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The Unpredictability of Strong Earthquakes: New Understanding and Solution of the Problem

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Abstract—The inefficiency of short-term forecasting of strong earthquakes is obvious. New methods and hypotheses about the preparation of seismic events are interesting, but exact and reliable forecasts will not result. This unpredictability is undoubtedly determined by the nonlinearity, self-similarity, a chaotic (nonstochastic) character, and bifurcation dynamics of a seismic process in a fractal geomedium. Superdependence of geodynamic systems on initial conditions and parameters, vagueness of distinctions between background and anomalous structures and states, along with rigid requirements on the adequacy and representativity of forecasts, inevitably lead to the failure to solve the problem. This work continues the long-standing scientific discussion on earthquake prediction, which was resumed after the publication of our work (Koronovskii et al., 2019).

Keywords: strong earthquakes, short-term forecast, nonlinear geosystem, chaotic dynamics, mechanism of seismicity, unpredictability

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INTRODUCTION

In the opinion of many researchers, strong earthquakes are in principle predictable. At the same time, reliability and inaccuracy of forecasts, especially short-term ones, are well-known. For many years, a discussion has been continued in the world seismological society that was started by K.J. Geller and his team (Geller et al., 1997). They see a way to overcome the failures in the development of more adequate ideas about the nature of seismicity based on improving the monitoring of the lithospheric processes. A different position within the nonlinearly dynamic approach to studying geocatastrophes was stated in (Naimark, 1997, 1998a, 2000; Zakharov, 2011, 2013) and was developed in (Koronovskii and Naimark, 2009, 2012; Naimark and Zakharov, 2012; Zakharov, 2014). In the scientific discussion (September–October, 2019; Institute of Physics of the Earth, RAS), the problem of unpredictability was considered in light of the two competing conventional "rupture" and currently developed "degassing" hypotheses. Some conclusions of the first hypothesis were considered in the published work discussed at that time (Koronovskii et al., 2019); the second hypothesis was reflected in the monograph (Gufeld, 2019) and in statements made by Gufeld.

Here, we first analyze the adequacy of these empirical hypotheses of preparation of seismic events, including the results of tectonophysical modeling, with critical estimations of the proposed forecast recommendations. Then, we generalize the characteristics of the statistical distributions of structural elements of the geomedium and seismic events (by size and magnitude, respectively). However, the emphasis on the independence of this material on hypothetical structures drastically changes the focus of the problem: the fundamental factors of unpredictability enter the foreground. As a result, the principal and irremovable impediments to solving the forecasting problem become obvious. It is impossible to evaluate the plausibility and practical importance of such conclusions without taking the specific character and the modern state of short-term forecasting into account, as well as the demands on forecasts.

Short-term forecasting and the demands on it. Short-term forecasting establishes certain conditions for taking urgent measures to minimize human losses and material damage caused by a particular predicted catastrophe (Koronovskii et al., 2019). Its adequacy and feasibility are provided by close tolerances on completeness, accuracy, and reliability of the main parameters of the expected event. As an example, the location is determined by the coordinates of an epicenter with a radius ($R = 30$ km) of a round epicentral zone with a permissible error of ± 30 km. We also indicate the boundaries and sizes of the larger sector of predicted responsibility (SPR). The energy released during earthquakes is characterized by the magnitude (M) with a permissible error from ±1 to ±0.1, from smaller to greater values of magnitude. The threshold magnitude of strong earthquakes is 5.5 ± 0.5. The time is determined by the date of the expected earthquake with a permissible error of ±3 days and an advance of the forecast of 0.5–0.3 days to the expected event.

The forecasting performance is characterized by (a) a low number of confirmed forecasts, in which case many unpredicted earthquakes are not taken into account; (b) the forecasting effectiveness or reliability, that is, the ratio of the number of successfully predicted earthquakes to the number of earthquakes recorded during the studies in the magnitude range from 5.5 ± 0.5 and greater within the limits of the assigned SPR. In this respect, sufficient effectiveness should be at least 85–90%, while the effectiveness reached for the actual forecasts is usually several percent. The anomalously high effectiveness that is reached rarely and locally is not representative when assessing global utilization of the tested procedures, since, as a rule, it cannot be repeated. We emphasize that the presented quantitative restrictions in terms of SPR sizes and errors in time and magnitude can be the subject of discussion, but their stringent certainty is a necessary condition of forecast feasibility.

State of the problem. We reviewed the current state of short-term forecasting in the earlier works (Koronovskii and Naimark, 2009, 2013; Koronovskii et al., 2019); here, we give a brief summary. The share of accurate short-term predictions of strong earthquakes is no more than a few percent among the recorded ones. The differences between anomalous structures and states from the background ones and foreshocks from the corresponding main earthquakes are often vague and problematic. The ratios of prediction estimates of expected earthquakes are ambiguous for precursor anomalies with characteristics of particular real events, the attempts at averaging are ineffective and are almost useless in short-term forecasting. Most seismic catastrophes remain unexpected despite the improvement of the equipment and methods of monitoring, recording, processing, analyzing the data, and interpreting the results.

All reports without exception about supposed high effectiveness of short-term forecasting are cases of unrepresentative, local, short-term success and/or the results of forecasting with an accuracy that does not meet the demands.

Current concepts of earthquake preparation: precursors and prospects. 1. *The rupture model.* According to the conventional ideas, an earthquake is the final catastrophic stage of local reconstruction of a hierarchically organized fault-block structure of the geomedium and the corresponding physical fields. One important component of the model is the anomalies of different scales that occur at the nodes of the rupture network, the concentrations of tectonic stresses that are considered as hypothetic precursors of sudden slips (faults), and, as a consequence, earthquakes with certain energy that are expected at certain places and times.

Under conditions of constraints by deformations and displacements, even smooth distortions of the fault planes, but more often dislocations at intersections and sublateral junctions of ruptures may prevent motions of aggregations and separate plates, blocks, and their fragments along the faults. As an example, a shear along the active fault divides the intersected passive fault into two transversally mutually spaced segments, thus blocking longitudinal movements along them. During the activation of the intersected fault, the displacements along it destroys the blocking transverse scarp ("hitch"); the intersecting fault then becomes intersected and blocked. Similarly, a large fault that is blocked sublaterally by active smaller dislocations is complicated by hitches that impede the displacements along it. As time passes such serrations may become smoother and then be renewed. The sharp end closures of fractures and active faults serve as stress concentrators.

The angular protrusions of nonuniformly protruded and/or rotated blocks may prevent the movements in the interplate and interblock fractured zones. During development, numerous ruptures in small or medium blocks split larger blocks, which generates more or less significant earthquakes. Finally, in a certain large massif, the obstacle that blocks it slips along a large rupture and becomes detached (main shock), followed by the release of a large amount of energy in the form of seismic waves and failures on the daylight surface. Similar situations were simulated many times during laboratory tectonophysical modeling.

This generated the ideas that the main shock should be preceded by certain structural changes, including "foreshocks" (weaker earthquakes preceding the main event) and the corresponding geological–geophysical, geodetic, and other anomalies that noticeably disturb the relatively stable ("background") state of the geomedium. It was expected that upon being revealed during monitoring, these would be reliable precursors of seismic catastrophes. According to (Lyubushin, 2014), many such precursors display similarity to the physical and chemical behavior patterns of the geomaterial in experiments that simulate the preparation of a seismic catastrophe focus. Many precursors, such as direct (lithospheric), indirect (meteorological, biological, and cosmic), elementary, and combined, have been proposed.

The strategy of short-term seismic forecast based on these prerequisites has been used for more than 50 years. However, none of the precursors achieved their expectations separately or in combination with others: real earthquakes differed considerably from the forecasts in some or all three indices or did not occur. The successful forecasts that meet the current requirements are no more than several percent of the recorded number of strong earthquakes.

Although the search for reliable precursors has continued, there is a growing conviction that not only certain precursors but also the initial geophysical model of the seismic process are inadequate. This is supported by the arguments that themselves are not free of ambiguities. As an example, according to (Gufeld, 2019), in the surface layer of the Earth's crust, hitches of protrusions at the boundaries of the geoblocks that are expected (by analogy with the results of laboratory modeling of contact interactions between uneven surfaces) are hardly possible under constraint conditions. The opinion that the rupture model is based primarily or even exclusively on the results of laboratory experimentation is an exaggeration. The features of many real movements at different scales, orientations, and times that are directly observed by geologists are quite obvious; hitches of the respective scales occur due to movements at the moments of detachment; the occurrence of frequent weak and less frequent moderate earthquakes is quite ordinary.

The ambiguity of the ratios of precursors to predictions and predictions to events led I.L. Gufeld to the conclusion that the proposed earthquakes precursors are not predictions and cannot and should not be (further, we will consider the possibility of a different interpretation of this ambiguity).

Can a strong earthquake occur without a precursor? On the surface and in the near-surface layers, a strong earthquake is always expressed by the displacement of blocks along a large fault. In a hierarchically structured medium it occurs as a result of sequence of dislocations: from scattered small to grouped middle ones, tending towards the large main rupture in the volume of a corresponding rank. It is exactly such pattern that is simulated by the conventional tectonophysical modeling. The statement that "monolithic" rock samples are used in this case is erroneous. An experiment always reveals that the sample had structurally weakened zones of different scales that were initially unnoticed but manifested themselves cyclically and successively and "reverse-cascaded" under the load, as dislocations from small to large in each cycle as the load increased (as described in more detail in (Naimark, 1998b, 1998c; 2003)). A seismic event of the respective rank corresponds to movements along each of such dislocations followed by the appearance of hitches. The parameters of the expected main shock can seemingly be predicted by the degree and character of the anomality of such projected precursors.

According to Gufeld, harmonics with periods from hours and days to many years were found in the mode of weak seismicity and focal mechanisms indicate considerable inhomogeneity and randomness of local stress fields. Their rapid different-scale and asynchronous variations under conditions of quasiconstant gradients of lithostatic pressure and temperature cannot be related to slow tectonic motions. According to Gufeld, this can mean that the surface layer reacts to earthquake preparation not directly or as a precursor of particular events but indirectly, when it marks the activation of other depth processes that cause the variations in the stress state so that the measurements at one point reflect the situation in a vast territory. However, it is not infrequent in such cases that an appropriate local precursor perturbation of any parameter spaced at up to 1000 km from the epicenter and distant in time from 1 day to many years is selected retrospectively, while ignoring the depth factor. In this respect, some of the strongest events are missed and other events were projected but did not occur. The analysis of the seismic regime (quiescence, ring seismicity, migration of foci of weak earthquakes, etc.) shows the significant uncertainty of prediction of seismic hazards with respect to time and place.

According to Gufeld, if the monitoring data do not discover a stable relation to cyclicity of a seismic process, they cannot predict an earthquake but can reflect the action of the processes that are determined indirectly by the preparation of seismic acts, e.g., by variations in the speed of the Earth's rotation. The disturbances of different parameters, which are observed in the surface layer and reflect a regional process, are not necessarily precursors of particular earthquakes. Due to this fact, according to Gufeld, the development of principles and methods for short-term forecasting of seismic hazards based on the conventional, significantly empirical rupture model is unpromising. However, the possibility of detecting seismic hazard features is not excluded. The hopes rest on a new concept that, however, has to cope with own problems.

(2) The "degassing" model. According to (Gufeld, 2019), strong earthquakes are impossible deeper than 5–6 km under conditions of slow tectonic motions and limit stress (without local concentrations). However, they occur and always unexpectedly. Can they be predictable? It is proposed that they can if we know the nature of the events and the character of interblock interactions, as well as the parameters of the geophysical regime that make it possible to identify the background and pre-catastrophic state of the medium, as well as to localize the epicentral zone.

According to this concept, the interaction of the ascending hydrogen fluxes with a solid geomedium phase continuously changes the volume of its structural elements and the stress state. The sizes of "emerging" deformation waves control the energy of earthquakes. The slow flow of rock masses is replaced with rapid large-scale motions after short-term consolidations of blocks with a fractured interblock medium. The local perturbations of different parameters match particular earthquakes in the surface layer ambiguously.

In the background regime, at quasiconstant gradients of pressure and temperature in the lithosphere, the main factor of continuous variations in inteblock seismicity is elastic waves of distant seismicity and periodic variations in the volume of structural elements that affect the stress field. Disturbances of accommodation in the boundary structures are asynchronous in the adjacent zones.

The transition to the precatastrophic state is expressed by localization of seismicity (a "seismic node"). This consists of continuous and sometimes rapid structural changes (without relation to tectonic motions), floating of differently oriented deformation waves, rapid skips of a seismic node, whose duration (a hazard period) varies in a particular zone from several hours to several days. In the subduction zone, synchronization of vibrational motions indicates a probable epicentral zone of the pending strong earthquake. The transition to desynchronization lasts from several hours to several days. The contact zone of the plates is marked by hypocenters. The magnitude of the seismic background is no greater than 6.0–7.0 inside a subsiding oceanic plate.

In this respect, the time and magnitude of a probable event are not predicted and their precursors are absent. Focal mechanisms show inhomogeneities of interblock stress fields; the seismic process is nondeterministic. Continuous interplate seismicity of a different level does not destroy an oceanic plate, such mechanical hitches do not occur (Gufeld, 2019).

Conventionally, the stress concentration on hitches along the boundaries of moving blocks should be a trigger for strong earthquakes. Blocking of motions at some places should perturb the fields of temporal consolidation. This served as the basis for the idea of seismic gaps and cyclicity of their strong earthquakes, which, according to Gufeld, raises questions.

Why does the cycle duration vary highly under relatively stable external and internal P–T conditions? If a strong earthquake did not occur in the zone of the former focus for about 70 years, does it mean that the cycle is completed? What is the cycle stage at the moment? What are the features of a foreshock as a precursor of a possible strong earthquake? Do foreshocks "have no visiting cards," as I.L. Neresov stated (Gufeld, 2019, p. 43)? Are strong earthquakes fortuitous? What does the seismic activity period of tens and hundreds of years reflect? The assessment of the dependence of the vibration mode on the state of the neighboring zones requires simultaneous monitoring of motions of different scales of all parts in the mega-fault-block structure.

The geomedium is acted on simultaneously and continuously by different background natural forces. Here, the issue of which factor acts on which processes or state of the medium, which processes occurred in the medium afterwards, and whether control monitoring reflects these processes it remains unanswered. Strong crustal earthquakes are not predictable at present. It is an illusion that weak seismicity as a reaction of the medium to the external action causes unloading of tectonic stresses. Even for the strongest earthquakes, a small part of the background elastic energy determined by the lithostatic load above the boundary of the crust is released (Gufeld, 2019).

Preliminary conclusions: on the path toward a new understanding of the problem. The rupture concept of short-term forecasting by precursors was tested for adequacy for many years. The modest possibilities of empirical forecasting based on this concept are evidently close to exhaustion. The applied research has been reduced to searching for new potentially more effective (but as a result disappointing) precursors and to displaying rare local successes. The theories of conventional versions of the study concept have not been developed significantly.

However, based on the modern nonlinear-dynamic approach, the theoretical potential of the rupture model turned out to paradoxically manifest itself in the explanation and substantiation of the impossibility of obtaining qualitative forecasts. A nonlinear rupture-forming process in a hierarchically structured (fractal) coarsely discrete medium was analyzed in the range of micro-megaruptures; the "depth–surface" range was not considered (Naimark, 1998c, 2001, 2003). The known problems, real possibilities, and degree of adequacy of tectonophysical modeling were assessed in this context due to short-term forecasting of strong earthquakes (Naimark, 1997, 2009). We used particular methods as examples to show how instability, bifurcation of a nonlinear process and medium fractality occur and manifest themselves, as well as how and why this leads to unpredictability or unreconstructability of the study process (Koronovskii and Naimark, 2013). The explanations of forecast failures were proved to be weak due to exceptionally insufficient exploration and the conclusion about unproductivity of such further attempts was substantiated.

Taking nonlinearity into account, as well as the strong nonequilibrium of geodynamic systems, the coarsely discrete fractality of the medium, and the bifurcation of deformation and failure process, we should expect a significantly chaotic state of the seismic regime. Reliable and accurate forecasting is hindered by the fact that there can be not even one pair of identical precursors such that a successful prediction for one of them would repeat for the second one; the smallest differences of the precursors turn out to be significant for forecasting, dooming a recurrent similar prediction to failure (the details are given below).

In the actively developed degassing concept, a key problem of short-term seismic forecasting, according to Gufeld, is the indeterminacy of a seismic process: even if the onset of a hazard period is identified, the probability and magnitude of the projected event can hardly be determined. Recommendations for identifying and using precursors based on the results of laboratory physical modeling were groundless. The ideas about geomedium fractality and a seismic process as dynamic chaos are considered by Gufeld as interesting but do not reveal what is happening in the medium, and why it behaves this way and not some other way; therefore, it is premature to discuss the quality of future forecasts. What is most important, according to Gufeld, is to learn to reliably recognize the transition from the background to the pre-critical regime, as well as to identify the epicentral zone of the expected event when studying the real spatial distribution of real seismicity in the real geomedium.

Below we consider whether we can achieve reliable and accurate short-term forecasting by implementing this program.

The fundamental factors of unpredictability. The possibility of positive or negative solution of this problem is determined by the characteristics of a seismic process as linear or nonlinear: whether is has properties of self-similarity, is dependent on initial conditions or independent of them, is deterministic or stochastic, or recurrent or chaotic. Such characteristics are accepted not on the basis of some hypotheses on the nature of the process but by following the results of analyzing statistical distributions and time series of the earthquakes that have already occurred and the existing structures. This determines the feasibility and objectivity of the conclusions.

According to the degassing concept, a seismic process is identified as nondeterministic. What particular meaning should this have in terms of the above alternatives? The answers to this and the following similar questions are given by the results of fractal and dynamic analysis of geodynamic systems (Zakharov, 2014 and their references).

Linear dynamic systems are characterized by deterministic behavior where the assignment of an initial state of a system determines the only solution for any moment both in the future (prediction) and in the past (retrodiction). In this respect, the variations in the initial conditions and/or parameters of the system certainly has an influence on the result (prediction accuracy), while this influence also has a linear character, which allows deterministic forecasting with an acceptable accuracy even if initial data and system parameters are assigned inaccurately.

Under a stochastic effect of a set of mutually independent factors, the ambiguous assignment of the randomly varying initial state and parameters violates the possibility of deterministic forecast, and yet statistically determines the mean probabilistic solution for any sufficiently long period in the past or in the future. This is represented by a normal Gaussian (or related) statistical distribution of different-scale events or structural elements. In this respect, the mean value, coinciding with the mode and median of distribution (or approaching them), is also *typical* and illustrative of the data set; therefore, it can be used as a characteristic of this set and the "tails" of the distribution decay so fast that they can be neglected. In this case, small inaccuracies in assigning an initial state slightly change the predicted probability of numerically predominant moderate events (e.g., earthquakes, if their statistics had the same character); at the same time, "large" events (strong earthquakes), whose probability significantly deviates from the mean value can be considered negligibly rare.

In contrast to linear dynamic systems, the behavior of nonlinear ones depends strongly on the slightest variations in the initial state and/or parameters. This results in exponential divergence of initially similar trajectories of dynamics. In addition, when the governing parameter reaches certain critical values, multiple losses of stability occur with skipping (bifurcations) to another theoretically equally possible but qualitatively different regime. When the initial conditions are not assigned absolutely accurately, the coordinates of the bifurcation point are unpredictable, such as "the choice" of the variant of bifurcation skipping at any feasible degree of detail and accuracy of study. The system exhibits the external features of chaotic behavior, although it does not have the element of randomness. Such a feature is called *deterministic chaos*. The behavior of such systems is irregular but differs from completely random genuine (*stochastic*) chaos. As a result, such systems are unpredictable and irreversible, i.e., they are characterized by very strong boundedness or even the impossibility of both prediction and retrodiction.

Deterministic chaos generates power laws of distributions that are a "sign" of deterministic-chaotic systems; the values of their parameters make it possible to reveal the properties of these systems. Power-law distributions have properties that differ significantly from the normal: the mean value coincides neither with the mode, nor with the median. In data sets that have a power-law distribution, e.g., of rupture sizes, earthquake energy (e.g., (Zakharov, 2014) and references) that are bounded from above, the mean value is determined by the largest member for arbitrary large samples (Pisarenko and Rodkin, 2007). Figure 1 presents an example of a power-law distribution of earthquakes by energy and its difference from the normal distribution. The addition of one large value displaces the mean value to the right, decelerating the decay of the "tail" in the distribution plot. "Large" objects (or events) are encountered more often; they cannot be neglected, as in the case of a normal distribution.

The fundamental basis for the occurrence of power laws is *critical* states (on the verge of stability) where a small effect may transfer the system to a chaotic regime. There are systems that maintain the critical state due to self-organizing; in this case, we speak of *self-organized criticality* (SOC).

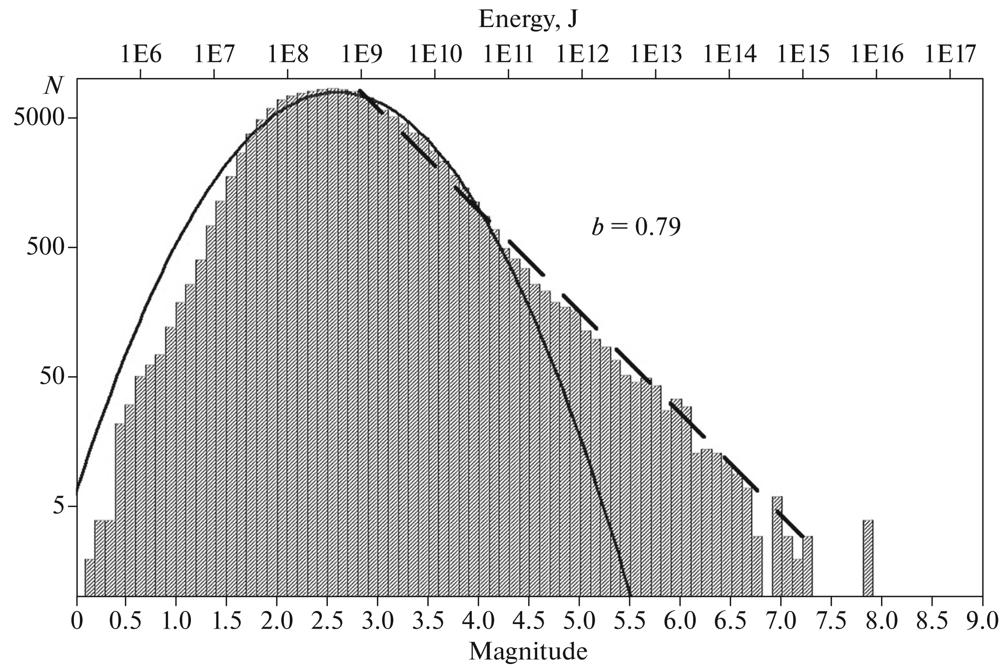

Fig. 1. The distribution of the number of earthquakes with magnitude (energy) for Japan according to the JMA catalog for 1973–2007, the recurrence plot (the dashed line) and the estimate of parameter b in the Gutenberg–Richter law. Here, the normal distribution with the same mean value and dispersion is designated by the solid line.

In the studies of the structure and dynamics of nonlinear processes in the lithosphere, including catastrophic ones such as earthquakes, statistical distributions by the power law are typical, which indicates their self-similarity (fractality). We summarize the results described in (Zakharov, 2014).

The power-law distribution of geoblocks by sizes in a wide scale range, from grains to plates, indicates the self-similarity of block boundaries of the Earth (both blocks and separating ruptures) as a hierarchy with sizes that increase geometrically with an exponent of 2–5 (on the average 3.5 ± 0.9) regardless of their properties or a method of formation.

The common power law for the distribution of plates and blocks point to their self-similar hierarchy from the largest to the smallest; in this respect, their own hierarchy is revealed in the interblock zones. The interplate stresses are the consequence of plate interactions and global dynamics. When the strength limits are exceeded the medium is destroyed by the elasto-brittle or visco-plastic mechanism, followed by the appearance of different-scale ruptures and blocks with fractal properties.

Based on analysis of the self-similarity characteristics for a seismic process, which are expressed in the parameters of power laws (the Gutenberg–Richter law, the Omori law, and the law of fractal distributions of earthquake foci and faults) and the dynamic characteristics of time series of seismicity and series of displacements of GPS points (after the removal of trends), the consistency of hierarchical properties (fractal dimensionality of earthquake epicenters and active faults and the b parameter in the Gutenberg–Richter law) was established in the seismotectonic system. This indicates that the seismotectonic system that generated them is not stochastic but is to a certain degree deterministic; in this respect, it contradicts the ideas of periodicity (complete determinism) of strong earthquakes. Here, no characteristic dimensions are identified in sets with power-law distributions of structural elements and seismic events.

Thus, the evaluation of a seismic process as stochastic (random) does not correspond to factual data. The deterministic dynamics of a nonstochastic system are perceived as chaotic and turn out to be almost unpredictable. A reliable and accurate prediction solution would be obtained only in assigning an "absolutely accurate" initial state that is abstractly conceivable but not feasible. More precisely, a possible range of inaccuracies in assigning an initial state and/or parameters for "successful" prediction exists as does the horizon of prediction, but they are not determined either, due exactly to the deterministic–chaotic character of the system and the possible proximity of the system to bifurcation points whose exact locations are also not known.

The nonlinear interactions of fluid flows and tectonic deformation are characterized by strong dependence on the system parameters (e.g., PT conditions), when avalanches and catastrophes may occur under a trigger action.

The terms "background" and "critical seismicity," foreshocks and "main" events that are required in forecasting assume that some levels are identified. However, for the case of the self-similarity of seismic processes, a certain number of weaker events in a broad range of magnitude and without any special identified levels accounts for an event of a certain magnitude. For a homogeneous power law, correct classification by value, size, force, and energy is impossible.

The deterministic-chaotic properties of the seismotectonic system explain the situations where certain single-type anomalies that are similar in intensity and sizes may be precursors of events with different energies that occurred after different times and at different distances from the projected epicenter. Here, the unexpected "groundlessness" of the ambiguity in the ratio for an observer is apparent. We note the metaphor of I.L. Nersesov: different predictions are recorded accurately on the "visiting cards" of different foreshocks but at such a tiny level (almost infinitely tiny) that we cannot differentiate between them.

Based on the fractal and dynamic analysis of the seismotectonic systems at different spatial-temporal scales (thousands of kilometers and dozens of years during the analysis of seismicity and faults, hundreds–thousands of kilometers and years during the analysis of series of seismic energy release, and hundreds of kilometers and months for aftershock processes), coordinated self-similarity of a seismotectonic process was established in time, space, and by energy, which is expressed in the power laws. The seismotectonic system is included in the class of deterministic-chaotic systems with self-organized criticality and chaotic behavior, for which the boundedness of prediction of states and dynamics has a fundamental character (Zakharov, 2014).

This is the main cause of the level of reliability of seismic forecasting, not insufficient observation (Koronovskii and Naimark, 2009, 2012; Naimark and Zakharov, 2012). The mechanism of the preparation of seismic event is such that it generates unpredictable chaotic dynamics.

CONCLUSIONS

The necessary scientific prerequisites for adequate solution of this problem occurred long ago: In 1901, A.M. Lyapunov, the theory of stability of dynamic systems, the divergence of initially similar trajectories, Lyapunov indices; in 1945, B. Gutenberg, Ch. Richter, the law of earthquake recurrence; in 1961, E. Lorenz, Lyapunov divergences in weather forecasts, strange attractors, dynamic chaos, the butterfly effect; 1975, B. Mandelbrot, the fractal geometry of nature; 1987–1989, P. Bak, self-organized criticality (SOC) and seismicity as its manifestation. The discussions about the possibility and ways of achieving effective short-term forecasts of strong earthquakes began more than 50 years ago and are likely to be continued. However, we are sure that this problem is almost solved: reliable and accurate prediction of strong earthquakes cannot be possible.

The history of the problem includes quite a dramatic issue: the fiasco of a prediction strategy based on two fundamental hypotheses that are not feasible. Precursors as natural and by definition putatively reliable signals of future disasters demonstrate individual and combined variability of their correlations with real seismic events. The natural-science hypotheses of seismicity mechanisms as heuristic beacons (by definition) that are thought to be targeted directly to solving the problem propose only very general mutually contradictory assumptions that do not promise results that meet the practical demands of short-term forecasts.

The causes of such discreditation, which are independent of the experience and qualifications of researchers, defects of procedures, or insufficient technical equipment or funding of research, have not been eliminated and have a fundamental character. An unambiguous answer to the question of the possibility of short-term forecasting of strong earthquakes has been obtained not due to, but in contravention of, the geophysical hypotheses, i.e., not on the conventional basis of assumptions on the mechanisms and precursors but by using modern fractal and dynamic analysis of the structures and processes in the lithosphere according to the particular data on the character of the statistical distributions of the real elements of the geomedium and actual events. It follows from the above that the degree of development of the theoretical–methodical foundations of such analysis made it possible to bring it into wide use much earlier. In searching for definite answers to the major questions of whether stable quality short-term forecasting of strong earthquakes was feasible, and if not, whether it can be feasible in the future, fractal and dynamic analysis of the structures and states of geosystems is the top priority. Explaining how and why "everything happens one way and not another" in terms of geology, geophysics, and geochemistry is a matter of natural-science hypotheses.

In this respect, neither the existing nor potential future hypotheses on the mechanisms of earthquake preparation will reject the conclusions about the nonlinearity and self-similarity of the seismic process and the fractality of the geomedium obtained independently. These factors determine the unpredictability of separate events in geodynamic chaos.

In anticipation of possible further discussion, we present the major statements of our position about the problem.

(1) Warnings about short-term seismic hazards should be rather accurate and reliable; otherwise, they will not comply with their purpose. Rigid require-

ments for the accuracy and reliability of short-term forecast are an important precondition and criterion of its adequacy and feasibility.

(2) A seismic process is nonlinear and extremely "sensitive" to the smallest inaccuracies in the characteristics of any precursor and conditions of its appearance, which a fortiori eliminates the possibility of increasing the effectiveness of forecasting at any real detail of study. It is impossible to record a precursor as a reference in order to accurately predict an earthquake of a certain energy at a certain time and place by analogy. Successful short-term forecasts are singular and appreciably random.

(3) The identification of foreshock and main events, as well as background and anomalous structures and states, is always a fortiori problematic in a fractal geomedium regardless of any hypothetical mechanism of seismicity.

(4) Stable effective short-term forecasting requires establishing initial conditions at least with "absolute" accuracy, which cannot be possible. Such forecasting is not feasible in principle.

(5) Good forecast procedures should provide good forecasts. All examples thus far of successful short-term forecasts of earthquakes are, without exception, cases of unrepresentative local short-term success and/or results predicted with an accuracy that does not meet the practical demands. In this respect, the theoretical substantiations of the fundamental impossibility of complete, reliable, and, accurate short-term forecasting are ignored.

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