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著者(和文)	元山舞
Author(English)	Mai Motoyama
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Tidal response of higher eigenmode in the early Earth's ocean and its acceleration effect on the Moon's orbital evolution

Mai Motoyama

Doctoral Dissertation

Department of Earth and Planetary Sciences

Tokyo Institute of Technology

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Abstract

The ocean tide of the Earth has affected the evolution of the Moon's orbit as well as the solid Earth tide. Recent studies reveal that the ocean nearly covered the entire surface of the early Earth, the seawater volume was possibly larger than the present, and the tidal energy dissipation occurs mostly by the internal tide in the present deep ocean. Modeling the global ocean with the internal tide, we analyzed the tidal response for varied parameters of the ocean depth and drag coefficient of internal tide. In the analysis the numerical calculation was performed to depict qualitative time evolutions of the lunar orbit and the Earth's rotation rate. In order to understand the response mechanism in the early ocean, the tidal response is viewed from eigenmode oscillations, obtaining the approximated response function to be compared with the numerical calculation. Numerical and semi-analytical calculations show that the resonance of the eigenmode oscillation could occur in the global ocean of the early Earth. In the global ocean of temporally constant depth, such an eigenmode resonance occurs once or twice during the first 2.5 billion years, which is associated with step-like increases in the Moon's orbital radius and in the length of day (LOD) of the Earth. The step-like increase is sensitive to the internal tide coefficient which represents the roughness of the ocean bottom topography. The increase becomes steeper during short time span if the internal tide coefficient is smaller (i.e., the bottom topography is smoother). If the internal tide coefficient is larger (i.e., the bottom topography is rougher), total changes in the Moon's orbit and LOD around the resonance are more significant, although those increases are not so rapid. It is also recognized that total changes in the Moon's orbit and LOD during the first 2.5 billion years are larger if the global ocean is deeper. The global ocean model of decreasing depth, which is suggested by the recent studies, shows the eigenmode resonance occurs during the first 2.5 billion years similarly to the ocean model of temporally constant depth except for the case of the ocean formation

at 0.5 billion years after the Moon's formation. In subsequence, different behaviors of the tidal response appear when the ocean depth is changing. The global ocean sustains a tidal response near the resonance for a long time span. In some cases the same eigenmode resonance occurs twice at the end of decrease in the ocean depth. These tidal response yields continuous increases in the Moon's orbital radius and LOD. One of the characteristic features is that those total changes are similar regardless of the internal tide coefficient except for very small values, roughly satisfying an geological evidence of 2.5 Ga LOD. These calculation results in both global ocean models suggest that the eigenmode oscillation in the global ocean would play an important role in the early evolution of the Earth-Moon system. The model proposed in the present study is applicable for validation of possible tidal response in the early Martian ocean. As a preliminary study, we discuss free oscillations in the polar ocean in order to study possible tidal effects on the early Mars.