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THE PROBLEMS OF LITHOSPHERIC GEODYNAMICS

Abstract. The mechanics of viscoelastic lithosphere where the dynamic source of its development determined forces of inertia of internal asynchronous rotation and viscous forces from a spherical current of Kuett in asthenosphere is constructed. These forces define the nature of internal geodynamic pressure and tangential tension. It is found that depending on a difference of angular speeds of internal covers of Earth lithosphere can be in conditions of comprehensive expansion or compression. The mechanism of local changes of thickness of a lithosphere as a result of instability of deformation of a lithospheric cover of Earth under the influence of the internal pressure and volume forces of inertia of rotation is found. Stability of deformation is investigated by a Leybenzon-Ishlinsky method. The main stressed and deformed state is considered at an invariable form of border of a body, and revolted taking into account turns of elements of borders of a body in the course of transition to an adjacent form of balance. Asymmetric forms of the indignations leading to loss of stability of an ellipsoid of rotation are defined. Exponential growth of components of indignations in time, accompanied by oscillatory changes takes place. Within a viscoelastic rheology of a lithosphere the stress-strain state of lithospheric plates at bilateral compression is analyzed. Investigated the formation of folds, arising from the interaction of the plates in the zones of inter-plate boundaries. The interaction of the lithosphere with the underlying asthenosphere with bilateral compression plates. The critical effort of loss of stability of the non-isotropic plate lying on the resilient basis at its bilateral compression is found. The swelling of a viscoelastic earth's plate on a viscid astenosphere at values of compressive forces, larger critical, grows under the exponential law eventually until the condition of applicability of model of a reference linear body is violated. When material of an earth's plate is modelled by a viscid body the deflection also grows in time under the exponential law.
Key words: stress-strain state, deformation, viscoelastic, lithosphere, asthenosphere, Earth.

Introduction. In Kazakhstan, many problems in the mechanics of the Earth in its unified inter-pretation set by academician Zh. S. Erzhanov and solved by his pupils [1, 2]. In researches of deep geody-namics to the fore a problem with the study of the structure and the processes occurring in the boundary between the mantle and the core layer [3]. The mechanism of interaction between the internal and external layers of the Earth is based on the dynamics of the Earth's axial rotation. Influences of endogenous processes apply to all external covers of the Earth.

Works [4-20] from a position of mechanics of a deformable solid body are devoted to research of tectonic development of Earth. Here on elastic, viscoelastic and viscoplastic models of a lithospheric cover of Earth global and local regularities of tectonic movements are studied.

The basis of the modern concept of tectonics of lithosphere's plates is made by the following provisions:

- the precondition about division of the top part of firm Earth into two covers, a lithosphere and an asthenosphere, significantly differing viscous properties;
- the lithosphere is subdivided into limited number of the plates, seven large and as much the small;
- divergent, convergent and transform borders between plates define nature of mutual movements of plates;

- movements of lithosphere's plates submit to laws of spherical geometry;
- the seduction completely compensates spreading;
- the reason of movement of plates in mantle convection.

The most part of earthquakes, volcanic eruptions and orogeny processes occurring on a planet is dated for area of borders between plates. Thus concentration of epicenters of the strongest earthquakes on the globe in rather accurately limited belts defines outlines of borders of lithosphere's plates.

The problem of delimitation of lithosphere's plates by mechanic-mathematical methods is unresolved and actual.

Theoretical fundamentals of tectonics of plates are based on two essentially important prerequisites. First, the most external cover of Earth called by a lithosphere directly lies on the layer called by an asthenosphere which is less strong, than a lithosphere. Secondly, the lithosphere is divided into rather small number of plates on which borders almost all tectonic, seismic and volcanic activity takes place [21-23]. Plates move relatively each other therefore form zones of expansion, thrusts, under thrusts and shifts. In tectonics of plates of methods of mechanics of a deformable solid body and the theory of stability of deformable systems the powerful impulse gives the efforts on introduction which have increased now to further development of science about Earth.

Main results. The case of unmatched rotation of the Earth's lithosphere and mantle is considered. The nature of internal geodynamic pressure and tangential stresses determines by the Cuetta's spherical flow in asthenosphere layer. The equilibrium problem of visco-elastic lithosphere was formulated and solved. The lithosphere is under operating of volumetric centrifugal forces of inertia and forces of viscosity of asthenosphere layer on its base surface. The new qualitative properties of an external display of visco-elastic deformations in lithosphere of the Earth was detected and shown. The process of their stabilization was studied. The distributive mechanism of disturbances with depth along a meridian and parallel was found. The mechanism of formation three axes of Earth's figure was obtained.

$$u_R = \frac{\gamma\omega_1^2}{60\overline{G}g(\overline{m}-1)}\left[\frac{(\overline{m}-2)R}{2}\left(\frac{3\overline{m}-1}{\overline{m}+1}R_0^2 - R^2\right) + \frac{2(\overline{m}-2)(3\overline{m}-1)R_1^2(e_1^2-1)R}{(e_1^3-1)} + \right.$$
$$\left. + \frac{(3\overline{m}-1)e_1^3R_1^5(e_1^2-1)}{(e_1^3-1)R^2}\right] + \frac{\gamma\omega_1^2}{84\overline{G}g(\overline{m}-1)}\left[4(\overline{m}-2)R^3 + \frac{12}{\overline{m}}K_8R^3 + \right.$$
$$\left. + 2K_{10}R_1^2R + \frac{2(5\overline{m}-4)R_1^5}{\overline{m}R^2}K_9 - \frac{3e_1^2R_1^7}{R^4}K_7\right]P_2(\cos\theta);$$

The Earth's lithosphere can be under conditions of comprehensive dilating or compression depending on a difference in rotation with mantle was shown. For a viscoelastic lithosphere the field of movements under the influence of centrifugal forces of inertia is received:

$$u_\theta = \frac{\gamma\omega_1^2}{84\overline{G}g(\overline{m}-1)}\left[(\overline{m}-2)R^3 + \frac{7\overline{m}-5}{\overline{m}}R^3K_8 + \right.$$
$$\left. + K_{10}R_1^2R + \frac{2(\overline{m}-2)R_1^5}{\overline{m}R^2}K_9 + \frac{e_1^2R_1^7}{R^4}K_7\right]\frac{dP_2}{d\theta};$$

and the field of the movements caused by forces of viscosity of a secondary current in an asthenosphere layer:

$$u_R = \frac{1}{\overline{G}}\left\{\left[\frac{4\overline{\nu}-2}{1+\overline{\nu}}\frac{RR_1^3}{4(R_0^3-R_1^3)} - \frac{R_0^3R_1^3}{4R^2(R_0^3-R_1^3)}\right]\sigma_0^{(i)}P_0(\mu) + \right.$$
$$+\left[\overline{\nu}\left[(56-40\overline{\nu})\frac{1}{R_0^8} + 40(1+\overline{\nu})\frac{1}{R_0^5R_1^3} - \frac{96}{R_0^3R_1^5}\right]6R^3 - \right.$$

$$-\Big[(80\overline{\nu}^2 - 560)\frac{1}{R_0R_1^5} + (168+168\overline{\nu}-24\overline{\nu}^2)\frac{1}{R_0^3R_1^3} +$$

$$+(392-168\overline{\nu}-56\overline{\nu}^2)\frac{R_1^2}{R_0^8}\Big]R + (5-4\overline{\nu})\Big[(56+40\overline{\nu})\frac{R_0^2}{R_1^5} + (196+80\overline{\nu})\frac{1}{R_0^3} -$$

$$-(140+40\overline{\nu})\frac{R_1^2}{R_0^5}\Big]\frac{1}{R^2} + \Big[(-28-48\overline{\nu}-20\overline{\nu}^2)\frac{R_0^2}{R_1^3} + (168+48\overline{\nu})\frac{R_1^2}{R_0^3} -$$

$$-(140-20\overline{\nu}^2)\frac{1}{R_0}\Big]\frac{3}{2R^4}\Big]\times\left[(304\overline{\nu}^2-784)\left(\frac{R_0^2}{R_1^8}+\frac{R_1^2}{R_0^8}\right)+(2800-240\overline{\nu}^2)\times\right.$$

$$\left.\times\left(\frac{1}{R_0^5R_1}+\frac{1}{R_0R_1^5}\right)-\frac{4032}{R_0^3R_1^3}\right]^{-1}\sigma_2^{(i)}P_2(\mu)+$$

$$+\left[\overline{\nu}\left[(-112+80\overline{\nu})\frac{1}{R_0^8}+80(5-\overline{\nu})\frac{1}{R_0^5R_1^3}-\frac{288}{R_0^3R_1^5}\right]6R^3+\Big[(240\overline{\nu}^2-336\overline{\nu})\frac{R_1^2}{R_0^8}+\right.$$

$$+(336\overline{\nu}-1680)\frac{1}{R_0^3R_1^3}+(1680-240\overline{\nu}^2)\frac{1}{R_0R_1^5}\Big]R-(5-4\overline{\nu})\times$$

$$\times\Big[(-168-120\overline{\nu})\frac{R_0^2}{R_1^5}+\frac{168}{R_0^3}+120\overline{\nu}\frac{R_1^2}{R_0^5}\Big]\frac{1}{R^2}-\Big[(280+144\overline{\nu}-40\overline{\nu}^2)\frac{R_0^2}{R_1^3}-$$

$$-144\overline{\nu}\frac{R_1^2}{R_0^3}+(40\overline{\nu}^2-280)\frac{1}{R_0}\Big]\frac{3}{2R^4}\times\left[(304\overline{\nu}^2-784)\left(\frac{R_0^2}{R_1^8}+\frac{R_1^2}{R_0^8}\right)+\right.$$

$$\left.+(2800-240\overline{\nu}^2)\times\left(\frac{1}{R_0^5R_1}+\frac{1}{R_0R_1^5}\right)-\frac{4032}{R_0^3R_1^3}\right]^{-1}\tau_2^{(i)}P_2(\mu)\Big\}\,;$$

$$+(392-168\overline{\nu}-56\overline{\nu}^2)\frac{R_1^2}{R_0^8}\Big]R+(2-4\overline{\nu})\Big[(56+40\overline{\nu})\frac{R_0^2}{R_1^5}+(196+80\overline{\nu})\frac{1}{R_0^3}-$$

$$-(140+40\overline{\nu})\frac{R_1^2}{R_0^5}\Big]\frac{1}{R^2}-\Big[(-28-48\overline{\nu}-20\overline{\nu}^2)\frac{R_0^2}{R_1^3}+(168+48\overline{\nu})\frac{R_1^2}{R_0^3}-$$

$$-(140-20\overline{\nu}^2)\frac{1}{R_0}\Big]\frac{1}{R^4}\Big]\times\left[(304\overline{\nu}^2-784)\left(\frac{R_0^2}{R_1^8}+\frac{R_1^2}{R_0^8}\right)+(2800-240\overline{\nu}^2)\times\right.$$

$$\left.\times\left(\frac{1}{R_0^5R_1}+\frac{1}{R_0R_1^5}\right)-\frac{4032}{R_0^3R_1^3}\right]^{-1}\sigma_2^{(i)}\frac{dP_2}{d\theta}+\left[(7-4\overline{\nu})\left[(-112+80\overline{\nu})\frac{1}{R_0^8}+\right.\right.$$

$$+80(5-\overline{\nu})\frac{1}{R_0^5R_1^3}-\frac{288}{R_0^3R_1^5}\Big]R^3+\Big[(240\overline{\nu}^2-336\overline{\nu})\frac{R_1^2}{R_0^8}+$$

$$+(1680-240\overline{\nu}^2)\frac{1}{R_0R_1^5}+(336\overline{\nu}-1680)\frac{1}{R_0^3R_1^3}\Big]R-$$

$$-(2-4\overline{\nu})\left[(-168-120\overline{\nu})\frac{R_0^2}{R_1^5}+\frac{168}{R_0^3}+120\overline{\nu}\frac{R_1^2}{R_0^5}\right]\frac{1}{R^2}+$$

$$+\left[(280+144\overline{\nu}-40\overline{\nu}^2)\frac{R_0^2}{R_1^3}-144\overline{\nu}\frac{R_1^2}{R_0^3}+(40\overline{\nu}^2-280)\frac{1}{R_0}\right]\frac{1}{R^4}\Bigg]\times$$

$$\times\left[(304\overline{\nu}^2-784)\left(\frac{R_0^2}{R_1^8}+\frac{R_1^2}{R_0^8}\right)+(2800-240\overline{\nu}^2)\left(\frac{1}{R_0^5R_1}+\frac{1}{R_0R_1^5}\right)-\frac{4032}{R_0^3R_1^3}\right]^{-1}\tau_2^{(i)}\frac{dP_2}{d\theta}\Bigg\},$$

where R_0, R_1 - radiuses of external and internal surfaces of a lithospheric envelope; $P_0(\mu)$, $P_2(\mu)$ - polynoms of Legendre; $\sigma_0^{(i)}$, $\sigma_2^{(i)}$, $\tau_0^{(i)}$ - the sizes answering to forces of viscosity of an asthenosphere layer.

$$u_\theta=\frac{1}{2\overline{G}}\left\{\left[(7-4\overline{\nu})\left[(56-40\overline{\nu})\frac{1}{R_0^8}+40(1+\overline{\nu})\frac{1}{R_0^5R_1^3}-\frac{96}{R_0^3R_1^5}\right]R^3-\right.\right.$$

$$-\left[(80\overline{\nu}^2-560)\frac{1}{R_0R_1^5}+(168+168\overline{\nu}-24\overline{\nu}^2)\frac{1}{R_0^3R_1^3}+\right.$$

The mechanism of emergence of global tectonic breaks on which there is a splitting of a lithospheric cover into lithosphere's plates, is investigated by mathematical methods of the theory of stability of deformable systems.

The main stressed-deformed state of an elastic and viscous ellipsoid of rotation is investigated. The equation of elastic balance and the main ratios are defined in degenerate elliptic coordinates of s, μ, φ.

The ellipsoid rotates round its pivot-center symmetry with a constant angular speed ω and is under the influence of the uniform pressure q attached to its surface in the positive direction to a normal.

The balance equations in movements look like:

$$\frac{1}{1-2\nu}grad\ div\,\overline{u}+\nabla^2\overline{u}=\frac{1}{G}grad\ \Phi,$$

where $\Phi=-\frac{1}{2}\frac{\gamma}{g}\omega^2r^2$ - potential of centrifugal forces, $\overline{u}$ - movement vector, G - shift module, ν - Poisson's coefficient, $j=\rho g$ - specific weight, g - gravity acceleration, ρ - density.

The common decision of the equations of balance is defined through the biharmonic functions expressed by means of tesserae spherical functions

$$P_n^m(s)P_n^m(\mu)\cos m\varphi,\quad P_n^m(s)P_n^m(\mu)\sin m\varphi.$$

Asymmetric forms of the indignations leading to loss of stability of an ellipsoid of rotation are defined.

Components of indignations are expressed through three any constants which are found from boundary conditions.

Let's consider stability of a non-isotropic plate of length a, of thickness H subject to bilateral compression and lying on the deformable elastic basis.

Let's define reaction of the basis at loss of stability of a plate. Equilibrium equations in movements u,w of the indignant condition of the basis have an appearance:

$$\frac{G_0}{1-2\nu_0}\frac{\partial\theta}{\partial x}+G_0\nabla^2u=0,\qquad \frac{G_0}{1-2\nu_0}\frac{\partial\theta}{\partial z}+G_0\nabla^2w=0,\tag{1}$$

where $\nabla^2=\frac{\partial^2}{\partial x^2}+\frac{\partial^2}{\partial z^2}$ – Laplacion, $\theta=\frac{\partial u}{\partial x}+\frac{\partial w}{\partial z}$, G_0 - shift modulus, ν_0 - basis Poisson's ratio.

We will take the solution of equilibrium equations (1) meeting a limitation condition on infinity in a look

$$u(x,z) = \varphi_1(z)\cos m_1 x, \qquad w(x,z) = \varphi_2(z)\sin m_1 x, \tag{2}$$

where

$$\varphi_1(z) = (A_1 - A_2 z)\exp(m_1 z), \quad \varphi_2(z) = \left(A_1 + A_2 \frac{3 - 4v_0 - m_1 z}{m_1} \right)\exp m_1 z,$$

A_1, A_2 – the arbitrary constants, $m_1 = \frac{n\pi}{a}, n$ – integer.

Expression for a rated stress has an appearance:

$$\sigma_z = 2G_0\left[A_1 m_1 - A_2\left(2v_0 - 2 + m_1 z\right)\right]\exp(m_1 z)\sin m_1 x. \tag{3}$$

We will also define constants A_1 and A_2 from a condition of rigid coupling of a plate with the basis:

$$w\big|_{z=0} = w_0\big|_{z=0}, u = -\frac{h_1}{2}\frac{\partial w}{\partial x}\bigg|_{z=0} = u_0\big|_{z=0}, \tag{4}$$

where u, w - horizontal and vertical movement of a plate,, u_0, w_0 – movements of the basis on border $z = 0$. Let's say that vertical movements of a plate at $z = 0$ has an appearance:

$$w = \ell \sin m_1 x,$$

where ℓ – maximal deflection.

Then from a condition (4) we will define:

$$A_1 = -\frac{1}{2} m_1 h_1 \ell, \qquad A_2 = -\frac{(2 - m_1 h_1) m_1}{2(3 - 4v_0)}\ell. \tag{5}$$

Substituting values A_1, A_2 in expression (3), we will determine the size of normal pressure on border $z = 0$:

$$q = \sigma_z\big|_{z=0} = -2G_0\left[\frac{2m_1(1 - v_0)}{3 - 4v_0} + \frac{1 - 2v_0}{2(3 - 4v_0)} h_1 m_1^2 \right]\ell \sin m_1 x = -\frac{4G_0 m_1(1 - v_0)}{3 - 4v_0} w - \frac{(1 - 2v_0) h_1 G_0}{3 - 4v_0}\kappa, \tag{6}$$

where $\kappa = -\frac{\partial^2 w}{\partial x^2}$ – curvature of a plate at $z = 0$.

We investigate the equation of neutral equilibrium of a plate

$$\frac{\partial^4 w}{\partial x_1^4} - \left(K_1^2 - K_3^2\right)\frac{\partial^2 w}{\partial x_1^2} - K_2^2 \frac{\partial^2 w}{\partial z_1^2} = 0. \tag{7}$$

where

$$K_1^2 = \frac{12 G_2 (1 - \nu_1^2)}{E_1 \rho^3 (1 - \rho)}, \quad K_2^2 = \frac{12 E_2 (1 - \nu_1^2)}{E_1 \rho^3 (1 - \rho)}, \quad K_3^2 = \frac{12(1 - \nu_1^2) P}{E_1 \rho^2} = K^2 P,$$

$\rho = \frac{h_1}{h}$, $h = h_1 + h_2$, E_1 – elastic modulus, ν_1 – Poisson's ratio, h_1 - thickness of a rigid layer; $E_2 = \frac{2G_2(1 - \nu_2)}{1 - 2\nu_2}$ - transversal module, G_2 - shift modulus, ν_2 – Poisson's ratio, h_2 - thickness of the weak layer; $x_1 = \frac{x}{h}$, $z_1 = \frac{z}{h}$; u, w - horizontal and vertical movements, $P = ph_1$ – regional pressure.

Boundary conditions have an appearance:

$$w = 0, \frac{\partial^2 w}{\partial x_1^2} = 0 \text{ at } x_1 = 0 \text{ and } x_1 = \frac{a}{h}, \tag{8}$$

$$\frac{\partial w}{\partial z_1} = 0 \text{ at } z_1 = \frac{H}{h} = r, \tag{9}$$

$$\frac{\partial w}{\partial z_1} = -q^*(x_1) = K_0^2 \left[4(1-v_0)w - \frac{\rho(1-2v_0)}{m} \frac{\partial^2 w}{\partial x_1^2} \right] \text{ at } z_1 = 0,$$

where

$$K_0^2 = \frac{(1-2v_2)(1-\rho)mG_0}{2(3-4v_0)(1-v_2)G_2},$$

$m = m_1 h -$ the pure wave number.

We will find value of critical effort:

$$P_{kp} = \frac{1}{K^2}\left\{ m^2 + K_1^2 + \frac{3K_2^2}{m^2 r^2}\left[1 + \frac{rK_0^2}{2}\big(4(1-v_0) + \rho m(1-2v_0)\big)\right] - \right.$$

$$\left. -\sqrt{1 + \frac{r^2 K_0^4}{4}\left[4(1-v_0) + \rho m(1-v_0)\right]^2 + \frac{rK_0^2}{3}\left[4(1-v_0) + \rho m(1-2v_0)\right]} \right\}. \tag{10}$$

When material of an earth's plate is modelled by a viscid body the deflection grows in time under the exponential law.

Recommendations. It is discovered that action of centrifugal force of inertia causes following geodynamic phenomena: with time and at value change of Poisson's constant the zero value of radial movement displaces along a meridian and is a possible disturbance and a trigger mechanism of tectonic stresses; with increase of Poisson's constant the compression close to a pole increases, and the expansion in the field of equator decreases and meridian movement increases. The mechanic-mathematical model of process of emergence of global tectonic breaks is presented by local changes of thickness of a lithosphere as a result of loss of stability of deformation of an ellipsoidal lithospheric cover of Earth under the influence of the internal pressure and volume forces of inertia of rotation. The lithospheric cover is rigidly linked to an adjacent continuous ellipsoid of rotation. The critical effort of loss of stability of the non-isotropic plate lying on the resilient basis at its bilateral compression is found.

Conclusion. It is shown that the account of the secondary flow in asthenosphere layer results in following properties: the positive value of radial movement increases with time and with depth, i.e. the lithosphere has a state of comprehensive expansion. With increase of a difference between angular velocities of lithosphere rotation and a mantle the value of radial and meridian movements reverses their mark and the lithosphere passes converts to the state of comprehensive compression. It is established that the main reason of emergence of global tectonic breaks on which there is a splitting of a lithospheric cover into lithosphere's plates, loss of stability of a lithospheric cover of Earth under the influence of the internal pressure and volume forces of inertia of rotation is. The swelling of a viscoelastic earth's plate on a viscid astenosphere at values of compressive forces, larger critical, grows under the exponential law eventually until the condition of applicability of model of a reference linear body is violated. When material of an earth's plate is modelled by a viscid body the deflection also grows in time under the exponential law.

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ЛИТОСФЕРАЛЫҚ ГЕОДИНАМИКАНЫҢ ПРОБЛЕМАЛАРЫ

Аннотация. Тұтқыр-серпімді литосфераның механикасы жасалған, оның дамуының динамикалық негізінен ішкі асинхронды айналу инерциялық күші мен сұйық астеносферадағы Куэтта сфералық ағымнан тұиқыр күштер аныіталған. Ол күштер ішкі геодинамикалық қысымның табиғатын және жанама кернеулерді анықтайды. Жердің ішкі қатпарларының келісілмеген айналуына сәйкес литосфераның тең жақты өсуі немесе сығылуы табылған. Ішкі қысым және көлемді айналу инерция күштер әсерінен Жер литосералық қабатының тұрақсыздық нәтижесінен литосфераның қалыңдығының тетігі жергілікті өзгерістер табылды. Лейбензон-Ишлинский әдісімен тұрақтылық деформациялау зерттелген. Дене шекара нысаны өзгермейтін кезінде негізгі кернеулі-деформациялық күй қаралды және ауытқу жағдай дене шекара бұрылыстар элементтерінің қосымша тепе-теңдік нысан үдерісінде көшу ескере отырып. Айналу эллипсоид орнықтылығын жоғалтуға әкеп соғатын қалыптан асимметриялық нысандар анықталған. Уақыт қалыптан ауытқу компоненттерінің экспоненциалдық өсуі орынды сүйемелденетін ауытқуы өзгерістермен. Тұтқыр-серпімді реология шеңберінде екі жақты сығу литосфера плиталардың кернеулі-деформациялық күйлері талданады. Плиталар шекара аймақтар өзара іс-қимыл арқылы қатпарлар құрылу процестер зерттелді. Литосфера плиталар екі жақты сығу кезінде литосфера мен астеносфера өзара іс-қимыл қаралды. Екі жақты сығу кезінде серпінді негізі жататын анизотроптық плитаның тұрақтылық жоғалу құдікті күш табылған. Қысым күш құдікті күштең үлкен кезінде тұтқыр-серпімді литосфералық плитаның дөңістену уақыт бойынша экспоненциал заңмен өседі стандартты сызықты дене моделі қолдану шартқа сәтке дейін. Егер литосфералық плитаның материалы тұтқыр дене болған кезде уақыт бойынша экспоненциал заңмен дөңістік сондай-ақ өседі.

Түйін сөздер: кернеулі-деформациялық күй, деформация, тұтқырсерпімділік, литосфера, астеносфера, Жер.

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ПРОБЛЕМЫ ЛИТОСФЕРНОЙ ГЕОДИНАМИКИ

Аннотация. Построена механика вязкоупругой литосферы, где динамическим источником ее развития определены силы инерции внутреннего асинхронного вращения и вязкие силы от сферического течения Куэтта в астеносфере. Эти силы определяют природу внутреннего геодинамического давления и тангенциальных напряжений. Найдено, что в зависимости от разности угловых скоростей внутренних оболочек Земли литосфера может находиться в условиях всестороннего расширения или сжатия. Найден механизм локальных изменений толщины литосферы в результате неустойчивости деформирования литосферной оболочки Земли под действием внутреннего давления и объемных сил инерции вращения. Устойчивость деформирования исследована методом Лейбензона-Ишлинского. Основное напряженное и деформированное состояние рассмотрено при неизменной форме границы тела, а возмущенное с учетом поворотов элементов границ тела в процессе перехода к смежной форме равновесия. Определены асимметричные формы возмущений, приводящих к потере устойчивости эллипсоида вращения. Имеет место экспоненциальный рост компонентов возмущений во времени, сопровождаемый колебательными изменениями. В рамках вязкоупругой реологии литосферы анализируется напряженно-деформированное состояние литосферной плиты при двустороннем сжатии. Исследованы процессы образования складок, возникающие в результате взаимодействия плит в зонах межплитных границ. Рассмотрено взаимодействие литосферы с подстилающей астеносферой при двустороннем сжатии литосферной плиты. Найдено критическое усилие потери устойчивости анизотропной плиты, лежащей на упругом основании, при ее двустороннем сжатии. Выпучивание вязкоупругой литосферной плиты на вязкой астеносфере при значениях сжимающих усилий, больших критического, с течением времени растет по экспоненциальному закону до тех пор, пока не нарушается условие применимости модели стандартного линейного тела. Когда материал литосферной плиты моделируется вязким телом, прогиб также растет во времени по экспоненциальному закону.

Ключевые слова: напряженно-деформированное состояние, деформация, вязкоупругость, литосфера, астеносфера, Земля.

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REFERENCES

[1] Erzhanov Zh.S., Kalybaev A.A., Baimukhametov A.A., Korzhymbaev T.T. (1986) Motion and stability of shared Earth. Almaty: Science. 238 p. (in Rus.).

[2] Baimukhametov A.A. (2003) Mechanics of geooscillations. Almaty: Science. 244 p. ISBN: 9965-07-241-8 (in Rus.).

[3] Sorokhtin O.G., Chilingar G.V., Sorokhtin N.O. (2010) Theory of development of Earth. Moscow: IICR. 752 p. ISBN: 978-5-93972-768-6 (in Rus.).

[4] Erzhanov Zh.S., Egorov A.K., Garagash I.A., Iskakbaev A., Koksalov K. (1975) The theory of a crust folds. M.: Science. 238 p. (in Rus.).

[5] Koksalov K.K. (1999) Stability of an ellipsoidal lithospheric cover. Almaty: RIO VAK RK. 190 p. (in Rus.).

[6] Koksalov K.K., Baimukhametov A.A. (2013) Formation of lithosphere's plates owing to loss of stability of deformation under the influence of the internal pressure and forces of inertia of rotation // International Journal of Academic Research. Vol. 5, N 4. P. 5- 9. DOI: 10.7813/2075-4124.2013/5-4/A.1

[7] Structural geology and tectonics of plates. In three volumes. / Under the editorship of K. Seifert. M.: World. 1990, 1991 (in Rus.).

[8] Le Pishon Ks., Zh.Franshto, Bonin Zh. (1977) Tectonics of plates.

[9] Sheydegger A.E. (1987) Geodynamics bases.

[10] Turcotte D.L., Schubert G. (1985) Geodynamics. Applications of Continuum Physics to Geological Problems. New York.

[11] Unksov V.A. (1981) Tectonics of plates. Leningrad (in Rus.).

[12] Alliso A., Palmer D. (1984) Geology.

[13] Myasnikov V.P., Fadeev V.E. (1980) Hydrodynamic models of evolution of Earth and planets of terrestrial group. Moscow (in Rus.).

[14] Lobkovsky L.I. (1988) Geodynamics of zones of spreading, seduction and two-story tectonics of plates. Moscow (in Rus.).

[15] Grushinsky N.P. (1976) Theory of Earth figure. Moscow (in Rus.).

[16] Shimbirev B.P. (1975) Theory of Earth figure. Moscow (in Rus.).

[17] Carey S.W. (1991) Theories of the Earth and Universe. A History of Dogma in the Earth Sciences. Stanford University Press.

[18] Zharkov V.N., Trubitsin V.P. (1980) Physics of a planetary subsoil. Moscow (in Rus.).

[19] Leybenzon L.S. (1951) Meeting of works. Moscow (in Rus.).

[20] Ishlinsky A.Yu. (1954) Consideration of a question of stability of balance of elastic bodies from the point of view of the mathematical theory of elasticity. Ukrainian Mathematical Journal, 4(2): 15-23 (in Rus.).

[21] Blend D. (1965) Theory of a linear viscoelasticity.

[22] Baimukhametov A.A., Egorov A.K., Koksalov K.K. (2012) Mathematical model of tectonic process at mountain formation // International Journal of Academic Research. Vol. 4, N 3. P. 34 -37. DOI: 10.7813/2075-4124.2012/4-3/A.3

[23] Baimukhametov A.A., Martynov N.I., Ramazanova M.A., Tanirbergenov A.G. (2017) Applied aspects of researches of mathematical modellings of salt diapirizm in oil and gas business // News of the National academy of sciences of the Republic of Kazakhstan. Series of geology and technical sciences. Vol. 2, N 422. P. 185-193. ISSN 2518-170X (Online), ISSN 2224-5278 (Print). https://doi.org/10.32014/2018.2518-170X

[24] Kenzhaliyev B.K., Surkova T.Yu., Yessimova D.M. Concentration of rare-earth elements by sorption from sulphate solutions // Complex Use of Mineral Resources. 2019. N 3. P. 5-9. https://doi.org/10.31643/2019/6445.22

[25] Mochamad B. Triyono, LilisTrianingsih, Didik Nurhadi. Students' employability skills for construction drawing engineering in Indonesia // World Transactions on Engineering andTechnology Education. 2018. Vol. 16, Issue 1. P. 29-35.

[26] Kenzhaliyev B.K., Berkinbayeva A.N., Sharipov R.H. (2015). Research of the Interacting Process of Copper-Base Alloys with Leaching Solutions under the Action of Different Physicochemical Factors // American Journal of Applied Sciences. 12(12), 982-992. https://doi.org/10.3844/ajassp.2015.982.992

[27] Kenzhaliyev B.K., Dosymbaeva Z.D., Iskhakova R.R., Suleimenov E.N. (2015). Investigation into the Use of Electrochemical Extraction to Draw Gold from Refractory Ores // American Journal of Applied Sciences. 12(11), 857-864. https://doi.org/10.3844/ajassp.2015.857.864

[28] Lavrinenko S.V., Arpentieva M.R., Kassymova G.K. (2019). Motivation of technical university students and its impact on the effectiveness of the educational process // International youth scientific conference "Heat and mass transfer in the thermal control system of technical and technological energy equipment" (HMTTSC 2019). https://doi.org/10.1063/1.5120670

[29] Kenzhaliyev B.K., Iskhakova R.R., Dosymbayeva Z.D. (2015). Sorption Extraction of Noble and Non-Ferrous Metals from Process Leaching Solutions // American Journal of Applied Sciences. 12(11), 875-884. https://doi.org/10.3844/ajassp.2015.875.884

[30] Almagambetova A., Tileubay S., Taimuratova L., Seitmuratov A., Kanibaikyzy K. Problem on the distribution of the harmonic type Relay wave// News of the National academy of sciences of the Republic of Kazakhstan. Series of Geology and Technical Sciences **2019**. 1(433): 242-247 (in Eng.). ISSN 2518-170X (Online), ISSN 2224-5278 (Print). https://doi.org/10.32014/2019.2518-170X.29