

A numerical study of a long-term dynamo evolution with special reference to the Moon

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(月のダイナモの長期的な進化に関する数値的研究)

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論文内容の要旨

The dynamo action is absent in the current Moon unlike the Earth, while it is believed that it worked in the Moon during 4.25 - 3.56 Ga and produced the surface magnetic field of $O(10) \mu T$ [Garrick-Bethell et al. 2009; Shea et al. 2012; Cournede et al. 2012; Suavet et al., 2013]. It is argued that this surface field intensity decreases by at least an order of magnitude by ~ 3.3 Ga after this epoch, and the decline is due to the termination of the dynamo or the transition to different dynamo mechanisms [Tikoo et al., 2014]. The lifetime of the ancient lunar dynamo, that is, long-lived or short-lived, is still in debate. Thermal history models suggest that a compositionally-driven dynamo is the most likely among various mechanisms of the ancient lunar dynamo ever proposed [e.g., Laneuville et al., 2014; Scheinberg et al., 2015]. It remains to be elucidated that how and when the ancient lunar dynamo was maintained, and how and when it terminated.

In order to understand these unresolved issues of the lunar dynamo, here we investigate the evolution of a long-term dynamo driven by compositional convection using numerical dynamo simulations. Since it is difficult to perform long-term numerical simulations on a geological time scale taking continuous inner core growth into account, we trace a lunar dynamo evolution in a discrete manner. Stepwise inner core growth is considered from $\chi = r_i/r_o = 0.1$ to 0.7

with an interval of 0.1, where r_i and r_o are the inner and the outer core radii. The Rayleigh number Ra is given to be consistent with the thermal history of the lunar core in each run. We focus on two dynamo evolution models at different values of the reference Rayleigh number.

We have found two mechanisms for the termination of the lunar dynamo: one is a sudden termination after sustenance of a strong dipolar dynamo, and the other is a termination after transition from a strong dipolar dynamo to a weak non-dipolar dynamo. We have also shown that convection in the tangent cylinder (an imaginary cylinder parallel to the spin axis and touched to the inner core at the equator) is strong for a dipolar dynamo, while it is weak for a non-dipolar dynamo in the case of $\chi = 0.5$.

According to the findings, we interpret the lunar paleointensity variation, in which a sudden

decline is observed at ca. 3.3 Ga. Such a decline could be explained either by a sudden termination of the lunar dynamo without a remarkable decrease in strength, or by a termination after a regime change of the lunar dynamo accompanying a detectable intensity drop. In either case, it is suggested that the paleointensity drop can be explained by a single dynamo mechanism of a long-lived, compositionally-driven dynamo.