https://doi.org/10.26565/2410-7360-2024-61-06
UDC 550.34+550.42

Received 2 October 2024
Accepted 10 November 2024

Impact of the Petrivsko-Kreminsky deep fault on the fluid migration in rocks of the Svyatohirsk brachyanticline

Anton Pyvovarov
MSc (Earth Science), V. N. Karazin Kharkiv National University, Kharkiv, Ukraine,
e-mail: anton.pyvovarov.2002@gmail.com, https://orcid.org/0009-0005-5188-5472

ABSTRACT

Introduction. Deep regional faults serves as primary pathways for fluid mass migration in the Dnipro-Donetsk aulacogen, particularly affecting fold faults and anticline structures. The interaction between heated fluid migration and structural development is evident in the Svyatohirsk brachyanticline structure and the Petrivsko-Kreminsky deep fault, where numerous geochemical and thermohydrodynamic inversions demonstrate their systematic influence on adjacent structures.

Problem definition. This study examines how the Petrivsko-Kreminsky deep fault and its secondary fractures impact hydrogeochemical and thermohydrogeodynamic processes in the Svyatohirsko-Kamyanska deposit area. The periodic tectonic activation of crustal-mantle centers intensifies heat and mass transfer in fluid flows, particularly in unloading zones along deep faults, where rapid and impulsive migration of heated fluid masses occurs, transporting rock particles and charged ions from underlying strata and the basement.

Purpose of the article. The research aims to analyze the impact of the Petrivsko-Kreminsky regional deep fault on the Svyatohirsk brachyanticline structure and its associated geological processes, focusing on the mechanisms of fluid migration and their influence on rock formations.

Analysis of recent research. Previous studies have documented significant thermohydrodynamic anomalies in Upper Cretaceous sediments, with temperatures ranging from 23°C to 27°C compared to background temperatures of 10°C to 12°C.

Tectonical configuration. The Svyatohirsk brachyanticline, formed during the Palatinate phase of Hercynian tectogenesis, contains numerous discontinuous faults attached to the Petrivsko-Kreminsky deep fault. Modern tectonic movements are reflected in varying uplift rates: 1.4-2.9 mm/year for the hanging wing and 5.2-11.1 mm/year for the lying wing, creating visible relief differences.

Deep fault impact on fluid migration. These fault structures facilitate vertical fluid and heat flow migration from deeper crustal and mantle layers. This results in localization of hydrogeochemical inversions, evidenced by groundwater enrichment with endogenous elements (helium, radon, argon, CO2). The isotopic composition ($\delta^{13}C$: 5-8‰) indicates thermometamorphic origin and deep degassing processes from the mantle. The activity of deep faults has impacted the lithological composition, increasing reservoir rock density through pyritization, ferruginousness, secondary quartz, and carbonation processes.

Geological model and practical significance. Deep-seated fractures act as conduits for heated fluid migration, disrupting natural thermal gradients and causing thermohydrogeodynamic inversions. These processes contribute to secondary mineralization and cementation of fracture networks within reservoir rocks, significantly influencing the region's lithological characteristics. The model reveals that during both current and future tectonic activations, this process will continue intermittently, though with progressively less impact on the cement substance, while leading to accumulation of endogenous gas. The correlation between inversions and tectonic structures offers significant potential for identifying geological features and predicting hydrocarbon accumulations, particularly in areas where deep fault zones intersect with anticline structures.

Keywords: *Svyatohirsk brachyanticline, Petrivsko-Kremisnky deep fault, fluid migration, heated fluid flows, thermos- and mass- migration.*

In cites: Pyvovarov Anton (2024). Impact of the Petrivsko-Kreminsky deep fault on the fluid migration in rocks of the Svyatohirsk brachyanticline. Visnyk of V. N. Karazin Kharkiv National University, series "Geology. Geography. Ecology", (61), 76-84. https://doi.org/10.26565/2410-7360-2024-61-06

Introduction. Deep regional faults are the primary pathways for the migration of fluid masses. The Dnipro-Donetsk aulacogen is characterized by the co-sedimentary development of various geological structures, including anticlines, monoclines, and faulting, with notable disjunctive apophyses of deep faults. Throughout its entire history of formation and development, deep faults have exerted a continuous and systematic influence on adjacent structures. This impact is particularly pronounced in fold faults, especially anticline structures, which significantly contribute to the accumulation of transported fluid flows [1].

The interaction between the migration of heated fluid masses and the further development of structures, both lithologic-facies and geodynamic, is clearly evident in the case of the Svyatohirsk brachyanticline structure and the Petrivsko-Kreminsky fault. This interaction is substantiated by the presence of numerous manifestations of geochemical and thermohydrodynamic inversions within the brachyanticline.

Thus, comprehending the continuous and systemic interaction between deep faults and anticline structures is a crucial element in modeling the lithologic and structural features of the region. A thorough correlation analysis is necessary for the accurate prediction of the fluid dynamic parameters of rocks and structures that are influenced by regional deep faults.

Problem definition. Previous studies have indicated that the location of the Svyatohirsk structure on the anticline is a fundamental factor in the formation of the features and composition of Lower Permian and Carboniferous sediments [1]. However, the author argues that the periodic tectonic activation of crustal-mantle centers, associated with the Svyatohirsk brachyanticline structure and its adjacent areas, amplifies the ongoing processes of heat and mass transfer in fluid flows. These processes are particularly intensified in the unloading zones formed along deep faults, which facilitate the rapid and impulsive migration of heated fluid masses. These fluids transport rock particles from underlying strata and the basement, along with charged ions, in the form of heat. This mechanism is central to establishing a plausible model of the Svyatohirsk structure [5].

Purpose of the article. The purpose of this article is to examine the impact of the Petrivsko-Kreminsky regional deep fault on the Svyatohirsk brachyanticline.

Analysis of recent research. The presence of regional deep faults and their impact on other intra-aulacogenic structures has been substantiated in the scientific publications of V. Suyarko, O. Bartashchuk, and V. Gavrysh. V. Sukhov conducted direct practical research on the Svyatohirsk brachyanticline, during which he identified thermohydrodynamic anomalies in the Upper Cretaceous sediments (K_2) [5].

Tectonical configuration. The Svyatohirsk brachyanticline is an integral component of the Dnipro-Donetsk paleorift, situated in its southeastern part, and represents a Paleozoic fold formed through consedimentary development. This structure was created during the Palatinate phase of Hercynian tectogenesis and subsequently underwent several stages of evolution during sedimentation in the Paleozoic, Mesozoic, and Cenozoic eras [9].

In relation to the Paleozoic sediments, the Svyatohirsk brachyanticline structure is conventionally located within the Pivnichno-Volvenkivsko-Torsko-Drobyshivske anticline, which contributed to the formation of the Kamyanska, Spivakivska, Torsko-Drobyshivska, Pivnichno-Volvenkivska, and Svyatohirsk anticlines. The anticline is bordered to the north by the Bilohirsko-Kamyanskyi trough and to the south by the Komyshuvachsko-Lymanska syncline.

Seismic surveys conducted by JSC Ukrgasvydobuvannya have identified numerous discontinuous faults, likely to be disjunct apophyses of the Petrivsko-Kreminsky deep fault [5]. These findings are complemented by the author’s research, which mapped the presence of discontinuous deep faults within the Kamyanska brachyantic fault, part of the Svyatohirsk region (Fig. 1).

Correlation of the lineaments and deep faults. It is well-established that riverbeds are often aligned along fracture zones in the Earth's crust, which are the result of deep faults originating from the mantle. In the study area, two major rivers – the Syverskyi Donets and the Oskil – are present, with

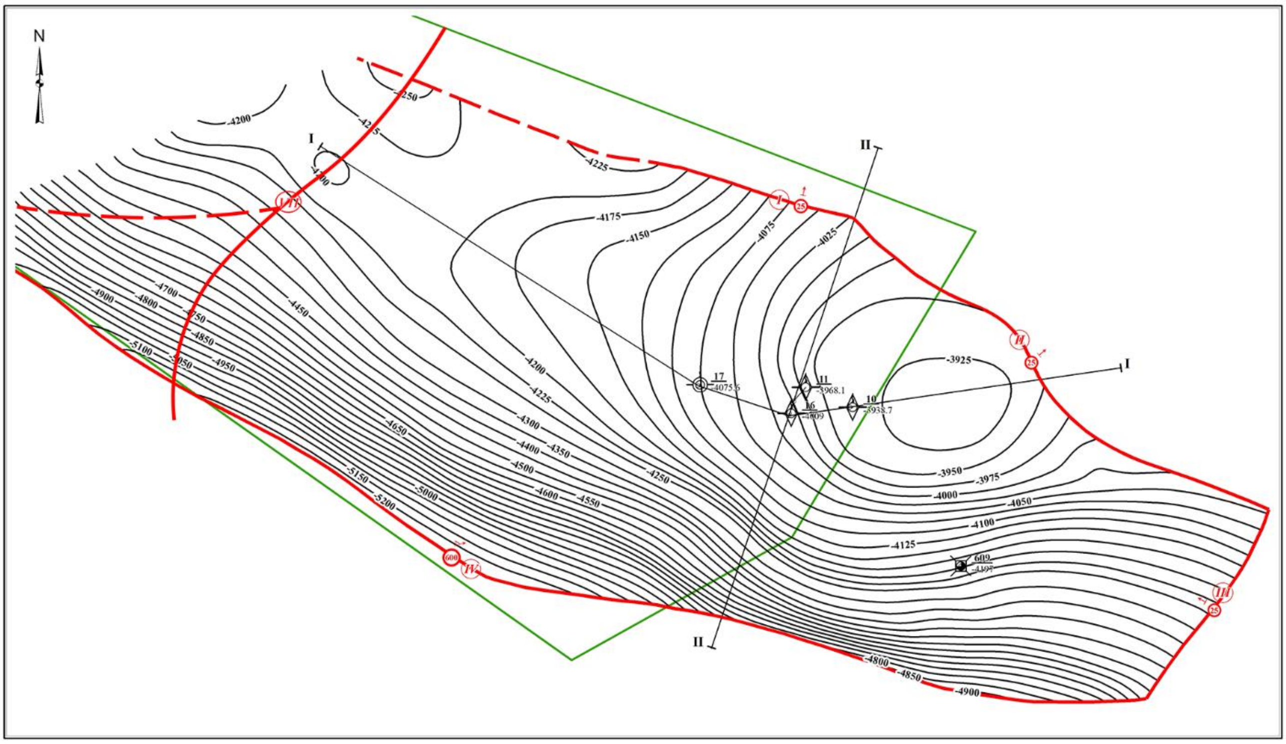

Fig. 1. Structural map of the Svyatohirsk Brachyanticline
(based on UkrNDIGas materials (year 2019) with additions by the author (year 2021))

the former being a tributary of the latter. This suggests that the riverbeds coincide with a point where two multidirectional fault zones intersect, corresponding to the courses of these rivers (Fig. 2) [3].

According to the classification of deep faults in the Dnipro-Donetsk aulacogen, the Petrivsko-Kreminsky fault is categorized as a deep fault (as per V. Suyarko [7]) and plays a crucial role in controlling upward fluid flows and geodynamic stresses, including those affecting the Svyatohirsk brachyanticline. The existence of this fault is corroborated by the spatial orientation of cracks, which are perpendicular to the directions of geodynamic stresses that have occurred during various stages of tectonic activation of the structure.

Modern tectonic movements are reflected in the varying rates of uplift of the wings of the brachyanticline: the hanging wing rises at a rate of 1.4–2.9 mm/year, while the lying wing rises at a rate of 5.2–11.1 mm/year, a difference that is clearly visible in the relief of the region [5]. Earlier studies suggested that the location of the Svyatohirsk structure on the anticline was the main factor influencing the formation of the features and composition of Lower Permian and coal deposits. However, the authors propose that the periodic tectonic activation of crustal-mantle centers near the Svyatohirsk brachyanticline promotes the heat and mass transfer of fluid flows in the unloading zones created by deep faults. These faults facilitate the impulsive migration of heated fluid masses, which transport rock particles from underlying strata and the basement, as well as energetically charged ions in the form of heat [4, 5].

Geochemical and thermohydrogeodynamic inversions are the result of deep fault activity, which saturates aquifers with endogenous fluids and heat flows. Water from shallow wells within the Svyatohirsk brachyanticline demonstrates hydrogeodynamic inversion, characterized by increased concentrations of chlorides and trace elements of deep origin (such as mercury, helium, argon, iodine, bromine, etc.), as well as significant pressure in the hydrogeothermal field.

The activity of deep faults has also impacted the lithological composition of the region, increasing the density of reservoir rocks, particularly sandstones. This is evidenced by the composition of their cement mass, which includes pyritization, ferruginousness, secondary quartz, and carbonation.

The deep fault impact for a fluid migration. The influence of the Petrivsko-Kreminsky fault and its numerous disjuncts results in a hydraulic connection between all aquifer complexes, facilitated by the vertical discharge of fluids along the faults. Tectonogenic fractures act as conduits for the migration of fluid masses, which are accelerated by the mantle heat flow, thereby activating convection processes within the aquifers. This process is accompanied by dehydration and secondary mineralization of cement, leading to the observed hydrogeochemical inversion in the Svyatohirsk area [8].

Research conducted by V. Suyarko and V. Sukh-

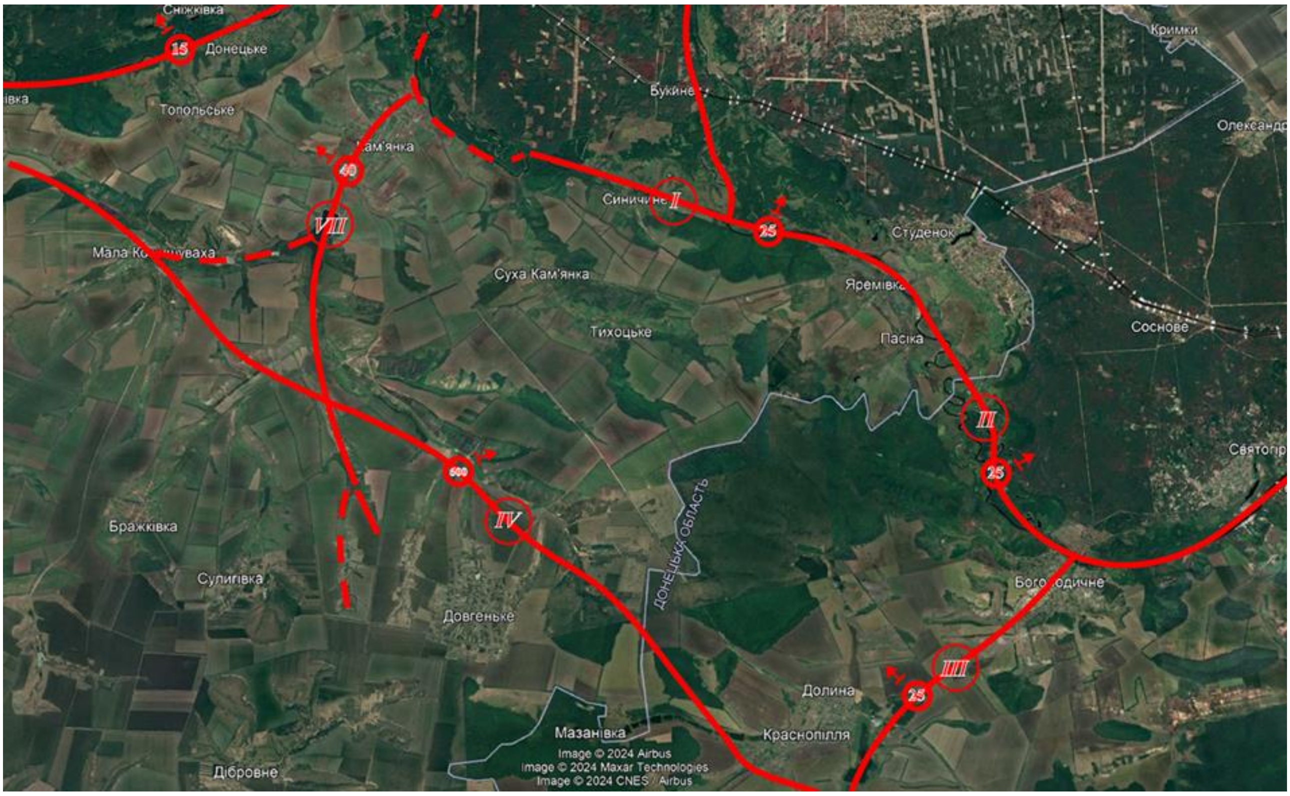

Fig. 2. Schematic diagram of the location of tectonic fault zones and their correlation with linearities on satellite images (made by Anton Pyvovarov, 2024)

khov identified thermohydrodynamic anomalies in Cretaceous and Jurassic rocks, with temperatures ranging from 23–27°C compared to a background temperature of 10–12°C. These findings confirm the high activity of the hydrogeothermal field [5]. Such anomalies accelerate catagenetic and metagenetic changes in rocks and promote the secondary cementation of fractures formed during the tectonic activation of the Laramide phase.

Geological model. Metamorphogenic fluids migrating along unloading zones create hypogenic anomalies in the overlying aquifer complexes, as evidenced by the presence of helium, radon, argon, and CO_2 in groundwater [5]. A distinctive feature of hydrogeothermal processes is the saturation of fractures with carbonate-clay cement, which results from the reaction between underlying carbonate rocks and mantle-derived CO_2.

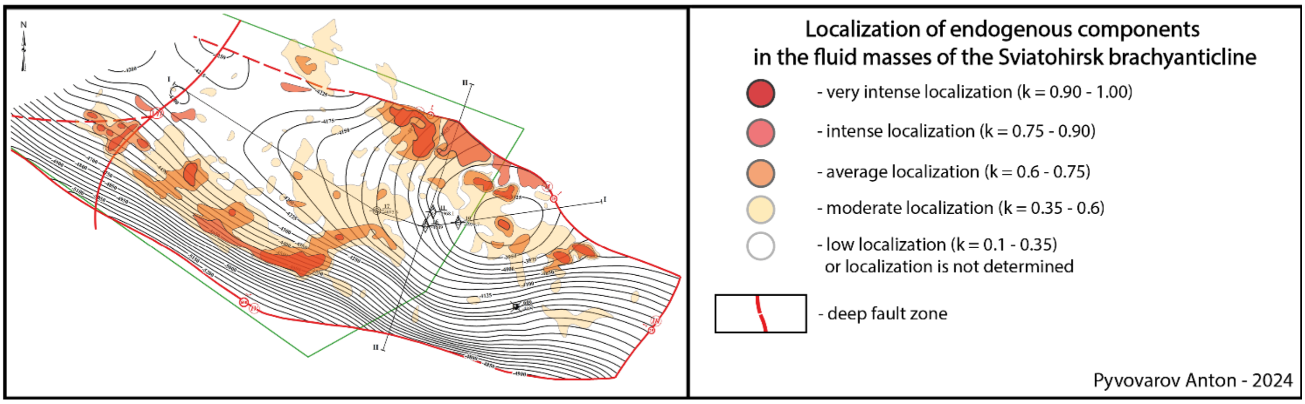

Fig. 3. Schematic map of the localization of endogenous components in the ascending fluid flows of the Svyatohirsk brachyanticline (by Anton Pyvovarov, 2024)

The concentration of CO_2 increases with depth, indicating its endogenous origin, which is characteristic of fluids of thermal genesis, such as metamorphic, hydrothermal, volcanic, and catagenetic fluids. Its isotopic composition ($\delta^{13}C$: 5-8‰) is consistent with methane carbon (CH_4), confirming mantle degassing and thermometamorphic genesis [4, 9].

The dissolution of endogenous components and their localization in depressional zones signals interval-impulsive tectonic activation and provides evidence for the deep origin of certain hydrocarbons within the Svyatohirsk brachyanticline (Fig. 3). The presence of reservoir rocks and dense fluid reservoirs has facilitated the accumulation of migrated fluids.

Considering the numerical predominance of disjunctive structures and the significant influence of the Petrivsko-Kreminsky fault, the hydraulic interconnectivity of all aquifer complexes has been established. This connectivity arises from vertical unloading along fault zones, facilitating the migration of fluid masses through fractures of tectonic origin. These migrations are intensified by mantle-derived heat flows, which trigger conventional geochemical processes upon entering overlying aquifers. Such processes are characterized by dehydration and the secondary redistribution of minerals into the cement matrix. Consequently, hydrogeochemical inversion of groundwater is observed in the regions of the Svyatohirsk and Kamyanska brachyanticlines [15].

The hydrogeochemical inversion induced by the migration of mantle-derived heated fluids facilitated secondary alterations in the lithological composition of the Carboniferous reservoir cement matrix. This is particularly evidenced by the presence of carbonate cement with a high concentration of carbon dioxide (CO_2) enriched in heavy carbon isotopes ($\delta^{13}C$). This geochemical inversion also triggered substantial secondary cementation of tectonic fractures formed during the Palatinate tectogenesis. Supporting this, the uneven distribution of porosity and fracture zones along the Petrivsko-Kreminsky fault highlights the role of these processes. Moreover, the territory of brachyanticlines exhibits scattered, irregular, and anomalous porosity localization, underscoring the influence of ascending flows of heated hydrothermal fluids. These processes ultimately resulted in the occlusion and dense cementation of fractures with carbonate and pyritized-iron cement.

The interdependence between tectonic activation and fluid migration, followed by temporary fluid localization, is a key factor influencing the gas content of the Svyatohirsk brachyanticline. The upward movement of thermal masses, transporting heated fluids enriched with endogenous components from deeper strata, reacts with the formations they pass through (primarily due to temperature) and accumulates in the reservoir formations. During periods of relative dormancy, these fluid masses interact with the surrounding rocks, becoming integrated into the hydrogeochemical and geodynamic systems of the region [29, 30, 34].

Secondary reactions can affect the temperature regime of the reservoir. The temperature difference between the lower and upper parts of the formation leads to convective fluid movements within the reservoir. Additionally, excessive subcapillary pressure is generated, pushing the fluid to the point of maximum resistance. If the reservoir is isolated, these processes create zones of abnormal reservoir pressure (ARP), which are common in the Svyatohirsk brachyanticline. If the reservoir is not isolated, hydraulic forces induce vertical and, when ARP is released, laminar-vertical fluid flows (including oil and gas) from lower to upper aquifer complexes. These flows form hydrogeochemical anomalies and accumulate in the next reservoir [16].

During both current and future tectonic activations, this process will continue intermittently, though with progressively less impact on the cement substance (due to the prior erosion of "rapid migration" channels in unloading zones), while leading to an accumulation of endogenous gas. Traps that have already accumulated gas will undergo further intermittent, short-term degassing due to the temporary depressurization of the existing fluid traps (Fig. 4).

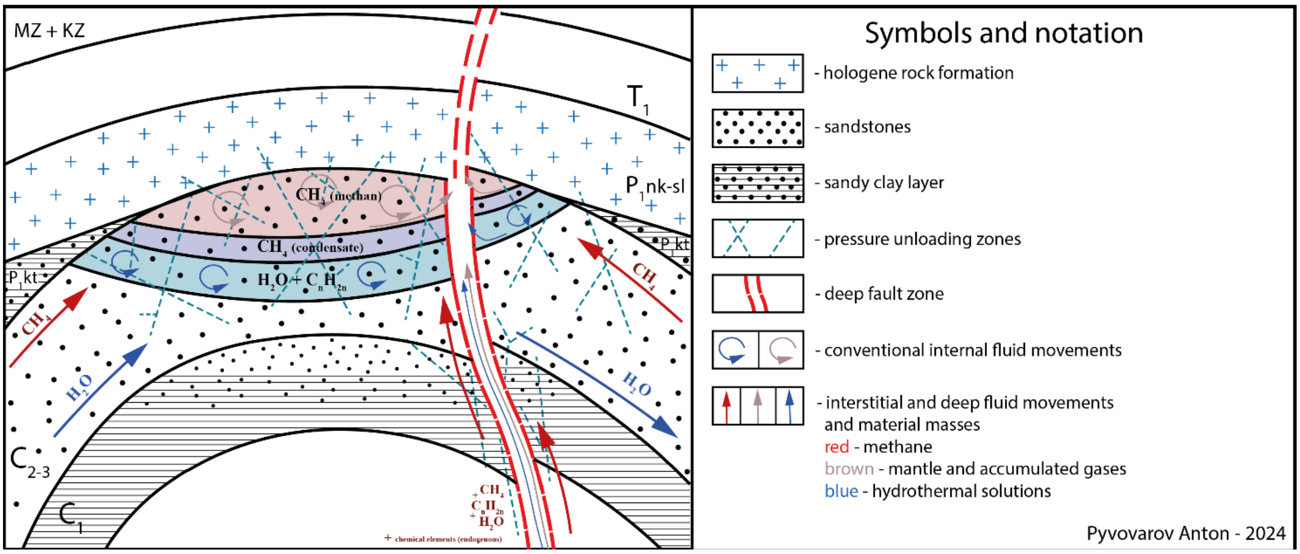

Fig. 4. Schematic model of hydrocarbon accumulation formation within the Sviatohirsk brachyanticline (by Anton Pyvovarov, 2024)

The practical significance. The geological model and methodology for correlating inversions with tectonic structures offer significant potential for identifying geological features and processes within the Earth's crust. By analyzing and correlating various types of inversions, this approach aids in the identification and prediction of hydrocarbon accumulations.

The geodynamic activation of regional deep fault zones is intrinsically linked to centers of heat and mass transfer within the mantle-crustal interface. These processes are driven by degassing phenomena and thermal activity originating from crustal-mantle centers. Such activation induces significant anomalies in geological and hydrogeochemical systems, fostering the development of localized hydrocarbon accumulation zones within anticline structures. Furthermore, these processes facilitate the lithological and petrographic evolution of such zones, characterized by enrichment with hydrothermal solutions that alter the mineralogical and structural composition of the host rocks [17].

A schematic map (Fig. 5) has been developed to delineate the predicted areas for further exploration and prospecting activities. This map incorporates the following key factors:

- The location of hydrogeological complexes relative to deep fault zones;
- Indicators of fracture and pore space within productive horizons;
- Enrichment of aquifer fluids with endogenous components;
- Geochemical types of aquifer complexes;
- Thermohydrodynamic parameters in relation to the zones of disjunctive faults;
- Correlation between hydrogeochemical and thermohydrodynamic inversions;
- Lithological and petrographic composition of reservoir rocks, with particular focus on the filling of fracture and pore spaces with regenerative and clay-carbonate cement.

Conclusions. The research has demonstrated that the fluid dynamic interaction between the brachyanticline structure and the deep fault, along with its apophyses in the form of secondary disjuncts, results in geochemical and thermohydrogeodynamic inversions. These inversions are driven by heat flows and mantle degassing, which facilitate the interaction between oscillatory and folding movements and fluid migration along depressional zones. Deep faults play a critical role in transporting upward heated fluid masses, leading to hydrogeoche-

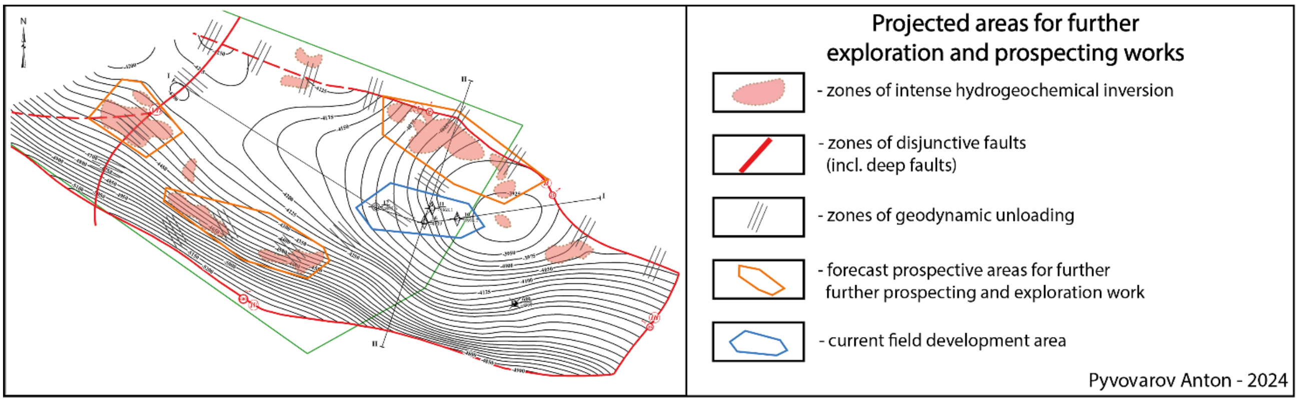

Fig. 5. Schematic map of the projected areas for further exploration and prospecting within the Svyatohirsk brachyanticline (by Anton Pyvovarov, 2024)

chemical anomalies. The heating and disruption of the natural thermal gradient generate thermohydrogeodynamic inversions. The unique lithological composition of the reservoir rocks is characterized by significant cementation of tectonogenic fractures, likely originating during the Palatinate phase of Hercynian tectogenesis, with secondary cementation occurring due to the influence of powerful or localized tectonic activations.

The interplay of hydrogeochemical and thermodynamic inversions has also contributed to lithological transformations, notably the secondary cementation of tectonogenic fractures. These fractures, formed during and after the Palatinate phase of tectonic activation, were progressively sealed by migrating fluid masses. Changes in thermobaric conditions during the post-Laramie tectonic phase further exacerbated this process, resulting in a pronounced decline in porosity and permeability. Hydrothermal anomalies are evident along the entire extent of the Petrivsko-Kreminskyi deep fault zone. The enrichment of aquifer complexes with endogenous components–such as the heavy isotope ^{13}C, mercury, bromine, and iodine–may serve as indicators of abiogenic hydrocarbon presence. Furthermore, the interval saturation of hydrocarbons is attributed to mantle degassing, which occurs due to the unblocking of migration pathways and the establishment of mantle-crustal heat and mass transfer centers.

A comprehensive understanding of the model's principles, mechanisms, and specific features governing hydrocarbon accumulation within the Svyatohirsk brachyanticline is essential for advancing research on hydrocarbon genesis. This knowledge is critical for predicting potential hydrocarbon-bearing structures not only within the Dnipro-Donetsk Basin but also in other geological contexts worldwide.

Refinement and detailed parameterization of the current model can enhance its applicability to diverse geological formations. This could also substantiate the existence of abiogenic hydrocarbons within geological structures influenced by deep fault zones, frequently observed as lineaments. Such findings could significantly impact hydrocarbon exploration strategies and expand theoretical frameworks for understanding hydrocarbon origins.

Список використаної літератури

1. *Бартащук О. В., Суярко В. Г. Горизонтальні переміщення геомас у континентальних рифтових геоструктурах (на прикладі Дніпровсько-Донецького палеорифту). Частина 1: Структурні прояви тектонічної течії в фундаменті. Вісник Харківського національного університету імені В. Н. Каразіна, серія «Геологія. Географія. Екологія». 2018. № 49. С. 10-23. DOI: https://doi.org/10.26565/2410-7360-2018-49-02*
2. *Гавриш В. К. Глубинное строение и эволюция Припятско-Днепровско-Донецкого и Кенийского рифтов. Тезисы докладов 27-го МГК, Секция 07 Тектоника. Москва: Наука, 1984. Т. 3. С. 207-208.*
3. *Бартащук О. Системна організація диз'юнктивної тектоніки консолідованого фундаменту Дніпровсько-Донецького палеорифту. Частина 1: Лінеаменти. Вісник ХНУ. Серія «Геологія, географія, екологія». 2016. Вип. 45. С. 14-22. DOI: https://doi.org/10.26565/2410-7360-2016-45-02*
4. *Helgeson H. C. Thermodynamics of hydrothermal systems at elevated temperatures and pressures. Amer. J. Sci. 1969. Vol. 267. P. 729-804. DOI: https://doi.org/10.2475/ajs.267.7.729*
5. *Сухов В. В. Гідрогеологічні особливості розвитку суфозії та карсту карбонатних порід на території Святогірського історико-архітектурного комплексу: дис. ... канд. геол. наук. Харків, 2016. 157 с.*
6. *Белоконь В. Г. Неотектонические движения в Донбассе и их связь со структурными элементами. Материалы по геологии Донецкого бассейна. Москва: Наука, 1968. С. 11-15.*
7. *Суярко В. Г., Гаврилюк О. В. Про джерела надходження та міграцію брому у підземних водах (на прикладі Дніпровсько-Донецького авлакогену). Вісник Харківського національного університету імені В. Н. Каразіна.*

Серія: «Геологія. Географія. Екологія». 2014. № 41(1128). С. 70-75. DOI: https://doi.org/10.26565/2410-7360-2014-41-11
8. *Суярко В. Г. Прогнозування, пошук та розвідка родовищ вуглеводнів: підручник. Харків: Фоліо, 2015. 26 с.*
9. *Гавриш В. К. Роль глубинных разломов в формировании структур Днепровско-Донецкой впадины. Геологический журнал. 1965. Т. 25. № 6. С. 13-21.*
10. *Cowie P. A., Roberts G. P. Tectonic Faults: Causes, Mechanisms and Consequences. Wiley-Blackwell, 2001.*
11. *Brown G. C., Taylor S. D. Hydrothermal systems and geochemistry: Fluid migration along faults and the formation of mineral deposits. Earth-Science Reviews. 2007. Vol. 83, No. 3-4. P. 145-174. DOI: https://doi.org/10.1016/j.earscirev.2007.04.002*
12. *Lister G. S., Davis G. H. The origin of metamorphic core complexes and detachment faults. Journal of Structural Geology. 1989. Vol. 11, No. 1. P. 65-94. DOI: https://doi.org/10.1016/0191-8141(89)90036-9*
13. *Menzies M., Cox M. The Tectonic Evolution of Continental Rifts. Geological Society Special Publication. 2015. Vol. 249. P. 75-101. DOI: https://doi.org/10.1144/GSL.SP.2005.249.01.05*
14. *Peacock D. C. P., Sanderson D. J. Displacement Transforms and the Aseismic Faulting Process. Journal of Structural Geology. 1991. Vol. 13, No. 6. P. 747-752. DOI: https://doi.org/10.1016/0191-8141(91)90033-F*
15. *Corti G., Bonini M. Fault Evolution and Fluid Migration in Continental Rifts: Evidence from the East African Rift. Journal of Geophysical Research: Solid Earth. 2003. Vol. 108, No. B11. P. 2509. DOI: https://doi.org/10.1029/2002JB002166*
16. *Ingram M., Manning C. Fluid Flow Along Fault Zones in the San Andreas Fault System. Tectonophysics. 2000. Vol. 324, No. 1-4. P. 161-172. DOI: https://doi.org/10.1016/S0040-1951(00)00117-X*
17. *Morrow C. A., Knipe R. J. Fault-Related Rocks: A Photographic Atlas. Wiley-Blackwell, 2015.*
18. *Sibson R. H. Structural permeability of fluid-driven fault-fracture meshes. Journal of Structural Geology. 1996. Vol. 18, No. 8. P. 1031-1042. DOI: https://doi.org/10.1016/0191-8141(96)00032-6*
19. *Faulkner D. R., Jackson C. A.-L., Lunn R. J. et al. A review of recent developments concerning the structure, mechanics, and fluid flow properties of fault zones. Journal of Structural Geology. 2010. Vol. 32, No. 11. P. 1557-1575. DOI: https://doi.org/10.1016/j.jsg.2010.06.009*
20. *Miller S. A., Nur A., Olgaard D. L. Earthquakes as a coupled shear stress-high pore pressure dynamical system. Geophysical Research Letters. 1996. Vol. 23, No. 2. P. 197-200. DOI: https://doi.org/10.1029/95GL03691*
21. *Scholz C. H. The Mechanics of Earthquakes and Faulting. 2nd ed. Cambridge University Press, 2002.*
22. *Taira A., Hill M., Firth J. et al. Sediment deformation and fluid migration in the Nankai Accretionary Prism. Proceedings of the Ocean Drilling Program, Scientific Results. 1992. Vol. 131. P. 88-103. DOI: https://doi.org/10.2973/odp.proc.sr.131.131.1992*
23. *Tobin H. J., Saffer D. M. Elevated fluid pressure and extreme mechanical weakness of a plate-boundary fault. Nature. 2009. Vol. 449, No. 7164. P. 76-78. DOI: https://doi.org/10.1038/nature06064*
24. *Wibberley C. A. J., Shimamoto T. Internal structure and permeability of major fault zones: The outcrop study from the Median Tectonic Line in Mie Prefecture, Southwest Japan. Journal of Structural Geology. 2003. Vol. 25, No. 1. P. 59-78. DOI: https://doi.org/10.1016/S0191-8141(02)00014-7*
25. *Audet P., Bürgmann R. Possible control of subduction zone slow-earthquake periodicity by silica enrichment. Nature Geoscience. 2014. Vol. 7. P. 764-769. DOI: https://doi.org/10.1038/ngeo2224*
26. *Evans J. P., Chester F. M. Fluid-rock interaction in faults of the San Andreas system: Inferences from fault rock geochemistry, fault mechanics, and fault-zone structure. Journal of Geophysical Research: Solid Earth. 1995. Vol. 100, No. B7. P. 13007-13020. DOI: https://doi.org/10.1029/94JB03189*
27. *Sibson R. H., Rowland J. V. Stress, fluid pressure, and structural permeability in seismogenic crust, North Island, New Zealand. Geophysical Journal International. 2008. Vol. 172, No. 3. P. 837-848. DOI: https://doi.org/10.1111/j.1365-246X.2007.03642.x*
28. *Fisher A. T., Becker K. Channelized fluid flow in oceanic crust reconciles heat-flow and permeability data. Nature. 2000. Vol. 403, No. 6765. P. 71-74. DOI: https://doi.org/10.1038/47463*
29. *Peacock S. M. Fluid processes in subduction zones. Science. 1990. Vol. 248, No. 4953. P. 329-337. DOI: https://doi.org/10.1126/science.248.4953.329*
30. *Montési L. G. J. Controls on the variation of fault spacing with depth in brittle lithosphere. Journal of Geophysical Research: Solid Earth. 2004. Vol. 109, No. B4. DOI: https://doi.org/10.1029/2003JB002800*
31. *Chester F. M., Evans J. P., Biegel R. L. Internal structure and weakening mechanisms of the San Andreas Fault. Journal of Geophysical Research: Solid Earth. 1993. Vol. 98, No. B1. P. 771-786. DOI: https://doi.org/10.1029/92JB01866*
32. *Bickle M. J., McKenzie D. The transport of heat and matter by fluids during metamorphism. Contributions to Mineralogy and Petrology. 1987. Vol. 95. P. 384-392. DOI: https://doi.org/10.1007/BF00371705*
33. *Borradaile G. Magnetic susceptibility, petrofabrics and strain. Tectonophysics. 1988. Vol. 156, No. 1-2. P. 1-20. DOI: https://doi.org/10.1016/0040-1951(88)90279-X*

References

1. *Bartashchuk, O. V., & Suyarko, V. G. (2018). Horizontal displacements of geomasses in continental rift geostructures (on the example of the Dnipro-Donetsk paleorift). Part 1: Structural manifestations of tectonic flow in the*

basement. V. N. Karazin Kharkiv National University Bulletin, Series "Geology. Geography. Ecology", 49, 10-23. https://doi.org/10.26565/2410-7360-2018-49-02 [in Ukrainian]
2. *Gavrysh, V. K. (1984). Deep structure and evolution of the Prypiat-Dnipro-Donetsk and Kenyan rifts. In Abstracts of the 27th IGC, Section 07 Tectonics (Vol. 3, pp. 207-208). M.: Nauka.*
3. *Bartashchuk, O. (2016). System organization of disjunctive tectonics of the consolidated basement of the Dnipro-Donetsk paleorift. Part 1: Lineaments. KhNU Bulletin, Series "Geology, Geography, Ecology", 45, 14-22. https://doi.org/10.26565/2410-7360-2016-45-02 [in Ukrainian]*
4. *Helgeson, H. C. (1969). Thermodynamics of hydrothermal systems at elevated temperatures and pressures. American Journal of Science, 267, 729-804. https://doi.org/10.2475/ajs.267.7.729*
5. *Sukhov, V. V. (2016). Hydrogeological features of the development of suffosion and karst of carbonate rocks on the territory of Sviatohirsk historical and architectural complex [Doctoral dissertation]. Kharkiv. [in Ukrainian]*
6. *Belokon, V. G. (1968). Neotectonic movements in Donbas and their connection with structural elements. In Materials on the geology of the Donetsk basin (11-15). M.: Nauka.*
7. *Suyarko, V. G., & Havryliuk, O. V. (2014). On the sources of bromine inputs and migration in groundwater (on the example of the Dnipro-Donetsk aulacogen). Visnyk of V. N. Karazin Kharkiv National University, Series "Geology. Geography. Ecology", 41(1128), 70-75. https://doi.org/10.26565/2410-7360-2014-41-11 [in Ukrainian]*
8. *Suyarko, V. G. (2015). Prediction, prospecting and exploration of hydrocarbon deposits: Textbook. Kharkiv: Folio. [in Ukrainian]*
9. *Gavrysh, V. K. (1965). The role of deep faults in the formation of structures of the Dnipro-Donetsk depression. Geological Journal, 25(6), 13-21.*
10. *Cowie, P. A., & Roberts, G. P. (2001). Tectonic Faults: Causes, Mechanisms and Consequences. Wiley-Blackwell.*
11. *Brown, G. C., & Taylor, S. D. (2007). Hydrothermal systems and geochemistry: Fluid migration along faults and the formation of mineral deposits. Earth-Science Reviews, 83(3-4), 145-174. https://doi.org/10.1016/j.earscirev.2007.04.002*
12. *Lister, G. S., & Davis, G. H. (1989). The origin of metamorphic core complexes and detachment faults. Journal of Structural Geology, 11(1), 65-94. https://doi.org/10.1016/0191-8141(89)90036-9*
13. *Menzies, M., & Cox, M. (2015). The Tectonic Evolution of Continental Rifts. Geological Society Special Publication, 249, 75-101. https://doi.org/10.1144/GSL.SP.2005.249.01.05*
14. *Peacock, D. C. P., & Sanderson, D. J. (1991). Displacement Transforms and the Aseismic Faulting Process. Journal of Structural Geology, 13(6), 747-752. https://doi.org/10.1016/0191-8141(91)90033-F*
15. *Corti, G., & Bonini, M. (2003). Fault Evolution and Fluid Migration in Continental Rifts: Evidence from the East African Rift. Journal of Geophysical Research: Solid Earth, 108(B11), 2509. https://doi.org/10.1029/2002JB002166*
16. *Ingram, M., & Manning, C. (2000). Fluid Flow Along Fault Zones in the San Andreas Fault System. Tectonophysics.*
17. *Morrow, C. A., & Knipe, R. J. (2015). Fault-Related Rocks: A Photographic Atlas. Wiley-Blackwell.*
18. *Sibson, R. H. (1996). Structural permeability of fluid-driven fault-fracture meshes. Journal of Structural Geology, 18(8), 1031-1042. https://doi.org/10.1016/0191-8141(96)00032-6*
19. *Faulkner, D. R., Jackson, C. A.-L., Lunn, R. J., Schlische, R. W., Shipton, Z. K., Wibberley, C. A. J., & Withjack, M. O. (2010). A review of recent developments concerning the structure, mechanics, and fluid flow properties of fault zones. Journal of Structural Geology, 32(11), 1557-1575. https://doi.org/10.1016/j.jsg.2010.06.009*
20. *Miller, S. A., Nur, A., & Olgaard, D. L. (1996). Earthquakes as a coupled shear stress-high pore pressure dynamical system. Geophysical Research Letters, 23(2), 197-200. https://doi.org/10.1029/95GL03691*
21. *Scholz, C. H. (2002). The Mechanics of Earthquakes and Faulting (2nd ed.). Cambridge University Press.*
22. *Taira, A., Hill, M., Firth, J., Berner, U., Brückmann, W., Byrne, T., ... & Zhang, J. (1992). Sediment deformation and fluid migration in the Nankai Accretionary Prism. Proceedings of the Ocean Drilling Program, Scientific Results, 131, 88-103. https://doi.org/10.2973/odp.proc.sr.131.131.1992*
23. *Tobin, H. J., & Saffer, D. M. (2009). Elevated fluid pressure and extreme mechanical weakness of a plate-boundary fault. Nature, 449(7164), 76-78. https://doi.org/10.1038/nature06064*
24. *Wibberley, C. A. J., & Shimamoto, T. (2003). Internal structure and permeability of major fault zones: The outcrop study from the Median Tectonic Line in Mie Prefecture, Southwest Japan. Journal of Structural Geology, 25(1), 59-78. https://doi.org/10.1016/S0191-8141(02)00014-7*
25. *Audet, P., & Bürgmann, R. (2014). Possible control of subduction zone slow-earthquake periodicity by silica enrichment. Nature Geoscience, 7, 764-769. https://doi.org/10.1038/ngeo2224*
26. *Evans, J. P., & Chester, F. M. (1995). Fluid-rock interaction in faults of the San Andreas system: Inferences from fault rock geochemistry, fault mechanics, and fault-zone structure. Journal of Geophysical Research: Solid Earth, 100(B7), 13007-13020. https://doi.org/10.1029/94JB03189*
27. *Sibson, R. H., & Rowland, J. V. (2008). Stress, fluid pressure, and structural permeability in seismogenic crust, North Island, New Zealand. Geophysical Journal International, 172(3), 837-848. https://doi.org/10.1111/j.1365-246X.2007.03642.x*
28. *Fisher, A. T., & Becker, K. (2000). Channelized fluid flow in oceanic crust reconciles heat-flow and permeability data. Nature, 403(6765), 71-74. https://doi.org/10.1038/47463*
29. *Peacock, S. M. (1990). Fluid processes in subduction zones. Science, 248(4953), 329-337. https://doi.org/10.1126/science.248.4953.329*

30. *Montési, L. G. J. (2004). Controls on the variation of fault spacing with depth in brittle lithosphere. Journal of Geophysical Research: Solid Earth, 109(B4).* https://doi.org/10.1029/2003JB002800
31. *Chester, F. M., Evans, J. P., & Biegel, R. L. (1993). Internal structure and weakening mechanisms of the San Andreas Fault. Journal of Geophysical Research: Solid Earth, 98(B1), 771-786.* https://doi.org/10.1029/92JB01866
32. *Bickle, M. J., & McKenzie, D. (1987). The transport of heat and matter by fluids during metamorphism. Contributions to Mineralogy and Petrology, 95, 384-392.* https://doi.org/10.1007/BF00371705
33. *Borradaile, G. (1988). Magnetic susceptibility, petrofabrics and strain. Tectonophysics, 156(1-2), 1-20.* https://doi.org/10.1016/0040-1951(88)90279-X

Вплив Петрівсько-Кремінського глибинного розлому на міграцію флюїдів в породах Святогірської брахіантикліналі

Антон Пивоваров
Магістр геології нафти і газу (Науки про Землю),
Харківський національний університет імені В.Н. Каразіна, Харків, Україна

Досліджено вплив Петрівсько-Кремінського глибинного розлому та його апофіз на формування системи гідрогеохімічних і термогідрогеодинамічних процесів у межах Святогірської брахіантикліналі (Кам'янська площа) Дніпровсько-Донецького авлакогену. Розломні розривні структури визначені як ключові канали вертикальної міграції флюїдів і теплових потоків з глибинних шарів земної кори та мантії. Ця динамічна система призводить до формування зон, що характеризуються вираженими гідрогеохімічними інверсіями, про що свідчить значне збагачення підземних вод ендогенними компонентами, зокрема гелієм, радоном, аргоном і вуглекислим газом (CO_2). У досліджуваних водоносних горизонтах зафіксовано термогідродинамічні аномалії з підвищеними температурами в діапазоні від 23°C до 27°C (при фонових 10°C до 12°C). Такі аномалії стимулюють розвиток конвективних процесів, що своєю чергою пришвидшують катагенетичні та метагенетичні перетворення всього розрізу порід. Ці процеси зумовлюють вторинні літологічні зміни, які проявляються у вигляді цементації умовного порово-тріщинного простору в породах-колекторах, зокрема через перевідкладення карбонатної маси, перенесеної внаслідок взаємодії з агресивним CO_2 із нижчезалягаючих горизонтів. Зони розвантаження, представлені порово-тріщинуватим простором уздовж зони глибинного розлому та його апофіз, виконують роль каналів для висхідної міграції розігрітих флюїдальних мас. Це порушує тривіальний тепловий градієнт і сприяє активізації інтернально-пластових процесів. Крім того, засвідчено, що аномалії вмісту важкого ізотопу вуглецю ($\delta^{13}C$) у підземних водоносних комплексах свідчать про термально-метаморфічне походження та процеси дегазації, що підтверджує ендогенний характер флюїдальних мас. Подібний характер флюїдів чітко простежується вздовж зони глибинного розлому та його диз'юнктивних апофізів. Комбінація термогідрогеодинамічних та гідрогеохімічних інверсій мають сигніфікативний вплив на процеси катагенезу та метагенезу, що простежується у літолого-фаціальному складі пізньокарбонових пісковиків (C_3). Кореляція різного роду інверсій та їх систематизація і прив'язка до глибинних розломів і диз'юнктивних тектонічних порушень має важливе значення для розуміння механізмів взаємодії тектонічних структур з гідрогеологічними умовами та можуть бути використані в подальших геологічних дослідженнях і для оцінки ресурсної бази вже з урахуванням флюїдодинамічних параметрів порід-колекторів, що мають систематичний вплив від глибинних розломів і проходять вздовж зони розвантажень.

Ключові слова: *Святогірська брахіантикліналь, Петрівсько-Кремінський глибинний розлом, міграція флюїдів, потоки розігрітих флюїдальних мас, тепломасоперенесення.*

Надійшла 2 жовтня 2024 р.
Прийнята 10 листопада 2024 р.