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Investigating the effect of fractures on unusual gas emission in coal mines; case study of Parvadeh coal mine, Iran

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ABSTRACT

In the present study, an investigation was carried out on Parvadeh coal mine in Tabas, Iran, to survey the effect of fractures on unusual methane gas emission in coal mines. This coal mine was chosen to be investigated because of its high methane gas content in the coal body and available data from sensors in desired locations. Gas concentration monitoring programs were carried out at the mine site and a large amount of data were collected and analyzed. It is revealed that there is a good correlation between excavating the fracture-bearing faces and high methane gas emission events at the mine site. High gas emissions have been observed before, during, or after excavating the fracture-bearing faces. When gas content is high and all boundary conditions are met, rockbursts, faults movement and also mining activities can trigger unusual gas emission, and sometimes the gas gushes are violent enough to fit into the category of gas outbursts. Since the fracture generation is happening before the increase of gas concentration in the air, a sensitive and highly accurate microseismic monitoring system can be used to detect locations of rock fracturing, thus provide an effective means to issue warnings of high gas emission in the working area.

Keywords: *Coal mine; Fracture; Gas outburst; Parvadeh; Unusual methane gas emission*

1. Introduction

Coal has the largest fossil fuel resources in the world, with proven reserves that are adequate to meet the expected demand, without much increase in production costs [1]. Coal deposits contain mine gas mostly methane in quantities which are functions of the degree of coalification and permeability of the overburden rocks. When influenced by mining activities, this gas is emitted into the coal mine [2]. Coal is a porous material that contains gases such as methane (CH_4) and carbon dioxide (CO_2), nitrogen (N_2), hydrogen sulphide (H_2S), and sulphur dioxide (SO_2), but the major composition is CH_4 and CO_2 [3]. The amount of coal mine methane generated at a specific operation depends on the productivity of the coal mine, the gassiness of the coal seam and any underlying and overlying formations, operational variables, and the geological conditions [4]. The amount of methane gas that can be stored in coal seams varies from 0.0003 to 18.66 m^3/t, and up to 25 m^3/t [5]. As mining activities disturb the balanced state of stress and gas pressure in the coal body, rocks can fail and as a result gas can emit into the opening. There are two types of gas emission in coal mines including normal and unusual. Normal gas emission usually happens uniformly in the temporal and spatial spaces. The highest gas emission can be expected when coal is extracted so that the normal gas emission rate is usually proportional to the production rate. Gas outburst, the extreme of unusual gas emission, is a sudden ejection of gas, coal and rock from a coal face and surrounding strata. An outburst is mainly due to the release of internal energy stored in the coal seam [6]. Gas outbursts, characterized by the abrupt release of high density and large volumes of gases at certain locations in a mine, have been the cause of major disasters in the coal mining industry [7, 8].

Methane associated with a gas outburst usually cannot be diluted quickly by ventilation and can be ignited either by open lights, smoking, and sparking from mining equipment. Methane mixtures are explosive in the range of 5 to 15% in the air [3]. There is a certain minimum gas content that must be present if a gas outburst is to occur in a coal seam [9]. This critical value depends on the overall strength of the coal seam or part of the coal seam, permeability of the coal seam, and other geological conditions associated with it. In general, a gas content greater than 8 to 9 m^3/t is considered high enough to initiate an outburst if other conditions, such as coal and rock properties and mining-induced stress, are favorable [5, 9].

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Although the precise mechanism of gas outbursts, with respect to the gas/coal/rock system, is still unresolved, many researchers agree that the most important factors that influence the occurrence of gas outbursts are:

- Gas content in the coal seam,
- Tectonics or geological disturbances,
- Properties of the coal and rock,
- And mining-induced stress state in the coal seam and rock.

When all four factors are combined to create a critical condition, gas outbursts and/or rockbursts will result. Without a gas content that reaches a critical level, gas outbursts cannot happen. When the gas content and the ratio of insitu stress magnitude to coal/rock strength are high, a mining development can alter the stress field thus triggering a gas outburst [3, 10].

In this study, an important feature of coal seam disruption due to fractures has been studied in detail. As will be seen from case histories of unusual gas emission in Parvadeh coal mine in Iran, it seems that there exists a good correlation between the excavating fracture-bearing faces and gas unusual emissions or outbursts.

2. Unusual Gas Emission and Fractures

In the 18 December 2012, the Parvadeh underground coal mine in Iran faced a fatal accident in which 8 workers died. Unfortunately lack of data in that time period made us to use data from earlier period to investigate on issue and try to extend the results. Most of such accidents happen at small mines owned by private companies all over the world that have a poor management and do not care about the safety regulations which can be considered as the main reasons of events. However, the unusual methane gas emissions in several cases coincidentally happened at the time when reaching to fracture-bearing faces including joints, faults or even face and butt cleats while excavation. Fractures and failure in coal often trigger the emission or outburst of gas (methane etc.), which flows through the fractured rock strata into the opening, from the adjacent coal seams [11]. Thus a correlation between the occurrence of gas outbursts and excavation in fracture-bearing faces is expected. Large amount of methane gases can erupt into the openings damaging the gas monitoring and ventilation systems. Sparks can also be generated due to the collisions of rocks and equipment leading to possible gas explosions. This phenomenon is one of the major causes of coal mine casualties in recent years and the governments and the coalmining industries are strongly recommend to work together to address this challenge.

As will be discussed, the case histories show the linkage between the coal mine unusual gas emission and natural faults activities. Actually, the occurrence of an unusual gas emission/outburst event and facing a fault can be totally independent, but so many other coincidences have to be considered. Perhaps, something accidental may contain certainties. Although there is no established correlation between faults and gas explosions, facing fractures is considered to be one of the major factors that lead to unusual gas emissions in coal mines.

3. Geological Setting of Parvadeh Coal Mine

There are two main basins of coal resources in Iran including one in northern and another in the central Iran which are well known as Alborz and Central basins, respectively. Tabas coalfield is a major contributor to Iran metallurgical coking coal deposits which is located in Tabas block in Central Iran [12]. It is divided into different sub-zones namely Parvadeh, Nayband and Mazinu [13]. The Tabas block is bounded to the east by Nayband right-lateral strike slip fault and to the west by the Kalmard-Kuhbanan right-lateral strike slip fault [14]. The general trend of folds and faults at east of this area is E-W (azimuth of 95°-100°), while at west is N-S. The E-W folds (fault related folds) developed as a result of movement on the E-W faults, which are branches of the greater Nayband fault. Structural elements of this area formed in a simple shear system, which was strongly oblique-convergent [15].

The coal bearing strata of the Tabas coalfield consists mainly of sediments of the upper Triassic-middle Jurassic age including Nayband formation and Ghadir member with major coal zone thickness of approximately 100 m. Coal seams in this zone are trended SE-NW with a dip direction to SW. They outcrop for approximately 6.5Km. Coal seams in this region are affected by a faulting system striking E-W that has moved coal seams vertically. This movement seldom rises to 5 m and in some case, no movement can be seen and just some fractures or cracks are visible. Coal seams are mostly low dipped (7°-9°) but seams around outcrops and faults margin have high dips (20°-25°). The proved reserve in this region is estimated to be 820 million tones and the average gasification of seams is approximated 14 m^3/t.

Parvadeh coal deposit in the middle of Tabas coalfield is located about 75Km south of Tabas, Central Iran where the climate is hot and dry. This deposit is structurally a long anticline which orients E-W. The study area is one of the very active and complicated areas from the viewpoint of tectonics and seismicity in Iran. Sediments in this area form vast platforms with low dip. The low dip and impervious structure of them cause low porosity and permeability and hence accumulation of methane gas in depth.

The Parvadeh region includes six zones named A, B, C, D, E and F divided by major faults. The B and C coal zones are minable based on their quality and quantity. B2 and C1 are the major coal seams in these zones [12] as C1 is shown in Figure 1. Rock units in this region include siltstone, sandstone, shale, sandy siltstone and limited limestone and ash coal.

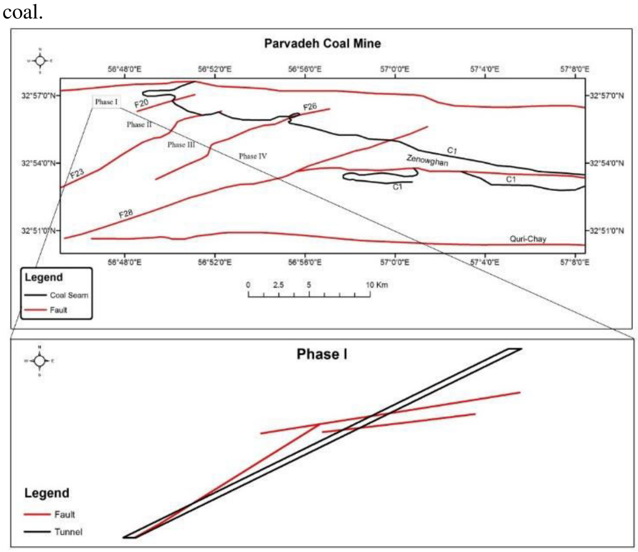

Figure 1. The location of Parvadeh coal mine and the target tunnel (Named Slope-1).

4. Results and Discussion

4.1. Gas Emission Monitoring

Monitoring system is comprised of a surface control station, underground branch stations, electricity supply, sensors, mining equipment control system, and software system. Continuous methane gas concentration monitoring is conducted at the faces, mined areas, and ventilation exits, at a sampling frequency of 5 reading/min. The accuracy of gas concentration monitoring is 0.1% and gas ventilation systems control gas concentration in the air. Gas in the coal seam is drained through pumping before, during, and after mining.

Gas drainage is conducted in real-time at the face. According to the regulations of methane gas control in Parvadeh coal mine, the electric drills are not permitted to be used when the gas concentration in the airflow reaches 1.0%, and operation has to be halted when it reaches 1.5%. Consequently, the methane gas safety limit is 1.0%.

4.2. Fracture Effect on Unusual Gas Emission

A fracture forms a discontinuity that may have a large influence on the mechanical behavior (strength, deformation, etc.) of soil and rock masses in tunnel, foundation, or slope construction [16]. In this study, methane gas concentration before, during and after excavating the fracture-bearing faces in target tunnel (crossed by three faults) located in phase one of Parvadeh coal mine was considered and data from the nearest sensor to the excavation face were selected for the investigation. Geologic cross sections of the excavation faces were also provided daily by geologists. Typical curves of methane gas concentration variation with related geologic cross sections of excavation faces are presented in Figure 2 and Figure 3. Gas concentration fluctuations is presented in graphs related to the mining activities and the time of excavating the fracture-bearing faces.

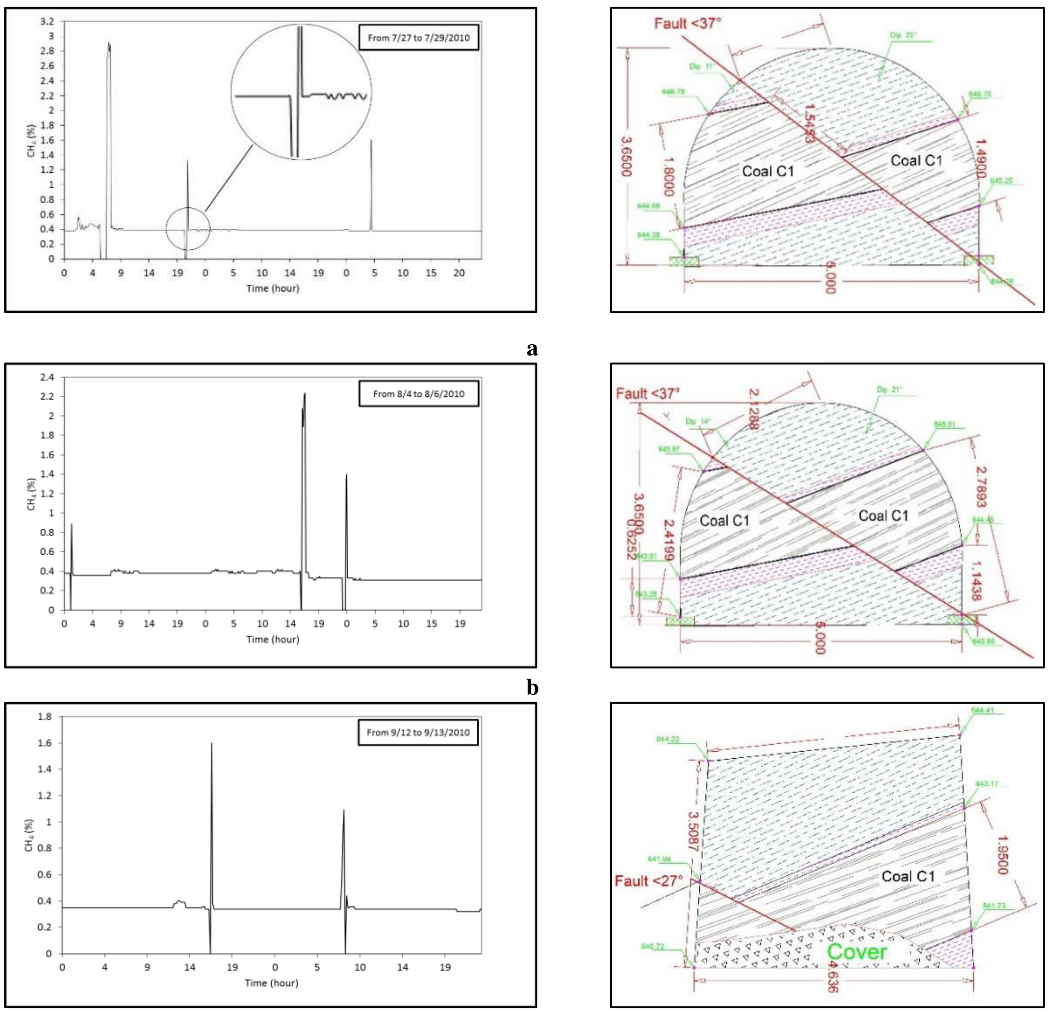

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Figure 2. Methane gas concentration variations and related geologic cross sections at mining face of Parvadeh coalmine: (a) from July 27 to 29, 2010; (b) from August 4 to 6, 2010; (c) from September 12 to 13, 2010. One important phenomenon observed in presented cases is the decrease of gas concentration before starting to excavate the fracture-bearing faces.

Gas concentration increases substantially right after excavating the fracture-bearing faces. One important phenomenon observed in some cases is the decrease of gas concentration before starting to excavate fracture-bearing faces (Figure 2). About 10 to 30 minutes after beginning the excavation, the gas concentration decreases and during excavating coal, gas concentration increases rapidly 10 to 30 min thereafter. It should be pointed out that the decrease of gas concentration right before the excavation is not universal, as observed and shown in Figure 3.

In contrast with graphs shown in Figure 2, there is no reduction in gas concentration right before excavation. The methane gas concentration is usually several times higher than the background value before, during, or after excavating the fracture-bearing faces in mining area; the magnitude of concentration depends on the number of fractures and intersections, their direction and also length. Afterwards, the methane gas concentration returns to the background value due to approaching to the non-fractured zone and maybe stopping the mining operation. High methane gas concentration is generally associated with excavating the fracture-bearing faces and also in some cases, seismic events [3]. The correlation is objective and supported by good repetition in the monitoring records, so that increasing in fractures causes more gas emission.

Recorded methane gas concentration in a period of two months for target tunnel from 11 July to 11 September 2010 is presented in Figure 4. The average concentration of emitted gas was relatively low and stable during excavating in non-fractured faces, and some fluctuations are observed while excavating in fractured faces.

It is seen from the insitu experimental results that under certain conditions, there is a good correlation between unusual gas emissions and excavating the fracture-bearing faces. Unusual gas emission can happen before, during, or after excavating a fracture-bearing face and high gas emission during that can be very dangerous, because it is very easy to cause a gas explosion.

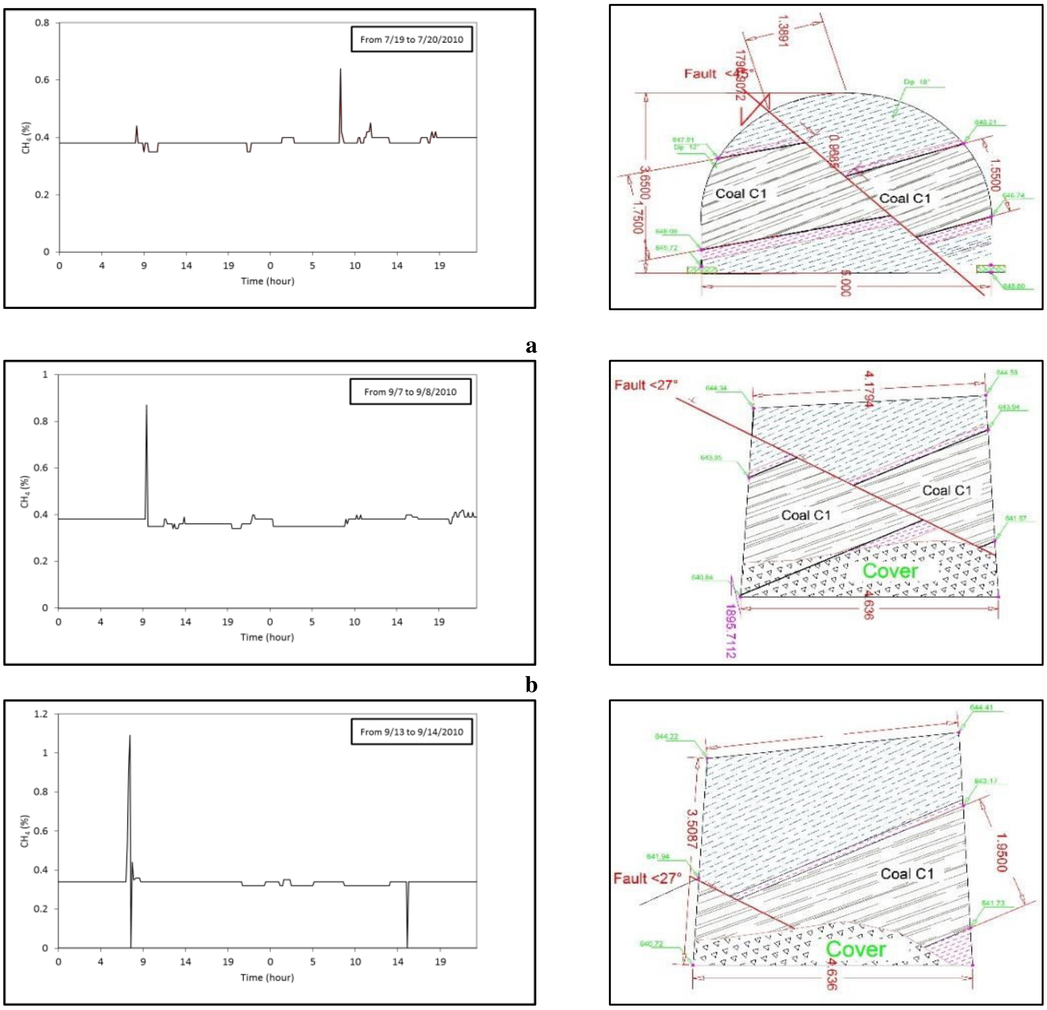

Figure 3. Methane gas concentration variations and related geologic cross sections at mining face of Parvadeh coalmine: (a) from July 19 to 20, 2010; (b) from September 7 to 8, 2010; (c) from September 13 to 14, 2010. No reduction in gas concentration observed in presented cases.

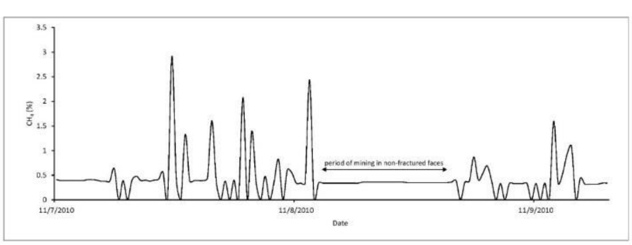

Figure 4. Methane gas concentration variations in a period of two months from 11 July to 11 September 2010.

4.3. Mechanism of Fracture-Induced Gas Emission

Coal possess the adsorption property and is a complex porous material, as well. The surface area of micro-cavities whose diameters are less than 10-6 cm is 97.3% of the total coal surface area. The specific area of coal is very high which can be as high as 200 m^2/g. Consequently, coal is an excellent natural adsorbent. At depth, methane gas exists in the forms of free and adsorption states in voids and fissures of coal seams and confining rock layers. Experimental studies revealed that 90 to 95% of methane gas in coal exists in the form of an adsorption state [17].

The balanced stress state in coal seams and host rocks can be disturbed by mining activities. Stress redistribution in the rock mass can result in the generation of small fractures in both coals and rocks, and the reduction of pore pressure [18, 19]. The adsorbed methane gas desorbs and other free gases move to places where the pressure is low and the porosity is high. Abrupt irruption of gas from the coal fractures can happen. The existence of gas is the prerequisite of gas outbursts in coal mines. To prevent unusual gas emission or in other words, outbursts, it is commonly required to drill deep holes in advance before mining starts in coal seams which are rich in methane gases [20, 21].

It is concluded from the present data that the methane gas adsorption pressure is high in deep ground at the mine site. The energy release and dynamic forces due to desorption and expansion of methane gases in the coal fissures are very high, under the disturbance of mining activities and other vibrations. Hence, the dynamic conditions for gas outbursts exist in deep ground with high methane gas content [22]. Furthermore, when the coal seams are in critical or sub-critical tension states, the desorption of methane gases with pressures in the range of 3.5 to 8.2MPa may itself induces violent failure of rock masses, leading to rockburst events.

Excavation of an opening causes stress redistribution around the opening, leading to confinement reduction in the radial direction and compressive stress increase in the tangential direction. Sometimes, tensile stress can be generated in the radial direction of the opening due to material heterogeneity [23]. As a result, tensile fractures can be generated on the walls, resulting in roof and floor coal seam separation from the host rocks and large rock deformation towards the mining opening [20]. At the same time, methane gases stored in the coal in the form of adsorption start to desorb and expand and the pore pressure can increase substantially. High-pressure gases entering into coal fractures can generate high tensile stresses near the crack tips, leading to crack propagation and coalescence. Under high ground stress and gas pressure conditions, fractures in the coal can propagate further.

In most of cases shown in Figure 2, methane gas concentration decreases abruptly in the air of tunnel and adjacent to face before starting to excavate a fracture-bearing face. This is because micro-fractures in coals and rocks increase rapidly right before excavation, and part of the free gases existing on the coal surface are directed to fractures so that under continuous gas drainage condition, the gas concentration in the air can decrease. Immediately after gas drifting, high-pressure methane gases start to desorb and expand, promoting and accelerating the initiation and propagation of fractures. Under these conditions, rockbursts can even result if the strength of the rock mass is reached. The occurrence of rockbursts can generate large amount of fractures in the coal body and host rocks, and methane gases can drift to the fractures in a very short period of time. As a result, methane gas concentration in the air can decrease further. When the expansion forces of the high-pressure gases exceed the strength, usually the residual strength of the coal and rocks, abrupt methane gases will gush out and the measured gas concentration in the air will drastically increase.

Some fault zones in coal mines form enclosed systems and methane gases can be trapped and stored in these geological structures. When the gas expansion forces and confinements of coals and rocks are at the critical state, a disturbance of the balanced state due to mining activity or vibration from probable rockbursts can trigger the gas to expand suddenly, leading to coal and/or gas outbursts.

A chart illustrating the factors contributing to unusual gas emissions/gas outbursts and rockbursts in coalmines is presented in Figure 5 which can be used as a guide to safe mining. One of the important aspects is the perturbation of the in-situ stress field at the mine site by mining activities which consists the stope geometry, mining method and excavation rate factors. Geological structures also play an important role in determining the intensity of unusual gas emission that fractures, including regional faults, can be named as its major factor. It should be noted that no seismic events in the vicinity of Parvadeh coal mine occurred in the considered time period; therefore, safe mining in Parvadeh coal mine can be conducted by considering all factors of mining activities and geological structures. Other aspects are stable or do not have a significant effect in this case study.

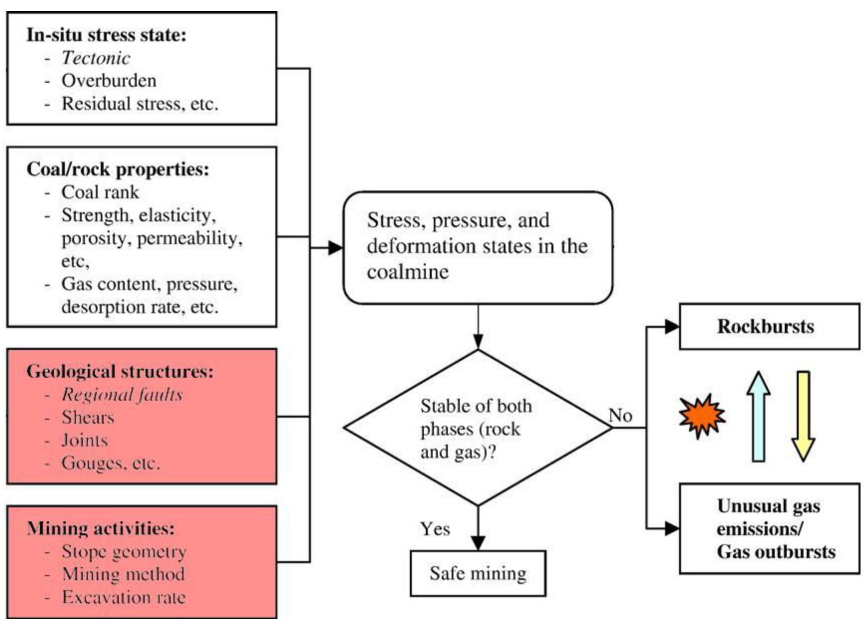

Figure 5. Factors that contribute to the occurrence of unusual gas emissions/gas outbursts and rockbursts in coalmines (modified after [3]). Mining activities and geological structures play the most important roles in the case of unusual gas-emission due to excavating the fracture-bearing faces.

5. Conclusion

Parvadeh coal mine in Iran was chosen to investigate the unusual gas emission relationship with excavating the fracture-bearing faces because of its high methane gas content in the coal body and available data from sensors in desired locations. High methane gas concentration is generally associated with excavating the fracture-bearing faces and also in some cases, the seismic events. One important phenomenon observed in most cases is the reduction of gas concentration before starting to excavate fracture-bearing faces, but this was not universal in some other cases and no reduction in gas concentration was observed before excavation. The increase of methane gas concentration in the air means that micro-fractures have been generated in the coal body. Since the fracture generation is happening before the increase of the gas concentration in the air, a sensitive and highly accurate microseismic monitoring system can be used to detect locations of rock fracturing to provide an effective means to issue warnings of high gas emission in the working area.

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