Characteristics and evolutions of gas dynamic disaster under igneous intrusions and its control technologies

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ABSTRACT

Globally, thermal events related to igneous intrusions are widespread in major coal-producing countries. The occurrence, size and distribution of these events play important roles in coal mining safety. The sill distribution area is relatively large in China, which has a particularly serious influence on the damage of coal seams and mining safety. In the Haizi coal mine, magmatic activity is intense and widely distributed and has resulted in 11 coal and gas outburst accidents under a 120-m-thick igneous sill. To study the effect of sill intrusions and their relationship with gas outbursts, samples from the outburst coal seams (Nos. 7, 8, 9 and 10) were taken from the Haizi coal mine at various distances from the sill. We found that under the effect of entrapment and thermal evolution of the igneous sill, the coal pore structure was developed, the gas adsorption capacity was enhanced, and gas outburst risk was increased. The rules of bed separations evolution under the sill were analyzed which indicated that large separation quantities are developed as gas enrichment areas in the bending zone after mining, which brings dynamic disasters risk and good drainage conditions at the same time. The gas pre-extraction technology for the first mining seam and the pressure relief gas drainage technologies via surface wells and distant penetration boreholes were established. Given the practice in the Haizi coal mine, it was determined that the gas drainage technologies could eliminate gas outbursts and promote mining safety under this unique geologic condition.

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1. Introduction

In China’s long geologic history, magmatic activity has been frequent and widespread since the Yanshan movement in the Mesozoic (Yang, 1996; Yang and Tang, 2000). Igneous intrusion provides a high-pressure and high-temperature environment for coal seams, which promotes the thermal evolution of coal seams, speeds up the generation of gas, and brings enormous changes in coal metamorphism, pore structure, and adsorption-desorption characteristics (Golab and Carr, 2004; Stewart et al., 2005; Wang and Zhang, 2006; Dai and Ren, 2007; Saghafi et al., 2008; Rimmer et al., 2009; Jiang et al., 2011; An et al., 2013). Generally, with the enhanced of coal metamorphism degree caused by igneous intrusions, gas content and gas diffusion rate correspondingly increase (Gurba and Weber, 2001), which often causes safety problems related to gas control in coal mines. Of the numerous coal and gas dynamic disasters worldwide, a large number have been caused by igneous intrusions, including occurrences in South Africa, Australia, Ukraine and China (Anderson, 1995; Saghafi et al., 2008; Jiang et al., 2011; Sachsenhofer et al., 2011).

The distribution area of sill is relatively large in China, which causes particularly serious influence on mining safety. Current research has focused on the rule of bed splitting development under thick hard rock masses via the thin-elastic-plate bending theory, physical simulation, numerical simulation and field measurements (Teng and Yan, 1999; Guo, 2000; Zhao et al., 2002; Wu et al., 2011), as well as associated factors and evaluation indexes (Palchik, 2005; Tan et al., 2013). However, few researchers have investigated the gas disaster evolutions mechanism under the thick sill.
The gas drainage technologies could eliminate gas outbursts and promote mining safety (Noack, 1998; Creedy and Tilley, 2003; Cheng et al., 2009), which are expected to become increasingly challenging as deeper and more gassy coal seams are mined (United Nations ECE and Methane to Market Partnership, 2010).

Nowadays, regional gas control techniques must be firstly adopted before tunneling or mining in outburst coal seams which include protective seam mining and pressure-relief gas drainage for multiple seams and regional gas pre-drainage for a single seam, among which the protective seam mining technology is the most economical and effective method (Brandt and Sdunowski, 2007; SAWS, 2008; Cheng et al., 2009). Effective gas drainage in the adjacent more gassy seams could turn them into less gassy seams, thus realizing the objective of extraction of both coal and gas in a safe environment (Cheng et al., 2009; Wang and Cheng, 2012; Daniel et al., 2013). It is considered that appropriate technologies chosen would be the key for coal mining safety and economy in outburst coal seams.

Igneous rock is dense and hard, has good integrity, and is usually in unconformable contact with the surrounding rock mass. The occurrence, size, and distribution of the intrusive igneous rock play important roles in coal mining safety. When a thick-hard igneous sill exists in the overlying strata, the physical characteristics of the underlying coal seams change, and the collapse and failure development rules take on new meanings, which could increase the risk of gas outbursts in the underlying coal seam. Based on theoretical analysis, laboratory testing, and field observations, we analyzed gas disaster characteristics and evolutions rules under the igneous sill in the Haizi coal mine. Gas control methods for safe and high efficient exploitation of coal and gas were proposed and tested. The research results could provide useful references for gas dynamic disaster control under similar geologic conditions.

2. Geological setting

The Haizi coal mine is located in the north of the Linhuan mining field in the Huaibei coal field, Anhui province, China, and its designed production capacity is 1.2 million tons per year, with a mining depth ranging from 500 to 1025 m. The Nos. 7, 8, 9 and 10 coal seams are the primary mineable coal seams. Since the early period of the Indo-China movement, the depth of coal seams in the Haizi coal mine has reached about 3000 m. Coal seams were affected by hypozonal metamorphism and the degree of coalification reached gas or fat coal stage (maximum vitrinite reflectance \( R_{\text{max}} \) ranged from 0.7% to 0.9%), which then entered the main period of gas generation (the primary generation) with the amount of generated gas reaching 220 m³/t. Strata of this area were uplifted after the Indosinian tectonic movement. During the early-middle period of Yanshan, magmatic activity has become more widespread in the Huaibei coal field, and deep crustal magma gushed along the Su-Bei Fault and intruded into the Haizi coal field along the Daliju Fault (Yang, 1996). The thick igneous rock that intruded the No. 5 coal seam had a great influence on the underlying coal seams due to a temperature of approximately 300 °C. This regional thermal metamorphism increased the coalification degree of the underlying coal seams, which were turned into the stages of coking coal, lean coal, and even antrachite (\( R_{\text{max}} \) ranged from 2% to 2.8%). Meanwhile, coal seams generated large amounts of gas for a second time (Secondary generation), with the amount of generated gas reaching 340 m³/t. The coal seam gas generation history of the Haizi coal mine is shown in Fig. 1.

The igneous rock is distributed as a sill in the middle and western part of the Haizi coal mine, as shown in Fig. 2, and its strike is 6.5 km long. This igneous sill is in a stable condition in the I102 mining area above the roof of the No. 7 coal seam and is usually more than 120 m thick. The rock is mainly diorite and diorite-porphyrite and appears as either light gray or green—gray with a plaque-like structure, which is clearly shown in the whole-block structure characteristics.

3. Gas disaster characteristics under the sill in the Haizi coal mine

The study of the mechanisms of coal and gas outbursts is at the qualitative comprehensive effects hypothesis stage, and the argument is that an outburst is caused by comprehensive effects, including ground stress, gas and the physical mechanical properties of coal (Yu, 1979, 1992). In the Haizi coal mine, magmatic activity is intense and widely distributed which has brought great influence on coal, gas and ground stress, and has resulted in 11 gas outburst accidents under a 120-m-thick sill.

3.1. Coal structure characteristics under the sill

Four samples were collected in the Haizi coal mine from the No. 86, I102 mining areas which were covered by the sill, and one sample was chosen from the normal region (I101 mining areas) without sill covering for comparison. The test results showed that thermal evolution effect of igneous intrusions promotes coal metamorphism (Fig. 3). Generally, the \( R_{\text{max}} \) increases with depth, whereas the \( R_{\text{max}} \) of Nos. 7, 8, 9, and 10 coal seams become smaller with increasing distance from the sill, mainly due to thermal metamorphism. However, the vitrinite and \( R_{\text{max}} \) of the coal sample, collected from the I101 mining area without sill covering, are smaller than the area covered by the sill.

The high temperature baking effect of the sill on the underlying coal seam makes the number and scale of stomata in coal significantly increase. The stomata are mainly elongated linear, honeycomb or flower-shaped pores, and their number, pore diameter, pore axis and the porosity of coal increase with the duration time and increasing temperature. Meanwhile, the thermal stress generated by thermal expansion and the tensile stress generated by contraction of organic volatile matrix in local area superimpose and accelerate the formation and expansion of micro-cracks in the coal

![Image](image-url)
(Wang et al., 2008). Closer to igneous sill, porosity and specific surface area of coal samples increase, and the number and scale of the pyrolysis holes obviously increase in the Haizi coal mine (Fig. 3). As shown in Fig. 4, the sample of the No. 7 coal seam contains a large number of pyrolysis holes which the maximum diameter is approximately 30 μm. A few holes appear in the No. 10 coal seam collected from the II102 mining area with the maximum diameter approximately 4 μm. However, a sample from the II101 mining area uncovered by the sill is unaffected by the thermal metamorphism, and few stomas appear.

Besides, under the condition of a high baking temperature, the coal consistent coefficient ($f$) was reduced below 0.5 which was easily crushed to powder in the soft seam and took on the typical characteristics of “tectonic coal”.

### 3.2. Gas pressure and gas content under the sill

Igneous sill is considered an impermeable rock bed with an extremely low permeability (Qiao et al., 2011). With the existence of the sill in the Haizi coal mine, all of the underlying coal seams’ gas adsorption capacity increase, the gas pressure and content increase, as shown in Fig. 5 and Fig. 6. Beneath the sill, the gas pressure and gas content become larger. The gas pressure gradients of the middle coal seam group (Nos. 7, 8, 9 coal seams) are larger than the pressure of the No. 10 coal seam which is 200 m deeper. And gas content of the middle coal seam group is larger than 8.8 m³/t, which is obviously larger than the content of the No. 10 coal seam and had exceeded the outburst critical value 8 m³/t (Wang et al., 2012).

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**Fig. 2.** Sampling locations and sills distribution in the Haizi coal mine.

**Fig. 3.** Physical parameters of the coal samples.
The gas parameters of the tests conducted in the II101 and II102 mining areas are shown in Table 1. During the mining of the No. 10 coal seam, calculated gas pressure ranged from 0.4 to 2.07 MPa, gas content ranged from 4.56 to 10.03 m³/t, and average absolute gas emission was 19.02 m³/min in the II101 mining area (without sill covering). Whereas in the II102 mining area (covered by the sill), the gas pressure ranged from 1.02 to 3.46 MPa, gas content ranged from 8.12 to 19.3 m³/t, and average absolute gas emission was 27.71 m³/min. Moreover, a gas outburst accident occurred in the II102 mining area, and the limit amount of gas absorption (Langmuir volume) in the II102 mining area is much larger than in the II101 mining area.

3.3. Stress distribution under the sill

Among the main comprehensive factors of coal and gas outburst, high ground stress is the primary and necessary condition for outburst (Zhu, 1997; Chen et al., 2013; Guo et al., 2012; Wang et al., 2014). The igneous intrusions produce additional tectonic stress and thermal stress on nearby coal-rock masses that destroy surrounding rocks and change the ground stress distribution. The stress distribution at two ends of the workface goaf changed under the sill, and the stress concentration value and range increased, numerical simulation calculation results based on geological conditions in the Haizi coal mine are shown in Fig. 7 (Wang, 2009). It is well known that the geological structure and mining stress concentration zones are the key zones for outburst. Given the increase in stress concentration around the stope, covered by the sill, the gas outburst risk also increased.

3.4. The influence of the sill on gas occurrence and gas outburst

The high baking temperature and pressure caused an increase in the metamorphic grade and the number of micro-pores of the coal seams under the sill, enhanced gas absorption and generated large amounts of gas. Given the extreme thickness and low permeability of the sill in the Haizi coal mine, it could trap the gas and provided excellent conditions for gas storage as a natural barrier for gas migration. The intrusion stress of the thick sill imposed additional stress on the underlying coal seams, which formed a soft-coal layer that was easy to crush into powder. Under these multiple functions of
gas and stress, coal seam gas content, gas pressure, and gas emission rate increase, it became easier for coal and gas outbursts to occur. There were 11 gas outburst accidents from 1984 to 2009, of which there were five in the No. 7 coal seam, five in the No. 8 coal seam, and one in the No. 10 coal seam, as shown in Table 2. All of the outburst sites are located under thick-hard sill. Compared with each previous outburst, we found that the frequency and relative gas emission amount generally tended to decrease as the distance from the sill increased, which could indicate that the outburst risks of Nos. 7 and 8 coal seams are much greater than that of the No. 10 coal seam.

4. Gas disaster evolutions during the protective seam mining

4.1. Pressure relief gas storage and transportation characteristics

All of the coal seams present an outburst risk with high gas pressure and content under the igneous sill, and the No. 10 coal seam with a relative lower gas outburst risk provides a lower protective seam for Nos. 7, 8, and 9 coal seams in the Haizi coal mine. Given the extreme thickness, large compression strength (144.21 MPa) and integral structure of the sill, the sill is considered as the main key stratum of the coal mine (Qian et al., 1996; Miao et al., 2005; Xu et al., 2005; Wang et al., 2010). After the protective seam was mined, the thick sill stopped the upward movement of the overlying strata and prevented subsidence. A few vertical fractures and large quantities of bed separations were not completely closed at the roof and floor of the protected seams (Wu et al., 1997; Zhao et al., 2002; Wang et al., 2010), as shown in Fig. 8. The sill controls the entire overlying strata movement and will not subside or break for a long time after the protective seam mining. The pressure relief effect is generally better than normal under these special geologic conditions (the coal-rock mass permeability greatly increases and the stroke resistance of the gas flow largely decreases). In addition, the fractures and bed separations become good channels for gas migration. Gas can then continuously flow into the separations along several vertical fissures with the concentration difference as the driving force. The separation zone in the bending zone is the region of gas enrichment, where pressure relief gas is accumulated from the protected coal seams, as shown in Fig. 8. All of these data provide a theoretical basis for pressure relief gas drainage under these special geologic conditions.

Table 1

<table>
<thead>
<tr>
<th>Number</th>
<th>Sampling location</th>
<th>Gas pressure (MPa)</th>
<th>Gas content (m³ t⁻¹)</th>
<th>Total amount of absolute gas emission (m³/min)</th>
<th>Adsorption constants</th>
<th>Dynamic situation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Langmuir volume (m³ t⁻¹)</td>
<td>Langmuir pressure (MPa)</td>
</tr>
<tr>
<td>1</td>
<td>II102</td>
<td>1.02–3.46</td>
<td>8.12–19.3</td>
<td>27.71</td>
<td>31.6753</td>
<td>0.9586</td>
</tr>
<tr>
<td>2</td>
<td>II101</td>
<td>0.4–2.07</td>
<td>4.56–10.03</td>
<td>19.02</td>
<td>19.3298</td>
<td>1.1477</td>
</tr>
</tbody>
</table>

Fig. 6. Variations of coal seam gas content measured from surface well in the Haizi coal mine.

Fig. 7. Stress distribution around the stope of the No. 10 coal seam working face (modified from Wang, 2009).
4.2. Calculation of gas volume and pressure in bed separations

The deflection of coal or rock can be calculated by the Ritz method, which is based on the plate theory (Wang, 2009), as shown in Fig. 9. The space of the bed separation can be described according to the deflection difference between two adjacent strata, which is shown as follows:

\[
\Delta w = \frac{\frac{q_2}{D_2} - \frac{q_1}{D_1}}{\frac{3}{\pi^4} \left( \frac{3}{a^2} + \frac{3}{b^2} + \frac{2}{a^2 b^2} \right)}
\]

\[
\Omega_{\text{Total}} = \sum \frac{ab}{4\pi^4} \left( \frac{\frac{q_2}{D_2} - \frac{q_1}{D_1}}{\frac{3}{a^2} + \frac{3}{b^2} + \frac{2}{a^2 b^2}} \right) = \sum \frac{1}{4} ab \Delta w
\]

where \(\Delta w\) is the deflection difference between two adjacent strata; \(a\) is the length of the plate; \(b\) is the width of the plate; \(q\) is the uniform load above the plate. \(D = Eh^4/12(1 - \mu^2)\), which is the flexural rigidity; \(E\) is the elasticity modulus; \(\mu\) is the Poisson's ratio; \(h\) is the thickness of the plate.

For calculating gas volume and pressure in bed separations, the following assumptions were applied to simplify the model: (1) the gas pressure in bed separations and pressure relief coal seams were equivalent due to the interconnected crack between bed separations and middle coal seams; (2) the gas that gushed from middle coal seams to the goaf of the No. 10 coal seam was disregarded; (3) only pure gas existed in the bed separations without any other liquid or solid. Gas content equation and mass conservation equation are used for calculating gas volume and pressure in separations. The equations are shown as follows,

\[
\begin{align*}
X &= \frac{Vp T_0}{P_0 \gamma} \frac{a b^2 p}{1 + b^2 p} e^{n(t_0 - t)} \left( \frac{1}{1 + 0.31 W} \right) \\
\sum Xm &= X' m + Q
\end{align*}
\]

where \(X\) is the original gas content of middle coal seams, \(m^3/t\); \(X'\) is the pressure relief gas content of middle coal seam, \(m^3/t\); \(m\) is the mass of coal seam, tons; \(Q\) is the gas reserve in the bed separation, \(m^3\); \(V\) is the pore volume of unit coal mass, \(m^3/t\); \(n\) is a coefficient, \(n = 0.02/(0.993 + 0.07 p)\); \(p\) is the gas pressure in the coal seam or bed splitting, MPa; \(T_0\) and \(p_0\) are the absolute temperature and pressure, respectively, in standard state, K and MPa; \(\gamma\) is the gas compression coefficient; \(a\) is the Langmuir volume of coal, \(m^3/t\); \(b\) is the reciprocal of Langmuir pressure, MPa^{-1}; \(t_0\) is the lab temperature, K; \(t\) is the coal temperature, K; and \(A\) and \(W\) are the ash content and water content of coal, respectively, %.

Characteristics and occurrence of coal seams in the Yangliu coal mine are similar to the actual in the Haizi mine. At 5 PM on July 17, an accidental ejection of gas and water from the surface well over working face 10414 in the Yangliu coal mine under the two thick
igneous rocks, the duration of the accident was 33 h and 30 min and volumes of ejected gas and water were 166.4 km³ and 7.8 km³, respectively (Fig. 10). Based on the theoretical calculation equations, the geological condition and gas occurrence condition in the Yangliu coal mine (Table 3), the absolute gas pressure and gas volume in the bed separation were calculated as 1.01 MPa and 431.2 km³, respectively, which corresponded with the accident situation.
5. Safe and high efficient exploitation of coal and gas under the sill

For the different distributions of geological structures and coal seam occurrence, and difference grades of gas dynamic disaster, the corresponding regional gas control technologies are also inconsistent. The appropriate technologies chosen in different zones and grades would bring the economy and safety of gas control. According to the occurrence of igneous sills, gas occurrence and gas disaster grade (generally divided by the gas pressure value from the mining practices) in the Haizi coal mine, we have optimized regional gas control technologies comprehensively, as shown in Fig. 11.

5.1. Gas pre-drainage technology applied to the first mining seam

In the Haizi coal mine, the No. 10 coal seam was chosen as the first mining seam, namely the protective seam. With the mining depth increasing, the outburst risk of the No. 10 coal seam increased significantly. According to the distribution of igneous sills and the grade of gas disaster, regional gas control technologies were categorized and appropriately adopted in different hazardous areas to improve the economy and safety of gas control for the No. 10 coal seam, as shown in Fig. 12.

Regional verification work should be strengthened in non-outburst risk area. When the coal seam original gas pressure of the working face in outburst risk area is smaller than 3.0 MPa (Fig 12a), we drill grid penetration with spacing 5 m to extract gas from the coal roadways and their two sides with a minimum of 15 m firstly until the gas pressure and gas content decreased below critical values (0.74 MPa and 8 m$^3$/t, respectively) for safely tunneling. After the coal roadways were mined and the negative pressure ventilation system was created, the bedding boreholes with spacing 3–5 m along coal seam for gas pre-drainage of the coal mass inside the working face could be used. When the gas pressure is equal or larger than 3.0 MPa (Fig 12b), we could drill grid penetration boreholes from the rock lane in the floor roadway to reduce gas pressure below 3.0 MPa firstly, with borehole spacing 5 m and 10 m for the coal roadway area and whole inside working face respectively. Then the bedding boreholes method could be used for draining the coal seam gas inside the working face.

5.2. Pressure relief gas drainage technologies under the sill

The permeability of Chinese coal seams is usually a magnitude of $10^{-4} - 10^{-3}$ mD, which is four orders of magnitude lower than the U.S. and three orders of magnitude lower than Australia (Wang and Cheng, 2012; Karacan et al., 2011). In China, the gas content and primary reservoir pressure is lower and coal rank is relatively higher which results in poor effect of using the fractured surface well for pre-drainage (Lou et al., 2013). By using the mining effect of the protective seam (i.e., the No. 10 coal seam), the ground stress of adjacent overlying coal-rock masses is relieved, the unloading coal-rock masses are damaged and fractured, and the coal seam permeability increases significantly, which provides good conditions for high-efficiency gas drainage (Cheng et al., 2004; Zhou et al., 2011; Kamalaldin, 2012; Chen and Cheng, 2013). With the existence of the gas enrichment region under the special geologic conditions in the Haizi coal mine, the surface well and distant penetration boreholes for draining pressure relief gas can be established after protective seam mining, as shown in Fig. 13a.

Fig. 13b shows the variation in the amount of gas drainage vs. time from the No. 1 surface well drilled in the II1017 working face of the Haizi coal mine. We can see that maximum amount of gas drainage reached 11 m$^3$/min and the concentration was 60%, and during the period from day 29 to 195, the amount of gas drainage remained stable at approximately 6.34 m$^3$/min and the concentration remained at 35.6%. Records show that the drilling boreholes

![Fig. 11. Appropriate regional gas control technologies chosen in different hazardous areas in the Haizi coal mine.](image-url)
drained 3.23 Mm³ gas from March 2005 to June 2006. The rate of gas drainage reached 72% in the middle coal group, where the gas drainage radius was over 300 m.

Fig. 13c shows the variation in the amount of gas drainage vs. time from the No. 1 borehole drilled in the 5th drilling field in the II1021 working face of the Haizi coal mine. At the stable period (from days 47 to 118), the amount of gas drainage remained stable at approximately 4.6 m³/min, and the concentration remained at 90%. Records show that the drilling boreholes drained 4.86 Mm³ of gas from March 2006 to March 2007. The rate of gas drainage reached 73% in the middle coal group, where the gas drainage radius was over 100 m. The measured gas pressure of the No. 7 coal seam within the pressure relief area in the II1021 workface decreased from 1.6 MPa to 0.4 MPa after five months of drainage, which was less than the critical value of 0.74 MPa and indicated that the outburst risk of the middle coal group was eliminated.

6. Gas control effect of the Haizi coal mine

Utilizing gas control methods in the Haizi coal mine, the annual output has increased steadily in recent years, the death rate per
millions of tons has decreased gradually, and the mine has been safely mined for two consecutive years, as shown in Fig. 14.

The utilization of coal mine methane (CMM) spurs methane drainage, promotes mining safety, and reduces greenhouse methane emissions, which shows that the flaring of every cubic meter of methane could reduce 15.9 kg of CO₂-equivalent emissions (Cheng et al., 2011). As a mine involved in the Clean Development Mechanism (CDM) projects, the Haizi coal mine has strengthened methane utilization by using an electrical generation system with an installed capacity of 3500 kW. From 2008 to 2012, the rate of gas drainage and utilization increased to 63% and 67%, respectively, the total amount of gas drainage and utilization reached approximately 60 Mm³ and 38.60 Mm³, respectively, and the amount of electrical generation reached 50.86 million kilowatt-hours, which is shown in Fig. 15. Calculations indicate that as much as 613.7 thousand tons of CO₂ emission reduction could be achieved.

7. Conclusions

1) A 120-m-thick igneous rock is located over Nos. 7, 8, 9, and 10 coal seams which is distributed as a sill that intruded along the No. 5 coal seam in the middle and western part of the Haizi coal mine. With increasing distance from the sill, the coal metamorphic grade, number of micro-pores, and specific surface area for each seam gradually decreased. Under the effect of thermal evolution and entrapment of the sill, the underlying coal seams generated a large amount of gas, the gas adsorption capacity was enhanced, and the risk of gas outburst increased.

2) The rules of bed separation evolution under the igneous sill were analyzed which indicated that large quantities of bed separations are developed as gas enrichment areas in the bending zone while the thick sill does not break for a long time after mining. On the basis of theoretical analyses and numerical calculations, the separation gas volume and pressure can be obtained, which shows an ability of ejection gas and water from the surface well under the special condition.

3) According to the coal seam occurrence, distribution of igneous sills and the grade of gas disaster, regional gas control technologies were categorized and appropriately adopted in different hazardous areas. Under the sills, pressure relief gas drainage technologies via surface wells and distant penetration boreholes with a large drainage radius, were proposed and applied. Given this practice in the Haizi coal mine, it was found that gas drainage technologies could eliminate gas outburst and promote mining safety under these special geologic conditions.

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