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GEOPHYSICS

# Global Variations of the Earth's Seismic Regime in the Years 1965–2005

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Significant variations of the Earth's seismic regime in the period 1965–2005 were revealed on the basis of a new methodical approach. The frequency of large earthquakes during an 11-yr interval (1982–1993) was three or more times lower than in the preceding period. This was accompanied by their intense activation in the entire range of seismic source depths.[1]

The seismic regime is traditionally displayed as recurrence graphs of earthquakes of various magnitudes. The evolution of seismic processes is commonly characterized by the total number and total energy of all earthquakes over a certain time interval. Such an integral presentation of the seismic regime smoothes away specific natural features of its spatiotemporal evolution and thus hampers their investigation [1, 2].

The results obtained in our work are based on a principally new method designed for the study of the seismic regime: the sequence of seismic events is analyzed in magnitude intervals that display the hierarchical nature of the block structure of the geological medium. We investigated successions of large earthquakes on the Earth in the years 1965–2005 differentiated by the magnitude interval $M = 7.0 \pm 02$, $7.5 \pm 0.2$, $8.0 \pm 0.2$, and $8.5 \pm 0.2$. This interval overlaps a wide energy range of $M$ from 6.8 to 8.7 (Fig. 1). The last interval also includes the two largest earthquakes with $M = 8.8$. The total number of events was more than 600. The interval width of $\pm 0.2M$ includes errors in the determination of this value. The step of $0.5M$ also has a physical sense because of its relation to the hierarchical structure of the block–fault medium [3–6]. Hereinafter, magnitude $M$ corresponds to the $M_s$ value determined from surface seismic waves.

[1] When this paper was being printed, the region was subjected to two earthquakes with centers located in a breach within the central Kuril arc (November 15, 2006, $M = 8.3$; January 13, 2007, $M = 8.2$).

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Over the 40-yr period beginning from 1965, none of seismic events was missed in the world catalogs of earthquakes of the considered range of magnitudes and source depths. All these data are ordered to the highest extent in the ANSS catalog [7] used in this study.

Figure 2 shows cumulative graphs of the temporal accumulation rate of seismic events of the magnitude intervals mentioned above. The abscissa shows ordinal numbers $N$ in the sequence of earthquakes, while the ordinate shows years $Y$ of their origin. Let us define events with hypocenters at a depth $h$ of no more than 70 km and more than 70 km as shallow-focus and deep-focus earthquakes, respectively. The solid and thin lines approximate the data points related to shallow-focus and deep-focus earthquakes, respectively. The linear approximation is characterized by a high correlation coefficient (0.9 or higher). Only a fragment of the graph for shallow-focus earthquakes with $M = 7.0 \pm 0.2$ is shown on the right side, because their number is too great. The horizontal scale of this graph is compressed approximately 2.5 times for the purpose of more convenient comparison. The thin line approximates the whole data array of these events over the 40-yr period, whereas the solid line is drawn similarly to other graphs.

The slope of straight segments characterizes the accumulation rate of seismic events of the respective magnitudes. The lower the slope, the higher the rate. The increase in steepness indicates a decrease in the frequency of earthquakes. In the case of similar frequency of earthquakes in each succession, absolutely all moments of their origin, including those in the 40-yr period, would have been located strictly in straight lines. The deviations observed in reality are caused by nonlinear development of geodynamic processes that affect the stress–strain state of the medium and the manifestation of seismicity. This phenomenon was demonstrated on a regional scale in [3–6, 8]. The present paper shows for the first time its manifestation on a global scale.

Analysis of the configuration of graphs reveals specific features of the evolution of global seismicity in

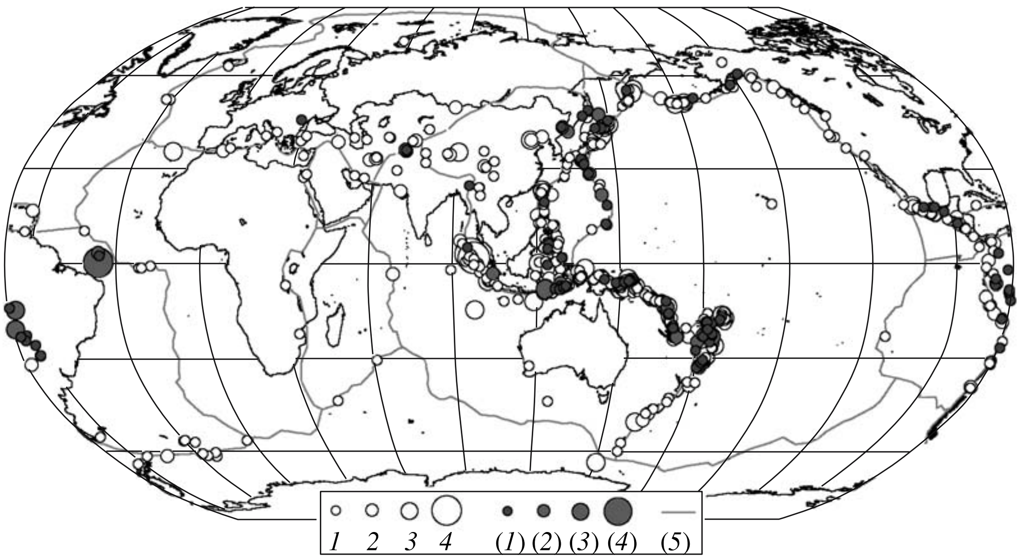


**Fig. 1.** Epicenters of large earthquakes on the Earth in the years 1965–2005. (*1–4*) Earthquakes with magnitude of 7.0 ± 0.2, 7.5 ± 0.2, 8.0 ± 0.2, and 8.5 ± 0.2 and hypocenter *h* not deeper than 70 km; (*1*)–(*4*) earthquakes with the same magnitude and hypocenter *h* deeper than 70 km; (*5*) boundaries of lithospheric plates. Only the state boundary of Russia is shown.

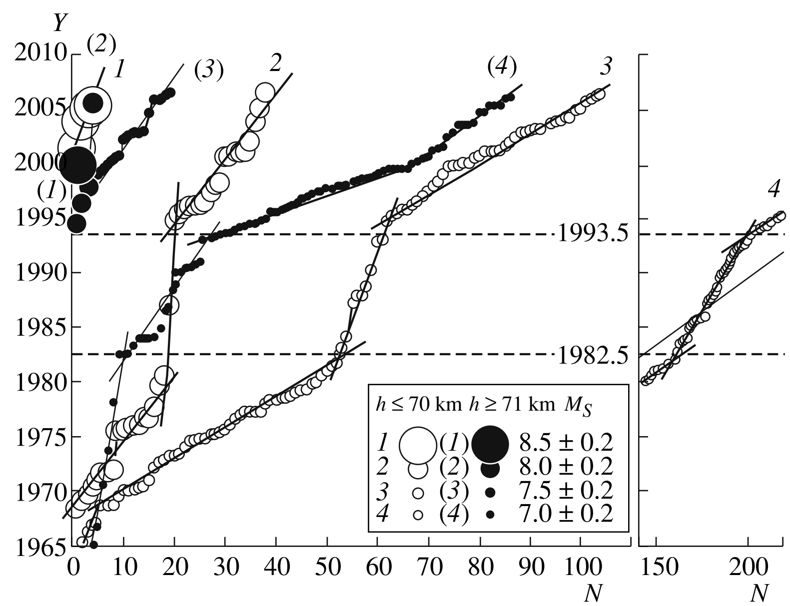


**Fig. 2.** Cumulative graphs of planetary seismic events with magnitude of 7.0 ± 0.2, 7.5 ± 0.2, 8.0 ± 0.2, and 8.5 ± 0.2 in the years 1965–2005. (*1–4*) Linear approximation of the origination of earthquakes with hypocenter not deeper than 70 km; (*1*)–(*4*) the same for the seismic events with hypocenter deeper than 70 km.

time (Fig. 2). First of all, we can note a significant slowing down of the origin of all shallow-focus earthquakes during an ~11-yr interval from mid-1982 (1982.5) to mid-1993 (1993.5). This interval is limited in Fig. 2 by horizontal dashed lines. This deceleration is clearly seen in a fragment of the graph for $M = 7.0 \pm 0.2$. It is notable that the accumulation rate of seismic events changed rather rapidly. This is expressed in a sharp break of graphs at the end of the anomalous interval. Both before and after the relative seismic quiescence, the frequency of shallow-focus earthquakes not only grows, but also retains the same accumulation rate of events.

In order to compare the frequency of earthquake origin, the table shows the numbers of earthquakes of the chosen magnitude for equal (11-yr) periods before, during, and after the seismic quiescence. In all cases, the events are counted from the middle of a year as in the

Number of earthquakes with various magnitudes ($M$) in 11-yr intervals before, during, and after seismic quiescence

| $Y$, year | $M = 7.0 \pm 0.2$ | $M = 7.5 \pm 0.2$ | $M = 8.0 \pm 0.2$ | $M = 8.5 \pm 0.2$ |
|---|---|---|---|---|
| Depth of hypocenters $h \leq 70$ km | | | | |
| 1993.5–2005.5 | 141 | 39 | 17 | 4 |
| 1982.5–1993.5 | 40 | 9 | 1 | 0 |
| 1971.5–1982.5 | 111 | 36 | 12 | 0 |
| Average | 97 | 28 | 10 | ~1 |
| Depth of hypocenters $h > 70$ km | | | | |
| 1993.5–2005.5 | 53 | 12 | 4 | 1 |
| 1982.5–1993.5 | 22 | 0 | 0 | 0 |
| 1971.5–1982.5 | 2 | 0 | 0 | 0 |
| Average | 26 | 4 | ~1 | ~0 |

anomalous period of seismic quiescence. As can be seen, within the 1982.5–1993.5 interval, the earthquakes with $M = 7.0 \pm 0.2$ and $7.5 \pm 0.2$ were three to four times more rare and those with $M = 8.0 \pm 0.2$ were ten or more times more rare than in the preceding and subsequent 11-yr intervals. The largest seismic events with $M = 8.5 \pm 0.2$ or more, which were absent in the two first intervals, became virtually regular in 2001–2005. Such events include catastrophic earthquakes near the Sumatra coast on December 26, 2004 ($M = 8.8$) and on March 28, 2005 ($M = 8.5$), which were accompanied by giant tsunami waves and numerous victims. Before this moment, the world's largest earthquake ($M = 8.5$) had occurred in Alaska in 1964. The 40-yr interval considered in the present paper began after this event.

Another no less important circumstance consists in the fact that deep-focus seismic activity started immediately after the universal quiescence of shallow-focus seismicity. Moreover, earthquakes with $M = 7.5 \pm 0.2$ and higher were not recorded at all, whereas the final time interval was marked by 12 earthquakes with $M = 7.5 \pm 0.2$, 4 earthquakes with $M = 8.0 \pm 0.2$, and one earthquake with $M = 8.8$. The latter earthquake, unique in magnitude, occurred in the Atlantic Ocean at a depth of about 90 km near the eastern coast of South America. Earthquakes with $M = 7.0 \pm 0.2$ were extremely rare before the final active stage. For instance, such earthquakes occurred five times per year in mid-1993 and later, whereas their frequency was 2.5 times less during the seismic quiescence and 26.5 times less before this period.

The average frequency of shallow- and deep-focus earthquakes in the respective ranges of magnitudes (table) virtually coincides with similar values taken from integral graphs of the recurrence of earthquakes on the Earth. This circumstance and the completeness of the earthquake catalog used in our work confirm the reliability of our results.

The nature of global variations of the seismic regime may be interpreted in terms of the modern global geodynamics of lithospheric plates vividly expressed in seismicity. The events with $h > 70$ km (filled circles in Figs. 1 and 2) are related to the plunging of lithospheric plates into the Earth's upper mantle in subduction zones along the island arcs at oceanic margins and in relicts of such zones at continents [3, 5]. The shallow-focus centers (open circles) occur largely in continents and oceanic rift zones. However, both types of events are undoubtedly triggered by a common seismogeodynamic process that embraces our planet as a whole.

The explanation of the observed pattern of global seismogeodynamics during the considered 40-yr period does not exclude, at least, two scenarios. The universal seismic quiescence in this period was probably caused by a slow creep and virtually aseismic plunging of the lithosphere into subduction zones, which attenuates the general stress state of the Earth's lithospheric shell and diminishes the number of seismic displacements. No large earthquakes occur within subduction zones because of the temporal absence of significant hitches on sliding planes.

According to another scenario, the universal seismic quiescence is related to the accumulation of stress in the lithosphere of continents and oceans due to attenuation of plunging of the lithosphere into subduction zones. The resumption of active subduction led to the universal relaxation of stress in the lithosphere and the reactivation of the entire depth interval. Other explanations are also possible. Nevertheless, the clearly expressed quiescence and other variations of the seismic regime over the possible depth range of seismic sources is an irrefutable fact and the nature of this phenomenon is accounted for by the specific features of the Earth's geodynamics.

The Earth is evolving under highly nonequilibrium conditions and characterized by a tendency to self-organization [9, 10]. The global oscillations of the lithosphere are caused by the adjustment of the geologic medium to the long-term effects of planetary-scale forces. In this regard, the alternation of increase in elastic stress and its subsequent relaxation in the form of slow deformations and fast release of stresses in earthquake sources turns out to be the most economical self-organizing geodynamic regime, because this process includes consecutive repetitions of phenomena of the same type. Although a geodynamic system changes its state continuously, the Earth as a whole occurs in dynamic equilibrium promoted by the observed periodicity.

The accumulation and relaxation of geodynamic stresses give way to one another, reflecting thereby the discrete-continuous nature of the geodynamics of the Earth's crust and the entire lithosphere. These processes and phenomena may also be reflected in the regional seismogeodynamics. Therefore, they should be taken into account in the long-term prediction of strong earthquakes.

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