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GEOLOGY

Energy of Tectonic Process and Vortex Geological Structures

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At present, the existence of effects of Earth's pulsations [1] and tectonic reconstructions [2], which generate the compression, extension, and shear zones, as well as their relation to the rotation of the earth, do not raise any doubts [3]. Quantitative description of such tectonic effects within the framework of wave concepts requires development of the corresponding rotational-elastic model of the geophysical medium.

Recently, the concepts about the geophysical medium as a nonclassic nonlinear block medium [4–6] have become commonly accepted [7]. The available data directly point to the rotational, torsional, and vortical character of the motions of blocks, plates, and other geological structures of the planet [8]. It is important to note the following opinion of many geologists and geophysicists engaged in this field: the above-mentioned motions, which can be "independent," "natural," "unrelated to nonzero divergence and vorticity," and elastic, are directly related to the rotation of the planet [9]. The geophysical rotating media incorporate a new type of elastic rotational waves with a characteristic velocity of 1 cm/s, and such waves are actually tectonic waves [10, 11].

The consideration of the structure of the boundaries of lithospheric plates as shear deformation zones in the light of the wave tectonic concept led to formulation of a hypothesis about a clockwise rotating planetary vortex. Within the framework of this hypothesis, precisely such polar vortex of planetary scale should cause the observed anticlockwise rotation of the ensemble of all lithospheric plates [8, 9].

Let us estimate the energy of the tectonic process within the framework of the concept of the geophysical medium.

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The energy of the tectonic process is obviously determined by sizes (masses) L of plates (and blocks) and velocities V of their motion. It follows from the most general considerations that the existence of dependence $L(V)$ is a principle moment that actually governs the physics of the dislocation mechanism of tectonic plates along the Earth's surface. Indeed, in the case of the existence of the dependence between such (actually, vector) values, which unambiguously govern the energies of the moving plates, there are grounds for the supposition about the momentum nature of the tectonic process in a rotating planet.

The problem of the energy of tectonic process was not posed before in this aspect. However, peculiarities of manifestation of tectonic energy were analyzed in an implicit form. First, the problem of the existence of relation $L(V)$ is problematic at present: arguments exist both for and against it [8, 9]. Second, we believe that the momentum nature of the tectonic process in the Earth is supported by the correlation revealed between the mean polar distance of the plates and the velocities of subduction and spreading [8, 9, 12].

The analysis of the available data on the sizes of plates and the velocities of their motions along the boundaries during the last 150–165 Ma allowed us to obtain the following results [8, 9]. First, the available data (N = 61) do not reveal a statistically significant $L(V)$ relationship, i.e., relationship between lengths of zones and velocities of subduction, rifting, and spreading: experimental data points on the L–V plane (plate size $650 < L$ (km) $< 18\ 000$, motion velocity $5 < V$ (mm/yr) < 112) uniformly fills an approximately round field (Fig. 1a). Second, the analysis of only data on rifting and spreading velocities (RS-data, Fig. 1b, $N = 29$) makes it possible to distinguish reliably the following statistically significant dependence:

$$\log L_1[\text{km}](\pm 0.33) = (0.43 \pm 0.15)\log V_1[\text{mm/yr}] + (3.17 \pm 0.26). \quad (1)$$

Third, sufficiently representative RS-data on measurements within duration intervals smaller than 20 (5–

33) Ma, which the authors managed to find from the magnetic anomaly numbers [8, 9], define the following close relations ($N = 21$):

$$\log L_2[\text{km}](\pm 0.3) = (0.7 \pm 0.3)\log V_2[\text{mm/yr}] + (2.9 \pm 0.5). \quad (2)$$

Fourth, analysis by the least squares method did not reveal any statistically reliable relation $\log L(\log V)$ for subduction (S) data ($N = 32$).

Thus, analysis of data on the length of rifting–spreading zones and velocities of the motion of plate boundaries within these zones points to the existence of two mechanisms with characteristic times of ~150 (144–165) Ma for mechanism (1) and ~20 (5–33) Ma for mechanism (2).

We note that the $\log L \approx \log V$ correlation, which is close to relation (2), was obtained in [12] for both spreading and subduction processes. The shape (extension) and minimal values of subduction (Fig. 1c) and rifting-spreading (Fig. 1b) regions of the location of initial points are similar. These regions have different densities of data points: the RS-data are quite uniformly distributed over the entire region, while the denser S-data are concentrated in the region of maximal values of the zone length. It seems that the regions of short (1000–2000 km or less) subduction zones are insufficiently studied, resulting in an artificial data deficit. In other words, the analysis performed in this work and the data obtained by other researchers indicate that the two mechanisms discussed above are typical of all tectonic processes including subduction.

In order to determine the tectonic energy of the moving plate, we shall assume that its kinetic energy is equal to $E = \frac{1}{2}mV^2$, where $m \approx \rho L^{\alpha}$ is mass of the plate and ρ is its volumetric ($\alpha = 3$), areal ($\alpha = 2$), or linear ($\alpha = 1$) density. Then, differentiating the relation for the energy, substituting in the obtained differential equation dL for dV determined from relation $\log L \approx \beta \log V$, and integrating the obtained relation for the energy of the plate with length L moving with velocity V, we obtain expression $E/E_0 = (V/V_0)^{2+\alpha\beta}$ or

$$E \approx V^{2+\alpha\beta}, \quad (3)$$

where $\beta \approx 0.45 \pm 0.13$ for the mechanism described by relation (1) and $\beta \approx 0.7 \pm 0.3$ for (2); $E_0 = \frac{1}{2}\rho L_0^{\alpha} V_0^2$, L_0, and V_0 are the energy, length of the plate, and velocity of the motion of its boundary at the beginning of the process.

Relations (1)–(3) show significant differences in the dependence between the energy of plates and the velocity of their motion for each of the mechanisms. Indeed, we get the following relations in the limiting cases:

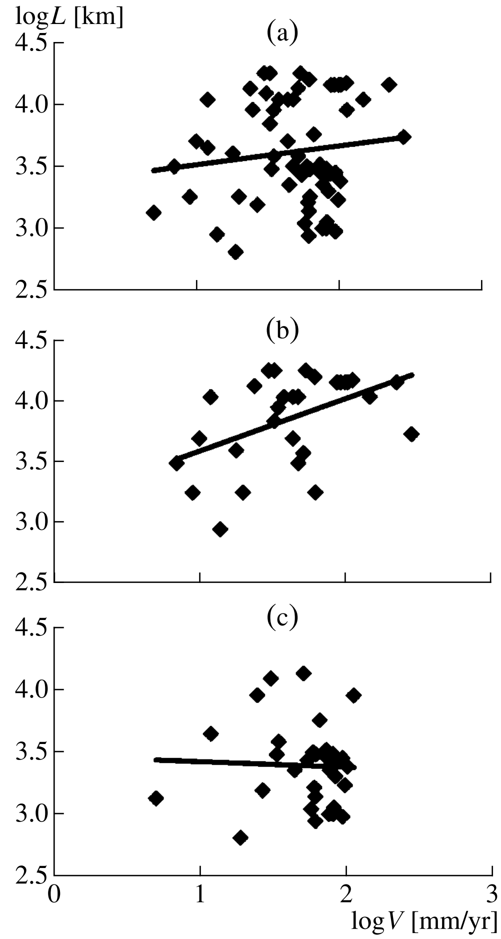

Fig. 1. Data characterizing the relation $\log L(\log V)$ between lengths of plates L and velocities of their motion V according to [8]. (a) Velocities of subduction, rifting, and spreading ($N = 61$); (b) velocities of rifting and spreading ($N = 29$); (c) velocity of subduction ($N = 32$).

For mechanisms (2) when $\beta_{max} \approx 1$ at $\alpha_{max} \approx 2.5$ ($2 < \alpha < 3$, for example, at small times, we obtain the formation of a plate),

$$E_1 \approx V_1^2. \quad (4)$$

For mechanisms (1) when $\beta_{min} \approx 0.3$ at $\alpha_{min} \approx 1$ (for example, at large times, the size of the plate increases practically in one direction),

$$E_2 \approx V_2^5. \quad (5)$$

We see that the obtained plate tectonic relations (1)–(2) and (4)–(5) are close to the corresponding wave solutions for solitons and exitons of the rotational seismotectonic problem [10, 11]. Thus, a tectonic process in the framework of the rotational-elastic model [8–11] has specific corpuscular-wave properties, which allows us to consider seismotectonic blocks and tectonic plates of the planet as interrelated structures. The result of their interaction is a set of rotational-elastic seismotectonic solitons and exitons, which form a self-consistent tectonic wave field (according to [13], "self-organization… with nonzero divergences and vortices"). Within these concepts, the new global tectonics is actually a corpuscular component of the tectonic process without taking into account the rotation of the planet.

It is noteworthy that interest in the problem of rotational structures has soared during the last ten years in the earth sciences [8, 9, 14] (analogy with transition from a "ruler" to "divider") against the background of failures in the New Global Tectonics [14, 15]. We see the development of a clear process of the quest for a new tectonic paradigm that can be based on concepts of the rotational-elastic tectonic model [7–10] described in the present work.

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