R009-20
B 会場 ：9/27　 AM2 （10:45-12:30）
10:45～11:00

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Obliquity-Driven Early Mars Climate Evolution and Valley Network Formation

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We have studied the evolution of surface water environment on early Mars (Kamada et al. 2021 and 2022). Two opposing theories have been proposed to explain these fluvial landforms such as valley networks (VNs) formed 3.8 - 3.6 billion years ago. We evaluated two scenarios, "warm and wet" and "cold and icy". The "warm and wet" hypothesis proposes that Mars once had a thick atmosphere that caused a global warming enough for liquid water to exist. Conversely, the "cold and icy" hypothesis posits that Mars has always been as cold as it is today.

The long-term variation in obliquity can affect significant influence to both scenarios, as eccentricity and orbital inclination. Changes in obliquity shifted the distribution of solar insolation on early Mars, which critically affected climate dynamics and surface water cycling. Although the evolution of Martian obliquity is characterized by chaotic behaviour, making it difficult to accurately predict the obliquity of early Mars, it's statistically likely that the obliquity was about 37.62 degrees ± 13.82 degrees.

Here, we applied possible obliquity cycles to the GCM simulations with full couplings of atmosphere, hydrosphere, and cryosphere. The complicated obliquity variation of early Mars was simply assumed based on a Fourier series with a mean obliquity value of 40 degrees, and long-term oscillation periods of ~10^5 years. We assumed a $CO_2/H_2O/H_2$ mixed atmosphere with surface pressures of between 1 bar and 2 bar, H_2 mixing ratios of between 0% and 6%, and geothermal heat flux of 55 mW/m^2. We assumed the existence of a northern ocean and lakes in our model with the amount corresponding to a 500 m Global Equivalent Layer (GEL) in the initial state and implemented a pre-True Polar Wander topography to investigate the global water cycle of early Mars before the late Tharsis formation.

We found that long-term variations in the obliquity of Mars have significantly affected the thermal structure of the atmosphere, thereby influencing its climate and the formation of VNs. When the H_2 mixing ratio was lower, periods of higher obliquity led to the formation of ice sheets at lower latitudes. Conversely, during periods of lower obliquity, equatorial ice sheets would melt, and the meltwater would flow into rivers. This pattern of freeze-thaw cycles would have created a dynamic water cycle on early Mars, with changing obliquity driving repeated cycles of ice accumulation and melting, potentially contributing to the formation of the VNs. On the other hand, a higher H_2 mixing ratio in the atmosphere led to a warm, precipitation-dominated climate. The resulting rainfall would have created river systems that formed near the equator during periods of higher obliquity and at higher latitudes during periods of lower obliquity. This constant movement of water would have been a significant driver of erosion, contributing to the formation and development of the VNs. Furthermore, this study has shown that about 50% of the VNs could be attributed to snowmelt streams at a 3% H_2 mixing ratio, while about 70% of the VNs could be explained by rain-fed rivers at a 6% H_2 mixing ratio. These proportions are higher than the estimates made assuming fixed obliquity, indicating that long-term obliquity variations play a significant role in the formation of VNs.