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Effects of Water Amount on the Surface Environment of Terrestrial Planets: High Pressure Ice and Carbon Cycle

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Terrestrial planets with several wt% of H_2O are theoretically predicted in habitable zone, where planet can sustain liquid water on its surface [Raymond et al., 2004]. Terrestrial planets in extrasolar planetary system are expected to have a large variety of water amount. In this study, we define two planetary modes; one is a planet that covered with ocean entirely (ocean planet) and the other is a planet that has oceans and lands (partial ocean planet), like Earth. We consider surface environment of terrestrial planets with various water amount focusing on CO_2, which is an important determining factor of the surface environment.

Carbon cycle stabilizes the surface temperature of the Earth. Weathering processes are the continental weathering and the seafloor weathering which occurs in oceanic crusts. On the Earth, the amount of atmospheric CO_2 (P_{CO2}) is maintained at low level because of efficient continental weathering [Walker et al., 1981]. However, the efficiency of the continental weathering depends on the land fraction [Tajika and Matsui, 1993]. On the other hand, the seafloor weathering is poorly constrained; several models that depend on pH [Caldeira, 1995] or hydrothermal circulation [Sleep and Zahnle, 2001] or seafloor temperature [Brady and Gislason, 1997] have been proposed.

On the ocean planets, seafloor weathering is important because the continental weathering dose not work. The increase of water amount has two effects in P_{CO2}; one is the enhancement of the seafloor weathering due to temperature rise and the other is the increase of the degassing rate of CO_2, caused by the increase of the total amount of CO_2. P_{CO2} in the ocean planets is determined by the competition between both processes. In addition, a planet with large water amount may form high-pressure (HP) ice on the seafloor [Leger et al., 2004]. In such a case, any weathering processes will not work and P_{CO2} will be extremely high. On the other hand, high surface temperature may prevent it.

In this study, we focus on the carbon cycle and HP ice and aim to clarify the relationship between the water amount on surface P_{CO2}. In particular, we discuss the difference in P_{CO2} between partial ocean and ocean planets.

We built a carbon cycle model by adding the seafloor weathering to the Earth's carbon cycle model by Tajika and Matsui [1992]. Degassing rate is depended on the total amount of carbon. We assume carbon is also supplied with water. We discuss the dependence on the land fraction in partial ocean planets or the water amount in ocean planets. We examined the P_{CO2} in equilibrium state in which degassing and regassing are balanced. We also consider effect of HP ice on carbon cycle.

On the partial ocean planets, we found that continental weathering is the dominant weathering process when the land fraction is 0.1 or more. Even if the degassing rate is five times as large as the current value of the Earth, P_{CO2} on the partial ocean planets is lower than $30P^*$ (P^* is atmospheric CO_2 level in the current Earth). On ocean planets, we found that the increase of degassing rate surpasses the enhancement of the seafloor weathering efficiency upon the increase of water amount. Even if seafloor weathering works most efficiently, P_{CO2} increases with increase of water amount and P_{CO2} becomes about 1000 P^*. In the case that HP ice is formed on the seafloor, a cycle of HP ice formation (the disappearance of the seafloor weathering) and disappearance (the resume of the seafloor weathering) is expected to occur. In cases that water amount is larger than 120 Earth's ocean mass, HP ice is formed and P_{CO2} is expected to rapidly increase with increase of water amount. Our results suggest that P_{CO2} on an ocean planet is significantly different from that of partial ocean planets, on which the continental weathering works efficiently. Our results also suggest that the process of determining P_{CO2} changes with the water amount, and surface environment varies greatly with it.

Keywords: carbon cycle, seafloor weathering, high-pressure ice, carbon dioxide, terrestrial planet, extrasolar planet