# Tracing coalbed gas dynamics and origin of gases in advancement of the working faces at mining areas Preloge and Pesje, Velenje Basin

# Spremljanje sestave premogovega plina in izvor plinov z napredovanjem čela delovišč na pridobivalnih (rudarskih) območjih jam Preloge in Pesje, Velenjski bazen

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**Received:** May 9, 2011 **Accepted:** September 7, 2011

**Abstract:** During excavation of lignite in the Velenje Coal Mine coalmine, seam problems with gas outbursts occur. Geochemical investigations are designed to help predict, prevent, and manage coal mine gas outbursts and to study their origin and mechanisms. However, geochemical studies of the coalbed gases in the Velenje basin have been initiated since year 2000. Temporal changes in chemical and isotopic composition of "free" seam gases were observed as a function of the advancement of the working face –120/B, G2/C and –50/B within boreholes jpk-28/10, jpk-30/10, jpk-31/10, jpk-22/09 and jpk-23/09. Mass spectrometry and isotope mass spectrometry methods were used to determine gas composition and perform gas characterization. Coalbed gases in the Velenje basin are highly variable in both their concentrations and stable isotope composition. Major gas components are $CO_2$ and methane. Concentrations and isotopic studies revealed several genetic types of coalbed gases: endogenic $CO_2$ (including $CO_2$ originating from dissolution of carbonates), microbial methane and $CO_2$.

**Izvleček:** Med izkopavanjem lignita se lahko pojavljajo plinski izbruhi, zato je pomembno izvajati nadzorne meritve premogovnih plinov na odkopih. Geokemične raziskave premogovnega plina so pomembne

*Original scientific paper*

za razumevanje mehanizma nastanka, preprečevanja in napovedovanja plinskih izbruhov. Raziskave premogovnega plina v Velenjskem bazenu potekajo od leta 2000. Časovne spremembe v kemijski in izotopski sestavi “prostih” premogovnih plinov smo spremljali kot funkcijo približevanja čel delovišč 120/B, G2/C in –50/B v vrtinah jpk-28/10, jpk-30/10, jpk-31/10, jpk-22/09 in jpk-23/09. Sestavo in izotopsko sestavo premogovnih plinov smo določili z metodama masne spektrometrije in izotopske masne spektrometrije. Premogovni plini v Velenjskem bazenu se spreminjajo tako po vsebnosti kot tudi po izotopski sestavi. Glavni plinski komponenti sta $CO_2$ in metan. Raziskave vsebnosti in stabilnih izotopov premogovnih plinov kažejo različne izvore plinov: endogeni $CO_2$, (vključno s $CO_2$, ki nastaja zaradi raztapljanja karbonatov) ter mikrobni metan in $CO_2$.

**Key words**: coalbed gas composition, working faces, carbon isotopes, gas origin, Velenje basin
**Ključne besede**: sestava premogovnih plinov, odkopi, ogljikovi izotopi, izvor plinov, Velenjski bazen

## INTRODUCTION

An increasing demand for coal, as a result of changes in the availability and cost of other fossil fuels, has re-focused attention on the problem of outbursting in deeper coal mines. When the rate of advance of the cutting face is slow, better opportunities for the slow escape of the gases under high pressure in the virgin coal exist. However, at the faster rates of advance of the coal face now required, less time is available for the equalization of gas pressures and mining induced stresses. Thus, the hazard of instantaneous outbursting of gas and coal is increased, although under favorable circumstances some control may be achieved by gas drainage (Smith & Gould, 1980). It is generally assumed that the pressure and volume of gases held within the virgin coal play a major part in producing outbursts; however, some doubt still exists as to whether outbursts are actually triggered by gas pressure or by stresses induced in the rock itself during mining operations (Flores, 1998).

The most trivial definition of coalbed gas is “gas from coal”. Coalbed gas usually consist of hydrocarbons (mainly methane), $CO_2$ in concentrations from 0 to greater than 99 %, and occasionally small percentages of nitrogen (Clayton, 1998). A numbers of models were developed to describe sources of hydrocarbon gases (Shoell, 1983, Kotarba, 1990, Scott, 1993, Kotarba, 2001, Aravena, 2003). Stable carbon isotope analyses of methane and $CO_2$ can be applied to identify the origin of coalbed gases, their migration pathways, and accumulation processes. There are three main sources of hydrocarbon gases and $CO_2$ in sedimentary basins: abiogenic, microbial and thermogenic gas (Scott, 1993). In general, thermogenic gases are typically associated with high rank coal, whereas microbial gases are typically associated with low rank coals and could have been produced throughout the basin history, as long as the coalbeds were never pasteurized. Abiogenic sources of gas are typically found in deep subsurface (Sherwood Lollar et al., 2006).

Details of isotopic composition of different lithotypes of lignite and the origin of coalbed $CO_2$ gas based on tectonic events during formation of the basin using cluster analysis and CDMI index (carbon dioxide methane index) of different gases are presented in Kanduč et al. (2005a) and Kanduč & Pezdič (2005b). The study revealed levels of microbial methane and $CO_2$, and endogenic $CO_2$. Unexpected organic arsenic compounds found in Velenje lignite indicated their relation with biogeochemical degradation of organic material (Šlejkovec & Kanduč, 2005c).

The aim of the study is to explain concentrations and origin of gases as a function of the advancement of the working faces –120/B, G2/C and –50/B in mining areas of Preloge South, Preloge North and Pesje in Velenje Basin.

## Materials and methods

### Sampling procedure

Sampling of coalbed gas was performed at working faces –120/B (mining area Preloge South), G2/C (Preloge North) and –50/B (Pesje) from November 2009 till November 2010, in the lignite seam of the Velenje basin with purpose to determine concentrations ($CO_2$, methane, $N_2$ and $O_2$) and $\delta^{13}C$ of methane and $CO_2$ from pillar coal in advancement with the working face (Figure 1). Boreholes were drilled in pillar coal to a depth of 20 m. After drilling, the capillary tube was inserted in the borehole. Boreholes (jpk-28/10 - Preloge South, jpk-30/10, jpk-31/10 - Preloge North, jpk-22/09 and jpk-23/09 - Pesje) and working faces (–120/B, G2/C, and –50/B) are shown on Figure 1. "Free gas" emitted from the borehole was collected in a 50 mL plastic syringe and then transferred to a 12 mL evacuated ampoule with a septum. After sampling "free gas" from the boreholes, the ampoules were stored at normal atmospheric conditions until analysis. Free gas includes both the volatiles filling the pores and cracks within the coal structure and some gas degassed from the coal during drilling and sampling (Kotarba, 2001). Some boreholes were compressed in advancement of the working faces, which caused too much air contamination in boreholes and therefore unable the interpretation. In this study only data of coalbed gases, which contained below 50 % of air were used for interpretation.

## Analytical procedure

Determinations of the concentrations of methane, $CO_2$, nitrogen, oxygen and argon were performed using a home-made mass NIER spectrometer. The method of singular decomposition of matrix was used, to obtain the simultaneous analysis of the gases. The precision of the method was ±3 %.

Isotope composition of methane, $CO_2$ was determined using an Europa 20-20 continuous flow isotope ratio

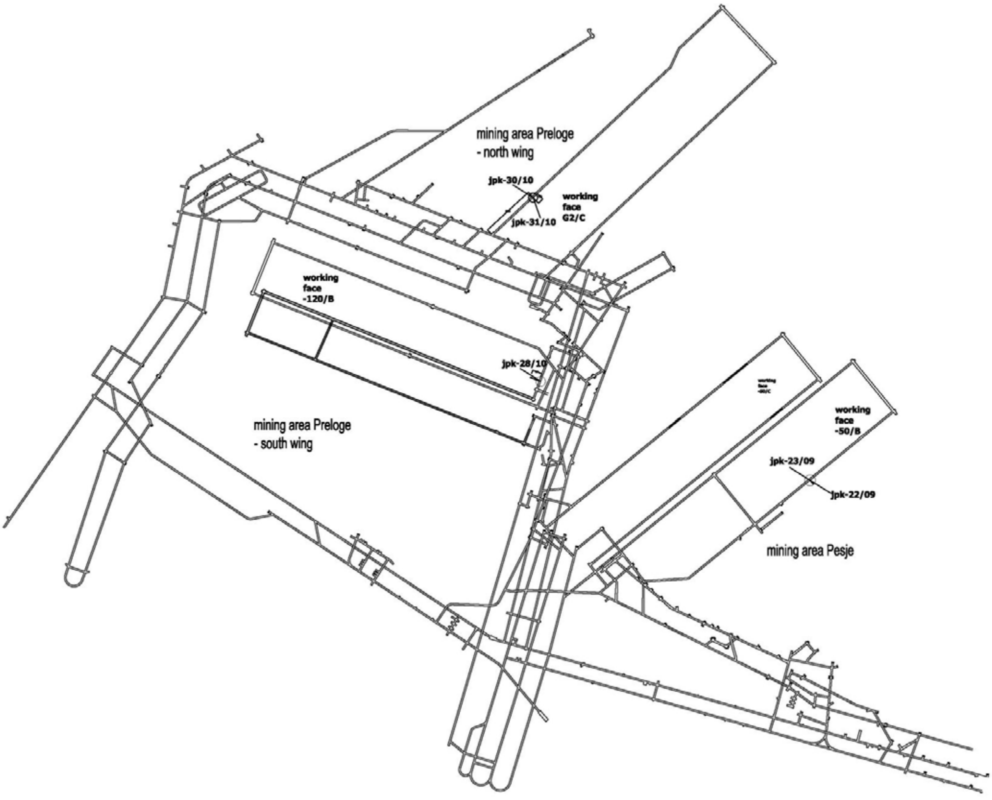

**Figure 1.** Map of sampling locations of coalbed gases from the lignite strata at working faces (–120/B – Preloge South, G2/C – Preloge North and –50/B - Pesje)

mass spectrometer with ANCA – TG preparation module. First water was removed and then $CO_2$ was directly analyzed for $^{13}C$ content. For methane measurements first $CO_2$ was removed and then methane was combusted over hot 10 % platinum CuO (1000 °C). The methane completely converted to $CO_2$ was then directly analyzed for isotopic composition of carbon ($\delta^{13}C$). Working standards calibrated to IAEA (International Atomic Energy Agency) reference materials were used with value of –3.2 ‰ for $CO_2$ and value of –47.5 ‰ for methane relatively to VPDB (Vienna Pee Dee Belemnite). Analytical precision for carbon isotope composition is estimated to be ±0.2 ‰. The stable carbon isotopes are presented in the δ – notation relative to VPDB standards and expressed in parts per million (Coplen, 1996) as follows (O'Neil, 1979):

$$\delta^{13}C_{vz} = \frac{R_s - R_{RM}}{R_{RM}} \cdot 1000 \quad [‰] \qquad (1)$$

Where:
$R_s$ – ratio $^{13}C/^{12}C$ in sample
$R_{RM}$ – ratio $^{13}C/^{12}C$ in reference material

## Results and discussion

"Free gases" accumulated within the lignite coal seam showed a considerable variability in concentrations and isotopic composition. Due to air contamination within boreholes and the capillary system samples were recalculated on an air - free basis. Major gas components were $CO_2$ and methane. Only one sample from our study had nitrogen, meaning that it was in excess. Concentrations of $CO_2$ varied from 20.8 % to 86.9 %, methane from 13.1 % to 58.9 %. Geochemical index CDMI $((CO_2/\ (CO_2 + CH_4) \times 100\ \%)$ vary from 26.1 % to 86.9 % and stable isotope ratios varied in the following ranges: $\delta^{13}C_{CO2}$ from –12.5 ‰ to 2.3 ‰ and $\delta^{13}C_{CH4}$ from –69.1 ‰ to –26.9 ‰ (Table 1).

High correlation (*r* between 0.95 and 1) is obtained between methane and $CO_2$ concentrations (Figure 2) in a lignite seam within boreholes as a function of the advancement of the working faces (–120/B, G2/C and –50/C). Working faces from different mining areas (Preloge North, Preloge South and Pesje) have different composition of coalbed gases. At all investigated mining areas Preloge South (–120/B), Preloge North (G2/C) and Pesje (–50/B) $CO_2$ prevails under methane (Figure 2). The highest $CO_2$ concentrations are observed in mining are Preloge South (except 1 sample) where $N_2$ concentrations were in excess of air (Table 1). The results of areas of high and low methane concentrations (Figure 2) are in physicochemical properties of $CO_2$ and methane (Atkins, 1994). Fissures generated

**Table 1.** Composition of coalbed gases and isotopic composition of carbon ($\delta^{13}C$) of coalbed gases ($CO_2$ and methane) at working faces: –120/B, G2/C and –50/B within boreholes jpk – 28/10, jpk – 30/10, jpk – 31/10, jpk – 22/09 and jpk – 23/09. CDMI index = $(CO_2/(CO_2 + CH_4) \times 100\ \%)$

**Working face -120/B, borehole jpk-28/10, mining area Preloge South**

| Date of sampling | Distance of the working face (m) | $CH_4$ (vol. %) | $CO_2$ (vol %) | $N_2$ (vol. %) | CDMI index (%) | $\delta^{13}C_{CO2}$ (‰) | $\delta^{13}C_{CH4}$ (‰) |
|---|---|---|---|---|---|---|---|
| March 3, 2010 | 191 | 13.1 | 86.9 | 0.0 | 86.9 | -5.7 | -62.7 |
| March 12, 2010 | 160 | 58.9 | 20.8 | 20.3 | 26.1 | -7.9 | -64.4 |
| March 17, 2010 | 151 | 13.8 | 86.2 | 0.0 | 86.2 | -7.1 | -63.1 |
| April 9, 2010 | 92 | 17.5 | 82.9 | 0.0 | 82.6 | -4.8 | -50.6 |
| May 4, 2010 | 45 | 20.5 | 79.5 | 0.0 | 79.5 | -9.6 | -69.1 |
| May 11, 2010 | 37 | 19.8 | 80.2 | 0.0 | 80.2 | -8.1 | -62.7 |
| May 13, 2010 | 32 | 23.0 | 77.0 | 0.0 | 77.0 | -8.6 | -62.9 |
| May 14, 2010 | 31 | 20.0 | 80.0 | 0.0 | 80.0 | -8.5 | -61.9 |
| May 18, 2010 | 30 | 24.3 | 75.7 | 0.0 | 75.7 | -12.5 | -63.3 |
| June 1, 2010 | 30 | 29.1 | 70.9 | 0.0 | 70.9 | -7.6 | -51.1 |

**Working face G2/C, borehole jpk-30/10, mining area Preloge North**

| Date of sampling | Distance of the working face (m) | $CH_4$ (vol. %) | $CO_2$ (vol %) | $N_2$ (vol. %) | CDMI index (%) | $\delta^{13}C_{CO2}$ (‰) | $\delta^{13}C_{CH4}$ (‰) |
|---|---|---|---|---|---|---|---|
| August 18, 2010 | 341 | 42.2 | 57.8 | 0.0 | 57.8 | 1.8 | -31.0 |
| August 31, 2010 | 316.4 | 43.5 | 56.5 | 0.0 | 56.5 | -1.1 | -37.2 |
| September 22, 2010 | 307.5 | 46.1 | 53.9 | 0 | 53.9 | -6.6 | -29.8 |
| November 30, 2010 | 152.1 | 42.3 | 57.7 | 0.0 | 57.7 | 0.9 | -50.0 |

**Working face G2/C, borehole jpk-31/10, mining area Preloge North**

| Date of sampling | Distance of the working face | $CH_4$ vol. % | $CO_2$ vol % | $N_2$ vol. % | CDMI index (%) | $\delta^{13}C_{CO2}$ (‰) | $\delta^{13}C_{CH4}$ (‰) |
|---|---|---|---|---|---|---|---|
| August 20, 2010 | 335.3 | 45.7 | 54.3 | 0.0 | 54.3 | -1.7 | -45.5 |
| August 27, 2010 | 316.4 | 30.7 | 69.3 | 0.0 | 69.3 | -9.1 | |
| September 22, 2010 | 307.5 | 36.6 | 63.4 | 0.0 | 63.4 | -3.9 | -60.4 |
| November 30, 2010 | 152.1 | 43.3 | 56.7 | 0.0 | 56.7 | -0.7 | -50.3 |

**Working face -50/B, borehole jpk-22/09, mining area Pesje**

| Date of sampling | Distance of the working face | $CH_4$ vol. % | $CO_2$ vol % | $N_2$ vol. % | CDMI index (%) | $\delta^{13}C_{CO2}$ (‰) | $\delta^{13}C_{CH4}$ (‰) |
|---|---|---|---|---|---|---|---|
| November 16,2009 | 267 | 41.3 | 58.7 | 0.0 | 58.7 | 2.28 | -26.9 |
| December 14, 2009 | 214 | 19.9 | 80.1 | 0.0 | 80.1 | -4.76 | -44.4 |
| January 11, 2010 | 181 | 33.1 | 66.9 | 0.0 | 66.9 | -0.70 | -42.6 |
| February 22, 2010 | 79 | 24.5 | 75.5 | 0.0 | 75.5 | -2.1 | -58.0 |
| February 24, 2010 | 76 | 28.0 | 72.0 | 0.0 | 72.0 | -4.4 | -60.6 |
| March 15, 2010 | 35 | 42.1 | 57.9 | 0.0 | 57.9 | -0.1 | -48.3 |
| March 22, 2010 | 26 | 27.6 | 72.4 | 0.0 | 72.4 | 1.0 | -56.6 |

**Working face -50/B, borehole jpk-23/09, mining area Pesje**

| Date of sampling | Distance of the working face | $CH_4$ vol. % | $CO_2$ vol % | $N_2$ vol. % | CDMI index (%) | $\delta^{13}C_{CO2}$ (‰) | $\delta^{13}C_{CH4}$ (‰) |
|---|---|---|---|---|---|---|---|
| November 16,2009 | 267 | 38.7 | 61.3 | 0.0 | 61.3 | 0.44 | -49.4 |
| February 22, 2010 | 79 | 24.5 | 75.5 | 0.0 | 75.5 | -2.2 | -58.3 |
| February 24, 2010 | 76 | 28.0 | 72.0 | 0.0 | 72.0 | -4.4 | -60.6 |
| March 8, 2010 | 48.2 | 19.2 | 80.8 | 0.0 | 80.8 | -1.3 | -54.6 |
| March 15, 2010 | 35 | 26.0 | 74.0 | 0.0 | 74.0 | -2.5 | -59.6 |

with advance of the working face enable migration of methane through lignite seam in surrounding strata or to a surface, while $CO_2$ remains adsorbed in lignite seam.

Figures 3 A, B and C show concentrations of $CO_2$ and methane at researched mining areas (Preloge North, Preloge South and Pesje) in advancement of the working face (–120/B, G2/C and –50/B). Generally, at all working faces it was observed that methane migrates faster than $CO_2$ with advance of the working face, therefore the trend of maximum of methane concentration coincides with minimum $CO_2$ concentrations (Figures 3 A, B and C). Temporal changes of coalbed concentrations ($CO_2$ and methane) fluctuate with the rate of advancement of working faces (Figures 3 A, B and C). At the working face –120/B it was observed that at the distance of the working face 92 m (rate of advancement of working face 2.5 m/d) caused highest concentrations in methane and lowest concentration in $CO_2$ (Figure 3 A). At the distance of the working face 45 m (rate of advancement of the working face cca. 2 m/d) the next maximum of $CO_2$ was detected, coinciding with minimum of methane concentrations. After May 13 the rate of working face approaching to borehole jpk-28/10 gradually slowed down (rate of advancement

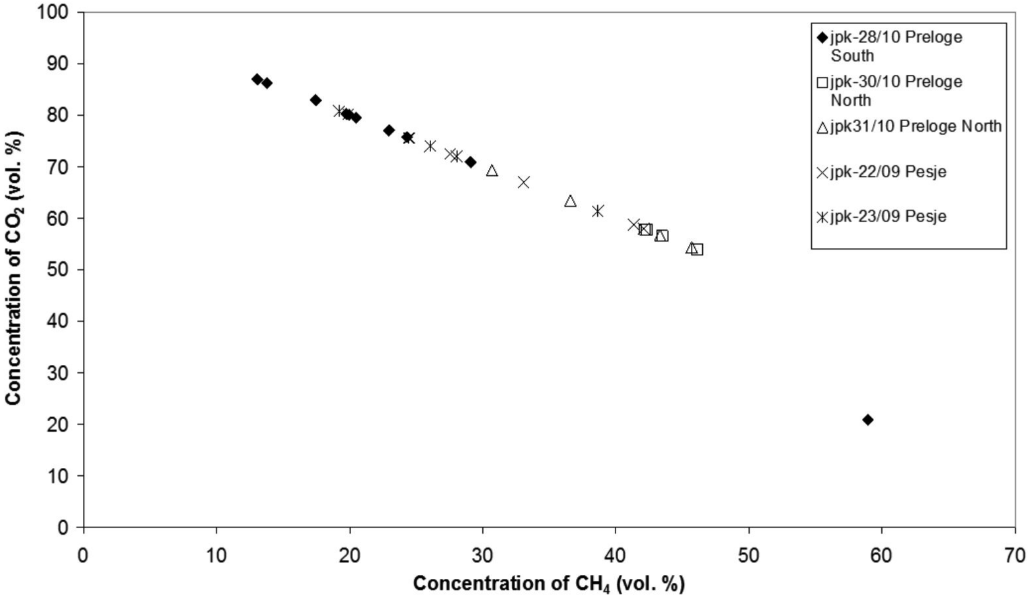

**Figure 2.** Concentration of $CO_2$ versus concentration of methane in lignite seam in advancement of the working faces (–120/B Preloge South, G2/C Preloge North, –50/B Pesje)

of working face cca. 1 m/d) causing lower fluctuations in concentration of $CO_2$ and methane. At the working face G2/C no trends of increasing/decreasing of $CO_2$ and methane concentrations are observed, probably due to constant approaching of the working face with average rate 1.9 m/d to the boreholes jpk-30/10 and jpk-31/10 (Figure 3 B). The rate of advancement of the working face –50/B was from 0.9 m/d to 2.4 m/d. Maximum methane and minimum methane concentrations were traced within borehole jpk-22/09 at the distance of the working face 35 m (rate of advancement of working face cca. 2.2 m/d) (Figure 3 C). Approaching of the working face also influence on stress situation at working face (Figure 4). During excavation of lignite secondary fissures are generated due to rearrangement of primary stress conditions, enabling releasing of coalbed gas preserved in pores of coalbed reservoir. These stress conditions are presented in Figure 4 modified after William (1999). Results of changing of stresses were investigated by three axis cells build in lignite structure. The research revealed that at the distance of 120 m from the working face vertical stresses start to increase. At the distance of 80 m from the working face shearing and collapsing of lignite structure occur; vertical stresses continue to increase while horizontal and transverse stresses decrease. At the distance of the working face 30–50 m from three axis cell vertical stresses are so high that the lignite structure collapse (Zavšek, 1990). Research of temporal variations of concentrations ($CO_2$ and methane) within borehole 780H IV at working face -80c similar trends as at working faces –120/B, G2/C and–50/B in concentrations of $CO_2$ and methane were observed; at the distance of the working face 177 m and 122 m maximum concentrations of methane were traced and coincide with minimum concentrations of $CO_2$ (Kanduč, 2004). Besides the rate of advancement of the working face concentrations of methane and $CO_2$ measured in lignite seam within boreholes (jpk-28/10, jpk-30/10, jpk-31/10, jpk-22/09 and jpk-23/09) also depends on permeability and porosity of lignite seam. When methane and $CO_2$ reaches strata with high permeability such as fault zones, their concentrations start to increase, therefore also areas with high concentrations of methane and $CO_2$ might be expected. $CO_2$ behaves at certain condition (above its critical temperature 31.1 °C and critical pressure 7.39 MPa, expanding to fill its container like a gas but with a density like that of a liquid) as supercritical fluid (Atkins, 1994), meaning that could be at liquid and gas phases. The conditions of critical temperature and pressure for $CO_2$ are possibly reached at working faces causing its adsorption (liquid phase)/desorption (gas phase). Areas with high $CO_2$ content (CDMI index) might be potentially danger-

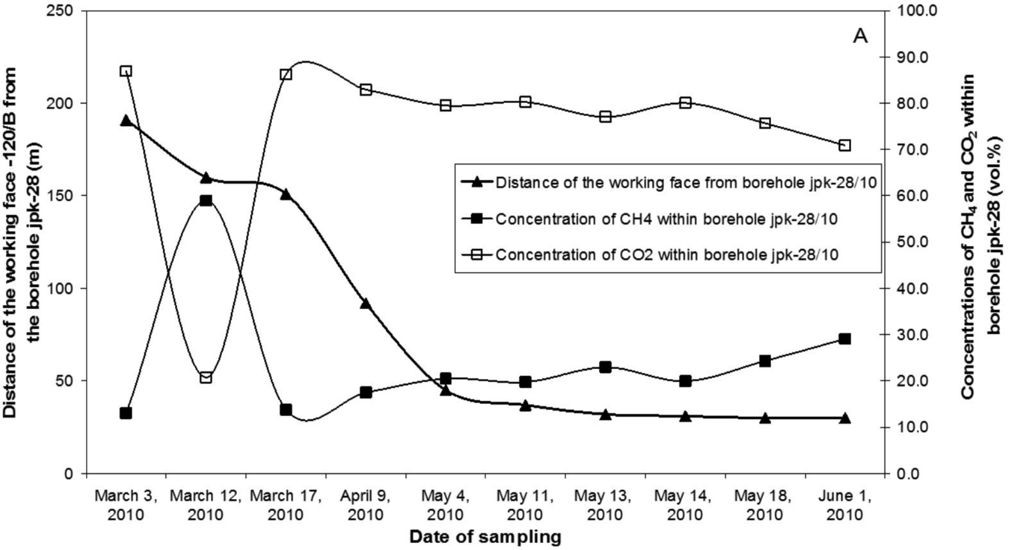

**Figure 3A.** Concentration of methane and $CO_2$ versus date of sampling in advancement of the working face –120/B (Preloge South)

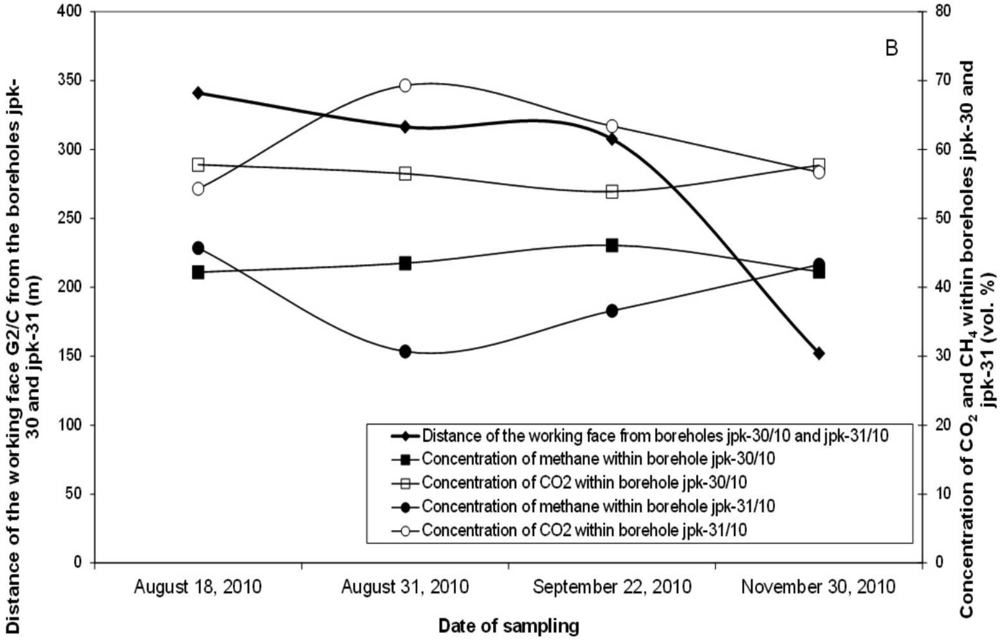

**Figure 3B.** Concentration of methane and $CO_2$ versus date of sampling in advancement of the working face G2/C (Preloge North)

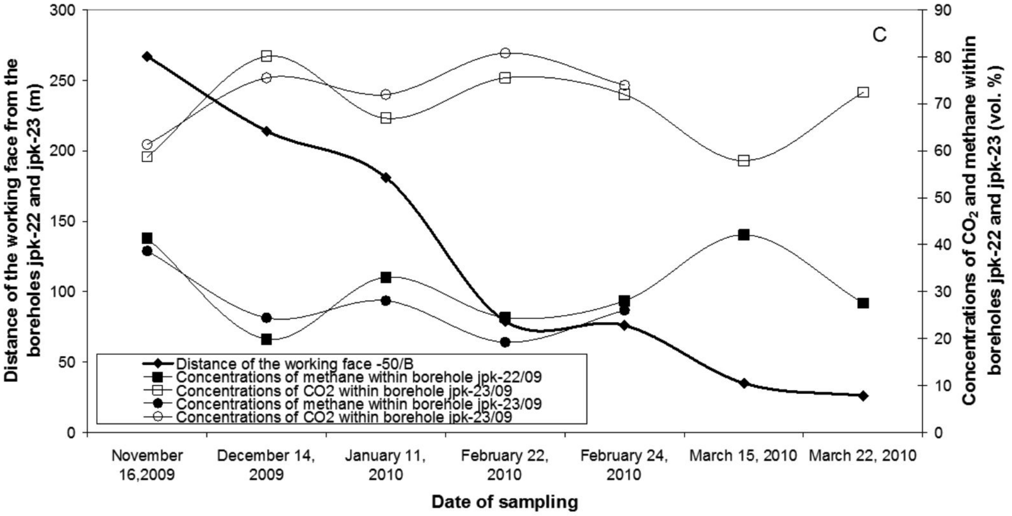

**Figure 3C.** Concentration of methane and $CO_2$ versus date of sampling in advancement of the working face –50/B (Pesje)

ous for gas outbursts (Clayton, 1998). Anyway, investigation of gas concentrations at each working face should be further related to petrological characteristics of lignite (lithotype type e. g. xylite, detrite), tectonically characteristics (characteristics of fault zones) and geotechnical conditions (pressures, porosity and permeability) to get better insight to coalbed gas migration as well sorption/desorption processes, especially $CO_2$ through lignite.

Interpretation of coalbed gases from investigated mining areas of Pesje and Preloge was performed according to previous study of tracing inorganic and organic carbon cycles in different geological media (calcified xylite, carbonate lenses in the lignite seam, lignite and Pliocene, Triassic and Lithotamnium aquifers) (Kanduč et al., 2010, in review). From the results it was concluded that coalbed gases in the Velenje Basin are mainly microbial (bacterial) origin, while $CO_2$ could be also endogenic. Microbes that generate methane (methanogens) could have either of been deposited with the coal sediments in the geologic past or transported in more recently with active groundwater recharge. To thrive methanogens require an anoxic, aqueous environment with organic carbon substrates and the absence of other free-energy electron acceptors, such as $NO_3^-$ and $SO_4^{2-}$. Fermentative bacteria degrade complex organic matter in coalbeds (e.g. structures of carbohydrates, proteins and lipids that originate in vegetation and sediments) to simpler molecules including acetate ($CH_3COOH$), fatty acids, $CO_2$ and $H_2$ gas. Acetogenic bacteria thrive on fatty acid products to produce acetate, with $CO_2$ and $H_2$ by products (Kotelnikova, 2002). The products of these reactions support a variety of methanogens. Some methanogens use an acetate food source to produce $CO_2$ and methane, according to following reactions:

$$CH_3COOH \rightarrow CH_4 + CO_2 \quad \text{Acetate fermentation} \tag{2}$$

While other methanogens use the hydrogen gas to reduce $CO_2$:

$$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O \quad CO_2 \text{ reduction} \tag{3}$$

or

$$HCO_3^- + 4H_2 \rightarrow CH_4 + 2H_2O + OH^- \quad CO_2 \text{ reduction} \tag{4}$$

We applied diagrams $\delta^{13}C_{CH4}$ versus $\delta^{13}C_{CO2}$ (Figure 5) to explain the origin of methane and $\delta^{13}C_{CO2}$ versus CDMI index (Figure 6) to explain the origin of $CO_2$. $\delta^{13}C_{CH4}$ (Figure 4) in the Velenje basin indicate the successive origin of methane: microbial ($CO_2$ reduction) with $\delta^{13}C_{CH4}$ values from –40 ‰ to –50 ‰, microbial (acetate fermentation) with $\delta^{13}C_{CH4}$ less than –50 ‰ and mixed origin between these two (Clayton, 1998). Enrichment with $^{13}C$ in methane could be also due to microbial oxidation of methane, which results in an enrichment of residual methane with the $^{13}C$ isotope and depletion of $^{12}C$ in generated $CO_2$ (Figure 5).

It is known that coalbed lignite strata were formed in the Pliocene in a calm sedimentary environment (Markič & Sachsenhofer, 1997), but the proportion of early stage microbial gas retained in the lignite structure (Smith & Pallaser, 1996) is difficult to estimate. Microbial methane in Velenje basin was generated by microbial reduction and/or by microbial fermentation. Also recent microbial activity (methanogenic and methanotrophic bacteria) might generate microbial

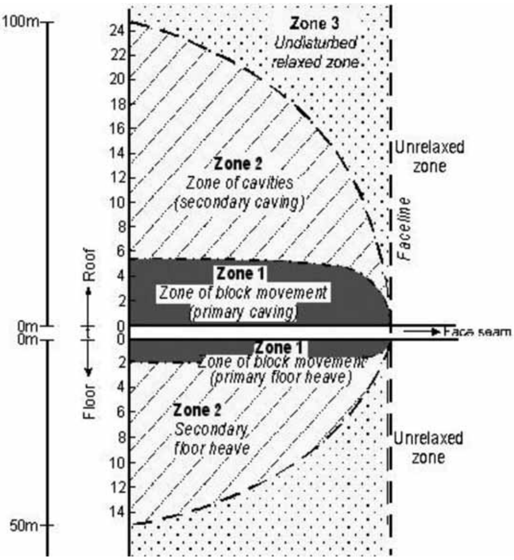

**Figure 4.** Geomechanical conditions and generation of secondary fissures due to longwall method of excavation of lignite, causing a realese of coalbed gases inside of demolished zone (adapted after Williams, 1999)

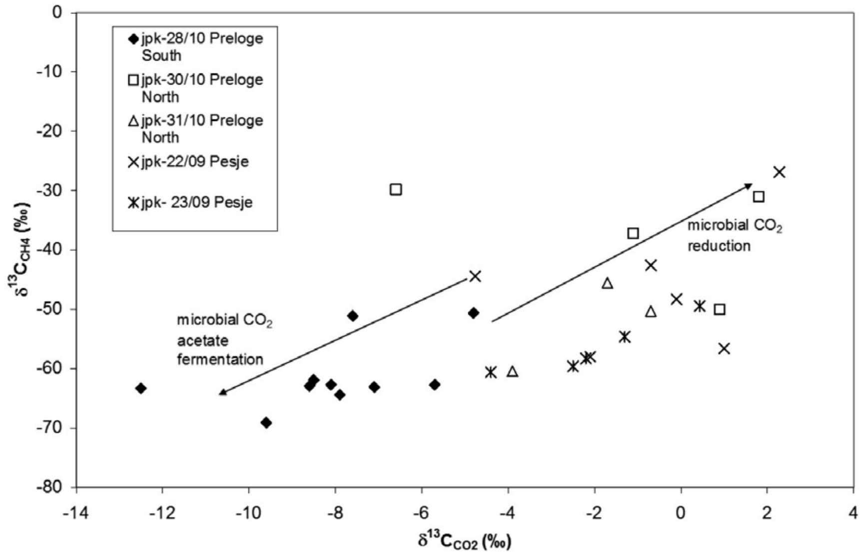

**Figure 5.** Interpretation of the origin of methane in the Velenje basin using $\delta^{13}C_{CH4}$ versus $\delta^{13}C_{CO2}$ in a lignite seam at boreholes (jpk – 28/10, jpk – 30/10, jpk – 31/10, jpk – 22/09 and jpk – 23/09) in advancement of the working faces (–120/B, G2/C and –50/B)

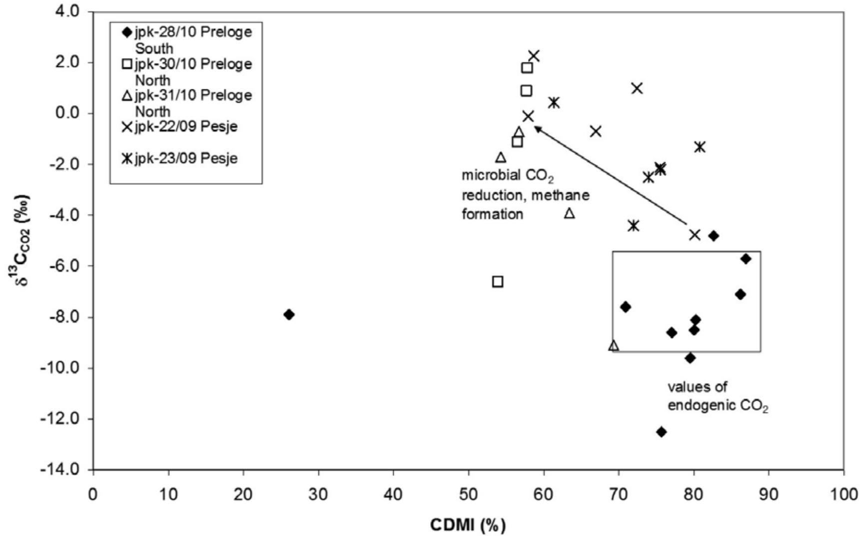

**Figure 6.** Interpretation of the origin of $CO_2$ at working faces (–120/B, G2/C in –50/B) using $\delta^{13}C_{CO2}$ versus CDMI index in a lignite seam in boreholes (jpk – 28/10, jpk – 30/10, jpk – 31/10, jpk – 22/09 and jpk – 23/09) ahead of the working faces (–120/B, G2/C and –50/B)

gas (Kotelnikova, 2002). Methane and $CO_2$ were/are generated by microbial fermentation process while methane was/is generated by $CO_2$ reduction process. $CO_2$ generated by fermentation process is characterized by $\delta^{13}C_{CO2}$ similar that organic matter around –25 ‰, while microbial reduction process results in an enrichment with the $^{13}C$ of residual $CO_2$ (Figures 5 and 6). Microbial $CO_2$ reduction is characteristic in mining area Preloge North, while at Preloge South $\delta^{13}C_{CH4}$ indicate bacterial origin via fermentation. At mining area Pesje both microbial ($CO_2$ reduction and methane fermentation) processes generated methane formation (Figure 5).

The origin of $CO_2$ is interesting due to its relation with outbursts in coalmines. High concentrations of carbon dioxide in seam gases in Australian coals occur in regions of igneous activity and associated faulting and this component has been described as being of presumed pneumatolytic origin (Smith & Gould, 1980). In our study CDMI index versus $\delta^{13}C_{CO2}$ (Figure 5) was used to explain the origin of $CO_2$ (Kotarba, 2001) and indicate endogenic $CO_2$ (including $CO_2$ originating from carbonates) and $CO_2$ of microbial origin in relation to microbial methane (working face Preloge North, jpk-30/10) discussed above. At working face Pesje –50/B (jpk-22/09 and jpk-23/09) $\delta^{13}C_{CO2}$ indicate microbial and endogenic origin (Figure 6). Typical endogenic values of $\delta^{13}C_{CO2}$ are about –7 ‰ (Kotarba, 2001) and high CDMI index found in our study (at working face Preloge South, jpk-28/10) are probably related to the tectonics of the Šoštanj and Smrekovec faults at the time of formation of the Velenje basin.

$\delta^{13}C_{CO2}$ derived from carbonates is dependent on $\delta^{13}C$ of carbonates and the temperature of their degradation. The resulting products are clay minerals and $CO_2$. Supposing that dolomites underwent thermal decomposition and are located below lignite seam along the Šoštanj fault zone values of $\delta^{13}C_{CO2}$ from –2 ‰ to –6 ‰ might indicate $CO_2$ of thermal decomposition of dolomites (Figure 6). This source of $CO_2$ has similar values as endogenic $CO_2$ from the fault zones and can not be distinguished with $\delta^{13}C_{CO2}$.

Also secondary processes should be considered since they might camouflage the origin of gases. Migration of gases as a secondary process caused by reduction of pressure in lignite seam causes enrichment in light $^{12}C$ isotope in methane and in $CO_2$. During migration of coalbed gases, gases of different origin might be mixed together and complicate interpretation of gas origin.

## CONCLUSIONS

Gas outbursts remain for coalminers one of the main problems in the Velenje coalmine, therefore geochemical investigations are one of the important parameters used in case of prediction or prevention gas outbursts.

Concentrations of methane and $CO_2$ change in advance of the working face. Areas with high $CO_2$ concentrations accompany with low methane concentrations and could be related with the rate of advancement of the working face. The rate of advancement of the working face is one of the crucial parameters influencing on gas composition at working faces.

Concentrations and stable isotope studies of coalbed gases at working faces allow the possible interpretation of the origin of coalbed gas in the Velenje basin. Considering also the results of previous studies, it can be concluded that coalbed $CO_2$ from investigated working faces is endogenic and bacterial origin. Methane is microbial origin (formed through microbial fermentation and/or $CO_2$ reduction). Secondary processes like migration, adsorption/desorption and mixing of gases of different origin during excavation complicate the interpretation of gas origin and were neglected in interpretation of the origin of coalbed gases. Examination of the origin of nitrogen (at locations with excess of nitrogen) in coalbed gases from Velenje Basin needs further research.

## Acknowledgements

This study was conducted in the framework of project Z1-2052 funded by the Slovenian Research Agency (ARRS) and the Velenje Coalmine d.d. The authors are also grateful to Mr. Tedej Zagoričnik, Mr. Robert Lah and Mr. Stojan Žigon for technical support, assistance in the field sampling and laboratory analyses. Sincere thanks to Dr. Jennifer McIntosh for improving the English of the manuscript.

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