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The transformation of the lithospheric figure caused by the evolutionary development of the Earth

A. Tserklevych, *Y. Shylo, O. Shylo, *(Lviv Polytechnic National University)*

SUMMARY

The transformation of the lithosphere shape caused by the evolutionary development of the Earth is considered. Based on the concept of "evolutionary deviation of the plumb line", the surface tangential forces arising during the transformation of the figure are calculated. The calculated forces show consistency with the directions of movement of the continents and tectonic plates.

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Introduction

At the present stage of studying the shape of the Earth, there are four types:

- the shape of the planet in the hydrostatic state (mainly theoretical studies, starting with Newton), which is used to assess the isostatic and stress state of the Earth;
- the figure of the physical surface (or geometric figure), which, in relation to the Earth, describes the surface of the continents and the ocean floor (geologists and geophysicists in geodynamic studies use the term "lithosphere surface figure");
- a dynamic figure, which is associated with the moments of inertia of the celestial body, for the Earth is a triaxial ellipsoid of inertia;
- gravitational figure, which covers all masses, including the water surface, and is characterized by the main level surface - the geoid.

To adequately understand how the structure-forming tectonic processes occur on Earth, determine the gravitational field and calculate the coordinates of points on the earth's surface, it is necessary to know exactly how the shape of our planet changes and whether it changes at all. The geodynamic activity of the Earth is uneven in space and time, the probable periodicity of the main processes of geodynamic evolution of our planet. The time scale of geological phenomena (millions and billions of years) is far beyond the duration of experiments implemented by geodetic methods. We see only what the Earth shows us in an infinitesimal period of its geological evolution, and we are practically deprived of the opportunity to reproduce the processes we want to study. On the other hand, the facts about the internal structure and evolution of the Earth, obtained by various methods of geology and geophysics, fit into an extremely complex picture of dynamic phenomena and therefore despite long study of geological processes in the upper Earth's crust, the nature of geodynamic forces still remains hypothetical. However, these facts can be tried to explain on the basis of certain, often hypothetical assumptions, in accordance with the fundamental laws of physics and mechanics and mathematical modeling. The shape of the surface of the lithosphere is geometrically rotated relative to the shape of the geoid, and in geological time the orientation of these shapes and the parameters of the ellipsoids that approximate them have changed. This arrangement of the lithosphere shape and the geoid shape can create a stress that is aimed at bringing the mass distribution of the lithosphere in line with the shape of the geoid. According to the parameters of evolutionary changes in the shape of the lithosphere surface, it is possible to determine the acting mass forces that determine the dynamics of the stress state of the Earth. To do this, it is advisable to represent the shape of the lithosphere biaxial or triaxial ellipsoids.

Methods of investigation

Consider the tangential mass forces that occur due to changes in the position of the axis of the lithosphere relative to the axis of rotation. We introduce the concept of deviation of “geoevolutionary” plumb line and assume that the tangential forces are proportional to the angle γ, which is defined as the angle between the direction of the plumb lines in the past geological epoch and the direction of the plumb lines at a given point. Note that the ellipsoid E_L in the past approximately represented the level surface of our planet. Now he is responsible for the ellipsoid E_L'. It is clear that the dimensions of the ellipsoid E_L' in comparison with E_L the changed, since the external surface of the lithosphere has changed. Accordingly, the parameters of the ellipsoids are not identical. However, we can assume that the surface of the Earth in the past roughly coincided with the surface of ellipsoid E_L', and in the case of such an assumption, the angle between the directions of the plumb lines (normal line to surface ellipsoids) is formed γ (fig.1).

Here are the final formulas for determining the tangential mass forces acting on the elementary masses of the surface shell of the planet due to the reorientation of the physical surface relative to the geoid (Tserklevych, 2017):

$$F_{\varphi} = \frac{Bg}{R}\sin 2\varphi_0 \; - \frac{Cg}{R}\sin 2\varphi_0 \sin^2 \lambda_0 + + \frac{2Dg}{R}\cos 2\varphi_0 \sin \lambda_0; \qquad (1)$$

$$F_{\lambda} = \frac{Cg}{R}\cos^2 \varphi_0 \sin 2\lambda_0 + \frac{Dg}{R}\sin 2\varphi_0 \cos \lambda_0. \qquad (2)$$

where $B, C, D-$ constant coefficients that functionally depend on the parameters of the biaxial ellipsoid of the lithosphere figure, g – the average value of the acceleration of gravity, R – the average radius of the Earth, φ_0 and λ_0 – latitude and longitude of the corresponding point.

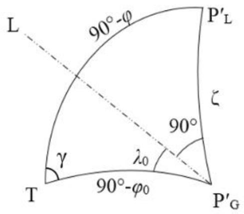


***Figure 1** Illustration to the definition of angle* γ

Now consider the forces that affect the Earth's lithosphere due to changes in its compression, caused by a slowdown in its speed. It is believed that the shape of the Earth is close to the surface of the gravitational potential (ellipsoid of rotation), which is the sum of the gravitational potential and the potential of centrifugal forces. The need to take into account these forces is associated with the acceleration or deceleration of the planet's rotation. Because of this, the shape of the Earth does not correspond to the altered shape of the surface of the gravitational potential, and therefore additional tangential mass forces may appear in the lithosphere. Consider the definition of these forces in accordance with the theoretical developments of M.V. Stovas (Stovas, 1975).
If we go from potential to acting forces, we get:

$$F = \frac{1}{3}\omega^2 r (1 + 3\sin^2 \varphi)^{1/2}. \qquad (3)$$

Formula (3) shows the total force that occurs when the compression of the ellipsoid of rotation. In contrast to the solution of the problem through the reorientation of the physical surface, where the components of the total force are forces in the plane of the meridian and the prime vertical. Obviously, in this case it is advisable to consider one horizontal (in the plane of the meridian) and vertical component, which is directed along the normal to the ellipsoid (see Fig.2). Since the component of the total force passing tangent to the prime vertical will be zero.

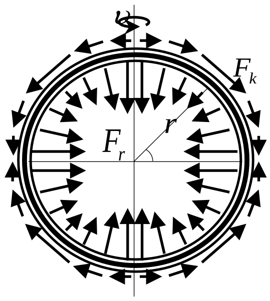


***Figure 2.** Illustration to the definition of forces* F_r *i* F_k

Therefore, the meridional component is written as

$$F_k = \frac{\omega^2 r \left(1 + 2(1-\alpha)^2 \sin\varphi \cos\varphi\right)}{3\left((1-\alpha)^4 \cos^2\varphi + \sin^2\varphi\right)^{1/2}}, \qquad 4)$$

and vertical

$$F_N = \frac{\omega^2 r \left((1-\alpha)^2 \cos^2\varphi - 2\sin^2\varphi\right)}{3\left((1-\alpha)^4 \cos^2\varphi + \sin^2\varphi\right)^{1/2}}. \qquad (5)$$

If we transform the vertical component from the tangent normal to the direction of the radius-vector, we obtain

$$F_r=\frac{\omega^2 r\left((1-\alpha)^2\cos^2\varphi-2\sin^2\varphi\right)\left((1-\alpha)^2\cos^2\varphi+\sin^2\varphi\right)}{3\left((1-\alpha)^4\cos^2\varphi+\sin^2\varphi\right)^{1/2}} \tag{6}$$

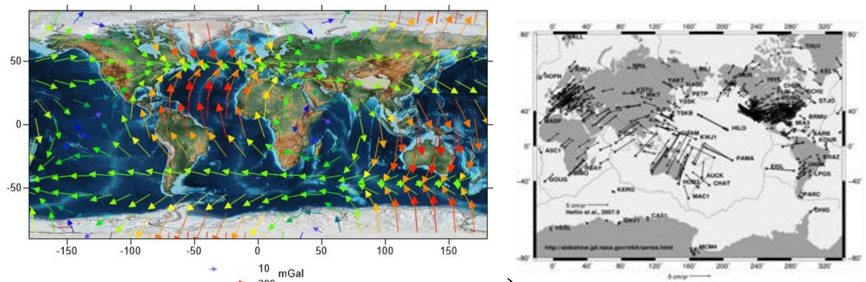
Carefully analyzing the notation (4) and (5), we can see that: at critical latitudes (45°) the radial component is zero, at the poles and equator is equal to the total force, and the tangential component behaves the opposite - at critical latitudes is equal to the total force, and at the poles and the equator is zero. These expressions analytically demonstrate the mass radial and tangential forces that arise due to fluctuations in the speed of rotation and, accordingly, changes in the compression of the planet.

Initial and geological data

The calculation of the parameters of biaxial and triaxial (Tserklevych, 2016) ellipsoids was performed on the basis of data from the digital model of the Earth's surface ETOPO1 (NCEI, 2016). For this model, the heights were averaged within 5ºx5º trapezoids. To model the transformation of the Earth's figure and assess the impact of its reorientation on the stress-strain state of the lithosphere in distant geological epochs, two variants of raster maps of paleoreconstructions of continents and water surfaces were used, which were independently created by R. Blakey and K. Scotese. Since all raster images are created sequentially in certain colors, with some assumptions, finding a connection between the image heights of the model ETOPO1 and raster maps of paleoreconstructions, we can move to a certain approximation to the digital surface relief model (DSRM) of the Earth's lithosphere.

Results of investigations

Tangential mass forces resulting from a change in the position of the axis of the figure of the lithosphere relative to the axis of rotation are shown in Fig.3a. Note their consistency with the contours of the continents. The planetary picture of distribution of vectors of tangential mass forces presented by us very well coincides with the direction of vectors of horizontal displacements of permanent stations on GNSS measurements which are shown in fig. 3b which are taken from the site (https://i.ytimg.com/ vi / KxJXiV4oTx0 / maxresdefault .jpg). The exceptions are two continents: North America and Australia, for which the motion vectors of permanent stations by GNSS measurements have the opposite meaning.



a) b)

Figure 3. *a – Maps of tangential forces versus the background of continents and oceans. The arrows indicate the tangential forces in milligals., b –. Map of horizontal displacement vectors of permanent GNSS stations (https://i.ytimg.com/vi/KxJXiV4oTx0/maxresdefault.jpg)*

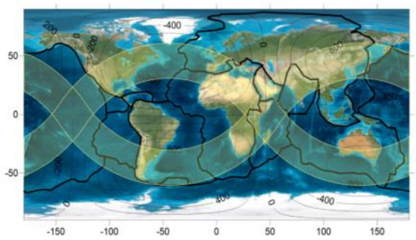


Figure 4. *Maps of the distances between ellipsoids approximating the surface of the lithosphere and the geoid of the Earth*

Figure 4 shows a map with inscribed isolines of heights, which determine the distances between the surfaces of ellipsoids, representing generalized the Earth's lithosphere and the geoid. This map shows the so-called "tectonic watershed", in the form of a broad arc-shaped strip, which characterizes the largest rise of the ellipsoid approximating the surface of the lithosphere, relative to the surface of the general-Earth ellipsoid, which display the geoid.

This strip of "tectonic watershed" almost exactly coincides with he boundaries of tectonic plates (with the exception of the South American and Pacific ones). In addition, if we connect the largest depressions of one ellipsoid with the other in this figure by arc-shaped strip, then we can notice a similar coincidence with other boundaries of the tectonic plates. Accordingly, these two bands, which highlight the peculiar structural planetary "watershed" and "thalweg" on the globe, cover almost all the boundaries of the main lithospheric plates. This fact suggests the determining role of the mutual arrangement of two ellipsoids approximating the lithosphere of the Earth and the geoid, and rotational-gravitational forces in the structure-formation processes of the formation of the boundaries of lithospheric plates. The maximum uplift or sinking of the ellipsoid that is approximating the surface of the lithosphere relative to the general-Earth ellipsoid, that representing the geoid reaches +-960 m (Tserklevych, 2018).

Recommendations and conclusions

According to the results of computer modeling of the reorientation of the shape of the Earth's lithosphere, certain regularities that reflect the structure-forming processes have been revealed. It is shown that the figure of the lithosphere surface has a different orientation relative to the figure of the geoid.

Based on the concept of "evolutionary deviation of the plumb line" and the assumption that the tangential forces are proportional to the angle defined as the angle between the direction of the slope lines in the past geological epoch and the current direction at a given point, calculated the horizontal forces in the upper shell.

The calculated fields of the tangential force vectors show good agreement with the direction of spatiotemporal movement of the continents and tectonic plates and almost complete coincidence with the horizontal components of the shear vectors of GNSS stations.

This convincingly indicates that lithosphere masses under the action of vortex rotational-gravitational forces under their long-term influence can acquire creep properties.

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