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GEOCHEMISTRY

Principal Differences in the Structural Position of Earthquake Epicenters on Land in the Southern Magadan Region and on the Shelf of the Sea of Okhotsk near Magadan

Academician of the RAS **N. A. Shilo[a], Yu. Ya. Vashchilov[a], and L. Yu. Kalinina[b]**

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This paper presents the results of investigation of the relation between the earthquake epicenters with ruptures distinguished from gravimetric data collected on land in the southern and central Magadan region and on the shelf of the Sea of Okhotsk near Magadan (hereafter, SSO region). Quantitative analysis of the correlation between the indicators of seismic activity in the studied regions and the values characterizing tectonic fragmentation of the Earth's crust allowed us to distinguish principal differences in the spatial distribution of earthquakes on land and under the sea.

On land, the earthquake epicenters are confined to margins of maximal fragmentation (maximal values of the discordance measure of fractures) and to the fractures. On the shelf, they are concentrated in the central parts of blocks (predominantly, local basins). Such differences in the structural position of earthquakes on land and on the shelf are related to the general process of deepening of the bottom of oceans and seas during and after the Mesozoic cycle of tectonomagmatic activation, which is demonstrated by the existence of seamounts with flat summits (guyots). Deepening of the bottom in the ocean and seas is related to cooling (and consequent contraction) of anomalously heated marine and oceanic lithosphere, the asthenosphere, and possibly the entire mantle.

Statistical analysis of the spatial distribution of the epicenters of crustal earthquakes on land in the southern and central Magadan region, on the one hand, and in the SSO region, on the other hand (Fig. 1), demonstrated the existence of principle differences in their structural position relative to the elements of deep fault tectonics. The elements of deep fault tectonics (blocks and fractures at their borders) were distinguished from gravimetric data as bands of increased horizontal gradients in the gravity field. Application of the gravity field as an instrument for distinguishing fractures and blocks allowed us to compare the structural data and earthquake epicenters on land and in the sea basin, because identification and investigation of fault tectonics on the sea bottom is possible only on the basis of the results of marine geophysical studies (in our case, the gravity field).

Study of the correlation between the earthquake epicenters with ruptures is based on comparison of the indicators of seismic activity in the study regions with the values characterizing tectonic fragmentation of the Earth's crust and the stressed state of a tectonic situation, such as discordance measure and density of fractures [2, 3]. Discordance measure D is the value that characterizes the degree of fragmentation of the surfaces of various objects by differently oriented fractures and fissures [1, 2]. The area-normalized value of discordance measure is determined as the sum of the absolute values of pairwise vector products of rectilinear segments approximating the fracture:

$$\|D\| = \frac{1}{S}\sum_{i=1}^{m}\sum_{k=1}^{m-i}[\mathbf{l}_i \times \mathbf{l}_{i+k}] = \frac{1}{S}\sum_{i=1}^{m}\sum_{k=1}^{m-i}|l_i l_{i+k}\sin(\alpha_{i+k} - \alpha_i)|,$$

where $\mathbf{l}_i$ is vector fracture; m is total number of fractures; $(\alpha_{i+k} - \alpha_i)$ is the angle between the directions of orientation of rectilinear fractures in general or of individual segments of curved fractures; and S is the area used for calculation of the $\|D\|$ value, which is the area of the window of the corresponding palette.

The authors determined the specific number of earthquakes δN and specific energy of earthquakes δE as the indicator of seismic activity. Their values were found from the following formulas:

[a] *Northeastern Interdisciplinary Scientific Research Institute, Northeastern Scientific Center, Far East Division, Russian Academy of Sciences, ul. Portovaya 16, Magadan, 685000 Russia*

[b] *Northern International University, ul. Portovaya 13, Magadan, 685000 Russia;*
e-mail: vashchillov@neisri.magadan.ru

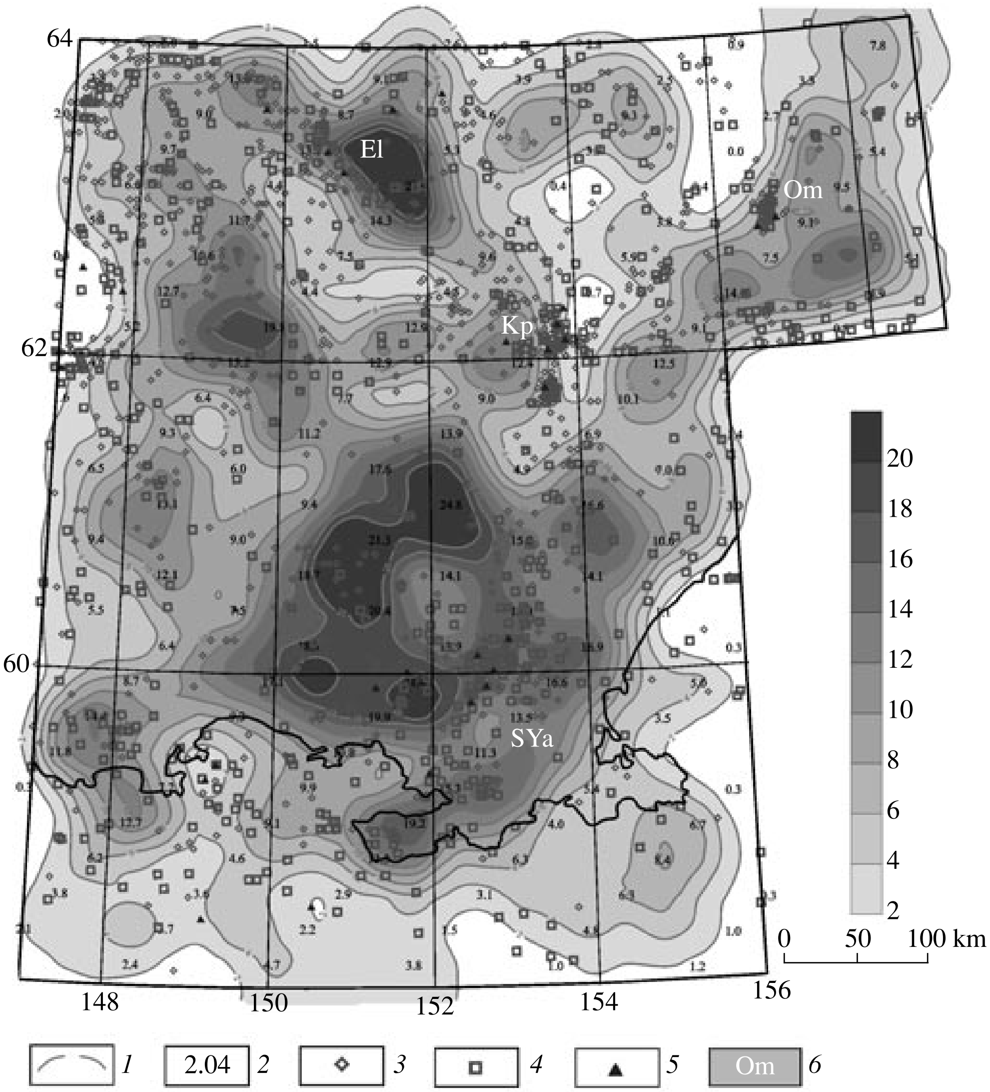

Fig. 1. Scheme of contour lines of fracture discordance based on the gravimetric data and spatial distribution of earthquake epicenters in the central Magadan and SSO regions. (*1*) Discordance contour lines; (*2*) calculated values of discordance measure of fractures; epicenters of earthquakes of energy class (*K*): (*3*) <8.5, (*4*) 8.5 ≤ *K* < 12, (*5*) ≥ 12; (*6*) seismic nodes: (SYa) Srednii Yam, (El) El-El'gen, (Om) Omsukchan, (Kp) Kupka.

$$\delta N = \frac{N}{S}, \quad \delta E = \frac{1}{S}\sum_{i=1}^{N} E_i,$$

where N and E_i are the number and energy of earthquakes, respectively, whose epicenters are located within the regions with fixed values of the discordance measure of fractures, and S is the area of these regions. Such a statistical approach to the study of structural position of earthquake epicenters is applicable for large regions with a small population and a scanty network of seismic stations, unlike, for example, Japan, where each fracture is studied specifically in detail.

Analysis of the scheme of contour lines of discordance in the fractures distinguished on the basis of gravimetric data on land in the southern and central Magadan region (Fig. 1) and statistical dependence of the indicators of seismic activity on the discordance measure of fractures (Fig. 2) showed that the maximal seismic activity is confined to the boundaries of anomalies of increased discordance measures or in other words to the zones of increased horizontal gradients of discordance contour lines (margins of the regions of increased fragmentation of the Earth's crust). Thus, the maximal specific number of earthquakes and maximal specific energy of earthquakes corresponds to the regions with moderate values of the discordance measure in fractures (Fig. 2).

Earthquakes of energy class $K \geq 12$ in the SSO region, and, correspondingly, the maximal energy of earthquakes correspond to the regions with decreased values of the discordance measure of fractures (Fig. 3).

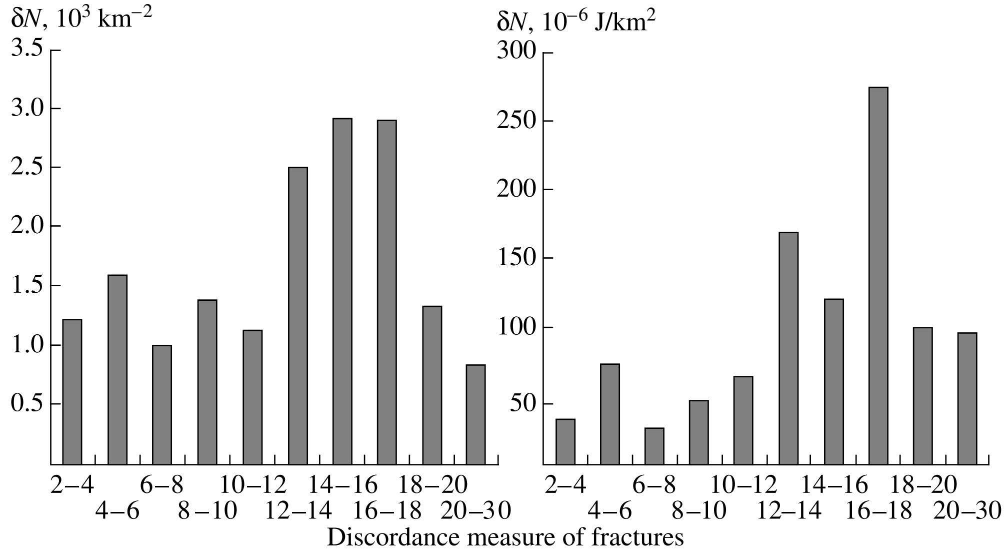

Fig. 2. Results of the analysis of the correlation between the discordance measures of fractures based on the gravimetric data with the indicators of seismic activity in the central Magadan region. (δN) The ratio of the number of earthquakes to the area of the region between two neighboring contour lines of discordance; (δE) the ratio of the energy of earthquakes to the area of the region between two neighboring contour lines of discordance.

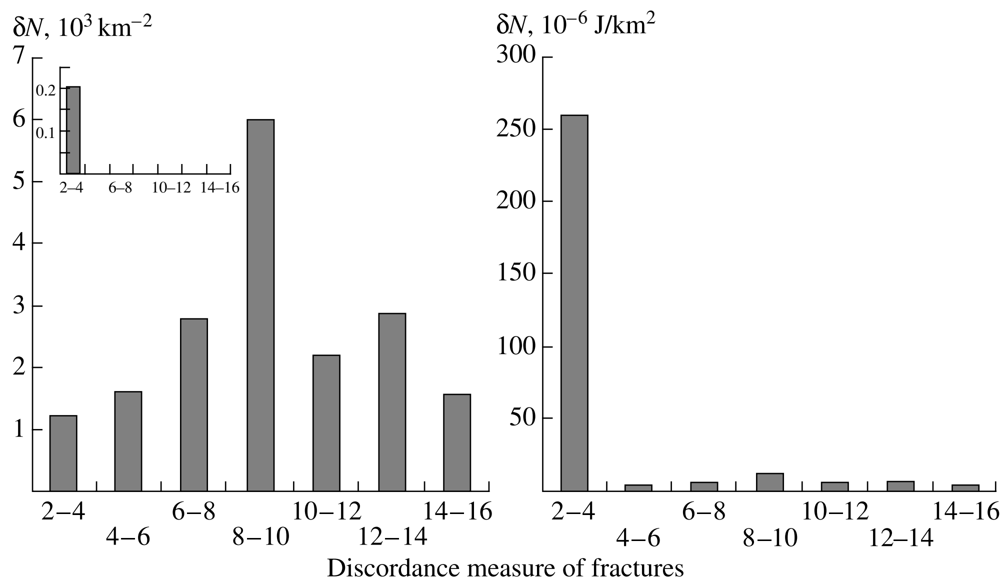

Fig. 3. Results of the analysis of the correlation between the discordance measures of fractures based on the gravimetric data with the indicators of seismic activity in the SSO region. (δN) The ratio of the number of earthquakes to the area of the region between two neighboring contour lines of discordance (inset shows the dependence of the specific number of earthquakes, δN, on the discordance measure of fractures for earthquakes of energy class $K \geq 12$); (δE) the ratio of the energy of earthquakes to the area of the region between two neighboring contour lines of discordance.

The spatial distribution of earthquakes related to the density (specific length) of the fractures was considered along with the discordance measure of these fractures. The density is determined as the sum of the length of fractures in the palette window divided by the area of the window [3]. It was found that earthquakes of energy class $K \geq 12$ on the shelf are also confined to the regions of lower densities of fractures. Such a binary relation of the regions with maximal earthquake energy on the shelf to the zones with decreased discordance and density of the fractures allows us to interpret this phenomenon as the tendency of epicenters of seismic shocks to the central parts of the blocks. A more thorough analysis indicates that such blocks are frequently represented by local depressions in the Meso–Cenozoic sedimentary cover of the shelf, which is distinguished by decreased values of the gravity field.

S.A. Fedotov and his adherents [4, 6] came to similar conclusions after studies of the structural positions of epicenters of crustal earthquakes in the Kamchatka Peninsula. They demonstrated the lack of any correlation between the spatial distribution of epicenters of crustal earthquakes and Holocene fractures. The off-fracture location of earthquake epicenters is characteristic of the Pacific Ocean and the continent/ocean transition zone with marginal seas, islands, and peninsulas. The genesis of such earthquakes is caused by Mesozoic and post-Mesozoic processes, which led to subsidence of the ocean and uplift of continents [5, 7]. Subsidence of the ocean is supported by the existence of guyots (seamounts at depths of 1000–2000 m with flat summits). Such processes are caused by thermal isostasy (or thermal contraction) of planetary (oceans, marginal, and internal seas), regional (basins within the seas and oceans), and local scales related to the cooling of the lithosphere and asthenosphere after the powerful Late Mesozoic heat wave emission to the surface that was a notable event in the Earth's geological history. In the Late Mesozoic, the bottom of the oceans and internal and marginal seas served as the most significant thermal conductor of the Earth's internal heat to the surface.

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