BOTTOM SEDIMENT THICKNESS AS AN INDICATOR OF SEDIMENTATION RATE AND DEPOSITION ENVIRONMENT ON THE NORTHWESTERN SHELF OF THE BLACK SEA

Tyuleneva, N.V.,[1] Suchkov, I.A.,[2] and Fedoronchuk, N.A[3]

Department of Physical and Marine Geology, Odessa I.I. Mechnikov National University, Odessa, Ukraine 65058, [1] riatalia.tyuleneva@gmail.com, [2] marine@paco.net, [3] fedoronch@gmail.com

Keywords: Ho/ocene sediment thickness, sedimentation rate, paieogeography, northwestern Black Sea she if

Introduction

The northwestern Black Sea shelf is an outstanding area for research. On one hand, its geomorphological features and geological structure make it possible to trace the course of transgressions, and on the other hand, the place is rich in paleoanthropologic data on the adjoining land surface (Yanko-Hombach, 2011). Detailed reconstructions of its geologic history allow an understanding of the environmental influence on human development, and the results of investigation may be used to search for ancient human settlements within the shelf area now covered by sea.

In this work, we present data about the distribution of thicknesses in Holocene sediments (Drevne- and Novochernomorian time) and their connection with the bottom relief of the northwestern Black Sea shelf.

The objectives of the research were:

- to characterize the relief of the study area;
- to construct sediment thickness maps for Drevne- and Novochernomorian time;
- to estimate the sedimentation rate during the Holocene.

In the study area, during the period from 1976 to 2006, many cores were collected across the whole northwestern continental shelf of the Black Sea. The results of the investigation are based on extensive sampling of bottom sediments and the analysis of more than 3000 gravity and piston cores as well as 250 boreholes. These data are the result of previous geological surveys that were carried out by Prichernomorskoe State Regional Geological Enterprise "Prichemomor GRGP" (Odessa, Ukraine) and Odessa I.I. Mechnikov National University.

Geomorphologic characteristics of the northwestern Black Sea

The northwestern part of the Black Sea shelf includes the Dniester-Danube coastal waters in the west, the Dnieper-Dniester interfluves, the Tendra spit and Dzharilgach Island in the north, and the western part of the Crimean peninsula in the east (fig. 1). Its width is up to 170 km and its extent about 270 km. Maximum sea depths are -55 meters. The surface of the shelf before the Chernomorian transgression was represented by an alluvial plain which was formed under the influence of such large river systems as the Danube, Dniester, Yuzhniy Bug, and Dnieper (Zenkovich, I960; Ionin et al., 1987; Fesyunov, 1996). In the course of the Chernomorian transgression, the shelf was flooded by the sea, and its surface was partly flattened by the sediments (Fedoronchuk et al., 2010). The system of palcoriver valleys, paleo-terraces, ancient shorelines, and sandbars are represented on the surface of the shelf, which was formed during the late Wurm glaciation. The main subaeral relief elements despite partial wave reworking were preserved and are visible, though they are covered with a layer of marine sediments. Positive relief forms are represented by the Odessa and Dniester sandbanks, and the Budak, Western Tendra, and Dniester elevations (fig. 1). Elevations are the ancient watersheds that were characterized by the presence of mesa relief forms (Radzvil and Polovka, 2002). Uplifted areas lie at a water depth of less than 30 m, usually in the interval between -17 and -23 m.

The Odessa sandbank is the largest accumulative form on the shelf; its area is 178 km . It rises over the bottom surface an average of about 10-15 meters. The Odessa trench separates the Odessa sandbank from the shoreline, whieh is situated some 5-8 km to the north. This accumulative formation started to form in the Middle Pleistocene and consists of sediments from the first, second, and third terraces above the floodplain. The Odessa sandbank is a submarine continuation of the Kinburnskaya spit (fig. 1).

The Dniester sandbank is situated about 12-16 km from the shore; its length is 12 km, its width 6 km. It follows an E-W direction.

The Budakskoe elevation is situated some 10 km from the shore. The minimum water depth above it is - 20 m.

The western Tendra elevation is situated westward of the Tendra spit; it has submeridianal extension and an asymmetric shape: its northern part is 5 km in width, and its southern is 20 km. Water depth above its surface is 20 m.

Negative topographic forms in the shelf are represented by the Odessa trench, the Paleo-Dnieper, the Paleo-Dniester, and the Paleo-Sarata valleys.

The Odessa trench has a U-shaped profile, and its bottom becomes deeper in the western direction. The width of the trench varies from 4.5 to 9 km, and the maximum depth is 22 m. The Odessa trench was formed by the Paleo-Dnieper and Paleo-Yuzhniy-Bug waters during the late Pleistocene. The Paleo- Dnieper valley occupies the central part of the inner shelf. Maximum water depths within the valley are in the southern part (-30 m).

The Paleo-Dniester valley has distinctively shaped relief, and its width is up to 10-25 km. The Paleo- Sarata valley is a narrow depression with a width between 3 and 5 km.

Results

To study the patterns of sediment accumulation, their processes, and their connection with bottom relief, maps of the thickness of Drevne- and Novochernomorian sedimentary deposits were constructed. Also, the rate of sedimentation was estimated. Determinations of sediment age were based on the results of bulk, uncalibrated radiocarbon dating by Sibirchenko et al. (1983). The results of radiocarbon dating are not corrected according to a reservoir effect due to the uncertainty in the correction. That is why the precision may vary over wide ranges (Major et al., 2006). According to available age estimations, the Drevnechernomorian sediments were formed in the time range between ca. 10.5 and 7.1 ka BP and the Novochernomorian, from ca. 7 ka BP until the present.

The distribution of Drevnechernomorian bottom sediments is shown in fig. 2. The thickness of the studied sediments varies from 0.05 to 1 meter within the outer shelf (water depths greater than 35 m), and from 1 to 10 meters in the north (within the valleys of the Paleo-Dnieper, Paleo-Dniester, and Paleo- Sarata). The outlines of the Paleo-Dnieper valley match the isopach of 1 -2 meters, those of the Paleo- Dniester and Paleo-Sarata valleys, 0.5-1 m. Maximum thickness is encountered in Odessa Bay at 18.2 m. These sediments are absent in the area of the Odessa and Dniester sandbank, and the Tendra spit. According to radiocarbon dating (Sibirchenko et al., 1983), the sediment formation rate during Drevnechernomorian time was estimated. Maximum sedimentation rate is within Odessa Bay (5.35 m/1000 yrs), and for the Dnieper-Bug liman (3.5 m/1000 yrs), for the Dniester coastal waters (up to 5.3 m/1000 yrs), and for the Paleo-Sarata and Paleo-Dnieper (up to 0.8-0.6 m/1000 yrs, respectively). The outer shelf with a water depth more than 35 meters is characterized by a sedimentation rate of 0.3 m/1000 yrs. Mean sedimentation rates are in Table 1. Odessa Bay, the Dnieper-Bug liman, the Dniester coastal waters, the Paleo-Dniester, the Dnieper depression, the Paleo-Sarata, and the western Tendra elevation are characterized by high sedimentation rates. At the end of Drevnechernomorian time, favorable paleogeographical and geomorphological conditions arose and deep sediment thicknesses were formed within the western Tendra elevation area.

Novochernomorian bottom sediment thicknesses (fig. 3) vary from-0.1 to 0.4 meters on the outer shelf and from 10 to 18 meters within the river mouth areas in the north. Maximum thickness can be encountered in the Dnieper-Bug liman (18 m). Bottom sediments of Novochernomorian age are widespread in the study area. The Odessa sandbank, and the Dniester and Tendra elevations are outlined by isopach 0.5, 0.2-0.5 and 0.3-0.5 meters, respectively.

In the Dnieper-Bug liman, average sediment thicknesses are from 1.5 to 12 m, in Odessa Bay; in the Paleo-Dniester, from 0.5 to 5 m; in the Paleo-Dnieper, from 0.3 to 5 m; and for the Paleo-Sarata, up to 0.15 m. The areas with high sediment thicknesses concur with depressions, though during Novochernomorian time, these areas had smaller sizes and were displaced toward the northern direction.

The duration of the Novochernomorian time is about 7100 years (Sibirchenko et al., 1983). The maximum sedimentation rate for the Dnieper-Bug liman is 2.9 m/1000 yrs; for Odessa Bay it is up to 0.35 m/1000 yrs; for the Dniester coastal waters, up to 1.4 m/1000 yrs; lor the Paleo-Sarata up to 0.3 m/1000 yrs; for the Dnieper depression 0.2 m/1000 yrs; and for areas of the shelf with water depths greater than 35 m, up to 0.1 m/1000 yrs. On the elevations, sedimentation rates are low and vaiy from 3 to 7 cm per 1000 years. Average sedimentation rates for the Drevnechernomorian and Novochernomorian time were calculated (Table 1).

Table 1. Average sediment accumulation rate (m/1000 yrs)

Areas within the NW shelf of the Black Sea	Drevnechernomorian time	Novochernomorian time
Odessa Bay	4.95	0.22
Dnieper-Bug liman	0.67	1.4
Dniester coastal waters	1.35	0.36
Dniester elevation	0.06	0.096
Paleo-Dniester	0.4	0.05
Dnieper depression	0.33	0.14
Budak elevation	0.09	0.12
Paleo-Sarata	0.2	0.07
Western Tendra elevation	0.1	0.08
Central part of the shelf	0.02	0.05

Conclusions

The distribution of thickness within the Drevne- and Novochernomorian sedimentary deposits is closely associated with bottom relief. During periods when the recent shelf surface was land, certain features of the bottom relief were formed. Subsequently, these relief features caused incremental sediment thicknesses in the depressions.

During Drevnechernomorian time, the ancient limans were situated farther to the south than recent ones, and their position determined the environments and patterns of sediment formation. The limans on the shelf correspond to paleoriver valleys, and these areas are characterized by the accumulation of deep sediment thicknesses (from 5 to 10 m). Such areas as Odessa Bay, the Dnieper-Bug liman, the Dniester coastal waters, the Paleo-Dniester, the Dnieper depression, and the Paleo-Sarata are characterized by high sedimentation rates. This is connected to a large volume of terrigenous material brought by river flow. In the Dnieper and Dniester depressions, accumulation of sedimentary material took place close to the shoreline of the early Holocene. A s the result of northward movement of the coastline, the character of the distribution of sediment thicknesses changed. Such shelf accumulative forms as the Odessa and Dniester sandbanks are usually formed by terrigenous sediments from rivers, but besides this source, washout, re-sedimentation of ancient accumulative formations (Ischenko, 1971), and shore abrasion (Shnyukov et al., 1985) also make a contribution. The Holocene sediments of the Odessa sandbank are represented by dark-grey mud with shell detritus and anisomerous sand followed by shell sediments. The source of the sand in this area is Dnieper alluvial deposits. According to Pazyuk and Rychkovskaya (1972), Odessa sandbank mineralogical composition is similar to recent Dnieper alluvial deposits.

Several patterns in the distribution of bottom sediments during the Novochernomorian can be noted: deep thicknesses of sediments can be encountered in paleoriver valleys on the shelf, but these areas have smaller sizes and are displaced closer to the recent coastline in comparison with those of Drevnechernomorian time. Sediment accumulation processes led to bottom surface flattening. For example, the Paleo-Sarata valley features are smoothed in the modern relief, even though this area was characterized by high average sedimentation rates during Drevnechernomorian time (Table 1). This shows that the Paleo-Sarata valley was a negative geomorphological site during the Drevnechernomorian. On the contrary, during Novochernomorian time, this area shows low rates of sediment accumulation, which could be the result of gradual flattening and burial by sediments. River mouth areas and depressions within the northwestern Black Sea shelf are the places of avalanche sedimentation. Our results confirm data obtained from previous research (Shnyukov et al., 1985; Fesyunov, 2000).

Bottom relief flattening in the shelf was caused mostly by burial of depressions. Wave erosion of positive relief forms was not significant for several reasons: (1) high speed of the transgression, (2) active accumulation of terrigenous sediments on the shelf, and (3) shallow depth of wave influence on bottom sedimentary deposits. As a result, a lot of positive paleorelief forms on the bottom were covered by a layer of recent sediments. Thus paleorelief forms were protected and preserved from significant erosion processes.

Even so, the limited thickness of the overlapping sediment layer was sufficient to prevent washout processes of these relief forms. Nevertheless, at the present time on the shallow shelf (at water depths from 15 to 18 m), positive relief forms are under the influence of scour. Similar processes probably took place in the past, and this allows us to suggest that small forms of ancient relief could be destroyed by wave activity. Large forms of ancient relief probably did not experience strong erosion during the Holocene and can be traced because of the shallow thickness of the overlapping sediments.

As a whole, the paieogeography of the study area (position of the coastlines, relief of the bottom surface) has a strong influence on the distribution of bottom sediments. During the Holocene, the connection between sediment thickness and relief forms can be traced.

Maximum thicknesses correspond to depressions and to river mouth areas, minimal thicknesses to positive forms of ancient relief. The processes of sediment formation on the shelf of the northwestern Black Sea during the Holocene resulted in flattening of the bottom surface.

References

Fedoronchuk, N.A., Suchkov, I.A., and Tyuleneva N.V. 2010. Osnovnie cherty sovremennogo osadkonakoplenia v raione ostrova Zmeinii [Main features of recent sedimentation within the Zmiinyi Island area]. In *Collection of Scientific Works of the Institute of Geological Sciences NAS of Ukraine* 3: 204-211. (In Russian)

Fesyunov, O.K. 1996. Donnie landshafty severo-zapadnogo shel'fa Chernogo moria [Bottom landscapes of the northwestern Black Sea shelf]. *Priroda 2:* 71-76. (In Russian)

Fesyunov. O.E., 2000. Geoekologiia severo-zapadnogo shel'fa Chernogo moria [Geoecology of the Northwestern Black Sea Shelf]. Astroprint, Odessa. (In Russian)

Ionin, A.S., Medvedev, V.S., and Pavlidis, Y.A. 1987. Shel'f: rel'ief, osadki i ikh formirovanie [Shelf: Relief, Sediments and their Formation], Mysl, Moscow. (In Russian)

Ischenko, L.V. 1971. Dinamika nanosov vcrkhnei chasti shel'fa na vzmorie Dnestrovskogo iimana [Sediment dynamics of the upper part within the Dniester liman coastal waters]. In Nevesskiy E.N., Leont'ev O.K., eds, *Geoworfologiia i litologiia beregovoi zoni morei.* Nauka, Moscow, pp. 148-154. (In Russian)

Major, C.O., Goldstein, S.L.. Ryan, W.B.F., Lericolais, G., Piotrowski, A.M., and Hajdas, I. 2006. The co-evolution of Black Sea level and composition through the last deglaciation and its paleoclimatic significance. *Quaternary Science Reviews* 25(17-18): 2031-2047.

Pazyuk, L.I., and Rychkovskaya, N.I. 1972. Pro mineralogichnii sklad ta genesis piskiv centralnoi chastini Odeskoi banki na Chornomy mori [About sand mineralogical composition and origin of the central part of Odessa sandbank in the Black Sea]. *Geologiia uzberezhzhia i dna Chornogo ta Azovs 'kogo moriv u mezhakh URSR* 5: 43-51. (In Ukrainian)

Razdvil, A.A., and Polovka, C.G. 2002. Vpliv tektono-magmatichnih i stryktyrno-geomorfologichnih faktoriv na sychasne reliefoutvorenna chclfu u pivnichno-zahidnii chastini Chornogo mora ta formuvanna rodovish korisnikh kopalin [Influence of tectono-magmatic and structuralgeomorphological factors on modern relief forming in the northwestern part of the Black Sea and deposit forming], *Geologichmi zhurnal* 2: 42-48. (In Ukrainian)

Shnyukov, E.F., Melnik, V.I., Inozemcev, Yu.I., Kholosheva, D.P., Tcykhotskaya, N.N., Lutcyv, Ya.K., Ogorodnikov, V.L, Grigoriev, A.V., Bondarenko, V.G., Frolova. L.M., Lebedev, Yu.S., Kirichenko, O.N., Ivanov, Yu.K., Alenkin, V.M., Morgunov, Yu.G., Limonov, A.F., Kuprin, P.M., Fedorov, P.V., Sherbakov, F.A., Balandin, Yu.G., Naumenko, P.I., Voskoboynikov, V.M., Krakovskiy, B.I., Konikov, E.G., Yanko. V.V., Kotlov, V.F., and Shekhotkin, V.V. 1985. fn *Geologiia shelf a USSR. Litologiia [Geology of the USSR's Shelf. Lithology*]. Naukova dumka, Kiev. (In Russian)

Sibirchenko, M.G., Karpov, V.A., and Ivanov, V.G., 1983. Technical Report about Bottom Sediments Lithological Composition in the Black Sea for the Purposes of Geological-lithological Map Compilation. Marine Geological Survey Detachment SRGE "Prichernomorgeologiya", Odessa, Ukraine. (In Russian)

Tyuleneva, N.V. 2010. Usloviia osadkonakopleniia na severo-zapadnom shel'fe Chernogo moray v Bugazskoe vremya (Ranniy golotsen) [Sediment forming conditions within the northwestern Black Sea shelf during Bugazian time (Early Holocene)]. *Geologiia i poleznye iskopaemye Mirovogo okecina [Geology and Mineral Resources of the World Ocean*] 4: 65-74. (In Russian, with English abstract)

Yanko-Hombach, V.V., Smyntyna, E.V.. Kadurin, S.V., Larchenkov, E.P., Motnenko, I.V., Kakaranza, S.D., and Kiosak, D.V. 2011. Kolebaniia urovnya Chernogo moray i adaptatsionnaya strategiia drevnego cheloveka za poslednie 30 tysyach let [Oscillations of the Black Sea level and ancient human adaptive strategy during the last 30 ka], *Geologiia i poleznye iskopaemye Mirovogo okeana [Geology! and Mineral Resources of the World Ocean]* 2: 61-94. (In Russian, with English abstract)

Zenkovich, V.P. 1960. Morfologiia i dinamika sovetskikh beregov Chernogo moria [Morphology and Dynamics of the Soviet Coasts of the Black Sea], Izd-vo Akademii nauk SSSR, Moscow. (In Russian)