ISSN 1028-334X, Doklady Earth Sciences, 2007, Vol. 417, No. 8, pp. 1221–1223. © Pleiades Publishing, Ltd., 2007.
Original Russian Text © L.L. Romashkova, V.G. Kossobokov, 2007, published in Doklady Akademii Nauk, 2007, Vol. 416, No. 5, pp. 686–689.

GEOPHYSICS

Global Seismic Symptoms of Lithosphere Instability at the Approach of the December 26, 2004, Sumatra–Andaman Megaearthquake

L. L. Romashkova and V. G. Kossobokov

Presented by Academician V.I. Keilis–Borok May 9, 2007

Received May 29, 2007

DOI: 10.1134/S1028334X07080193

Interaction between earthquakes at distances significantly exceeding their geometrical sizes is an important property of the Earth's seismic dynamics. Many researchers have investigated examples of such interactions on local and global scales [1–4]. Long-range interaction does not mean direct transfer of stresses from one earthquake to another, but most likely a sequence of large-scale processes in the Earth's interior. Long-range interaction is a general feature of many complex hierarchic dynamic systems [4, 5]. The study of this phenomenon is important both for understanding processes occurring in the lithosphere and for predicting future strong earthquakes.

The process of earthquake preparation, which covers a region many times greater than the linear size of the future source, is an important example of the interaction between seismic activities at large distances [4, 6]. General symptoms of the instability of dynamic systems are manifested at the approach of a strong seismic event in the area of its preparation. Many of these symptoms are known in geophysics as seismic precursors of earthquakes [4], e.g., higher correlation of seismic activity, variation of the energetic level and regularity of earthquakes, spatiotemporal redistribution of the density of events, distortion of the frequency–magnitude balance, and others. The expectation time to the moment of a strong earthquake for different precursors varies from a few hours to tens of years. The use of seismic precursors is the basis of many algorithms of earthquake prediction [7–9].

The catastrophic earthquake source near the coasts of Sumatra on December 26, 2004, was approximately 1500 km long, which implies that the territory of its preparation is comparable with the size of the Earth. Thus, it is natural to expect that the general symptoms of instability before this earthquake, if they existed, could have been manifested on a global scale.

In this work, we considered the problem of the existence of global-scale intermediate-term seismic symptoms of instability before the megaearthquake. Such symptoms are manifested over the entire lithosphere of the Earth over several years. In this case, the lithosphere is considered as a single whole, which is the ultimate scale of the complex hierarchic dynamic system. Time variations of empiric frequency–magnitude distributions of global seismicity at several depths are analyzed on the basis of two world earthquake catalogs (NEIC [10] and CMT [11]). This allows us to detect the variations in earthquake activity at different ranges of magnitude and depth. The magnitudes of different types (mb, M_S, and M_W) are considered together simultaneously in the time periods determined by the complete and uniform data (Table 1) for all earthquakes from the catalogs without distinguishing the foreshocks and aftershocks. The geographical coordinates are not taken into account. Only the information about the time, magnitude, and depth of the events is used.

The intermediate-term dynamics in variations of the frequency–magnitude distribution is estimated by parameters b (slope of the frequency–magnitude plot)

Table

Data	Period, years	Depth intervals, km
NEIC, mb	1969–2004	0–100, 100–300, 300–500, 500–700
NEIC, M_S	1969–2004	0–50
CMT, M_W	1977–2004	0–100, 100–300, 300–500, 500–700

Note: Magnitude M_W was calculated according to [12].

International Institute of Earthquake Prediction Theory and Mathematical Geophysics, Russian Academy of Sciences, Profsoyuznaya ul. 84/32, Moscow, 117997 Russia; e-mail: lina@mitp.ru

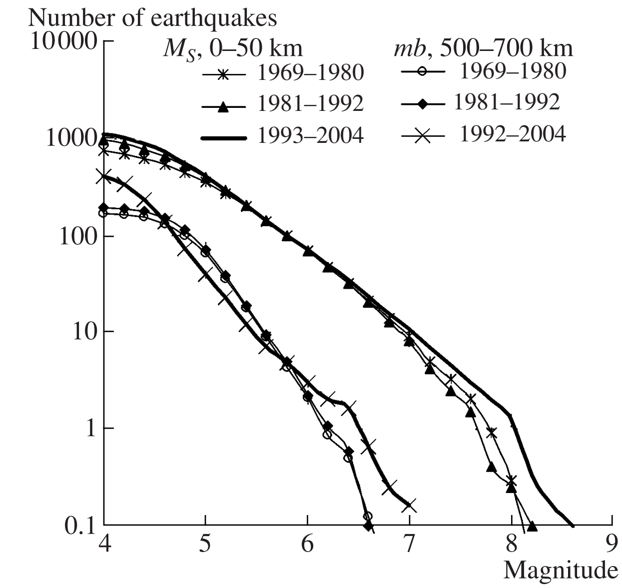

Fig. 1. Annual average frequency–magnitude distributions of global seismic activity in three consecutive periods of time (1969–1980, 1981–1992, and 1993–2004) for magnitudes *mb* and M_S. Distributions in the first and second periods practically coincide. The latter period is characterized by an increase in the slope of the plot for strong events (M_S) and downward deflection for earthquakes of moderate magnitudes (*mb*).

and *CON* (deviation of the plot from the straight line), which are calculated for a set of consecutive intervals of magnitudes using the formulas

$$b(M_1, M_2) = \frac{\log_{10}N(M_1) - \log_{10}N(M_2)}{\Delta M}, \qquad (1)$$

$$CON(M_1, M_2) = \log_{10}N\left(\frac{M_1 + M_2}{2}\right) - \frac{1}{2}(\log_{10}N(M_1) + \log_{10}N(M_2)), \qquad (2)$$

where $N(M_i)$ is the number of earthquakes with magnitude M_i or higher in the 6-yr running time interval with a step of 6 months; the value of $\Delta M = M_2 - M_1$ is assumed equal to 0.5 for *mb* and 1.0 for M_S and M_W.

The results of the analysis allow us to state the following.

From the end of the 1960s to the middle of the 1990s, the global seismic activity was quite stable in time at all depths. Starting from the representativity level of the catalog downward to the bend in the strong earthquake interval ($mb \geq 6.0$, $M_S \geq 7.0$, and $M_W \geq 7.0$), the frequency–magnitude plots for magnitudes *mb*, M_S, and M_W have intervals close to linear ones. The slope coefficient *b* of the linear interval for all types of magnitudes practically does not depend on depth: ~1.45 for *mb*, 0.8 for M_S, and 1.0 for M_W.

Starting from the mid-1990s, one can note a qualitative change in the form of the frequency–magnitude distribution. This process is observed over the entire depth of the lithosphere and is recorded in the analysis of each of the magnitude scales studied. Variation of surface earthquakes is characterized by general straightening of the frequency–magnitude plots (*mb*, M_S, and M_W) due to an increase in the number of strong events. For the intermediate events and especially for deep earthquakes, the form of the plots (*mb* and M_W) changes even more drastically from concave to convex.

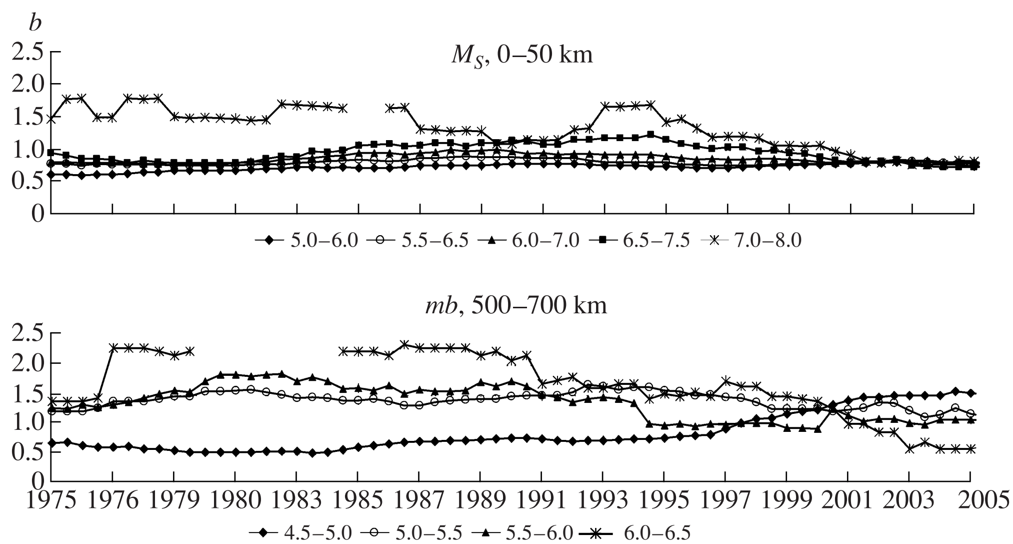

Fig. 2. Time variations of the slope coefficient *b* of the frequency–magnitude for several consecutive intervals of magnitudes. (M_S) Surface earthquakes; (*mb*) deep earthquakes. Dates along the horizontal axis correspond to moments of the end of 6-yr running intervals. After 2000, the distribution is linear for M_S (slope coefficient $b \approx 0.8$) and convex for *mb*.

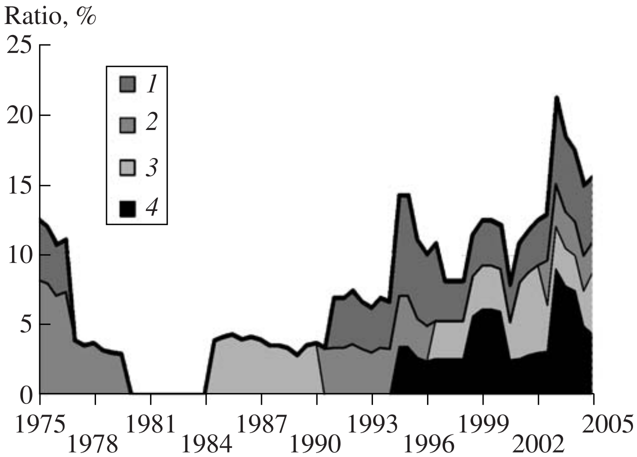

Fig. 3. Time variations in the ratio of the number of deep (500–700 km) earthquakes to surface (0–100 km) earthquakes for $mb \geq 6.5$. Grayscale gradations show the contribution of each of the four regions of deep seismic activity: (*1*) South America; (*2*) Northwestern Pacific Ocean; (*3*) Southeast Asia; (*4*) Southwestern Pacific Ocean. Dates along the horizontal axis correspond to the moments of the end of 6-yr running time intervals.

Figures 1 and 2 illustrate the dynamics of variations in the frequency–magnitude distribution and parameter *b*.

A comparison of variations at different depths revealed a global redistribution of the flux of seismic energy release over the decade before the Sumatra–Andaman earthquake toward an increase in the number of the strongest deep events ($mb \geq 6.5$) relative to the number of surface earthquakes of the same magnitude. Activation was recorded simultaneously (on the intermediate-term scale) in all four regions of deep seismic activity (Fig. 3). At the same time, we recorded a decrease in the number of moderately deep earthquakes ($5.0 \leq mb \leq 6.0$) relative to the surface events of the same magnitude.

Further comparison of the global frequency–magnitude distributions of different magnitude scales revealed qualitative changes in intermagnitude ratios in the last decade. For the surface earthquakes, the relation between magnitudes M_W and M_S approached a linear law ($M_W = C_1M_S + C_2$, $C_1 < 1$) over the entire interval of M_W values from 5.5 to 9.0. In contrast, the previous years were characterized by a significant deviation from linearity M_W values greater than 7.0. For deep earthquakes at the interval of M_W from 5.5 to 7.0, the slope of the plot of linear regression of M_W–mb decreased from ~1.7 to nearly 1.0.

Thus, the analysis of the seismic regime of the Earth's lithosphere on the intermediate-term scale revealed significant deviations in the decade prior to the Sumatra–Andaman megaearthquake on December 26, 2004. These deviations are rather consistent with the classic symptoms of instability in a dynamic system before a catastrophe. The global symptoms of preparation of a megaearthquake can be described by functionals known as precursors of strong earthquakes of a smaller magnitude. In particular, a megaearthquake (as before the December 26, 2004, event) can be predated by an increase and acceleration of seismic activity, variations in the frequency–magnitude distribution, spatial redistribution of seismicity, variations in intermagnitude relations, and other patterns of the collective behavior. The results of the study point to the following facts: (1) the presence of global-scale intermediate-term tectonic processes in the lithosphere; (2) the critical state of the Earth's lithosphere in the last decade. The latter fact was recently confirmed by the occurrence of the Sumatra–Andaman megaearthquake.

ACKNOWLEDGMENTS

This work was supported in part by the Presidium of the Russian Academy of Sciences (program "Variations in the Environment and Climate: Natural Catastrophes") and the EC grant of the Sixth Framework Program (Priority FP6-2003-NEST-PATH "Tackling Complexity in Science", Project E2–C2 "Extreme Events: Causes and Consequences").

REFERENCES

1. V. H. Benioff, Bull. Geol. Soc. Am. **62**, 331 (1951).
2. A. G. Prozorov and E. Ya. Rantsman, Dokl. Akad. Nauk SSSR **207**, 341 (1972).
3. E. V. Vilkovich and M. G. Shnirman, Vychislit. Seismol. **19**, 27 (1982).
4. V. I. Keilis-Borok, Rev. Geophys. **28** (1), 19 (1990).
5. D. L. Turcotte, W. I. Newman, and A. Gabrielov, in *Geocomplexity and the Physics of Earthquakes* (Washington D.C., AGU, 2000).
6. I. P. Dobrovolsky, S. I. Zubov, and V. I. Miachkin, Pure Appl. Geophys. **117**, 1025 (1979).
7. *Long-term Prediction of Earthquakes: Methodical Recommendations*, Ed. by M.A. Sadovskii (IFZ AN SSSR, Moscow, 1986) [in Russian].
8. V. G. Kossobokov, L. L. Romashkova, V. I. Keilis-Borok, and J. H. Healy, Phys. Earth Planet. Inter. **111** (3/4), 187 (1999).
9. *Nonlinear Dynamics of the Lithosphere and Earthquake Prediction*, Ed. by V.I. Keilis-Borok, A. Soloviev, (Springer, Berlin, 2003).
10. GHDB (Global Hypocenter Data Base) (Denver, 1989).
11. G. Ekstrom, A. M. Dziewonski, N. N. Maternovskaya, and M. Nettles, Phys. Earth Planet. Inter. **148**, 327 (2005).
12. H. Kamatory, J. Geophys. Res. **82**, 2981 (1977).