ГЕОЛОГІЯ

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HYDROGEN AS AN INDICATOR OF GEODYNAMIC PROCESSES IN COAL-BEARING STRATA

І. Д. Багрій, В. І. Альохін, С. Д. Аксьом, І. В. Васильєва, С. О. Кузьменко. ВОДЕНЬ ЯК ІНДИКАТОР ГЕОДИНАМІЧНИХ ПРОЦЕСІВ ВУГЛЕНОСНИХ ТОВЩ. *Проблема розробки та впровадження пошукової технології, яка забезпечить захист гірничих виробок та унеможливить катастрофи при розробці вугільних родовищ особливо актуальна зараз, коли питання природоохоронних засобів та підвищення безпеки праці на вугільних шахтах стоїть дуже гостро. Нова розробка безпечної пошукової технології вугільних родовищ, що запропонована авторами, дозволить завчасно відслідковувати, виділяти місця можливих проявів газодинамічних явищ та приймати оперативні рішення для їх усунення. Авторами проведено аналіз сучасного стану вуглевидобутку в Україні і в світі в цілому; обґрунтовано доцільність використання безпечної пошукової технології в зонах розвитку шахтних полів для виділення перспективних ділянок концентрацій водню в місцях вуглевидобутку, що слугують прямими детонаторами газодинамічних явищ, а також доведено доцільність випереджальних заходів, що унеможливить появу газодинамічних явищ. Вперше в світовій практиці було запропоновано новітні підходи щодо зміни парадигми безпеки видобутку вугілля, які попередять непрогнозовані ГДЯ та пов'язані з ними матеріальні та людські втрати. Технологія базується на застосуванні пошукових газогеохімічних методів для картування місць накопичення газово-водневих скупчень та їх ділянок і разом з комплексом геолого-геофізичних методів дозволяє виділяти площі можливих аварійних процесів в зонах розвитку шахтних полів. На великому масиві проведених польових робіт, площової та профільної зйомок доведена доцільність застосування пошукової технології для обґрунтування використання закладання випереджальних дегазаційних свердловин для запобігання некерованих вибухонебезпечних процесів і технічних катастроф. Запропонована технологія була апробована на чисельних видобувних об'єктах в процесі пошуково-екологічних досліджень в зонах розвитку діючих та відпрацьованих шахтних полів.*

Ключові слова*: пошукова технологія, шахтні поля, водень, газодинамічні явища, дегазація, безпека.*

И. Д. Багрий, В. И. Алёхин, С. Д. Аксём, И. В. Васильєва, С. А. Кузьменко. ВОДОРОД КАК ИНДИКАТОР ГЕОДИНАМИЧЕСКИХ ПРОЦЕССОВ УГЛЕНОСНОЙ ТОЛЩИ. *Проблема разработки и внедрения поисковой технологии, которая обеспечит защиту горных выработок и сделает невозможными катастрофы при разработке угольных месторождений особенно актуальна сейчас, когда вопрос природоохранных мероприятий и повышения безопасности труда на угольных шахтах стоит очень остро. Новая разработка безопасной поисковой технологии угольных месторождений, предложенная авторами, позволит заблаговременно отслеживать, выделять места возможных проявлений газодинамических явлений и принимать оперативные решения для их устранения. Авторами проведен анализ современного состояния угледобычи в Украине и в мире в целом; обоснована целесообразность использования безопасной поисковой технологии в зонах развития шахтных полей для выделения перспективных участков концентраций водорода в местах угледобычи, которые служат прямыми детонаторами газодинамических явлений, а также доказана целесообразность опережающих мероприятий, что сделает невозможным возникновение газодинамических явлений. Впервые в мировой практике были предложены новые подходы изменения парадигмы безопасности добычи угля, которые предотвратят непрогнозируемые ГДЯ и связанные с ними материальные и человеческие потери. Технология базируется на применении поисковых газогеохимических методов для картирования мест накопления газово-водородных скоплений и их участков и вместе с комплексом геолого-геофизических методов позволяет выделять площади возможных аварийных процессов в зонах развития шахтных полей. На большом массиве проведенных полевых работ, площадных и профильной съемок доказана целесообразность применения поисковой технологии для обоснования использования закладки опережающих дегазационных скважин для предотвращения неуправляемых взрывоопасных процессов и технических катастроф. Предложенная технология была апробирована на многочислен-*

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ных добывающих объектах в процессе поисково-экологических исследований в зонах развития действующих и отработанных шахтных полей.

***Ключевые слова**: поисковая технология, шахтные поля, водород, газодинамические явления, дегазация, безопасность.*

Formulation of the problem. One of the leading problems of today, hindering the development of scientific progress, is the use of existing energy sources, which carry irreversible destructive processes in the environment and lead to global man-made phenomena and natural disasters, despite rather costly environmental measures. In practice, such processes are closely linked to the use of outdated technologies of energy production and their operation, which does not meet today's demands of the development of progress.

Today, most developed countries are on the path of using alternative energy and renewable sources and resources. It is obvious that the primary problem is the development of hydrogen alternative energy, as it is a prerequisite for solving all other problems.

Thus, the hydrogen energy revolution can radically change the foundations of world energy and the planetary ecological situation of the future. In addition, the application of our proposed technology for identifying geodynamic active zones, promising for industrial hydrocarbon exploration, will allow to determine the location of possible manifestations of gas-dynamic phenomena for further operational decisions on the safe conduct of mining operations. In this regard, we substantiated and set tasks to assess the prospects for detecting promising accumulations of endogenous hydrogen in the lithosphere in the framework of scientific academic developments, environmental and mining aspects of oil and gas structures and mine facilities of coal basins of Ukraine.

The subject of research is the hydrogen of coal-bearing strata, gas - dynamic phenomena in the coal mines. **The object of research** - coal mines O.F. Zasyadka mine and Krasnolimanska mineof the Donetsk coal basin.

Analysis of recent research and publications. The idea of degassing of the Earth as a global process of its self-organization was developed by V.I. Vernadsky in a number of works published in 1911, 1912, 1924 [1].

This concept has had and continues to have a powerful growing influence on modern Earth sciences. Suffice it to note the works of A.P. Vynohradov on hydrosphere and atmosphere formation regularities (comprehensive substantiation of the role of aqueous-carbonic fluid as the final product of degassing); D.S. Korzhynskyi – on "transmagmatic solutions"; V.A. Sokolov – on geochemistry of natural gases; A.V. Sydorenko – on "breath" of ancient sedimentary-metamorphic strata; V.I. Smyrnov, A.D. Shchehlov and others – on participation of mantle fluids in endogenous ore formation; O.A. Bohatykov, N.L. Dobretsov, F.A. Letnykov, A.A. Marakushev, I.D. Ryabchykov, L.N. Koharko, O.B. Usenko and others – on fluid regime of magmatism and metamorphism; V.K. Markhinin, G.S. Shteynberg, V.I. Kononov, S.V. Byelov, A.M. Portnov and others – on the role of degassing processes in volcanism (especially noteworthy are the works of E.F. Shnyukov on mud volcanism – a bright and specific manifestation of the processes of Earth degassing); A.B. Ronov, N.M. Strakhov, A.A. Makhnach, S.G. Neruchev, Ya.E. Yudovich and others – on the general patterns of accumulation of carbonate and black shale formations; I.K. Karpov, V.S. Zubkov, V.A. Bychinskyi and others – on modeling the processes of rising hydrocarbons (HC) from the mantle into the earth's crust, the conditions of their metastability and deep detonation [1, 3, 7].

The idea of the key role of hydrogen in degassing of the Earth is developed in the works of V.M. Larin, F.A. Letnykov, A.A. Marakushev, V.V. Khmelyovska, A.V. Shcherbakov, N.D. Kozlova, Yu.A. Kolyasnikov, V.M. Shestopalov, V.I. Starostenko, A.N. Ponomarenko [4, 7].

At the same time, the Ukrainian school was formed, which develops various aspects of fluid dynamics, degassing and deep foundations of abiogenic naphthides formation. The innovative research of E.B. Chekalyuk, works of V.B. Porfyryev, N.P. Semenenko, G.N. Dolenko, V.A. Krayushkin, A.Ye. Babynets, M.P. Balukhovskyi, V.K. Havrysh, I.I. Chebanenko, V.P. Klochko, M.I. Pavlyuk, I.M. Naumko are widely known [13].

The purpose of the article is the following: analysis of the current state of coal mining in Ukraine and in the world as a whole; substantiation of feasibility of using a safe search technology in the development zones of mine fields for allocation of perspective sites of hydrogen concentrations in the places of coal mining which serve as direct detonators of the gas-dynamic phenomena, and the feasibility of precautionary measures that will prevent gas-dynamic phenomena.

Presentation of the main research material. Hydrogen anomalies mapped by hurricane concentrations within a wide range of research are of undoubted exploratory interest not only as energy source phenomena, but also in terms of geoecological forecasts for making decisions on safety in the areas of development of exploration and oil and gas works (Khrestyshche, Pryazovske, Gulf of Mexico, where there were emissions that have led to significant human losses), as well as in the area of operating mine fields.

In the course of the work the materials of world experience were used and generalized, as well as own long-term academic developments, which ultimately gave grounds for scientific substantiation of new approaches in research of gas-dynamic phenomena (GDP) due to hydrogen component and possibility of development and introduction of safe mining technology in the coal industry.

The traditional point of view on the cause of GDP is that a mine working approaches a gas-saturated methane-bearing area under conditions of degassing, metamorphism, and emergency processes. And very often powerful emissions occur in the absence of appropriate gas methane concentrations, which is not notified by specially tuned methane-sensitive hardware devices. Such emergency processes cannot be explained either from a geochemical or a technological point of view. So, after each accidental tragic emission, they talk about the human factor, or about outdated equipment.

Sudden emissions of coal and gas with significant human casualties since 1800 in France, Switzerland (Agrap mine, about 300 people died), in Russia since 1900 (Ulyanovska mine, Kemerovo region, 2007 – 110 people died) man, Kuzbas, 2010 – 100 people died), are traditionally studied and treated by almost only one version – sorption-methane. Practically all other geological, geophysical, geochemical theories of the origin of GDP have been subjected to significant criticism but were not taken into account.

The tragic events associated with the manifestation of gas-dynamic phenomena during coal mining cover a wide geographical range: France, Belgium, Germany, Russia, Turkey, Poland, Spain, Bulgaria, Norway, Ukraine. In time – from the beginning of the development of coal seams to the present time. All this obliges to look for new approaches and interpretations to the solution of an extremely acute problem – safety of production, and most importantly, protection of human life and health [1-4].

But, unfortunately, the official point of view remains unchanged. Neither the state nor private companies are interested in research, discussions, concentration of efforts and funding of the necessary environmental and industrial research.

In our opinion, many misunderstandings are primarily due to the fact that the causes of explosions continue to be considered traditional (sorption) forms of methane in coal and its gas-dynamic emissions (classic sudden emissions of coal and gas, for which a lot of hypotheses and theories have been developed and regularities have been established). But all previous research has not led to the development of effective technologies for safe coal mining.

Under the general formulation of "methane explosions", explosions of other gases actually occur, the role of which has not yet been taken into account at all. According to the authors of numerous studies, it is these gases that become the "detonator" and involve the hydrogen component in the chain reaction. According to G.G. Grytsko methane itself explodes only in a fairly narrow concentration range of 4.5-16% (maximum explosion hazard at 9.5%; at 1%, electricity is cut off in the mine, at 2% people are taken out of the mine).

Homologues of methane – heavy hydrocarbons as propane, ethane, butane – are more explosive in a much larger range than methane.

In case of accidents in coal mines, the possible cause of hydrogen explosion is not taken into account. Although, most likely, according to our work and the research of some scientists, this is the whole point.

In the course of the authors' analytical, applied and field studies of GDP, it was found that the explosion hazard threshold is significantly reduced if methane is replaced by hydrogen or its mixture with methane, propane or other homologues.

Multifactor interpretation of gas-geochemical data and a complex of geological, geophysical, geothermal and aerospace information allowed to create the latest technology (patents: *"Method for assessing the forecast of gas accumulations with hydrogen in the bowels of the earth", "Method for current forecast of sudden emissions of coal massif and gas"*) mapping of diffuse gas-hydrogen flows from their genetic sources to places of industrial accumulations and areas of possible emergency processes in the development zones of mine fields. The proposed technology has been tested at numerous mining sites in the process of exploratory and environmental research in the development zones of operating and worked-out mine fields in the presence of GDP with human casualties. [5].

Detailed areal and profile atmo-gas-geochemical surveys using SAGS search technology (structural-atmo-geochemical studies) in the development zones of mine fields made it possible to map anomalous areas of hydrogen concentrations, which, according to the results of numerous studies, serve as direct detonators of GDP.

In the course of many years of study of GDP, based on the latest technologies, we came to the conclusion that explosions cause deep gas breakthroughs in mine workings, which are caused by structural, local, regional and planetary processes based on the hydrogen component – the main detonator of emergency processes and GDP. This theory opens up a relatively new direction and introduces new multifaceted perspectives in the prediction and prevention of catastrophic phenomena. [6, 7]

The results of studies of hydrogen concentrations directly in mine workings, as well as over the projections of operating mines, by their hurricane values, are of undoubted exploratory interest both in terms of geoecological forecasts and for for making decisions on the industrial safety of uncontrolled explosive processes, which cause significant destruction in confined mine spaces, incurring material losses, stopping production cycles for a long period, and most importantly – leading to significant human casualties [8].

Below we present in the original language the statement of an outstanding scientist, corresponding member of the RAS, full member of the Academy of Mining Sciences, Doctor of Technical Sciences, Professor, prominent specialist in geomechanics, rock pressure, coal mining technology, technological development of coal industry of the Russian Federation G.G. Gritsko:

"Are emissions and explosions in coal mines sudden? The answer to this question, alas, is obvious. They are sudden – insofar as for more than 100 years knowledge about these processes has been narrow-minded, fixated on purely mechanistic or technological concepts.

And for decades it has been customary to investigate the causes of explosions in mines, find (or appoint?) "scapegoats" and wait for the next explosion. And our "room" gas protection equipment really protects, but whom and from what? It is "looking in the wrong direction", and Aleksey Stakhanov began to turn off "it", covering the coal with a tarpaulin, keeping methane in it.

In disasters in coal mines, the possible "fault" of hydrogen is not taken into account. Although, most likely, this is the whole point. It is my deep conviction that in coal mining, ecology and safety, there is a lack of scientific geological planetarity, modern non-traditional approaches.

Structural, local, regional and planetary processes not only consist of phenomena and mechanisms that have not yet been taken into account, but are also completely insufficiently studied. They represent a relatively new subject of research and open new multilateral perspectives in predicting and preventing catastrophic events".

Below are the results of many years (since 2009) of detailed areal and profile studies in areas of development of gas-dynamic phenomena of mine fields in the coal basins of Donbas: operating O.F. Zasyadko mines (Pivnichna and Pivdenna sections), Krasnolymanska, and Lviv-Volyn coal basin – Stepova and Lisova mines.

O. F. Zasyadka mine is one of the historical mines of Donbass. The mine is located in the city of Donetsk, has been in operation since 1958, and produces 1,200 to 1,500,000 tons of coal a year.

There were a number of major accidents with human casualties at the mine: in May 1999, August 2001, June 2002, September 2006, December 2007, January 2015. The biggest accident at the mine was a major catastrophe. November 18, 2007.

On March 4, 2015, an explosion occurred at the mine due to methane emissions. At the time of the accident, there were 230 miners in the mine, 33 of them were killed and 16 were injured.

The results of detailed profile and areal studies in the North and South sections in the zones of manifestations of gas-dynamic phenomena give every reason to assert that the vast majority of emergency processes took place in areas of high hydrogen concentrations (Fig. 1, 2).

The Krasnolymanska coal mine is a large coal mine located in the south-east of Ukraine in Donetsk Oblast. The Krasnolimanska mine field is located in the Pokrovsky district of the Donetsk region of Ukraine.

The mine was built according to the project of the Dniprodiproshaht Institute in 1958 and produces 3370 thousand tons of coal per year.

The mine is dangerous due to sudden emissions of coal and gas; dangerous for explosive coal dust.

Similar detailed areal studies were carried out at the production areas of the Krasnolymanska mine – hydrogen was identified in 32 observation points (Fig. 3).

The most abnormally high gas concentrations were found between the Fedorivskyi and Hlybokoyarskyi downthrow faults, as well as in the southern wing of the Hrushivskyi fault, where accidental emissions took place, which resulted in human casualties.

The spatial distribution of indicators of hydrogene content and other investigated gases in the subsoil air and the absence of geodynamic processes (block stability) suggest that the most intensive hydrogen flow with possible gas-dynamic phenomena occurs between the faults: Hlybokoyarskyi and Fedorivskyi, Hrushivskyi and Hlyboyarskyi, as well as on the continuation of the Fedorivskyi fault.

Stepova Mine is located in the Lviv-Volyn coal basin, in the village of Hlukhiv, Sokal district, Lviv region. The mine is super-category in terms of methane, dangerous in terms of explosiveness of coal dust.

There were accidents at the mine. The big accident was on April 2, 2008. The fire was extinguished for three months.

The big explosion occurred on March 2, 2017 on the horizon of 550 m, in 119 conveyor lanes. At that time, 172 miners worked at the mine, including 34 miners at the emergency site. The methane explosion killed 8 and hospitalized 23 miners.

Lisova mine is located in the Lviv-Volyn coal

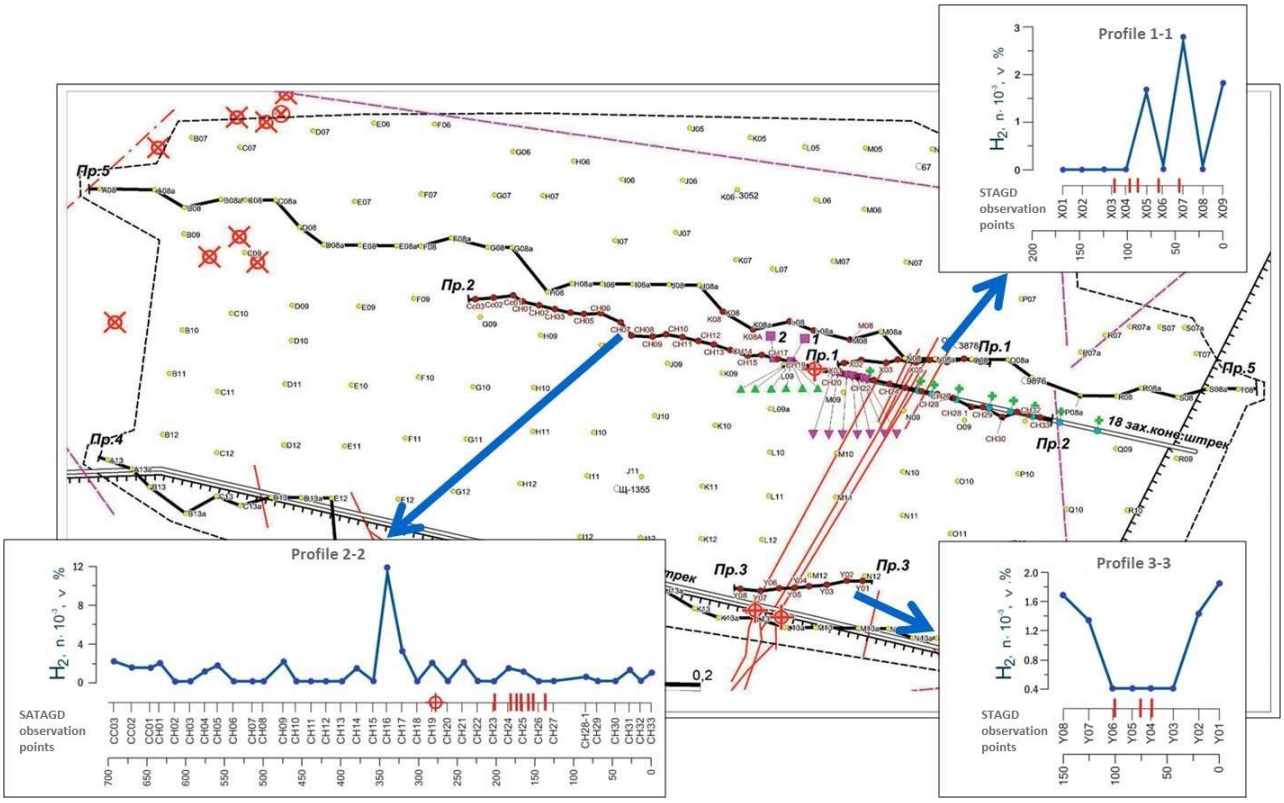
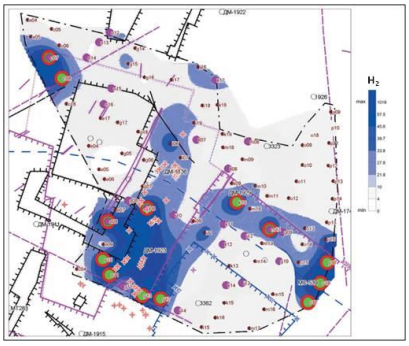
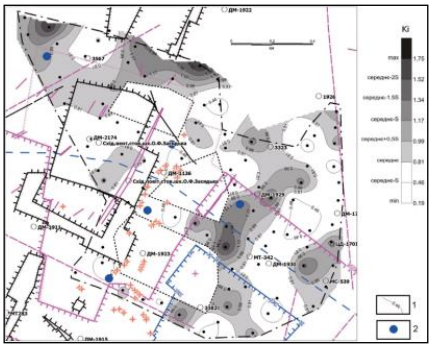


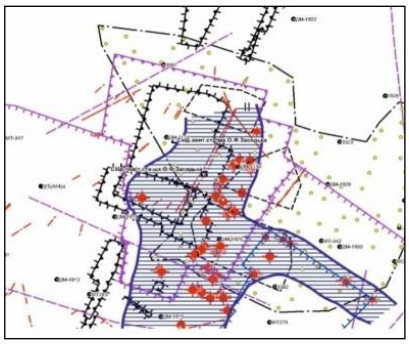
Fig. 1. Results of hydrogen detailing profile and areal studies (O.F. Zasyadko mine – Pivnichna). Graphs of dependence of H_2 – hydrogen anomalies and gas-dynamic phenomena



Scheme of spatial distribution of indicators of hydrogen content in subsoil air



Scheme of spatial distribution of indicators of the integral coefficient values (Ki = Rn/Rnf + Tn/Tnf + CO_2/CO_{2f})/3) in subsoil air



Scheme of spatial arrangement of the areas of gas-dynamic phenomena

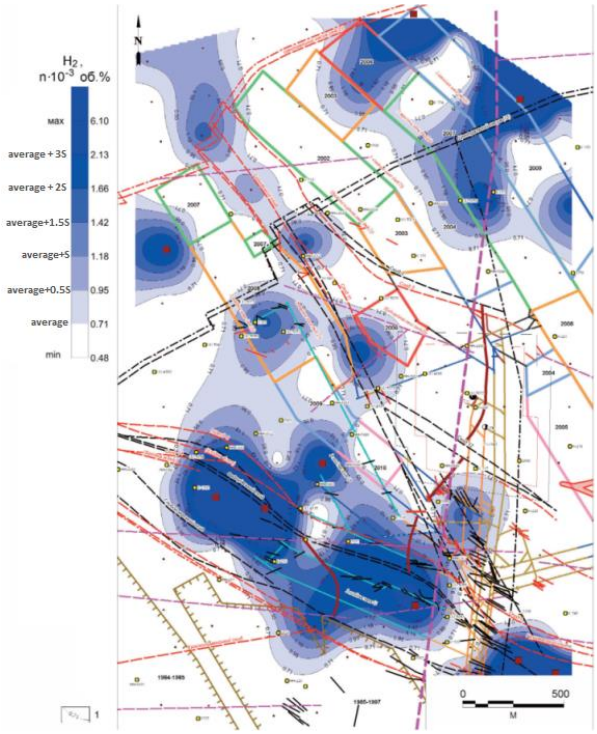
Fig. 2. Results of hydrogen detailing profile and areal studies (O.F. Zasyadko mine – Pivdenna)

basin, in the village of Silets, Sokal district, Lviv region. Actual coal production in 2003 amounted to 120 thousand tons of coal. The maximum depth is 515 m.

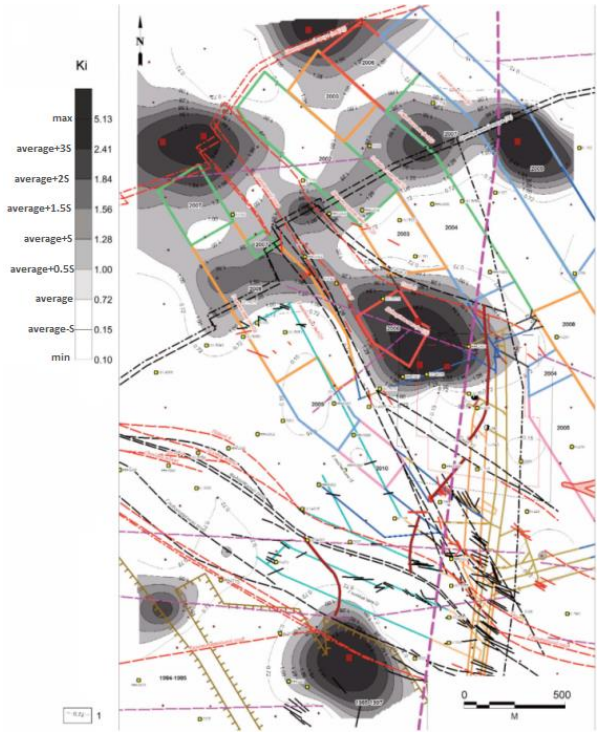
On May 29, 2019, two miners died as a result of a roof collapse.

This approach allowed to adjust the results of surface surveys with data from coal mining, distribution of gas saturation of rocks and mine workings, reasonable interpretation of STAHGS data, as well as to provide a forecast for safe mining by laying advance degassing wells. Detailed area and profile studies of hydrogen anomalies and geodynamic situation in the development zones of mine fields of Mezhyrichanske and Zabuzke coal deposits of Chervonohradskyi geological-industrial region and Velykomostivske gas field within Lviv-Volyn coal basin, in the areas of development of mine with manifestations of GDP (human casualties) – "Stepova", "Lisova" were carried out (Fig. 4).

Analysis of the results of the studies carried out in the above areas revealed that the possible causes of gas-dynamic phenomena were not the sudden opening of methane-bearing reservoirs and the inflow of significant amounts of methane into mine workings, but the passage by mine workings of are-

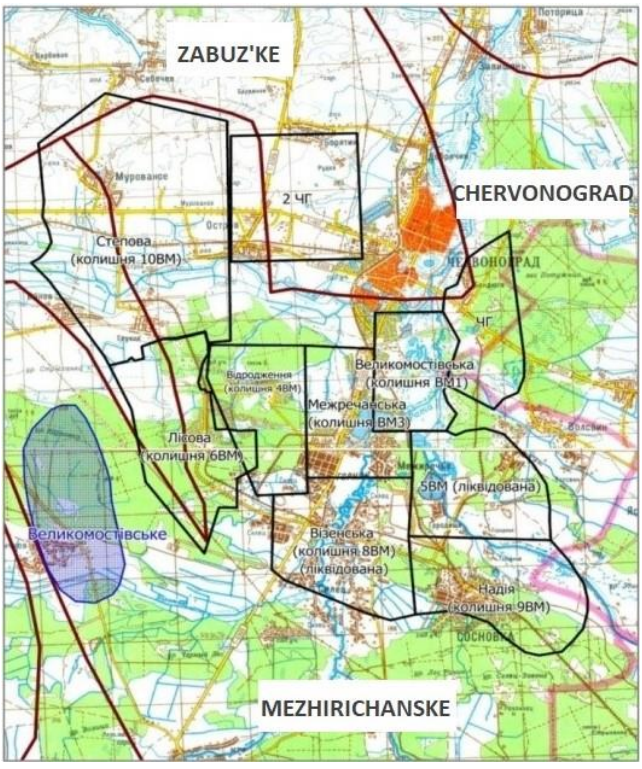


Scheme of spatial distribution of indicators of hydrogen content in subsoil air

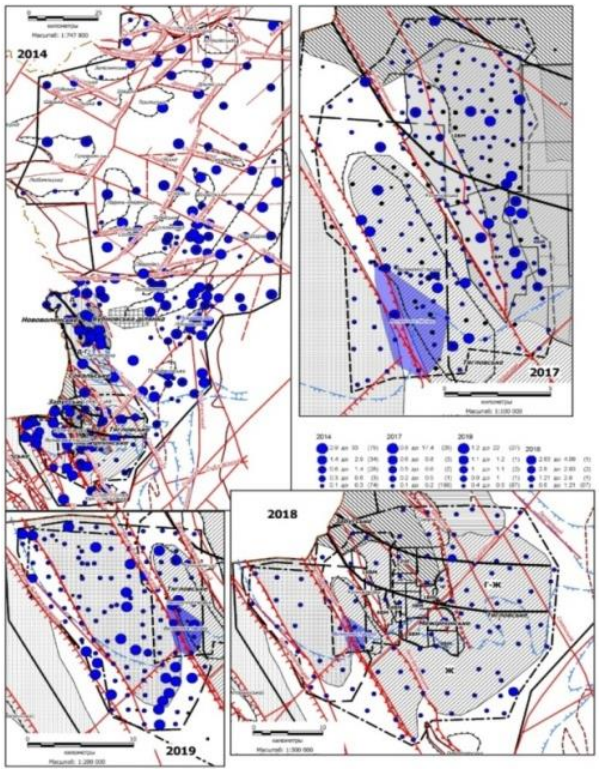


Scheme of spatial distribution of indicators of integral coefficient values (geodynamic zones Ki = Rn / Rn) in subsoil air

Fig. 3. Results of hydrogen detailing areal and profile surveys in emergency emission zones (Kransolymanska mine)



Location of Mezhyrichanske and Zabuzke coal deposits within the Lviv-Volyn coal basin



Scheme of distribution of hydrogen content ($H_2 \times 10^{-3}$, vol.%) in subsoil air

Fig. 4. Scheme of distribution of hydrogen content in the subsoil air of the Lviv-Volyn coal basin

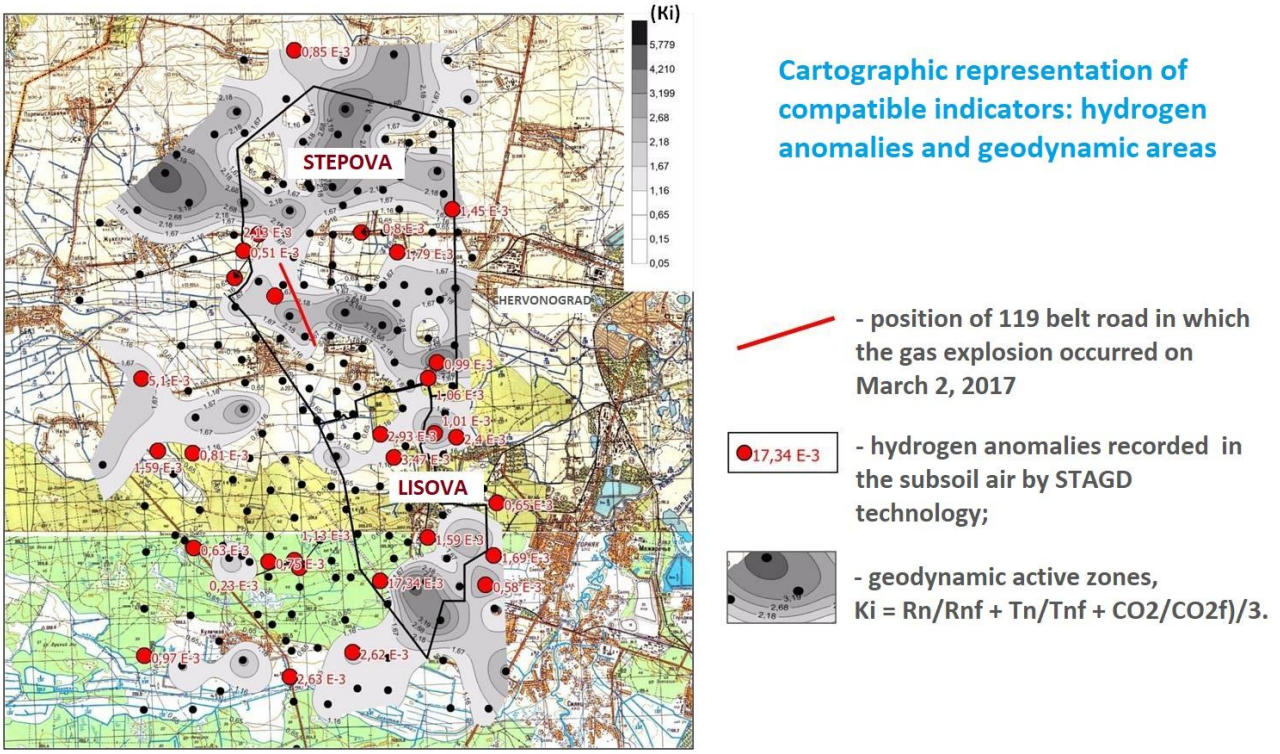


Fig. 5. Scheme of cartographic display of indicators of hydrogen anomalies and geodynamic areas

as with abnormally high hydrogen concentrations, which do not coincide with geodynamic zones and increased methane values (Fig. 5).

Conclusions.

As result of the carried out works complex researches carried out, the factual material was processed and the following conclusions formulated:

1. The results of long-term (since 2009) detailed area and profile researches in the zones of development of gas-dynamic phenomena of mine fields of coal basins were analyzed. Donetsk coal basin: operating mines OF Zasyadka mine (North, South), Krasnolimanska mine. Lviv-Volyn coal basin - mines "Stepova" and "Lisova".

The results of detailed profile and area studies in these areas in the areas of manifestations of gas-dynamic phenomena give every reason to believe that the vast majority of emergency processes took place in areas of high concentrations of hydrogen.

2. For the first time in the world practice, new approaches were proposed and substantiated to change the safety paradigm of coal mining, which will prevent the manifestations of unpredictable GDP and the associated material and human losses.

3. Analysis of the results of a complex of fundamental and applied research at coal mining facilities allows, according to the proposed technology, to identify and map the studied areas of abnormal hydrogen concentrations, their characteristics and use it as reliable markers for operational decisions for safe mining by laying advance degassing wells, which will ultimately make emergency GDP impossible.

4. The expediency of application of the proposed technology for substantiation and allocation of geodynamic active and stable zones and blocks promising for industrial exploration of hydrocarbons, determining the locations of possible manifestations of GDP and complex making operative decisions for safety of mining works is proved. And, unfortunately, the research carried out by scientists and the results obtained have not yet found worthy support from the President of Ukraine, state line ministries, commercial structures and the Academy of Sciences.

Such conclusions were obtained by us during the processing of significant factual material, as well as the results of areal and detailed profile gas-geochemical surveys both in the mine workings and on the projections of mine fields (stope mine workings) on the day surface.

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HYDROGEN AS AN INDICATOR OF GEODYNAMIC PROCESSES IN COAL-BEARING STRATA

Formulation of the problem. The problem of developing and implementing exploration technology that will ensure the protection of mine workings and prevent catastrophes in the development of coal deposits is especially relevant now, when the issue of environmental protection and safety at coal mines is very acute.

Analysis of recent research and publications. The idea of degassing of the Earth as a global process of its self-organization was developed by V.I. Vernadsky in a number of works published in 1911, 1912, 1924. This concept has had and continues to have a powerful growing influence on modern Earth sciences. The idea of the key role of hydrogen in degassing of the Earth is developed in the works of V.M. Larin, F.A. Letnykov, A.A. Marakushev, V.V. Khmelyovska, A.V. Shcherbakov, N.D. Kozlova, Yu.A. Kolyasnikov, V.M. Shestopalov, V.I. Starostenko, A.N. Ponomarenko.

The purpose of the article is: analysis of the current state of coal mining in Ukraine and in the world as a whole; substantiation of the possibility of using the technology of safe search for hydrogen in minefield development zones.

Presentation of the main research material. The new development of safe exploration technology for coal deposits, proposed by the authors, will allow to track in advance, to identify places of possible manifestations of gas-dynamic phenomena and to make operational decisions to eliminate them. The technology is based on the use of exploratory gas-geochemical methods for mapping the places of gas-hydrogen accumulations and together with a set of geological and geophysical methods allows to allocate areas of possible emergency processes in the development zones of mine fields. On a large massif of field work of areal and profile surveys, the feasibility of using search technology has been proven to justify the use of advance degassing wells to prevent uncontrolled explosive processes and technical disasters. The proposed technology has been tested at numerous mining sites in the process of exploration and environmental research in areas of operating and developed mine fields.

Conclusions. For the first time in the world practice, new approaches were proposed and substantiated to change the safety paradigm of coal mining, which will prevent the manifestations of unpredictable GDP and the associated material and human losses.

Analysis of the results of a complex of fundamental and applied research at coal mining facilities allows, according to the proposed technology, to identify and map the studied areas of abnormal hydrogen concentrations, their characteristics and use it as reliable markers for operational decisions for safe mining by laying advance degassing wells, which will ultimately make emergency GDP impossible.

The expediency of application of the proposed technology for substantiation and allocation of geodynamic active and stable zones and blocks promising for industrial exploration of hydrocarbons, determining the locations of possible manifestations of GDP and complex making operative decisions for safety of mining works is proved. And, unfortunately, the research carried out by scientists and the results obtained have

not yet found worthy support from the President of Ukraine, state line ministries, commercial structures and the Academy of Sciences.

Keywords: search technology, mine fields, hydrogen, gas - dynamic phenomena, degassing, safety.

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