SONATINA-6 NCN

Environmental monitoring of coal mining area: insights from stable isotope measurements of methane excess

Monitoring środowiska na obszarach wydobycia węgla kamiennego: zastosowanie badań izotopowych strumieni metanu

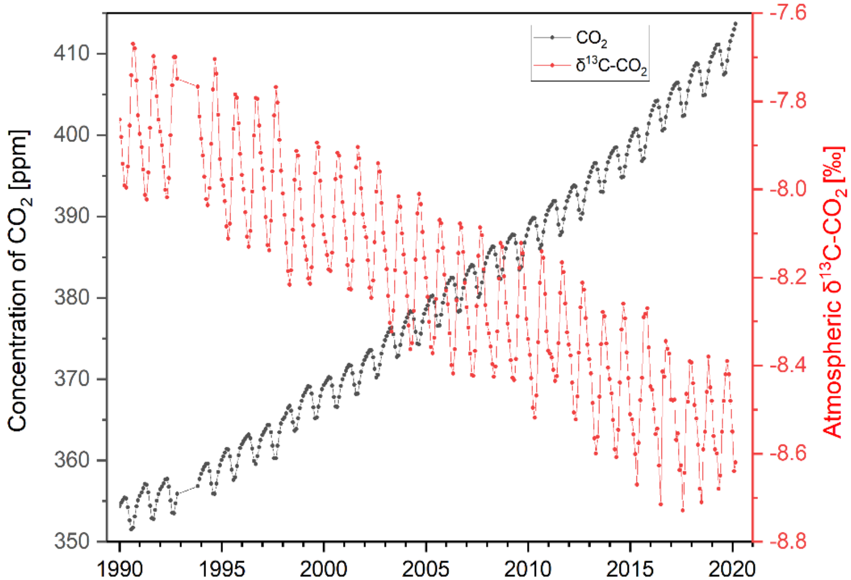
Yaroslav BEZYK

Kraków, 05.04.2024

Stable isotopic signatures of methane sources

Global GHG budget

Increase in global CO_2 and CH_4 concentrations in the atmosphere

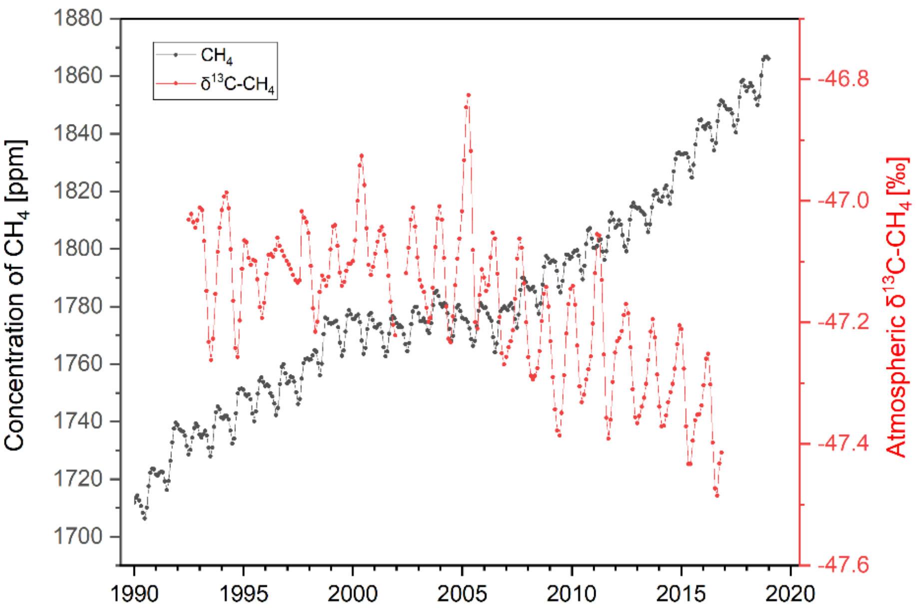


February 2024: 424.55 ppm CO_2
February 2023: 420.30 ppm CO_2

November 2023: 1934.16 ppb CH_4
November 2022: 1923.63 ppb CH_4

What ^{13}C Tells Us

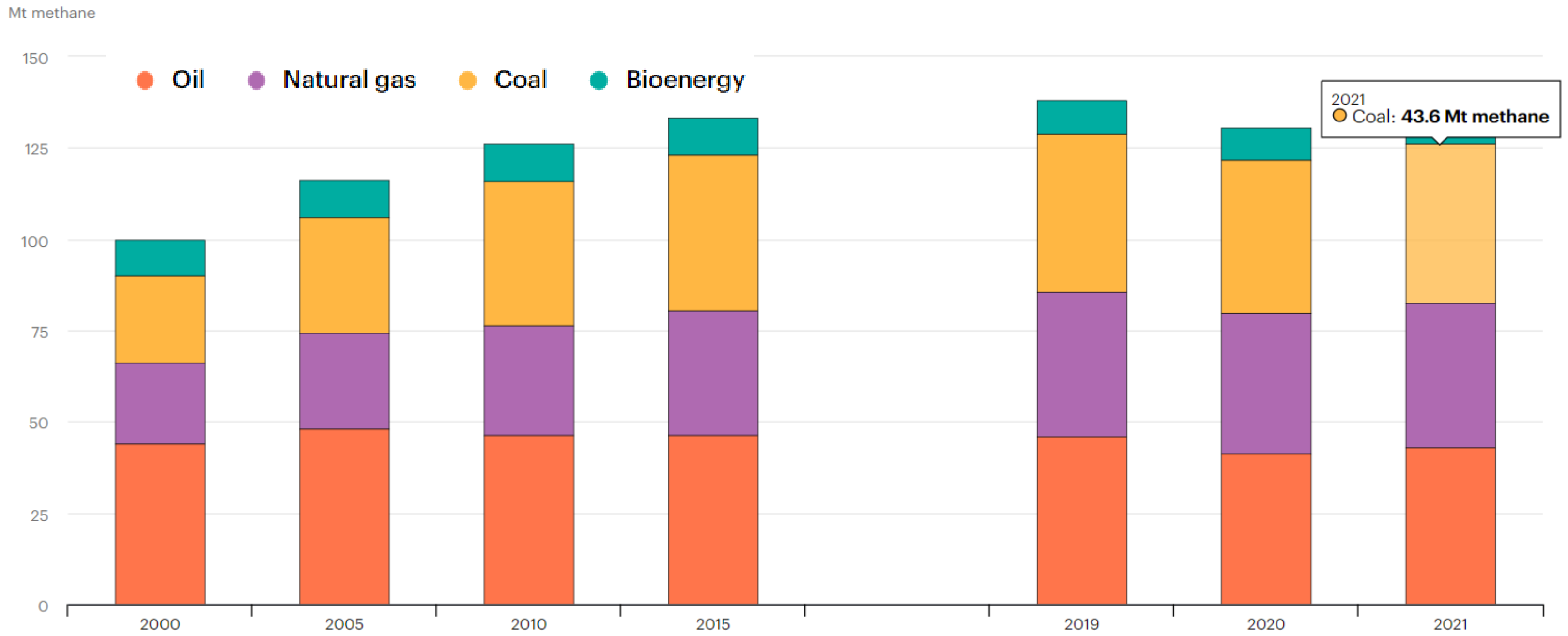
Recall that the Suess Effect is the observed decrease in δ^{13}C and Δ^{14}C values due to ***fossil fuel emissions***, which are **depleted in ^{13}C** and do not contain ^{14}C.



Source: National Oceanic and Atmospheric Administration (NOAA); https://gml.noaa.gov/ccgg/trends/

Global GHG budget

Global methane emissions from the energy sector over time, 2000-2021

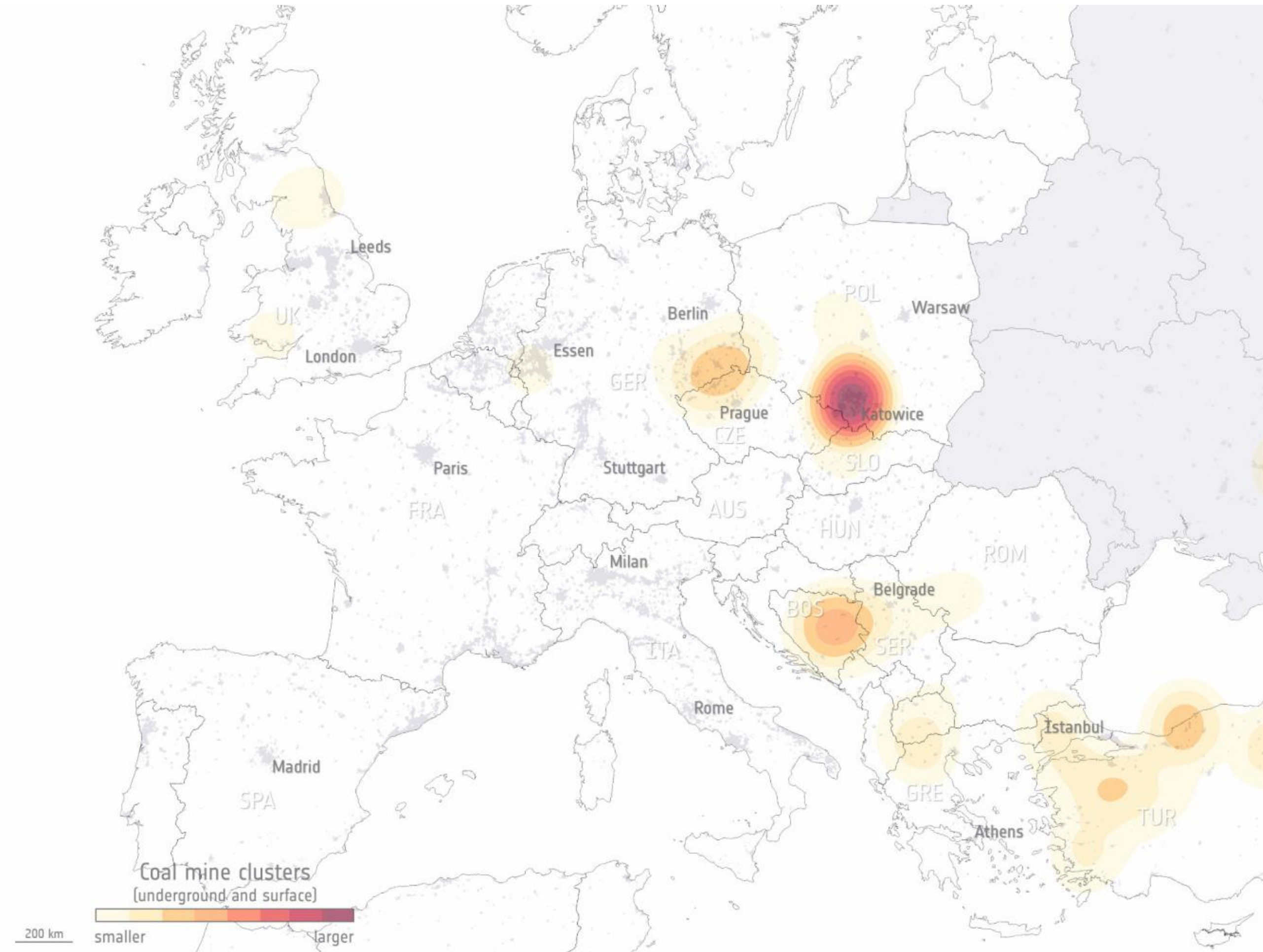


- ***Global CH_4 emissions from the coal sector***, according to the IEA, were estimated to be 43.6 Mt in 2021.
- Coal ***mining is the second main source of methane emissions* in Poland** (37.1% in 2021), according NIR.
- The application of a coal mine monitoring system implies ***large uncertainty of methane emissions***.
- The broad discussion by the EU Council (***EU Methane Action Plan***).

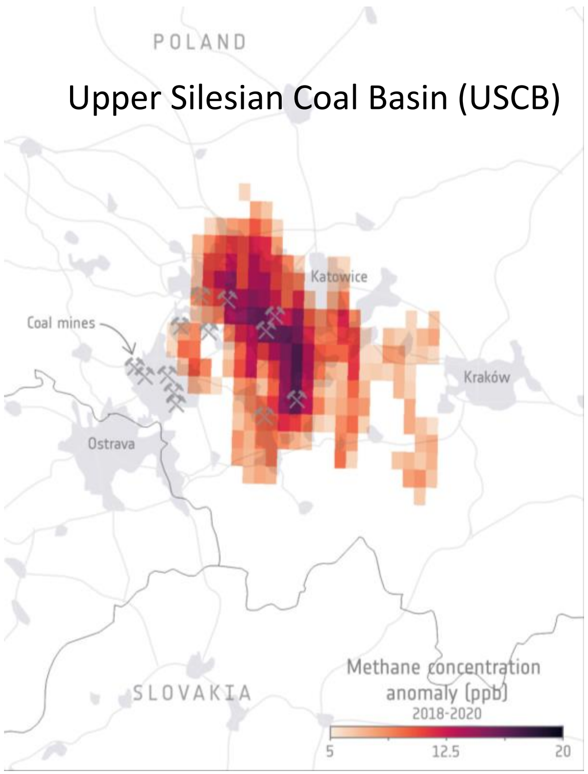
Source: https://www.iea.org/data-and-statistics/charts/global-methane-emissions-from-the-energy-sector-over-time-2000-2021

Methane emissions in Poland

Methane emissions from coal mining, 2018 – 2020



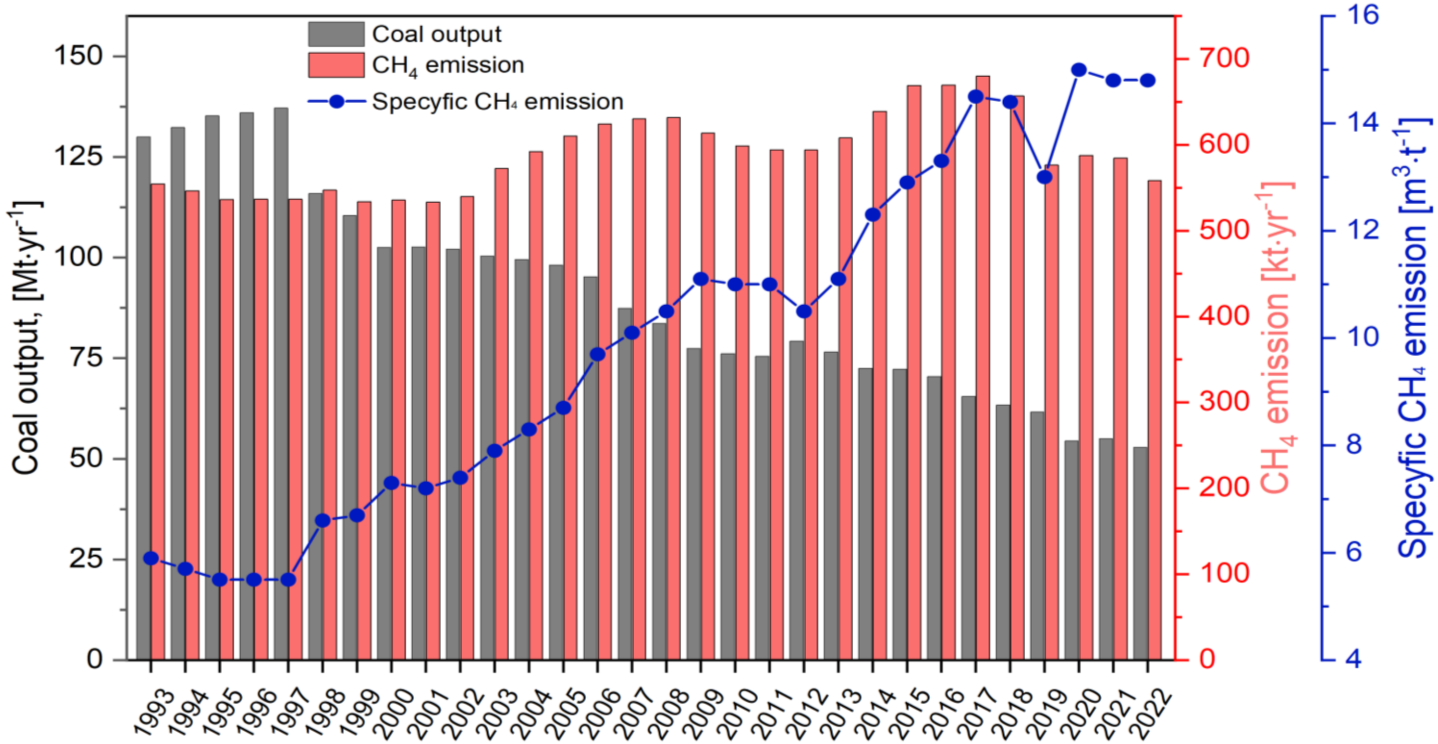
Satellite measurements from the Tropomi instrument onboard Sentinel-5P



Source: https://www.esa.int/Applications/Observing_the_Earth/Copernicus/Sentinel-5P/Methane_detected_over_Poland_s_coal_mines

Methane emissions in Poland

Methane emissions from coal mining, 2018 – 2020



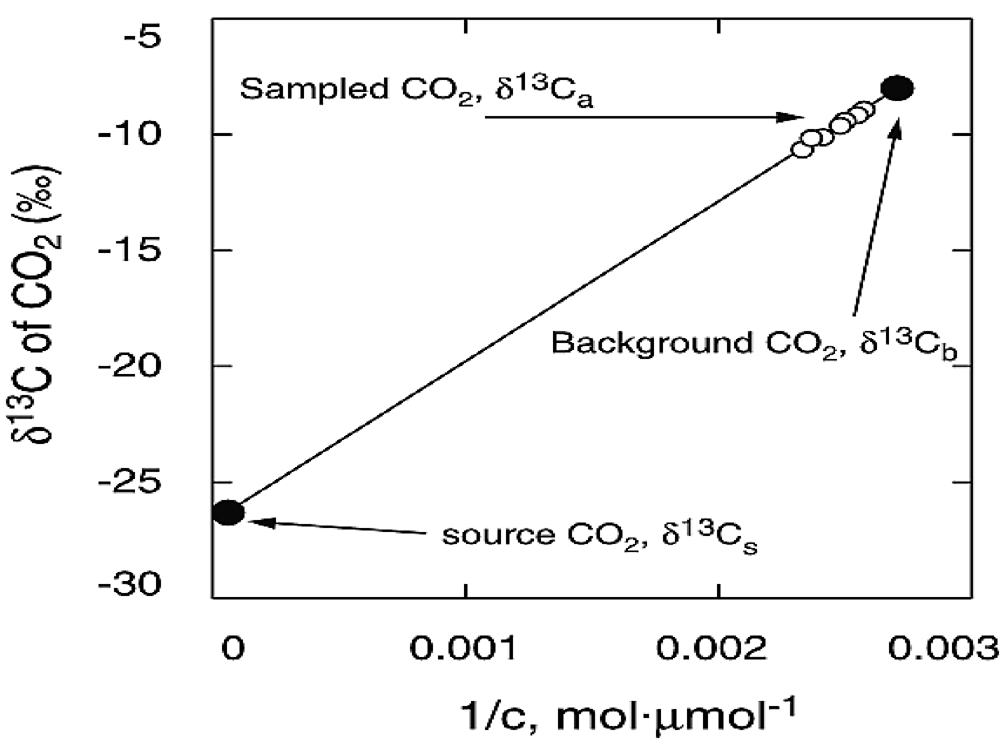
Tendency:

- ***increase the value of methane content*** in the deposit with a depth of coal-bearing strata;
- ***deeper the coal mines*** go into exploitation (coal is extracted at depth of 800 m below m.s.l., even exceeding 1000 m).
- the specific methane emission – ***release of CH_4 per 1 t of extracted coal*** (reached 15 $m^3 \cdot t^{-1}$ in 2020).

Source: WUG (State Mining AuthorityOcena stanu bezpieczeństwa pracy, ratownictwa górniczego oraz bezpieczeństwa powszechnego w związku z działalnością górniczo-geologiczną w 2022 roku, Wyższy Urząd Górniczy w Katowicach, 2023.

Research background

Stable isotopes as environmental tracers



The isotopic $^{13}C/^{12}C$ ratio is expressed in the delta notation ($\delta^{13}C$) in reference to the VPDB scale:

$$\delta^{13}\mathrm{C} = \left(\frac{\left(\frac{^{13}\mathrm{C}}{^{12}\mathrm{C}}\right)_{\text{sample}}}{\left(\frac{^{13}\mathrm{C}}{^{12}\mathrm{C}}\right)_{\text{standard}}} - 1 \right) \times 1000$$

Isotopic source identification:
linear mixing model
Keeling Plot Approach

$C_s + C_{bg} = C_{mix}$
(s: source; bg: background; *mix*: measured sample)

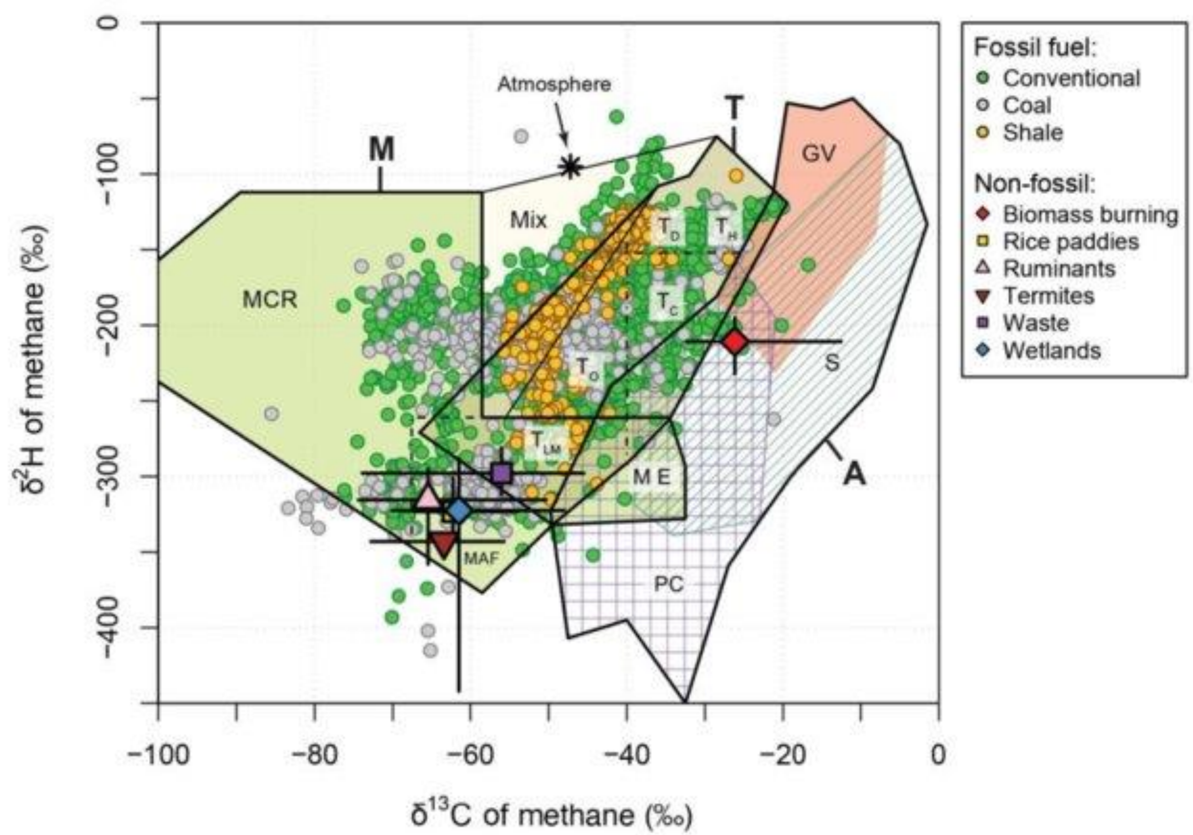
$$\delta_m c_m = \delta_{bg} c_{bg} + \delta_s c_s$$

$$\delta_m = \frac{c_{bg}}{c_m}(\delta_{bg} - \delta_s) + \delta_s$$

Source: Keeling, 1958; Pataki et al., 2006

Research background

Stable isotopes as environmental tracers



The natural abundance of:
^{12}C – 98.892 %,
^{13}C – 1.108 %;

^{1}H – 99.9844 %,
^{2}H – 0.0156 %;

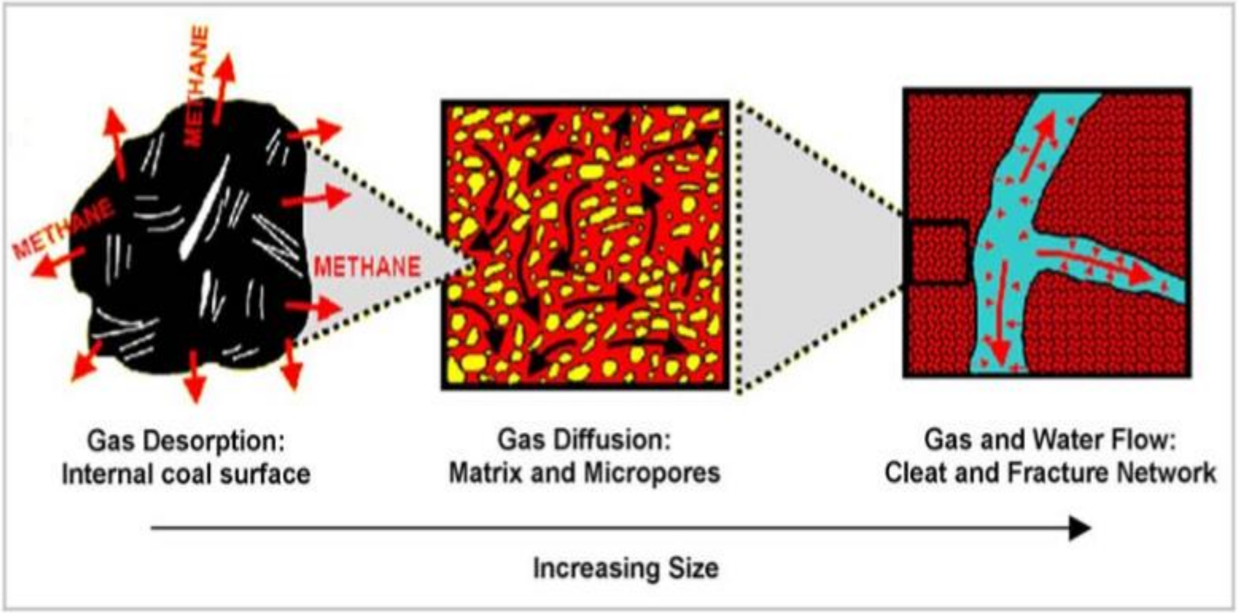
Overview of methane source signatures ($\delta^{13}C$, $\delta^{2}H$)
M: microbial; T: thermogenic; A: abiotic;
MCR: microbial CO_2 reduction; MAF: microbial acetate fermentation;
ME: microbial in evaporitic environment;

Source: Sherwood et al. 2017; Way et al., 1950; Pierson, 1993.

Stable isotope geochemistry of coalbed methane

Methane migration in coal seam

The pattern of methane release from the coal seam and surrounding strata



Coalbed gas exists in forms:

- ***adsorbed gas*** (80–90 % of the total CH_4 content in coal seams)
- ***free gas*** (10–20 %) presented in the pores and cracks within the coal structure,
- < 1 % of ***dissolved gas*** content in the coal-containing water.

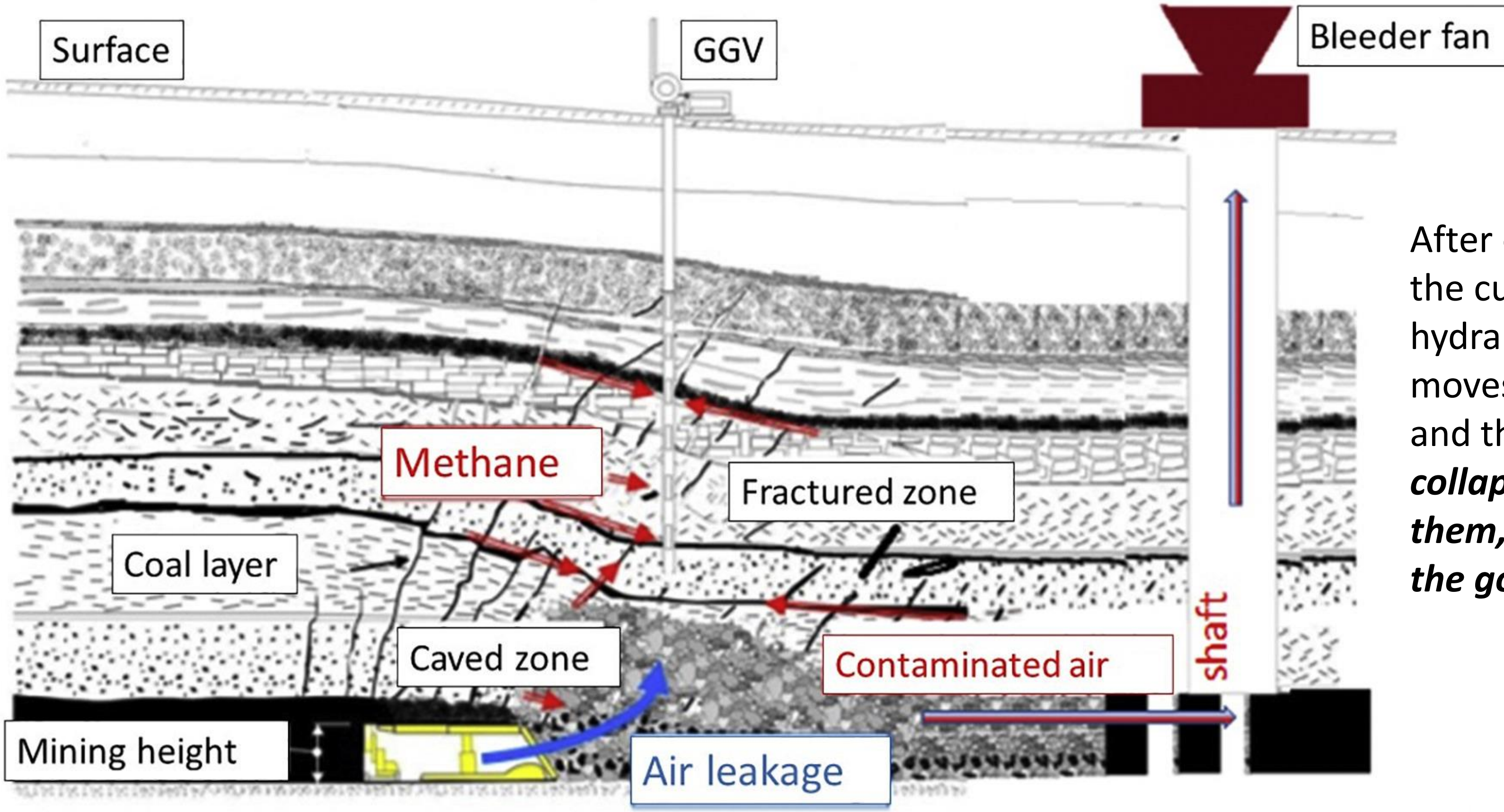
Methane is being emitted into the mine workings from:

- active/fresh face on the ***longwall and goaf zone*** (overlying strata collapsed into the void left by longwall mining);
- ***mined coal itself*** being taken to the surface on the conveyor belts;
- ***surrounding strata*** (geologic discontinuities, such as faults, fractures, fissures in walls, roof and floor) as a result of lower pressures in the mining area;

Source: Coalbed Methane. Coal Mine Methane Recovery: A Primer. U.S. Environmental Protection Agency. September 2009 EPA-430-R-09-013.

Active mining methane emissions

Compaction of strata after removal of the mined coal seam



After completing the cut, the hydraulic shield moves ahead, and the ***roof collapses behind them, forming the gob zone***.

The properties of the strata and CH_4 emission potential:

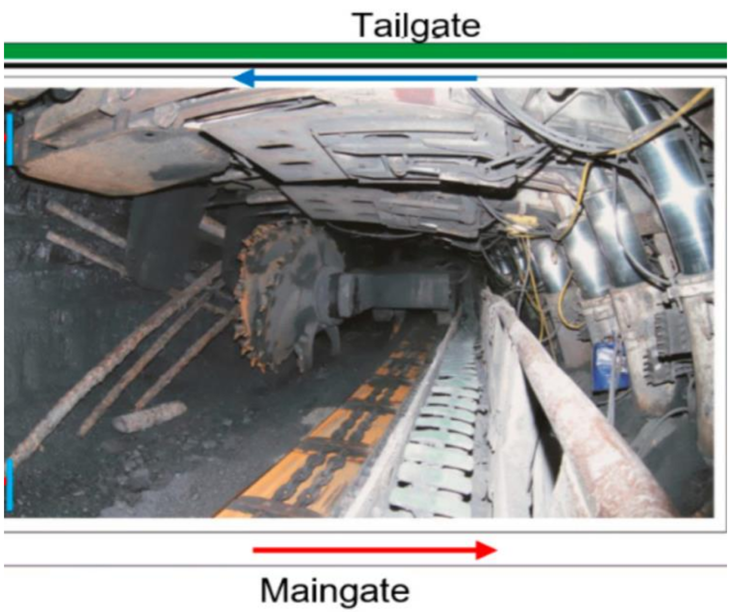
- Strata (overlying rock mass) disturbance created by longwall mining;
- creating tensional stress and enhancing permeability;

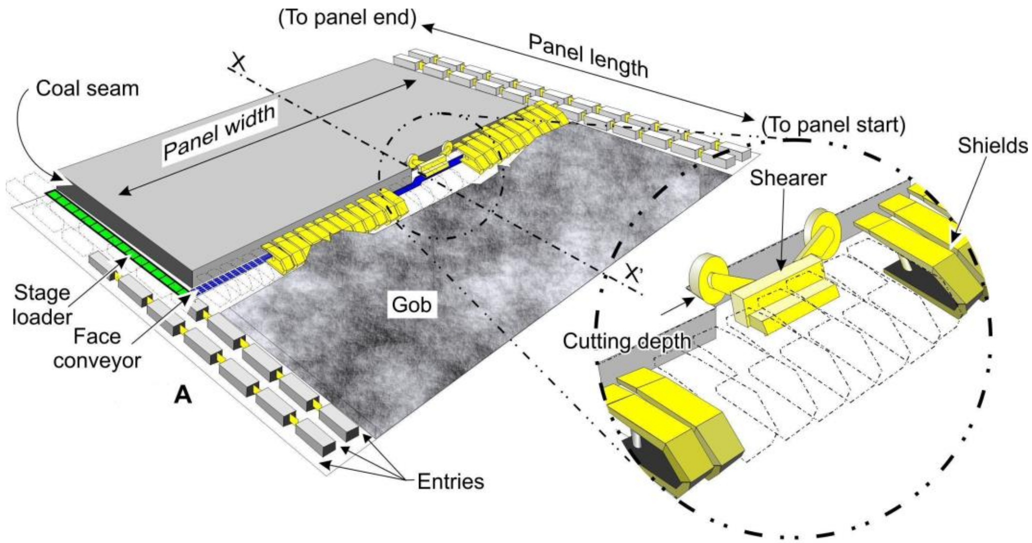
Source: Karacan, C. Özgen; Warwick, Peter D. (2019). Assessment of coal mine methane (CMM) and abandoned mine methane (AMM) resource potential of longwall mine panels: Example from Northern Appalachian Basin, USA. International Journal of Coal Geology, 208(), 37–53. doi:10.1016/j.coal.2019.04.005

Parameters related to longwall coal extraction

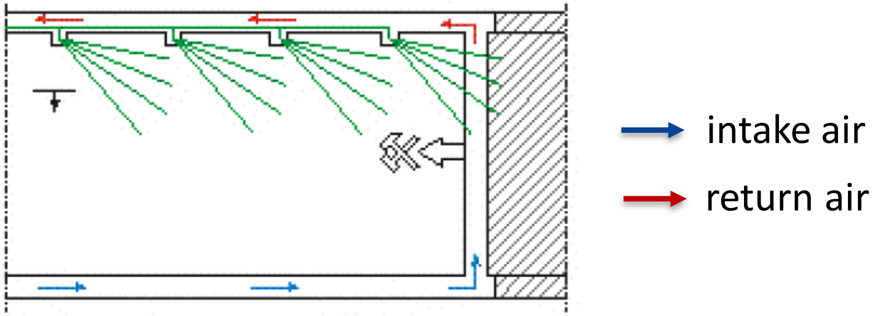
Longwall coal mining operations

Machines included in the longwall complex:
(I) longwall shearer;
(II) bottom scraper conveyor;
(III) powered roof support in the longwall;
(IV) section of the powered roof supports.





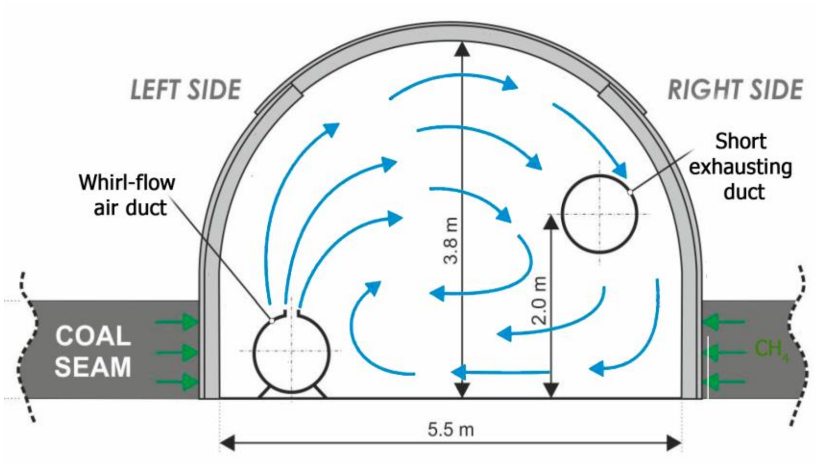
Methane drainage of longwalls



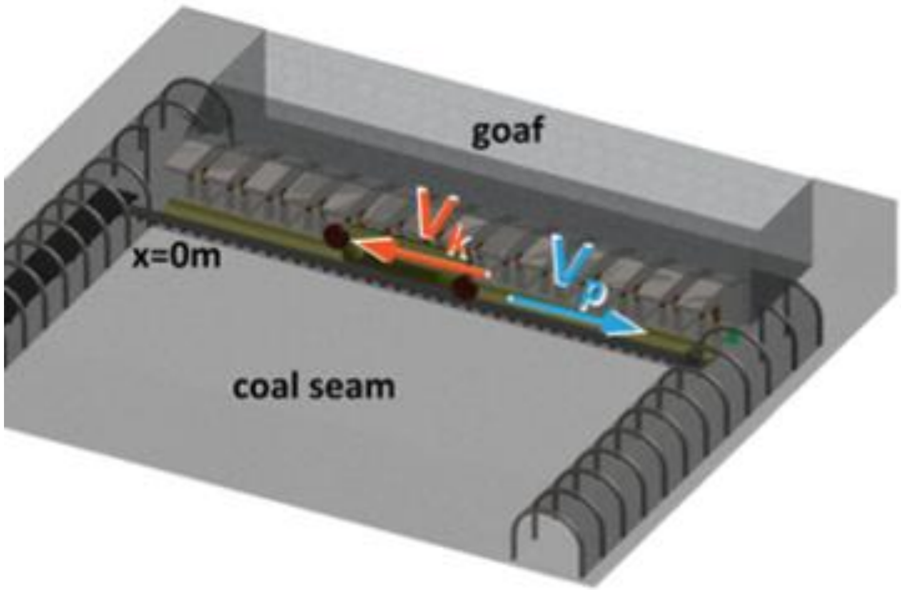
Source: Szurgacz, D.; Tutak, M.; Brodny, J.; Sobik, L.; Zhironkina, O. The Method of Combating Coal Spontaneous Combustion Hazard in Goafs—A Case Study. *Energies* **2020**, *13*, 4538. https://doi.org/10.3390/en13174538
Obracaj, D.; Korzec, M.; Deszcz, P. Study on Methane Distribution in the Face Zone of the Fully Mechanized Roadway with Overlap Auxiliary Ventilation System. *Energies* **2021**, *14*, 6379. https://doi.org/10.3390/en14196379
Karacan, 2008a

Parameters related to longwall coal extraction

Ventilation system in methane-rich coal seams



Methane-air mixture is drained out by **the underground mine ventilation system**, becomes considerably diluted (***less than 1 % CH_4***) and is discharged through the **exhaust ventilation shafts** into the atmosphere.



Depending on the specific coal seam,
the **gas occurring in coal beds contains**:

- 80–95 % of CH_4,
- < 3 % of CO_2, N2,
- proportions of hydrocarbons (ethane, propane, ethylene, acetylene).

Source: Szurgacz, D.; Tutak, M.; Brodny, J.; Sobik, L.; Zhironkina, O. The Method of Combating Coal Spontaneous Combustion Hazard in Goafs—A Case Study. *Energies* **2020**, *13*, 4538. https://doi.org/10.3390/en13174538
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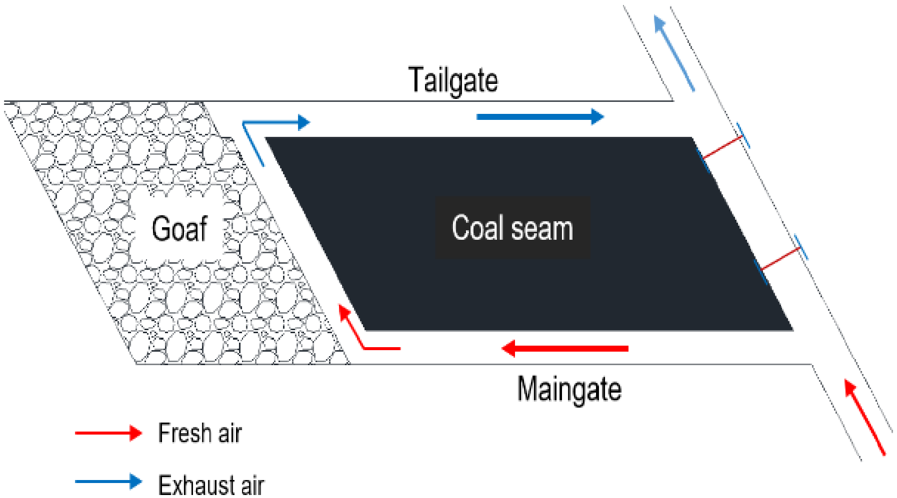
Wierzbicki, M., Skoczylas, N., & Kudasik, M. (2017). *The Use of a Unipore Diffusion Model to Describe the Kinetics of Methane Release from Coal Spoil in the Longwall Environment. Studia Geotechnica et Mechanica, 39(2), 81–89.* doi:10.1515/sgem-2017-0018

Ventilation of active longwall coal face

Discharging methane emissions into the mine ventilation air



U-type ventilation system

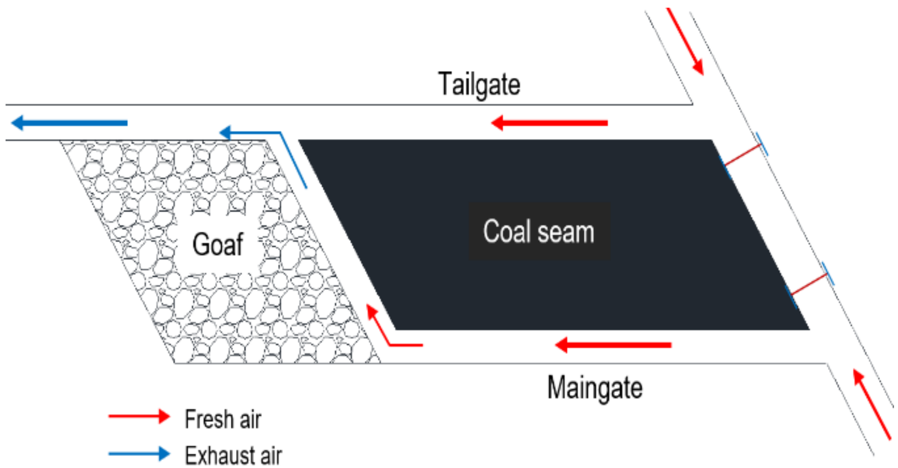
discharges the air through the tailgate that runs along the body of coal

Advantages:

- limits heating and spontaneous combustion of coal left in the goaf zone;

Disadvantages:

- risks of high CH_4 accumulations and its spontaneous combustion hazards;



Y-type ventilation system

air through the tailgate that runs along the goafs

Advantages:

- substantially higher velocity of airflow decrease CH_4 level along the longwall;

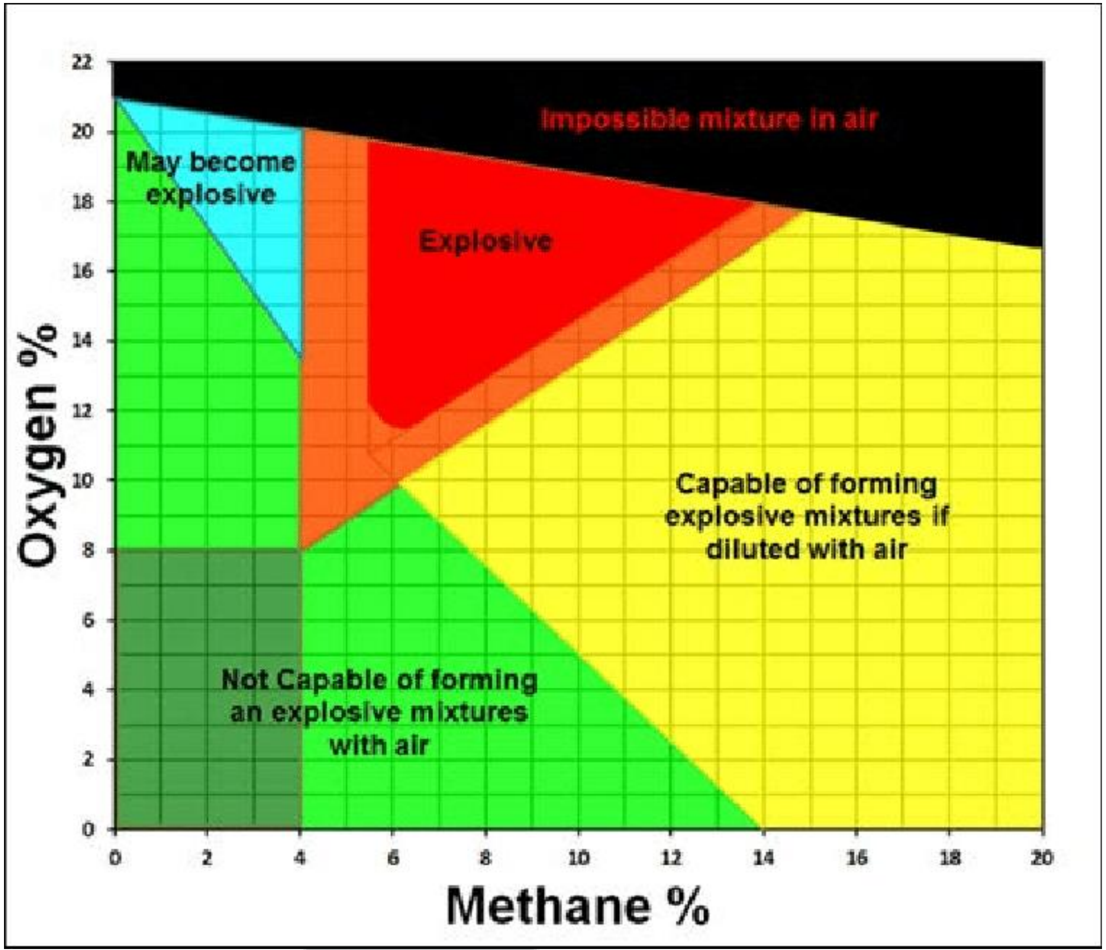
Disadvantages:

- flow of air rich in oxygen intensified process of coal oxidation, heating in the goaf zone;

Source: Tutak, M.; Brodny, J.; Szurgacz, D.; Sobik, L.; Zhironkin, S. The Impact of the Ventilation System on the Methane Release Hazard and Spontaneous Combustion of Coal in the Area of Exploitation—A Case Study. Energies 2020, 13, 4891. https://doi.org/10.3390/en13184891

The explosive potential for CH_4 and air mixtures

The state of methane hazard in coal mines

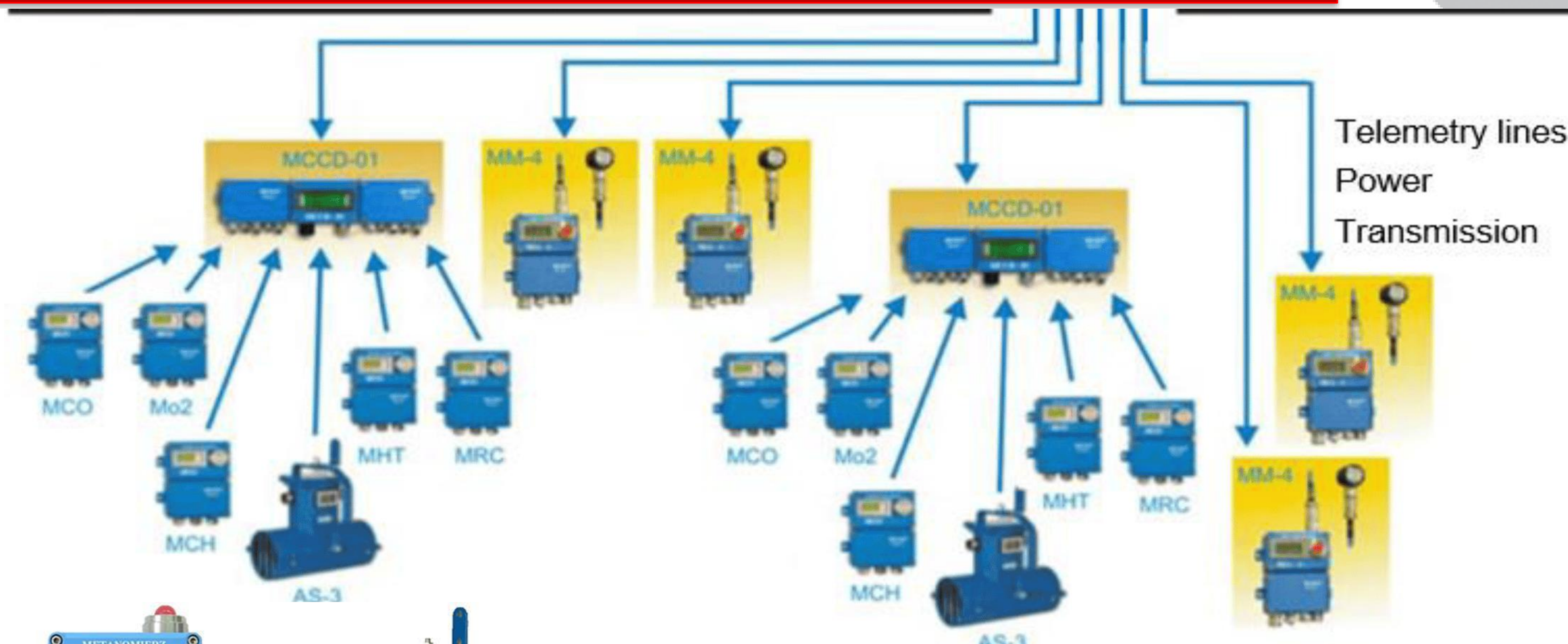


Explosive gas regions:

- ***explosive region*** (red),
- ***fuel-rich inert region*** that can become explosive when fresh air or oxygen is added (yellow);
- ***inert region*** where no explosive composition is possible (green and dark green;
- ***fuel-lean inert region*** (blue).

Source: J. Marts, R. Gilmore, J. Brune, G. Bogin Jr., J. Grubb & S. Saki. Accumulations of Explosive Gases in Longwall Gobsand Mitigation through Nitrogen Injection and Face Ventilation Method. Colorado School of Mines , USA, 2014.

System for monitoring ventilation parameters



thermocatalytic methanometer

ultrasonic anemometer

Measurement error of MM-4:

± 0.1% for concentrations in range of 0 ÷ 2 % CH_4;
± 0.5% for concentrations of 2 ÷ 5 % CH_4;
± 3% for concentrations of 5 ÷ 60 % CH_4;
± 5% for concentrations of 60 ÷ 100 % CH_4.

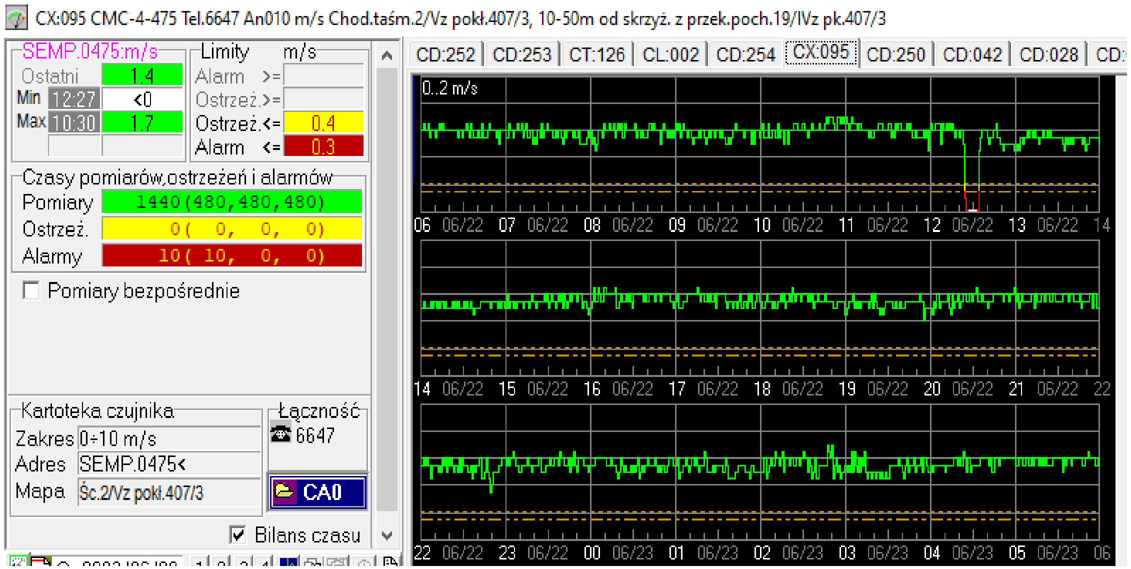
Measurement error of AS-3:

± 0.1 m/s in range of 0.1 – 10 m/s

Source: Brodny, J.; Felka, D.; Tutak, M.; Applying an Automatic Gasometry System and a Fuzzy Set Theory to Assess the State of Gas Hazard during the Coal Mining Production Process. Engineered Science, 2023, 23, 891. http://dx.doi.org/10.30919/es891
Mróz J., Felka D., Broja A.,Małachowski A. Devices for measuring ventilation parameters and methane concentration as well as concept of complex monitoring of methane hazard in longwall area. Mining – informatics, automation and electrical engineering. No. 1 (529) 2017. http://dx.doi.org/10.7494/miag.2017.1.529.7

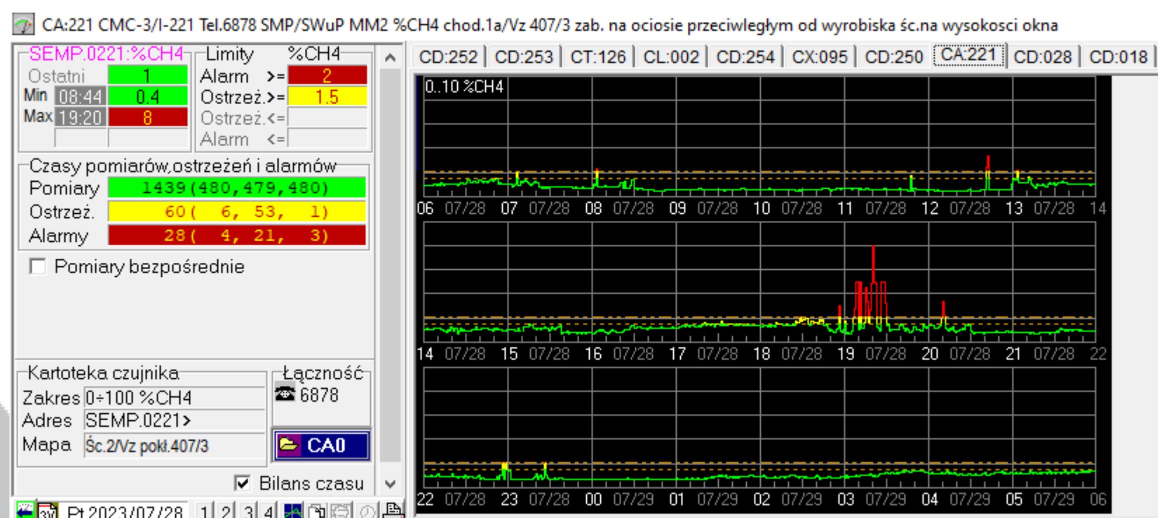
System for monitoring environmental parameters

Online measurement of airflow velocity and CH_4 concentration



AS-3 type anemometer

thermocatalytic methanometer



Current statement and preliminary results

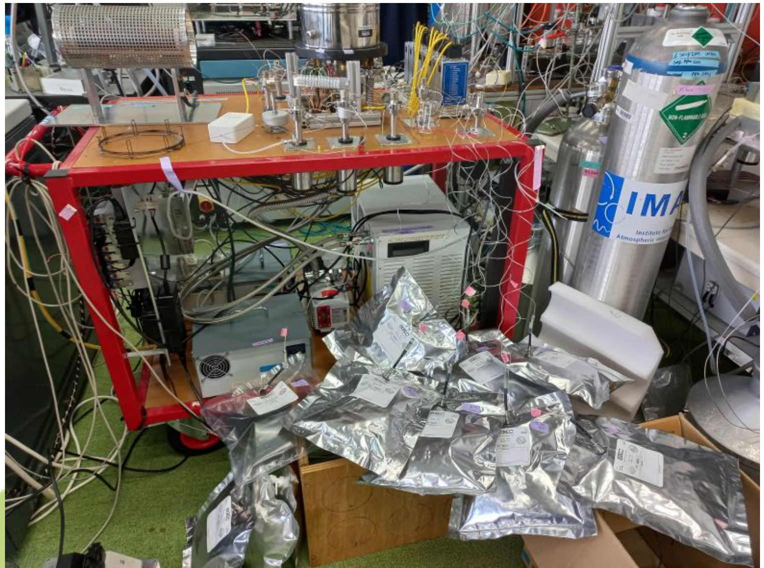
Experimental set-up

Instrumentation

Picarro CRDS (Cavity Ring-Down Spectroscope, **G2201-i**) for measuring concentrations of $\delta^{13}C$ in CO_2 and CH_4.
(precision: CO_2: 210 ppb; $\delta^{13}C$: 0.16‰; CH_4: 50 ppb; $\delta^{13}C$: 0.55‰).

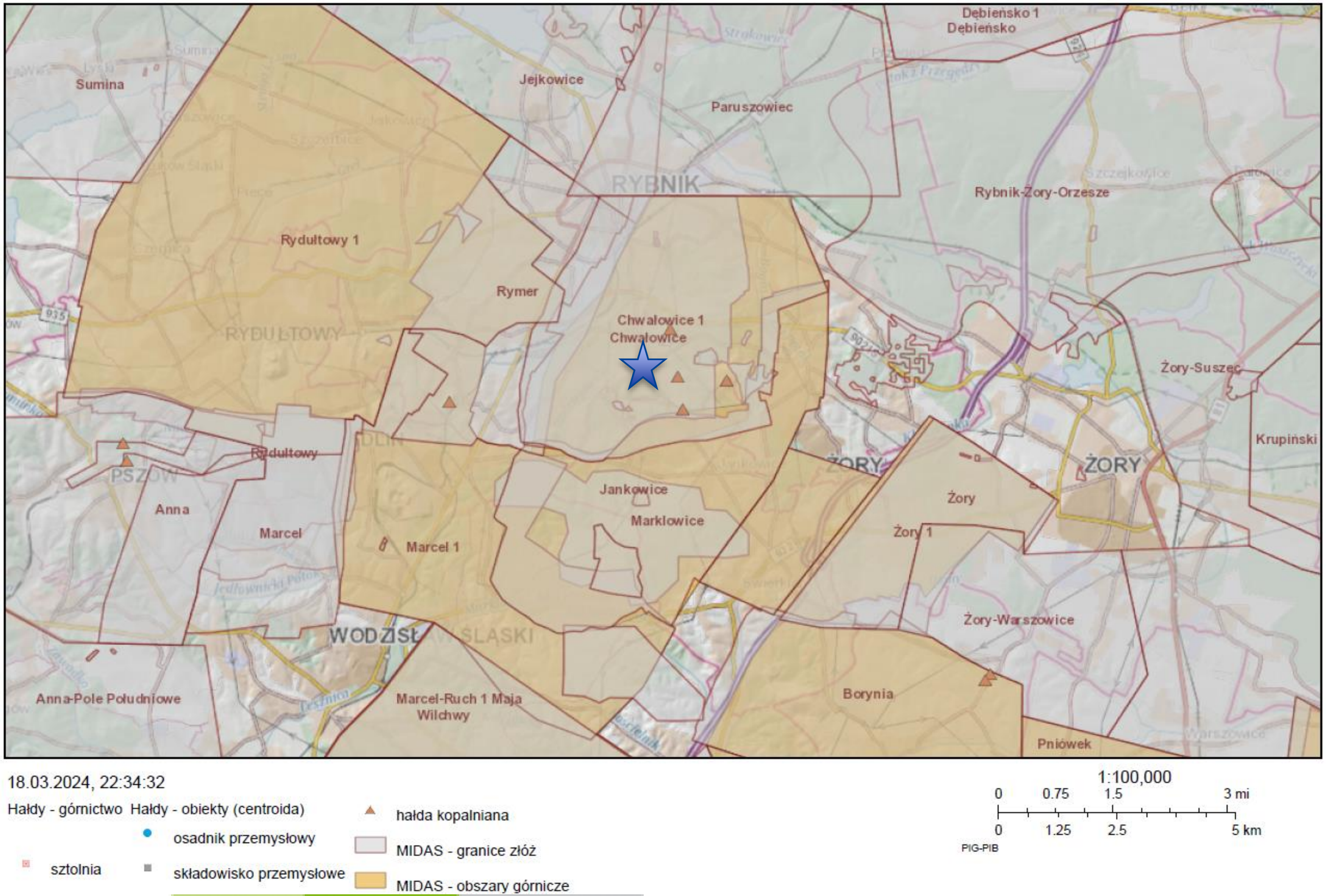
Continuously Flow Isotope Ratio Mass Spectrometry (**CF-IRMS**) at **Utrecht University** for determining CH_4 isotopes ($\delta^{13}C$, $\delta^{2}H$).
(precision: $\delta^{13}C$-CH_4: 0.07‰; $\delta^{2}H$-CH_4: 1.7‰).

Trace gas analyzer **mGA-918 OA-ICOS** (Off-axis integrated cavity output spectroscopy) **Los Gatos** for analysis of CH_4 and CO_2 (precision 1s, 1 sec: CH_4: 1 ppb; CO_4: 0.4 ppm).



Study area and study site

South-western part of USCB – Rybnik Mining District



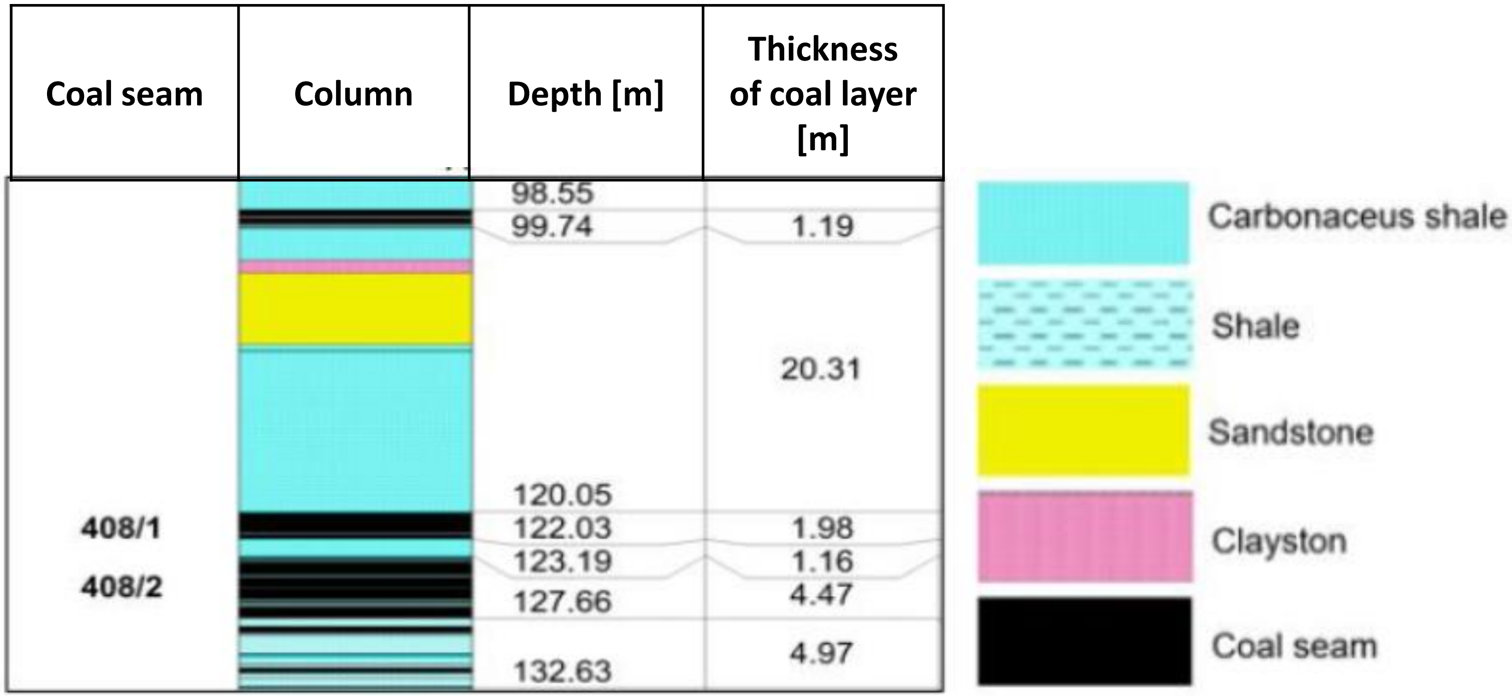
PGG KWK ROW
Ruch ***Chwałowice***

The ***mining area covers 21.76 km²***, with extractable ***resources amount to 144,643 thousand tons of coal.***

Source: Państwowy Instytut Geologiczny: https://cbdgportal.pgi.gov.pl/haldy/

Geology and mine operating conditions

Lithostratigraphic column of coal seam



The total thickness of the coal seams is in the ~6–8 m range,
with a depth in the ***~450–700 m range***, and
the ***thickness of the coal bed ranges from 1.6 to 2.0 m***.

Source: Tutak, Magdalena; Brodny, JarosÅ�w; Szurgacz, Dawid; Sobik, Leszek; Zhironkin, Sergey (2020). The Impact of the Ventilation System on the Methane Release Hazard and Spontaneous Combustion of Coal in the Area of Exploitation. Case Study. Energies, 13(18), 4891–. doi:10.3390/en13184891

Measurements and sampling methodology

The number of coalbed gas samples was collected in relation to the distance from:

- ***the longwall face***, where mining activities had been performed (670 m deep),
- ***across walkways of mine workings*** (650 – 390 m deep),
- ***towards the ventilation shaft*** *(390 m deep)*.
- ***inside of the exhaust ventilation shaft*** (surface channel).

Samples of ***raw bituminous coals and coal-bearing rocks*** were collected.

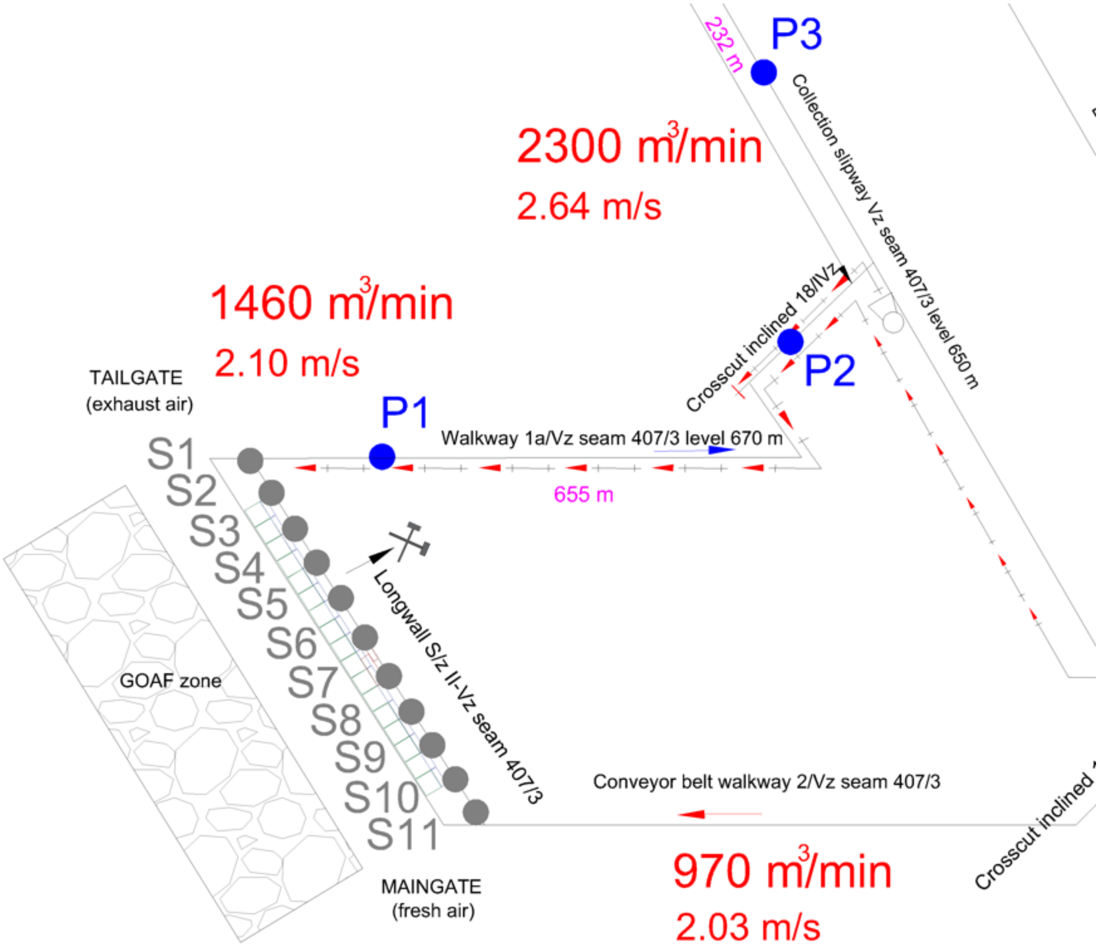
Measurements and sampling procedure

Schematic cross-section of sampling points in the underground coal mine workings

Single longwall section

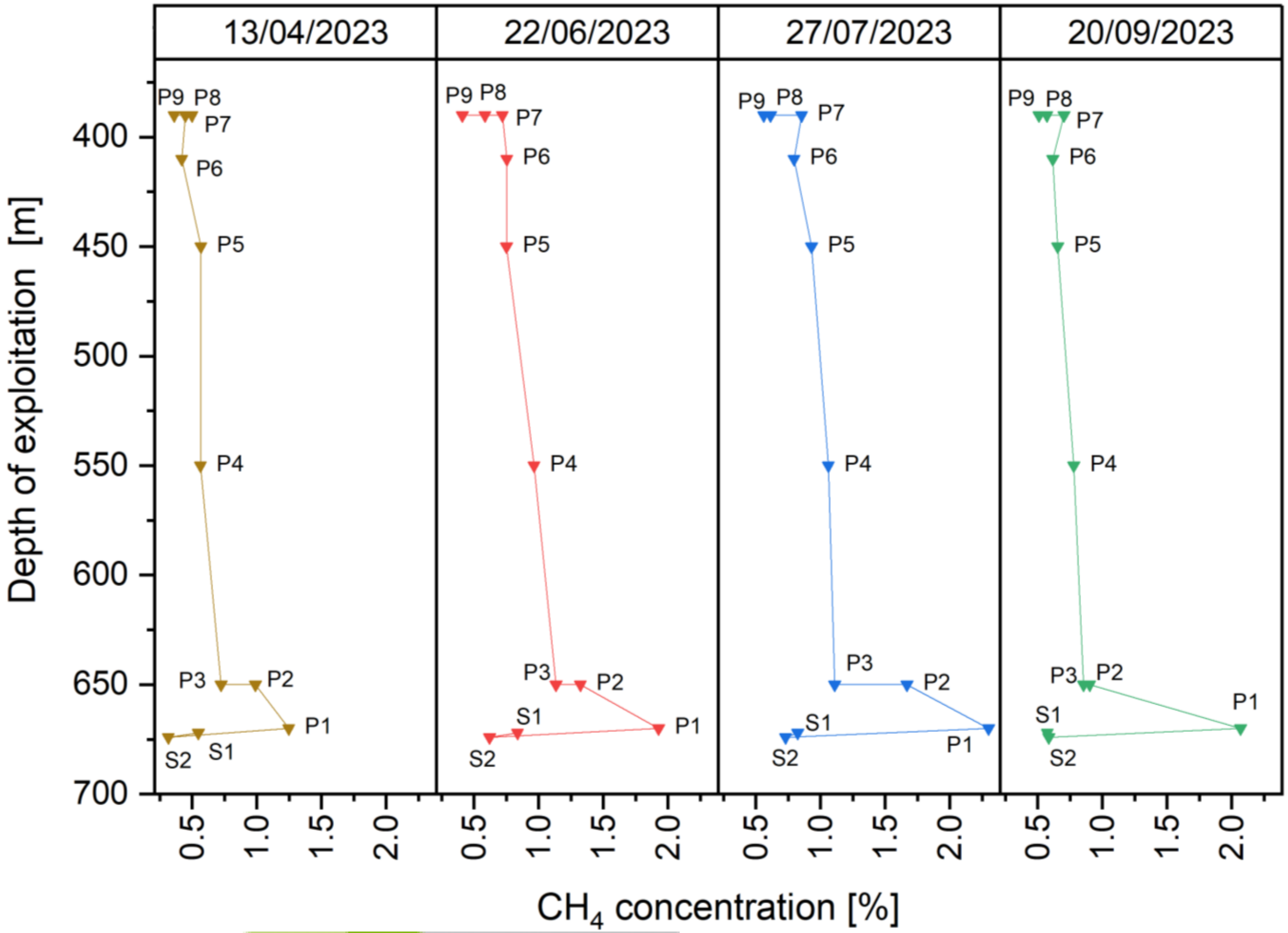
Longwall S/z II-Vz seam 407/3

Longwall length: ~169 – 175 m
Longitudinal inclination: 11° – 15°
Transverse inclination: 2° – 8°
Wall run: ~ 958 – 968 m
Seam thickness 1.4 – 1.90 m
Average daily progress – 4.0 m
Daily extraction – 2000 Mg
Methane hazards: category III



Variation in methane content with depth

CH_4 concentration in ventilation air of mine workings corresponding to the depth of exploitation



S1-S2 – samples collected along longwall coal face (tailgate);
P1-P9 – samples of ventilation air in mine workings;

Methane content in coal (*daf) seam ***increases with depth***;

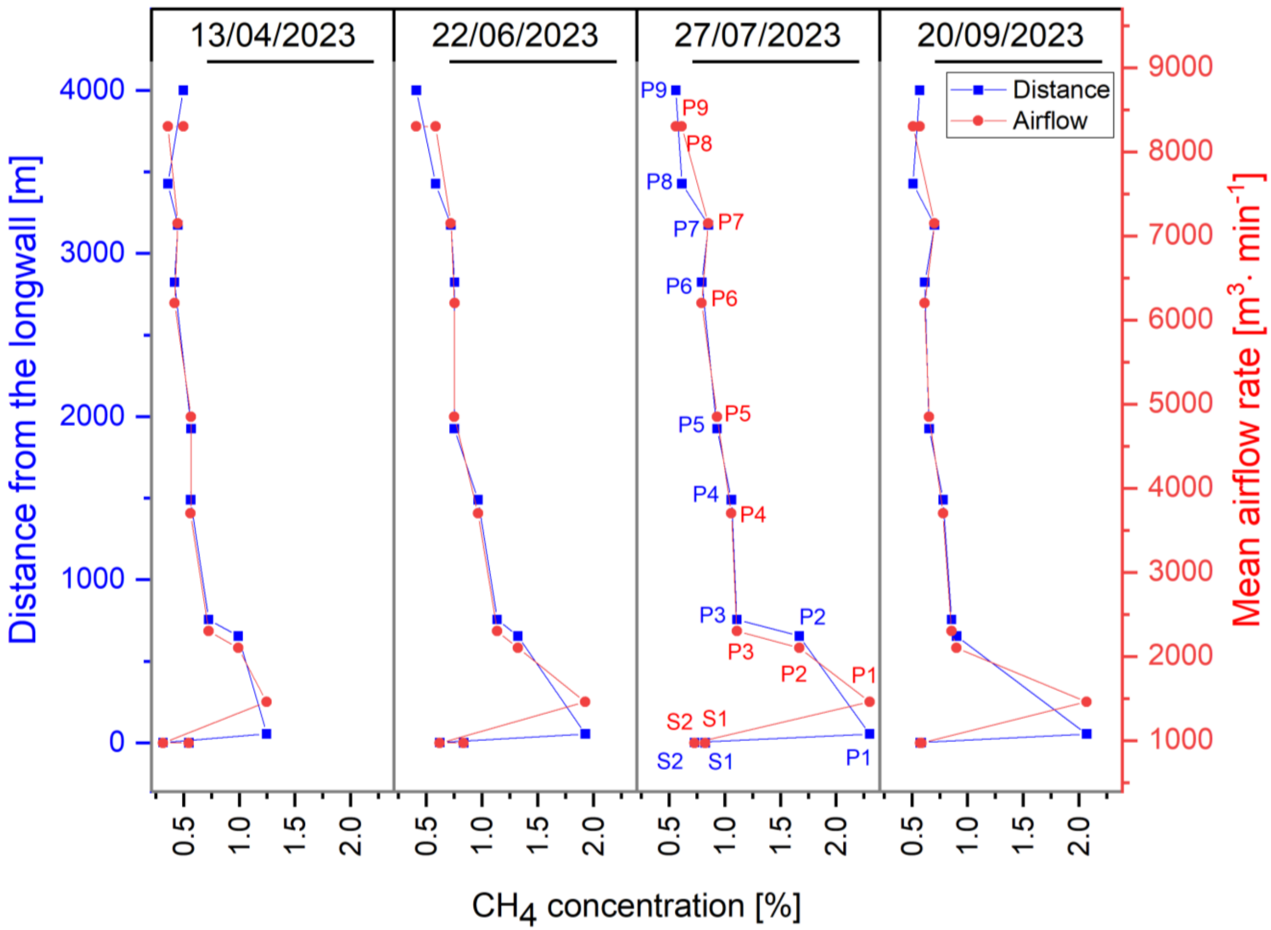
CH_4 ***being diluted*** with the rise of ventilating air stream;

Accumulation (high-methane zone) occurring in areas of bends and obstructions in the airway.

***coaldaf** – dry ash free coal substance the pure coal substance, without moisture and ash

Variation in methane content in mine workings

CH_4 concentration in mine workings in relation to the ventilation airflow rate and distance from the longwall coal face



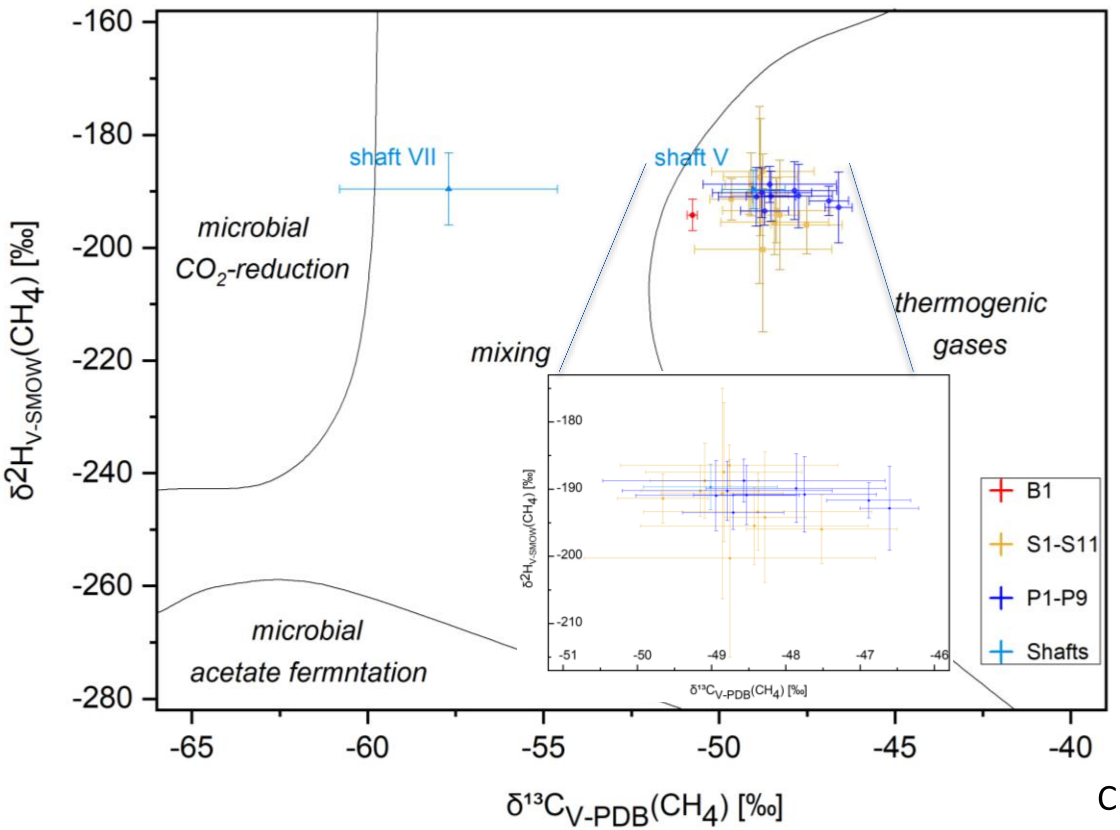
Decrease in CH_4 content is associated with a ***dilution effect with the distance from the exploitation longwall*** towards the ventilation shaft.

The higher velocity of the ventilation air stream has **a pronounced dilution effect on gas content**.

Accumulation of CH_4 occurring in areas of bends and obstructions in the airway.

Isotopic composition and origin of coalbed gases

Methane $\delta^{13}C$ vs δ^2H for coalbed and coal mine CH_4 in USCB



B1 – free gas samples taken from the borehole;
S1-S11 – samples collected along longwall coal face;
P1-P9 – samples of ventilation air in mine workings;
Shafts – samples collected inside of the exhaust ventilation shaft (surface channel).

- shaft V – depth 399.77 m;
- shaft VII – depth 543.25 m (flooded in 420 m);

A major share of CH_4 emissions from mining activities is represented by ***thermogenic gas origin***.

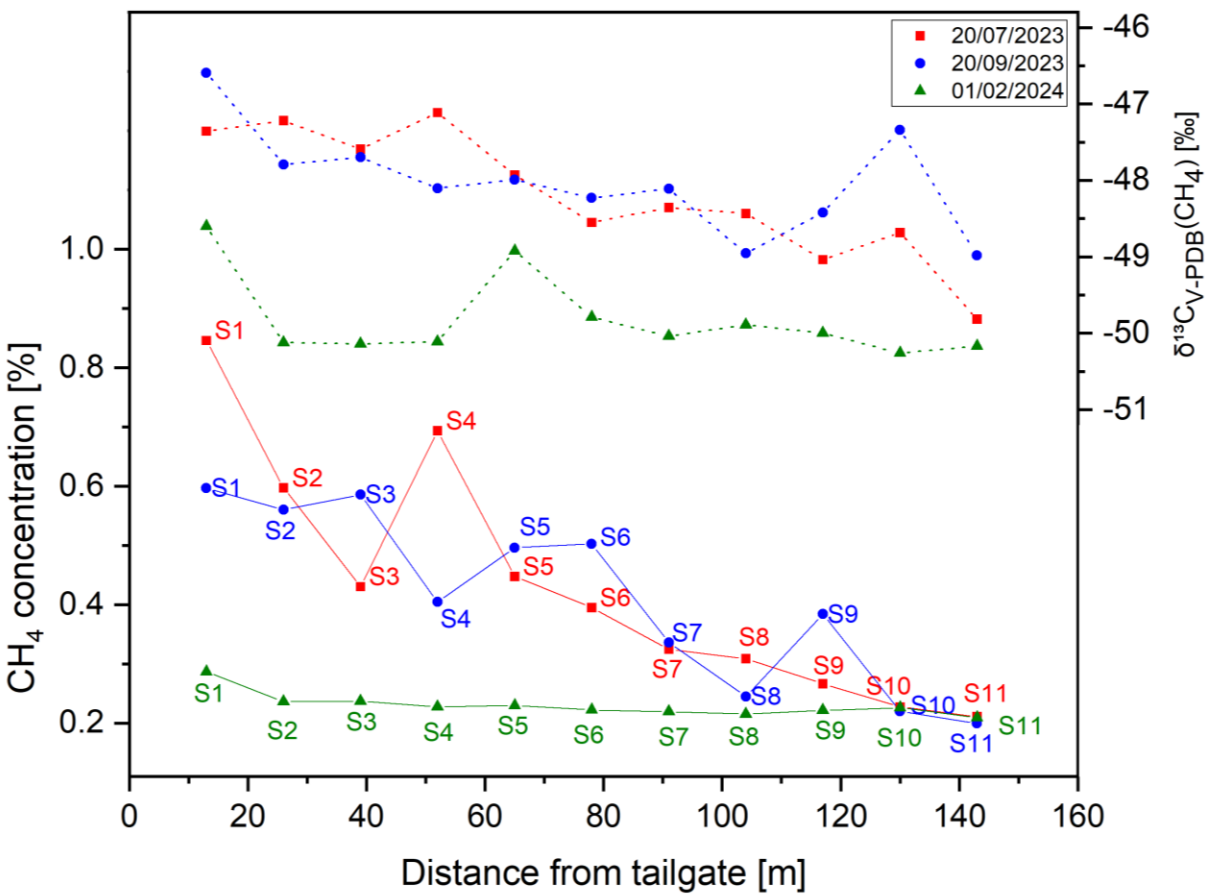
CH_4 depleted in ^{13}C from ventilation shafts confirmed the presence of ***secondary microbial gas sources*** (as result of invasion of meteoric water with nutrients for methanogens).

Empirical compositional and isotopic classifications from ***Whiticar, 1999*** was applied for discrimination of different origins of coalbed gases.

shaft VII
$\Delta^{13}C(CO_2-CH_4)$ values from 40.3 to 49.6 – ***acetate fermentation pathway of CH_4***
αCO_2-CH_4 values from 1.042 to 1.053 – acetate fermentation.

Isotopic composition and origin of coalbed gases

Concentration and isotopic composition ($\delta^{13}C$) of CH_4 sampled in single sections of the longwall face

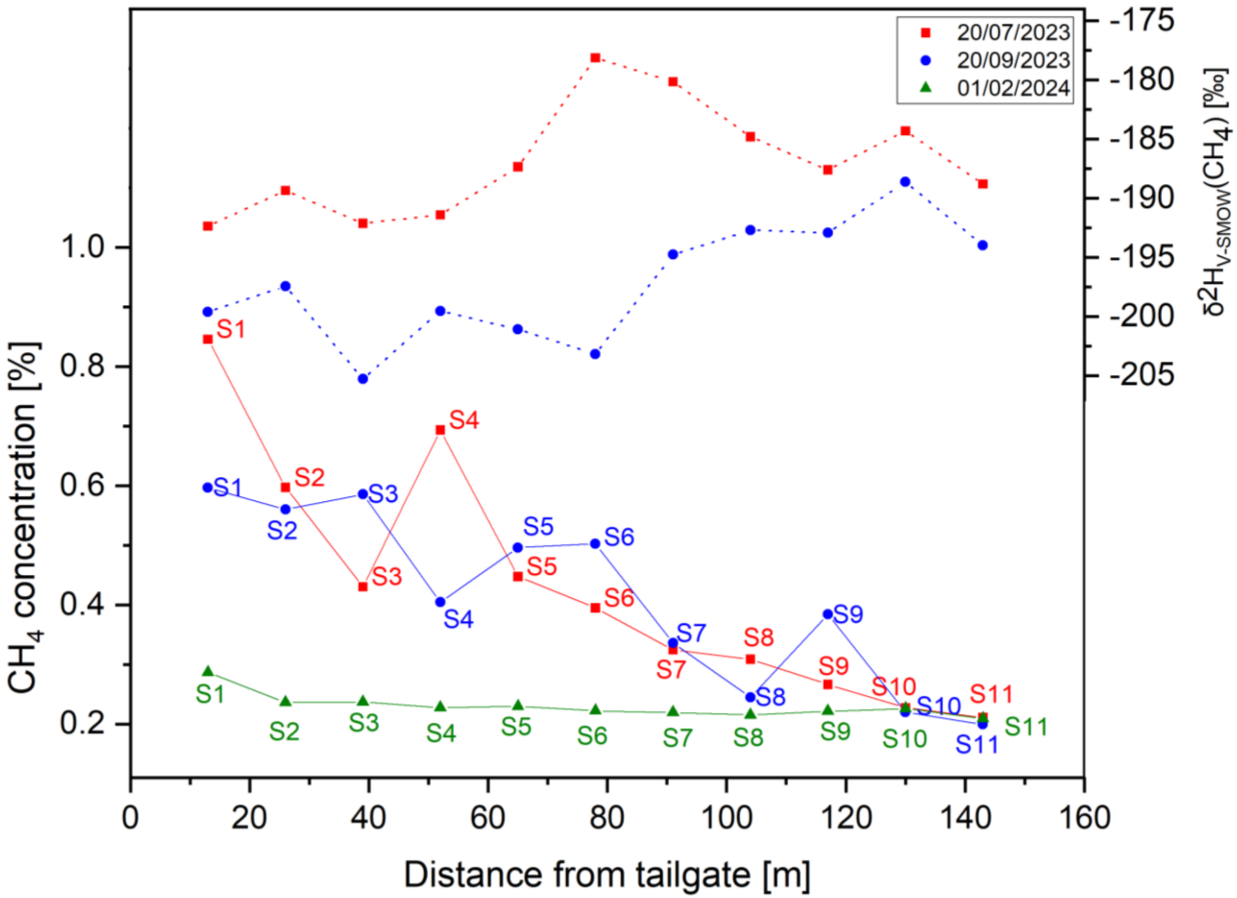


S1-S11 – samples collected along longwall coal face;

The decrease in CH_4 level downwards from the tailgate (S1) (return airflow) towards maingate (S11) (intake airflow) ***being diluted with the rise of ventilating air stream*** supplied to the longwall.

Isotopic composition and origin of coalbed gases

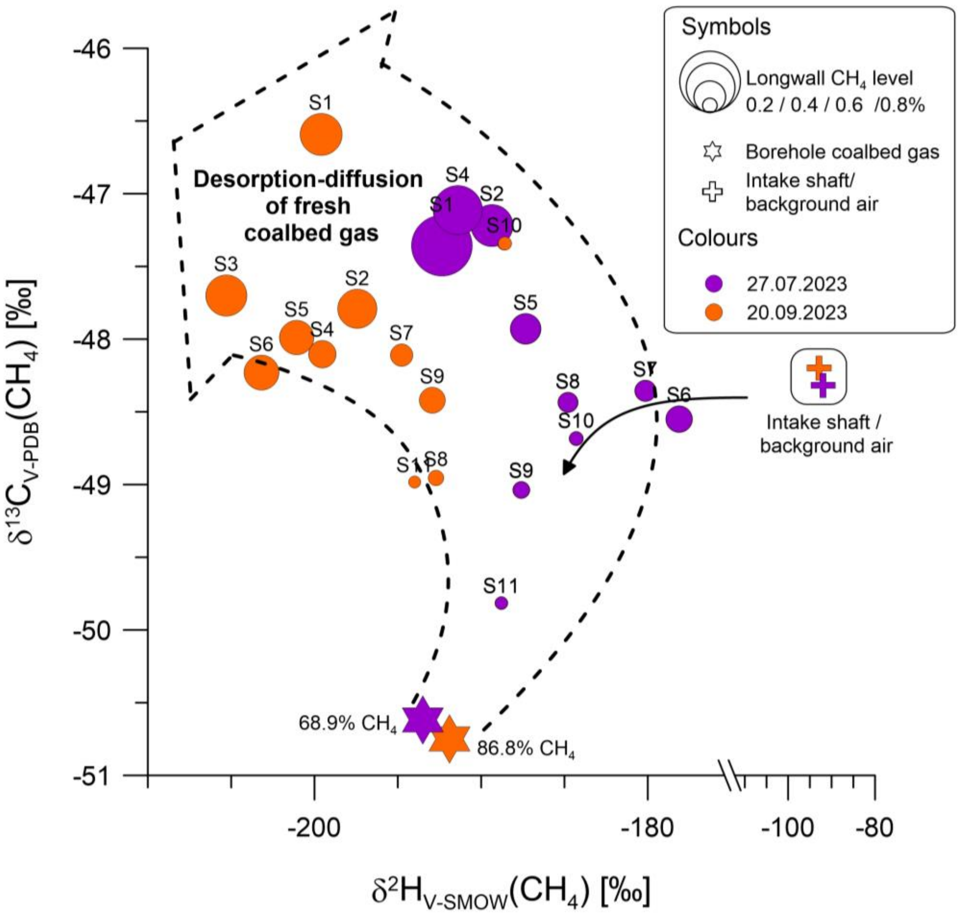
Concentration and isotopic composition (δ^2H) of CH_4 sampled in single sections of the longwall face



The decrease in CH_4 level downwards from the tailgate (S1) (return airflow) towards maingate (S11) (intake airflow) ***being diluted with the rise of ventilating air stream*** supplied to the longwall.

Isotopic composition and origin of coalbed gases

Cross-plot of CH_4 isotopic compositions ($\delta^{13}C$, $\delta^{2}H$) of coalbed gas samples collected in single sections of the longwall face



The arrow represents ***trend for enrichment in*** ^{13}***C*** during primary desorption from longwall face exploitation.

The ***concentration of*** CH_4 ***decreases*** in the maingate (S11) being diluted with fresh air from ventilating airflow.

The ***dilution effect is not proportional*** along the longwall face and CH_4 concentration increases towards the tailgate side (S1).

Ventilation air does ***not have a pronounced dilution effect*** as CH_4 becomes progressively more enriched in ^{13}C with slight ^{2}H depletion.

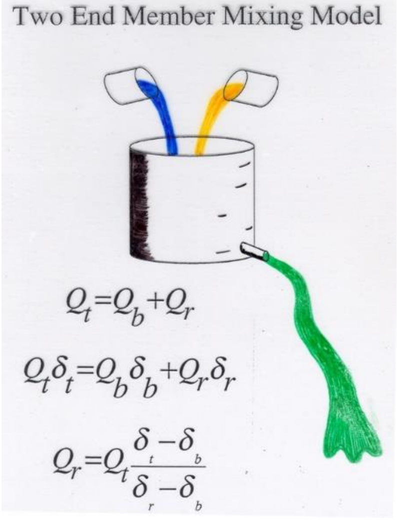
Isotopic composition and origin of coalbed gases

Mass balance of methane in the area of the longwall coal face

Longwall section / End-member 27/07/2023	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11
$\delta^2H_{coal\ borehole}$	-192.4±2.8‰										
$\delta^2H_{ventilation\ air}$	-93.3±1.5‰										
$\delta^2H_{total\ longwall}$	-192.36	-189.35	-192.12	-191.40	-187.33	-178.12	-180.14	-184.79	-187.59	-184.30	-188.79
Q_{coal}/Q_{total}	98%	95%	98%	97%	93%	84%	86%	91%	93%	90%	95%
$Q_{vent.\ air}/Q_{total}$	2%	5%	2%	3%	7%	16%	14%	9%	7%	10%	5%

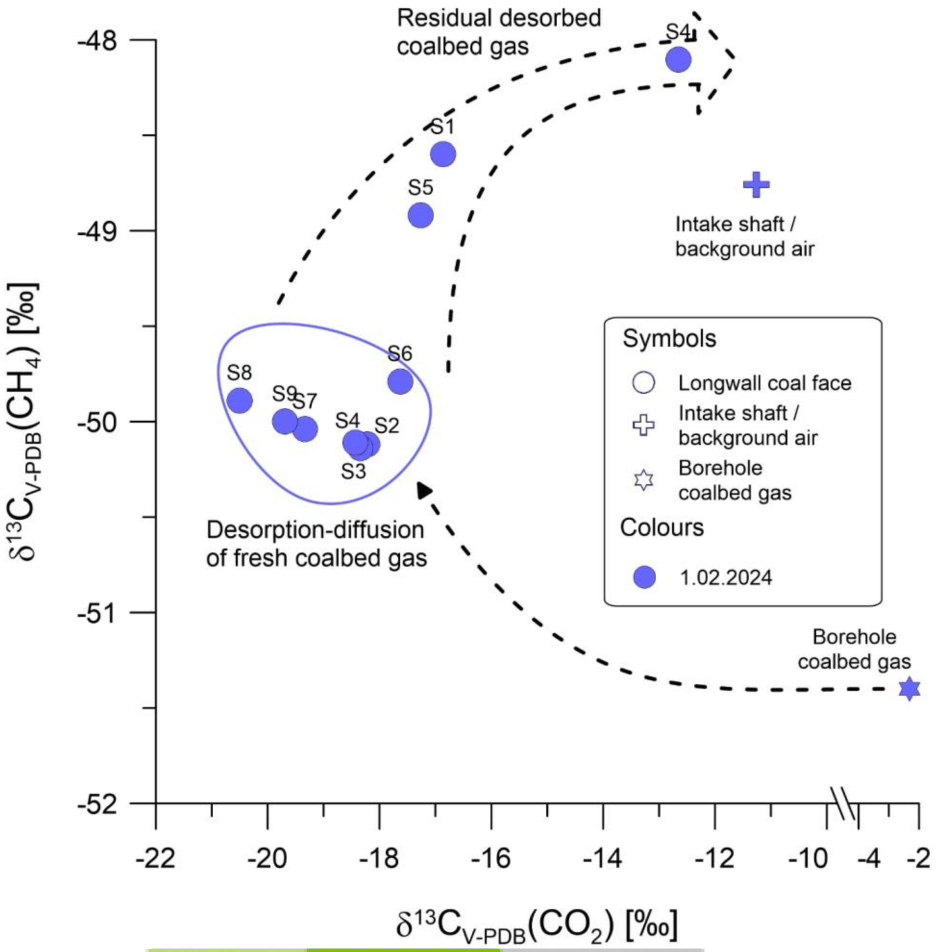
Longwall gases as a ***mixture of borehole CH_4*** and ***ventilation air*** from the surface background.

Isotopic mass balance calculations



Isotopic composition and origin of coalbed gases

Cross-plot of carbon isotopic compositions ($\delta^{13}C$) of CH_4 vs CO_2 of coalbed gas samples collected in single sections of the longwall face



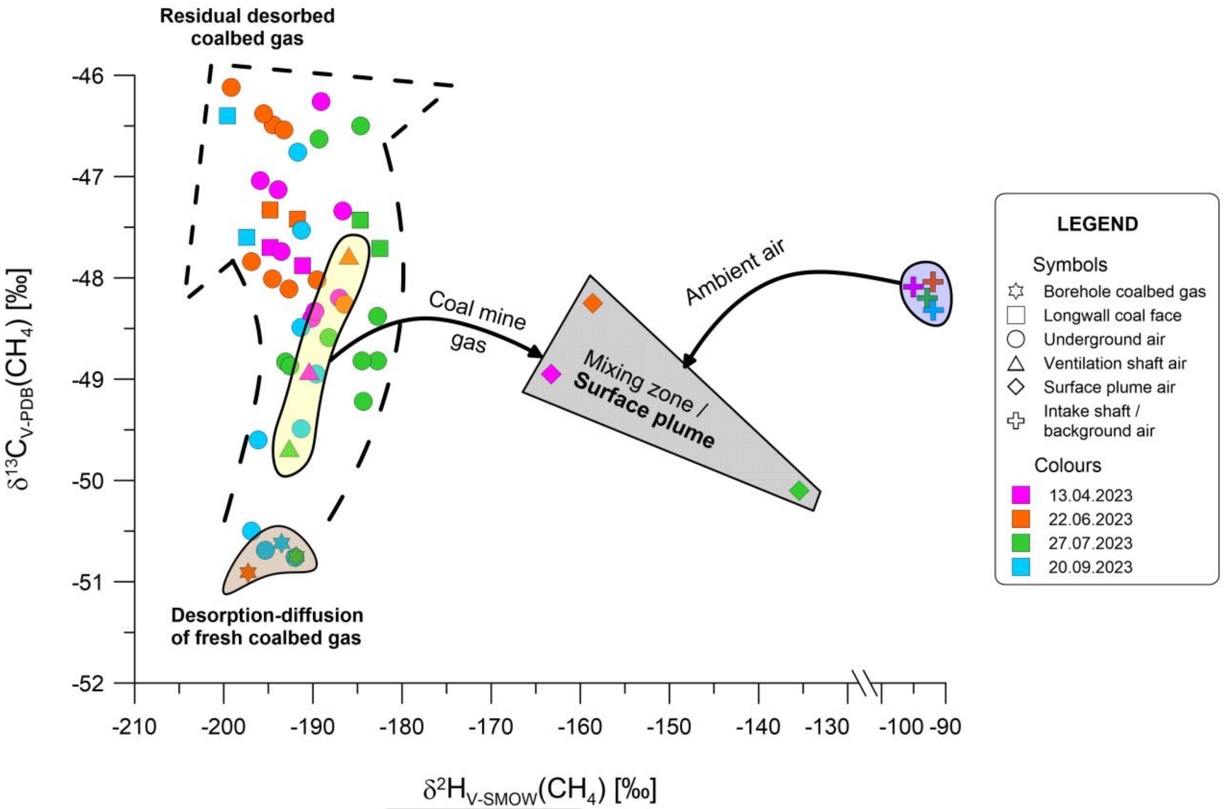
Primary CO_2 (occurs in 1.2–2.3 % v/v) in the seam borehole mostly enriched in ^{13}C (−2.6±0.4‰) implies the ***gas generation from underlying carbonates derived from metamorphism***.

Typically, ***CO_2 in thermogenic*** gases has $\delta^{13}C$ values in a range from −20 to −18 ‰ (Smith and Pallasser, 1996).

Residual CO_2 from coalbed progressively evolves towards **^{13}C isotope enrichment**.

Isotopic composition and origin of coalbed gases

Cross-plot of CH_4 isotopic compositions ($\delta^{13}C$, $\delta^{2}H$) of coalbed gas samples collected in ventilation air of mine workings



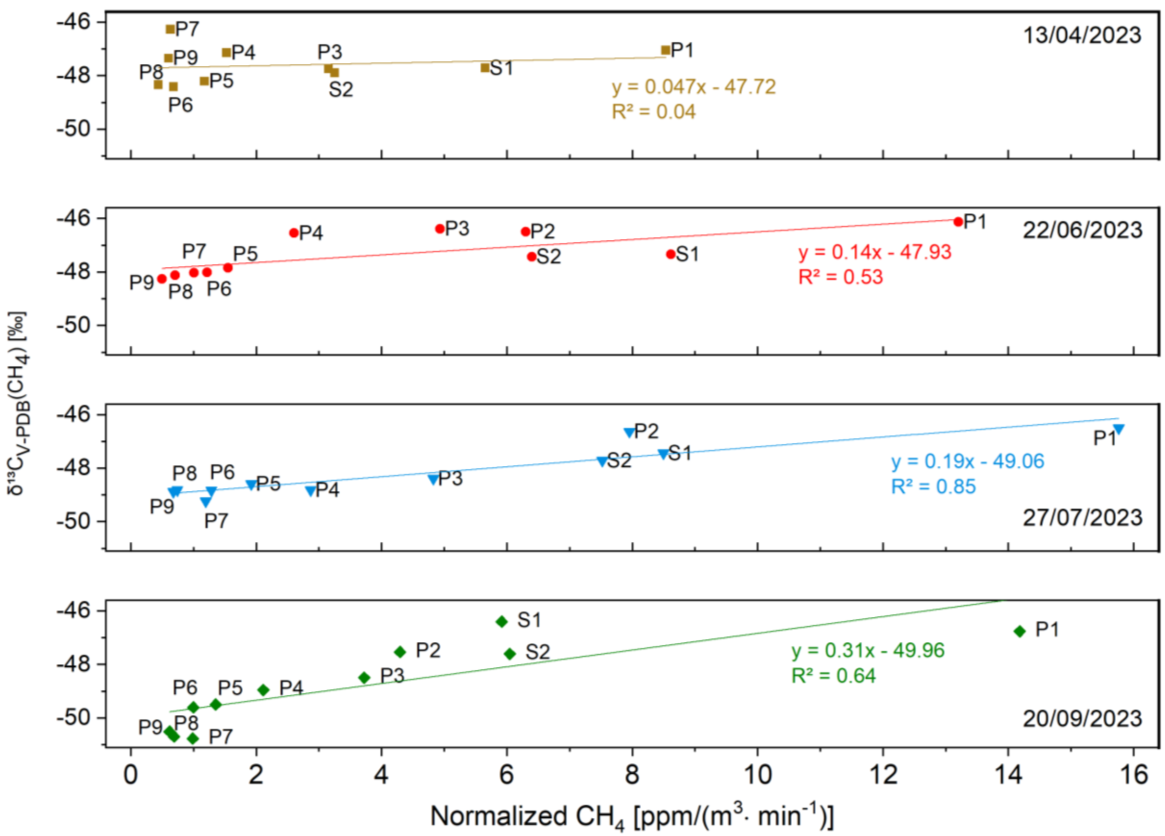
^{13}C-enrichment in methane mixture flowing through the mine workings generally arises from the ***diffusion and desorption processes***.

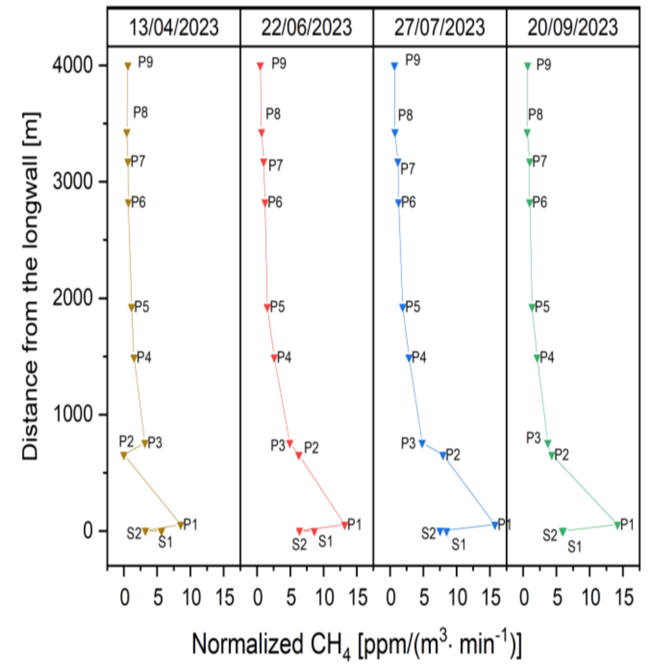
During ***gas migration*** to the upper levels ***and mixing*** desorbed CH_4 from the exposed body of coal ***undergoes underground fractionation*** with corresponding isotopic offsets.

Sampling points from the surface plumes are on a ***mixing line between the ventilation shafts and the ambient air***.

Isotopic composition and origin of coalbed gases

Airflow-normalized CH_4 concentration and its $\delta^{13}C$ in ventilation air of mine workings corresponding to the distance from the longwall coal face

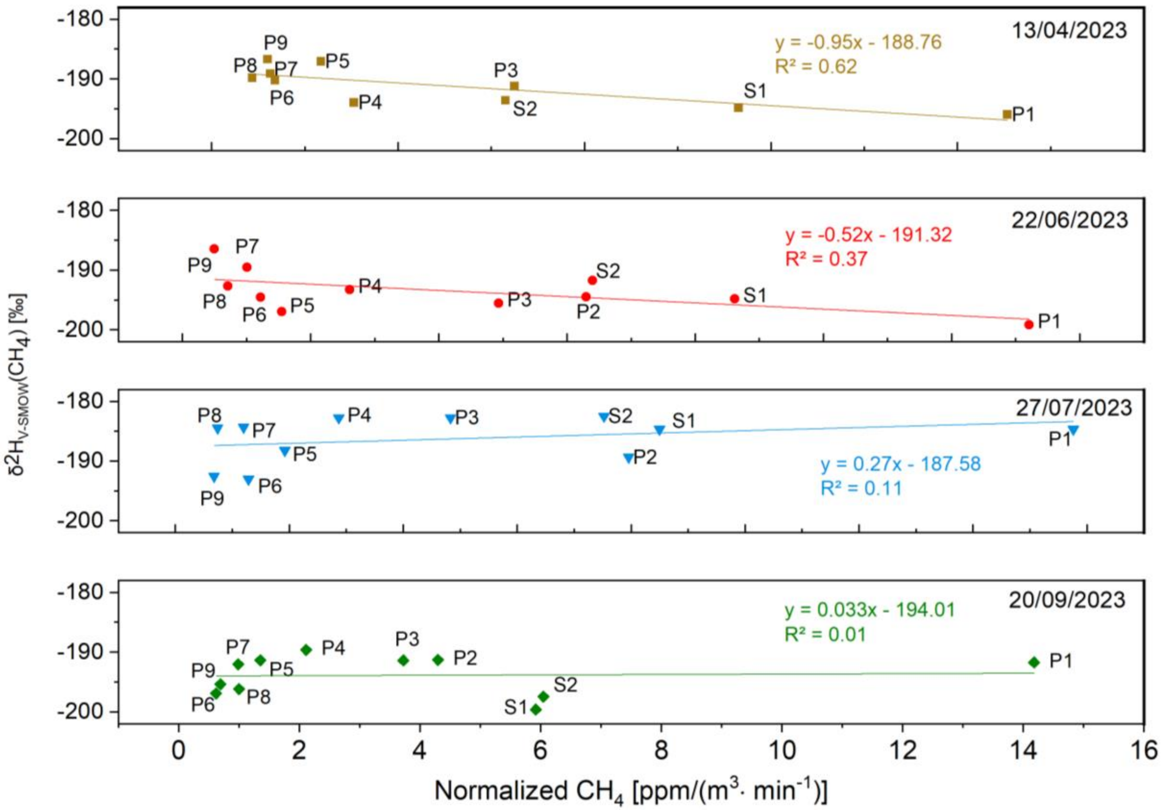


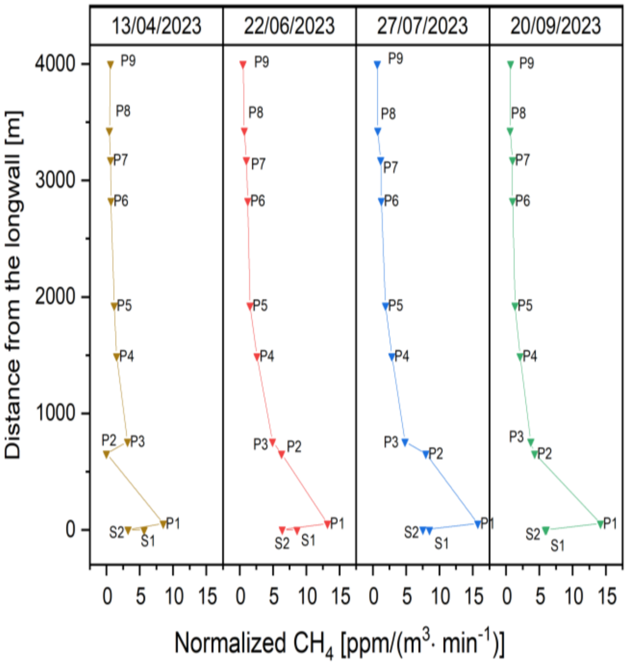


Initially ***^{13}C-depleted methane diffusing out of freshly exposed coal*** is rapidly removed from the mine with the air stream from the longwall along slipways of mine workings and the ***residual gases gradually become isotopically heavier.***

Isotopic composition and origin of coalbed gases

Airflow-normalized CH_4 concentration and its δ^2H in ventilation air of mine workings corresponding to the distance from the longwall coal face



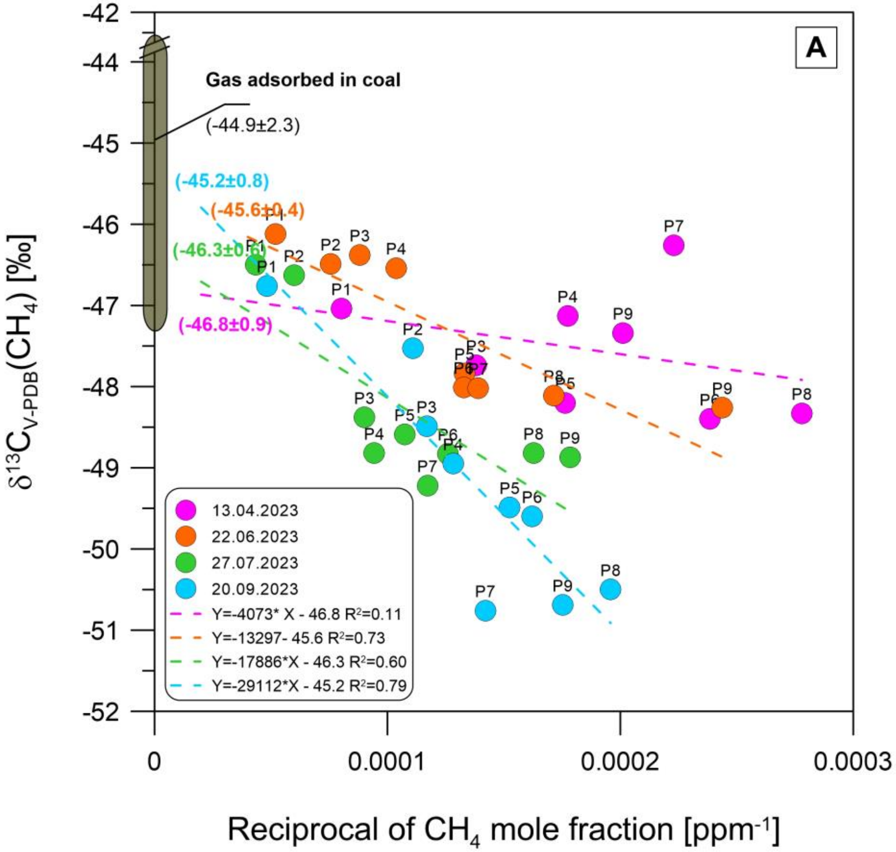


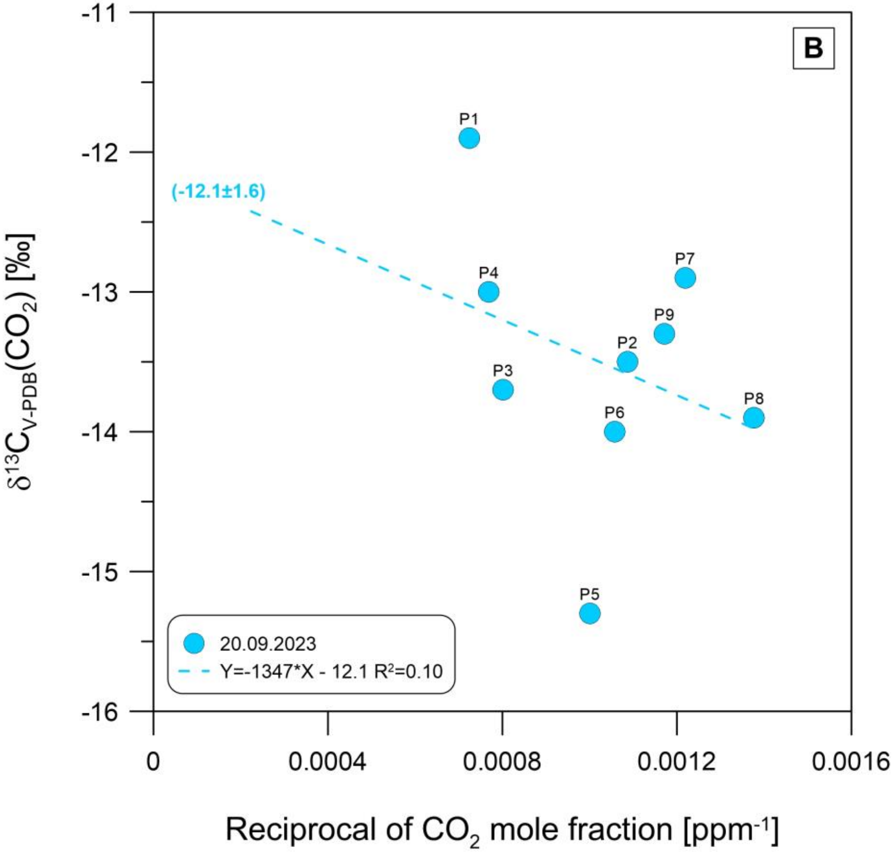
In practice, it can be migration and possible ***admixture of gas sources***:
- CBM from ***different sections of the coal face***;
- gases generated from ***different intersected coal seams***;
- generated from ***different source rocks.***

*Different trend recorded for stable hydrogen isotopes (^2H) in CH_4, showing different fractionation effects, possibly due to the **lower natural abundance** compared to carbon.*

Isotopic composition and origin of coalbed gases

The $\delta^{13}C-CH_4$ and $\delta^{13}C-CO_2$ source signatures calculated based on the Keeling plot approach

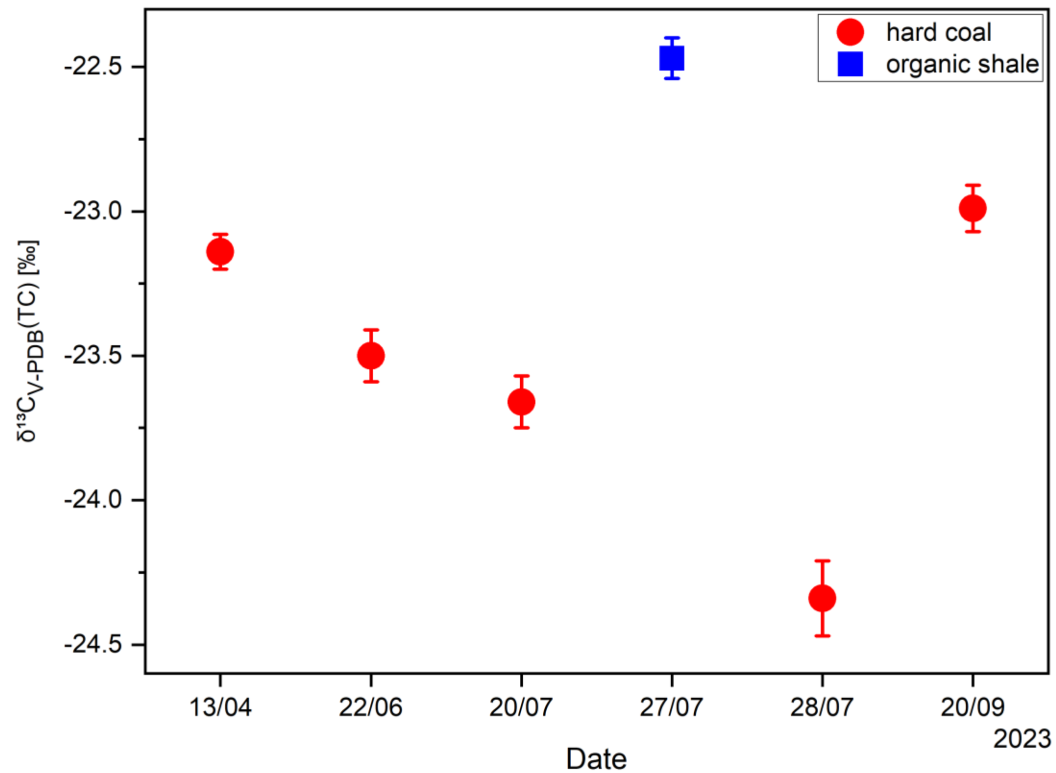




*The CH_4 values determined using the Keeling plot model indicate a source of **desorbed gases** from different coal sections or coal seams enriched in ^{13}C.*

Isotopic composition of investigated coals

Carbon isotope composition δ^{13}C-TC of hard coal samples



Samples of ***fresh/raw bituminous coals*** and coalbearing rocks were collected near longwall.

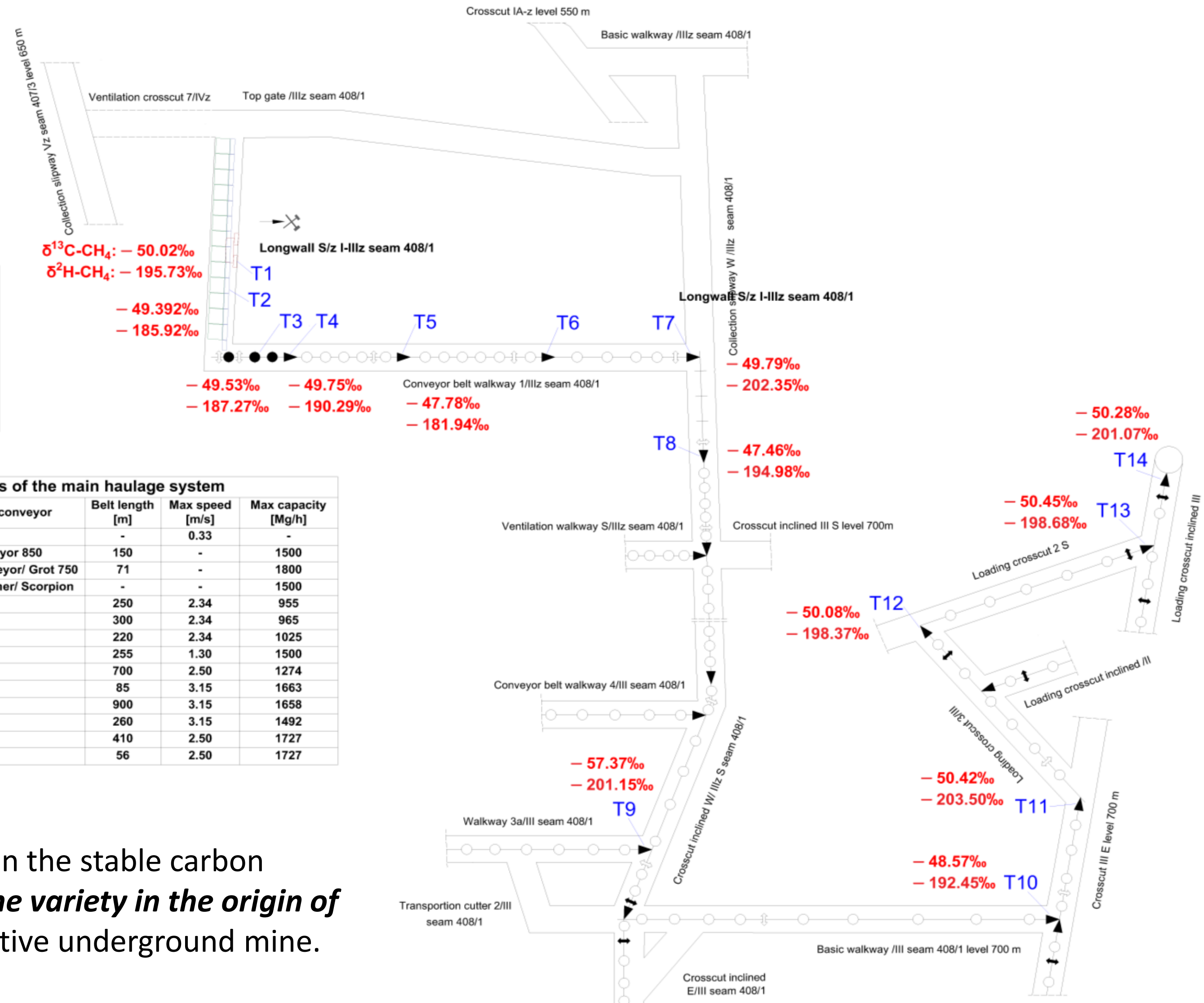
Nearly the same δ^{13}C values (–23.5 ± 0.5‰) in semi-closed underground system confirmed ***homogeneity of a coal seam***.

Isotopic composition of investigated coals

Coal haulage system – transport of mined coal from working faces to the surface

Longwall S/z I-IIIz seam 408/1

Longwall length: ~162 – 245 m
Longitudinal slope: 15° – 21°
Transverse slope: 1° – 13°
Wall run: ~ 535 – 570 m
Seam thickness 1.3 – 1.9 m
Daily extraction – 3000 Mg
Methane hazards: category III



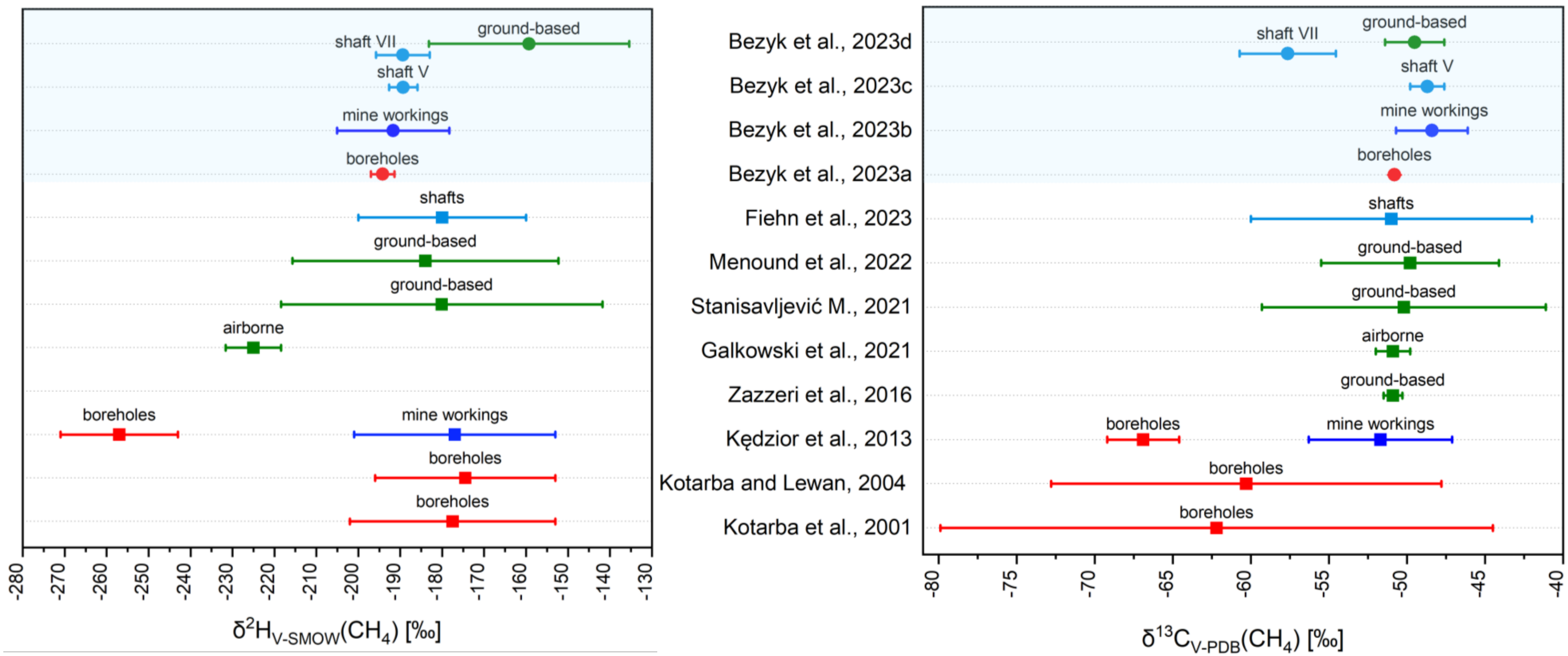
Conveyors of the main haulage system

Sampling point ID	Type of the belt conveyor	Belt length [m]	Max speed [m/s]	Max capacity [Mg/h]
T1	Longwall shearer	-	0.33	-
T2	Armoured face conveyor 850	150	-	1500
T3	Bottom scraper conveyor/ Grot 750	71	-	1800
T4	Dredging spoils crusher/ Scorpion	-	-	1500
T5	PT-1/ Gwarek-1000	250	2.34	955
T6	PT-2/ Gwarek-1000	300	2.34	965
T7	PT-3/ Gwarek-1000	220	2.34	1025
T8	PT-4/ Gwarek-1000	255	1.30	1500
T9	Intermet-1200	700	2.50	1274
T10	Intermet-1200	85	3.15	1663
T11	Pioma-1200	900	3.15	1658
T12	Pioma-1200	260	3.15	1492
T13	Pioma-1400	410	2.50	1727
T14	Bogna-1400	56	2.50	1727

Identifying alterations occurring in the stable carbon isotopic signature to ***represent the variety in the origin of the gases in a coal seam*** in an active underground mine.

Previous studies

Overview of CH_4 isotope signatures from USCB in Poland



A wide range of $\delta^{13}C$, δ^2H values (***mixture of thermogenic and microbial origins***) from the underground coal mines is reported in previous studies .

The ***aircraft observations*** in the area of USCB included a ***mixture of CH_4 sources*** (e.g. biogenic, coal mine methane, natural gas leaks).

The ***usage of δ^2H*** as a tracer of CH_4 plume (**ground-based surveys**) is particularly important, as there is an ***overlap in the $\delta^{13}C$*** from biogenic and fossil fuel sources.

Methane emission rates

Average CH_4 emission from individual ventilation shafts

Shaft	Date	Cross-sct. area [m^2]	Air velocity [$m \cdot s^{-1}$]	Airflow rate [$m^3 \cdot min^{-1}$]	CH_4 concentr. [%]	CH_4 Flow rate [$m^3 \cdot min^{-1}$]	Mine reported CH_4 Flow rate [$m^3 \cdot min^{-1}$]	Emission rate [$t \cdot day^{-1}$]
	26/06/2023		13.3	12768	0.15	19.49±0.67	20.52	**20.13±0.69**
V	28/07/2023	16	13.4	12864	0.36	46.59±1.34	41.20	**48.10±1.38**
	22/09/2023		13.0	12480	0.42	52.30±2.25	54.79	**54.01±2.33**
	23/03/2023		3.3	3663	0.02	0.70±0.06	0.37	**0.73±0.07**
VII	27/07/2023	18.5	3.5	3885	0.02	0.67±0.02	0.77	**0.69±0.02**
	26/09/2023		4.4	4884	0.12	5.80±0.36	6.31	**5.99±0.37**

$$Q_{CH_4} = C_{CH_4} \cdot 60 \cdot v_{ch} \cdot A_{ch} / 100$$

Q – methane flow rate [$m^3 \cdot min^{-1}$]

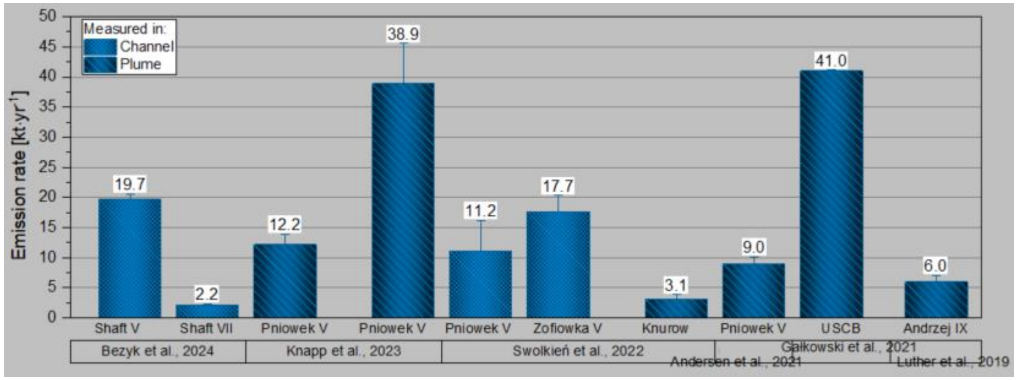
C_{CH_4} – methane concentration [%]

v_{ch} – air velocity in ventilation channel [$m \cdot s^{-1}$]

A_{ch} – cross-section of ventilation channel [m^2]

ρ – methane density (0.717 $kg \cdot m^{-3}$)

The increase in CH_4 in shafts is caused by ***changes in mining activities*** *in coal seams,* ***preparing a new section of the coal deposit for exploration***.



Summary

Identification of the ***genesis, transport process, and migration pathways of coalbed gases*** resulting from coal mining activities.

Investigation of the ***influence of physical processes, site-specific conditions, and parameters of mine operations*** on variations in composition of coalbed methane.

Determination of alterations occurring in the stable isotopic signature to represent the ***variety in the origin of the gases in coal seam*** in an active underground mine.

Characterizing the origin and volume of CH_4 generation (biogenic – lighter isotopically vs thermogenic – heavier) may help ***identify methane-bearing zones***.

Isotopic tracing may ***link the mining observations and atmospheric monitoring*** perspectives to follow up methane emissions from mining activities in the USCB.

Estimation results in a ***lower range of variations in isotopic signatures of methane in the ventilation shaft*** than were reported in previous studies.

Thank you for attention!

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