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GEOPHYSICS

Parameters of Seismotectonic Deformations of the Earth's Crust in the Baikal Rift Zone Based on Seismological Data

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The peculiarities of the deformation of the Earth's crust in the Baikal rift zone (BRZ) are studied sufficiently well in the seismological aspect (see, for example, [1, 2] and others). At the same time, problems related to the separation of local and regional characteristics of seismotectonic deformations (STD) and to the quantitative estimate of the seismogenic component of the general tectonic process remain pressing.

The objective of this work is to distinguish the regimes of seismotectonic deformation of the Earth's crust in the BRZ during a 50-yr (1950–1999) period of seismological observations and to determine the mean velocities of STD. The STD values were calculated on the basis of integral information about the source parameters of earthquakes with $M \geq 4.5$ because the main part of the released seismic energy is accumulated precisely in such sources. The reconstruction of deformation regimes was performed on the basis of a more complete database including solution of the mechanism of the sources of 3300 seismic events with $M \geq 1.0$.

According to [2, 3], the STD velocity in a seismoactive volume was found from the sum of tensors of seismic moments of earthquakes normalized by the shear modulus, volume, and time. The values of seismic moments (M_0) defined the energy contribution of each source. The data used in the study was quite representative because the sum of M_0 events with known mechanisms was greater than 80% of the sum M_0 of all earthquakes recorded instrumentally. The sought parameters were estimated in three high-seismicity regions distinguished on the basis of geomorphological peculiarities and independent position in the main structure-forming elements (Fig. 1). The thickness of the seismogenic layer was assumed equal to 20 km.

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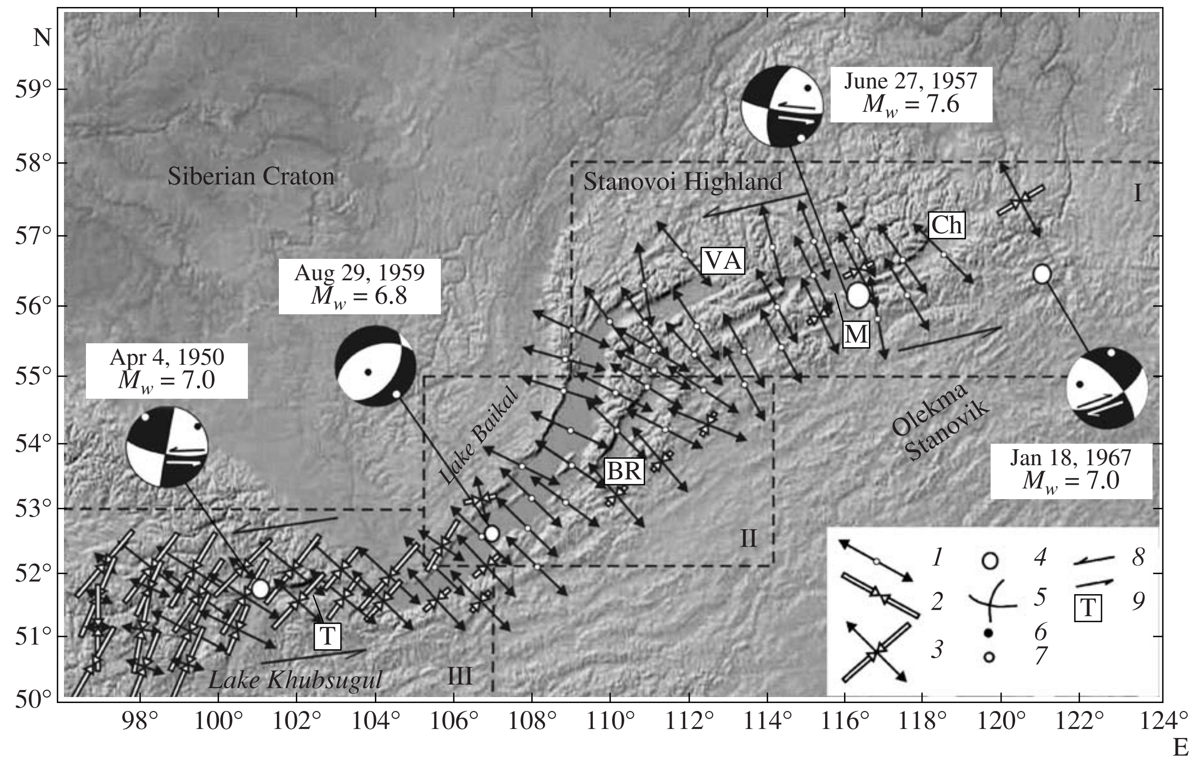
The results of calculations showed that during the time period studied here, the descent velocity of the ground surface along the vertical component E_{zz} over the entire territory varies within $(0.08–2.31) \times 10^{-9}$ yr^{-1} (the accuracy of estimates does not exceed half of the order of magnitude). The recalculated vertical displacement velocity with respect to the thickness of the layer is equal to $(0.16–4.62) \times 10^{-2}$ mm · yr^{-1}. The greatest velocity in all parts of the rift zone was recorded along the horizontal shear component E_{xy}, which varied from 10^{-8} to 10^{-10} yr^{-1}. The minus sign (table) points to sinistral shear displacements along the sublatitudinal plane. As compared to the other parts of the rift, the northeastern sector is characterized by greater values of velocities, probably related to the activation of sublatitudinal compressive stress (most likely from the Sea of Okhotsk or North American plates). The presence of a local mantle source of deformations is not excluded here.

Modern seismotectonic regimes—northwestern (in the northern quadrant) elongation, which is most clearly manifested in the Earth's crust of the central BRZ, and shears at the flanks—during at least the Holocene did not change strongly [4]. If the mechanisms of the earthquake sources of historical, ancient, and instrumental periods reflect the same trends of stress release in the lithosphere and the total seismic moment of historical earthquakes (table) are taken into account, the STD velocities in the BRZ over the last 300 yr were sufficiently high and did not exceed the calculated velocities by one to two orders of magnitude.

In order to determine the direction and dominating regimes of STD using the method of Yunga [3], the entire territory of the BRZ was divided into circular overlapping cells with a radius of approximately 80 km. Summation of matrices of individual mechanisms with unit weight coefficients was performed within the cells. After this, the eigenvalues of the mean matrices and orientation of the main deformation axes were found.

The figure shows that orientation characteristics of the deformation tensor are strictly distributed in space



Orientation characteristics of seismotectonic deformations in the Baikal rift zone (in the plane of the earth's crust). (*1–3*) Major deformation axes reflecting the main regimes of STD: (1) elongation (extension), (*2*) contraction (compression), (*3*) shear (lengths of the axes correspond to the relative values of deformations); (*4*) epicenters of strong earthquakes; (*5–7*) focal mechanisms (in the projection of the lower hemisphere) with the data and moment magnitude of the seismic event: (*5*) nodal planes, (*6*, *7*) axes of compression and extension stresses, respectively (regions of compression are shaded); (*8*) sinistral shear displacements according to the geological data; (*9*) Cenozoic depressions: (T) Tunka, (BR) Barguza, (VA) Verkhnyaya Angara, (M) Muya, (Ch) Chara. Locations of (I) northeastern, (II) central, and (III) southwestern seismoactive regions, for which mean STD velocities were calculated (table), are highlighted with a dashed line.

(elongation is directed to the northwest or in the submeridional direction, whereas contraction is directed to the northeast). The form of STD clearly follows the main structural plan of the rift zone: in the transition regions from the center to sublatitudinal flanks, the dominating northwestern elongation is replaced by the shear regime. At the northeastern closure of the BRZ (middle flow of the Olekma River), this trend is not so clear because statistically reliable data are lacking before 1999. Nevertheless, studies of recent years [5] confirm the presence of a shear deformation field in this region. The important role of shears in the BRZ, especially in its regions with sublatitudinal orientation, has repeatedly been emphasized in the literature (see, for example, [6, 7] and others). Such types of motions are also clearly manifested in the sources of the strongest earthquakes localized in this region (figure).

The velocities of the horizontal motions of the Earth's crust determined from the geological data in some active fault zones vary from 0.5 to 5 mm · yr^{-1} [7]. Deformations rates along the horizontal shear component were calculated from the materials of geodesic measurements in individual regions of the vast territory in various periods using different technical means. For example, according to the observations of the linear-angular network in the Olekma and North Muya geodynamic sites, the deformation rates were estimated in the range from 4×10^{-6} yr^{-1} to $(37.5 \pm 1.4) \times 10^{-6}$ yr^{-1}, respectively [8, 9]. During the Muya earthquake of 1957 ($M_w = 7.6$), the displacements of the basic triangulation points of class I (displacement by 72 cm, on average [10]) occurred with a horizontal velocity of 21.3 ± 6.7 mm · yr^{-1} [7]. At the South Baikal prognostic site, the deformations varied from 10^{-8} to 10^{-9} yr^{-1} on the basis of GPS observations [11]. In this region, the dominating deformation regimes showed the following zonality and gradual change (from southwest to northeast): contraction, shear, elongation, and again shear.

Thus, according to the materials presented above, the mean velocities of seismotectonic deformations of the Earth's crust in the BRZ over a 50-yr period of seismological observations are lower approximately by two orders of magnitude than the velocities measured by geological and geodesic methods. The shear components of the mean tensor of STD velocity in the region are characterized by the highest values due to high power consumption of rift structures with sublatitudi-

Components of the mean velocity tensor of seismic tectonic deformation of the Earth's crust in three seismoactive regions of the Baikal rift zone based on the data about the mechanisms of the earthquake sources with $M \geq 4.5$ (1950–1999)

Seismoactive regions	V, 10^3 km^3	T, yr	ΣM_0, 10^{27} dyne · cm	N	$\langle E_{ij} \rangle$, 10^{-9} yr^{-1}					
					E_{xx}	E_{yy}	E_{zz}	E_{xy}	E_{yz}	E_{zx}
I. Northeastern	4750	50	1.64	69	–2.52	4.84	–2.31	–14.4	–9.73	–4.32
		300	*33.3							
II. Central	4020	50	0.06	38	0.11	0.12	–0.23	–0.30	0.08	0.07
		160	*3.05							
III. Southwestern	4710	50	0.33	42	–0.39	0.47	–0.08	–3.77	0.22	–1.11
		100	*9.69							

Note: (V) Seismoactive volume; (T) time period used in the calculations; (ΣM_0) total seismic moment of earthquakes with known mechanisms (the sign * denotes values obtained with account for all events, including historical ones); (N) the number of focal mechanisms; (E_{ij}) components of mean STD velocity (the minus sign corresponds to contraction (compression), the absence of a sign corresponds to elongation (extension) of the material). Geographical coordinate system: x is directed to the east, y is directed to the north, z is directed upward.

nal orientation and the consequent generation of the strongest shear-type earthquakes ($M \geq 7.0$) in this region.

A number of problems appear in the comparison of seismological information with the geological–geodesic data. The solution of these problems is related to the application of different assumptions and approaches (discrete geological–geodesic investigations in space and time; discrimination of physically different components from the GPS measurements, choice of the model of earthquake source, and others). Nonetheless, the data on the parameters of the modern deformations of the Earth's crust in the BRZ based on the methods mentioned above demonstrate a high degree of agreement.

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