Hydrogeochemical features of pore-waters of bottom sediments of the shelf and limans of the Northwestern Black Sea region

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Хидрогеохимични особености на поровите води от дънните седименти на шелфа и лиманите на Северозападния Черноморски регион

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Abstract. The article presents information on the chemical composition and salinity of pore-waters of the Holocene bottom sediments in the shelf and limans from the Northwestern Black Sea region. The specific features of the water quality distribution laterally and in depth are considered. The peculiarities of the structure of hydrogeochemical sections confirm the transgressive-regressive character of the sea level change.

Analysis of the geological structure, hydrogeochemical and paleoclimatic features allowed to substantiate the hypothesis of the use of limans as sources of salt in the Holocene period.

Based on the information on the hydrochemical features of bottom sediments and changes in sea level, the reconstructions of paleogeographic sedimentation environments during the late Pleistocene-Holocene time on the northwestern shelf and limans of the Black Sea are presented.

Keywords: Black Sea, shelf, liman, pore-waters, salinity.

Резюме. Статията предоставя информация за химичния състав и солеността на течната фаза (поровите води) на холоценовите дънни седименти на шелфа на Черно море (между река Дунав и Кримския полуостров) и лиманите на северозападното Причерноморие: Джантшейски, Будацки, Днестровски, Хаджибейски, Куялници, Тилигулски, Березански, Днепро-Бугски, а също така и Сасик, Шагани, Алибей и Бурнас.

Използва се методът на палеогеографска реконструкция, който се основава на изучаването на законите на променливостта на минерализацията и състава на поровите води. Изследвани са особеностите на разпределение на свойствата на поровите води по площ и в дълбочина. Установено е, че минерализацията на поровите води на дънните седименти на шелфа и лиманите на Черно море варира от няколко грама на литър до 200–250 g/l, т.е. от солена вода до

разсол. Според химичния състав поровите води на дънните седименти на шелфа са от сулфатен тип. Други преобладаващи компоненти в поровите води на лиманите на Черно море са натрият, хлорът и магнезият. На шелфа солеността на поровите води на древночерноморските седименти е по-ниска от солеността на поровите води на новочерноморските седименти. Намаляването на солеността с дълбочината се дължи на влиянието на новоевксинското обезсоляване. Най-големи амплитуди на колебания на минерализацията са установени за Дунавския шелф. Тези колебания са придружени от промени в качествения състав на поровите води – преди всичко от промяната на съдържанието на сулфати и карбонати.

Поровите разтвори в дънните седименти на лиманите, въпреки известна метаморфизация, наследяват особеностите на химичния състав на водите на лиманите. Най-висока минерализация се наблюдава в Тузловската групата на лиманите, където средната минерализация е повече от 100 g/l. В затворените лимани колебанията са по-изразени, отколкото в откритите устия. Установени са структурните особености на хидрогеохимичните участъци, които потвърждават трансгресивно-регресивния характер на промените в морското равнище. При промяната на солеността на поровите води на долните утайки на лиманите по дълбочина се отбелязват от 2 до 4 пика на соленост, които са почти синхронизирани във времето и са свързани с регресивната серия от утайки.

Въз основа на информацията за хидрохимичните особености на дънните утайки и промените в морското равнище са представени реконструкции на палеогеографските условия на утаяване, съществували през късноплейстоценско-холоценско време на северозападния шелф на Черно море и причерноморските лимани.

Ключови думи: Черно море, шелф, лиман, поровите води, соленост.

1. Introduction

Bottom sediments of the sea shelf and limans are a multicomponent system consisting of mineral, gaseous and liquid phases. The composition and properties of this system are due to the situation of sedimentation and subsequent lithogenesis processes. The study of the composition and properties of the liquid phase (pore-waters) of bottom sediments provides additional information on the processes of sedimentation and lithogenesis, the possibility of its use in the paleogeographic reconstructions. An extensive bibliography exists on this subject (Vernadsky, 1933; Valyashko, 1955, 1971; Shishkina, 1972; Shcherbakov et al., 1978; Konikov, 1983, 1993; Voskoboinikov et al., 1984; Shnyukov, 1985; Gursky, 2003).

There are salt limans in the littoral area of the Northwestern Black Sea region within which a natural process of salt crystallization occurs due to climatic factors. As it is known, the salt used to have an exchange value in many regions of the world (Ivanova, 2014).

The purpose of the work is to identify regional features of the chemical composition in pore-waters of bottom sediments to reconstruct hydrogeochemical sedimentation environments within the northwestern shelf and limans of the Black Sea, and to justify the hypothesis of the use of limans as salt sources during the Holocene.

2. Area and research targets

The subjects of our research are the Black Sea shelf (between the Danube River and the Crimean peninsula) and the limans of the Northwestern Black Sea region: Sasyk, Dzhangshay, Shaganyi, Alibey, Burnas, Budaki, Dniestr, Khadzhibey, Kuyalnik, Tiligul, Berezan, and Dnieper-Bug (Fig. 1).

3. Data and methodology

In the study area there are more than 2000 wells and points of bottom sediment sampling. In most of the wells, the composition of the fauna of mollusks, the structure and the grain-size distribution of the sediments were studied. In some wells, the chemical composition of pore-waters and the physical properties of sediments were studied, and their age was determined.

Fig.1. Map-scheme of the research area

The results of the chemical analysis of pore-waters in the bottom sediments of the north-western shelf and limans of the Black Sea were analyzed.

The data of the Department of Engineering Geology and Hydrogeology of the Odessa National University and the Black Sea Search and Review expedition „Krygeologiya“, as well as data from other studies (Burkser, 1928; Tageeva et al., 1962; Shishkina, 1972; Babinets et al., 1981; Shihaleeva, 2013; Cherkez, 2017) were used.

The method of paleogeographic reconstruction was used; it was based on the study of the regularities of the variability of TDS content (Total Dissolved Solids – TDS) and the composition of pore-waters, although the application of this method involves some difficulties. Paleoreconstructions have been criticized (Olsztynsky, 1977) due to the fact that biochemical, diagenetic and other processes change the overall picture. However, subsequent studies have shown that these changes have occurred over the centuries (Babinets et al., 1981; Voskoboinikov et al., 1982, 1984; Konikov, 1993). Therefore, the use of these methods is fully justified for the paleoreconstruction of the recent geological past.

4. Results and discussion

4.1. The geological structure of the bottom sediments of the shelf and the limans of the Black Sea

The northwestern shelf of the Black Sea acquired a modern appearance as a result of flooding of the coastal strip during the late Pleistocene and Holocene transgressions (Konikov, 2006; Pedan, 2013). Holocene sediments form an almost continuous cover in the subaerial base. They are distinguished by a great genetic variety: marine, lagoon, liman, coastal-marine, alluvial, deluvial, etc. They are presented by sandy-argillaceous sediments and shells. The thickness of the Holocene sediments varies from the centimeters to 18–20 and more meters, decreasing to 1.0–1.5 m to the outer boundary of the shelf.

Fig. 2. Geological section across the Alibey liman

Stratigraphy: 1 – Holocene; 2-3 – Upper and Lower Pleistocene; Genetic types of sediments: 4 – alluvial; 5 – marine; 6 – liman-marine; Lithology: 7-9 – loamy, clayey and sandy silts, respectively, 10 – sand; 11 – mollusk shells; 12 – muddy sand; 13 – clay; 14 – loam; 15 – sandy loam.

16 – well number; 17 – age of sediments.

The Holocene age of sediments of both the shelf and limans is confirmed by faunistic determinations and absolute datings (Neveskii, 1967; Konikov et al., 2006).

Important objects for restoring the events of the Holocene history of the Northern Black Sea region are the study of the lithological and facial structure of the limans. The liman deposits represent cyclically constructed strata (Voskoboinikov et al., 1982; Konikov, 1993; Konikov et al., 2006) (Fig. 2).

In lithological structure, these cycles represent alternations in strata of clayey mud, aleurolitic mud, and muddy shell. The average thickness of these strata is from 0.5–1.5 m up to 2.5 m. The cyclical structure of the Holocene deposits is also expressed in the variability of chemical composition and salinity of pore-water, as well as changes in the physical and mechanical properties of precipitation, and chemical composition. The rhythmic pattern in the distribution of these characteristics is caused by transgressive-regressive fluctuations in the level of the Black Sea basin (Konikov et al., 2006) (Table 1, Fig. 3).

When comparing the curves of sea-level fluctuations, the generalized values of the composition indexes, and the properties of muddy bottom sediments, one can approximately estimate the rate of accumulation of precipitation in the limans for the last 6.2 thousand years. These velocities are 1.5–2.5 mm/year, which is 3–10 times higher than the sedimentation rate on the northwestern shelf (Shcherbakov et al., 1978).

4.2. TDS content (Total Dissolved Solids – TDS) of pore-waters of bottom sediments of the Black Sea shelf

According to the classification of Vernadsky (1933), the degree of the TDS content of pore-water in the bottom sediments of the shelf and the limans of the Black Sea

Table 1. Stratigraphic of regional geological sections

Epoch	Subdivision	Horizon	Strata			Age, ky BP
			after Fedorov (1978, 1982)	after Nevesskaya (1965), Nevesskiy (1967)	after Voskoboinikov et al. (1982), Konikov (2004, 2005)	
Holocene	Upper	Novochemomorean	Recent (transgression)	Recent (transgression)	Recent (transgression)	0.0 – 0.5
			Korsunian regression after Shilik (1972, 1997)	Dzhemetinian	Medieval regression (Little Ice Age)	0.5 – 0.7
			Nymphaean transgression		Nymphaean transgression	0.7 – 2.0
			Phanagorian regression		Phanagorian (Olbian) regression	2.0 – 2.6
	Middle	Novochemomorean	Novochemomorean	Kalamitian	Kalamitian transgression	2.6 – 3.8
			Regression		Khadzhibeian regression	3.9 – 4.4
			Novochemomorean	Khadzhibeian	Lower Novochemomorean transgression	4.4 – 5.8
	Lower	Drevnechemomorean	Drevnechemomorean	Vityazevian	Tyrasean regression	5.8 – 6.3
					Upper Drevnechemomorean transgression	6.3 – 7.5
			Regression	Bugazian	Drevnechemomorean transgression	7.5 – 8.2
					Lower Drevnechemomorean	8.2 – 8.9
	Drevnechemomorean	Regression	8.9 – 9.5			
	Upper	Neoeuxinian	Neoeuxinian	Neoeuxinian transgression	9.5 – 17.7	
				Neoeuxinian regression, Antsky alluvium after Gozhik (1984)	17.7 – 25.0	

varies from brackish water to strong brines. Pore-waters of bottom sediments were studied in separate regions of the Black Sea shelf: Danube avandelta, Dnieper Trough, Karkinitzky Bay (Fig. 4).

The main regularities that are revealed as a result of the research are the following. First, the salinity of the pore-waters of the deposits differs significantly from the salinity of the present-day Black Sea water. According to Shishkina (1972), it averages 19 g/l, and in the bottom layer reaches 22 g/l, while the salinity of the porous waters of the Holocene shelf deposits ranges from 4 g/l to 35 g/l.

The nature of the distribution of the salinity of interstitial waters differs in depth from the distribution of the salinity of the pore-waters of the sediments of the deep-sea basin of the Black Sea (Shishkina, 1972), and also the data obtained for the deposits

Fig. 3. Level changes of the Black Sea

Fig. 4. Variation in the TDS content of pore-waters of the shelf bottom sediments

of the northwestern part of the shelf (Tageeva et al., 1962). Salinity of the deep-sea basin of the Black Sea is gradually reduced from values equal to the salinity of modern Black Sea water to 6–8 g/l. At depths of 10–12 m from the bottom surface, the salinity values do not exceed 1–2 g/l. The TDS content of the pore-waters of the deposits of the northwestern shelf of the Black Sea is approximately equal to the average salinity of its water, or 2–3 g/l less.

The results of the investigations showed that in the water of the Drevnechernomorean sediments the salinity is 9–15 g/l, in the Novochernomorean sediments it ranges from 8 to 33 g/l. The decrease in the salinity of waters with depth is apparently due to the influence of Neoeuxinian desalination.

The greatest amplitudes of the TDS content oscillations of the pore-waters of the Novochernomorean sediments are established for the Danube section and vary from 4

to 35 g/l, the average value increasing from 19 g/l to 24 g/l with depth, the dispersion decreases. At all sites, significant fluctuations in the mean values of the mean were registered.

In the chemical composition of water, calcium chloride is often presented along with salts that are typical for ocean water, which is due to ion exchange reactions between the mud solution and the sediment (Valyashko, 1971; Konikov, 1993).

4.3. TDS content of pore-waters of bottom sediments of the limans of the Northwestern Black Sea region

Pore solutions in the bottom sediments of the limans of the Northwestern Black Sea region are usually sedimentogenic waters of chloride-sodium hydrochemical type. Despite a certain metamorphism, they inherited the main features of the chemical composition of the waters of the limans (Voskoboinikov et al., 1984).

Primarily, this applies to the general mineralization of pore solutions. The salt content of the limans varies from 5 to 230 g/l in terms of both area and depth (Fig. 5, 6). The minimum mean value of TDS content is observed in the interstitial waters of the Berezan and Tiligul Limans (16 g/l), although the range of salinity fluctuations is different (8.8–26.4 and 8.7–52.8 g/l, respectively).

Average values of the TDS content in the pore-waters of Sasyk Liman and Khadzhibey Liman are 46 and 40 g/l respectively, with similar ranges of salinity changes (14.8–93.0 and 8.7–107.2 g/l). As it turns out, the highest TDS content is observed in the Tuzlovskaya group of lakes, where the average value is 112 g/l, with an amplitude up to 190 g/l. According to the data (Babinets et al., 1981), the TDS content of the pore-waters within Dniestr Liman ranges from 1 to 34 g/l, while in the Dnieper-Bug Liman, it ranges from 10 to 25 g/l. The salinity distribution of pore-waters within bottom sediments in terms of the area and depth of the limans is rather variable.

Stratification is clearly manifested in the sharp fluctuations of TDS content in depth. These fluctuations are accompanied by changes in the qualitative composition of the pore-waters, primarily by a change in the content of sulfates and carbonates. As for the change in salinity of the pore-waters within the bottom sediments of the

Fig. 5. Variation in the TDS content of pore-waters in liman bottom sediments

Fig. 6. Hydrogeochemical well columns

limans, 2–4 peaks (maxima) of salinity (almost synchronous) are noted in depth. Their presence can be explained by the transgressive-regressive nature of the Black Sea level regime during the Holocene.

For the closed limans (Khadzhibey, Budaki, Alibey), these peaks are more evident than for open limans (Tiligul, Berezan). Open limans are characterized by small fluctuations in the TDS content of the pore solution. The relationship between cyclicity in the salinity change of pore-waters from limestone deposits with sea-level fluctuations in the limans is beyond doubt (Babinets et al., 1981; Konikov, 1983).

Analysis of the dependence of the liman water-salt regime on the climate humidity in the Northwestern Black Sea region allows to be identified two groups of limans: (1) Tiligul, Khadzhibey, Shaganyi, Alibey, Burnas, and (2) Dnieper-Bug, Dniestr, and Berezan. With regressive sea-level decline and inadequate moisture conditions, the runoff of „small“ rivers could have been significantly reduced or completely stopped. At such a time, the limans turned into lakes in which the concentration of salts in the water was caused by evaporation. With sufficient climate humidification, when atmospheric precipitation exceeded evaporation (in cold and humid climate stages), freshwater runoff would increase and desalination of these limans could occur.

However, the salinity of the pore-waters of the sediments within the limans of this type indicates that the TDS content of their waters in the past was not lower than the salinity of the modern sea. Thus, it is possible to associate the high salinity of pore-waters in the first group of the limans with regressions – Tyrasean, Khadzhibey and Phanagorian. The climate at this time in the Northwestern Black Sea region was relatively arid.

Large rivers flow into the limans of the second group. For this reason, the dependence of the water-salt regime of these limans on the degree of the climate humidity for the study area is not manifested to the same extent as it is for the first group of limans. This occurs because the runoff of the rivers Dnieper, Southern Bug, and Dniestr originates mainly during humid climates.

The outflow occurs mainly during humid climates.

Therefore, with regression of the sea, these limans were desalinated, and with transgressive increases in sea level, the salinity of their waters increased but did not exceed the salinity of the water of the modern sea. These events, which were accompanied by a change in the hydrochemical conditions in basins receiving insignificant fresh water intake, were repeated as is shown on the concave-convex diagrams of the interstitial water salinity.

4.4. Paleogeographic reconstruction of hydrogeochemical structures of sedimentation

The studied Holocene sediments of the shelf and the limans, taking into account salinity and chemical composition, were accumulated in various paleo environments/conditions, which is confirmed by lithological studies.

Within the northwestern shelf of the Black Sea, the thickness of the Holocene sediments is much lower than the bottom sediments of the limans of the same age and is 1.5–2.0 m. According to the lithological structure, the bottom sediments of the limans have a greater vertical heterogeneity than the shelf. The shelf is characterized by lateral facies variability. Ancient coastlines serve to distinguish various facies situations on the shelf. These lines are determined by the sediments of coastal-marine wave accumulative forms, and morphometrically they are determined by sharp bends of the shelf surface.

Using the information on the amplitude of Holocene transgressive-regressive phases of the Black Sea basin (Konikov et al., 2006), contours of ancient basins within the shelf are defined.

For the purposes of hydrochemical reconstructions of sea and salt basins in the chemical composition of porous waters, it is advisable to use a classification based on this of Valyashko (1971) with the clarifications of Konikov (1993). Depending on the chemical composition and TDS content, the following types of waters are distinguished: bicarbonate-calcium, sulfate-sodium, sulfate-magnesium and chloride-calcium.

According to the chemical composition, the pore-waters of the bottom sediments of the shelf are of the sulfate-magnesium and chloride type. The predominant component of the chemical composition of the pore-waters of the limans is sodium chloride (up to 80%) and magnesium chloride. Limans differ from each other in the different content of sulfate compounds of calcium, magnesium and sodium. It is also noted that within the limits of each liman the content of these compounds varies, which is caused by the metamorphism process.

The map-scheme of the hydrogeochemical conditions of sedimentation that existed in the late Euxinian-Holocene time was constructed on the basis of data on the lithologic composition (Voskoboinikov et al., 1984; Konikov et al., 2006), as well as information on the chemical composition and TDS content of the pore-waters of the bottom sediments (Babinets et al., 1981; Konikov, 1993; Gursky, 2003) (Fig.7). The map shows coastlines corresponding to the Tiras (6.3 thousand years ago) and

Khadzhibey (4.4 thousand years ago) maximum declines in the level of the Black Sea. They delineate within the shelf ancient limans, lagoons and bays. The outlines during Phanagorian time the basin (a peak level – 10 m) on the shelf in the map scale differs slightly from the contours of the modern bank.

Thus, at the end of the Neoeuxinian – beginning of the Holocene on the shelf there were lagoons with a water salinity of 8–15 g/l and a fauna of the Caspian type, which gives reason to consider them as Neoeuxinian and Drevnechernomorean. Gradual increase in salinity to 25–35 g/l occurred 4–7 thousand years ago and is associated with

Fig. 7. Map-scheme of the hydrogeochemical conditions of sedimentation within the shelf and limans

general sea salinity, as well as a decrease in sea level in the Tyrasian and Khadzhibeian regressive phases, which caused the salinity of the lagoons and limans that existed at the time. In the Novochernomorean time the salinity of the waters changed, since the mineralization of the pore-waters of these deposits varied from 10–15 to 25–35 g/l. The salinity of the pore-waters of modern sediments is 15–20 g/l, i.e. it is equal to the TDS content of the modern Black Sea water.

5. Conclusion

Pore-waters of modern liman-sea silt are a convenient object to study the formation of structure and properties of sediments in the early stages of diagenesis.

The TDS content and composition of pore-waters, in spite of their definite metamorphism, mainly reflect the relict salinity of the waters of the shelf and the limans and are well correlated with historical data on the mode of connection between the limans and the sea.

A study of the salinity and chemical composition of the pore-waters of the bottom sediments made it possible to conclude that the liman-lagoon sedimentation environments within the shelf existed during the Late Neoeuxinian and Drevnechernomorean seasons, up to about 4500 years ago.

The TDS content of the pore-waters of the Black Sea shelf and some limans varies from a few g/l to 200–250 g/l. The range of changes in the salinity of the pore-waters of the liman deposits is much larger than the range of changes in the salinity of the sediments of the Black Sea shelf. The maximum values of mineralization of the waters of the shelf sediments are 30–35 g/l, maximum sediments at various depths recorded maximal salinity values up to 200–250 g/l.

Hydrogeochemical cross sections are in good agreement with the results of paleogeographic reconstructions. In the change in the salinity of the pore-waters of the bottom sediments of the estuaries, from 2 to 4 almost synchronous peaks of the salinity maxima are recorded in depth. These peaks are confined to regressive series of precipitation.

A rise in salinity of liman water during regressive cycles of the Black Sea, as well as climatic conditions (climate aridization), give grounds to assume that, during the study period, there was a natural precipitation of salt due to saltiness of the limans, especially in the limans fed by small rivers. Analysis of the geologic structure, and hydrogeochemical and paleoclimatic features of the Northwestern Black Sea region has shown the validity of the proposed hypothesis about human use of these limans as salt springs in the Holocene period.

References

- Babinets, A.E., A.A. Sukhorebriy. 1981. On the hydrogeochemical features from bottom data of the limans of the Northwestern Black Sea region. *Geological journal*, 41(2), 104–111 (in Russian).
- Burkser, Ye.S. 1928. Salt lakes and estuaries of Ukraine (hydrochemical sketch). All-Ukrainian Academy of Sciences. In: *Proceedings of the Physics and Mathematics Department*, VIII (1), Kyiv, 341 p. (in Ukraine).
- Cherkez, E.A., V.N. Kadurin, S.V. Svetlichnyi. 2017. Mineral paragenesis of brine and bottom sediments of the Kuyalnik liman and their genetic systematics. *Odesa National University Herald. Geography and Geology*. 22(1), 198–211 (in Russian).
- Ivanova, S.V. 2014. Mining of salt in the North Pontic and Crimea (by archaeological and ethno-logical sources). *Archeology and the long history of Ukraine*. 2 (13), 7–18 (in Russian).
- Gurskiy, Yu.N. 2003. *Geochemistry of Lithohydrosphere of Inland Seas*. Vol. 1. Methods of study and the processes of formation of the chemical composition of interstitial waters in the bottom sediments from the Black, Azov, Caspian, White, Baltic seas. GEOS, Moscow, 332 p. (in Russian).
- Konikov, E.G. 1983. *Composition, structure, properties and pore waters of the Holocene sediments of the northwestern shelf of the Black Sea and the Black Sea limans*. Abstract of the thesis of geological-mineralogical sciences candidate. Odessa, 164 p. (in Russian).
- Konikov, E.G. 1993. Hydrochemical evolution of the Azovo-Black Sea basin in the Late Pleistocene and Holocene. *Oceanology*, 33(2), 217–223 (in Russian).
- Konikov, E.G. 2006. Sea-level fluctuations and coastline migration in the northwestern Black Sea area over the last 18 ky based on high-resolution lithological-genetic analysis of sediment architecture. In: Yanko-Yjmbach, V., A. Gilbert, N. Panin, P. Dolukhanov (eds.). *The Black Sea Flood Question: changes in coastline, climate, and human settlement*, Dordrecht: Springer, 405–435.

- Konikov, E., G. Pedan. 2006. Geological-lithological structure of limans as a key to decoding late Neoeuxinian and Holocene history of the Black Sea. In: Yanko-Hombach, V., I. Buynovich, A., Chivas, A.S., Gilbert, R.E., Martin, and Mudie P. (eds.). *Extended Abstracts of the Second Plenary Meeting and Field Trip of IGCP 521 Project Black Sea-Mediterranean corridor during the last 30 ky: Sea-level change and human adaptation*, (August 20-28, 2006, I.I. Mechnikov Odessa National University, Odessa, Ukraine), Astroprint, Odessa, 89–91.
- Nevessky, E.N. 1967. *Processes of Sedimentation in the Coastal Zone of the Sea*. Nauka, Moscow, 255 p. (in Russian).
- Olshytiynskiy, S.P. 1977. Paleogeographic reconstruction of the chemical composition of interstitial waters. In: Veklich, M.F., A.T. Artiushenko, (eds.). *Paleogeograficheskie osnovy ratsional'nogo ispol'zovaniia estestvennykh resursov*, Naukova dumka, Kiev, 74–76 (in Russian).
- Pedan, G.S. 2013. Features of the development of estuary coasts of the abrasion-landslide type (northwestern Black Sea region). *Odesa National University Herald. Geography and Geology*, 18, 1(17), 205–212 (in Russian).
- Valyashko, M.G. 1955. The main types of natural water and the conditions for their formation. *Reports of the Academy of Sciences of the USSR*, 102(2), 315–318 (in Russian).
- Valyashko, M.G. 1971. Fundamentals of the geochemistry of natural waters. In: *Geochemistry of groundwater*. Izdatel'stvo Moskovskogo Universiteta, Moscow, 93–119 (in Russian).
- Vernadskiy, V.I. 1933. *History of the minerals of the earth's crust. V.2. History of natural water*. Goshimtehizdat, Leningrad, 202 p. (in Russian).
- Voskoboinikov, V.M., M.F. Rotar', E.G. Konikov. 1982. Relationship between rhythmic composition of thick Holocene layers of the Black Sea region lagoons and oscillatory level regime of the Black Sea. In: *Sea Level Fluctuations*. Izdatel'stvo Moskovskogo Universiteta, Moscow, 264–274 (in Russian).
- Voskoboinikov, V.M., E.G. Konikov, M.F. Rotar'. 1984. Hydrogeological and hydrochemical features of limans. In: Shnyukov, E.F. (eds.). *Geology of the Ukrainian Shelf. Limans*. Naukova dumka, Kiev, 81–102 (in Russian).
- Shishkina, O.V. 1972. *Geochemistry of marine silt waters*. Nauka, Moscow, 228 p. (in Russian).
- Shihaleeva, G.N., A.A. Ennan, I. I. Shihaleev, A. N. Kiryushkina, I. S. Kuzmina. 2013. Long-term dynamics of the water-salt regime of the Kuyalnik liman. *Odesa National University Herald. Chemistry*, 18, 3(47), 67–77 (in Russian).
- Shcherbakov, F.A., P.N. Kuprin, L.I. Potapova, A.S. Polyakov, E.K. Zabelina, V.M. Sorokin. 1978. *Sedimentation on the continental shelf of the Black Sea*. Nauka, Moscow, 210 p. (in Russian).
- Shnyukov, E.F. 1985. *Geology of the Ukrainian Shelf of the Black Sea. Lithology*. Naukova Dumka, Kiev, 189 p. (in Russian).
- Tageeva, N.V., M.M. Tihomirova. 1962. *Hydrogeochemistry of bottom sediments of the Black Sea*. Izdatel'stvo Akademii Nauk SSSR, Moscow, 146 p. (in Russian).

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