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ROCK BUMP – THE REASON OF METHANE OUT BURST IN THE COAL MINE?

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The proposed model presents a rock bump (a technogeneous earthquake) as a shock wave emergence on the inside wall of a mine. In such a case, an unloading, tensile wave is generated which moves in the opposite (into the wall) direction. A shock wave is accompanied by medium motion in the direction of shock wave propagation with the velocity significantly less than that of the wave. Phenomena, occurring on the inner surface of a mine result in coal dustfall and methane dissolution in the coal that causes an explosion.

Key words: nonpotential part of geomagnetic field, Schmidt-Bauer currents, rain currents and evaporation currents

Introduction

Within the developed shock-wave model of an earthquake, the author considers a rock bump as a technogeneous earthquake. Possible consequences of a rock bump such as fast methane and coal dust emissions followed by component outbursts are discussed. These phenomena occur in the result of the emergence of a shock wave at the surface of a coal bed. A shock wave is generated in a rock as the medium reaction on lithostatic unbalance due to the disturbance of its integrity during shaft work, i.e. due to the formation of rock pressure.

At one of the largest coal mines in the world, at «Raspadskaya» mine in the South of Kuzbass, explosions with the interval of four hours occurred at night on May 9, 2010. The second explosion was significantly stronger than the first one and it occurred at the time when rescuers had already descended into the mine. People died. The cause for the explosion is considered to be methane and coal dust emissions and careless handling of fire. May a rock bump (technogeneous earthquake) be the cause of the tragedy? To answer this question, we shall give some information on a rock bump.

About 3 thousand rock bumps (RB) are registered annually at the North-Ural deposit of bauxite. There is a Monitoring and Warning Service for RBs, local underground

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earthquakes with rock displacements, at the North-Ural Bauxite Mine (SUBR). The strong rock bump which occurred at this mine on February 13, 2010 was identified as an earthquake by seismologists (http://echo.msk.ru/news/656402-echo.phtml). The Geophysical Service RAS gave the magnitude of 4.7 to this technogeneous event. The Geophysical Service of USA gave the magnitude of 4,6. A question arises, may the magnitude (M) of a rock bump be more than, for example, 6 or 7, if not, what maximum magnitude may a RB have?

Model

Earthquake sources, ranged according to the magnitude M, are orderly distributed not only in time (Guttenberg and Richter law) but in space as well [1]. It turned out that average statistical distances d_M (km) between the epicenters of the closest pairs of seismic sources with the size L_M (km) and the magnitude are described by the relations:

$$d_M = 10^{0.6M-1.94};\ L_M = 10^{0.6M-2.5}.$$

The value d_M practically characterized the average size of geoblocks capable to generate earthquakes with magnitude M. The coefficient 0.6 by indicates the change of source size L_M and the corresponding distances between epicenters d_M by 2 times for each successive step of 0.5 of a magnitude unit. The value d_M/L_M is equal to 3.63 and does not depend on earthquake magnitude. For example, for the magnitude $M = 3$, $d_M \approx 700$ m, and $L_M \approx 200$ (Fig. 1).

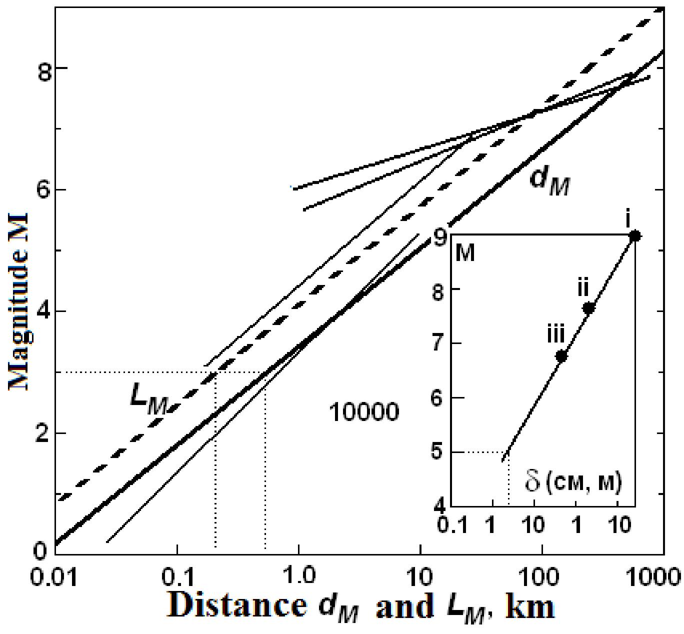

Fig. 1. Earthquake magnitude M, geoblock size d_M, fracture length L_M [1]. Thin lines are the data on fracture length of different authors. On the insert: dependence of $M-\delta$. Dots show earthquake parameters in Sumatra (i), Altai (ii) and California (iii).

Numerous observations of seismologists allowed us to detect the relation between earthquake magnitude and fracture length (thing lines in Fig. 1). For a RB, the fracture length is associated with mine size (a geoblock). According to [1], the magnitude $M = 4.7$ corresponds to $L_M \approx 2.5$ km, and $d_M \approx 8$ km. Linear size of a technogeneous earthquake source could reach such a value. Estimate the maximum possible values of L_M and d_M taking into account the known size of this mine. The Raspadskaya mine field size: strike length is 12.7 km, vertical extent is 4.3 km, area is 54.5 sq.km. (http://premier.gov.ru/-visits/ru/11167/info/11170/). It is natural to consider the maximum mine size to be the geoblock size. According to Fig. 1, when a geoblock has the size of $d_M \approx 13$ km, the maximum magnitude of an earthquake may reach $M = 5$, the fracture length is $L_M = 3.8$ km. It is a very strong earthquake. We would like to remind that these are the maximum possible values for a mine with Raspadskaya mine size. For example, for an earthquake with the magnitude of $M = 6$, $L_M \approx 15$ km, and $d_M \approx 50 - 60$ km, which is evidently larger than the medium size of the mine. In this case, we deal with a tectonic earthquake. Here is one more example. The source size of one of the strongest earthquakes occurred on December 26, 2004 near Sumatra island with $M = 9$ is $L_M \approx 1000$ km.

For more than a hundred of years, the mankind has been trying to answer the question, what an earthquake is. As it is known, there is no a simple answer for the question. According to the version of experts and readers of the popular LiveScience journal, one of the ten mysteries of the Universe is formulated as follows: What occurs in the hart of an earthquake? It is not a casual question. Modern seismology cannot answer it, nevertheless, we shall try to answer it realizing that nobody knows the definite answer so far, and any attempt to do it may be only some approaching to it.

The author suggests principally new physics of an earthquake, the so called shock-wave (SW) model [2, 3]. According to this model earthquake phenomenon may be presented as three subsequent stages of one process: 1 – SW initiation deeply inside the Earth; 2 – SW propagation from a hypocenter to the Earth surface and 3 – SW emergence at the Earth surface. During the SW emergence at the surface, an unloading (rarefaction) wave is generated which interacting with the original SW causes generation of so called “strong motions” on the Earth surface, such as: ground fractures and splits, loosening, rise and fall of water level, ground vibration similar to that of a liquid, spring formation and so on. All these processes are characteristic to the phenomena occurring during SW emergence at the surface of a solid [4]. The peculiarity of a SW is the fact that, in contrast to acoustic waves, behind the SW front, mass transfer takes place with the velocity significantly less than that of a SW. Mass transfer is a well characterized fact, which is called a slip in seismology. It is usually interpreted as a frictional sliding of a material along a formed fracture and it is a consequence of a SW propagation through a solid. In the generally accepted model of modern seismology, this phenomenon is called “emergence at the surface of an earthquake source”. In principle, such interpretation is applicable in our model, but instead of a fracture emergence (which is not real) we understand the processes accompanying a SW emergence at the surface.

Let’s consider a model, where a weak shock wave is involved. Such a wave, for example, cannot melt the substance of the medium where it propagates and, moreover, evaporate it [4]. The finite state of a substance after the unloading is supposed to be solid. The final volume of the unloaded substance V_x differs little from the normal volume of a solid V_o. At the same time, we shall consider the shock wave to be not too weak to neglect the effects associated with solid strength. Pressure in a body compressed by a shock wave is supposed to be isotropic just as in gas or in liquid. It is fair when the pressure is great in comparison to ultimate strength, critical shear stress and so on.

In this case, the sound velocity is determined by the compressibility of a substance, compression modulus just as in gas or in liquid.

Let a plane shock wave with constant amplitude (pressure , mass velocity u, volume V, which is a little less than the normal volume V_o) propagate through a solid. At the definite time, the wave emerges at a free surface which is considered to be parallel to the shock wave front surface. A weak shock wave, where the compression is small, $V_o - V << V_o$, does not differ from the acoustic compression wave and is described by acoustics formulas. It propagates through the body with sound velocity c_o. The pressure in it is related with mass velocity as $p = \rho_o c_o u \sim (\rho_o = 1/V_o)$. From the moment $t = 0$ of the shock wave emergence at a free surface, an unloading wave, which is also an acoustic one, propagates backward though the body. In a substance it has sound velocity (which slightly differs from sound velocity in normal conditions c_o). Wave pressure drops from the initial to zero, and the substance acquire the velocity u', associated with pressure change $\triangle p = -p$ by the acoustic formula: $u' = -\frac{\Delta p}{\rho_0 c_0} = \frac{p}{\rho_0 c_0}$ (Fig. 2); density slightly decreases: final density ρ' differs a little from normal density of a solid, $(V_1 - V_o << V_o)$. It is clear from the comparison of the formulas $p = \rho_o c_o u$ and $u' = p/\rho_o c_o$ that the additional velocity acquired by a substance during the unloading u' is equal to the mass velocity in a shock wave, i.e. when a weak shock wave emerges at a free surface, substance velocity doubles, $u_1 = u + u' \approx 2u$. Let's see, what effects a SW emergence at the inner surface in a mine may have.

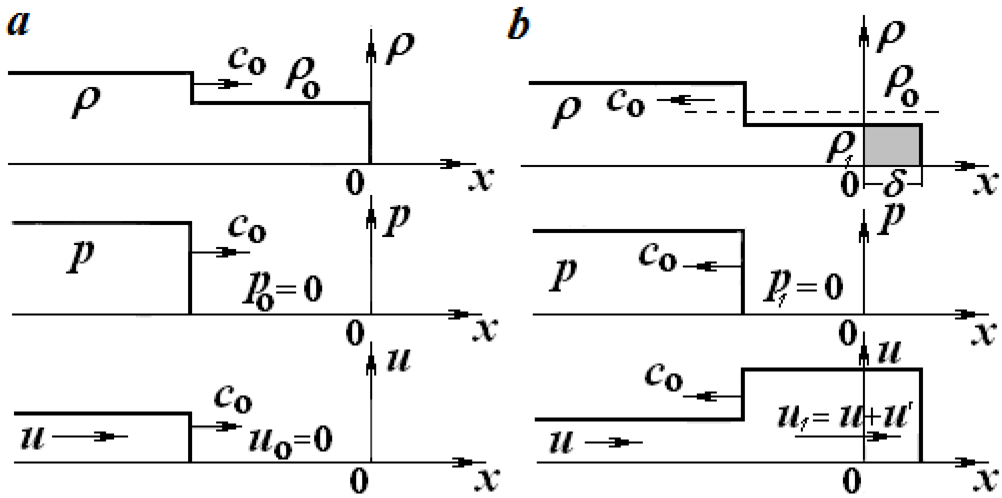

Fig. 2. Profiles of density, pressure and velocity during a weak shock wave emergence at a free surface a) before the emergence $t < 0$; b) after the emergence $t > 0$ [4]. The section marked by gray shows that media loosening occurred after a SW passage, and a layer with the thickness δ and the density $\rho_1 < \rho_o$ was formed

It is known that in the mines at the depth of 300-600 m, the so called dynamic effects of rock pressure in the form of rock «bursts», shocks and rock bumps are sometimes observed. «Burst» occurs as a rebound of a rock piece from the stressed massive accompanied by sharp sound. A shock or a rock bump of the internal action is a failure deep in rocks without an outburst into the mine. Its external manifestations are sharp sound, rock shacking, rock falling from the mine surface, and an air wave during strong shocks. It follows from the aforesaid that these phenomena accompany a shock wave emergence at a «free» surface.

As an example, we shall show the effects of «bursts» of tank inner armor fragmentations formed after a composite shell impact on the outer side. These effects are well known and studied. Bursts of armor fragmentations and injuries of tank crew occur in the result of emergence of a shock wave formed after a shell impact on the tank armor, its inner surface. Similar effects are observed at the moment of earthquakes. "Bursts" usually occur in rocky ground. When there are sedimentary water-saturated rocks, springs, water fountains, are formed as it occurred, for example, during the Chuiskoe earthquake, Altai, in 2004 [3].

Let's estimate the value of substance loosening δ, formed after a SW emergence. It is likely to be proportional to earthquake magnitude M, so suppose that $M \sim lg\delta$. According to the observations during the Chuiskoe earthquake in 2003, $M = 7.5$, $\delta = 100$ cm, during the Northridge earthquake, California, in 1994, $M = 6.7$, $\delta = 50$ cm [2]. For comparison, during the earthquake in Sumatra (2004) $M = 9$, the loosening was 20 m. We construct a dependence of $M \sim lg\delta$ for three given earthquakes (an insert in Fig. 2). Continuing it to the region of smaller magnitude we obtain quite an approximate estimate of the loosening value for a mine with a SW $M = 5$, $\delta \approx 3$ cm. To estimate the effect, we suppose that the medium density after a SW propagation ρ' is about 0.9 from ρ_o, (ρ_o is set to be equal 2 g/cm^3), then $\triangle p = 0.2$ g/cm^3. We calculate the quantity of the substance emitted from the mine surface of 1 cm^2, or from the volume equal to 1 cm$^2 \times \delta = 3$ cm^3. It is about 0.6 – 0.8 g. The content of the emitted substance is methane and coal dust. The relation between these two components is known, there are 30 m^3 of methane for a ton of coal. In our case, there is ≈ 1 g of coal (coal dust) and ≈ 30 cm^3 of methane. As it is known, explosive methane concentration is 5%, that means that in the air volume 600 cm^3, an explosion may occur. As we have related our estimates to the coal surface area of 1 cm, the dangerous methane concentration may appear up to the distance of 6 m from the surface, on which a shock wave emerges not considering the methane diffusion rate in the mine air.

The presence of methane significantly affects the coal dust explosion. When methane is absent, the coal dust explodes if its content in the air is not less than 30-40 g/m^3. When there is 2% of CH4, the dangerous concentration of dust decreases to 10 g/m^3, and if there is 3% of methane, this concentration decreases to 5 g/m^3. To prevent an explosion, it is enough to decrease the dust concentration to 5 g/m^3, and to 1 g/m^3 allowing for some margin. Thus, the dangerous concentration of dust is considered to be 10 g in 106 cm^3, or for the area of 1 cm^2, the volume of 105 cm^3 should contain the volume of 1 g of dust.

Not knowing the character and the rate of dust mixing in a mine, it is not possible to calculate the time for formation of explosive concentration. Nevertheless, it is possible to estimate the range of velocities of continuum motion at the moment of emergence of a SW at the surface. We apply the data on velocities of medium motion at the moment of Northridge earthquake (1994) [2]. The uniqueness of the earthquake is that the principle shock fell within a special test field to control the so called «strong motions». In the epicenter of this earthquake, the registered velocity of medium motion was ≈ 100 cm/s. The magnitude is higher than that accepted for estimates $M = 5$ by two units. Consequently, the velocity u' should be about 100 times less, and it may be considered to be equal to 1 cm/s. For the time between two explosions, equal to about 104 s, the particle will pass the distance of $l \approx 100$ meters. The linear size (distance to the wall) of the explosion volume will be not less than 100 meters. We should only find the source of explosion initiation.

It is known from the solid state physics, that during distraction (grinding) of a substance having a crystal structure and low electroconductivity, the newly formed particles acquire the electric charges of both polarities. The total charge of particles is equal to zero since the basic material is electrically neutral. All the coal put into a mill barrel after grinding is divided into two parts equal in mass with similar electric charge values but opposite in electricity sign. When the troboelectric charges are absent, particle charges acquired in the result of grinding do not manifest themselves. There is no a total electric field of any particle assembly. If the charge sign depend on particle size, which occurs with ash particles during a volcano eruption, charge separation is possible in a moving coal dust stream. For example, in an ash cloud erupted by a volcano, small particles acquire the negative charge and heavier particles acquire the positive charge [5]. Evidently, heavy ones have larger moment and propagate further than the negative ones for the «allotted time». As it follows from [5], the formed tension reaches a breakdown. Generation of electric discharges in volcano ash [6], in the dust during massive explosions and in flour production is well known. This situation is possible when the mixture of coal dust and methane or pure methane is emitted during a rock bump. A spark causes explosion of such a mixture. In the model, we considered two subsequent explosions. At first, methane explodes, and when the dust has taken quite a large volume of a mine, coal dust explodes. Another variant is possible, the first explosion is the foreshock, and the second one is the primary shock. It does not principally change the case.

The shock-wave model of an earthquake is based on new approaches in the explanation of the known experimental results obtained in the investigations of rock samples during their compression at heavy press. The authors of a number of papers observed the phenomenon of spontaneous increase of acoustic emission (AE) intensity which also spontaneously stopped (Fig. 3a) [7].

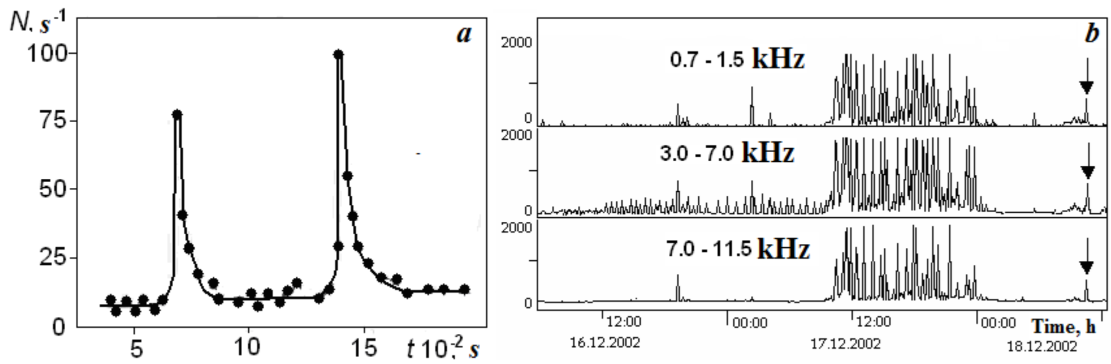

Fig. 3. *a*) Fracture formation rate in a diabase when a sample is constantly influenced by monoaxial compressive stress [7]. *b*) Geoacoustic signals registered before the earthquake on 18.12.2002 (K = 12.1) in Kamchatka (IKIR). The event time is indicated by an arrow [11]

The author [8] made an attempt to explain this phenomenon from the point of view of self-organization of a coherent structure on the basis of interaction of sound waves with opening fractures. A supposition was made that the effect of AE intensification has something in common with optical superfluorescence [9]. The interesting fact, investigated in detail in some works in Japan and China, is that the acoustic superfloures-cence effect occur not in all types of rocks [2]. For example, the research of AE regimes of granites (granodiorites) of two different types, Oshima (fine-grained) and Inada (coarse-grained), showed that the samples almost do not differ in appearance, and under the loading on a press, they behave in a differently [10]. On the series of granite samples for Oshima, there is a constant effect of sharp increase of AE intensity, called the acoustic superfluorenscence, but there is no such an effect on the series of granite samples of Inada type. The result has been multiply confirmed. This gives ground to suppose that deep in the ground, there should be geological bodies which rheology allows self-organizing processes to be developed and, finally, earthquakes to be generated. In other bodies, which are identical to the first ones from the first sight, such phenomena cannot occur.

The results of numerous laboratory experiments and natural observations (Fig. 3a) show that at the background of constant acoustic signal ($I = dN/dt \sim N$) emitted by a rock loaded sample, explosive growth (chain reaction type) of the number of opening fractures N (acoustic pulses) per a time unit $t, dN/dt \sim N^2$ [7] takes place. There is no clear understanding of the physics of this phenomenon.

Suppose that in a medium volume under an ambient pressure, some acoustic pulse sources are formed. These may be opening fractures, forming dislocations, formation and break-ups of medium hydrogen bounds and so on. Under the certain circumstances, each of these dislocations emits an acoustic pulse. The sum of such pulses is the acoustic background. Let's imagine a situation when such dislocation is connected with other dislocations by an unclear relation so that it (the dislocation) stimulates the others to emit acoustic pulses. For example, acoustic waves, generated during the distraction of N dislocations, may promote the distraction of other $(N-1)$ dislocations connected (linked, involved) with them. In the result, the acoustic background increases from N pulses per a time unit to $N + N(N-1) = N^2$. Similar processes are generally called cooperative ones in physics. The principle moment in this model is still the unclear physics of such connection. Indeed, when one tries to explain the acoustic superfluorenscence of a small rock sample, the mechanism, in which an opening fracture generates an acoustic pulse which causes the opening of other prepared microcracks by a not quite clear way and everything repeats all over again, is logical. There is no limit caused by the finite sound velocity in a sample. But such mechanism is not applicable when we are talking about large distances comparable with the size of an earthquake source.

As an example, we show a record of acoustic signals, registered in Kamchatka and having the direct relation with a preparing earthquake. High-frequency acoustic signals are generated in the intermediate vicinity (not more than one or two kilometers) from a receiver. The earthquake occurs at the depth of about 30 km and at the distance of about 100 km from a receiver. Nevertheless, the receiver somehow «feels» the earthquake. Some time before the event, the acoustic background increases sharply and decreases back sharply as well. This follows by a time interval called «seismic quiescence» by seismologists (Fig. 3b) [11].

Is generation of a SW possible in a row? Apparently, it is, since observations of anthracite piece behavior under compression on a press shows the same picture of acoustic superfluorescence (Fig. 4) [12] as in the diabase in Fig. 3a.

The data, showing the evident relation between an earthquake and methane outburst are known, for example [13]. But there are no enough grounds to say that every explosion on a mine is due to an earthquake (rock bump). The matter is that in the case of Raspadskaya mine, the Geophysical Service SB RAS, having an extensive network of seismical stations in the region of the explosion, could not estimate the magnitudes of the first and the second explosions due to very unclear seismogram records.

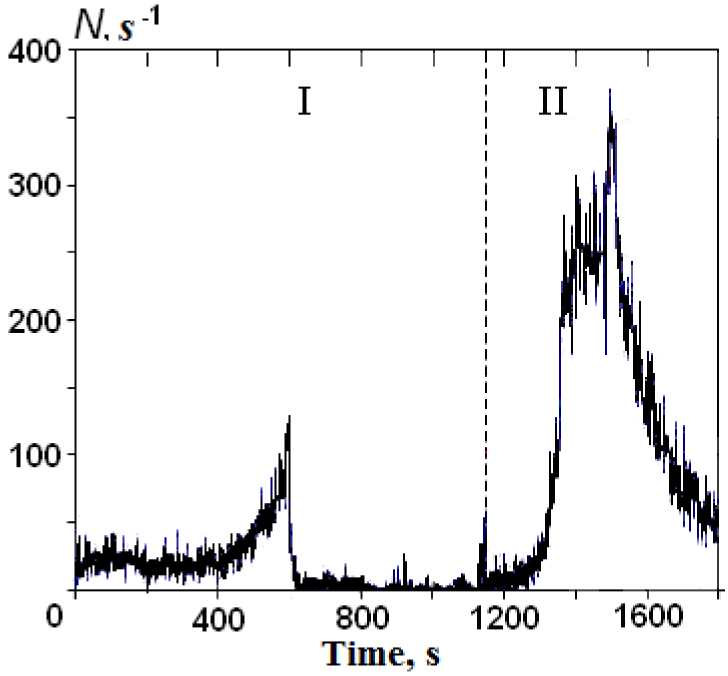

Fig. 4. Change of AE activity in time during monoaxial coal deformation in the second cycle (II) after a triaxial axisymmetric compression in the first cycle (I) [12]

Conclusions

May a rock bump be predicted? This question can be rephrased. May an earthquake be predicted, its location, time and intensity? So far, we can answer these questions only negatively. Are there any premises to solve it? Looks like, it is so. If a seismically hazardous region behaves the way it is shown in Fig. 3b, i.e, after acoustic emission intensification comes the period of seismic silence (calm), than there is a shock at the end. If we succeed to understand the physics of this phenomenon, it seems there are premises for it, than a short-term forecast of a rock bump in a mine is possible. If we succeed to find out if the duration of acoustic silence is associated with earthquake magnitude, than we shall have the possibility to predict the intensity of a rock bump. Of course, a noisy mine is not the best place for acoustic sensors. The possible solution of the problem is the significant difference in frequency ranges for the sources, natural and technogeneous ones.

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