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GEOLOGICAL FACTORS AFFECTING THE SORPTION PROPERTIES OF COAL

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Abstract. The sorption capacity of coal is a crucial characteristic for evaluating its gas content, the safety of mining operations, and the environmental impact of methane emissions. Effective coal degassing reduces the risks of sudden outbursts and decreases the volume of greenhouse gas emissions into the atmosphere. Existing methods for determining sorption capacity are labor-intensive and expensive, which limits their use. There is also no clear understanding of the influence of regional and local geological factors on the sorption properties of coal.

Research objective: to investigate the sorption properties of coal samples from various mines and coal beds in the Donets Basin using EPR spectroscopy and to identify the factors influencing the sorption capacity of the coal matter. The total number of researched samples is 45, ranging from grade LF to grade L. The selection of different beds within the same grade allowed determining the impact of lithofacies conditions on the sorption capacity of coal, and from different mines – thermodynamic processes; comparison of indicators from samples taken from disturbed and undisturbed areas – tectonic processes. Research on the impact of geological factors on the sorption properties of coal matter was performed using EPR-spectroscopy and petrography through the evaluation of changes caused by external factors in the structure and texture of fossil organics at the nano- and microlevels. It is shown that with increasing metamorphism (from brown coal to anthracite), the volatile matter content and oxygen groups decrease, carbonization increases, and micro- and mesoporosity changes. The best sorption properties are observed at the average degree of metamorphism, when functional groups and porous structure are preserved. Further graphitization reduces surface activity. Differences in sorption capacity within a bed are caused by tectonic influences, and between beds – by lithofacies conditions. Tectonics forms cracks and pores, changing permeability. Lithofacies influence the initial properties of coal matter: ash content, sulfur content, and composition. The use of EPR-spectroscopy for researching the formation of coal matter properties allows for the effective, rapid, and sufficiently accurate definition of the sorption capacity of coalified organic matter taking into account the specific impact of regional and lithofacial factors on the properties and state of coal.

Keywords: coal matter, sorption properties, geological factors, EPR-spectroscopy, petrographic studies.

1. Introduction

A key issue in the coal industry is degassing of coal beds – a preventive step to lower the gas content in workings, avoid sudden coal and gas outbursts during mining, and lessen the environmental impact by preventing harmful greenhouse gas emissions into the atmosphere.

One of the main indicators that characterizes the gas-bearing capacity of the massif is the sorption capacity of coal. Documents such as [1–3] provide, along with other indicators, a required determination of the sorption capacity of coal matter.

Research on gas sorption properties of coal is conducted in all coal-mining basins worldwide, including the USA, Canada [4], China [5, 6], Australia [4, 7], Indonesia [8], South Africa [9], Poland [10, 11], India [12], and other countries. In Ukraine, scientific works [13–16] are dedicated to this topic. They present research results on the "coal-gas" system, particularly its properties and the interaction between sorbate and sorbent.

The determination of coal's sorption capacity is performed using various methods based on measuring how gases are absorbed by coal. The main methods include: gravimetric method (measuring the change in the mass of a coal sample during gas absorption under controlled pressure and temperature conditions), volumetric method (determining how much gas is absorbed by coal in a closed system as pressure changes), chromatographic method (analysing the concentration of gas remaining in the gas phase after contact with the coal sample), manometric method or methane

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sorption isotherm method (measuring the equilibrium gas pressure in a closed volume at different concentrations to determine the sorption isotherm), calorimetric method or microcalorimetry (measuring the thermal effect during gas adsorption on the coal surface), desorption method (measuring the volume of gas released from coal when pressure decreases or heating occurs), and another volumetric method (placing a coal sample in a chamber where methane gas is supplied under a known pressure and measuring how much gas is absorbed by the coal under steady-state conditions).

The choice of method depends on the research objectives, available equipment, and required measurement accuracy. Volumetric and manometric methods are most often used, since they allow obtaining sorption isotherms and evaluating the potential gas retention capacity of coal. The main thing is that all the methods used are labour-intensive – the duration of the experiment, difficult to use and expensive, so the number of determinations of the sorption capacity of coal in Donbas, in general, is insignificant.

As a result of the conducted research, the following was established: the sorption of methane by coal increases with an increase in the degree of their metamorphism; the amount of sorbed gas is directly dependent on the specific surface area of the substance; with increasing pressure, it increases and practically reaches the limit at pressures of 6 MPa, and a further increase in pressure causes only a slight increase in sorption (the increase in sorption in the pressure range of 5 – 10 MPa does not exceed 5 – 10%) [17]. With an increase in temperature, humidity and ash content of coal, it decreases. But the coal of the Donets basin is characterized by a fairly wide range of changes in all qualitative indicators and, firstly, is subject in general and in detail to changes in the accumulation conditions of each bed, and secondly, to further processes of coal transformation, which by their physico-chemical nature are determined by the impact of thermodynamic conditions. Therefore, the sorption capacity of coal, which was selected in different beds and under different tectonic conditions, can vary significantly.

The M. S. Poliakov Institute of Geotechnical Mechanics of the National Academy of Sciences of Ukraine developed and successfully tested a new method for determining the ultimate sorption capacity of coal matter using electron-paramagnetic resonance (EPR-spectroscopy) [18]. This method allows us to estimate the sorption properties of coal with high accuracy, which is important for predicting the behaviour of coal in different conditions. The advantage of this method is the study of coal at the molecular level, at which the properties of any substance are formed. In research, this makes it possible to consider the peculiarities of the lithofacies formation in the bed and the influence of thermodynamic conditions, in particular, tectonic action. The method of estimating sorption properties is based on the detection and quantitative analysis of paramagnetic centers that are capable of physical interaction with gases.

According to the theory, the methane sorption process has a complex physico-chemical nature and occurs at the molecular level [19]. Sorbate-methane molecules and the surface of the coal that sorbs them are in equilibrium in an undisturbed rock massif. Changes in temperature, pressure, and concentration of components in the rock massif, i.e., external factors, lead to disequilibrium. In this case, several structural rearrangements occur at the micro- and nano-levels, which are reflected in the diffusion, sorption, and physical-mechanical properties of coal. Therefore, to study the peculiarities of coal sorption capacity in different mining and geological conditions, it is necessary to use physical methods of researching coal matter at the micro- and nano-levels.

It is established that the main characteristics that affect the adsorption capacity of gas in coal beds are the chemical composition of the adsorbent, porosity, pore space structure (pore-size distribution), temperature, pressure, humidity, and degree of coal metamorphism [20]. Micropore volume positively correlates with adsorption capacity – micropores have the largest specific surface area and are the main regulators of gas adsorption [21].

The work [22] also notes that the occurrence depth, molecular size of gases, gas affinity for coal, density, porosity, coal grade, and similar factors are the main elements that determine the adsorption capacity of coal. The work [23] states that the most important factors affecting the sorption capacity are also the type and content of mineral substances (ash content), while the maceral composition of the coal is of limited significance.

The use of physical methods for researching coal matter, and in particular electron paramagnetic resonance (EPR), allows us to trace the effects of external factors on the structure of the matter at the atomic-molecular level. The properties of the matter and its structure are judged by the kinetic characteristics in the process of coal-and-gas interaction. EPR spectra reflect all the changes that have occurred in the coal matter since sedimentation. The totality of all these processes affects the width and shape of each individual line of the EPR spectrum in coal, so their careful analysis can reveal the role and impact of lithological-facial and thermodynamic conditions on the sorption capacity of coal.

The purpose of the research: to investigate the sorption properties of coal samples from various mines and coal beds in the Donbas region using EPR-spectroscopy, geological analysis, and petrography, and to determine the factors influencing the sorption capacity of the coal matter.

2. Methods

Samples were taken from various mines and coal beds ranging from grade LF to grade L. The total number of researched samples is 45. The selection of different beds within the same grade will allow determining the impact of lithological-facial conditions on the sorption capacity of coal, and from different mines – the impact of thermodynamic processes; comparison of indicators from samples taken from disturbed and undisturbed areas will allow determining the impact of tectonic processes.

The value of the sorption capacity of the coal matter was calculated based on the parameters of the spectrum measured on specially prepared coal samples selected according to the current DSTU [24]. According to the methodology [18, 25], a particle size class of 0.10–0.16 mm was chosen as a reference for conducting research and measurements.

The following spectrum parameters were used when researching the sorption capacity of coal using the EPR method:

- the integral intensity of the EPR spectrum in the sample, which is directly proportional to the concentration of paramagnetic centers (PMC) in the matter under research and depends on the state of the coal matter, that is, on the intensity of external (tectonic) influences on the coal bed;
- the signal width *ΔH* and its shape reflect the genesis of paramagnetic centers, which allows determining the nature of the paramagnetism in the coal sample;

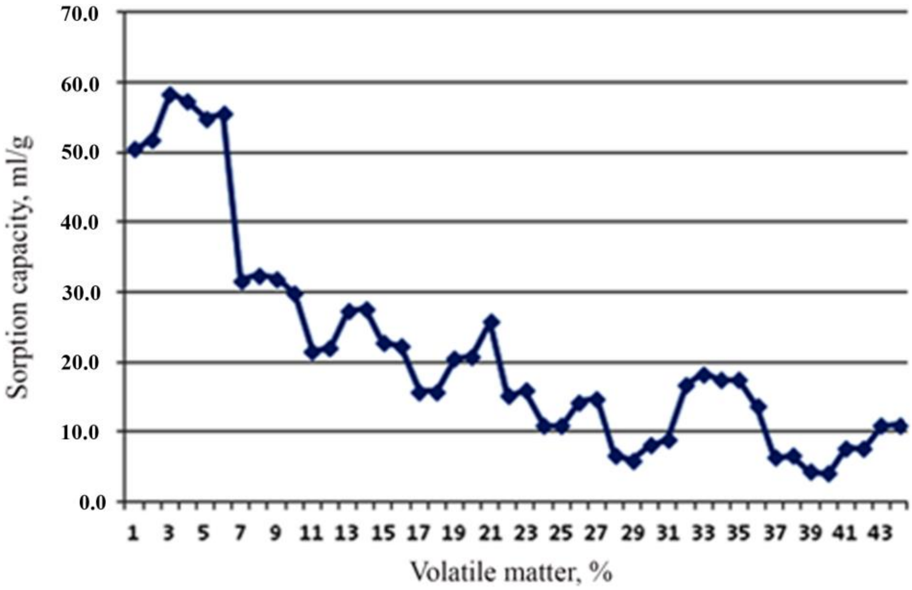

Figure 1 – Graph of the sorption capacity of coal depending on the degree of metamorphism.

According to the data obtained, pair correlation coefficients were calculated, and a graph of the change in the sorption capacity of coal versus the degree of metamorphism of coal was constructed.

Let us consider the mining-geological factors that influence its fluctuations in coal of the same degree of metamorphism.

3. Results and Discussion

The obtained results align with generally accepted ideas, which suggest that as the degree of catagenesis increases, aromatic nuclei grow while aliphatic bridges connecting them gradually shorten and disappear. It is clear that the sorption capacity increases with the degree of coal metamorphism, meaning metamorphism is the main (regional) factor affecting it (correlation coefficient ≈ -0.83). However, when considering the signal width indicator, the relationship with sorption capacity is nearly absent (correlation coefficient ≈ -0.377). This is likely because the processes that occurred during coal formation and subsequent coalification of coal beds and causing aromatization of organic compounds, condensation of aromatic rings, and affecting sorption capacity are of the same nature.

Research on differences in the sorption capacity of grade L coal at the S.M. Kirov and Kholodna Balka (bed $h_{10}^{в}$) mines will allow us to determine the external processes that influenced the state of the coal matter. The mines are located in the eastern part of the Donetsk-Makiivka region (DMR) of the Donbas. Overall, all indicators (volatile matter yield, ash content, sulfur content) are comparable for one bed developed by different mines. But the S.M. Kirov Mine has a lower coal sorption capacity than the "Kholodna Balka" mine, with smaller values of the initial spectrum width and PMC concentration.

The S.M. Kirov Mine is located in the northeastern part of the district, between the Iasynivska thrusts and its branches, which has a northeastern strike. The dip of the thrusts is to the southeast at an angle of 45°; the amplitude of the first is about 100 m, the second is 20 m. Small-amplitude disturbances, mainly thrusts, have a northeastern strike; faults are subperpendicular to them, which indicates their simultaneous formation. Such disturbance of the mine field promotes degassing and loosening of the massif.

The Kholodna Balka Mine is located in the center of the eastern part of the DMR between the arcuate (concentric) Markivskyi (amplitude is about 50 m) and Dulynskyi (amplitude is 70–140 m) thrusts on the southern wing of the Makiivka-Riasnianska syncline of sublatitudinal strike. The morphology of these thrusts indicates their later formation (after the formation of the syncline); the concentric shape indicates the action of various compressive forces. Low-amplitude fracturings, mostly thrusts, are mainly located near large disturbances and subparallel to them, which indicates syngenetic formation. That is, coal beds were under compression conditions, which is confirmed by the larger values of the spectrum parameters at this mine (PMC is 6.5×10^{19} g^{-1}; the width of the initial spectrum is 5.7 E). The obtained data indicate the impact of tectonic conditions on the state of the coal matter, and, as a result, the sorption properties of coal. In addition, mining conditions at the mines differ significantly (Table 2).

Table 2 – Geological and industrial characteristics of mines.

Mines	Volatile matter yield, %	Inflow water, m^3/day	Gas content, m^3/t	Gas capacity, m^3/t daf	Coal mining, t	Depth, m	Number of beds, St.
S.M. Kirov Mine	9.0	116	30	16–25	760–950	260	3
Kholodna Balka	9.5	726	18	60–75	500–600	760	1

At the S.M. Kirov mine, bed $h_{10}^{в}$ is undermined by 2 beds (unlike the Kholodna Balka mine), which leads to its partial unloading and resulting in additional tensile forces arising in the bed, which leads to an increase in gas content and a decrease in the sorption capacity of coal (see Table 1).

LS-grade coal is represented by samples from the Yasynivska Mine (DMR) (bed m_3) and the mine named after M. I. Kalinin (bed l_3) (Central region). The sorption capacity of coal at the Yasynivska Mine in the researched samples is practically the same, 29.8–31.9 ml/g; while at the M.I. Kalinin Mine, sorption capacity of coal, determined by the EPR method, is less and ranges from 15.5 to 27.6 ml/g.

The beds of the mines differ significantly in terms of lithological-facial conditions. The bed m_3 (transgressive sedimentation conditions) has a stable working thickness throughout the area (slightly restored), while the bed l_3 (regressive sedimentation conditions) is characterized by significant washouts, indicating unstable sedimentation conditions.

The tectonic conditions of the mines also differ. The Yasynivska Mine is located between the Kalynivska and Yasynivska flexures in the northern part of the Zuivska anticline. In the western part of the mine field, there is the sub-meridional French thrust (dip of the fault plane to the west, amplitude 150 m), and from the east, the Yasynivsky thrust (dip of the fault plane to the east, amplitude 100 m). Sub-meridional compressive forces, which occurred after the inversion of the tectonic regime, led to the formation of sub-latitudinal low-amplitude normal faults. Similar location conditions and results of determining the sorption capacity of coal are also characteristic of the Kalynivska-Skhidna Mine (DMR).

Unlike the Yasynivska Mine, the M.I. Kalinin Mine (bed l_3) is located on the steep (dip angle is 60º) northern wing of the Horlivka anticline (Fig. 2).

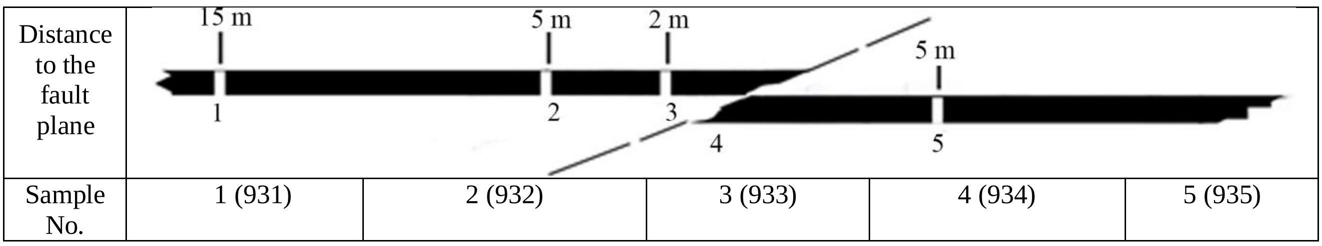

Figure 2 – Sampling diagram at the M.I. Kalinin Mine (the bed l_3).

On average, the sorption capacity of coal, as determined by EPR, in the selected samples is 21.6 ml/g. However, sample No. 932 has a capacity of 15.75 ml/g, while sample No. 934, located in the zone of the fault plane of a low-amplitude thrust, has a capacity of 27.5 ml/g. Since sample No. 934 was taken from the fault plane of the thrust, it can be argued that tectonic processes have caused structural changes in the gelified component of the coal, likely related to the destruction and breakdown of the coal's molecular structure. These changes likely resulted in an increased sorption capacity. In contrast, the structural changes in sample No. 932 are less significant, which corresponds to its lower sorption capacity.

The petrographic method was used to research the disturbance of coal. The determined indicators that estimate: area (S), perimeter (P), and shape (*Circularit*[1]) of coal particles within the thin section (Table 3).

The maceral composition of coal in the samples was determined through petrographic studies. Macerals behave differently depending on the grinding method: vitrinite is easily abraded, while inertinite splits. These features of macerals explain the low (0.86) value of the inertinite redistribution coefficient (see Table 3) and the larger perimeter of coal particles in sample No. 934, which was taken from the fault plane

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1. The smaller is its value, the more the particle shape differs from the shape of a circle, and the larger is its active surface.

zone. The shape indicator values suggest similar shapes across all samples. However, the particle areas vary, indicating heterogeneity in the disturbance of the coal bed.

Table 3 – Results of petrographic studies.

Indicators		Sample No. 931	Sample No. 932	Sample No. 933	Sample No. 934	Sample No. 935
Content inertinite, %		12	6	6	7	12
Inertinite redistribution coefficient [3]		2.42	2.50	2.83	0.86	2.42
Indicators of micro-disturbance of particles coal <0.05 mm	S	22	27	33	32	13
	P	4	4	4	6	3
	C	0.798	0.812	0.823	0.788	0.851

The analysis of technological indicators of coal showed that in the fault plane (sample No. 934) and at a distance of 15 meters (sample No. 931) from it, the coal ash content is 2–3%; in other samples, it is increased to 9–17%. Such differences are due to the presence of pyrite, which in the researched coal is in the form of concretions and interlayers. The presence of pyrite and its changes in area are related to the bed accumulation conditions.

Differences in micro-disturbance and coal ash content, which are revealed so locally (within 20 m), may be due to the morphology of the swamp surface and the associated flowability of water in local areas, which is confirmed by the lithological-facial conditions of sediment accumulation in this bed.

Therefore, the obtained data suggest that in a coal bed, heterogeneous in petrographic composition, located between strong sandstones, local areas of varying degree of disturbance were formed during the uplift of the Horlivka anticline. This created different conditions in each of them for the activation of degassing processes.

At the regional level (macro level), the degassing process is confirmed by the insignificant gas-bearing capacity of the bed and the absence of gas-dynamic phenomena. Traces of gas migration were noted in all samples (Fig. 4).

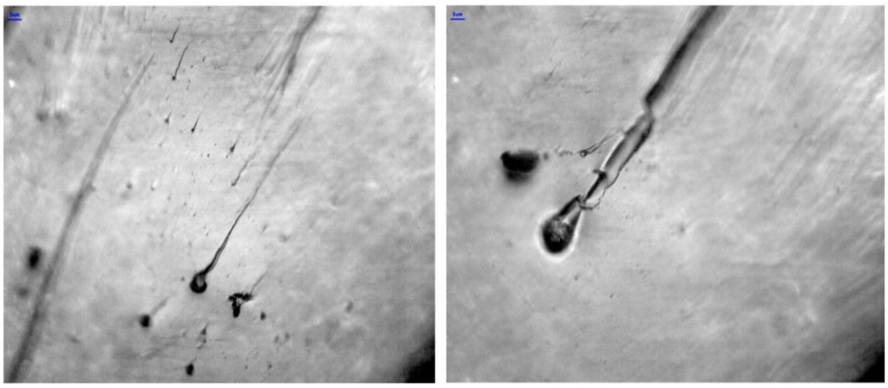

Figure 4 – Traces of gas manifestations in the coal of bed l_3 at the M.I. Kalinin Mine (samples No. 932, No. 934). Image size is 152×114 µm

In general, the gas permeability of coal is insignificant, but in folded, fractured coal beds, there are many cracks. Passing from crack to crack, the gas leaves cavities of various sizes in the bed body. The value of the indicator – Pv (the ratio of void areas to the unit area of coal on which these voids are determined), in sample No. 934 (18%) exceeds the analogous values of other samples (12–14%). Eighteen percent of the coal surface area is affected by cavities (sample No. 934). Sorption in this sample is maximal (see Table 3). Therefore, petrographic studies indicate the heterogeneity of bed disturbance at the micro level, which is due to the conditions of sediment accumulation, which affects the sorption properties of coal.

The presented data prove that the differences in the sorption capacity of coal are the cumulative result of the action of tectonic processes and lithological-facial conditions of sediment accumulation. Sorption properties of coal of grade F were researched by EPR-spectroscopy at the DMR mines – O.F. Zasiadko Mine (beds l_4 and m_3) and Tsentralna (Pokrovsky district) (m_3). The smallest values of the sorption capacity of coal are characteristic of the bed l_4 (≈ 5.9 ml/g) at the O.F. Zasiadko Mine; sorption capacity of coal bed m_3 at the O.F. Zasiadko Mine and the Tsentralna mine are commensurate and average 15.3 ml/g.

The analysis of the spectral parameter indicators shows that with the value of the concentration index of PMC in the coal matter sample of bed l_4, characteristic of grade F, the values of the ΔH index correspond to grade LF. That is, the structural transformations in the matter of bed l_4, at the O.F. Zasiadko Mine lag behind the degree of chemical transformations, which may be the result of a difference in the initial geological conditions of sedimentation during the formation of a coal bed. So, there is a thin layer of sapropelites in the roof of bed l_4. It should be noted that the macromolecules of humus and sapropel coal are different. The macromolecule of humus coal is built from an aromatic nucleus, which is associated with the hydroaromatic, aliphatic, and other groups of atoms surrounding it. The sapropelite macromolecule consists of aliphatic chains connected by cross-links; there are few heteroatomic and other labile bonds in it. Unlike humus coal, the destruction of sapropel coal macromolecules occurs mainly through carbon bonds, the breaking of which requires much greater activation energy.

Petrographic studies showed that the coal bed l_4 at the O.F. Zasiadko Mine, like the m_3 coal bed, consists of almost 90% of gelified substance (microcomponents of the vitrinite group), but the rest of it is represented not by fusinite, but by liptinite, which has minimal sorption capacity and increased viscosity, which prevents the development of (Fig. 5) microcracks.

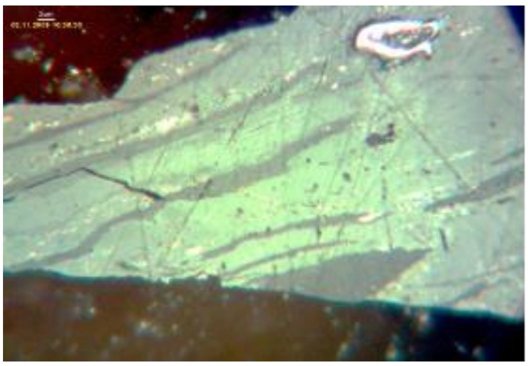

Figure 5 – Development of cracks in gelified substance, which is hindered by strong, viscous microcomponents of the liptinite group

This is another geological factor that affects the sorption properties of coal. Micro-disturbance of coal beds contributes to the crushing of coal and, as a result, an increase in the surface area capable of interacting with oxygen. In addition, the resulting cracks are channels for the delivery of sorbent and the desorption of methane. But in addition to tectonic disturbance, coal has, perhaps not such a high-amplitude, but most often a much more developed network of endogenous cracks (shrinkage cracks) and a system of regional (planar) cleavage cracks (Figs. 6, 7).

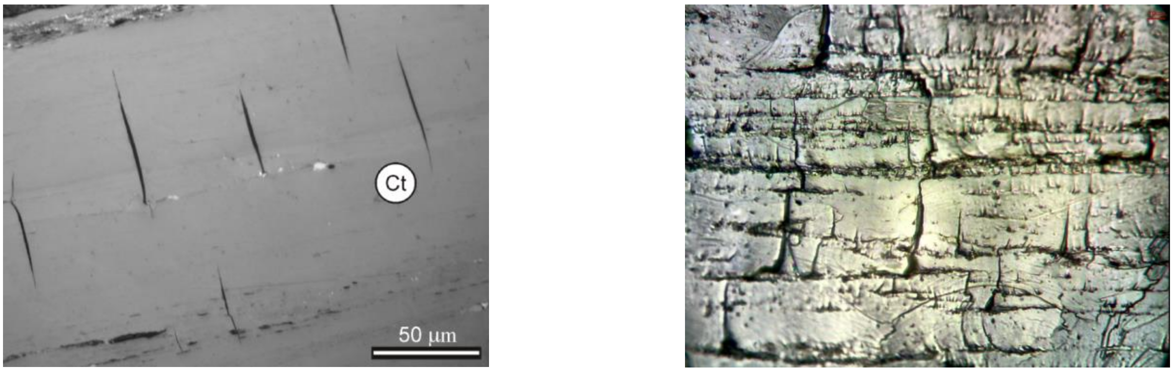

Figure 6 – Endogenous desiccation crack in clarein lithotypes of coal.

A) in a piece bounded by spalling cracks; B) in a polished block section;
C) under a microscope

Figure 7 – Cleavage cracks

Thus, cleavage cracks are observed in mine conditions every 20–30 cm; in an individual piece of coal, which is separated from the bed in the face due to spalling cracks, every 3–5 cm; in a polished block section every 2–5 mm, and under a microscope – every 20–600 µm.

Collection of oriented samples in the workings of the O.F. Zasiadko Mine allowed us to note the peculiarity in the development of regional cleavage fracturing for the considered beds: 1) cracks in bed l_4 extend from west to east, in the bed m_3 – from north to south; 2) the frequency of fractures in the bed m_3 is several times higher than in bed l_4.

Considering that the mining of both beds is carried out in the west-north direction, in the case of bed l_4, natural degassing occurs, which is confirmed by the absence of traces of gas emission (Fig. 8) and a decrease in the sorption capacity of coal.

Therefore, it is evident that both the lithological-facial conditions of coal deposition (liptinite, sapropelite) and the bed exploitation conditions of beds l_4 and m_3 influenced the differences in the sorption capacity of the coal.

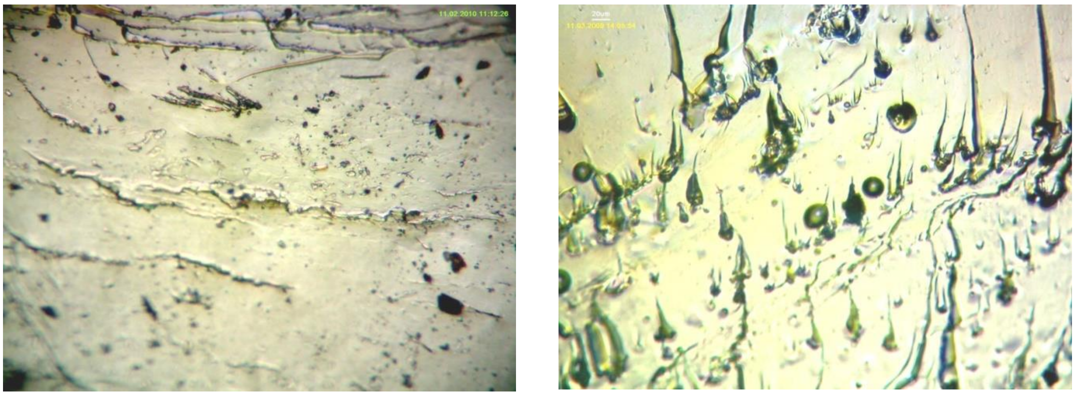

Figure 8 – Absence of traces of gas emissions in bed l_4 (left);
large number of traces of gas emissions in bed m_3 (right)

The sorption capacity of coal of grade LF was researched [26] at the Yuvileina and Blahodatna mines (bed c_5), located in the Western Donbas (Pavlohrad-Petropavlivk district), and the Trudivska Mine (beds m_3 and l_4), which is located in the Donetsk-Makiivka district.[2]

Petrographic studies showed that the selected coal samples are similar in the degree of coalification, that is, the organic matter of the samples was exposed to approximately the same temperature and pressure during geological development (Table 4).

Table 4 – Results of research on the maceral composition of coal.

Indicators	Mines		
	Blahodatna (bed c_5)	Yuvileina (bed c_6)	Trudivska (bed m_3)
Volatile matter yield	46.39	43.11	44.39
Number of gas generation traces per 100 μm^2	0.5	1.3	absent
Vitrinite	73	79	83
Inertinite	3	3	16
liptinite	24	18	1
Average sorption capacity of coal, ml/g	7.6	10.9	6.4

But the sorption capacity of coal varies. According to EPR data, the lowest sorption capacity is characteristic of coal from the Trudivska Mine: bed l_4 – 4.1 ml/g; bed m_3 – 6.4 ml/g. The complex tectonics of the Donetsk-Makiivka region caused an extremely uneven distribution of methane in the coal-bearing strata; in the Trudivska group of mines, deep degassing of coal-bearing strata is observed, reaching 450–500 m vertically from the surface, which is confirmed by the absence of traces of gas generation (see Table 4).

[2]The features of bed l_4 accumulation were presented above.

The following are characteristic of the beds at the mines of the Western Donbas: 1) gentle bedding (dip of rocks to the north and northeast at angles of 3–5°); 2) slightly undulating surface of deposits; minor disturbance by low-amplitude ruptures (type of faults); 3) increased liptinite content. At significant contents (over 20%), liptinite gives the coal greater fusibility, increases the volatile matter yield, hydrogen content, and heat of combustion, which is characteristic of bed c_5 (Blahodatna Mine). But, unlike the Blahodatna Mine, a zone of low-amplitude disturbance was detected by seismic exploration at the Yuvileina Mine, which can be traced in all coal beds and extends diagonally from the southwest to the northeast for a distance of up to 3 km. Therefore, bed c_6 (Yuvileina Mine) is characterized by greater disturbance and a smaller amount of liptinite. The combination of these factors could lead to an increase in the sorption capacity of coal at this mine.

Additionally, the relative methane content in the mine workings of bed c_6, which was mined under the protection of bed c_6^1 in the upper horizons of the central part of the mine field, is insignificant or there is no gas at all. In non-fractured areas, the relative methane content of mine workings corresponds to their gas content. An exception is the longwalls near tectonic disturbances (tectonically screened trap), where the methane content increases sharply due to methane inflow from deep horizons, entering the mine workings through disturbed zones.

Thus, based on the research, a preliminary conclusion can be drawn that the different ability of coal to sorb methane from all the analyzed coal beds is determined by a combination of a sequence of unequal factors of different nature. Primary factors include coal metamorphism, while secondary factors include tectonic processes, lithological-facial conditions of sediment deposition, and features of the petrographic composition of coal.

4. Conclusions

1. Metamorphism is the primary (regional) factor influencing the sorption capacity of coal, as it causes structural and chemical changes under the effects of temperature, pressure, and geological time. As the degree of metamorphism increases (from lignite to anthracite), the volatile matter content and oxygen groups decrease, making the coal more carbonized. During metamorphism, the micro- and mesoporosity of coal change. With higher levels of metamorphism, the coal structure becomes more graphite-like, which reduces the number of active centers for sorption because the structure becomes more crystalline and less reactive.

2. Differences in the sorption capacity of coal within a single bed are mainly caused by tectonic processes, while variations between different beds are primarily due to lithofacial conditions. Tectonic processes (faults, pressure, landslides, tectonic stresses) are recorded locally, in this case within one bed. Tectonic deformations create additional fractured or porous structures, increasing the surface area available for sorption. Beds can undergo compaction or, alternatively, disintegration, which alters their permeability and gas absorption capacity. Additionally, tectonic shifts can open new pores or modify existing ones, directly impacting sorption capacity. On the other hand, lithological-facial conditions refer to the environmental settings in which coal-

bearing layers formed – such as swamps, deltas, and lagoons. These conditions form the initial properties of coal, including chemical composition, ash content, type of organic matter, and degree of hydrolysis. They are determined by factors like the type of original vegetation, which affects the chemical structure of humus matter, sedimentation conditions that influence reduction levels, sulfur content, ash content, and impurity and mineral formation. These facial conditions also impact porosity and the number of active centers.

3. Using EPR-spectroscopy to research coal matter properties enables quick, effective, and accurate evaluation of the sorption capacity of coalified organic matter, considering the specific impact of regional and lithofacial factors on the properties and condition of coal.

Conflict of interest

Authors state no conflict of interest.

REFERENCES

1. Ukraine Ministry of Coal Industry (1989), *NPAOP 10.0-5.25-89, Instruktsiya po bezopasnomu vedeniyu gornykh rabot na plastakh, opasnykh po vnezapnym vybrosam uglya, porody i gaza* [NPAOP 10.0-5.25-89, Instructions for safe mining operations in seams dangerous for sudden emissions of coal, rock and gas], Ukraine Ministry of Coal Industry, Kyiv, Ukraine.

2. Ukraine Ministry of Coal Industry (2005), *Standart Ministerstva ugol'noy promyshlennosti Ukrainy, Vremennyye ukazaniya po prognozu emissionnoy opasnosti ugol'nykh plastov i porod, sklonnykh k gazodinamicheskim yavleniyam* [Standard of the Ministry of Coal Industry of Ukraine.Temporary guidance on the forecast of the emission hazard of coal seams and rocks prone to gas-dynamic phenomena], Ukraine Ministry of Coal Industry, Kyiv, Ukraine.

3. Ukraine Ministry of Coal Industry (2015), *DKZ: Metodicheskiye rekomendatsii po geologicheskomu izucheniyu gazonosnosti ugol'nykh plastov i vmeshchayushchikh porod dlya podscheta zapasov i otsenki resursov gaza (metana) podzemnykh ugol'nykh mestorozhdeniy* [DKZ Methodological recommendations for the geological study on the gas-bearing capacity of coal seams and host rocks for the calculation of reserves and the assessment of gas (methane) resources of underground coal deposits], State Commission of Ukraine on Mineral Reserves, Kyiv, Available at: http://www.dkz.gov.ua/ua/diyalnist/normativno-pravova-baza (Accessed 16 July 2025).

4. Perera, M.S.A., Ronjith, P.G., Choi, S.K., Airey, D. and Weniger, P. (2012), "Estimation of Gas Adsorption Capacity in Coal: A Review and an Analytical Study", *International Journal of Coal Preparation and Utilization*, vol. 32(1), pp. 25–55. http://doi.org/10.1080/19392699.2011.614298

5. Gao, D., Hong, L., Wang, J. and Zheng, D. (2019), "Adsorption simulation of methane on coals with different metamorphic grades", *AIP Advances*, vol. 9, 095108, https://doi.org/10.1063/1.5115457

6. Dong, K., Zhai, Z. and Guo, A, (2021), "Effects of Pore Parameters and Functional Groups in Coal on CO2/CH4 Adsorption", *ACS Omega*, vol. 6, pp. 32395−32407. https://pubs.acs.org/doi/full/10.1021/acsomega.1c02573

7. Jamiu M., Ekundayo and Rezaee, R. (2019), "Volumetric measurements of methane-coal adsorption and desorption isotherms – effects of equations of state and implication for initial gas reserves", *Energies*, vol. 12, 2022. https://doi.org/10.3390/en12102022

8. Raharjo, S., Bahagiarti, S., Purwanto, H.S., and Rahmad, B. (2018), "The effect of coal petrology on the capacity of gas methane absorption in coal formation Tanjung Barito in Binuang Region, South Kalimantan", *Earth and Environmental Science*, vol 212, 012029. https://doi.org/10.1088/1755-1315/212/1/012029

9. Okolo, G.N., Everson, R.C., Neomagus, H.W.J.P., Sakurovs, R., Grigore, M. and Bunt, J.R. (2019), "Dataset on the carbon dioxide, methane and nitrogen high-pressure sorption properties of South African bituminous coals", *Data in Brief*, vol. 25, pp. 40–53. https://doi.org/10.1016/j.dib.2019.104248

10. Czerw, K. and Baran, P. (2019), "Sorption of carbon dioxide on the lithotypes of low rank coal", *Adsorption*, vol. 25, pp. 965–972. https://doi.org/10.1007/s10450-019-00122-5

11. Wojtacha-Rychter, K., Howaniec, N. and Smolinskii, A. (2020), "Effect of porous structure of coal on propylene adsorption from gas mixtures", *Scientific Reports,* vol. 10, 11277. https://doi.org/10.1038/s41598-020-67472-x

12. Kumar, H., Mishra, M.K. and Mishra, S. (2019), "Sorption capacity of Indian coal and its variation with rank parameters", *Journal of Petroleum Exploration and Production Technology*, vol. 9, pp. 2175–2184. https://doi.org/10.1007/s13202-019-0621-1

13. Saranchuk, V.I., Ayruni, A.T. and Kovalev, K.E. (1988), *Supramolekuliarna orhanizatsiia, struktura ta vlastyvosti vuhillia* [Supramolecular organization, structure and properties of coals], Naukova Dumka, Kyiv, Ukraine.

14. Alekseyev, A.D. (2010), *Fizika uglya i gornykh protsessov* [Physics of coal and mining processes], Naukova Dumka, Kyiv, Ukraine.

15. Bulat, A.F Skipochka, S.I., Palamarchuk, T.A., and Antsiferov, V.A. (2010), *Metanogeneracia v ugolnyh plastah* [Methane generation in coal seams], Lira, Dnipro, Ukraine.

16. Bulat, A.F., Lukinov, V.V., Pimonenko, L.I. (2012), *Geologicheskiye osnovy i metody prognozirovaniya vybrosoopasnosti uglya, gornykh porod i gaza* [Geological foundations and methods for forecasting the outburst hazard of coal, rocks and gas], Monolitm, Dnipro, Ukraine.

17. Bezruchko, K.A., Burchak, O.V., Pymonenko, L.I. and Chelkan, V.V. (2024), “Sorption capacity and natural gas content of coal beds of Donbas”, *Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu*, vol. 4, pp. 18–26. https://doi.org/10.33271/nvngu/2024-4/018

18. Bezruchko, K.A., Burchak, O.V., Pymonenko, L.I., and Chelkan, V.V. (2023), "Method for determining the ultimate sorption capacity of coal matter by EPR-spectroscopy", Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu, vol. 1, pp. 5-9. https://doi.org/10.33271/nvngu/2023-1/005

19. Bulat, A., Burchak, O., Trachevskyi, V. and Tokar, A. (2023), "Evolution of Electron Structure of the Methane-Coal Sorption System Components and Properties", in Guz, A.N. (ed.), Book series «Advances in Mechanics. Advanced Structured Materials», vol. 191, pp. 91-101, https://doi.org/10.1007/978-3-031-37313-8_5

20. Dameng Gao, Lin Hong, Jiren Wang and Dan Zheng. (2019), “Adsorption simulation of methane on coals with different metamorphic grades”, *AIP Advances*, vol. 9, 095108, https://doi.org/10.1063/1.5115457

21. Dong, K., Zhai, Z. and Guo, A. (2021), “Effects of Pore Parameters and Functional Groups in Coal on CO2/CH4 Adsorption”, ACS Omega, vol. 6, pp. 32395−32407. https://pubs.acs.org/doi/10.1021/acsomega.1c02573

22. Kumar, H., Mishra, M.K. and Mishra, S. (2019), “Sorption capacity of Indian coal and its variation with rank parameters”, *Journal of Petroleum Exploration and Production Technology*. https://doi.org/10.1007/s13202-019-0621-1

23. Carroll, R.E. and Pashin, J.C. (2003), “Relationship of sorption capacity to coal quality: CO2 sequestration potential of coalbed methane reservoirs in the Black Warrior basin”, *Proceedings of the International Coalbed Methane Symposium*, Tuscaloosa, USA, vol. 0317, pp. 1–11. available at: https://www.gsa.state.al.us/img/Energy/Carroll%200317.pdf (Accessed 16 December 2024).

24. Ukraine Ministry of Coal Industry (2015), *DSTU 3472:2015 Buryye ugli, kamennyye ugli i antratsit. Klassifikatsiya* [DSTU 3472:2015 Brown coals, Hard coals and Anthracite. Classification], DP UkrNDNC, Kyiv, Ukraine.

25. Bezruchko, K.A., Burchak, O.V., Pymonenko, L.I., Karhapolov, A.A. and Chelkan, V.V. (2022), “The determining ultimate sorption capacity of coal matter by the EPR-spectroscopy”, *Proceedings of the All-Ukrainian Conference “From Mineralogy and Geognosy to Geochemistry, Petrology, Geology and Geophysics", MinGeoIntegration XXI*, 28–30 September 2022, Kyiv, Ukraine, pp. 105–109.

26. Bezruchko, K.A., Pymonenko, L.I., Burchak, O.V., Balalaiev, A.K., and Baranovskyi, V.I. (2023), “Research of coal substance in beds at "Yuvileina" and "Blahodatna" mines (Western Donbas)”, *Proceedings of the IV International Scientific Conference “Modern Problems of Mining Geology and Geoecology”*, 26–27 November 2023, Kyiv, Ukraine, pp. 29–33, https://doi.org/10.59911/conf.mpmgg.2023

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ГЕОЛОГІЧНІ ЧИННИКИ, ЩО ВПЛИВАЮТЬ НА СОРБЦІЙНІ ВЛАСТИВОСТІ ВУГІЛЛЯ

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Анотація. Сорбційна здатність вугілля є найважливішою характеристикою з огляду оцінки його газоносності, безпеки гірничих робіт та впливу емісії метану на довкілля. Ефективна дегазація вугілля знижує ризики раптових викидів та скорочує обсяги надходження парникових газів в атмосферу. Існуючі методи визначення сорбційної здатності э трудомісткими та дорогими, що обмежує їх використання. Також немає чіткого розуміння впливу регіональних і локальних геологічних факторів на сорбційні властивості вугілля.

Мета досліджень: методом ЕПР-спектроскопії дослідити сорбційні властивості зразків вугілля з різних шахт і вугільних пластів Донецького басейну та визначити чинники, що впливають на сорбційну здатність вугільної речовини. Загальна кількість досліджених проб складає 45 від марки Д до марки П. Вибір різних пластів в межах однієї марки дозволив визначити вплив на сорбційну здатність вугілля літолого-фаціальних умов, а з різних шахт – термодинамічних процесів; порівняння показників з проб, які були відібрані з порушених і непорушених ділянок – тектонічних процесів. Дослідження виконувалось методом ЕПР-спектроскопії для визначення концентрації парамагнітних центрів, коефіцієнта ароматизації, порушеності структури та зв'язку цих характеристик із сорбційною здатністю. Підтверджено, що метаморфізм є одним з головних факторів, що впливає на сорбційну здатність вугілля, визначаючи його структурні та хімічні зміни. Доведено, що зі зростанням метаморфізму (від бурого вугілля до антрациту) зменшується вміст летких речовин і кисневих груп, підвищується карбонізація, змінюється мікро- та мезопористість. Найкращі сорбційні властивості спостерігаються при середньому ступені метаморфізму, коли зберігаються функціональні групи та пориста структура. Подальша графітизація знижує активність поверхні. Відмінності сорбційної здатності в межах пласта зумовлені тектонічними впливами, а між пластами — літофаціальними умовами. Тектоніка формує тріщини та пори, змінюючи проникність. Літофації впливають на початкові властивості вугілля: зольність, сірчистість, склад. Напрямок гірничих виробок також впливає на структуру та окиснення вугілля, змінюючи сорбційні властивості, особливо через тріщини, вологість і контакт з повітрям.

Ключові слова: вугільна речовина, сорбційні властивості, геологічні фактори, ЕПР-спектроскопія, петрографічні дослідження.