ISSN 2712-8008
Volume / Том 22 №3 2022
Journal Homepage: http://vestnik.pstu.ru/geo/

Perm Journal of Petroleum and Mining Engineering

UDC 622.831.322
Article / Статья


# The nature of sudden destruction of the near-contour part of the massif during the driving of development workings in the mine of the Gremyachinsky mining and processing plant

**Sergei S. Andreiko, Svetlana Yu. Nesterova**

Mining Institute of Ural Branch of the Russian Academy of Sciences (78a Sibirskaya st., Perm, 614007, Russian Federation)

# Природа внезапных разрушений приконтурной части массива при проходке подготовительных выработок в руднике Гремячинского горно-обогатительного комбината

**С.С. Андрейко, С.Ю. Нестерова**

Горный институт Уральского отделения Российской академии наук (Россия, 614007, г. Пермь, ул. Сибирская, 78а)

Received / Получена: 22.04.2022. Accepted / Принята: 18.11.2022. Published / Опубликована: 22.12.2022

*Keywords:*
Gremyachinskoye potash deposit, mine, potassium-magnesium salt layer, carnallite-halite layer, development workings, sudden destruction, near-contour massif, gas emissions, gas-dynamic phenomena, salt and gas emissions.

Currently, in the mine of the Gremyachinsky mining and processing plant, when driving workings along the industrial sylvinite layer, mining technical situations arise associated with the need to open and cross the development workings of the carnallite-halite layer of the potassium-magnesium salt layer. As a rule, such mining and technical situations are confined to the anticlinal folds of the potassium-magnesium salt formation. Driving development workings with the Ural-20R combine along the rocks of the carnallite-halite layer is accompanied by sudden destruction of the contour part of the massif and combustible gases outgassing. Since the beginning of mining and preparation work in the mine of the Gremyachinsky mining and processing plant, several cases of sudden destruction of the near-contour part of the massif have been recorded, which were accompanied by gas emissions, threatened the lives of miners and disrupted the rhythm of the mine.
The article presents the results of the analysis of the geological and mining-technical conditions for the occurrence of sudden destruction of the near-contour part of the massif in the conditions of the mine in the Gremyachinsky mining and processing plant. Based on the results of the geological and mining-technical conditions analysis for the occurrence, course and results of the completed process of massif near-contour part destruction, as well as the testimony of eyewitnesses and visual inspection of the destruction places directly in mine workings, common signs were identified that were characteristic of gas-dynamic phenomena in the form of sudden salt and gas outbursts. A classification assessment of the gas-dynamic phenomena type was performed using decision rules for attributing gas-dynamic phenomena to a certain type. Methods were proposed to prevent gas-dynamic phenomena in the form of sudden outbursts of salt and gas during the driving of development workings through the rocks of the carnallite-halite layer of the potassium-magnesium salt formation by tunneling and cleaning machines in the conditions of the mine of the Gremyachinsky mining and processing plant.

*Ключевые слова:*
Гремячинское месторождение калийных солей, рудник, пласт калийно-магниевых солей, карналлит-галитовый слой, подготовительные выработки, внезапное разрушение, приконтурный массив, газовыделения, газодинамические явления, выбросы соли и газа.

В настоящее время в руднике Гремячинского горно-обогатительного комбината при проходке выработок по промышленному сильвинитовому пласту возникают горнотехнические ситуации, связанные с необходимостью вскрытия и пересечения забоями подготовительных выработок карналлит-галитового слоя пласта калийно-магниевых солей. Как правило, такие горно-технические ситуации приурочены к антиклинальным складкам пласта калийно-магниевых солей. Проходка подготовительных выработок комбайном «Урал-20Р» по породам карналлит-галитового слоя сопровождается внезапными разрушениями приконтурной части массива и газовыделениями горючих газов. С начала ведения горно-подготовительных работ в руднике Гремячинского горно-обогатительного комбината зафиксировано несколько случаев внезапных разрушений приконтурной части массива, которые сопровождались газовыделениями, угрожали жизни шахтеров и нарушали ритмичность работы рудника.
В статье представлены результаты анализа геологических и горно-технических условий возникновения внезапных разрушений приконтурной части массива в условиях рудника Гремячинского горно-обогатительного комбината. На основании результатов анализа геологических и горно-технических условий возникновения, протекания и результатов закончившегося процесса разрушения приконтурной части массива, а также показаний очевидцев и визуального осмотра мест разрушений непосредственно в горных выработках выявлены общие признаки, характерные для газодинамических явлений в виде внезапных выбросов соли и газа. Выполнена классификационная оценка вида газодинамических явлений с помощью решающих правил по отнесению газодинамических явлений к определенному виду. Предложены способы предотвращения газодинамических явлений в виде внезапных выбросов соли и газа при проходке подготовительных выработок по породам карналлит-галитового слоя пласта калийно-магниевых солей проходческо-очистными комбайнами в условиях рудника Гремячинского горно-обогатительного комбината.

© **Sergei S. Andreiko** (Author ID in Scopus: 6506180352) – Doctor of Engineering, Professor, Head of Laboratory of Geotechnological Processes and Mine Gas Dynamics (tel.: +007 (342) 216 75 02, e-mail: ssa@mi-perm.ru).
© **Svetlana Yu. Nesterova** (Author ID in Scopus: 57200331766) – PhD in Engineering, Associate Professor, Researcher of Laboratory of Geotechnological Processes and Mine Gas Dynamics (tel.: +007 (342) 216 58 42, e-mail: sveta_ber@inbox.ru).

© **Андрейко Сергей Семенович** – доктор технических наук, профессор, заведующий лабораторией геотехнологических процессов и рудничной газодинамики (тел.: +007 (342) 216 75 02, e-mail: ssa@mi-perm.ru).
© **Нестерова Светлана Юрьевна** – кандидат технических наук, доцент, научный сотрудник лаборатории геотехнологических процессов и рудничной газодинамики (тел.: +007 (342) 216 58 42, e-mail: sveta_ber@inbox.ru).

Please cite this article in English as:
Andreiko S.S., Nesterova S.Yu. The nature of sudden destruction of the near-contour part of the massif during the driving of development workings in the mine of the Gremyachinsky mining and processing plant. *Perm Journal of Petroleum and Mining Engineering*, 2022, vol.22, no.3, pp.144-150. DOI: 10.15593/2712-8008/2022.3.6

Просьба ссылаться на эту статью в русскоязычных источниках следующим образом:
Андрейко С.С., Нестерова С.Ю. Природа внезапных разрушений приконтурной части массива при проходке подготовительных выработок в руднике Гремячинского горно-обогатительного комбината // Недропользование. – 2022. – Т.22, №3. – С.144–150. DOI: 10.15593/2712-8008/2022.3.6

## Introduction

In the world underground development of potash salt deposits is significantly complicated by gas-dynamic phenomena in the form of sudden outbursts of salt and gas, collapses of roof rocks (destruction of soil rocks) accompanied by gas release, combined-type phenomena and sudden squeezing of the bottom-hole part of the rocks. Gas-dynamic phenomena in the development of sylvinite layers are fast-flowing processes of destructing the marginal part of the massif and removal of crushed rock by a flow of expanding gas into the mine workings. Due to such factors of gas-dynamic phenomena as suddenness, high speed of rock pieces scattering, significant volumes of destroyed rocks, release of flammable gases, shock wave - all types of gas-dynamic phenomena pose a serious threat to the lives of miners, destroy expensive tunneling and mining equipment, disrupt the rhythm of work in potash mines. Driving development workings in the Gremyachinsky Mining and Processing Plant mine using Ural-20R heading and cleaning machines in carnallite-halite layer rocks is accompanied by sudden destruction of the marginal part of the massif and gas emissions of flammable gases. Since the beginning of mining and processing works in the Gremyachinsky Mining and Processing Plant mine, several cases of sudden destructing the marginal part of the massif have been recorded which were accompanied by gas emissions, threatened the lives of miners and disrupted the rhythm of the mine. In order to develop scientifically sound methods for predicting and preventing such sudden destruction of the marginal part of the massif, it is necessary to analyze the conditions of occurrence, course and results of the completed destruction process.

## Mining and geological conditions of development workings in the Gremyachinsky Mining and Processing Plant mine

The Gremyachinsky potash deposit (GPSD) is located in the Kotelnikovsky district of the Volgograd region. The development of the deposit's reserves is carried out by the Gremyachinsky Mining and Processing Plant (MPP) mine of EuroChem-VolgaKaliy LLC.

In the most complete sections of the Gremyachinsky potash deposit, the halogen strata of the deposit are divided into five rhythm packs, each of which is composed of anhydrites and dolomites in the lower part and mainly of rock salt in the upper part [1–7]. From bottom to top, the following rhythm packs are distinguished: Pogozhskaya (VI), Antipovskaya (VII), Pigarevskaya (VIII), Dolinnaya (IX), and Yeruslanskaya (X) rhythm packs (Fig. 1).

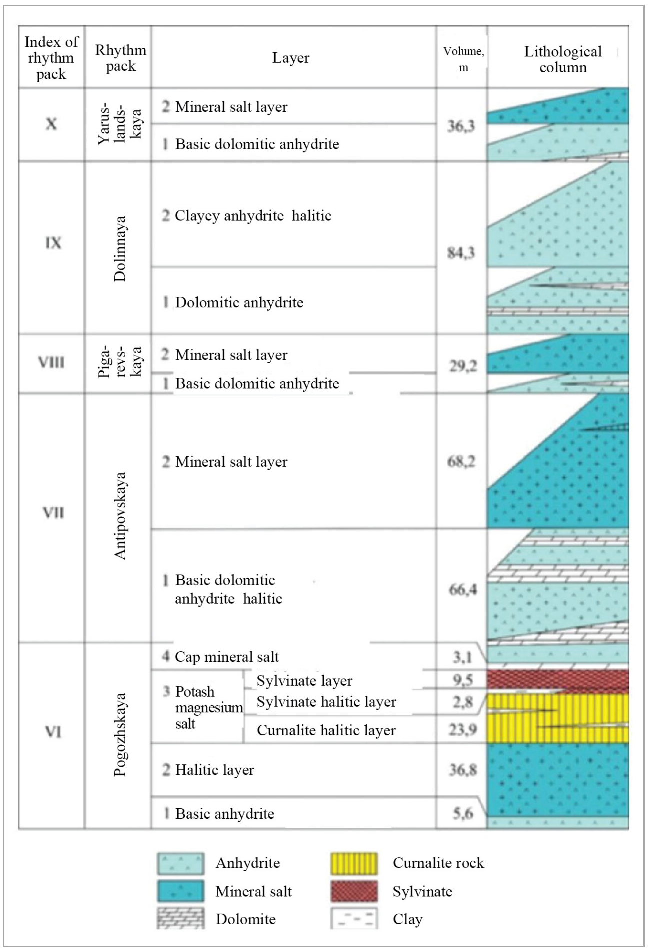


Fig. 1. Stratigraphic section of the potash layer in the Gremyachinsky potash deposit

The Pogozhskaya rhythm pack (VI) is the most consistent part of the halogen strata and can be traced over the entire area of the deposit without significant changes in composition and structure. The rhythm pack is subdivided into four layers (from bottom to top): basal anhydrite, halite, potassium-magnesium salts, and overlying rock salt. The basal anhydrite layer (VI-1), conditionally distinguished within the rhythm pack, is composed of gray and dark gray, fine-crystalline, massive or unclearly layered anhydrite rock. The layer thickness varies from 1.8 to 18.0 m. The halite layer (VI-2) is represented by light gray and pink, less often dark gray, medium-coarse crystalline, massive rock salt. The dark gray colour is due to finely dispersed admixture of clayey material. Veins and small nests of carnallite are noted throughout the layer. The NaCl content in the layer ranges from 83 to 95 %. The thickness of the formation is in most cases 40–55 m. In individual wells it decreases to 10–12 m or increases to 53–67 m.

The potassium-magnesium salt layer (VI-3) is distinguished by the presence of carnallite and sylvinite rocks in the upper part of the section. Based on lithological and mineralogical-geochemical features, this layer is subdivided into three layers (from bottom to top): carnallite-halite, sylvine-halite and sylvinite (productive). The carnallite-halite layer is traced almost everywhere. It is represented by alternating carnallite-halite, halite-carnallite and halite with an admixture of carnallite layers with thicknesses from 1–2 to 3 m. Carnallite-halite and halite-carnallite varieties have a conglomerate-like texture - halite inclusions of different sizes (from 1–2 to 6–17 cm) are cemented by carnallite. Halite inclusions are light gray to gray, heterocrystalline, sometimes with a finely dispersed admixture of anhydrite material. Carnallite is medium-coarse crystalline, pinkish, meat-red. The carnallite content in carnallite-halite rocks is up to 20-30 %, in halite-carnallite rocks - up to 40-50 %. The layer thickness varies from 4-7 m to 10-20 m. Sometimes the layer thickness increases to 40-64 m.

The sylvine-halite layer is traced in about half of the sections of geological exploration wells.

In the absence of a sylvine-halite layer, the sylvinite deposit is underlain directly by a carnallite-halite layer. The layer is represented by alternating light-grey fine-medium-grained, massive rock salt and pinkish-light-grey, sometimes white fine-medium-grained, rarely coarse-grained massive or rhythmically layered, unclearly rhythmically layered, sometimes contaminated with anhydrite material, sylvinite. The thickness of the sylvinite-halite layer in the sections of boreholes that have exposed the layer is a few meters, sometimes the thickness of the sylvinite-halite layer increases to 9–15 m.

The sylvinite layer is considered as an industrial sylvinite formation in mining and industrial terms. The layer is represented by light-grey, grey, pinkish-grey, fine-medium crystalline sylvinite, rarely (in layers) coarsely crystalline. The thickness of the sylvinite layer varies from 2.3 to 20.8 m, averaging 9.46 m.

The overlying rock salt layer (VI-4) is developed almost everywhere and is located between the sylvinite layer (productive deposit) of the Pogozhskaya rhythm pack and the basal anhydrite-dolomite layer of the overlying Antipovskaya rhythm pack. The layer is represented by rock salt of light gray, gray, dark gray, sometimes with a pinkish tint; mainly fine- and medium-grained, with separate interlayers of coarse-grained; massive, layered and unclearly layered. The bedding of the interlayers is predominantly horizontal, sometimes angles of up to 5–10˚, 20˚ and even 50˚ are noted. Anhydrite and clayey material is noted almost everywhere in the form of finely dispersed admixture or separate interlayers up to 0.05–0.15 m thick. The thickness of the bed varies from 0.6–0.9 m to 3–5 m. The total thickness of the Pogozhskaya rhythm pack deposits varies from 54.3 to 136.8 m, averaging 81.6 m. The Antipovskaya rhythm pack (VII) consists of two beds: basal dolomite-anhydrite-halite and rock salt. The basal dolomite-anhydrite-halite bed (VII-1) is subdivided into four layers: anhydrite, magnesite-dolomite-anhydrite, anhydrite-halite, and dolomite-anhydrite. The thickness of the anhydrite layer varies from 1.5 to 8 m, mostly 2.5–3.5 m. The magnesite-dolomite-anhydrite layer is not developed everywhere. The magnesite-dolomite-anhydrite layer varies in thickness from 2 to 20 m. The anhydrite-halite layer is absent in a significant number of wells and the overlying dolomite-anhydrite layer is located either on the anhydrite layer or on the magnesite-dolomite-anhydrite layer. The dolomite-anhydrite layer is developed almost everywhere. It is represented by the alternation of dark-gray dolomite with areas of brownish pelitomorphic-microgranular and light-gray, pelitomorphic-microgranular anhydrite. The layer thickness varies from 12.5 to 37.4 m. The thickness of the basal dolomite-anhydrite-halite layer varies from 37.5 to 107.6 m and averages 66.4 m.

The results of studying the gas content of the potassium-magnesium salt layer under the conditions of the Gremyachinsky MPP mine showed that natural gases in salt rocks are contained in free and bound (micro-included) form. The gases include nitrogen, methane, heavy hydrocarbons (ethane, propane, butane, pentane), hydrogen, carbon dioxide, and other flammable and inert gases in insignificant quantities [1–11].

The gas content of free gases in carnallite-halite rocks varies from 0.02 to 0.32 $m^3/m^3$, with an average value of 0.17 $m^3/m^3$. The gas content of free gases in carnallite rocks varies from 0.15 to 1.16 $m^3/m^3$, with an average value of 0.30 $m^3/m^3$. The blend composition of free gases in carnallite rocks is as follows: CH4 - 32.31 %; H2 - 4.69 %; C2H6 - 0.44 %; C3H8 - 0.02 %; iC4H10 - 0.001 %; nC4H10 - 0.005 %; N2 - 62.51 %; CO2 and other gases - 0.02 %. The total content of combustible gases (methane + hydrogen) is 37.01%. The total content of heavy hydrocarbons from the methane series is 0.46 %.

The gas content of the carnallite-halite layer in the potassium-magnesium salt formation in terms of bound gases varies from 0.011 to 0.072 $m^3/m^3$, with an average value of 0.039 $m^3/m^3$. According to the blend composition, the bound gases are methane-nitrogen. Hydrogen was also found in the bound gases of the carnallite-halite layer. The total content of methane hydrocarbons reaches 0.21 %, and the nitrogen content is 74.98 %.

### Sudden destruction of the perimeter massif during the driving development workings in the Gremyachinsky Mining and Processing Plant mine

World practice of underground mining in potash salt deposits shows that underground mining is significantly complicated at almost all deposits, up to and including the closure of potash mines by gas-dynamic phenomena (GDP) [12–29]. Over the past three decades, significant contributions have been made to the study of the nature, mechanism, development of forecasting methods and prevention methods for gas-dynamic phenomena in potash mines [26, 30–34]. The implementation of research results in practice has made it possible to significantly reduce the frequency and intensity of gas-dynamic phenomena in mines, but the GDP problem is still far from its final solution; gas-dynamic phenomena continue to occur during preparatory and cleaning mining operations. Thus, in the conditions of the Gremyachinsky potash salt deposit in the Gremyachinsky MPP mine, during preparatory mining operations on the carnallite-halite layer rocks, several cases of sudden destructing the near-marginal part of the massif were recorded.

Preparation of all panels in the mine field of the Gremyachinsky MPP mine is envisaged as a seam, with the location of workings in the roof of the sylvinite seam. The driving panel preparatory workings is envisaged by a combine method using combines in combination with a self-propelled car and a bunker-loader. The workings are driven with a width on the ground of 5.1 m, a height of 3.7 m and a cross-sectional area of 20.2 $m^2$. At the stage of preparatory mining operations, advanced exploration of the sylvinite seam is carried out using underground drilling wells in order to clarify the nature and complexity of possible tectonic disturbances. In this regard, the first intensive gas emission was recorded during drilling an underground exploration borehole in exploration drift No. 1. During drilling exploration borehole in the depth interval of 3.4–3.5 m in the carnallite-halite layer of the potassium-magnesium salt formation, gas emission from the borehole occurred with the ejection of drill fines and dust, accompanied by an air shock wave. In this case, the drilling tool with the core barrel were discarded, and the drilling rig in the working was shifted by approximately 1.0 m. During the driving transport drift No. 2, a sudden destructing the near-face part of the massif occurred in the bottom-hole part, accompanied by gas emission (Fig. 2, *a*).

The excavation of transport drift No. 2 was carried out in the carnallite-halite layer of the potassium-magnesium salt formation. As a result of the sudden destructing the marginal part of the massif, the right gearbox of the berm cutters up to the magnetic station of the combine was filled with destroyed rock weighing 0.4 tons. The cavity of the sudden destruction had an oval shape, the size of the cavity base was 1.0 × 0.5 m, the height of the cavity was 1.0 m.

The next sudden destructing of the marginal part of the rocks weighing 0.3 tons occurred in the bottom-hole zone - in the right side of transport drift No. 1, which excavation was carried out in the carnallite-halite layer of the potassium-magnesium salt formation. The sudden destruction was accompanied by gas emission, the content of flammable gases in the bottom-hole zone exceeded the maximum permissible concentration which led to the operation of the stationary equipment for continuous automatic monitoring flammable gas content installed on the Ural-20R combine.

The sudden destructing the near-edge part of carnallite-halite rocks with a volume of 32.2 $m^3$ occurred from the roof of the working during the excavation of exploratory drift No. 2 (Fig. 2, *b*).

As a result of the resolution, the cutting element and the gearbox engine of the berm cutters in the Ural 20-R combine complex were partially covered with destroyed rock. With a design width of 5.10 m, the actual width at the site of destruction was 5.81 m. The height of the workings, with a design value of 3.70 m, was 6.60 m. The concentration of combustible gases in the working face after destruction significantly exceeded the maximum permissible concentration and was 4 %.

### The nature of sudden destructing the marginal part of the massif during the drilling workings in the rocks of the carnallite-halite layer

In order to determine the nature and classify the types of sudden destructing the marginal part of the massif that occurred in the Gremyachinsky MPP mine during the drilling workings in the carnallite-halite layer, analyzing conditions of occurrence, course and results of the completed destruction process based on eyewitness testimony and facts, as well as visual inspection of the destruction sites directly in the mine workings was made.

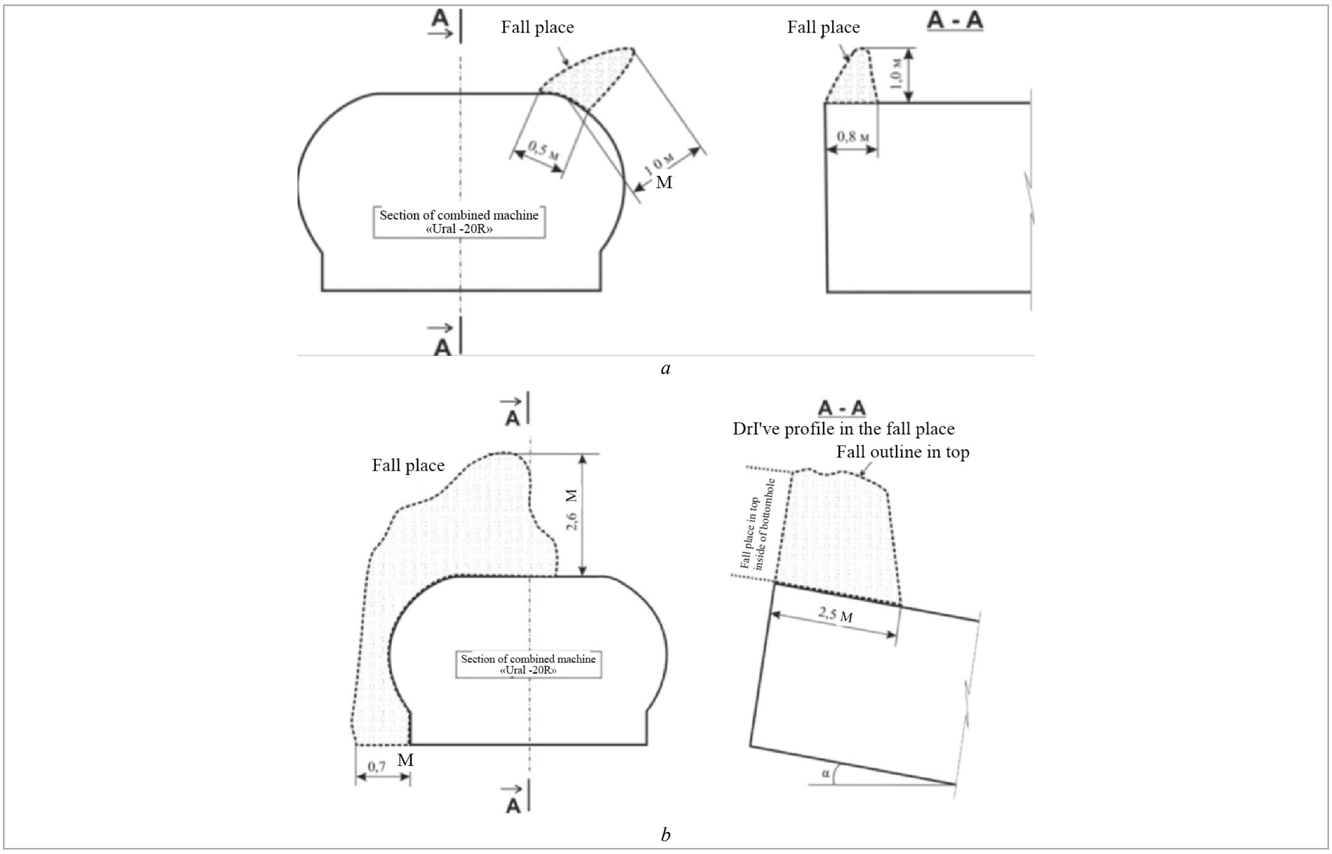


Fig. 2. Sudden destructing the marginal part of the rocks: *a* – in transport drift No. 2 (Gremyachinsky MPP mine); *b* – in exploration drift No. 2 (Gremyachinsky MPP mine)


Fig. 3. Cavity form appeared after the sudden destructing the marginal massif: *a* – in the wall of the exploratory drift No. 2; *b* – in the face of the transport drift No. 1

As a result of the analyzing the cases of destructing the marginal part of the workings during their development by the Ural-20R combine, the following general signs were identified, characteristic of gas-dynamic phenomena (GDP) in the form of sudden salt and gas emissions [12-15, 26, 30, 31]:

– locality of the show during sudden destructing the marginal rock part which are confined to the gas-bearing carnallite-halite layer;

– in all cases after sudden destructing the marginal part of the rocks the presence of flammable gases in the working face was recorded, which concentration reached 4 % with the local ventilation fan operating;

– suddenness and high speed of destructing the marginal part of the rocks (in none of the cases were precursors of destruction noted – roof deflections, peeling of the sides, formation of cracks in the roof and sides of the workings);

– the shapes of the cavities after sudden destructions have an arbitrary shape with rounded walls (Fig. 3);

– the walls of the cavities are broken by concentric cracks (see Fig. 3);

– the destroyed carnallite-halite rock is represented by small fractions and thin plates as well as convex-concave plates outlining the cavities which indicates the destructing the marginal part of the rocks by the mechanism of layer-by-layer separation, characteristic only of salt and gas emissions.

Thus, based on the analysing cases of sudden destructing the marginal massif during the development of workings by the Ural-20R combine along the carnallite-halite layer at the Gremyachinsky MPP mine, they should be classified as sudden outbursts of salt and gas. The most general prerequisite for the development of a sudden outburst of salt and gas can be considered a fullfiling a known condition of the form [12]:

$$\frac{\sigma_p}{m_г \cdot \left(P_м - P_в\right)}, \qquad (1)$$

where $\sigma_p$ – tensile strength of carnallite-halite layer rocks; $m_г$ – gas pressure application surface; $P_м, P_в$ – gas pressure in the rock mass and the mine workings, respectively.

At this stage of research, it can be assumed that the nature of salt and gas emissions during the excavation of mine workings in the carnallite-halite layer rocks is due to the presence of local gas-saturated zones, which formation occurred, apparently, during epigenetic (secondary) processes caused by folding and migration of gas-saturated aqueous solutions which was accompanied by the accumulation of gases in local areas of rocks with reduced strength [30, 31]. To formalize the procedure for determining the type of gas-dynamic phenomenon that occurred in the Gremyachinsky MPP mine, decisive criteria have been developed that allow the correct determinating the type of gas-dynamic phenomenon that occurred. In the process of developing criteria for classifying types of gas-dynamic events that occurred during mining operations at carnallite-halite seams of potassium salt deposits, the sizes of gas-dynamic event cavities were measured, their locations in the seam and chamber were determined, the presence of concentric cracks on the cavity walls and geological faults at the gas-dynamic event site were recorded. Analysis of gas-dynamic event cases during mining of carnallite-halite seams showed that they should be divided into four types: sudden outbursts of salt and gas from the roof and walls of workings, sudden collapses from the roof and walls of workings. The following 10 parameters were used in the statistical analysis of parameters characterizing the type of gas-dynamic phenomenon: X1 – distance from the gas-dynamic event cavity to the face; X2 – working width; X3 – height of the phenomenon cavity; X4 – major axis of the lower base of the phenomenon cavity; X5 – minor axis of the lower base of the phenomenon cavity; X6 – presence of concentric cracks on the cavity walls; X7 is the number of layers penetrated by the phenomenon cavity; X8 is the cavity shape; X9 is the rock in which the phenomenon cavity ends; X10 is the presence of discontinuous disturbances in the developed layer and enclosing rocks. Since some of the parameters were qualitative, heuristic advancement was used which consists in the fact that qualitative parameters were marked with “labels” using a dichotomy (0; 1), and then these “labels” were used as the measurement result along with other quantitative parameters. Since not all of the used parameters, by which it was supposed to divide the GDP into groups, are equally useful, the most informative of them were selected. To solve this problem, singlestep discriminant analysis (SDA) was used where F-statistics based on the criterion of one-way variance analysis are used to select the most informative indicators [35, 36]. To divide the GDP into groups, as a result of implementing the SDA procedure, decision rules were obtained in the form of discriminant functions. Discriminant functions allow us to determine the type of the GDP that occurred. It refers to the type that corresponds to the largest numerical value of the discriminant function obtained by substituting the measured indicators into discriminant equations, which have the following form. For sudden emissions $f_{em}$ and collapses $f_{col}$, from the roof of workings:

$$f_{em} = 12X_8 + 7{,}6X_3 + 4{,}1X_6 + 3{,}4X_{10} - 18{,}7, \quad (2)$$

$$f_{col} = 3{,}0X_8 + 2{,}1X_3 + 1{,}7X_6 + 1{,}4X_{10} - 1{,}3. \quad (3)$$

For sudden outbursts and collapses from the sides of workings:

$$f_{em} = 9{,}9X_8 + 4{,}7X_9 + 0{,}5X_3 + 11{,}6X_4 - 19{,}1, \quad (4)$$

$$f_{col} = 2{,}5X_8 + 1{,}0X_9 + 2{,}5X_3 - 2{,}5X_4 - 6{,}7. \quad (5)$$

where X9 = 1.0, if the GDP cavity is located in the carnallite-halite layer; X9 = 0, if it is located in any other layer.

After substituting the numerical values into equations (2) and (3) or (4) and (5), some discriminant indices $f_{em}$ and $f_{col}$ are determined. If $f_{em} > f_{col}$, then the phenomenon that occurred is related to sudden outbursts, if $f_{em} < f_{col}$, it is related to collapses. While substituting the numerical values characterizing sudden destruction of the marginal massif in the Gremyachinsky MPP mine, it was found that they are related to sudden outbursts of salt and gas. In accordance with the obtained classification criteria of gas-dynamic phenomena in the Gremyachinsky MPP mine, it is advisable not to use the term "fall" while analyzing similar destructing the marginal part of rocks in the future, since it does not reflect the real mechanism of destruction involving gas and can only characterize the local fallout of a part of rocks and minerals separated from the massif into the mine workings under the action of gravitational forces - the dead weight of the rocks. It should be noted that in addition to gas-dynamic phenomena, technological collapses of roof rocks can occur in the Gremyachinsky MPP mine. The causes of technological collapses are the separation of rock and its fall under the action of its own weight. Technological collapses of rocks are sometimes preceded by deflection of the layer, formation of cracks, cracking of rocks during their destruction. Collapses are accompanied by local sound effects without subsequent gas emission. Cavities of technological collapses have an irregular shape, large dimensions at the lower base and a significantly smaller height compared to the base, the walls of the cavity are uneven, often stepped. The collapsed rock is destroyed into sharp-angled pieces and slabs of arbitrary sizes, often represented by individual blocks and boulders. Due to the fact that technological collapses do not relate to GDP, their registration is not carried out by the geological service of the mine.

## Conclusion

Based on the analysing the conditions of initiation, course and results of the completed destruction process, eyewitness accounts and facts, as well as visual inspection of the destruction sites directly in the mine workings of the Gremyachinsky MPP mine, the following conclusions can be made: 1. Sudden destructing the marginal part of the workings during their excavation have signs characteristic of gas-dynamic phenomena in the form of sudden salt and gas emissions. Such signs are: locality of show of sudden destructing the marginal part of the rocks which are confined to the gas-bearing carnallite-halite layer; the presence in all cases after the sudden destructing the marginal part of the rocks in the working face of combustible gases, which concentration reached 4 % with the local ventilation fan operating; suddenness and high speed of destructing the marginal part of the rocks (in none of the cases were there precursors of destruction - roof deflections, side peeling, formation of cracks in the roof and sides of the workings); the shapes of the cavities after sudden destructions have an arbitrary shape with rounded walls; the walls of the cavities are broken by concentric cracks; the destroyed carnallite-halite rock is represented by small fractions and thin plates as well as convex-concave plates outlining the cavities which indicates the destructing the marginal part of the rocks by the mechanism of layer-by-layer separation, characteristic only of salt and gas emissions.

2. The nature of salt and gas emissions during the excavation of mine workings through the rocks of the carnallite-halite layer is due to the presence of local gas-saturated zones, which formation occurred, apparently, during epigenetic (secondary) processes caused by folding and migration of gas-saturated aqueous solutions which was accompanied by the accumulation of gases in local areas of rocks with reduced strength. 3. In order to formalize the procedure for determining the type of gas-dynamic phenomenon that occurred in the Gremyachinsky MPP mine, criteria have been developed that reflect the causality of the phenomena and allow, based on the conditions of occurrence, progression and results of the completed process of destructing the marginal part of the workings, to determine its type and assess the main causes of its occurrence.

## References


1. Kutyrlo V.O. Osobennosti stroeniia kaliinoi zalezhi Gremiachinskogo mestorozhdeniia [Some structural peculiarities of the Gremyachin potash lode deposit]. *Litasfera*, 2009, no. 1 (30), pp. 86-94.
2. Moskovskii G.A., Goncharenko O.P., Svidzinskii S.A. Usloviia formirovaniia dolomit-magnezit-angidritovykh porod iz krovli produktivnogo gorizonta Gremiachinskogo mestorozhdeniia kaliinykh solei (iug Privolzhskoi monoklinali) [Conditions for the formation of dolomite-magnesite-anhydrite rocks from the roof of the productive horizon of the Gremyachinsky potash deposit (south of the Volga monocline)]. *Geologiia, geografiia i global'naia energiia*, 2011, no. 2 (41), pp. 75-80.
3. Iartseva T.A. Variatsii mineralogo-geokhimicheskikh parametrov v razreze solenosnoi tolshchi Gremiachinskogo mestorozhdeniia kaliinykh solei (Volgogradskaia oblast') [Variations in mineralogical and geochemical parameters in the section of the salt-bearing strata of the Gremyachinsky potassium salt deposit (Volgograd region)]. *Metallogeniia drevnikh i sovremennykh okeanov*, 2013, no. 19, pp. 92-95.
4. Moskovskii G.A., Svidzinskii S.A., Goncharenko O.P., Baranovskaia M.A. Karnallit-galitovye porody i galitity galogennykh obrazovanii Gremiachinskogo mestorozhdeniia i ikh rol' v formirovanii produktivnogo sil'vinitovogo gorizonta [Carnallite-halite Rocks and Halite of Gremyachinskoye Field' Halogenous Formations and Their Role in Productive of Sylvinite Horizon Foundation]. *Izvestiia Saratovskogo universiteta. Novaia seriia. Nauki o Zemle*, 2013, vol. 13, no. 1, pp. 84-87. DOI: 10.18500/1819-7663-2013-13-1-84-87
5. Moskovskii G.A., Goncharenko O.P., Ilin K.K. Desalting of sodium and potassium chlorides at the final stages of halogenesis: Evidence from the Gremyachinsk potash deposit in the Caspianbasin. *Lithology and Mineral Resources*, 2016, vol. 51, no. 1, pp. 86-91. DOI: 10.1134/S0024490216010041
6. Moskovskii G.A., Goncharenko O.P. Solomon M.V. Rhythmic Structure of the Productive Sylvinite Lode in the Gremyachinsk Deposit (Southern Volga Monocline). *Lithology and Mineral Resources*, 2018, vol. 53, no. 2, pp. 170-177. DOI: 10.1134/S0024490218010078
7. Gavrilenko V.V. Osobennosti vertikal'noi izmenchivosti veshchestvennogo sostava poleznoi tolshchi Gremiachinskogo mestorozhdeniia kaliinykh solei (Volgogradskaia oblast') [Features of the vertical variability of the material composition of the useful strata of the Gremyachinsky potash deposit (Volgograd region)]. *Metallogeniia drevnikh i sovremennykh okeanov*, 2019, no. 1, pp. 245-249.
8. Sharafutdinov R.R., Ivanov O.V. Opredelenie komponentnogo sostava sviazannykh gazov v porodakh Gremiachinskogo mestorozhdeniia kaliinykh solei [Determination of component composition of related gases in the rocks of Gremyachinsk deposit of potassium salts]. *Aktual'nye problemy okhrany truda i bezopasnosti proizvodstva, dobychi i ispol'zovaniia kaliino-magnievykh solei. Sbornik materialov I Mezhdunarodnoi nauchno-prakticheskoi konferentsii*. Ed. G.Z. Fainburg. Perm': Permskii natsional'nyi issledovatel'skii politekhnicheskii universitet, 2018, pp. 236-244.
9. Kochnev I.I. Opredelenie kolichestvennoi sostavliaiushchei gazonosnosti gornykh porod po sviazannym gazam Gremiachinskogo mestorozhdeniia kaliinykh solei [Determination of quantitative part of gas content in rocks on associated gases of the Gremyachinsk deposit of potassium salts]. *Problemy razrabotki mestorozhdenii uglevodorodnykh i rudnykh poleznykh iskopaemykh*, 2018, no. 1, pp. 337-339.
10. Ivanov O.V. Rezul'taty issledovanii gazonosnosti i gazodinamicheskikh kharakteristik porod v vyrabotkakh okolostvol'nogo dvora rudnika Gremiachinskogo GOKa [The results of studies of gas content and gas-dynamic characteristics of rocks in the workings of the near-shaft yard of the Gremyachinsky mining and processing plant]. *Strategiia i protsessy osvoeniia georesursov. Sbornik nauchnykh trudov*. Perm': Gornyi institut Ural'skogo otdeleniia RAN, 2018, iss. 16, pp. 313-316. DOI: 10.7242/gdsp.2018.16.82
11. Sharafutdinov R.R. Eksperimental'nye issledovaniia gazonosnosti i gazodinamicheskikh kharakteristik porod po svobodnym gazam Gremiachinskogo mestorozhdeniia kaliinykh solei [Experimental studies of gas content and gas-dynamic characteristics of rocks based on free gases of the Gremyachinsky potassium salt deposit]. *Problemy razrabotki mestorozhdenii uglevodorodnykh i rudnykh poleznykh iskopaemykh*, 2018, no. 1, pp. 376-379.
12. Proskuriakov N.M. Vnezapnye vybrosy porody i gaza v kaliinykh rudnikakh [Sudden outbursts of rock and gas in potash mines]. Moscow: Nedra, 1980, 263 p.
13. Kovalev O.V., Livenskii V.S., Bylino L.V. Osobennosti bezopasnoi razrabotki kaliinykh mestorozhdenii [Features of safe development of potash deposits]. Minsk: Polymia, 1982, 96 p.
14. Proskuriakov N.M., Kovalev O.V., Meshcheriakov V.V. Upravlenie gazodinamicheskimi protsessami v plastakh kaliinykh rud [Control of gas-dynamic processes in potash ore beds]. Moscow: Nedra, 1988, 239 p.
15. Proskuriakov N.M. Upravlenie sostoianiem massiva gornykh porod [Managing the state of the rock mass]. Moscow: Nedra, 1991, 368 p.
16. Beresnev S.P. et al. Issledovanie mekhanizma formirovaniia opasnykh po gazodinamicheskim iavleniiam zon v porodakh kaliinogo gorizonta [Research of the mechanism forming the zones that are dangerous on gas and dynamic phenomena in the first potash level rocks]. *Gornyi zhurnal*, 2010, no. 8, pp. 31-33.
17. Podlesnyi I.A., Beresnev S.P., Andreiko S.S., Nekrasov S.V., Litvinovskaia N.A. Geomekhanicheskoe modelirovanie vnezapnykh razrushenii porod pochvy gornykh vyrabotok [Geomechanical modeling of sudden destruction of soil rocks in mine workings]. *Gornyi zhurnal*, 2010, no. 8, pp. 28-30.
18. Barbikov D.V., Andreiko S.S., Ivanov O.V., Bobrov D.A. Otsenka gazodinamicheskikh kharakteristik gornykh porod Krasnoslobodskogo razloma [Estimation of gas-dynamic characteristics of rocks of the Krasnoslobodsky fault]. *Gornyi zhurnal*, 2018, no. 8, pp. 38-42. DOI: 10.17580/gzh.2018.08.04
19. Andreiko S.S., Ivanov O.V., Litvinovskaia N.A. Prognozirovanie i predotvrashchenie gazodinamicheskikh iavlenii iz pochvy pri prokhodke podgotovitel'nykh vyrabotok v podrabotannom massivy solianykh porod [Forecasting and prevention of gas-dynamic phenomena from the soil during the excavation of development workings in undermined salt rock massifs]. Perm': Permskii natsional'nyi issledovatel'skii politekhnicheskii universitet, 2015, 159 p.
20. Andreiko S.S. Predotvrashchenie gazodinamicheskikh iavlenii pri provedenii uklonov, vskryvaiushchikh IV kaliinyi gorizont, v usloviiakh Starobinskogo mestorozhdeniia kaliinykh solei [Prevention of gas-dynamic phenomena during slopes that open up the IV potash horizon in the conditions of the Starobinskoye potash salt deposit]. *Strategiia i protsessy osvoeniia georesursov. Sbornik nauchnykh trudov*. Perm': Gornyi institut Ural'skogo otdeleniia RAN, 2014, iss. 12, pp. 227-229.
21. Andreiko S.S. Statistical criteria and estimation results for regularities of gas-dynamic phenomenon distribution in potash deposits. *Journal of Mining Science*, 2003, vol. 39, no. 4, pp. 354-363. DOI: 10.1023/B:JOMI.0000023186.58971.f8
22. Hedlund F.H. The extreme carbon dioxide outburst at the Menzengraben potash mine 7 July 1953. *Safety Science*, 2012, vol. 50, iss. 3, pp. 537-553. DOI: 10.1016/j.ssci.2011.10.004
23. Molinda G.M. Investigation of Methane Occurrence and Outbursts in the Cote Blanche Domal Salt Mine, Louisiana. U.S. Department of the Interior, Bureau of Mines. RI 9186, no. PB90-270083, 1988, pp. 1-21, available at: https://stacks.cdc.gov/view/cdc/9590 (accessed 01 February 2022).
24. Iannacchione A.T., Grau R.H., Sainato A., Kohler T.M., Schatze S.J. Assessment of Methane Hazards in an Anomalous Zone of a Gulf Coast Salt Dome. U.S. Department of the Interior, Bureau of Mines, RI 8861. 1984. pp. 1-26, available at: https://www.cdc.gov/niosh/mining/userfiles/works/pdfs/ri8861.pdf (accessed 01 February 2022).
25. Polianina G.D. Gazy solianykh porod i gazoproiavleniia v rudnikakh Verkhnekamskogo mestorozhdeniia [Gases of salt rocks and gas manifestations in the mines of the Verkhnekamskoye field]. *Gornyi zhurnal*, 1995, no. 6, pp. 145-150.
26. Polianina G.D., Zemskov A.N., Paderin Iu.N. Tekhnologiia i bezopasnost' razrabotki Verkhnekamskogo kaliinogo mestorozhdeniia [Technology and safety of development of the Verkhnekamskoye potash deposit]. Perm': Knizhnoe izdatel'stvo, 1990, 262 p.
27. Baryakh A.A., Fedoseev A.K. Geomechanical forecast for distribution of fissuring areas in the saliferous measures of the Upper Kama potash salt deposit. *Journal of Mining Science*, 2007, vol. 43, no. 5, pp. 462-471. DOI: 10.1007/s10913-007-0048-9
28. Aptukov V.N., Skachkov A.P., Konstantinova S.A. Micromechanical characteristics of karnallite, sylvinite and rock salt at Upper Kama deposit. *Journal of Mining Science*, 2010, vol. 46, no. 4, pp. 352-358. DOI: 10.1007/s10913-010-0044-3
29. Asanov V.A., Anikin V.V., Beltyukov N.K., Evseev A.V., Toksarov V.N. Tool control method of strain-stress state of marginal salt rocks. *Eurasian Mining*, 2013, no. 4, pp. 20-24.
30. Andreiko S.S., Kalugin P.A., Shcherba V.Ia. Gazodinamicheskie iavleniia v kaliinykh rudnikakh: genezis, prognoz i upravlenie [Gas-dynamic phenomena in potash mines: genesis, forecast and management]. Minsk: Vysheishaia shkola, 2000, 335 p.
31. Andreiko S.S. Mekhanizm obrazovaniia ochagov gazodinamicheskikh iavlenii v solianom porodnom massive [The mechanism of formation of foci of gas-dynamic phenomena in a salt rock massif]. Perm': Permskii gosudarstvennyi tekhnicheskii universitet, 2008, 196 p.
32. Nesterov E.A. Sovershenstvovanie tekhnologii degazatsionnykh rabot pri otrabotke sil'vinitovykh plastov v usloviiakh shakhtnykh polei rudnikov OAO "Sil'vinit" [Improvement of decontamination works technology during sylvinite layers mining in the mine fields of "Silvinit"]. *Vestnik Permskogo natsional'nogo issledovatel'skogo politekhnicheskogo universiteta. Geologiia. Neftegazovoe i gornoe delo*, 2013, vol. 12, no. 6, pp. 120-127.
33. Litvinovskaia N.A. Prognoz i predotvrashchenie gazodinamicheskikh iavlenii iz pochvy podgotovitel'nykh gornykh vyrabotok v usloviiakh podrabotki [Prediction and prevention of gas-dynamic phenomena from the soil of preparatory mine workings under undermining conditions]. *Gornyi informatsionno-analiticheskii biulleten'*. Moscow: Moskovskii gosudarstvennyi gumanitarnyi universitet, 2010, no. 4, pp. 180-186.
34. Andreiko S.S. Problema gazodinamicheskikh iavlenii pri sovershenstvovanii tekhnologii sloevoi vyemki Tret'ego kaliinogo plasta v usloviiakh Starobinskogo mestorozhdeniia kaliinykh solei [The problem of gas-dynamic phenomena when improving the technology of layered mining of the Third potash seam in the conditions of the Starobinskoye potash salt deposit]. *Strategiia i protsessy osvoeniia georesursov. Sbornik nauchnykh trudov*. Perm': Gornyi institut Ural'skogo otdeleniia RAN, 2018, iss. 16, pp. 300-307. DOI: 10.7242/gdsp.2018.16.80
35. Andreiko S.S., Shamanskii G.P., Laptev B.V. Mnogomernye statisticheskie kriterii klassifikatsii gazodinamicheskikh iavlenii na rudnikakh Verkhnekamskogo kaliinogo mestorozhdeniia [Multidimensional statistical criteria for the classification of gas-dynamic phenomena in the mines of the Verkhnekamskoye potassium deposit]. *Fiziko-tekhnicheskie problemy razrabotki poleznykh iskopaemykh*, 1985, no. 1, pp. 85-91.
36. Andreiko S.S, Bei M.M., Laptev B.V. Kriterii tipizatsii gazodinamicheskikh iavlenii na karnallitovykh plastakh Verkhnekamskogo kaliinogo mestorozhdeniia [Criteria for typification of gas-dynamic phenomena in carnallite beds of the Verkhnekamskoye potash deposit]. *Ventiliatsiia shakht i rudnikov. Aeropylegazodinamika gornykh vyrabotok. Sbornik nauchnykh trudov*. Leningrad: Leningradskii gornyi institut, 1987, pp. 49-54.


## Библиографический список


1. Кутырло В.О. Особенности строения калийной залежи Гремячинского месторождения // Літасфера. – 2009. – № 1 (30). – С. 86–94.
2. Московский Г.А., Гончаренко О.П., Свидзинский С.А. Условия формирования доломит-магнезит-ангидритовых пород из кровли продуктивного горизонта Гремячинского месторождения калийных солей (юг Приволжской моноклинали) // Геология, география и глобальная энергия. – 2011. – № 2 (41). – С. 75–80.
3. Ярцева Т.А. Вариации минералого-геохимических параметров в разрезе соленосной толщи Гремячинского месторождения калийных солей (Волгоградская область) // Металлогения древних и современных океанов. – 2013. – № 19. – С. 92–95.
4. Карналлит-галитовые породы и галититы галогенных образований Гремячинского месторождения и их роль в формировании продуктивного сильвинитового горизонта / Г.А. Московский, С.А. Свидзинский, О.П. Гончаренко, М.А. Барановская // Известия Саратовского университета. Новая серия. Серия: Науки о Земле. – 2013. – Т. 13, № 1. – С. 84–87.
5. Moskovskii G.A., Goncharenko O.P., Ilin K.K. Desalting of sodium and potassium chlorides at the final stages of halogenesis: Evidence from the Gremyachinsk potash deposit in the Caspianbasin // Lithology and Mineral Resources. – 2016. – Vol. 51, № 1. – С. 86–91. DOI: 10.1134/S0024490216010041
6. Moskovskii G.A., Goncharenko O.P. Solomon M.V. Rhythmic Structure of the Productive Sylvinite Lode in the Gremyachinsk Deposit (Southern Volga Monocline) // Lithology and Mineral Resources. – 2018. – Vol. 53, № 2. – P. 170–177. DOI: 10.1134/S0024490218010078
7. Гавриленко В.В. Особенности вертикальной изменчивости вещественного состава полезной толщи Гремячинского месторождения калийных солей (Волгоградская область) // Металлогения древних и современных океанов. – 2019. – № 1. – С. 245–249.

8. Шарафутдинов Р.Р., Иванов О.В. Определение компонентного состава связанных газов в породах Гремячинского месторождения калийных солей // Актуальные проблемы охраны труда и безопасности производства, добычи и использования калийно-магниевых солей: сборник материалов I Международной научно-практической конференции / под ред. Г.З. Файнбурга; Пермский национальный исследовательский политехнический университет. – Пермь, 2018. – С. 236–244.
9. Кочнев И.И. Определение количественной составляющей газоносности горных пород по связанным газам Гремячинского месторождения калийных солей // Проблемы разработки месторождений углеводородных и рудных полезных ископаемых. – 2018. – № 1. – С. 337–339.
10. Иванов О.В. Результаты исследований газоносности и газодинамических характеристик пород в выработках околоствольного двора рудника Гремячинского ГОКа // Стратегия и процессы освоения георесурсов: сб. науч. тр. / ГИ УрО РАН. – Пермь, 2018. – Вып. 16. – С. 313–316. DOI: 10.7242/gdsp.2018.16.82
11. Шарафутдинов Р.Р. Экспериментальные исследования газоносности и газодинамических характеристик пород по свободным газам Гремячинского месторождения калийных солей // Проблемы разработки месторождений углеводородных и рудных полезных ископаемых. – 2018. – № 1. – С. 376–379.
12. Проскуряков Н.М. Внезапные выбросы породы и газа в калийных рудниках. – М.: Недра. – 1980. –263 с.
13. Ковалев О.В., Ливенский В.С., Былино Л.В. Особенности безопасной разработки калийных месторождений. – Минск: Полымя, 1982. – 96 с.
14. Проскуряков Н.М., Ковалев О.В., Мещеряков В.В. Управление газодинамическими процессами в пластах калийных руд. – М.: Недра, 1988. – 239 с.
15. Проскуряков Н.М. Управление состоянием массива горных пород. – М.: Недра, 1991. – 368 с.
16. Исследование механизма формирования опасных по газодинамическим явлениям зон в породах калийного горизонта / С.П. Береснев [и др.] // Горный журнал. – 2010. – № 8. – С. 31–33.
17. Геомеханическое моделирование внезапных разрушений пород почвы горных выработок / И.А. Подлесный, С.П. Береснев, С.С. Андрейко, С.В. Некрасов, Н.А. Литвиновская // Горный журнал. – 2010. – № 8. – С. 28–30.
18. Оценка газодинамических характеристик горных пород Краснослободского разлома / Д.В. Барбиков, С.С. Андрейко, О.В. Иванов, Д.А. Бобров // Горный журнал. – 2018. – № 8. – С. 38–42.
19. Андрейко С.С., Иванов О.В., Литвиновская Н.А. Прогнозирование и предотвращение газодинамических явлений из почвы при проходке подготовительных выработок в подработанном массивы соляных пород. – Пермь: Изд-во Перм. нац. исслед. политехн. ун-то, 2015. – 159 с.
20. Андрейко С.С. Предотвращение газодинамических явлений при проведении уклонов, вскрывающих IV калийный горизонт, в условиях Старобинского месторождения калийных солей // Стратегия и процессы освоения георесурсов: сб. науч. тр. – Пермь: ГИ УрО РАН. – 2014. – Вып. 12. – С. 227–229.
21. Andreiko S.S. Statistical criteria and estimation results for regularities of gas-dynamic phenomenon distribution in potash deposits // Journal of Mining Science. – 2003. – Vol. 39, № 4. – P. 354–363. DOI: 10.1023/B:JOMI.0000023186.58971.f8
22. Hedlund F.H. The extreme carbon dioxide outburst at the Menzengraben potash mine 7 July 1953 // Safety Science. – 2012. – Vol. 50, iss. 3. – P. 537–553.
23. Molinda G.M. Investigation of Methane Occurrence and Outbursts in the Cote Blanche Domal Salt Mine, Louisiana [Электронный ресурс] // U.S. Department of the Interior, Bureau of Mines. RI 9186, No. PB90-270083. – 1988. – P. 1–21. – URL: https://stacks.cdc.gov/view/cdc/9590 (дата обращения: 01.02.2022).
24. Assessment of Methane Hazards in an Anomalous Zone of a Gulf Coast Salt Dome [Электронный ресурс] / A.T. Iannacchione, R.H. Grau, A Sainato, TM Kohler, S.J. Schatze // U.S. Department of the Interior, Bureau of Mines, RI 8861. – 1984. – P. 1–26. – URL: https://www.cdc.gov/niosh/mining/userfiles/works/pdfs/ri8861.pdf (дата обращения: 01.02.2022).
25. Полянина Г.Д. Газы соляных пород и газопроявления в рудниках Верхнекамского месторождения // Горный журнал. – 1995. – № 6. – С. 145–150.
26. Полянина Г.Д., Земсков А.Н., Падерин Ю.Н. Технология и безопасность разработки Верхнекамского калийного месторождения – Пермь: Кн. изд-во, 1990. – 262 с.
27. Baryakh A.A., Fedoseev A.K. Geomechanical forecast for distribution of fissuring areas in the saliferous measures of the Upper Kama potash salt deposit // Journal of Mining Science. – 2007. – Vol. 43, № 5. – P. 462–471. DOI: 10.1007/s10913-007-0048-9
28. Aptukov V.N., Skachkov A.P., Konstantinova S.A. Micromechanical characteristics of karnallite, sylvinite and rock salt at Upper Kama deposit // Journal of Mining Science. – 2010. – Vol. 46, № 4. – P. 352–358. DOI: 10.1007/s10913-010-0044-3
29. Tool control method of strain-stress state of marginal salt rocks / V.A. Asanov, V.V. Anikin, N.K. Beltyukov, A.V. Evseev, V.N. Toksarov // Eurasian Mining. – 2013. – № 4. – P. 20–24.
30. Андрейко С.С., Калугин П.А., Щерба В.Я. Газодинамические явления в калийных рудниках: генезис, прогноз и управление. – Минск: Вышэйшая школа, 2000. – 335 с.
31. Андрейко С.С. Механизм образования очагов газодинамических явлений в соляном породном массиве. – Пермь, Изд-во Перм. гос. техн. ун-та, 2008. – 196 с.
32. Нестеров Е.А. Совершенствование технологии дегазационных работ при отработке сильвинитовых пластов в условиях шахтных полей рудников ОАО «Сильвинит» // Вестник ПНИПУ. Геология. Нефтегазовое и горное дело. – 2013. – Т. 12, № 6. – С. 120–127.
33. Литвиновская Н.А. Прогноз и предотвращение газодинамических явлений из почвы подготовительных горных выработок в условиях подработки // Горный информационно-аналитический бюллетень. – М.: МГТУ. – 2010. – № 4. – С. 180–186.
34. Андрейко С.С. Проблема газодинамических явлений при совершенствовании технологии слоевой выемки Третьего калийного пласта в условиях Старобинского месторождения калийных солей // Стратегия и процессы освоения георесурсов: сб. науч. тр. – Пермь: ГИ УрО РАН. – Вып. 16. – 2018. – С. 300–307.
35. Андрейко С.С., Шаманский Г.П., Лаптев Б.В. Многомерные статистические критерии классификации газодинамических явлений на рудниках Верхнекамского калийного месторождения // Физико-технические проблемы разработки полезных ископаемых. – 1985.– № 1. – С. 85–91.
36. Андрейко С.С, Бей М.М., Лаптев Б.В. Критерии типизации газодинамических явлений на карналлитовых пластах Верхнекамского калийного месторождения // Вентиляция шахт и рудников. Аэропылегазодинамика горных выработок: сб. научн. тр. – Л.: Изд-во ЛГИ. – 1987. – С. 49–54.

Funding. The research was supported by RFBR grant No. 20-45-596017.
Conflict of interest. The authors declare no conflict of interest.
The authors' contribution is equal.