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International experience of gas emission and gas outburst prevention in underground coal mines

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INTERNATIONAL EXPERIENCE OF GAS EMISSION AND GAS OUTBURST PREVENTION IN UNDERGROUND COAL MINES

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ABSTRACT: With increasing depth of cover, control of gas emissions and prevention of gas outbursts has become a more and more important issue in mine design and mine operation. Long term experience in these fields exists, especially in Australia, Germany, China, Kazakhstan and Ukraine. Based on local conditions including geology, market conditions and mining regulations, different approaches have been developed in these countries. Changes in these parameters have however exposed the limitations of traditional solutions. While the Australian approach is based on the premise that gas content will be reduced below specific threshold values ahead of mining, opportunities of pre-drainage are limited in low permeability coal such as that encountered e.g. in Germany and China. In the case of multi seam mining, a highly effective increase in permeability can however be achieved through pressure relief by unconventional mining sequences. Although practiced at several mines in Europe and Asia, realising this in open market conditions requires a high quality of planning in regard to mine layout, mine development and gas drainage as well as the appropriate geotechnical assessments. A key factor is access and extraction of the first seam at or near to virgin gas contents. Mining at high gas contents by applying local exploration and pressure relief drilling has been practiced in a successful and safe way in several European mines. This has to be connected with a proper management system and safety system, allowing efficient reactions to identified hazards. Apart from international experience and development, the paper will also discuss current and future approaches of technology transfer. Merging the future development in gas drainage with unconventional approaches is therefore an opportunity for accessing deep and difficult deposits.

INTRODUCTION

Methane and in some deposits carbon dioxide, are the predominant gases contained in coal. These gases are adsorbed to the coal matrix and also occur within voids in both, coal and surrounding rock. Gas is released as a result of mining coal and the subsequent pressure release in the surrounding strata. At certain concentrations and volumes, these gases cause major risks of explosions and asphyxiation. Methane is known as a source of underground explosions resulting in large numbers of fatalities. More recent accidents as at Pike River Mine in New Zealand and Upper Big Branch Mine in the USA are in our mind. Apart from being a safety risk in the mine operation, methane from coal mines is an energy source which could be utilised by various technologies for heat or power generation. Regarding the climate, methane is also identified as a greenhouse gas, which is 21 times more harmful to global warming compared to carbon dioxide (United Nations Economic Comission for Europe, 2010). Hence, systematic capture and utilisation is a major target in terms of sustainability and reduction of carbon taxes.

The release of gas during mining is a complex process depending on various factors. Among others, the gas content, permeability, stresses, coal structure, tectonic faults and the stratigraphic sequence of coal and rock layers have an influence (Lama and Bodziony, 1996). In certain conditions, gas is released suddenly, known as a gas outburst. This phenomena has occurred in most coal producing countries during the history of coal mining. With the recent development of the worldwide market, technical and political conditions, mining of coal prone to gas outbursts nowadays only takes place in a few countries. A lot of experience gained in the past has disappeared. Today apart from Australia, gas outbursts are a significant problem in China, Kazakhstan, Ukraine, Germany, Turkey and Mexico.

In most cases, gas desorption is a slow process. In longwall operations, gas is released from the coal face as well as from adjacent seams and rock layers. In a first stage, gas emissions are controlled by diluting and discharging the gas by the mine ventilation system. It is the nature of this process, that the gas concentration passes the explosive range. The zone where this happens, requires particular consideration. If gas emissions cannot be controlled by ventilation only, gas drainage is necessary.

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Although being common problems in the international coal mining industry, different measures are carried out for both, gas emission control and gas outburst prevention. Some of these differences are fundamental. These differences are a result of individual geological conditions, mining practices, technological standards, market environments and experiences. Furthermore, there are unequal structures of state authorities and safety regulations. On the one hand there are flexible, risk assessment based regulations as e.g. in Australia or Germany and on the other hand there are rather inflexible, strict regulations as in the CIS countries or China. However, all of them have their own reasonable background in historic mine accidents and local mining practices.

Apart from the regulations there are fundamental differences in the geology of mined coal deposits. While conditions at Australian coal mines are currently characterised by depths of below 500 m, medium to high permeability and single seam mining, the coal mines in China, CIS countries and Europe are often characterised by depths of more than 500 m, permeability far below 0.1 Milidarcy and multi seam mining. In coal mining a maximum mining depth of more than 1500 m has been reached in Germany (Hucke, *et al.*, 2006) and in doing so, gas management controls have experienced some limitations at these depths. The information about the actually practised methods of gas emission control and outburst prevention as reviewed in this paper has mainly been gathered from various engineering assignments in different countries.

GAS OUTBURST PREVENTION

Particularly in the case of gas outburst prevention the internationally applied strategies possess significant differences. In Australia the gas outburst risk is assessed based on gas content tests during exploration (Black and Aziz, 2010). Based on gas composition and coal structure outburst threshold values are defined. If these threshold values are exceeded, the gas content has to be reduced by pre-drainage. The results are checked by compliance tests. Surface to In-seam (SIS) or Underground In-seam (UIS) drilling is used with high efficiency in most cases. Where pre-drainage has been unsuccessful, remote controlled heading has been used e.g. at BHP's Appin Colliery (Henderson, *et al.*, 2008). From its introduction, the system of threshold values has been successful with no fatalities caused by gas outbursts. Although factors additional to the gas content lead to an actual gas outburst risk, by this procedure a key factor is eliminated. Hence, no further parameters have to be investigated and assessed. In the recent past however, areas of low permeability have resulted in insufficient pre-drainage results and the consequent sterilisation of coal reserves. Considering the development of mines towards greater and greater depths and new projects targeting deeper deposits, this may therefore become a more crucial issue in the future.

About 70% of the worlds' underground coal production is from China which operates a high number of gassy mines (United States Environmental Protection Agency, 2010). In China, the gas outburst risk of coal seams is classified based on four factors: the gas pressure, tectonic faults, the desorption rate and the coal strength (Xue, *et al.*, 2010). This classification is valid for an entire seam at a mine. Hence, the differences in the distribution of gas contents, desorption rates and coal strength, especially at tectonic faults, are not assessed in a selective way. For the prevention of gas outbursts the reduction of gas contents has priority. Pre-drainage is applied using underground in-seam boreholes or penetrating the target seam by cross measure boreholes at high density. In cases of low permeability, drainage periods of around five years are common. Alternately heading and pre-drainage at the coal face is a further method resulting in considerable regular downtimes of roadway development. Wherever possible, over- or undermining is also used to increase permeability (Figure 1). This is known as sacrificial or protection seam mining. If gas contents however cannot be reduced in a reasonable way, local measures such as water injection are applied. In China, gas outburst prevention follows fixed and detailed procedures with a low grade of flexibility. Cost control is not of importance with the priority being maximum safety. Notwithstanding the strict regulations and intense drilling programs, gas outbursts with fatalities still occur.

Some of the largest gas outbursts in the world have occurred in Kazakhstan with a maximum of 1.3 million m^3 of gas being released during one coal and gas outburst (Baimukhametov, *et al.*, 2009). The level of risk and the number of gas outbursts have resulted in a strict and area wide classification of whole seams or parts of seams. This classification is based on the depth and the occurrence of outbursts in the past. As in China, protection seam mining is applied wherever possible. Otherwise, pre-drainage using UIS or SIS boreholes is carried out, but efficiency is limited due to low permeability at depths of up to 800 m. Local drilling of pressure relief boreholes is the main method used in in-seam developments. As most historic gas outbursts have occurred in contact with tectonic faults, exploration drilling in advance of the heading plays a major role. The effectiveness of pre-drainage or pressure relief is checked during heading by special short in-seam boreholes allowing an assessment of coal fine volumes and gas release. Similar assessments are common within other Commonwealth of Independent States (CIS) countries and Europe. These measures are in accordance with strict regulations and detailed procedures which are fixed for each single heading. Although work is done according to regulations and very intense exploration and pressure relief drilling is carried out, gas outbursts with fatalities have still occurred during the last few years. As heading advance is significantly limited with this method, essential work is done on improving the assessment of the gas outburst hazard and the identification of tectonic faults in advance of the heading.

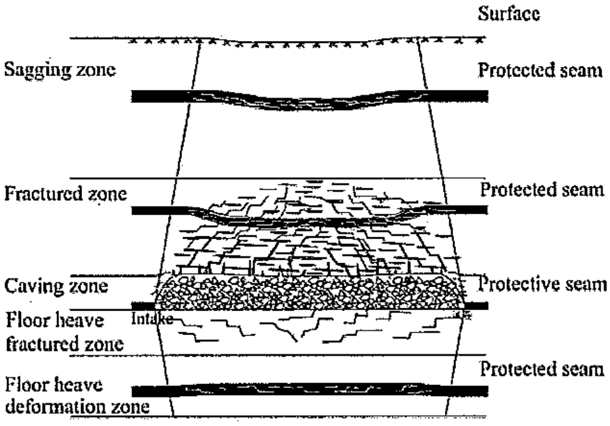

Figure 1 - Pressure relief by over- and undermining (Cheng, *et al.*, 2011)

In Ukraine the gas outburst risk of a seam is defined based on depth, coal rank and gas content. During development and extraction, seismo-acoustic monitoring methods have been developed by local institutes and are used for the identification of actual hazards. Pre-drainage is usually not efficient due to low permeability, but multi seam mining sometimes allows a reduction of gas contents by over- or undermining. Local measures of outburst prevention are common, such as inductor shock firing. This measure is based on a considerable different philosophy as gas outbursts are provoked by blasting with the workforce being removed from the area beforehand.

Currently two mines in Germany, Ibbenbueren and Prosper-Haniel mine coal prone to gas outbursts. Since 1903 alone in the state of North Rhine Westphalia more than 400 gas outbursts have been reported (Imgrund, 2012). Due to continuous improvement of identification of hazardous zones and prevention measures no fatalities have occurred since 1990. Gas outburst prevention in the German mining industry is based on a selective risk assessment in two stages. In a first step, the suspicion of a gas outburst hazard is checked. For this, gas content tests are carried out during exploration and later during the in-seam development. Usually the threshold value is 9 m³/t desorbable gas content, but in the case of tectonic faulting, abutment pressure or gas emission anomalies, the value is reduced to 5.5 m³/t (Mine Inspectorate of the State of North Rhine-Westfalia, 1996). As in other countries, the reduction of gas content is a prior target. Due to very low permeability at depth of greater than 1000 m, pre-drainage is however a limited option. Stress relief by over- or undermining is systematically used where possible. If threshold values are exceeded and gas contents cannot be reduced prior to heading advance, exploration drilling is done in progressive stages depending on the level of the gas content (Figure 2).

Fan shaped sets of boreholes are drilled in advance of the heading, usually covering a section of one week heading advance. A safety zone around the roadway is maintained by overlapping all sides. Furthermore, desorption is assessed by using the online monitoring and referring the gas emissions to the coal production and gas content. As a further step, an actual gas outburst hazard is checked based on the results of these measures. Pressure relief drilling is executed in case of an actual hazard being identified (Figure 3). The equipment is the same as that used for exploration boreholes, however critically, the procedure in this case targets a controlled elimination of the gas outburst hazard under safe conditions. Special Trigger Action Response Plans (TARPs) are also used to lower the risk levels even further.

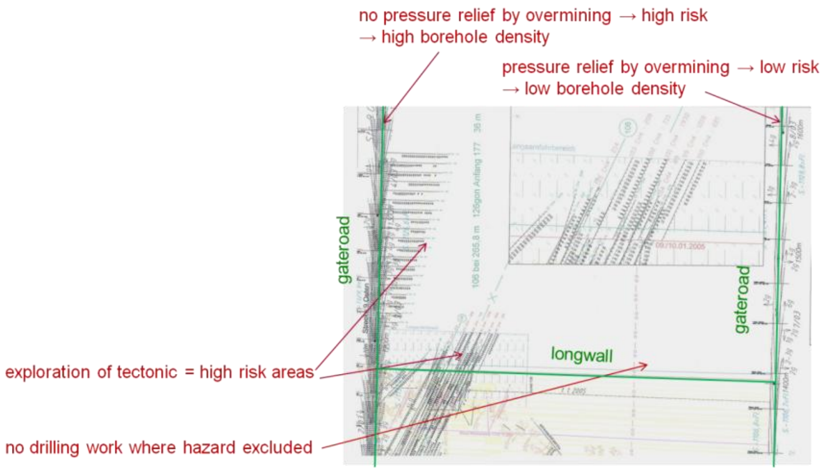

Figure 2 - Selective exploration and pressure relief drilling

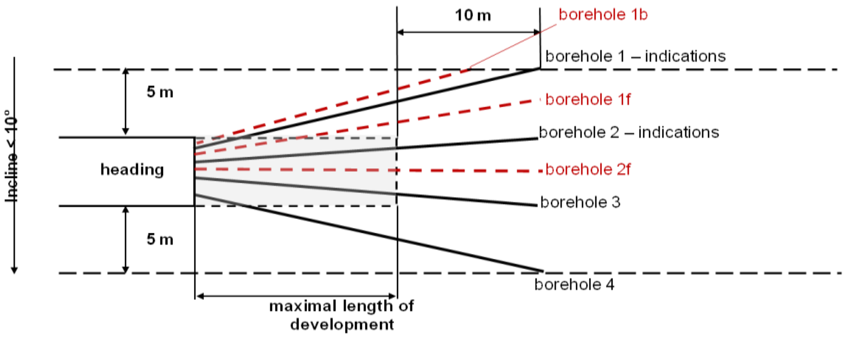

Figure 3 - Pressure relief drilling (Kunz and Imgrund, 2010)

As gas outbursts cannot be avoided by 100 %, the residual risk has to be managed systematically. Avoiding injuries and fatalities therefore is the main target. This is achieved by a management structure adjusted to the outburst risk and certain measures covering e.g. increased monitoring and communication systems, supply of breathable air, removal of the workforce from endangered areas and remote mining (e.g. with ploughs). Downtimes and costs associated with the safety measures are reduced as far as possible by a selective assessment of the gas outburst risk.

GAS EMISSION CONTROL

Although some methods of ventilation and gas drainage are basically similar throughout the world, there are also considerable country specific differences. Ventilation of longwalls in Australia typically utilises U or Y systems depending on gas emissions and the risk of spontaneous combustion. Access is by two or three heading roadways. This allows ventilation layouts and air flows to be adjusted to the expected gas emissions. Some mines use bleeder systems with part of the return air being discharged via the back end of the longwall panel. The high longwall output in many cases requires pre-drainage even below gas outburst threshold values and further post drainage from the gob area. Due to the comparative low depth and predominant single seam mining, post drainage is successfully executed by surface gob wells drilled in advance of the longwall face. Underground cross measure boreholes are less common, but floor holes are drilled in some mines.

In Chinese longwalls the U system of ventilation is common with some companies also using Y system ventilation based on double used roadways. However, single entry gate roads are state of the art. At high seam thickness, some mines use additional superjacent gate roads. As an additional return airway they are positioned in the upper section of the seam with 2.5 % CH_4 general body being permitted. Based on mine safety regulations, gas drainage is required at defined levels of gas emissions. Especially in single seam operations e.g. in Shanxi Province, pre-drainage by UIS boreholes is executed. While parallel boreholes being drilled from the gate roads are the traditional method, directional longhole drilling recently has been applied e.g. at Shenhua Group. Underground cross measure boreholes are the most usual practise where seams in the roof are a major source of gas emissions. Usually these boreholes are drilled in advance of the longwall from niches in the tail gate or from small raises driven from the tail gate into the roof of the worked seam (Figure 4).

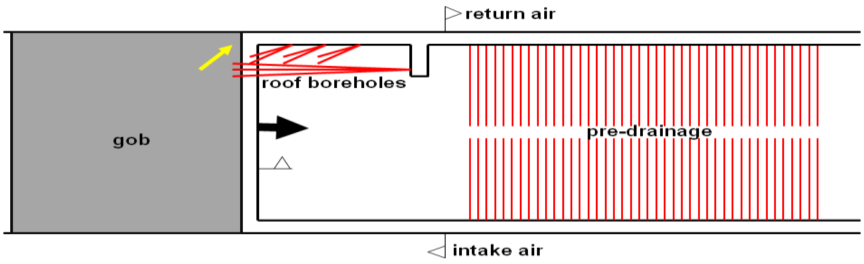

Figure 4 - Typical gas drainage layout at Chinese mine

Some mines apply gas drainage roadways driven in the roof of the worked seam and parallel to the tailgate (Figure 5). Being sealed by a dam and not being accessible after drivage, gas is drained directly from this roadway.

At low to medium depth, some mines (e.g. at Inner Mongolia and Anhui Provinces) apply surface goaf wells. A further very common system is draining gas from the sealed goaf area. For this, the tail gate is closed in the rear of the longwall by bags filled with waste rock or sand. Goaf gas is drained via pipes inserted into these dams and operated on suction. It is the nature of this layout, that the drained gas is close to or even within the explosive range. Often a mixture of different gas drainage methods is used.

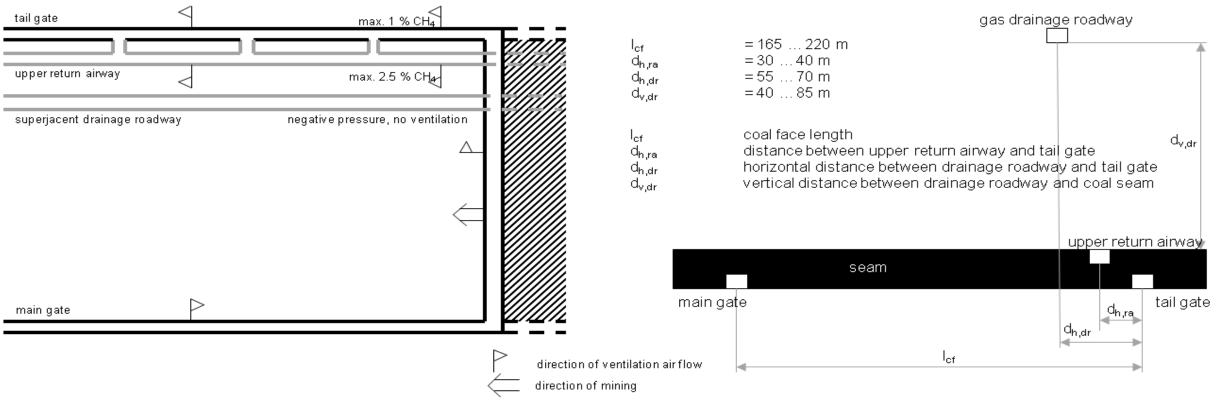

Figure 5 - Thick seam mining with superjacent tail gate and gas drainage roadway

The layout of Russian longwall panels is quite close to Australian methods with two entry heading gate roads being common. U system, but at higher gas emissions also Y system ventilation is applied. Some mines in Siberia use bleeder systems. Pre-drainage is mandatory at gas contents of 9 m³/t. Parallel UIS boreholes are drilled from the gate roads. The efficiency is often very low due to low permeability of the coal. Post drainage utilises cross measure roof holes drilled from the return airway or by surface gob wells (Figure 6).

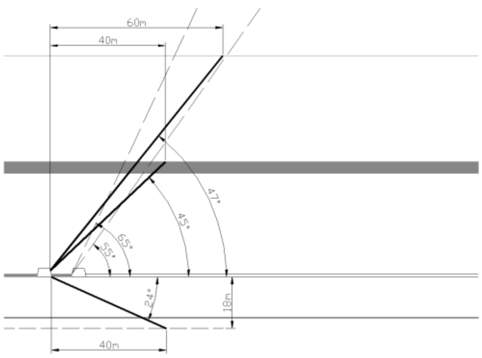

Figure 6 - Underground cross measure roof and floor boreholes drilled from gate road

Within the European Union, coal mines in Germany, the UK, Poland, Czech Republic and Romania apply gas drainage. According to the respective national regulations, either U system or Y system ventilation is preferred. While Y system ventilation and double used roadways are not permitted in the UK due to the risk of spontaneous combustion, this method has been successfully used in Germany and Poland even in seams prone to spontaneous combustion. The gob area is sealed by a concrete roadside pack. The system of double use roadways is also used due to the need to avoid irregular subsidence and zones of abutment pressure in multi seam mining. Gas drainage is applied where ventilation alone is not capable of controlling gas emissions. Pre-drainage has been successful in some cases, but compared to Australia or the US, the efficiency is low due to permeabilities down to 10^{-4} Milidarcy (Meiners, 1987). In Germany good pre-drainage results have been achieved in cases of previous over- or undermining. However, in multi seam environments, post drainage by roof and floor boreholes is often required.. Surface gob wells are not common due to high depth, existence of gob areas in the roof and difficult access from the surface due to scattered ownership or buildings. Highly efficient cross measure boreholes are drilled at the return end of the longwall. In case of double used roadways boreholes are drilled after the main subsidence is completed and there is full access to the boreholes during the entire lifetime of a panel (Figure 7).

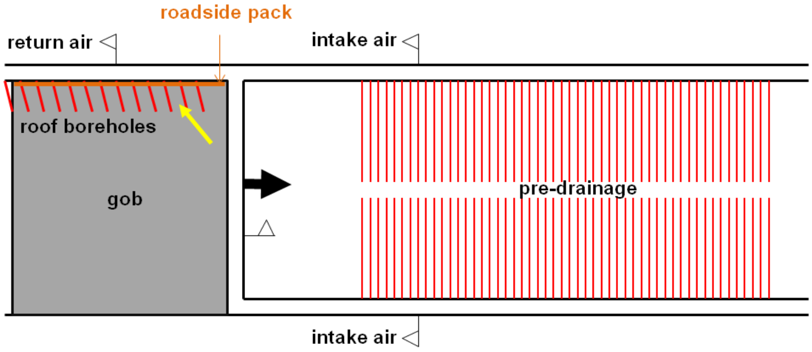

Figure 7 - Roof borehole layout at Y ventilation system

In the UK at some mines a back return system has been applied while access to the boreholes is limited to the area close to the longwall (Pitts, 2008). Further boreholes being served by a sacrificial pipeline (Figure 8).

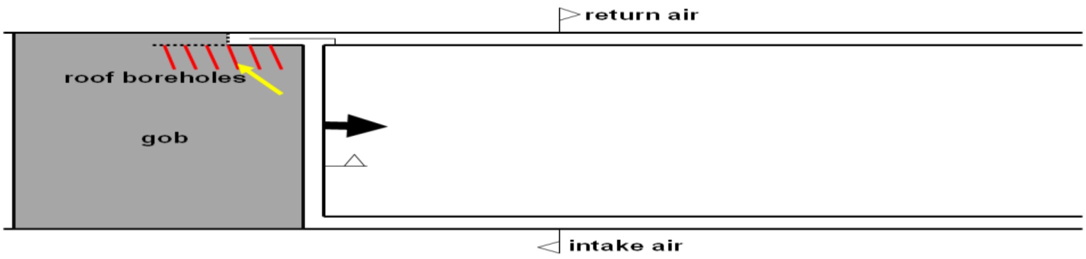

Figure 8 - Roof borehole layout at a UK coal mine

In the US both, room and pillar and longwall mining, are common methods with several mines combining the systems. Longwall panels usually are vented by a U system via multi entry gate roads. Bleeder systems are applied with 2 % CH_4 general body being permitted (U.S. Government, 2012). Pre-drainage is similar to Australia using UIS or SIS drilling. Low depth and high permeability allow efficient pre-drainage. Post drainage is basing on surface gob wells.

TECHNOLOGY TRANSFER OPTIONS

Any transfer of technology has to consider the fact that any measures of ventilation and gas drainage - and especially gas outburst prevention - have been adjusted to local conditions. These conditions are not only related to geology and mining methods, but also the structure of legislation and authorities as well as the history of mine accidents. Mine safety regulations e.g. in the CIS countries or China are very strict and detailed instructions are defined for both mine design and operation. Duly authorised institutes have to be involved in key stages of mine planning and approval processes. In contrast to this, in Australia and

Western Europe a risk assessment based approach is common. However, there is some potential in transferring overseas approaches and adjusting them to other environments. Merging international experience may bear opportunities for the Australian coal mining industry as well as for Australian technology to be transferred overseas.

In Australia the risk assessment regarding gas outburst hazards is primarily based on gas contents and coal structure. The system of threshold values has been very successful since its introduction based on the investigations of Lama (Black, 2011). Today, zones of lower permeability at increasing depths lead to difficulties in pre-drainage (Gray, 2012). Apart from the ongoing research and development of pre-drainage technologies, recent development targets defining threshold values are more selective. Nevertheless, the potential of this approach is limited if the coal cannot be pre-drained to the required threshold values. With respect to German and Chinese approaches, safe mining is also feasible at gas contents exceeding gas outburst threshold values. There are a wide range of factors which lead to a gas outburst, including but not being limited to desorption rates, permeability, gas pressure, coal strength and structure, tectonics and stress regimes. For operational practice, it is reasonable to assess those parameters which are crucial and also allow an easy measurement with low risk of errors or wrong interpretation. In most cases gas outbursts are limited to tectonic faults. German mines have made good experience with focus on local measures of exploration and pressure relief drilling according to tectonic faulting. As also small scale faults with displacement far below the seam thickness can cause a gas outburst hazard, the assessment of surface exploration borehole data and seismic measurement is not sufficient. Underground exploration drilling and proper projection of the course of faults by surveyors and geologists is a base of gas outburst risk assessment. The assessment can be executed step wise based on different parameters. As a further parameter, desorption can be assessed by using the stationary ventilation and gas monitoring and referring gas emissions to the gas volumes originally stored in the removed coal. Being more complex than an assessment based on gas contents only, there must be a clear management structure, an efficient flow of information and clear TARPs in place.

In Australia as well as in Europe and Asia there is much experience in pre-drainage, but with fundamental differences. The productivity of gassy Australian mines and intense research and development has resulted in a high level of pre-drainage technology, especially directional drilling and hydro fracturing, as well as an in deep understanding of processes occurring along gas drainage such as shrinkage and swelling of the coal matrix. At worst, local or area wide mining conditions, which are characterised by e.g. high depth, intense tectonic faulting and low permeability, state of the art drainage technologies may come to a temporary or even ultimate dead end. Experience from China, Kazakhstan and Europe shows that stress relief by over - or undermining is an efficient way to increase permeability. Leaving pure empirical approaches behind, numeric modelling is a fundamental support in understanding geotechnical and gas related aspects along with over- or undermining (Figure 9). While undermining of target seams clearly reduces gas contents, the negative and positive effects on strata control have to be considered as well. Last but not least, multi seam mining with unconventional mining sequences requires a well organised production schedule.

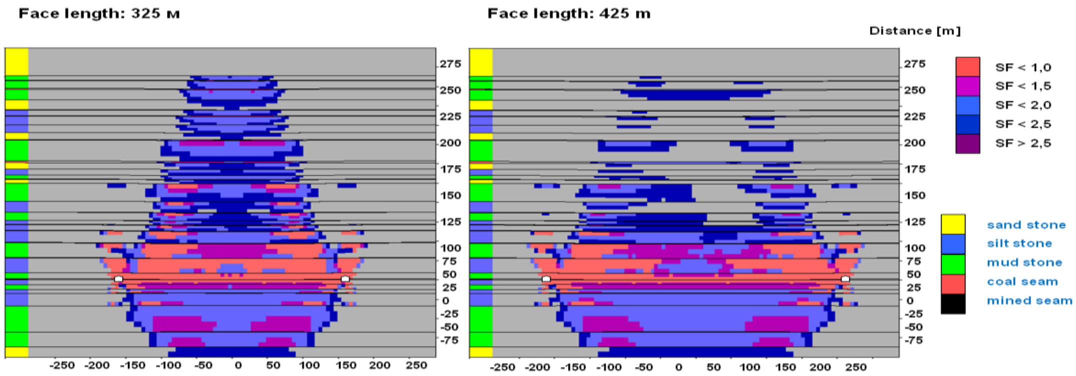

Figure 9 - Example of numeric modelling of gob zone with Flac 2D

At sections where directional drilling or hydro fracturing is not feasible due to either local tectonic faults or low permeability, limited use of exploration and pressure relief drilling from the coal face may be an alternative to abandoning coal reserves. As this requires coal seams to be mined at gas contents above generally accepted threshold values, this obviously requires higher safety standards and proper management of the residual risk.

In multi seam mining in Europe and China, double use roadways, underground cross measure boreholes and special gas drainage roadways are recognised as effective control measures. Accepting that these are fundamentally different from Australian and US mining layouts and gas drainage layouts, certain aspects of these approaches bear big advantages for multi-seam mining and mining at increased depth. Moreover, acknowledging the fact that the economic environments and ground conditions in the CIS countries, China, Europe and Australia are quite different, the cost of these supposedly expensive measures can be reduced through appropriate modifications to the mining and/or gas drainage process.

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