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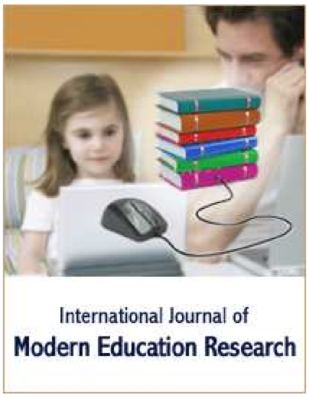

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Rotation elastic fields in solid body modern concept and its implications in geosciences

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Abstract

The article discusses and extends the known concept on higher of blocks in the structure of geomedium by Peive–Sadovsky. It is shown that interaction of structural geoblocks generates force moment. This allows construction of rotation model of geomedium, assumption of the existence of “rotation” waves and explanation of rheidity properties of geomedium. It appears that representative values of “rotation” wave velocities are close to the velocities of pendulum waves (μ-waves by Oparin).

1. Introduction

Richard Feynman specified: “There is no “relativity of rotation.” A rotating system is not an inertial frame, and the laws of physics are different.” [1].

The recent advance in the geosciences are the substantiation of the block structure of a geological and geophysical environment (geomedium) and the canonicity of its discontinuous properties [2–6]. However, the researchers did not understand significance of the block structure of geomedium concerning each individual block [7]. Rotation of a block-structure geomedium is subject to the laws of classical mechanics.

Actual properties of geoblocks are the focus of in-depth studies [8]. Many-years experimental and theoretical research has defined a new branch in the mining science—non-linear geomechanics with its conceptualization of linear nesting of geoblocks on adjacent structural levels of their hierarchy and pendulum waves intrinsically relating to deformation waves [9, 10]. Development of this scientific branch has yielded many practically and theoretically important results [11–14].

In 2004 the “pulsed” behavior of seismic energy emission in high stress rock masses was revealed [15] and the existence of pendulum waves in block-structure geomedia was substantiated by experiments [16–18]. In 2005 it was proved that the pulsed seismic energy emission is an important diagnostic indictor of stress–strain state in rocks [19]. Field automated rock mass deformation data acquisition has been designed, and attenuation of pendulum waves has been examined in varied conditions [20–22].

Issues of control over non-linear quasi-static and wave processes in rocks masses with structural hierarchy of blocks have been decided [14, 20, 21]. Apparent and actual velocities of transversal waves generated by oscillation of blocks under impact action have been determined, and propagation of pendulum waves under pulse effect of the type of "rotation center" has been investigated [14]. The ample research revealed new properties of block geomedia but it took no account of motion of the Earth.

This article discusses rotation properties of geoblocks as the parts of the rotating body of the Earth.

Rotational motion of geoblocks and the Earth's rotation around its axis are very important factors in geodynamics. A comprehensive review on this matter is given in [23]. Rotational motion of individual geoblocks, tectonic plates, etc. is a common phenomenon. For example, Siberian plate occurred at near-equatorial and low north latitudes with quasi-fluctuating rotation relative to terrestrial meridian with amplitude up to 45° during Paleozoic–Mesozoic–Proterozoic ages (2.5–1 billion years ago), and at the beginning of Neo Proterozoic era (1.6–1 billion years ago) the plate counterclockwise turned by 90° [24]. The other lithosphere plates and geological structures move as well: Pacific plate has been moving around Hawaiian hot point with period of 6–7 million years and amplitude to 10° for recent 40 million years [25].

Spine rates of geological structures and geoblocks vary within wide ranges. With the advanced equipment-aided areal survey and the obtained data analysis techniques, first of all, long-term geophysical monitoring, including dense GPS observation over vast areas of the Earth surface, it is possible to narrow the spin rate ranges. Long-term geophysical explorations displayed that the Easter Ireland (300×400 km^2) in the Pacific Ocean has turned nearly at 90° for almost 5 million years of its existence [26], which matches with the spin rate of 0.5π rad/$5 \cdot 10^6$ year $\approx 3 \cdot 10^{-7}$ rad/yr. The 10-year dense GPS network survey in Central Asia shows that this area ($38° \le \varphi$ N $\le 45°$, $69° \le \lambda$ W $\le 81°$) is a set of 28 blocks 50 to 500 km in size, rotating every which way at rates 03–5 ms/yr (or 10^{-10}–10^{-8} rad/yr) [27]. Thus, the most plausible spin rate range of geoblocks and plates is wide, 10^{-8}–10^{-6} rad/yr, and these rotations are connected with the Earth rotation [23].

Lithosphere is continuously in motion in consequence of which geoblocks progressively migrate along the Earth surface. For instance, let a geoblock move from *A* to *B* during a certain time (Fig. 1a). This defines rotation properties of the block structure of the lithosphere. Spin rate Ω of coordinate system rigidly connected with the body (Earth) appears in a sense independent of this coordinate system—all such systems at a set time revolve mutually parallel axes at rates Ω equal in absolute value [28]. For this reason, each geoblock (and/or plate), irrespective of its size, has the same angular momentum M oriented in parallel to the Earth rotation axis: $\mathbf{M} = m\mathbf{\Omega}$ [28], where *m* is spin inertia of the geoblock (plate), that may change when the geoblocks move and, as a consequence, deform. Movement of the lithosphere could change orientation of the angular momentum: $\mathbf{M_1} \to \mathbf{M_2}$, but this is impossible since the angular momentum is to be preserved and the geoblock is to move together with the Earth at the spin rate Ω. This brings about a force moment *K* imposed to the geoblock by the lithosphere (Fig. 1b).

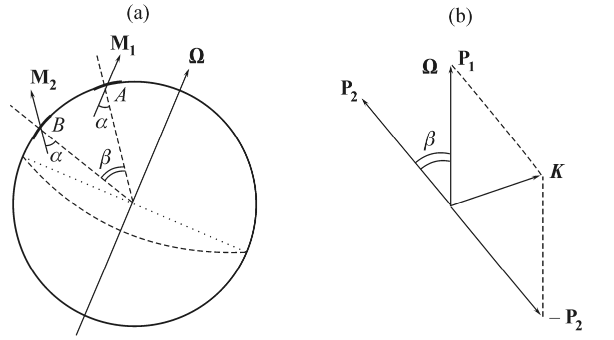

Fig 1. *(a) Geoblock travel from A with the angular momentum M_1 to B with the angular momentum M_2 (rotation by angle β) and (b) generation of the force momentum K.*

To define the value and orientation of $\mathbf{M_1}$, we, first, imaginary stop the geoblock at *B* (the block is assumed a homogeneous sphere) by applying elastic stresses with force momentum $-\mathbf{P_2}$ to it, then, bring the geoblock to initial state rotation with the momentum $\mathbf{M_1}$ by subjecting it to elastic stresses with the force momentum $\mathbf{P_1}$. On the assumption that conversion of kinetic energy of the geoblock rotation to elastic stresses and backward is isothermal, without energy loss ($|\mathbf{P_1}| = |\mathbf{P_2}| = \mathbf{P}$), we obtain from the cosine theory for the momentum *K*:

$$|\boldsymbol{K}| = 2P\sin\beta/2. \tag{1}$$

It is important that elastic stresses with the force momentum *K* are applied to the surface of the geoblock from the side of its ambient medium (lithosphere).

In this manner, we shift to a model where motion of a geoblock in a geomedium rotation at the spin rate Ω is physically equal to the motion of a geoblock under *intrinsic angular momentum* M (rotation by angle β), and the latter generates the elastic field with the force momentum (1) in the vicinity of the geoblock. The generated elastic stresses are the consequence of the law of conservation of angular momentum.

The intrinsic momentum M (spin, in point of fact) has a specific geodynamic property: it does not vanish owing to plastic strain of the geoblock. Therefore, rotation stresses with the force momentum (1) as a result of progressive motion of the geoblock (because of the turn angle β increase) "accumulate" in the lithosphere, which offers an explanation of the known property of the geomedium—energy saturation [29].

For the first time, the inner movement potential of a geomedium was highlighted by Academician Peive in 1961

[2]. Mechanically, the model of a finite volume continuum with angular momentum was based by Academician Sedov in 1969 in terms of magnetic media [3]. Definition of natural lumpiness (block structure) of a geomedium was introduced by Academician Sadovsky in 1979 [3]. Canonical representation of discontinuous properties of a geomedium and its objects was given by. Oparin in 2007 [5, 6]. Ponomarev analyzed mechanical, geological and geophysical properties of geomedia and deduced on *intrinsic energy potential* of a geomedium in 2008 [29]. “The paradigm on volumetric mobility … of the coherent earth crust … must be taken one of the keystone of geodynamics” [31].

In the early 1990s [32, 33], the rotation model of a geoblock with intrinsic momentum was constructed to describe seismicity within the Pacific Ocean margin based on the experimental data on rotation of solid meso-structures at big angles, lumpiness by Sadovsky and the known data on interconnection between seismicity and the Earth rotation. In after years, it has become clear that all this information may be reduced to geological-and-geophysical blocky (by Peive–Sadovsky), mechanical macroscopic (by Sedov), zero-shift rotational (by Panin [34]) and mesomechanical canonically discontinuous (by Oparin [5, 6]) conceptualization [35, 36].

2. Rotation Stresses and their Properties

Let a sphere-shape rock block with diameter R_0 rotate in response to its own angular momentum in immovable enclosing rock mass $r \geq R_0$ and create elastic stress with the force moment (1). Aiming at assessment of the elastic stress σ, elastic energy W and force moment $\boldsymbol{K}$, we formulate a problem, including the equation of elastic equilibrium:

$$\operatorname{grad}\operatorname{div}\boldsymbol{U} - a\cdot\operatorname{rot}\operatorname{rot}\boldsymbol{U} = 0$$

with zero displacement at infinity:

$$|\boldsymbol{U}| \to 0 \quad \text{at} \quad r = (x_1^2 + x_2^2 + x_3^2)^{1/2} \to 0,$$

zero force applied to the block with volume V:

$$F_i = \int \sigma_{ij} n_j dS = 0$$

and non-zero force moment independent of the block size:

$$K_i = \int x_k e_{ikl} \sigma_{lj} dS_j.$$

Here, $a = (1-2\nu)/2(1-\nu)$, ν is Poisson’s ratio; R_0 is domain radius; e_{ikl} is Levi-Civita tensor. Integrating in the last two expressions is carried out over the surface of the rotating block.

The authors have solved the problem analytically, in the spherical coordinates (r, θ, φ) with the origin $r = 0$ in the block center and with the plane $\theta = 0$ orthogonal to K for the force moment K:

$$K = -8\pi^{3/2}\Omega R_0^4 \sqrt{\frac{\rho G}{5}} \sin\beta/2 \tag{2}$$

The minus sign means that the force moment is applied to the geoblock by the lithosphere. The energy W is:

$$W = \frac{16}{15}\pi\rho\Omega^2 R_0^5 \sin^2\beta/2 \tag{3}$$

and the stress is:

$$\sigma_{r\varphi} = \sigma_{\varphi r} = 4\Omega R_0^4 r^{-3} \sqrt{\frac{\rho G}{5\pi}} \sin\theta \sin\beta/2, \; r \geq R_0. \tag{4}$$

The other stresses are zero. Here, $\rho \approx 3$ g/cm^3 and $G \approx 10^{12}$ dyne/cm^2 are density and shear modulus of the geomedium; $\Omega = 7.3 \cdot 10^{-5}$ rad/s is spin rate of the Earth rotation. Direct substitution of the original equations by (2)–(4) proves correctness of the latter.

Numerical factors in (2) and (4) are 1.3 and 2.8 times lower than in the same expressions derived in [33, 35], due to assumptions made there. Consequently, earlier estimates accurate to order of magnitude hold true. In particular, for magnitude $M \approx 8$ (7.5–8.5) earthquakes with typical source radii $R_0 \approx 100$ km, theoretical $K \approx 10^{27}$ dyne/cm and $\sigma \approx 10^2 - 10^3$ bar absolute obtained from (2) and (4) coincide with the experimental seismic moments and earthquake focus stress [37]. Turn angle of the block–earthquake source is to be $\beta_0 = 10^{-4} - 10^{-2}$ rad, which fits the spin rate $10^{-7} - 10^{-4}$ rad/yr for such earthquake periodicity once 100–1000 years.

So, the spin rate range defined within the rotation model meets the spin rate range obtained based on geophysical measurements, which speaks well for the discussed rotation model and its implications.

Parameter β is not critical for the rotation model: if $\beta = 0$ in the block medium, rotation stress with force moment vanishes. Accordingly, for a nonlinear geomedium, aboutness of the model and experimental spin rates is reckoned as indication of “internal” coordination consistency of the block structure and momentum of geomedium.

The model of two blocks R_{01} and R_{02} spaced at l allowed analytical energy of the block interaction, W_{int} [33] in:

$$W = G\int (a_1 + a_2)^2 dV = G\int a_1^2 dV + G\int a_2^2 dV + 2G\int a_1 a_2 dV = W_1 + W_2 + W_{int},$$

where $a_{1,2}$ are elastic strain tensors generated by the two rotating blocks separately. We calculated the third summand equal to double product of the first and second invariants of stress tensor for elastic energy and obtained as a result:

$$W_{int} = \frac{3}{2}\pi\rho\,\Omega^2 R_{01}^4 R_{02}^4 l^{-3}\cos\phi, \qquad (5)$$

where ϕ is angle between the moments of the blocks. On the strength of this energy, the blocks rotate one the other. The force moment governed by the block interaction is found by differentiating (5) with respect to ϕ:

$$K_{int} = -\frac{3}{2}\pi\rho\,\Omega^2 R_{01}^4 R_{02}^4 l^{-3}\sin\phi \qquad (6)$$

Force moment (6) is applied to the surfaces of each block so that to decrease the interaction energy. This moment has the same value but different directions for the two blocks.

For the equal size blocks $R_{01} = R_{02}$, the ratio of interaction moment (6) to intrinsic moment (2) is:

$$\frac{K_{int}}{K} = \frac{3}{16\sqrt{5\pi}}\frac{\Omega R_0}{V_S}\left(\frac{R_0}{l}\right)^3 \frac{\sin\phi}{\sin\beta/2} = \chi,$$

whence it follows that the interaction moment grows with the higher centrifugal force $V_R = \Omega R_0$ (i.e., with the higher spin rate Ω and larger block size R_0; $V_S = \sqrt{G/\rho}$ is *S*-wave velocity). The maximum ($\sin\phi = 1$) "moment" span $l = l_{0K}$, where the elastic field moment K_{int} (6) is equal ($\chi = 1$) to the intrinsic moment *K* (2) of the block, with the accepted parameters of the model *m*, is written as:

$$l_{0K} = \sqrt[3]{\frac{3}{8\sqrt{5\pi}}}\beta_0^{-1/3}\left(\frac{V_R}{V_S}\right)^{1/3} R_0 \approx R_0 \qquad (7)$$

Thus, the "limit" interaction moment, like molecular interaction forces of particles in the classical elastic theory, is short-range (not to exceed the sizes of the blocks).

Similarly, calculating the ratio of block interaction energy (5) to intrinsic energy (3) for the span $l = l_{0W}$ of the "limit" energy interaction yields:

$$l_{0W} = \sqrt[3]{6}R_0\beta_0^{-2/3} \approx 10^2 R_0 \qquad (8)$$

This expression means that elastic field of the energy interaction is long-range (two orders of magnitude higher than the sizes of the blocks).

So then, interaction of blocks in a geomedium in non-inertial coordinates is of wave-particle type. First, the short-range interaction takes place in the form of exchange of K_{int} (6) between the neighbor blocks rather than owing to their interface friction (as in elastic moment theory), which would obstruct the block interaction within the frames of the rotation model. The illustration of such interaction are the strongest earthquakes-duplets (and multiple quakes) with near focuses. Aside from earthquakes, intensive free oscillations are always excited over vast areas of ground surface. Second, the long-range interaction occurs in the form of exchange of energies W_{int} (5) between the blocks at large distances (much bigger than the sizes of the blocks). The examples of this the well-known migration of earthquake focuses along seismic belts, for many tens of thousands of kilometers [38], remote foreshocks and aftershocks [39] and earthquake couples [35].

Physics often associates the short-range and long-range interactions with wave (via medium where the particles are) and particle (via interfaces of the particles) interactions. Constituent elements of a block-structure geomedium can be assumed "elementary" particles. Accordingly, in terms of physics, interaction of blocks within the frames of the rotation model images the wave-particle duality: movement of geological blocks, tectonic plates and other subsoil structures exhibits particulate and wave features. Let us illustrate the aforesaid in terms of the block interaction in the rotation model.

3. Rotation Waves in the Rotating Block-Structure Geomedia

For a block that generates elastic field with the force moment (2), which interacts with elastic fields generated by other equal-size blocks in a chain of masses, the law of motion was derived in the form of the sine-Gordon equation (SG) [32]. A seismic belt was modeled as a one-dimension chain of mutually interacting earth crust blocks holding earthquake sources. Each block had inertia moment *I* and volume $V = 4\pi R_0^3$. Considering that, the block motion equation is: $I\frac{\partial^2\beta}{\partial t^2} = K_1 + K_2$, where K_1 is force moment to match the elastic stress field generated by an individual block according to (2); K_2 is force moment of interaction of the block with the other blocks in the chain. It was assumed that K_2 was proportional both to elastic energy accumulated during motion of the given block $V\frac{\partial^2\beta}{\partial z^2}$ and to elastic energy of the other blocks in the chain. As a result, the dimensionless form of the block motion equation is:

$$\frac{\partial^2\theta}{\partial\xi^2} - \frac{\partial^2\theta}{\partial\eta^2} = \sin\theta,$$

where $\theta = \beta/2$, $\xi = k_0 z$ and $\eta = v_0 k_0 t$ are dimensionless coordinates; *z* is length of the chain of masses (blocks); *t* is time. Assuming the wave length close to the blocks size, $\lambda \approx R_0$, and wave number $k_0 = 2\pi/R_0$, the representative velocity v_0 of the process is:

$$v_0 = \sqrt{\frac{15}{8\pi^2\sqrt{5\pi}}\Omega R_0\sqrt{G/\rho}} \approx \sqrt{\frac{\sqrt{15}}{8\pi^2}V_R V_S} = 0.2\sqrt{V_R V_S} \quad (9)$$

The law is preconditioned by the elastic field force moment (2). The SG equation is due to the law of conservation of angular momentum. In this case, it is possible to exclude friction between blocks in the chain as against the classic elastic momentum theory, e.g. [40]. As a consequence, this approach, so long as solutions (2) and (3) of the rotation problem on stress field around a rotating block under action of the intrinsic moment are obtained within the classic elasticity [41] with the symmetric stress tensor (4), allows physically "transparent" interpretation of representative velocity of a geophysical process described by the SG equation.

It follows from (9) that with constant G, ρ, R_0, v_0 only depends on the spin rate Ω, which means that such processes are actually initiated by the Earth rotation [42]. That was the reason for choosing the name of the model—rotation model [32, 33]. With the above-accepted parameters of the crust, $v_0 = 10 - 10^2$ m/s.

Another case analyzed was a chain of nonuniformly rotating blocks, with deviation of force moments from equilibrium positions μ, considering friction forces α along boundaries, which better matched a real-life seismic process. As earlier, friction was not included in the interaction analysis as block-and-block engagement factor but as a lossy factor that obstructs the rotation interaction of the blocks. As a result, the authors obtained the law of motion for a block in a chain in the form of the modified SG equation [42]:

$$\frac{\partial^2\theta}{\partial\xi^2} - \frac{\partial^2\theta}{\partial\eta^2} = \sin\theta + \alpha\frac{\partial\theta}{\partial\eta} + \mu\delta(\xi)\sin\theta$$

that was solved by perturbation method by McLaughlin and Scott. Here, δ is Dirac function. Original conditions agreed with the average strain rates in seismically active areas. The friction coefficient α and nonuniformity factor μ were taken to match the data on the real faults. According to the analysis, for the slow seismic process when interaction between the blocks–sources of earthquake is contributed to by slow motion—creep, asymptotic velocity of translation of rotation deformations is $c_0 \approx 1 - 10$ cm/s [42]. In this manner, we can assume that the representative velocity $\{v_0, c_0\}$ of translation of solitonic-type rotation deformations (stresses with force moment) in the frames of a block-structure geomedium model can be written as:

$$c_0 = \gamma\sqrt{V_R V_S}, \quad c_0 \approx 1 - 10 \text{ cm/s}, \qquad (10)$$

where $\gamma = K^{-1} \approx 10^{-4}$ is non-linear parametric characteristic of a real-life chain of blocks (different-dimension, nonuniformly rotating because of friction, i.e., a set of earthquake sources in a seismic belt); $K = 10^3 - 10^5$ is a geomedium nonlinearity coefficient equal to a ratio of the third order elastic moduli to the second order elastic moduli (linear elasticity moduli) [14].

An SG-equation can have many solutions. Modeling of motion in long molecular chains [43] showed that wave motion in those chains could be described by a soliton or an exiton—solutions (1) and (2) in Fig. 2, respectively. Such solutions have typical "limit" velocities matching the maximum excitation energies $E_{\max}$: V_{01} and V_{02}.

Figure 3 displays migration velocities of the Pacific zone earthquakes [44]. The global migratory movement I (along the whole seismic belt) and the local migratory movement II (inside of strong earthquake sources) $M_{1,2}(\lg V_{1,2})$ described by the maximum velocities $V_{1,2,\max}$ and the related maximum magnitudes $M_{1,2,\max}$ are:

$$M_1 \approx 2\lg V_1,\ V_{1,\max} \approx 1-10 \text{ cm/s},\ M_{1,\max} = 8.5-9, \quad (11)$$

$$M_2 \approx \lg V_2,\ V_{2,\max} \approx V_S - V_P \approx 4-8 \text{ km/s},\ M_{2,\max} = 8.3. \quad (12)$$

The model curves for molecular chains (Fig. 2) and experimental curves for chains of earthquake sources (Fig. 3) qualitatively agree, which allows interpreting migration relations (11) and (12) as soliton and exiton solutions of the SG-equation with intrinsic limit velocities $V_{01} = V_{1,\max}$ and $V_{02} = V_{2,\max}$. The limit velocity of soliton solution $V_{01} = 1 - 10$ cm/s (curve *1* in Fig. 2) matches the intrinsic velocity c_0 (10) in the framework of the rotation model of a nonlinear block-structure geomedium, which permits interpretation of the latter as the limit velocity V_{01} of the soliton SG-equation solution.

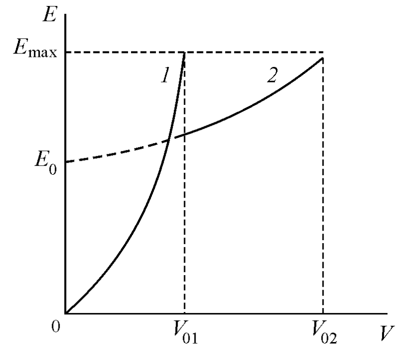

Fig 2. *The SG-equation wave solutions E(V) [43]: 1—solitons; 2—exitons; V_{01}, V_{02} —intrinsic velocities matching the maximum energies $E = E_{\max}$ of the soliton ($0 \le E \le E_{\max}$, $0 \le V \le V_{01}$) and exiton ($0 \le E_0 \le E \le E_{\max}$, $V_{01} \le V \le V_{02}$) solutions, respectively; $E_{\max}$ — maximum excitation energy of the entire chain of molecules (earthquake sources in a seismic belt) when V = 0.*

Based on the mathematical aboutness of the wave equations for long one-dimensional chains of blocks (I and II, relations (11) and (12) in Fig. 3) and for chains of molecules (curves *1* and *2* in Fig. 2), it was assumed that interaction of constituents of the chains obeyed the same physical laws.

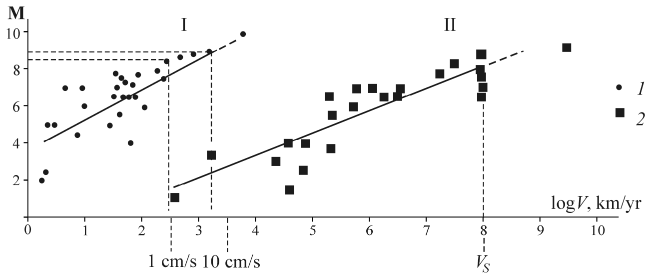

Fig 3. *The global migration I (1—along a seismic belt) and the local migration II (2—inside strong earthquake sources individually) of the Pacific zone earthquakes [35]:* $M(\log V)$ *were found by mid-square method;* V_S *—S-wave velocity.*

The SG-equation soliton solutions are known to have properties relating the properties of the real elementary particles [45], and exitons are the perturbances that are transformed into regular waves on a linear approximation [43], the *P*- and *S*-waves in the case discussed. Consequently, the soliton and exiton solutions with the maximum velocities $V_{01} \approx c_0$ and $V_{02} = V_S \div V_P$ in the framework of the rotation model may be a new type of elastic waves in solids—rotation waves [46, 47] responsible for particle-and-wave interactions of geoblocks in rotation geomedia.

4. Superplasticity (Rheidity) of Geomedium

There is a lot of evidence about ground surface motions as "Earth's humps" in the line of earthquake sources [23]. For instance, "… a wave 20–39 cm high ran across the surface of the terrace, and the earth momentarily turned into a plastic substance, .. and in an eyewink the terrace surface was flat and perfectly even again. Not a sign of deformation": [31]. Or, "during the earthquake…waves 1.2–1.8 m high and 3 m long ran on the concrete roadway and the sidewalk but not a crack appeared in the concrete" [48]. Analysis of the instrument-recorded movements nearby the sources of the strong Parkfield earthquake in California in 1966 concluded that the ground motion (with characteristic duration within 10–100 s) nearby the originated fault was more typical of a fluid [49]. The rocks in the vortex structures, perhaps, for hundreds of thousands (10^{12} s) of millions (10^{13} s) of years, "had been formed as curved solid structures in place, owing to upper mantle substance, rather than straight-line structures that were later bended mechanically" [50].

"Coil-like" forerunners of earthquakes were associated with fluctuations of ground surface with typical periods of approximately 100 days (10^5 s). For example, the "dome-like" puff-up (Saint-Andreas, USA) over the area of 2.10^4 m across and ~ 0.5 m high. The puff-up broke china and vanished safely without meeting expectations of seismologists [51]. Another phenomenon of the kind might be the one in Valdai Hill in 1601 described by a chronicler: "Out of the Lake Brosn, out of water, a sand mountain came, seven fathoms high from the water bottom, and stood there for twelve days… Upon twelve days, it fell for seven fathoms, and it became as it was" [52]. In summer 2011 a wide area 435 m long and 50 m wide on the Tamansky Peninsula had been heaved up to 3.5 for a month, though neither seismic nor volcanic activity was registered in the vicinity [53]. Analysis of the analogous events [51] showed that their "different signs and fleetness resemble a liquid process."

Based on the geophysical and geological databases on "slow" motions within 10–10^{13} s in geomedia, geologists introduced rheidity [54, 55] or superplasticity deformations of the Earth as "solid material flow" [31] in the 1930s. The present authors will show that the rheidity state is a direct consequence of rotation of the geoenvironment.

According to the review of rheological properties of the Earth [44], the Debye temperature θ_d of the geoenvironment may be written as [56]:

$$\theta_d \approx 10^{-3}\overline{V}(H)\sqrt[3]{\rho(H)}, \tag{13}$$

where $\overline{V}$ is average excitation velocity in the geoenvironment, cm/s; ρ is density of the geoenvironment, g/cm^3; *H* is depth. At the average velocity of 1–10 km/s (defined by the *P*- and *S*-waves velocities) in the lithosphere and upper mantle, the Debye temperature is quite high: $\theta_d \approx 660°$, $K \approx 1000$°C at H = 100 km, and agrees well with the developed model of the physics of Earth [56].

The situation is radically different on the transfer to the rotation mode c_0 (10) governed by the joint movement of a set of geoblocks, tectonic plates and geological structures. The intrinsic limit value of c_0 (10) is five orders less than the *P*- and *S*-wave velocities and has low Debye temperature:

$$\theta_d \approx 10^{-2} K$$

that defines the possibility of quantum, friction-free superfluid motion of the geoenvironment—the rheidity [54, 55] and superplastic flow in solid [31].

The Debye temperature is proportional to maximum possible vibration frequency of the geoenvironment particles [57], or meso-volumes for a solid or geoblocks, tectonic plates and other geological structures for the Earth. This vibration frequency for the Earth, as shown in [58], is the Chandler frequency of vibration of all the constituent geoblocks in a seismic belt. The vibration of the belt as an aggregate is governed by the "zero" vibration energy E_0 (Fig. 2).

5. Discussion of the Results. The Rotation Waves and Pendulum Waves (μ-Waves by Oparin)

An important condition of the rotation model is the symmetric property of the stress tensor generated by moving blocks in a nonlinear geomedium, (4), which agrees with the basic physical principle of the classical elasticity theory [41]. At the same time, mathematical modeling often addresses the nonsymmetrical stress tensor.

It was mentioned in [59] that "the first edition course by Landau and Lifshitz contained restraining theories on asymmetry of stress tensor. The misconception has only recently been amended." The first edition of the course by Landau and Lifshitz came off the press in 1944, while the second proof of the stress tensor symmetry based on the generalized macroscopic theory was presented by the followers of Landau and Lifshitz in the fourth edition of "The Elasticity Theory" published in 1987 (refer to e.g. [41]). Who amended "the misconception" and why it was "the misconception" was not discussed in [59]. The question of admissibility of the stress tensor asymmetry in physical problems was raised in [60], where, nonetheless, no solid opponency of the physical sense of the stress tensor symmetry can be found. The concept of the asymmetrical stress tensor as "divergence of a higher order tensor" (refer to relation (5.2.24) [60]) is actually discussed in the course by Landau and Lifshitz, and it is shown there that "this asymmetrical tensor can be reduced to the symmetrical form" [41]. The growing declarations for the stress tensor nonsymmetry [40, 59, 60, etc.] are probably an attempt to proving the *physical* feasibility of using mathematical continuums with nonsymmetrical stress tensors in solving problems of mesomechanics [34, 61] and geomechanics [40, 59, etc.]. For instance, the absence of the physical sense of the Cosserat brothers' model to be the basis for the moment elastic theory ([refer to [62]) was exhibited almost immediately after the model introduction in 1910 [63]. "The nonexistence of elastic–viscoelastic waves" running along lithosphere fault in the framework of such models was highlighted in [64].

Clearly explained from the theoretical standpoint, the stress tensor symmetry is supported by the experimental measurement data for more than 300 years. Physically objectless discussion of applicability of the models with the nonsymmetrical stress tensor to solving physical problems is the discussion of violating the law of conservation of angular moment in interaction of a body's macroparticles, in point of fact, which only says on the absence of such models and a solid and a geoenvironment where turns of constituent blocks could be matched with the stress tensor symmetry [35]. The rotation model of a rotating block-structured geomedium with the symmetrical stress tensor succeeded the "matching" and is, therefore, physically substantiated [32, 33, 35, 36, 42, 44, 46, 58, 65–67].

The theoretical model soliton and exiton solutions describe natural migration of earthquake sources either in the bounds of a seismic belt or in the bounds of a strong earthquake source. Characteristic velocities of the soliton and exiton waves, $V_{01} \approx c_0$ and $V_{02} \approx V_S \div V_P$, respectively, are the limits of maximum possible velocities of excitation transfer in geodynamic processes of the global (wave) and (local) moment migration of earthquake sources. According to the classification [68], these waves correspond to slow and fast tectonic waves. These velocities are governed by the parameters Ω, R_0 and V_S, intrinsic for the entire planet [44]. This "dualism" is related, in general, to the rotation waves in a nonlinear rotating block-structured medium and the gravitational perturbations and the associated forerunners of earthquakes and eruptions [69], and allows describing the rotation waves by the non-Euclidean models of deformation of materials at different structural levels [70]. The analysis of the concept of geomedium's block structure led Prof. Revuzhenko and his colleagues to a kin deduction on applicability of "the non-Archimedean space and time" to description of properties of block-structured media.

The wave-and-particle dualism clearly shows in processes with quantum-close dimension: photoeffect, microparticle diffraction. Nonetheless, after the classical studies by de Broglie and Einstein, it has been positively ascertained that the dualism being the inherency of a material regardless the space and time. Short-range and long-range interaction of geoblocks, being macroscopic particles in terms of their size and life, can be taken as the confirmation of the wave-and-particle dualism of de Broglie and Einstein, on the one hand; on the other hand, it opens new prospects for investigating the nature of this dualism [35].

Physically, more information on a deformation process is not provided by the block turn angle β but by its derivative with respect to time, i.e., the rotation deformation velocity that is the function of the Earth's spin rate Ω and the velocity of a rotation wave which is an isolated *S*-wave polarized perpendicularly to propagation direction [42]. Suchwise representation of the rotation waves allows comparing them with the pendulum waves (μ-waves by Oparin).

The same block approach, just from the viewpoint of fracture growth in space, when the main processes are the "composition and decompositions of the Earth substance" [72], is used to show the existence of the pendulum waves as determinants of geodynamic processes [73]. As the rotation waves, the pendulum waves have their velocities lower than the *P*-wave velocities. Experimental illustration of the pendulum waves is shown as the oscillation process in chains of rigid blocks analogous to the chain of blocks in the rotation model. In the chains of rigid blocks, two types of waves are distinguished [20] as in the rotation model. Laboratory experiments yielded the pendulum wave velocity range 10^2–10^3 m/s [72], including the values close to seismic wave velocities. The in situ velocities of the pendulum waves, 1–10 cm/s [72], are close to the characteristic velocity of the rotation waves, $c_0 \approx V_{01}$.

Thus, within the wave geodynamics, the both approaches [23, 24, 26, 27, 29, 33, 35, 37, 46, 65–67] and [5, 8, 10, 11, 20, 72, 73] independently yield close results.

Moreover, the introduction of a simple turn in the form of a "point" pulsed effect of the type of "rotation center" in a block model [14] ended with "splitting" of pendulum waves into pendulum waves with different velocities. On this basis, the rotation and pendulum wave are referred to the same class phenomenon—interaction of geoblocks in a rotating medium through the elastic field with the force moment. Probably, the methods used to study the pendulum waves [20] would be of use to development of recording methods for the rotation waves that are traced using indirect, noninstrumental techniques, like the tectonic (deformation) waves [68].

Analysis of the in situ stress measurements taken in mines in the north of Eurasia showed that the Earth crust, with its definite structure, self-organizes, re-structures to avoid accumulation of energy and generates a new structure only upon arriving at the end of its resources [11]. The restructuring is described using the pendulum and rotation waves. The united geodynamic and geomechanical approaches within the framework of the rotation and pendulum concept will hasten the development of a deterministic forecast of stress state in a geoenvironment [74].

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