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Viscosity structure dependence of large-scale polar wander rate of the Earth: A potential impact of a low-viscosity zone

HARADA, Yuji[1*] ; XIAO, Long[1]

[1]China University of Geosciences

In this study, we make an attempt to quantitatively evaluate an effect of presence of a low-viscosity layer inside the mantle of the Earth on the timescale of its polar wander. In particular, we perform model calculation of the viscoelastic Love number which characterizes the mechanical response of the interior of the Earth, and then investigate how the timescales and strengths of some relaxation modes in the Love number depend on the viscosity structure. I compare the structure dependence of these relaxation modes with that of the polar wander speed. For the sake of convenience of this numerical calculation, we simplify the multilayered structure of the Earth and assume its incompressibility to compute the relaxation modes.

In this calculation, we apply the quasi-fluid approximation which makes it possible to integrate the polar motion equation as a non-linear one. Its reason is because the linear approximation is not allowed for the large-scale polar wander as dealt with in here. Following the applicable condition of the quasi-fluid approximation, we consider load history which timescale is slower than the characteristic one of the viscoelastic deformation of the asthenosphere.

As a result of the calculation mentioned above, we find that the timescale of the polar wander depends almost only on the longest relaxation mode. It is a remarkable point here that, in fact, the ratio of the strength of this relaxation mode governing the polar wander to the total viscoelastic Love number is not so large. In other words, this fact means that the other modes which amplitudes of tidal deformation are more dominant have almost no effect with respect to the timescale of the polar wander. Apparently, this might seem to be a peculiar result.

The reason for this dependence is because the timescale only of the above-mentioned longest mode is much longer by a few orders of magnitude compared to those of the other modes. A mode with a longer time constant of viscous relaxation has an effect which stabilizes rotation axis in a longer term even if its strength is smaller. Oppositely, a mode with a shorter time constant contributes less to the long-term rotational stability because of its faster relaxation even if its strength is larger.

In the light of this result, we can tell that the structure dependence of the true polar wander rate also basically reflects just that of the relaxation time of this longest mode. Actually, even assuming the internal structure without the low-viscosity layer inside the mantle, we still find the influence of this mode to be prominent. Once we take the existence of the low-viscosity layer into account, lower its viscosity is, shorter the timescale of the longest mode is. It can be less than forty percent at shortest. However, if this viscosity becomes lower than a certain value, the timescale of this mode is asymptotic to a constant value. Such a trend results from that this layer behaves as a fluid rather than a viscoelastic body in a sufficiently long timescale due to its too low viscosity.

Here we conclude from the calculation result shown above that the presence of the low-viscosity layer inside the Earth generally shortens the timescale of the large-scale polar wander, and also that this impact mainly stems from the variation in the timescale of the longest relaxation mode. Indeed, the preexisting works have already discussed the dependence of the timescale of the large-scale polar wander on the internal structure of the Earth as well. However, they have not examined the impact of the low-viscosity layer therein, considering a more simplified viscosity structure. Also, they have not clearly stated that the major controlling factor on the true polar wander speed. On the contrary, this work estimates the timescale of the polar wander with explicitly including the impact of this layer, and shows the non-negligible effect of the heterogeneous viscosity structure on the large-scale polar wander.

Keywords: true polar wander, the Earth, mantle, low-viscosity layer, relaxation mode, time constant