Volatile cycle across the Earth-like planet –Impact to plate tectonics and climate

*Takashi Nakagawa[1]

1. Department of Earth Sciences, The University of Hong Kong

I will present a reasonable scenario for the long-term evolution of the surface environment associated with the plate tectonics as a result of the dynamics of the deep planetary interior. The plate tectonics is believed to continue over a few billion years, driven by the mantle convection. Still, it is not quite clear when the plate tectonics is initiated, which is suggested from the various geological constraints (e.g., review article by Korenaga, 2013). The plate tectonics also controls the volatile cycle (water/carbon) across the deep interior (e.g., Nakagawa and Nakakuki, 2019). As a result, the plate tectonics also affects the long-term climate evolution because the volcanic outgassing process may change the chemical composition and optical property of the atmosphere-ocean system (e.g., Kadoya and Tajika, 2019). To find out the reasonable scenario of the evolution of the surface environment, I develop a coupled model of the thermal evolution of the rocky planet and energy balance climate evolution. With a developed model, I explore how the onset timing of the plate tectonics controls the volatile cycling across the deep interior and its impact on climate evolution.

The main findings are as follows: 1. The plate tectonics is likely to be initiated around 1.5 to 3 Ga to explain the reasonable scenario of the water cycling that may reveal the present-day volume of the surface seawater. The total amount of water in the planetary system would be around ten times as much as the present-day volume of the surface seawater, and the silicate mantle may have a few Ocean mass initially. However, the expected subduction flux may be an order of magnitude larger than that constrained by the water solubility experiments (Iwamori, 2007) and sea-level change associated with the tectonic plate (Karlson et al., 2019). 2. For the climate evolution, the stable climate so that may allow the planet to have the liquid water is found when the plate tectonics is successfully operated, but the snowball limit cycle solution is found when the plate tectonics is not operated (Stagnant lid planet). As a consequence, the volcanic activities (i.e., the volcanic outgassing) associated with the plate tectonics is essential to keep the planet warm so that the liquid water may be found, that is, the planetary surface is a habitable condition.

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