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The Technogenic Bachat Earthquake of June 18, 2013 (*ML* = 6.1) in the Kuznetsk Basin—the World's Strongest in the Extraction of Solid Minerals

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Abstract—The Bachat earthquake that occurred in Kemerovo oblast on June 18, 2013 with a local magnitude of *ML* = 6.1 is the strongest in a series of events in the vicinity of an open-pit mine of the same name, as well as the world's largest technogenic earthquake in the extraction of solid minerals. Research on the seismicity in the environs of the mine using local networks of temporary stations began several years prior to the earthquake and continues today. We present the results of this research. Particular attention is given to monitoring of the seismic regime of technogenic activation of the Bachat coal mine and its nature.

Keywords: Bachat earthquake, induced seismicity, technogenic earthquake, Kuzbass

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INTRODUCTION

The Bachat earthquake occurred on June 18, 2013, at 23:02 UTC (June 19, 2013, at 06:02 LT) with c *ML* = 6.1, *mb* = 5.5, and epicenter coordinates of 54.29° N, 86.17° E in the area of the eponymous coal mine in the Kuznetsk Basin (Kuzbass).

The Bachat coal mine, founded in 1949, is one of the largest in the Kuzbass, with the following dimensions: 10 km in length, 2.2 km in width, and 320 m in depth. The mean annual coal extraction in the mine is more than 9 mln t.

As a result of macroseismic surveying of the territory (Emanov et al., 2015c), in villages near the epicenter, the tremor rate reached seven points and destruction to buildings was noted. Some cities of the Kuzbass (Gur'evsk, Belovo, Kiselevsk, etc.) were in the five-point zone, and the earthquake was felt outside of Kemerovo oblast (Fig. 1).

Figure 2 shows photographs of ruptures recorded along the entire length of the mine (around 10 km). The photos were taken in the first days after the earthquake. Later, the ruptures were evened out with bulldozers. A bulldozer track is seen in Fig. 2a. Figure 3 shows photos of the characteristic damage to buildings during the Bachat earthquake. In the area near the epicenter, the majority of buildings are one-story houses. This earthquake damaged hundreds of houses to various degrees.

STUDY OF PRIOR INDUCED SEISMICITY

The seismicity near the Bachat coal mine was studied earlier (Emanov et al., 2016b, 2016c). The regional network of seismic stations did not allow the recording of small events; therefore, technogenic seismicity was recorded only for the strongest earthquakes. Frequently, arguments about the nature of an event arose: was it an earthquake or an industrial blast?

Since 2005, to study the seismicity in the vicinity of Kuzbass mines, temporary network stations have been used. Particularly detailed and long-term experiments have been carried out in the area of the city of Polysaevo (Emanov et al., 2009b). The technogenic nature of earthquakes and the close relationship with underground excavation has ceased to raise any doubt.

The grounds for research in the vicinity of open mineworks was the large earthquake in the Kuzbass that occurred on February 9, 2012 at 13:24 UTC (20:24 LT) with a local magnitude of *ML* = 4.3 and epicenter coordinates of 54.28° N, 86.15° E, which hit

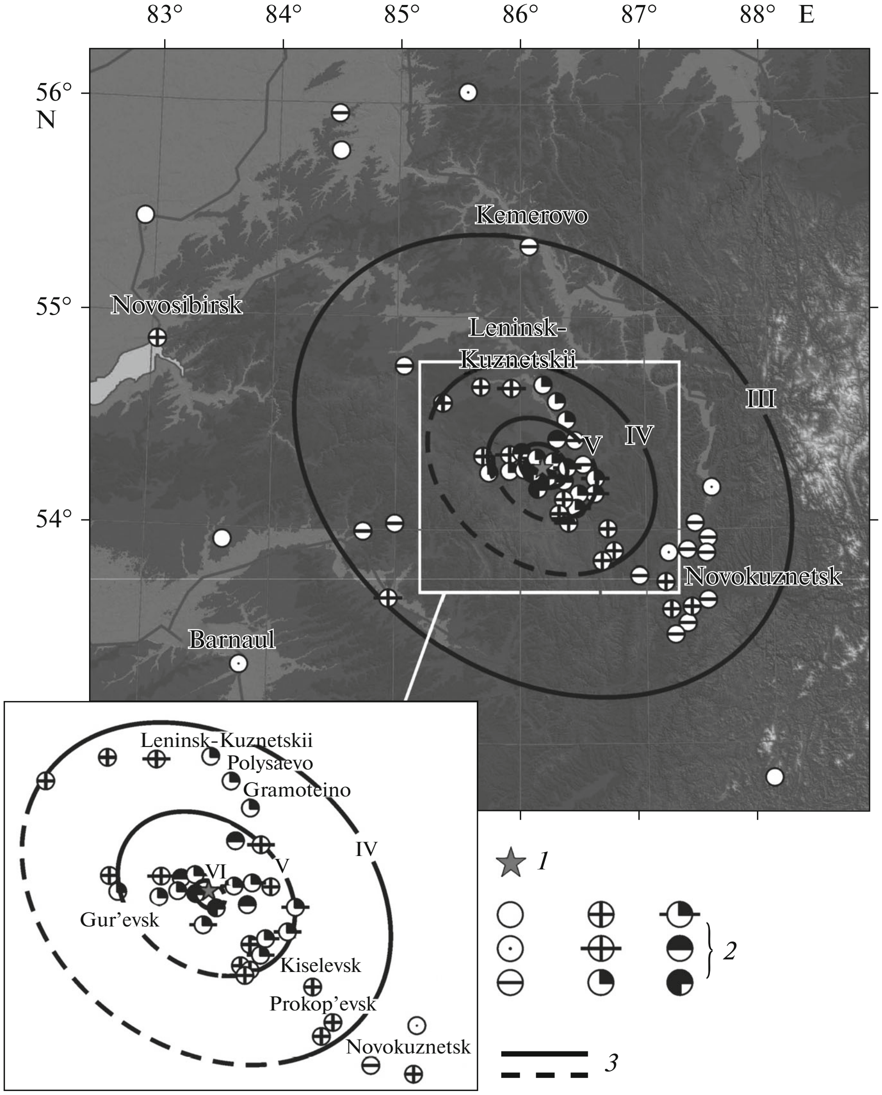


Fig. 1. Map of isoseismals of Bachat earthquake of June 18, 2013, constructed from results of macroscopic investigation of the territory. (*1*) Epicenter of Bachat earthquake (*ML* = 6.1); (*2*) points; (*3*) isoseismals.

the side of the Bachat mine (Fig. 4). This event generated perceptible vibrations in a majority of cities in Kemerovo oblast, as well as striking a large social resonance that served as grounds for detailed study of the mine's seismicity.

Operations with explosives are carried out daily at the mine, which are permitted only in the daytime. In local time, this even occurred in a time off limits for explosives, but the presence of strong surface waves in the seismograms of the regional network of stations testified to the source of waves near the daytime surface. The management of the Bachat coal mine categorically refuted the possibility of an blast. In addition, the energy of this event at a minimum exceeded by unity the energy of the largest industrial blasts conducted in this mine. If it was not an blast, then there are grounds to assume that the extraction of coal in the mine is concomitant with a dangerous seismotectonic process that can be tracked by recording earthquakes with small energies.

Observations by a temporary local network of 25 stations in the area of the Bachat coal mine and its environs were performed in the period of March 2–May 15, 2012 (Emanov et al., 2014b). The seismic stations, equipped with Baikal AS-75 autonomous complexes for recording seismic signals (Semibalamut and Rybishkin, 2003) and SK-1P short-term seismic sensors, were placed on the daytime surface both immediately in the areas where coal extraction was taking place, and in populated areas in the territory, approximately 30 × 15 km in area (see Fig. 4). Such a dense observation system makes it possible to study in detail the seismic regime of the activated area and its structure (Aref'ev, 2003).

Fig. 2. Photographs of ruptures formed along sides of Bachat mine during main impact of Bachat earthquake: (a)–(c) see text.

Within the operational period of the network of stations (73 days), around 193 seismic events were recorded within the coordinates 54°–54°30′ N, 85°30′–86°30′ E. Short-delay industrial blasts and technogenic earthquakes were distinctly diagnosed from the shape of the record (Figs. 5, 6), but a detailed study of the nature of the events relied not only on the results obtained by seismological methods, but also on exact information from explosive experts at the mine.

Figure 5 shows the records of industrial blasts at close stations of the temporary network. The short-

Fig. 3. Destruction of buildings during Bachat earthquake (village of Bachatskii, 4 km from epicenter).

delay character of the blast process ensures small resolution of the seismograms. In fact, the field of longitudinal waves masks the arrival of transverse waves, and the trains of surface waves are starkly pronounced. The arrivals of transverse waves are well distinguished, and surface waves from earthquakes insignificantly yield in intensity to the surface waves in the records of industrial blasts.

The energy characteristics and positions of the epicenters of seismic events were determined with the LocSat program (Bratt and Bache, 1988) using the IASPEI91 global velocity model (Kennet, 1991). For earthquakes recorded at the center of the network of stations, more precisely, located in the area of the Bachat mine and the northwest outskirts of the Gur'evskoe deposit, to refine the position of the hypocenter, the HYPOINVERSE-2002 program was used (Klein, 2002) with the aid of a local velocity model.

The energy characteristics of the events are represented in units of local magnitude ML, which is related to the bulk magnitude M_S by (1) and, accordingly, can be converted to units of discharged energy E_S (joules) using formula (2) (Bormann, 2009):

$$M_S = 1.27(ML - 1) - 0.016ML^2; \quad (1)$$

$$\log E_S = 4.4 + 1.5(1.27(ML - 1) - 0.016ML^2). \quad (2)$$

Figure 7 shows the epicenters of seismic events recorded by the temporary stations. The stations are placed such that the largest accuracy in determining the positions of epicenters is obtained in the area of the Bachat and Shestaki mines, which is notably reflected in the number of recorded seismic events in the area of these mines. A small number of events has been recorded near the Gur'ev ore deposit and quite a few in the area of the Krasnobrodskoe open-pit mine. In addition, a linear chain of events has been distinguished that is not associated with mining enterprises. With respect to the latter, it is possible to assume that these events pertain to natural seismicity unrelated to technogenic processes. Based on the events in the area of the Krasnobrodskoe mine, which is remote from the stations, it does not seem possible to determine depths with good accuracy; in addition, there is no information on industrial blasts conducted at the minr.

Let us analyze the energy and time distributions of seismic events in the vicinity of the Bachat and

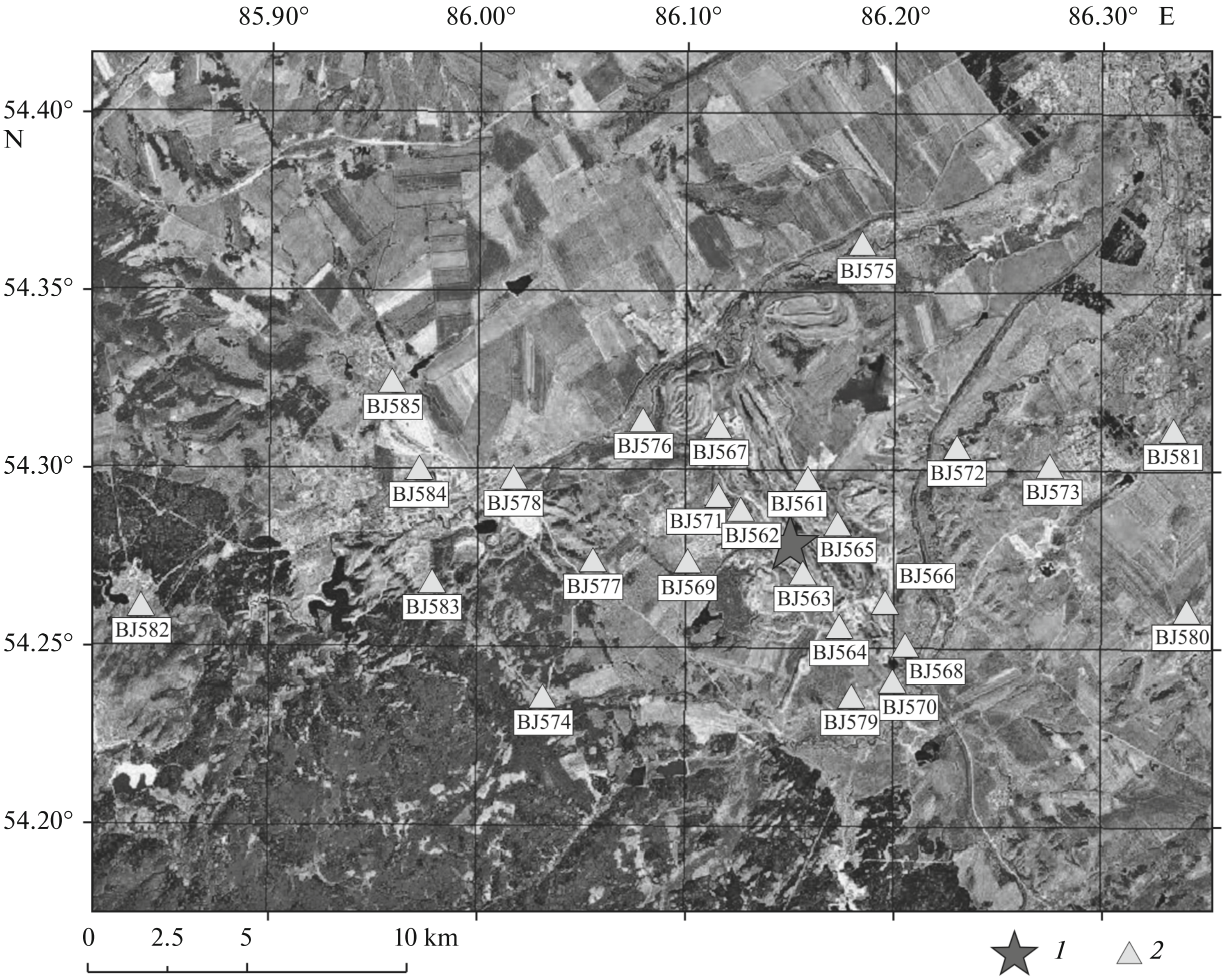


Fig. 4. Location of epicenter of earthquake of February 2, 2012 (*1*), $ML = 4.3$, and seismic stations (*2*) of temporary network for recording weak earthquakes (March 2–May 14, 2012) in area of Kuzbass.

Shestaki mines (Fig. 8). More events were recorded in the daytime hours (See Fig. 8a), namely, from 13:00 to 18:00 LT, which makes it possible to indirectly refer these events to industrial blasts. These events have a higher seismic energy (mainly, $ML = 1.5–3.3$) (see Fig. 8b).

Figure 9 shows the positions of the epicenters of seismic events recorded in the operational period of the local network in the area of the Bachat coal mine. We had at our disposal records of operations with explosives at the Bachat coal mine, so the events were strictly identified by type. For the Shestaki mine and the Gur'ev ore deposit, there was no such information, so the types of events were determined from indirect features: time of day and type of recording at the seismic stations.

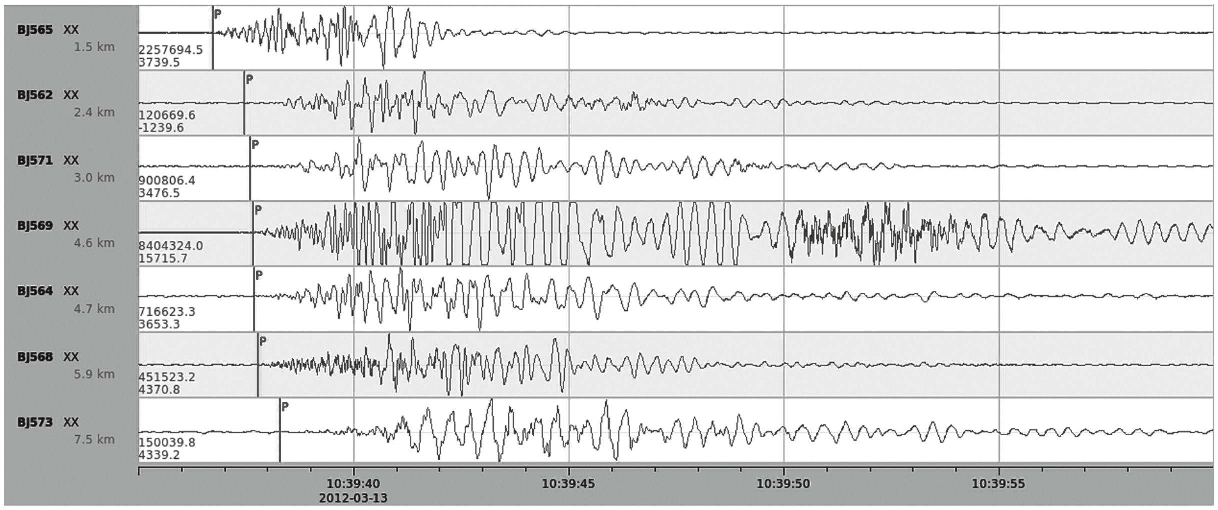
During the operation of the temporary network, 49 total technogenic earthquakes were recorded, 38 of which were immediately in the Bachat mine.

The maps in Fig. 9 show that the strongest ($ML = 2.2–3.3$) events are industrial blasts,—denoted as "assumed blast" in the area of the Shestaki mine and Gur'ev ore deposit—have magnitudes of $ML = 1.5–2.3$; events with smaller energies were also noted ($ML = 1.0–1.3$). Technogenic earthquakes, with the exception of one, have smaller energies ($ML = 0.4–2.0$) than industrial earthquakes.

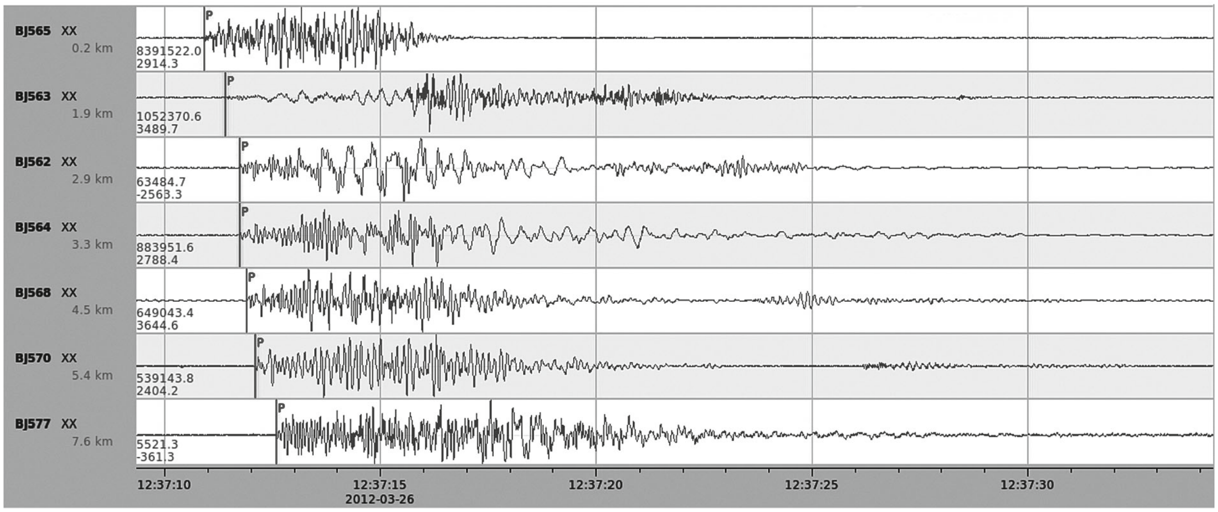
Taking into account the formula for recalculating the magnitudes ML into seismic energy E_S (2), we find that for technogenic earthquakes, seismic energy on the order of $10^4–10^5$ J has been distinguished in the background regime, whereas energies on the order of $10^7–10^8$ J are characteristic of industrial blasts. It is possible to conclude that in the area of the Bachat mine, background-level earthquakes are recorded, weaker in total mass than industrial blasts by 2–3 orders of magnitude. The same earthquake energy is recorded near the Shestaki mine.

In the records of technogenic earthquakes, both *P*- and *S*-waves are clearly distinguished, which is most likely related to the position of the focus at some depth with respect to the daytime surface. Depths were calculated for 31 earthquakes: their values vary from 1.2–

March 13, 2012, 17:39 LT, $ML = 2.9$



March 26, 2012, 19:37 LT, $ML = 2.6$



April 6, 2012, 19:27 LT, $ML = 2.8$

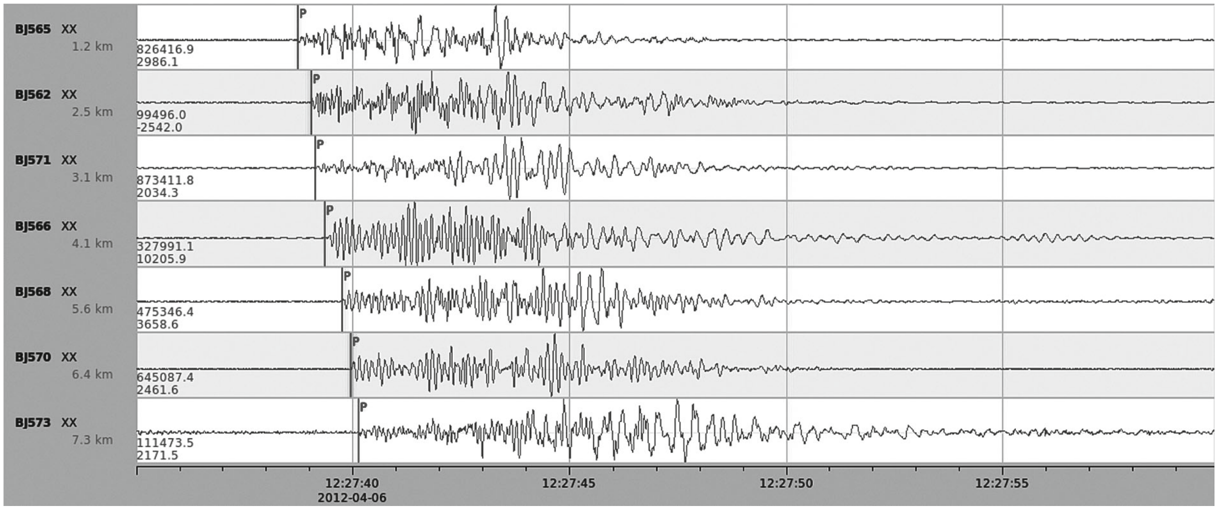
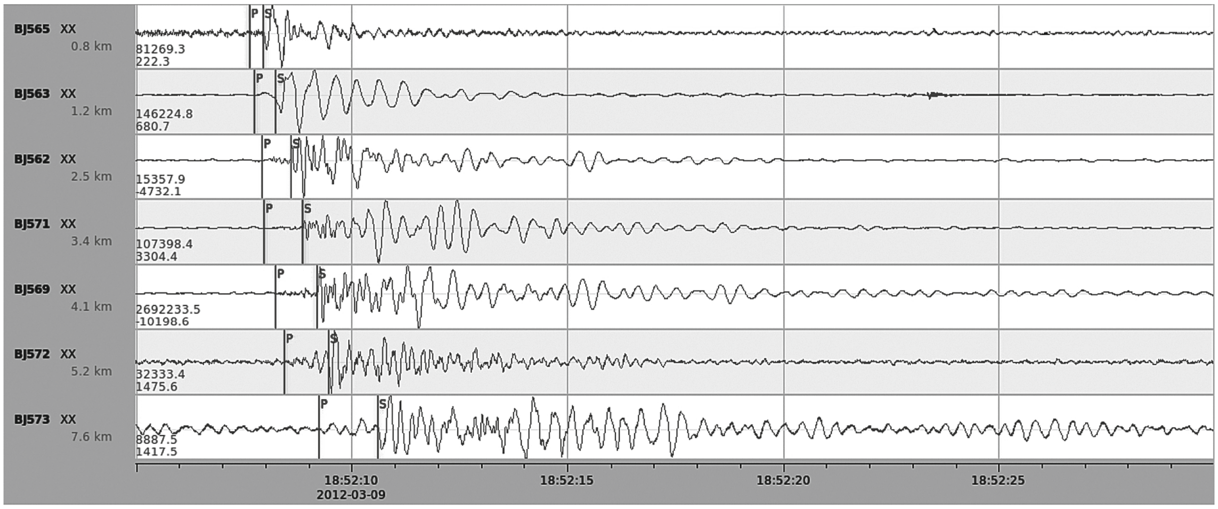
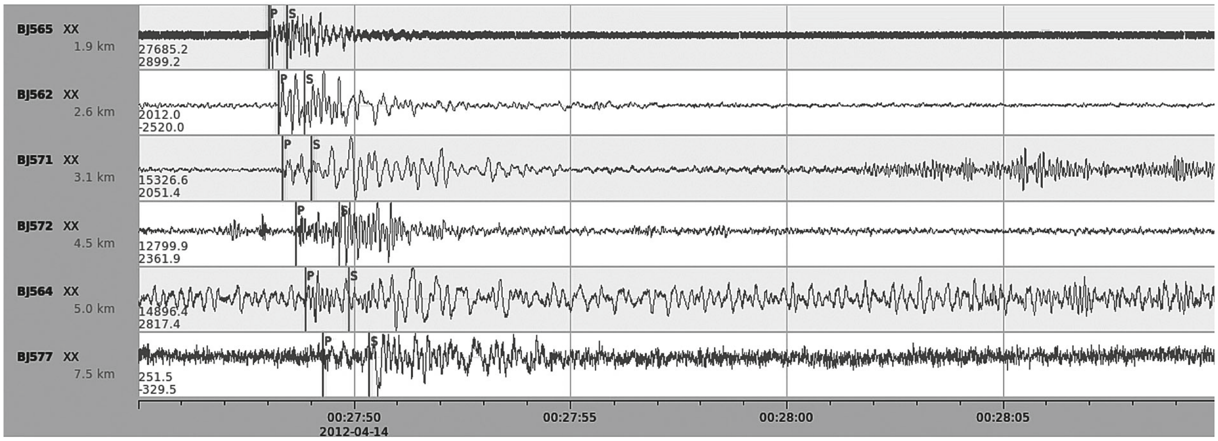


Fig. 5. Examples of records of industrial blasts at Bachat mine by seismic stations of temporary network, 2012.

March 10, 2012, 01:52 LT, $ML = 1.9$



April 14, 2012, 07:27 LT, $ML = 1.4$



April 25, 2012, 07:15 LT, $ML = 1.7$

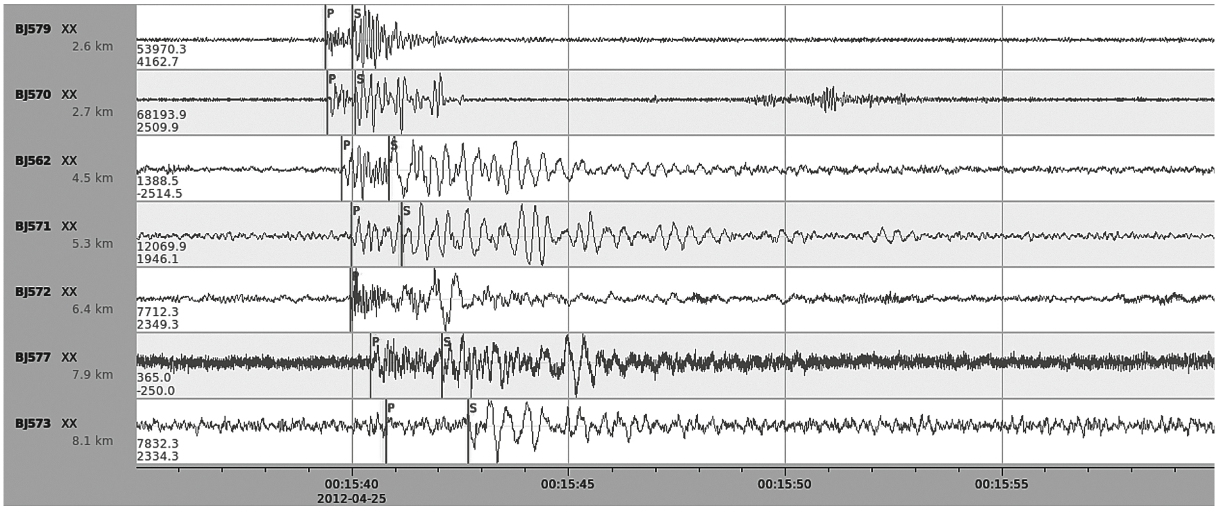


Fig. 6. Examples of records of technogenic earthquakes at Bachat mine by seismic stations of temporary network, 2012.

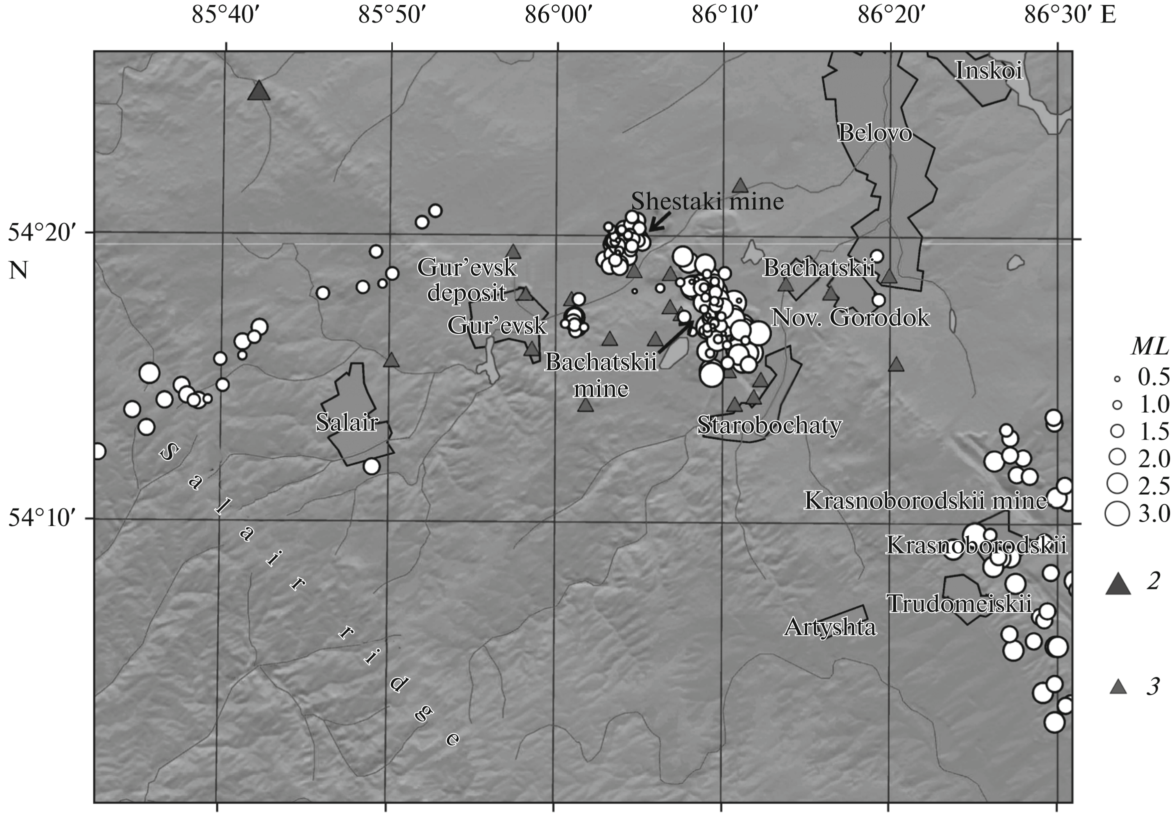


Fig. 7. Map of epicenters of seismic events recorded by seismic stations of temporary network in the period of March 2–May 14, 2012, in area of Kuzbass: (*1*) seismic events, (*2*) Salair stationary seismic station, (*3*) seismic stations of temporary network.

3.1 km with the maximum at a depth of around 2 km (Fig. 10). When an event with a high signal/noise ratio was recorded by the entire network, the depth error was 0.2 km.

The strongest technogenic earthquake recorded during operation of the local network had a magnitude of $ML = 2.9$ and occurred on March 5, 2012 at 09:46 UTC.

In 2012 through the first half of 2013, in the area of the Bachat mine, perceptible earthquakes occurred, the strongest of which (on March 4, 2013 at 17:30 UTC) had a local magnitude of $ML = 3.9$ and caused appreciable vibrations in cities and villages in central Kuzbass.

Despite recommendations for constant monitoring of induced seismicity in the area of the Bachat mine, the network of stations here up to the Bachat earthquake of 2013 did not exist, and the regional network recorded seismic events only with magnitudes of $ML = 2$ or higher.

BACHATSKOE EARTHQUAKE OF JUNE 18, 2013, $ML = 6.1$

The Bachat earthquake of June 18, 2013 was accompanied by a strong aftershock process. To record it, a network of ten temporary stations was placed near the strip mine. The first seismic stations were set up only a few hours after the main shock, and the network was in full operation by June 21. In connection with weather conditions, the network configuration undergoes changes: in the summer period (end of May–beginning of October), the seismic stations are set to work autonomously, buried in the soil; in the winter period (from October to May), they are transferred to heated basements. The temporary network in the vicinity of the Bachat mine has been operating for more than three years.

Six days after the earthquake (June 24), a seismic station was placed in the epicentral area, which could transmit data to a processing center in real time in order to obtain rapid information on strong earthquakes in the area of the strip mine. In June 2014, the seismic station was transferred to another area with retention of rapid data transmission.

Observations with the temporary network of stations is an efficient but resource-intensive process. For example, data arrive at the processing center only after 2–3 months. At the end of 2014–beginning of 2015, in broadening the network of stations in the Kuzbass (Emanov et al., 2015b), four seismic stations with real-time data transmission to the processing center were set up in the area of the Bachat mine. The small monitoring network has been successfully operating as an element of the regional network of stations, ensuring increased sensitivity and accuracy in the local region. In addition, a temporary set of five stations with autonomous recording apparatus continues to record seismic events. Events are processed in one system with the regional stations and Kuzbass monitoring stations as a whole (Emanov et al., 2015b). The use of automatic stations has made it possible to bring the rapidity of monitoring of the activated zone of the Bachat mine to a new level. The speed of event processing in the automatic mode rarely exceeds 1 min. The data of the temporary stations, which record information without its transmission to the center over comm channels, are used for subsequent fine-tuned processing.

Stationary automatic stations of the monitoring network are equipped with Guralp CMG-6T-M wideband velocimeters and Guralp CMG-5TC-M accelerometers with Baikal 8.1 recorders. The temporary stations have SK-1P seismographs and Baikal AS-75 recorders. The importance of carrying out monitoring is related to the fact that coal extraction in the given mine is constantly increasing, and the technogenic impact on the seismically activated area is only increasing in kind.

The data, just like in 2012, are processed by a SeisComP3 system (Weber et al., 2007; Hanka et al., 2010). The position of the hypocenter is calculated with the LocSat program (Bratt and Bache, 1988) using the IASPEI91 global velocity model (Kennet, 1991). The energy of events is estimated from the local magnitudes *ML* (Bormann, 2009). To specify the position of hypocenters of some earthquakes with $ML > 1.5$, HYPOINVERSE-2000 software is applied (Klein, 2002) with the aid of a local velocity model, For 20 strong aftershocks, the mechanisms of the foci were calculated with the FPFIT (Reasenberg and Oppenheimer, 1985).

Processing of data from the temporary network of seismic stations was completed within the period of July 18, 2013–August 31, 2015. Within this time, 1698 earthquakes with magnitudes in the range of $0.1 \le ML \le 4.2$ were recorded. Their energy distributions are presented in Table 1.

The recurrence graph, constructed from the data in Table 1, shows a nonlinearity (Fig. 11), expressed in a disproportionately high number of earthquakes with a magnitude of 3.5, four of which occurred already a year after the main quake, in August–September 2014. On the whole, we can say that the representative recording of seismic events in the area of the Bachat mine begins with a magnitude of $ML = 1$ (see Fig. 11). For the magnitude interval of 1–3, a linear approximation was done with determination of the parameters of the recurrence graph:

$$\log N = -0.941ML + 3.969. \quad (3)$$

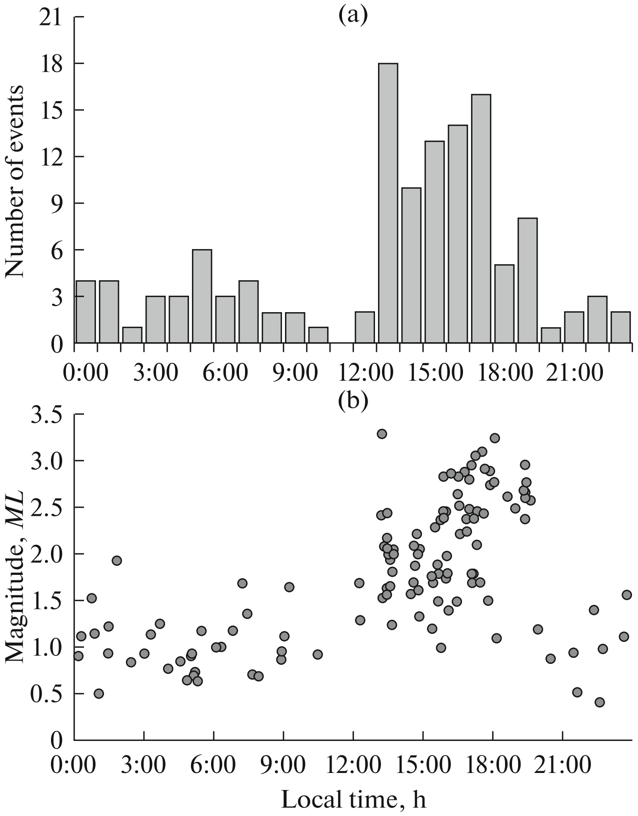


Fig. 8. Number of events depending on time of day (a) and their unfolding in terms of energy (b) in the vicinity of the Bachat and Shestaki mines in the period of March 2–May 14, 2012.

For the period of September 1, 2015–August 31, 2016, the stationary network together with the four automatic monitoring stations in the area of the Bachat mine recorded 15 earthquakes in the magnitude range of $0.8 \le ML \le 2.1$.

Figure 12 shows a map of the earthquake epicenters in the entire studied period from June 18, 2013 through August 31, 2016. The seismic process is spatially associated with the mine and with the small Shestaki mine located in the northern extension of the Bachat mine. The position of the earthquake epicenters mainly corresponds to the plan of the mine and only in the southeastern extremity has branching of the seismic

Table 1. Number of recorded earthquakes of different magnitude in the area of the Bachat mine in the period of June 18, 2013–August 31, 2015

ML	6.0	5.5	5.0	4.5	4.0	3.5	3.0	2.5	2.0	1.5	1.0	0.5	0	Total
Number of earthquakes	1	0	0	0	1	10	14	30	132	406	885	213	6	1698

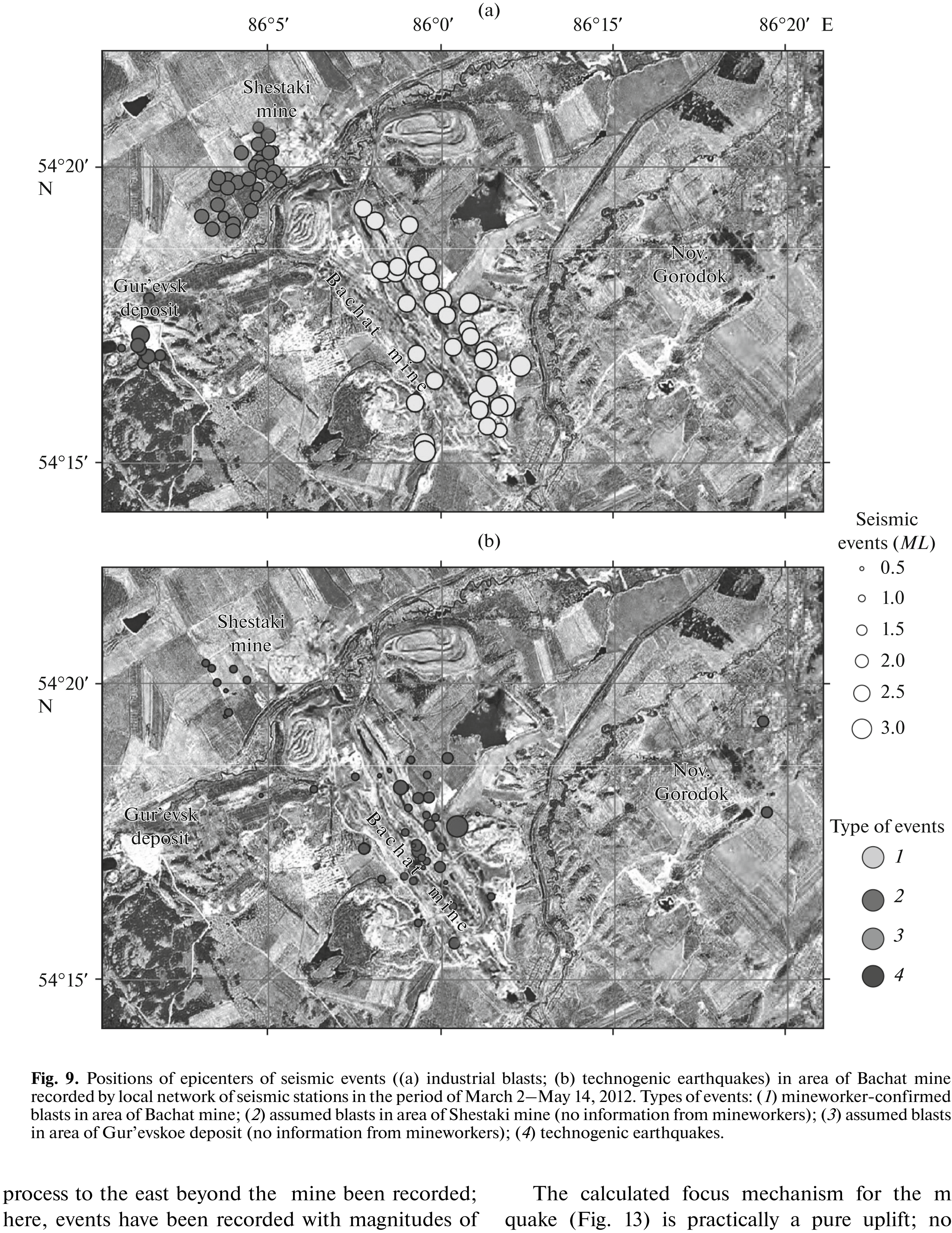


Fig. 9. Positions of epicenters of seismic events ((a) industrial blasts; (b) technogenic earthquakes) in area of Bachat mine recorded by local network of seismic stations in the period of March 2–May 14, 2012. Types of events: (*1*) mineworker-confirmed blasts in area of Bachat mine; (*2*) assumed blasts in area of Shestaki mine (no information from mineworkers); (*3*) assumed blasts in area of Gur'evskoe deposit (no information from mineworkers); (*4*) technogenic earthquakes.

process to the east beyond the mine been recorded; here, events have been recorded with magnitudes of 1–2. The strongest events, including the main quake, occurred nearer to the western side of the Bachat mine pit and in its southern extremity (see Fig. 12).

The calculated focus mechanism for the main quake (Fig. 13) is practically a pure uplift; nodal planes, one of which is the rupture plane, are located along the expanse of the mine, which may be one piece of evidence of the technogenic nature of this

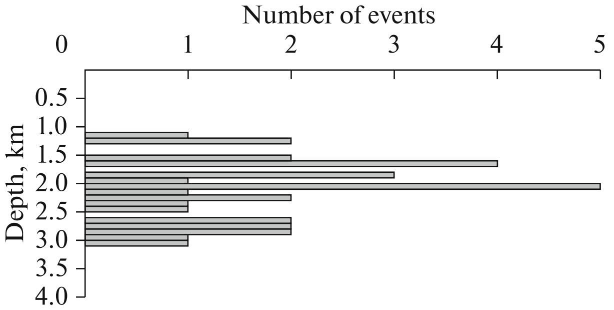


Fig. 10. Histogram of depths of technogenic earthquakes recorded by temporary network of seismic stations in 2012 in area of Kuzbass.

earthquake. In addition, the strength of the quake testifies in favor of the technogenic nature of the Bachat earthquake—a magnitude of around 6 correlates with the dimensions of the focus on the order of 10 km, which is comparable to the legth of the coal mine and the extent of the region hit by aftershocks (the epicenters of the majority of them fall within the mine pit).

The focal mechanisms of strong earthquakes with $ML > 2$ indicate the predominance of vertical movements at the foci. The main type of mechanisms are uplifts with differently oriented nodal planes; faulting and shear faulting have also been noted (see Fig. 13).

For certain strong earthquakes in 2013–2014, processing was done with determination of depth using HYPOINVERSE-2000 (Klein, 2002). Figure 14 shows a map of events with depths and the cross-section along the AB line. In the area of the epicenter of the Bachat earthquake, the largest number of large events is focused, and the deepest (the greater part of events have depths of 2–4 km and only a small number of them have depth down to 5 km). Along the cross-section to the northwest, the depths of earthquakes decrease, and in the northern extremity of the Bachat mine, the events occur almost immediately under the mine works (depths from hundred of meters to 2 km. Under the Shestaki mine, earthquakes again occur at depths of 2–4 km (see Fig. 14).

Comparing the date of the temporary networks in 2012 and 2013–2014 (see Figs. 8, 14), it is possible to see a depth correspondence of the technogenic earthquakes up to and after the Bachat earthquake. In both cases, the area under the mine was activated to depths of 4–5 km. Without a doubt, we are dealing with technogenic activization of the subsurface in the vicinity of mineworks.

MONITORING OF THE SEISMIC PROCESS WITH TIME

Figure 15 shows a diagram of the earthquake distribution over the Bachat mine in the time–magnitude plane; the spatial coordinates are excluded. Comparing the result of automatic processing (*2*) and refined processing with the used of time stations (*1*), we see that the automatic processing represents the seismic process in a somewhat combined form. Such data are useful: they well determine the upper energy level of the seismic activity of the mine area, provide real-time information on the coordinates of dangerous events, and allow conclusions about seismic hazard in coal extraction in the mine. The data obtained from a denser network with refined processing are the basis for analysis in order to predict new activations and large technogenic earthquakes.

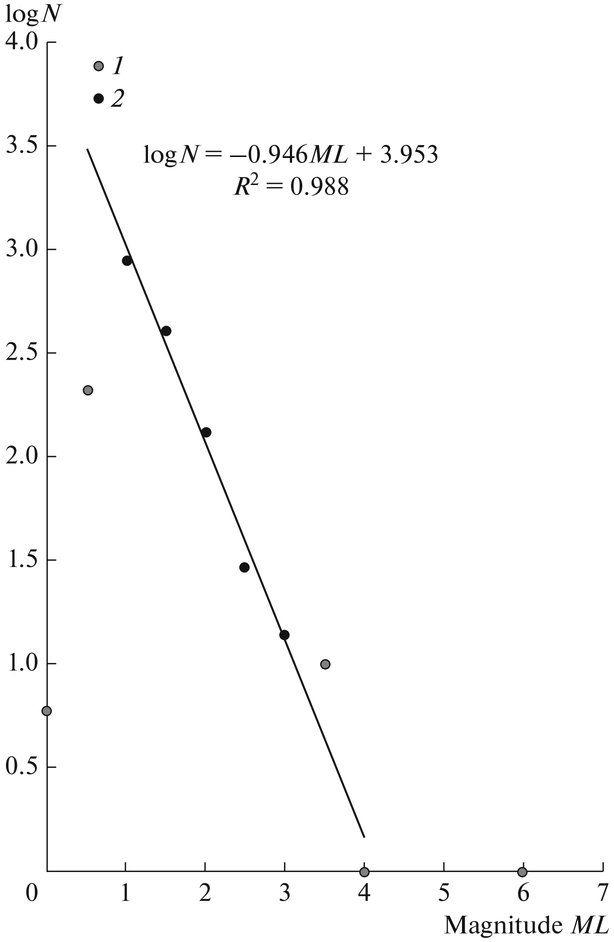


Fig. 11. Recurrence graph of earthquakes recorded in area of Bachat mine in the period of June 18, 2013–August 31, 2015. (*1*) All data; (*2*) representative data.

The data in Fig. 15 show that the development of the seismic process in time is quite nonuniform. It proceeded the most actively from June 18, 2013, to the beginning of October 2013. Then, up to May 2014, the intensity of the seismic process was comparable to the intensity of summer 2012 (Emanov et al., 2015a, 2015c). Since May 2014, the number of technogenic earthquakes has increased, and since September 2014, earthquakes with $M > 3$ have been recorded. Such a

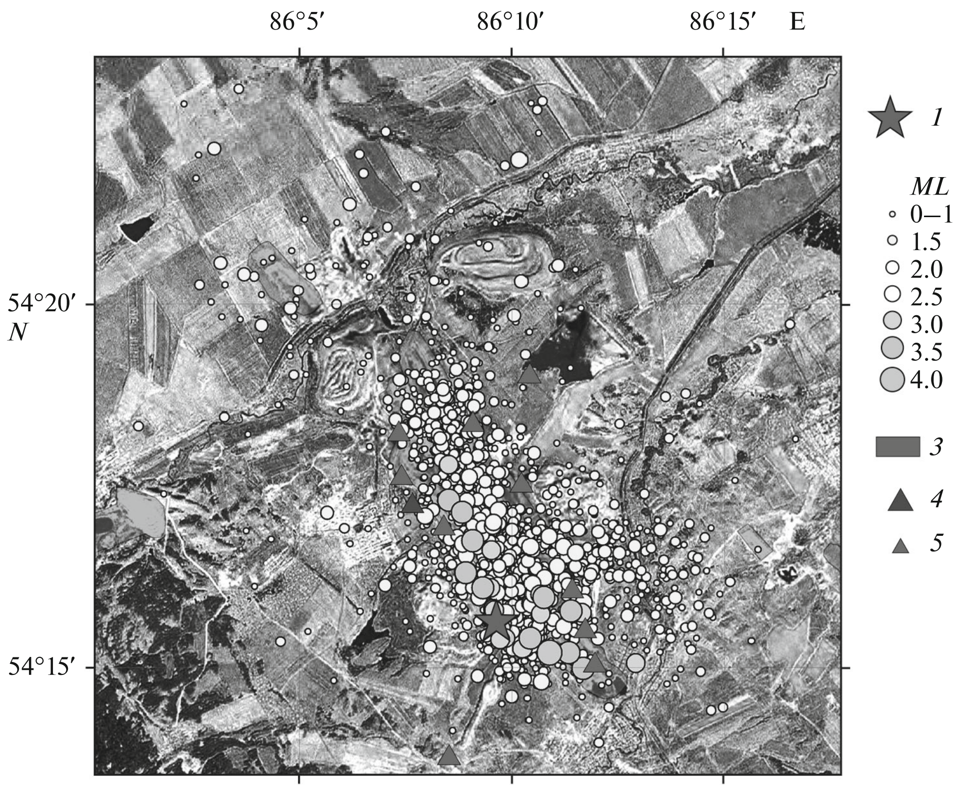


Fig. 12. Location of epicenters of earthquakes in area of Bachat mine in the period of June 18, 2013–August 31, 2015: (*1*) epicenter of Bachat earthquake of July 8, 2013; (*2*) earthquakes within the period of July 18, 2013–August 8, 2016; (*3*) coal mines; (*4*) seismic stations with real-time data transmission (one season, 2013); (*5*) autonomous seismic stations.

situation was observed up to March 2015, beginning from which and to the end of August 2016, strong earthquakes with $M > 2.1$ were not recorded again; here, the number of weak earthquakes (according to the temporary network data) remained the same as in the preceding period.

For a more detailed analysis, we have constructed maps of earthquake epicenters for the highlighted periods (Fig. 16). Figure 16d also shows the positions of seismic stations that were recording in 2015–2016: four of them were automatic with data transmission to the processing center in Novosibirsk in real time over cellular channels, and five were temporary stations.

Figure 16a shows that the majority of earthquakes in the first, most seismically active four months were concentrated in the southern extremity of the mine; here, the strongest aftershocks and the greatest density of events were recorded. In the period of relative quiescence, from October 2013 through April 2014 (see Fig. 16b), the intensity of the seismic process and the spatial position of epicenters are similar to those of the operational period of the temporary network in 2012 (see Fig. 9): three to four earthquakes a week with magnitudes of $ML = 1–2$. An increase in the number of events in the gap from May 2014 through March 2015 was also accompanied by a shift of the main mass of earthquakes, both strong and weak, to the north (see Fig. 16c).

In the subsequent operation period of the network, from April 2015 through August 2016 (see Fig. 16d), quiescence was again observed: the majority (~94%) of earthquakes recording over 5 months of operation of the temporary network (from April through August 2015) comprise events with magnitudes of $ML \le 1.5$. The seismic process is also comparable in intensity with that in 2012 and the period of first quiescence, from October 2013 through April 2014 (see Fig. 16b).

Within all observation periods, the presence of seismicity has been noted near the Shestaki mine neighboring the Bachat at the level of earthquakes with magnitudes not exceeding $ML = 2$ (see Figs. 9, 16).

The main information on induced seismicity obtained in the area of the Bachat mine can be briefly explained as follows.

(1) The earthquake of February 19, 2012, with $ML = 43$ is the strongest event in the Bachat mine within the activation period about which there is no detailed information.

(2) The experiment with the temporary network of March 2–May 14, 2012 revealed a background seis-

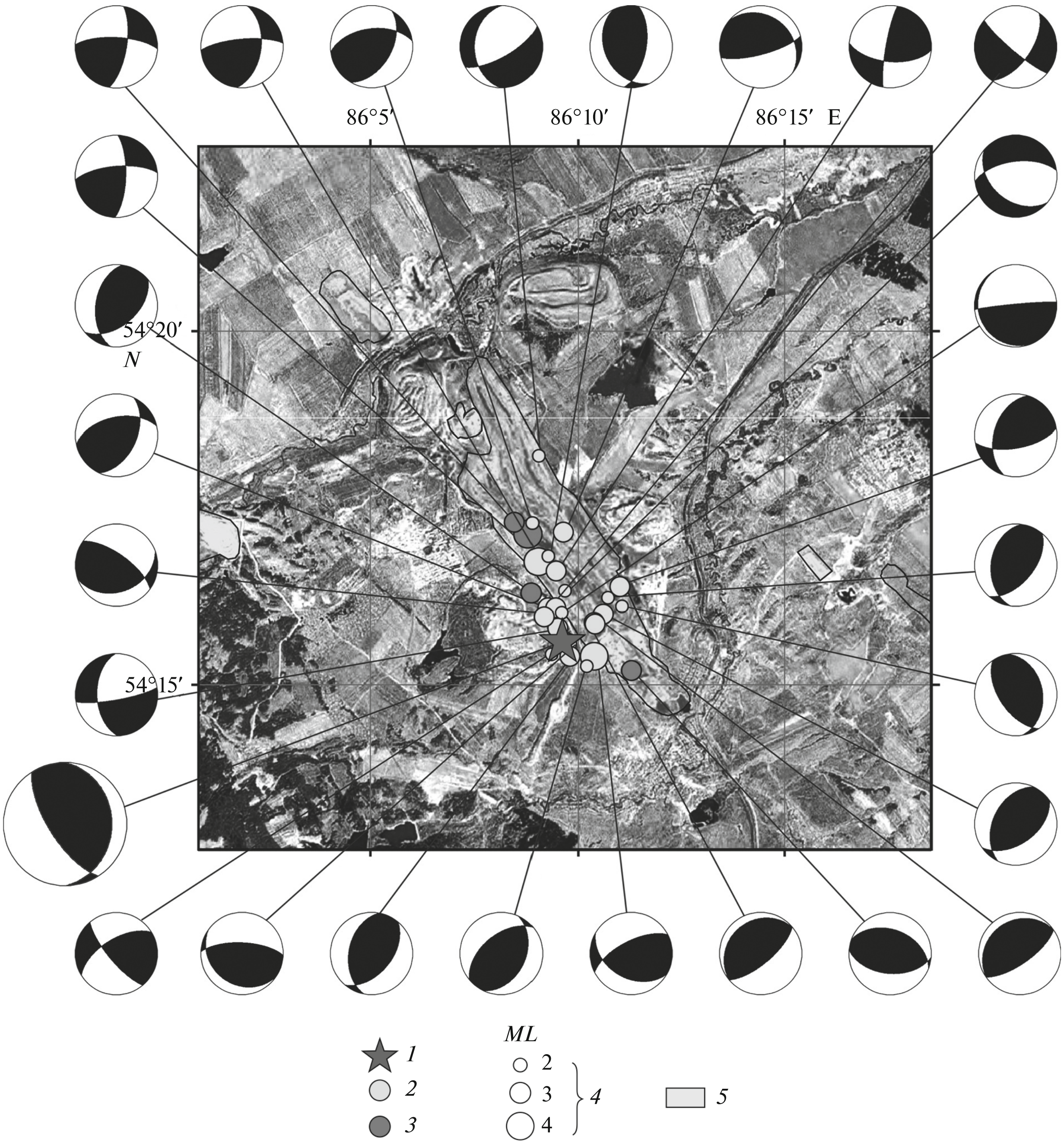


Fig. 13. Focal mechanisms of Bachat earthquake and large aftershocks: (*1*) epicenter of Bachat earthquake of July 8, 2013; (*2*) events of 2013; (*3*) events of 2014; (*4*) intensity of events; (*5*) coal mines.

micity regime with $ML \leq 2$ and an intensity of three to four events per week with $ML = 1–2$.

(3) The earthquake of March 4, 2013 with $ML = 3.9$ is the second strongest earthquake. Today, it is impossible to state with certainty whether this was a foreshock or an independent activation of an area of the mine.

(4) The earthquake of June 19, 2013, with $ML = 6.1$ is one of the world's largest technogenic earthquakes with a strong aftershock process, the strongest of which $ML = 3.5–4$; an increased number of weak earthquakes were recorded through October 2013 (around 4 months).

(5) From October 2013 through April 2014, the seismic regime is analogous to the background with $ML \leq 2$ and an event density the same as in 2012.

(6) From May 2014 through March 2015, the subsurface of the mine was again seismically activated. A

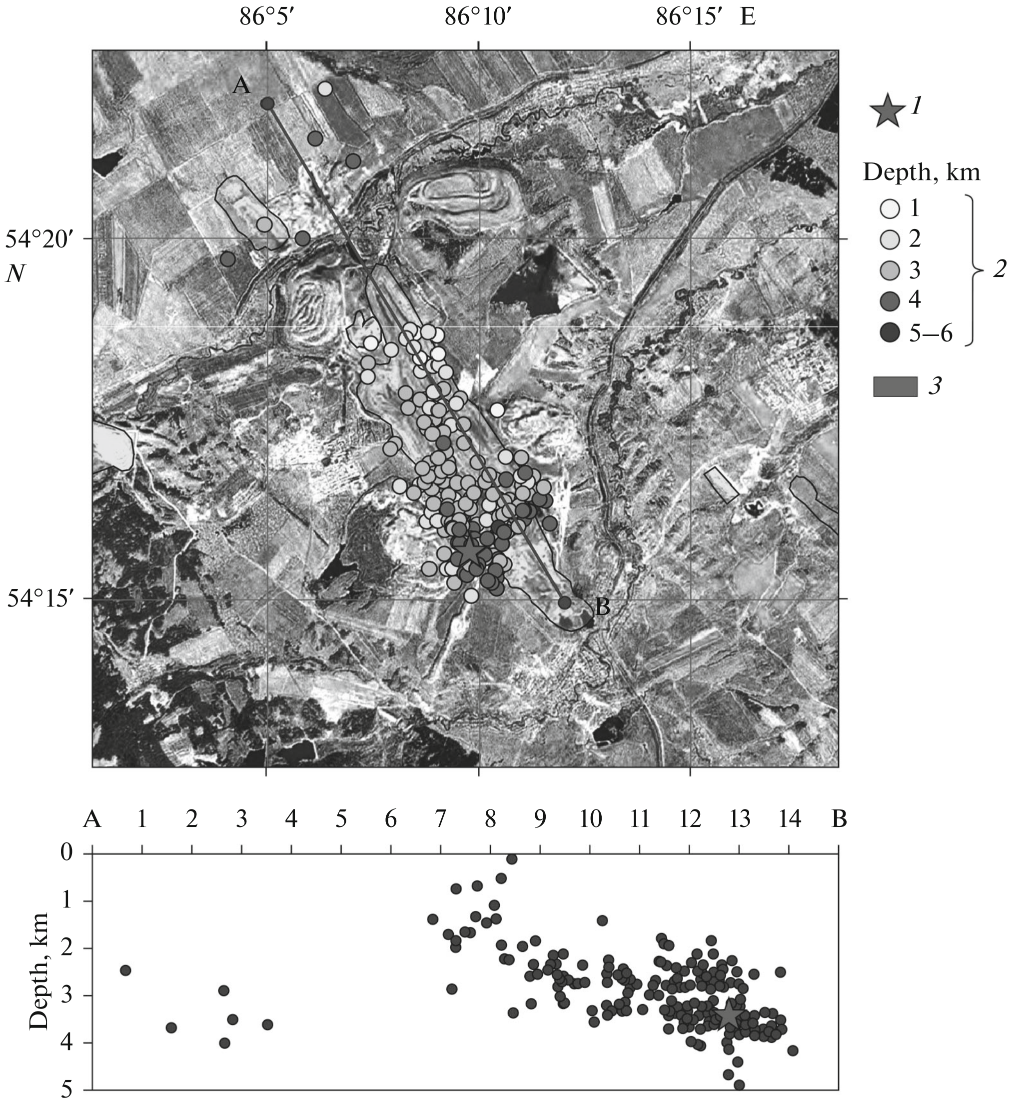


Fig. 14. Depths of aftershocks of Bachat earthquake (2013–2014): (*1*) epicenter of Bachat earthquake of July 8, 2013; (*2*) aftershocks of Bachat earthquake with $ML > 1.5$ for period of June 18, 2013–July 9, 2014; (*3*) coal mines.

series of earthquakes with $ML \geq 3$ occurred, four of which had a local magnitude of 3.5 and the density of weak earthquakes increased manifold. Activation in its characteristics has a swarming character by which it substantially differs from previous activations of the subsurface of the mine.

(7) From June 2015 to today, the maximum energy regime of events with $ML \leq 2$ corresponds to the twice observed background for the given mine.

Unfortunately the information of small-energy earthquakes in the mine is incomplete, which is important for a more substantiated conclusion on the background seismicity regime and predicting the long-term development of the seismic process in the Bachat mine. Experiments on the seismic monitoring of mines is also quite efficiently done in other regions (Kozyrev et al., 2009). Monitoring research at mining enterprises is becoming a mandatory procedure in ensuring the safety of mining operations.

RECURRENCE GRAPH

To compare the characteristics of the seismic regime of the epicentral region of the Bachat earthquake with other natural and technogenic activations in the Altai-Sayan region, recurrence graphs were constructed from the data of certain local observation with the temporary network of stations. So that the data of different observation periods can be compared, the values of magnitude M_S are converted to local magnitudes ML using formula (1).

The earthquake recurrence graph for the entire Altai-Sayan region has been constructed from long-term data (1734–2014), which includes information

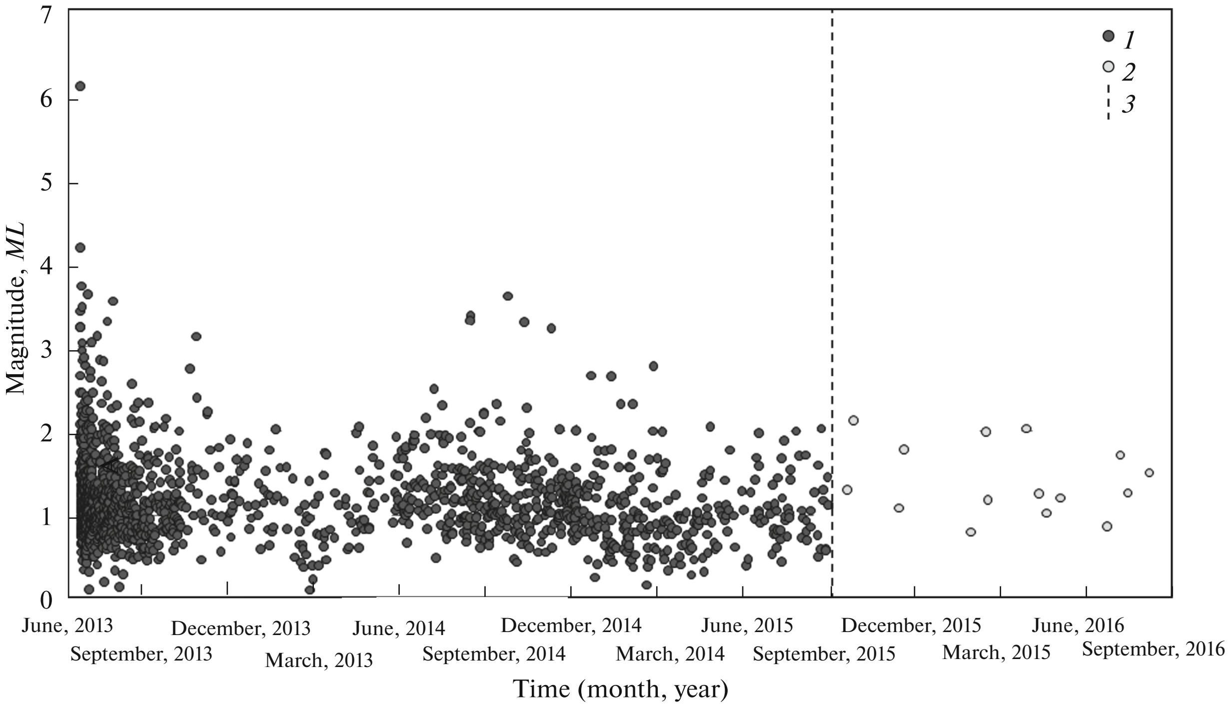


Fig. 15. Diagram of earthquake distribution around Bachat mine in time–magnitude plane for period of June 18, 2013–August 31, 2016: (*1*) processing of data from seismic stations of temporary network; (*2*) processing of data from seismic stations of stationary network; (*3*) boundary of catalog of processing of data from temporary and stationary stations.

for different observation periods: historical (until the beginning of the 20th century), instrumental with rare remote stations (since the beginning of the 20th century to 1962), and instrumental with a regional network of analog (1963–2000) and digital (since 2000) recording. Despite the fact that the representativeness of earthquake recording in the last 15 years has been quite high, the recurrence graph is linear with $ML = 3$ (Fig. 17).

For the Altai-Sayan mountain region, on the whole, the earthquake recurrence corresponds to the angle of inclination $b = 0.772$ (see Fig. 17), which is lower than the same characteristic for earthquakes of the area of the Bachat earthquake: $b = 0.941$ (see Fig. 11). The differences in the angle of inclination in the recurrence graph for induced seismicity in the area of the Bachat mine from that of natural seismicity are quite significant.

In the last decade, local networks of seismic stations have been used to study both the aftershocks of natural earthquakes and induced seismicity near mines and the ore deposits of the Kuzbass. The recurrence graph for natural seismicity has been constructed for the epicentral zone of the Chuiya earthquake of 2003, which was studied by detailed observations in this zone for more than 10 years (Emanov et al., 2009a, 2015a) (Fig. 18a).

The recurrence graphs for induced seismicity have been constructed from materials of a study by local networks of stations (10–30 stations in the activated zone with a size of around 100 km^2) in Kemerovo oblast: near the city of Osinniki in 2005 (Emanov et al., 2007) (Fig. 18b), after a large accident in the Raspadskaya shaft in 2010 (Emanov et al., 2012) (Fig. 18c), and in the area of Polysaevo in 2007–2009 (Emanov et al., 2009b) (Fig. 18d). In the area of Polysaevo, induced seismicity was recorded near underground mineworks with active lava, the seismic process shifted together with the working faces, and the structure of induced seismicity depended on changes in the structure of active underground mineworks with time (Emanov et al., 2009b).

Table 2 summarizes the data used (the number of events) and obtained characteristics of the recurrence graph (*b* is fractionality) for all considered territories. Clearly, the fractionality for natural activation in the Chuiya-Kurai zone is smaller, whereas for all technogenic activations, it is larger than for the region on average.

From the presented technogenic activations, the seismicity of the Bachat mine is characterized by the lowest fractionality. Here, other considered activations are associated with areas of underground mineworks. An increase in the fractionality value means a large number of small-energy earthquakes in the total number of events. In other words, a larger fractionality corresponds to a larger time for the preparation of larger earthquakes for the same activity in terms of the

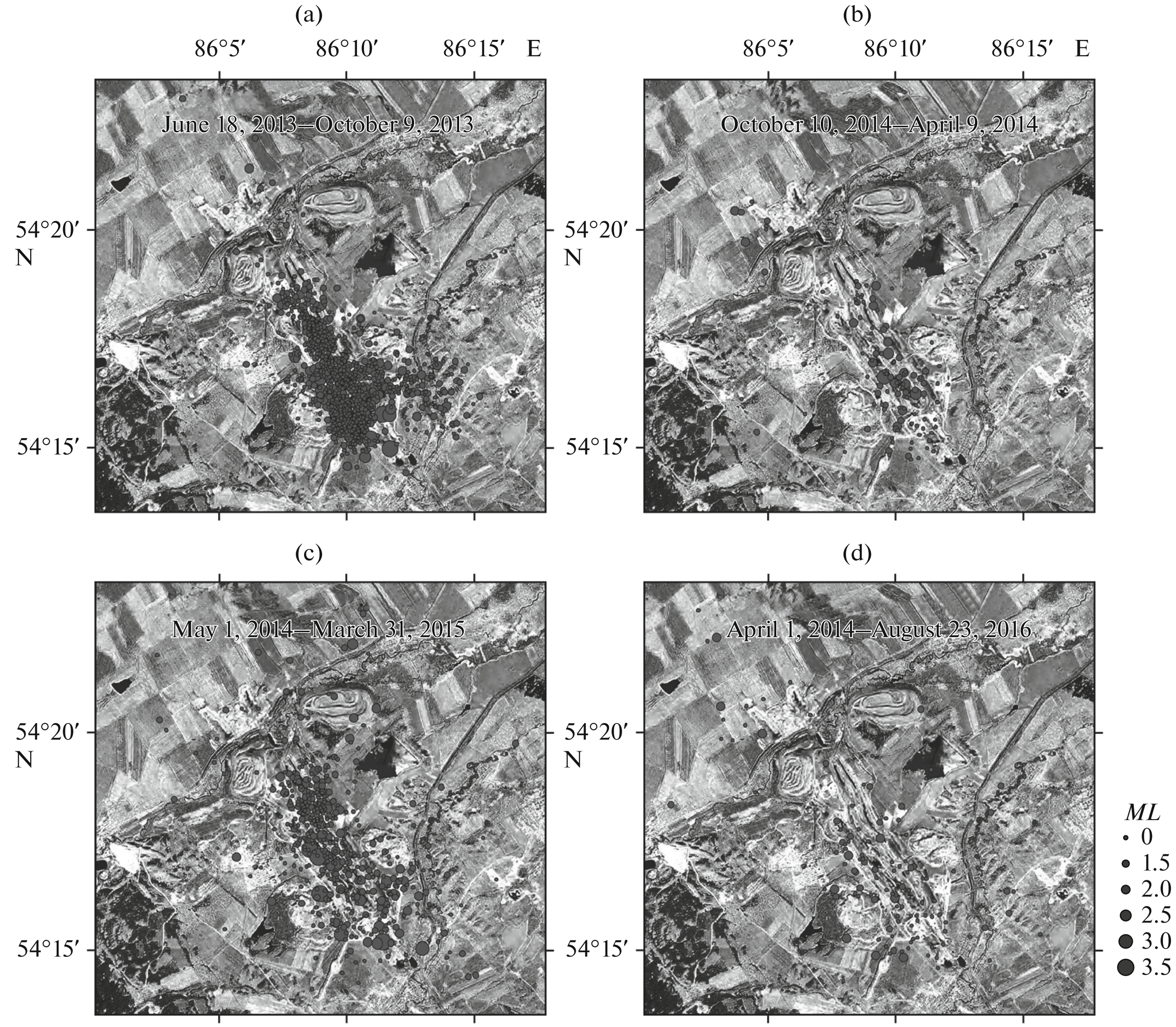


Fig. 16. Maps of epicenters of earthquakes recorded in epicentral region of Bachat earthquake for different time periods (a–d) and positions of seismic stations of permanent and temporary networks in 2015–2016 (d).

Table 2. Information on data used in determining the recurrence graph and its characteristics for different territories

Territory	Observation period	Number of earthquakes	Slope of recurrence graph	Representative magnitude (*ML*)
Altai-Sayan region as a whole	1734–2014	74992	0.772	3
Chuiya–Kurai zone	1734–2014	6617	0.717	2.5
Bachat mine	2013–2016	1698	0.941	1
Osinniki	2005	201	1.254	1
Raspadskaya shaft	2010	721	1.286	0
Polysaevo	2007–2009	3851	1.771	1.5

number of earthquakes. In accordance with the obtained data for the Bachat mine, the share of large earthquakes in the seismic process is higher than in the studied activations near underground mineworks. The fractionality for activations near each other in Osinniki and in the Raspadskaya shaft is approximately the same, which speaks to the similarity of their seismic regimes. The largest parameter b value has been noted for events in the are of Polysaevo. On the whole, this is a quite unique seismically activated zone with up to 70 technogenic earthquakes or more per day, but the energy of events is significantly weaker than at the Bachat mine.

NATURE OF THE BACHATSKOE EARTHQUAKE

The question on the nature of any large earthquakes in the Kuzbass is argumentative from the first day after the event, since the question of responsibility for the consequences of the earthquake does not immediately arise. Managers of coal extraction enterprises are content with the explanation "natural earthquake." And until the event's coordinates were determined by the rare regional network, making it impossible to blame specific companies for earthquakes, as well as determine their depths, an earthquake could be decaled tectonic in nature, and companies could walk away scot-free.

The development of the network of seismological stations in the Kuzbass has allowed a new level of accuracy in determined the coordinates of events (Emanov et al., 2015b). Today, earthquakes are spatially located with great accuracy and, as shown in (Emanov et al. 2015b), the foci of increased seismicity are in areas of mineworks and are not related to fault tectonics, which has allowed the conclusion of dominant induced seismicity in the Kuzbass as opposed to natural. At the modern level of development of the seismological network in the Kuzbass, natural seismicity can easily be differentiated from induced. Yakovlev et al. (2013) proposed to distinguish a new class of earthquakes: technogenic–tectonic. One of the criteria for distinguishing such a class of events is their energy. In (Adushkin, 2015, 2016; Adushkin and Turuntaev, 2015), the features of technogenic–tectonic earthquakes are described more specifically:

(1) These are strong earthquakes with magnitudes greater than 2.8 and an energy class greater than 9.

(2) Similar earthquakes occur in energy-saturated media with a high seismic potential.

(3) The trigger character of these earthquakes is related to the impact of external technogenic sources.

(4) The foci of similar earthquakes form in the upper layers of the Earth's crust, and realization of the focus has no visible connection with the time and place of technogenic impacts.

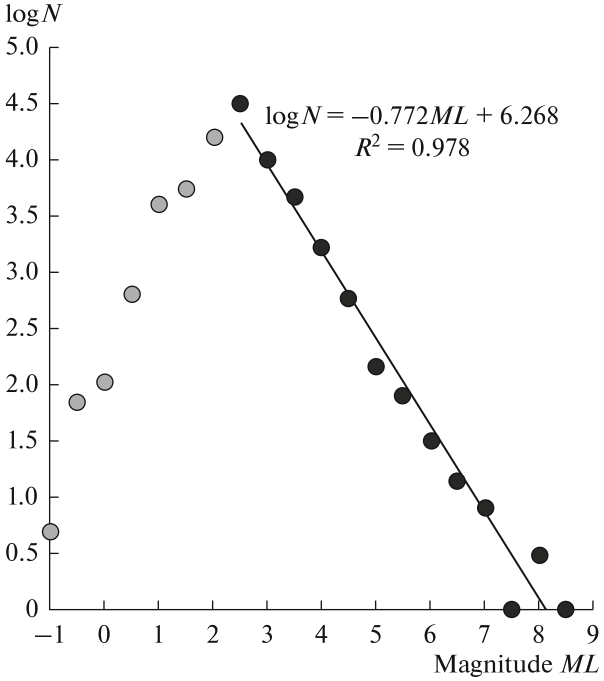


Fig. 17. Recurrence graph of earthquakes in Altai-Sayan fold region for period of 1734– 2014.

(5) The immediate trigger of such earthquakes with a tectonic nature of the focus can be prolonged technogenic impact that is weaker than the response reaction of the medium.

(6) A hidden self-regulation mechanism of the preparation of such earthquakes during simultaneous participation but a different contribution of energy saturation of the massif and external technogenic impacts substantially complicates explanation of the causes and mechanisms of their occurrence.

(7) Determination of such earthquakes as technogenic–tectonic reflects the dual nature of their occurrence, when during preparation of the focus, two simultaneous factors participate: the main one, in the form of a natural stressed state, and the triggering one, in the form of an external technogenic impact, in the absence of which such an earthquake would not occur.

Possibly, similar, arbitrarily occurring technogenic–tectonic earthquakes of a catastrophic nature have, to some extent, the independent appearance of earthquakes occurring in the nature–human system in relation to the increase in scales and depth of mineral extraction. The number and intensity of such a type of earthquakes will increase with time due to increasing subsurface exploitation.

We present the specific features of technogenic–tectonic earthquakes in abbreviated form with respect to the original (Adushkin and Turuntaev, 2015). In our study, we do not consider the question of the validity of highlight the class of technogenic–tectonic earth-

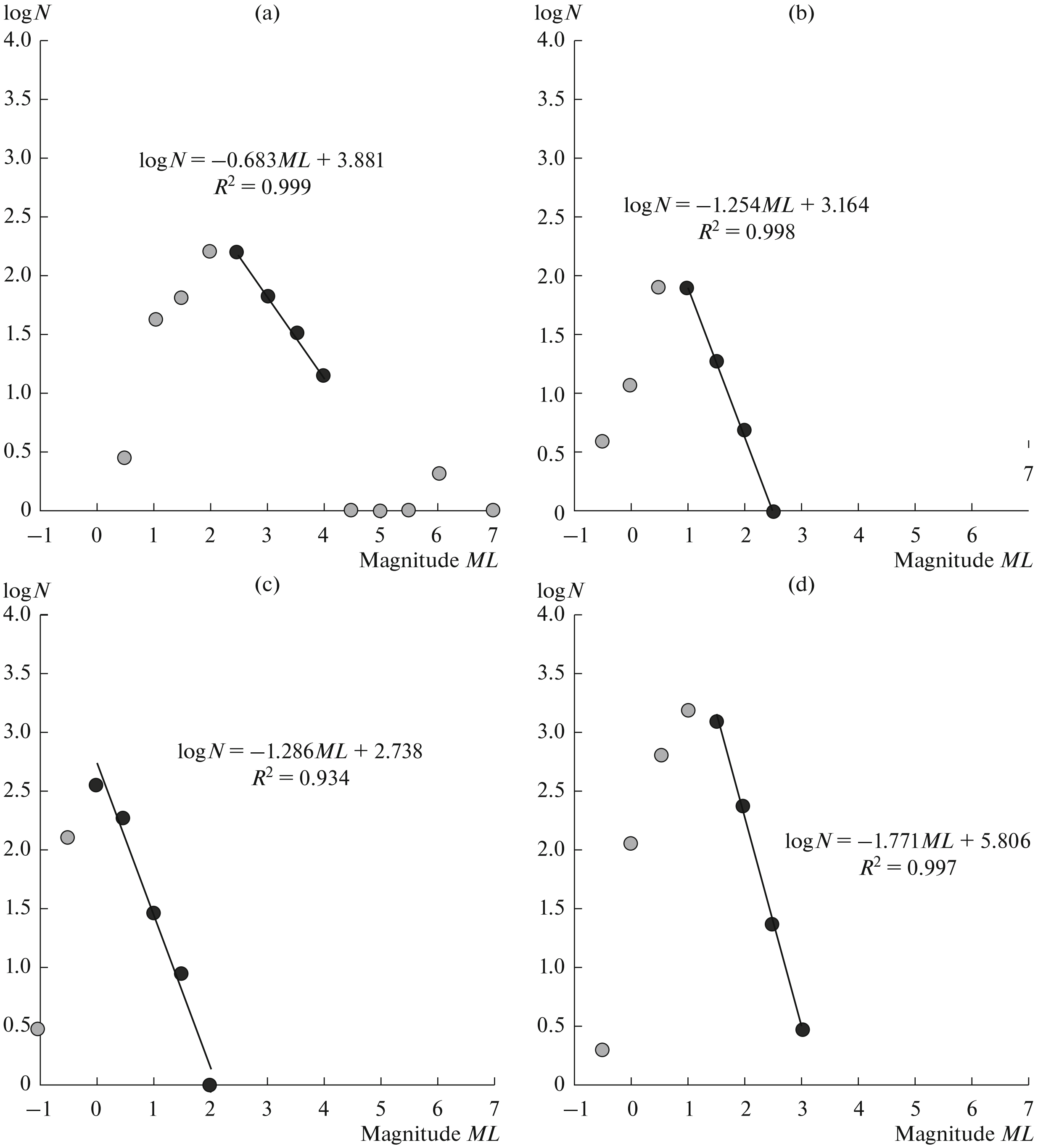


Fig. 18. Recurrence graphs of earthquakes for seismically activated zones of Altai-Sayan region: (a) natural seismicity, Chuiya-Kurai zone; (b–d) areas of technogenic seismicity: (b) Osinniki, 2005; (c) Raspadskaya shaft, 2010; (d) Polysaevo, 2007–2009.

quakes from the total number of events; we only specifically address the Bachat earthquake, its nature, and the specific features of seismic activation proceeding near the mine. The specific features of technogenic–tectonic earthquakes are explained for better convenience in comparing a given seismic activation to the highlighted class of events and validly refer a given earthquake to a particular class.

Before discussing the nature of the Bachat earthquake, it is necessary to consider the conditions in which it occurred and recall the patterns of natural seismicity in the Altai-Sayan mountain region on the whole and the given geological structure in particular.

The Bachat mine is located in the Kuznetsk Basin, which is a tectonic structure of the Altai-Sayan mountain region. Reliable date on the velocity structure of the basin have been obtained from seismic deep sound (SDS) data on two profiles, one of which was carried out along (Krylov et al., 1974) and the other transverse to it (Krylov et al., 1970, 1971). When generalizing the SDS results in West Siberia (Puzyrev and Krylov, 1971), a block structure of the Earth's crust in the Altai-Sayan mountain region was noted; the Kuznetsk Basin was isolated as a separate block, in which the size of the Earth's crust reaches 38–41 km; i.e, it is 5–10 km smaller than in the adjacent mountain areas, the concatenation with which occurs over zones of deep faults. The surface of the intensively metamorphosed folded base of the basin is at depths of 714 km, and the boundary velocity along it varies from 6.1 to 6.5 km/s. Sediment is the gradient medium with an increase in velocity with depth from 4.0 to 4.5 km/s above to 6.0 km/s below. According to geological data (Vasil'ev et al., 2011), the size of sediments in the Kuznetsk Basin is around 9 km. The sediment column is has been folded (*Ugol'naya baza*..., 2003; Novikov et al., 2008, 2013). The amplitudes of folds from the side of the Salair Ridge where the Bachat mine is located are especially large. In the area of the mine, the coal seams have close-to-vertical bedding; therefore, coal extraction goes downward along the seam. Whereas now the depth of the mine is around 350 m, extraction is planned to reach 550 m. According to SDS data (Krylov et al., 1970), this is the largest depth before the basement of the basin on the Salair side.

Geomorphologically, the Kuznetsk Basin has a block structure (Novikov et al., 2013), and the Bachat mine is within one of the basin's blocks. Belitskii (1959) noted the interesting presence of fine fracturing ranging the length of faults depending on their structural position. According to the results of tectonic studies (Ovsyuchenko et al., 2010), the basin's block structure can reflect on the processes of induced seismicity. In addition, at the southern extremity of the basin are ruptured faults associated with the large Kuznetsk earthquakes of 1898 and 1903 (Lavrent'ev, 1971). These events were clearly natural earthquakes and fit the patterns of development of the seismic process in the Altai-Sayan mountain region.

The general patterns of the natural seismicity of the Altai-Sayan fold region are as follows (Emanov et al., 2005):

(1) The determining influence on the occurrence of the seismic process of the block structure of the Altai-Sayan mountain region. The combination of uplifted massifs with basins has created a cellular structure, which exerts ordered resistance to collisional action from the Dzungar Basin.

(2) In the region's seismic regime, the background seismicity and seismic activations related, as a rule, to large earthquakes are distinguished.

(3) The background seismicity as first glance is chaotic; over the course of time, it is ordered in accordance with the block structure of the Altai-Sayan mountain region, being concentrated primarily in the mountain framing of basins. Basins are larger than blocks of fragmented mountain ridges, durable blocks. They are resistant to collision processes, whereas the background seismicity is associated mainly with destroyed mountain framings of basins.

(4) The stability of the manifestation of tectonic processes in the background seismicity in terms of time, as well as the hierarchy of these processes in terms of the rate of manifestation in the seismicity.

(5) Seismic activations manifest themselves as a nonstationary regime of a particular geological structure. The strong seismic activations of the structure of the Altai-Sayan region formed around the largest earthquakes, primarily as the aftershock process. All large earthquakes of the Altai-Sayan mountain region occurred in the mountain framing of basins.

We have formulated the given properties of seismicity in the Altai-Sayan mountain region by processing series of more than 50 years of observations; their validity is has been substantiated for all of the geological structures, including the Kuznetsk Basin and its mountain framing.

The Kuznetsk Basin has been filled by a sediment layer larger than have other basis in the Altai-Sayan mountain region, and during horizontal compression, concentration of the background seismicity in the mountain framing of the basin should have manifested itself. Figure 19 shows the epicenters of seismic events recorded in one year in the Kuzbass (2013). Clearly, almost the entire territory is covered by daytime (*1*) events (industrial blasts are set off during the day). In the nighttime, industrial blasts are forbidden, which is rigorously observed; therefore, nighttime events (*2*) are grouped into local zones of known seismic activity of mining companies: the area of shafts nearl Polysaevo, the Bachat mine, the area of Osinniki, the open-pit mine near the village of Malinovka, the Raspadskaya shaft near the city of Mezhdurechensk, etc. In most of these areas, experiments have been conducted with local networks of stations and the technogenic nature of earthquakes has been proved (Emanov et al., 2007, 2009b, 2012). Single nighttime events in the basis likely testify to the existence of technogenic seismicity of a lower energy level on the part of mining companies. In Kuznetsk Altai and Salair, rare singular events at night have also been recorded. In the hierarchy of structures, in terms of manifestation of seismic activity in the Altai-Sayan region, the Kuznetsk Basin and its mountain framing are characterized by a slow tectonic process in comparison to other basins of the region (Emanov et al., 2005).

Thus follows the conclusion that in the Kuzbass, induced seismicity concentrated in places where minerals are extracted dominates over natural seismicity. The area of the Bachat mine is only one of the technogenic activizations, although energetically it is the strongest. Natural seismicity concentrated in the

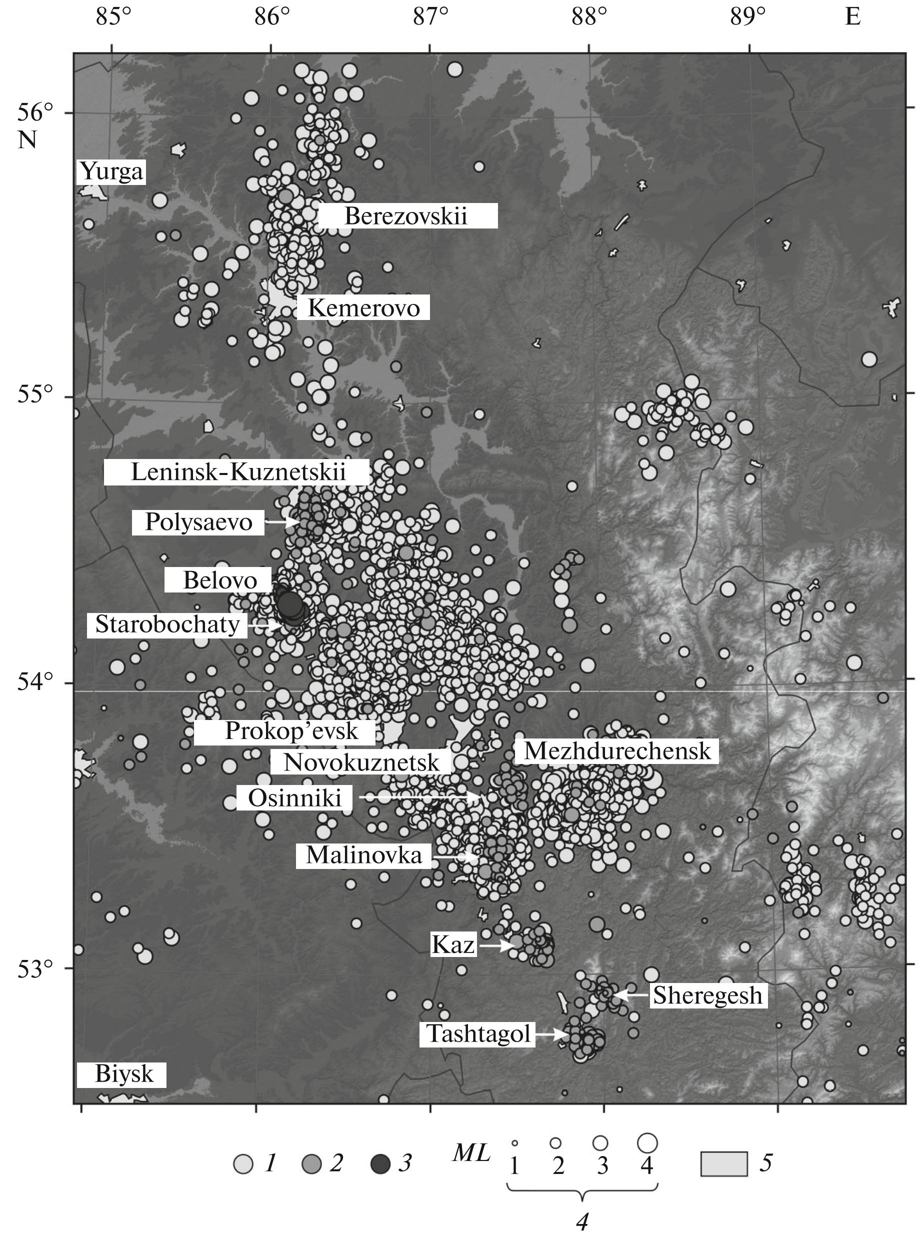


Fig. 19. Map of seismic events in Kuzbass in 2013: (*1*) daytime (10:00–19:59) events; (*2*) nighttime (20:00–09:59) events; (*3*) aftershocks of Bachat earthquake, July 8, 2013; (*4*) magnitude, *ML*; (*5*) populated areas.

mountain framing does not manifest itself as structures of seismic events.

The largest earthquakes in the Altai-Sayan mountain region are associated with the mountain framings of basins. The most exact and detailed studies were carried out for the Chuiya earthquake of 2003 (Emanov et. al, 2009b). The aftershock process went beyond the boundaries of the mountain framing along the outskirts of basis. This specific feature corresponds to the views on orogeny in Altai, when mountains broaden owing to the destruction of basins (Florensov, 1978).

The results of seismological studies in the Bachat mine make it possible to draw the following conclusions on the specific features of the seismic activation and nature of its occurrence and development.

(1) The seismic process over the area is closely related to open mineworks, and at depth it propagations from the base of the mine to 4–5 km. The sedimentary rocks of the basin adjacent to the mine were activated.

(2) The seismic regime of technogenic activation is continuous and nonstationary: periods of background-level seismicity, decreased in terms of energy

of the strongest earthquakes and with a rarefied frequency of weak events, and periods of activations with strong earthquakes and increased frequency of weak events are distinguished. The duration of seismic activations is 1–3 months. With the last five years, four activations have been recorded, three of which have generated large earthquakes: February 19, 2012 with $ML = 4.3$; March 4, 2013, with $ML = 3.9$; and June 18, 2013, with $ML = 6.1$. The last activation ended with a series of perceptible earthquakes with a local magnitude of 3.0–3.5.

(3) Large earthquakes and weak events form a spatially unified process with a slope of the recurrence graph that differs from natural seismicity.

(4) The mechanism of the Bachat earthquake was upthrusting with the orientation of one of the planes of the motion along the major axis of the mine. The orientation corresponds to technogenic impact.

Analyzing the Bachat earthquake, let us turn to the classical definition of induced seismicity: "Induced seismicity is the intensification of seismic activity related to human engineering activity" (Nikolaev, 1994). Without a doubt, the Bachat earthquake and the entire activation of the Bachat mine falls under the definition of induced seismicity. It should be noted that induced seismicity always occurs in a medium in a stressed state; any geological medium has its own stressed state. In contrast to cases when an earthquake occurs due to technogenic impact or at great depth, in this case, activation occurs that is closely related to an object that exerts a technogenic impact on the medium. Clearly, the large energy of the Bachat earthquake distinguishes it from other typical technogenic earthquakes. It is difficult to imagine that the extraction of minerals can generate such strong stresses in the earth's core. On the other hand, a large increase in coal extraction has been noted in the Kuzbass: whereas in 1950, 37 mln t of coal was extracted, and of that 1 mln by open mineworks, in 2013, 203 mln t has been extracted, 126 mln of which by open mineworks. On the whole, more than 8 bln t of coal have been extracted in the Kuzbass. Adding to this the movement of rocks into mine dumps, it is possible to understand how great the technogenic impact on the subsurface of the Kuznetsk Basin has been.

In the Kuzbass, not only the Bachat mine is such a large scale business. At the Kedrovskoe, Mokhovskoe, Talda, Kaltan, Krasnobrodskoe, and other mines are being mined in amounts comparable to the Bachat. In the areas of other mines, such large earthquakes as the Bachat have not been recorded, but weak seismicity has not been studied. It should be noted that before 2012, nothing on the induced seismicity at the Bachat mine had been known.

The Bachat earthquake is unique in terms of energy, but it is spatially correlated with the mine, and the orientation of the focal mechanism corresponds to the orientation of the major axis of the mine. The earthquake occurred in sediments that filled the Kuznetsk Basin; it had a small depth of the focus; the seismic activation at the level of weaker earthquakes is spatially related to the Bachat earthquake; and the recurrence graph has a slope that differs from natural seismicity.

The pulsating regime of inducted seismicity of the Bachat mine is characteristic of technogenic seismic activations in the extraction of solid minerals (Oparin et al., 2005; Adushkin and Oparin, 2016).

The aforementioned facts point to the technogenic nature of the Bachat earthquake. Such a strong seismic event was mainly caused by strong technogenic impact, most likely related to the movement of masses during open mineworks. Undoubtedly, it is impossible to exclude the natural conditions of the Kuznetsk Basin, which in the size of sediments exceeds all other basins of the Altai-Sayan fold region. Horizontal compression, like in the entire region, should result in the development of the seismic process in the Kuznetsk range and in the Salair. Seismicity in the form of spots near mineworks is still more proof of the technogenic nature of Kuznetsk Basin earthquakes.

CONCLUSIONS

(1) The seismic regime of technogenic activation near the Bachat mine is continuous and nonstationary: periods of background-level seismicity, decreased in terms of the strongest earthquakes and rarefied frequency of weak events have been distinguished, as well as periods of activation with strong and large earthquakes and increase frequency of weak events. The duration of seismic activations is 1–3 months. In the last five years, four activations have been recorded, three of which generated large earthquakes: February 19, 2012 with $ML = 4.3$; March 4, 2013, with $ML = 3.9$; and June 18, 2013, with $ML = 6.1$. The last activation ended with a series of perceptible earthquakes with a local magnitude of 3.0–3.5. The pulsating character of seismic activation of the subsurface of the mine testifies to the increased seismic hazard of this part of Kemerovo oblast and the necessity of instrumental monitoring of the development of the process.

(2) The Bachat earthquake and the entire induced seismicity near it is spatially associated with the mine, the orientation of the focal mechanism of this earthquake corresponds to the orientation of the major axis of the mine, it occurred in the sediments of the basin, it has a small depth of the focus, and the recurrence graph has a slope differing from natural seismicity. All this points to the technogenic nature of the Bachat earthquake and seismic activation in the spatiotemporal framework of which it occurred.

(3) The concentration of earthquakes in the form of accumulations near coal mineshafts and open mines testifies to the dominance of induced seismicity over natural in the studied region.

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