Erosion and Replenishment of Atmosphere and Ocean on Earth during Heavy Bombardment

*Yui Kozasa[1], Hidenori Genda[2], Hiroyuki Kurokawa[2], Shigeru Ida[1,2]

1.Department of Earth and Planetary Sciences, Tokyo Institute of Technology, 2.Earth-Life Science Institute, Tokyo Institute of Technology

After the Earth’s formation, Earth experienced a lot of collisions of small objects such as asteroids and comets. These impacts, the so-called heavy bombardment, should have a great influence on the Earth’s atmosphere. For example, the atmosphere can be eroded by the impact and also can be replenished by the volatile in the asteroid bodies. At the same time, Earth’s ocean might exist in the early stage (Wilde et al., 2001). Therefore the ocean would also experience the erosion and replenishment by these impacts. The purpose of this work is to investigate the effects of these impacts on atmosphere and ocean throughout this heavy bombardment event.
There are several previous papers on atmospheric erosion caused by just one impact (Svetsov 2000, 2007; Shuvalov 2009, 2014). In these papers, the eroded atmosphere mass by a single impact was analytically and/or numerically investigated, and its dependence to impact parameters (e.g. impactor diameter, impact velocity, atmosphere pressure,) is formulated as the equations with several parameter sets. For a long-term evolution, de Niem et al. (2012) focused on the atmosphere erosion and replenishment during LHB (late heavy bombardment), which is thought to happen during 3.8 Ga. During LHB, the total impactor mass is less than 0.01% of Earth mass. By Monte Carlo approach, de Niem et al. (2012) found that the atmospheric pressure strongly increases both in Earth and Mars during LHB.
In our study, we also use a Monte Carlo calculation of atmosphere and ocean simultaneously. To consider the whole term of heavy bombardment, we computed until the total impactor mass reaches 1% of the Earth mass. We also used several atmospheric erosion models to study how the mass change behavior depends on the model. To regard the ocean mass evolution, the erosion mass of ocean is taken from the target loss mass in Svetsov (2009), which was calculated simultaneously with the atmospheric erosion. We applied the water density as the target density. For Monte Carlo calculation, we used the current size distribution of the Main belt asteroids. Impact velocity distribution is taken from a numerical model, and we used three parameters for the volatile and water content of asteroids.
As a result, the atmosphere is extensively eroded in the model of Svetsov (2000, 2007), and the atmospheric pressure converges to a certain value, which depends on the concentration of volatile amount in impactors, regardless of the pre-existing atmospheric pressure. However, the erosion of the atmosphere is minor in the model of Shuvalov (2014). The behavior of the atmospheric mass strongly depends on the erosion models used in the computation. The ocean erosion did not depend on the atmosphere in spite of the impact energy dependency to atmosphere pressure in Svetsov (2009). The erosion of the ocean is moderate than that of atmosphere. Therefore, the final ocean depth depend on the pre-existing ocean mass and water content of the impactor.
From the results of Svetsov (2000, 2007) model, the combination of extensive erosion of atmosphere and moderate erosion of ocean would explain the difference of H/C ratio between carbonaceous chondrites and the Earth’s hydrosphere or bulk silicate Earth (Hirschmann & Dasgupta 2009). Also, the erosion of pre-existing atmosphere is considerable. It depends on the parameter, but the remaining ratio would be only 0.0001~10%. For this, the heavy bombardment can erode massive H-He protoatmsophere, even if the Earth got the surrounding nebular gas (Ikoma & Genda 2006). The erosion of pre-existing ocean might explain the problem that the Earth is depleted in halogen elements such as Cl, Br, and I (Sharp & Draper 2013), by thinking the elements being dissolved into

pre-existing ocean. However, in this study the ocean erosion was not effective. The erosion of pre-existing ocean is estimated about 20%, and it is not enough to explain the whole depletion of Halogen.

Keywords: heavy bombardment, atmospheric erosion, oceanic erosion