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GEOPHYSICS

Rigidity of Tectonic Structures in the Central East European Platform

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The block-hierarchic division, nonlinearity, and geodynamics of the Earth's crust are determined in many respects by the deformability of fracture-type tectonic structures. The deformability is characterized by two parameters, normal rigidity (k_n) and shear (k_s) rigidity:

$$k_n = \frac{d\sigma_n}{dw_n}, \quad k_s = \frac{d\tau}{dw_s},$$

where σ_n and τ are the normal and shear effective stresses, respectively, at the edges of the tectonic disturbance (hereafter, fracture); w_n and w_s are the relative normal and shear displacements of the edges, respectively.

At the same time, the rigidity of different sectors of the tectonic structure significantly governs their modern activity and the intensity of interactions between geospheres at the Earth's core–atmosphere interface [1, 2].

In this paper, we present the results of experimental measurement of the mechanical rigidity of the Oka sector of the deep Nelidovo–Ryazan tectonic structure (NRTS) and auxiliary faults of order II [2, 3]. The k_n and k_s values were based on recording nonlinear effects of the propagation of low-amplitude seismic waves across the mentioned fracture. In the NRTS, k_n = 0.05–0.19 MPa/mm; k_s = 0.012–0.034 MPa/mm. In fractures of order II, these parameters are equal to 0.28–1.0 and 0.08–0.29 MPa/mm, respectively.

Our research shows that the rigidity of fractures varies in time. Moreover, time variations of the rigidity of tectonic structures of the same periodicity correlate with time variations in the microseismic background amplitude in the frequency range 0.1–2 Hz (the correlation coefficient ranges from –52 to –63 at a significance level not less than 0.95). This fact could indicate a common cause of the perturbation of the long-period component of the microseismic background and the mechanical characteristics of fractures.

Figure 1 presents a scheme of the Oka sector of the NRTS. Fractures at the flanks of the major structure were distinguished as a result of geomorphologic analysis of satellite images [3], measurements of bulk activity of subsoil radon [4], and application of the method of microseismic diagnosis of fracture activity [5].

In order to determine the mechanical characteristics of tectonic structures, we used the seismic method of diagnosis based on recording the amplitude variation of seismic waves propagating through a fracture fluctuation of medium continuity [1, 6]. Tectonic structures of orders I and II were considered as a flat layer, whose elastic properties differ from the corresponding characteristics of the enclosing massif. In the case of normal incidence of a longitudinal or transverse wave, the normal k_n (correspondingly, shear k_s) rigidity of the tectonic structure is determined according to the following formulas [1]:

$$k_n = \frac{\pi\rho C_p}{T_p\sqrt{K^2-1}}, \quad k_s = \frac{\pi\rho C_s}{T_s\sqrt{K^2-1}},$$

where ρ, C_p, and C_s are the density of medium and the velocity of propagation of longitudinal and transverse waves, respectively; T_p and T_s are the periods of the corresponding waves of fluctuations; K is the ratio of maximum amplitudes of displacement velocities in the seismic wave before and after the fracture.

In 2003–2005, seismic signals propagating across tectonic structures were measured at three-component on-line seismic recording points located at the opposite edges of the studied fractures (Fig. 1). In order to study the mechanical properties of the NRTS, the on-line recording points were located in pits at the boundaries

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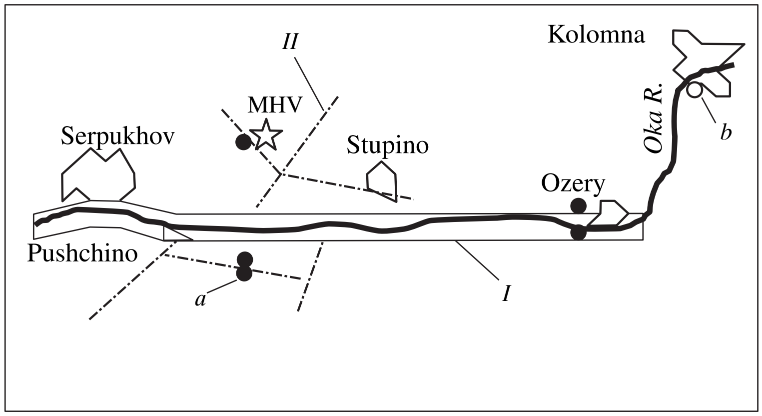

Fig. 1. Scheme of the seismic observation site. (*I*) Boundaries of the Oka sector of the NRTS; (*II*) fractures of order II; (*a*) on-line recording points; (*b*) Shchurovo open pit. Asterisk denotes the Mikhnevo geophysical observatory of the Institute of Geosphere Dynamics (station MHV).

of the Oka floodplain in summer and at the basements of capital constructions (Settlements of Sen'kovo and Alekseevka, Moscow district) in winter. The distance between the recording points was approximately 2 km. Structures of order II were studied using hidden temporal recording points [2] located with a spacing of 50–100 km along the fracture edges.

Seismic waves caused by extensive explosions in open pits mines of the Moscow district and relaxation impulse microoscillations were analyzed [7]. We examined signals propagating normally to the fractures (the incidence angle of seismic waves with respect to the tectonic structure did not exceed 40°, which provided sufficient accuracy of determination of the structure rigidity using normal (with respect to the fracture) components of longitudinal and transverse oscillations [1]).

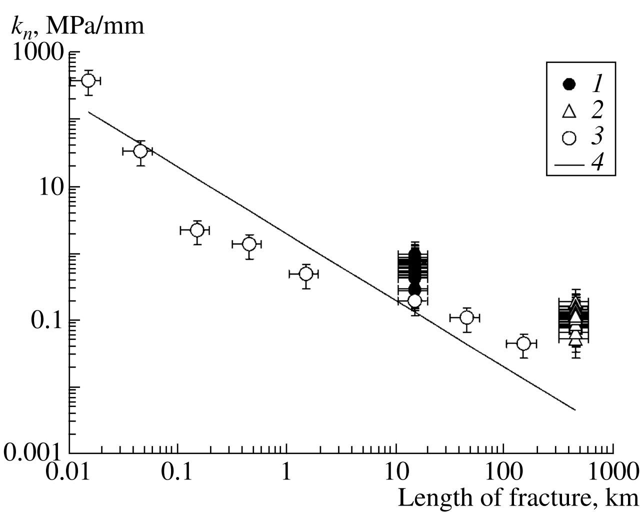

Fig. 2. Rigidity of fractures. (*1, 2*) Oka sector of the NRTS: (*1*) structure of order II; (*2*) NRTS; (*3*) data adopted from [1]; (*4*) calculation using the formula $k_n = \frac{2 \times 10^3}{L}$, where L is the length of fracture, m.

Figure 2 presents the results of experimental data obtained in our work as normal rigidity of tectonic structures of orders I and II. It is noteworthy that the obtained k_n values, first, correlate well with the known data [1] and, second, correspond to the accepted concepts about the rigidity of tectonic structures of higher orders.

Table 1 presents experimental values of the rigidity of tectonic structures. The low value of the $\frac{k_s}{k_n}$ ratio in the NRTS attracts attention. In the elastic approximation, the normal and shear rigidities are related as

$$\frac{k_s}{k_n} = \frac{1-2\nu}{2(1-\nu)},$$

where ν is the Poisson coefficient of the material filling the major fracture.

The $\frac{k_s}{k_n} = 0.19$ ratio (Table 1) corresponds to $\nu = 0.38$, a value characteristic of clayey and water-saturated grounds. Hence, the major NRTS fracture [1] is represented by clayey filler and partly water-saturated soft rock. The $\frac{k_s}{k_n}$ ratio for tectonic structures of order II is equal to 0.29 ($\nu \approx 0.3$). Hence, the structures mentioned above are represented by fractures filled with sand and grus [1].

Let us present the structure of the tectonic fracture as the major fault (width l_c) filled with soft material and an auxiliary fracture system with a significantly higher rigidity [1]. Estimating the l_c value using the formula $l_c = \frac{\rho_1 C_{p1}}{k_n}$, where ρ_1 and C_{p1} are the density and veloc-

Table 1. Mechanical characteristics of tectonic structures

Parameter	Tectonic structure	
	NRTS	Order II
Mean value k_n, MPa/mm	0.12	0.67
Mean value k_s, MPa/mm	0.022	0.19
Mean value $\frac{k_s}{k_n}$	0.189	0.29
l_c	12	2
G, MPa	$1.4 \cdot 10^3$	$1.34 \cdot 10^3$

Table 2. Correlation coefficients

Parameter	Tectonic structure	
	NRTS	Order II
K_{ns}	–0.57	–0.63
K_{ss}	–0.52	–0.56

ity of latitudinal waves, respectively, in the major fracture filler (MFF), we get $l_c \approx 12$ and 2 m for the NRTS and faults of order II, respectively.

Estimation of the deformation modulus G of the MFF using the obtained k_n and l_c values yields approximately the same values of G for the NRTS and structures of order II (Table 1).

A more detailed analysis shows that the scatter in the obtained experimental k_n values is related to the manifested time variations in rigidity rather than the accuracy of measurements and the experimental data processing. Figures 3 and 4 present time variations in the k_n and k_s values for the tectonic structures of orders I (NRTS) and II. It is clearly seen that the rigidity of fractures in the Earth's crust regularly changes with time. The period of rigidity variations is approximately equal to 1 yr, which corresponds to seasonal cyclicity of the amplitude variations in the microseismic background (Figs. 3, 4) [8]. One can see a high correlation between the coefficients of the normal and shear rigidities of tectonic structures and amplitude variations in the long-period component of the microseismic background. Table 2 presents the coefficients of linear correlation K_{ns} and K_{ss} between the microseismic background amplitude (range 0.1–2 Hz) and the normal and shear rigidity, respectively, of tectonic structures (in all cases, the significance level is not less than 0.95).

It is noteworthy that the values of both the normal and shear components of fracture rigidity determined on the basis of an explosion-induced seismic wave are

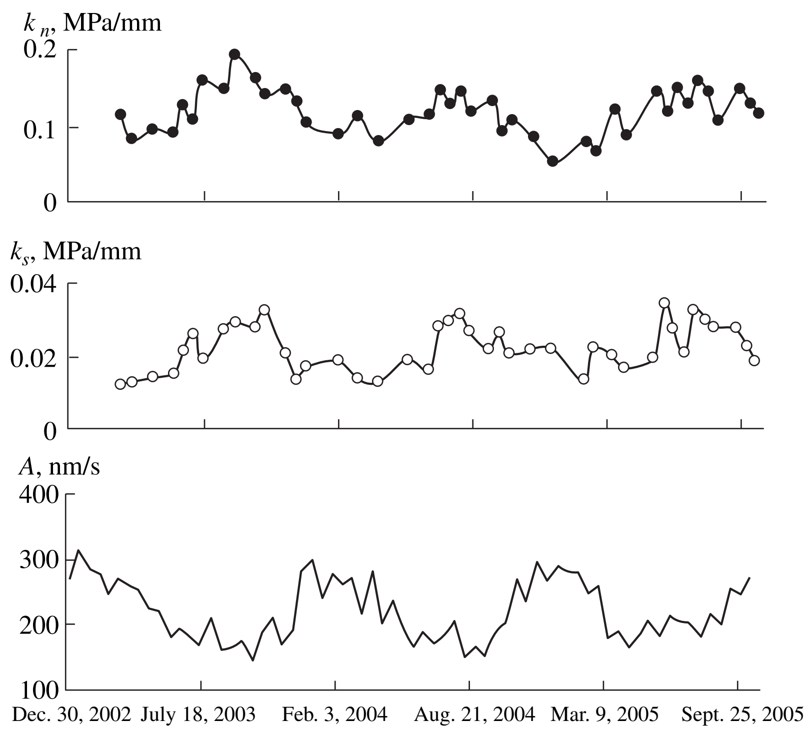

Fig. 3. Variations in the normal k_n and shear k_s rigidities of the NRTS. (A) Amplitude of microseismic background in the frequency range 0.1–2Hz.

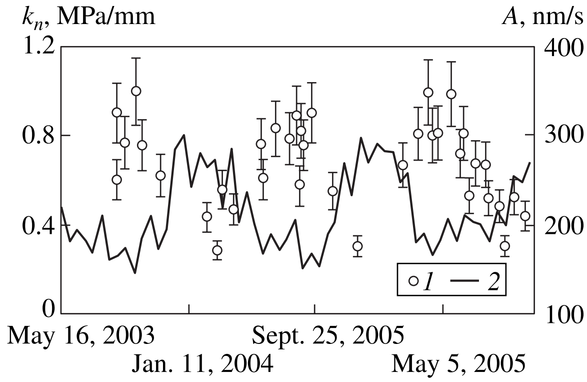

Fig. 4. Variations in (*1*) normal rigidity of the tectonic structure of order II; (*2*) variations in the amplitude of microseismic background in the frequency range 0.1–2 Hz. Vertical dashes denote accuracy of rigidity determination.

generally 1.2–1.3 times lower than the values based on the characteristics of relaxation impulse oscillations. This is natural and does not contradict the previously found decreasing tendency of fault rigidity with increasing deformation amplitude [1].

Taking into consideration previous results suggesting the presence of time variations in the bulk activity of subsoil radon in fault zones [2, 4] and the present experimental data, we can draw the following conclusions. Fractures in the Earth's crust are dynamic rather than static systems. This is manifested in the variation of their rigidity with time. This implies that the present-day block-hierarchic structure of the Earth's crust should be considered an evolutionary rather than conserved system.

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REFERENCES

1. G. G. Kocharyan and A. A. Spivak, *Dynamics of the Deformation of Rock Massifs* (Akademkniga, Moscow, 2003) [in Russian].
2. V. V. Adushkin and A. A. Spivak, in *Dynamic Processes in the System of Interacting Internal and External Geospheres* (GEOS, Moscow, 2005), pp. 142–163 [in Russian].
3. A. A. Spivak, G. N. Ivanchenko, S. B. Kishkina, et al., in *Geophysical Processes in the Lower and Upper Shells of the Earth* (IDG RAS, Moscow, 2003), pp. 108–118 [in Russian].
4. V. V. Adushkin and A. A. Spivak, Dokl. Earth Sci. **402**, 556 (2005) [Dokl. Akad. Nauk **402**, 92 (2005)].
5. V. V. Adushkin, A. A. Spivak, and V. G. Spungin, Geoekologiya, No. 4, 19 (1997).
6. V. V. Adushkin, V. N. Kostyuchenko, G. G. Kocharyan, and D. V. Pavlov, Dokl. Earth Sci. **368**, 958 (1999) [Dokl. Akad. Nauk **368**, 103 (1999)].
7. A. A. Spivak, Dokl. Earth Sci. **363**, 1172 (1998) [Dokl. Akad. Nauk **363**, 246 (1998)].
8. A. A. Spivak, S. B. Kishkina, D. N. Loktev, and V. M. Ovchinnikov, Dokl. Earth Sci. **398**, 1016 (2004) [Dokl. Akad. Nauk **398**, 400 (2004)].