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Full Length Research Paper

Geomorphology and climate conditions that determine sedimentation in Mamaia bay

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The beach evolving in the Mamaia sea area represents a recent geological deposit, which was built mainly from the contribution of north-south oriented long shore terrigenous sediments, but also from biogenic sediments, which have been transported towards the beach, mostly through the shore transverse transport (onshore-offshore). Between 1977 and 1987, several project proposals for the protection of the entire touristic Mamaia beach were analyzed. Several different concepts were presented, due to the fact that each interpretation had to start with the new data on the erosion state and each solution readjustment added new dimensions to the construction site and also to the required financial investments. Eventually, the decision was to start with a series of processes which involved longitudinal-type protection works, known to offer great efficiency on the dissipation of the energy flux propagated with each wave, and also the dam-chain type which is parallel to the shore. At the end of 1988, following some severe storms, the processes for the Mamaia resort coastal protection were initiated under a state of urgency. These measures represented the fourth draft developed over a period of ten years and demanded the build of six longitudinal dikes out of the nine required by the initially presented protection solution.

Key words: Coastal processes, coastal hydro-technical structures, beach, sedimentation, sand dunes.

INTRODUCTION

Romanian coast that stretches over a length of 244 km is about 6% of the total shoreline Black sea. The landscape consists of sandy beaches (about 80% of total Romanian coast) and relatively high land with cliffs (about 20%).

It is well known that the Romanian Black sea coast is divided genetically and geomorphological (Panin et al., 1999) in two main units (Figure 1):

i) The Northern shoreline unit, which runs from Baia Musura (border with Ukraine) to Cape Midia is of accumulative type, beaches built in front of Danube Delta;
ii) The Southern shoreline unit, situated between Cape Midia and the Vama Veche village (border with Bulgaria) is of main erosional origin with a relative higher relief and loess cliff (especially its southern part). It is divided into two subunits, the transition (Cape Midia and Cape Singol) and southern (Cape Singol and Bulgarian border).

Mamaia beach is part of the transition subunit and is the largest beach in the southern unit of the Romanian coast. The barrier sand was formed about 3000 to 4000 years ago in a marine gulf (Caraivan, 1982). The gulf was blocked by a sand barrier at a depth of approximately 2 m. In the newly-formed lagoon there was freshwater and silt-clay mixtures and a relatively large amount of peat-like plant material started to accumulate. As the sea level rose, the barries sands was flooded, and the sand deposits have been translated along from the surf zone towards the shore and were then deposited over peat accumulations. The current sedimentation conditions were then established; the alluvial material brought in by the Danube was transported along the coast and captured in the Clisargic field. The actual barrier sands was thus formed, delineating the Siutghiol Lake's freshwater lagoon.

COASTAL HYDROTECHNICAL STRUCTURES

The circumstances in which the coastal and sedimentologycal processes are being handled are influenced by the two promontories (Cape Clisargic and

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Figure 1. Romanian black sea coast.

Cape Singol), which support the hydrotechnical structure, the Midia harbor on the northern end and marina Pescărie on the southern end, but they are also affected by the coastal protection structures (the groin and the detached breakwaters located in the southern part of Mamaia bay area), which exert a major influence on today's sedimentary processes in Mamaia's coastal area.

Over the years, Midia harbor, through its natural configuration, has presented interest for setting up harbors ever since the 20th century. The main stages (which had an essential role in controlling the coastal processes) for developing this harbor were (Spataru, 1986):

1) In the year 1938, a project for building a hydro-technical structure "Taşaul Naval Base" was developed,

which led to the production of a 900 m section at the basis of the southern breackwater;
ii) In the year 1950, the Midia area was established as port terminus for the Cernavodă-Poarta Albă-Năvodari project version for the Danube-Black sea canal. As it follows, between 1950 to 1953, the southern breackwaters was extended by approximately 1400 m and there was also built, a 800 m section for the offshore breackwater;
iii) In the year 1977, the Midia harbor was extended, following the finalization of the Petrochemical Midia-Năvodari plant. The offshore breackwater was enlarged up to1.1 km, under an angle of N 30°in order to ensure a natural depth of approximately 9 m depth, needed to allow ship access.

The Pescărie marina, located in the south of the Mamaia Bay was initially designed to house the equipment used to build the detached breackwater in Mamaia and also for the linked dams and the ones parallel to the Constanța shore area.

The hydro-technical protection structures for the Mamaia resort beach were designed to limit the magnitude of the erosion phenomena. In order to reach this goal, certain soft expeditious protection measures were considered, for some sections of the Mamaia beach. Tagged as rapid intervention processes, or tests for some potentially simpler solutions, these measures consisted of:

a) Beach nourishment, without any structural shore protection, usually on the southern area of Mamaia resort. This sand was frequently quickly removed by waves during storm period.
b) Rockfill deposits on the beach, at the sea-land interface. This solution was inadequate for the Mamaia tourist beach, as the rockfill sank in the sand.
c) The construction of a fence made from plastic tubes (Photo 1) located at the edge of the swash area, without any protection for the bottom. The process turned out to present low efficiency and reliability.
d) The doubling of the tube fence using a string of cored out cubes placed on the beach (Photo 1). The measure presented only a partial protection effect and limited in time.
e) The placement of reed fences on the beach during the cold season, in order to protect the sand from the wind's direct affliction. (Photo 2). This measure is efficient and used all over the Mamaia tourist beach.

In most cases, the beach protection conducted through these actions, have had a limited or a short termed role, showing that the matter demands a coherent framework approach, starting with the analysis of the ongoing geomorphological phenomena and using pattern verification in order to acknowledge the behavior and efficiency of the proposed solutions. These actions were followed by structural procedures (the groin and the detached breackwaters).

The issue on the protection of the Mamaia beach was first brought up in the year 1975 (Tanase et al., 1992), when the dangers of destroying Parc hotel's pool became imminent (south part of Mamaia beach). In the winter of 1977 to 1978, a groin was built, its actions being supported through beach nourishment brought from Tăbăcărie Lake (about 27000 m^{3}sand). This groin had an important role in protecting the local beach but it is also an obstacle by retaining littoral drift which affects the adjacent beach. Thus, depending on the direction and sedimentary transport, this hydro-technical structure represents a sedimentary trap, which determines the accretion/erosion process (Photos 3 and 4).

The destructive effects, located in the southern section of the Mamaia tourist beach, have been amplified by several successive severe storms, between 1979 to 1981 and 1985 to 1988. Between 1977 and 1987, different actions were taken into consideration in order to protect the entire Mamaia tourist beach area. Various solutions were presented, as each retake had to start with the new

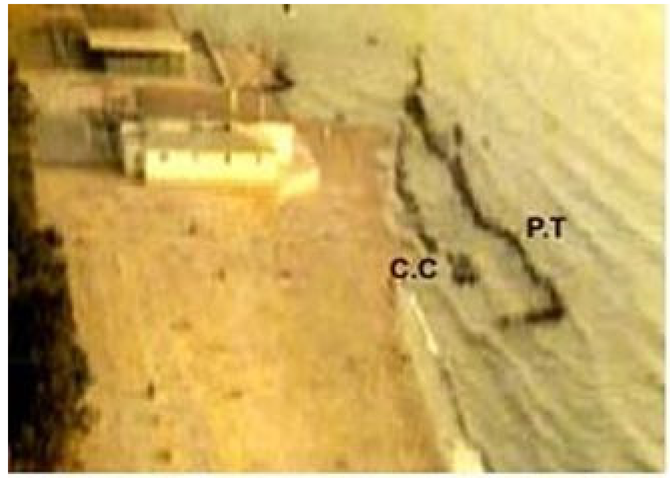

Photo 1. Protection using plastic tubes (P.T) and cored out cubes (C.C.) Southern part of Mamaia beach (1981).

Photo 2. Soft beach protection measure with reed fences during cold season (13 I 2002).

Photo 3. Local effects of accretion on the backshore - groin in southern part of Mamaia bay (13 I 2002).

Photo 4. Local effects of erosion on the backshore - groin in southern part of Mamaia bay (17 III 2003).

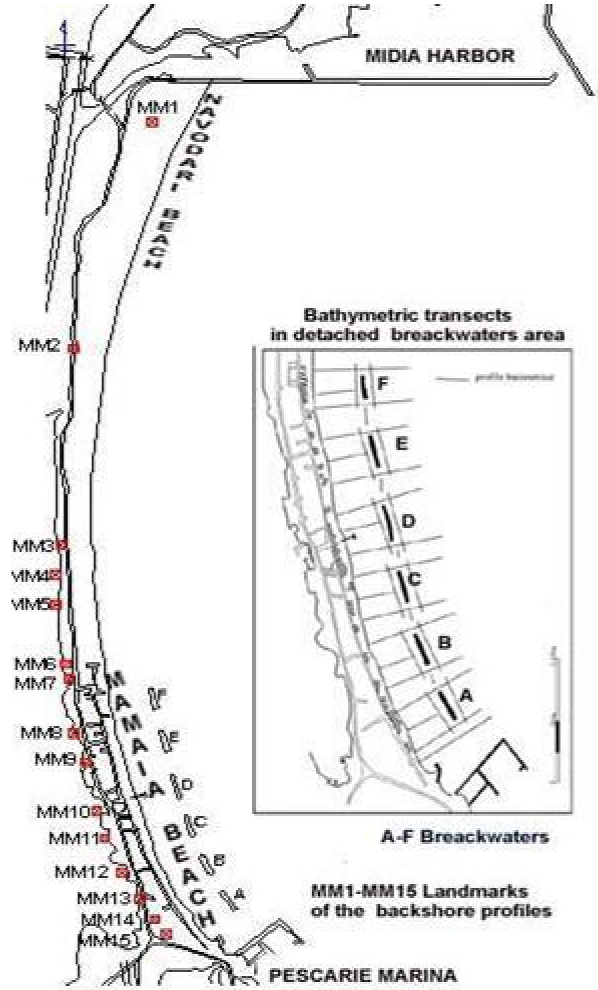

Figure 2. Landmarks and orientation terminal sections bathymetric measurements.

data on the erosion state and each solution rehabilitation added new dimensions to the construction site and also to the needed financial investments. Finally, the decision was to start with a series of processes which involved hard shore-perpendicular structure protection, known to offer great efficiency on the dissipation of the energy flux propagated with each wave, and also the detached breakwaters which is parallel to the shore, that are constructed to reduce wave energy and promote accretion of protected beaches. At the end of 1988, following some severe storms, the processes for the Mamaia resort coastal protection were initiated under a state of urgency. These measures represented the fourth draft developed over a period of ten years and demanded the built of six longitudinal dikes out of the nine required by the initially presented protection solution. They were located at about 5 m depth, with a length of about 300 m and the windows of them, about 200 m. These actions for the protection of the Mamaia beach were carried out in several stages (Figure 2): In 1988, the construction for the A and B breakwaters was initiated; in 1989 the construction for the C, D and E breakwaters was initiated; in 1990 the construction for the F breakwater was initiated.

At the same time, backshore section was filled with about 500 000 m^3 of sediments brought from Siutghiol Lake.

Coastal dynamics in Mamaia bay

The beach evolving in the Mamaia bay represents a recent geological formation, which was built mainly from the contribution of north-south oriented long shore terrigenous sediments, but also from biogenic sediments, which have been transported towards the beach, mostly through the shore transverse transport (onshore-offshore). Depending on its relation to the shore, the beach is divided into two different types: The beach itself (attached to land in the northern area, Photo 5) measuring approximately 5 km and; barrier sands (Photo 6), representing the separation between beach and land through an 8 km-long lagoon (Siutghiol Lake). The beach therefore develops in coastal areas with moderate or weak tides, where there are considerable psammitic material resources. Mamaia bay has sediment resources and micro tide regime, thus being convenient for marine beach formation.

The current breakwaters configuration in the Midia

Photo 5. Beach connected to land (MM1).

Photo 6. Barrier beach (MM3).

harbor (the 1.1 km-long offshore dam and the 2.4 km-long southern dam, both placed at depths of about 9 m) represents a coastal hydro-technical structure that has a major perturbing effect on sediment transport conditions (stream, wave, sediment flow) in Mamaia bay. The main effects of these breackwaters relate to:

- offshore disturbe (depths of over 10 m) of a significant part of the sediment volume involved in the long shore sediment transport, that can no longer be found in the sediment balance of the Baia Mamaia beach;

Mamaia bay sediment is redistribution due to the facilitation of sediment accumulation in the shadow sector of the Midia breackwaters and in the shelter area of the southern breakwater, as well as of sediment reduction in the southern part of the Mamaia Bay.

The sand deficit of the Romanian shore was accentuated, especially in the Mamaia beach area by the construction of the Midia harbor breackwaters in 1953 (Spataru, 1986). He estimates that between 1953 year and 1975, about 5 000 000 m^3 of sand accumulated between the breackwaters instead of supplying the sediment transport towards Mamaia beach. From 1961 to 1985, in the erosion zone (8 km-long along the shore and 4 km-long offshore) 32 000 000 m^3 of sand were redeployed.

In the seabed geomorphological evolution in the Midia harbor area (Dănuț, 1990), the following was found:

i) Sand deposits, revealed by the 150 to 600 m offshore translation of 6 to 9 isobaths, in the Midia harbor area;
ii) Sediment material deposits, displayed in a parallel manner to the Midia harbor dams.

Geomorphology of Mamaia bay

In the coastal area, geomorphological processes are cyclical and correspond to climate peculiarities divided into two main seasons: winter (October to March) and summer (April to September), during which the activity of geo-hydro-dynamic factors is differentiated according to the degree of sea agitation, shoreline configuration, underwater relief structure, marine obstacle presence and liquid and solid river flow rates. The first semi-cycle, also known as stormy/cold season, mainly features high levels of environment energy and, implicitly, the most important destructive effects. The other one, the summer/warm season, features low intensity sea agitation and, as effects, the beach rebuilding processes. Therefore, when the cycles end, certain equilibrium of processes could be found; however, the real sediment balance of the Romanian shore is usually negative.

RESEARCH METHODS

All field measurements, analysis, data processing and interpretation of results have been achieved in the monitoring program for coastal erosion of Nationale Institute for Research and Development “Grigore Antipa” Constanța achieved since 1980.

Survey of beach profiles

The beach sections were done with the use of topographic equipment (Ni 025 and Sokkia level - medium accuracy class), on the backshore and were performed on 15 sections (coded from north to south, MM1-MM15, Figure 2), perpendicular to the general direction of the sea-land interface during 1980-2005 period.

On these profiles, the defining attributes of the backshore morphology were noted; vegetation limit, berm, scarp (micro cliff), biogenic material deposits, traces of storm, wave run up/down. The distance between measurement locations was generally of 300 to 400 m (in the Mamaia resort beach).

The data fund of beach sections was stored and processed using modules Coastal Engineering Design and Analysis System (CEDAS) v. 4, module Beach (Beach Morphology Analysis Package - BMAP), codes that consist of specific models for analyzing beach processes.

The bathymetric sections from 1988, 1992, 1994, 1996, 1998 and 2000 were used to evaluate the hydraulic structures’ protective effects in the southern part of the Mamaia tourist resort (namely of the 6 (A-F) breackwaters) (Figure 2). The bathymetric section data was obtained with the use of a SDH-13 echo sounder placed on a rubber boat. To this end, about 36 sections of bathymetric measurements on electro sensitive paper were recorded from the depth of 0.50 to about 8.0 m depth. The processing of the results was done by direct data comparison, with a specific module Beach Morphology Analysis Package and the Surfer v. 6 soft.

Granulometries of beach sediments

Beach sediment data were collected from dunes, backshore, and swash and near shore and grain size analysis was performed (Anastasiu and Jipa, 1983; Jipa, 1987) through dry sieve analysis for the samples collected during the 1988 to 2001 period. The assignment of sediment grain size classes was done according to the Udden-Wentworth granulometric scale (Folk and Ward, 1957). Particle size analysis of sediment granulometric distribution was based on statistical parameters, mean, sorting, skewness, kurtosis, and grain size scale, medium bioclasts (PM), fine bioclasts (PF), very fine bioclasts (PFF), very coarse sand (NFF), coarse sand (NG), medium sand (NM), fine sand (NF), very fine sand (NFF), very coarse silt (SG).

RESULTS AND DISCUSSIONS

Inshore beach changes

The annual bathymetrical transects modifications analysis between 1988 and 2000 brought about by the presence of the Mamaia beach protection structures, indicated the “tombolo” incipient or the “double salient” (Hsu and Silvester, 1990) sediment deposit formation tendency in the normal line’s direction for each of the protection dams.

The detached breackwaters submerged area modifications (Dănuț, 1999) was found:

1. Upon the completion of the protection dams and the beach nourishment in the years 1988 and 1989, a considerable quantity of sand was deposited at the swash zone’s limit, which was afterwards transported onto the submerged beach by waves and streams. Thus, about 3.8 hectare of beach were rebuilt in the backshore and swash zone, and the near shore deposits totaled 340,000.00 m^3 for the 1988 to 1990 period, and 205 000 00 m^3 for 1990 and 1991;
2. During the first stage (1988 to 1992), the near shore deposits displayed preferential patterns, usually toward the northern ends of the dams. In the second stage (1994 to 1996 years), sediments were deposited especially in the central part of the dams, taking the form of incipient tombolo (Figure 3);
3. Following the space between the dams, the deposits were minimal and they were mainly recorded during the first stage (1988 to 1992). In the second stage (1992 to 2000), the processes alternated: erosion (1994 to 1996 years) and mild accretion (1998 to 2000 years) (Figure 3).

The backshore retreated considerably, between 1981 and 1988 (from 50 to approximately 5 m), and once the coastal protection measures were applied (detached breakwaters and beach nourishment), the beach was rebuilt (125 m wide in 1991 and 106 m wide in 1993) (Figure 4). In the next phase, the erosion process became dominant, as the beach reconstruction measures, with sediment supplies (from the Siutghiol Lake), were discontinued, the beach reaching a width of 70 m in 2005 (Figure 4).

The sea-land interface contour, as an effect of the protection dams in the swash zone, assumed a certain rhythmicity, due to the formation of salient sedimentary units (Figure 4: Picture 17 II 1993 / 30 III 2005). Thus, in the central protection area of the normal shore line, these sediment formations developed.

Their spatial position varies depending on the wave regime, currents and the available sediment amount. They frequently disappear during severe storms and they recovered during calm periods in the area between the breackwaters, close to the shore, the sea-land contact line curves and towards the backshore area.

The sediments that were used from the Siutghiol Lake for reconstructing the beach had a considerable contribution of very fine particles. That is why, one year after the sanding, in the backshore area close to the MM14 landmark, during the summer season, several portions of wet beach appeared, while during the cold season, “buckets” made of very fine sand and coarse silt could be seen (Figure 4: Picture 13 III 1992).

Dune formation

In the vicinity of the Black Sea shore, the climate regime is greatly affected by the sea aquatory both thermally and dynamically, by changing the heat balance and the rugosity of the underlying surface. In various European regions, rapidly-evolving cyclone and anticyclone baric formations which depend on the atmosphere’s thermal structure interact, thus, resulting in a non-permanent wind regime on the Romanian shore. There are numerous cases when wind direction and speed change on a daily basis or even during the same day.

Air mass movements represent the dynamic factors which generate currents and waves, as well as deflation in the sub aerial beach area. The sand particle transportation under the wind’s action can take three forms; creeping, saltation or suspension, depending on wind speed and direction, beach topography (slope and sediment deposit height), petrographic composition, sediment structure and texture, vegetation presence, surface humidity and anthropic factors.

Dune formation (Shore Protection Manual, 1984) starts when an obstacle reduces wind speed, allowing sand to deposit. Once these dunes are formed, they become obstacles for the sand migration towards land. Thus, they work as a geomorphological unit involved in keeping the sand in the beach coastal system. The wind speed that

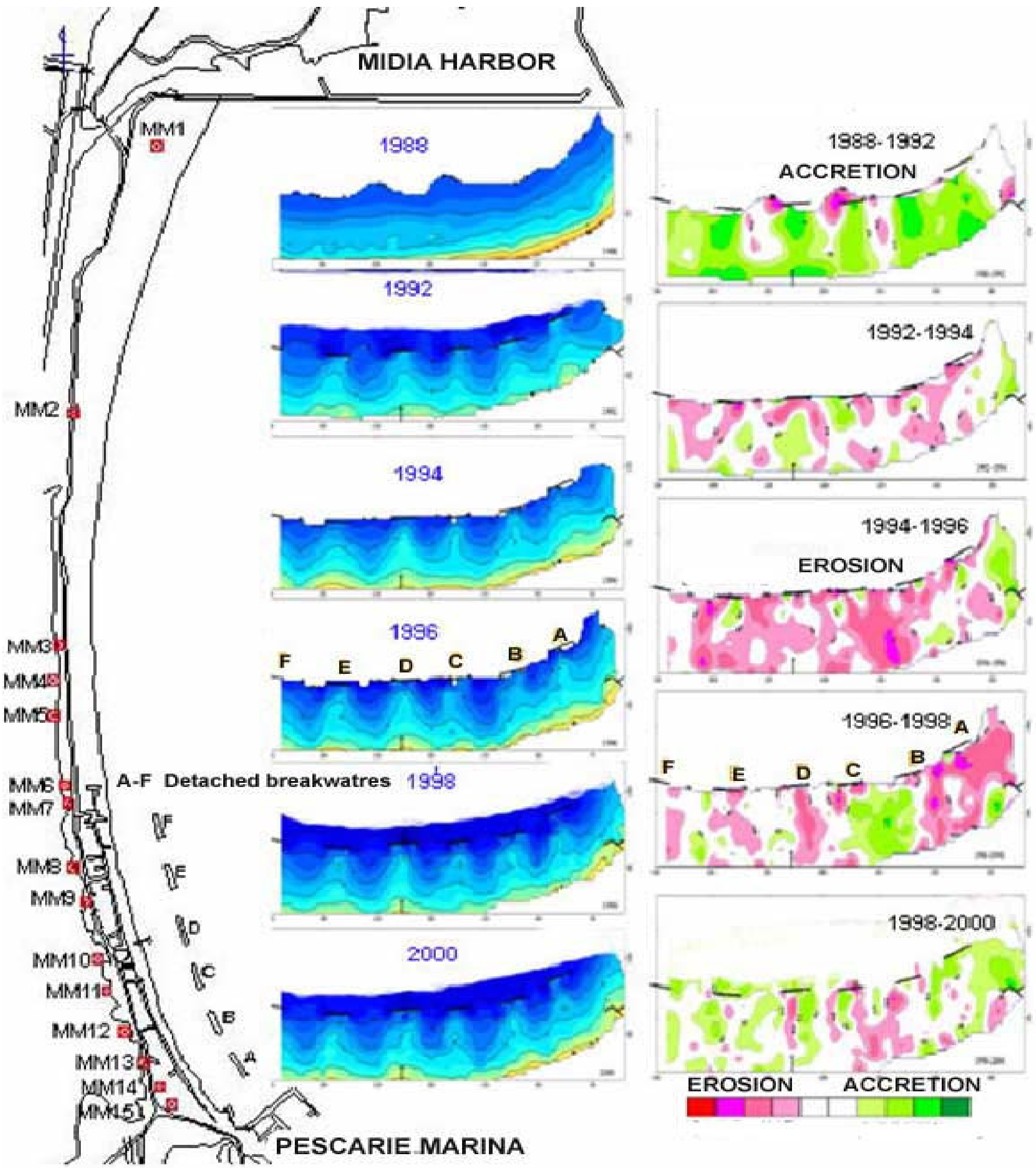

Figure 3. Beach evolution in the breakwaters area (southern of Mamaia bay, 1988 to 2000).

activates sediment particles on a dry beach is generally of 5 to 6 m/s, and goes up to 10 to 12 m/s on a wet surface (Leo and Van, 1998).

In the case of the Mamaia Bay backshore, there are favorable conditions for dune formation and maintenance; availability of a sediment source, beach width, vegetation presence/absence, coastal hydrotechnical structures, shoreline orientation, wind regime.

On the Mamaia Bay backshore, and foreshore, fine sediments are deposited, especially granulometric fractions of fine and very fine sand. In the superficial layer in the dune area, based on the analysis of samples collected in 2001 on 6 profiles (MM1, MM2, MM3, MM7, MM11, MM14), the following granulometric features were established (Dănuț, 2009; Dănuț et al., 1992) (Figure 5):

i) In the northern sector (Năvodari beach, MM1) and in the center of the Mamaia beach (MM7), the fine sand category prevailed (over 85%) - mean of 0.15 mm, very good and good sorting, negative symmetry granulometric distribution, leptokurtic platykurtic and mesokurtic kurtosis;

ii) The southern sector of the Mamaia tourist beach (MM11 and MM14), the sediments had a high percentage

Figure 4. Backshore evolution at the sea-land interface (MM14, Mamaia beach, 1981 to 2005).

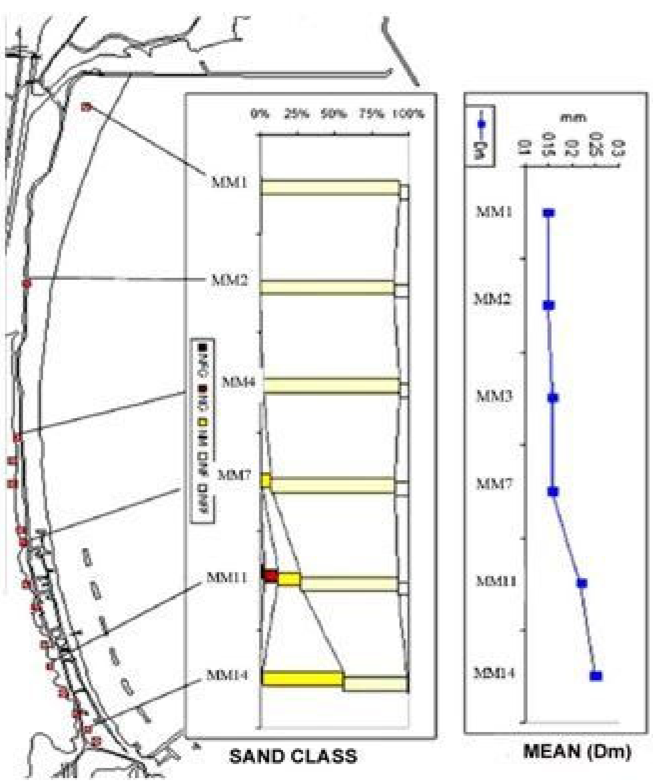

Figure 5. Dunes zone sediments texture (Mamaia bay, 2001).

of medium and coarse sand (up to 56%) - mean of 0.22 to 0.25 mm, well and moderately sorting, fine skewed and leptokurtic skewness.

In the sum, from the wind regime analysis, it was established that there have been favorable conditions for dune development between 1980 and 2000, when storms (selection criterion is the range of at least 18 h faster than 10 m / s) totaled about 511 h/year and wind speed during cold seasons frequently went past 5 m/s (Dănuț, 2009).

The beach width has been unstable, ranging from 30 m (MM15) to over 120 m in the sector of the Mamaia tourist resort (MM4 to MM6). During severe storms, the sub aerial beach was flooded about 70 - 100 m from the backshore; therefore dunes were generally formed more than 80 m away.

On the Mamaia tourist beach, during the cold season, dune-type sediment units were formed, as an effect of soft protection measures - reed fences. These units are redistributed by beach profile leveling during summer (Photos 7 and 8).

All throughout the 12.5 km-long backshore of Mamaia bay, about 50% of the area is covered by dunes, especially in the central sector, where they are stabilized by vegetation, and about 40% of the beach dune-type sediment units are formed during the cold season, as an effect of the protection measures that were used in the Mamaia resort (Figure 6).

Figure 6. Dune sectors in Mamaia bay.

Photo 7. Sediment deposits winter season (23 November, 2004).

Morphologically, ecologically, as well as from the landscape perspective, the importance of dunes is obvious for the natural coastal environment. Moreover, the sand that forms the dunes represents an important sediment reserve for coastal area dynamic processes that involve sediment migration from the emerged beach towards the submerged one during severe storms and the other way around during calm periods, the process actually ensures the natural protection of the beach.

Photo 8. Beach shore leveling summer season (2 April, 2004).

Conclusions

Beach of Mamaia Bay is the recent sedimentary deposits. The current coastal processes are carried out in a cell sedimentation conditioned by natural factors (geo-hydro-meteorological conditions) and the anthropogenic (Cape Singol, Clisargic and ports are located on structures, coastal protection, groin, breackwaters). With the construction of breakwaters for Midia harbor, disturbance occurs in sediment along shore drift and redistribution of them in the Mamaia Bay. Thus, there is an accumulation of sediments in the northern area of Mamaia Bay, the sectors of shelter of the breakwaters and a reduction of sediment with a decrease in their southern portion, respectively Mamaia beach resort.

The sand deficit of the Romanian shore was accentuated, especially in the Mamaia beach area by the construction, in 1953, of the Midia harbor breackwaters. As a result of beach erosion during 1986 to 1988, the tourist beach in the southern portion of the tourist beackshore of Mamaia, during severe storms was completely flooded. Thus, they have adopted measures to protect the structural measures accompanied by six detached breakwater and soft measure with replenished sand in 1988 to 1990.

These dams provide a sediment trap forming structures such as tombolo and salient. Initially, they had protective nature of the beach, but then, the fact that none have continuous nourished sand and other structural protections, has made erosion to be predominant.

The active erosion has an effect on the southern Mamaia Bay, but during 2005 to 2007, a Master Plan was developed for the southern Romanian coast. As a result, a plan was designed to protect the coastal zone, where the southern part of Mamaia beach has been selected as priority project for implementation of coastal protection and rehabilitation. These measures consist of detached breakwater rehabilitation, building of jetty to retain sand, building of three submerged breakwaters and nourished sand.

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