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HYDROGEOLOGICAL ASPECTS OF THE GENESIS, MIGRATION AND FORMING OF HYDROCARBON FIELDS IN THE SOUTHERN PART OF THE PRE-BLACK SEA AQUIFEROUS BASIN

The model of forming of hydrocarbon deposits in the aquatic part of the Pre-Black Sea aquiferous basin substantiates by the set of hydrogeochemical, gas-geochemical, geotemperature, and hydrodynamic data. The model is based on modern views on the geodynamic history of development and makes it possible to state that the formation of gas-vapour systems occurred in the lower reaches of the sedimentary stratum of the riftogen at high pressures and temperatures and the presence of water. The basis of gas-vapour systems was both thermocatalytic and subcrustal (mantle) gases. Active heat and mass transfer of fluids during Alpine tectonogenesis continues to this day, which is confirmed by geothermal anomalies caused by the upward discharge of groundwater, endogenous gases – methane, helium, carbon dioxide, hydrogen, etc. The probable migration paths are sublatitudinal disjunctive dislocations and decompression zones in areas where tensile forces were manifested against the background of regional compression, for example, in places where faults of different directions intersect. As a result of gas migration, especially through clayey rocks, sorption of heavy hydrocarbons occurred, which determined gas-geochemical zoning. Gas migration was realized in a free high-temperature gas-vapour phase, which filled the traps, displacing or compressing the formation water. Active heat and mass transfer affects to the hydro- and gas-hydrogeochemical zoning and the filling of existing traps with hydrocarbons.

Practical significance. Hydrogeochemical features such as water-dissolved gases and condensation water are the direct indicators of oil and gas potential. Hydrogeological model can be used to forecast deposits in other oil and gas-bearing regions (in particular, the Carpathian Foredeep).

Keywords: Pre-Black Sea aquiferous basin, Karkinit-Northern Crimean trough, hydrogeological peculiarities, water-dissolved gases, condensate waters, hydrocarbons, vertical migration.

Introduction. The study of modern hydrogeological conditions, in comparison with geodynamic history of the development of research area and regional features of the distribution of heat flow makes it possible to clarify the patterns of formation, preservation and presence of hydrocarbon deposits.

The Pre-Black Sea aquiferous basin is located between the southern slope of the Ukrainian Shield in the north, the deep-water depression of the Black Sea in the south, the Odesa fault in the west and the Orekhovo-Pavlohrad fault in the east. Their main structural elements are the slope of the East European Platform, the Karkinit-Northern Crimean trough and the Black Sea-Novoseliv uplift.

At the level of Cretaceous deposits, the aquiferous basin is based on a large structure of riftogenic nature. According to modern data, the boundaries of this structure are the north of the Plain Crimea and the northwestern shelf of the Black Sea (North Crimean riftogen). At the level of Cenozoic sediments is the Karkinit-Northern Crimean trough. These regional structures are parts of the Black Sea megatrough (Fig. 1).

In the section of the aquatic part of the basin, basal (Proterozoic–Mesozoic), Lower Cretaceous (Aptian–Albian) terrigenous; Upper Cretaceous, Paleocene, Eocene carbonate; Maikopian terrigenous and Neogene (Miocene) carbonate-terrigenous complexes are distinguished. There are no saline sediments in the section (Ivaniuta, 1998).

In the water area of the Pre-Black Sea aquiferous basin, gas deposits have been established in most aquifer complexes – from the Upper Cretaceous to the Neogene. Oil deposits in the water area of the basin have not yet been established, but oil shows have been noted during reservoir testing. The deposits are confined to local uplifts, grouped into zones confined to sublatitudinal faults – gas at depths of over 500 m, gas condensate – about 1800 m. The deposits in carbonate reservoirs are mainly disjunctively disrupted, the deposits in the reservoirs of the Maikopian series are layered vaults, not disrupted disjunctively, but often limited lithologically.

The geodynamic development of the Black Sea Basin includes several stages of tectonic-magmatic activation due to the extension of the lithosphere and the opening of sea basins. Rift structures arose in some epoches of the Mesozoic. In the second half of the Alpine tectonogenesis, tension forces prevailed, which led to the deflection of the sides of the Black Sea Depression and the formation of structures

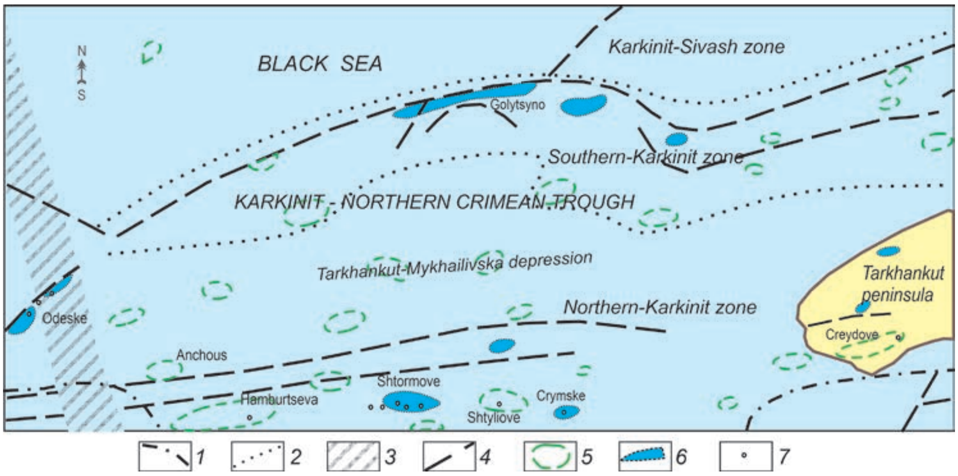

Fig. 1. Tectonic map of the region (fragment after B. Polukhtovych, S. Zakharchuk in (Gozhyk, 2007)):
1 – boundary of Karkinit–Northern Crimean trough; *2* – boundaries of structural zones; *3* – zone of Odesa fault; *4* – disjunctive dislocations; *5* – local uplifts in K_1 sediments; *6* – gas deposits; *7* – boreholes used in section

promising for hydrocarbon accumulations. Such conditions are typical for the Karkinit-Northern Crimean trough. Tectonic processes in the Oligocene, Late Miocene, Pliocene were complicated by vertical movements of the Earth's crust associated with active heat and mass transfer of fluids during the Alpine tectonogenesis and continue to this day (Pavlyuk et al., 2002). As confirmation, geothermal anomalies are recorded, caused by the upward discharge of groundwater, endogenous gases – methane, helium, carbon dioxide, hydrogen, etc. Since the research area is characterized by the presence of low-permeable rocks in the section (1–10 m^3/day), the discharge of water occurs mainly through fault zones. Active heat and mass transfer has affected the hydro- and gas-hydrogeochemical zoning and the filling of existing traps with hydrocarbons.

Purpose. Substantiation of the model of forming hydrocarbons fields on the base of geological, hydrogeological geochemical, gas-geochemical peculiarities of gas and gas-condensate deposits.

Methodology. The investigations of formation waters, natural and water dissolved gases were based on the methods of chemical, elementary spectral, atomic absorption and gas chromatographic analysis completed in the laboratories of JSC "Chornomornaftogaz", Lviv Branch of Ukrainian State Research Institute and Institute of Geology and Geochemistry of Combustible Minerals of National Academy of Sciences of Ukraine.

Analysis of previous studies. It was established that the Black Sea aquiferous basin belongs to high-temperature areas (the value of the geothermal gradient is 4.66 °C/100 m, which is typical for gas-bearing areas). The differentiation of the thermal field in the Karkinit trough is 54 to 80 mW/m^2 (Kutas, 2010). The differentiation of the geothermal field increases from 62 % at a section of −3000 m to 86 % at a section of −1000 m. The calculated temperatures at the maximum depths of gas-bearing complexes (5–8 km) are for the Lower Cretaceous and Basal – 184–297 °C, Upper Cretaceous – 152–222 °C, Paleocene – 99–164 °C, Maikopian – 67–110 °C. The most submerged part of the Karkinit-Northern Crimean trough (Tarkhankut-Mikhailivska depression) is characterized by a temperature minimum, dislocations from its northern and southern sides are characterized by temperature maximums (Gozhyk, 2007). Such a distribution of thermal and geotemperature fields demonstrates, on the one hand, a thick layer of low-thermally conductive sediments in the most submerged part of the trough, and on the other hand, convective heat and mass transfer in the near-shore fault zones, above which there are positive anomalies. Geobaric conditions and filtration parameters of the rocks made it possible to assume the movement of waters of the elision aquifer system from the most submerged zone of the Karkinit-Northern Crimean trough towards its sides. The upward discharge of groundwater and endogenous gases is carried out by zones of increased permeability into the above-located complexes (I. V. Kolodiy & Medvid, 2018, 2019). Infiltration water pressure systems are on the northern periphery of the basin.

Results. Based on the analysis and interpretation of literature sources and our own material from hydro-gas-geochemical and geobaric data, a detailed geological-hydrogeological model of the formation of hydrocarbon deposits of the northern shelf of the Black Sea is presented. Gas-hydrogeochemical studies (I. V. Kolodiy, 2014; Zhabina et al., 2015) have established that the absolute gas saturation of waters increases with depth, reaching 3850 cm^3/dm^3 in the basal (Proterozoic) aquifer complex, while the highest relative (reduced to depth) characterizes the Maikopian and Paleocene productive complexes. The composition of water-dissolved and free gases is methane (C_1 – 90–98 % vol), with a small amount of methane homologues (0.03–6.3 % vol), and non-hydrocarbon components ($CO_2 + N_2$ – 0.8–3.1). The differentiation of the composition of gases has been established. Superdry gases ($C_1/C_{2+} > 10\,000$) present in the Neogene and partly Maikopian, dry – (C_1/C_{2+} 10 000–300) in the Maikopian and occasionally Eocene, medium dryness – (C_1/C_{2+} 300–50) in the Paleocene and Eocene. Fatty gases (C_1/C_{2+} <50) present in the Paleocene, Upper Cretaceous Jurassic, occasionally Eocene and Maikopian complexes. Gases of gas condensate deposits are characterized by $C_1/C_{2+} < 20$. The lowest contents of non-hydrocarbon components – $CO_2 + N_2$ – 0.8–1.7 are in the industriallly gas-bearing Maikopian and Paleogene complexes, the highest are from the Upper Cretaceous to the Basal (3.1–2.8) and in the Neogene complex (2.9).

Despite the fact that the maximum relative (depth-adjusted) values of gas saturation of formation waters, selected under the most optimal conditions, in deposits and exploration areas reach high values, they do not reach the maximum possible (according to the geothermobaric conditions of the area). The mechanism of formation of deposits due to degassing of the water pressure system is unlikely. Gas-geochemical zoning reflects the differentiation of the composition of gases during their migration.

Hydrogeochemical zoning of the inversion type is due to the change with depth of chloride magnesium-sodium, chloride-sodium, calcium-sodium medium and weak brines with waters of the same types, but significantly lower salinity and the appearance of hydrocarbonate-sodium and sulfate-sodium waters in Paleocene and Upper Cretaceous deposits, which is due to the lithological and geothermal features of the section. Comparison of hydrogeochemical and gas-hydrogeochemical data allowed us to find that increased methane content is characteristic of low-sulfate chloride-sodium, calcium-sodium salt waters of the Neogene, Eocene and Maikopian complexes, and heavy hydrocarbons are characteristic of waters of lower mineralization, relatively enriched with sulfates and hydrocarbonates (sulfate-chloride and hydrocarbonate-chloride types) (Fig. 2). Such features of the distribution of water-dissolved gases indicate a spatial relationship, and not their genetic conditionality.

The presence of natural condensation waters in the base of the deposits are the most significant hydrogeological phenomena characterizing only carbonate Paleocene and Upper Cretaceous productive reservoirs. Most often they form mixtures with waters of geochemical background. In addition to low salinity, they have a specific ion-salinity composition – high contents of HCO_3, NH_4 and other trace elements (I. V. Kolodiy, 2001; V. V. Kolodiy, 1971). Their preservation to this day indicates a significant rate of subvertical migration of gas-vapour mixtures, high-temperature sources of hydrocarbon generation and geologically recent time of formation of deposits. The methane carbon of the P–XI horizon of the Golitsyno deposit is isotopically heavy ($\delta^{13}C$ – 3.62 %, – exceeds the limits of biogenic synthesis) (V. V. Kolodiy & Kolodiy, 2002). This gives grounds to argue about the formation of hydrocarbon compounds, including during the processes of inorganic synthesis (Fig. 3).

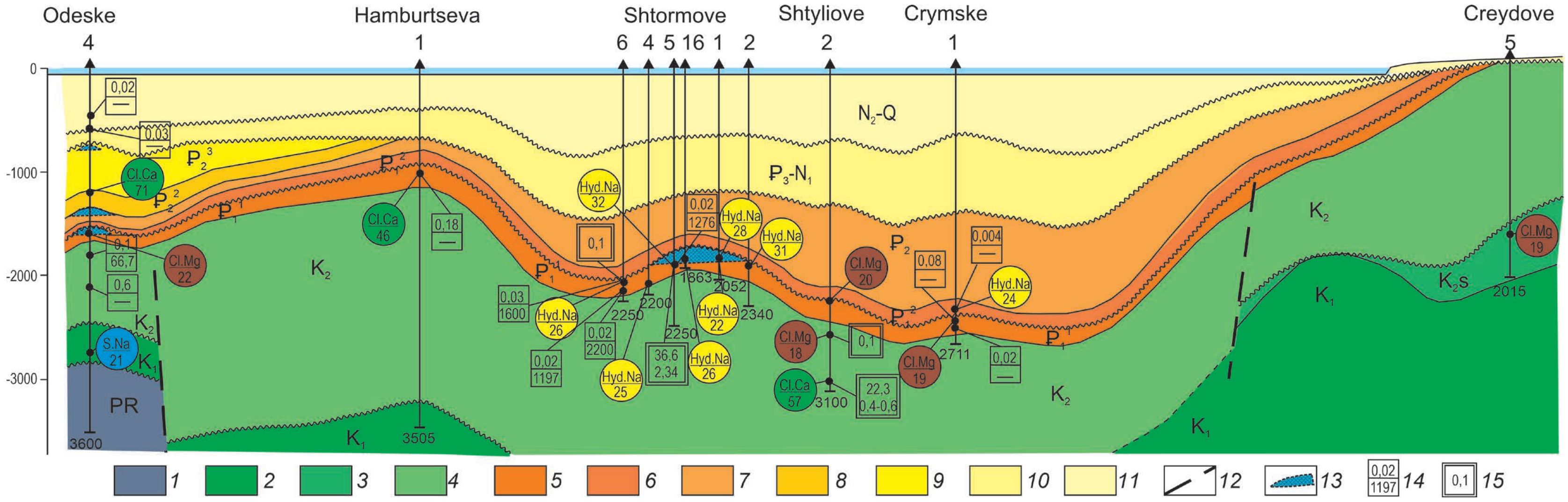

Fig. 2. Geological-hydrogeological section from Odesske to Creydove gas fields (geological base after B. Polukhtovych, S. Zakharchuk in (Gozhyk, 2007)): *1–9* – stratigraphic complexes: *1* – metamorphic PR, *2* – terrigenous K_1, *3* – terrigenous K_2s, *4* – carbonate K_2, *5–6* – carbonate $₽_1$, *7–9* – carbonate $₽_2$; *10* – terrigenous $₽_3$–N_1 (Maikopian); *11* – carbonate–terrigenous N_2–Q; *12* – disjunctive dislocations, *13* – gas deposit, *14* – flow of water, dm^3/sec (on top)/gas saturation in water, sm^3/dm^3 (on bottom); *15* – flow of gas, gas condensate (thousand m^3/day). *Formation waters*: in a circle: type of water (on top)/salinity, g/dm^3 (on bottom). Colors: blue – S.Na, green – Cl.Ca; yellow – Hyd.Na, brown – Cl.Mg

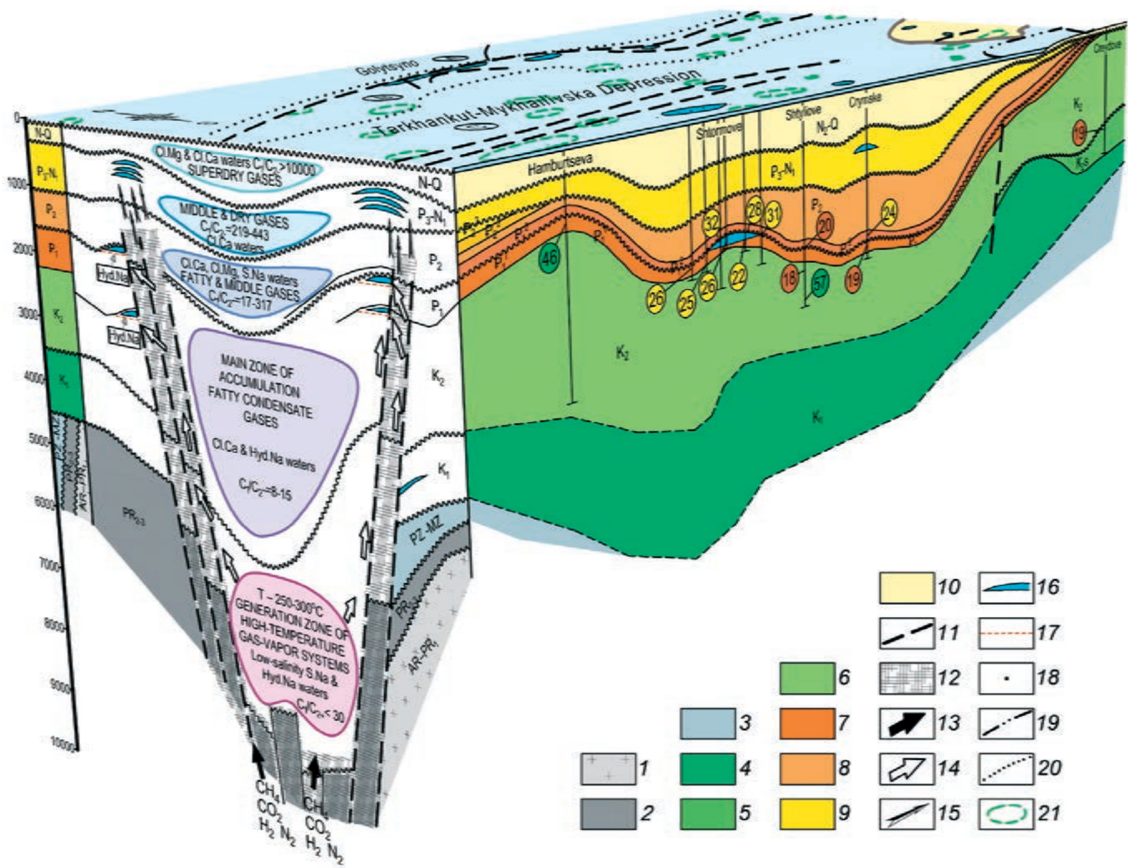

Fig. 3. Basic geological-hydrogeological model of hydrocarbons fields forming in the Pre-Black Sea aquiferous basin (according to V. V. Kolodiy & Kolodiy, 2002, with additions, 2024). On the top – fragment of tectonic map; on the left – model of hydrocarbon fields forming (section between Shtormove and Golytsyno gas fields); on the right – longitudinal geological-hydrogeological section of Tarkhankut-Mykhailivska depression. According to seismic data, the base of the Lower Cretaceous deposits in the deepest part of the depression lies at a depth up to 8–10 km:

1–9 – stratigraphic complexes: *1* – crystalline basement AR–PR_1, *2* – metamorphic PR–PZ, *3* – metamorphic T–J, *4* – terrigenous K_1, *5* – terrigenous K_2s, *6* – carbonate K_2, *7* – carbonate P_1, *8* – carbonate P_2, *9* – terrigenous P_3–N_1 (Maikopian); *10* – carbonate-terrigenous N_2–Q; *11* – disjunctive dislocations; *12* – zones of increased fractured rocks; *13* – migration flow of subcrustal gases; *14* – migration flow of gas-vapour systems through carbonate formations in fault zones; *15* – filtration flow of gases through clayey rocks; *16* – gas deposit; *17* – condensation waters; *18* – boreholes; *19–20* – tectonic elements: *19* – boundary of Karkinit–Northern Crimean depression; *20* – boundaries of zones (A – Karkinit-Sivash zone; B – Southern-Karkinit zone; C – Northern-Crimean zone); *21* – local uplifts in K_1 sediments. *Formation waters*: in a circle – salinity (g/dm^3). Colours: green – Cl.Ca; yellow – Hyd.Na; brown – Cl.Mg

Conclusions. The formation of gas-vapour systems occurred in the lower reaches of the sedimentary rift layer at high pressures and temperatures and the presence of water. The basis of gas-vapour systems were both thermocatalytic and subcrustal (mantle) gases. The migration of gas-vapour systems proceeded quite quickly in the subvertical direction through zones of disjunctive faults and rock fracturing. As a result of gas migration, especially through clayey rocks, sorption of heavy hydrocarbons occurred, which determined gas-geochemical zoning. Gas migration was realized in the free high-temperature gas-vapor phase, which filled the traps, displacing or compressing the formation water. The processes of formation of hydrocarbon gas deposits were superimposed on the hydrogeochemical situation that had formed at the time of migration (Late Miocene).

Practical significance. Hydrogeochemical pecularities such as water-dissolved gases and condensation water are the direct indicators of oil and gas potential. Hydrogeological model can be used to forecast deposits in other oil and gas-bearing regions (in particular, the Carpathian Foredeep).

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ГІДРОГЕОЛОГІЧНІ АСПЕКТИ ПОХОДЖЕННЯ, МІГРАЦІЇ ТА ФОРМУВАННЯ РОДОВИЩ ВУГЛЕВОДНІВ ПІВДЕННОЇ ЧАСТИНИ ПРИЧОРНОМОРСЬКОГО ВОДОНАПІРНОГО БАСЕЙНУ

На основі гідрогеохімічних, газогеохімічних, геотемпературних, гідродинамічних даних обґрунтовано модель формування покладів вуглеводнів акваторійної частини Причорноморського водонапірного басейну. Модель базується на сучасних поглядах на геодинамічну історію розвитку і дає змогу стверджувати, що формування газопарових систем відбувалося в низах осадової товщі рифтогену за високих тисків і температур та наявності води. Основою газопарових систем були як термокаталітичні, так і підкорові (мантійні) гази. Активне тепломасоперенесення флюїдів протягом альпійського тектоногенезу продовжується дотепер, що підтверджується геотермічними аномаліями, спричиненими висхідним розвантаженням підземних вод, ендогенних газів – метану, гелію, вуглекислого газу, водню тощо. Шляхами імовірної міграції є субширотні диз'юнктивні дислокації та зони розущільнення на ділянках, де на тлі регіонального стискання проявлялися сили розтягу, наприклад, у місцях перетину розломів різних напрямків. Унаслідок міграції газів, особливо через глинисті породи, відбувалася сорбція важких вуглеводнів, що і зумовило газогеохімічну зональність. Міграція газів реалізувалася у вільній високотемпературній газопаровій фазі, яка заповняла пастки, витісняючи або стискаючи пластову воду. Активне тепломасоперенесення впливає на гідро- і газогідрогеохімічну зональність і на заповнення вже наявних пасток вуглеводнями.

Гідрогеохімічні характеристики, такі як розчинені у воді гази та конденсаційні води, є прямими ознаками нафтогазоносності. Гідрогеологічна модель може бути використана для прогнозування покладів в інших нафтогазоносних регіонах (зокрема Передкарпатському прогині).

Ключові слова: Причорноморський водонапірний басейн, Каркінітсько-Північнокримський прогин, гідрогеологічні особливості, водорозчинені гази, конденсаційні води, вуглеводні, вертикальна міграція.