

Wave Moment Geodynamics

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Abstract

The work presents a review of natural-science representations on the rotary motion of matter and its piecewise structure. Development of dense GPS-networks allowed to experimentally confirm the concept of block structures of the geophysical environment and to prove rotary character of block movement. An analysis of both the migration of earthquake sources and the movement of sections of tectonic plates' borders has allowed to reveal general properties of such movements and to prove their wave nature. It is shown that within the limits of rotational model, blocks and plates are interconnected among themselves by the elastic long-range fields forming a uniform planetary geodynamic field. It is offered to use the geodynamic solutions of rotational model in the one class of phenomena as a basis at the construction of a new geological paradigm – wave moment geodynamics.

Key words: block, plate, rotational wave model, moment geodynamics.

1. INTRODUCTION

The cyclicity of global processes on the Earth, their pulsations and reconstructions has already ceased to be a matter of contention between specialists; the main interest has shifted to problems of their nature and causes. The influence of the Earth's rotation on the its deep structure, on deformation of the Earth's crust, and on the self-organization of the geological medium is also beyond question.

The interest in vortex geological structures (Xie 2004) has sharply grown in the recent decade. The search for a new geological paradigm based on the principle of transfer from "ruler" to "compass", which is related to the moment character of the natural geological medium (Vikulin 2008, Vikulin and Tveritinova 2008, Vikulin *et al.* 2011), is obvious.

Tectonophysics assumes that all physical phenomena inside the Earth and on its surface are established and known, which comes into deep conflict with the data. This is why the physics of the Earth has been "extended" at the expense of geodynamics in recent decades (Vikulin 2009, 2011). Under these conditions, it is necessary to study geoprocesses at a new qualitative level.

The character of deformation of the continental lithosphere has long been the subject of much controversy in geodynamics (Kuzikov and Mukhamediev 2010). In the overwhelming majority of cases, the discussion concerns data on the Asian territory affected by the collision of the Indian and Eurasian plates. It became clear more than 30 years ago that this collision formed active faults and deformations of the crust, which are spread over more than 2000 km up to Central Asia. Nevertheless, as yet there is no consensus on the method of describing the character of the resulting deformation leading to the north-south contraction of the Asian crust (see *e.g.*, Thatcher 1995). There are two extreme opinions on this question. According to one of them, it is supposed, by analogy with tectonics of rigid lithospheric plates, that the intensely deformed crust represents an ensemble of relatively large blocks or microplates. In this case, the main deformation is a consequence of displacements along large faults, and the deformation of blocks is negligible (Replumaz and Taponnier 2003). The crust contracts due to the east-west squeezing-out of blocks. The alternative notion is based on the fact that the deformation of the continental lithosphere is distributed over the volume and corresponds to the rheological model of a nonlinearly viscous liquid, and the crust contracts due to its thickening (Flesch *et al.* 2001). Within the framework of this model, the horizontal deformation of the upper brittle crust can be presented as occurring due to movements along multiple minor faults at approximately the same velocities.

Apart from these extreme points of view, there are intermediate notions, for example, about a certain combination of weakly- and strongly-deformed sites of the lithosphere. The described problem has acquired a status of one of the most important problems of geodynamics. The absence of its solution restrains the development of adequate rheological models of the lithosphere and the subsequent passage from kinematic calculations to the determination of stress fields.

It is implicitly supposed in the block model of crust deformation that block boundaries are discontinuity lines of the velocity field or, at least, blocks are separated by zones of increased velocity gradients. Evidently, one of the first attempts to reveal the block structure of the field of present-day horizontal velocities directly from GPS measurements with the use of the laws of classical mechanics was made in Kuzikov and Mukhamediev (2010). In this work, on the basis of data from the Central-Asian GPS network, regions, which within a certain degree of accuracy move as simply connected rigid two-dimensional bodies, *i.e.*, experiencing rotations, apart from translatory transfers, were revealed in the horizontal velocity field. The spaces between these regions are characterized by increased deformations.

The structure of the vector field of present-day horizontal velocities on the Earth's surface is investigated with the use of the territory covered by the Central-Asian GPS network (30°-45°N, 69°-81°E), as an example (Kuzikov and Mukhamediev 2010). A method of identification of groups of GPS points (statistically rigid clusters), for which the rate of change in distances between them is virtually zero, is proposed and realized. Of all the sites of the Central-Asian GPS network, 323 points were selected for clustering. These sites were measured from three to eleven times over an 11-year interval of observations (1995-2005). The estimates of errors of velocity measurement for these sites must not exceed 1.0 mm/yr. As a result, 29 statistically rigid clusters, containing from 3 to 17 GPS sites, were identified, and the kinematic regimes of motion of regions corresponding to these clusters were determined with respect to the stable part of Eurasia (Fig. 1). With the general direction of the translatory motion of regions toward the north, the majority of them rotate counterclockwise. Angular velocities of instantaneous of a region are from -2.99 to 8.05 ms/yr, on average 2.04 ms/yr.

A quantitative spatial comparison of present-day regions and the interregional space zones with two fault schemes in the Quaternary time has been made by Kuzikov and Mukhamediev (2010). The results of the analysis showed that, at a probability of ≥ 0.99 , faults fall with the same frequency both into the territories of regions and into the space between them. Thus, at least at present, there is no spatial correlation between the interregional space zones

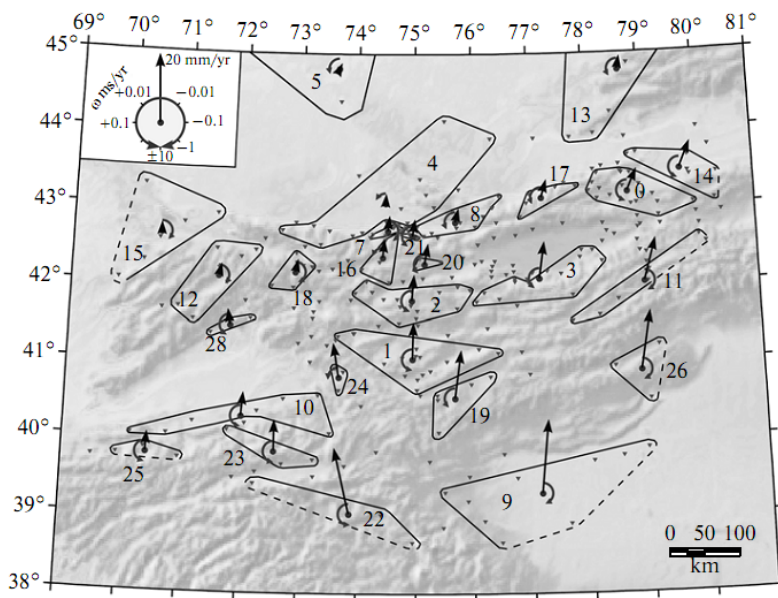


Fig. 1. Configurations of the minimum regions and kinematic characteristics of their motions (with respect to the relatively stable Eurasian plate) for the part of the territory covered by the Central-Asian GPS network (Kuzikov and Mukhamediev 2010). The rectilinear arrows show the translatory horizontal velocities of the mean radius vectors of the position of GPS sites included in the identified region. The oriented arcs show the angular velocities ω (\pm ms/yr) of instantaneous rotation of regions. The triangles mark the analyzed GPS sites. 0, 1, 2, ..., 28 are the numbers of the clusters; seven of them (7, 9, 11, 12, 15, 18, and 26) rotate clockwise.

and active faults. At the same time, the general directions and kinematic regimes of the interregional space zones and faults coincide. Such a set of facts can indicate that the general global tendency of the geodynamic process, caused by the Indian–Eurasian collision, is retained in this region (Kuzikov and Mukhamediev 2010).

Thus, rotation of domains-blocks allocated on the basis of GPS-data does not influence the general global tendency of the geodynamic process proceeding in the region. And at the same time, rotations of such domains-blocks essentially influence local regional stress fields.

GPS-data (Kuzikov and Mukhamediev 2010) and rapid development of rotational theoretical (De Rubeis *et al.* 2010, Teisseyre 2010) and experimental (Lee *et al.* 2009a, b) seismology shows exclusive importance of rotary motions of geophysical blocks and tectonic plates at construction of tectonophysics processes models.

All these data indicate that the development of a new geological paradigm is necessary. This paper brings a macroscopic, block-like view on rotation processes related to global dynamics of the Earth. It is an opposite approach to the continuum asymmetric theory (Teisseyre 2010, Teisseyre and Górski 2011). The statement of the problem in this aspect is a result of our previous studies (Vikulin 2006, 2008, Vikulin and Ivanchin 2000, Vikulin and Tveritinova 2008, Vikulin *et al.* 2011).

2. INITIAL DATA

2.1 Theoretical comprehension of rotational motion

The first (rotational) vortex quantitative model of the world structure (after qualitative antique ones) was proposed by P. Laplace late in the 18th century. In the middle of 19th century, important hydrodynamic results were obtained and the vortex theory of matter was created.

In the middle of the 19th century, the mathematicians P. Dirichlet and B. Riemann made a revolutionary contribution to the fundamentals of the theory of equilibrium figures (Antonov and Kondratèv 1995). They first considered the stationary figures of equilibrium of rotational gravitating bodies and discovered a class of two-parametric equilibrium ellipsoids – Riemann's ellipsoids (Riemann 1861), which it used for a research of star's and planet's characteristics (Antonov and Kondratèv 1995, Chandrasekhar and Roberts 1963).

As the beginning of the “vortex” stage in geology, we may consider the publication of the work by the Chinese geologist Lee Syguan (Lee 1928), where *vortex structures* (Lee Syguan's term) in geological sections of China were first highlighted and described. As a result of repeated geodetic works, Japanese researchers (Fujiwhara *et al.* 1933) first drew the conclusion that a rotational motion of the Earth's crust blocks occurs.

In the 1950s M.V. Stovas noted that a change in the angular speed of the Earth's rotation causes a change in its polar compression and serves as a cause for the particular stress state in the latitudinal zones between 30° and 40° in both hemispheres (Vikulin *et al.* 2011).

2.2 Blocky wave tectonics

In the 1960s, A.V. Peive substantiated the block structure of the Earth's crust and a new mechanism of motion – the proper source of the block motion (Vikulin and Tveritinova 2008). The spatial waviness of large tectonic ruptures is determined by tectonophysical studies, *i.e.*, during crack propagation at a certain rate, twisting occurs (Magnitskiy 1967). The first mechanical model that permitted a solution in the form of slow tectonic waves was con-

structed by Elsasser (1969). In the 1970s, L.I. Sedov noted the importance of mechanical problems with the proper momentum of macroscopic-sized volumes of a substance; T. Rikitake presented the data of high-precision first-class geodetic measurements, which demonstrated that Honshu Island was, in essence, the aggregation of touching vortex (according to Lee (1928)) structures (Vikulin 2009).

In 1972, O.I. Slenzak developed Lee Syguan's notions regarding vortical geological structures at a new qualitative level (Vikulin 2011). As a result of his studies, which were conducted in 1950-1970, the existence of large (1000 km and more in diameter) vortex structures was proven and the conclusion was made that they are independent as a type of lithospheric tectonic structure, which cannot be created by external sources of motion in the form of drifting continents or displacements along planetary faults. According to Vikulin *et al.* (2011), the rocks from which the vortex structures were created in a solid state instead of (and at the expense of) the upper-mantle substance and from the very beginning they were formed as arc-shaped structures rather than being subjected to mechanical bending (being initially rectilinear structures). Systems of vortex formations are connected as a unified hierarchical tectonic planetary structure.

2.3 Blocky models of the geophysical medium

In the 1970s M.A. Sadovskii established the blocky (piece-wise) character of the geophysical medium and jointly with his colleagues developed its model, and I.V. Melektsev proposed the vortex volcanic hypothesis and considered some its consequences; in particular, Iceland's rotation clockwise at a rate of 5×10^{-4} deg/yr was shown (Vikulin *et al.* 2011). On the basis of the data from long-term detailed instrumental investigations in different geophysical fields, it is indicated that the Easter and Juan Fernandez Plates (their cross sectional sizes are 300-400 km), which are situated in the southwest part of the Pacific Ocean, rotate. The Easter Plate rotated by almost 90° over 5 million years, which corresponds to a rotation rate of about 10^{-5} deg/yr. The isolines of all the geophysical fields that display the rotational motion of these plates are presented by spiral lines. Based on the geophysical and geological data, the rotational motion of the Earth's crust blocks, which are also earthquake sources, has been shown.

2.4 Wave rotational-vortex models of nonlinear geomedia

In 1993, a radically new approach towards studying the physics of the Earth and geodynamics was proposed by A.I. Dmitrievskii, I.A. Volodin and G.I. Shipov (Vikulin *et al.* 2011). These authors introduced the concept of the "system movement of matter" based on a new theory of vacuum and the

field of inertia. Characteristic movements of the geological and geophysical media in the context of these representations lead to different types of vortex and helical structures. The experimental detection of the evidence that deformation solitons exist in geophysical fields served as a basis for the mathematical wave model of the rotational movements of rock blocks that was constructed by V.N. Nikolaevskiy (Nikolaevskiy 1996). A review of wave tectonic studies was given in a generalizing papers by Bykov (2008) and Gershenzon *et al.* (2009); basic data on parameters and sources of the non-linearity of rock massifs were presented and nonlinear wave processes were considered at different structural levels of geological objects.

2.5 The beginning of a new stage of developing the concepts of vortex geodynamics

The first scientific seminar that considered vortical geological movements combined with physical, geophysical, geographic, and other data and phenomena was held on 23 March 2003, in Petropavlovsk–Kamchatskii at the Institute of Volcanic Geology and Geochemistry of the Far East Branch of the Russian Academy of Sciences (now the Institute of Volcanology and Seismology of the Far East Branch of the Russian Academy of Sciences). Using a large amount of experimental and theoretical data, all the collections show that the geophysical medium is very nonlinear and self-organized and even “live”. In 2007, a collection of papers was published where vortex movements are broadly discussed; among other things, it was first proposed there to use vortical geodynamical movements and their peculiarities as the basis of a new geological paradigm (Teisseyre 2010, Vikulin *et al.* 2011).

3. TWO TYPES OF INTERACTION OF GEOMEDIUM BLOCKS

The phenomenon of migration of earthquake sources (their regular distribution in space and time) is beyond question, it is the nature of the migration that remains unclear (Bykov 2008). The presence of such patterns is physically equivalent to the statement of the interactions among earthquake sources (Vikulin 2008, Vikulin and Krolevets 2002).

The migration patterns of earthquake sources have been well studied (Vikulin 2006, 2008, Vikulin and Ivanchin 2000). All the data on the rate of migration of Pacific earthquake sources in the axes of the migration rate V versus earthquake magnitude M are presented in Fig. 2, where it is seen that the entire rate field is divided into two fields of dots. One of them (I) corresponds to the global migration of earthquake sources along the overall Pacific Ocean outskirts:

$$M_1 \approx 2 \log V_1, \quad V_{1,\max} = 1-10 \text{ cm/s}, \quad M_{1,\max} \approx 9 \quad . \quad (1)$$

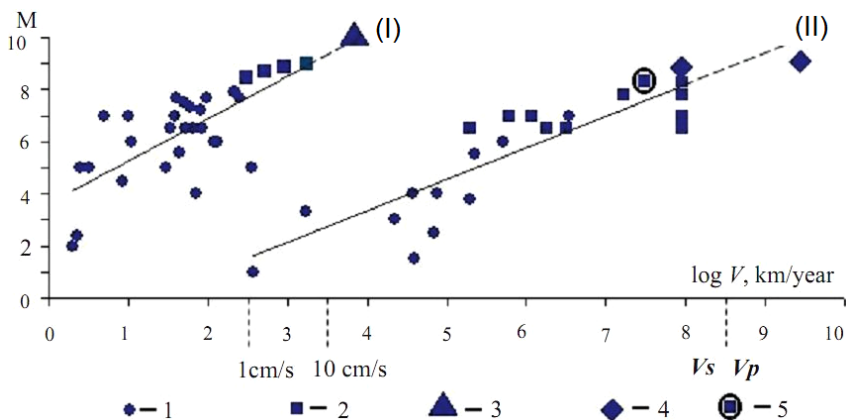


Fig. 2. Values of migration rates of Pacific earthquakes and the appropriate functions $M(\lg V)$ (Vikulin *et al.* 2011). Circles, 1, present the earlier data (Vikulin 2006, Vikulin and Ivanchin 2000). Markers, 2-5, relate to the data obtained later (Vikulin 2009). Among them, triangles, 3, present the migration rate of the strongest earthquakes—duplets with $M_W = 8.1-8.7$ in 1897-1901 along the outskirts of the Pacific Ocean; rhombs, 4, designate the rate of migration of shocks in duplets (4 Nov. 1952, Kamchatka, $M_W = 9.0$ and 13 Nov. 1963, the Kuril Islands, $M_W = 8.7$); markers 5 relate to the migration rate corresponding to the magnitude maximum $M = 8.3$ of the foreshock that occurred 40 s before the main shock of the Chilean earthquake in 1960 ($M = 8.3$, $M_W = 9.5$). Values $V_p = 8$ km/s and $V_s = 4$ km/s are the longitudinal and lateral seismic velocities, respectively. Lines I and II are the $M_1(\log V_1)$ dependence of the magnitude on the rate of global migration along the Pacific Ocean outskirts and the $M_2(\log V_2)$ dependence of the local migration of foreshocks and aftershocks in the sources of strong earthquakes, respectively.

The second field (II) corresponds to the local migration of foreshocks and aftershocks in earthquake sources:

$$M_2 \approx \log V_2, \quad V_{2,\max} = V_s \approx 4 \text{ km/s}, \quad M_{2,\max} \approx 8.0-8.5, \quad (2)$$

where $V_{1\max}$ and $V_{2\max}$ are the maximum values of migration rate in the areas of limiting values of the magnitudes $M_{1\max}$ and $M_{2\max}$, respectively, which are known as the velocity of creep and the lateral seismic wave velocity, V_s . In going from the earthquake magnitude M to its source size L and the released energy E , from the first equations in systems (1) and (2) we obtain the block “corpuscular” equations

$$\log L_1 \approx 0.8 \log V_1, \quad (3a)$$

$$\log L_2 \approx 0.4 \log V_2, \quad (3b)$$

and the “energetic” equations

$$E_1 \approx V_1^{3.6} \approx V_1^4, \quad (4a)$$

$$E_2 \approx V_2^{1.8} \approx V_2^2, \quad (4b)$$

for the representation of interactions between the earthquake sources.

The study of foreshocks and aftershocks in the sources of large earthquakes has shown that the rate of their migration in a direction from west to east exceeded the east-west migration rate by a value equal to the Doppler effect that is related to the Earth's rotation about its axis (Vikulin 2009, 2011, Vikulin *et al.* 2011). In appropriate experiment, the source is the wave geodynamics process spreading with definite frequency and wave-length inside the rotating Earth; the receiver is the seismic network, which is fixed relative to the Earth and registers earthquakes, aftershocks and foreshocks, which are a "trace" of geodynamics process. Thus, the migration of earthquake sources is in essence a wave process.

An analysis of the data on the sizes of plates and the rates of motion of their borders for the last 150 million years has made it possible to reveal two statistically significant relationships (Vikulin and Tveritina 2008):

$$\log L_1[\text{km}](\pm 0.33) \approx (0.7 \pm 0.3) \log V_1[\text{mm/yr}], \quad 5 < \tau_2 \leq 100 \text{ million years}, \quad (5a)$$

$$\log L_2[\text{km}](\pm 0.3) \approx (0.43 \pm 0.15) \log V_2[\text{mm/yr}], \quad 0 < \tau_1 \leq 5 \text{ million years}, \quad (5b)$$

where $\tau_{1,2}$ are the duration values determined by the numbers of magnetic anomalies from the data of Heirtzler *et al.* (1968) regarding the "relative" time intervals, according to which Eqs. (5a) and (5b) were set up. The correlation formula $\log L \approx \log V$, which is similar to Eq. (5a), was derived for processes of spreading and subduction in (Isacks *et al.* 1968, Morgan 1968). The relationship $V \approx L^3$ or $\log L \approx 0.33 \log V$, which determines the self-consistent activation of the faults of Central Asia and is similar to Eq. (5b), was obtained by S.I. Sherman and E.A. Gorbunova (Vikulin *et al.* 2011).

Let us note that seismic equations (3a) and (3b) are similar to tectonic functions (5a) and (5b) (Vikulin and Tveritina 2008).

4. A MODEL OF GEOMEDIUM MOTION

4.1 Statement of the problem

Geophysical and geological media are rotational. The value and direction of the angular speed are independent of the selection of the coordinate origin to which a body's rotation may be related (Landau and Lifshitz 1976). Therefore, we can refer to the angular speed of a body's rotation without indicating this origin, which, in principle, allows us to consider macroscopic geophysical blocks and geological plates as objects with their proper mo-

ments and to assume that their aggregate is the geomedium. The values of the moments of blocks and plates in this medium must obviously be independent of their sizes (Vikulin 2006, 2008).

The meaning that we assign to the concept of the “proper moment of a block” is closest to the “proper angular momentum of a finite volume of continuum medium” (Vikulin *et al.* 2011). Our approach, where an elastic field surrounding a macroscopic volume (block or plate) “inherits” its proper moment (circulation), differs radically from the approaches of other authors who either neglect the Earth’s rotation or take it into consideration formally in the context of the moment theory of elasticity (Bykov 2008, Nikolaevskiy 1996). The difference of our model from Kosser’s continuum is the following: blocks and plates do not simply have rotational degrees of freedom; they have their proper moments, which, in the case of a rotating medium (geomedium), yield several specific consequences (Vikulin 2006, 2008, 2009; Vikulin and Ivanchin 2000, Vikulin and Krolevets 2002, Vikulin and Tveritina 2008).

4.2 Solving the problem of an elastic field around a block

The field of elastic stresses which occurs in an infinite medium rotating at angular speed Ω about a ball-shaped block with radius R_0 was determined as the solution to the elastic equilibrium equation in the area $r > R_0$ under zero boundary conditions at infinity, with a zero force acting on the block, and with the moment of force being independent of the block dimension R_0 . The analytically obtained solution to the problem for the moment of force K of the elastic field that is directed perpendicular to the plane of its rotation and for the elastic energy W of the field is written as

$$K = -4\pi^{3/2} \Omega R_0^4 \sqrt{\frac{2\rho G}{5}} \sin \beta / 2, \quad (6a)^1$$

$$W = \frac{16}{15} \pi \rho \Omega^2 R_0^5 \sin^2 \beta / 2. \quad (6b)$$

From Eqs. (6a)-(6b), using the model parameters as follows: medium density $\rho = 3 \text{ g/cm}^3$, shear modulus $G = 10^{11} \text{ N/m}^2$, angular speed of the Earth’s rotation about its axis $\Omega = 7.3 \times 10^{-5} \text{ rad/s}$, and block dimension $R_0 = 100 \text{ km}$, which corresponds to an earthquake source with magnitude $M \approx 8$, we obtain $K \sim 10^{28-30} \text{ d}\cdot\text{cm}$ and $W \sim 10^{16-18} \text{ J}$, which are similar in their order of magnitude to the seismic moment and the released elastic en-

¹In (Vikulin 2006, 2008, 2009; Vikulin *et al.* 2011) an analogous expressions for the moment of force are wrong.

ergy, respectively, actually recorded in earthquakes with $M \approx 8$. These values are reached with a rotational angle of the block (of the earthquake source) $\beta \approx \beta_0 \approx 10^{-(3-4)}$ rad. With a duration of a seismic cycle (repetition of the strongest earthquakes at the same site) of 100-1000 years, we find the model estimation for the speed of block rotation (change in angle of rotation β_0) of $10^{-(4-6)}$ deg/year, which is close to the speed of block rotation in (Kuzikov and Mukhamediev 2010, Vikulin and Tveritina 2008).

4.3 Two blocks. Long-range action

The elastic energy around two rotating blocks is equal to

$$W = G \int (a + b)^2 dV = G \left(\int a^2 dV + \int b^2 dV + 2 \int abdV \right),$$

where a and b are the tensors of elastic deformation created as a result of the rotations of the first and second blocks, respectively; integration is performed over the entire volume of the body. The first two summands in the right-hand part of the expression for elastic energy are the proper elastic energies; each of these is calculated on the basis of Eq. (6b). The third summand defines the expression for the energy of interaction between the first and second blocks

$$W_{\text{int}} = 2G \int abdV.$$

The expressions for the interaction energy W_{int} and for the appropriate K_{int} are derived as

$$W_{\text{int}} = \frac{3}{2} \pi \rho \Omega^2 R_{01}^4 R_{02}^4 l^{-3} \cos \phi, \tag{7a}$$

$$K_{\text{int}} = -\frac{3}{2} \pi \rho \Omega^2 R_{01}^4 R_{02}^4 l^{-3} \sin \phi, \tag{7b}$$

where R_{01} and R_{02} are the characteristic sizes of the blocks, l is the distance between their centers, and ϕ is the angle between their moments of forces.

In the case of equivalent blocks, we obtain

$$\frac{K_{\text{int}}}{K} = \frac{3}{8} \sqrt{\frac{5}{2\pi}} \frac{V_R}{V_S} \left(\frac{R_0}{l} \right)^3 \frac{\sin \phi}{\sin \beta/2} \approx \alpha, \tag{8a}$$

$$\frac{W_{\text{int}}}{W} = \frac{45}{32} \left(\frac{R_0}{l} \right)^3 \frac{\sin \phi}{\sin^2 \beta/2} = \delta, \tag{8b}$$

where $V_S = \sqrt{G/\rho}$ is the transverse seismic velocity and $V_R = \Omega R_0$.

From Eq. (8a) it is clear that the inertial moment effects of interaction, which are related to the rotation of blocks inside a rotating body, become more significant as the speed at which the body rotates becomes higher and the block size or the earthquake magnitude become greater. In other words, the maximum ($\sin\phi = 1$) «moment» distance $l_{0,K}$ on which the moment of an elastic field K_{int} (7b) will be in the order of size equal ($\alpha = 1$) to the own moment of K -field (6a), at small ($\beta \approx \beta_0 \approx 10^{-(3-4)}$ rad: $\sin \beta/2 \approx \beta/2$) angles of rotation of the block and at $V_s \approx 4$ km/s, will be defined from a parity.

In other words, the maximum ($\sin\phi = 1$) «moment» distance Λ_K , at which the moment of an elastic field K_{int} (7b) is in the order of magnitude equal ($\alpha = 1$) to the own moment of K -field (6a), at small ($\beta \approx \beta_0$) angles of rotation of the block and at $V_s \approx 4$ km/s, will be defined from the ratio

$$\Lambda_K = \sqrt[3]{\frac{3}{4}} \sqrt{\frac{5}{2\pi}} \sqrt[3]{\frac{V_R}{V_S}} R_0 \beta^{-1/3} \approx 0.1 R_0. \quad (9a)$$

Obviously, the «limit-moment» action between two earthquakes sources, as a matter of fact, is a short-range action of the particle.

From Eq. (8b) it is seen that the maximal ($\cos\phi = 1$) distance Λ_E at which the interaction energy W_{int} (7a) will be close in its order of magnitude to the proper energy W (6b) of the block ($\delta = 1$), will be determined from the expression

$$\Lambda_E \approx 2\beta^{-2/3} R_0 \approx 10^2 R_0, \quad (9b)$$

at which the value of the angle of rotation was assumed as $\beta \approx \beta_0$. It is obvious from Eq. (9b) that elastic deformations with the limit energy of the field inside rotating blocky bodies propagate for a distance that exceeds the block dimensions by 2 orders of magnitude; in other words, limit-energy action is the field of a long-range action of the wave.

4.4 Chain of blocks

The motion equation for a block with coordinate x (along the chain) at time moment t can be written as

$$\frac{\partial^2 \theta}{\partial \xi^2} - \frac{\partial^2 \theta}{\partial \eta^2} = \sin \theta, \quad (10)$$

where $\theta = \beta/2$, $\xi = k_0 x$, $\eta = c_0 k_0 t$ are dimensionless coordinates. The wavenumber k_0 and the speed c_0 are determined from the following equations:

$$k_0^2 = \frac{3\pi\Omega}{wV} \left(\frac{3V}{4\pi} \right)^{4/3} \sqrt{\frac{\rho G}{15}}, \quad c_0^2 = wV/I, \quad (11)$$

where $V = 4/3\pi R_0^3$ is the block volume, I is its moment of inertia, and w is the linear density of the seismic energy released in the chain (Vikulin 2006, 2008).

Equation (10) is known as the Sine–Gordon (SG) equation. Equations of this kind are fairly widely used in solving different geodynamics problems (Bykov 2008, Gershenzon *et al.* 2009).

4.5 Wave solutions to the SG equation

Equation (10) has many solutions; among them are solutions in the form of localized waves, namely, solitons, which are frequently encountered in technical, physical, and geophysical applications (Bykov 2008, Gershenzon *et al.* 2009). Solutions called exitons (by A.S. Davydov; see Vikulin 2008) are possible for a long chain of blocks when we can neglect the influence of its ends (these are also the seismic belts of the planet, including the Pacific Ring of Fire). The qualitative dependences of the excitation energy E on the propagation speed V of solitons (sol, I) and exitons (ex, II) are given in Fig. 3 and are written as

$$E_{\text{sol}} \approx V_{\text{sol}}^n, \quad 0 \leq E_{\text{sol}} \leq E_{\text{sol,max}}, \quad 0 \leq V_{\text{sol}} \leq V_0, \quad (12a)$$

$$E_{\text{ex}} \approx V_{\text{ex}}^p, \quad 0 < E_0 \leq E_{\text{ex}} \leq E_{\text{ex,max}}, \quad V_0 \leq V_{\text{ex}} \leq V_1, \quad n > p, \quad (12b)$$

where V_0 and V_1 are the characteristic rates of the process proceeding in a chain of interacting blocks, E_0 is “zero” oscillation’s energy of seismic belt, as a whole, or Chandler oscillation’s energy (Vikulin 2009, Vikulin and Krolevets 2002).

4.6 Characteristic rate of a seismic process

By analogy to the traditional elastic waves (the case of tectonic approximation; Nikolaevskiy 1996), assuming that the exiton wavelength λ_0 is equal to the size of the seismic focal block ($\lambda_0 \approx R_0$, $k_0 \approx 2\pi/R_0$), we derive from Eq. (11) the following theoretical model expression for the characteristic rate c_0 of the wave process in a chain of interacting blocks (Vikulin 2006, 2008, 2009, 2011):

$$c_0^2 = \frac{3\sqrt{15}}{8\pi^2} \Omega R_0 \sqrt{\frac{G}{\rho}} \approx V_R V_S, \quad (13)$$

or, with the above-assumed parameters of the model,

$$c_0 \approx (1-10) \text{ cm/s}. \quad (14)$$

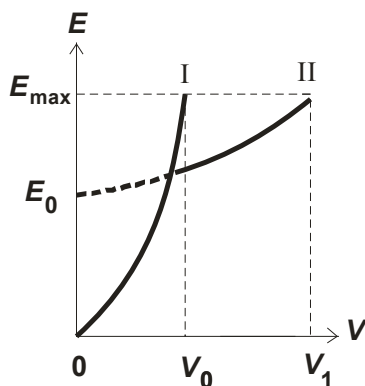


Fig. 3. Wave solutions to the SG equation, Curves I and II denote solitons and exitons, respectively; V_0 and V_1 are the characteristic rates of the process as the limiting velocity of the soliton and exiton solutions; $E_0 > 0$ is the minimal (“zero”) energy of the soliton excitation as the oscillation chain, as whole; E_{\max} is the maximum energy of the process (Vikulin 2006, 2008, 2011).

The equations of the “slopes” of the global ((3a) and (4a)) and local ((3b) and (4b)) migration dependences (see I and II, respectively, in Fig. 2) are not contradictory to the similar theoretical “slopes” of the soliton (12a) and exiton (12b) dependences (see I and II, respectively, in Fig. 3). The model value of the speed c_0 , according to Eqs. (13) and (14), is equal to the limiting rate of the global migration of the sources of Pacific earthquakes $V_{1, \max}$ (1) and, thus, is, in essence, the characteristic rate of the process V_0 (12a)-(12b):

$$c_0 \approx V_{1, \max} \approx V_0. \quad (15)$$

In total, this makes it possible to assume that the global and local dependences of the magnitude and energy of earthquakes upon the rate of migration of their sources (Eqs. (1)-(4)) are the soliton (Eq. (12a)) and exiton (Eq. (12b)) solutions to the SG equation (Eqs. (10)-(14)), which describes the motion of a chain of rotating geoblocks.

The characteristic rate of the process (Eqs. (13) and (15)) with an accuracy to the numerical multiplier may be presented as the geometric mean of the values of the “centrifugal” (V_R) and seismic transversal (V_S) velocities. Thus, the model name was given by its authors (Vikulin and Ivanchin 2000), namely, the rotating elastic-wave model.

4.7 Motion of plates

The “direct” problem of the calculation of the stress field around thin plates moving over the surface of a ball under the action of proper moments was

not solved because of the obvious mathematical difficulties. However, it follows from the geodynamic essence of the problem that fields of stresses around tectonic plates must not differ in physical properties from similar fields around geophysical blocks. The verification of this suggestion is the above-noted similarity of seismic patterns (3a)-(3b) and those of tectonics (5a)-(5b); the latter are actually extensions of the seismic patterns into the range of smaller values of the tectonic rate. It has been shown (Vikulin and Tveritinova 2008) that the “energy” of tectonic patterns (5a)-(5b) based on the mechanism of the planet vortex is determined by the equations

$$E_1 \approx V_1^4, \quad (16a)$$

$$E_2 \approx V_2^2, \quad (16b)$$

which are close to the appropriate seismic energy equalities (4a)-(4b).

Thus, the similarity of the block (3a)-(3b) and energy (4a)-(4b) seismic equations to the similar plate (5a)-(5b) and energy (16a)-(16b) tectonic equations obtained in the proper-moment approximation indicates that the rotational-wave model describes the total aggregate of the interacting geophysical blocks and tectonic plates on the Earth. In other words, the rotational-wave model describes seismotectonic planetary processes. It seems to us that using these concepts it will be possible to explain the large (several hundred kilometer) amplitudes of the oscillations of the Pacific Ocean outskirts in the last 40 million years (Takeuchi 1986).

5. WAVE MOMENT ACTION AS THE BASIS OF A NEW PARADIGM OF GEOLOGY

The Earth and its shape constantly tend to the equilibrium state. Active volcanism, seismicity, and tectonics have taken place throughout the entire history of the Earth; among other things, these main geodynamic processes also determined the Earth’s shape. Through all of the Earth’s history, these processes have been manifested in the form of cyclonic movements in the atmosphere and hydrosphere and vortex structures in the solid Earth that are different in their natures but unified in their essence.

In compliance with the Dirichlet problem and its Dedekind–Riemann solutions, the equilibrium ellipsoidal shape of a rotating gravitating drop is provided by vortex flows occurring inside the drop and on its surface (Vikulin 2009, Vikulin *et al.* 2011). Over large (geologic) time intervals, the Earth may be considered as a “liquid” body. Therefore, the vortex movements that exist in the atmosphere and hydrosphere of the Earth and on its “solid” surface may be considered as flows that correspond to solutions of the Dirichlet–Dedekind–Riemann problem about the equilibrium form of the

Earth with the both geological and geophysical vortical structures and movements in the one class of phenomena (Vikulin 2011, Vikulin *et al.* 2011). The above-described seismotectonic waves may be also assigned to the same class of solutions.

Thus, it is possible to consider a blocky rotating Peive–Sedov–Sadovskii geomedium and the wave elastic-rotational solutions that we obtained for it as the basis for a concept, within whose limits the geodynamic processes can be described analytically.

The main dissimilarity of our proposed moment (and/or wave and/or vortex) geodynamics from global tectonics (Le Pichon 1968, Morgan 1968, Heirtzler *et al.* 1968, *etc.*) consists in the following. The tendency of the rotating Earth to a homogeneous ellipsoidal figure and the probability of the existence of Dirichlet–Dedekind–Riemann vortex movements “switches on” the basic engine of wave geodynamics, *i.e.*, the moment wave mechanism of rotation of its “elementary” volumes. In doing so, a planetary (self-organized) elastic field is generated where the interaction of plates and blocks and, as a consequence, their motion, is provided by means of rotational geodynamical waves. In other words, moment wave geodynamics is the rotation of the Earth about its axis plus global tectonics.

Our proposed concept is in harmony with the tectonic vortex approach but has a substantial distinction: it contains a radically new moment (that is not translationally and globally tectonic! See: Le Pichon 1968, Morgan 1968, Heirtzler *et al.* 1968, *etc.*) mechanism for the “generation” of vortex-wave movements of a geomedium, which is substantiated physically, geophysically, and geologically. It is precisely this moment mechanism, as the geological-physical data indicate, that makes it possible to associate these movements of a geomedium in the context of the Dirichlet–Dedekind–Riemann problem with geodynamical anomalies, including gravitational anomalies in the form of geoid waves (Magnitskiy 1967) (which are moment ones by nature; Vikulin *et al.* 2011) and probably with gravitational waves (Teisseyre 2010, Vikulin *et al.* 2011) and probably with a graceful (no friction) motion of the geomedium (Vikulin 2011), due to the fractal changeability of the geomedium.

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