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GEOPHYSICS

New Data on Quasi-Periodical Regularities in Activation of Fractures in Real Time Based on Monitoring of Magnitudes of Seismic Events: Case Study of the Baikal Rift System

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An algorithm for researching a quantitative index of seismic activity (QISA) of faults on the basis of geoinformational technologies was proposed in [1]. The index provided a ranking of the faults by degrees of their recent activity on the real time scale and enabled analyses of contributions of faults varying in ranks in the seismic process. Being represented numerically, the index made it possible to unambiguously distinguish active, low-active, and inactive faults within the recent geological development stage. According to QISA, a number of faults in the Baikal rift system (BRS) were revealed to have been quasi-periodically reactivated [1]. However, the QISA does not take into account the energy characteristic of the process and does not suggest any assessment of the geological and geophysical importance of the activation of individual faults and its possible consequences, which are linked to the prediction of strong seismic events.

New techniques applied to the research of temporal changes in the energy (class) of earthquakes controlled by the same faults allowed us to introduce a magnitude (energy) index of seismic activity (MISA) of faults ξ_k, which is the value of the class of the maximum seismic event, $k_{\max}$ ($k = \log E$, J; $k = 4 + 1.8M$, where M is magnitude [2]) per fault length, L (km) for assumed width of the area of its dynamic influence, M_w (km) per given time interval, t (yr). It is estimated as

$$\xi_k = k_{\max}(M_w, k, t), \quad (1)$$

where $k_{\max}(t)$ is the maximum class (or magnitude) of the earthquake in the area of dynamic influence of the fault and M_w per given time period, t. The width of the area of dynamic influence of the fault M_w is estimated as

$$M_w = bL, \quad (2)$$

where L is length of the fault (km); b is the coefficient of proportionality which depends on L and, according to the empirical data, ranges from 0.03 to 0.09 for transregional and local faults, respectively. Herein, taken into account is the known concept that the relative width of the area of dynamic influence of the fault disproportionately lags behind the increase in its length [3]. Since the depths of penetration of faults correlate well with their lengths [4], the MISA estimated as per the proposed algorithm characterizes the temporal variation of maximum values of the energy activity of linear elongated near-fault volumes of rocks involved in the deformation process during the formation and/or tectonic activation of these specific faults.

Testing of the introduced MISA is carried out with the use of the database on the BRS. Since the Baikal territory is among the regions of high social importance for Russia, its fracture tectonics and seismicity have been studied in much detail. Seismicity of the BRS is predetermined by its structural position at the boundary of the Transbaikal and Siberian lithospheric plates in Central Asia. The ancient suture between these plates determines the current overall S-shaped structural plan of the BRS with a relatively regular pattern of faults (see, for example, [4]). Most of these faults are tectonically active in the Cenozoic. However, the earthquake epicenter field of the BRS is not fully consistent with the known fault-block pattern of the region [5]. Detailed analyses of spatial distribution of earthquake epicenters in the area of dynamic influence of the faults within only the 40-yr instrumental record period show that the faults differ in the degree of activity when QISA is applied for relevant estimations [1]. By variations in the QISA values, three groups of faults, including those in the recent destruction zone of the lithosphere, are distinguished and suggested to have been quasi-periodically reactivated in the real time intervals.

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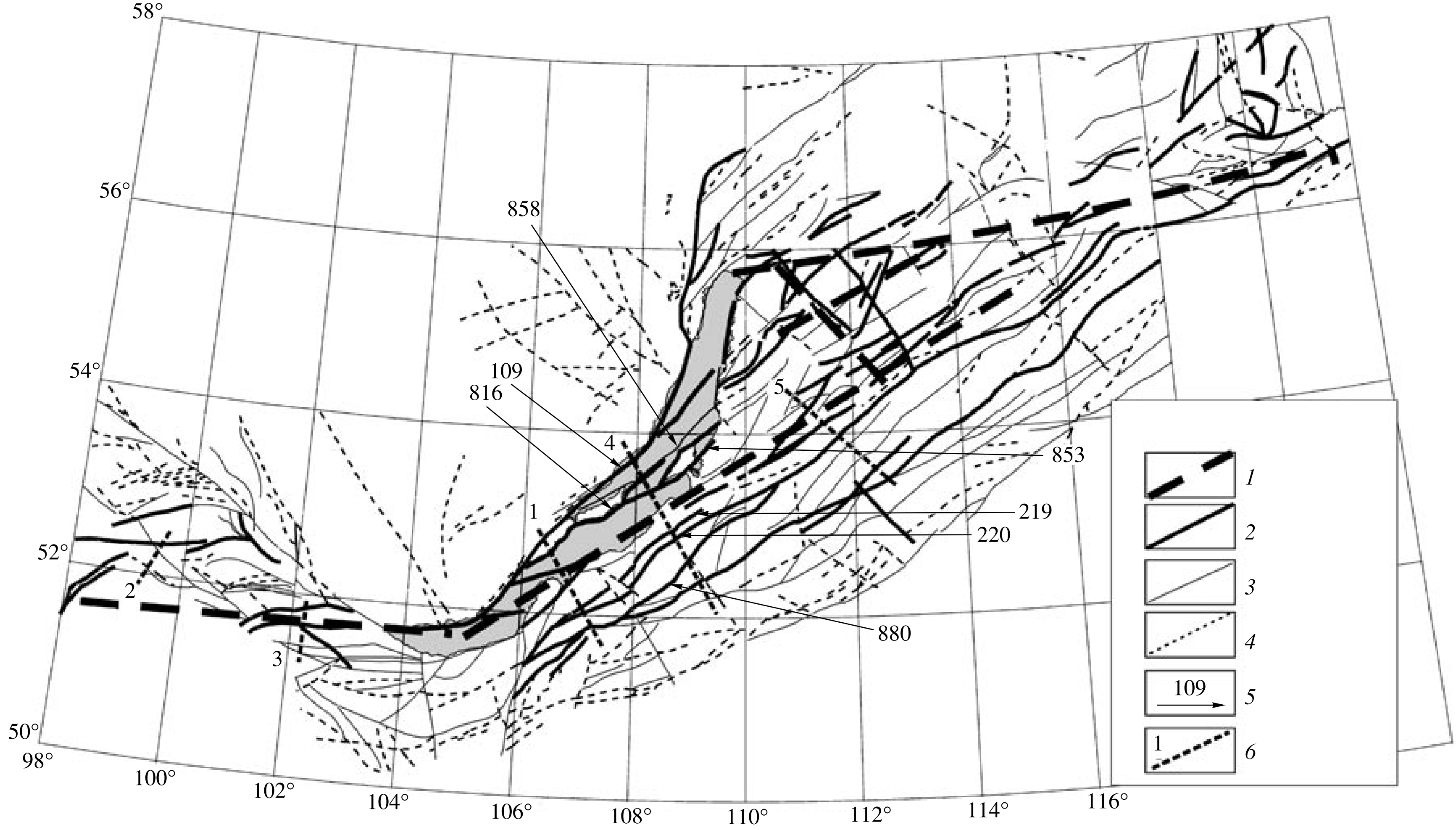

Fig. 1. Active fault map of the Baikal rift system based on the magnitude index of seismic activity (MISA). (*1*) Axes of the zone of recent lithospheric destruction; fault groups: (*2*) with MISA ≤ 12 (highly active), (*3*) MISA from 10 to 11 (active), (*4*) MISA from 8 to 9 (low active); (*5*) numbers of faults as per the catalogue; (*6*) location of sections and their numbers.

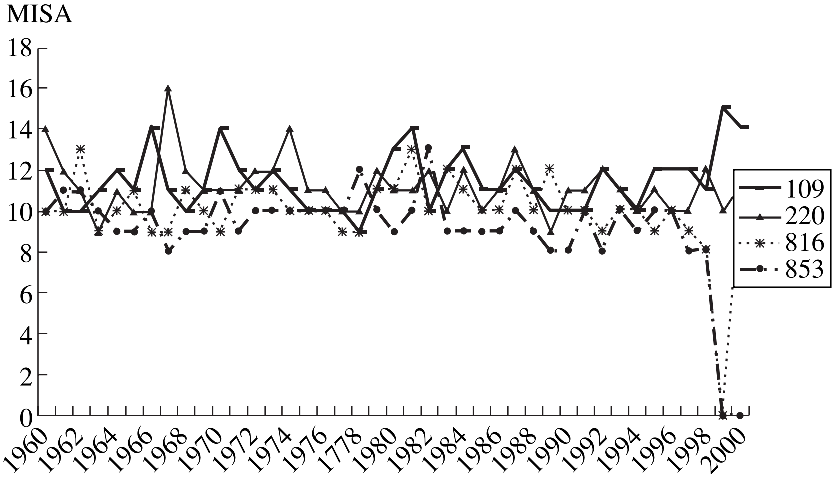

Fig. 2. Variations of MISA values for the BRS faults along section 4.

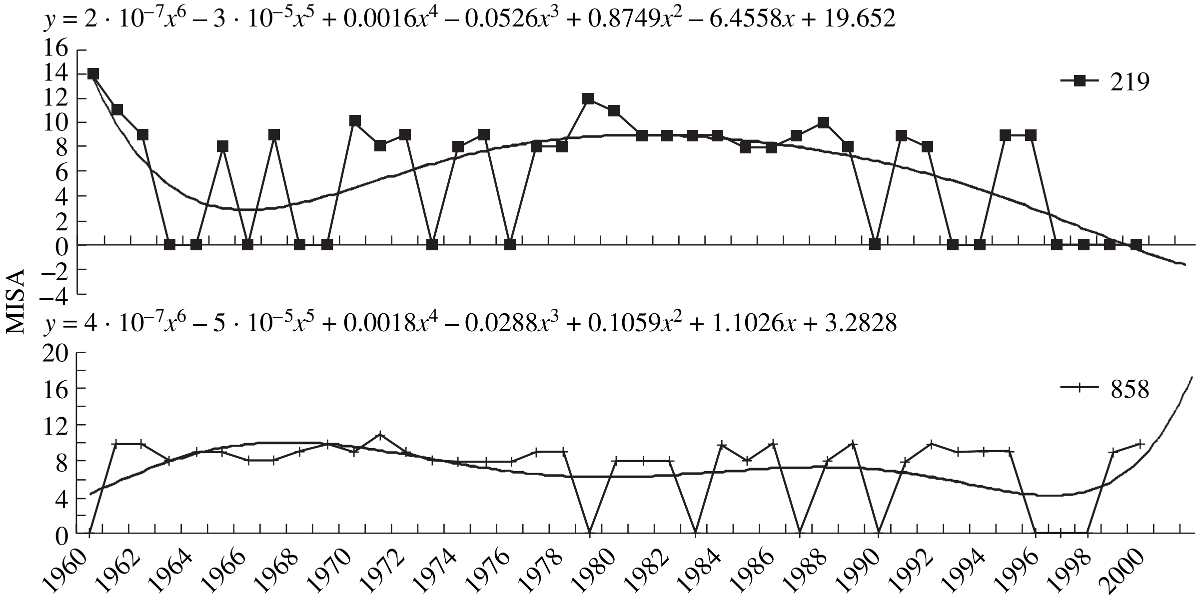

Fig. 3. Variations of MISA values for individual faults and their approximating polynomial curves.

More detailed analyses of the parameters of seismicity and the MISA values of the faults in the BRS make it possible to resolve two principally new problems: (1) to assess the maximum energy potential of the major faults in the BRS for the past 40 yr (Fig. 1), and (2) on the real time scale, to trace short-period oscillations of the energy of seismic events associated with some individually considered faults (Fig. 2).

According to the MISA values within the instrumental record period, three groups of the BRS faults are distinguished as follows: highly active with $\xi_k \geq 12$, active with $\xi_k = 10 - 11$, and low active with $\xi_k = 8 - 9$ (Fig. 1). The faults of the first two groups, mainly located within the boundaries of the BRS, are consistent with its general strike. Their density is evidently increased in the axial segments of the intricate zone of recent destruction of the lithosphere [5]. By comparing the obtained pattern with the BRS fault-tectonics maps, including the active fault map [6], it is concluded that the faults in the BRS are being selectively reactivated in terms of seismicity during the recent (at least half a century long) tectonic development stage. Moreover, their selective seismic reactivation is unsteady.

Sections shown in Fig.1 are analyzed to study short-period seismic reactivation of individual fractures. As an illustration, section 4 across the central part of the BRS (Fig. 1) is chosen. Asynchronous quasi-periodicity of seismic reactivation calculated from the maximal

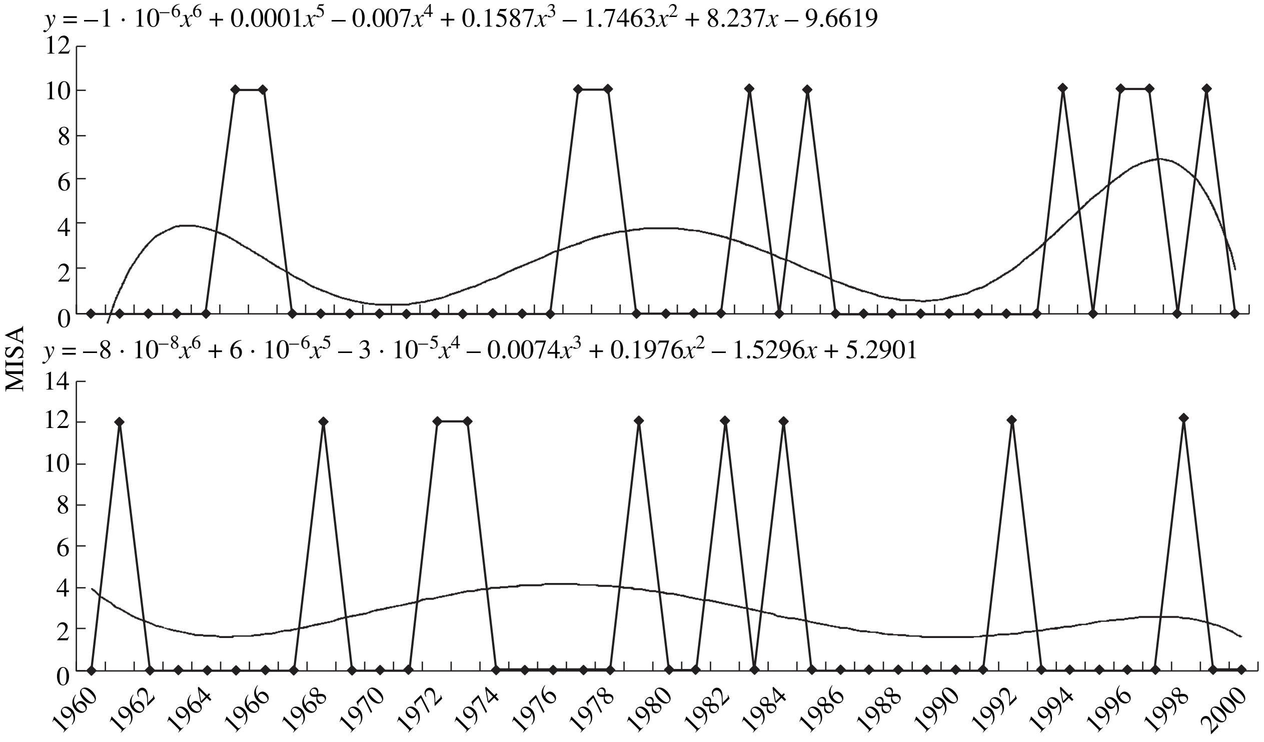

Fig. 4. Comparative characteristics of variations of MISA values for energy classes (upper plot) 10 and (lower plot) 12 of fault 220.

MISA values for different fractures is well observed in the graph in Fig. 2. The analysis of this graph suggests that a periodical variation in MISA is characteristic of each fault, though the extreme values of the periods are sometimes inconsistent. It is reasonable to suppose that each of the areas of geodynamic influence of faults, which are seismically active in the assumed energy classes of earthquakes, has its peculiar regularity of the seismic process. Such regularity consists in different time boundaries of conventional start-up of the reactivation period. This is a reason why the extreme points in the quasi-periodic pattern of ξ_k variations for different faults display a lack of coincidence. Figure 3 shows polynomial approximations for two subparallel faults in section 4 (#219, length 220 km; #858, length 130 km) that are almost 100 km apart. A regular pattern of variations in ξ_k based on polynomial approximations is conspicuous. It is also noticeable that extreme values of ξ_k are shifted in time and reflect the lack of coincidence of the maximal values of reactivation of the individual faults. Moreover, the analyzed faults do not all have a well-defined periodicity of reactivation. To secure more specific data related to the periodicity of reactivation of these and some other faults in sections 1, 4, and 5, time periods of the maximum reactivation were estimated from the data on the most representative earthquakes of classes 10 and 12 (Fig.4). By processing the data on all faults in sections 1, 4, and 5, it is established that the reactivation period amounts to 18.9 ± 2.1 yr for class 10 (frequency 0.05 yr^{-1}) and 20.9 ± 3.0 yr for class 12 (frequency 0.05 yr^{-1}). Thus, seismic reactivation of individual faults is quasi-periodical both in time and space, and the periodicity varies for different energy classes.

How do the data described above correlate with the known regularities of spatiotemporal variations of geophysical and, in particular, earthquake epicenter fields? Time cycles of seismic processes are considered in a number of publications (see, for example, [7–9]). Numerous examples of complex patterns of time variations of the geophysical medium are reviewed in [10]. According to [7–10], time variability of natural geophysical fields is diverse. Time variations of fields differ for various regions, volumes of the medium, parameters, and frequencies of recorded waves, including seismic ones. However, geological parameters of the medium, in particular, those of faults as structures determining the localization of many processes, were not subject to temporal analyses. Therefore our research is distinguished from many other studies. It demonstrates that, should the analysis be targeted at a set of factual data within the spatially established areas of dynamic influence of specific faults, then considerably more options seem available for obtaining unambiguous solutions related to controlling functions of fault tectonics in a number of recent processes. In [11], Kuz'min suggests a new class of the recent movements of the earth's surface and denotes them as parametrically induced tectonic deformations of fault zones. His research shows that, in fault zones of seismically active and aseismic regions, superintensive movements (deformations) of the earth's surface may occur under the impact of extremely weak external sources. Particular attention should be given to his conclusion since faults develop as open nonequilibrium systems with nonlinear properties. They are characterized by variable qualities of structural organization reflected by order and chaos which are periodically substituted by each other [12]. In addition, nonlinearity of the properties suggests that the fault zone being impacted by any seemingly insignificant external factors may be subject to considerable structural transformations including superintensive deformations [11]. By recognizing a new type of recent activity of faults, it is emphasized that weak external factors may significantly affect the areas of dynamic influence of faults. This necessitates additional analytical studies of the fault-block pattern of the lithosphere and its upper layer (crust), both being stressed and unstable. Such studies should be conducted in terms of the mechanics of destruction of large rock volumes. As reasonably stated by Gol'din, "the block-hierarchic pattern of the crust (composed of a combination of faults varying in ranks - S. Sh.) is not only an arena hosting geodynamic processes, but also an active participant of these processes" [13, p. 52]. According to this approach, faults are the most mobile local areas within large volumes of the lithosphere that are involved in intense deformation during their tectonic reactivation. The knowledge of the periodicity of reactivation of faults is a key to advanced understanding of space-and-time regularities of processes controlled by the faults and fault-block patterns of the lithosphere.

Thus, the introduced parameter of MISA allows us, first, to distinguish quasi-periodic variations in activity of faults on the real time scale and, second, to classify their activity in terms of the magnitude index reflecting their seismic energy release. In its turn, the energy release evidences the continuing development of the faults marked by intense destruction in the areas of their dynamic influence.

Based on the concepts of regions of earthquake generation [14], as well as our results published in [1] and those presented herein, it should be accepted that in the seismically active zones, the seismic process (which is generally well described by classical equations such as [2] and others) is mainly controlled by temporal variations in the activity of an ensemble of faults which compose the fault-block pattern of the tectonically active lithospheric zone. The activity of the fault ensemble seems to be determined by different-period wave deformation processes in the lithosphere and the destruction of its brittle part that takes place in the permanent regional stress field according to the laws of destruction of the low-elastic medium.

With the use of the proposed algorithms, monitoring of seismic events in the regions of dynamic influence of seismically active faults offers a means of developing principally new visions of the complex short-period reactivation of faults and enables a more detailed assessment of its role while we are facing the challenges of short- and medium-term prediction of earthquakes.

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