https://doi.org/10.33271/nvngu/2023-5/012

V. S. Savchuk,
orcid.org/0000-0001-6750-9221,
V. F. Prykhodchenko,
orcid.org/0000-0002-7658-8758,
D. V. Prykhodchenko,
orcid.org/0000-0003-3035-5702,
N. V. Khomenko*,
orcid.org/0000-0003-1509-3054

Dnipro University of Technology, Dnipro, Ukraine
* Corresponding author e-mail: Khomenko.n.v@nmu.one

INFLUENCE OF THE GEOTECTONIC REGIME ON PROPERTY FORMATION OF COAL IN THE NORTHERN EDGES OF THE DONETSK BASIN

Purpose. To determine the influence of the geotectonic regime during accumulation of carbon formation on development of coal-bed properties of the northern Donbas.

Methodology. To perform the tasks set, a number of research methods were used which include petrographic, chemical and technological, facies and tectonic, computational, statistical and analytical, informational, chronological, genetic, comparative and other methods.

Findings. The effect of the geotectonic regime on the formation of coal properties has been established. It is proved that the change in the number of maceral groups is of a regular nature. The reduction in the number of maceral groups of liptinith and irtinitis, in the light of the increase in the number of maceral wind group, is taking place in the direction of the growth of the total amplitude and average speed of the oscillating movements of the Earth's crust during the accumulation of carbon formation.

Originality. Coal formation is considered regarding a unified geodynamic perspective as an integral part of a complex set of natural processes that accompanied the development and interaction of deep structures (plates) of the lithosphere. The main attention is paid to the peculiarities of the composition and quality of coal formed under geodynamic conditions with different motion nature of the lithosphere. For the first time, comparative analysis of the coal-bearing formation of the middle Carboniferous period of the Old and Northern Donbas has been performed. Detailed petrographic and chemical-technological characteristics are given to the coal seams of the Northern Donbas. The peculiarities of the composition and quality of the coal of the deltaic-bog-marine formation have been determined for the first time compared to the coal of other formations of the Middle Carboniferous.

Practical value. Regional ("provincial") peculiarities of coal composition and quality of deltaic-bog-marine and alluvial-bog-marine formations of northern Donbas regions have been defined, which will allow substantiating the directions of its rational use. The proposed approach makes it possible to predict coal content as well as composition and quality of coal in the areas of distribution of bituminous coal. The expediency and prospects of adding the coal of northern Donbas to the fuel base of Ukraine are proven.

Keywords: *coal-bearing formation, geotectonic conditions, metamorphism, petrography, quality, grade*

Introduction. The structure of fossil fuel reserves in Ukraine includes 94.5 % of coal, 2.0 % of oil, and 3.6 % of natural gas. Ukraine's coal reserves reach 3.5 % of the world's total ones [1]. In terms of anthracite reserves, the country ranks third in the world. The country is one of the ten largest coal-producing countries and has enough coal for 429 years.

With the proclamation of Ukraine's shift towards carbon-free energy in 2020–2021, when the share of thermal power plants (TPPs) in electricity generation was reduced to 26 % [2], it turned out that this leaves the power system without efficient means of load control. The conclusion on the expediency to continue at least a third of electricity generation operations at TPPs, including coal-fired TPPs in coal-mining countries such as China [2, 3], was fully confirmed with the beginning of the full-scale aggression of the Russian Federation, when coal-fired TPPs were again considered to be a key factor in uninterruptible power supply. Therefore, the combustion of gas coal which is mined in the government-controlled territories and is available in the global market remains relevant. According to the New Energy Strategy (NES) of Ukraine, in 2035, TPPs and combined heat and power plants (CHPPs) will generate about 63 billion kWh of electricity, and the role of coal-fired power plants will continue taking the lead in managing peak loads. It is also estimated that the share of electricity generation by TPPs and CHPPs in this period will be no less than 12 % [4].

Since there will be no complete abandonment of coal as a fuel in the coming years, it is necessary to determine the specifics of the raw material base of Ukraine's solid fuel power sector in the near future [5]. It is required to substantiate the possibility of involving the highest quality and most affordable coal reserves.

The global "carbon-free" energy trend is applying increasingly stringent environmental requirements to fossil fuels that will be further combusted in existing boiler units to produce electricity and heat. Rapid response to consumer demand requires a systematic approach to comprehensive study on coal properties and creation of a more reliable knowledge database to make decisions on its rational use [6, 7].

The analysis of the primary factors of coal properties formation showed that the most important of them are the sink rate of peatlands, the degree of watering and the degree of flowage, which are controlled by the tectonic conditions of sedimentation [8, 9]. Tectonics is the main factor that controls all the parameters of the coal-bearing rock mass from its formation to surface conditions of mining. The study on the conditions of their formation and change has proved that all the factors are genetically interrelated and when studying one phenomenon, it is necessary to consider other phenomena that are closely related to it [10, 11]. Therefore, one of the most urgent problems in coal geology is to identify the relationship between the geological conditions of coal seam formation and the petrographic composition and operational characteristics of coal. A successful solution to this problem is possible provided the tectonic factor, which controls the chemical and technological properties of coal and determines its consumer value, is studied in detail.

This integrated approach to coal quality forecasting research allows us to show that the solution of any theoretical and practical issue of coal geology should be based on the knowledge of the regularities in the structure of coal-bearing formations.

In this context, coal deposits located in the northern edges of the Donetsk basin are worth considering. These are deposits with proven coal reserves of about 10–12 billion tonnes (forecast reserves – up to 25 billion tonnes), which are not currently being extracted.

Literature review. Many researchers consider the tectonic factor to be the main one in the accumulation and evolution of peat deposits. The tectonic conditions of coal-bearing rock mass formation are studied with geotectonic research methods. The publication of the article "Coal Accumulation as a Geotectonic Problem" by H. Stille (1925) was crucial for coal geotectonics. Its publication marked the beginning of the classical stage of coal geotectonics development. The paper was the first to substantiate the relation of most characteristics of coal-bearing strata with differences in the degree of their mobility.

Classical (geosynclinal) coal geotectonics got widespread use in the works by domestic geologists as well.

In 1920, M. O. Usov specified the influence of the geotectonic factor in the process of peat accumulation, showing that it can occur only under favourable geotectonic conditions. This gave rise to the development of geotectonic classifications of coal-bearing formations.

It was not until 1934 that G. O. Ivanov proposed a general classification of coal-bearing formations, dividing them into geosynclinal, platform and transitional types. In 1937, he developed his ideas in much more detail. The final version of the classification was published only in 1946.

Most of the subsequent classifications by such geologists as V. P. Vasiliev, O. B. Bludourov, Yu. A. Zhemchuzhnikov, G. F. Krasheninnikov, O. I. Pinchuk, Ya. M. Chernousov, E. O. Pohrebytskyi and others who classified coal-bearing formations on the basis of geotectonics, were in fact variations of this division.

There are many variants of coal basin classifications. Frequently, the issue of classification of coal basins is solved along with the classification of coal-bearing formations. When considering the complex of sediments that contain coal seams, two concepts are used: coal-bearing strata and coal formation. The definition of "coal-bearing strata" is a self contained term. It is not related to the determination of the conditions of formation of these deposits, their tectonic position, patterns of coal seams in it, changes in the composition and quality of coal, both in terms of literal and in terms of the area of coal seams.

When defining the concept of coal-bearing formation and studying coal deposits, the genetic approach is used. The doctrine of coal-bearing formations is based on the system of basic concepts and ideas of coal geotectonics, which studies the peculiarities of accumulation, transformation and localisation of coal-bearing complexes in the Earth's crust in view of the uniform laws of development and principles of structuring of the geological space. Almost all classifications of coal-bearing formations are genetic in nature and are based on the genetic principle, i. e. geotectonic conditions of formation.

There is no conventional genetic classification of coal-bearing formations, and the issue remains the most difficult and controversial one. Based on its results, coal geotectonics was divided into two areas – geostructural and geostructural-phasic ones, with the lithologic-facies research area being extensively used.

Zhemchuzhnikov Yu. A. was the first to draw attention to the possibility of the simultaneous existence of several types of coal-bearing formations in one large region. Further studies showed that the change in the types of coal-bearing formations throughout the Donetsk basin is accompanied by their change in time. The Upper Visean coal-bearing formation of the Western Donbas, which is located only on the platform slope of the Ukrainian Shield, lengthens into the Bashkirian and Moscovian coal-bearing strata located both on the trough and on its platform slopes. Later, this approach allowed Yu. A. Zhemchuzhnikov to establish the variability of the petrographic composition in the stratigraphic scale of the Donetsk basin. It was determined that the petrographic composition of Early Carboniferous coals differs significantly from that of Middle Carboniferous coals. Therefore, it was noted that the coals of different coal-bearing formations of the Donetsk Basin are substantially different in terms of both petrographic composition and chemical and operational peculiarities. The main cause of this phenomenon, in his opinion, is the geotectonic conditions of coal-bearing strata formation. Further, A. V. Makedonov, M. L. Levenstein, G. F. Krasheninnikov, and others pointed out the need to distinguish the Lower Carboniferous coal-bearing formation in the Donetsk Carboniferous section. V. S. Popov noted that the fundamental differences between the Late Visean and Middle Carboniferous coal accumulation are related to the different nature of tectonic movements in these epochs.

The comparative analysis was widely used in subsequent years to study coal from different coal-bearing formations of the Donetsk basin [12, 13].

Describing the history of the geological development of the Donbas coal-bearing formation, O. Z. Shirokov distinguished three coal-bearing formations in the Donetsk basin: the Lower Visean, Upper Visean and Middle-Upper Carboniferous. The Lower Visean coal-bearing formation is a platform formation (of the Moscovian Basin type) and is located on the southern slope of the Voronezh Anteclise outside the Donetsk Basin. Generalising characteristics of the composition and quality of coal in the Carboniferous formations of the Dnipro-Donetsk Depression was given by O. Z. Shirokov and S. V. Savchuk back in 1983. The work considered three coal-bearing formations in detail: the Early Visean, Late Visean and Middle-Late Carboniferous. Comparison of coals from the latter two coal-bearing formations revealed significant differences in their petrographic composition, recoverability and chemical and technological properties.

Subsequently, the determination of the geodynamics peculiarities of the Don-Dnipro Trough at the boundary of the Early and Middle Carboniferous allowed substantiating the cause of the interruption in sedimentation and extinction of biocenoses and clarifying the boundaries of the Lower and Middle Carboniferous [14].

A considerable number of the studies that followed were aimed at determining the influence of facies conditions of peat accumulation on the petrographic composition of coal, as well as on the chemical composition of their ash and chemical and technological properties [15, 16].

According to G. F. Krasheninnikov, the concept of "coal-bearing formation" is not a "tectonic" or "climatic" concept, but a historical and geological one. In his opinion, in defining the concept of "formation", the factors of commercial value of the mineral raw materials contained therein are always applied. It is from this perspective that it is expedient to identify coal-bearing formations which are the most characteristic for the Donetsk Basin carbonification, and to establish their petrographic, chemical and technological peculiarities. Long-term study on peat accumulation conditions in the Greater Donbas allowed him to identify three coal-bearing formations in the Carboniferous. The Lower Carboniferous bog-lagoon-marine formation was classified as the oldest. The second, yet the most important formation in practical terms, is the Middle Carboniferous alluvial-bog-marine formation. The next coal-bearing formation of Donbas includes the deltaic-bog-marine formation, which was identified in the Middle Carboniferous in the north of the Greater Donbas. In his opinion, the Northern Donbas featured the most stable position in terms of the degree of basement mobility during the peat accumulation epoch. The coal content of this formation is significantly reduced compared to the previous formation. Thus, G. F. Krasheninnikov, unlike the previous researchers, identified two coal-bearing formations in the Middle Carboniferous of the Donbas: alluvial-bog-marine and deltaic-bog-marine, which differ in the degree of basement mobility during their accumulation.

Comparison of the composition and quality of coal from these formations, which are at the same stage of metamorphism, makes it possible to determine the influence of geotectonic conditions on the formation of coal properties.

The purpose of the work is to determine the influence of geotectonic conditions of development of coal-bearing coal formations in the northern edges of the Donbas on their petrographic, chemical and technological properties.

Methods. The methodological basis of the research involved the principle of systematicity. It was used to summarise the results of the individual methods applied in the study: petrographic, computational, statistical and analytical, informational, chronological, genetic, comparative and other methods.

The use of chronological, genetic, statistical and analytical methods allowed us to select the research objects and provide them with an integrated geological description.

The macroscopic and microscopic characteristics of the coal composition were studied using petrographic methods, and the degree of its metamorphism and reduction was determined.

The use of chemical and technological methods allowed for a comprehensive characterization of the quality of coal seams, both in alluvial-bog-marine formations and in deltaic-bog-marine formations.

To consolidate the obtained results regarding the composition and quality of coal, a database was created, and modern methods of analysis and interpretation were applied.

In the final stage of the work, the comparative method was used, which allowed identifying the influence of the geotectonic regime on the formation of the composition and quality of coal.

Results. First, let us consider the formation peculiarities of these coal-bearing areas.

The industrial coal-bearing capacity in the Lozivska district is associated with the Bashkirian ($C_2^1-C_2^4$) and Moscovian ($C_2^5-C_2^7$) stages of the Middle Carboniferous, which represent the natural northwest extension of the productive strata of the open Donetsk Basin. The maximum number of industrial seams is associated with C_2^6 and C_2^7 coal beds. In terms of paleogeographic conditions, the coal-bearing strata are classified as alluvial-bog-marine formations.

According to G. F. Krasheninnikov, Starobilsk coal-bearing area, located in the northern part of the Greater Donbas, belongs to the deltaic-bog-marine formation, whose geological age corresponds to suites $C_2^3-C_2^7$. It is genetically and geographically related to the alluvial-bog-marine formation of the Central Donbas but has its own peculiarities which allowed it to be classified as a separate type. In general, this formation represents a zone of transition from alluvial-bog-marine to marine conditions on the eastern slope of the Voronezh Anteclise and the Moscow Syncline.

Let us consider and compare the characteristics of these coal-bearing formations. Taking into account the peculiarities of coal formation in these areas, we will compare them based on the coal thickness of the Moscovian Formation. Table 1 provides the key information regarding their structure.

The coal-bearing regions differ in terms of their extent. For instance, Starobilsk coal-bearing area is almost twice the size of Lozivska coal-bearing region (Table 1). It is worth noting that the depth of the Moscovian Formation deposits is the same in both areas. Additionally, the total thickness of the Moscovian stage in Lozivska coal-bearing region averages 667 meters, while its thickness in Starobilsk coal-bearing area is lower, reaching about 490 meters. The coal content of this formation is significantly lower compared to the alluvial-bog-marine formation of the Lozivska coal-bearing region. Essentially, the coal content coefficient, both general and industrial, depends on the thickness of the seams. In the stratigraphic section, their maximum values are associated with C_2^6 seam. The formations differ not only in the total number of seams but also in the number of commercially significant coal seams. Lozivska coal-bearing region contains 38 seams, of which 16 have reached working thickness, and only 7 are of industrial significance. Starobilsk coal-bearing region, on the other hand, has a lower total number of seams and a smaller number of workable seams, including industrial coal seams.

It has been proven that despite the greater overall thickness of all Moscovian Formation seams in Lozivska coal-bearing area, the thickness of the working seams is smaller there than in Starobilsk coal-bearing area (Table 1). In general, the alluvial-bog-marine formation features higher coefficients of both general and industrial coal content. Unlike the seams in Lozivska area, the seams in Starobilsk area are more stable, and their structure is predominantly simple.

Significant differences can be noted in the composition of the enclosing rocks as well. In the first case, sandstone predominates in the composition of the rocks, while in the second case, mudstone becomes more prevalent, often with a significant amount of limestone and clay containing montmorillonite. All of these factors indicate an increased influence of marine conditions.

The cyclic structure of the sections of these formations is their characteristic feature. However, the cycles differ in thickness almost twofold (Table 1). In general, it should be noted that the development of coal formations has occurred under different geotectonic conditions. The alluvial-bog-marine formation of the Lozivska coal area was formed in the zone of transition from movable platform structures to folding structures of the Dnipro-Donetsk Depression, while the deltaic-bog-marine formation of Starobilsk area was formed in the mobile platform zone. Regarding the degree of mobility, the latter occupied a more stable position during the peat accumulation epoch, which resulted in the formation of differences in the geological characteristics of these coal formations.

The coal properties are controlled by the stage of metamorphism, petrographic composition, and degree of recovery. It should be noted that the degree of coal metamorphism in these formations is the same, so the difference in their composition and coal quality depends solely on the geotectonic regime of coal-bearing strata formation.

For a long time, we have been conducting studies on generalising the composition and quality of coal in the northern edges of the Donbas region, namely in Lozivska coal area and Starobilsk coal area [17, 18]. This allows us to compare the composition and quality of coal from these two coal-bearing formations. Additionally, we have provided data on the composition and quality of coal seams from the Middle Carboniferous of the Greater Donbas region, which were formed in an alluvial-bog-marine environment but in a more moveable zone, in the fore deep.

The coal from the Moscovian stage of the deltaic-bog-sea formation in Starobilsk coal district is in a low stage of carbonization, belonging to Class 03, and is at the O_3 stage of metamorphism [17]. The value of vitrinite reflectance (Ro, %) in the coal seams ranges from 0.42 to 0.48 %, with an average value of 0.46 %. According to the International Classification of in-Seam Coal (ISO 11760), these coal seams are classified as low-rank subbituminous coal, specifically within category A (Low-rank A, subbituminous coal).

Regarding the source material, the coal in Starobilsk area belongs predominantly to the humic group. Coal of mixed origin, known as sapropelic-humic coal, is of secondary importance and is found in the form of thin layers, mostly near the roof, and less frequently in the middle part of the seams. The seams contain mineral impurities and interburdens. The mark that coal leaves on a porcelain plate is dark brown.

Macroscopically, the layers are composed of semi-glossy dense thin-laminated strong coal with lenses of fusain and pyrite scattered throughout the layers. The coal features a cracked texture. The cracks are filled with calcite.

Table 1

Comparative characteristics of coal-bearing formations of the Moscovian Stage of the northern edges of the Donbas

Parameter	Formation	
	Middle Carboniferous, Moscovian Stage	
	Lozivska coal-bearing area	Starobilsk coal-bearing area
Geological age	C_2	C_2
The area of the coal-bearing region, km^2	2840	5155
The thickness of coal seams, m		
C_2^7	340	160
C_2^6	160	140
C_2^5	267	213
Average	256	176
The total number of coal seams.	38	26
The working thickness of coal seams	16	7
Industrial	7	3
Depth of occurrence, m	160–1500	170–1490
The total thickness of all layers, m	14.3	8.6
Working seam thickness, m	0.6–2.35	0.6–3.35
Seam structure	Complex (2–3 or more benches)	Simple
Durability (in terms of thickness and extent)	Not durable	Durable and relatively durable
Total carbon content factor	2.2	1.94
Industrial carbon content	1.7	0.99
Coal grades	Long-flame	Lignite – Long-flame
The composition of enclosing rocks, %	Sandstones (58 %), siltstones and mudstones (41 %), limestone (1.9 %)	Siltstones and mudstones (78 %), sandstones (15), limestones (7.3)
Section structure	Cyclic: cycles of 12–15m	Cyclic: cycles of 15–40m
Paleogeographic conditions	Alluvial-bog-marine	Deltaic-bog-marine
Mode of occurrence	Block structure, monoclinic occurrence, 3–5°	Monoclinic occurrence, sometimes fractured
Tectonic position	Transition zone from movable platform structures to folding structures of the Dnipro-Donetsk Depression	The slope of the Voronezh Anticline
Geotectonic conditions		Movable platform

In terms of microstructure, the coal seams are predominantly duroclarain (65 %), clarain (33 %), and occasionally clarain-durainous (2 %), indicating a mixed composition. The micro-component composition of the seams is shown in Table 2.

The coal is predominantly composed of micro-components of the vitrinite group (*Vt*). The vitrinite matter is generally well-preserved. There occur remnants of Sigillarian periderms, rachises of pteridosperms, numerous oval parenchyma cells, leaf tissues, and sporangia.

Components of the inertinite group are mainly represented by fusinite, which is distributed in the form of lenses and small interburdens throughout the seams. Many tissues feature well-preserved cellular structures. Macrinite is the second most abundant component in terms of prevalence. Semifusinite, like micrinite, is present in small quantities. The sum of the inertinite components is relatively high compared to coal from other areas.

The lipoid components feature numerous horizons of resin-like bodies, sporopollenin products, numerous microspores, thin-walled megaspores, and fragments of thin cuticles. Residues of algae are observed in small quantities. It should be noted that there is a higher content of liptinite macerals compared to the Carboniferous coal of the Donbas.

Mineral inclusions in coal (MI) can be divided into epigenetic and syngenetic types. Syngenetic inclusions consist of quartz, calcite, mica, kaolinite, pyrite, siderite, and chalcedony. They occur in the form of lenses, layers, crystals, grains, and concretions. Among the syngenetic inclusions, finely dispersed pyrite prevails. Associated rock layers in coal seams are composed of clayey and carbonaceous argillite, occasionally carbonaceous siltstone. Thin kaolinite layers with a significant amount of hydrous mica are characteristic of l_7 and k_2^n seams.

According to the VNIGI classification, the coal belongs to the helitolite class and is typically represented by a lipoid-fusinite-helitite type. Lipoid-fusinite-helitite and fusinite-helitite types occur in a significantly smaller amount. Based on its petrographic properties, in-seam coal falls into the category of strongly metamorphosed and moderately metamorphosed groups.

The coal of the Moscovian stage in the alluvial-bog-marine formation of Lozivska coal-bearing region is also at a low stage of coalification. The reflectance value of vitrinite (Ro, %) in the coal seams ranges from 0.46 to 0.48 %, with an average weighted value of 0.47 %. The coal of the Moscovian stage, as well as the coal of the coal-bearing region as a whole, belongs to class 03 of O_3 stage of metamorphism [18].

According to the source material, the coal from the Lozivska area also belongs to the group of humic coals. Coal of mixed origin (sapropelite-humic coals) hardly ever occur.

Table 2

Petrographic composition by component groups of the coal seams from the Moscovian stage of various formations in the northern edges of Donbas region

Petrographic composition by component groups	Starobilsk area Deltaic-bog-marine formation	Lozivska area Alluvial-bog-marine formation	Carboniferous coal of Donbas Alluvial-marsh-sea formation
	from – to/average, %		
vitrinite (*Vt*)	77.3–78.1 77.7	82.0–86.2 83.9	75.0–95.0 86.0
semi-vitrinite (*Sv*)	0.6–0.9 0.7	1.1–1.4 1.3	1.0–3.0 1.5
inertinite (*I*)	10.7–12.9 12.1	6.6–10.2 8.8	3.0–10.0 7.5
liptinite (*L*)	8.7–10.6 9.5	5.6–6.5 6.1	1.0–7.0 4.0 5.0
sum of lean components (ΣLC)	11.3–13.3 12.5	7.5–11.1 9.7	4.5–10.9 8.5

Externally, the coal from these seams appears semi-matte, close to semi-lustrous, with uneven banding ranging from fine to coarse. Occasionally, it may display streakiness with inclusions of medium-sized or sometimes large fusain lenses.

The coal features a resinous lustre. Its fracture is uneven, occasionally exhibiting a stepped appearance. The presence of fusain lenses causes brittleness to the coal. Endogenous and exogenous cracks are clearly visible, with thin films of pyrite and deposits of predominantly clay minerals often observed along the crack walls. Occasionally, there may occur deposits of calcite.

The microstructure of coal seams is predominantly clarain (97.4 %) and occasionally duroclarain (2.6 %), of mixed composition.

The vitrinite group mostly prevails in the petrographic composition of coal.

The structure of the main components of the vitrinite group is predominantly fragmental and attritic-fragmental, less frequently fragmental-attritic and attritic. The gelified substance is reddish-brown, often with a well-defined xylovitrene structure.

The inertinite group slightly outnumbers the liptinite group. Small lenses of fusinite and micrinite are most prevalent. Certain layers are enriched with large lenses of xylene-fusain.

The liptinite group is rather diverse. It includes lipoid- attrite, microspores, megaspores with thickened exines, and cuticles. Resinous bodies can also be found in small quantities.

The degree of coalification of coal seams is quite diverse, ranging from slightly coalified to well coalified. As we move up the stratigraphic section, the number of seams composed of more recovered coal types increases. Typically, the colour of spores and cuticles is yellow.

Mineral inclusions in coal are predominantly represented by iron sulphides, calcite, and kaolinite, with quartz occurring less frequently. Iron sulphides appear as small grains or lens-like structures. There occur fusains which contain pyrite-filled cell cavities. Calcite mainly fills endogenous fractures, while kaolinite is found only in fractures of vitrain. Coal generally belongs to the class of gelitolite and is represented by the lipoid-fusinite-gelite type.

The data obtained allows us to conclude that the coal from Starobilsk coal-bearing area differs from the coal of Lozivska coal-bearing area both in terms of gross petrographic composition and the distribution and content of individual macerals. It contains fewer vitrinite group macerals and more inertinite and liptinite group macerals. It is worth noting the higher content of resinous bodies and the presence of algae remains. In terms of the typical petrographic composition, the coal from Lozivska coal district is similar to the Middle Carboniferous coal of the Old Donbas. The coal also differs in terms of recovery degree. The coal from the Northern Donbas is more recovered compared to the coal from the Lozivska coal area. The discrepancies in the petrographic composition of the coal confirm the different conditions of peat formation in these regions, which is also supported by their chemical and technological properties.

The chemical and technological characteristics of the coal seams from the Moscovian Formation are given in Table 3.

Starobilsk area (deltaic-bog-marine formation) features increased values of maximum moisture content (W_t^r, %). These values vary between 4.0 and 28.3 % across different boreholes. The analytical moisture content (W^a, %) is also characterised by increased values, ranging from 1.0 to 25.0 % in certain coal seams. The coal seam k_2^n shows the greatest variability in both maximum moisture content and analytical moisture. The values of W_t^r and W^a for k_2^n seam in Bohdanivske deposit are significantly higher than those of the seam occurring in other areas of Starobilsk region [17].

The ash content of the coal seams, taking into account impurities (A_{cs}^d, %), within the deposit area ranges from 14.1 to 20.7, while the ash content of coal benches (A_{cs}^d, %) ranges from 12.8 to 15.1 %. The coal in the deposit consists of 3–5 % of low-ash coal, 53–57 % of medium-ash coal, 30% of high-ash coal, and 6–11 % ash-rich coal. The predominant type of coal in all the seams is medium-ash coal with the ash content ranging from 8 to 16 %.

Table 3

Chemical and technological parameters of coal of Moscovian Stage from various formations in the northern edges of the Donbas

Parameter	Site		
	Starobilsk area Deltaic-bog-marine formation (Long-flame)	Lozivska area Alluvial-bog-marine formation (Lignite – Long-flame)	Middle Carboniferous coal of the Donbas Alluvial-bog-marine formation (Long-flame)
	average value		
W_t^r, %	14.8	14.1	13.0
W^a, %	7.9	5.8	4.0
A_{cs}^d, %	15.9	16.7	28.0
$A_{c.b}^d$, %	14.1	14.7	14.3
S_t^d, %	4.1	3.3	3.5
V^{daf}, %	43.3	41.7	43.0
Qs^{daf}, MJ/kg	29.9	30.9	30.1
Q_i^r, MJ/kg	22.1	23.1	18.5
C^{daf},%	76.2	75.6	75.0
H^{daf}, %	5.3	5.4	5.5
$(N+O)^{daf}$, %	15.0	13.9	13.0

The chemical composition of coal ash is represented by silicon dioxide and titanium dioxide, as well as aluminium, iron, calcium, magnesium, potassium, sodium, phosphorus oxides, and sulphur trioxide. Compared to the chemical composition of coal ash from the Middle Carboniferous coal of the Donbas, the coal from the area under study is characterized by an increased content of Fe_2O_3, CaO, MgO, SO_3, Na_2O, and a decreased content of SiO_2, Al_2O_3 and K_2O (Table 4).

Based on the mass fraction of sulphur (S_t^d, %), the coal belongs to the groups of high-sulphur and very high sulphur coals. The ratio of pyritic sulphur to organic sulphur does not follow the statistical relationship established for the Donbas coal. The coal is characterized by an increased content of organic sulphur.

The volatile matter yield (V^{daf}, %) for individual boreholes varies between 32.0–58.9 % The variability of this parameter across different areas ranges from 38.3 to 45.1 %, which is typical for long-flame coal. No significant changes in the values of this parameter were observed both within the literal and across the stratigraphic section.

The higher heating value of coal (Q_s^{daf}, MJ/kg) varies from 23.6 to 34.0 across different coal seams, and its average values are lower than those of coal from Lozivska coal area and the Central Donbas region (Table 4). The lower heating value (Q_i^r, MJ/kg) ranges from 16.2 to 25.7, and its average values take an intermediate position compared to other areas [18].

The coal also differs in terms of the elemental composition. The carbon content varies from 61.6 to 82.8 % across different boreholes, while the hydrogen content varies within 2.6–8.9 %. The nitrogen and oxygen content ranges from 5.0

to 25.2 %. The coal is characterized by increased values of carbon and oxygen content.

According to the current Ukrainian standard (DSTU 3472-2015), coal from all seams is classified as bituminous coal, grade Long-flame.

Lozivska coal area (alluvial-bog-marine formation) features lower maximum moisture content and analytical moisture content compared to the coal from Starobilsk coal area, but higher than the coal from the Central Donbas region (Table 4). The ash content, including impurities, (A_{cs}^{d}, %), and the ash content of coal benches, compared to the coal from Starobilsk coal area, are slightly increased (Table 3). The chemical composition of the ash in Lozivska coal area does not significantly differ from the chemical composition of the ash in the Middle Carboniferous coal of the Old Donbas. The ash composition of coal in Lozivska area widely includes the following compounds: SiO_2, Fe_2O_3, Al_2O_3, SO_3, CaO (Table 4).

It should be noted that there is an increased content of MgO and Na_2O oxides in the ash compared to the chemical composition of the ash of coal from the Old Donbas.

The sulphur content in the stratigraphic section varies from 2.9 to 4.0 % and, on average, is characterized by lower values compared to coal from other areas (Table 3). Based on the total sulphur content, the coal under study belongs to the group of sulphurous coals.

The volatile matter yield of the coal in the region varies from 41.0 to 42.7 % in separate seams. No stratigraphic regularities in the change of this indicator have been found, similar to the case of the Starobilsk area.

The higher specific heat value of coal (Q_s^{daf}, MJ/kg) varies on average from 30.7 to 32.5 across individual seams I.

Table 4

Chemical composition of the ash in coal of Moscovian Stage from various formations in the northern edges of Donbas

Oxides, dioxides, and trioxides	Starobilsk area Deltaic-bog-marine formation	Lozivska area Alluvial-bog-marine formation	Coal of the Middle Carboniferous period in the Donbas Alluvial-bog-marine formation
	from – to/average, %		
SiO_2	19.2–32.6 23.9	30.6–38.7 35.3	40.0
Al_2O_3	9.6–13.1 11.5	14.4–20.4 17.5	19.5
Fe_2O_3	22.5–34.9 30.3	22.2–26.8 24.5	25.9
TiO_2	0.3–0.4 0.4	0.63–0.74 0.69	–
CaO	11.7–13.2 12.3	5.1–9.8 7.25	5.2
MgO	1.8–1.9 1.9	2.87–3.65 3.3	1.4
SO_3	13.1–18.2 15.5	4.79–10.82 7.28	4.6
K_2O	0.8–1.2 0.9	1.53–1.86 1.69	1.7
Na_2O	3.0–3.3 3.1	1.46–2.40 1.87	1.3
P_2O_5	0.2–0.3 0.23	0.26–0.28 0.27	0.4
Type of ash according to W. R. Clare	ferruginous	siliceous	siliceous

It should be noted that certain coal samples feature caking properties.

According to the Ukrainian State Standard DSTU 3472-2015, coal from the seams is bituminous coal and is classified as Long-flame coal. According to the International Classification of in-Seam Coal (ISO 11760), it falls under the category of Low-rank subbituminous coal, specifically sub-category A.

Conclusions. The data obtained indicate a significant influence of the geotectonic regime on the formation of petrographic and chemical and technological properties of coal.

The conducted research confirms that development of coal formations occurred under different geotectonic conditions. The deltaic-bog-marine formation of the Starobilsk area was formed in the zone of a mobile platform, the alluvial-bog-marine formation of Lozivska area was formed in the transitional zone from mobile platform structures to folded structures of the Dnipro-Donetsk Depression, and the alluvial-bog-marine formation of the Old Donbas was formed in the geosynclinal zone.

Differences in the genetic order have been established in the geological characterization of coal formations from the Moscovian Stage in the northern edges of the Donbas. Despite the fact that the coal seams of both formations in the northern edges of the Donbas are at the same stage of metamorphism and, according to the International Classification of in-Seam Coal (ISO 11760), belong to Low-rank subbituminous coal, subcategory A, they significantly differ in terms of petrographic composition as well as chemical and technological properties.

The increased mobility of the foundation during the peat accumulation epoch contributed to the formation of coal with a petrographic composition containing more vitrinite macerals and fewer inertinite and liptinite macerals. The coal features different degrees of recovery: the coal seams of Starobilsk area are more highly coalified compared to the coal seams of the Lozivska coal area. The coal also differs in terms of chemical and technological properties. It has been found that the coal from Starobilsk area, compared to the coal from the Lozivska coal area, features higher moisture content and less mineral impurities. They are characterized by higher sulphur content, and volatile matter yield. Their elemental composition is characterized by higher carbon and oxygen content and lower hydrogen content.

The difference in geotectonic conditions of peat formation has led to differences in the chemical composition of coal ash. According to the chemical composition of coal, the ash from the deltaic-bog-marine formation belongs to the ferruginous type of ash, while the ash from the alluvial-bog-marine formation is classified as siliceous ash based on the ratio of oxides.

The results of the research expand the theoretical understanding of the patterns of coal composition and quality formation and deepen the understanding of the historical peculiarities of the Middle Carboniferous coal formation development.

References.

1. *Report of the EITI Ukraine* (2020). Retrieved from https://www.geo.gov.ua/wp-content/uploads/presentations/ukr/UA_EITI_Short_Report_2020_UA.pdf.

2. Cherniavskyi, M. V. (2021). State and Prospects of Thermal Power Generation in the Conditions of Ukraine's Course on Carbon-Free Energy. *Ekotekhnologii i resursosberezheniye,* (4), 4-16. https://doi.org/10.33070/etars.4.2021.01.

3. Yang, Yo., Li, Ch., Wang, N., & Yang, Z. (2019). Progress and prospects of innovative coal-fired power plants within the energy internet. *Global Energy Interconnection, 2*(2), 160-179. https://doi.org/10.1016/j.gloei.2019.07.007.

4. Liga 360 (n.d.). *Energy Strategy of Ukraine for the period until 2035 "Security, Energy Efficiency, Competitiveness"*. Retrieved from https://ips.ligazakon.net/document/NT1513.

5. Kulikov, P., Aziukovskyi, O., Vahonova, O., Bondar, O., Akimova, L., & Akimov, O. (2022). Post-war Economy of Ukraine: Innovation and Investment Development Project. *Economic Affairs (New Delhi), 67*(5), 943-959. https://doi.org/10.46852/0424-2513.5.2022.30.

6. Stukalo, N., Lytvyn, M., Petrushenko, Y., & Omelchenko, Y. (2020). The achievement of the country's sustainable development in

the conditions of global threats. *E3S Web of Conferences,* (211), 01029. https://doi.org/10.1051/e3sconf/202021101029.
7. Stukalo, N.V., Lytvyn, M.V., Petrushenko, Y.M., & Kolinets, L.B. (2021). The concept of sustainable development of Ukraine in the context of global threats. *Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu,* (3), 178-183. https://doi.org/10.33271/nvngu/2021-3/178.
8. Ivanova, A.V., Zaitseva, L.B., & Spirina, O.I. (2018). Geotectonic regime of formation of the coal-bearing deposits in the Western Donets Basin (Ukraine). *Geological journal*, (1), 66-79. https://doi.org/10.30836/igs.1025-6814.2018.1.126569.
9. Ivanova, A.V., & Zaitseva, L.B. (2014). The role of geodynamics in the peat accumulation and coal material-petrographic composition formation in Western Donbas. *Tectonics and Stratigraphy*, (41), 40-48.
10. Bartashchuk, O. (2020). Collision deformations of the Dnieper-Donets depression. Article 3. Geodynamic model of tectonic inversion. *Geology & Geochemistry of Combustible Minerals 1*(182), 40-51. https://doi.org/10.15407/ggcm2020.01.040.
11. Bezruchko, K.A., Pymonenko, L.I., Burchak, A.V., & Suvorov, D.A. (2018). Transformation of the energy state of the molecular structure of coal in the process of metamorphism. *Journal of Geology, Geography and Geoecology, 27*(1), 30-34. https://doi.org/10.15421/111827.
12. Savchuk, V., Prykhodchenko, V., Prykhodchenko, D., & Tykhonenko, V. (2021). Comparative characteristics of the petrographic composition and quality of coal series C12 and C13 of the Prydniprovia Block. *Journal of Geology, Geography and Geoecology, 30*(1), 145-152. https://doi.org/10.15421/112113.
13. Savchuk, V., Prykhodchenko, V., Prykhodchenko, D., & Tykhonenko, V. (2014). Petrographic Characteristic of Middle Carboniferous Coal of Bashkirian Formation in Lozovskoi Coal Area of Western Donbas. *Progressive Technologies of Coal, Coalbed Methane, and Ores Mining*, 417-421. ISBN 9780429226946.
14. Uziuk, V.I., & Shvartsman, O. (2012). Composition, quality, genesis of coal, stratification, correlation, and conditions of the coal-bed h7 cut forming on the territory of Donetsk–Makiivka area of Donbas. *Visnyk of the Lviv University. Series geological,* (26), 83-96.
15. Shulga, V.F., Zaitseva, L.B., Ivanova, A.V., & Pankova, M.G. (2010). Climatic zoning and petrographic composition of Early Carboniferous coals in the East European Platform. *Heolohichnyi zhurnal, (1),* 58-65.
16. Ivanova, A.V. (2020). High-chlorine coal as a deferred demand product. *Heolohichnyi zhurnal*, *4*(373), 34-42. https://doi.org/10.30836/igs.1025-6814.2020.4.206734.
17. Kuzmenko, O.O. (2012). Assessment of Starobelsk coal-bearing area of the North Donbas coals as an energy feedstock. *Geo-Technical Mechanics,* (102), 158-165.
18. Prykhodchenko, D.V. (2012). Characteristics of the composition and quality of coal from C27 seam of Lozivska perspective area in the Western Donbas. *Visnyk Dnipropetrovskoho Universytetu. Series: Geology. Geography, (14),* 17-22.

Вплив геотектонічного режиму на формування властивостей вугілля північних окраїн Донецького басейну

В. С. Савчук, *В. Ф. Приходченко*, *Д. В. Приходченко*, *Н. В. Хоменко*[*]

Національний технічний університет «Дніпровська політехніка», м. Дніпро, Україна
[*] Автор-кореспондент e-mail: Khomenko.n.v@nmu.one

Мета. Визначити вплив геотектонічного режиму під час накопичення вугленосної формації на формування властивостей вугільних пластів північних окраїн Донбасу.

Методика. Для виконання поставлених завдань використано комплекс методів досліджень, що включає петрографічний, хіміко-технологічний, фаціально-тектонічний, розрахунковий, статистико-аналітичний, інформаційний, хронологічний, генетичний, порівняльний та інші методи.

Результати. Встановлено вплив геотектонічного режиму на формування властивостей вугілля. Доведено, що зміна кількості мацеральних груп має закономірний характер. Зменшення кількості мацеральних груп ліптиніту та інертиніту, на тлі підвищення кількості мацеральної групи вітриніту, відбувається в напрямку зростання загальної амплітуди й середньої швидкості коливальних рухів земної кори під час накопичення вугленосної формації.

Наукова новизна. Вуглеутворення розглянуто з єдиних геодинамічних позицій як невід'ємну частину складного комплексу природних процесів, що супроводжували розвиток і взаємодію глибинних структур (плит) літосфери. При цьому головна увага приділена особливостям складу та якості вугілля, формування якого відбувалось у геодинамічних умовах із різним характером рухливості літосфери. Уперше проведена порівняльна характеристика вугленосних формацій середнього карбону Старого й Північного Донбасу. Вугільним пластам Північного Донбасу надана детальна петрографічна й хіміко-технологічна характеристика. Уперше визначені особливості складу та якості вугілля дельтово-болотно-морської формації, у порівнянні з вугіллям інших формацій середнього карбону.

Практична значимість. Визначені регіональні («провінційні») особливості складу та якості вугілля дельтово-болотно-морської та алювіально-болотно-морської формацій північних окраїн Донбасу, що дозволить обґрунтувати напрями його раціонального використання. Запропонований підхід дає можливість прогнозувати вугленосність і склад та якість вугілля на площах поширення енергетичного кам'яного вугілля. Доведена доцільність і перспективність залучення вугілля північних окраїн Донбасу до паливної бази України.

Ключові слова: *вугленосна формація, геотектонічні умови, метаморфізм, петрографія, якість, марка*

The manuscript was submitted 15.02.23.