Evolution of hydrological and glaciological activities on early Mars before late Tharsis formation

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The present Mars is cold and arid environment with little stable water on surface. However, the planetary environment on early Mars would have been quite different from that on the current Mars. Many observations have shown geological evidences for the past Martian environment, which should have been moderate enough to allow both the large-scale surface runoff and ice-sheet activities. These well-known geological evidences are called as “valley networks (VNs)”.The orientation of VNs in the boundary between the Late Noachian and Early Hesperian (3.85-3.6 Ga) should have been influenced by the Tharsis bulge, which is the largest volcanic plateau centered near the equator in the western hemisphere of Mars, but the formation epoch of the Tharsis bulge is still under debate [e.g. Phillips et al. 2001; Anderson et al. 2001].Recent work such as Bouley et al. [2016] suggested that the Tharsis rise might have been largely emplaced after the formation of the valley networks during the Noachian and Hesperian boundary. The location of the pole of Mars has shifted due to the great mass of volcanic material in the load of Tharsis. This phenomenon is called as “True Polar Wander”.

We have developed a paleo-Mars global climate model (PMGCM) assuming a $CO_2/H_2O/H_2$ atmosphere under the ‘Faint Young Sun’ condition (with a solar luminosity of ~75% of the current value) for surface pressures of between 0.5 and 2 bar, and obliquity between 20 and 60 degrees. The PMGCM has a hydrologic cycle module, which includes ocean thermodynamics and processes of water vapor advection, convection, condensation and precipitation, as well as the calculations of surface fluvial activities assuming the rainfall infiltration (base or direct runoff) and surface erosion and transportation associated with river channel activities [Kamada et al., 2020]. Also, here we implemented the pre-True Polar Wander topography [Bouley et al., 2016] to investigate the global water cycle of early Mars before late Tharsis formation. In addition, we newly developed a surface glaciological scheme and implemented into the PMGCM, which estimates the surface erosion and transportation associated with glacier activities from the accumulation, ablation, spatial velocity and temperature fields of the surface ice.

When we assumed an H_2-rich ancient Martian atmosphere and dense surface pressures (more than 1.5 bar), the PMGCM showed that the global mean annual temperature of early Mars would exceed the melting point of water in all obliquity cases, as shown in Kamada et al. [2020] which assumed the current Martian topography. However, with lower obliquities, precipitation was rather restricted in both polar regions, with less precipitation in the regions of observed VNs. In contrast, with higher obliquities, there were enough snow precipitation in southern low to middle latitudes, because larger obliquities brought larger seasonal variations in the middle to high latitudes and mixed atmosphere more complicatedly. Additionally, apparent ice sheets were formed alongside the VNs regions, which should help surface or basal glacial dynamical movements on early Mars.

Our fluvial diagnosis model in the PMGCM showed that there would have been almost no apparent precipitation-fed surface runoffs and accompanied sediment transport in southern low to middle latitudes, and fluvial activities would have been limited to seashore or lakeshore regions. Instead, in higher obliquity cases, glaciers with basal temperatures above the melting point of water would make basal sliding and bring lots of melt-water, which would feed surface runoff in Martian southern low to middle latitudes when we assumed the terrestrial-like geothermal heat flux (30 mW m^{-2}). Moreover, such surface runoff activities would erode soft deformable bed-rock, and form U-shaped and V-shaped valleys over the long time. Our simulation results would suggest that observed VNs would have formed by glacial activities rather than riverine activities.

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