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Semi-analytical estimation of the ocean tide on the early Earth

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We have investigated the ocean tide on the early Earth using semi-analytical method. The tidal force of the Moon exerted on the Earth is considered to have been an order of magnitude larger at the early time than at present, since the Earth-Moon distance was smaller (Goldreich, 1966). Abe et al (1997) and Abe and Ooe (2001) performed numerical simulation of the early Earth's ocean tide, estimating amplitudes of $\sim$0.1 m for three uniform depths of the ocean (1000 m, 2600 m and 4200 m). They pointed out that such small amplitudes are caused by the difference of periods between the early Earth's rotation and the free oscillation of the ocean. This result is important to study the ancient surface environment on the Earth. However the accurate ocean depth on the early Earth has not been established yet, although it could be several times as large as the current. The free oscillation of a thin layer of the ocean with a certain constant depth over the Earth can be described with Laplace's tidal equations. Longuet-Higgins (1968) numerically solved the Laplace's tidal equations, showing the relation between the eigenfrequency and Lamb's parameter. Based on his results, we have derived semi-analytical expression for the relationship between the ocean depth and the Earth's rotation period as possible resonance of various oscillation modes. If the Earth's angular velocity have changed in a range of 1 — 4.8 times relative to the present value, the ocean depth for the resonance is estimated to be 17 — 420 km for ${P_2}^2$ mode, 0.5 — 13 km for ${P_3}^1$ mode, and 18 — 480 km for ${P_3}^3$ mode. These results indicate that semidiurnal mode (${P_2}^2$) would have been very small as shown by previous studies, unless depth of the early ocean was more than six times greater than the current. However ${P_3}^1$ mode could be larger than ${P_2}^2$ mode due to resonance during the orbital evolution of the Moon, although the amplitude depends on attenuation due to eddy viscosity of the ocean.

Keywords: Ocean tide, Dynamical evolution of earth-moon system, primitive Earth, eigenfrequency, eigenfunction, tidal force