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Investigation of the influence of the geodynamic position of coal-bearing dumps on their endogenous fire hazard

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Abstract. The paper investigates the hypothesis according to which one of the factors influencing the spontaneous combustion of coal-bearing dumps is its geodynamic position, i.e. its location in the geodynamically dangerous zone (GDZ) at the boundary of the Earth crust blocks. This hypothesis is put forward on the basis of scientific ideas about the block structure of the Earth crust and the available statistical data on the location of burning dumps and is studied using computer modeling. A dump located in the area of Eastern Donbass was chosen as the object of research. The simulation results show that the penetration of air into the dump body from the mine through the GDZ, which crosses the mining zone, is possible at an excess pressure of 1000 Pa created by the main ventilation fans. The fire source appearance in the dump body causes an increase in the temperature of the dump mass and becomes a kind of trigger that "turns on" the aerodynamic connection between the dump and the environment, carried out through the GDZ. It is concluded that the establishment of an aerodynamic connection between the mine workings and the dump through the GDZ can be an important factor contributing to the endogenous fire hazard of coal-bearing dumps. The simulation results can be used in the development of projects for monitoring coal-bearing dumps and measures to combat their spontaneous combustion.

***Key words*:** coal-bearing dump; spontaneous combustion; geodynamically dangerous zone; permeability; porosity, modeling; boundary conditions; air filtration

Introduction. Despite the development of coal mining and processing technologies, some of it ends up in dumps, which creates an environment for their spontaneous combustion [12, 21], especially when the temperature rises [22]. Harmful gases released during the burning of dumps, combustion products, combustion chemical elements negatively affect the environmental situation in coal-mining areas [24, 25], pose a threat to public health [12, 20], necessitate to perform work on monitoring the situation [10, 26]. On a number of dumps, relapses of spontaneous combustion are observed after extinguishing fires and recultivation using modern fire-fighting technologies [11].

Formulation of the problem. Despite the fact that the mechanisms of spontaneous combustion of coal-bearing dumps have not yet been fully studied, the main contributing factor is the intake of air to the dump mass. Therefore, to reduce the fire hazard of dumps and limit the effect of the air flow on them, it is recommended to choose valley-like places for their placement, and orient the long axes of the dump in the direction of the prevailing winds. Technologies for piling dumps provide for compaction operations, layer-by-layer stow and other preventive measures that prevent the entry of atmospheric air into the dump body [19].

In [14], a hypothesis was put forward, developed in [16], that the air supply to the dump mass and the subsequent spontaneous combustion of dumps is facilitated by their location in geodynamically dangerous zones (GDZ). GDZ got its name due to the fact that dangerous geodynamic phenomena are associated with them during the development of the subsurface – rock bursts, abnormal development of deformations in the rock mass and on the surface, accidents at engineering structures [9]. In many cases, GDZ represent zones of modern tectonic activity of the Earth crust and therefore are represented in the rock mass as linear zones of increased disturbance [15]. The increased GDZ violation gives them a high permeability, which can further increase due to the reactivation of fracturing and violations during the development of displacement processes. When a coal-bearing dump is located in such a zone, air supply to the dump mass is possible due to its transfer from the mine workings (Fig.1), which is the main idea of the presented work.

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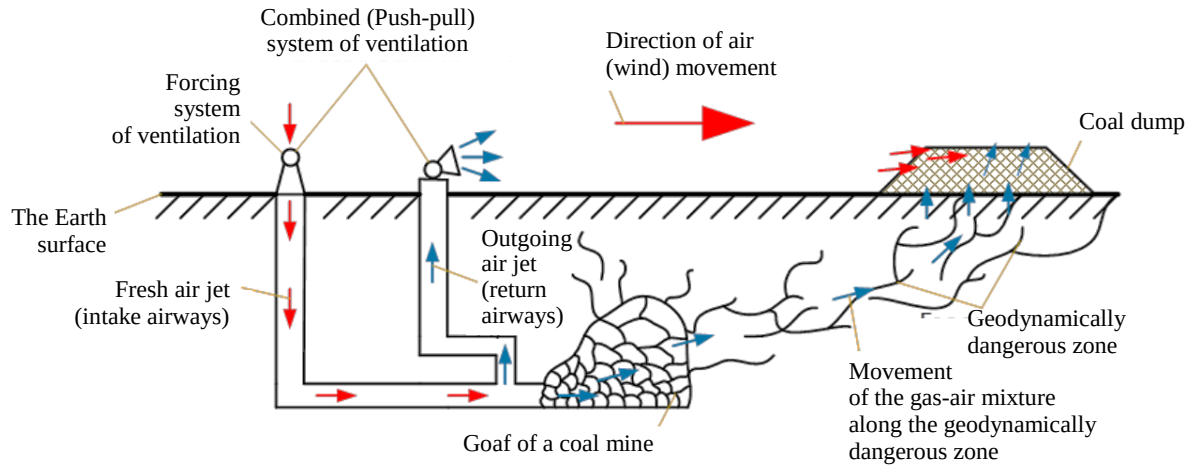


Fig.1. Scheme of aerodynamic connection of mine workings and the dump on the surface by means of GDZ

The confidence that the proposed process of gases mass transfer through the GDZ can be realized in reality is based on existing studies on the confinement of burning dumps to the GDZ [14, 16], as well as studies on the degassing of the Earth interior through fault zones [7], shift troughs during the flooding of mines [6, 11], other research results [2-4, 10].

In this paper, the problem of computer modeling of the gases mass transfer processes through the GDZ into the dump body located on it is considered. In domestic and foreign practice, the tool "computer modeling" is widely used to solve aerogasdynamic issues in the field of mining science [5].

Methodology and research results. *About the geodynamic nature of GDZ*. The practice of mining operations at many deposits in the 20th century established the zonality of the geodynamic phenomena occurrence. The idea of early detection of such geodynamically dangerous zones (GDZ), which arose in this regard, led to the emergence of the method and concept of geodynamic zoning, described in [15] and in later studies. This concept is based on the idea of the interaction of global geodynamic and local geomechanical processes in the Earth crust that occur during the development of the subsurface and the Earth surface.The detection of such an interaction is considered as one of the most important results of geomechanic-geodynamic studies of the 20th century [1]. The large blocks of the Earth crust involved in the modern tectonic process consist of blocks of a lower hierarchical rank, divided into even smaller blocks. In this way, we can consistently come to the block structure of the mine fields. Due to their tectonic activity, the blocks and their boundaries are reflected in the modern relief of the Earth surface, which allows them to be detected and identified. Although some boundaries of modern tectonic blocks of the Earth crust inherit large tectonic disturbances in the rock mass, they are often represented in the rock mass by linear zones of increased tectonic disturbance and fracturing without significant displacement of coal seams and therefore were not distinguished by geologists on geological and industrial maps [15]. For example, there are estimates for Kuzbass, according to which only 35 % of all block boundaries active in the last segment of geological history are expressed as major violations. The rest are newly formed [13]. The requirement to take into account the presence of GDZ is contained in a number of instructional and methodological documents on mining safety. When setting the task of the proposed study, the authors relied on this concept of geodynamic zoning.

Classification of the relative location of GDZ and coal-bearing dumps. In the Eastern Donbass (Rostov region) in 2015, there were 202 coal-bearing dumps, 33 of which were in the combustion stage. In the area, work was carried out on geodynamic zoning and analysis of the confinement of burning coal-bearing dumps to the boundaries of crustal blocks, or GDZ, having a certain width [14]. GDZ are identified on the ground, and their width is estimated by the formula [8] B = 10*N*, where *N*

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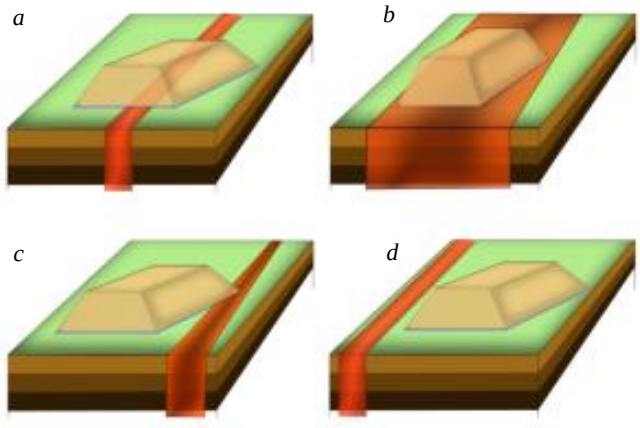


Fig.2. Classification of the relative location of dumps and GDZ:
a – GDZ crosses the dump; *b* – the dump is located in GDZ;
c – GDZ has contact with the dump; *d* – GDZ does not cross the dump

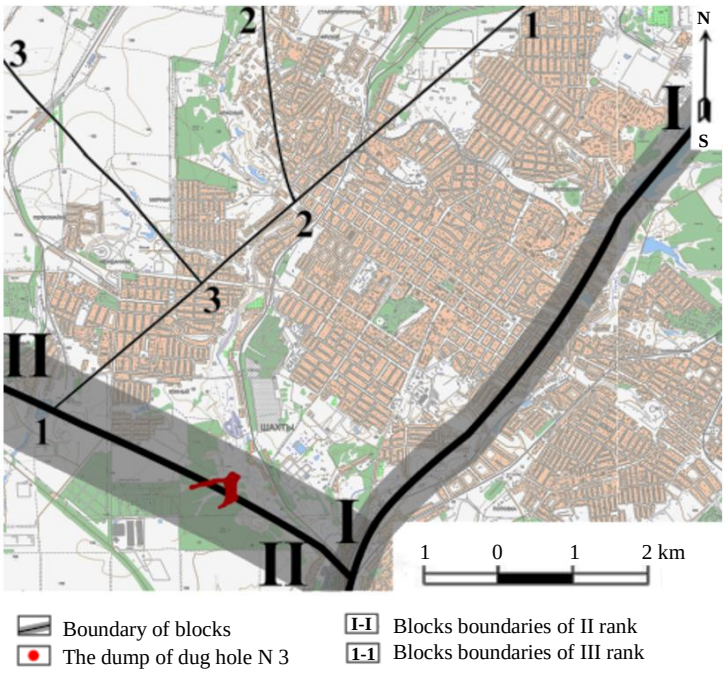


Fig.3. Scheme of the dump of dug hole N 3 of the "Yuzhnaya" mine relative to GDZ of various order

is the amplitude of the relative movement of neighboring blocks of the same rank. The formula is obtained on the basis of practical experience in studying fracture zones near discontinuous faults and generally correlates with other similar estimates of the width of the zones of violations influence [17].

In the area of the Shakhty and Novoshakhtinsk of Eastern Donbass, dumps of various shapes and sizes have been formed. The area of the dumps *S* ranges from 0.04 to tens of hectares, i.e. their linear dimensions *R* range from the first tens to several hundred meters. At the same time, the width of the zones of influence of the blocks boundaries (GDZ) *r*, allocated during the work on geodynamic zoning, is from 50 to 1200 m. Taking into account these data, a classification of the relative location of dumps and GDZ is compiled (Fig.2).

Fig.2, *a* characterizes the situation $r < R$, i.e. when the width of GDZ *r* is less than the width of the dump *R*, and GDZ crosses the coal-bearing dump, dividing it into two parts. Fig.2, *b* characterizes the situation $r > R$, when the width of the GDS *r* is greater than the width of the dump *R*, as a result of which the dump is completely located in the GDZ. This type is typical for dumps located on the boundaries of blocks of grades I-II of large width. Fig.2, *c* – the dump touches the GDZ with one of its parts. Fig.2, *d* – GDZ passes away from the coal-bearing dump, without crossing it.

In [14], it is assumed that for any of the relative positions (Fig.2), the dump is confined to GDZ. With the total area of geodynamically dangerous zones occupying about 10 % of the studied territory, 40 % of burning dumps are located in them, i.e. the concentration of burning dumps in these zones is several times higher than the average in this territory. We consider such a statistical distribution of burning dumps as a confirmation of the hypothesis that burning dumps are confined to GDZ.

Computer modeling. To simulate and study the processes of mass transfer of air to the dump mass from the mine workings through the GDZ, it was decided to choose a dump completely located in the GDZ (Fig.2, *b*). An example is the dump of dug hole N 3 of the Yuzhnaya mine, located on the boundary of blocks II of grade II-II with a width of 1200 m (Fig.3). This dump is located in the southwest of Shakhty. The dump was put into operation in 1975 and by 1990 it was fully formed. The shape of the dump is plateau-like with a maximum height of 21 m. As of 2015, the dump was classified as burning, despite the recultivation works carried out in 2013. Clay was used to extinguish the dump, the thickness of the insulating layer was 0.2-0.6 m. In the north-eastern part of the dump,

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a watercourse and washouts were recorded. 10 combustion foci were detected on the dump. In accordance with the passport for the dump, according to the environmental hazard, the object belongs to the category "very dangerous" and is unpromising for processing.

The boundary of blocks II-II in the studied area is fixed by such fragments of relief as straightened and knee-shaped sections of riverbeds, talvegs of gullies and ravines, a saddle. From west to east, these fragments are represented by a section of the riverbed of the Bolshoy Nesvetay River below the village of Sambek; a beam passing through the village Nizhnesolenny; a saddle near the altitude mark of 162 m; the upper part of the Uyuk beam; the Bugultai and Tsuryup beams; a series of ravines on the steep bank of the Ayuta River north of the village Novogrigoryevka; the upper part of the Bulukhta beam in the area of the village Maysky; by a knee-shaped bend of the Turbut beam channel; then GDZ passes under the dump of the Yuzhnaya mine and the dump of the dug hole N 3 of the Yuzhnaya mine, it is fixed by a straightened section of the channel in the lower reaches of the Atiukhta River, by a knee-shaped bend of the Grushevka River at the junction of the I-I boundary.

In the tectonic plan of the boundaries of II-II blocks, it probably inherits a large linear tectonic structure of Mesozoic age, since it corresponds to it in strike and location.

Initial and boundary conditions. The simulation was carried out in the ANSYS CFD software package. The working hypothesis implies the intake of air into the dump body from a mine located next to the dump and crossed by the GDZ. According to the data on the geometric characteristics of the studied object (the dump of the dug hole N 3 of the Yuzhnaya mine) and data on GDZ (Fig.3) a geometric model of the dump and the surrounding space has been developed. We assume that since the dump is completely located in the GDZ, the closer it is to the mine, the higher the porosity and permeability of the rocks due to the reactivation of cracks by displacement processes. In this regard, the rock mass is divided into three zones with different porosity and permeability indicators and, accordingly, is represented in the model by three domains (Fig.4, *a*). The dump is represented by a separate domain. A domain representing atmospheric air is formed over dumps and rocks. The source of air entering the dump is set on the lower surface of zone 3. Inside the dump body, a center of heating of the dump mass is formed in the form of a surface with a high temperature.

The resulting geometric model is divided into finite elements, and the values of porosity and permeability (see the table) are set for the corresponding domains according to data from the reference literature ([23], etc.). The aerodynamic parameters of the model are shown in Fig.4, *b*.

In the model, the gas-air mixture moves to the dump from the mine side due to an excess pressure of 1000 Pa. This pressure is usually created in the mine workings by the main ventilation fan. The composition of the gas-air mixture is formed due to the emission of methane during coal mining and atmospheric air used for ventilation, i.e. it contains oxygen [18].

It is assumed that the supply of oxygen to the dump mass contributes to the development of exothermic reactions and an increase in its temperature. In this regard, in the model, the surface temperature simulating the combustion focus of the dump mass, is set equal to 100, 200, 300 and 400 °C.

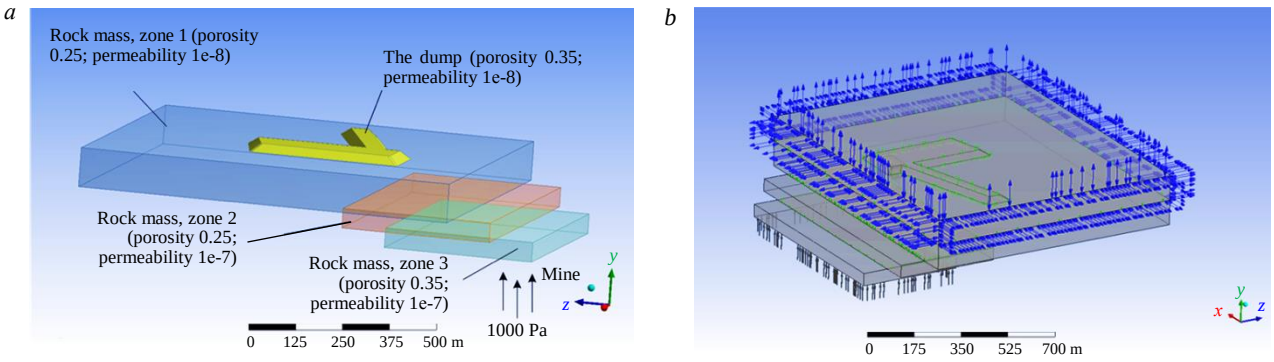


Fig.4. Model of the dump of dug hole N 3 of the Yuzhnaya mine, initial conditions: *a* – general view of the model, indicating the characteristics of the properties of rocks and the dump; *b* – visualization of surfaces with specified introductory parameters

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Porosity and permeability of the rock mass and the dump in different zones (according to Fig.4)

Zones	Porosity, %	Permeability, m^2	Note
Dump	35	1e-8	Dump body, above the GDZ
Rock mass, zone 1	25	1e-8	Rocks located in the GDZ
Rock mass, zone 2	25	1e-7	Rocks located in the GDZ
Rock mass, zone 3	35	1e-7	Rocks located in the GDZ

The simulation results are shown in Fig.5-7. Modeling in the body of the dump surface with a high temperature (100, 200, 300, 400 °C) shows that with an increase in the temperature of the heated surface, the temperature of the gases above it increases proportionally (Fig.5). The temperature gradient is not symmetrical relatively to the center of the figure, this is due to the trajectory of the gas flows coming from the mine.

As the temperature of the gases increases, the velocity of their ascending flows inside the dump increases, which is reflected in Fig.6. The air movement vectors are constructed along a secant plane passing through the dump and crossing the heated surface. The air velocity corresponds to the color in which the vector is colored. The velocity scale is shown in Fig.5, 6.

To confirm the conclusion about the influence of the properties of rocks (porosity and permeability) forming the basis on which the dump is placed on the possibility of gas movement, additional modeling was carried out for the conditions of the dump location outside the GDZ (Fig.7). In additional modeling based on data [16, 23], porosity is assumed to be 15 % for base rocks outside GDZ, permeability 1e-14 m^2, porosity is assumed to be 25 % for rocks in GDZ, permeability 1e-8 m^2.

Figure 7 shows that the air velocity is identified only in the part of rocks located in GDZ, in undisturbed GDZ rocks the air velocity is close to or equal to zero. In Fig.7, *a* – the air movement is represented by streamlines with the corresponding color depending on the velocity of air movement. The streamlines are built in domains representing the rocks on which the dump is located. Figure 7, *b* shows the air movement in the rocks under the dump using vectors, the color also characterizes the velocity of air movement.

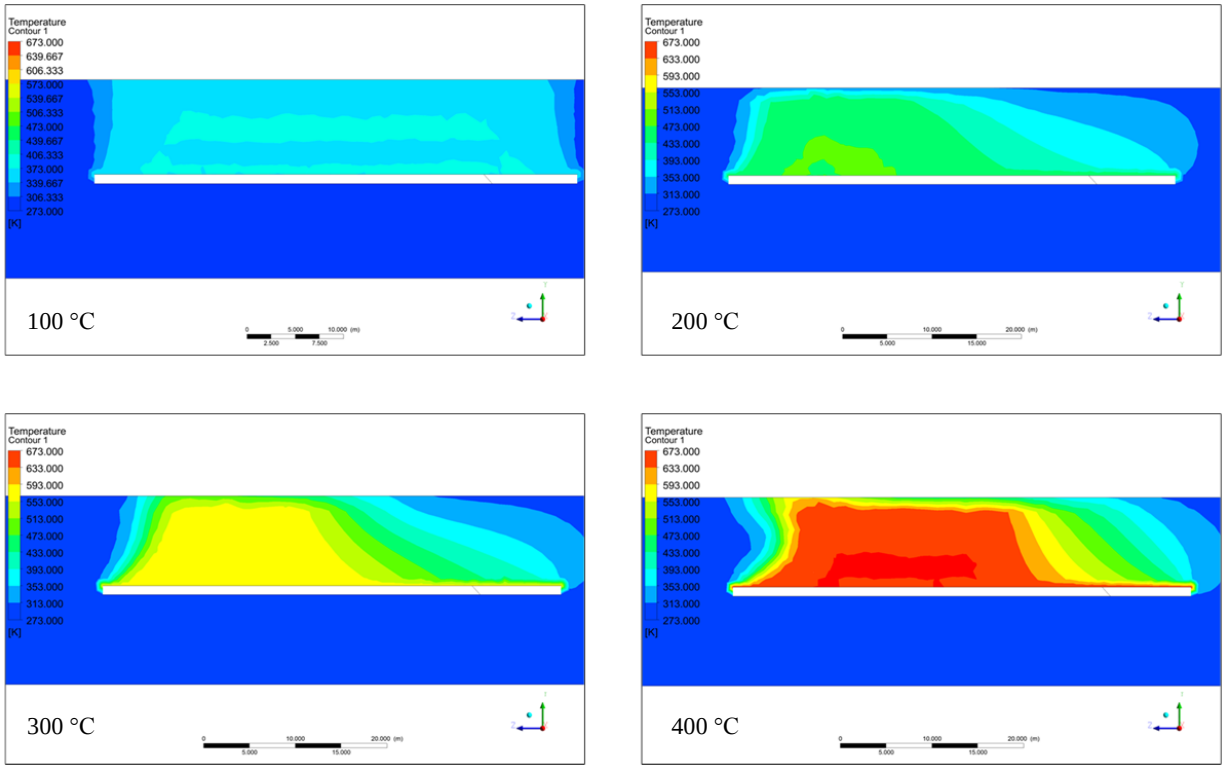


Fig.5. Air temperature above the heated surface

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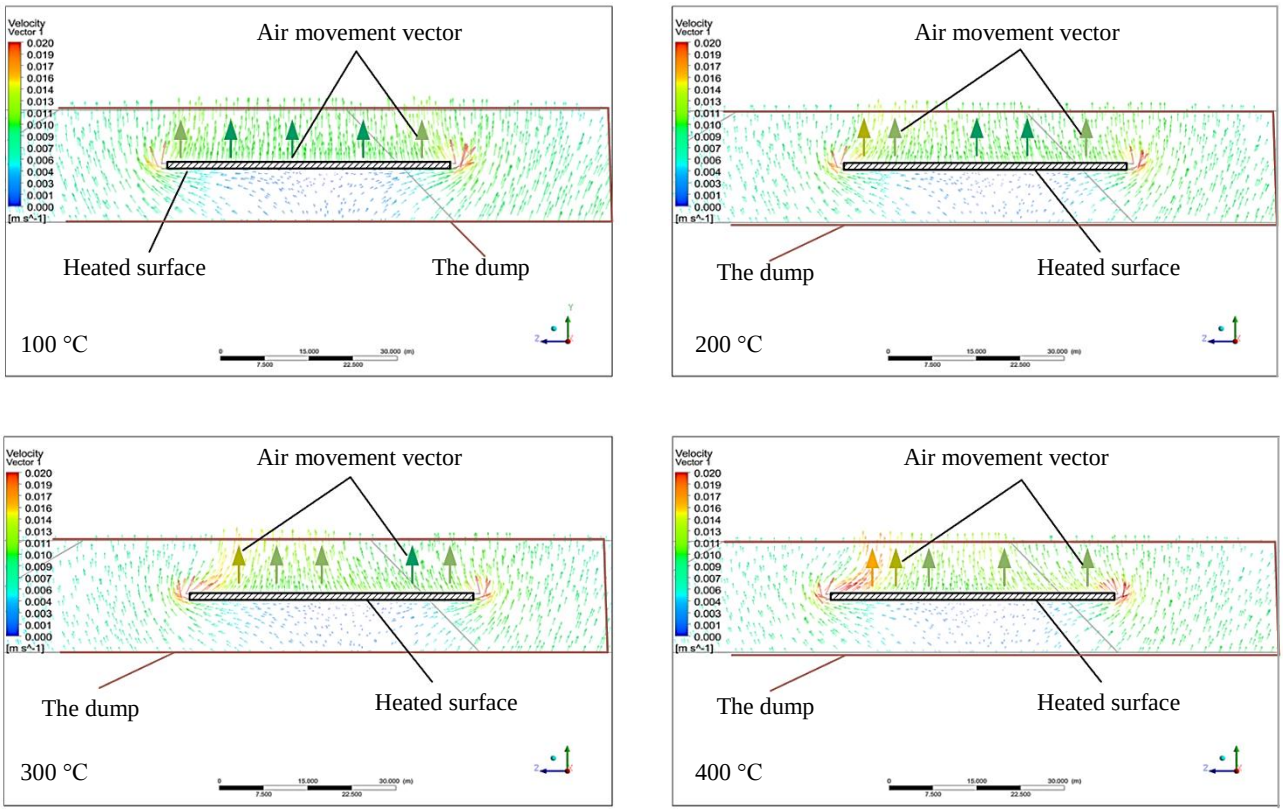


Fig.6. Air movement vectors in the zone near the heated surface

a *b*

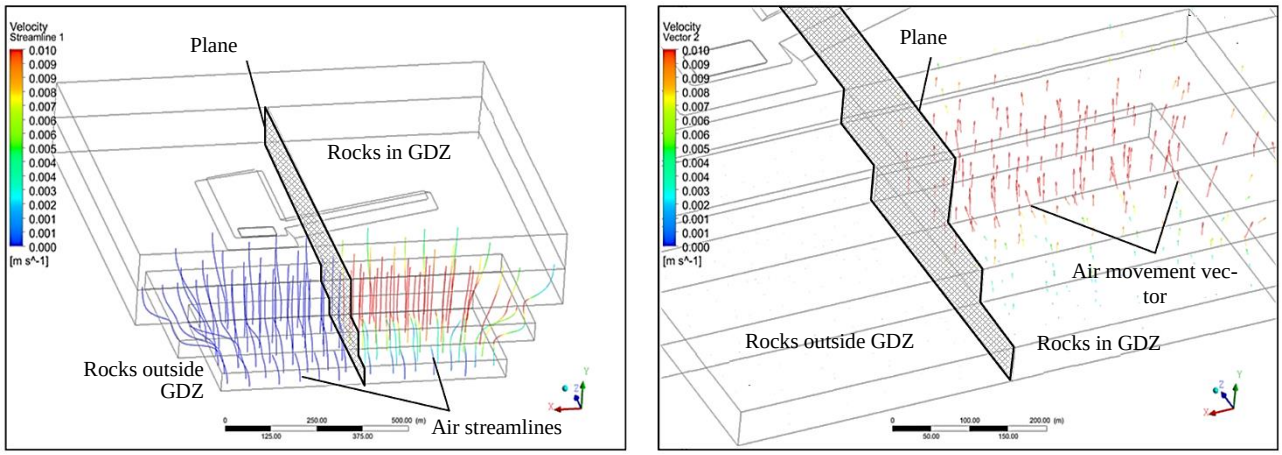


Fig.7. Comparison of air velocities in rocks with different porosity and permeability indicators (separated by a plane): *a* – air streamlines, with color indication; *b* – vectors showing the direction and velocity of air

Discussion. The research is based on the concept of geodynamic zoning, based on the idea of the interaction of global geodynamic and local geomechanical processes in the development of the subsurface and the Earth surface. To study the effect of GDZ on the conditions of coal-bearing dumps combustion, one of the typical situations was chosen when the dump is completely located in a wide geodynamically dangerous zone. This situation corresponds to the position of the dump of dug hole N 3 of the Yuzhnaya mine, the field of which is connected to the dump through GDZ and is accepted in the computer model as a source of air intake into the dump body.

The obtained results of the study of the air movement from the mine through the GDS and further into the dump body can be interpreted as confirmation of the hypothesis that burning coal dumps are confined to geodynamically dangerous zones. From the simulation results of the air velocity in the

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dump presented in Fig.6, it can be seen that its values can range from 0.001 to 0.020 m/s. There are data from studies of the range of fire-hazardous air filtration velocities through the accumulation of coal matter, at which the most favorable conditions for self-heating of coal are created. The intake of mine air to the dump through GDZ turns out to be quite sufficient to start an exothermic reaction and the dump mass combustion. Further, if there is a heated surface inside the dump and its temperature increases, the velocity of the air flow above it inside the dump also increases, which becomes an additional reason for the influx of gases to this zone with an increased temperature and into the dump as a whole. The created situation contributes to the appearance of an endogenous fire and an increase in its area.

The presence of oxygen in the area of the possible fire is recognized as the main limiting factor for the onset of spontaneous combustion. It is precisely the prevention of the air flow to the internal parts of the dump that is the main focus of prevention measures. It follows from the simulation results that the presence of GDZ, which acts as a channel for the supply of gas from the outside, removes the restriction on the intake of air into the dump. In the presence of several factors contributing to the appearance of a combustion focus inside the dump, the effect of the studied factor increases with increasing temperature and at some point, apparently, can become decisive, providing sufficient air supply to the combustion.

Conclusion

1. The conducted studies show that GDZ, as regional elements of the geodynamic state of the rock mass, can act as channels supplying air to the dumps body located within their boundaries. The location of the dump in GDZ removes restrictions on the air flow into the dump body from existing mines. The effect is enhanced when there is a focus of high temperature inside the dump, which can make the studied factor decisive for spontaneous combustion and indicate the observed confinement of burning dumps to GDZ.

2. The results of the conducted research are in line with the ideas about the complex impact of GDZ on the environment of mining areas. The noted effect of the possible gases mass transfer to dumps can also manifest itself in other situations and explain the flow of mine “dead” air to residential and industrial premises.

3. The authors believe that the noted effect should be taken into account in integrated development projects of territories of mining districts.

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