BLACK SEA BASIN: SEDIMENT TYPES AND DISTRIBUTION, SEDIMENTATION PROCESSES

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Abstract. The paper presents a part of the scientific activity of GEOECOMAR team during the IAEA project RER 2/003 *Marine Environmental Assessment of the Black Sea Region*, on board of R/V "Prof. Vodyanitskyi" and in laboratories. The Black Sea presents different sedimentological and geochemical characteristics in the eastern and western sub-basins. Whole sections of the Upper and Middle Holocene sediments were revealed in most cores recovered from the whole Black Sea basin. Scientific methods (grain size, X ray investigations, rate of sedimentation and radiogenic measurements, geochemistry characteristics of water and sediments) showed the general distribution of the bottom sediments, at the surface and downward, syn- and postdepositional sedimentary structures, lithological and geochemical compositions. As a result of detailed sedimentological studies in the whole Black Sea basin, for the first time a complete picture of the current grain size composition in the Upper Holocene sediment sections, was obtained. The data show that the deposits were accumulated in rather variable lithodynamic conditions (e.g. shelf, continental rise, abyssal plain). Processes of redeposition (e.g. turbiditic currents) have played an important role. At some stages "zero sedimentation" dominated, and during other periods scanty terrigenous material was accumulated.

Key words: Black Sea, sedimentology, sediment types, sedimentation processes.

INTRODUCTION

Beginning with 1990, radionuclides in the Black Sea were classified as "hazardous substances and matter" by the Convention on the Protection of the Black Sea against Pollution (Bucharest, 1992), because of their toxicity, persistence in the environment and bioaccumulation characteristics (IAEA Report, 2002). Besides their primary importance as contaminants, radionuclides also represent important tools for assessing the fate of other pollutants.

According to "Protecting the Oceans from Land-based Activities" Report, the Black Sea countries rank radioactive substances as a 3rd priority in the region, behind nutrients and sewage contaminants (GESAMP-UNEP, 2001).

Considering that the assessment of marine pollution is a compulsory condition for protection, rehabilitation proposals and management of resources, the project "Marine Environmental Assessment of the Black Sea Region" – RER 2/003 was created to fill the gaps in the knowledge of the radioactive and non-radioactive contamination state of the Black Sea basin.

The main objectives were to develop the capacity to reliably assess marine pollution in the Black Sea countries using nuclear techniques and to operate regionally co-ordinated monitoring and emergency response programmes for radionuclides in the marine environment.

Within this larger scope, the sedimentological investigations aimed to provide sedimentary material and support data for artificial radionuclides and non-radioactive pollutants survey.

The sedimentological investigations were focused on specific activities, such as recovery of continuous undisturbed sediment columns, for the assessment of anthropogenic radionuclides and other non-radioactive pollutants, supplying litho-bio-stratigraphic detailed observations and descriptions, X-ray imaging, collecting samples for laboratory analyses (grain size, chemistry, biology) and producing a sedimentological interpretation as support for the study of pollutants distribution.

Material and Investigative Methods

The International Atomic Energy Agency – IAEA Vienna has organized two cruises in the Black Sea, in the framework of the Regional Technical Co-operation Project RER/2/003 for the project "Marine Environmental Assessment in the Black Sea Region". The first covered the NW Black Sea basin (Fig. 1), concentrating on the northwestern major depositional systems, as Danube Delta, with Delta Front and Danube Prodelta (Panin *et al*., 1997), the mouths of the Dniester and Dnieper rivers, the continental shelf with their specific zones, "sediment starvation zone" and the area influenced by the southward drift, and the continental shelf break, located between 100 –200 m water depth. The second cruise was taken in the eastern part of the Black Sea basin. It focused on the continental shelves, such as Kerch area (Fig. 1), characterized by the influence of suspended matter which flows from Sea of Azov and by the local marine currents, Batumi area-Coruh polygon, located under the influence of water and sediment inputs of the river Coruh, Anatolian Coast-Synop polygon area, influenced by the offshore main currents.

The deep sea part of the whole Black Sea basin representing the largest depositional zone, with the water depth greater than 500 m was also investigated.

During the cruises, undisturbed sediment cores were taken in all sediment stations with a Mark II – 400 midicorer (Fig. 2), equipped with four perspex tubes, 10 cm i. d., 60 cm long. 241 cores were recovered from 40 stations.

The most representative cores were X-rayed immediately after recovery, using a XTEC Lasery 90 P equipment, supplied by IAEA, using a Class II Laser with a brand BX 1 stationary anode tube, focal spot 1.0 mm x 1.0 mm 9 (single focus) per NEMA Std. XR 5/1984 and automatic line compensation.

One core per station was sliced using an extruder, cutting plates and plastic rings of different thickness (0.5-4 cm). To avoid contamination the outer margins of slices were removed. The samples were stored and refrigerated on board. A detailed macroscopic litho-bio-stratigraphical description was completed for each sediment core. One section was kept intact, to allow estimates of areal inventories.

Post-cruise grain size analyses were done by combining the dry sieving method, used for particles larger than 4 phi (0.063 mm), with the pipetting method for particles with ranging from 4 to 10 phi (0.063-0.001 mm).

Lithological Composition and Internal Structures of Sediments

Preliminary descriptions of lithological composition of the collected sediment cores were outlined on board and completed post-cruise with data provided by the laboratory grain size analyses.

The grain size types were nominated after Folk's nomenclature. The sediments were divided according to their content of $CaCO_3$, in a similar way as for the international map of the Black Sea sediments (Emelyanov, Shimkus, Kuprin, 1996), in the following groups: non carbonate (<10% $CaCO_3$), low calcareous (10-30% $CaCO_3$), carbonate (50-70% $CaCO_3$) and high carbonate (>70% $CaCO_3$). When coccoliths are abundant, both in carbonate and high carbonate muds, they are nominated coccolith oozes.

Really sapropelic are the muds with TOC contents within the range 5,5-16,5 %corresponding, if a conversion factor of 1.7 is used (Forstner, Wittmann, 1983) to 30-50 % total organic matter.

Visual investigations on all deep sea sediment sections showed microlaminated non carbonate and low calcareous muds, enriched in organic matter, that were called sapropelic muds.

X-ray radiographs of sediment sections were taken, the method representing an important tool for documenting chronological interpretation, layer thickness, lithological composition and internal structure of sediments, including post-depositional disturbances, such as bioturbations, slumps, gas bubbles.

The interpretation of X-ray radiographs revealed the following aspects on the representative cores:

Core BS 98-07 – the top consists of massive mixed sediment. A sharp limit was located between the upper bed and the one underneath. At 15 cm depth there is an amalgamated shell bed with a sandy clay and clayey sand matrix. A reverse-graded distribution of shells is present.

Core BS 98-10 – alternation of shell and fine grained sediment beds (silty clay). A shell bed with a sandy clay matrix is present in the upper part of the core and lies on a mixed sandy clay sediment bed with rare shell fragments. In the middle part of the core a silty clay bed shows thin shell levels. At the base of the core a shell bed, with mixed sediment matrix (clayey silt and silty clay), is present. A normal vertical graded shells distribution is observed.

Core BS 98-16 – alternation of fine grained sediment beds (clay, silty clay and silty sand), with distinct parallel lamination: upper part - a silty clay and mixed sediment alternation, middle - a clay/silty clay alternation, dominated by clay levels, lower part - a clayey sand/silty sand alternation with indistinct laminae, deformed by the sampling tube.

Core BS 98-17 – clay/silty clay alternation, with clear parallel lamination. A reverse graded bedding is present;

Core BS 2K-02 (0-20 cm – X-ray interval) – fine sediment, unclear internal structure, vertical burrows;

Core BS 2K-04 (0-15 cm) – fine sediment with massive structure and unclear lamination to the base;

Core BS 2K-05 (0-15 cm) – fine to very fine sediment layers, with whole shells and shell hash intercalations;

Core BS 2K-06 (0-6 cm) – whole shells and shell fragment layers;

Core BS 2K-07 (0-14 cm) – shell layers with irregular bases on burrowed clayey silt basement;

Core BS 2K-08 (0-14 cm) – whole big shells and shell layers;

Core BS 2K-09 (0-30 cm) - parallel microlaminated and microbanded structures in very fine sediments (coccolithic ooze and sapropelic mud);

Core BS 2K-14 (0-50 cm) – fine and very fine sediments, sandy mud to silty mud, massive or laminated; unclear burrows;

Core BS 2K-15 (0-20 cm) – coarse to fine interbedded sediment layers; lenses with coarser sediment (sand); unclear burrows;

Core BS 2K-17 (1-30 cm) – fine to very fine interbedded layers (mud to clayey silt), burrowed, vertical and horizontal worm tubes;

Core BS 2K-18 (0-30 cm) – alternation of fine to very fine sediment layers; vertical worm tubes in a mud to silty clay succession; parallel lamination in the silty clay layer;

Core BS 2K-19 (0-24 cm) – 1-10 cm deep, convolute lamination (turbiditic layer) in very fine sediments (coccolithic ooze); parallel lamination 10 - 24 cm deep;

Core BS 2K-20 (0-30 cm) - very fine sediments (mud to silty clay) with parallel lamination; lenses filled with coarser sediment 24 - 26 cm deep turbiditic layer;

Core BS 2K-20 – (0-48 cm) – tabular cross bedding to the top of the core; microlaminae and lenses and possible lumps of fine sediment 30 - 35 cm deep;

Core BS 2K-23 (0-36 cm) – parallel lamination with circular structures (cross section on warm channels); massive internal structure to the base;

Core BS 2K-23 – (0-55 cm) – parallel lamination in (coccolithic ooze), interbedded with massive layers of fine sediment, rich in organic matter (sapropelic mud) to the base;

Core BS 2K-26 (0-37 cm) – molluscs and gastropod shells (*Mytilus* and *Modiolus*), rare to the top and crowded to the base with a very fine matrix;

Core BS 2K-27 (0-40 cm) – gradual transition from clay to silty clay, affected by vertical and horizontal burrows;

Core BS 2K-28 (0-42 cm) – very fine sediments, burrowed, with channels in vertical and horizontal positions; some mollusc shells to the top;

Core BS 2K-29 (0-40 cm) – shell layers interbedded with fine sediment beds; many vertical burrows;

Core BS 2K-30 (0-32 cm) – large *Mytilus* shells and shell hash layers into a muddy matrix; burrows are present;

Core BS 2K-31 (0-43 cm) – fine sediment (mud) with whole shells and shell hash intercalations; burrows;

Core BS 2K-33 (0-60 cm) – very fine sediments (mud with rare clay intercalations) with internal massive structure; unclear laminations.

On the basis of X-ray studies, and detailed examination of core sediments, the main sedimentary structures identified were:

- massive bedding is a common feature;
- normal and inverted graded bedding (e.g. BS 98-01, BS 98-06);
- parallel to convolute laminations in fine deep sea sediments (e.g. BS 98-09, BS 98-13, 14, 15, 16, 17, BS 2K-18, BS 2K-23). The structure is marked by millimetric individual laminae made by coccolithic oozes and sapropelic mud, with sharp limits (Fig. 3);
- burrow structures and living worm tubes (e.g. BS 98-02 – BS 98 04, BS 98-06, BS 98-08, BS 98-10, BS 98-11, BS 98-12). The burrowed structure should be taken into account when radionuclide and other properties distributions are studied and interpreted;
- gas structures, are characteristic to the Black Sea bottom sediments, being associated with the sediment very rich in organic matter (e.g. BS 98-02, BS 98-03, BS 98-06 and BS98-12);
- plant roots (BS 98-03, BS 2K-02) and wood fragments (cores BS2K-20, BS2K-23);
- lens structures (e.g. BS 98-03 and BS 98-10, BS 2K-14, BS 2K-1), consisting of millimetric structures filled with dark clay (BS 98-03, BS 98-04) or with *Mytilus* and *Modiolus* shell fragments (BS 98-10);
- fish molds (e.g. BS 2K-23) on the surfaces of sapropelic mud laminae.

The presence of living worms and the trace fossils (vertical and horizontal tubes, mixed layers) demonstrated that some lithological columns are not indicated to calculate rates of sedimentation on the basis of radionuclide distributions. Many cores, from the eastern part of the Black Sea basin, are included in this category (e.g. BS 2K-14, BS 2K-15, BS 2K-17, BS 2K-1, BS 2K-26 to BS 2K-31).

Sedimentological studies point out that the coccolithic ooze and sapropelic mud, accumulated at more than 660 m depth, indicate a periodic sedimentation, total accumulation time being about 2500 (Degens, 1970). The rate of deposition can be locally higher, this aspect being marked by the presence of sand, wood fragments or detrital carbonates, interbedded between coccolithic ooze layers (e.g. BS 2K-20, water depth 1530 m), their characteristics suggesting a turbiditic origin.

The role of grain size studies was to investigate the vertical sedimentation, as well as turbidity flows, the redeposition processes, to assess the base of geochronological studies and for revealing the evolution of industrial contamination history.

Sediment Types and Sedimentological Characteristics

Western Part of the Black Sea Basin

Danube Prodelta. Terrigenous mainly non-carbonate muds ($CaCO_3$≈10%) dominate the Upper Holocene sediment sections. Due to the high sedimentation rates, which do not allow the development of molluscs, shells and their fragments are absent or scarce near the Danube mouths (BS 98-04, BS 98-03); H_2S is frequently present in sediments enriched in organic matter. Fluid and semiliquid muds make up the top "fluffy" layer (0-3, 0-4 cm) of the core.

Near the mouth of the Sulina distributary (BS 98-04), the grain size composition was rather homogenous. The lower part of the core (15-20 cm) is composed of well sorted silts and the upper one (0-15 cm) – mainly of muds with rare interlayers of silts. The changes in grain size composition result from grain size differentiation of the Danube sediments, during their accumulation in the eroded channel.

In the section of terrigenous Upper Holocene sediments from the southern part of Prodelta (BS 98-03) several rhythmic sequences of clayey silts and silty clays were identified. In the lower part of the section (45-53 cm) interlayers of mixed sediments and sandy mud were observed. Southward of the Danube Delta (BS98-02 and BS98-01) the shelly material is more abundant in sediments, particularly in the lower part of the cores determining a higher concentration of the sandy fraction. The shells and shell fragments are either dispersed over the entire sections or concentrated in single layers. The fluffy layer was not observed here. In the area of the BS 98-01 core brownish shells, covered with Fe-Mn films, were found on the sea floor, as evidence of zero modern sedimentation. The amount of shells and detritus is rather variable. Visual observation and $CaCO_3$ determinations show that their amount increases considerably at depths greater than 14.5 cm, but its concentration is also important in some thin interlayers. The uneven distribution of shelly material determines the heterogeneity of grain size composition of sediments. They are represented in the lower part, mainly by sand, in the upper section by alternating clayey sands and silts and in the surface layer, by silty clay.

A complex of mollusks, with *Modiolus phaseolinus* typical for Upper Holocene, was observed everywhere in BS 98-01 core (sea depth is 56 m) in the upper part of the section (0-12 cm). Besides, here are *Mytilus galloprovincialis, Cardium* and fresh-water molluscs (*Dreissena, Monodacna*). Deeper, between 13-35 cm, *Mytilus galloprovincialis*, typical for Middle Holocene, prevails and *Cardium, Dreissena, Monodacna* are permanently present. *Modiolus phaseolinus* has never been met. *Mytilus* shells are present in the whole BS 98-02 core.

The extrapolation of the sedimentary rates, calculated using the Chernobyl trace identified at 7 cm depth, allows an approximate calculation of age in the lower part of the core, estimated at the beginning of the XVII century (Shimkus, 2002, IAEA Report).

Dnieper Prodelta. The cores collected in this region (Fig. 1), at a sea depth up to 20 m, consist in an alternation of clay silt interlayers and silty clay. Rare shells of *Cardium, Mytilus, Paphia* and others were found in them. The macrofauna composition indicates young sediments, most probably Upper Holocene. The changes of grain size composition are connected to the cyclic accumulation of Dnieper sediments, with addition of more or less abrasion material.

Middle Zone of the North-Western Shelf. Closer to the Danube Prodelta (core BS 98-08) the Upper Holocene sediments (0-12 cm) are mainly represented by sands and sandy clays. Similar to the BS 98-01 core, the sand is represented by unbroken shelly material with shelly detritus and variable amounts of clay. The ratios of unbroken shells to their detritus determine the grain size profile of sediments under conditions of low accumulation of clayey material. The bad sorting (sizing) of Middle Holocene sediments can be the effect of more intensive accumulation of the Danube sediments during the eastward advancing of the Danube Prodelta.

To the Dniester mouth zone, the Upper Holocene is composed mainly of shells of benthic molluscs with little addition of mud. The shelly material is predominant and determines the grain size composition, consisting mainly in sandy and coarser fractions. The sharp changes of clay fraction concentrations, increasing in the upper part of the core, are related to quantitative fluctuations of terrigenous pelitic material, mostly clay. The presence of sandy clays in some interlayers, is, most likely, caused by the intensification of the Dnieper sediment runoff accumulation.

Lower Zone of the North-Western Shelf. The cores recovered sections of Upper and Middle Holocene sediments at water depths of 76 and 65 m, respectively. Muddy sediments from both stratigraphic units have a considerable addition of shelly material unevenly distributed along the section.

Sandy and coarser fractions are entirely composed of shelly material. The layers were formed under more active lithodynamic conditions that promoted grinding of shelly material or accumulation of fine-dispersed shelly detritus from adjacent regions.

The Upper Holocene is characterized by an alternation of sandy muds and sandy clays with muds; the Middle Holocene consists of muddy sands covered by sandy mud.

The Upper Holocene substage was singled out by the domination of *Modiolus phaseolinus* (0-15 cm). The characteristic sediments are silty clay and sandy clay in the upper part, and clayey sand – in the lower. The distribution of grain size types in this section of Upper Holocene indicates repeated changes of lithodynamic conditions during its formation and repeated increases and decreases of the intensity of clayey material accumulation, as well as of shelly detritus. The Middle Holocene substage (15-33 cm) is characterized by the presence of large shells of *Mytilus* and their detritus. The lower part of the core (30-32 cm) is represented by silty detrital sand with rare unbroken shells of *Dreissena*. These deposits emphasize a discordant bedding of Holocene section on the Pleistocene one.

The BS 98–12 core (water depth 107 m) was divided in Upper Holocene (0-17 cm) and Middle Holocene (17-38 cm) subhorizons. In the lower part of the Middle Holocene a transition to a Pleistocene layer of shelly detritus with remains of brackish new-euxinic fauna (*Dreissena* and *Monodacna)* was observed.

Upper Holocene is composed of silty clays alternating with layers of clays and mixed sediments. The sediments were accumulated in calmer hydrodynamic conditions that promoted the supply of terrigenous material from the Danube Prodelta.

Middle Holocene deposits are represented and shelly silt, i.e. by alternation of shelly (about 80% $CaCO_3$) silty sands, clayey sands and mixed sediments. In the Upper Holocene the clay fraction content is obviously increased compared to the Middle Holocene.

The data indicate that in the lower zone of the north-western Black Sea shelf the sediments were accumulated under active lithodynamic conditions, intensified in the first half of the Middle Holocene and in certain stages of the Upper Holocene. The lithodynamic activity was probably caused by the impact of internal waves upon the shelf edge and periodic origin of anticyclonic eddies. The latter caused a spotty character of spatial distribution of bottom sediments of different types, accumulated under oscillatory sea level rise, in the shelf marginal zone during the Middle and Upper Holocene.

Lower Zone of the North-Western Shelf. Detailed litho-sedimentological studies were performed on cores BS 98-10 and BS 98-11 (Fig. 4), which recovered sections of Upper and Middle Holocene sediments at water depths of 76 and 65 m, respectively. Muddy sediments from both stratigraphic units have considerable addition of shelly material unevenly distributed along the section. The $CaCO_3$ concentration was 50-60% for the most part of the cores. Only in some interlayers it either decreased to 20-40% or increased to 70%. Sandy and coarser fractions are entirely composed of shelly material. The absence of a significant quantitative correlation between the $CaCO_3$ concentration and the concentrations of the >0.63 mm and >0.1 mm fractions points to the fact that finer shelly detritus is also present. These layers were formed under more active lithodynamic conditions that promoted grinding of shelly material or accumulation of fine-dispersed shelly detritus from adjacent regions.

In **core BS 98-10** (Fig. 4; sea depth 76 m) Upper (0-23 cm) and Middle Holocene (23-35 cm) horizons were singled out. In the former one shells of *Modiolus phaseolinus* prevail, and in the latter - large shells of *Mytilus galloprovincialis* are present. The Upper Holocene is characterized by an alternation of sandy muds and sandy clays with muds; the Middle Holocene consists of muddy sands covered by sandy muds.

In **core BS 98-11** (Fig. 1; sea depth 65 m) the Upper Holocene substage (0-15 cm) was singled out by the domination of *Modiolus phaseolinus*. The characteristic sediments are silty clay and sandy clay in the upper part, and clayey sand in the lower.

The distribution of grain size types indicates repeated changes of lithodynamic conditions during its formation and repeated increases and decreases of the intensity of clayey material accumulation as well as of shelly detritus.

The Middle Holocene substage (15-33 cm) is characterized by the presence of large shells of *Mytilus* and their detritus. The lower part of the core (30-32 cm) is represented by silty detrital sand with rare unbroken shells of *Dreissena*. These deposits emphasize a discordant bedding of Holocene section on the Pleistocene one.

The **BS 98-12 core** (Fig. 1; sea depth 107 m) was divided in Upper (0-17 cm) and Middle Holocene (17-38 cm) subhorizons. In the lower part of the core (38-41 cm) a transition to a Pleistocene layer of shelly detritus with remains of brackish new-euxinic fauna (*Dreissena* and *Monodacna*) was observed.

Upper Holocene is composed of silty clays alternating with layers of clays and mixed sediments. Middle Holocene deposits are represented and shelly silt, i.e. by alternation of shelly (about 80% $CaCO_3$) silty sands, clayey sands and mixed sediments.

The clay fraction content is obviously increased compared with the Middle Holocene. According to these data, Upper Holocene sediments were accumulated in calmer hydrodynamic conditions that promoted the supply of terrigenous material from the Danube Prodelta. The data indicate that in the lower zone of the north-western shelf the sediments were accumulated under active lithodynamic conditions, intensified in the first half of the Middle Holocene and in certain stages of the Upper Holocene. The lithodynamic activity was probably caused by the impact of internal waves upon the shelf edge and periodic origin of anticyclonic eddies. The latter caused a spotty character in the spatial distribution of bottom sediments of different types, accumulated under oscillatory sea level rise, in the shelf marginal zone during the Middle and Upper Holocene.

North-Western Continental Slope*.* All the cores were recovered from the western halistatic region, which includes the central part of the continental slope. The top part of all the cores is overlaid by a fluid or semiliquid "fluff" layer, 3.5-4.5 cm thick, enriched in organic matter and several heavy metals. Continuous accumulation of fine laminated carbonate coccolith oozes, enriched in organic matter, took place during Upper Holocene. Sapropelic fine laminated muds and sapropels are widespread in the Middle Holocene. The obtained cores are similar in lithological composition but they reveal different parts of the Holocene. The bottom part of Upper Holocene section is represented by a thin layer (1-4 cm) of coccolithic ooze, accumulated during the first appearance of *E. huxleyi* in the Black Sea. A thin transition layer of sapropelic mud (2-3 cm) marks the short period of its disappearance. Then the main layer of coccolith ooze continue upwards in the section.

The BS 98-13 core, sampled from the upper zone of the slope, near the submerged Vityaz canyon, consists of muds. The concentrations of pelitic material are rather high. They are higher in the Upper Holocene, representing 80-90 %. Coccoliths, with a size varying from 0.004 to 0.001 mm, greatly influence the concentration of this size fraction, and in a lesser degree the concentration of subcolloids (<0.001 mm) and aleurite fractions. There are traces of qualitative correlation between contents of $CaCO_3$ and fraction of 0.05-0.001 mm. Clay minerals determine the concentration of <0.004 mm fraction.

In the Middle Holocene the grain size profile of the core is controlled mainly by the grain size composition of terrigenous material.

Another core, collected from the upper zone of the slope near underwater valley, roughly 100 km north-east of the above described region (BS 98-09, water depth 600 m) recovered only a section of the Upper Holocene, represented by coccolithic muds. Their grain size composition is rather homogeneous, silty clays alternating with clays dominating. Five rhythmic sequences of silty-clay-clay were identified, pointing to a definite cyclic recurrence in sediment accumulation. Rhythmic changes are observed in the concentrations of the clay fraction, connected mainly with accumulation of clay material.

The role of coccoliths in the formation of grain size profile of sediments is considerably lower than in the Upper Holocene sediments in station BS 98-13. The lower carbonate concentrations in muds (30-50% of $CaCO_3$) points to that.

The BS 98-16 core, collected from the lower zone of the continental slope (water depth 1980 m), recovered a full section of the Upper Holocene and a large part of the Middle Holocene. It is represented by the same lithofacies as BS 98-13 and BS 98-09 cores, i.e. coccolith and sapropelic muds. The Upper Holocene sediments consist of rhythmic alternation of sandy clay and clay. This points to an obvious domination of the fine-dispersed pelitic material in coccolith muds. More often the concentration of clay fraction varies between 70-80%. The silty fraction displays great qualitative fluctuations (15-45%).

The Middle Holocene non-calcareous sapropelic muds correspond to clayey silts as regards grain size composition. This indicates an intensive accumulation of terrigenous silty-clayey material at this time and considerable difference of sedimentary conditions between Middle and Upper Holocene.

Anatolian Continental Slope*.* The BS 98-17 core (Fig. 1), sampled from the lower zone of the slope (water depth 1912 m) consists entirely of Upper Holocene low-calcareous terrigenous muds. Detailed sedimentological investigations showed a rather homogeneous grain size composition, the sediments being dominated by well sorted muds, with a single interlayer of silt. These muds have almost no sandy material. The coarse aleurite fraction is rather scanty, but the pelitic material is abundant (about 70% and more). A definite rhythm is observed in the changes of aleuritic and pelitic material concentrations.

The sediment composition resemble the so called "homogenites", formed by fast settling of fine-dispersed material from the cloud of nearbottom suspension, which appeared as a result of the rolling of bottom sediments, probably by seismic shocks.

The section was probably formed as a result of repeated settling of terrigenous material transported by turbiditic flows all over the adjacent submarine valley.

This may explain the presence of rhythmic grain size changes.

In core BS 98-18, collected from the upper continental slope (water depth 485 m), in the area near the Bosphorus canyon (Turkey), the black semiliquid terrigenous silts are, probably, of Upper Holocene age. They are underlaid along an uneven boundary by sandy clay with lens texture, due to the presence of soft clayey pebbles. Large *Dreissena* and *Monodacna* specimens have been revealed in the upper part of the layer.

Eastern Part of the Black Sea Basin

Kerch Area. The Kerch Strait is located between the Sea of Azov and the Black Sea. The Sea of Azov, as a shallow basin, is controlled by the water and sediment discharges of Don and Kuban rivers, the water surplus flowing from the Sea of Azov to the Black Sea. The sediment input is trapped in the Azov Sea, the changes of water, sediments and pollutants being limited in space.

The bottom sediments are mainly fine (mud, clay, silt). Near shores a larger amount of sand is mixed with mud or clay. In the deepest part of the sea (>10 m water depth) the fine sediments show a large quantity of ostracods. The sedimentation rates were calculated for Holocene deposits using the stratigraphic zonation. During the Late Holocene 0.5-0.8 kg/m^2 of sediments were deposited. During Middle (6,000-3,000 ky) and Early (7,000-6,000 ky) Holocene, minimum 2 kg/m^2 sediments were deposited (Shcherbakov, 1991). A significant part of the bottom sediment are the bivalve populations. Around Kerch area banks of *Mytilus* and *Ostrea* are present.

Three cores, (BS 2K-02, BS 2K-04, BS 2K-05) were located near the Crimea coast, one of them (BS 2K-04) in the abyssal area of the Black Sea, at 2,147 m water depth.

The cores BS 2K-06 to BS 2K-09 are located along a transect beginning in front of the Kerch Strait and with a general direction from north to south, water depth varying between 18 m and 611 m (Fig. 1).

Core BS 2K- 02, located at 36 m water depth, is dominated by sandy silt (0-10 cm depth) and clayey sandy silt with various intercalations between 10 cm and 20 cm depth. Living worms are present. Shell fragments are present under 3 cm depth. At 20-22 cm depth, in the core, *Cardium* shells and *Mactra* (?) form a continuous layer.

Core BS 2K-05 is dominated by sandy mud to clay and silty clay. Shell hash is dispersed. Rare whole *Modiolus phaseolinus* shells were located at 26-28 cm. At 33-35 cm a shelly layer with whole *Modiolus phaseolinus* and *Paphia* shells was described.

On the Kerch transect the surface bottom sediments are dominated by mud and silty mud (cores BS 2K-07 and BS 2K-08) and sandy silt in the southwestern part of the Crimea coast. To the shoreline (core BS 2K-06) the bottom sediments are mixed with many shells and shell fragments, oxidized on the surface.

At 600 m water depth (core BS 2K-09) the bottom sediments are dominated by clay, mud and silty clay (0-20 cm). The entire sediment core consists in coccolithic mud – it is greenish gray, very soft, microlaminated and enriched in organic matter. Biological studies indicate Upper and Middle Holocene substages.

The Coruh Polygon. The area is located on the Georgian continental shelf (Fig. 5) and receives a contribution in sediments of 11 100 m^3, 4 400 m^3 r of which remain on the coastal area and 6 700 m^3 discharge into the deepest part of the basin (Shimkus, 1997). The most important sediment contribution comes from the Coruh, Riomi, Inguri and Kodori mountain rivers. The highest contribution as water input comes from river Coruh (6.3 Km^3/y); the same river delivers $7.5x10^6$ t/y sediment, representing 31% of the terrigenous contribution of Anatolian and Caucasian areas (Algan *et al.*, 1997). The main flow direction of the marine current, active in front of the river Coruh mouth, is from south to north, with some local coastal orientations. All these currents contribute to the deposition of sediment along the coast, on the shelf and on the continental slope.

Sedimentological and biological observations were made on cores BS 2K-14, BS 2K-15, BS 2K-17 and BS 2K-18. The core BS 2K-14 is dominated by mud and clayey silt (0-20 cm depth), soft to compact, with lenses of sand/silt and irregular laminae, with many burrowing holes. The core BS 2K-15 penetrated a succession of silty sand (0-11 cm depth), sandy silt, clayey silt and clayey sandy silt. Vertical and horizontal burrows disturb the sediment. Several whole shells of *Paphia* are present. At 70 m water depth core BS 2K-17 (Fig. 1) was located. Mud (0-10 cm) and clayey silt (10-53 cm) dominate the sediment column. Small and large channels, very abundant vertical and horizontal burrows disturb the sediment. The core BS 2K-18 penetrated a succession of mud, silt, sandy silt, clayey silt and silty clay layers. Burrows and slumping structures are present. The burrows are filled with brownish gray silty clay. The age of the bottom sediment of Coruh area is Upper Holocene.

Sinop Polygon. The studied area is situated on a narrow Turkish continental shelf (Fig. 6). The annual sediment contribution of different rivers is 2410 m^3 (Algan *et al*., 1997). All the rivers are short, with small drainage areas, the sediment sources being located in Caucasus Mountains and on Anatolian highland. An important part of the bottom sediment is transported to the deep sea zone through submarine canyons.

The core BS 2K-26 is dominated by sandy mud, mud and silty clay. Many large *Mytilus galloprovincialis* shells are concentrated to the core top. Between 3-4 cm and 17-22 cm there are many *Modiolus phaseolinus* shells. The core BS 2K-27 is dominated by mud and clayey silt with rare intercalations of silty clay. Vertical and horizontal burrows disturbed the sediment. At 10-12 cm and 26-28 cm shells of *Mytilus* are present. The BS 2K-28 core showed a succession of mud and silty clay with an intercalation of clayey silt at 18-19 cm depth. Living worms, in the vertical position, are present. The age of the sediment is Upper Holocene.

The molluscs from core BS 2K-29 show that the biocoenosis is of Holocene and Neoeuxinian stages (analyses by IOBAS, Bulgaria – IAEA Report, 2004). It seems likely that the shells of molluscs and their fragments are deposited under the influence of marine currents, waves action and rise of the Black Sea level. The presence of oval shaped mineral grains (1-6 mm) in the mud and shell detritus indicates dynamic conditions of sedimentation. The dominance of shell detritus over whole mollusc shells, between 40-24 cm, is a characteristic feature of shallow environment in littoral and sublittoral zones, with more active influence of marine waves than water currents. In the interval ranging from 0 to 24 cm depth, whole shells increase to full domination over shell detritus in the uppermost part. The differences among these intervals are explained by the raising Black Sea level (e.g. creation of deeper water conditions with the decreasing influence of the waves and the increasing influence of the marine currents).

Abyssal Area. During the Upper Holocene the accumulation of fine laminated carbonate coccolith oozes, enriched in organic matter took place. Sapropelic mud and sapropels are widespread beginning with the Middle Holocene. The lower part of the Upper Holocene section is represented by coccolith ooze, accumulated during the first appearance of *Emiliana huxleyi* in the Black Sea.

The laminated sedimentary sequences in the abyssal Eastern Black Sea basin (Unit I – coccolithic ooze; Unit II – sapropelic mud) are continuous and can be traced throughout the entire basin (Ross and Degens, 1974). Unit I, representing an alternation of white and black laminae, has a base starting with the first occurrence of the characteristic conditions: the decreasing in rainfall, reducing of the river discharges, tolerable salinity ($>11^0/_{00}$) for the coccolithophoride *Emiliana huxleyi*. The first invasion period contains ≈50 couplets of white/black laminae which have about 0.3 mm thickness each (Hay *et al*., 1991). White laminae are dominated by the presence of *Emiliana huxleyi* while black laminae contain mostly terrigenous matter.

Unit II which is also called the “sapropelic unit”, is dominated by high concentration of terrigenous matter representing a large contribution of river discharges. This unit is also laminated, but the laminae are very thin and not so easily distinguishable. The deposition of the turbiditic layer, at the base of Unit I, indicates the presence of a higher energy. Three major processes control the variability of the hemipelagic sedimentation: primary production, river input and storms introducing resuspension. The hemipelagic sediment is transported offshelf by advection or diffusion and settles out in decreasing concentrations at a distance from shore (Honjo *et al*., 1987).

The laboratory analyses identified in a sapropelic mud sample from Core BS2K-23 a nannofloral assemblage consisting mainly in the species *Braarudosphaera bigelowii* (Gran & Braarud) Deflandre, which represents 90% from the total assemblages. Besides *Braarudosphaera bigelowii*, few very rare species were also identified. These species are: *Calcidiscus leptoporus* (Murray & Blackman) Loeblich & Tappan, *Coccolithus pelagicus* (Wallich) Schiller, *Syracosphaera pulchra* Lohmann.

The appearance of *Braarudosphaera bigelowii* in monospecific assemblages or with a remarkable frequency (as it is in the encountered assemblage) reflects a decrease in salinity. Its abundance also indicates an important input of terigenous material. It is known that the bloom of this taxon is due to the presence of a great quantity of nutrients from the fine grained siliciclastic material.

The analyses performed on a coccolithic ooze level (core BS 2K-23, 30 cm depth) showed a very rich and diversified nannofloral assemblage containing taxa - *Calcidiscus leptoporus* (Murray & Blackman) Loeblich & Tappan, *Calcidiscus macintyrei* (Bukry & Bramlette) Loeblich & Tappan, *Coccolithus pelagicus* (Wallich) Schiller, *Umbilicosphaera sibogae* (Weber van Boose) Gaarder, *Holodiscolithus macroporus* (Deflandre) Roth, *Rhabdosphaera claviger* Murray&Blackman, *Reticulo-fenestra minuta* Roth, *Pseudoemiliana lacunosa* (Kamptner) Gartner, *Pontosphaera multipora* (Kamptner) Roth, which characterize open sea environmental conditions .

The spore-pollen spectra (Atanassova, Bozilova, 1992) reflects the changes in the terrestrial vegetation which are not synchronous with the changes in the paleoecological conditions of the Black Sea basin, the boundary between Late Glacial and Holocene being marked at 10 300 ys B. P. This age is generally accepted for continental deposits (Bozilova, 1982). Khrischev, Shopov, (1978), Dimitrov (1982) estimated the age of the Pleistocene/Holocene (Bulgarian shelf) boundary at about 9000 years B.P.

If Neoeuxinian sediments have been redeposited it is possible that the event happened approximately 8 000 years B.P. when a faster rate of sea level rise occurred.

CONCLUSIONS

As a result of detailed studies of bottom sediment cores from the whole Black Sea basin, the first complete picture of the paleoenvironments determining the current grain size composition in the Upper and Middle Holocene sediment sections, was obtained. The data show that the deposits were accumulated in rather variable lithodynamic conditions. Processes of redeposition have played an important role. At some stages "zero sedimentation" dominated while during other periods scanty terrigenous material was accumulated.

In the Danube and Dnieper prodeltas a certain cyclic recurrence was revealed in accumulation of terrigenous material of different grain size composition. It was caused by the cyclic accumulation of sediments from these rivers with larger or smaller addition of eroded bottom material. Different regions of the Danube Prodelta are characterized by different grain size composition of the Upper Holocene sediments, pointing to heterogeneity of sedimentary conditions.

On the Black Sea shelf area especially fine grained sediments (mud to fine sand, with a rich fauna of bivalves) are accumulated, mainly in the local basins. A very important rate of sedimentation (4 cm/y) is characteristic for the delta areas and the limans, placed in the northwestern part of the basin, where very large quantities of sediments are retained.

A large central part of the north-western Black Sea shelf area is characterized by very low rates of accumulation (sediment starving shelf). Shelly sediments with or without little mixture of muddy material are wide spread here. The top layers are usually shells covered with carbonate and thin Fe-Mn crusts. This indicates a lack of terrigenous pellitic material deposition. Short bio-turbated sediment sections, with some shelly horizons, are characteristic both for Upper and Middle Holocene sediments, showing lack of deposition and reduced sedimentation stages. They are not suitable for sediment dating by means of radio-nuclides and ^{210}Pb and for studies of contamination history because of bioturbation and hiatuses in sedimentation.

The steeper slopes, toward the deep sea area, form a zone of reduced rate of sediment accumulation.
In the north-western halistatic region, where in the Upper Holocene and in the Middle Holocene, coccolith muds and sapropelic muds, respectively were accumulated, the identified heterogeneity of grain size composition is connected with grain size differentiation of terrigenous material and biological productivity of Coccolithoforida.

A certain influence of the bottom landscape upon the grain size composition is also traced. More fine-dispersed, mainly pelitic (clayey) material was accumulated in the Middle and Upper Holocene on the positive morphostructures, and silty-clayey material in submerged valleys. In one region of the lower zone of the Anatolian slope a section of "homogenites" was revealed; it formed in the course of accumulation of fine-dispersed material transported by nearbottom turbiditic flows,.

Many sediment sections from the north-western shelf are not suitable for precise dating of sediments accumulated during the historical time and for analysing the history of anthropogenic contamination (Trimonis, 1975, Shimkus, Komarov, 1993, 1994, Shimkus *et al*., 1994, Tvalchrelidze M., Machitadze N., 1997, Oaie, Secrieru, 1998, Secrieru, Oaie, 2004), since discontinuities in sediment accumulation are present. Several cores from the Danube and Dnieper prodeltas and all cores from the north-western continental slope may be used for this purpose (Oaie, Secrieru, 2002, 2004), their sediments being accumulated mainly by vertical sedimentation.

Ancient sedimentological studies (Shimkus *et al*, 1975, Shimkus et al, 1988, Shimkus, Komarov, 1996, Shimkus, 1997) show that the rate of sediment accumulation is higher in the eastern part of the Black Sea basin. The main causes are the contribution of the rivers in the Caucasus and Anatolian areas and the very narrow continental shelf allowing the escape of the better part of the sedimentary material to the deep sea. Large quantities of coarse to fine sediments are carried into the sea and, transported directly in the deepest part of the basin.

In the Kerch area, between Ukraine and Russia, the surface bottom sediments are dominated by mud, silty mud (cores BS 2K-07 and BS 2K-08) and sandy silt. Near the coast (core BS 2K-06) the bottom sediments are mixed with many shells and shell fragments, oxidized on the surface. The sediments from the Coruh Polygon (Georgia) are represented mainly by mud and silt, greatly disturbed by biological activity. Similar sediment types, with the local addition of a significant sandy fraction (BS 2K-26), are present in the Sinop area (Turkey). Shell detritus is a constant component of the sediments.

The presence of oval shaped mineral grains (1-6 mm) in the mud and shell detritus indicates dynamic conditions of sedimentation. The dominance of shell detritus over whole mollusk shells is a characteristic feature of shallow environment in littoral and sublittoral zones, with more active influence of waves.

The laminated sedimentary sequences, Unit I – coccolithic ooze and Unit II – sapropelic mud, appear continuously in the eastern Black Sea abyssal basin and can be traced throughout the entire basin. Occasionally, turbiditic layers emerge as intercalations in both units (Oaie in IAEA Report, 2002).

Complete sections of the Upper Holocene sediments (0-3 Ky) were revealed in most cores recovered from the whole Black Sea basin. In the north-western part of the basin, full sections of Middle Holocene were present only in two cores (BS 98-11, BS 98-12). For the eastern part of the basin, only BS 2K-04 and BS 2K-05 cores penetrated the Middle Holocene deposits, represented as usual by incomplete records, due to the limited length of the cores. Complete sections of Upper Holocene sediments were noticed at deeper water sections.

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