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GAS CONTENT AND SAFETY FACTORS OF THE DONETSK COAL BASIN DEPOSITS IN UKRAINE

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Abstract. The subject of the article is the process of changing of the terrigenous deposit properties in the Donetsk coal basin. During the research, classical geological methods of mineralogy and petrography were used. They allow obtaining comparable results of the formation and transformation of terrigenous deposits and their properties that affect the safety of mining operations and the possibility of associated gas production.

The complex of structural-mineralogical and physical-mechanical transformation factors of terrigenous deposits of the Donetsk coal basin at different substages of catagenesis is considered, which leads to an increase or decrease in gas content, a change in the properties and state of the studied rocks under the influence of changing thermogasdynamic parameters with an increase in the paleodepth of coal and rock occurrence, and the transformation of their structural parameters into more resistant to new conditions.

The mineralogical parameters that significantly affect the reservoir properties of rocks specifically for the conditions of the Donetsk Basin include primary sedimentary and secondary carbonates. The process of structural transformation of primary carbonate into secondary one leads to a significant decrease in the porosity and permeability of sediments.

The previously established boundary of middle and late catagenesis in the area of low volatile bituminous coal occurrence is a natural barrier to the existence of gas-bearing rocks (except coals). This barrier is characterized by the transition of the prevailing intergranular pore space to a mixed type of reservoirs (pore, fissured-pore and fissured) with low total porosity and gas permeability. The Donetsk coal basin deposits of the late substage of catagenesis do not have significant accumulations of methane (semi-anthracite, anthracite, meta-anthracite), sandstones are not hazardous for outbursts, gas is present only in coal seams and interlayers, as well as in disturbed zones.

The main factors of the properties of terrigenous deposits of the Donetsk coal basin, which affect gas content and outburst hazard, are the structure of sandstones, the degree of sorting, the number of fractions, the degree of compaction of deposits, tectonic processes, the amount and composition of cement, primarily secondary carbonates, as well as the current substage of a particular sandstone.

Keywords: coal basin, gas content, petrography, sandstones, structure.

1.Introduction

In recent years, the deposits of the Donetsk coal basin are considered not only as a coal province, but also as a gas-bearing one with significant gas reserves. The political, economic and energy problems of Ukraine in combination favor the acceleration of work aimed at forming an infrastructure for the extraction and utilization of mine and coal methane, as well as improving the safety of mining operations by reducing the outbursts of the coal rock mass [1–3]. Most of the Donetsk coal basin mines exploit gas-bearing coal seams and have a certain category of methane content. Even the mines in the western part of the basin, which extract coal at depths of 300–800 m, in weak (from 2–4 MPa to 5–10 MPa) rocks with high porosity (up to 20–25%), have dangerous concentrations of methane (explosion at the mine "Yubileyna" in 2002). The increase in the depth of development and the intensification of mining operations at the largest mines of the Donetsk coal basin reveals the urgent need for a more detailed study of geological, mining-technical, hydrogeological, physical-mechanical factors of gas content for the subsequent development of new, scientifically based principles of complex degassing of coal-rock massifs, with the aim of increasing the safety of mining operations at coal mines and increasing the volume of utilization of methane - an associated energy raw material.

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In Ukraine, 3–4 miners die per 1–1.5 million tons of mined coal, according to statistics. These figures are significantly higher than in mining enterprises in the USA, England and other technologically advanced countries of the world. As a result of the research and subsequent analysis of the current situation, the main, in the authors' opinion, reasons for the high accident rate due to increased gas content in mine workings were identified.

2. Methods

The results presented in the article were obtained by studying samples taken from mines and preparations made from them using methods of classical petrography and mineralogy and subsequent processing of primary data using traditional statistical mathematical methods.

3. Results

The first reason for the high accident rate is that the technical capabilities of Ukrainian technologies for degassing gas-saturated coal rock massifs in the Donetsk coal basin mines with highly loaded longwalls have reached their current limits. The second reason is the desire of miners in these conditions to increase the load on longwalls to intensify coal production, which naturally leads to the rise of methane content in mine workings and mined-out spaces. The result of these reasons, together with an insufficient level of technological discipline, may be an accident at a mining enterprise with negative consequences.

In this regard, studying the factors of rocks gas content to increase the volume and quality of preliminary degassing of promising areas with subsequent utilization of methane, as well as for gas production in the territories of closed mines (technogenic deposits), is an urgent problem. The solution to this problem will allow using an additional source of energy resources, improve the environmental situation, reduce gas-dynamic phenomena in the fields of existing and planned mines in the future, which, in general, will affect the cost of coal raw materials.

Gas in the terrigenous deposits of the Donetsk coal basin is found mainly in coal and sandstone beds with favorable reservoir properties. In the work of V. Zabihailo and O. Shyrokov [4], it is indicated that coal contain a large number of pores of sorption volume, and their capacity in relation to sorbed gases is significantly higher than that of rocks. However, taking into account the ratio of the volumes of rocks and coals in the massifs, it should be considered that with comparable values of rock and coal moisture in similar thermodynamic conditions the main mass of gases is in rocks, not in coal beds.

The factors of coal beds gas content are studied quite well both at the exploration and additional exploration stages and during subsequent coal mining. The research of the above parameters is dictated by the need to predict and resist to gas-dynamic phenomena that carry both economic and social costs.

Rocks as potential gas collectors have been studied much less. Basically, such studies were grounded on the need to determine the degree of outburst hazard of coal-bearing sandstones. Previously, a regular stratigraphic relationship between the out-

burst hazard of sandstones and the degree of their transformation was established [5]. Only sandstones of the middle substage of catagenesis are outburst-hazardous [1]. Approximately, this is the stratigraphic interval from gas coal grade to low volatile coal grade (the rock catagenesis degree and coal coalification do not fully coincide). Let us consider the factors of gas content of rocks, as well as their outburst hazard in more detail.

The presence of significant volumes of oil and gas manifestations in the Donetsk coal basin deposits is well known. Suffice it to say that, according to the authors of [6], geological exploration made it possible to discover several dozen oil and gas manifestations within the basin. However, it is too early to talk about the widespread development of the Donetsk coal basin as an oil and gas province. The main problem is the extremely low filtration properties of the rocks. The work [4] provides factual data according to which the values of the gas permeability coefficient of the sandstones of the C_2^6 suite in the southwestern part of the basin, containing coals of different degrees of coalification, from gas to anthracite rank, vary from hundredths and thousandths to 654.2×10^{-15} m^2. Moreover, these data are given for gas permeability determined parallel to bedding, and the values of the gas permeability coefficient determined normally to bedding vary in an even narrower range, from hundredths and thousandths, to 77.7×10^{-15} m^2.

The authors of the work [7], based on laboratory studies, established that in the terrigenous rocks of the Black Sea region, the conditioned reservoirs of the pore type are sandstones with a porosity of more than 6%, permeability of more than 1×10^{-15} m^2 and pore gas saturation of more than 70%. For reservoirs of the mixed fracture-pore type, the lower limit of conditions is a porosity of more than 3%, permeability of 0.1×10^{-15} m^2 and gas saturation of more than 45%. Developed fracturing significantly increases the permeability of rocks, hence the decrease in the limiting values of reservoir factors.

It is interesting that for modern conditions of mines in the Donetsk-Makiivka district, the reservoir properties of sandstones of the mixed or fracture-pore type are typical. With an average porosity of 4 to 6%, gas saturation of pores is 30–40%, permeability, on average, is hundredths and thousandths of a millidarcy, which, according to the above-mentioned authors, is at the level of the lower limit of conditioned reservoirs. In other words, there is gas in the mines of the specified district, but due to low permeability (approximately an order of magnitude lower than the limit given by the authors) its free outflow from the rock is limited. However, when the underworked strata collapses, in zones of tectonic disturbances or geomechanical shifts, methane is released in large volumes. It should be noted that these mines produce coals of the middle catagenesis and an increase in the paleo-depth of mining and the transition from middle to late catagenesis entails a change not only in gas content, but also in the outburst hazard of rocks.

The mines in this area may be located just a few kilometers from each other, but the work are carried out in zones of different substages of catagenesis, with coals of different grades and properties of rocks and coals that differ significantly.

For such conditions and coals, as in the above example, the reservoir properties of sandstones of the mixed or fracture-pore type are characteristic. With an average porosity of 2–4% and gas saturation of pores of 10–20%, the permeability, on average, is thousandths of a millidarcy, which, according to the above authors, is less than the lower limit of conditioned collectors. In the mines of the given region, sandstone emissions may occur (at the middle substage of catagenesis), and may not occur (at the late substage of catagenesis), where their gas content is already insignificant, and methane gas is concentrated in fact in coal seams and interlayers. Coal emissions in such mines are confined mainly to positive structures (anticlines) or tectonically disturbed zones.

From this it is evident that different rocks and substages of secondary transformations of coal-bearing sandstones are characterized by different filtration properties, and the main conditions influencing the filtration properties of rocks in general and the Donetsk coal basin deposits in particular are controlled by their structural-mineralogical and other lithological parameters. Let us consider them in more detail.

The structure of sedimentary rocks is actually responsible for the formation of reservoirs. Sandstones in various sedimentary basins of the world [8] are the main reservoir of both gas and liquid, and gas condensate (gas-liquid) hydrocarbons. Here, the structural parameters are determined not only by the grain size and degree of roundness, but also by the number of sand fractions in a particular sandstone; the type and amount of cement; the ratio of the moisture-gas parameter in open pores; the homogeneity or degree of sorting of the sizes of detrital grains, which naturally increases with the degree of catagenesis, etc. (Fig. 1, 2). The latter factor significantly affects the transformation of primary cement into secondary cement, with a decrease in both porosity and permeability. It should be noted that coarse-grained well-sorted sandstones are characterized by a higher rate of transformation of primary cement into secondary cement, compared to fine- or medium-grained sandstones with poor sorting. This factor may be the cause of increased gas content of fine- and medium-grained sandstones compared to coarse-grained ones at the substage of middle catagenesis. The permeability of the latter may be significantly lower.

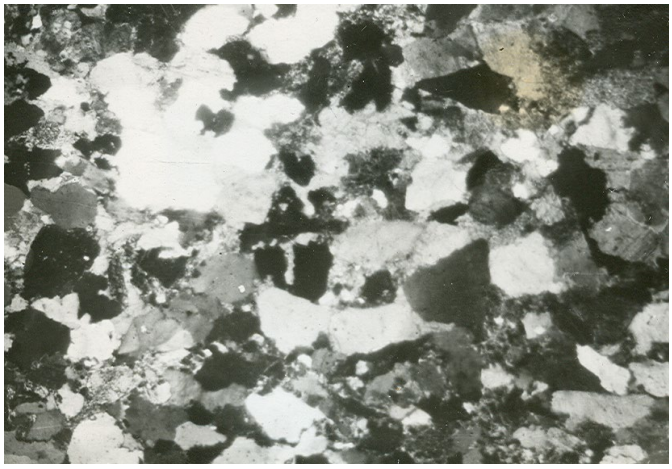

Figure 1 – Outburst-hazardous sandstone l_7Sl_8 from the 21-bis mine, facies of underwater river outflows, medium-grained, weakly rounded, little altered, thin section, magnification 100^X

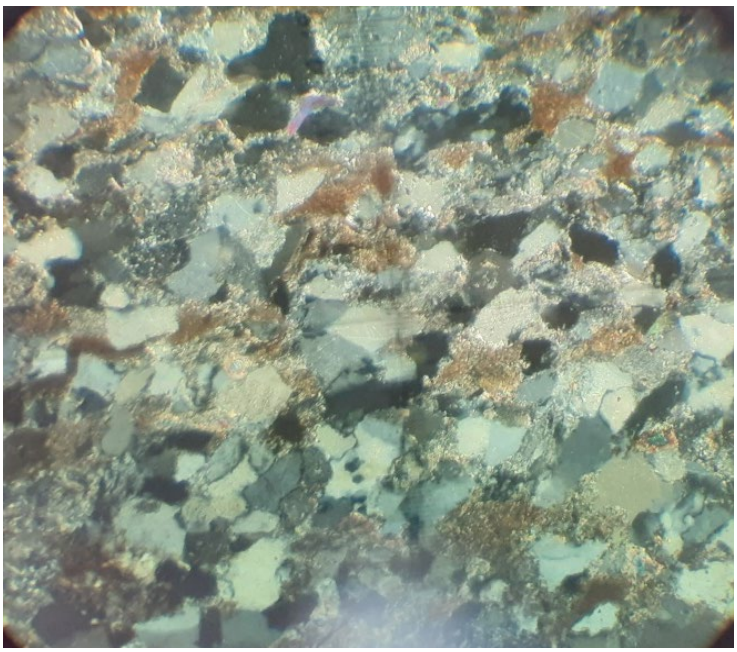

Figure 2 – Outburst-hazardous sandstone d_3Sd_4 from the Pokrovsk mine, coastal marine facies, fine-grained, sorted, weakly rounded, little altered, thin section, magnification 100^X

Previously, researchers [1, 4, 7] established the pressure (about 53 MPa) at which large fragmental grains in sandstones begin to break down. They also established a qualitative pattern of decreasing intensity of sand grain crushing as their size decreases. This process characterizes the tendency of virtually any structure to be the most stable in specific conditions according to the existing laws of thermodynamics.

From these facts, the following qualitative regularity can be deduced, according to which coarse-grained sandstones will have favorable reservoir properties in the upper parts of stratigraphic horizons, approximately at the stages of early and, partially, middle catagenesis. For the Donetsk basin, these are rocks containing high volatile bituminous coals. Since the degree of catagenesis and carbonification have a well-known discrepancy, these comparisons are given as indicative, since each specific exploration site or mine field may have its own characteristic features and differences.

The degree of sorting is also an important factor for the reservoir properties of terrigenous sediments in general and sandstones in particular. The higher is the degree of grain size variation (more fractions in a particular rock), the lower is the effective porosity of a given stratigraphic layer. This factor is well known and is often demonstrated by teachers who place gravel in one container, and then almost the same volume of sand in the same container, and then liquid.

Accordingly, sandstones with good sorting and a smaller number of fractions have significantly higher effective porosity and more significant gas permeability and productivity. Here it should be remembered that the number of fractions depends both on the conditions of sediment formation at the sedimentogenesis stage and on the conditions of transformation of these sediments during lithogenesis: from sedimentogenesis to the late substage of catagenesis. Figures 2 and 3 show examples of sandstone with good and poor sorting.

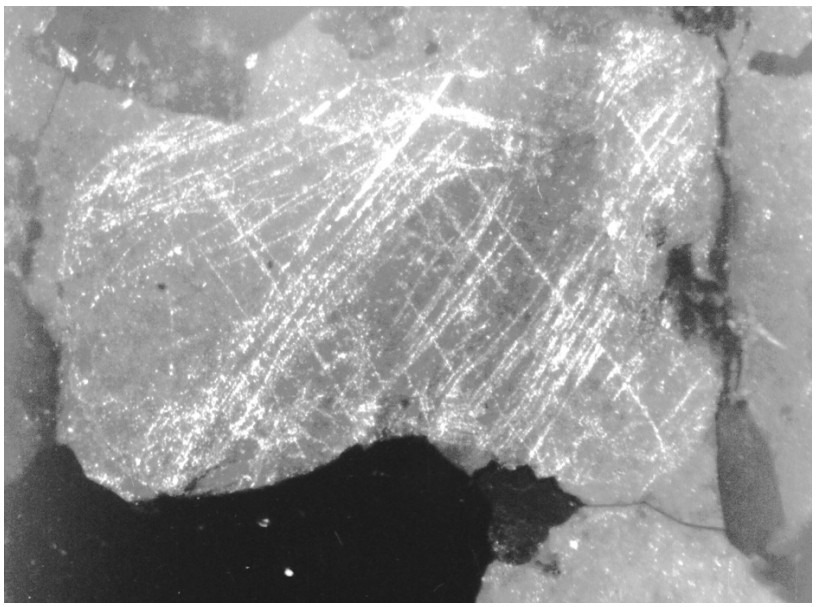

Figure 3 – Boehm stripes, sandstone l_1Sl_2, mine Capitalna, side lighting, poor sorting, fluvial facies, magnification 100^X

The degree of compaction of sedimentary deposits is the next important and one of the main indicators characterizing the total porosity, permeability and the fundamental possibility of the presence of gas accumulations in specific rocks. This factor is a consequence of geostatic (actual), lithostatic (calculated) and tectonic (vertical and horizontal in the complex) stresses. If the pressure of overlying deposits (gH) can be calculated by restoring eroded paleo-deposits, then the pressure of tectonic stresses is currently quite difficult to estimate. The Donetsk coal basin, unlike other coal basins, has undergone significant tectonic stress, as indicated by the angles of rock dip – up to 70^0 in the central regions, the presence of the Donetsk Upland, the Main Anticline, a significant number of disturbed zones [9], etc.

The combined pressure of overlying rocks and tectonic stresses led to significant compaction of carbon deposits, which had a negative effect on their reservoir properties. The oligomictic sandstones, consisting of 50–70% detrital quartz and about 20–30% cement, mainly clay or carbonate-clay composition, were subjected to maximum compaction. After a fairly rapid compaction due to cement, the sandstones began to compact due to a change in the structure of detrital grains.

Quartz is highly brittle, but elastic and plastic deformations are present in virtually all solids. Direct evidence of elasticity for quartz is the presence of the piezoelectric effect, which is widely used in lighters and other electromechanical devices. The presence of plastic deformations of all existing types in detrital quartz grains for carbon sandstones of the Donetsk Basin was described earlier [1]. This fact was proposed to be used as an indicator of the stress-strain state of the studied deposits. Larger grains will have a greater number of microdeformations, which is due to the smaller specific surface area of large grains, compared to medium- and fine-grained ones.

The values of the developed microdisturbance index (Km, %) grow towards the increase in grain size, decrease in cement, increase in paleodepth and tectonic stress-

es. Thus, this index is a complex factor that takes into account both the lithological-facial conditions of formation and subsequent transformation of sand deposits, and the stress-strain state of tectonic and geostatic effects on quartz grains.

The shape or degree of distribution of the detrital grain sizes in the strata of sandstone is the next important factor affecting the reservoir properties of rocks. As a result of the studies, an increase in grain diameters was found in the soil of layers, interlayers and, in general, sandstones. If the sandstone consists of several layers, then the stratigraphically early layers will, in general, have larger structures of detrital grains. This result is explained by the higher speed of water currents after the onset of regression (rise of the studied area and retreat of the coastline). The rise of the coastline leads to an increase in the speed of current and, ultimately, to the transfer of larger detrital grains. As a result of such changes, the lower layers of each layer or sandstone will have increased porosity under other comparable conditions at the early and middle substages of catagenesis.

It is necessary to take into account the specifics of each geological object. From the point of view of reservoir properties formation, such widely known parameters as dissolution under pressure (Ricke effect), redeposition of matter, corrosion, regeneration, widely developed in other basins, are not inherent in this basin [1]. The problem is that the Donetsk basin deposits experienced a fairly rapid rise and compaction of sedimentary matter already in the Late Carboniferous, which did not allow the development of the listed parameters. This result is explained by the lack of free water exchange due to increased compaction of terrigenous deposits. They received some development only at the border with the Dnipro-Donetsk Depression, which did not experience a rise. Even in such areas, the volume of regenerated quartz does not exceed 5–6%, and in the central, tectonically most complicated areas it is usually no more than 1–2%.

According to the research results, the most negative factor affecting the porosity and permeability of any sedimentary rocks is the presence of carbonates. It should be noted that primary carbonate (mechanical mixture of clay-carbonate sediments) is not a significant negative factor. But the process of structural transformation of primary carbonate of different forms, usually fine-grained, pelitomorphic components, into secondary, recrystallized, leads to clogging of micropores and a significant deterioration in porosity and, especially, permeability of sedimentary deposits (Fig. 4). This transformation occurs at temperatures of about 120–130^{0}C, in the area of development of medium volatile coals. This process significantly strengthens sandstones, causes corrosion of quartz by carbonates and affects their reservoir properties. Therefore, it is necessary to take into account not just the carbonate content, but the number of its secondary, recrystallized forms. It is established [1] that the amount of carbonates in rock cement less than 5% usually does not have a significant effect on the porosity and permeability of deposits.

Taking into account the above materials, the most optimal, in terms of reservoir properties, will be rocks with clayey, primarily kaolin cement.

In addition to structural and mineralogical factors, lithological factors have a significant impact on the redistribution of gas accumulations, and existing degassing

methods practically do not take into account the conditions of methane distribution in the massif. According to the data obtained, methane in the massif is in a free, sorbed, water-dissolved state and in the form of closed cement and grain porosity [10]. There are zones of free gas accumulation in local structures, paleoflows, tectonically disturbed fractured zones, areas covered by gas-screening rocks.

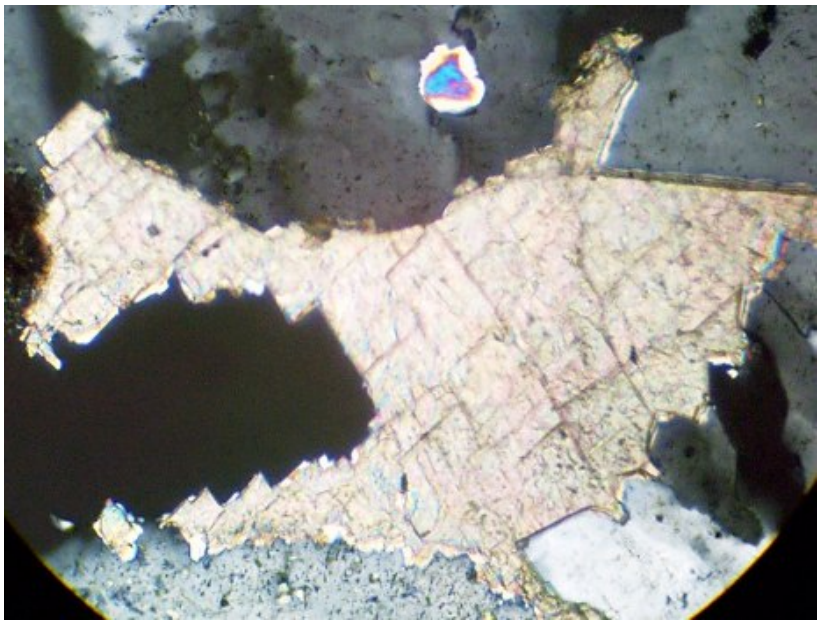

Figure 4 – Block structure of secondary carbonate; corrosion of quartz by carbonate, sandstone l_2Sl_3, magnification 100^X

Thus, the average values of reservoir parameters do not fully take into account the actual distribution of gas; only a comprehensive consideration of the maximum number of factors can ensure the efficiency of degassing and increase the safety of mining operations at a specific site [1].

4. Conclusions

Natural factors of gas content and gas permeability of Donetsk Basin rocks are based on structural and mineralogical parameters.

According to the results of the studies, the mineralogical parameters that influence the reservoir properties specifically for the conditions of the Donetsk Basin include the presence of primary sedimentary and secondary carbonates. At the same time, the presence of secondary carbonates formed at temperatures of about 120–130^0C in the area of medium volatile bituminous coals has a more significant effect on reservoir properties, especially if their volumes exceed 5% of the total amount of cement.

Secondary processes of corrosion, dissolution under pressure, transfer of matter, leaching, etc. are not characteristic of the conditions of the Donetsk basin and are manifested in small volumes only at the boundary of the studied basin with the deposits of the Dnipro-Donetsk Depression, where rock uplifts and increased tectonic stresses are not noted.

Structural factors, consisting of the size of detrital grains, the degree of their roundness, the degree of sorting (number of fractions), the index of microdisturbance of detrital grains also affect the volumes of gas accumulations and gas capacity. Thus, sandstone layers composed of coarse-grained fractions contain more significant volumes of gases at the early and part of the middle substages of catagenesis. Inequigranular sandstones, all other things being equal, form reservoirs with low effective capacity. Sandstones with a higher degree of sorting and roundness, with a small content of fractions, even if these are fine- or medium-grained fractions, are characterized by more favorable reservoir parameters.

The considered factors of gas content of rocks and coals are in a certain way connected with their outburst hazard. The specified gas-dynamic phenomena are widespread in rocks of the middle substage of catagenesis. Thus, the outburst hazard of sandstones, when mining operations approach the boundary of middle and late catagenesis, will decrease to complete disappearance. In parallel with this process, the permeability and gas content of rocks will decrease.

The outburst hazard of coals is also observed in late catagenesis deposits, up to and including anthracites. Only in the area of meta-anthracites, where gas content sharply decreases from 40–45% to 0–5%, coals become outburst-free.

Thus, each lithological type of rocks and coals, is characterized by its properties, conditions of structural and mineralogical transformations, a complex of physical-mechanical and geomechanical parameters, taking into account of which it is possible to control in a certain way the dynamic, gas-dynamic and thermal properties of coals and rocks, to increase the safety of mining operations, which is one of the main tasks of mining engineers and scientists dealing with problems of mining production.

Conflict of interest

Authors state no conflict of interest.

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ФАКТОРИ ГАЗОНОСНОСТІ ТА БЕЗПЕКИ ВІДКЛАДІВ ДОНЕЦЬКОГО ВУГІЛЬНОГО БАСЕЙНУ УКРАЇНИ

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Анотація. Предмет статті – процес зміни властивостей теригенних відкладів Донецького вугільного басейну. У роботі використані класичні геологічні методики: мінералогії та петрографії, що дозволяють отримувати порівняні результати формування та трансформації теригенних відкладів та їх властивостей, що впливають на безпеку гірничих робіт та можливість попутного видобутку газу.

Розглянуто комплекс факторів структурно-мінералогічних та фізико-механічних перетворень теригенних відкладів Донецького вугільного басейну на різних підстадіях катагенезу, що призводить до збільшення або зменшення газоносності, зміни властивостей і стану порід під дією термогазодинамічних параметрів зі збільшенням палеоглибини залягання вугілля і порід, і трансформації їх структурних особливостей у більш стійкі до нових умов.

Встановлено, що до мінералогічних параметрів, які суттєво впливають на колекторські властивості порід конкретно для умов Донецького басейну, відносяться первино-осадочні та вторинні карбонати. Процес структурної трансформації первинного карбонату у вторинний призводить до суттєвого зниження показників пористості та проникності осадочних відкладів.

Встановлена раніше межа середнього і пізнього катагенезу в районі залягання вугілля марки ПС, є природним бар'єром для існування газоносних порід (крім вугілля). Зазначений бар'єр характеризується переходом міжзернового порового простору на змішаний тип колекторів (поровий, тріщинно-поровий та тріщинний), низькою загальною пористістю та газопроникністю. Відкладення пізньої підстадії катагенезу для Донецького вугільного басейну не мають значних скупчень метану, пісковики не викидонебезпечні, газ присутній тільки у вугільних пластах та пропластках, а також у порушених зонах.

Основними факторами властивостей теригенних відкладів Донецького вугільного басейну, що впливають на газоносність і викидонебезпечність є структура пісковиків, ступінь відсортованості, кількість фракцій, ступінь ущільнення відкладів, тектонічні процеси, кількість і склад цементу, в першу чергу вторинних карбонатів, а також підстадія катагенезу.

Ключові слова: вугільний басейн, газоносність, петрографія, пісковики, структура.