New data on palaeogeographical changes during the Holocene in the Varna Lake region

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Abstract. The article presents the results of an integrated study of geological data based on three shallow cores from the Varna Lake area. The sedimentary sequences and the related archaeological artifacts were examined through lithological descriptions, a biostratigraphical analysis of the molluscan fauna, and an analysis of the geomorphological, archaeological and radiocarbon data. Continental, liman and marine facies conditions of sedimentation have been established by examining the sedimentary textures, stratigraphic and palaeoecological value of the molluscan subfossil fauna. This complex interpretation of data through different analyses allowed the highlighting of important stages in the palaeoecological development of the Lake of Varna and in human adaptation to changes in the coastal landscape at the beginning of the Holocene.

Keywords: biostratigraphy, geoarchaeology, palaeogeography, Varna Lake, Black sea.

Introduction

The palaeogeographic reconstructions of the Holocene and more specifically, sea level and climate fluctuations have a direct bearing on the emergence and development of human life. Attempts to illuminate the questions about the human settlements from Prehistory and Antiquity on the Western Pontic coast provoke much interest within the scientific community. The open discussion on the submerged settlements from the Eneolithic and the Early Bronze Age along the Bulgarian Black Sea coast constantly nourishes the idea of a possible of new archaeological artifacts. During the Quaternary, after the emergence of humanity, settlements concentrated in these areas because they were characterized by optimal climatic conditions and great biodiversity.

The problem of restoration of the palaeoecological conditions, in which human life has developed in the area of the Varna-Beloslav liman, is of particular relevance. The favourable environmen-
tial conditions have attracted humans from ancient times: This is shown by traces of human presence from the Late Paleolithic in The Little Cave near the town of Beloslav in the Varna district; and at the Mesolithic site Pobiti Kamani (Todorova, 1995) and by the existence of submerged Prehistoric settlements in the Late Eneolithic (4500–3800 cal. yr. BC) and Early Bronze Age (3200–2500 cal. yr. BC (Ivanov, 1993; Draganov, 1995). A number of submerged prehistoric settlements are known along the western coast of the Black Sea. Their existence has been indicated using geomorphological analysis and the methods of underwater archaeology. Out of the eighteen settlements that have been found up to present, thirteen are located in the Varna-Beloslav Lake (Hristova, Peev, 2014). The remains of eight submerged settlements from the second stage of the Eneolithic have been discovered (Ivanov, 1993), where all sites contained cultural remains, dating back to the Early Bronze Age. These submerged sites have been found at depths between 2.5 m and 9 m below present sea level (Ivanov, 1993; Lazarov, 1996).

Another key problem is the elucidation of the geological evolution of coastal lakes and/or existing river estuaries under the conditions of advanced early transgression until their transformation into firth with an oscillating sea connection. Some of the major recent studies related to the evolution of the Varna Lake have been published (Shopov, Yankova, 1987; Temniskova-Topalova, Atanasova, 1996; Filipova-Marinova et al., 2016).

**Geological setting**

The Gulf of Varna is situated between Cape St. George to the north and Cape Galata to the south (Fig. 1). This is the second-largest bay on the Bulgarian Black Sea coast following the Burgas Bay. The north and south shores are high and steep, whereas the west coast is low and accumulated. The shoreline is represented by abrasive and accumulative stretches, and the landslide processes make it difficult to identify the sea terraces. The coastline is made up of Sarmatian sandstones, clays and marls. The underwater coastal slope is likewise dominated by the Miocene sandstones and clays (Evlogiev, Evstatiev, 2016). Varna Lake is a typical firth situated in the western part of the Gulf of Varna. It is the largest firth by volume and depth along the northern Bulgarian Black Sea coast with an area of 17 km², a maximal depth of 19 m, and a water volume of 166 billion m³. At the bottom of the bay, a

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**Fig. 1. Location of boreholes in the Varna Lake area.** Abbreviation of geological boreholes: Zv_1 core (43°11ʹ06 N, 27°50ʹ31 E) and Zv_2 core (43°11ʹ03 N, 27°11ʹ32 E) on the southern coast – Zvezditsa village, Varna district; Dry Harbour core (43°12ʹ22 N, 27°52ʹ22 E) on the northern shore of the lake.

**Фиг. 1. Разположение на сондажите в района на Варненското езеро.** Абревиатури на геоложките сондажи: сондаж Zv_1 (43°11ʹ06 с.ш., 27°50ʹ31 и.д.) и сондаж Zv_2 (43°11ʹ03 с.ш., 27°11ʹ32 и.д.) на южния бряг – с. Звездица, област Варна; сондаж Сухото пристанище (43°12ʹ22 N, 27°52ʹ22 E) на северния бряг на езерото.
sandy strip has formed, separating Varna Lake from the sea. The lake was formed at the mouth of the Provadiya River by a sea-level rise during the Holocene after 7870 cal. yr. BP (Filipova-Marinova et al., 2016). Today the lake is separated from the sea by the constantly growing Asparuhovo sand spit. In reality, Varna Lake consists nowadays of two lakes: Varna and Beloslav.

Research into the formation of the lake has been conducted (Popov, Mishev, 1974). Drilling surveys located 650 m south of the dredged shipping channel have revealed a deep sequence of Holocene alluvial sediments that indicate oscillating sea-levels. The base of the river socle has been discovered at a maximum depth of 51.4 m. This has been overlain with a 0.6 m thick peat layer at a depth of 40 m, overlain by 18 m of marine sediments. Above these lies another indicator of subaerial deposits, with 1.5 m of peat, overlain with 14 m of sand mixed with shells and gastropoda, which proves marine inundation. Above these layers, there is a third peat layer with a thickness of 1 m, as well as accumulated clayey sand. The fossils at a depth of 33 m have been dated to the Holocene.

It is important to note that people have carried out several invasive construction activities in the area under investigation. Substantial changes and irreversible shifts have thus occurred on the coastline as well as the natural hydrodynamic and lithodynamic regime of the study area. The basin was a fresh-water lake with a limited flow into the Black Sea, supplied by groundwater and inflowing rivers until it was modified in 1909 to connect with Varna Bay through an artificial channel after which it became a brackish lagoon. The old sea-lake canal has a depth of 5 m. In 1975, a new canal was dug with a depth of 12 m. As a result, the salinity of the water subsequently rose to 15–16‰. In 1923, the Varna Lake was connected with the Beloslav Lake by the excavation of a shipping channel. Before these reconstructions, its height was no more than 1.4 m above the sea level. As a result, the natural sea-lake water exchange was damaged, irreversible changes were made to the shoreline, and significant changes to the landscape, where artifacts were probably destroyed.

Materials and methods
The presence of a representative factual material — geological samples from three cores with a different geomorphological position in the area of the present-day Lake Varna, is a good basis for stratigraphic correlation and palaeogeographic interpretation. The sedimentary sequences are described according to rock type and texture using the lithostratigraphic approach. To elucidate the environment of sedimentation and the determination of lithofacies, the texture characteristics of the sediments are described.

The analysis of the lithology and the biostratigraphic analysis of the mollusc fauna allowed to establish the stratigraphic sequences and the palaeoecological parameters of the geological environment, such as salinity and temperature. The starting point of the palaeoecological reconstruction was the assumption that all changes in the haline, lithodynamic and temperature regime of the basin, have been reflected in the palaeoecology of the mollusc-fauna inhabiting it — brackish, marine or mixed.

A correlation of geological and archaeological data from the three cores from the Varna-Beloslav Lake has been made (Fig. 1). On the southern coast, Zv_1 core (43°11’06 N, 27°50’31 E) and Zv_2 (43°11’03 N, 27°11’32 E) core were carried out in the region of Zvezditsa village, Varna district, as well as one core on the northern shore of the lake – Dry Harbour core (43°12’22 N, 27°52’22 E). On the basis of the collected geological samples, a litho- logical, biostratigraphic analysis was performed on the mollusc fauna of the lake and sea sediments and on the separated lithofacial conditions of sedimentation in the geological development of the liman during the Holocene. In the Laboratory of GEOgraphie De l’Environnement (GEODE) UMR-5602 CNRS/UTM, France, Toulouse a radiocarbon dating of key sediments was performed as part of the bilateral project “Sea Level Rise and Human Adaptation to Environmental Changes in the Bulgarian Black Sea Zone during the Holocene”, Bulgarian-French program RILA 01/8 (16.04.2015, Annex №1 03.11.2017) supported by the National Science Found at the Ministry of Education and Science in Sofia.

Results and discussion
Lithostratigraphical and palaeoecological characteristic
The coring site of Core Zv_1 (Fig. 2) is located on the southern side of Varna Lake, 3.2 km from the village of Zvezditsa, at an elevation of 1 m and with a total core length of 1240 cm. A vibrocorer drilling was performed, and a detailed lithological descrip-
tion and biostratigraphical analysis of sediment sequences have been made:

0–260 cm – loess-like soils, clay-sandy, with plant remains, high carbonaceous content; at a level of 180 cm buried black earth (continental facies).

260–480 cm – the lithological and textural characteristics of the sediments within the range determine the marine facies of sedimentation – sand, coarse- to medium-grained, quartzose, relatively well washed, sorted, with a gradual transition to the interval below with mollusk shells of *Dreissena polymorpha* (Pall.), fine shell debris and wood. At 480–500 cm there is a sharp, outwash boundary, presented by sand, quartzose, with gravel rounded (gravel bars).

480–1040 cm – the sediments revealed in the interval mark the liminal (marsh-lacustrine) conditions of sedimentation: 480–630 cm – silt, sandy clay; 630–680 cm – silty-clayey (muddy) matrix with plant remains, with an increase in the clay component and in the organic matter (transitions to marsh-lacustrine conditions); 680–850 cm – sand, diverse with a considerable content of shell debris, irregularly dispersed; 850–950 cm – sand, clayey. Among the dark gray clay sediments, molluscan taxa, typical of the Neweuxinian (Upper Pleistocene) complex have been identified: *Theodoxus pallasi* Lindh., *Theodoxus fluviatilis* (Linne), *Dreissena polymorpha* (Pall.). The nature of the facies described indicates that these species were probably resedimented in this part of the section. At the 1040 cm an outwash boundary is being observed, which is marked lithologically by sand, medium to coarse-grained, with gravel pieces (0.5–1 cm). Special attention in the described sedimentary cross-section is paid to the range of 950–1040 cm – the so-called “culture layer”. This cultural layer is represented by
dark sandy clays, finely laminated, and a piece of eneolithic pottery have been discovered at the level of 970 cm. Note that the pottery is very fragmented and it has been dated by comparison of its typology with better dated sites elsewhere.

950–1040 cm – clays, with parallel lamination, which indicated lake conditions.

1040–1120 cm – sand, clayey, medium to coarse-grained, with some gravels and single shells of *Dreissena polymorpha* (Pall.).

1120–1200 cm – sands, gray colour with gravels and presence of shells of *Dreissena polymorpha* (Pall.), *Rissoa splendida* (Eichw.) – resedimented species from Karangatian stage (Middle Pleistocene).

0–260 cm – continental facies

260–480 cm – marine facies

480–1040 cm – marsh-lacustrine facies

1040–1200 cm – liman with enhancing maritime influence.

The coring site of Core Zv_2 is located on the southern side of Varna Lake, 3.350 km from the village of Zvezditsa, at an elevation of 0.5 m, with a total length of 400 cm (Fig. 3). The drilling was carried out with a manual drilling pneumatic tool. The drilling section is shown in Fig. 2:

0–200 cm – 0–5 cm – mud, semiliquid, recent layer; 5–20 cm humus level; 20–200 cm – peat formed from the roots of marsh plants; transition to sand, brown to grey colour; medium-grained.

200–305 cm – clay, grey to black colour, very strong plasticity, with organic matter (OM), finely distributed. Brackish species such as the dominant *Dreissena polymorpha* (Pall.) and presence of typical freshwater forms such as *Theodoxus fluviatilis* (Linne), *Theodoxus pallasi* (Lindh). These species mark conditions of increasing salinity and prove the end of the Caspian phase. This part of the core section can be biostratigraphically correlated with Stage Ezeretz (E-I) from the Scheme of the correlation of the liman evolution stages during the Holocene of the Lake Shabla-Ezeretz (Shopov, Yankova, 1987).

305–388 cm – sand, clayey, grey to greenish-grey colour, very fine in size. Typical Mediterranean immigrants appear at a level of 305 cm: *Abra ovata* (Phil.), *Cardium edile* L., *Paphia discrepans* (Mil.), *Clessiniola variabilis* (Eichw.). The character of these sediments and mollusc fauna proves a new stage in the development of the liman – an opening to the aquatic environment and a strengthening of the sea influence. At the interval of 350 cm hitin remains have been found that were radiocarbon dated at 1720±30 cal. yr. BP and calibrated using data from tree rings (Bronk Ramsey, Lee, 2013; Reimer et al., 2013). The gray histogram of Fig. 4 gives a possible age of the sample 261–291 cal. yr. AD and/or 331–381 cal. yr. AD.

0–20 cm – continental recent facies

20–305 cm – lacustrine facies with accidentally marine influence

305–400 cm – liman with marine influence.

The coring site of Core Dry Harbour is located on the northern side of Varna Lake, at an elevation of 1 m (Fig. 2).

0–200 cm – soil.

200–650 cm – sand, clayey, light brown to brown-yellow with terrestrial species of Zonitoides sp. (Gastropoda classification).

650–820 cm – clay, dark brown, highly plastic, enriched with organic matter (OM) with porous texture, finely dispersed.

820–940 cm – sand, clayey, yellowish-brown with carbonate inclusions with a diameter of 1 cm.

940–1030 cm – clay, yellowish-brown to grey-green colour.

1030 m – outwash erosional boundary.
1030–1070 cm – transgressive marine phase: simultaneous presence of clay, sand and carbonate lenses; vortexing texture.

1070–1100 cm – clay, grassy green colour with a finely dispersed organic matter (OM), without fauna.

0–650 cm – continental facies

650–1030 cm – marsh-lacustrine facies

1030–1070 cm – marine facies.

Interpretation of geological cross-sections restoring the sedimentary environment

In the studied area, the carried out biostratigraphical analysis of mollusc fauna and of their paleoecological value and the method of treating them as facial fossils allow the following sedimentation settings to be established:

1) offshore type (sea-lake-liman). Sediments formed in such a coastal-marine environment are observed along the northern and southern side of Varna Lake. These are silt and sandy clay, which are formed in a marsh-lacustrine facies, which itself has been formed in the periodical restoration of the sea connection. The nature of the sediments and the mollusc fauna contained therein shows the oscillation of the transgressive phase, penetrating further into the bay.

Under these conditions, the clay component and/or the organic substance in the sediments is unevenly distributed. These sediments show very well-defined textures of parallel lamination, which together with the defined brackish mollusc fauna prove that a refreshing of the basin has taken place, converting it into a liman type of basin. The mollusc fauna, which is contained in the samples from the drillings in this facies, is a mixed type of marine and freshwater. Simultaneously, typical Mediterranean euryhaline immigrants such as *Cardium edule* L., *Abra ovata* (Phil.), *Paphia discrepans* (Mil.), *Rissoa splendida* (Eichw.) and typical liman species such as *Theodoxus pallasi* Lindh., *Theodoxus fluviatilis* (Linne) prove a slight salinity of about 5 ‰. The presented sections reconstruct the oscillations between a liman, a shallow sea and a coastal basin once again, that have occurred in a slow dynamic. This mixed tanatocenosis with presence of *Dreissena polymorpha* (Pall.) marks a stratigraphic affiliation to the Old Black Sea substage (Shopov, 1991) and correlates with Kalamitian layers (Nevesskaya, 1965) and Subboreal according to the Alpine stratigraphical scale (Hristova, 2021);

2) marine type. This type of lithofacies is characterized by the active hydrodynamic conditions and the strong presence of sands. They are grey-greenish in colour, medium to coarse-grained, relatively well washed, poorly sorted, with a gradual transition into brownish-grey sand with increasing silty-clayey (muddy) matrix and fine shell debris in the interval below. The maritime link is proved by mollusc shells of *Dreissena polymorpha* (Pall.) which are typical of the wider marine areas. The establishment of a relationship with the sea is evidenced by the nature of the sediments and the observed textures of normal and inverse gradation, as well as by the presence of gravel and small quartz grains, which are a typical indication of marine transgression penetrating into an existing river valley (the likely channel of a transgressive phase inflow). The stratigraphic position of the marine lithofacies (*Zv_1*) in combination with radiocarbon dating R_Date (1720) cal. BP (*Zv_2*) mark the transgressive phase of the Late

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Fig. 4. Radiocarbon dating of chitinous material of borehole *Zv_2* in the Laboratory of GEOgraphie De l’Environnement (GEODE) UMR-5602 CNRS/UTM, France, Toulouse: OxCal v4.2.4 Bronk Ramsey (2013); r:5 IntCal13 atmospheric curve (Reimer et al 2013)

Фиг. 4. Радиовъглеродно датиране на хитинов материал от сондаж *Zv_2* в Лабораторията на GEOgraphie De l’Environnement (GEODE) UMR-5602 CNRS/UTM, Франция, Тулуза: OxCal v4.2.4 Bronk Ramsey (2013); r:5 IntCal13 атмосферна крива (Reimer et al 2013)
Holocene, the so called Nymphaean transgression (Fedorov, 1963);
3) continental type. A continental type of sediments, which are revealed in the upper parts of the drilling sections: loess sediments (Zv_1) which are formed as a result of eolithic Quaternary sedimentation, and which build a loess superstructure on the sea terrace; a continental type of sediments that are related to the processes of modern soil formation and humus (Zv_2).

Conclusions

In this study the Late Holocene development of the Varna Lake is compiled. It demonstrates the pulsating sea-lake connection with a maximum marine influence. The stage is marked by the presence of marine sediments and has a radiocarbon dating at 1720 cal. yr. BP (in the borehole Zv_2). It represents a liman type of sedimentation, with periodic connections to the sea. The analyzed Holocene cores prove the occurrence of heterogeneous, mechanically formed tanatocenosis. It consists of: a) reworked Neoeuxinian Caspian species Dreissena rostriformis distincta Andrus and Monodacna caspia pontica Eichw.; b) Mediterranean immigrants as Cardium edule L., Hydrobia rentrosa Mnt.; c) marine euryhalinous species, inhabiting seawater with salinity close to the present day Black sea – Mytilus galloprovincialis Lam., Cardium exiguum Gmel., Cardium papillosum Poli and modern stenohalinous species Spisula subtruncata triangulata Ren., Pitar rudis Poli, Chione gallina Linne, Nassa reticulata Linne, Scala communis Lam.

The identified three facies settings exist simultaneously and prove the oscillatory nature of the emerging Late Holocene transgression – the Nymphaean transgression, which started about 2000 years ago.

The stage relates to the Subatlantic according to the Alpine stratigraphical scale, to the Dzemetinian layers (Nevesskaya, 1965) and is correlated with the New Black Sea regional substages (Shopov, 1991). As a result of the transgressive phase, the sea level rose to about 1–1.5 m above the current sea level. The coastal area on the two sides of the Varna Lake, as well as the existing ancient settlements, were gradually submerged.

Acknowledgements: The present study was supported by the project „Inventory of Late Antique and Medieval ports along the Western Black Sea“, funded by the National Science Fund of the Ministry of Education and Sciences of the Republic of Bulgaria (Grant Agreement no KII-06-Austria/11). The authors thank the anonymous reviewer for the careful reading of our manuscript and for many insightful comments and suggestions.

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Отговорен редактор Филип Мачев