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True polar wander of a quasi-fluid planet with a fossil shape: Effect of strain energy due to tidal deformation

Yuji Harada[1*]

[1]Shanghai Astronomical Observatory

Elastic strain energy stored in lithospheres of solid planets and satellites affect evolution of these rotation axes, especially true polar wander (hereafter "TPW"). If we suppose an ideal planet without a lithosphere which completely behave as fluid body, its figure always keeps hydrostatic state. In this case, its spin pole finally coincides with the principal axis of its moment of inertia tensor. It is because this state minimizes the rotational energy. On the other hand, in the case of more realistic planet with an elastic lithosphere, one previous research pointed out a possibility that its spin axis and principal axis are not coincident each other. This remarkable argument is concluded solely because of the fact that huge amount of strain energy is accumulated in a lithosphere due to tidal stress by long-term polar motion. Thus, a pole position is settled at the different place in order that this position minimizes total energy including not only rotational energy but also strain energy.

The content treated in the previous study shown above, however, is just a difference of paleo-pole positions before and after TPW. In other words, the previous study did not handle secular time variation of a spin pole location from an initial state to a final state.

In the present study, therefore, temporal variation of a paleo-pole position due to TPW is formulated and calculated based on the strain energy as mentioned above in the previous study. Especially, the quasi-fluid approximation is suitable to deal with large-scale and long-term variation of a paleo-pole position. Thus, an orientation of a paleo-rotation axis in each time step is estimated in here by following the conventional formulation with the quasi-fluid approximation for TPW, and simultaneously by taking total energy minimization into account. In practice, this procedure is physically same as to incorporate elastic torque due to tidal deformation of a lithosphere into the Liouville equation including the quasi-fluid approximation. In this study, like the previous one, only one symmetric surface load is regarded as a driving force of TPW for the sake of convenience. In this calculation, the variable parameters are defined as follows: a location of emplacement, duration of formation, and maximum of intensity of a load. The result with strain energy is compared with that without strain energy.

As a result, the case with the strain energy indicates different characteristics from that without the strain energy in the following points. First, the paleo-poles under the steady states are different each other even in the cases for same parameters. These results have no contradiction to the previous results concerning just the final condition. Second, also in the cases for same parameters, time scales when the paleo-poles reach the static limits are different. These results demonstrate the fact that strain energy within a lithosphere effectively weakens influence of a load on TPW. Although such influence has already been pointed out by the previous results just in the case of the steady state, the present results further revealed similar effect also on a characteristic time scale of TPW. Strictly speaking, however, it is impossible to estimate this exact time scale only by reducing an effective size of a load. This is because secular variation in strain energy induced by TPW inevitably occurs after variation of a load itself as driving force. This delay results from visco-elastic readjustment of centrifugal bulge in response to long-term polar motion.

In conclusion, the present results imply that strain energy is not necessarily negligible in terms of physical interpretation for realistic TPW of the planets and satellites in the solar system, especially characteristic time scales and time variation between the initial and final state of the spin axis.

Keywords: fossil shape, quasi-fluid approximation, polar wander, elastic lithosphere, tidal deformation, strain energy