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Recent Geodynamics

GEODYNAMICS AS WAVE DYNAMICS OF THE MEDIUM COMPOSED OF ROTATING BLOCKS

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Abstract: The geomedium block concept envisages that stresses in the medium composed of rotating blocks have torque and thus predetermine the medium's energy capacity (in terms of [*Ponomarev*, *2008*]). The present paper describes the wave nature of the global geodynamic process taking place in the medium characterized by the existence of slow and fast rotation strain waves that are classified as a new type of waves. Movements may also occur as rheid, superplastic and/or superfluid motions and facilitate the formation of vortex geological structures in the geomedium.

Our analysis of data on almost 800 strong volcanic eruptions shows that the magma chamber's thickness is generally small, about 0.5 km, and this value is constant, independent of the volcanic process and predetermined by properties of the crust. A new magma chamber model is based on the idea of 'thermal explosion'/'self-acceleration' manifested by intensive plastic movements along boundaries between the blocks in conditions of the low thermal conductivity of the geomedium. It is shown that if the solid rock in the magma chamber is overheated above its melting point, high stresses may occur in the surrounding area, and their elastic energy may amount to 10^{15} joules per 1 km^3 of the overheated solid rock. In view of such stresses, it is possible to consider the interaction between volcano's magma chambers as the migration of volcanic activity along the volcanic arc and provide an explanation of the interaction between volcanic activity and seismicity within the adjacent parallel arcs.

The thin overheated interlayer/magma chamber concept may be valid for the entire Earth's crust. In our hypothesis, properties of the Moho are determined by the phase transition from the block structure of the crust to the nonblock structure of the upper mantle.

Key words: geodynamics, force moment, rotational waves, rheid flow, gravitational waves.

Recommended by S.I. Sherman

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ГЕОДИНАМИКА КАК ВОЛНОВАЯ ДИНАМИКА БЛОКОВОЙ ВРАЩАЮЩЕЙСЯ СРЕДЫ

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Аннотация: В работе развивается концепция блоковой геосреды применительно к геодинамическому (сейсмическому и вулканическому) процессу. Работу, в целом, можно представить в виде четырех частей: *введения*, *шести разделов*, кратко описывающих разработанную ранее автором ротационную модель сейсмотектонического процесса, *трех разделов*, посвященных развитию блоковой концепции применительно к вулканическому процессу, и *обсуждения результатов*.

Во *введении* на примере анализа исследований, проводимых в течение последних десятилетий сотрудниками Института земной коры СО РАН, показывается, что концепция тектонофизического процесса Байкальской рифтовой зоны, разрабатываемая в рамках разломной тектоники на региональном уровне, не позволяет видеть всю картину в целом. Региональные концепции существенным образом опираются на представления

о разломах, представления о блоковой среде используются чисто формально. И, несмотря на большие успехи [*Sherman, 2014*], уже на первых этапах построения региональной модели ученые вынуждены вводить взаимосвязи между ее параметрами, тем самым резко ограничивая возможности интерпретации модели на заключительных этапах исследования. Отмечается, что принцип Сен-Венана в применении к задачам сейсмологии и геодинамики не может рассматриваться как фундаментальный.

В разделе «*Напряжения с моментом силы*» проводится построение механически очевидной модели движения блока, являющегося частью вращающейся среды – геосреды. Показывается (рис. 1), что в блоковой вращающейся и передвигающейся вдоль поверхности Земли геосреде генерируется упругое поле с моментом силы, которое действует на блоки через их поверхности. Такие свойства упругого поля являются следствием закона сохранения момента количества движения. Движение блока во вращающейся системе координат механически эквивалентно движению блока в невращающейся (инерциальной) системе координат под действием собственного момента силы (спина), который в окружающем блок пространстве создает упругое поле с моментом силы. Такие напряжения в геосреде накапливаются, что и может объяснить ее известное свойство – энергонасыщенность [*Ponomarev, 2008*].

В разделе «*Близкодействие и дальнодействие ротационного упругого поля*» показывается, что поле упругих напряжений с моментом в геосреде описывается симметричным тензором напряжений. Оно характеризуется близкодействием – «моментным» взаимодействием рядом расположенных блоков, и дальнодействием – «энергетическим» взаимодействием всех блоков сейсмического пояса, протягивающегося на десятки тысяч километров, что может являться отражением общего физического принципа – корпускулярно–волнового дуализма. В ротационной концепции не требуется привлекать модель Коссера, которая является математической, не физической.

В разделах «*О ротационных волнах в блоковых вращающихся геосредах*» и «*Новый тип геодинамических колебаний*» описывается разработанная ранее автором в рамках блоковой концепции геосреды модель ротационного сейсмотектонического процесса [*Vikulin, 2011*]. Характерными скоростями волновой модели являются $c_0 = \gamma\sqrt{V_R V_S}$, $c_0 \approx 1 - 10$ см/с (8) и (9) и V_S≈1–10 км/с (10). Значение первой c_0 – «солитонной» предельной скорости – определяется только угловой скоростью вращения Земли вокруг своей оси, откуда и название модели – ротационная. Вторая V_{ex} – «экситонная» предельная скорость – является скоростью упругих сейсмических волн. Отмечается, что такие же, по сути, деформационные волны [*Khachai O.A., Khachai O.Yu., 2012; Khachai et al., 2013*] инструментально зарегистрированы в шахтах. Проводится сопоставление теоретических модельных решений с данными о скоростях миграции очагов землетрясений. Отмечается и качественное и количественное совпадение с такими же и решениями и значениями характерных скоростей, соответственно. Формулируется вывод о том, что ротационные волны – это новый тип волн, являющихся для блоковых вращающихся сред такими же характерными, как и продольные и поперечные сейсмические волны.

В разделе «*Реидные свойства геосреды*» отмечено, что медленные ротационные волновые движения могут быть ответственными за сверхпластичные течения [*Leonov, 2008*] геосреды – ее реидные [*Carey, 1954*] свойства [*Vikulin, Ivanchin, 2013a*]. Отмечается, что физическим аналогом такого движения может являться сверхтекучесть.

В разделе «*Ротационные и маятниковые волны*» показывается, что описание волнового геодинамического процесса в рамках ротационной модели близко такому же, по сути, блоковому описанию с позиции концепции «композиции и декомпозиции вещества Земли» [*Oparin et al., 2010*]. Это позволяет ротационные и маятниковые, а также и деформационные [*Khachai O.A., Khachai O.Yu., 2012; Khachai et al., 2013*] волны отнести к одному классу явлений – взаимодействию блоков геосреды между собой посредством упругого поля с моментом силы.

В разделе «*Блоковая геосреда и вулканизм*» отмечается, что отражением блокового строения среды может являться магматический очаг, питающий извержения действующего вулкана.

В разделе «*О параметрах магматических очагов*» с использованием большого объема данных об извержениях вулканов планеты показывается, что толщина магматического очага является инвариантом наиболее общих статистических распределений, характеризующих вулканический процесс (рис. 3 и 4), и, как следствие, мало изменяющейся величиной Δh=0.5±0.1 км (19). Это позволяет толщину магматического очага рассматривать как постоянную величину, не зависящую от вулканического процесса, которая определяется геодинамическими параметрами земной коры, ее блоковым строением. При размерах кальдер до D=10–15 км и более форма очага близка блинообразной: $D \gg \Delta h$.

В разделе «*Магматический очаг как состояние земной коры*» для блоковой геосреды, вдоль границ которой возможны интенсивные пластические деформации [*Magnitskii et al., 1998; Turcotte, Schubert, 1985*], с использованием разработанной в материаловедении концепции «теплового самоускорения» [*Ivanchin, 1982*] проводится построение модели «тонкого» (блинообразного) магматического очага. В пределах земной коры в результате малой теплопроводности горных пород и интенсивной пластической деформации вдоль границы залегания кристаллического фундамента на глубине 6 км (Камчатка) может реализоваться состояние перегретого выше точки плавления вещества, находящегося в твердой фазе. При локальных плавлениях в очаге и увеличении его объема в окружающей очаг земной коре создаются упругие напряжения, величина которых может достигать 10^{15} Дж на 1 км^3 перегретой породы. Такие напряжения сопоставимы с напряжениями в очагах сильнейших тектонических землетрясений с магнитудами около 8 и более. «Энергетическая» близость магматических и сейсмических рядом расположенных очагов в рамках модели блоковой гесореды позволяет объяснить и взаимодействие вулканов между собой (миграцию вулканической активности [*Vikulin et al., 2010, 2012, 2013*]), и взаимодействие вулканизма, сейсмичности и тектоники [*Vikulin, 2011; Vikulin et al., 2013*]. Развитые представления распространяются на границу Мохо. Формулируется гипотеза, согласно которой подошва земной коры может представлять собой фазовую поверхность, ниже которой геосреда не является блоковой, способной к сдвиговому течению.

В разделе «*Обсуждение результатов*» рассматривается ряд возможностей ротационной модели. Проблема взаимосвязи энергонасыщенности, реидности и способности двигаться вихревым способом, с одной стороны, и сильной нелинейности геосреды – с другой, сформулирована как фундаментальная задача геодинамики и тектонофизики. Свойство энергонасыщенности геосреды, ее нахождение в напряженном состоянии [*Rykunov et al., 1979*], способном ее разрушить [*Bogdanovich, 1909; Ponomarev, 2008*], показывают, что землетрясение, скорее всего, происходит не в соответствии с теорией Ф. Рейда, т.е. не в результате создания локальных напряжений в очаге будущего землетрясения и преодоления предела прочности горных пород. Землетрясение в рамках развиваемой автором ротационной концепции является результатом дальнодействующего взаимодействия всех блоков земной коры и создания в области очага будущего землетрясения и прилегающих к ней блоков условий для их близкодействующего взаимодействия, которое может сопровождаться образованием свободной поверхности разрыва и излучением сейсмических волн. В рамках ротационной концепции механизм «зацепления» блоков и плит друг за друга и «выделения» тепла за счет трения их границ становится маловероятным.

Ключевые слова: геодинамика, момент силы, ротационные волны, реидное течение, гравитационные волны.

There is no “relativity of rotation.” A rotating system is *not* an inertial frame, and the laws of physics are different.

R. Feynman [*Feynman et al., 1964*]

Относительности вращения не существует. Вращательная система – *не инерциальная* система, и законы физики в ней другие.

Р. Фейнман [*Feynman et al., 1964*]

Geological time scale is close to the scale of the Universe. Geologists own chronicle, which recorded the events of history of the Earth, as well as the Universe.

D.V. Nalivkin [*Nalivkin, 1969*]

Масштаб геологического времени близок к масштабу Вселенной. Геологи владеют летописью, в которой записаны события истории Земли, а также и Вселенной.

Д.В. Наливкин [*Nalivkin, 1969*]

1. Introduction

The Baikal region and its neighbouring territories are the best studied among many areas subject to traditional geodynamic studies, including comprehensive geological and geophysical observations with regards to tectonophysical concepts. The research team under the leadership by Prof. S.I. Sherman from the Institute of the Earth's Crust, SB RAS has conducted detailed studies in this region for several decades. They have proposed and developed a tectonophysical model of the deep structure of faults in Central Asia [*Sherman et al., 1992, 1994*]. Results of their pioneering studies include the following:

– Large faults in lithosphere extension zones are physically modelled, and quantitative parameters of deformation in zones of large faults are established [*Sherman et al., 2001*];

– An original geodynamic model is developed to show how rift basins in Pribaikalie and Transbaikalie develop in space and time [*Lunina et al., 2009*];

– A seismic zone is modelled in terms of tectonophysics [*Sherman, 2009*]; the model shows that sources of rare strong earthquakes are clustered in linear or arc-shaped systems [*Sherman, 2013*] and migration velocities of earthquakes $K \geq 12$ ($M \geq 4$–5) range from 1 to 100 km per year [*Sherman, 2013; Sherman, Gorbunova, 2008*]; according to [*Vikulin et al., 2012a, 2012b*], these values do not contradict with the relevant global data;

– According to above-mentioned model, faults are activated by *slow strain waves of excitation* which are generated by interplate and interblock movements of the lithosphere [*Sherman, Gorbunova*, *2008*] and can also occur in zones wherein seismicity is slowly migrating [*Sherman*, *2009, 2013; Sherman et al., 2011*]; a general assumption is that $L \geq l$, wherein L is strain wave length and l is length of a fault activated by strain waves [*Sherman et al*., *2008*];

– It is revealed that two major fault zones in the Baikal rift zone and the Amur River region are related; active faults are identified in both regions; it is established that the fault activation is manifested by seismicity and caused by trigger mechanisms with the leading role of slow strain waves [*Sherman, 2013; Sherman et al., 2011*].

The above-mentioned tectonophysical model of the wide geodynamic zone, including Central Asia and the Amur River region, is based on the concept of the fault-block geomedium and the assumption that faults are activated in real time by slow strain waves, and the fault activation is accompanied by seismic events that sequentially take place along the faults. It is believed that developing the tectonophysical model of the seismic process can "give an insight to regularities of earthquake location in space and time and facilitate seismic forecasting" [*Sherman*, *2009*]. The current model is based on commonly accepted geological, geophysical and tectonophysical concepts of the geodynamic process. In general, it seems promising and compliant with the major concepts that are internationally accepted in modern geoscience. Undoubtedly, this model is an important contribution to the Earth sciences.

The above-mentioned research results are consolidated in [*Sherman*, *2014*]. S.I. Sherman and his colleagues have proposed and develop the tectonophysical concept of the Baikal rift zone development. In his book, S.I. Sherman states that their concept does not depend on *physical* concepts of seismicity (p. 6) and is thus universally applicable.

However, a review of the tectonophysical model of Central Asia with respect to the planetary scale [*Vikulin et al*., *2012b*] reveals a seemingly insignificant inconsistency and raises a number of important questions.

As mentioned above, the model estimates of velocities of earthquake sources migration along the faults are generally consistent with the global data. Nonetheless, the detailed analysis of migration velocities in geodynamic settings of all active zones of the Earth [*Vikulin et al., 2012a*] shows that this is not exactly the case. The model estimates of velocities of earthquake sources migration along the faults in Central Asia do not contradict with similar plots constructed for the Pacific margin and the Alpine-Hymalayan belt (i.e. compression zones), but are in conflict with the plots constructed for the Middle Atlantic ridge (i.e. extension zone). Thus, the earthquake migration estimates for Central Asia at the regional level are contradicting with the estimates at the planetary level. Otherwise, it has to be accepted that the studied region of Central Asia is not a rift, or it should be clarified that the earthquake migration estimates for the Baikal region refer to one of its flanges rather than to the entire rift zone. This poses the questions: – Which flange in particular? – What is the difference between the flanges? The regional model fails to provide answers to these questions.

In the regional tectonophysical models, including the model of Central Asia, the concept envisaging the block structure of the geomedium is applied formally or 'rhetorically' – such models are typically constructed with reference to boundaries between the blocks and block length values rather than blocks themselves and their volumes, and the models thus consider waves propagating along the boundaries between the blocks (i.e. along the faults), but not the waves propagating inside the block medium. This terminological 'swapping' – 'speaking about blocks, while thinking about faults'– is not just a habitual use of '*fault'* as a commonly accepted term with a 'standard' reference to the local stress accumulation mechanism (according to H. Rheid) and its modifications. In the regional tectonic models, the accumulated energy is not released – it is redistributed in the form of slow strain waves, while in seismic models, the energy is released by slow strain waves. The notions are substituted 'automatically' or 'by analogy' as a result of ignoring the major consequence of the geomedium block concept which states that stresses are redistributed in the geomedium's *volume* (p. 193–197, 332–334 in [*Sadovsky*, *2004*]). The idea of stress redistribution is supported by detailed seismic monitoring data obtained recently in mining projects in Russia [*Mulev et al*., *2013*]: "While a combined machine is moving inside the mine, the seismic energy release plot is changing; once the machine is stopped, the corresponding isolines in the plot are immediately 'frozen' in real time". In other words, even when an insignificant rock volume is 'extracted' from the massif, stresses are significantly redistributed[1]. The 'volume' mechanism of stress redistribution in the geomedium is in conflict with the tectonophysical (actually, 'fault-based') interpretation of the data obtained for Central Asia. In fact, an obscure issue is how a non-radiating fault, being only activated [*Sherman, Gor-*

[1] It follows from the instrumental seismological data published in [*Mulev et al., 2013*] that the Saint-Venant's principle (being local, according to [*Sedov, 1973*], p. 364–365) is not applicable to solving the geophysical problems. Seismologists and geophysicists consider the Saint-Venant's principle as fundamental (page 11 in [*Riznichenko, 1985*], though a sufficient justification of this approach is lacking. This problem is discussed in detail in [*Vikulin, 2014a*]. Below in the present paper, a geodynamic justification of the Saint-Venant's principle is provided under the rotation concept, and it is suggested that long-range interaction takes place between the geomedium blocks.

bunova, *2008*], can 'be aware' of the length of the wave passing through this fault.

The geomedium block structure is a challenging subject for both the Earth sciences and practical applications, and the key problem is to specify what part of the geomedium should be regarded as a block and what part is a boundary of this block. At the conference held in Irkutsk in August 2014, the report on this problem [*Tveritinova, Vikulin*, *2014*] sparked off a dispute that was lively, although not completed by any specific conclusion, and the participants agreed that the definitions need to be sorted out.

The seismic and geodynamic setting of the entire Baikal-Amur River zone as a global interplate boundary [*Sherman et al*., *2011*] has not been fully clarified yet, and the knowledge is mainly based on the regional and hypothetical conclusions that are 'cross-linked' only with regard to some separate ideas. With account of the current uncertainties, 'paving a pathway to regional earthquake forecasting' [*Sherman, 2009, 2014; Sherman, Gorbunova, 2008; Sherman et al., 1992, 1994, 2001, 2011*] may appear not that straight forward.

The 'regional' approach fails to provide a comprehensive view, and relationships between model parameters have to be introduced to design a model, which means setting up strong limitations on potential interpretations of consequences following the model at the final stage of modelling which is most important for geodynamics. A more general approach can facilitate finding original pathways to reviewing and solving *geodynamic* problems in the Earth sciences [*Vikulin et al., 2012a, 2012b*].

2. Stresses with force momentum in the geomedium composed of blocks

An important scientific achievement of the past decades is the justification of the hypothesis of the block structure of the geological medium [*Peive*, *1961*] / geomedium (p. 5–20 in [*Nikolaev*, *1987*]) / geophysical medium (p. 332–334 in [*Sadovsky*, *2004*]).

The Earth crust is subject to motions and changes as the crustal blocks and plates migrate on the Earth surface (Fig. 1). Properties of the crust are predetermined by the Earth *rotation* and its structure composed of the blocks that are subject to translational motions at the Earth surface [*Vikulin, 2010, 2011; Vikulin, Ivanchin, 2013a*].

The coordinate system, that is fixed for the body (i.e. the Earth), rotates with angular velocity $\mathbf{\Omega}$ that does not depend on the coordinate system as it is – in the given moment of time, all systems of the kind are rotating around axes (that are parallel to each other) with absolute velocity $\mathbf{\Omega}$ [*Landau, Lifshitz, 1973*]. Thus, regardless of its size, *any* block/plate is characterized by impulse momentum $\mathbf{M}$ that is independent of the block/plate size and origin and directed parallel to the body's (i.e. Earth's) rotation axis: $\mathbf{M} = \mathrm{I}\mathbf{\Omega}$, where I is inertia momentum of the block/plate. As shown in Fig. 1, *a*, crustal movements from position $\mathbf{M_1}$ to position $\mathbf{M_2}$ lead to changes in the direction of momentum, $\mathbf{M_1}\rightarrow\mathbf{M_2}$ because of the rigid relationship between the block and the Earth that rotates with angular velocity $\mathbf{\Omega}$. Under the impulse momentum preservation law, when the direction and, consequently, value of $\mathbf{M}$ is changed, the block is subject to force momentum $\mathbf{K}$.

The value and direction of force momentum $\mathbf{K}$ can be estimated theoretically as follows. It is assumed that the block is a uniform ball-shaped body that is stopped in position $\mathbf{M_2}$ and subject to elastic stresses with force momentum $\mathbf{P_2}$ (see Fig. 1, *b*). Then elastic stresses with force momentum $\mathbf{P_1}$ are applied to rotate the block to its initial state with momentum $\mathbf{M_1}$. With the assumption that kinetic energy of the block's rotation is converted to elastic stresses and vice versa without any loss of energy ($|\mathbf{P_1}| = |\mathbf{P_2}| = |\mathbf{P}|$), the cosine law is applied to force momentum $\mathbf{K}$:

$$|K| = 2|P|\sin\beta/2. \quad (1)$$

It should be noted that elastic stresses with force momentum $\mathbf{K}$ are applied to the block across its surface from the side of its *surrounding* crust and lithosphere [*Vikulin, Ivanchin*, *2013a*].

Therefore, in the rotation model [*Vikulin, 2009, 2010, 2011; Vikulin, Ivanchin, 2013a; Vikulin et al., 2010, 2013*], the block's movement with angular velocity $\mathbf{\Omega}$ is mechanically equivalent to its movement in the non-rotating/inert system of coordinates under the impact of its own force momentum $\mathbf{K}$ that generates an elastic field with force momentum (equation 1) in the medium surrounding the block (as a consequence of the impulse momentum conservation law).

The 'internal' and/or own [*Peive*, *1961*] momentum $\mathbf{M}$, that is actually a macrospin (p. 146–148 in [*Sedov*, *1973*]), has a specific feature – under the impulse momentum conservation law, the geomedium cannot be 'deprived' of it by any means, including plastic deformation. Thus, as a result of the translational motion of the block along the Earth surface (due to increasing block rotation angle β and constancy of the angle α, Fig. 1), rotation stresses with force momentum (equation 1) occur in the crust. The accumulation of such stresses provides an explanation [*Vikulin, Ivanchin*, *2013a*] of such a property of the crust as energy capacity (in terms of [*Ponomarev*, *2008*]). In fact, a similar conclusion was drawn by geologists at the end of the 19th century and in the early 20th century on the basis of observations of auto-destruction of rock samples

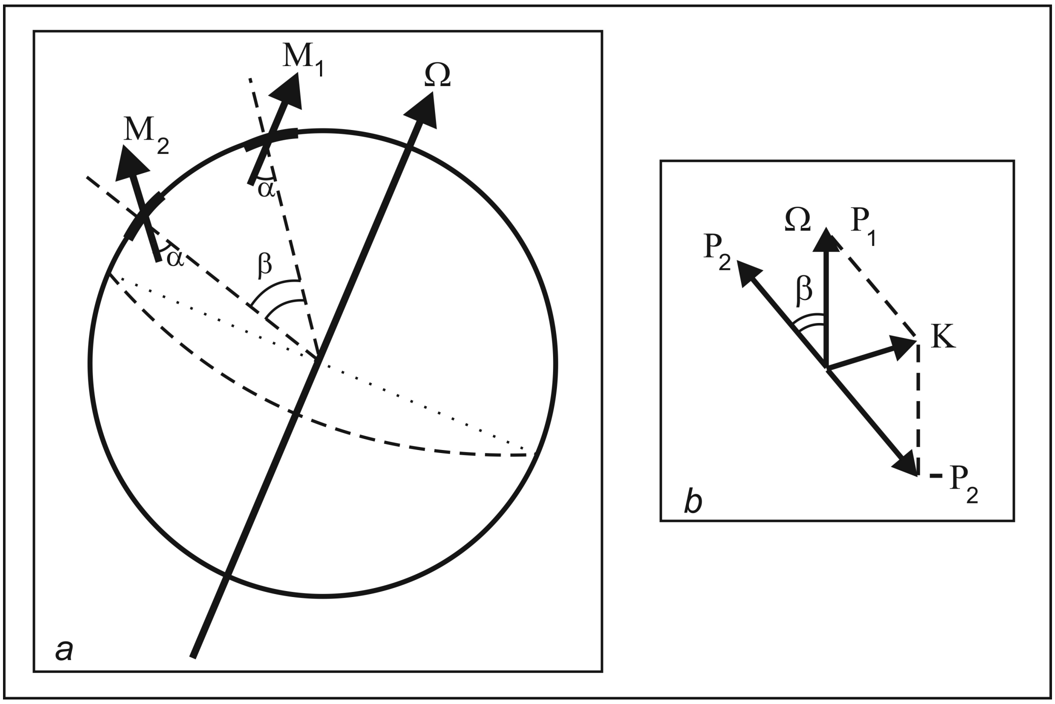

Fig. 1. While the crustal block moves from position $\mathbf{M_1}$ to position $\mathbf{M_2}$ (i.e. rotates by angle β) (a), stresses with force momentum **K** are 'generated' in the crust and the lithosphere, force momentum **K** is applied to the block from its surrounding medium (b). α – the angle between the momentum **M** and the vertical to the Earth surface, which remains constant during the block movement. See explanations in the text.

Рис. 1. Движение блока земной коры из положения с моментом импульса $\mathbf{M_1}$ в положение $\mathbf{M_2}$ (поворот блока на угол β) (a), сопровождающееся «генерацией» в земной коре и литосфере напряжений с моментом силы **К**, прикладываемым к блоку со стороны окружающей его среды (b). Пояснения в тексте.

extracted to the ground surface [*Bogdanovich, 1909*]. Besides, the fact that the Earth's crust is permanently subject to stresses is confirmed by the available geophysical data obtained by instrumental measurements [*Rykunov et al., 1979*; *Nikolaev, 2003*; *Chebotareva, 2011*; *Khachai O.A., Khachai O.Yu., 2012*].

3. Short- and long-range impacts of the rotational elastic field

The rotation concept (p. 124–136 in [*Vikulin, 2011*]) is applied to solve the following two-point boundary-value problem: a ball-shaped block has radius R_0; its own momentum is given by equation 1 for the inert non-rotating spherical system of coordinates (r, φ, θ) with the starting point (r=0) in the block's centre; angle φ is calculated in the plane located perpendicular to the block's rotation axis (θ=π/2); displacements at the infinite are zero; the non-zero-value force momentum does not depend on the block's size. According to theoretical estimations for the geomedium surrounding the block (i.e. $r > R_0$) [*Vikulin, 2010*], the stress field is estimated as follows:

$$\sigma_{r\varphi} = \sigma_{\varphi r} = 4\Omega R_0^4 r^{-3}\sqrt{\frac{\rho G}{5\pi}}\sin\theta\sin\beta/2 \qquad (2)$$

(values of other components are zero). The stress field is symmetrical[2]. Its energy is $W_0 = \frac{16}{15}\pi\rho\Omega^2 R_0^5\sin^2\beta/2$, and the force momentum/ seismic momentum is $K_0 = -8\pi^{3/2}\Omega R_0^4\sqrt{\frac{\rho G}{5}}\sin\beta/2$, where ρ=3 g/cm^3 and G=10^{11} n/m^2 are density and shear modulus of the crust, respectively, Ω=7.3·10^5 rad/sec is angular velocity of the Earth rotation around its axis, R_0 is typical size of the block/earthquake source with $M \approx 8$, and suffix number (0) refers to the block's 'own' energy and torque.

In [*Vikulin, 2010, 2011*], the model is applied to study the interaction between *any* two blocks with sizes R_{01} and R_{02}, which are located at distance l from each other. The interaction energy and force momentum are

[2] A fundamental role of 'stress tensor symmetry' for mechanics of continua, including the geomedium, is discussed in [*Vikulin, Ivanchin, 2013a*]. They also draw attention to the fact that the non-physical character of the model proposed by Cosserat E. and F. [*Cosserat E. et F., 1909*] was noted immediately after its publication (p. 26 in [*Hirth, Lothe, 1968*]).

estimated as follows: $W_{\rm int} = \frac{3}{2}\pi\rho\Omega^2 R_{01}^4 R_{02}^4 l^{-3}\cos\phi$, and $K_{\rm int} = -\frac{3}{2}\pi\rho\Omega^2 R_{01}^4 R_{02}^4 l^{-3}\sin\phi$, respectively. In case of equal-size blocks (R_{01}=R_{02}), interaction energy $W_{\rm int}$ and force momentum $K_{\rm int}$ become similar to their own energy W_0 and own force momentum K_0 ($W_{\rm int}$=W_0, and $K_{\rm int}$=K_0 [*Vikulin*, *2010*]) at distances l_{0W} and l_{0K} estimated in [*Vikulin, Ivanchin*, *2013a*] as follows:

$$l_{0W} \approx 10^2 R_0, \qquad (3)$$

$$l_{0K} \approx R_0. \qquad (4)$$

Equation (3) shows that the interaction between the blocks, which controls their energy exchange, is manifested across large distances exceeding the block sizes and can be thus termed the *long-range*[3] interaction. In seismology, such interaction is well-known and evidenced by the migration of earthquake sources along seismic belts for long distances amounting to dozens of thousand kilometres [*Vikulin et al., 2012a, 2012b*], as well as by remote fore- and aftershocks [*Prozorov, 1978*] and coupled earthquakes (p. 119–123 in [*Vikulin, 2011*]).

The instantaneous interaction between the blocks controls their momentum exchange and, according to equation (4), propagates to small distances not exceeding the block sizes. It can thus be called the *short-range* interaction. Such interaction is also well-known and evidenced by strong earthquakes, including coupled and multiple earthquakes with long-length sources (1000 km and more). Their sub-sources (with lengths ranging from 100 to 300 km) are involved in the instantaneous interaction and generate intensive own oscillations of the planet (p. 244–258 in [*Vikulin*, *2011*]).

The above-mentioned theoretical solutions obtained for stress field σ, elastic energies W_0 and W_{int} and momentums K_0 and K_{int} are applicable to *any* block and *any* couple of the geomedium blocks. The summary of the stress fields may show the planet's elastic field that is 'self-congruent' and predetermines a rotation component in motions of each geomedium block. The stress fields may vary by scale and have variable complex shapes in various geodynamic polygons due to the irregular structure of the geomedium and different modes of the geomedium block motions. In view of the above, the block rotation pattern in Central Asia is chaotic and multi-directional (Fig. 2). In other regions studied in other scales with insignificant local inconsistencies, stress field patterns may seem regular and manifested in geophysical fields by vortex, ring-shaped and other non-linear geological structures (see Figures 1, 2, 7 and 8 in [*Vikulin*, *2010*]).

In physics, short- and long-range actions are often related to corpuscular and wave interactions taking place across boundaries of particles and across the medium wherein the particles are located, respectively. Under the geomedium block concept, the blocks can be viewed as 'elementary' particles. Therefore, in terms of physics, the geodynamics of block interactions in the rotation model can be viewed as a manifestation of the general physical principle of corpuscular–wave dualism envisaging that movements of geophysical blocks, tectonic plates and geological structures have both corpuscular and wave features, as discussed below.

4. Rotation waves in the geomedium composed of rotating blocks

For the block that generates an elastic field with force momentum (1) and interacts with elastic fields generated by other blocks of similar sizes in a mass chain, the movement law is established as the sine–Gordon equation (p. 85–95 in [*Vikulin*, *2011*]). In this case, a seismic belt is modelled by a unidimentional chain of the crustal blocks/earthquake sources interacting with each other. Each block is characterized by inertia momentum I and volume $V = 4/3(\pi R_0^3)$.

The block motion can be given by the following equation: $I\frac{\partial^2\beta}{\partial t^2} = K_0 + K_1$, where K_0 is force momentum corresponding to the elastic stress field generated by an individual block; K_1 is force momentum controlling the interaction of the block with other blocks included in the chain. It is generally assumed that K_1 is proportional to both the elastic energy accumulated due to motions of the corresponding block ($V\frac{\partial^2\beta}{\partial z^2}$, where z is distance along the chain of mass/blocks) and the elastic energy of other blocks included in the mechanical chain. The block motion can be thus given by the following dimensionless equation:

$$\frac{\partial^2\theta}{\partial\xi^2} - \frac{\partial^2\theta}{\partial\eta^2} = \sin\theta, \qquad (5)$$

where $\theta = \beta/2$, $\xi = k_0 z$ and $\eta = v_0 k_0 t$ are dimensionless coordinates, and t is time. Taking into account that the wave length is close to the block size ($\lambda \approx R_0$), and wave number is $k_0 = 2\pi/R_0$, the following equation is obtained for process development velocity v_0 typical of the motion (equation 5):

$$v_0 = \sqrt{\frac{15}{8\pi^2\sqrt{5\pi}}\Omega R_0\sqrt{\frac{G}{\rho}}} \approx \sqrt{\frac{\sqrt{15}}{8\pi^2}V_R V_S} = 0.2\sqrt{V_R V_S}, \quad (6)$$

[3] As noted above, with account of the long-range interaction between the geomedium blocks, the local Saint-Venant principle becomes inapplicable to solving the problems of geodynamics. Flexural-torsional strain problems cannot be solved on the basis of this principle either (p. 33 in [*Bezukhov*, *1953*]).

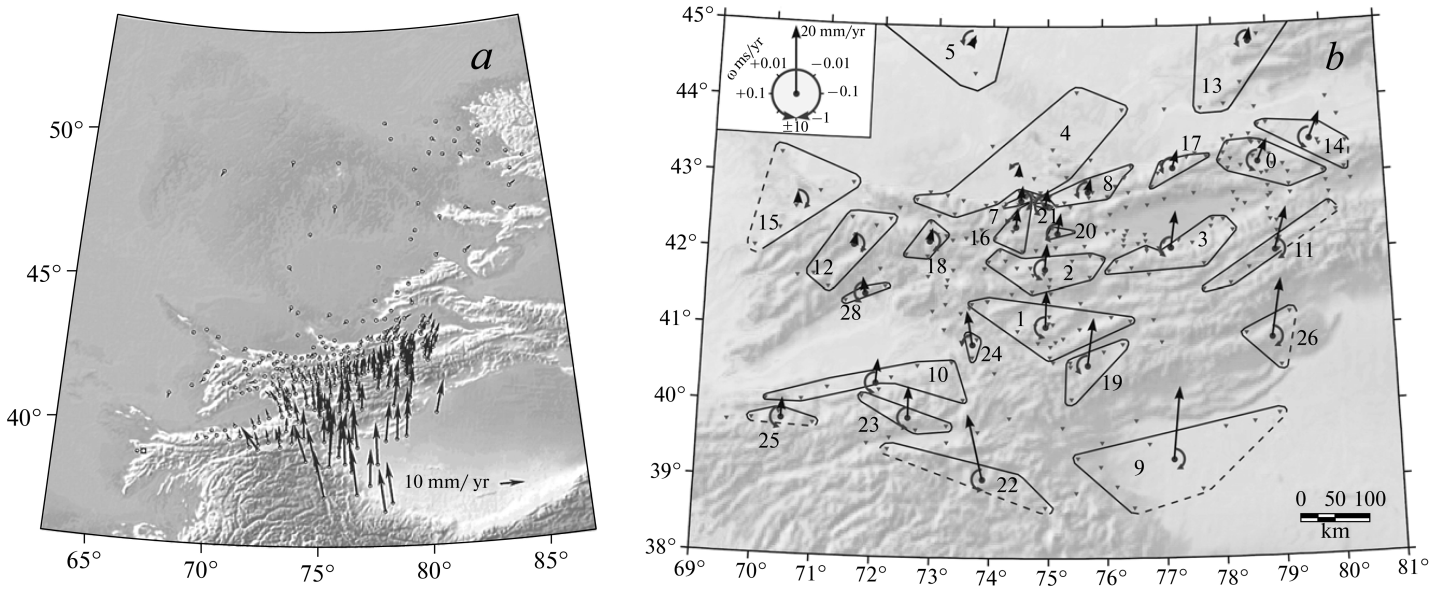

Fig. 2. GPS data obtained at 323 observation points in Central Asian polygon in the period from 1995 to 2005 [*Kuzikov, Mukhamediev*, *2010*].

Dots show the observation points. *a* – displacement vectors of the entire polygon; *b* – differentiated rotation of blocks (viewed as rigid bodies), according to data from clusters of observation points characterised by zero horizontal displacements against each other.

Рис. 2. Данные 323 пунктов GPS-наблюдений на Центрально–Азиатском полигоне в 1995–2005 гг., обозначенных точками [*Kuzikov, Mukhamediev*, *2010*].

a – вектора смещений всего полигона, в целом; *b* – дифференцированные вращения блоков как жестких образований, в каждом блоке выявленные по таким совокупностям наблюдательных пунктов, имеющих нулевые горизонтальные перемещения друг относительно друга.

where $V_R = \Omega R_0$, and $V_S \approx 4$ km/sec is velocity of a transversal seismic wave.

The form of equation (5) is predetermined by equation (1) used to estimate the force momentum of the elastic field generated by an individual block. It is thus assumed that sine–Gordon equation (5) and its right part ($sin\theta$) can be viewed, in terms of mathematics, as the law of impulse momentum preservation in wave processes. This is a principal assumption – when applied to the rotation problem of interrelated blocks arranged in a chain, it allows us not to consider any interaction between blocks due to friction along their boundaries, while the interaction needs to be considered in the elasticity theory (as shown, for example, in [*Nikolaevsky*, *1996*]). Logically, this approach facilitates a physically 'transparent' interpretation of the typical velocity (equation 6) of the geophysical process described by sine–Gordon equation (5), if the rotation problem of stress fields around the block, that is rotating due to its own momentum, is solved under the classical theory of elasticity [*Landau, Lifshitz*, *2003*] with a *symmetric stress tensor* (equation 2).

Equation (6) shows that if physical parameters G, ρ and R_0 are fixed, velocity v_0 depends *only* on angular velocity Ω (via inertia momentum I and volume V of the block). This means that the actual cause of such strain is *Earth rotation* (p. 237–243 in [*Vikulin*, *2011*]). This is why the model introduced in [*Vikulin*, *2011*] is called *"rotation model"*. Given the above-mentioned parameters of the crust, the typical velocity is $v_0 = 10 - 10^2$ m/sec.

In this case, we analyse a chain of irregularly rotating blocks characterised by deviations of force momentums that diverge from those in equilibrium positions (μ). In general, such a chain corresponds to the seismic process in nature. Friction α_f along the block boundaries is taken into account, though it is viewed not as a mechanism of interaction between the blocks due to their 'hitch-up' to each other (as envisaged in the elasticity theory), but as a dissipative factor that hinders the rotation interaction between the blocks. Based on the above, the law of block motions in the chain can be thus shown by a modified sine–Gordon equation (p. 237–243 in [*Vikulin*, *2011*]):

$$\frac{\partial^2\theta}{\partial\xi^2} - \frac{\partial^2\theta}{\partial\eta^2} = \sin\theta + \alpha_f\frac{\partial\theta}{\partial\eta} + \mu\delta(\xi)\sin\theta. \qquad (7)$$

A numerical solution of equation (7) is found by the McLaughlin–Scott method. In this case, $\delta(\xi)$ is the Dirac function. In the model, initial conditions are given with regard to an average strain velocity in seismically active regions, and coefficients of friction α_f and inhomogeneity μ correspond to those of real faults. If blocks/earthquake sources are interacting mainly due to creeping (i.e. in case of the slowly developing seismic process), an asymptotic value of rotation strain transfer velocity is $c_0 \approx 1-10$ cm/sec (p. 237–243 in [*Vikulin*, *2011*]).

Under the model envisaging that the non-linear geomedium is composed of blocks, it is acceptable that velocity $\{v_0, c_0\}$, that is typical of the transfer of solitonic rotation strain (i.e. stress with torque), can be estimated as follows [*Vikulin, Ivanchin*, *2013a*]:

$$c_0 = \gamma\sqrt{V_R V_S},\ c_0 \approx 1-10 \text{ cm/sec}, \quad (8)$$

where $\gamma = k^{-1} \approx 10^{-4}$ is non-linear parameter characterising a chain of blocks/cluster of earthquake sources that make up a seismic belt; the block/cluster is variable in size; its rotation is irregular due to friction; $k \approx 10^4(10^3-10^5)$ is geomedium non-linearity coefficient that is equal to the ratio between elastic constants of the third order and elastic constants of the second order, i.e. linear moduli of elasticity [*Nikolaev*, *1987*].

It is noteworthy that instrumental records in mines have also revealed 'slow' and 'fast' strain waves [*Khachai et al*., *2013*] and oscillation waves (μ-waves) [*Oparin et al*., *2010*].

5. A NEW TYPE OF GEODYNAMIC OSCILLATIONS

In our study, we compare experimental data on the migration of earthquake sources [*Vikulin et al*., *2012a, 2012b*] and theoretical solutions of the sine-Gordon equation (p. 124–136 in [*Vikulin*, *2011*]) [*Davydov*, *1982*] and find two solutions that correspond to limiting energies [*Vikulin*, *2010*], i.e. slow solitons (sol) and fast exitons (ex) (in terms of [*Davydov*, *1982*])[4]. The slow solitons control the global migration of earthquake sources within an entire seismic belt (i.e. 'long-range action of energy') with the following limiting velocity:

$$V_{sol} \le c_0 \approx 1-10 \text{ cm/sec}. \quad (9)$$

The fast exitons control the local migration of fore- and aftershocks in sources of strong earthquakes (i.e. 'instantaneous' *short*-range interaction) with a limiting seismic (s) velocity as follows:

$$c_0 < V_{ex} \le V_s \approx 1-10 \text{ km/sec}. \quad (10)$$

[4] Definitions of exitons differ in the literature [*Davydov, 1976; Ziman, 1974*, and others]. In this paper, solitons and exitons are viewed as excitations according to [*Davydov*, *1982*].

The slow solitons (9) and fast exitons (10), as a reflection of the general physical principle of wave-particle duality, are, in fact, a new type of geodynamic fluctuations. They are characteristic of the block rotating medium /geomedium in the same way as longitudinal and transverse seismic waves for a 'normal' body.

Based on plate dimensions and movement velocities of plate boundaries, two relationships are established between plate boundary length L and its movement velocity V, $L_{1,2}(V)$ (p. 313–316 and 317–322 in [*Vikulin*, *2011*]). Relationship $LgL_1 \approx (0.7 \pm 0.3)LgV_1$ is close to $LgL \approx LgV$ that characterizes spreading and subduction [*Zharkov*, *1983*; *New Global Tectonics*, *1974*] and actually corresponds to the 'long-range' soliton action (9). The second relationship $LgL_2 \approx (0.4 \pm 0.2)LgV_2$ is close to $LgL \approx 0.3LgV$ that determines fault activation in Central Asia [*Sherman, Gorbunova*, *2008*]. In our opinion [*Vikulin*, *2010*], it corresponds to 'instantaneous action' (10). Tectonic solitons and exitons, as excitations corresponding to relationships $L_{1,2}(V)$, control changes of the tectonic activity at the Earth surface, while seismic disturbances (9) and (10) predetermine the seismic activity migration along the belts.

The conclusion about the existence of "a new type of solitary waves" with "limiting velocity values" is also stated for non-local elastic solids [*Pamyatnykh, Ursulov*, *2012*]. The idea of a 'slow' mode "propagating with a velocity that is much lower than the velocity of sound in liquids, solid granules and gas" is theoretically and experimentally supported by results of theoretical and experimental studies [*Rudenko et al*., *2012*]. "The slow dynamics" and its impact on "the elastic properties of materials" are specified in [*Korobov et al*., *2013*]. The idea of the new type of rotation waves [*Vikulin*, *2010, 2011*], as the consequence of the concept envisaging that the geomedium is composed of rotating blocks, is consistent with results of theoretical and instrumental acoustic studies of 'normal' solids [*Korobov et al., 2013; Pamyatnykh, Ursulov, 2012; Rudenko et al., 2012*].

6. RHEID PROPERTIES OF THE GEOMEDIUM

There is much evidence of movements at the Earth's surface from earthquake focal areas which are manifestted by 'humps' and often accompanied by rotation [*Vikulin*, *2008*]. Such a case is described in [*Ionina, Kubeev*, *2013*] – during the catastrophic earthquake in China on 16 December 1920, "a missionary had to put his legs wide apart like a drinker trying to remain steady on his feet as he experienced strong rotational movements underneath" (p. 124). In 1930s, geophysical and geological data on 'slow' movements of the geomedium (typically lasting for 10–10^{13} sec) were consolidated, and terms of 'rheid deformation' [*Geological Dictionary, 1978; Carey, 1953*] and 'superplastic deformation' of the Earth were introduced to denote "a flow of the material in the solid state" [*Leonov*, *2008*]. It is shown below that the above-described state of the geomedium is a direct consequence of its motions due to rotation.

A review of definitions of the rheological properties of the Earth [*Vikulin*, *2009*] shows that the Debye temperature θ_d of the geomedium can be given as follows [*Zharkov*, *1983*]:

$$\theta_d \approx 10^{-3}\bar{V}(H)\sqrt[3]{\rho(H)}, \qquad (11)$$

where $\bar{V}$ is average velocity of excitations in the geomedium, cm/sec; ρ is density of the geomedium, g/cm^3; H is depth, km. If an average velocity (determined by longitudinal and transverse seismic velocities) for the lithosphere and upper mantle ranges from 1 to 10 km/sec, the Debye temperature is high enough. If H=100 km, $\theta_d \approx 660\ °C \approx 1000\ °K$, and these values correlate well with the common model of the Earth physics [*Zharkov*, *1983*].

The situation radically changes in case of transition to rotation mode c_0 (equation 8) that is determined by motions of the geomedium blocks, tectonic plates and geological structures in the aggregate[5]. According to equation 8, limiting velocity value c_0 is at least five orders lower than the longitudinal and transverse seismic velocities, and the Debye temperature (equation 11) is thus very low:

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

This provides for potential quantum, frictionless superfluid motions of the geomedium [*Vikulin*, *2013*], i.e. its rheidity [*Vikulin, Ivanchin*, *2013a*] and/or superplastic flow in the solid state [*Leonov*, *2008; Carey, 1953*].

The Debye temperature is proportional to the maximum possible frequency of oscillations of the complete set of particles composing the medium [*Ziman*, *1974*] or a set of mesovolumes of a solid body or all the geomedium blocks, tectonic plates and other geological structures of the Earth. According to [*Vikulin*, *2011*] (p. 244–258), in case of the Earth, the frequency is given by Chandler frequency typical of the aggregate oscillation of all the blocks in the seismotectonic belt. Actually, the oscillation of the entire belt is determined by the energy of 'zero' oscillations, i.e. energy E_0 (see. Fig. 6 in [*Vikulin*, *2010*]).

[5] The Earth crust is a solid body. Therefore, applying the Debye theory to geodynamic problems is reasonable in terms of physics, to prove a possibility of transition under the Debye theory to rotation mode c_0, a transition from elastic phonons to tectonic solitons (equation 9). An elastic phonon is a quantum of the interaction between 'point-size' atoms (i.e. atoms of zero size, without elastic own momentum) in the crystal lattice. A tectonic soliton is a carrier of the geodynamic interaction between (rotating) blocks of the geomedium. It has a considerable size and, respectively, its own torque.

7. ROTATION WAVES AND OSCILLATION (μ) WAVES

Under the geomedium block approach, considering fracturing and "composition and decomposition of the Earth material" as the major processes [*Oparin, Vostrikov*, *2010*], oscillation **(**μ**)** waves in the geomedium are viewed as waves that predetermine geodynamic processes [*Oparin et al.*, *2010*]. Velocities of both oscillation **(**μ**)** and rotation waves are lower than velocities of longitudinal waves. To experimentally substantiate the existence of μ-waves, oscillation is analysed in chains of rigid massive blocks that are analogous to the chain of blocks in the rotation model. Two types of waves are revealed in both the rotation model and the chains [*Oparin et al., 2007*]. According to estimations based on laboratory experiments [*Oparin, Vostrikov*, *2010*], velocities of oscillation **(**μ**)** waves amount to 10^2–10^3 m/sec and are close to seismic wave velocities. Oscillation **(**μ**)** wave velocities measured on site range from 1 to 10 cm/sec [*Oparin, Vostrikov*, *2010*] and are close to the typical rotation wave velocity, c_0 (equation 8).

As shown above, in the framework of the wave geodynamics, both the approach based on the rotation concept [*Vikulin*, *2009*, *2010*, *2011*; *Vikulin, Ivanchin*, *2013a*] and the approach considering "composition and decomposition of the Earth material" [*Oparin, Vostrikov*, *2010*; *Oparin et al.*, *2007*, *2010*] yield similar results, while being developed independently of each other. Therefore, the rotation and oscillation **(**μ**)** waves can be considered as a phenomenon of one and the same class – interaction between the geomedium/rotating medium blocks in the field of elastic stresses with a force momentum. The methods used to study the oscillation **(**μ**)** waves [*Oparin et al.*, *2007*] and strain waves [*Khachai et al.*, *2013*] may prove useful for developing a technology to ensure proper recording of the rotation waves, which are currently detected (similar to tectonic waves [*Bykov*, *2005*]) by indirect methods, and instrumental methods for this purpose are still lacking.

8. THE BLOCK GEOMEDIUM AND VOLCANISM

The above concepts of waves that occur during the seismotectonic process in the block geomedium seem to be applicable to volcanic processes. In fact, volcanic belts of the Earth, as well as seismically active zones are the largest linear structures of the planet. They occurred in the Early Cretaceous and developed in quite a synchronous pattern (p. 460 in [*Krasny, 2004*]). In studies of the three most active volcanic belts of the Earth – Pacific, Alpine-Himalayan and Mid-Atlantic belts, it is revealed that the volcanic activity migration, as well as the migration of seismic/tectonic activity, is a manifestation of the wave geodynamic process [*Vikulin et al.*, *2010*, *2012*].

A reflection of the 'block character' of the volcanic process and a 'quantum' characteristic of a single volcanic eruption is a magma chamber feeding the volcanic eruption which is an analogue of an earthquake in the seismic process. Several definitions of a magma chamber /reservoir/ are given in [*Vlodavets*, *1984*]. According to the most general definition that is not contradicting with the others, a magma chamber is an isolated volume feeding the volcano [*Geological Dictionary*, *1978*]. Processes taking place in the magma chamber have not been fully clarified yet [*Vlodavets*, *1984*; *Luchitsky*, *1971*; *Macdonald*, *1975*]. Nevertheless, in case of a sufficiently intense volcanic eruption when a large volume of volcanic material is conveyed to the ground surface, the size of a magma chamber can be estimated from the size of a caldera, i.e. a large circular-shaped area (with a diameter of 10 to 15 km and more) of the volcanic depression with sloping walls (that can be several hundred metres high) which formed due to eruption (p. 123 in [*Vlodavets*, *1984*]).

Many notions in volcanology have not been clearly defined yet, and a precise definition of 'caldera' is also lacking (p. 123–129 in [*Vlodavets*, *1984*]). The available data on calderas are reviewed in many publications, including [*Luchitsky*, *1971*; *McDonald*, *1975*; *Leonov, Grib*, *2004*; *Laverov*, *2005*; *Vikulin, Akmanova, 2014*; *Vikulin, Ivanchin*, *2015*]. In our study, without going into detail, we refer to the above-mentioned general definition of 'caldera'.

Our attempt to 'incorporate' the volcanic process in the geomedium block concept under the rotational approach is described below.

9. The parameters of magma chambers

Plotting the numbers and sizes of volcanic eruptions of the recent Kuril-Kamchatka volcanoes. In the region under study, the most complete and regionally consistent database, including numbers of recent (past 200 thousand years) eruptions and sizes of volcanic forms, is available for the Kuril-Kamchatka arc [*Vikulin, Akmanova*, *2014*]. Based on the data on 70 volcanoes that erupted 676 times (N) in the past 9.5 thousand years, the eruption repeatability is given in the range of volcanic explosivity indices $2 \le W \le 7$ [*Siebert et al.*, *2010*] as follows [*Vikulin et al.*, *2012a*, *2012b*]:

$$LgN=3.60-(0.48\pm0.06)W. \qquad (12)$$

With account of the relationship between the 'energy' characteristics of eruption and the volume of erupted material (W and V, respectively): $W=LgV+5$, $[V]$=km^3 [*Siebert et al.*, *2010*], the eruption repeatability (equation 12) can be given in terms of 'volume':

$$LgN=1.15-(0.48\pm0.06)LgV,\ [V]=\text{km}^3. \qquad (13)$$

By applying the mid-square method to analyse the data from [*Laverov*, *2005*] on recent volcanic forms, including calderas and large craters on cones and flat tops of underwater volcanoes (N=287), the following distribution of volcanic form numbers N by square areas S is yielded:

$$LgN=(2.32\pm0.16)-(0.47\pm0.14)LgS,\ [S]=\text{km}^2. \qquad (14)$$

The above equations show that the 'inclination angle' of the 'energy' and/or 'volume' distribution (W and V in equations 12 and 13, respectively) amounts to 0.48±0.06, which is practically coincident with the 'inclination angle' of the distribution of the volcanic form numbers by their square areas S (equation 14): 0.47±0.14. It should be noted that the volcanic eruptions number (N=676) and the volcanic forms number (N=278) are statistically significant. The energy range and the sizes of calderas in equations (12), (13) and (14) cover the whole spectrum of volcanic eruptions, including those with maximum values, $W_{max}=7$, $V_{max}\approx100$ km^3, and $S_{max}=20\times25$ km^2.

Essentially, equations (12), (13) and (14) show fairly general statistical distributions that are typical of the volcanic process taking place in a wide region within a large time period. The similar inclination angles of the energy (12) and/or volume (13) and square area (14) distributions suggest the following hypothesis: the ratio of erupted material volume V to area S of the resultant volcanic form (that is large enough) is constant:

$$V/S=\Delta h=const. \qquad (15)$$

Being actually an invariant of more general statistical distributions, hypothetical equation (15) has a fundamental importance for volcanology [*Vikulin, Akmanova*, *2014*].

Eruptions of volcanoes of the planet. The inclination angle of the volcanic eruption recurrence plot [*Vikulin et al.*, *2012a*] is given as follows:

$$LgN\approx-(0.52\pm0.05)W. \qquad (16)$$

It is equal to the inclination angle of a similar plot constructed for the Kuril-Kamchatka volcanoes (equation 12). With reference to the data on volcanoes of the planet [*Vikulin, Ivanchin*, *2015*], the volcanic eruption numbers are plotted against the areas of resultant calderas and volumes of erupted material.

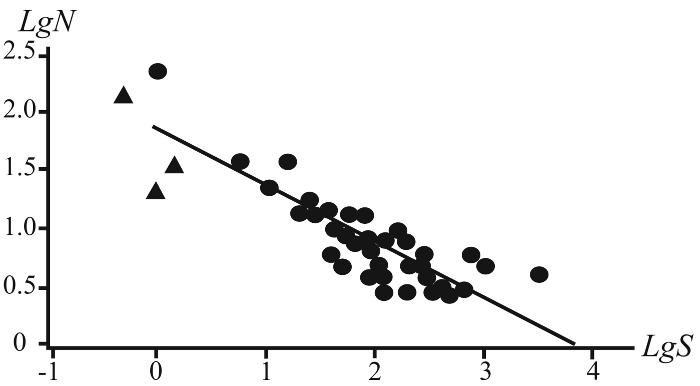

Fig. 3. Numbers of calderas (points) (N=373) and large craters on cones (triangles) (N=175) versus areas S (km^2).

Рис. 3. Распределение чисел N=373 кальдер (точки) и крупных воронок N=175 на конусах (треугольники) по величинам их площадей S (км^2), образованных на вулканах планеты.

Figure 3 shows a plot of numbers of calderas versus their areas: $LgN=f(LgS)$, N=373. In Figure 4, numbers of eruptions are shown versus erupted volumes: $LgN=f(LgV)$, N=125. The mid-square method is applied to analyse relationships shown in Figures 3 and 4 and given by equations (17) and (18), respectively (see below); correlation coefficients are 0.9 and 0.7, respectively. Intervals for averaging the initial values of S and V are increased with increasing values of S and V in order to provide a sufficiently uniform spacing of averaged values in the logarithmic scale.

$$LgN=(1.86\pm0.11)-(0.49\pm0.05)LgS,\ [S]=\text{km}^2, \qquad (17)$$

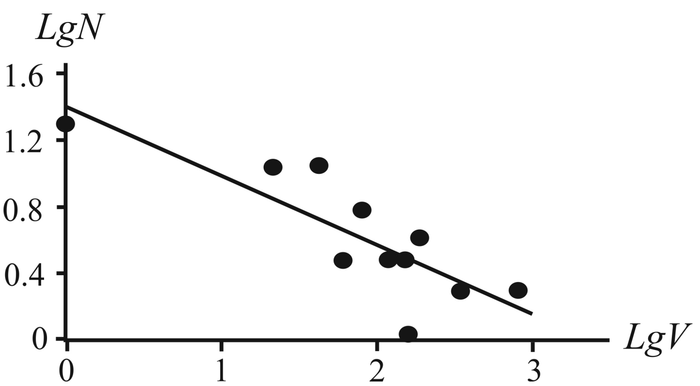

Fig. 4. Numbers of eruptions versus material volumes V (km^3) erupted by volcanoes of the planet (N=125).

Рис. 4. Распределение чисел извержений как функция объемов выброшенного материала V (км^3), N=125, при извержениях вулканов планеты.

$$LgN=(1.41\pm0.19)-(0.42\pm0.09)LgV,\ [V]=\text{km}^3. \qquad (18)$$

Parameters of calderas – diameter D, area S, and erupted material volume V – are variable in wide ranges: D=2÷150 km, S=2÷4.648 km^2, V=0.3÷3000 km^3. Nonetheless, it is established that the inclination angles of the plots showing the distribution of areas S (equation 17) and erupted material volumes V (equation 18) are similar, and the statistically significant reliability is high, minimum 0.7. This finding is actually similar to the conclusion that the ratio is constant in a wide range of scales of V and S.

Thus, the available data on the volcanic eruptions in the past 33 Ma support the hypothesis that $\Delta h=const$ (equation 15), i.e. does not depend on parameters of the volcanic process.

Thickness of a magma chamber. Based on the above, it is possible to estimate a magma chamber thickness from parameters of a volcanic eruption. For this purpose, equation (15) is used with data on volcanic eruptions with known values of S and V (N=125). The volumes of volcanic eruptions of the planet are recalculated by the method proposed by I.V. Melekestsev, taking into account the fact that densities of magma at different focal depths and densities of eruption products on the ground surface are different [*Laverov, 2005*]. It is shown that equation (15) is valid [*Vikulin, Akmanova, 2014*]:

$$\Delta h=0.5\pm0.1\ \text{km}. \qquad (19)$$

Minimum and maximum values of magma chamber thickness estimated from data on 125 volcanic eruptions (each with known caldera area S and erupted material volume V) range from a few meters to a few kilometres. These values do not contradict with thicknesses of molten granitoid layers formed while the rocks were irreversibly deformed during folding of the crust in the Pamirs [*Magnitskii et al., 1998*].

For a caldera with an average diameter D ranging from 10 to 15 km, a magma chamber which thickness is estimated from (19) is represented by a thin 'pancake-shaped' layer: $D>>\Delta h$.

Noteworthy are the following 'coinciding' features. Firstly, thicknesses of magma chamber Δh are close to heights of caldera sides h, and the minimum and maximum thickness values are generally close ($\Delta h\approx h$), which gives grounds to consider this fact in support of the hypothesis of a thin magmatic chamber with a permanent thickness. Secondly, as shown in Fig. 3, analytical equation (17) cannot be significantly changed by data on large craters on cinder cones (marked by triangles) (N=175, i.e. almost a half of the number of calderas, N=373). As such, distinctions between large craters on cinder cones and calderas are eliminated under the thin magma chamber concept, as shown in equations (15) to (19). In other words, the very concept of a caldera-generating eruption viewed as a 'specific' class of eruptions becomes meaningless.

Equation (19) is based on analyses of different data sets including (1) data on the entire planet and individual regions, specifically the Kuril-Kamchatka arc, Kamchatka, Kuril Islands and individual volcanoes located in the Kuril Islands and Kamchatka; (2) data covering different time periods, specifically data on volcanic eruptions of the Earth during the period of 33 Ma, and recent volcanic eruptions in the Kuril-Kamchatka region; (3) data from regions with different geotectonic settings; and (4) data on different types of volcanoes and different eruptions. Thus, there are grounds to consider that the small thickness of the magma pocket in equation (19) is a constant that *does not depend on the volcanic process* [*Vikulin, Akmanova, 2014*].

10. A MAGMATIC CHAMBER AS THE STATE OF THE CRUST

The model of a 'pancake-shaped' thin magma chamber in the crust. Recent instrumental geophysical studies conducted at volcanoes in the Kuril-Kamchatka region show that their magma chambers are generally located at depths from 5 to 30 km [*Anosov et al., 1990; Balesta, 1981; Fedotov, 1984; Ermakov, Shteinberg, 1999; Fedotov, Masurenkov, 1991*], i.e. within the crust composed of blocks. Therefore, the magma chamber thickness, which is independent of the volcanic process, may depend only on geodynamic movements of the blocks.

The following data can provide prerequisites for a statement of the problem. Heat generation in the crust due to mechanical movements of the crustal blocks was described in general terms by P.N. Kropotkin [*1948*]. Potential melting of the material in fault zones due to dissipative heating during shifting of the crustal blocks was noted in many publications on geodynamic modelling (for instance, p. 308–310 in [*Turcotte, Schubert, 1985*]). The first quantitative model of granitoid melting in the crust as a result of its intensive deformation during folding (a case of the Pamirs) was proposed in [*Magnitskii et al.*, *1998*]. It should be emphasized that under this approach it is not required to refer to the fluid concept in discussion of melting. The potential existence of polingenic magma chambers in the crust was substantiated in [*Ermakov*, *1977*] and confirmed by results of instrumental geophysical observations [*Balesta*, *1981*].

The thin 'pancake-shaped' magma chamber model is based on principles established in the material science of solids with intensive plastic deformation; in case of low heat transfer, the plastic deformation zone can become considerably heated under the impact of such deformations and even destroyed [*Ivanchin*, *1982*].

The main provisions of the model [*Vikulin, Ivanchin*, *2015*] are as follows. Local plastic deformation ε may be high ($\varepsilon \approx 1$) in sliding bands and low outside the bands ($\varepsilon \approx 0$). As the strain rate is exponentially dependent on stress and temperature, the temperature in the area subject to plastic deformation may increase due to heat emission. In case of a small thermal conductivity factor, when heating is not compensated, the temperature in the zone of intensive plastic deformation may continuously grow until transition to the thermal self-acceleration mode, which typically results in partial destruction of the deforming body, and in many cases such destruction results from melting.

A heated band may form under the following physically transparent conditions: on the one hand, deformation should be fast enough not to give time for the generated heat to be removed by thermal conductivity; on the other hand, it should be slow enough to provide a sufficient time for the plastic deformation rate and the specific heat capacity to decrease due to stress relaxation.

With account of the low thermal conductivity of the crust, thermodynamic calculations are obtained for the following conditions: a magma chamber is a solid that is heated to the temperature above its melting point; it is located at the depth of the crystalline basement boundary, H=5–6 km (Kamchatka) and composed of aluminium which thermal properties are similar to those of magma. (All the thermodynamic parameters of aluminium and their dependence on temperature and pressure are known). Based on the thermodynamic calculations, it is shown that when local melting takes place and the magma chamber's volume is increasing, an additional pressure is generated around the magma chamber and the field of elastic stresses occurs; its energy is about 10^{15} joules per 1 km^3 of the overheated rock. Considering the elastic energy accumulated around magma pockets, overheated magma chambers of relatively strong (W>4; V>0.1 km^3) eruptions appear to be similar to sources of the strongest earthquakes (M=8 and above) which lengths range from 100 to 200 km and above. In the block geomedium model, the similarity of the neighbouring magma chambers and seismic sources in terms of energy can be viewed as an explanation of both the interaction between volcanoes (i.e. migration of volcanic activity according to [*Vikulin et al.*, *2010*, *2012a*, *2012b*]) and the interaction between volcanism, seismicity and tectonics [*Vikulin*, *2011*; *Vikulin et al.*, *2013*].

The above general conclusion is supported by data on the three adjacent large cones of the northern eruption of the Tolbachik volcano in Kamchatka, which formed one after another during the eruption in 1975 and 'migrated' along the entire Tolbachik zone of cinder cones [*Fedotov, 1984*]. It is also supported by data on calderas (D=10 km and above) that migrated along the 500-km long Snake River valley in the USA; the calderas were formed during eight strongest eruptions (W≥6–7; V≥10–100 km^3) in the past 16 Ma [*Koronovsky*, *2012*], data on volcanoes that migrated along the central Pacific Ocean for distances from 800 to 1000 km and formed the chain of Hawaii Islands [*Mcdonald*, *1985*], and data on volcanic activity migration at the Earth surface [*Luchitsky*, *1971*].

The Mohorovicic discontinuity (Moho). It is stated in [*Peive*, *1961*] that the "most important conclusion of modern tectonics, which forces us to review our concepts, is that the crust ... is partitioned into blocks not only by a system of steeply dipping and vertical tectonic surfaces but also by gently dipping and horizontal surfaces. ... Deep tangential tectonic zones located in areas of high pressures and temperatures are zones with 'plastic flow' ... and primary magma chambers. ... Mechanical movements of the crustal material are the main source of this energy". According to [*Peive*, *1961*; *Magnitskii et al*., *1998*], mechanisms of plastic flow in thin layers along surfaces of the blocks are quite real and can be applied to other tectonic boundaries in the crust.

Among all the layers within the upper mantle, only the Moho is quite reliably established in all the regions of the Earth. Therefore, the concept of an overheated transition layer, which depth is constant, sounds reasonable with reference to the Moho, in the first instance.

It is not known whether the upper mantle located below the base of the crust is composed of blocks. We can only be certain that the crust has the block structure. Under the p–T conditions at the Moho, it can be expected that the geomedium below the crust may not be composed of blocks. In this case, another reason against the block structure is the assumption that a volume flow [*Leonov*, *2008*] is more typical of the substance below the Moho than a shear flow. Under the concepts of the rotational mechanics of the block geomedium [*Vikulin, 2011; Vikulin et al., 2013*] and the model of 'thermal explosion' and 'thermal self-acceleration' [*Ivanchin, 1982; Vikulin, Akmanova, 2014; Vikulin, Ivanchin, 2015*], it can be assumed that the base of the Earth's crust is represented by a phase surface, below which the geomedium (including the lithosphere and upper mantle) is not composed of blocks, and the shear flow cannot occur in it or may occur but to a lower extent than in the crust [*Vikulin, Ivanc*hin, *2013b*]. Our approach described above is close to the Moho model described in [*Pavlenkova*, *2013*].

Thus, the conclusion, which is fundamental for both volcanology and geodynamics, is that a magma pocket is a thin layer, and its thickness depends on properties of the crust. Our conclusion makes it possible within the framework of the rotation model [*Vikulin*, *2011*; *Vikulin, Ivanchin*, *2013b*; *Vikulin et al*., *2013*] to consistently 'mate' the views on the volcanic process [*Vikulin, Akmanova*, *2014*; *Vikulin, Ivanchin*, *2015*], the block geomedium concept and the idea of the wave geodynamic process.

11. Discussion of results

Our review shows that the regional tectonophysical studies of the Baikal fault zone [*Sherman*, *2014*] have some major shortcomings. In the reviewed regional studies and analyses, the fault structure of the geomedium was mainly referred to, while the block geomedium concept was not actually applied. The migration of earthquake sources was taken into account in the tectonophysical modelling of the regional processes, and an important conclusion was stated: "Deformation/strain waves should be introduced in the scope of the geophysical medium concept and viewed as its dynamic parameter" (p. 283 in [*Sherman*, *2014*]). However, in the cited publication, the strain wave process was considered mainly on the basis of the fault tectonics concept without any reference to the mechanism of stress redistribution in the geomedium's volume.

The present paper describes the rotation concept that can be useful for eliminating the difficulties associated with the need to take into account both the block structure of the geomedium and the wave process taking place in the geomedium. It is shown that the geomedium is a body composed of rotating blocks, and stresses with torque are generated in the geomedium. As a consequence of the momentum conservation law, such stresses predetermine the energy capacity (in terms of [*Ponomarev*, *2008*]) of the geomedium. In our study, the new type of rotation waves is reviewed, and it is shown that slow and fast strain waves (and/or tectonic waves [*Bykov*, *2005*] and/or oscillation **(**μ**)** waves [*Oparin, Vostrikov*, *2010*] and/or strain waves [*Khachai et al*., *2013*]) can occur in the geomedium composed of rotating blocks as a consequence of the wave-particle duality. The fast and slow strain waves are as typical for the geomedium composed of rotating blocks as longitudinal and transverse seismic waves for the 'normal' solid.

In the geomedium, movements can also take place as rheid and/or super-fluid flow [*Vikulin*, *2013*] and/or super-plastic flow [*Leonov*, *2008*; *Carey*, *1954*] which is most probably associated with the energy capacity of the geomedium and its ability to generate vortex, ring-shaped and other non-linear geological structures [*Vikulin*, *2014b*]. In terms of physics (p. 5–20 in

[*Nikolaev*, *1987*], this state of the geomedium corresponds to its geometric rotational–structural nonlinearity.

In geodynamics and tectonophysics, a fundamental challenge and *experiment crucis*, i.e. crucial/critical experiment [*Vikulin*, *2013, 2014a, 2014b*], is to reveal the relationship between the geomedium's energy capacity, rheidity and vortex motion ability, on the one hand, and it's clear nonlinearity [*Nikolaev*, *1987*], on the other hand.

Considering the geomedium's energy capacity [*Ponomarev*, *2008*] and its state of stresses [*Nikolaev*, *2003*; *Rykunov et al*., *1979*], which can destroy the geomedium [*Bogdanovich*, *1909*; *Ponomarev*, *2008*], it can be suggested that an earthquake is most likely to occur out of compliance with the Raid theory, i.e. not as a result of local stresses in the future earthquake source in excess of the tensile strength of rocks. Under the rotation concept proposed by the author, an earthquake in the energy-saturated medium (ready for destruction) can result from the long-range interaction between all blocks of the crust through a long/geological time span. Besides, it can occur as a consequence of specific conditions in the future earthquake source and its adjacent blocks which provide for the short-range interaction between the blocks and may be accompanied by the formation of a free surface of a fault and emission of seismic waves.

Magma chambers feeding volcanic eruptions are a reflection of the 'block character' of the volcanic process. Our analysis of the data on almost 800 strong volcanic eruptions, that were followed by the formation of calderas and the transition of large volumes of volcanic material to the ground surface, shows that the magma chamber's thickness is generally small, about 0.5 km, and this value is constant, independent of the volcanic process and predetermined by properties of the crust.

We propose the new magmatic chamber model based on the ideas of 'thermal explosion' and 'thermal self-acceleration'. It can supplement and develop the well-known concepts of potential heat generation in the crust [*Kropotkin*, *1948*; *Ermakov*, *1977*; *Turcotte, Schubert*, *1985*; *Magnitskii et al*., *1998*]. The model envisages intensive plastic movements along the boundaries of the blocks in conditions of the low thermal conductivity of the geomedium. If the solid material in the magma chamber is heated to the temperature above the melting point, elastic stresses with energy up to 10^{15} joules per 1 km^3 of the overheated rock can be accumulated in the area around the magma chamber. Such stresses are comparable to stresses in the sources of the strongest earthquakes. This can provide an explanation of the interaction between volcanoes (manifested by the migration of volcanic activity along the volcanic arc) and the interaction between the volcanic and seismic processes taking place in the adjacent and parallel belts.

Under the above concepts, the magma chambers are viewed as 'normal' blocks of the crust which have the same rotational properties as the blocks/earthquake sources.

This idea of thin overheated interlayers/volcanic chambers is valid for the entire crust of the Earth. In our hypothesis, it is stated that properties of the Moho are determined by the phase transition from the block structure of the crust to the non-block structure of the upper mantle.

12. Conclusions

Our conclusions [*Vikulin et al*., *2012b*], that are based on the physical and mathematical models developed by the author and his colleagues, are of fundamental importance for geodynamics. A brief review of the conclusions is given below.

1. In geodynamics, a currently popular idea envisages the mechanism of 'hitching' of blocks and plates with each other and heat 'emission' due to friction at their boundaries. However, it becomes 'useless' under the rotation concept – this mechanism is unlikely to occur. It is suggested by models of 'thermal explosion'/'self-acceleration' and intensive deformation due to geological processes [*Magnitskii et al*., *1998*] that overheated areas may occur in the crust, and phase transitions (from solids to liquids with free gas separation) may take place in such areas.

2. The concept of the geomedium composed of rotating blocks can facilitate solving the problems of geodynamics without any need to employ the currently popular models of magma ascent from the mantle (possibly, core) depths.

3. The problem of the Earth thermals and 'hot spots' can be considered from other positions. Within such zones, the kinetic energy generated by the rotation of the geomedium blocks and plates is partially converted into elastic stresses with torque (equation 1). It can be released not only by earthquakes, volcanic eruptions and tectonic plate movements, but also by the generation of heat that is redistributed inside the Earth and brought to the ground surface by various mechanism, including rotation waves with specific wave velocity c_0 (equation 8).

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