UDC 550.83

Eduard KUZMENKO[1a], Ihor CHUDYK[2], Sergiy BAGRIY[1b], Andrii YAREMA[3], Yurii NESPLIAK[4], Ihor CHEPURNYI[1c], Volodymyr ARTYM[5]

[1] Department of Geodesy and Land Management, Ivano-Frankivsk National Technical University of Oil and Gas, 15 Karpatska Str., Ivano-Frankivsk, 76019, Ukraine, tel. +380 (342) 50-47-61, e-mail: gbg2020@ukr.net; [1a] https://orcid.org/0000-0002-1994-0970. [1b]https://orc id.org/0000-0003-1190-6222, [1c] https://orcid.org/0000-0003-2109-3827
[2] Rector, Ivano-Frankivsk National Technical University of Oil and Gas, 15 Karpatska Str., Ivano-Frankivsk, 76019, Ukraine, tel. +380 (342) 72-47-16, e-mail: rector@nung.edu.ua; https://orcid.org/0000-0002-7402-6962
[3] Department of Geology and Exploration of Oil and Gas Fields, Ivano-Frankivsk National Technical University of Oil and Gas, 15 Karpatska Str., Ivano-Frankivsk, 76019, Ukraine, tel. +38 (0342) 72-71-21, e-mail: 05.03.1982@ukr.net
[4] Department of Oil and Gas Well Drilling, Ivano-Frankivsk National Technical University of Oil and Gas, 15 Karpatska Str., Ivano-Frankivsk, 76019, Ukraine, tel. +38 0342 72-71-37, e-mail: y.nespliak@gaz.net.ua
[5] Department of Construction and Civil Engineering, Ivano-Frankivsk National Technical University of Oil and Gas, 15 Karpatska Str., Ivano-Frankivsk, 76019, Ukraine, tel. +38 (0342)57-24-04, e-mail: viartym@gmail.com; https://orcid.org/0000-0002-8938-552X

https://doi.org/10.23939/jgd2024.01.085

GAS GROUND AND GEOPHYSICAL STUDIES OF THE ROZVADIV ZONE OF MUD VOLCANIZM ACTIVATION (LVIV REGION, UKRAINE)

The purpose of the research was to substantiate the scientific basis behind the formation of a mud volcano within a specific section of the Precarpathian depression. It also aims to examine the existence of a near-fault shallow gas deposit in the Rozvadiv area and its possible impact on gas-soil surveying and electrometry fields. The relevance of the work is determined by the need to solve the ecological problem of environmental pollution with hydrocarbon gases, as well as to establish and forecast the degree of emissions of the gas-mud mixture. At the same time, the problem of the presence (or absence) of the relationship between the influence of the Rudnyk gas-prospecting area, which is impacted by drilling, and the Rozvadiv deposit mentioned above is solved by comparing the results of gas-soil and geophysical surveys on a significant territory covering the specified areas. The research methodology consists of the following: 1) application of research with different physical justifications (gas-soil survey and electrometry); 2) comparison of the survey results from the same area and the same grid of observations; 3) detection of anomalies within the studied territory and their interpretation from the point of view of the development of mud volcanism. Research results. The information basis of gasometry involves direct measurements of free gas in a observation regular system in the soil environment atmosphere, their statistical characteristics, and calculated indicators of gas contamination. Therefore, the gas distribution maps are informative. The applied research using the method of Earth's natural pulsed electromagnetic field made it possible to differentiate the area according to the intensity degree of electromagnetic radiation, taking into account the different depths of the sources, and, thus, identify areas of stressed-strain state of rocks and qualify them by the causes. The scientific novelty lies in the following: 1) indicating the absence of connections between the massif impacted by drilling and a natural disaster; 2) specifying the causes of the natural disaster and its substantiated mechanism and classifying the event as a mud volcano. Practical significance. Interpretation of the obtained results makes it possible to determine the causes of the extraordinary geological event in the Rozvadiv area of the Lviv region, classify the event and its consequences as a manifestation of elements of mud volcanism, and establish the absence of a relationship between the specified event and man-made impact (drilling) of the geological environment in the neighbouring areas.

Key words: mud volcano, gas-soil survey, electromagnetic field radiation intensity, stress state, mining massif, deformations, well.

Introduction

The contamination of soil, water, air, and buildings by hydrocarbon gases poses a serious environmental threat in areas near oil and gas fields. Even minor leaks and emissions of these gases can result in explosive hazards in residential and industrial zones, whether the fields are currently developed or not. Similar incidents have been observed in the Pre-Carpathian region.

These conditions necessitate heightened caution in the residential and communal management of settlements near oil and gas fields. This is particularly true for the village of Rozvadiv, which is situated adjacent to the Rudnyky oil and gas area (Fig. 1).

On the night of April 26th to 27th 2023, a hazardous event occurred in the southwestern part of Rozvadiv village, characterized by mud volcanism. Gas-mud

emissions reaching heights of 6-7 meters were observed over an area of approximately 0.041 km². Boiling gas was released from several dozen wells with water levels around 6 meters. Following the gas-mud emissions, sinkholes several meters deep appeared in some areas. Boiling water was observed in the Dniester River, which borders the deformed surface area to the south. Several houses, farm buildings, and road surfaces were damaged. During the incident, a well was being drilled approximately one kilometer from the village of Rozvadiv, beyond the regulated danger zone of 500 meters. A gas deposit was encountered through the well at a depth of about 500 meters, and an increase in planned pressure was noted, which was mitigated by increasing the density of the drilling fluid. Thus, initially, the drilling of the well seemed to be the apparent cause of the mud volcanism in Rozvadiv village [Dyakiv at al., 2023]. Manifestations of mud volcanism may be associated with the consequences of drilling wells in deposits [Kopf, 2002; Panahi, 2005; Mazzini, 2009; Busetti et al., 2024]. However, this explanation was presented as an assumption.

In order to find a comprehensive solution to the issues concerning the potential impact of industrial activities, particularly well drilling, objective information about the state of hydrocarbon contamination in near-surface sediments and rock stress is essential. Therefore, the research was commissioned to evaluate the event using Earth's natural pulsed electromagnetic field methods and gas-soil surveying. This was done to monitor the stressed state of rocks and the extent of gas contamination in the natural environment within the territory of the village of Rozvadiv.

The purpose of research

The purpose of the research scientific explanation of the emergence of a mud volcano within a specific area of the Pre-Carpathian depression.

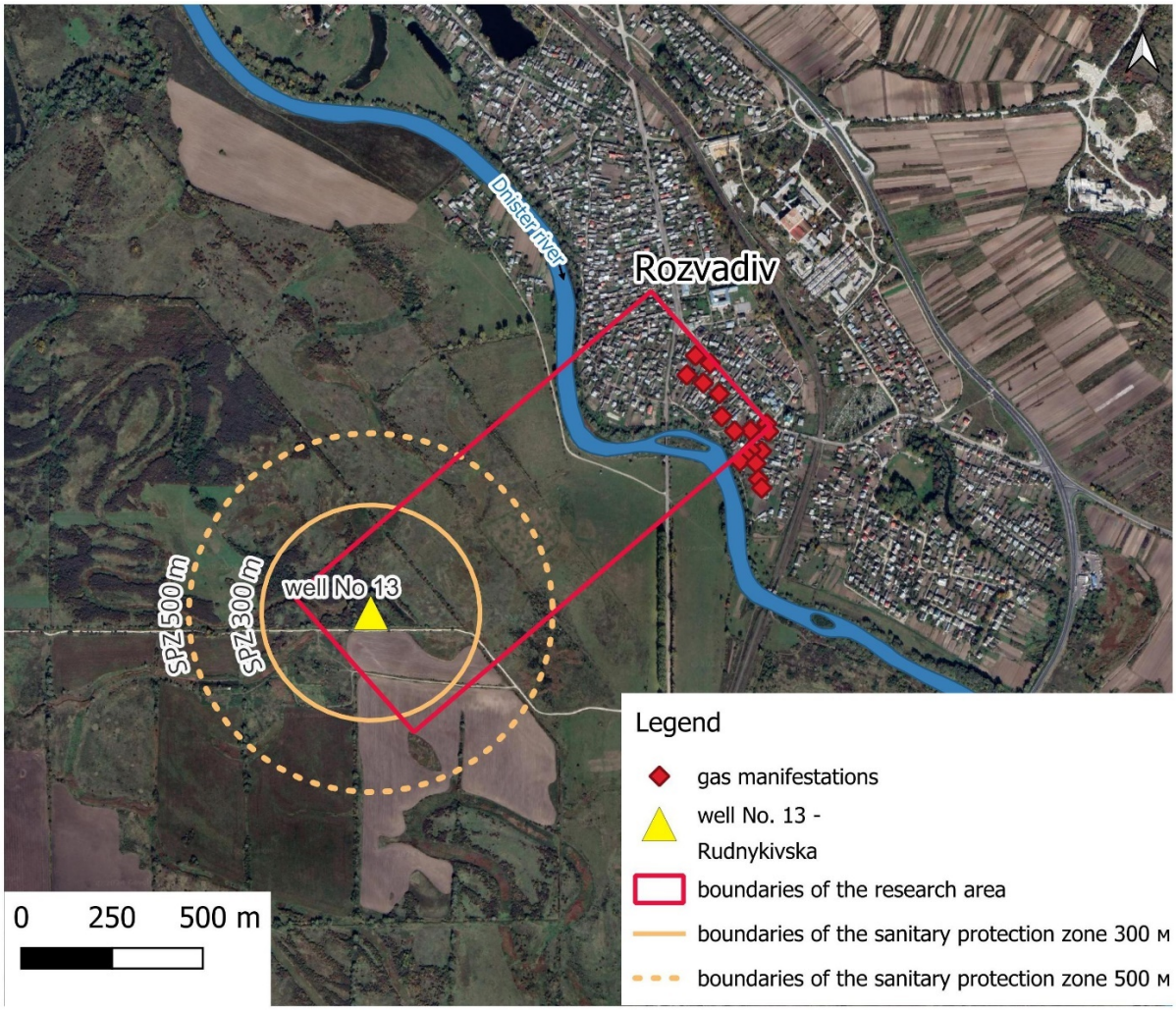


Fig. 1. Overview map of the research area

Peculiarities of the geological structure of the research area

The study area is situated in the eastern part of the Rudnyky area within the Carpathian foredeep. Detailed investigation was conducted utilizing deep drilling data, geophysical surveys, and geological studies.

The lithostratigraphic section of the Rudnyky area comprises Paleozoic, Mesozoic, and Cenozoic deposits. The Paleozoic and Mesozoic formations, including carbonate and terrigenous sediments, constitute the base of the Carpathian foredeep platform. Meanwhile, Cenozoic sediments form a Neogene molasse cover overlying these formations [Fedoriv et al., 2019; Ftemov et al., 2021; Riznychuk et al., 2021; Yarema et al., 2020; Artym et al., 2019].

The research area is situated in the northwestern part of the Bilche-Volytsia zone within the Carpathian foredeep. It lies in the contact zone of the Carpathian depression with the Rava-Ruska zone of the West European platform. (Fig. 2).

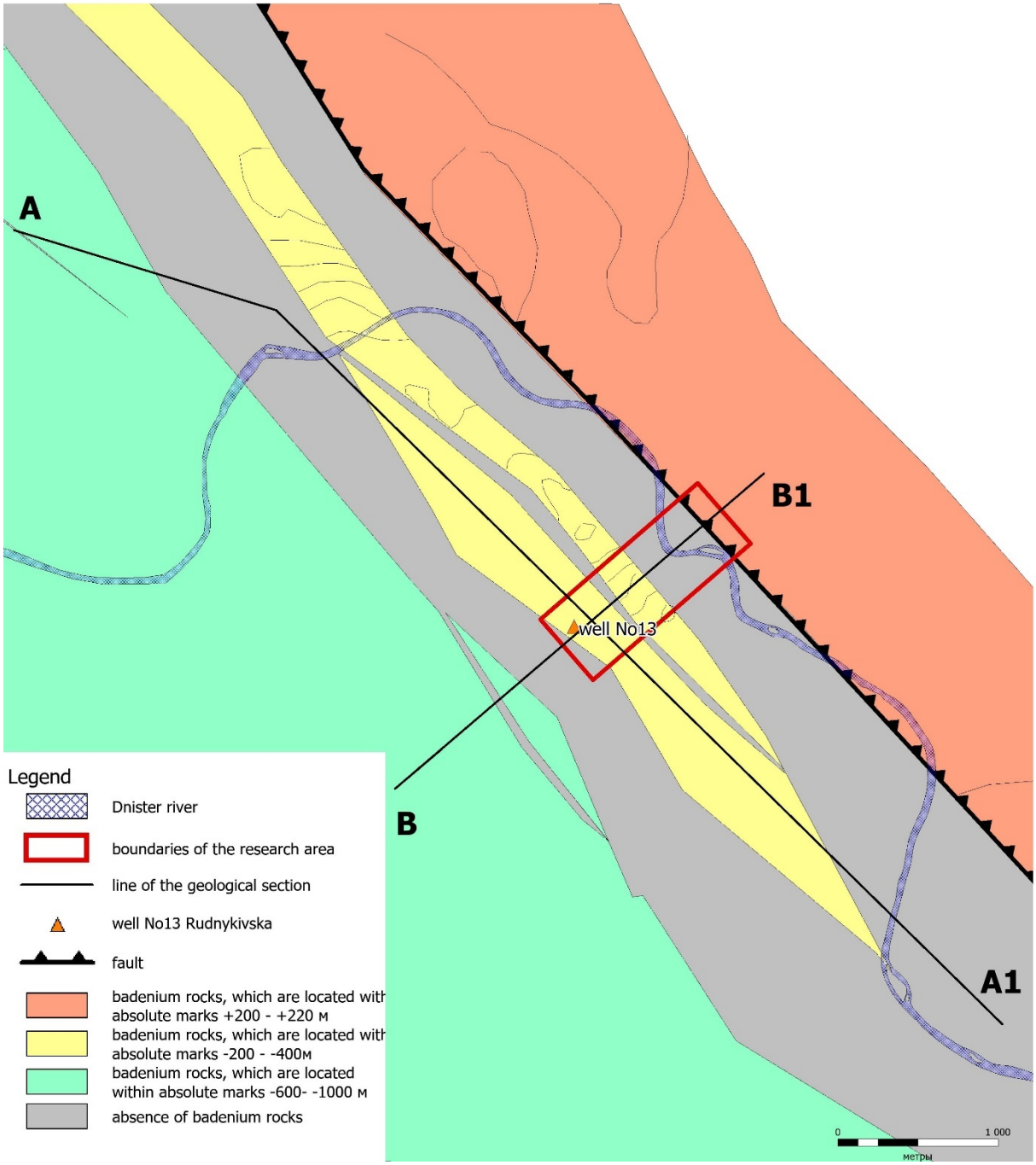


Fig. 2. Structural and geological map of the research area (created by the authors on the basis of data provided by "Georozvidka" LLC (Georozvidka…, 2019)

The primary tectonic and structure-forming elements within the study area are the Kalush and Horodok regional faults. These faults played a crucial role in the stepwise subsidence of the West European platform's basement during the formation of the Carpathian foredeep.

These faults are classified as faults with an amplitude of up to 1 km (at the pre-Neogene level), displaying a sub-Carpathian (northwestern) extension, with a lowered southwestern wing, according to their genetic type.

Regarding oil and gas geology, the study area is situated within the Bilche-Volytsia oil and gas region. This region is characterized by two levels of oil and gas reservoirs: sub-gypsum (Mesozoic), containing both oil and gas as well as gas condensate deposits, and super-gypsum (Baden-Sarmatian), known for its gas and gas condensate reserves.

The Rudnyky area, which is the focus of the research, is located within an oil and gas accumulation zone. This zone predominantly features gas and gas condensate deposits in the sub-gypsum layers and gas deposits in the super-gypsum rock complexes. It extends from the Ugersky deposit in the southeast to the Rudkiv deposit in the northwest within the Bilche-Volytsia oil and gas region.

The study area is directly associated with the Rozvadiv gas exploration facility, which was discovered following a local gas content forecast within the Rudnyky area.

Within the Rozvadiv exploration site, the potential for identifying new gas deposits is linked to the Carpathian and Campanian stages of the Cretaceous system. The exploration target covers depths ranging from 500 to 550 meters. A large gas deposit is expected. (Fig. 2-3).

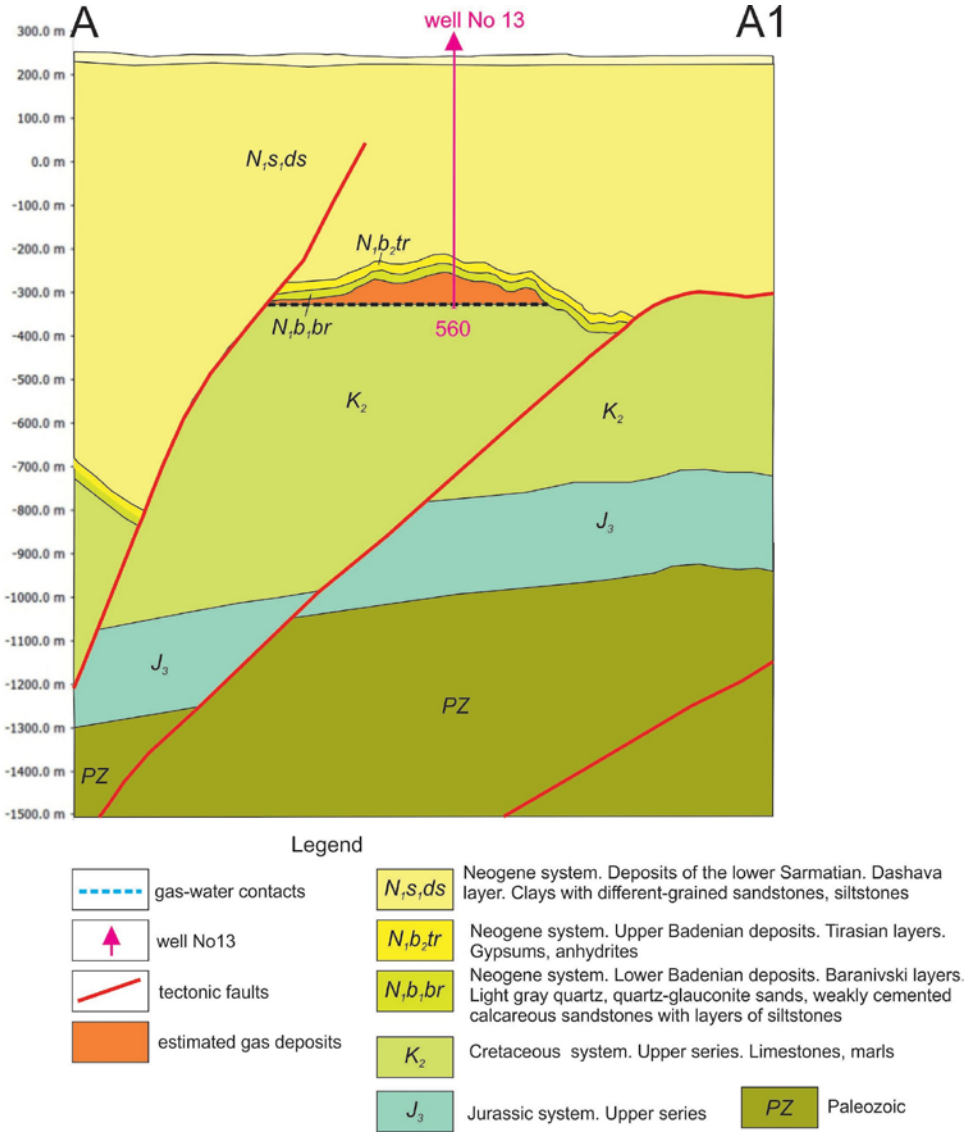


Fig. 3. Seismic-geological section along line A – A1 (created by the authors on the basis of data provided by "Georozvidka" LLC (Georozvidka…, 2019)

Methods and results

The methods chosen for the study include gas-soil surveying (GSS) and the geophysical method of Earth's natural pulsed electromagnetic field (ENPEMF), selected for their operational efficiency and relatively low cost.

Gas and soil survey. Gas-soil surveying is widely used both in Ukraine and abroad [Toutain et al, 1999, Schütze et al, 2012, Sechman et al 2013, 2022, Zarroca et al, 2012, Gryga et al, 2016 Baillie et al, 2019, Vyzhva et al, 2021, Bagriy et al, 2019].

Gasometric studies were conducted for the first time in the residential area of the village of Rozvadiv and its surrounding areas. The gasometry data comprises direct measurements of free gas conducted in a systematic observation pattern within the soil environment, along with their statistical characteristics and calculated indicators of gas contamination.

Based on the gasometric study results, a diagram of gasometric observations was generated, and maps showing methane content, total hydrocarbon gas content, as well as lower and upper explosive limits of a hydrocarbon gas mixture were created. A gasometric study was conducted in the soil environment at a depth of 0–m to quickly obtain primary objective information for future use. This study was carried out on hydrocarbon gases that are in a free state, within the housing stock of the village of Rozvadiv and the adjacent territory covering an area of 0.65 km².

Free gas testing, carried out from a depth of 0.75 m, is a fairly effective and highly productive method with the help of a completely sealed device by vacuuming the subsurface atmosphere. The device consists of a tube perforated at the bottom, made of a stainless-steel chromatographic column, a vacuum hose and a vacuum pump. The inner diameter of the tube is slightly more than 5 mm. During the process, 250 cm^3 of the subsurface atmosphere was evacuated at a vacuum of 1 atm, of which 10 cm^3 of gas was preserved in a sealed bottle with a capacity of 15 cm^3, previously filled with a saturated sodium chloride solution. This technology made it possible to repeat the analysis of one sample ten times, which significantly increased reliability and accuracy.

The area of the gas-soil excavation is set to 1.300×500 m. The observation system forms a regular grid of 100×125 m within the residential area of 50×62.5 m. It consists of 102 sampling points (Fig. 4). One sample of the gas-air mixture was also taken from the well.

The vacuum gas sampling system is characterized by self-control, ensuring absolute tightness. In case of any leak, the system will detect it, and sampling will not proceed. Highly sensitive gas analytical equipment enables the determination of minimum concentrations of hydrocarbon gases, allowing systematic analysis of the concentration field and formalized indicators.

The qualitative composition of the studied hydrocarbon gases includes methane, ethane, ethylene, propane, propylene, isobutane, normal butane, isopentane, normal pentane, as well as hexane and higher hydrocarbons.

Gas chromatography is a very important stage in the technology of creating gasometric information. This method is one of the most effective physical-chemical techniques for separating a mixture of substances. It involves repeating the process of separating the components between two phases – a stationary phaze with a large surface and a mobile phaze that moves relative to the stationary phaze. Gas chromatography is the main method of studying the composition of natural gases. It is a type of chromatographic method that separates light compoundsusing a gas mobile phase, and a solid sorbent stationary phase. The chromatogram becomes a source of information about the composition of the analyzed mixture. Qualitative analysis is based on the constancy of the release time of each component from the separation column, counted from the moment of sample introduction to the moment of registration of the component on the chromatogram. Quantitative characteristics of the analyzed substances are obtained by measuring the height or area of peaks. The dependence of the height or area of the peak on the concentration, as well as the release time of individual components, is established by preliminary calibration, carried out with artificially prepared control mixtures or pure gases.

The laboratory of monitoring research SODiMD, which is a part of PJSC "UKRNAFTA", conducted measurements on a chromatographic gas complex to determine the concentrations of carbohydrates in gas-air mixtures of rocks. The samples were selected from the territory of the village of Rozvadiv, Stryi district, Lviv region.

The maps show the results of hydrocarbon gasometric determinations in the atmosphere of the subsurface air within the territory of the village of Rozvadiv, including the total content of hydrocarbon gases (Fig. 4).

In this article, we will focus solely on some statistical characteristics of the main indicators of gas contamination. The minimum methane content at sampling points is 0.706×10-4% vol., while the maximum is 171.345×10-4% vol. It's noteworthy that the sample taken from the well exhibits the highest content, specifically 540.538×10–4 % vol [Oil and Gas Science…, 2023].

The minimum values of the total hydrocarbon gas content are 1.477 × 10–4 % vol., and the maximum values of the total hydrocarbon gas content are 123.854 × 10–4 % vol.The analysis of the maximum values of hydrocarbon gases indicates that the content of free hydrocarbon gases in the atmosphere of the soil environment of the territory of the village of

Rozvadiv, taking into account the highest value in the well, is ten times lower than the lower explosive limit of the mixture of hydrocarbon gases. Differential connections between the well 13-Rydnykivska and gas manifestations in the village of Rozvadiv are not observed.

A separate part of gas-soil surveying is the ***determination of explosiveness indicators and the degree of gas contamination***.

The main indicators of the explosiveness of natural gases are the lower and upper explosive limits, that is, those limits and concentrations at which they form an explosive mixture with air. The lower limit is characterized by the amount of gas sufficient for the normal combustion reaction. The lower explosive limit of a hydrocarbon gas corresponds to such a gas concentration in a gas-air mixture that its further reduction makes the mixture non-explosive.

The upper explosive limit is characterized by the air (oxygen) content, which is insufficient for the normal combustion reaction of hydrocarbons. The upper limit of explosiveness corresponds to such a content of hydrocarbons in a gas-air mixture, at which its further increase makes the mixture non-explosive.

An explosion will occur when the concentration of hydrocarbon gas in the air is between the lower and the upper limits and there is a source of ignition (open flame from a lit match, cigarette, spark). If the hydrocarbons in the air are less than the lower explosive limit or more than the upper limit, then such a mixture cannot explode. A jet of the gas mixture with a concentration of hydrocarbons greater than the upper explosive limit burns with a light flame, entering the atmosphere and mixing with air.

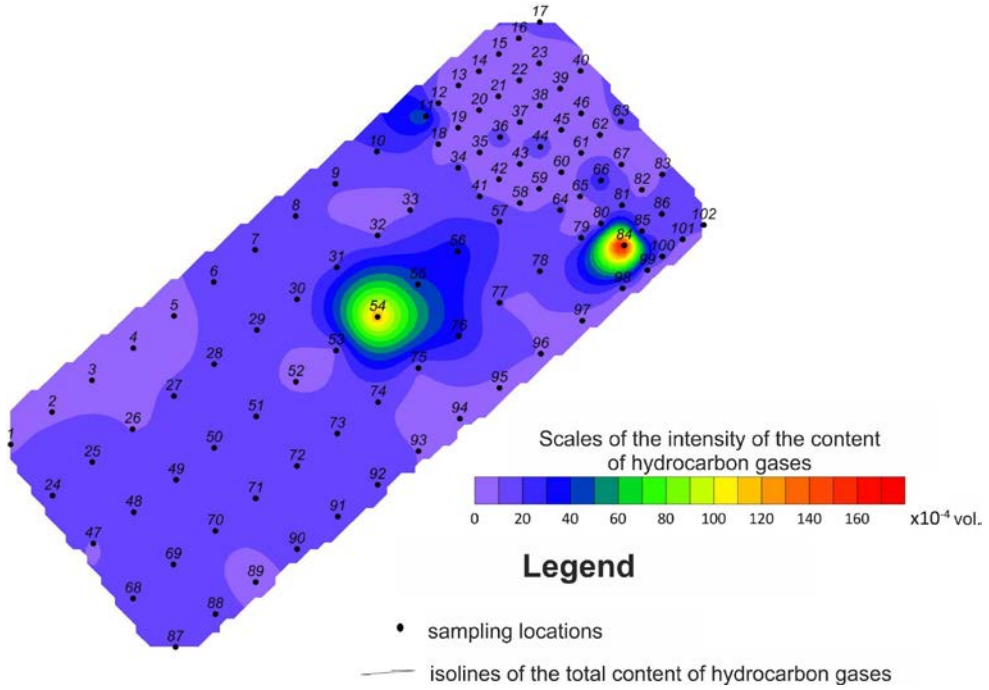


Fig. 4. Map of the total content of hydrocarbon gases in the soil environment in the areas of the village of Rozvadiv

The relevant regulatory documents, in particular, Table 1 provide these limits of the content (volume %) of natural gas (mixed with air) and its components in the air environment.

Since the natural gases under study are multicomponent mixtures of individual hydrocarbons, the calculation of the lower and upper explosive limits of such mixtures in volume percent was carried out according to the formulas:

$$L_{сум} = \frac{\sum_{i=1}^{N} C_i}{\sum_{i=1}^{N} \frac{C_i}{L_i}} \quad (1)$$

$$U_{сум} = \frac{\sum_{i=1}^{N} C_i}{\sum_{i=1}^{N} \frac{C_i}{U_i}} \quad (2)$$

where, L_i – the lower explosive limit of the i-th component of the mixture; U_i – the upper explosive limit of the *i*-th component of the mixture; C_i – the content of the *i*-th component in the mixture.

The value of the lower and upper explosive limits for each component is selected according to Table 1.

The provided formulas for calculating explosive limits are valid for atmospheric pressure conditions. When the pressure drops below atmospheric, the

concentration limits of explosiveness narrow, otherwise when the pressure rises above atmospheric, the limits expand.

After conducting a thorough analysis, it has been concluded that the area surrounding Rozvadiv village is not at risk of a hydrocarbon explosion. Specifically, there are no hazardous concentrations of hydrocarbon gases in the atmosphere or soil environment in the direction of well 13-Rudnykivska [Oil and Gas Science…, 2023].

Table 1

Explosive limits of selected hydrocarbons in air

Hydrocarbon	Explosive limit, volume %	
	lower	upper
natural gas (with a relative density of 0.6)	4,5	14,5
methane	4,4	17,0
ethane	2,9	13,0
propane	2,1	9,5
n-butane	1,8	8,4
isobutane	1,8	8,4
n-pentane	1,4	8,3
isopentane	1,4	8,3
hexane	1,2	7,7

The results of research using the method of the Earth's natural pulsed electromagnetic field

The utilization of the Earth's natural pulsed electromagnetic field (ENPEMF) method has recently seen increasing applications in addressing various engineering-ecological and geological-ecological issues [Dovbnich, et al., 2012; Kuzmenko, et al., 2018; Bagriy, et al., 2017; Dzioba, 2020; Deshchytsia, et al., 2016]:

- qualitative assessment of the overall natural field of mechanical stresses and monitoring its dynamics during routine observations.
- prompt identification and forecasting hazardous geological processes and phenomena such as landslides, karst formations, rock bursts, suffusion, collapses, and mine emissions.
- determination of activation of geodynamic mapping structures and characterization of fault zones.
- inspection of residential buildings, household premises, construction sites, and utilities to identify possible deformations of foundations, walls, and structures.

The work was carried out in the following stages:

Research on the territory including well 13 – Rudnykivska, the area of the village of Rozvadiv, and the area between them.

The studies were conducted over a territory measuring 1300x500 meters (Fig. 5). Research frequencies ranging from 2 to 16 kHz were chosen to achieve maximum research depths of over hundreds of meters. As evident from the presented maps, the orientation of the antennas did not affect the results.

The part of the territory situated on the right bank of the Dnister River (where the well is located) shows homogeneity in terms of ENPEMF intensity. Intensity changes are observed within the range of 3000-5500 pulses/second, indicating practically no difference in intensity. Thus, an objective visual analysis of maps for this part of the territory suggests that there is no connection between the well and the village of Rozvadiv.

However, distinct anomalies of ENPEMF are observed on the territory of Rozvadiv village, all located on the left bank of the Dnister. From our perspective, the explanation is as follows: the distinct boundary separating the non-anomalous territory from the anomalous one coincides entirely with the contact of the Carpathian foredeep with the East European Platform. The increase in electrical resistance on the platform territory results in an escalation of the radiation intensity of the Earth's electromagnetic field. This has been theoretically and practically proven, as demonstrated in our research reports [Oil and Gas Science…, 2023]. Naturally, the delineation of the deflection and platform limit is more accurate due to the larger scale of work and a denser observation grid.

The anomaly on the left bank is not homogeneous and is divided into two sections. Its northwestern, western, and southern parts show lower intensity and are inherent purely to the platform. However, its eastern and southeastern parts exhibit increased intensity, and importantly, they are geographically consistent with areas of gas manifestation. Therefore, these anomalies correspond to man-made phenomena during gas release.

In-depth analysis of the territory of the village of Rozvadiv.

Upon detailed examination of the territory of the village of Rozvadiv, comprehensive studies were conducted in areas where gas manifestations were recorded at all frequencies used: 36-50 kHz, 16-36 kHz, and 2-16 kHz. The rationale for using different frequencies lies in the fact that lower frequencies allow for deeper research.

The research findings are presented in Fig. 6. Frequencies of 36-50 kHz correspond to shallow depths in the first meters. At these frequencies, indistinct random anomalous zones associated with near-surface rocks are observed, which are not consistent with the consequences of gas manifestations. Thus, these depths are not related to the causes of the dangerous situation.

Frequencies of 16-36 kHz probably correspond to the depth of Quaternary alluvial formations and the covering part of the platform rocks (Fig. 6b). Therefore, they are consistent with the structural plan of the platform and cover the areas of alluvial deposits. During gas release, these deposits were distributed among the Quaternary formations.

Anomalies at frequencies of 2-16 GHz (Fig. 6a) coincide entirely in configuration with the territory of the "carbonated" wells' location. The damaged buildings in the village of Rozvadiv are within these anomalies.

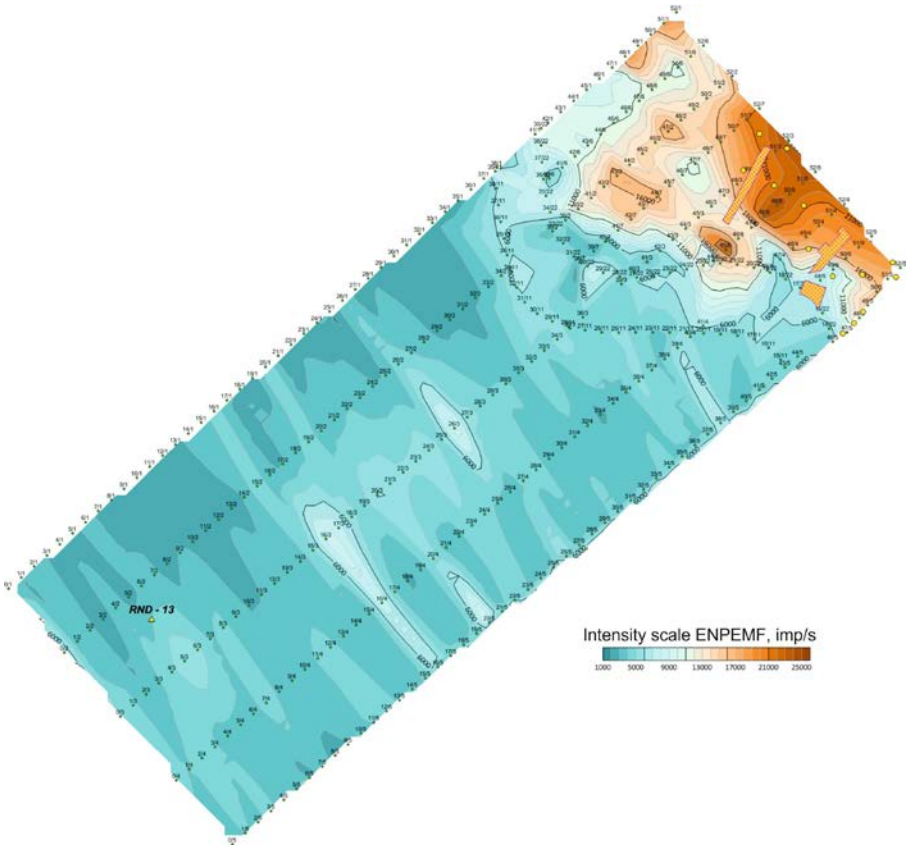
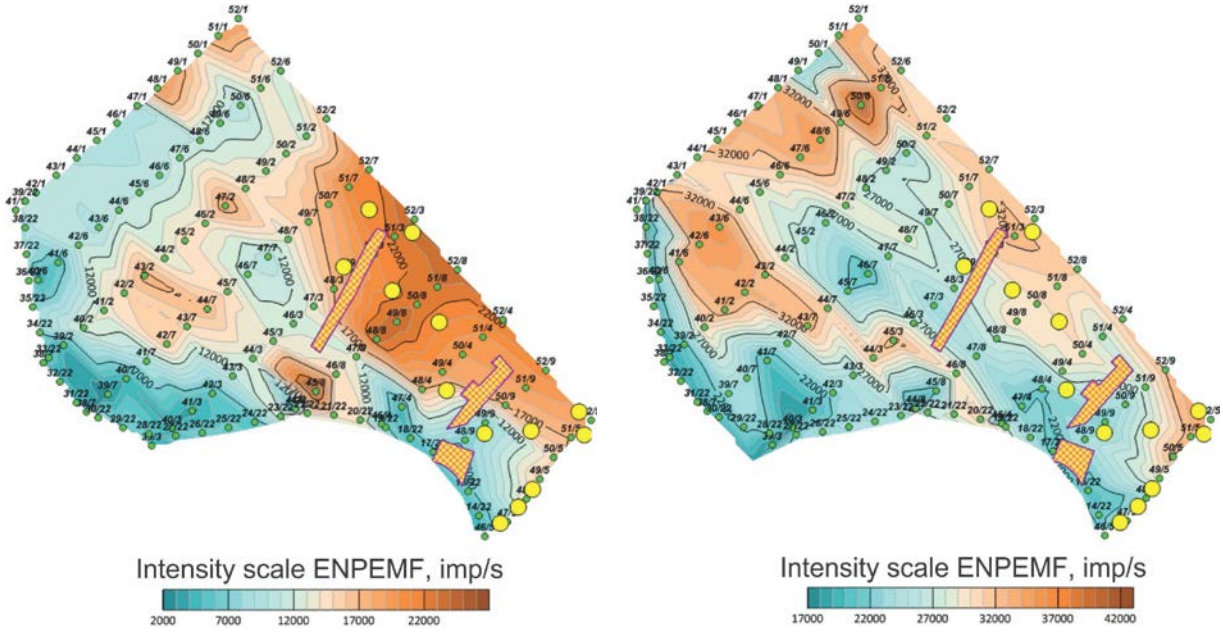


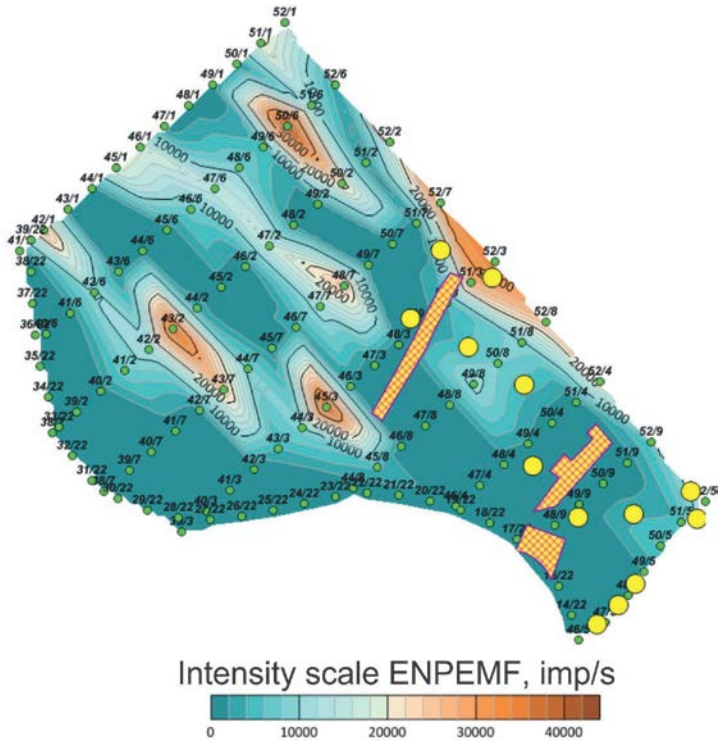
Fig. 5. The full vector of the electromagnetic field T, the area between the well № 13 – Rudnykivska and the village of Rozvadiv.



a ***b***

Fig. 6. Intensity of electromagnetic field radiation, detailed studies on the territory of the village of Rozvadiv:

a – frequency 2-16 kHz; b – frequency 16-36 kHz;



c

Fig. 6. Intensity of electromagnetic field radiation, detailed studies on the territory of the village of Rozvadiv:

c – frequency 36-50 kHz.

Study of the stress-strain state of rocks at the drilling site

To assess the stress-strain state (SSS) of rocks at the drilling site, the finite element method (FEM) . The purpose of the research is to assess the impact of a significant increase in pressure in the well (up to 50 MPa) on the state of the adjacent rock mass.

The simulation was done along a profile directed from the wells to the northeast, that is, directly to the village of Rozvadiv.

The basic physical and mechanical characteristics of the material are elastic modulus E, Poisson's ratio μ , compressive σ_M^C and tensile σ_M^P strength limits. A two-dimensional model is sufficient to describe the plane strain state. Safety Factor (SF) is selected as a parameter for assessing the SSS of the site. This parameter is determined by the equation

$$SF = \frac{[\sigma]}{\sigma_{eq}},$$

where $[\sigma]$ – maximum allowable stress; σ_{eq} – equivalent stress according to the selected strength hypothesis.

For such brittle materials as sandstones and siltstones with significantly different limits of compressive and tensile strength, Mohr's strength hypothesis is the most appropriate, according to which strength is ensured under the condition:

$$\sigma_{eq} = \sigma_1 - \nu\sigma_3 \le [\sigma] = \sigma_M^P$$

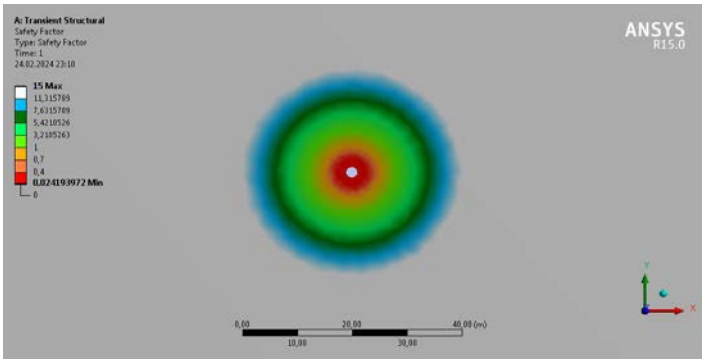
$$\nu = \frac{\sigma_M^P}{\sigma_M^C};$$

where σ_1, σ_3 – the main stress.

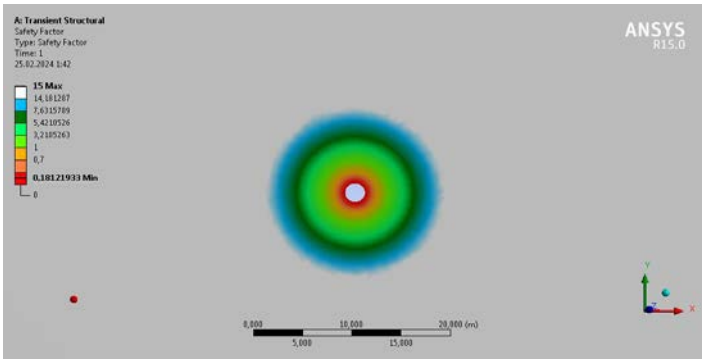
The area will have high fracturing when $SF \le 1$.

The simulation results are presented in Fig. 7.

Following the analysis of the results of the simulation of the stress-strain state of rocks for a real section (mainly siltstones and sandstones), the increase in pressure in the area during drilling extended to a distance of only 30–40 meters from the well.



a



b

Fig. 7. The effect of increasing the pressure in the well to 50 MPa on the SSS of rocks:

a – siltstone; b – sandstones.

Discussion of the results

In our opinion, the listed facts indicate that the source of gas and mud emissions is a separate near-surface and near-fault gas deposit of insignificant size.

Then the next question arises – what was the impetus for the activation of this deposit? There are three possible answers:

1) increased activity of the gas deposit uncovered by well 13 – Rudnykivska and the connection of this activity with mud volcanism;

2) regional causes (seismic activity) of the territory;

3) increase in solar activity.

Let us consider these hypotheses within their sequence.

The occurrence of an emergency in the village of Rozvadiv due to the impact of the drilling of the 13-Rudnykivska well is excluded. This has been proven by the results of gas-soil surveying, electromagnetic studies and modeling of formation pressure anomalies in the area adjacent to the well.

The analysis of the seismic activity of the territory, which includes the Rudnyky area and Rozvadiv area, shows the following. The nearest seismic station that provided information on seismic conditions is Morshyn, located approximately 40 km from the emergency area. However, on the night of April 26-27, seismic inactivity was observed at the station. Therefore, the assumption about the simultaneous impact of the seismic wave does not seem justified.

The only beyond-regional cause that can be accepted as probable is a change in solar activity, which is the same for the Rudnyky area and area of Rozvadiv. The number of sunspots changed from April 25 to April 27, 2023, from 72 to 110. This is a significant change that we have observed during our detailed research on solar activity. Our study focused on landslides, mudslides, and karst and it showed that the number of sunspots had changed rapidly three times in 2023. These changes had an impact on exogenous geological processes. Therefore, this hypothesis is not ordinary and has a right to exist, no matter how improbable it may seem.

Practical significance

The analysis of the results obtained has made it possible to identify the causes of an unusual geological event in the Rozvadiv area of the Lviv region. This event can be classified as a manifestation of mud volcanism, and its consequences can also be categorized

as such. Furthermore, it has been established that there is no correlation between the occurrence of this event and any human activity (such as drilling) in the surrounding areas.

Conclusions

The complex of experimental gas-geochemical and geophysical studies used, as well as the analysis of geological data, allows us to assess the existence of a connection between gas manifestations that were accompanied by the development of deformation processes of the earth's surface and the consequences of drilling and operation of the Rudnikovska-13 gas well. The obtained data on the maximum values of hydrocarbon gases in the soil environment within the studied area near the village of Rozvadiv demonstrate that their concentrations are ten times lower than the lower explosive limit of the hydrocarbon gas mixture. It was established that there is no clear connection between the Rudnikovskaya well – 13 and gas manifestations in the Rozvadiv.

The results of the interpretation and spatial modeling of geophysical research data using the ENPEMF method allowed for the zoning of the research area according to the degree of stress-deformed state of the rocks. Spatially, three separate zones are distinguished, which are consistent with the structural-tectonic zoning. The zone belonging to the Pre-Carpathian forward depression is the zone of the right bank of the Dniester River, where the Rudnikovska-13 well is located. The zone, which structurally belongs to the East European Platform, is located on the left bank of the Dniester River, the Rozvadiv is located here. The zone of the left bank of the Dniester River, which is affected by gas leaks in the Rozvadiv, is highlighted separately.

Absence of connection between well 13 – Rudnykivska and the anomalous field ENPEMF is noted. It is postulated that gas manifestations in the village of Rozvadiv are likely caused by the presence of a separate near-fault-near-surface gas deposit of insignificant size. This deposit is located within the junction of the Carpathian foredeep and the East European platform, which is a seismically active zone. The release of this deposit occurred in the form of gas-mud emissions and subsequent subsidence of the earth's surface. Elements of mud volcanism are unequivocally observed in this area.

During the research, an increased level of stress-strain state was observed in the village of Rozvadiv, indicating that the rock mass was not completely released. In particular, the intensity of the radiation of the electromagnetic field in the anomalous zones of the village of ruins reaches 22000 imp/s compared to background values of 5000–6000 imp/s outside the village. Therefore, further manifestations of gas emissions or subsidence of the Earth's surface are possible, but these processes will diminish over time.

Hence, any measures aimed at degassing the rock mass and reducing the risk of gas leaks to the surface are advisable. Therefore, it is logical to conclude on the necessity of monitoring similar studies in the areas of gas-mud volcanism and the expediency of conducting them under similar conditions.

References

Artym, I. V., Kurovets, S. S., Zderka,, T. V., Yarema A. V., & Kurovets, I. M. (2019) Development of the rocks fracturing model on the Carpathian region example. Conference Proceedings, *18th International Conference on Geoinformatics – Theoretical and Applied Aspects,* https://doi.org/10.3997/2214-4609.201902064 Retrieved from www.scopus.com

Bagriy, I. D., & Kuzmenko, S. O., & Uliana, Naumenko, Uliana, & Zubal, S. D.. (2019). New technology for exploration of hydrogen accumulations and forecast of geodynamic phenomena. 1–4. 10.3997/2214-4609.201903188

Bagriy, S., Kuzmenko, E., & Motkalyk, A. (2017). Prediction of karst cave-in processes at the Solotvyno rock salt deposit applying geophysical methods. The *16th International Conference Geoinformatics – Theoretical and Applied Aspects*, https://doi.org/10.3997/2214-4609.201701892 Retrieved from www.scopus.com

Baillie, J., Risk, D., Atherton, E., O'Connell, E., Fougère, C., Bourlon, E., & MacKay, K. (2019). Methane emissions from conventional and unconventional oil and gas production sites in southeastern Saskatchewan, *Canada. Environmental Research Communications*, 1(1), 011003. https://doi.org/10.1088/2515-7620/ab01f2

Busetti, M., Geletti, R., Civile, D., Sauli, C., Brancatelli, G., Forlin, E., ... & Cova, A. (2024). Geophysical evidence of a large occurrence of mud volcanoes associated with gas plumbing system in the Ross Sea (Antarctica). *Geoscience Frontiers*, 15(1), 101727., https://doi.org/10.1016/j.gsf.2023.101727

Deshchytsia, S. A., Pidvirny, O. I. Romaniuk, O. I., Sadovy, Yu. V., Kolyadenko, V. V., Savkiv, L. G., & Myshchyshyn, Yu. S. Assessment of the state of ecologically problematic objects of Kalush mining and industrial district by electromagnetic methods and their monitoring. *Science and innovations*, 5, 47–59.

Dovbnich, M. M., Stovas, G. M., & Kanin, V. O. (2012). Observations of ENPEMF and the vertical gradient of the Earth's magnetic field on the area of O. F. Zasiadko mine. Scientific works of UkrNDMI of NAS of Ukraine, 10, 342–348. (in Ukrainian).

Dyakiv, V., Pavlyuk, V., & Yaremovich, M. (2023) Geological manifestations, probable natural and

technological factors of activation of mud volcanism on the night of April 26 to 27, 2023 in the v. Rozvadiv, Striysky district, Lviv region. *Eight scientific-practical conference "Subsoil use in Ukraine. Prospects for investment"*, 473–480. (in Ukrainian).

Dzioba, U. O. (2020). Effectiveness of using the ENPEMF method for monitoring the state of the geological environment when solving applied engineering problems. *Bulletin of Odessa National University*,*25*, 2(37), 238–253. (in Ukrainian). https://doi.org/10.18524/2303-9914.2020.2(37).216574

Georozvidka LLC (2019) Detailed project of exploratory drilling on the Rudnikovskaya square (Lviv region, Ukraine). Lviv.

Gryga, M. Y., Bagriy, I. D., Starodubets, K. M., & Semenyuk, V. G. (2016, May). Geochemical data analysis and prediction of hydrocarbon accumulation in the territory of Rotmistrovka impact structure. In *15th EAGE International Conference on Geoinformatics-Theoretical and Applied Aspects* (Vol. 2016, No. 1, pp. 1–5). European Association of Geoscientists & Engineers. https://doi.org/10.3997/2214-4609.201600512.

Fedoriv V., Bagriy S., Piatkovska I., Femyak Y., Trubenko A. (2019) Petrophysic model for determin clayness of rocks by the results of complex geophysical researches. *18th International Conference on Geoinformatics – Theoretical and Applied Aspects*, https://doi.org/10.3997/2214-4609.201902116 Retrieved from www.scopus.com

Ftemov, Y. M., Fedoriv, V. V. & Maniuk, V. M. (2021) Petrophysical models for estimating filtration-capacity parameters of complex reservoir rocks at Kachalivske oil and gas condensate field. The *XXth International Conference "Geoinformatics: Theoretical and Applied Aspects*, https://doi.org/10.3997/2214-4609.20215521017 Retrieved from www.scopus.com

Kopf, A. J. (2002). Significance of mud volcanism. *Reviews of Geophysics*, 40. https://doi.org/10.1029/2000RG000093

Kuzmenko, E. D., Bahrii, S. M., & Dzioba, U. O. (2018). The depth range of the Earth's natural pulse electromagneticfield (or ENDEMF). *Journal of Geology, Geography an Geology*,27(3),466–477. https://doi.org/10.15421/111870.

Mazzini, A. (2009). Mud volcanism: Processes and implications. Marine and Petroleum Geology, 26, 1677–1680. https://doi.org/10.1016/j.marpetgeo.2009.05.003.

Oil and Gas Science and Technology Park LLC (2023) Report on the research work "Research using the methods of the pulsed electromagnetic field of the Earth and gas-soil surveying to control the stressed state of rocks and the degree of gasification of the natural environment in the territory of the village of Rozvadiv with the aim of providing recommendations on the degassing of the massif rocks and reducing the risk of leakage of gases and liquids to the surface". Ivano-Frankivsk.

Panahi, B. M. (2005). Mud Volcanism, Geodynamics and Seismicity of Azerbaijan and the Caspian Sea Region. In: Martinelli, G., Panahi, B. (eds) Mud Volcanoes, *Geodynamics and Seismicity. NATO Science Serie*s, vol 51. Springer, Dordrecht. https://doi.org/10.1007/1-4020-3204-8_7

Riznychuk, A. I., Famyak, Ya. M., Fedoriv, V. V., Charkovskyi, V. M., Deineha, R. O. & Stetsiuk, R. B. (2021) Technical and technological solutions to prevent destruction of the walls of directional wells in the mining and geological conditions of Ukrainian fields. Conference Proceedings, *15th International Conference Monitoring of Geological Processes and Ecological Condition of the Environment*, https://doi.org/10.3997/2214-4609.20215K2041 Retrieved from www.scopus.com

Sechman, H., Mościcki, W. J., & Dzieniewicz, M. (2013). Pollution of near-surface zone in the vicinity of gas wells. *Geoderma*, 197, 193–204. https://doi.org/10.1016/j.geoderma.2013.01.012

Sechman, H. (2022). Detailed analysis of gaseous components in soil gases around petroleum wells-An effective tool for evaluation of their integrity. *Applied Geochemistry*, 142, 105346. https://doi.org/10.1016/j.apgeochem.2022.105346

Schütze, C., Vienken, T., Werban, U., Dietrich, P., Finizola, A., & Leven, C. (2012). Joint application of geophysical methods and Direct Push-soil gas surveys for the improved delineation of buried fault zones. *Journal of Applied Geophysics*, *82*, 129–136. https://doi.org/10.1016/j.jappgeo.2012.03.002

Toutain, J. P., & Baubron, J. C. (1999). Gas geochemistry and seismotectonics: a review. *Tectonophysics*, 304(1-2), 1–27. https://doi.org/10.1016/S0040-1951(98)00295-9.

Yarema A. V., Zderka T. V., Kurovets S. S., Khovanets N. P. (2020) Gas-geochemical predicting and system assessment of oil and gas prospects for the purpose of increasing exploration efficiency. *Geoinformatics: Theoretical and Applied Aspects 2020*, https://doi.org/10.3997/2214-4609.2020geo148 Retrieved from www.scopus.com

Vyzhva, Serhii, & Solovyov, I., & Mykhalevych, I., & Kruhlyk, Viktoriia, & Lisny, G. (2021). Use of direct hydrocarbon indicators for forecasting hydrocarbons deposits. 1–5. https://doi.org/10.3997/2214-4609.20215K2109

Zarroca, M., Linares, R., Bach, J., Roqué, C., Moreno, V., Font, L., & Baixeras, C. (2012). Integrated geophysics and soil gas profiles as a tool to characterize active faults: the Amer fault example (Pyrenees, NE Spain). *Environmental Earth Sciences*, *67*, 889–910. https://doi.org/10.1007/s12665-012-1537-y

Едуард КУЗЬМЕНКО[1а], Ігор ЧУДИК[2], Сергій БАГРІЙ[1б], Андрій ЯРЕМА[3], Юрій НЕСПЛЯК[4], Ігор ЧЕПУРНИЙ[1в] Володимир АРТИМ[5]

[1] Кафедра Геодезії та землеустрою, Івано-Франківський національний технічний університет нафти і газу, вул. Карпатська 15, Івано-Франківськ, 76019, Україна, тел. +38(0342)50-47-61, ел. пошта: gbg2020@ukr.net; [1а] https://orcid.org/0000-0002-1994-0970, [1б] https://orcid.org/0000-0003-1190-6222, [1в] https://orcid.org/0000-0003-2109-3827

[2] Ректор, Івано-Франківський національний технічний університет нафти і газу, вул. Карпатська 15, Івано-Франківськ, 76019, Україна, тел. +380 (342) 72-47-16, ел. пошта: rector@nung.edu.ua; https://orcid.org/0000-0002-7402-6962

[3] Кафедра Геології та розвідки нафтових і газових родовищ, Івано-Франківський національний технічний університет нафти і газу, вул. Карпатська 15, Івано-Франківськ, 76019,Україна, тел. +38 (0342) 72-71-21, ел. пошта: 05.03.1982@ukr.net

[4] Кафедра Буріння свердловин, Івано-Франківський національний технічний університет нафти і газу, вул. Карпатська 15, Івано-Франківськ, Україна, 76019, тел. +38 0342 72-71-37, ел. пошта: y.nespliak@gaz.net.ua;

[5] Кафедра Будівництва та енергоефективних споруд, Івано-Франківський національний технічний університет нафти і газу, вул. Карпатська 15, Івано-Франківськ, 76019,Україна, тел. +38 (0342)57-24-04, ел. пошта: viartym@gmail.com; https://orc id.org/0000-0002-8938-552X

ГАЗОГРУНТОВІ ТА ГЕОФІЗИЧНІ ДОСЛІДЖЕННЯ РОЗВАДІВСЬКОЇ ЗОНИ АКТИВІЗАЦІЇ ГРЯЗЬОВОГО ВУЛКАНІЗМУ (ЛЬВІВСЬКА ОБЛАСТЬ, УКРАЇНА)

Метою досліджень є обґрунтування наукових засад виникнення грязьового вулкану в межах конкретної ділянки Передкарпатського прогину у звязку з наявністю природломного малоглибинного газового покладу на Розвадівській площі та відображення його елементів у полях газогрунтової зйомки та електрометрії. Актуальність роботи визначається необхідністю вирішення екологічної проблеми забруднення навколишнього середовища вуглеводневими газами, а також встановлення та прогнозування ступеня викидів газогрязевої суміші. При цьому вирішується задача наявності (чи відсутності) зв`язку впливу, порушеного за рахунок розбурювання Рудниківської газоперспективної площі та зазначеного Розвадівського покладу шляхом співставлення результатів газогрунтової та геофізичної зйомок в значному регіоні, що охоплює зазначені площі. Методика досліджень полягає: 1) у застосуванні досліджень із різним фізичним обгрунтуванням (газогрунтова зйомка та електрометрія); 2) порівнянні результатів зйомок, виконаних на одній площі та по однаковій сітці спостережень; 3)виявленні аномалій у межах дослідженої території та їх тлумачення з точки зору розвитку грязьового вулканізму. Результати досліджень. Інформаційну основу гозометрії складають безпосередні виміри вільного газу в регулярній системі спостережень в атмосфері грунтового середовища, їх статистичні характеристики та розрахункові показники загазованості. Тому, карти розподілу загазованості є інформативними. Застосовані дослідження методом природного імпульсного електромагнітного поля Землі дозволили диференціювати площу за ступенем інтенсивності електромагнітного випромінювання, зважаючи на різну глибинність джерел і, таким чином, виявити ділянки напружено-деформованого стану гірських порід та кваліфікувати їх у відповідності з причинами. Наукова новизна полягає у наступному: 1) у зазначенні відсутності зв’язків між порушеним за рахунок буріння масивом та природним катаклізмом; 2) у зазначенні причин природного катаклізму і його обгрунтованому механізмі та класифікації події як грязьового вулкану. Практична значущість. Інтерпретація одержаних результатів дає можливість визначити причини надзвичайної геологічної події на Розвадівській площі Львівської області, класифікувати подію та її наслідки як прояв елементів грязьового вулканізму, встановити відсутність зв`язку зазначеної події з техногенним порушенням (бурінням) геологічного середовища на сусідніх ділянках.

Ключові слова: газогрунтова зйомка, інтенсивність випромінювання електромагнітного поля, напружений стан, гірничий масив, деформації, свердловина, грязьовий вулкан.

Received 11.03.2024