RESEARCH ARTICLE

Climate of early Martian surface and loss of water – A review

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Abstract: Mars is one of the interesting planets for geoscientists to explore the presence of water on the surface of terrestrial planets. The age, geology and geomorphic processes of Mars are almost similar to Earth surface processes. However, earth has tremendous influence of tectonism. The Martian surface once it was flourishing with water flow and formations of fluvial channels, lakes, deltas and oceans. The planet Mars evolved through ages with different climatic conditions from warm wetter period to cold drier period. In the present paper, different climatic condition and the reasons for escape of water from surface of Mars are discussed.
Keywords: Climate Change; Loss of Water; Mars

1. Introduction

Similar to the Earth, channels and valleys were observed from several planetary surfaces. Long sinuous valleys observed in the surfaces of the Venus, Moon and Jupiter's moon Io were originated from lava. The branching valleys on the surface of the Saturn's moon Titan may be formed due to rivers of methane[4]. The dissected valley floor originated due to running water is noticed at many places on the Martian surface apart from the Earth in the Solar system. The branching valleys on Martian surface well preserved throughout ancient landscape resemble terrestrial river valleys. In addition to the valleys, the other landforms such as deltas, alluvial fans and lake beds are the indicators of erosion and depositional environment. There is no doubt that water was the erosive agent on the Martian surface. In the earlier Martian surface, the climatic conditions were very different from the present cold conditions; at least episodically water could flow across the surface[4]. The surface of Mars preserved record of warmer and wetter conditions in which running water played an important role in shaping the landscape. Several evidences are supporting for consensus picture of the phenomenological history of water on early Mars[2]. The present article discusses the climatic conditions in different Martian time periods and reviews the reasons for loss of water on Mars.

2. Martian Geological History

The Martian age is closely matching with the planet Earth around 4.5 billion years. The Martian time scale was estimated quite different from Earth geological time scale. The measurement of density of impact craters is the main criteria to estimate the absolute age of the Mars (**Figure 1**). The impact crater density studies on the Martian surface have provided three broad periods of time scale in the planet's geological history. The broad geological periods were named after the places on Mars that have large-scale surface features, such as large craters or widespread lava flows. The absolute age indicated that only approximate time period like oldest to youngest. The Martian time periods are given as follow[10].

Pre-Noachian represents the interval from accretion and differentiation of the planet about 4.5 billion years ago

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(Gya) to the formation of the Hellas impact basin, between 4.1 and 3.8 Gya. Most of the geologic record of this interval has been erased by subsequent erosion and high impact rates. The crustal dichotomy is thought to have formed during this time.

Noachian Period is named after Noachis Terra. This period covered the formation of the oldest surfaces of Mars in between 4.1 and about 3.7 billion years ago (Gya). Noachian surfaces are covered by numerous large impact craters. It is understand that the Tharsis bulge is evolved during this period. Moreover, it is associated with extensive erosion, formation of river valley networks, large lakes and oceans produced by liquid water.

Hesperian Period is named after Hesperia Planum, which is fall in the range of 3.7 to 3.0 Gya. This period marked by the formation of extensive lava plains. The formation of Olympus Mons probably began during this period. Catastrophic releases of water carved extensive outflow channels around Chryse Planitia and elsewhere. Ephemeral lakes or seas formed in the northern lowlands.

Amazonian Period is named after Amazonis Planitia. The Amazonian period fall 3.0 Gya to present. This period have few meteorite impact craters but are otherwise quite varied. Lava flows, glacial/periglacial activity, and minor release of liquid water continued during this period. The age of the Hesperian/Amazonian boundary is uncertain and could range anywhere from 3.0 to 1.5 Gya. The Hesperian is a transitional period between the end of heavy bombardment and the cold, dry Martian climate noticed in the present day.

3. Climatic conditions and water loss

The fate of water which was present on early Mars remains mysterious. There are several theories proposed for disappearance of water on Martian surface from Naochian to Amazonian time period. The escape of water on Martian surface closely associated with changes in climatic condition during these periods. The warmer and wetter condition prevailed during Noachian time period. Number of studies were suggested precipitation induced valley networks on Martian surface[7,1,3]. The catastrophic outflow channels were dominated during Hesperian time period. Such outflow channels were originated due to outburst of pressurized cryosphere[15,9,6]. Hesperian to Amazonian is transitional period, during which the climatic conditions were changed into cold and dry conditions. During this period the fluvial activities was ceased and loss of surface water noticed on the surface of the Mars.

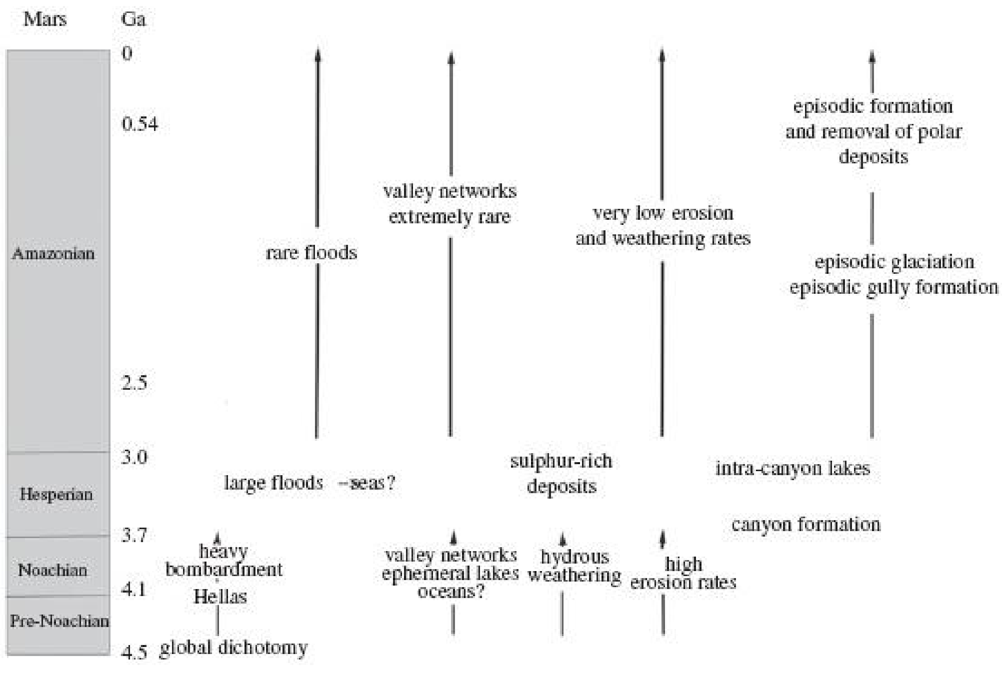

Figure 1. Geological Time scale on Mars. The timing water related activity on Mars indicates major changes from the late Noachian through the Hesperian as Mars changed from an era of high erosion rates, widespread fluvial activity[4].

There are several theories discussed on escape of water from Martian surface such as impact of solar wind erosion, solar wind ionosphere interactions and changes in the Martian rotational axis obliquity.

4. Impact of solar wind erosion on Martian Atmosphere

Hydrological models were adopted to investigate the temporal evolution of Martian groundwater hydrology during Noachian and early Hesperian epochs[2]. The results suggested that the more active hydrological cycle prevalent during in the Noachian period due to the result of a greater total inventory, causing a saturated near-surface and high precipitation rates. The late Noachian hydrologic, climatic and geochemical transition can be explained by a fundamental shift in the hydrological regime driven by a net loss of water due to impact and solar wind erosion of the atmosphere. The combined effect of all mechanisms is more than sufficient for the loss of 60m Global Equivalent Layer (GEL) of water. This huge volume of storage of water is necessary to induce the wet and arid hydrological transition in the late Noachian[5]. The net loss of water from Mars over the time is supported by both geomorphic evidence for a wetter surface on early Mars and isotopic evidence for water loss from the atmosphere. The observed geochemical evidence supported for climatic evolution of Mars in terms of a wet to arid hydrological transition in the late Noachian driven by net loss of water[5].

5. Solar wind-ionosphere interactions

Similar to Earth, Mars has been endowed with large quantity of water during accretion, equivalent to the content of several terrestrial oceans, corresponding to a several 10 km thick of GEL[16]. The present inventory of observable water on Mars is quite smaller, although not precisely known. The total water content of the two perennial polar caps corresponds to a GEL of 16m[17] propose a simple model based on serpentinization, a hydrothermal alteration process which may produce magnetite and store water. The model invokes serpentinization during 500 to 800 Myr, while a dynamo is active, which may have continued after the formation of the crustal dichotomy. The present magnetic field measured by Mars Global Surveyor in the southern hemisphere is consistent with a ~500m thick of GEL of water trapped in serpentine. Serpentinization results in the release of H2. The released H atoms are lost to space through thermal escape, increasing the D/H ratio in water reservoirs exchanging with atmosphere. The value of the D/H ratio in the present atmosphere (~5) is also consistent with the serpentinization of a ~500m thick water GEL. It is necessary to assess the role of non thermal escape in removing water from the planet. The solar wind-ionosphere interaction represented, that the contribution of oxygen escape to H isotopic fractionation is negligible. The results suggest that significant amounts of water (up to a ~330–1030m thick GEL) present at the surface during the Noachian, similar to the quantity inferred from the morphological analysis of valley networks, could be stored today in subsurface serpentine[7].

Mars' atmosphere was substantially more massive than it is today[13]. Prevailing formation theories of geologic features such as the valley networks necessitate the presence of flowing liquid water, which implies a warmer climate induced by a much thicker atmosphere. However, the mass of the early Martian atmosphere is not well constrained. Atmospheric mass loss predictions based on estimates of solar wind-induced ion sputtering and photochemical escape processes suggest that between 50% and 90% of Mars' atmosphere has been lost since the late Noachian (~3.8 Gya)[12].

6. Axis obliquity

The tilt of Mars rotational axis (25.2^0) is almost similar to the Earth's (23.5^0) rotational axis. Hence, Mars has seasons like the Earth. Mars orbit has, however, a significant eccentricity. This causes the seasons to have different lengths. At present, southern summer (158 days) is shorter and hotter than northern summer (183 days), but the length and intensity of the seasons change slowly with time as the various orbital and rotational parameters change. The astronomical parameter like the rotational axis or obliquity has a significant effect on the water cycle. The Earth's tilt undergoes little change but Mars' obliquity changes significantly. During the last 10 Myr, it has been as low as 15^0 and as high as 45^0. It is estimated that there is a 63% probability that the obliquity reached 60^0 in the last 1 Gyr[14]. At high obliquities when the summer pole faces the Sun, water ice sublimes from the poles and precipitates out at lower latitudes. Warming of ice on Sun-facing slopes during high obliquities could then provide melt water to cut small channels.

7. Hydrogen Escape from Mars

Sophisticated measurements made by a suite of instruments on the Mars Atmosphere and Volatile Evolution (MAVEN) spacecraft revealed that the ups and downs of hydrogen escape and that lead to water loss. The escape rate peaked up when Mars was at its closest point to the sun and dropped off when the planet was farthest from the sun. The rate of loss varied dramatically overall, with 10 times more hydrogen escaping at the maximum. MAVEN measurement produced unprecedented detail about hydrogen escape from the upper atmosphere of Mars, and this is crucial for extracting the total amount of water lost over billions of years[11].

Hydrogen in Mars upper atmosphere comes from water vapor in the lower atmosphere. Atmospheric water molecule broken apart by sunlight, releasing two hydrogen atoms from the oxygen atom that they had been bound to hydrogen. In addition, when Mars is closest to the sun, the atmosphere becomes turbulent, resulting in global dust storms and other activity. This could allow the water in the lower atmosphere to rise to very high altitudes, providing an intermittent source of hydrogen that can then escape[11] .

8. Conclusion

The relatively high erosion rates and presence of valley networks imply that during the Noachian, Mars was at least episodically warm and wet. In contrast, in the Hesperian, erosion rates are extremely low and valleys formation networks are rare. The characteristic feature of the Hesperian is the outflow channel, probably formed by eruptions of groundwater from below thick cryosphere. Mars has always maintained a cold, dry climate have provided much of the impetus for advocating valley network formation from hydrothermal circulation of groundwater[8].

Global-scale hydrological models used to explore what might have happened during this transitional period[2]. It suggest that during the Noachian, water was abundant, warm conditions prevailed and precipitation kept the near-surface close to saturation. However, loss of water as a result of large impacts and solar wind interactions resulted in a lowering of the groundwater table, precipitation became rarer but groundwater upwellings driven by topographic variations occurred locally. Their modelling demonstrates that the preferred locations for upwellings are those places where sulphates are found, such as Meridiani Planum. The upwellings presumably created local lakes, which, on evaporation, left behind the sulphate deposits that we observe. Further cooling and additional water losses led to more lowering of the global groundwater table and ultimately trapping of groundwater beneath a thick cryosphere.

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