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Influence of Earth rotation on continental motions

V.A. Zemtsov *

Russian Academy of Sciences, Karelian Research Centre, Institute of Geology, Pushkinskaya Street, 11, Petrozavodsk, 185910, Russian Federation

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Abstract

The paper addresses a question concerning the main driving forces of the rotational drift of continents. These forces are interpreted to produce 3rd hierarchical level tectono-dynamic structures in the Earth. The causative force is a torque friction force moment which arises spontaneously as a result of the Earth's rotation. Angular rotation velocity is the main characteristic of the rotational motion of a solid body, and in plate tectonics it is estimated with low accuracy from the assumption that every continent is a rigid slab carried by circulation of the asthenosphere. Astronomical observations and calculations of the instantaneous angular rotation velocities of the domains of modern Eurasia disprove this concept and permit a better understanding of the structural hierarchy of the Earth and interaction between the continental lithosphere and the lower mantle. This enables new models of rotation of a continent to be developed, to determine the force moment which makes it rotate. The force moment is shown to have a value depending primarily on the angular rotation velocity of the Earth's mantle and the dimensions and geographic position of the continent. Based on palaeomagnetic and geological data, similar patterns of rotational tectonics of the continental lithosphere may be recognized at earlier stages in the Earth's history.

Keywords: Continental rotation; Angular rotation velocity; Plate motions; Continental drift; Palaeomagnetism

1. Introduction

In 1856 the Austrian astronomer K. Schreder assumed that the angular rotation velocity of the Earth's crust differs from that of the core due to the physical difference between the crust and the much more ductile layers beneath. His assumption was supported by the planetary magnetic field generation, a theory for which was first developed by Joseph Larmor (1919), and from the characteristic genetic feature of planets and stars with their own magnetic fields that operate when the inner core rotates more rapidly than the mantle (Braginsky and Roberts, 1995; Starchenko, 2000). On the Earth this is supported by seismological observations (Song and Richards, 1996; Vinnik et al., 1998). The effects of the rotation of the whole Earth and lithosphere are generally not taken into account in geotectonics and important geodynamic processes have not been discussed in this context. In plate tectonics the movement velocities of lithospheric plates do not correlate with their dimensions (Zharkov, 1983). Hence, the interface between oceanic lithosphere and the asthenosphere is not one of decisive interactions, and this is probably the reason why the problem of the forces that drive the plates is still not fully clarified. One of the constituents of rotational forces, a "poloidal" component, was interpreted by Wegener in 1929 (Wegener, 1984) as a major force of continental "floating", but this was subsequently proved to be small and has not been considered in more recent publications on geodynamics.

The first attempt to evaluate effects of the transfer of atmosphere–lithosphere interactions to the Earth's interior was made by Stovas (1975) who unfortunately failed to develop his theoretical concepts. Tyapkin (1998) and Storetvedt (1997, 2005) distinguished planetary fracturing in the Earth's crust and related its origin to variations in the angular velocity and position of the Earth's relative rotational axis and tectonomagmatic events in the crust during the Earth's early geological evolution. Developing a new hypothesis of global wrench tectonics, Storetvedt (2005) noted that "degassing-driven heat and melt production in the topmost mantle has gradually built up an irregular low-velocity asthenosphere. In consequence, the overlying more brittle lithosphere has been prone to detach from the deeper parts, whereby events of latitude-dependent wrench deformation have ensued". However, it may be argued that

* Fax: +7 8142 780602.
E-mail address: zemtsov@krc.karelia.ru.

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circumferential stresses arising in the crust in this case are small. Therefore, the proposition that lithospheric rotations result only from changes in the rotation mode of the Earth may not be entirely convincing. Thus, modern astronomical, geodetic and geophysical observations, and particularly seismology and magnetic studies, have been advanced to provide decisive arguments in favour of mobile continents, possibly enabling them to drift for a long geological time even if the Earth rotates in a steady-state mode.

However, the contribution of rotational effects to continental motions remains an enigma. Developing rotational ideas, Vikulin (2002) deduced that "seismotectonic torsional waves" in the north-western part of the Pacific plate resulted from shear strains and plate rotation. He concluded that "rotational movements of lithospheric plates, which takes place because the Earth itself rotates, must give rise to stress fields formed around them that are calculated by solving a problem of a plate turning on the surface of a rotating ball". This is a problem in non-linear solid mechanics that should be solved for any continent as a third-rank tectono-dynamic terrestrial structure in the inertial coordinate system, but in any case, if it rotates, there is a moment of forces that retard its motions. The present paper is an attempt to solve the problem qualitatively.

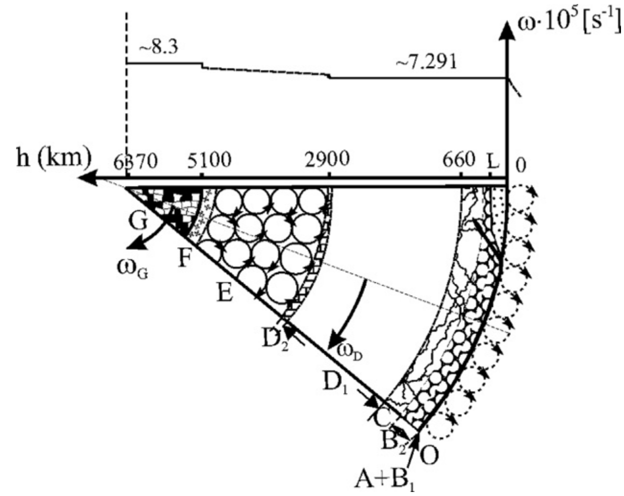

Fig. 1. Cross-section through the Earth's layers and divisions based on geophysical data (using the publications of Dziewonski and Anderson, 1981; Zharkov, 1983; Starchenko, 2000; Dobretsov et al., 2001; Zemtsov, 2005b), in the equatorial plane on the South Pole side and a plot of variations in their angular rotation velocities ω with depth h: A = the Earth's crust; B_1 = subcrustal mantle; A + B_1 = continental (dots) and oceanic (black symbols) lithosphere; L = Lehmann's boundary (220 km); B_2 = upper asthenosphere (small circles); C = lower asthenosphere (crack); B + C = upper mantle; D_1 = lower mantle (white); D_2 (CMB) = transition zone (bricks); E = outer core (whirls); F (ICB) = transition zone (small crosses); G = inner core (stone wall); O = outer layer.

2. Rotation of the Earth and its modern structure

Proper rotation is one of the main physical properties of the Earth. Whilst its mass does not seem to have changed significantly during the entire span of geological history, the shape and rotational mode of the ancient Earth seem to have differed substantially from those of the present day. The main change was probably connected with the gravitational trapping of the Moon ca. 3.9 Ga ago (Malcuit et al., 1992) as a result of which the Earth–Moon system was heated by virtue of energy dissipation when huge subtidal waves with amplitudes of more than 10 km were likely generated. It can be reasonably assumed however, that part of this energy was responsible for a mutual acceleration of the rotation velocity of these bodies and, consequently, for the general deformation of the Earth and mass transfer within it. If the entire Earth is understood as a uniform body of the first hierarchical level, then its rotational mode can be characterized by some average angular rotation velocity. On the second discrete level, the question "what is the present angular rotation velocity of the Earth?" becomes physically incorrect as there are at least several angular velocities applicable to the different Earth shells (Fig. 1).

In geodesy and astronomy, the angular rotation velocity of the Earth is understood as one full revolution of the Greenwich meridian and its average angular velocity value (ω), if the period of rotation of the planet T=86164.09891 [s] is measured in solar seconds (Lambert, 1961), is (Eq. (1)):

$$\omega = 2\pi/T \approx 7.29115 \cdot 10^{-5}[\mathrm{s}^{-1}]. \qquad (1)$$

Obviously, determination of the geographic longitude of a point on the Earth's surface as an angle counted from the zero meridian is connected with the problem of calculating super-precise time and its recording for further calculations. Wegener (1984) clearly appreciated the difficulty of determining longitudes and wrote in 1929: "I do not doubt that in the not so remote future the movement of North America relative to Europe will be measured precisely". During the first half of the 20th century radio and long-term observations were unable to estimate the longitudes of two fixed points on different continents to an accuracy of better than ±16 m (Shcheglov, 1974).

The modern flow structure within the Earth was described by Zharkov (1983) who wrote: "In the Earth's core there is relative longitudinal flow of liquid at a velocity of ~ 1 mm/s. This velocity is a million times greater than the velocities of tectonic movements of the lithosphere". It is probably in the liquid and electroconductive layer of the outer core that the planetary magnetic field is generated. The linear movement velocities of the Earth's Outer Core (V) at the Core–Mantle Boundary (CMB) and Inner Core Boundary (ICB) (see Fig. 1) can be estimated more accurately from the equations of magnetic hydrodynamics in an Archimedean heat layer of known thickness (Eq. (2)):

$$\Delta r = L - r = 2.2 \cdot 10^{6}[\mathrm{m}], \qquad (2)$$

where L is the radius of the liquid core and r is the radius of the solid core.

Considering these velocities as analogous to heated wind, Starchenko (2000) obtained Eq. (3) which can be used to estimate V at the CMB boundary:

$$V = (Ra)^{2/3}\frac{k}{L}, \qquad (3)$$