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BAROOSMOTIC ANALYSIS OF PROCESSES IN GROUND WATERS OF THE KOKHANIVKA–SVYDNYTSIA AREA (UKRAINIAN CARPATHIAN FOREDEEP)

BAROOSMOTYCZNA ANALIZA PROCESÓW W WODACH PODZIEMNYCH OBSZARU KOCHANOWSKO-ŚWIDNICKIEGO (PRZEDKARPACIE UKRAIŃSKIE)

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Abstract. A baroosmotic analysis of hydrogeological conditions was carried out in the Svydnytsia and Vizhomlia gas deposits as well as in the Kokhanivka oil deposit. It was demonstrated that in contrast to gas deposit, the oil deposits breaks the baroosmotic profile of boreholes into two independent parts: upper-normal and lower-abnormal where baroosmotic flows of H_2O are able to move down the section due to predominance of the capillary osmose in oil brines. High baroosmotic permeability of gas deposits causes not only the increased thermal conductivity of the section, but also the appearance of temperature anomalies.

Key words: oil and gas deposits, formational waters, baroosmosis, baroosmotic profile of boreholes.

Abstrakt. Przeprowadzono baroosmotyczną analizę warunków hydrogeologicznych na złożach gazowych Svydnytsia i Vizhomlia oraz złożu naftowym Kokhanivka. Pokazano, że w odróżnieniu od złóż gazowych złoże naftowe dzieli baroosmotyczny profil szybów wiertniczych na dwie niezależne części: górną – normalną i dolną – anomalną, gdzie baroosmotyczne strumienie H_2O mogą poruszać się w dół wzdłuż przekroju z przewagą kapilarnej osmozy w solankach naftowych. Wysoka baroosmotyczna przenikliwość gazowych złóż powoduje nie tylko powiększoną przewodność cieplną przekroju, ale i pojawienie się anomalii temperaturowych.

Słowa kluczowe: złoża ropy naftowej i gazu, wody złożowe, baroosmoza, baroosmotyczne profile szybów wiertniczych.

INTRODUCTION

Baroosmosis could be an important factor of spontaneous change in concentrations of pore and formational waters; it could cause the appearance of vertical hydrogeochemical zonality and, possibly, take part in filling of reservoir structure with hydrocarbons (Kushnir, 2008, 2009a). The reason for baroosmosis is the natural trying of underground water to bring its osmotic pressure (P_{osm}) in accordance with hydrostatic (or formation) one (P_{hydr}) at a given depth. This is why "H_2O osmotic head pressure" ($P_{o.h}$) could be measured as a difference between hydrostatic and osmotic pressures $P_{o.h} = P_{hydr} - P_{osm}$. In the case if $P = 0$ (i.e. $P_{hydr} = P_{osm}$), the baroosmotic balance is approached: baroosmotic flows stopped and regular rules of concentrational diffusion are starting to act. The velocity of baroosmotic flows should be defined by a gradient of osmotic head pressure of H_2O ($\Delta P_{o.h}$) in clay beds and its osmotic permeability value. During lowering of artesian water to a greater depth the osmotic pressure in this water is increasing, and when $P_{hydr} > P_{o.h}$ in the upper waterproof clay, a directed baroosmotic flow of the H_2O (with an admixture of NaCl) increases, and the consequence is the increased concentration of formation water. In all cases when $P_{o.h} \neq 0$, brine concentration in a bed will spontaneously change until osmotic pressure is equal to hydrostatic one, and thus baroosmotic balance is

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reached. This is why artesian waters, when moving downwards, have to change their concentration in order to maintain P_{osm} close to P_{hydr} in a given water-bearing horizon. To make it possible, the waters must reside in fine-porous beds or be divided by such beds (for example clays) from the next water-bearing horizons. In this study, the results of baroosmotic analyses in the Kokhanivka–Svydnytsia area (Western Ukraine) are presented.

OBJECT AND METHODS OF STUDY

The Carpathian Foredeep is a complex tectonic structure, and the hydrogeological system of the region is complicated by the occurrence of hydrocarbon deposits (Kolodiy *et al.*, 2004). However, a long-term quiet tectonic situation that happened after the Sarmatian bending and uplifting, was favourable for baroosmosis in all Neogene deposits (Kushnir, 2009a).

In the Kokhanivka–Svydnytsia area, there is one oil (Kokhanivka) and three gas (Svydnytsia, Vizhomlia and Retychyn) deposits. Figures 1–3 show the location of these de-

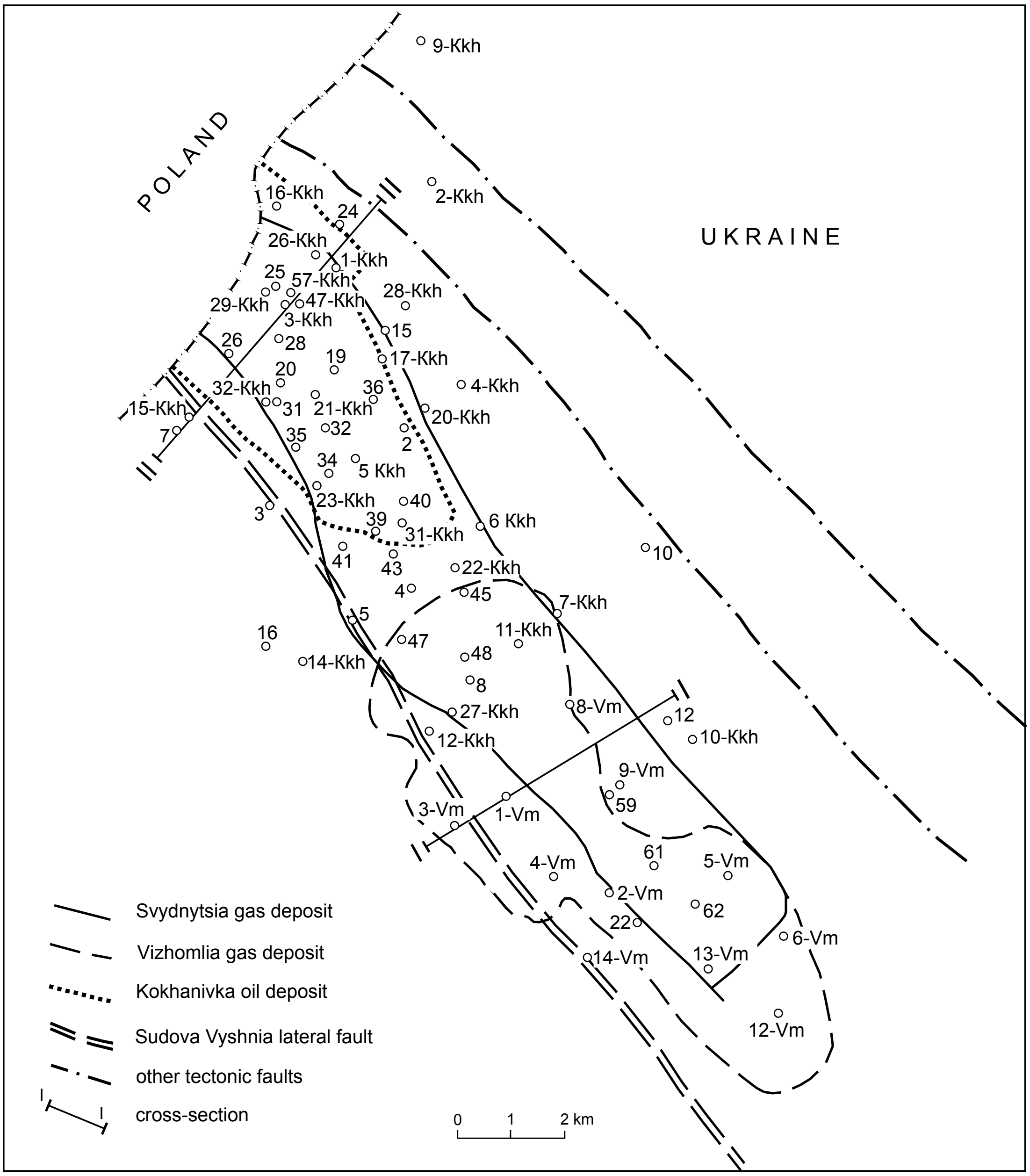

Fig. 1. Outlines of oil and gas deposits and location of the most important boreholes in the Kokhanivka–Svydnytsia area

The boreholes of Kokhanivka deposit are indicated by letters Kkh, of Vizhomlia – by letters Vm, those without letter indication belong to Svydnytsia deposit

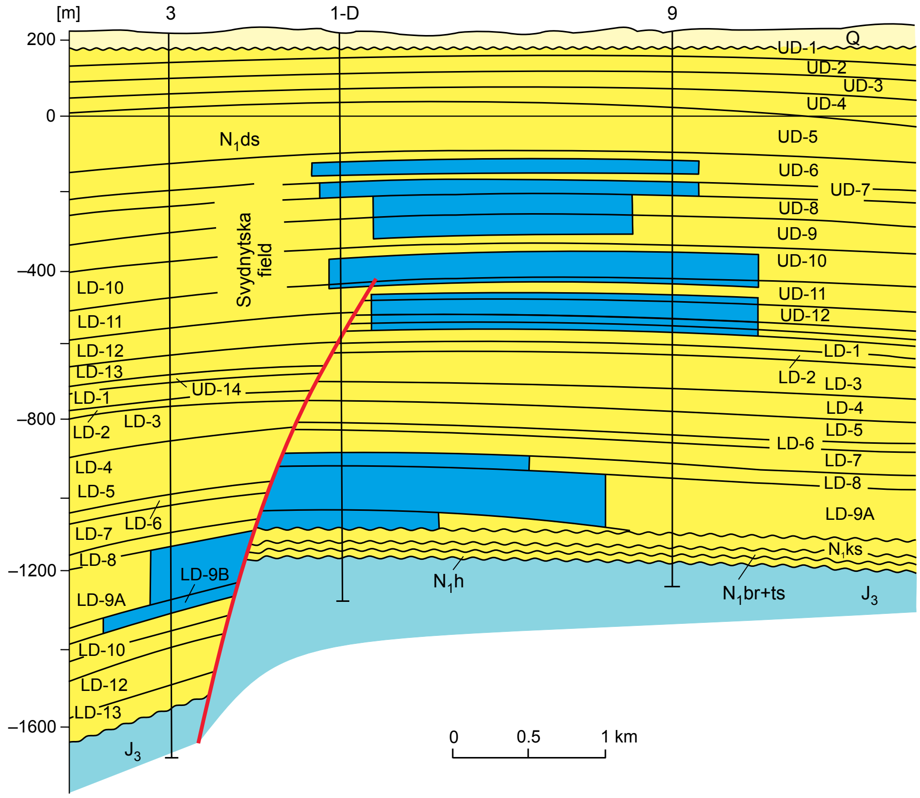

Fig. 2. Cross-section I–I of the Vizhomlia gas deposit

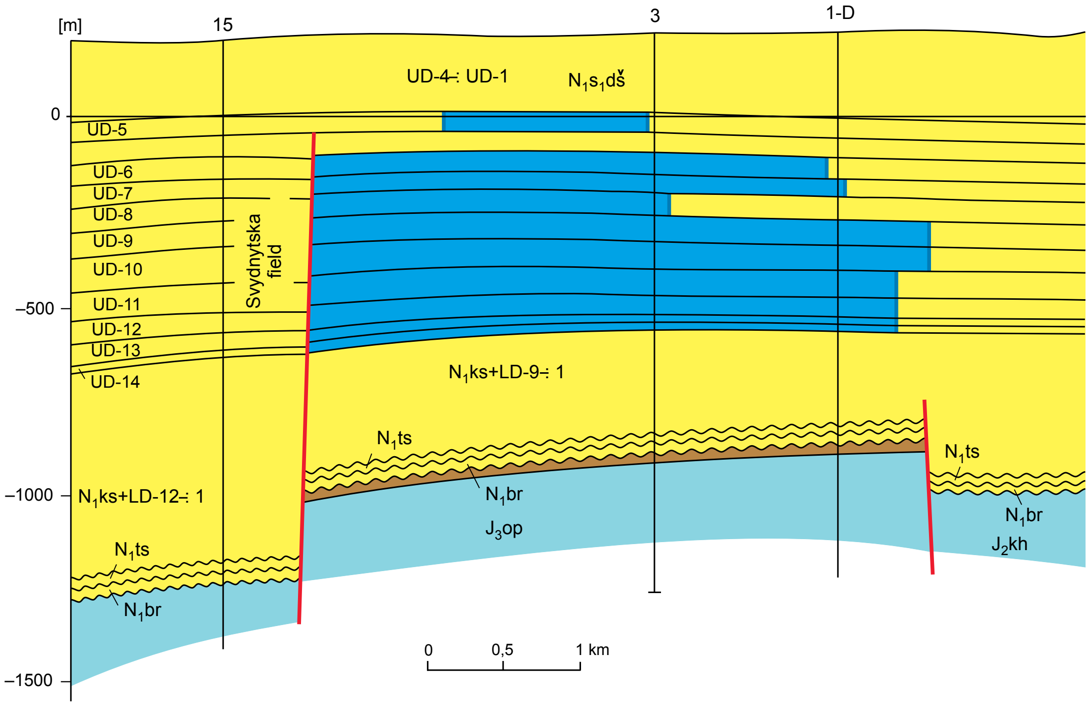

Fig. 3. Cross-section II–II of the Kokhanivka gas deposit

posits and the most important boreholes in the study area. The main features of these deposits (except the recently revealed Retychyn deposit) are presented in Shcherba et *al.* (1987) and Vul *et al.* (1998). For the waters of Sarmatian deposits of the outer zone of the Carpathian Foredeep, inverse hydrogeochemical zonality is typical (Shchepak, Savitsyn, 1963): marine waters of increased mineralization (up to 50 g/dm^3) of the Upper Dashava (UD) subsuite occur above diluted (15–25 g/dm^3) waters of the Lower Dashava (LD) subsuite. However, the waters of Jurassic deposits are brines of Cl–Ca type, and their mineralization increases downwards from 70 to ~150 g/dm^3. There is no visible influence of hydrocarbon deposits on the mineralization of formation waters.

Our study includes recalculations of all available analyses of formation waters in the Kokhanivka–Svydnytsia area, the determination of their chemical composition formulae and the calculation of their main baroosmotic features: osmotic pressure, osmotic head pressure and the degree of deviation from baroosmic balance state. The calculations were done by means of the methods described in Kushnir (2009b) and with the use of the following average section temperatures: 35ºC for Svydnytsia and 50ºC for Vizhomlia and Kokhanivka.

STUDY RESULTS

The main result of baroosmic analysis is the determination of osmotic head pressure of the water ($P_{o.h}$). Its changes in individual boreholes of the studied deposits are given in Figs 4–7. As far as the diagrams $P_{o.h} = f(H)$ are built for systems where the bed pressure is close to conditional hydrostatic one (P_{hydr}), when the $P_{o.h}$ and P_{hydr} lines are parallel, the mineralization of formation waters is constant at a given depth interval; the approach of $P_{o.h}$ to P_{hydr} line means dilution, and the deflection of $P_{o.h}$ line to the left means increase of concentration. The stability of the $P_{o.h}$ value at a certain depth range means baroosmotic quasi-balance in a given zone, when baroosmosis is almost discontinued, however the water state is still far from real baroosmotic balance (BO-balance), when $P_{o.h} = 0$ (Kushnir, 2008; Kushnir *et al.*, 2010, 2011).

The results were analysed according to hydrogeochemical features of individual deposits.

Svydnytsia gas deposit. The gas deposits are located in sand-clay horizons of the UD-5 and UD-8-10 subsuites (Fig. 2). Reservoirs of individual deposits are composed of numerous thin sandstone and siltstone layers, where the siltstones are often filled with formation waters. Deposit waters are marine low-metamorphosed, of elevated concentration (40–55 g/dm^3). Some waters of lower mineralization occur in the UD-11 bed (boreholes 10 and 11), and in the LD-12 bed. There was also freshwater found (0.35 g/dm^3, borehole 12). In our opinion, the freshwater occurrence is due to palaeoriver delta origin of these deposits (cf. Kurovets *et al.*, 2004).

Figure 4 shows that $P_{o.h}$ in all waters increases with depth, which forms baroosmotic flows of H_2O molecules up the section through the clay beds. However, a negative value of $P_{o.h}$ in borehole 5 at the depth of 380 m shows that the upward water movement is possible here. The value of deviation from the BO-balance state in the UD is considerably lower than in the LD, which is obviously due to a higher mineralization of seawater during UD formation. The difference in initial mineralization of the UD and LD waters influenced also the $P_{o.h}$ patterns in respective parts of the sections: in desalinized waters of the LD, the BO-concentration revealed itself in borehole 15 quite clearly, but in the UD water of borehole 6, it still does not show. However, this difference practically did not influence the chemical type and

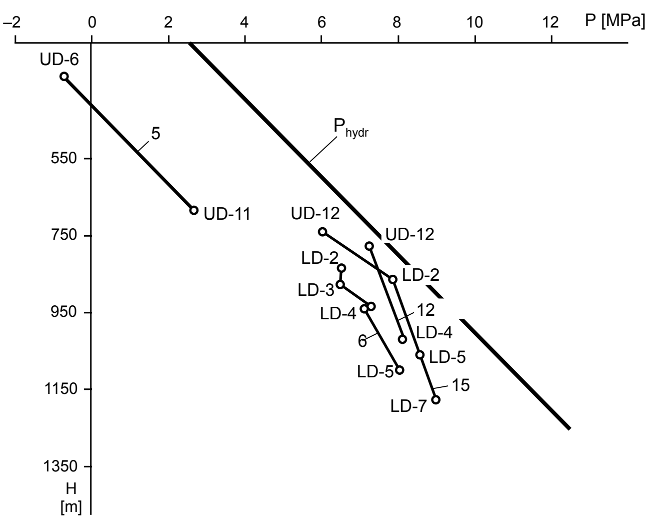

Fig. 4. Baroosmotic head pressure ($P_{o.h}$) in waters of the Svydnytsia gas deposit in boreholes

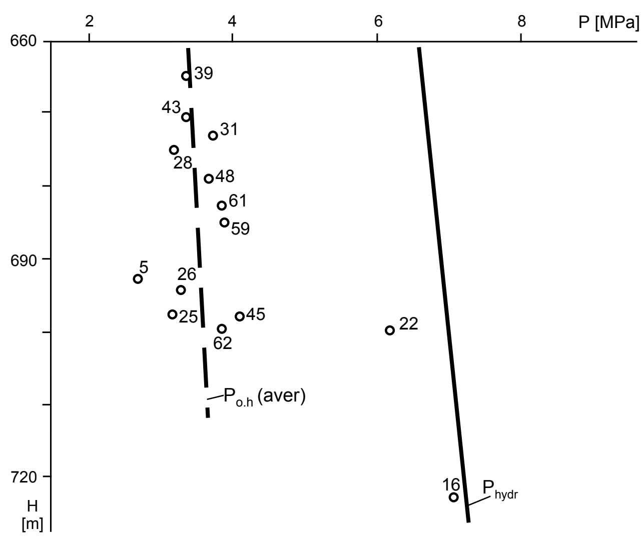

Fig. 5. Baroosmotic head pressure ($P_{o.h}$) in waters of the Svydnytsia gas deposit in UD-11 horizon

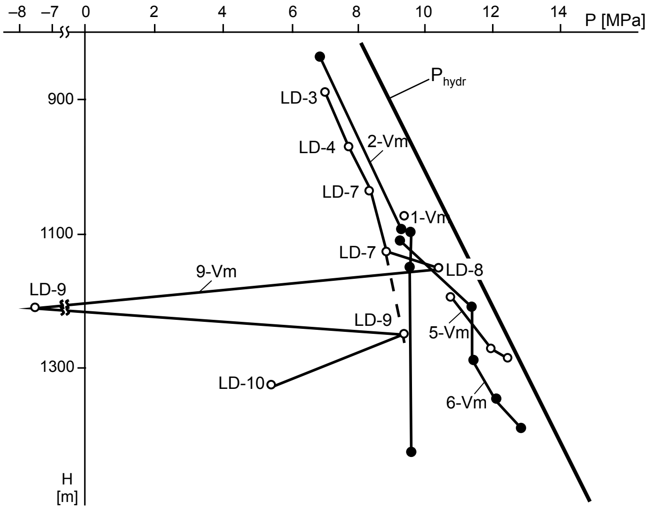

Fig. 6. Changes of baroosmotic head pressure ($P_{o.h}$) of water in boreholes of the Vizhomlia gas deposit

metamorphism degree of the waters, which is in accordance with the principles of BO-process.

Figure 5 shows the variability of $P_{o.h}$ in the waters of the UD-11 horizon in the whole Kokhanivka–Svydnytsia area. The figurative points form a large scatter field, the average of which (dotted line) moves somewhat off the P_{hydr}, so the weak intra-bed concentration increase is possible. However, what is more important, the lowest mineralization and highest $P_{o.h}$ values correspond to boreholes 62, 45, 59, 61, 31. According to Figure 1, they all are located at the ridge of the Svydnytsia fold in a zone of maximum gas accumulation. In our opinion, it proves that the main reason for mineralization variability of these waters is their mixing with condensation waters (Kolodiy, 1983) brought to the deposit together with gas flows.

Vizhomlia gas deposit. The Vizhomlia fold is located under the SE part of the Svydnytsia fold (Fig. 3). The thin-layered sand-clay beds of the LD subsuite (LD-8, LD-9A, LD-9B, and LD-10) are gas-bearing in the Vizhomlia fold. The deposit is divided by the Sudova Vyshnya lateral fault into two parts: the uplifted NE (Ragozne block) part and the subsided SW (Boniv block) part. The formational waters here are much more varied and more metamorphosed when compared to those of the Svydnytsia deposit. However, the chlorine concentration is higher than 74%-eqv, while the HCO_3^- concentration is below 18%-eqv and the SO_4^{2-} concentration is below 17%-eqv; the variability of cation composition is even higher. Water mineralization also significantly varies from one borehole to another, with chaotic variations with depth.

Figure 6 shows that $P_{o.h}$ changes have different patterns, but in every borehole, there are areas where $P_{o.h}$ increases with depth, and thus the upward BO-flow of H_2O molecules is possible. The most complete picture was obtained for borehole 9-Vm (located outside the deposit) which produced water from beds LD-3 to LD-10. In the LD-3 to LD-6 interval, the usual BO-concentration of formation waters takes place. However deeper, drastic fluctuations of $P_{o.h}$ appear, caused by dilution in the LD-8 and a high concentration of these waters. Nevetheless, the point for the lower part of the LD-9 is again at the basic BO-concentration line (dotted line). This allows us to say that this line reflects the ancient BO-profile for this section, which was deformed after gas deposition: in the LD-8 by dilution of formation waters with condensational ones and in the LD-9 and LD-10 by an inflow of deep waters. The impact of condensational waters from the LD-8 gas deposit on the formation waters of borehole 9-Vm is obviously due to its nearby location (Fig. 2).

The BO-profile for borehole 2-Vm is much simple: above the LD-4 horizon, it is similar to the one of 9-Vm, and below the LD-4, the $P_{o.h}$ remains practically unchanged to the N_1kr horizon. It means that above and below the LD-9 gas deposit in this borehole, almost a 300-m deep zone of BO-quasi-balance formed. A similar zone is also in borehole 6-Vm in the LD-8 horizon, although the gas deposit is located here in the LD-9B horizon. It is possible that in the LD-8 such zone was formed occasionally in the same waters. The impact of gas deposit on the LD-9B revealed itself in a significant dilution of formation waters. Similar dilution is apparent also in borehole 5-Vm. As a result, in boreholes 5-Vm and 6-Vm the mineralization decreases with depth. However, the general shape of the $P_{o.h}$ profile in these boreholes shows that in addition to condensational waters, there must exist at least one more factor for formational waters dilution here. It is possible that the squeezing-out of osmotically-fixed freshwater from clays takes place at these depths (Kushnir, 2009a).

Kokhanivka oil deposit. The Kokhanivka oil-bearing structure is located under the NW part of the Svydnytsia gas-bearing fold. The oil deposit is located in cavernous-fissured Jurassic limestones of the Rogozy Block, which are overlapped by Neogene deposits (Fig. 3). The waters of Jurassic deposits highly differ from those of the upper horizons of Sarmatian deposits. Here, they are of Cl-type and, as a rule, they have higher mineralization values that are closer to typically marine values of rNa/rCl (~0.85) and Cl/Br ratio (~300).

Figure 7 shows that BO-parameters of these waters change almost chaotically with depth. In borehole 9-Kkh, which is

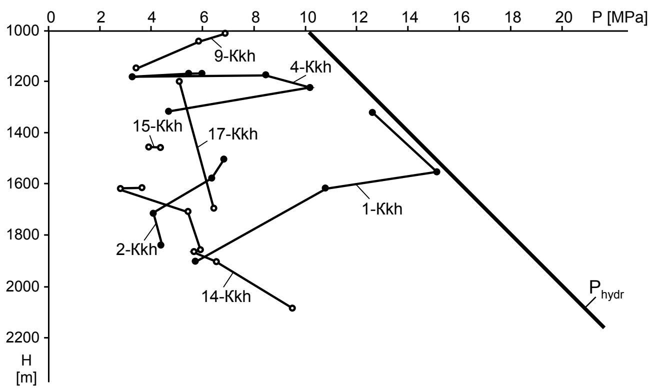

Fig. 7. Baroosmotic head pressure ($P_{o.h}$) in waters of the Kokhanivka oil deposit

located in the uplifted Rogozy block, the $P_{o.h}$ changes with depth inversely to the mineralization rate. The BO-flow of H_2O molecules must be directed down the section. In borehole 14-Kkh, which is located in the downcast Boniv Block, $P_{o.h}$ increases, although the mineralization rate is almost constant (~120 g/dm^3). Thus, even in saline waters, an upward BO-flow developed here. Such a flow and the corresponding $P_{o.h}$ pattern are called "normal", and the pattern where mineralization increases drastically, as in borehole 4-Kkh below 1200 m depth, and in boreholes1-Kkh and 2-Kkh below 1500 m depth, is called "anomalous". The anomalous patterns evidence that, in corresponding areas, the flow of H_2O molecules is mostly caused by capillary osmosis (Kushnir, 2008) which means that the impact of concentration is stronger than that of pressure. And only in borehole17-Kkh, where the mineralization under the oil deposit increases from 73 to 114 g/dm^3, the $P_{o.h}$ value increases with depth due to a sharp increase of P_{hydr}.

The comparison of Figures 4 and 7 shows that the hydrogeological system above the Kokhanivka oil deposit has practically nothing in common with that from below this deposit. These systems look isolated one from each other and there is even no osmotic relation between them. It means that even osmotically constrained water does not occur in the oil deposit. It is pushed out of the deposit by polar components of oil. As a result, the BO-pattern appears to be disrupted into two independent parts: the upper one, where the BO-flows are upward, and the lower one, where they are often downward. The osmotically pushed out water caused a sufficient decrease of concentration of oil waters near the deposit, which, in turn, was the reason for the capillary osmosis. Most geologists attribute the decrease in water mineralization of oil deposit only to the impact of solution waters of oil (Shchepak, Savitsyn, 1963; Kolodiy, 1983). In our opinion, this is not correct.

CONCLUSIONS

In a single structure of the Kokhanivka–Svydnytsia area, gas and oil deposits are located at more or less the same depth. If the BO-pattern in the oil deposit area is disrupted, the "hot" molecules from the lower part of the section cannot move to the upper one. So, the heat transfer will go by means of a slow procedure. In the area containing a gas deposit, such transition is easy to carry out and to conductometric constituent a significant "semiconvective" constituent is added. The latter constituent, with the flow of "hot" H_2O molecules, would result in sufficient temperature increase in the entire section. To check this conclusion, we collected all the available data on temperature of waters, oil and gas in the study area, and presented them in Figure 8. Our predictions have been confirmed. On the plot, two lines are visible, one of them (1) goes through the points of the oil deposit, and the other one (2) – through the points of the Vizhomlia gas deposit. The first one has a thermal gradient of 3.5, the second one – 3.8ºC/100 m. The temperature of all gases of the Vizhomlia deposit is 2–3ºC higher compared to the background, so a weak temperature anomaly is formed. In our opinion, it is the consequence of fast convective heat transfer, which resulted in the elevating of the temperature in the top beds of the deposit and its approaching to the temperature of the bottom beds of the deposit. The given example shows that temperature anomalies not always could be explained by a deep fluid impact through the nearby tectonic faults; many anomalies can arise due to the described procedure.

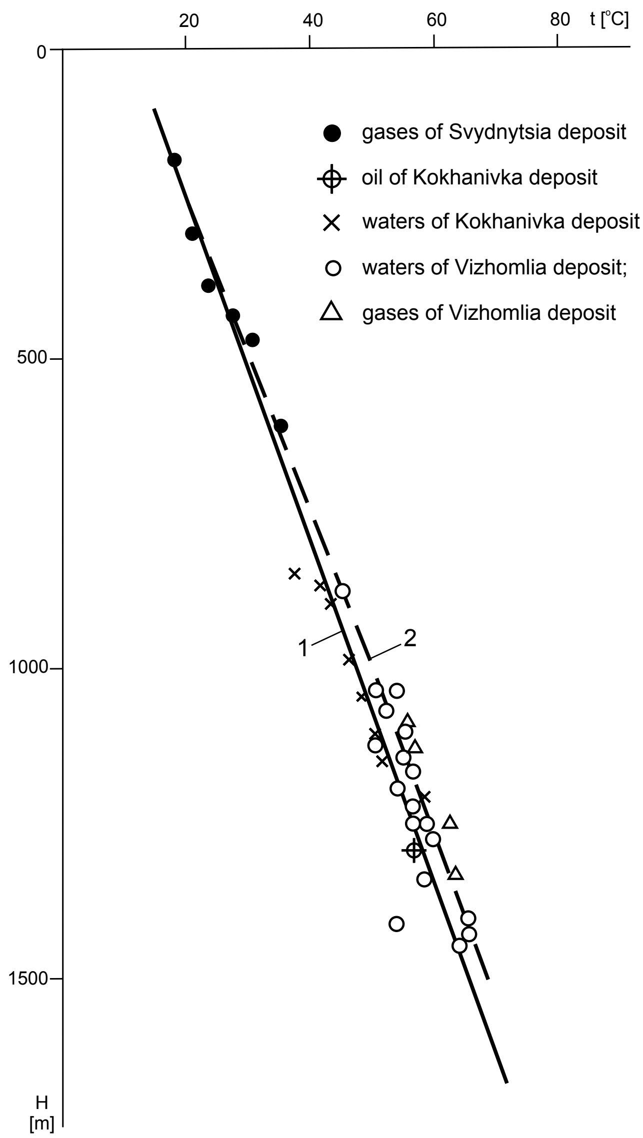

Fig. 8. Temperature changes in the Kokhanivka (1) and Vizhomlia (2) deposits

All this evidences that the method of baroosmotic analysis, in spite of its approximate calculations, could serve as an effective tool for hydrogeological studies not only in platform areas, but also in regions of recent tectonic activity. Its accuracy depends upon the number of water analyses in boreholes – the more analyses are used for calculations, the more reliable the result is.

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