosphere than at the present. However, recent models suggest that Mars may have had a thick atmosphere but may not have experienced mean annual temperatures above freezing. In this paper we report on models of liquid water formation and maintenance under temperatures well below freezing.

Our studies are based on work in the north and south polar regions of Earth. Our results suggest that early Mars did have a thick atmosphere but precipitation and hence erosion was rare. Transient liquid water, formed under temperature extremes and maintained under thick ice covers, could account for the observed fluvial features. The main difference between the present climate and the early climate was that the total surface pressure was well above the triple point of water.

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WET INSIDE AND OUT? CONSTRAINTS ON WATER IN THE MARTIAN MANTLE AND ON OUTGASSED WATER, BASED ON MELT INCLUSIONS IN SNC METEORITES. H. Y. McSween Jr. and R. P. Harvey, Department of Geological Sciences, University of Tennessee, Knoxville TN 37996, USA.

Constraints on the volatile inventory and outgassing history of Mars are critical to understanding the origin of ancient valley systems and paleoclimates. Planetary accretion models for Mars allow either a volatile-rich [1] or volatile-poor [2] mantle, depending on whether the accreted materials were fully oxidized or whether accretion was homogeneous so that water was lost through reaction with metallic iron. The amount of water that has been outgassed from the interior is likewise a contentious subject, and estimates of globally distributed water based on various geochemical and geological measurements vary from a few meters to more than a thousand meters [3]. New data on SNC meteorites, which are thought to be martian igneous rocks [4], provide constraints on both mantle and outgassed water [5].

The bulk water contents of SNC meteorites, measured after precombustion to remove terrestrial contaminants, are small, in the range of 130–350 ppm. However, because of low internal pressures on Mars, ascending magmas are subject to vesiculation, and they

would further desiccate on eruption and contact with the dry atmosphere. Also, the O isotopic composition of water released at high temperature from SNC meteorites suggests that some fraction of the water they contain is not magmatic, but is due to alteration by water already in the crust [6]. Thus bulk water contents are of little use in assessing how much water has actually been delivered to the surface. What is needed is an estimate of the water contents of SNC magmas prior to near-surface degassing and interaction with crustal water.

Many SNC meteorites contain crystals formed at depth and the cores of these crystals contain now-solidified pockets of trapped melt. Some melt inclusions contain daughter crystals of hydrous amphibole (kaersutite), a phase that does not appear in these meteorites outside the inclusions. Phase equilibria for kaersutite [7] indicate that it is only stable at pressures above 1.5 kbar, corresponding to depths on Mars of 11 km. This is below the self-compression depth for martian crust, and magma trapped at such depth is unlikely to have experienced vesiculation or interaction with crustal water. Kaersutite crystallizes only when the water contents of inclusion melts reach 4 wt% [7]. From the extent of inclusion solidification before the onset of kaersutite crystallization, we can estimate the amount of water in the magma at the time of trapping. The solidification histories for melt inclusions from SNC meteorites have been modeled using linear regression methods to solve a system of mass-balance equations [5,7]. The results for SNC melt inclusions typically indicate 50–75% crystallization before kaersutite forms, corresponding to initial water contents in these magmas of approximately 1.4 wt%.

If we assume that SNC magmas are representative of martian volcanism, we can combine this water content with visual estimates of the total volume of martian igneous materials [8] to obtain an outgassed water depth of approximately 200 m. This water estimate also rests on the assumption that intrusions in the subsurface effectively degassed, and may serve as a refined lower limit for martian water outgassed since 3.9 b.y. ago. Geological evidence for greater amounts of surface water [3,9] would then imply significant outgassing before formation of a stable crust or heterogeneous accretion of a veneer of cometary matter.

These data also have implications for the water content of the martian interior. The 36 ppm water for the mantle estimated from the geochemical model of [2] seems too low because it would imply an implausibly small degree of melting (0.2%, if water is perfectly incompatible and no subsequent fractionation of the magma occurred) to produce SNC magmas. For a more reasonable 10% melting, a magma with 1.4% water requires a source region containing 1400 ppm water. This value is too high because SNC meteorites clearly formed from fractionated magmas, but it does suggest that the martian mantle is significantly wetter than has been inferred from some past geochemical and geologic models [9], perhaps having a similar water content to the terrestrial mantle. This suggestion is not really surprising considering the enrichment of other volatiles in Mars [2], but it may require that water reacted incompletely with Fe during core formation. The conclusion that the martian mantle may have been quite wet (even as late as 1.3 b.y. ago, the age of SNC meteorites) is important in assessing its capacity to outgas significant amounts of water prior to 3.9 b.y. ago.

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THE YOUNG SUN AND PHOTOCHEMISTRY OF THE PRIMITIVE MARTIAN ATMOSPHERE. H. Nair, M. F. Gerstell, and Y. L. Yung, Division of Geological and Planetary Sciences 170-25, California Institute of Technology, Pasadena CA 91125, USA.

Many investigators of the early martian climate have suggested that a dense CO₂ atmosphere was present in order to warm the surface above the melting point of water [e.g., 1]. However, Kasting [2] recently pointed out that previous thermal models of the primitive martian atmosphere had not considered the condensation of CO₂. When this effect was incorporated, Kasting found that a purely CO₂ greenhouse is an inadequate mechanism to warm the surface.

Observations of young stars, both premain sequence and early main sequence, indicate that their ultraviolet luminosities are much higher than the present ultraviolet output of the Sun. If such behavior is a normal phase of stellar evolution, we may expect that the Sun also had a substantially enhanced ultraviolet luminosity in its youth [3]. This has significant implications for the martian atmosphere as CO₂ is rapidly dissociated by ultraviolet photons shortward of 2000 Å.

Our photochemical model shows that under the influence of the early solar ultraviolet spectrum, an initial reservoir of CO₂ is decomposed to the extent that CO and O₂ become the major components of the atmosphere. Large ozone densities arise due to the increased O₂ abundance. Similar investigations for the early terrestrial atmosphere have also shown that CO, O₂, and O₃ concentrations are markedly enhanced when the model atmosphere is subjected to more intense ultraviolet fluxes [4,5].

We will investigate the climatology of an atmosphere where CO₂ is a minor constituent but still the key radiative species. The thermal structure of the dust-free atmosphere is estimated by employing a simple radiative-convective model similar to that used by Gierasch and Goody [6]. Radiative heating rates are computed using the Caltech/JPL one-dimensional photochemical model. Thermal cooling rates for a martian atmosphere containing O₂, O₃, H₂O, N₂O, CO, and CO₂ are calculated using FASCODE [7] and k-distribution methods [8]. The effects due to pressure broadening of the infrared absorption lines of CO₂ by CO and O₂, as well as the radiative effects of increased ozone densities in the atmosphere, will be examined.

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