HOLOCENE DEPOSITS OF VARNA LAKE

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ABSTRACT. This article is an overview of the existing data on lithology and relationships of the bottom sediments and their significance for the reconstruction of the Holocene history of Varna estuary. With the end of the cold Younger Dryas stadial 11.5 ka ago comes the end of the last glacial stage and the Neoeuxinian basin, also called “ice-age fresh water lake”. The saltwater flooding through Bosporus during the Early Chernomorian transgressive phase caused flooding of the river mouths and formation of limans. Probably then started the accumulation of the Holocene deposits of the newly formed Varna liman. Previous studies of these deposits are based on data obtained from hundreds of boreholes drilled for the construction and maintenance of the navigation channels ensuring connection of the Varna Lakes with the Black Sea. New drilling has recently been carried out for the deepening of the channels, which provided more information about the Holocene deposits. Novochernomorian and Nymphean terraces, marking the high sea level during the Holocene history of the Black Sea, are well exposed on the lake shores. The section of the Holocene deposits at Nalbanka bay shows well traceable subsurface terraces marking sea level lowstands. The sea-level fluctuations have had an important influence on the ancient civilizations inhabiting Pontus Euxinus coast. The archaeological artifacts provide evidence of these fluctuations and important facts for the restoration of the Black Sea coastline in antiquity and Middle Ages.

Keywords: Varna Lake, marine terraces, estuary deposits

ХОЛОЦЕНСКИТЕ НАСЛАГИ НА ВАРНЕНСКОТО ЕЗЕРО

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РЕЗЮМЕ. Тази статия е преглед на съществуващите данни за литологията и взаимоотношенията на дънните утайки и тяхното значение за възстановяването на холоценската история на Варненския лиман. С края на студения Късен Дриас преди 11,5 ka идва краят на последния ледников период и Новоевксинския басейн, наричан още „пресноводно ледниково езеро“. Нахлуването на солени води през Босфора по време на ранночерноморската трансгресивна фаза предизвиква наводняване на речните устия и образуване на лимани. Вероятно тогава е започнало натрупването на холоценските утайки в новообразувания Варненски лиман. Предишните проучвания на тези седименти се основават на стотици сондажи, прокарани за изграждането и поддържането на навигационните канали, осигуряващи връзка на Варненските езера с Черно море. Наскоро бе проведено ново сондиране за удълбочаване на каналите, което предостави още информация за холоценските утайки. Новочерноморската и Нимфейската тераса, индикиращи високи морски нива през холоценската история на Черно море, са добре експонирани по бреговете на езерото. Разрезът на холоценските отложения в залива Налбанка показва добре проследими подповърхностни тераси, маркиращи ниски морски нива. Флуктуациите на морското ниво са оказвали важно влияние върху древните цивилизации, обитаващи брега на древния Понтос Евксинос. Археологическите артефакти предоставят доказателства за тези колебания и важни факти за възстановяването на бреговата ивица на Черно море в древността и Средновековието.

Ключови думи: Варненско езеро, морски тераси, лиманни отложения

Introduction

Limans and lagoons are typical nearshore basins along the Bulgarian Black Sea coast. They are Holocene water bodies formed during the sea level rise after the last glacial period. During the Vityazevian Stage of the Early Chernomorian transgressive interval (9–7 ka ago) the sea invaded the land and many limans were established along the Black Sea coast. Varna and Beloslav Lakes are among the largest limans along the Bulgarian coast formed in drowned river valley of the Provadia River. During the seventies of the last century Varna Lake was connected to the sea via navigation Channel 1 and to Beloslav Lake via navigation Channel 2 (Fig. 1). Hundreds of boreholes have been drilled for the construction and maintenance of these channels. Recently, more drillings were made by “Transport Construction and Reconstruction” Corp. in seven profiles accross Channel 1 which is of total length 6 695 m, average design depth 12.50 m and maximum navigation width – 310 m (Fig. 2). The new boreholes provided valuable information about the structure and composition of the estuary deposits and subsurface Holocene terraces. For the deepening of navigation Channels 1 and 2, connecting the Black Sea with Varna and Beloslav Lakes, new engineer-geological investigations were made. The present paper is a review of the previous results obtained during the construction of Channel 1 in the seventies of the 20th century, and during its reconstruction for navigation purposes made in 2019 and 2020.

Fig. 1. Situation map with the location of the channels connecting the Beloslav and Varna Lakes with the Black Sea

Fig. 2. Satellite map of the borehole profiles across Channel 1: *1*, profile; *2*, onshore borehole; *3*, marine borehole

Geological setting

Varna Lake is situated in the Varna depression, also known as Varna monocline with layers dipping 5–10° to the east. It is part of the Moesian Platform, which builds the post-Jurassic structural plan. The area is characterized by good outcrops of geological formations. A number of faults buried by the Quaternary sediments have been identified. The geological foundation of the Varna Lake is represented by several Paleogene and Neogene units, cropping out on the slopes of Varna and Avren Plateaus. They belong to the Avren, Ruslar and Galata Formations. In the higher parts sediments of the Frangja, Evksinograd, Odarci and Karvuna Formations are also exposed (Fig. 3).

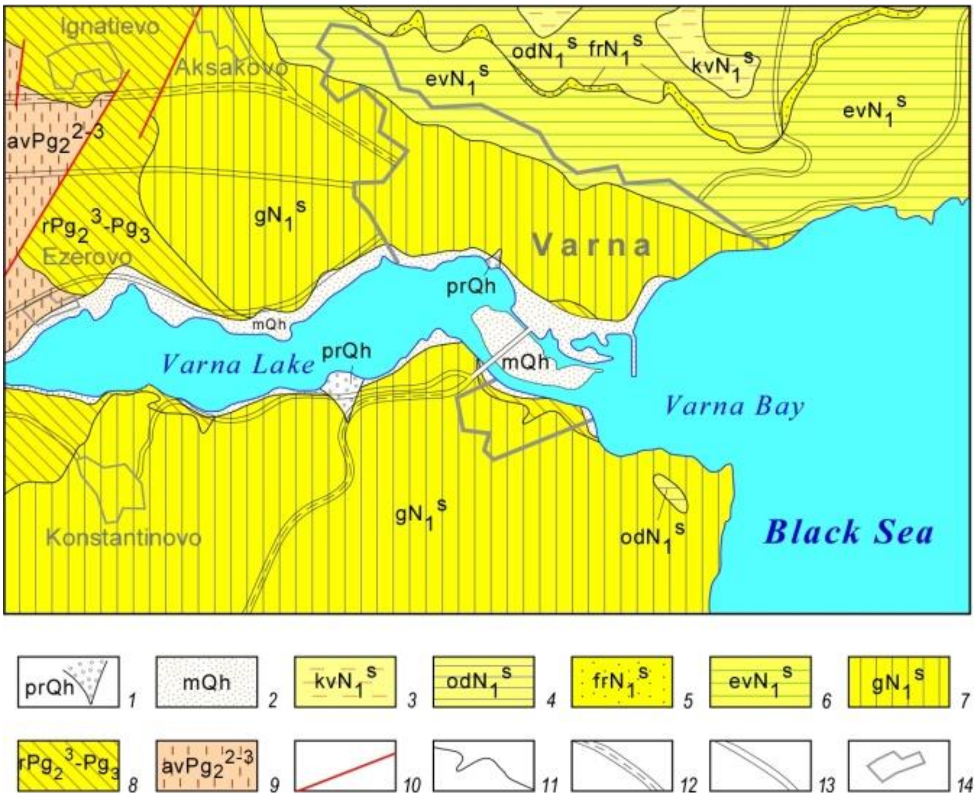

Fig. 3. Geological map of the area (after Cheshitev et al., 1992, with additional data): *1*, proluvial fans: boulders, gravel and sand (Holocene); *2*, modern sediments of the Novochernomorian and Nymphaean terraces: beach sands with shell clusters (Holocene); *3*, Mactra limestone – Karvuna Fm., Miocene, Sarmatian (Khersonian); *4*, detrital shelly and oolite limestone with clay and sand layers – Odarci Fm., Miocene, Sarmatian (Upper Bessarabian); *5*, oligomictic sands with thin sandstone layers and lenses – Frangja Fm., Miocene, Sarmatian (Volhynian); *6*, clays – Evksinograd Fm., Miocene, Sarmatian (Volhynian–Bessarabian); *7*, sands with layers of clays, sandstones and rarely conglomerates – Galata Fm., Miocene (Tarkhanian–Konkian); *8*, clays, sands and clayey sandstones with manganese ore – Ruslar Fm., Upper Eocene–Oligocene; *9*, marls with thin sandstone layers – Avren Fm., Middle–Upper Eocene; *10*, fault; *11*, lithostratigraphic boundary; *12*, highway; *13*, road; *14*, settlement

Geomorphological notes

Morphologically, Varna valley is located in the easternmost part of the Danube plain. The valley is surrounded by low uplands: Varna Plateau from the north with a height up to 370 m, and Avren Plateau from the south with a height of 180 m. These uplands are composed of Paleogene and Neogene rocks. The valley is formed by Provadia River, whose mouth was turned into an estuary during the Holocene transgression after the last ice age. The study area is part of the modern Black Sea coast, which has been subject to repeated flooding and drainage for the last 2 million years due to sea level fluctuations caused by the Quaternary glacial and interglacial stages. As a result, marine terraces have been formed, located above the modern sea level and below it. Above the modern water level of the Varna Lake several terrace surfaces at different altitudes are established by Koyumdzhieva (1962), Popov and Mishev (1974), and Evstatiev and Manov (1988).

Chaudinian terrace

Popov and Mishev (1974) correlate the flattened surfaces at an altitude of 90–100 m south of Asparuhovo neighborhood with the Chaudinian terrace. They are situated west of Galata Cape at an altitude of 90–100 m, and in Sakam dere – at 90 m.

Euxinian-Uzunlarian terrace

The presence of this terrace in the area is noted by Popov and Mishev (1974) at Cape Galata at an altitude of 35–40 m.

According to them it is proven by fossil fauna. Evstatiev and Manov (1988) also noted a terrace level at an altitude of 41–42 m recognized during geological engineering studies for the chemical plants on the northern shore of the Beloslav Lake. In the eastern part of the Varna Lake a terrace level at an altitude of 38–40 m is established in several places.

Old Karangatian terrace

The presence of this terrace level is established by Popov and Mishev (1974) within the city of Varna at an altitude of 18–25 m. They noted that no fauna was found and the age was determined by analogy with other parts of the coast. Evstatiev and Manov (1988) also described a wide terrace level at an altitude of 20–22 m near soda plants. They consider as its continuation the terrace surface on the northern shore of the Varna Lake at an altitude of 15–20 m.

Young Karangatian terrace

The sediments of this terrace in the area are first established on the northern shore of Varna Lake by Kojumdgieva (1962, 1964), 1 km west of Varna at "Yanko Kostov" cannery. It is described as a "second marine terrace" of Middle Pleistocene age in the explanatory note to the geological map of Bulgaria at a scale 1:100 000, map sheet Varna and Golden Sands (Cheshitev et al., 1994). The 50 cm thick basal layer of small to medium-sized conglomerate is followed by 8–12 m medium to coarse-grained sands. Popov and Mishev (1974) determined typical Karangatian fauna in the conglomerate layer proving the presence of a shallow bay in the Karangatian Sea.

Novochernomorian terrace

The presence of the Holocene terraces along the Bulgarian Black Sea coast is first noted by Fedorov et al. (1962) and Fedorov (1963). The Novochernomorian terrace near Varna Lake was established by Kojumdgieva (1962) at the same place where the Young Karangatian terrace is described. It contains bluish sands and silts with rich fauna, similar to the modern one, on the basis of which is determined Early Holocene age (Novochernomorian). Its presence was confirmed by a large number of boreholes during the geological surveys at the construction of the soda plants and the chemical plant "Varna". The foundation of this terrace is 3–5 m above sea level. Gravel, covered with gray-yellow fine-grained sand, silt and clay are deposited on this surface. According to Evstatiev and Manov (1988), the width of this terrace reaches 300–400 m and its boundaries with the higher Young Karangatian terrace and the lower modern lake terrace are often unclear.

Nymphean terrace

The Nymphean terrace is not well characterized along the Bulgarian coast. It is briefly mentioned in the works of Christov (1967) and Popov and Mishev (1974), but recently it was noted in several outcrops along the shoreline of the Burgas Lakes (Sinnyovsky et al., 2018, 2019). The youngest terrace in the studied area is very well defined at 1.5–2 m above sea level. Popov and Mishev (1974) described a wide "liman-marine terrace" 1–2 m above sea level, surrounding the lake from north, east and south reaching 2.8 km width between the lake and the sea. Evstatiev and Manov (1988) described it as a "modern lake terrace", which is represented by a variety of sediments – from coarse-grained sands with shell mussels to swamp clays and peat. It could be identified with the Nymphean terrace of Fedorov (1959), although in the Middle Ages the lake was probably a closed estuary. According to Shkorpil and Shkorpil (1921), initially the sea was widely connected with the lake that formed a sea bay. Although the historical sources are not reliable in terms of geological data, Shkorpil (1923) noted that during the battle between Vladislav Varnenchik and the Turks in 1444, the area between the lake and the sea was swamped, so it is possible that they were really connected.

Along the northern shore of the lake near the village of Kazashko, the sediments of the terrace are represented by sands with mussel shells. If the shells are of marine origin, then surely this surface can be identified with the Nymphean terrace. It is also possible that these deposits contain mixed or brackish-water fauna. Morphologically the younger Holocene terrace is well expressed along the entire shore of the lake and is covered with reeds everywhere (Fig. 4).

Fig. 4. The Nymphean terrace near the village of Kazashko with the coastal deposits of sands and shells

Sub-bottom terraces

Evstatiev and Manov (1988) summarized data from over 250 boreholes drilled along 15 km long and 0.5–1 km wide strip in connection with the port construction on the northern shore of the Varna Lake and compiled a map of the lake basement on which alluvial gravels marking sub-level terrace surfaces have been deposited. There are two well correlatable terrace levels. Against the background of these well expressed terraces some sublevels with a displacement of several meters were also recognized.

The lowest terrace recognized in the bottom deposits is at a depth of -28 to -35 m, but near the Asparuhovo Bridge it reaches -40 m. The base of the second, higher terrace in the lake deposits, which is very well expressed, from west to east sinks from -19 to -27 m. In the western part near the village of Ezerovo it is a flat surface with elevation between -19 and -20 m, but in the eastern part it is between -20 and -24 m (Fig. 5). Between the villages of Ezerovo and Kazashko, the terrace is cut by the Beglik valley, which flows into Varna Lake from the north. To the east towards the village of Kazashko the terrace surface is inclined from -20 m to -24 m. At the village of Kazashko this surface is crossed by parallel to the shore depression with a length of five to six hundred meters and a depth up to 5 m formed by the valley flowing into the lake immediately east of the village. Another flattened area of the second terrace follows to the east at a depth of about -26, -27 m, in which the Nalbanka valley is incised (Fig. 4). Gravel layers with a thickness of 1 to 5–6 m are located on the terrace socles of both terraces. The map of the surface of the second terrace (Evstatiev, Manov, 1988) shows that it follows the surface of the Holocene basement. It is represented by flat areas in which small ravines descending from the north are incised (Figs 5, 6). There are slight elevations and funnel-shaped depressions east of the village of Kazashko, where the thickness of the gravel layer covering the second terrace vary in the frame of 1–2 m. The surface of this gravel layer is inclined to the south and merges with the surface of the terrace socle at the transition between the two subsurface terraces.

Holocene deposits at the bottom of the lake

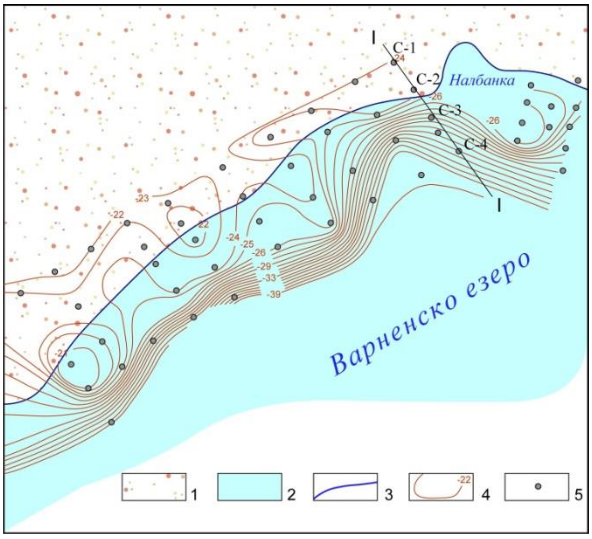

Fig. 5. Contours on the surface of the alluvial gravel layer of the second terrace, following the underlying Oligocene terrace socle (after Evstatiev and Manov, 1988, with additional data): 1 - land; 2 - water area of Varna Lake; 3 - shoreline; 4 - contours of the alluvial gravel on the second underwater terrace; 5 – drillings; I-I profile across the Holocene sediments illustrated on Fig. 5

After the Drevnechernomorian transgressive phase at 9 ka (Larchenkov and Kadurin, 2011) the Black Sea level rose to about -20 m. The saltwater flooding through Bosporus caused drowning of the river mouths and formation of limans. Probably then started the accumulation of the Holocene deposits of the newly formed Varna liman. The sediments at the bottom of the northern shore of the lake have been studied in great details based on the information of more than 250 boreholes, drilled during Transproekt's engineering-geological survey for the port construction.

A cross-section of the Holocene sediments deposited on the bottom of the lake is shown in Fig. 6, along the profile I-I from Fig. 5 (after Evstatiev and Manov, 1988). On the Nymphean terrace, surrounding the shoreline, there is a thin peat layer, which is formed in the Middle Ages during the high sea level (Nymphaean transgression) and continues its formation to these days (Fig. 6, unit 1). In the coastal zone, sands with accumulations of mussel shells are formed (Fig. 4; 6, unit 2). The youngest sediments, which are currently formed at the bottom of the Varna Lake, are the water-saturated silts (Fig. 6, unit 3) and sandy water-saturated silts (Fig. 6, unit 4). They correspond to the lithological Type 1 – sandy and clayey silts to sandy-silty clays with rare small gravels, established during the engineering-geological study conducted by "Transport Construction and Reconstruction" Enterprise in the upper part of all exploratory shore drillings with thickness from 0.50 to over 3.00 m.

Under these deposits there are sands with mussel shells, whose thickness under the peat is up to 1 m, but under the shallow part of the lake it reaches 5 m (Fig. 6, unit 5). They correspond to lithological Type 2 – fine-grained sand, in places clayey, with small to medium-sized gravels and crushed mussel shells, established during the engineering-geological study of "Transport Construction and Reconstruction" Corp. along the entire length of Channel 1 and at the beginning of Channel 2. In Nalbanka bay, these sands continue until the sharp deepening of the lake bottom due to the fault structure marking the northern shoreline. Below these deposits sandy clays with sand layers are penetrated (Fig. 6, unit 6). This unit pinches out in the direction of the lake. Below are limestone deposits (so-called "lake chalk"), whose thickness increases from 2–3 m below the Nymphean terrace to 5–6 m below the coastal zone (Fig 6, unit 7). Inside the carbonate deposits there is a lens of organogenic limestone up to 2 m thick (Fig. 6, unit 8). Below these carbonate deposits follow 3 m of consolidated mussel shells (Fig. 6, unit 9), 2 m of terrace deposits (Fig. 6, unit 10), 4 m of gray sandy clays (Fig. 6, unit 11), thin alluvial gravels (Fig. 6, unit 12), again thin clays (Fig. 6, unit 13), 3–4 m of sands (Fig. 6, unit 14) and alluvial clays (Fig. 6, unit 13) with a layer of sand and peat, underlying directly by the Oligocene socle (Ruslar Formation) to the land and gray sandy clays to the lake.

Further to the lake, laterally analogous of the sequence of units 11–14, the carbonate sediments are underlain by 5–6 m thick gray-green clay with mussel shells (Fig. 6, unit 15). In turn, this unit is underlain by 10 m alluvial clays and sandy clays with sandy layers (Fig 6, units 11, 13) at the base of which are the mentioned alluvial sands and gravels overlying the second river terrace. East of the village of Kazashko to the Nalbanka bay they cover directly the Oligocene socle (Ruslar Formation) at a depth of -20 to -26 m (Fig. 5). These clays can be compared with the lithological Type 3 – sandy-silty clay to clayey sand with clayey-sandy interbeds and crushed mussel shells, established during the engineering-geological study by "Transport Construction and Reconstruction" Enterprise in the marine drillings on the bottom of Channel 1. In the deep zone of the lake, south of the fault, under the modern water-saturated muds, a thick series of over 15 m clay muds with thin shell layers is disposed with a peat layer in the lower part which can be correlated also with the lithological Type 3. This unit covers sandy alluvial clays and river gravels. On the gravels of the second terrace there are up to 5–6 m thick sands of various particle size with fine-grained river gravels and yellowish sandstones. The deposits of the second terrace end with gray sandy clays, on which in many places a thin 0.5–1 m layer of buried peat is preserved, which at the railway near Nalbanka Bay is at a depth of -20 m (Figs 5, 6). Identical sequence is described by Popov and Mishev (1974) in a borehole drilled on the beach strip between Varna Lake and Black Sea, in which the second terrace level is established at a depth of 45.2 m. It is covered by 3 m gravel with sandy matrix.

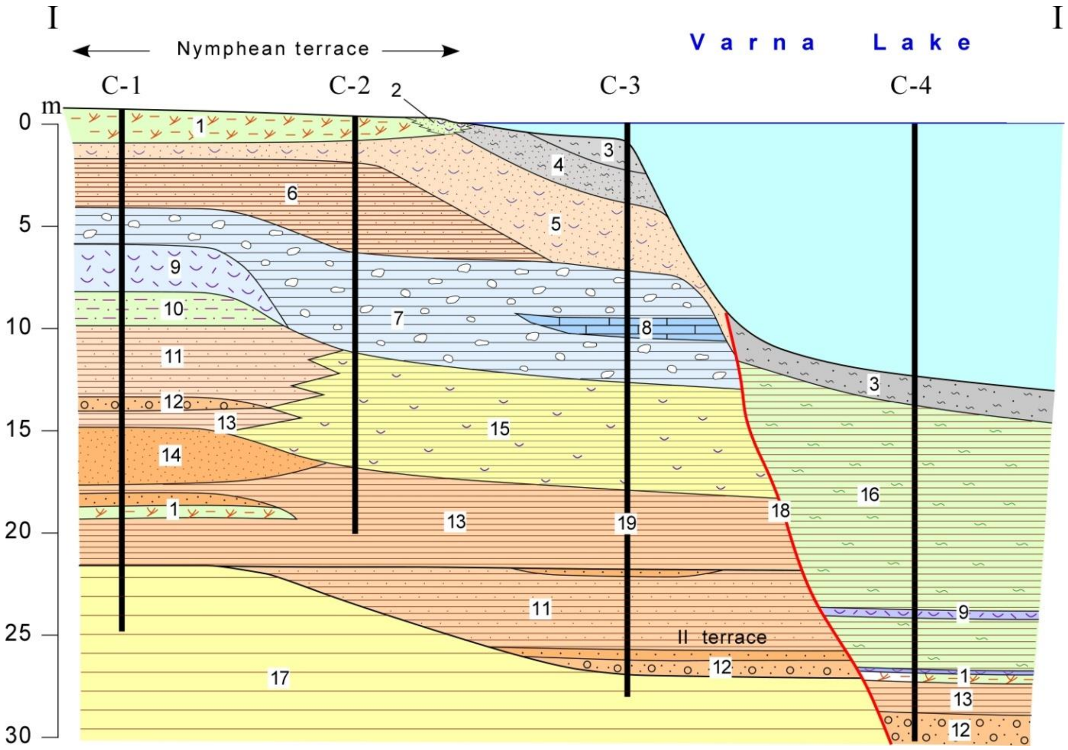

Fig. 6. Geological section along profile I–I in Fig. 5 west of Nalbanka bay on the northern shore of Varna Lake (according to Evstatiev and Manov, 1988, with additional data): *1*, peat; *2*, modern coastal deposits – sand and shell accumulations; *3*, water-saturated silt; *4*, sandy water-saturated silt; *5*, sands with mussel shells; *6*, sandy clay with sand layers; *7*, calcareous deposits (lake chalk); *8*, organogvnvn limestone; *9*, welded mussel shells; *10*, terrace deposits; *11*, gray sandy clays; *12*, alluvial gravel; *13*, alluvial clays; *14*, sands; *15*, gray-green clay with mussel shells; *16*, clay mud; *17*, Oligocene plinth (Ruslar Formation): clays, sands and clayey sandstones; *18*, fault; *19*, drilling

At a depth of 40 m is situated 60 cm thick peat layer covered by 3.5 m gray-bluish clay and 18 m marine mud – an evidence of swamp marine sedimentation. The rest of the section is represented by 1.5 m sand and 14 m sand with mussel shells, covered by 1 m thick peat layer and 2 m beach sands. The last investigations showed that Type 1 (water saturated sandy-silty clays) and Type 2 (fine-grained sand with crushed mussel shells) are prevailing to the depths of 14–15 m in all of the boreholes drilled for the deepening of the navigation Channel 1. In profile 3 it is very thin and is underlain by the sediments belonging to Type 3 (sandy-silty clay to clayey sand with crushed mussel shells) which is characteristic for the depths below 14 m. In profile 5 this interval between 6 and 15 m depth is represented by fine-grained sand.

Historical and archeological aspects

Until 1906, before digging the first chanel to the sea, Devnya Lake (Varna Lake) flowed down along the Devnya River (Shkorpil and Shkorpil, 1921) through which there was a stone bridge called “Tash Kyupryu” (Fig. 7). After the construction of the channel it became unnecessary and was destroyed in 1908. Thus, the waters of the lake were salted and its level, which was 1.4 m higher, is equalized with the sea level. The existence of a higher sea level in the Middle Ages is confirmed by historical sources. Shkorpil and Shkorpil (1921) noted that the lake was initially connected directly to the sea and was a sea bay. Then a barrier gradually begins to form from the sediments of the beach sand. The famous Asparuhov shaft was originally built on the beach, while now it is 600 m away from it. This is characteristic feature of the limans, indicating the sea level rise during the Middle Ages. According to Shkorpil (1923) during the famous battle in 1444 between the armies of Vladislav Varnenchik and the Turks, the area between Varna and the Asparuhovo district was swampy and the horses sank along with the heavily armed knights.

Fig. 7. Photograph of the stone bridge “Tash Kyupryu” over the Devnya River in front of the city gate of Varna, destroyed in 1908

On the other hand, the ancient pile dwellings, fortifications, breakwater walls and others, discovered at different depths in the Holocene deposits during the widening of the channel and other construction works, testify to a low sea level (3–4 m lower than it is today), which can be compared with the Phanagorian regression (Fedorov, 1956) proved by the remains of the ancient Greek colony of Khersones in Crimea, which are 3–4 m underwater. All these analogies show the great importance of the archaeological artifacts for restoration of the Holocene geological history.

Conclusions

The available lithological data about the Holocene deposits of the Varna Lake, obtained during the construction and maintenance of the navigation channels ensuring the connection with the Black Sea, provide excellent possibilities for interpretation of the Holocene history of this unique water basin, as evidenced by surface and subbotom lake terraces. The archeological artifacts, testifying for low lake level before the Odesos foundation, correspond to the geological evidence of low sea level in many places of the Black Sea coast. The question is whether the Varna estuary was closed during the Nymphean transgression in the Middle Ages or the sand barrier appeared after the Nymphean transgression. It should be resolved by investigation of the Nymphean fauna of the youngest liman-marine terrace.

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