

Influence of Earth rotation on continental motions

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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.

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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

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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.

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)):

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

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-

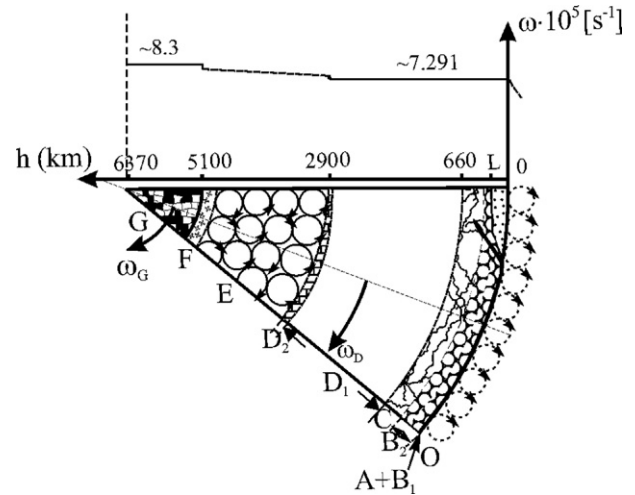


Fig. 1. Cross-section through the Earth’s layers and divisions based on geophysical data (using the publications of [Dziewonski and Anderson, 1981](#); [Zharkov, 1983](#); [Starchenko, 2000](#); [Dobretsov et al., 2001](#); [Zemtsov, 2005b](#)), in the equatorial plane on the South Pole side and a plot of variations in their angular rotation velocities ω with depth h : A = the Earth’s crust; B₁ = subcrustal mantle; A+B₁ = continental (dots) and oceanic (black symbols) lithosphere; L = Lehmann’s boundary (220 km); B₂ = upper asthenosphere (small circles); C = lower asthenosphere (crack); B+C = upper mantle; D₁ = lower mantle (white); D₂ (CMB) = transition zone (bricks); E = outer core (whirls); F (ICB) = transition zone (small crosses); G = inner core (stone wall); O = outer layer.

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)):

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

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:

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

where Ra is the Rayleigh number in the outer core, and k ($=10^{-5} \div 10^{-6} \text{ [m}^2\text{s}^{-1}\text{]})$ is the diffusion coefficient within it.

The Earth is the only planet where the heat flow is known and where the Rayleigh number in the liquid core can be estimated from the Bussinesque approximation — $Ra \approx 10^{16} \div 10^{18}$ (Starchenko, 2000; Dobretsov et al., 2001). Putting this value into Eq. (3), we obtain $V \approx 4 \text{ mm/s}$, which is four times faster than the above estimate obtained by Zharkov. If liquid flow on the surface of the outer core is laminar, then the core will slip relative to the mantle with a rapid increase in angular velocity (Eq. (4)):

$$\omega = V/r \approx 1 \cdot 10^{-9} [\text{s}^{-1}], \quad (4)$$

where r is the radius of the CMB boundary.

In fact, a poloidal (magnetic) α -field has a complex structure and is formed by viscous forces of internal friction between unclosed small-celled, convective whirl “cylinders” (Parkinson, 1983). In that case, ω characterizes an abstract ω -field or thin structure of the planetary field, and the proper angular velocities of rotation of the “cylinders” are much higher than the rotation velocity of the solid core. One should not directly use Eq. (3) to calculate the velocity of flow at the ICB boundary as in this case V varies with depth in a non-linear fashion. However, the positive velocity of flow in the liquid core relative to the lower mantle shows unambiguously that the velocity of rotation of the inner core is higher than that of the Earth’s mantle (ω_D). Calculations made by different geomagnetists show that the increase of angular velocity can be as great as $1 \cdot 10^{-5} \text{ s}^{-1}$ by virtue of the rapidly rotating core (Glatzmaier and Roberts, 1995; Starchenko, 2000).

The differential angular rotation velocity of the solid core does not need to be very high to generate a planetary magnetic field. The outer core can be assumed to be more viscous, i.e. it has the smaller Rayleigh number and diffusion coefficient and a turbulent mode of convection also persists within it. Clearly, at the ICB boundary the outer core also slips relative to the inner core and the linear velocity of flow will be slightly higher here than at the CMB boundary (Starchenko, 2000). However, even if the flow velocity is assumed to be the same at $\sim 4 \text{ mm/s}$, then, according to Eq. (4), angular velocities at the ICB boundary will rapidly increase by about three times because the radius of the inner core is smaller. This estimate is qualitatively supported by some 20-years of seismological observations of the travel times of P-waves as they pass through the inner core. These observations also lead to the conclusion that the core of the Earth rotates differentially relative to the lower mantle at a higher angular velocity of $1^\circ/\text{yr}$ (Song and Richards, 1996), although this value is only about 20% of the estimate obtained by geomagnetists. The values of the differential rotation of the inner core are the subject of active discussion and more convincing evidence comes from the adiabatic distribution of temperature, which can potentially help us to calculate the Rayleigh number with higher precision.

Strictly speaking, ω_D is an unknown value. The angular rotation velocity of the Greenwich meridian may differ slightly from ω_D because the asthenosphere has a degree of plasticity which can be recognised from the physical properties of peridotite

at Upper Mantle temperatures and from the propagation of seismic waves (Lithgow-Bertelloni and Richards, 1998; McNamara et al., 2001). However, its viscosity is much greater than that of the liquid layer E (Fig. 1). According to A.G. Kiryashkin, “the Rayleigh number at a depth of about 200 km, is practically constant at $Ra = 2.2 \cdot 10^{49}$ ” (Dobretsov et al., 2001). The linear equatorial velocity of the upper asthenosphere relative to the lithosphere, which is connected with the Earth’s rotation, can thus be calculated. Using Eq. (3) and assuming that the radius of the bottom of the lithosphere $L = 6.2 \cdot 10^6 \text{ m}$, we obtain $V \approx 5.8 \cdot 10^{-10} \text{ ms}^{-1} \approx 18 \text{ mm/yr}$. This qualitative estimate shows that the lithosphere could have slipped relative to the lower mantle if it had been integral instead of comprising an assemblage of plates. Thus, relative longitudinal eastward drift of the asthenosphere seems to occur, although it cannot have a strong influence on continental motions because continents as a rule move much faster, as will be shown below.

Thus, the geographic coordinates of any point on the Earth’s surface are not constant in time. As early as the 19th century, astronomers discovered Chandler oscillation, which was visible in the Northern Hemisphere by a small variation in the zenith angle of the Polar Star, and identified the secular movement of the Earth’s pole of rotation. The curve for the migration of the terrestrial pole (Fig. 2), called the polhode, gained practical importance for correcting coordinates. The position of the pole, the International Arbitrary Beginning (IAB), is recognized as the mean value of instant poles in 1903 since at that time the Chandler oscillation had its smallest recorded amplitude.

The analysis of the polhodes clearly shows that in the “Earth’s body” there are two more movements that differ in pattern and velocity and are related to the secular course of the

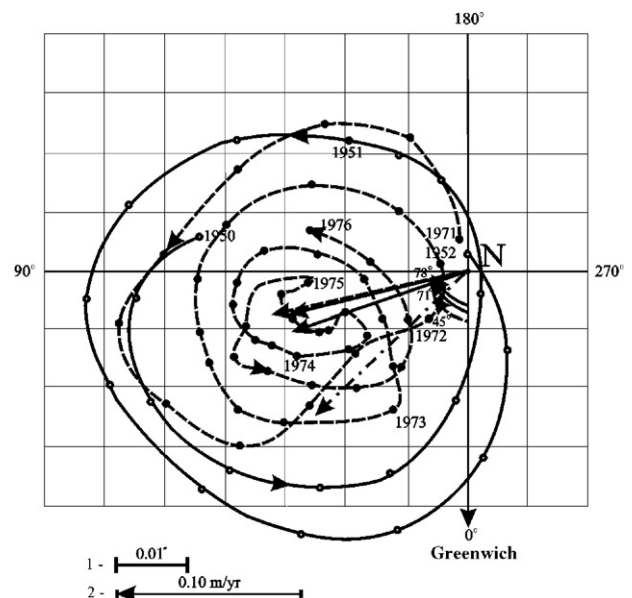


Fig. 2. Curves showing variations in the North Pole of rotation of the Earth (polhode) relative to the International Arbitrary Beginning in 1903 (N) and the mean vectors of the secular migration of the pole in 1930–1952 after Shcheglov (1974) — solid line; in 1971–1976 after Tsuboi (1982) — dotted line; in 1900–1925 after Wegener (1984) — dotted-point line. Instant positions of the pole = circles. A side of small squares — 3 m. 1 — horizontal scale in degrees; 2 — direction and value of secular course velocity.

pole. The secular course is the slow and apparent movement of the pole along the meridian; it manifests itself in that as time goes by, the instant poles make Chandler oscillations and move further away from IAB. From 1903 to 1976, the secular course of the North Pole (NP) was almost constant at $(100 \div 120) \pm 20$ mm/yr. However, at first it was directed towards the 45th meridian (in the west system), in the 1950s towards the 71st meridian and in 1976 it moved towards the 78th meridian, turning opposite to the real rotation of the Earth (Zemtsov, 2004a). Astronomers agree that this secular course cannot be explained by periodic changes in the axis of rotation of the Earth in space or by changes in the angle of its inclination to the ecliptic. “In the Earth’s coordinate system the axis is immobile, whereas the Earth’s body is moving slowly on it” (Shcheglov, 1974), i.e. pole migration is interpreted as slow rotation of the entire lithosphere of the Northern Hemisphere in a direction opposite to the apparent movement of the pole. From the physical point of view, such a generalization is unreal. Firstly, the complex secular movement of NP in the 20th century to the west, from the 71st to the 78th meridian and along them, can be alternatively interpreted as the rotational-forward drift of both Eurasia and North America relative to IAB in the direction opposite to the secular course vector. All five observatories of the Latitude Service were located on continental lithosphere, and the results of their measurements pertain only to the continents of Eurasia and North America as third-level hierarchical structures. It is no accident that sections of the Earth at the 71st–78th meridians and in the opposite meridians extend across these continents. This means that both continents rotate clockwise, but Eurasia moves away from the NP and North America moves toward the NP. Secondly, the Earth is not a perfect sphere, and its lithosphere will tend to split up as it moves along a meridian. If one mentally rotates the polar lithosphere to the latitude of the equator and considers it purely as a brittle cap with the polar radius smaller than the equatorial

radius by about 21.4 km, then the total thickness of fractures in the lithosphere will be $2\pi \cdot \Delta r \approx 135$ km. In this case the thin oceanic lithosphere would be expected to be the first to split up. Thirdly, common forward continental drift in the Northern Hemisphere can occur only when shear movements take place simultaneously along transform faults in the Arctic, Atlantic and Pacific Oceans. Finally, the North Pacific plate, as a structure of the fourth hierarchical level located between Eurasia and North America rotating clockwise, should rotate in the opposite direction.

3. Continent drift patterns

3.1. Global Positioning System (GPS) data

Eurasia is now covered with a fairly dense permanent satellite geodetic network (GPS monitoring). The sum of the data obtained in the past few years indicate that the general direction of plate motions is NE for Europe, SE for NE Asia and from SW to SE directions for SE Asia. The modern clockwise rotational drift of the Eurasian plate is clear (Fig. 3).

Detailed past decade GPS monitoring by 10 campaigns in the Eastern Tibet Plateau has shown that fast clockwise rotation is occurring around the large-scale vortex — “Eastern Himalayan Syntaxis” (EHS). Being limited by a drift analysis comprising only several current velocity vectors, Yuping et al. (2004) did not realise that the EHS is the novel central and rapidly rotating domain for the whole of Eurasia (Zemtsov et al., 2006). It has the approximate coordinates $E98.3^\circ$, $N30.7^\circ$ ($\pm 4.0^\circ$) and is located near Batan and the Lytankhe river outlet (Table 1). But Zhiliang et al. (2004) noted that there is a series of sub-order vortexes rotating around the EHS and that their velocities decline systematically from the inner ring to the outer one. Interestingly, the traces of general movements cut through the local geological structures. They tentatively interpret these

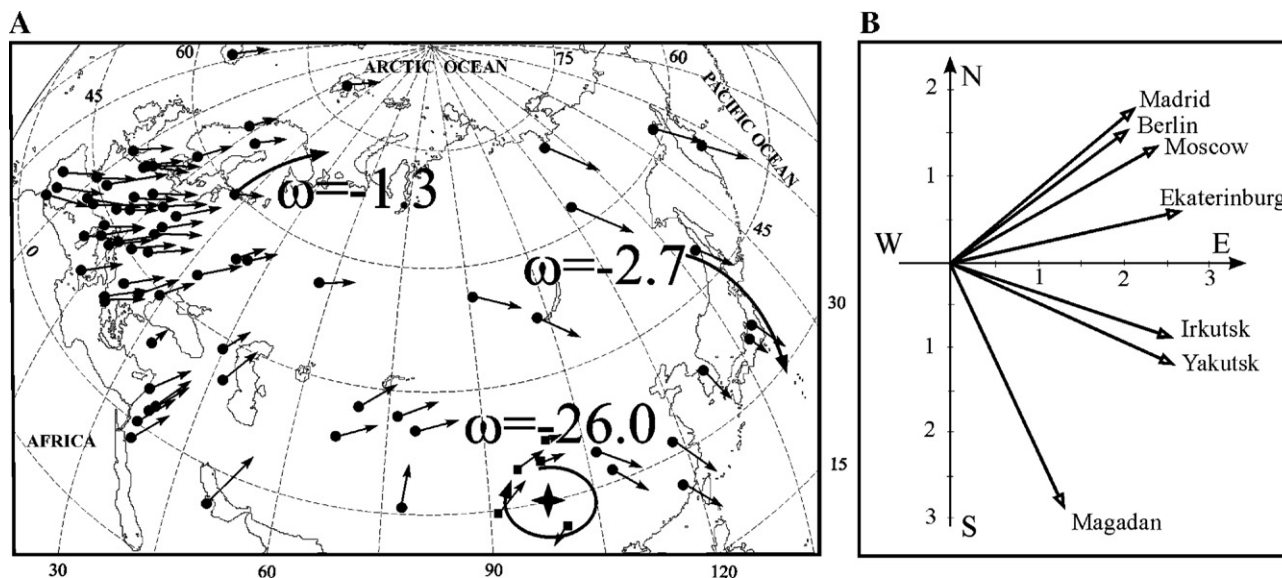


Fig. 3. (A) — scheme showing the horizontal linear velocity vectors (arrows) of GPS stations in Eurasia and the instantaneous angular velocities of rotation ($\omega \times 2\pi 10^{16} \text{ s}^{-1}$) at some domains of continent and (B) — some linear velocity vectors of GPS stations after Utkin (2002), cm/yr. Positions of GPS stations after Utkin (2002) = solid circles; positions after Yuping et al. (2004) = solid squares; centre of continental rotation = asterisk.

Table 1
Linear velocity vectors and geographic coordinates (degrees) of GPS stations in the Tibet Plateau and its environs (based on the data of Yuping et al., 2004)

Stations	Longitude	Latitude	V mm/yr	Direction
Lhasa	91.1	29.7	26.75 ± 1.27	N45.61E
GLM 1	94.8	36.2	16.65 ± 1.90	N549.77E
XRH 1	98.2	36.4	12.27 ± 1.57	N50.81E
CSD	99.1	40.3	2.76 ± 1.45	N78.53E
OLZ 3	98.4	25	10	S32W
Bangalore	77.6	13.1	41.68 ± 2.21	N26.18E

vortex motions and crustal deformations as a reflection of the lower crust rock rheology.

The main characteristics of the rotational motion of a solid body and that of a plate are the instantaneous angular rotation velocity vectors (ω). Their values can be estimated numerically by substituting data on the linear drift velocities of the GPS stations into Eq. (4) and calculating their distances (r) towards the rotation centre of Eurasia from the coordinates. For any rigid slab, ω must have a constant value. However, the calculations show that it actually changes several times within the continent (see Fig. 3, A), increasing in absolute value from the periphery of the continent to the rotation centre, where it reaches $29 \cdot 10^{-16} \text{ s}^{-1}$, for the Bangalore station in Table 1. The real

value of ω is somewhat smaller than the one calculated as there is an additional component of E to SE Eurasian drift. Furthermore, this vector has a minus sign and is directed into the Earth due to the clockwise continental rotation. Greatly different values of ω show that Eurasia, the largest modern continent, does not possess the main property of a rotating solid body, i.e. it is not a rigid plate, to a second approximation, but rather a complex structure comprising domains exhibiting differential rotational drift.

In North America the permanent GPS networks are used primarily to trace earthquakes and are hence concentrated mainly in the western USA (Melbourne et al., 2004). Like Europe, this part of the continent drifts NE and the entire North American plate also seems to be rotating clockwise. The assumption that the rotation patterns of Eurasia and North America are identical conforms to the geodynamic interpretation of the secular course of the North Pole described above.

3.2. Ancient rotational continental motions deduced from palaeomagnetic data

V. Utkin (2002) discussed the rotational drift of Eurasia and considered it to be “historically inherited”. This was suggested indirectly by the concentric arrangement of ridges in the Pamir–

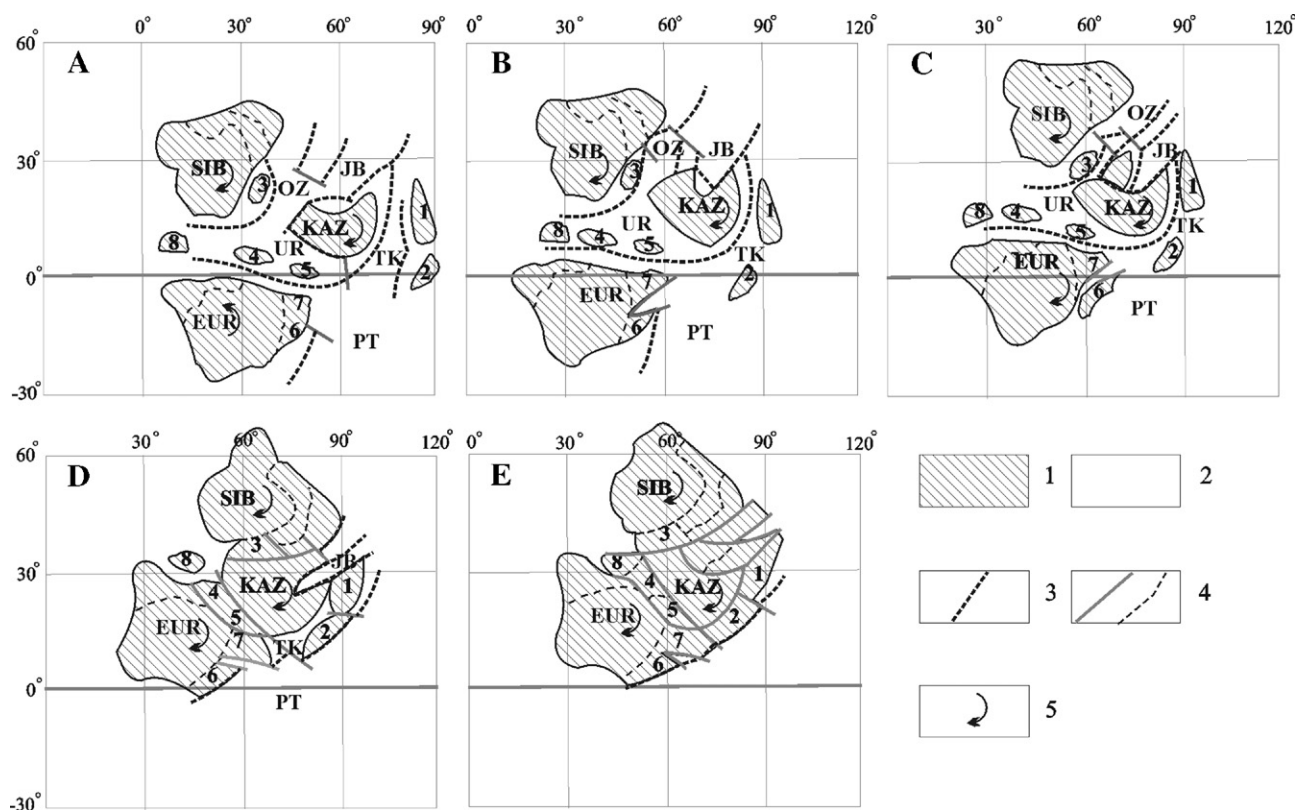


Fig. 4. Schemes showing geodynamic evolution of the Central Asian foldbelt omitting contiguous areas after Filippova et al. (2001) with some reductions: A — Early Devonian, B — Middle Devonian, C — Late Devonian, D — Late Carboniferous, E — Early Permian. Symbols: 1 — continents and microcontinents, 2 — oceans and backarc basins, 3 — subduction belts, 4 — other structural sutures and principal strike slip faults, 5 — sense of rotation of continental blocks. Acronyms denote continent (EUR = European, SIB = Siberian, KAZ = Kazakhstan) and oceans (UR = Uralian, TK = Turkestan, JB = Junggar–Balkhash, OZ = Ob–Zaisan, PT = Paleo-Tethys). Numerals mark microcontinents and continental blocks: 1 — Tarim, 2 — Baisun, 3 — Vartovsk–Nyuroolka, 4 — Khanty–Mansi, 5 — East Urals, 6 — Bechasyn–Karabogaz, 7 — Ustyurt–Karakum–Amu–Darya, 8 — Baydaratsky.

Tian Shan–Himalayas–Tibet system although the strongest indicator of the inherited pattern of Eurasian drift was provided by palaeomagnetic studies in the Urals. Utkin considered that a change in the rotation of the Eurasian plate (EAP) occurred in Early Permian time and related it to the completion of magmatism in the Urals. He argued that the subsequent behaviour of the plate was affected by a change in the structure of convective cells in the mantle. However, his arguments were based on old palaeomagnetic data and the interpretation seems unlikely because it conflicts with the modern forward drift of the EAP and available palaeomagnetic data from the Siberian and Kazakhstan blocks which indicate clockwise rotation for a long time before the Permian (Van der Voo, 1988; Smethurst et al., 1998; Filippova et al., 2001; Sennikov et al., 2004). Hence, it is not entirely correct to consider the drift of the EAP as historically inherited. Fig. 4 shows that as early the Middle Devonian the ancient European continent (Baltica) intersected the equator and moved from the Southern to Northern Hemisphere whilst changing the direction of its rotation in Early Carboniferous time. When it was south of the equator during the Lower Palaeozoic it was rotating counter-clockwise, whereas upon transition to the Northern Hemisphere the sense of rotation became clockwise. Volcanic activity in the Urals had already ceased by Permian times and by the Late Carboniferous the Baltica, Siberia and the Kazakhstan blocks had joined to form the EAP, which then continued drifting northwards and rotating clockwise. Palaeomagnetic data suggest that total rotation of the Urals during the past 255 ± 5 Ma has amounted to $55\text{--}60^\circ$ (Didenko and Ruzhentsev, 2001) and, to a first approximation; the average angular velocity of the EAP during this interval was $1.3 \pm 0.2 \times 10^{-16} \text{ s}^{-1}$ (Zemtsov, 2005a). According to GPS data (see Fig. 3) modern Europe has about the same ω

value. Interestingly, differential, slow (for Baltica) and fast (for Siberia) rotations seem to have existed before the Early Silurian (Filippova et al., 2001; Zemtsov et al., 2006). This is clearly the case after the Late Permian and can be observed at the present day (see Fig. 3, A). Thus, the fact that the contiguous subduction belts ceased to exist as late as the Early Permian cannot serve as an explanation of novel continental motions.

During Precambrian time Baltica intersected the equator more than once and each time its rotation seems to have changed in the above manner (Fig. 5). One possible exception was at the beginning of the Late Riphean, when Baltica was supposedly part of the putative Rodinia supercontinent although poor palaeomagnetic control (there are only about 40 determinations for Baltica in the time interval 1.5–1.0 Ga on the apparent palaeomagnetic pole wander path — APWP) and poor definition of Rodinia, (i.e. an inaccurate geodynamic reconstruction) give little credence to this exception (Pavlov et al., 2004). Thus it is tentatively concluded that large-scale forces that rotated the continents in the direction opposite to the rotation of the Earth existed during geological history when the centres of the continents were located far from the equator.

3.3. Driving forces of continental motions

Baluev and Moralev (2001) observed a somewhat different feature of the Precambrian evolution of Baltica: they noted that this block was rotating clockwise while moving away from the palaeoequator, and counter-clockwise when approaching the palaeoequator. They attributed this periodic change in plate rotation to the rotation of the Earth itself implying that it is affected by the Coriolis force (acceleration — f_c). However, such continental movement is impossible (even qualitatively)

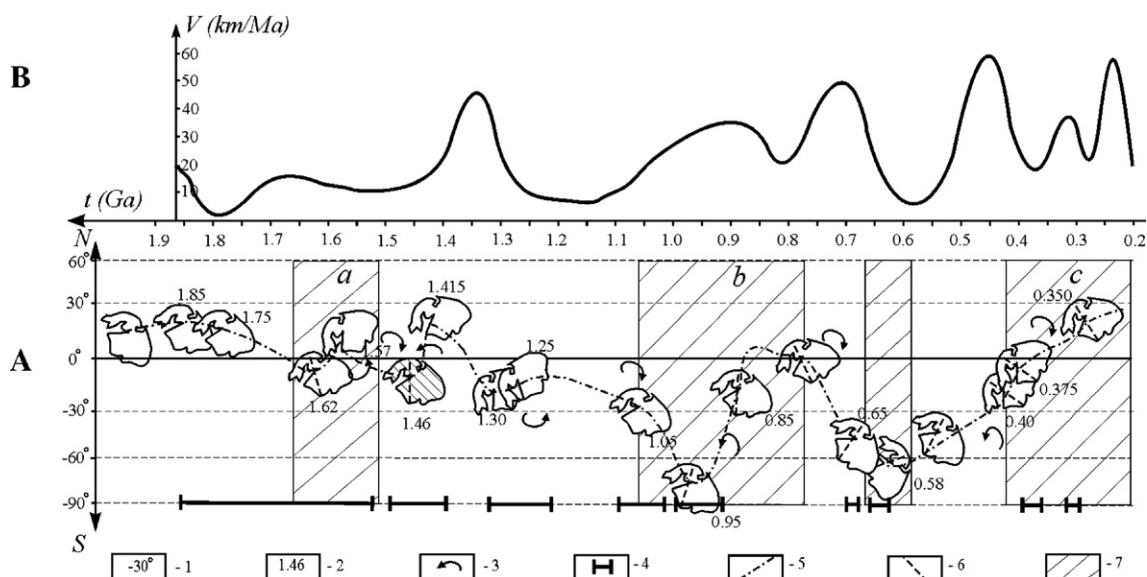


Fig. 5. Variations in the latitudinal position of Baltica from 1.9 Ga to the present with data on the manifestations of intraplate magmatism (A) and a plot of variations in the meridional velocity of its drift (B) — after Smethurst, Khramov and Torsvik (1998), Baluev and Moralev (2001) with some changes and additions, including new data (the contour of Baltica is filled with lines) — after Pavlov et al. (2004). 1 — palaeolatitude values; 2 — age, Ga; 3 — directions of rotation of Baltica; 4 — time intervals with intraplate magmatism; 5 — drift trajectory of Baltica from the arbitrary point St. Petersburg; 6 — modern meridian (30° E); 7 — time intervals during which Baltica is suggested to have been part of the putative supercontinents: a — Columbia and b — Rodinia, c — Pangaea.

because the velocity of plate movement (V) along the meridian is very low. Indeed, f_c is a constituent of navigation correction in gravimetry (Eq. (5)):

$$f_c = V^2/R, \quad (5)$$

where R is the radius of movement of an object with mass $m=1$.

In geophysics, the Coriolis force becomes a conspicuous effect in the formation of large river channels flowing at velocities of several kilometres per hour and causes their western banks to be selectively eroded. Plates, however, move at maximum velocities of about 150 mm/yr, and $f_c=0$, in contrast to the horizontal centripetal acceleration (f_1), which depends on the rotation mode of the Earth and the geographic latitude of the object (φ). Considering the object to be a rigid plate splitting up gravity acceleration (g) into constituents (Fig. 6), we obtain, to a first approximation, the direction and value (Eq. (6)) of the horizontal centripetal force (F_1), which affects the centre of the plate mass (m) as:

$$F_1 = m \cdot f_1 = (1/2)m\omega^2 R \sin 2\varphi, \quad (6)$$

where ω is the angular velocity of rotation of Greenwich.

$F_1=0$ at $2\varphi=0, \pi$, i.e. at the equator and at the poles. These positions are energetically advantageous for the continent. F_1 reaches a maximum at $\varphi=\pm 45^\circ$. Calculations show that here $F_1 \approx 5 \cdot 10^{10}$ N per 1 km^3 acting on the continental crust and that it is directed towards the equator (Zemtsov, 2004b).

Obviously, the effects of the horizontal centripetal force, mantle convection, density changes in the lithosphere, etc. cannot be used to interpret the rotational drift of continents or explain a change in the direction of their rotation on passing over the equator. It seems that large-scale forces rotating the continents, in the direction opposite to the rotation of the Earth, permanently exist when the centres of the continents are far away from the equator. To understand the physical nature of

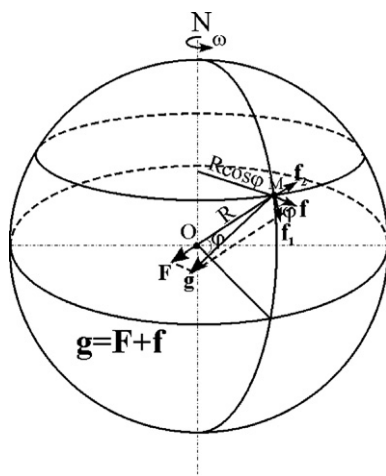


Fig. 6. Constituents of acceleration of gravity (g) for the spherical Earth: F — Newton force of attraction; f — centripetal acceleration (f_1 — horizontal constituent and f_2 vertical constituent). R — distance from the centre of the Earth (O) to point M with unit mass; φ — geographic latitude of point M .

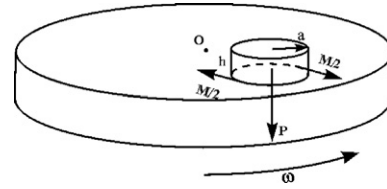


Fig. 7. Moment of friction torque forces (M) of a vertical cylinder with radius a and height h on a horizontal disc that rotates at angular velocity ω . $P=mg$ — force that presses the cylinder to the disc.

these forces, we can draw analogies with atmospheric vortexes (anticyclones) and the rotation pattern of floating ice in the Arctic Ocean (Zemtsov, 2004c). Anticyclones arise at Arctic and temperate latitudes and rotate clockwise in the Northern Hemisphere, but counter-clockwise in the Southern Hemisphere and form vortexes that are about 1000 km across. Descending on the interface of the rotating Earth, a heavy air column begins to whirl, presumably, by virtue of frictional torque forces as described in textbooks on theoretical mechanics. This physical problem has not yet been solved analytically as, unlike absolutely rigid bodies that can touch each other at a single point, natural bodies always touch one another at a site that, in principle, can rotate. In non-linear mechanics, a combination of such problems in which the radii of curvature of the contact surfaces are considered, is known as a contact problem in the theory of elasticity, plasticity and creep, although a rough model of such torsion can be created (Fig. 7).

If a site at which rotating bodies touch each other is horizontal, and the force which presses the upper body against the lower one is equal to the weight of the upper body (P), then the problem is simpler although friction-sliding forces on the bottom of the upper body will have different directions and magnitudes and, if summed up, will give a torque friction force moment. If the moment of these forces is too low to overcome frictional resistance, the upper body will not move relative to the lower one. The limit of the torque friction force moment (M) depends on the distribution of pressure on the bottom of the upper body, and such factors as the shape, size and elastic properties of bodies (Eq. (7)):

$$M = \mu P, \quad (7)$$

where μ is the torque friction coefficient and has the dimension of length.

This coefficient, in turn, depends on the dimensionless sliding friction coefficient (f) and the area of contact of bodies. For a cylinder with radius (a) it can be estimated theoretically as:

$$\mu = (\pi/4)fa \approx 0.79fa. \quad (8)$$

Analysis of the simplified Eqs. (7) and (8) leads to an important geophysical conclusion. As the torque friction coefficient on the bottom of a cylinder increases with increase in its radius, M is an approximate function of a^3 and P is an approximate function of a^2 . Thus, for any value of $f < 1$ and constant height of the cylinder h , there exists a critical radius a

at which $(M/\mu) \geq P$, i.e. the upper body will be detached from the lower one and will begin to move on the rotating surface of the lower body. The pattern of this movement becomes obvious: the cylinder will rotate primarily in the direction opposite to the rotation of the disc. The effect of torque frictional forces can be modelled, for example, when making polished sections on a grinding wheel. Fig. 7 can therefore be regarded as a rough model of a continent with radius a and thickness h , which drifts on the surface of the homogeneous mantle (Zemtsov, 2004d, 2005b). The rotation of Eurasia is likely to follow the same physical pattern. In reality of course, each continent has a huge mass, its surface is not flat at the base and a number of secondary interactive geodynamic forces operate.

The spherical interface between the continental lithosphere and the asthenosphere is probably formed spontaneously by virtue of a change in the elastic properties of the mantle and its partial melting associated with a natural rise in temperature (T) with depth at the expense of the heat released from the core and lower mantle so that, at a relatively small depth of 100 km, T can be as high as 1500 K. If the moment M on the bottom of the continent exceeds the force of attraction attributed to its base area, it will begin to rotate spontaneously in the direction opposite to the rotation of the base. The temperature of the base may be expected to rise as a result of the torque friction.

The depth h appears to be located within zones with the minimum mechanical quality factor of the Earth's mantle, which has a layer of low mechanical strength at a depth of $90 \div 450$ km (Zharkov, 1983). For the largest continents, such as Eurasia, Africa and South America, Lehmann's seismic discontinuity is located in this interval at a depth of 220 km. The nature of this interface can be explained by a transition from anisotropic lithosphere to essentially isotropic Upper Mantle. Therefore, seismically anisotropic mantle zones located at higher levels indicate that rock flow can occur in them (Gaherty and Jordan, 1995). Furthermore, the possibility cannot be ruled out that several, rather than one, subparallel zones of shearing with differentiated rotation are present at the base of the continental lithosphere. DSS data also show that at a depth of 90–120 km in the sub-continental mantle a second global layer with elastic wave velocity inversion and high electrical conductivity

(i.e. fluid-saturated) is present, and at similar depths substantial crustal–mantle heterogeneous masses are isostatically balanced (Pavlenkova, 2006). High seismicity qualitatively corroborates both of these mantle interfaces: following the Harvard catalogue, Rodkin (2004) has studied the possible depths of mantle earthquakes and attributed seismicity to the “ripping up” of the upper mantle or an upward breakthrough of fluids to a zone of smaller lithostatic pressures.

A maximum torque moment arises in a continent if the centre of its mass is located at the poles of planetary rotation. For example, the modern Antarctic Continent has a huge area and tendency to retain quiescence in the inertial coordinate system (Fig. 8), i.e. it must spontaneously rotate counter-clockwise in the opposite direction to the Earth's rotation at a maximum angular velocity ω_p in any terrestrial system (Zemtsov, 2004b,d).

In contrast, in the Northern Hemisphere, as already shown, continents are found to rotate clockwise, with their direction changing at the equator. Thus, they rotate like the Foucault pendulum rocking plane: if the pendulum is at latitude φ , then, in the Earth's coordinate system, this plane rotates relative to any meridian at angular velocity ω_φ , which proves experimentally that the Earth itself rotates (Eq. (9)):

$$\omega_\varphi = \omega_p \sin \varphi. \quad (9)$$

In fact, the rotation of the Foucault pendulum rotation plane is apparent. In the inertial coordinate system it retains its position in space, while the Earth's coordinate system, i.e. the Earth itself, rotates. On crossing the equator where $\varphi=0$, the direction of rotation of its rocking plane changes.

4. Conclusions

As a result of Earth rotation acting on the base of a novel Eurasia regarded as the 3rd level rigid hierarchical structure, to a first approximation, there exists a spontaneous moment of frictional torque forces, which results in rotational continental motions in a direction opposite to the real rotation of the Earth, namely clockwise. The rotational drift of Eurasia results from its position as the largest continent in the Northern Hemisphere and from the rotation of the Earth itself. The continental rotation is corroborated by 100-years of astronomical monitoring of the secular course of the Earth's rotation pole and the changing coordinates of the GPS networks. It is confirmed indirectly by P-wave velocity inversion and high electrical conductivity of the continental mantle at depths of 90–120 km accompanied by high seismicity in this zone and the Lehmann boundary (220 km). Both zones can be defined as probable elastic interfaces of the continent.

The epicentre of the present rotation of Eurasia seems to be located in the Eastern Himalayas, far from the geometrical centre of the continent. Eurasia does not possess the main property of a rotating solid body and is not a rigid plate, to a second approximation. Within the continent, the instantaneous angular rotation velocity values change several times, increasing in absolute value from the periphery of the continent to the central domain of rotation. The continent has a complex structure with domains

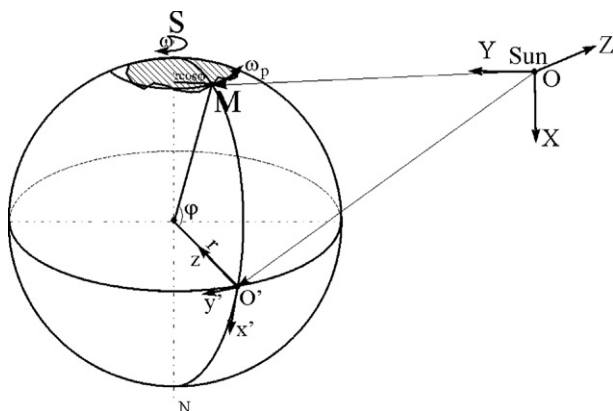


Fig. 8. Assumed rotation of the Antarctic Continent (ω_p) in the inertial coordinate system — X, Y, Z .

that have a differential rotational drift complicated by external factors.

The results of palaeomagnetic studies of Precambrian–Mesozoic rocks from Baltica, Siberia and the Urals appear to support the assumption that a change in the sense of rotation of the continent on intersecting the equator is a general historical pattern of continental motions. This testifies to the active geodynamics of continents and the minor role of oceanic plates as the 4th hierarchical level structures. This could potentially be used to unambiguously determine the polarity of the palaeopoles on an APWP.

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