energies

Article

The Impact of the Coexistence of Methane Hazard and Rock-Bursts on the Safety of Works in Underground Hard Coal Mines

Justyna Swolkień * **and Nikodem Szlązak**

Faculty of Mining and Geoengineering, AGH University of Science and Technology Kraków, 30-059 Kraków, Poland; szlazak@agh.edu.pl
* Correspondence: swolkien@agh.edu.pl

Abstract: Several natural threats characterize hard coal mining in Poland. The coexistence of methane and rock-burst hazards lowers the safety level during exploration. The most dangerous are high-energy bumps, which might cause rock-burst. Additionally, created during exploitation, safety pillars, which protect openings, might be the reason for the formation of so-called gas traps. In this part, rock mass is usually not disturbed and methane in seams that form the safety pillars is not dangerous as long as they remain intact. Nevertheless, during a rock-burst, a sudden methane outflow can occur. Preventing the existing hazards increases mining costs, and employing inadequate measures threatens the employees' lives and limbs. Using two longwalls as examples, the authors discuss the consequences of the two natural hazards' coexistence. In the area of longwall H-4 in seam 409/4, a rock-burst caused a release of approximately 545,000 cubic meters of methane into the excavations, which tripled methane concentration compared to the values from the period preceding the burst. In the second longwall (IV in seam 703/1), a bump was followed by a rock-burst, which reduced the amount of air flowing through the excavation by 30 percent compared to the airflow before, and methane release rose by 60 percent. The analyses presented in this article justify that research is needed to create and implement innovative methods of methane drainage from coal seams to capture methane more effectively at the stage of mining.

Keywords: methane hazard; rock-burst; the safety of exploration

Citation: Swolkień, J.; Szlązak, N. The Impact of the Coexistence of Methane Hazard and Rock-Bursts on the Safety of Works in Underground Hard Coal Mines. *Energies* **2021**, *14*, 128. https://doi.org/10.3390/en14010128

Received: 2 December 2020
Accepted: 24 December 2020
Published: 29 December 2020

1. Introduction

Extraction of coal in hard coal mines in Poland involves numerous natural and technical hazards [1,2]. When designing a new section's exploitation, it is necessary to identify the levels of natural hazards and apply the conclusions in the final design. The identification and prevention of natural hazards require state-of-the-art methods, technology, instruments and machinery, as well as relevant expertise and know-how.

Polish hard coal mines have to cope with adverse geological conditions and the presence and coexistence of the following hazards [1,2]:

- methane
- coal dust explosion
- rock-bursts, cave-ins
- fire
- water
- rock-and-gas outbursts
- climate

Because mining in Poland reaches more profound levels every year, the degree of co-existing hazards rises considerably. At present, the average depth of exploitation is 800 m below sea level, but in many mines it is even greater than 1000 m and probably will increase in the years to come [2]. That means growth in methane release and higher virgin temperature of the rocks, which causes the climate conditions for deterioration and the endogenous fire hazard to rise. The presence of all these factors combined can lower the safety level of working underground.

The considerable depth of exploitation of coal seams contributes to the increase in the scale of natural hazards. With increasing depth, the methane content in the coal seams increases. On the other hand, decreasing the rock-mass permeability with the rise of the stress state causes a reduction of methane drainage efficiency. The exploitation of coal seams at these depths increases the risk of bumps and rock-bursts. Improperly selected methods of preventing these threats may contribute to the sudden release of methane and the danger of miners' death.

Some of the most severe threats existing in Polish mines are methane and rock-burst hazards [1,2]. Using inadequate prevention methods can, as a consequence, lead to casualties. The present article highlights the implications of their coexistence and draws attention to the necessity of implementing appropriate preventive measures. In the beginning, the authors focus on describing the very nature of methane hazard and its prevention; in subsequent sections, they show the effects of the coexistence of the methane and rock-burst hazards, using longwalls in two Polish mines as examples.

The description of the presented events was the part of the scientific report carried out under the supervision of Nikodem Szlązak, co-author of the article, and commissioned by the Higher Mining Institute in Katowice and the Mining Commission for the Study of the Disaster Causes [3].

2. Sources of Methane Origin and Methods of Methane Hazard Prevention

In the Upper Silesian Coal Basin's coal measures—considering its area and hitherto identified layers—the presence of methane varies, and its distribution is very uneven [4,5]. In the northern and central parts of the Basin, methane is virtually non-existent or very scarce. On the other hand, its southern part has a very high methane content [4,5]. For example, this situation exists in Brzeszcze and Silesia mining plants suited in its eastern part, and in the western region, the Rybnik Coal Area is the most methane prone.

The presence of methane does not correlate with specific stratigraphic layers [4,5]. It exists at all levels except for the Libiąż layers. The same layers contain methane in some areas while being free from it elsewhere. There is no close correlation between the degree of carbonization and the methane content in the carboniferous [4,6]. In some mines, heavily metamorphosed coal contains minimal amounts of methane. On the other hand, much less metamorphosed coal in, e.g., the Silesia mining plant is characterized by high methane content. An essential factor for methane content in coal is the type of overburden's thickness, but this is not the only condition of methane's presence in larger amounts. The research conducted so far makes it possible to conclude that methane found in coal deposits exists in two primary forms [7]:

- sorbed methane linked through its physical–chemical properties with coal substance;
- free methane found in the pores and fractures in the barren rock and coal seams.

Nevertheless, a close connection between methane content and tectonics exists as dislocations are clear boundaries separating blocks with different methane concentration degrees.

Studies into the methane content of the rock mass, conducted in the prospecting holes in the south-western part of the Basin, confirmed the existence of a zone with high methane content in the roof of the carboniferous formation above the overburden [8]. Figure 1 presents methane content changes, depending on the depth below the carboniferous roof [8]. The high-methane-content zone's thickness is approximately 200 m, with the methane content often exceeding 10 m^3 CH_4/Mg daf. Next, methane content sinks from 2 to 5 m^3 CH_4/Mg daf, only to rise above 11 m^3 CH_4/Mg daf at a depth of 700–900 m. Below 1000 m, free nitrogen and helium occur. The first peak of methane content corresponds to the presence of the impermeable overburden at a depth of 150–200 m below the carboniferous roof; it is caused by a high degree of metamorphism in the carboniferous formation at a considerable depth, which had the following consequences: A greater degree of carbonification and a higher reduction in the amount of volatile matter, an increased amount of thermogenic methane in coal, reduced coal hardness and coal's sorption capacity. These factors, combined with a large methane content and reduced coal hardness, contribute to the emergence of a high-pressure gradient within the so-called gas trap. That causes methane release into the excavations to grow, which may be the reason for methane and rock outbursts.

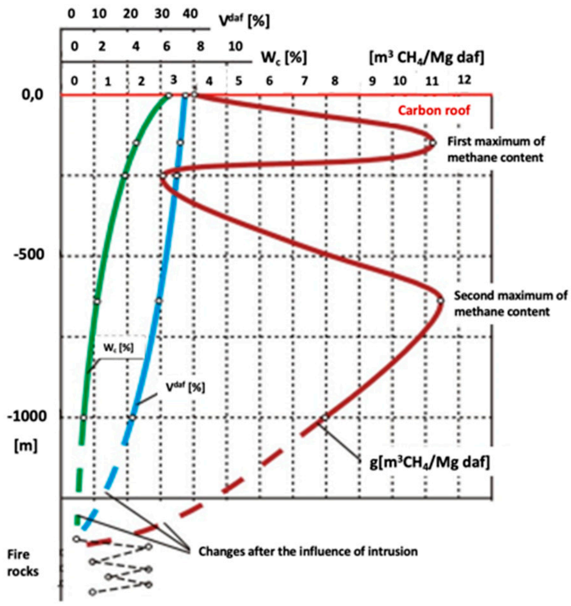


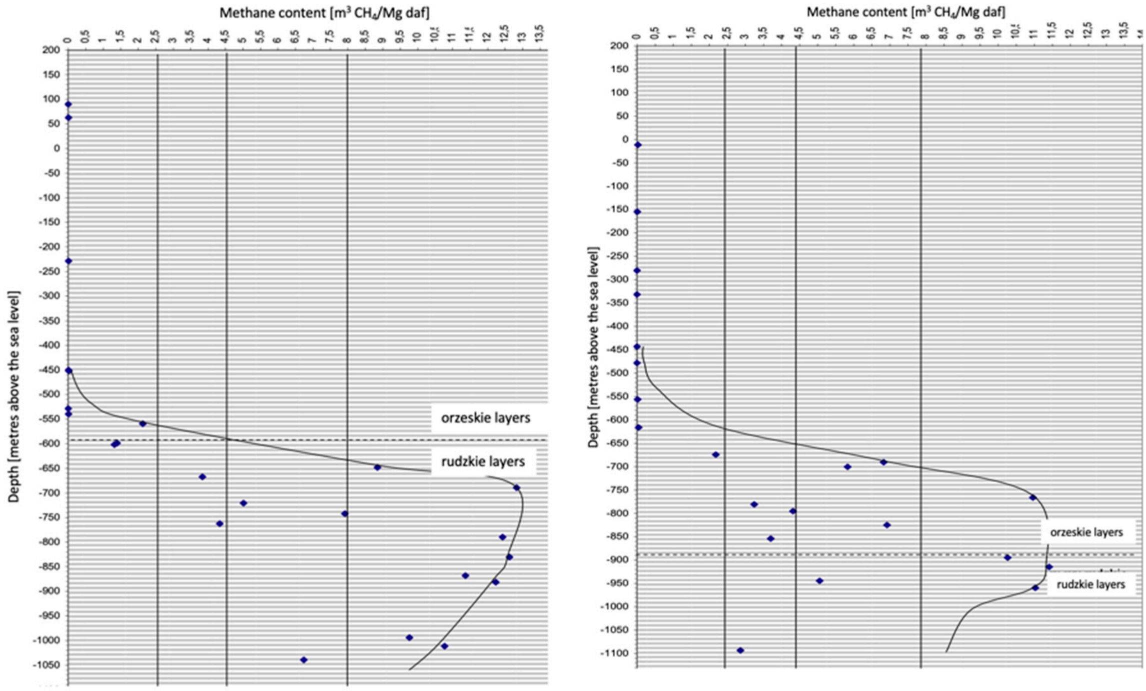
Figure 1. The averaged changes in methane content g, moisture content W_c and volatile parts V^{daf} in the coal deposits of the Rybnik Coal Basin. Adapted from Tarnowski J. 1971 [8].

Figure 2 presents the distribution of methane content according to depth in the Dębieńsko deposit [9]. What follows is that coal extraction from seams with high methane concentration calls for implementing accurate measures to lower methane release into excavations. The proper assessment of methane hazards, forecasts, monitoring, hazard control and implemented preventive measures is crucial for the safety of exploitation in that type of seams.

Methane hazard prevention involves both procedures for identifying and controlling methane hazards and the methods of removing explosive accumulations of methane from excavations. In hard coal mines, the prevalent methods implemented to stop methane hazard are as follows [1,10]:

- sufficient ventilation lets avoiding the emergence of methane 'fuses' or local accumulations of methane in excavations ventilated by airflows generated by the main fans and in workings ventilated using a separate ventilation system;
- methane drainage from coal seams through drainage boreholes, drilled from underground excavations or the surface;
- methanometric systems to control methane concentration in mine air, using sensors deployed in the different types of workings following the applicable regulations;
- supplementary ventilation devices installed in places with limited ventilation and local accumulations of methane.

Methane drainage from the rock mass is the most effective method of minimizing methane hazard, reducing methane release into working spaces and eliminating or minimizing the occurrence of such events as outflows, sudden outbursts of methane and coal [11–23]. The procedure that has proved to be the most efficient is draining methane from the rock mass and from waste areas secured with stoppings and transporting it to the surface, using the depression caused by pumping in a methane drainage station. This method helps maintain sufficient ventilation parameters and involves specific requirements regarding the choice of methods for developing coal seams containing methane. Polish coal mines use pre-extraction methane drainage only sporadically (if at all) because the low permeability of coals means that this method is inefficient [22,24–26].



Borehole Szczygłowice 15
(**a**)

Borehole Dębieńsko Głębokie 8
(**b**)

Figure 2. The distribution of methane content according to depth within a selected area: (**a**) Description for borehole Szczygłowice borehole; (**b**) description for borehole Dębińsko Głębokie 8 [9].

3. Examples of Overlapping of Methane and Outburst Hazard

3.1. Research Objectives

The methane content in a seam decreases during extraction as methane is drained and released into workings, where ventilation air dilutes it to lower methane concentration. Specially constructed pillars protect, active for an extended period, mining excavations in seams with a high methane content. In such conditions, methane in seams that form the safety pillars is not dangerous as long as they remain intact. A bump or a rock-burst in this area can release a large amount of methane into the working, removing oxygen from the mine atmosphere and threatening the personnel deployed there. In such cases, the lives of the miners working in these excavations are at risk not only because of a possible sudden energy discharge that deforms or destroys the working; another threat is the released methane, which displaces all oxygen from the excavation.

Here we describe the examples of such occurrences. They refer to actual accidents recorded in longwall H-4 in seam 409/4 in mine X and longwall IV in seam 703/1 in mine Y, where bumps of energy $1.9 \cdot 10^8$ J and $9.8 \cdot 10^7$ J respectively, caused the rock-burst and sudden methane outflow in both of them.

3.2. The Methodology of the Research

According to Polish mining regulations [27], all coal mines are equipped with the SMP-NT/A environmental parameters monitoring system with CMC-3MS telemetry centers and an integrated CST security system with CST-40A telemetry exchanges. Automatic methane measurement protects all longwalls and faces supplied with electricity following the requirements of applicable regulations and as agreed by the Ventilation Department's Head. The SMP-NT/A methane sensors with continuous recording protect all ongoing faces and longwalls and are powered directly from telemetry centers or, if possible, using in-house central units. The monitoring system is usually equipped with sensors to measure methane concentration, carbon monoxide, oxygen, air velocity, temperature, pressure and more. An intrinsically secure telecommunications network allows sending data to and from the sensors to the telemetry centers.

Diagrams of the longwalls' gasometric system, and the arrangement of CH_4 and CO sensors, are presented in Figures 3 and 4. Additionally, figures show the analyzed sensors marked with a blue rectangle.

Based on the analysis of the methane sensors indications for the longwalls mentioned earlier, it was possible to assess the consequences of the coexistence of methane and outburst hazard. The observations included sensors:

1. For the longwall H-4 in seam 409/4:
   - ➢ Sensor MM187-RW-placed in the Drift H-2 to seam 409/3 in the distance of 10–15 m before the crosscut with the Transport Glade H-2 in seam 409/1 and 409/2 (Figure 3);
   - ➢ Sensor MM 123-RW placed in the Drift H-2 to seam 409/3 in the distance of 10–15 m before the crosscut with the Transport Glade H-2 in seam 409/1 and 409/2 (Figure 3).
2. For the longwall IV in seam 703/1:
   - ➢ Sensor G of CH_4 (1.5%) placed in the Researcher roadway 3a-E-E1 in seam 703/1 at the height of the longwall window (Figure 4);
   - ➢ Sensor M of CH_4 (1.5%) placed in the Researcher roadway 3a-E-E1 in seam 703/1 5 m ahead of a transformer (Figure 4).

The description of the events that occurred in longwalls H-4 in seam 409/4 and IV in seam 703/1 was the part of the scientific report commissioned by the Higher Mining Institute in Katowice and the Mining Commission for the Study of the Disaster Causes [3].

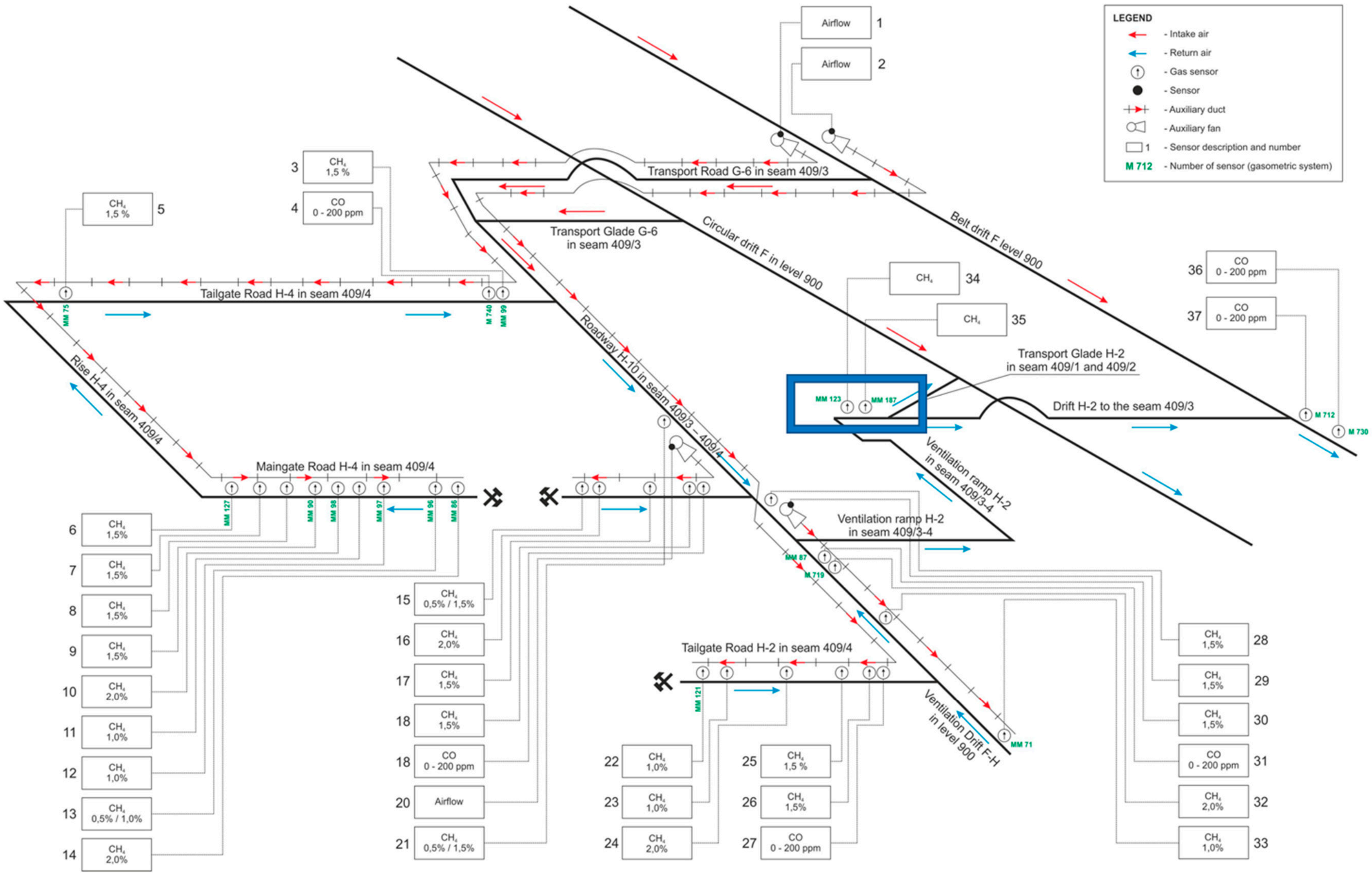


Figure 3. Diagram of the gasometric system and ventilation in the area of longwall H-4 in seam 409/4.

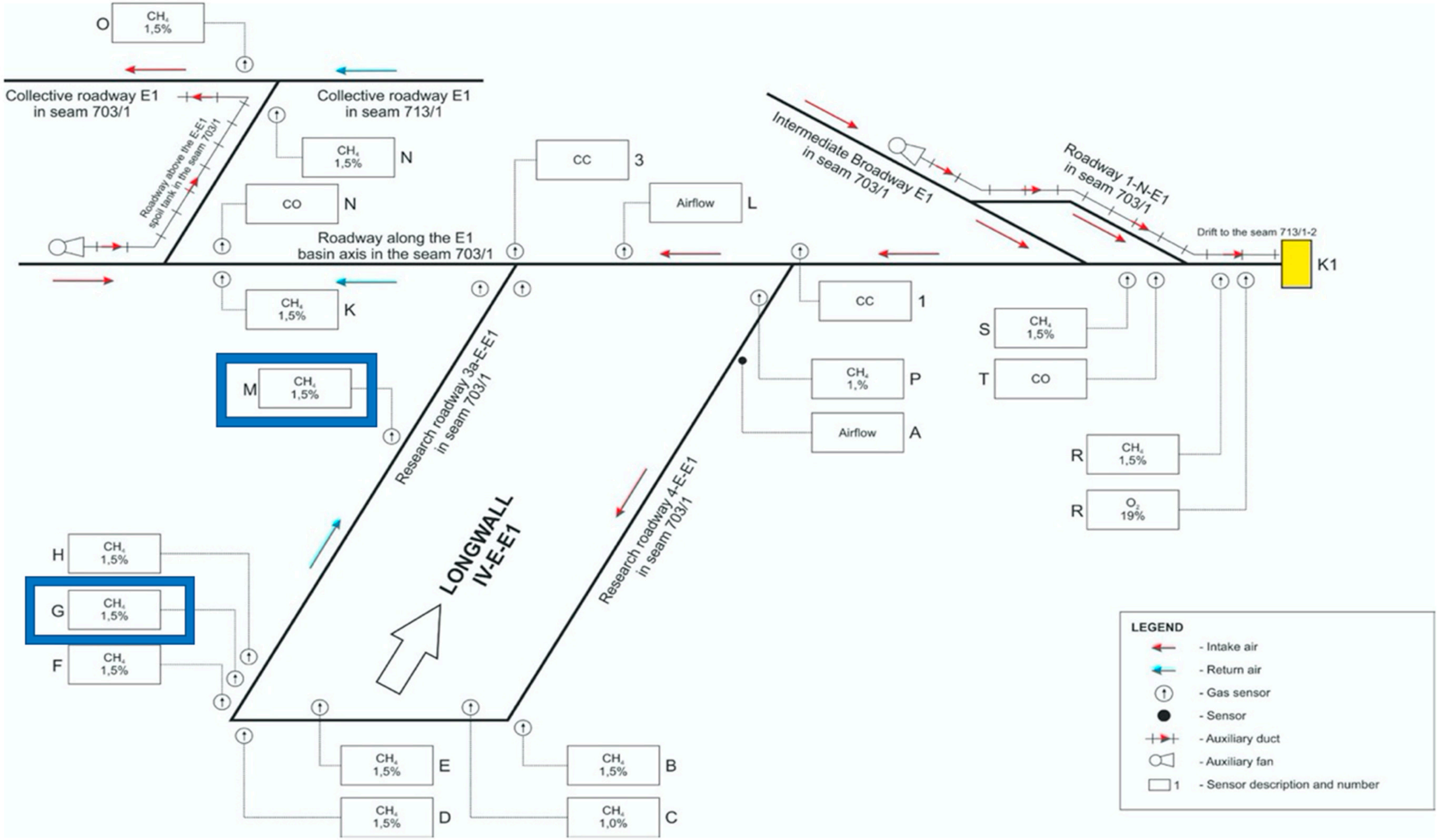


Figure 4. The arrangement of the sensors of the methanometric system in longwall IV seam 703/.

Before the event, in the H-4 longwall area in seam 409/4, the coal mine carried out preparatory works in three longwall fronts; two in the Tailgate Road H-4 (two longwall faces led on compaction), and one in the Tailgate Road H-2. Additionally, in this area, the F-H Ventilation drift was carried out. Figure 3 presents a diagram of the H-4 longwall's ventilation area along with the placement of gasometric system sensors. Additionally, Figure 5 shows the map of the developed longwall H-4.

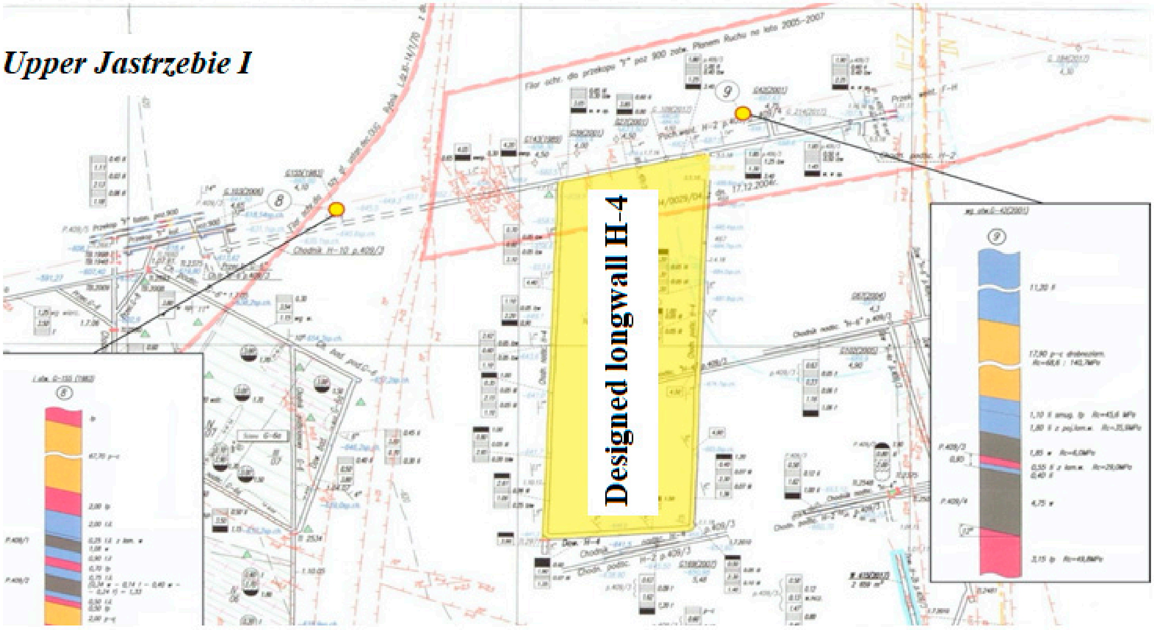


Figure 5. The map of the developed longwall H-4 in seam 409/4.

4. Results and Discussion

4.1. The Area of Longwall H-4 in Seam 409/4 in Mine X

Realization of the preparatory works in the deposit H required air from the Belt drift and the Circular drift F, both on the level 900 m, of 1570 m^3/min and 1020 m^3/min, respectively. After airing the workings, the air was discharged via the H-2 Ventilation ramp in seam 409/3-4, to the Circular and Belt drift F on the level 900 m (1070 m^3/min and 1520 m^3/min, respectively).

The part H in the seam 409/4 lays in the central and southern parts of the "Jastrzębie Górne I" mining area, in the monoclonal part of the deposit, at a depth of ~815 m to ~990 m. It was accessible from the south through the Circular and Belt drift F, both on the level 900 m and north and south through the Transport Glade H-2 and Drift H-2, also on 900 m.

There is an "eastern" fault h~15–45 m with the N-S course in the eastern border of the analyzed section, while the western edge of it is a "Jastrzębie" fault h~25–30 m with the same course. Parallel faults accompany these disturbances with discharges up to h > 5 m. A standard fault h~5–1 m with a path similar to the W-E direction runs through the central part of the section H and at a distance of ~30–75 m from the "eastern" fault in the eastern region, the fault h~0.5–2.5 m runs parallel. In the southern part, on the other hand, there are assumed reverse faults h~2.5–5 m. In its border parts, there are latitudinal faults from h~6 m to h~30 m.

Beforehand, the coal mine carried exploitation in three longwalls in the upper seam 409/3 transversely to the direction of the deposit's extent.

The data from the automatic methane measurement system's sensors and the airflow balance allowed calculating the section H area's absolute methane bearing capacity [3]. Before the event, methane emission was equal to 10.36 m^3 CH_4/min, among which faces of the Road H-4 and H-10 generated 6.00 m^3 CH_4/min. The remaining 4.36 m^3 CH_4/min came from the Tailgate Road H-2. The calculated values indicate that the discharge was much lower than it resulted from the absolute methane bearing capacity forecasts made for these workings.

The area in which the incident took place showed previous seismic activity. From 4 April 2018 until a rock-burst on 5 May 2018, the total number of bumps in section H was 134. Most of them produced energy of approximately 10^2–10^3 J. Only six of them had energy approximating 10^4 J.

Table 1 shows the effect of the bumps on methane release into excavations during the period preceding the accident under analyzes.

Table 1. The effect of the bumps on methane release into excavations in section H [3].

Excavation	**A Bump in the Area in Section H with an Energy Equal to or Higher 1×10^4 J**			
	25.04.2018	**30.04.2018**	**01.05.2018**	**04.05.2018**
Roadway H-10 seam 409/3-409/4	none	none	none	increase by 0.1%
Tailgate Road H-4	none	increase by 0.1%	increase by 0.1%	
Maingate Road H-4	none	increase by 0.1–0.2%	increase by 0.1% increase by 1.0% (behind the dust collector) increase to 1.7% (the sensor in the face area)	none
Ventilation drift F-H level 900	increase by 0.1%	none	none	increase by 0.5%
Drift H-2 to the seam 409/3	none	none	none	none

The table data shows that section H's bumps did not significantly increase the workings' methane concentration. It did not exceed 0.5%, except for the H-4 Maingate Road on 1 May 2018; the methane concentration behind the dust collector increased by 1.0%, and the sensor in the face area showed 1.7% of methane. Taking the above into account, bumps with energy up to 10^4 J or higher do not pose a potential threat of rock-burst and a sudden outflow of methane. The low energy bumps do not cause sudden desorption of methane into the excavation. Therefore, one can conclude that the applied rock-burst prevention in such events was sufficient.

On 5 May 2018 at 10:58:00, a bump with 1.9×10^8 J's energy occurred, causing a rock-burst in section H, releasing a large amount of methane into the excavations [3]. The bump was so strong that people staying in the buildings located above the ground felt it. The burst epicenter's localization was in the area of Roadway H-10 in seams 409/3 and 409/4, marked with a purple dot in Figure 6. The consequence of the rock-burst was the destruction of the roadway.

Figure 6. The map of seam 409/3 in the area of longwall H-4 with indicated spots where bumps occurred with an energy of 10^6–10^8 J.

Figure 7 presents the distribution of methane content in seam 409/4 in section H, clearly showing that methane content in the excavation of longwall H-4 was significantly lower than along the Roadway H-10 and Ventilation ramp H-2 of seam 409/3-409/4. The lower methane content measured in seam 409/4 during the creation of development workings for longwall H-4 resulted from the degasification of seam 409/4 through earlier extraction in seam 409/3. In the area of Roadway H-10, the methane content approximated 8 m^3 CH_4/Mg daf, whereas, in the longwall H-4, it varied between 0.440 to 4.007 m^3 CH_4/Mg daf. Creating a safety pillar protecting the openings into a section of the deposit caused the high methane content in seams 409/3 and 409/4 (Figure 5). In this part, rock mass was not disturbed and the coal mine did not proceed with drainage.

The bumps of high energy usually cause the rock mass disturbance, like in longwall H-4 and a sudden large emission of methane. For that reason, they can pose a severe threat to the working crews' health and safety. Due to this, coal mines should take steps to increase rock-burst prevention.

After a bump occurred on 5 May 2018, sensors MM-123 and MM-187 recorded high methane concentration levels (Figure 3). Of all the analyzed sensors of the methanometric system in section H, those two survived. They were installed in Drift H-2 leading to seam 409/3, 10 to 15 m ahead of a crossing with Transport Glade H-2 in seams 409/1 and 409/2 (Figure 3).

As a consequence of the bump described above, multiple accidents occurred in which seven employees suffered; five of them lost their lives, while the other two suffered minor injuries. Additionally, methane release of such magnitude followed the accident on 5 May 2018 delayed the rescue operation.

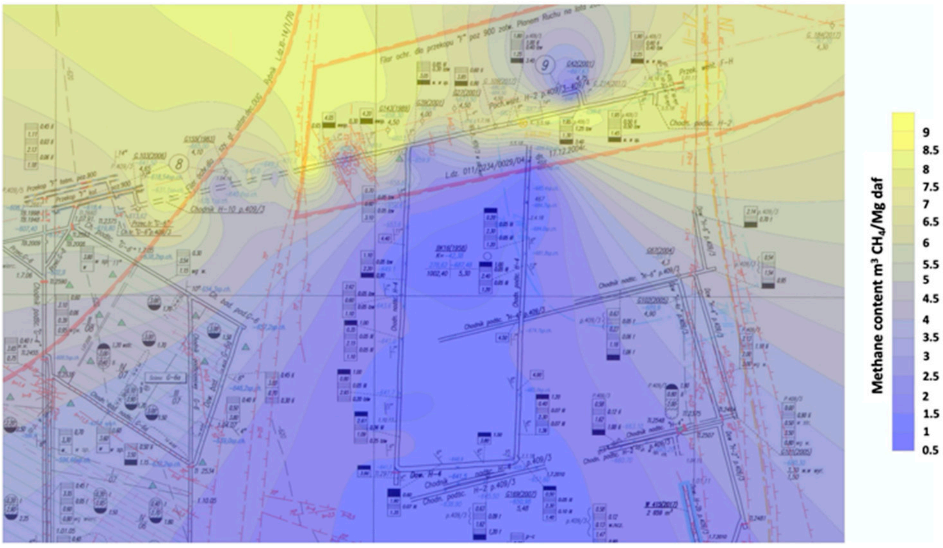


Figure 7. Isolines of methane content in the area of longwall H-4 in seam 409/4 [3].

Figure 8 presents the MM-123 and MM-187 sensors' concentrations after the accident (marked in Figure 3) [3]. The results presented in the figure show that it increased to over 60% on the bump day. Then it dropped to around 10% within the next two days. On 7, 9 and 12 May, the MM-187 sensor showed a methane concentration above 30%. Concentration on the MM-123 sensor rose to 22% on 7 May, and then fell below 10% and remained at this level until 9 May. After that date, concentration on both sensors, except the 12 May (sensor MM-187), remained below 5%.

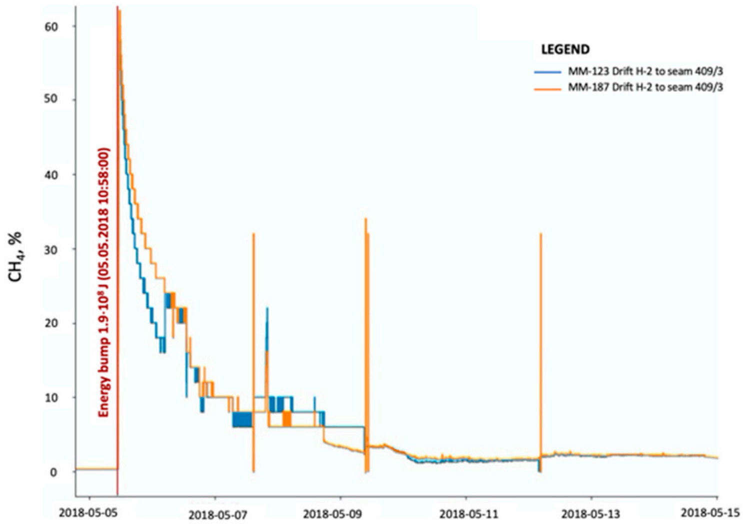


Figure 8. The values of CH_4 concentration recorded by sensors MM-123 and MM-187 (5–15 May 2018)—both sensors marked with rectangles in Figure 3.

Based on an analysis of the sensors' values, it is possible to evaluate methane release from section H, in which the bump and the resulting rock-burst occurred on 5 May 2018 at 10:58. The analysis reveals releasing approximately 545,000 m^3 of methane into excavations. Thus, the average methane release into excavations from section H was tripled compared to the period preceding the burst [3], which caused the accident discussed here to occur.

4.2. The Area of Longwall IV in Seam 703/1 in Coal Mine Y

The development of longwall IV in the seam 703/1 was being proceeded in the Fourth Category conditions of methane and the Second Degree of rock-burst hazard. A bump occurred on 22 January 2019 at 23:35:41 with an energy of 9.8×10^7 J. It resulted in a rock-burst in the area of crossing a longwall face with a ventilation heading. Figure 9 presents the map of the seam with the highlighted longwall IV with the greenish color. Figure 4, on the other hand, shows the arrangement of the methanometric system's sensors in the workings at longwall IV. Additionally, the figure shows the analyzed sensors marked with a blue rectangle.

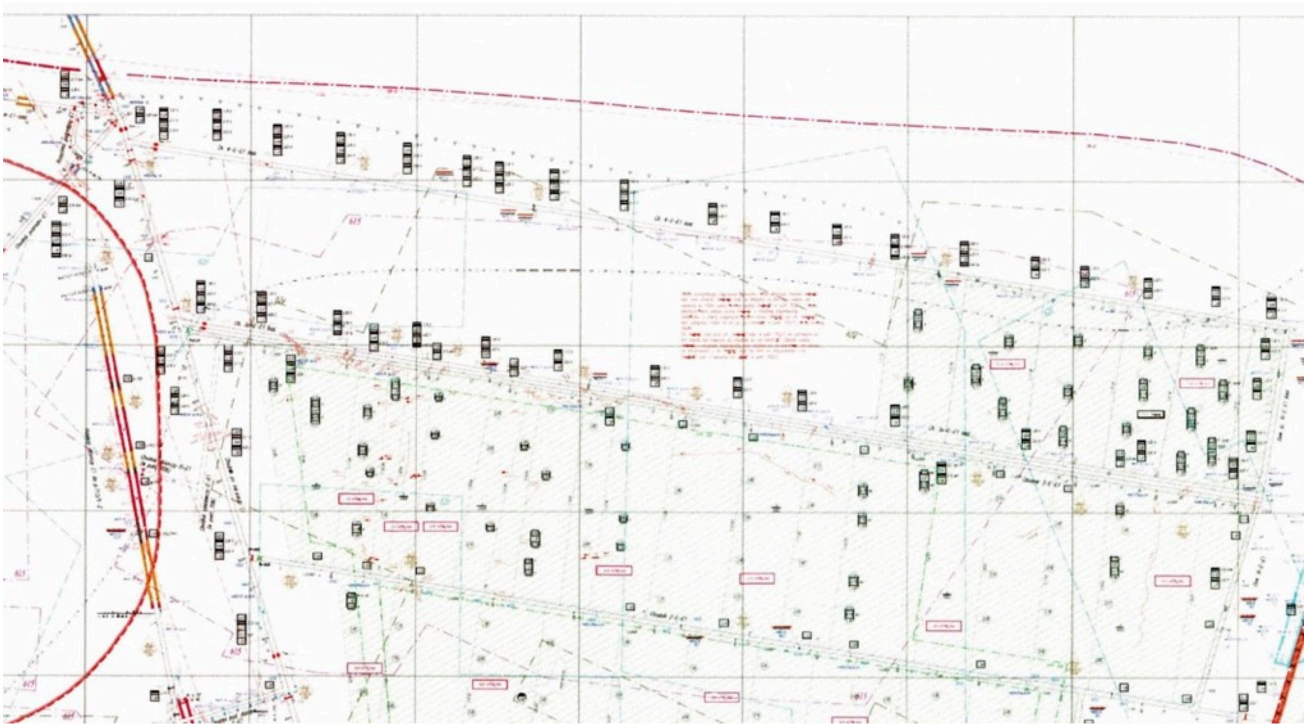


Figure 9. Seam 703/1 with longwall IV.

The data from the automatic methane measurement system's sensors and the airflow balance allowed calculating the section IV area's absolute methane bearing capacity. Before the event, it was equal to 14.47 m^3 CH_4/min, among which the drainage system captured 3.9 m^3 CH_4/min. The remaining 10.57 m^3 CH_4/min was released to the excavation.

The burst caused the longwall's final section and ventilation heading's deformation and, in the end, methane release into the excavation. The accident proved fatal to one employee, working in the crossing area of the longwall and the roadway. The airflow through the longwall excavation was reduced to 30% compared to the one before the burst.

Changes in methane concentration on the sensor in the longwall and roadway presented in Figure 10 clearly show what happened with the methane concentration at the moment of the accident. Sensor G (Figures 4 and 10) recorded a sharp increase in methane concentration from below 0.4% to 5% at the incident. Next, the concentration fluctuated between 2.2% and 4.3%, then it began to drop, reaching a value below 1.5% around 2:00 a.m. Between 4:00 a.m. and 8:00 a.m. on 23 January, methane concentration fluctuated wildly, from 1% to 1.8%. It was not until 8:00 a.m. that concentration dropped significantly below 1.5%.

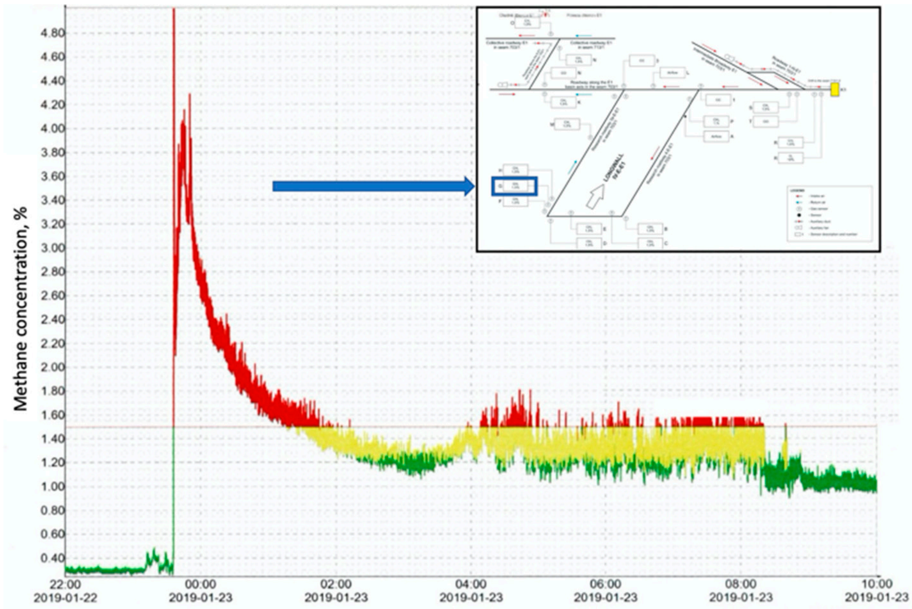


Figure 10. A change in methane concentration after the burst recorded by a CH_4 (G) sensor installed in the Researcher roadway 3a-E-E1 in seam 703/1 at the height of the longwall window (sensor G in Figure 4) [3].

Additionally, in Figure 11, we see the methane concentration changes recorded by sensor M (Figures 4 and 11) in the Research roadway 5 m ahead of a transformer. The highest recorded value was 7%. After a sharp increase at the time of the accident, the concentration began to drop sharply, reaching 2.6% at 4:00 a.m. From now on, it started decreasing more slowly to the value of 1.8% by 10:00 a.m.

The burst caused an additional outflow of 4500 m^3 CH_4 within 12 h, which means that methane release increased by 60% compared to the period before [3].

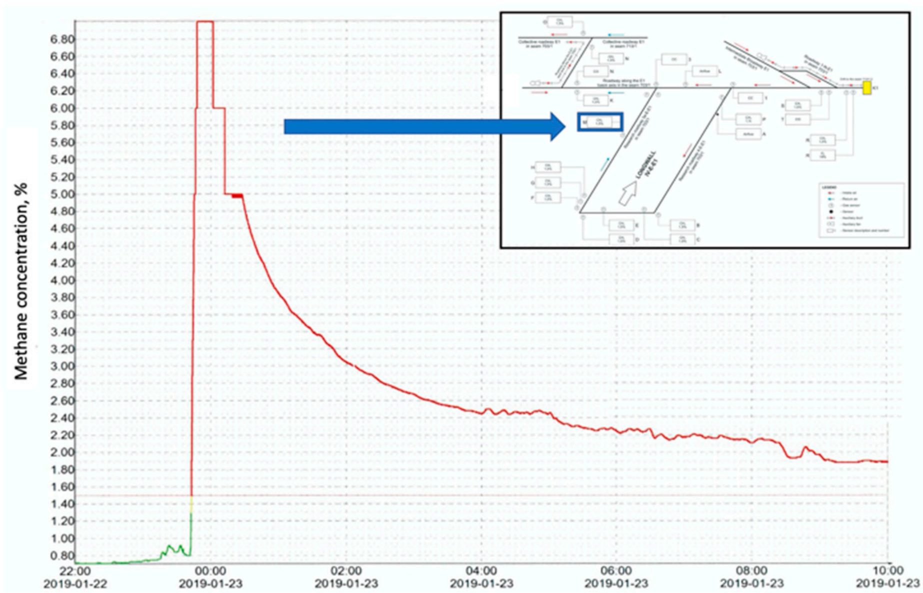


Figure 11. A change in methane concentration after the burst recorded by a CH_4 (M) sensor installed in Researcher roadway 3a-E-E1 in seam 703/1 5 m ahead of a transformer (sensor M in Figure 4) [3].

Both accidents analyzed here involved a bump and a resulting rock-burst, causing a massive outflow of methane into a longwall excavation. The discharge, combined with airflow reduction, led to the removal of oxygen from mine air. Of particular significance is the rock-burst occurrence, which destroyed the excavation structure and changed airflow distribution. The resulting accidents caused seven casualties.

To sum up:

- A bump of high energy in section H caused the rock mass's disturbance and a sudden large emission of approximately 545,000 m^3 of methane into the excavations.
- Such a large amount of methane was undoubtedly influenced by creating a safety pillar protecting the openings into a deposit section (Figure 5).
- In this part, rock mass was not disturbed and the coal mine did not implement any drainage methods.
- The average methane release into excavations after the rock-burst was tripled compared to the period before the burst.
- From 5 August 2018 to 15 August 2018, the sensors' methane concentration changed from 60% to approximately 35% (Figure 8).
- The accident resulted in five casualties.
- A bump in the longwall IV area in seam 703/1 occurred on 22 January 2019 and resulted in a rock-burst in the area of crossing a longwall face with a ventilation heading.
- The amount of air flowing through the excavation decreased by 30% compared to the airflow before.
- The burst caused an additional outflow of 4500 m^3 CH_4 within 12 h, which means that methane release increased by 60% compared to the period before.
- The accident proved fatal to one employee, working in the crossing area of the longwall and the heading.

An analysis of these events provides strong evidence that coal extraction under the conditions of co-existing methane and rock-burst hazards requires implementing methods of forecasting and adequate preventing measures. The implemented measures must be able to prevent rock-burst.

5. Conclusions

The natural hazards existing in mines often aggravate each other, increasing the risks to personnel working in excavations. Both accidents analyzed here involved a bump and a resulting rock-burst, causing a massive outflow of methane into a longwall excavation.

Usually, bumps with energy up to 10^4 J or higher do not pose a potential threat of rock-burst and a sudden outflow of methane. Thus, the prevention methods implemented in coal mines regarding this particular hazard are well designed. Low energy bumps do not cause sudden desorption of methane into the excavation. The most dangerous are high-energy bumps like those which caused accidents in the aforementioned longwalls.

Additionally, creating a safety pillar protecting the openings can cause high methane content in seams, which might be released during the rock-burst. In this part, rock mass is usually not disturbed, which causes creating so-called gas traps. The discharge of methane due to rock-burst, combined with airflow reduction, leads to the removal of oxygen from mine air.

The analysis carried out in the article concludes that it is vital to research on designing and implementing innovative methods of draining methane from coal seams as a preventive method against sudden methane outflows. Undoubtedly it will increase the efficiency of methane capture during mining operations. It is necessary to develop methane drainage procedures to increase the amount of captured methane by drilling boreholes above the extracted seam as the longwall progresses. The implemented method should involve drilling long methane drainage boreholes fitted with pipes, combined with the currently used methane drainage system, particularly at longwalls mined using a U system of retreat longwall mining.

Regardless of the attempts to decrease the amount of methane in coal seams, it is necessary to monitor the rock-mass stresses and maintain ongoing prevention of rockbursts.

Author Contributions: Author Contributions: N.S. developed a concept and methodology for the presentation of research results. J.S. contributed analysis tools, analyzed data, and wrote the paper. All authors have read and agreed to the published version of the manuscript.

Funding: The article was prepared as part of the Subsidy for the Maintenance and Development of Research Potential at Faculty of Mining and Geoengineering AGH University of Science and Technology No. 16.16.100.215.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: Upon authors' request.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Szlązak, N.; Zasadni, W. *Wpływ Zagrożenia Tąpaniami Na Dobór Profilaktyki Pożarowej W Kopalniach Węgla*; Uczelniane Wydawnictwa Naukowo-Dydaktyczne AGH: Kraków, Poland, 2004. (In Polish)
2. Szlązak, N.; Borowski, M.; Obracaj, D.; Swolkień, J.; Korzec, M. Selected Issues Related to Methane Hazard. In *Hard Coal Mines*; Uczelniane Wydawnictwa Naukowo-Dydaktyczne AGH: Kraków, Poland, 2004.
3. Szlązak, N.; Tręczek, S. *Analysis of the Methane Hazard in the Context of a Rock Collapse with Effects in Workings Made in Seams 409/3 and 409/4, Which Occurred on 5 May 2018 at 1058 at JSW S.A. KWK "Borynia-Zofiówka-Jastrzębie" Front "Zofiówka," Taking into Account the Methods Used and Preventive Activities*; Higher Mining Institute: Niger, Niamey, Unpublished document; 2018. (In Polish)
4. Kotarba, M. *Geomechaniczne Kryteria Genezy Gazów Akumulowanych W Serii Węglonośnej Górnego Karbonu Niecki Wałbrzyskiej*; Geologia No. 49; Zeszyty Naukowe AGH: Kraków, Poland, 1988. (In Polish)
5. Czapliński, A. *Węgiel Kamienny*; Wydawnictwo AGH: Kraków, Poland, 1994. (In Polish)
6. Kotarba, M. *Geneza Metanu Występującego W Serii Węglonośnej GZW IDZW*; Wydawnictwo AGH: Kraków, Poland, 1994.
7. Zwietering, P.; Overeem, I.; Van Krevelen, W.D. Chemical structure and properties of coal 13. Activated diffusion of gases in coal. *Fuel* **1956**, *35*, 66–71.
8. Tarnowski, J. *Występowanie Metanu W Złożu Południowej Części Rybnickiego Okręgu Węglowego*; Komunikat nr 541: Katowice, Poland, 1971. (In Polish)
9. Geological Documentation of the "Dębieńsko 1" Hard Coal Deposit in Categories B, C1, C2. Geological and Ecological Company "Grafit". 2007. Available online: https://docplayer.pl/56540786-Ii-interdyscyplinarna-sesja-wyjazdowa-doktorantow-politechniki-slaskiej.html (accessed on 15 September 2008). (In Polish).
10. Krzystolik, P.; Kobiela, Z. Ocena efektywności metod podziemnego odmetanowania złóż węgla kamiennego w Polsce na przykładzie kilku kopalń. *Wiadomości Górnicze* **1999**, *6*, 265–270. (In Polish)
11. Brunner, D.J.; Schwoebel, J.J.; Brinton, J.S. Modern CMM Drainage Strategies. First Western States CMM Recovery and Use Workshop, April 19–20, EPA Coalmine Methane Outreach Program. J.S. 2005. Available online: www.epa.gov/cmop (accessed on 15 September 2008).
12. Coal Mine Staff (Ed.) C.R.—Collective Review: Brzeszcze Mine—Yesterday and today. In *Brzeszcze*; Review; Beskidzka Press Publisher: Brzeszcze, Poland, 2003. (In Polish)
13. Creedy, D.P.; Kershaw, S. Firedamp prediction—A pocket calculator solution. *Min. Eng.* **1988**, *2*, 377–379.
14. De Villiers, A.W. Methane drainage in longwall coal mining. *J. South. Afr. Inst. Min. Metall.* **1989**, *89*, 61–72.
15. Diamond, W.P. *Methane Control. for Underground Coal Mines*; Information Circular 1994; U.S. Bureau of Mines, IC 9395, United States Department of the Interior: Washington, DC, USA, 1994.
16. Fang, Z.; Li, X.; Wang, G.G.X. A gas mixture enhanced coalbed methane recovery technology applied to underground coal mines. *J. Min. Sci.* **2013**, *49*, 106–117. [CrossRef]
17. Karacan, C.Ö.; Ruiz, A.F.; Cotè, M.; Phipps, S. Coal mine methane: A review of capture and utilization practices with benefits to mining safety and to greenhouse gas reduction. *Int. J. Coal Geol.* **2011**, *86*, 121–156. [CrossRef]
18. Kissel, F.N. *Handbook for Methane Control in Mining*; National Institute for Occupational Safety and Health: Pittsburgh, PA, USA, 2006.
19. Krause, E.; Łukowicz, K. Methane drainage in Polish hard coal mines. Achievements and perspectives. In Proceedings of the 11th International Scientific and Technical Conference "Rockbursts 2004", New Solutions in the Field of Preventing Rockbursts and Methane Hazards, Ustroń, Poland, 8–10 November 2004. (In Polish).
20. Noack, K. Control of gas emissions in underground coal mines. *Int. J. Coal Geol.* **1998**, *35*, 57–82. [CrossRef]
21. Szlązak, N.; Kubaczka, C. Impact of coal output concentration on methane emission to longwall faces. *Arch. Min. Sci.* **2012**, *57*, 3–21.

22. Szlązak, N.; Borowski, M.; Obracaj, D.; Swolkień, J.; Korzec, M. Effectiveness of coal mine methane drainage in Polish mines. In Proceedings of the Twenty-ninth Annual International Pittsburgh Coal Conference: Coal—Energy, Environment and Sustainable Development, Pittsburgh, PA, USA, 15–18 October 2012.
23. Whittles, D.N.; Lowndes, I.S.; Kingman, S.W.; Yates, C.; Jobling, S. The stability of methane capture boreholes around a log wall coal panel. *Int. J. Coal Geol.* **2007**, *71*, 313–328. [CrossRef]
24. Roszkowski, J.; Szlązak, N. *Selected Problems of Methane Drainage in a Coal Mine*; Uczelniane Wydawnictwa Naukowo-Dydaktyczne: Kraków, Poland, 1999. (In Polish)
25. Ajruni, A.T. *Prognozirovanie I Predotvraŝenie Gazodinamičeskih Âvlenij v Ugol'nych Šahtah*; Nauka: Moskva, Russia, 1987.
26. Szlązak, N.; Borowski, M.; Obracaj, D.; Swolkień, J.; Korzec, M. *Odmetanowanie Górotworu W Kopalniach Węgla Kamiennego*; Wydawnictwa AGH: Kraków Poland, 2015. (In Polish)
27. Regulation of the Minister of Energy on Detailed Requirements for Operating Underground Mining Plants. 23 November, 2016 Journal of Laws 2017, Item 1118, Warsaw. Available online: https://dziennikustaw.gov.pl/DU/rok/2017/pozycja/1118 (accessed on 15 September 2008). (In Polish)