Results of coal gas desorption experiments, laboratory sorption experiments on lignite samples and in-situ seam gas pressure - rock stress measurements

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Abstract. Understanding the principles of coal seam gas behaviour require a great number of experimental tests, monitoring campaigns, equipment design and numerous correlations between gained data. Research work on Velenje lignite and "in-situ" monitoring on long-wall faces consisted of coal's gas content experiments and mine monitoring campaigns. Gas content is commonly measured with standard desorption methods by using direct method which measures actual released gas volume from sample. According to some widely-known methods (US Bureau of Mines direct method, Australian Standard method), gas content determination methodology for Velenje lignite was developed. Mine monitoring included seam gas pressure and rock stress measurements, accompanied by gas sampling for composition and isotopic analysis. Observations showed definite correlations between listed parameters when measured results were combined into combined analysis.

Keywords: Coal seam gas, desorption experiments, seam gas pressure, rock stress.

1 Introduction

Coal mining in thick lignite seams by using long-wall mining methodologies is an approach towards efficient and effective way of coal deposits extraction. By expanding the size of long-wall face, the amount of crushed coal often cause increased additional releases of coal seam gases (carbon dioxide, methane) and possible rock bursts, often accompanied by gas outbursts [1]. Lignite seam at Coal Mine Velenje represents large volume reservoir for coal seam gases. Carbon dioxide represents major share in total gas balance and is mostly adsorbed to coal or is trapped in micro-pores of the coal structure, while methane is accumulated by the

surface of coal seam, just under the roof-strata clay seam [2]. It is obvious that free methane is present also in lover sections of the coal seam as its presence is detected and concentrations are monitored in return air of every working long-wall face [3].
Experimental work as laboratory desorption experiments (gas content determination), adsorption experiments and continuous mine monitoring (coal seam gas behaviour, geotechnical monitoring) result in understanding the interaction between events of gas releases accompanied by geotechnical factors.

1.1 Coal seam outline

Lignite deposit in Velenje basin is amongst the thickest in worlds scale with maximum thickness of over 160 metres and depth of 150 – 500 m below ground level. Its size spreads over an area of 8,3 km × 2,5 km and contains about 130 millions of mineable coal reserves.
Coal seam is placed on floor strata of andesitic rocks, sands, breccia and Triassic dolomite. Above coal deposit there is a thick layer of isolative clay, sand and interchangeable layers of clay, silt, sand, mud-stone and under surface alluvial deposits.

1.2 Velenje mining method outline

The Velenje long-wall mining method was developed on classical coal faces equipped with friction legs and iron beams. A true revolution in the support system development was represented by hydraulic support system with a conveyor sitting on a base, lemniscate-guided shield, an option of total control (prevention) of caving-in in the foot-line section and electro-hydraulic control system. The entire long-wall excavation process is based on the consideration of natural characteristics, provision of adequate safety and the prediction of impacts on the environment. According to Velenje mining method coal face is divided in the foot-line section (lower excavation section) and the hanging wall (upper excavation section) section (Figure 1). The allowed face height at the long-wall depends on the thickness of clay insulating layers in the hanging wall, which protect the face from the inrush of running sand and water. Following the criteria of „Safe mining below water bearing strata at Velenje Coal Mine" the allowed working height is calculated according to preliminary stated variations.

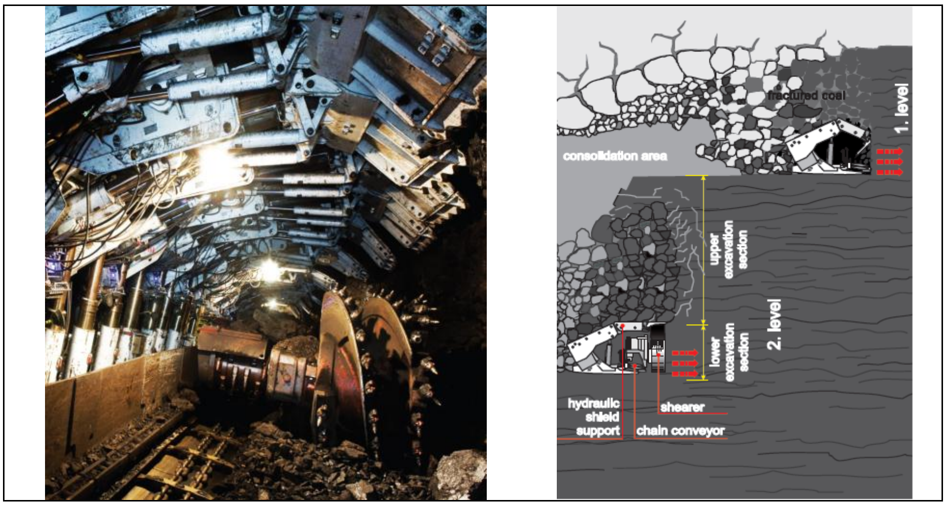


Figure 1: Long-wall face with hydraulic steel shield support, shearer and chain conveyor (left) and schematic presentation of lignite seam division into levels, together with sequence of sub-caving excavation in levels (left) (Premogovnik Velenje, 2011)

2 Experimental work

Gas content in coal is determined by variations of desorption experiments amongst which US Bureau of Mines direct method and Australian Standard method [4] represent direct gas content determination method that uses physical principles of gas release from coal samples.

Proposed direct experimental methods measures actual desorbed gas from core coal samples by using desorbed gas over-pressure in canister where sample is kept to supplant desorption solution in an inverted graduated cylinder. The volume of supplanted solution is the actual desorbed gas volume from the sample.

Literature [4] usually suggest desorption experiments as sequence driven test in steps to determine total desorbed gas content as follows:

$$Q_{total} = Q_{lost} + Q_{desorbed} + Q_{residual} \quad (1)$$

Total desorbed gas content consists of lost gas (Q_{lost}) which is determined analiticaly basing on initial quantities of actual desorbed gas ($Q_{desorbed}$). Residual gas ($Q_{residual}$) is quantity of gas that stays adsorbed to coal micro-structure and could be released only after crushing the sample.

Based on observation and results of previous desorption experiments [5], [6], [7], [8], [9], [10] research of lost gas content, litho-type influence and equipment design (Figure 2) that answers Velenje lignite desorption properties started.

a) b)

Figure 2: Modified equipment for desorption experiments. Lost gas content determination equipment (left), laboratory desorption equipment (right) (Jamnikar, 2011-2012).

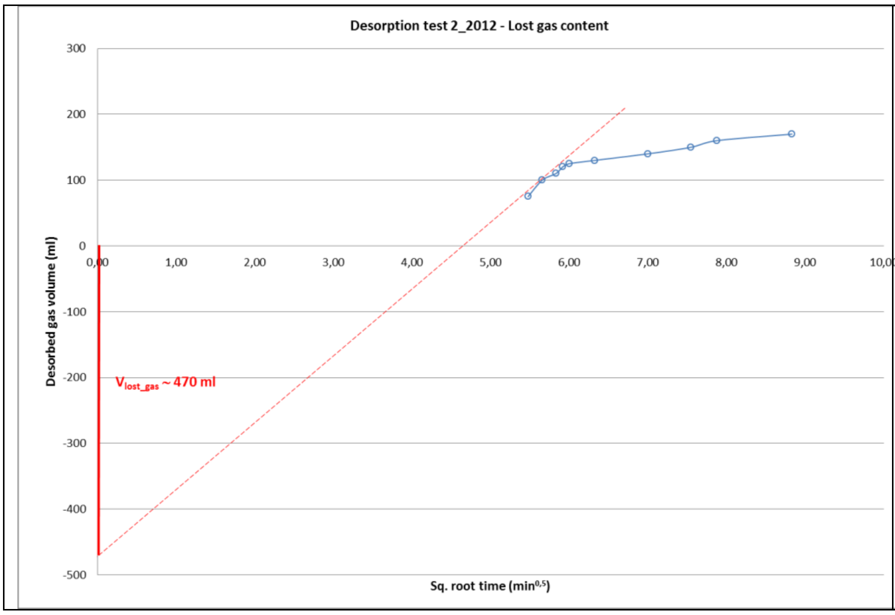
Desorption experiments continued in April 2012 when equipment was successfully tested. First samples were taken from bore-hole jgm 55 (-2°)/12 in Mine Preloge.

2.1 Gas content determination experiment 2/2012

Sample brief litho-type analysis: fine dethrite (dD) [11]

Lost gas content determination, Laboratory desorption experiment

Gas content determination - Desorption test 2/2012 started as lost gas content determination experiment in mine (Figure 3) and continued in laboratory by monitoring gas release together with sampling of desorbed gas. Figure 3 shows graphical presentation of desorption measurements within more than 78 minutes after sample coring. Gas release stopped after that time at volume 170 ml. In processing, a tangent was added to time-volume curve to determine lost gas volume, shown as crossing of tangent with negative Y-axis. The crossing value represents approximate lost gas value of 470 ml. Sample was transferred to laboratory after lost gas content determination for standard two-month experiment time.



Desorption_lost gas	
Time_test (min0,5)	Volume_des gas (ml)
5,48	0
5,48	75
5,66	100
5,83	110
5,92	120
6,00	125
6,32	130
7,00	140
7,55	150
7,87	160
8,83	170

Figure 3: Desorption experiment 2/2012 – Lost gas content

3 Mine monitoring

3.1 Seam gas pressure monitoring

Seam gas pressure monitoring was established with purpose to correlate gas pressure behaviour in dependence of long-wall face approach with geotechnical monitoring, especially stress measurements. Geotechnical monitoring over past years showed certain dynamics of rock stress manifestation in dependence of distance to long-wall face. Presumably, wave of rock stress increase caused changes in permeability of coal seam which was described also as "opening and closing" of fault and crack system. Described effect of stress caused permeability changes of coal, observed in laboratory experiments was discussed in papers [12], [13]. An emphasis was put on measuring well construction (Figure 4) for seam gas pressure monitoring. Its construction and sequence of drilling are targeting total tightness to prevent gas leakage from coal seam and well.

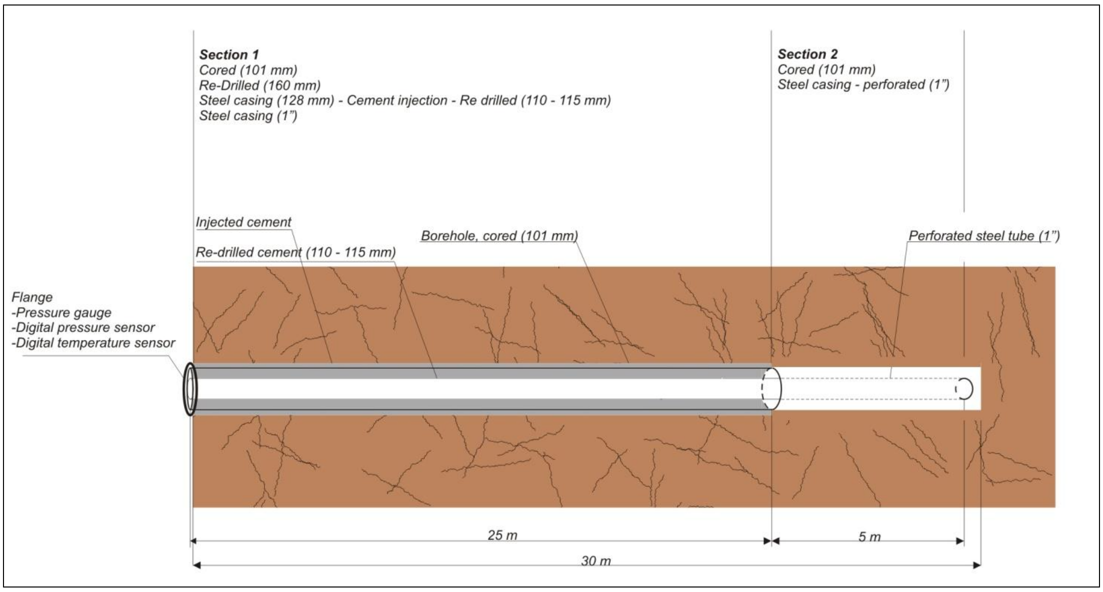


Figure 4: Scheme of seam gas monitoring well construction (Jamnikar, 2010)

3.2 Rock stress monitoring

Rock stress monitoring is an established methodology on long-wall face influence observations. Stress cells are built into bore-holes which are drilled with different orientations and inclinations. Rock stress monitoring design normally dictates bore-holes drilling into excavation pillars in order to detect influence of advancing long-wall face.

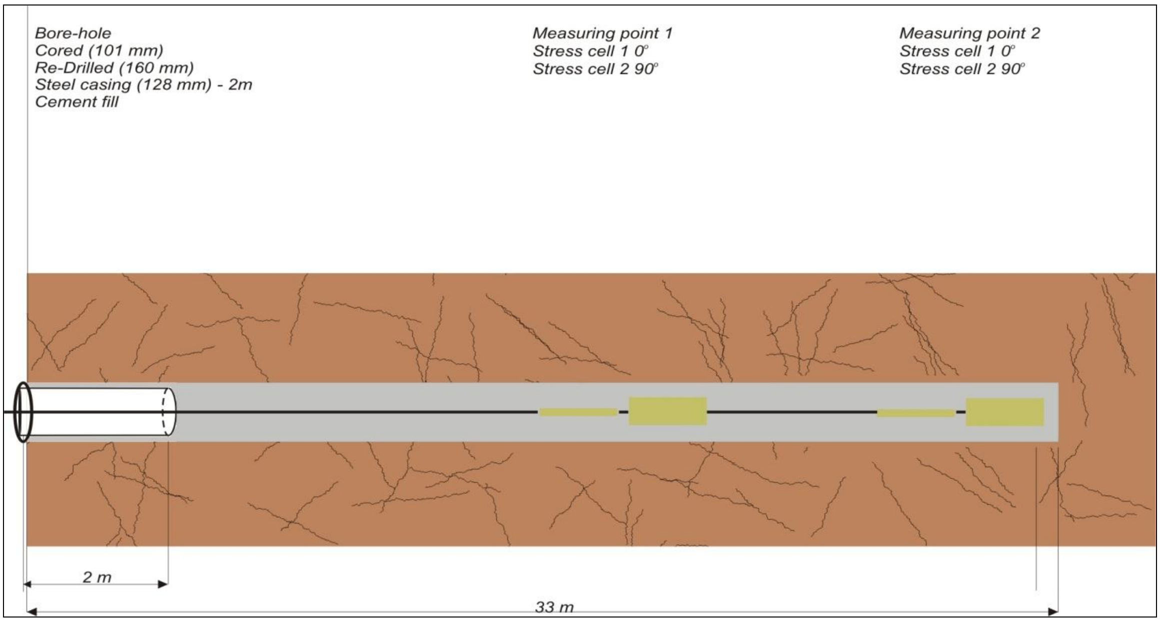


Figure 2: Scheme of rock stress monitoring well construction (Jamnikar, 2012)

3.3 Mine monitoring at long-wall face K. -50 C (Mine Pesje)

Long-wall face K. -50 C (Figure 6) was chosen for multiple – monitoring field because of its specific location in the coal seam. Due to general CM-Velenje excavation concept, sub-caving methodology and geological features, excavation pillar was divided into two sections with different gas and stress state properties. NW part of excavation pillar was located directly under solid (virgin) coal and intact roof strata whereas SE part was located under pre-mined coal and deformed roof strata. Historical recordings of excavation results show increased gas accumulations and increased rock stress in excavation areas where mining is performed for the first time.

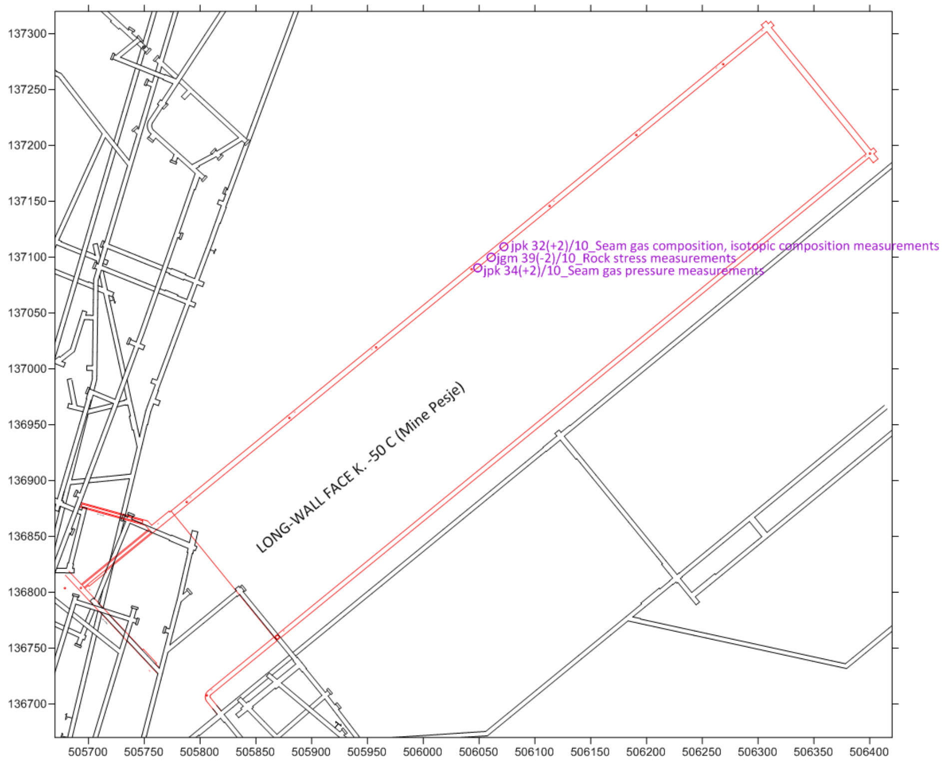


Figure 6: Location of seam gas pressure and rock stress measurements at long-wall face K. -50 C (Mine Pesje)

Combined presentation of seam gas pressure and rock stress measurement results are shown on Figure 20 below. Measuring point at long-wall face K. -50 C was equipped with seam gas pressure monitoring well (jpk 34 (+2˚)/10), rock stress monitoring well (jgm 39 (-2°)/10) and gas sampling and isotopic composition analysis well (jpk 32 (+2˚)/10) (Figure 6).

Well jgm 39 (-2°)/10 was equipped with two pairs of stress cells, amongst which pair of cells at 25m depth was chosen for further discussions due to better recordings of dynamic stress changes ahead of the advancing long-wall face.

Results from rock stress monitoring (jgm 39 (-2°)/10) and seam gas pressure monitoring (jpk 34 (+2°)/10) are combined together on a single chart. Figure 7 represents comparison of stress and gas pressure changes. Stress change is shown in MPa while gas pressure is scaled in bars. Values of stress and gas pressure changes are presented in dependence of long-wall face advance.

In the chart influence of stress state changes and gas pressure dynamics is presumably explained by "cleat system opening and closing". When long-wall face distance to monitoring point is more than approximately 70 meters, stress influence causes several in-seam deformations. Seam gas is allowed to move freely through seam and measured gas pressure decreases. When long-wall face approaches towards monitoring point, rock stress rises, the cleats are closing and seam gas is trapped into closed volume. This phenomenon is recorded in seam gas pressure rise. Seam gas pressure rises until the peak of maximum coal strength is achieved (50 – 30 m). After stress peak is achieved (30 – 0 m), deformations of excavation pillar rises and seam gas escapes from cleat system.

Additional gas behaviour is observed in isotopic composition of carbon isotope ^{13}C in carbon dioxide and methane as it was discussed in papers [14], [15], [16]. Figure 7 show changes in isotopic composition of carbon isotope ^{13}C in carbon dioxide and methane analysed (Institute Jožef Stefan) from gas samples taken at well jpk 32 (+2˚)/10 and represent further study and research task.

Values of isotopic composition CO_2 ($\delta\ ^{13}C_{CO2}$) from gas sampling in long borehole jpk 32 (+2°)/10 were changing in time of LW advancing from 1,0 to -9,7 ‰. Values $\delta\ ^{13}C_{CO2}$ between -10 to -5 ‰ are typical for coal gases with higher amount of CO_2 concentration and correlate with endogenic source of CO_2. Higher values of CDMI index (Carbon dioxide – Methane Index) and positive values of isotopic composition of $\delta\ ^{13}C_{CO2}$ show mixed origin of carbon dioxide between biogenic (CO_2 reduction) and endogenic CO_2.

Initial values of methane isotope $\delta\ ^{13}C_{CH4}$ were varying around -60 ‰ which indicated origin of methane in coal seam as reduction of CO_2. At the distance from the LW face around 300 m we observed the change in the methane isotope composition in coal gas samples. Values of methane isotope $\delta\ ^{13}C_{CH4}$ became lower from -45 to -31 ‰ that alternative type of methane – microbic methane, migrated through the coal seam. As discussed before, stress influenced permeability changes were seen in seam gas pressure changes and also in gas migrations in coal seam.

Alternative values remained the same until methane escape through the rock stress caused cleat/ porous system. After structure deformation, original gas state with low values of isotopes δ $^{13}C_{CH4}$ was observed [3].

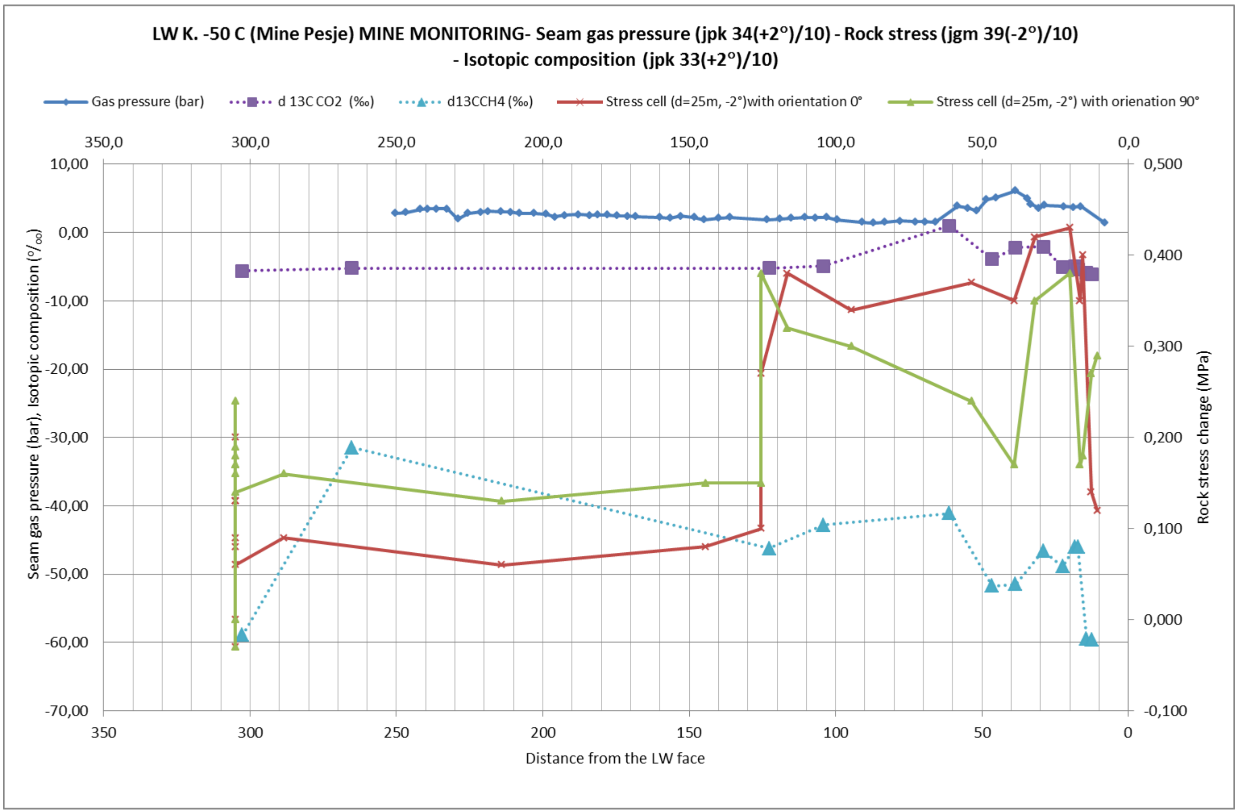


Figure 7: Relation between seam gas pressure and rock stress state change in dependence of distance to long-wall face. Rapid increase of stress at distances 305 m and 125 m represent stress cell settings with additional fluid injection.

4 Conclusions and future work

Investigation in field of desorption and gas content determination included review of knowledge, experiments and methodology on field in world's scale, experiments, performed on samples from Coal Mine Velenje and methodology and equipment design that match Velenje lignite properties.

Desorption experiments included repetitions of experiments from previous campaigns, followed by modifications in sample treatment (crushing) and lost gas content determinations.

Mine monitoring was divided into seam gas pressure measurements and rock stress measurements for which dedicated measurement methodology and monitoring objects were developed. Results of both were combined after data interpretations showed possible correlations that were assumed even before seam gas pressure monitoring was established.

In addition, seam gas pressure and rock stress measurements interpretations were accompanied with seam gas and isotopic composition results that describe migration principles of coal seam gases.

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For wider interest

Underground coal mining still represents hazardous operations and dealing with natural forces amongst which coal and rock-bursts represent possible threats for miner's safety.

Research into hazardous events prevention precautions consists from coal gas content determination experiments and mine monitoring campaigns of gas behaviour analysis and coal excavation influence on surrounding coal masses.

Mine monitoring included seam gas pressure and rock stress measurements, accompanied by gas sampling for composition and isotopic analysis. Observations showed definite correlations between listed parameters when measured results were combined into combined analysis.

Research work is targeting final result - understanding coal seam properties concerning gas behaviour and rock stress distribution influence that answers challenge of underground gas drainage of coal seam.