THE IMPACT OF DANUBE FLOODS ON THE SEDIMENTOGENESIS OF THE BLACK SEA LITTORAL ZONE

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Introduction

As is well known, deltas are sedimentary systems formed by the deposition of detrital material carried by rivers to their mouths in either marine or lacustrine basins (Panin, 1989). The Danube delta is a unique area. It is one of the most rapidly accumulating parts of the Black sea shelf. The solid matter component of the inflow represents 133 million tons of debris added to the Black Sea every year. Of this amount, the Danube inputs 83 million tons (Shyisky, 2003). These processes of sedimentation and deposition have been ongoing in the study area for several thousand years and have led to the creation of a huge mineral mass. The present paper presents actual data on the changes in sedimentation conditions for the Danube Delta during different seasons. Investigations of the sedimentation process require simultaneous examination of varied environmental factors. In this paper, data on water depth, salinity and temperature conditions, oxygen content, pH, and grain characteristics of the deposits were considered. As weather varies over the course of a year, time series analysis was proposed to show the changes over different seasons in hydro-chemical, hydrologic, and sedimentary characteristics, which are definitely very important in the entire process of sedimentation within the study area.

Study area

Preliminary studies were conducted in three stages: in the spring (May), summer (July), and autumn (October). Sampling of sediment and water was carried out in the Kilia Danube Delta in the mouth of Bistry channel, and in two more sections—seaside of the Vostochny and Starostambulsky branches (20th isobaths). In Fig. 1, the research area is indicated within the rectangle.

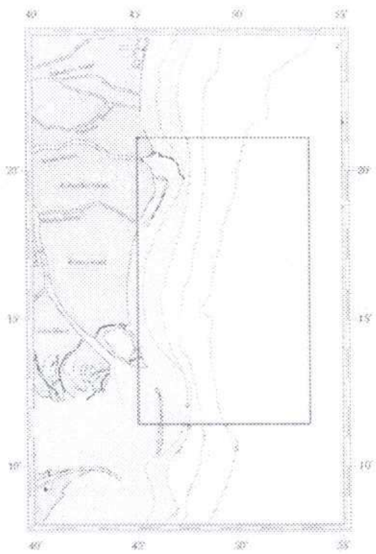

Figure 1. Research area

Materials and methods

During May sampling have been examined 18 stations; 34 water samples were collected to determine hydro-chemical parameters, and 16 samples of deposits were obtained to determine grain size distributions. In July, 24 stations were sampled; 49 water samples were collected to analyze for hydro-chemical parameters, and 20 sediment samples were taken to study grain size characteristics. In October, 25 water samples for hydro-chemical examination and 14 samples of deposits for the grain size analysis were retrieved from 18 stations. During the sample collection, the bathometer of Molchanov was used for water sampling and the Peterson grab (0.1 m^2) for collecting sediments (Bordovskii, Ivanenkov, pH, and temperature measurements were made using the WTW - Conductivity meter LF 318, Oximeter LF 420, and pH-320 in the laboratory of the Ukrainian Scientific Center of the Ecology of the Sea. Sediment analysis employed a combined method. Determination of the moisture level of the deposits was followed by a sieve analysis using mesh sizes of 4, 2, 1, 0.5, 0.25, 0.1, and 0.05. After this, the decanting method—based on Stokes's Law, according to which the velocity of free fall of fine, spherical particles through a liquid will be different for different sizes (Hjulstrom, 1935). Data from the mechanical analysis of the samples were arranged on the phi scale, such that the Wentworth grade is equal to one phi unit (Krumbein, 1939). Cumulative curves were drawn for each sample, using phi as the independent variable. The median and quartiles were read directly in the phi notation. For statistical purposes, the median was chosen as an average value, and sort level ratio was expressed by using the "Quartile method," where the sorting level ratio can be found as So = VQ1/Q3 (Trask, 1932).

Results

Sampling in the spring was performed during a strong 10 m/s wind blowing from northern, eastern, and southern compass points. The wind and upwelling were impeded suspension transfer and as a result suspension was discharged in the wellhead area with the water depth of about 15 m. The maximum transfer of suspension to the sediments was observed in Bistry channel. In the spring, the formation of hydro-chemical conditions in the research area was due to an additional supply of water, the transformation of the Danube hydrologic conditions of the region, and the development of productive- destructive processes. According to the results of satellite data (NOAA-19), the entire coastal area from the Cape of Saint George to the Odessa Gulf was under the influence of coastal upwelling. However, the places of greatest upwelling were confined to the wellhead areas of the Danube Delta. The water temperature in these areas of local upwelling on the northern seaward side of Kilia lobe of the Danube Delta was 11-13°C. The temperature at the riverine beach of the estuary was 18.8 to 19.0°C. Thus, warm river water was being discharged into the narrow coastal zone. On the seaward part of the area, local upwelling activity was observed. This led to a significant spatial heterogeneity in the thermal characteristics of the seawater (the difference is significant: 11.4 to 19.0°C).

The cold water areas on the surface have a higher salinity—more than 14 %o—and at depths of 5-20 m— more than 17$‰_0$. This indicates that cold water masses of marine genesis were brought in as countercurrents under the pressure of the How of fresh river water. The water was stratified by the salinity parameter because of the upwelling phenomenon. According to the hydro-chemical indicators, the strong front between the river water and the area of divergence caused by the upwelling contributed to the formation of two water masses with different hydrologic and hydro-chemical indicators. The amount of dissolved oxygen in the water varies from 8.12 to 11.0 ml/dm^3. The content of dissolved oxygen and pH value indicate the active development of photosynthetic processes (Garkavaya et al., 2006).

Visual imagery from NASA (USA) of the Danube region in the summer showed that the flow out from branches south of the Kilia delta was almost unidentifiable as separate streams. This was caused by the strong flow of the river, which filled because of positive rainfall anomalies over the European continent. The thermal regime of the water in the surface layer of Kilia delta in midsummer was different, leading to a spatial inhomogeneity in the water. The temperature of river water was 2-3 °C lower than the surrounding seawater, and this is generally characteristic of the winter and spring periods. The maximum water temperature (about 26°C) was found in the southeastern sector of the study area.

The thermocline lay was found at the water depths near 10-15 m. As a result, at these depths was situated natural thermal front. To the west, in shallow water, an almost complete uniformity of water temperature at about 20-13°C was found, and to the east, the bottom water temperature dropped to near 10-11°C. Distribution of salinity to the seaward side was not typical for July because this is the season of low water in the Danube. All this month nto the Danube, a high level arose, which is often greater than the critical flood stage level. Furthermore, river water in the delta could be compared with the maximum period of high water (Berlinsky et al„ 2006). In this regard, freshened water with a salinity less than 1.5- 2.0 $‰_0$ occupied the entire surface horizon of the study area. At a distance of 8 km from the coastline, the salinity of the surface layer was 8.4 %o, and the bottom water revealed a maximum for the study area: 17.7 %o. These observations during a period of abnormally high flow for the Danube River showed, broadly, the presence of extremely low levels of salinity in the surface layer and transparency of water. Surface water from the Bistry channel demonstrated the lowest dissolved oxygen content in absolute values: <5.6 ml/dm^3. At the same time, in the eastern part of the study area, the content of O2 varied from 7.5 to 10.5 ml/1 cc. The same pattern was observed in the spatial distribution of its saturation. Near the 20th isobath, the level of hypoxia was only 2.7-3.2 ml/dm^3. This area was under the direct influence of surface stream flows from the Bistry and Starostambulsky channels. The surface distribution of pH was low 7: 7 in the wellhead area of Bistry channel and higher values (about

8.5) in the western part of the polygon. Closer to the seaward side, the pH ratio was about 8.0-8.3. In the deeper part of the area, there were lower values of pH (<8) due to the development of hypoxia or conditions which could be created after hypoxia (Popov et al., 2002; Ukrainsky and Popov, 2009).

In the autumn the water temperature on top was about 13-15^{C}C and increased toward the seaward direction. The bottom layer revealed the start of winter vertical circulation; the temperature increased there at a depth of 7 m. The distribution of salinity in the bottom layer was typical for the estuarine zone. The haloclinc was found almost at the river mouth of the Bistry channel. The content of dissolved oxygen in the surface layer of the seaward side was high, 9.46 ml/dm^{J}. In the bottom layer, a reduction in dissolved oxygen to about 8.36-7 ml/dm^{1} was detected. The distribution of pH, which is dependent on the transformation of river water and the development of biological processes, was changing in the surface layer from 8.84 to 7.91. This decreasing pH was the result of high turbidity as a consequence of dredging work in the Bistry branch. In the bottom layer, pH varied from 8.62 to 7.83. It was also related to the large amount of suspended matter in the area. In the bottom horizon of the northern part of the research area, the minimum pll value of 7.53 was found. This is evidence of adverse conditions for the development of productive processes; it could have been caused by the introduction of marine water because salinity in the surface and bottom layers was 17.38-17.80 %o.

Sediments

When all samples of bottom deposits were plotted as cumulative curves on a single sheet, the figure resembled a wide, dark band with several lighter zones within it. These zones roughly differentiate three types of sediments within the environment (Krumbein, 1939): very fine and fine sands, sands with "tails" of silt and shells, and clay with "tails" of silt and very fine and fine sand.

The first type consists mainly of clay and has a tail of silt, very fine, and fine sand. These curves are not symmetrical. The grain size median values average about 0.004 mm. The samples are well sorted. This kind of sediment is typical of all seasons. In the maps, it corresponds to the underwater continuation of the Bistry branch, and it reaches almost the 20th isobaths after which it turns to the south and proliferates along the coastline.

The second band of curves is typical of all seasons as was the first, but in contrast, it is predominantly sandy and consists of more than 50 % very fine and fine sand. Additionally, it has a tail of coarse sand with an insignificant percentage of shells. Thus, the grain size median average is about 0.12 mm in October and 0.25 mm in July and May. The sediments are very well sorted. This kind of sediment proliferated between the 10th and 15th isobaths.

The third type began to form in July and shows much greater development in October. This type includes more than 60 % sand but also contains silt and some shells. The median average of the grain size is about 0.15 mm. The sediments are poorly sorted. They proliferated from the 20th isobaths 0 the seaward; obviously, these are marine sediments that were affected by river suspension.

Conclusions

In the spring, the formation of hydro-chemical conditions on the seaward side was caused by additional water supply and the transformation of the Danube waters, hydrological conditions of the region, and the development of productive-destructive processes. The main feature of 2010 was an unusually protracted period of high water and high levels in the Danube, which affected the hydrological structure of marine water in the summer. Distributions on the seaward side were not typical. Transformed Danube water with salinity above 2.00 %o occupied the surface layers to the 15th isobath, at a distance of 8 km from the coastline, salinity was 8.4 %o. In the bottom layer, seaward salinity varied from 2 %o (at a depth of 10 m) up to 17.7 %o at a depth of 20 m. The distribution of suspended matter along the coast of the Danube Delta was due to its removal from the river flow (abnormal for this autumn season) and hydrological conditions of the surrounding area. In the surface horizon, high level turbidity covered the entire coastal half of the study area to the 15 m isobaths. In autumn, a strong wind in the landfill area created two different freshwater mass structures with a salinity of about 1 %o, and other with the values of salinity 2- 16 %o. Formation of the geochemical regime in the seaward area in October 2010 was due to the high level of water in the Danube and a significant turbidity, which hampered the development of productive processes.

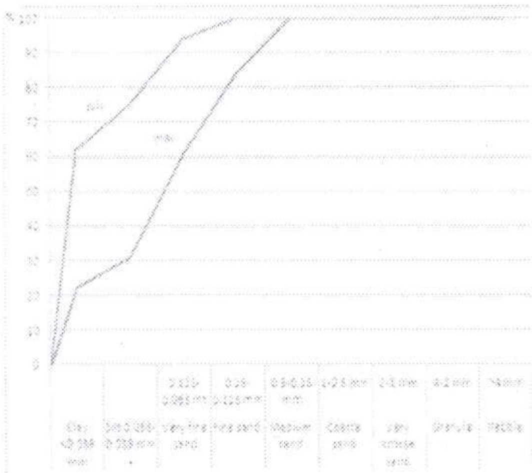

Figure 2. Typical cumulative curves for sediments sampled in July and May 2010 near the coastline.

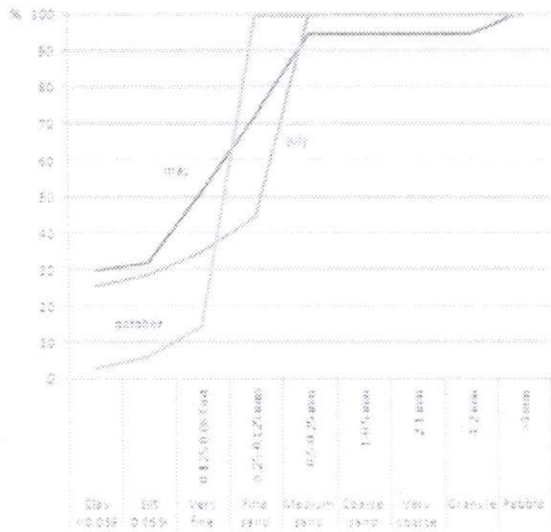

Figure 3. Typical cumulative curves for sediments sampled in May, July, and October 2010 near the 30th isobaths.

The sediment content also differed depending on the season. There are two curves in Figure 2. One is typical for spring and one for summer. This sediment was collected from the same stations near the 5th isobath. We can see that the content of clay had increased enormously by 40 % during the summer flood. Furthermore, in Figure 3, we can see 3 kinds of curves typical for each of sampling seasons. These samples were collected in the marine part of delta, at the same stations but in different seasons. According to this graph, the bottom deposits became coarser with distance from the coastline. Thus, we can say that the strong flood and the removal of large amounts of material from the river in summer 2010 were reflected in the bottom deposits. However, the composition of the debris removed from the Danube also depends on the distance from the shoreline. This is a consequence of the Danube's influence on the sediment composition of the coastal area of the Black Sea.

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