ISSN 1028-334X, Doklady Earth Sciences, 2007, Vol. 417A, No. 9, pp. 1402–1406. © Pleiades Publishing, Ltd., 2007.
Original Russian Text © A.A. Malovichko, A.G. Gamburtsev, A.K. Voinov, L.V. Nekrasova, 2007, published in Doklady Akademii Nauk, 2007, Vol. 417, No. 4, pp. 545–549.

GEOPHYSICS

Specific Features of Dynamics of Induced Seismicity in Mining Regions of the Urals

Corresponding Member of the RAS A. A. Malovichko[a], A. G. Gamburtsev[b], A. K. Voinov[c], and L. V. Nekrasova[d]

Received May 30 2007

DOI: 10.1134/S1028334X07090231

Seismic events in mines are related to both natural and induced processes [1–5]. Unique factual data obtained in the course of comprehensive monitoring in two mining districts of the Ural region make it possible to formulate the issue, reveal and compare specific features of the dynamics of seismic processes, and elucidate cause-and-effect relations between the external (induced and natural) influences, on the one hand, and seismic events, on the other hand.

We can assume that natural rock bodies are multioscillatory systems functioning in seasonal and other regimes. Rocks are likely to be capable of synchronization with external influences and desynchronization. The medium probably does not respond to some weak actions at certain time intervals. However, it responds to strong influences (for example, earthquakes). In some cases, seismologists attempt to investigate influences on rocks related not only to internal tectonic processes, but also to tidal, geomagnetic, heliomagnetic, induced, and other processes.

Variations in different indicators in various spheres and time scales are characterized by specific features depending on time. These variations are often unpredictable, because the apparent external causes responsible for them are lacking. The response of objects to external influences is commonly nonlinear, e.g., an unexpectedly strong response to very weak influences (trigger effect). Therefore, it is essential to determine critical situations that provoke such phenomena. Plurality of influences plays a significant role. In such cases, the object responds at first to a certain influence. This scenario can include phenomena provoked by a series of interrelated events. It is particularly difficult to define cause-and-effect relations in natural and induced systems, e.g., mining objects. Rock massifs in such systems are subjected to strong natural and induced impacts. Therefore, elucidation of the causes responsible for a seismic event is a difficult task. At the same time, the mining researcher can forecast the site of a future seismic event. This is an advantage of the mining researcher relative to seismologists who often cannot even approximately forecast a future hypocenter.

We investigated the possible influence of some factors on specific features of the dynamics of induced seismicity for two mining regions of the Urals located at a distance of 200 km from each other: the Kizelovsk coal basin (KCB) and the North Ural bauxite mine (NUBM). The influence of mining works led to the development of intense induced processes in the Earth's interior (primarily, seismicity of different scales). With respect to the frequency and character of rock burts, the KCB was recognized as the most hazardous area in the 1950s and 1960s. In the 1970s–1980s, the NUBM became the most hazardous area. In order to control and forecast rock bursts in both basins, automatic seismic monitoring systems were installed in the KCB zone with an area of 1.8 × 1.8 km^2 and in the NUBM zone with a larger area (approximately 2 × 10 km^2). The seismic systems have provided a unique database over the past more than 20 years.

We recorded numerous seismic events ranging from very weak events (energy 50 J) to rock burts and induced earthquakes (energy class equal to 7 and 8). Energy values for the NUBM are approximately two orders of magnitude higher (1.8 × 10^8 J) than those for the KCB. Almost the entire excited seismicity in the NUBM is concentrated in three mines (nos. 13–15). The diurnal and monthly mean time series for mines 13–15, the entire NUBM area, and the KCB were processed. We examined two parameters: the number of seismic events N per day and the maximal energy E released per day. We also analyzed time series for indices of the heliomagnetic and geomagnetic activities, lunar–solar tides, and the Earth's rotation speed. The

[a] *Geophysical Survey, Russian Academy of Sciences, pr. Lenina 189, Obninsk, Kaluga oblast, 249020 Russia*
[b] *Institute of Physics of the Earth, ul. Bol'shaya Gruzinskaya 10, Moscow, 123995 Russia; e-mail: azgamb@mail.ru*
[c] *OAO Sevuralboksitruda, uk. Vatutina 5, Severoural'sk, Sverdlovsk oblast, 624480 Russia*
[d] *Mining Institute, Ural Division, Russian Academy of Sciences, ul. Sibirskaya 78a, Perm, 614007 Russia*

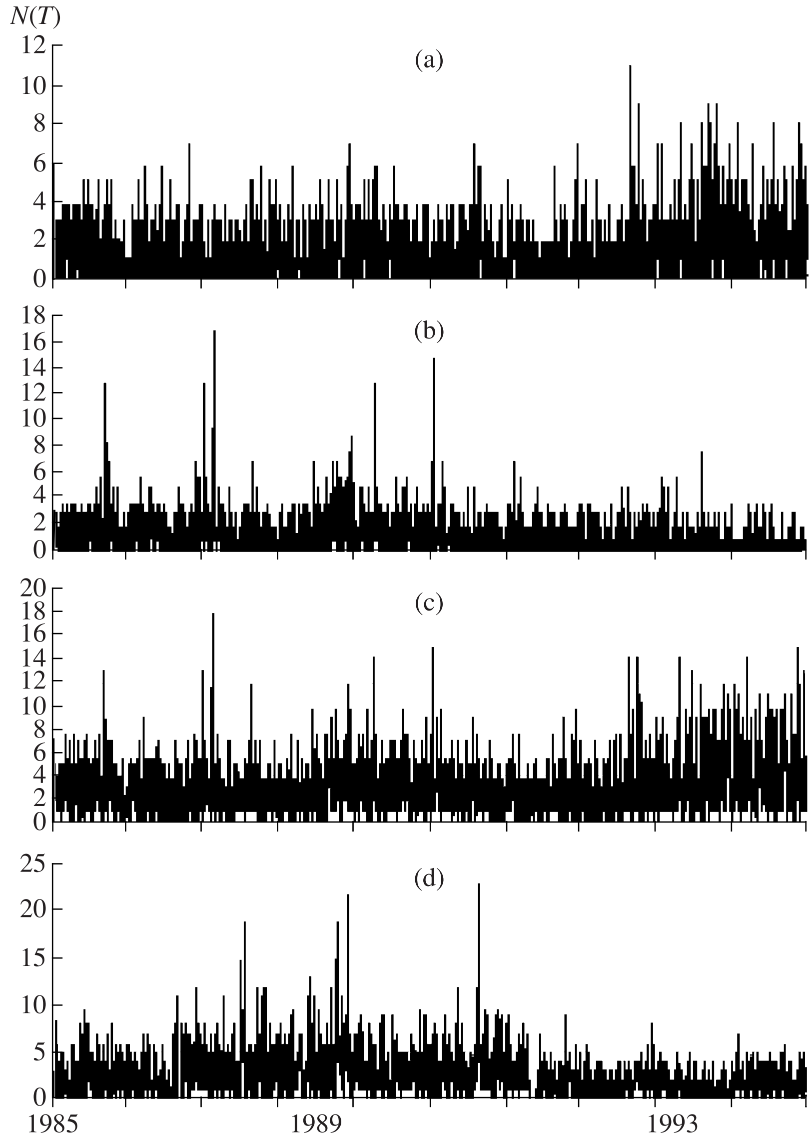

Fig. 1. Time series of the number of seismic events in (a, b) mines 14 and 15, respectively, of the NUBM, (c) the entire NUBM area, and (d) the KCB area.

influence of a particular day of week was also investigated. In general, the total time interval compared for the KCB, mines 14 and 15 of the NUBM, and the entire NUBM was equal to 11 yr (1985–1995).

Comparison of the data revealed the following regularities. The $E(T)$ series for Mine 15 and the entire NUBM turned out to be very similar. The correlation coefficient between them at the zero shift is equal to 0.998 (number of observation points, $n > 3600$). In mines 13 and 14, the E value is five to six times smaller than in Mine 15. The correlation coefficient between different mines or between individual mines and the entire NUBM is very low. Thus, the $E(T)$ series for the entire NUBM is defined by the series for Mine 15. The $E(T)$ series for the NUBM and KCB lack any correlation.

Time series of the number of events $N(T)$ show a different pattern. Figure 1 presents the $N(T)$ series for mines 14 and 15 of the NUBM, the entire NUBM, and the Kizelovsk Mine. One can see that the first half of time series for the entire NUBM is defined by events recorded in Mine 15. The second half of the time series is defined by events recorded in mines 13 and 14. The $N(T)$ series for mine pairs 13/14, 13/15, and 14/15 lack any correlation during the whole comparative time interval. Thus, the time series show individual patterns even within a small sector, such as the NUBM.

Comparison of the $N(T)$ series for different basins showed that the time series has a very small number of similarities, although calculations of correlation coefficients in the moving time window revealed some coincidences at certain time intervals. The strongest events,

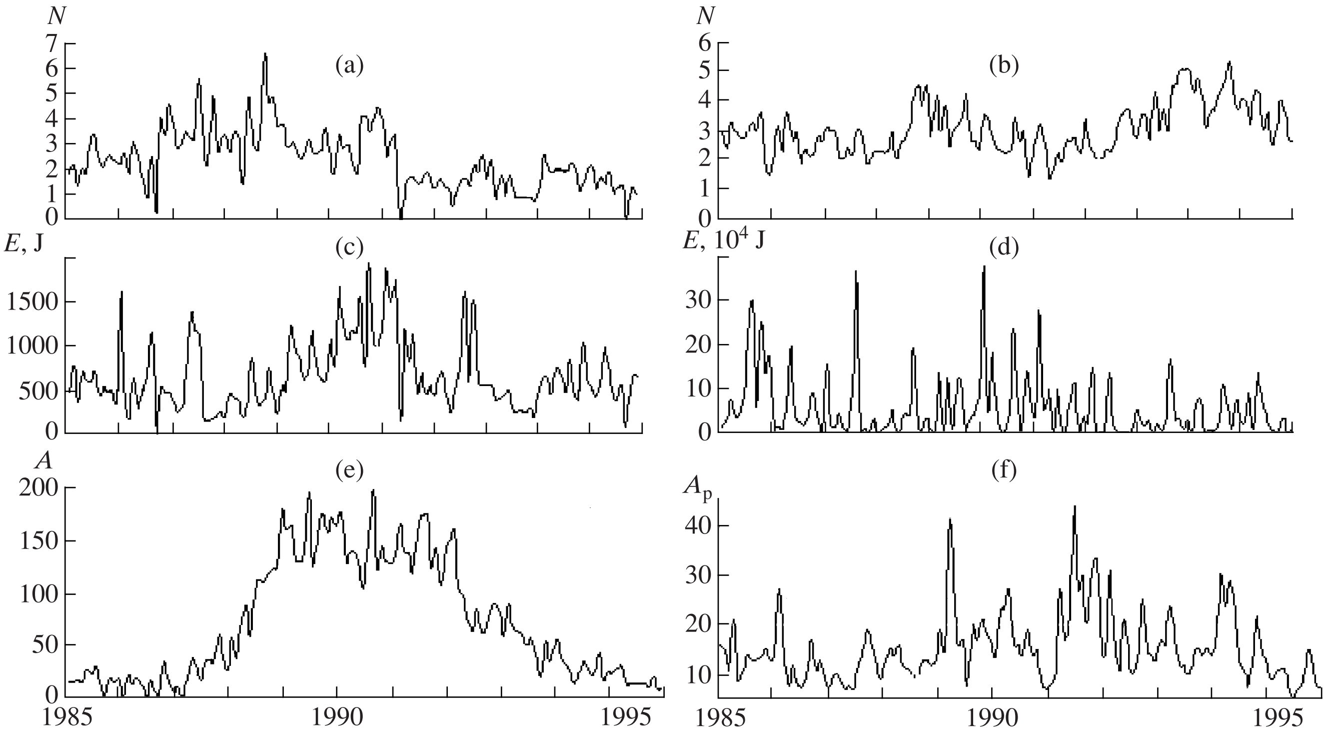

Fig. 2. Monthly mean numerical series for daily seismic events in (a, b) mines of the KCB and NUBM, respectively; (c, d) time dependence of the maximum energy in these mines; (e) Wolf numbers; and (f) geomagnetic indices.

probably related to various causes, occurred in these basins at different time intervals. Figure 2 presents the monthly mean time series $N(T)$ and $E(T)$ in two mines, the Wolf numbers, and the A_p index. $E(T)$ plots do not take into consideration the strongest events (we omitted 12 events with $E > 5 \cdot 10^4$ J for the KCB and 4 events with $E > 1.5 \cdot 10^7$ for the NUBM). One can see that maximum E values for the KCB mainly coincide with the maximal (or gradient) sectors of the Wolf number plot and the more perturbed sectors of the $A_p(T)$ plot. The maximal apparent similarity is typical of the monthly mean series $N(T)$ and $E(T)$ for the KCB and the Wolf number, but the maximum envelope of the $N(T)$ plot coincides with the growth time of the Wolf number in 1987–1989 (its gradient is likely to be an essential property). Explicit similarity, as for the KCB, is lacking in the NUBM. Thus, we can assume that the influence of solar and geomagnetic anomalies is apparently absent in the NUBM.

Spectral–temporal diagrams presented in Fig. 3 show the following pattern. The spectral–temporal structure (STS) is more ordered for the KCB relative to the NUBM. The KCB plots show four rhythms with periods of 1.6 yr, ~1.5 months, 7 days, and 3.5 days. Moreover, the amplitude of rhythms is variable in time. The STS pattern for the NUBM series is mosaic and more variable in time. Nevertheless, the STS pattern demonstrates several characteristic features repeated for different series. The spectral–temporal diagrams of $N(T)$ series clearly show amplitude-variable rhythms (rhythms typical for the KCB included), but they are less distinct and observed in a more noisy background. Let us recall that rhythms with periods of approximately 1.6 and 0.5 yr, as well as 28, 14, 7–8, and 3 or 4 days are sufficiently distinct for the Wolf number, but these rhythms are not recorded in the entire time interval. Indices A_p and K_p are characterized by rhythms of approximately 1 yr, 0.5 yr, 14 days, and 7 days.

Thus, processes in mines are characterized not only by correlations with geomagnetic and heliomagnetic indices, but also by the presence of common rhythms, particularly in the Kizelovsk Basin. This statement does not mean that the processes are governed only by variations in the indices. They likely play an essential role in the formation of the seismic regime of underground workings. In some cases, this role can be qualified as a “trigger.” Comparison of the time series shows that many events in mines are independent of variations in geomagnetic and heliomagnetic indices. Seismic events also lack any correlation with variations in the Earth’s rotation speed and syzygies. The weekly and half-weekly rhythms revealed in our work are also present in social and medical processes, geomagnetic activity indices, and the Earth’s rotation speed. In our case, the rhythms are likely to be induced by social factors. The maximums and minimums of these rhythms fall on Thursdays and Sundays, respectively.

Thus, we can make the following conclusions:

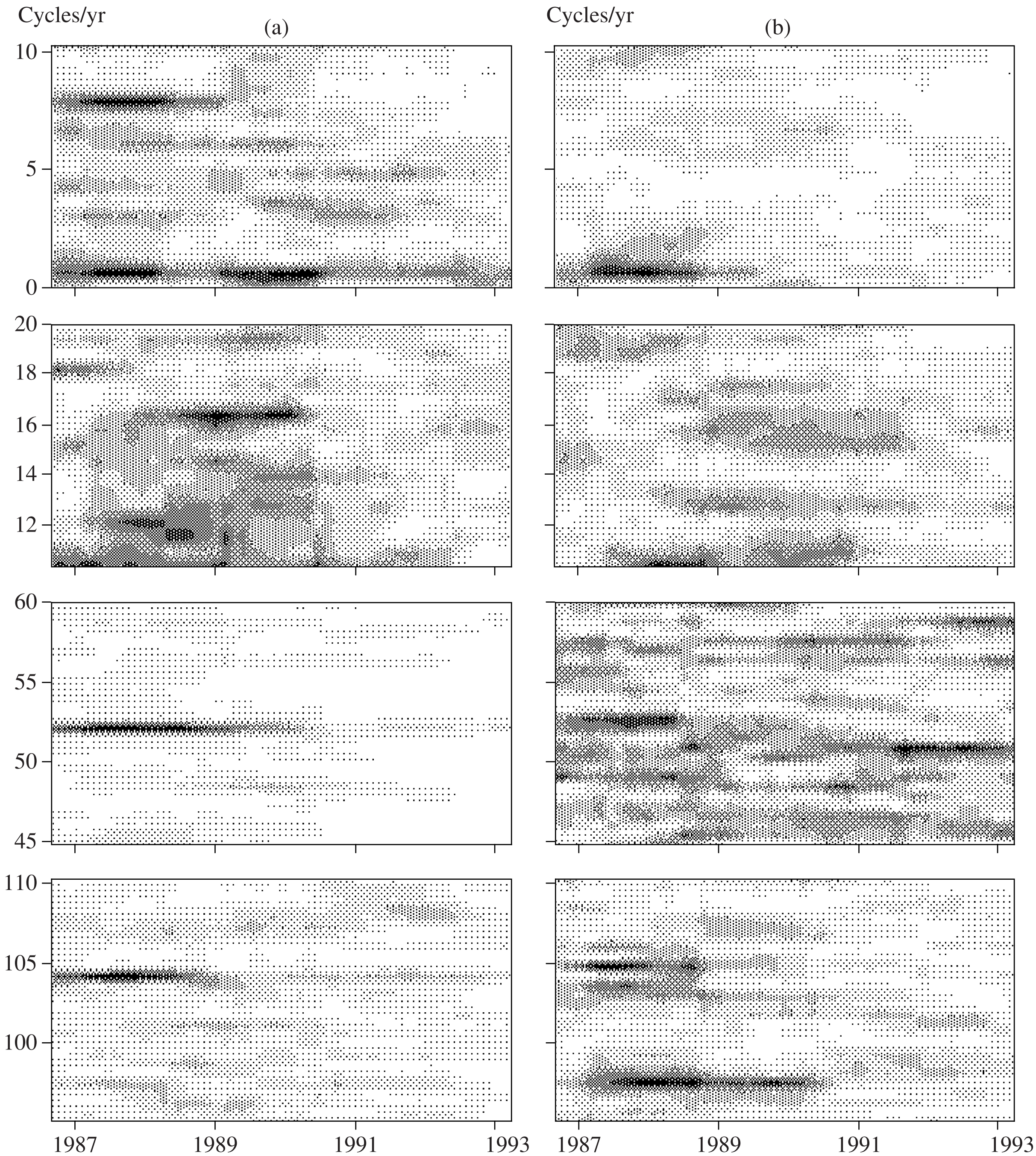

Fig. 3. Spectral–temporal diagrams of the number of seismic events in (a) KCB and (b) NUBM (Mine 15) for different frequency windows in the annual cycle.

(1) The series of seismic events include trend, rhythmic, impulse, and noise components. The series are characterized by a variable polyrhythmic structure.

(2) The time series for seismic events have complex specific patterns with different levels of energy emission and different degrees of correlation with the geomagnetic and heliomagnetic indices.

(3) In the Kizelovsk Basin, series of seismic indicators show a stronger correlation with series of the Wolf number and A_p index, relative to the NUBM. Processes in the North Ural Basin are probably more vulnerable to anthropogenic influences.

REFERENCES

1. A. A. Malovichko, A. D. Zav'yalov, and A. A. Kozyrev, in *Natural Hazards in Russia: Seismic Hazards* (Kruk, Moscow, 2000), pp. 243–293 [in Russian].
2. E. I. Mikulin, V. A. Kolesov, V. G. Selivonik, et al., in *Forecast and Prevention of Rock Bursts in Mines* (AGN, Moscow, 1997), pp. 109–173 [in Russian].

3. I. M. Petukhov, V. A. Litvin, and L. V. Kucherskii, *Rocks Burts and Their Control in Mines of the Kizelovsk Basin* (Permizdat, Perm, 1969) [in Russian].
4. A. A. Malovichko, L. V. Nekrasova, and F. V. Sysolyatin, in *Physics and Mechanics of Rock Failure: Implication for the Forecast of Dynamic Phenomena* (VNIMI, St. Petersburg, 1995), pp. 206–215 [in Russian].
5. V. V. Adushkin and S. B. Turuntaev, *Induced Processes in the Earth's Crust: Hazards and Catastrophes* (INEK, Moscow, 2005) [in Russian].
6. L. N. Bol'shev and N. V. Smirnov, *Tables of Mathematical Statistics* (Nauka, Moscow, 1983) [in Russian].
7. N. A. Agadzhanyan, O. I. Aptikaeva, A. G. Gamburtsev, et al., *Human Ecology in the Changing World* (Yekaterinburg, 2006) [in Russian].
8. A. G. Gamburtsev, *Seismic Monitoring of the Lithosphere* (Nauka, Moscow, 1992) [in Russian].
9. *Atlas of Temporal Variations in Natural, Anthropogenic, and Social Processes* (Yanus-K, Moscow, 2002), Vol. 3 [in Russian].