# Geoenvironmental Issues Concerning the Black Sea Basin

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***Abstract*—**This paper presents the geographic data and the reasons to study the Black Sea basin. The paper also describes the Black Sea tectonic evolution models, its platform conditions, especially in the Romanian sector, the deep sea basin conditions and its anomalous magnetic theory. The geoenvironmental impact data of Black Sea basin, taking into account its fresh water discharge, coastal discharge, with coastal (beach-forming) sediments and marine (deep-water) sediments, sediments in the Romanian Sector, erosion with its causes and effects.

***Keywords*—**Black Sea basin, tectonic theory, anomalous magnetic theory, sedimentation, erosion

## I. Introduction

### *A. Geographic Data*

The Black Sea is a natural inland water basin situated between south-eastern Europe and the Anatolian Peninsula separating Eastern Europe and Western Asia. The Black Sea is connected to the Atlantic Ocean via the Mediterranean Sea, by the Sea of Marmara and Aegean Sea. The Bosporus Strait connects the Black Sea to the Sea of Marmara and the strait of the Dardenelles connects it to the Aegean Sea. The Black Sea is also connected to the Sea of Azov by the strait of Kerch, a shallow channel about 45 km long.

Six countries share the Black Sea coast: Bulgaria and Romania at west, Russia and Ukraine at north, Georgia at east, Turkey at south. The lengths of their respective coastlines are: Bulgaria - 354 km, Romania - 244 km, Russia - 800 km, including the Azov Sea, Ukraine – 2,782 km, including the Azov Sea, Georgia - 310 km, Turkey – 1,329 km.

The geographical characteristics of the Black Sea are: total area – 423,000 sq km (441,000 sq km including the shallow Azov Sea), maximum depth – 2,212 m, average depth – 1,315 m, volume – 547,000 cubic km, wave height up to 6-7 m, wave length up to 90-100 m, tidal variations -3 to 10 cm, average winter temperature of seawater -4°C, average summer temperature of seawater -22-24°C and average salinity 17,5 ‰.

The Black Sea consists of two main basins separated by a continental ridge. The western basin is oceanic in nature while the eastern basin is believed to have a thinned continental basement. Data for the timing and mechanism of opening of both basins come mainly from the geology of the surrounding regions, but are very limited from the basins itself [47].

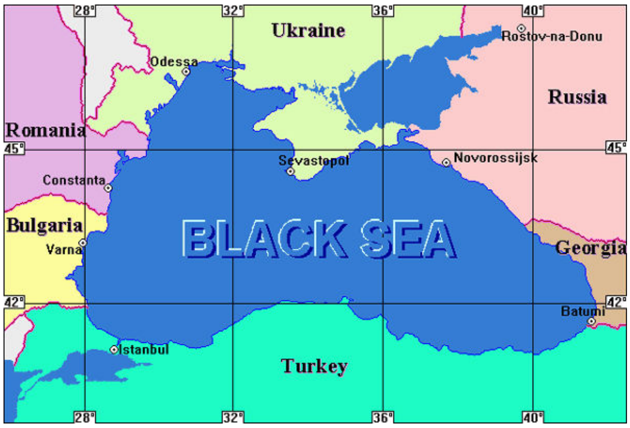

Fig.1 Black Sea map

### *B. Reasons to Study the Black Sea Basin*

There are several important reasons why the Black Sea seems to be the most interesting marine basin for study.

First, the water area of the Black Sea is situated at the boundary of arid and humid regions. The role of eolian material is very important here and that is why the data for both arid and humid regions, occupying more than half of the total World Ocean area, can be obtained within a single basin. The Black Sea is a key region for the south European climate as it is the source for the south European rainfall [33].

Secondly, the Black Sea is the largest stagnant basin in the World. The horizontal transport of suspended matter is weaker than in the other seas and occurs only in the shelf regions. The Black Sea is almost entirely isolated from the world's oceans being connected to the Mediterranean only through the Bosphorus Strait, a 35 km natural channel, 40 m deep and 700 m wide. It leads to the Sea of Marmara and then to the Aegean Sea through the Strait of the Dardanelles. This natural system makes the replenishment of the bottom waters of the Black Sea with new seawater in the Black Sea very slow; it takes hundreds of years. Therefore the Black Sea is now the largest natural anoxic water basin in the world. This means that 87% of its volume is practically devoid of marine life [34].

Thirdly, the Black Sea is a solar sea. Analyzing the daily temperature changes in a number of control fields in the course of 8-10 years, scientists have proved the existence of temperature anomaly in the sea surface temperatures on a global scale. The dynamics of the atmospheric processes at the time of the anomaly creates conditions for the increase of the solar radiation, reaching the sea surface [24]. The processes leading to the increase of the solar radiation, reaching the Black Sea surface were studied by numerous marine research institutions and laboratories in many countries which are situated on the Black Sea shore. They are experts in marine research, having already gathered a large amount of relevant data. The Black Sea offers very good conditions for the use of the satellites. By using simultaneously data from several satellite systems and ground stations, scientists have tried to analyze the correlation between sea surface temperature and the atmospheric processes in the troposphere and the stratosphere. The warming of the sea water observed spreads from west to east at a speed of 13-16 kph. The analysis shows a strong correlation between the surface anomaly and the ozone layer thickness. The changes in the solar radiant flux are compared to the solar eruption. This natural anomaly may cause ecological changes.

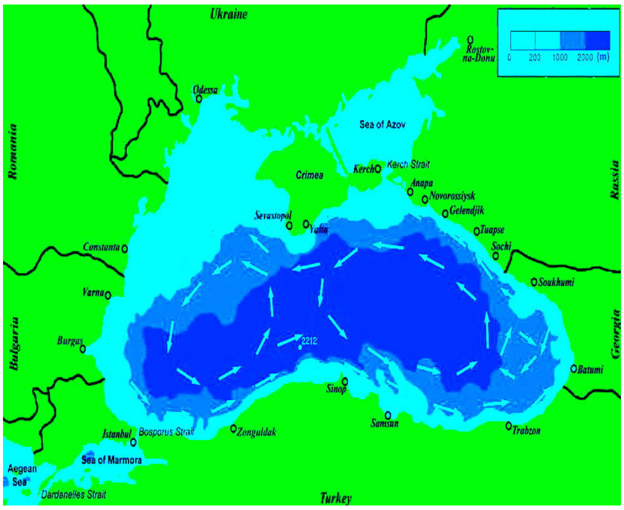

Fig.2 The two main basins of Black Sea

## II. Tectonic Theory versus Anomalous Magnetic Theory on the Black Sea Basin Origin

### A. Tectonic Theory

#### 1) Black Sea Tectonic Evolution Models

The conceptions of the Black Sea basin origin show clearly their contradictions.

The problem of the Black Sea basin origin directed researches attention since the end of the 19th century. Appeared in the early works of E. Suess in 1886, the problem has today two complete conceptions.

The first one assumes the basin as a remnant in the Alpine folding belt. This conception shows that the basin was an ancient "matrix geosyncline depression" [29] as well as a fragment of the most ancient oceanic crust [43]; [26]. This theory assumes that the Black Sea is a large Cretaceous-Tertiary basin. It consists mainly of two large subbasins separated by the NW-SE trending Mid-Black Sea ridge. The West Black Sea basin is floored by oceanic crust overlain by over three thick flat-lying sediments probably of Cretaceous and younger in age [22]; [9]; [38]. The northwest trending East Black Sea basin has a thinned continental or oceanic crust overlain by less than 10 km thick sediments, which are intersected by large number of faults. It is generally accepted that the Black Sea opened during the Mesozoic as a back-arc basin above the northward subducting Tethyan oceanic lithosphere [2]; [45]. An important feature of the Black Sea region is its position within the ancient Tethys Ocean and the surrounding paleocontinents, which were progressing rapidly during Phanerozoic time. Such a conception is uncertain as indicated by the latest data on the deep basin structure and the sediment cover structure. According to the seismic reflection profile recording, the Black Sea basin was superimposed on the surrounding structures at least during the Cenozoic period, since that time the basin is progressing actively.

The second conception assumes a new formation origin of the basin. The so called Eucsinian basin preceded the modern sea. The time of the Black Sea basin origin was believed to be Late Neogene, but some authors assume the Early Quaternary.

There are two most widespread hypotheses considering the hypothesis of the consequent Black Sea basin new formation. The first one deals with the rapid vertical crust movement predominantly; the second one deals with the crust spreading predominantly. The latter is based either on the idea of the riftogene rupture, followed by the "granite metamorphic" crust gapping within the basin, or on so called suboceanic basin aerial spreading idea. The aerial spreading hypothesis overcomes discrepancies between the primitive plate tectonic patterns of the suboceanic mediterranean basins genesis - the Black Sea basin being one of them - and the real geological and geophysical data. In such a case there are spreading structures within the basins and so called "tectonic density" - like orogeneses and folding systems - along their periphery as the riftogenesis indications. The Zavaritzky-Benioff zones are believed to be an additional indication because they compensate partially the sea floor spreading [51].

The contradictions between the conceptions of the region origin and its Late Alpine progress are accounted by the complex jointing of various tectonic structures (from the ancient platform to the recent basin geostructures and the orogenic surroundings) marked by heterogeneity as well as different coverage of the areal exploration [19]; [40].

There are distinguished tectonic elements of different rank (structural as well as substantial complexes). Eurasian and Arabian plates together with the Rodopy-Pontian subduction suture and Arkhangelsky-Andrusov lineament should be regarded as global structures.

The transition earth crust type of the plate frontal areas does not contradict the seismic data available.

A kinematic model for the opening of the Black Sea, based largely on data from onshore areas, is the third conception regarding the formation origin of its basin and was suggested in 1994. The model involved separate mechanisms for the origin of the West and East Black Sea basins. The West Black Sea basin was believed to have opened by the rifting of a continental fragment from the Odessa shelf starting in the Albanian-Cenomonian. This continental fragment drifted south bounded by two major strike-slip faults, opening the oceanic West Black Sea basin in the north and closing the Tethyan Ocean in the south. During the Early Eocene this collided with the Sakarya Zone in the south, thereby causing a change-over from extension to compression in the Black Sea [31]. The eastern half of the Black Sea including the East Black Sea basin, Mid- Black Sea ridge and the easternmost part of the West Black Sea basin opened through the anti-clockwise rotation of a large continental block around a pole situated in Crimea. The rotation was believed to have been contemporaneous with the rifting in the West Black Sea basin.

Although the mechanisms for the opening of the West and East Black Sea basins have been generally accepted [38]; [1]; [53], there have been important disagreements on the timing of opening of the Black Sea as well as the location of some of the faults [31].

*2) Platform Conditions*

The platform conditions are manifested in the north - western Black Sea, including Bulgarian, Rumanian, and the north - western Black Sea shelves, and the northern parts of the Crimean peninsula, Azov Sea and Kuban territory. The ancient East European plate and the recent epihercynian Scythian and Moesian plates are outlined there as well as a zone which originated as an epiplatform orogenic foredeep in the Oligocene to Miocene time and involved in the platform conditions in the recent time [49]; [51]. The most part of this territory is characterized by con-denudation to con-sedimentation conditions.

The recent orogenic conditions areas are tending to elevate within the region. In some parts of the region the orogenic conditions seem to be formed in the initial orogenic stage in the Palaeocene to Eocene time, but other parts of the region were involved in the orogenic activity in the recent epoch only because of the permeability of the earth crust and of the high intensity volcanism processes [48]; [51].

The Black Sea continental and suboceanic platforms are distinguished within the Eurasian plate besides the mentioned frontal zone.

The continental platform is subdivided into the ancient East European platform and the recent Scythian and Moesian plates. Composed of the alteration of the Caledonian-Hercynian and the Kimmerian rocks, there are areas of different folding basement age within the Scythian-Moesian plate. The distal part, bordering the suboceanic Black Sea platform, consists of the Baikalian age rocks.

The crystalline crust of Moesia measures more than 25 km and is covered by up to 22 km of sedimentary rocks.

*3) Romanian Platform Conditions*

The North Dobrogea crust in Romania reaches a thickness of about 44 km and is probably composed of a thick Eastern European crust overthrusted by a thin 1–2 km thick wedge of the North Dobrogea Orogen. The deepening of the basement in the Dobrogea area is of 1–3 km. Based on seismic reflection data, for the Dobrogea area are predicted depths for the two major boundaries in the crust: 22 km for Conrad discontinuity and 45 km for Moho discontinuity. Within the North Dobrogea a 6 km thick sedimentary cover is observed and the Moho discontinuity reaches 42–43 km depth [36].

The major platform structures are Late Permian/Early Triassic rifts. The deformed rocks of the North Dobrogea Orogen include a complex polydeformed Variscan basement and a Permian–Cretaceous sedimentary and volcanic cover. The whole complex was overthrusted NNE-ward onto the Scythian Platform between the Late Triassic and the Late Jurassic.

The Scythian, Moesian and North Dobrogea crustal blocks are supposed to belong to the southeastern prolongation of the Trans-European suture zone and are separated by the Trotus and Peceneaga–Camena crustal faults. The Trotus/Peceneaga–Fault system is a distinct active structure with tectonic geomorphology and local offsets of 200 m, formed during the Quaternary and extended down to the Moho discontinuity and even deeper [52].

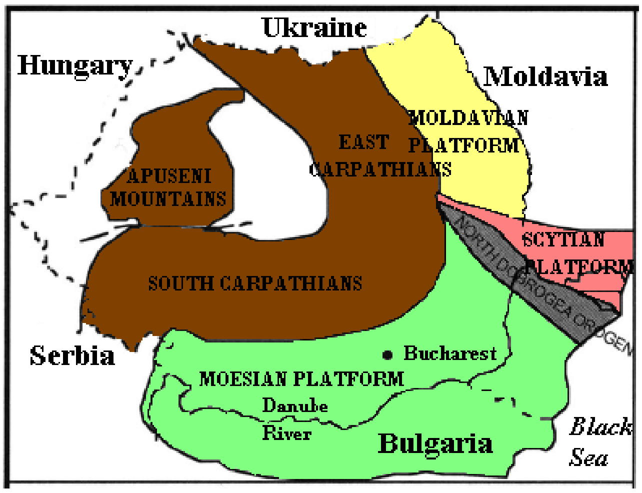

Fig.3 Romanian platform conditions

On the Moesian Platform the Capidava–Ovidiu and Intramoesian faults separate basements of different composition. The Capidava–Ovidiu Fault separates a greenschist basement to the north from a higher-grade metamorphic basement to the south.

The Peceneaga–Camena Fault and the Capidava–Ovidiu Fault are outcropping in the Dobrogea area near the Black Sea [52]. In the Moesian Platform the seismic refraction line crosses the Capidava–Ovidiu Fault and the Peceneaga–Camena Fault.

*4) Deep Sea Basin Conditions*

The deep sea basin conditions are the Azov and Black Sea region tectonic conditions. Such conditions existed within the Black Sea basin in the recent time, when the basin was restricted by the Black Sea continental slope along its periphery.

The total recent deep sea basin subsidence seems to manifest a common Cenozoic region tendency. The seismic data analysis makes it possible to retrace the Black Sea basin formation through the whole of the Cenozoic time. The Black Sea originated as a single basin in the Late Eocene and the Early Oligocene time. After the single basin origination, two deep water basins seemed to exist, in the Palaeocene to Eocene time: the East and the West Black Sea basins separated by the ablation zone within the Andrusov swell and the Arkhangelsky rise.

The elevation zone forming the shelf areas existed along the Maikopian periphery of the Black Sea deep basin. The Oligocene to Miocene downwarping belt, namely the Sorokin and Tuapse foredeeps, stretched within the northern part of the zone probably connected with the active formation of the Crimean and Caucasian orogenies. The subsequent Black Sea basin progress was accompanied by its broadening and superimposing on the above-mentioned orogenic foredeeps in the recent time together with their recent structural pattern change.

The Black Sea basin crust thickness is diminishing from 40-45 km within the surrounding land to 20-25 km within the basin central part. The East Black Sea basin crust thickness is about 25 km while the West Black Sea basin crust thickness is 20 km. Both in the west and in the east the Black Sea deep basin is characterized by the absence of the granitic layer. The "graniteless" crust zone is reduced in the east because of the heterogeneous tectonic elements involved in the basin formation process during the Cenozoic stage. These tectonic elements are characterized by a continental type thin crust. The basaltic layer thickness changes from 5-6 km within the West Black Sea basin to 12-18 km in the East basin. Its density is 2.97 g/cm$^3$ [51].

## B. *The Anomalous Magnetic Theory*

Until recently, the ideas about the age of the Black Sea basin have been based on land geological observations in the coastal areas, underwater observations, and on the data of seismic reflection and refraction studies and drilling. Formerly, the information led to a wide spreading of the age determinations: from the Jurassic to the Eocene. Recently, based upon the geological and geophysical data, the range of the estimated age has been considerably reduced, although this opinion is no commonly accepted. Therefore, to determine the age of the Western Black Sea basin using an analysis of the anomalous magnetic field is of interest [18].

The double-segmented character of the Black Sea manifested in the heat flow pattern lateral variations, in the anomalous magnetic T field pattern, and in the gravity isostatic anomalies field and in the Bouguer anomalies and presumably in the upper crust stress field according to the data on the earthquakes' mechanisms. A surplus mass over the isostatic compensation level is characteristic for the East Black Sea basin and a deficiency mass for the West basin. The studies revealed the low density substance layer in the basin's upper crust from 20 to 160 km depth. The layers beneath 250 km are characterized by more dense substance. At the same time the great positive anomalies of the observed field correspond to the both depocenters [51].

Interpretation of new data requires important revision regarding the timing of the Black Sea basin's opening. The following results were obtained: the West Black Sea basin appears to have opened in a short interval during the Campanian-Maestrichtian phase largely through rifting of a continental sliver from the Odessa shelf. This orthogonal rift type opening has preceeded the development of the Pontide magmatic arc [31]. The basin probably opened between 71.338 and 71.587 My B.P. The total duration of the opening was about 3 My B.P. (from 71.587 to 68.737 My B.P.) [44].

The Moesian Platform and the Scythian Platform, parts of the East European platform are characterized by distinct magnetic anomalies, which result from petrological differences in the crystalline basement, and by lithological differences of the detritic and carbonaceous platform cover.

Outside the deep sea basin the north - western Black Sea shelf [28] and the land part of the East European platform are marked by a series of contrast magnetic anomalies. One of them corresponds to volcanic Ilychevsk elevation, which makes it possible to interpret in such a manner some of the anomalies. Distal structures of the Ukrainian shield are also marked by the magnetic anomalies. This lineament seems to be most active in the Cretaceous time. The recent movements fixed the lineament as a steep flexure bending to the West Black Sea basin [50] together with a heat flow contrast anomaly. The Arkhangelsky-Andrusov lineament strike turns into the Thornquist line in the north-west and into the Zagross lineament in the south-east.

In contrast, the East Black Sea basin has formed through anticlockwise rotation of a large continental block during the Maastrichtian-Paleocene. This revision in the timing of opening of the West and East Black Sea basins has direct implications on the age of the sediments in these basins [31].

This result does not agree with the geological and geophysical data available. The geophysical field variations are reflecting the double-segmented character of the Black Sea basin, which was typical for the whole period of the basin's progress as a single structure that is from the Early Cenozoic. To solve this problem, new geological data and studies of the anomalous magnetic field are required [18].

# III. Sedimentation versus Erosion

## A. *Fresh Water Discharge*

The Black Sea basin has asymmetric form and covers 423,000 km$^2$ receiving river inputs from half Europe and part of Asia. The total fresh water discharged into the Black Sea is 353.3 $km^3$ per year and since it receives more fresh water than it loses from evaporation, the average salinity is low - 18‰.

The river discharges into this basin are built up in various nature and climatic conditions. There are about 500 rivers running to the Black Sea, differing from one another by the size of their catchment areas and their water mass fluctuation.

In the northwestern part of the Black Sea, 75-79% of the total volume of continental waters is delivered by the Don, Nipru, Bug, Nistru and Danube rivers. The total river discharge coming from the northwestern part of the Black Sea represents about 300 $km^3$ of water annually [14].

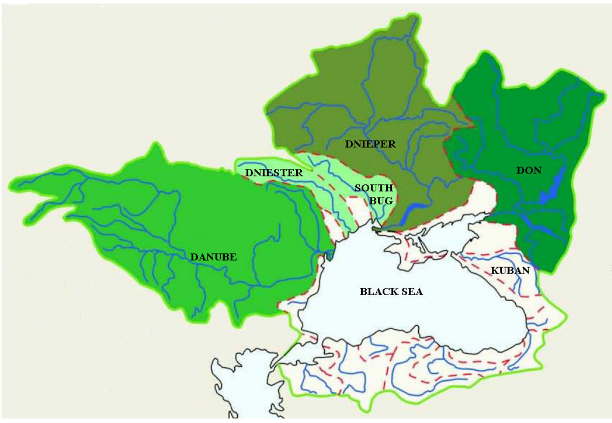


Fig.4 The rivers' basins of the Black Sea
*(from Black Sea GIS, 1997)*

Hydrological and hydrographic observations and measurements have been performed in the fluvial and littoral zone of Romania for more than 160 years [11]; [39]. In Romania, only temporary water streams discharge into the sea, except for the Danube, the largest river of the Black Sea basin, with a catchment area of 817,000 $km^2$, an expenditure of water in the river-mouth of 6,268 $m^3/sec$, and a specific runoff of 7.67 l/sec - $km^2$. The river discharge into the sea represents 198 $km^3$ of waters annually [3]; [7]; [10]; [25]; [27]; [44].

With this volume the Danube contributes with more than 70% of the total river discharge coming from the northwestern part of the Black Sea and about 56% of the total river discharge of the Black Sea.

The important volume of water delivered by the Danube to the Black Sea produces annual variations of the water level. Nearly in a centenary historical cycle, the Danube runoff periodically increased by 1.5-2.0 times, compared to the present time [35]. Its maximum values have been observed during periods of increased humidity in 1940-1941, 1955, 1967 and 1980. The northwestern rivers are characterized by a spring maximum (March-May) and a small peak in autumn. In spring, the Danube runoff increases by 1.5 times. The maximum values from spring to early summer (April-June) are typical for the largest rivers of the georgian watershed [15].

### *B. Sediment Discharge*

The rivers are the main sources of sediments. Their irregular supply from different catchment areas controls the nature of terrigenous sedimentation of the Black Sea [41]. The rivers discharge into the sea about 51.6 x $10^6$ $m^3$ of sediments that accumulate on coasts, deltas of large rivers and take part in the modern process of sedimentation of the Black Sea. Sediments originate in the land and their quality depends on the characteristics of the river basins and their transport capacity [14]. The land-derived terrigenous material is an important component of the recent sediments of the Black Sea basin.

The river sediment discharge from the watershed is rather irregular. The greatest discharge comes from the Northwestern region, drained by the largest rivers of the Black Sea basin: the Danube, the Dnieper and the Dniester. A relatively small part of the discharge is issued from small rivers of Crimea, Bulgaria and the northwestern Caucasus. The mountain watershed of Turkey and Georgia is in a middle position in terms of the amount of the river runoff [42]; [15]. The river sediment runoff has important annual fluctuations studied especially for the northwestern - Danube, Dnieper, Dniester, Bug - and northern rivers - Don, Kuban [35]; [32].

Fluxes of sedimentary material vary quantitatively, and also in the granulometric composition. In the mountain/plain rivers like Danube, the fraction of sandy-silty material increases considerably [42]. A total flux of the river sediments consists mainly of fine-dispersed suspended material, with lesser amounts of coarse-grained bed-load material.

The northwestern rivers supply more silty material in suspension compared to clayey fraction. Silt fractions exceed clay fractions in river-suspension of the Caucasian watershed in comparison with the Danube, the Dnieper and other rivers [46].

Sediments are divided into coastal and marine ones.

#### *1) Coastal (Beach-forming) Sediments*

The rivers transport weathered rocks from the elevated areas to lower ones. The final accumulation of detritus ends in seas and oceans. During this process, part of the alluvium accumulated in the coastal zone. The coastal zone acts as a filter for detritus discharging from the land to the sea, which delays the terrigenous material for further treatment or long preservation and supplies it to the sea [23]. In this process, the main role belongs to river-mouths, since the alluvial material is differentiated and sorted out in coastal (beach-forming) and marine (deep-water) materials. Thus, the river/sea mouth represents an important area for research.

The alluvium coming from the river enters the river-mouth as suspended load and bed load. Their mode of transfer depends on the grain-size of sediments. Usually, bottom sediments are coming form the coast, forming the beaches. Coarse suspended load may also end up as coastal deposits, especially in the case of mountain's rivers. Usually, beach-forming sediments are coarser than 0.25 mm on the deeper pebble shores, and coarser than 0.1 mm on sandy shores [8];

[17]; [16];[13].

Sea factors influence the river-mouth offshore sedimentation. Here, two zones of sedimentation can be distinguished: (i) a zone of wave action and (ii) a zone located below the wave base level [30]. A large amount of sediment is transported in form of bed load and coarse suspended load, forming submarine detritus fans and the submarine part of the delta. Usually, fresh river water transporting a large quantity of sediment does not mix with marine waters but spread into the 2-3 m thick surface layer, because the fresh river water is lighter than the marine water even if it contains sediments [21].

### 2) *Marine (Deep-water) Sediments*

In the marine area, after tearing off a river stream, the bottom bed loads move partially by force of inertia but, in general, under the wave influence. The suspended load falls out of the river stream as "sandy rain". Coarseness and intensity of this "rain" is very close to the river-mouth where it settles. Offshore, the river flow discharges into the sea forming clay fractions. Thus, river sediments accumulate in a coastal zone as continental or coastal sediments, but fine-grained sediment load moves over large areas and takes part in the process of marine sedimentation [41].

The Black Sea bottom relief is rather smooth; the maximum water depth is 2,212 m. Such a rather gentle bottom surface is reflecting the great regional subsidence intensity together with a slight movement differentiation. The recent sediments thickness is 860 m. The great sedimentation rate does not compensate the regular Black Sea bottom sinking. This peculiar feature of the basin sedimentation is exhibited in the sediment infilling character. The upper stage sediments consist of the terrigenous silt, clay layers, carbonates interbedded with the turbidites of the Meotian to Quartenary age. At the same time the turbidites do not contribute considerably to the Black Sea basin sediments infilling except for the peripheral parts neighbouring the great river systems, where such rivers as Danube, Don, Kuban, Bzyb, Kodori, Rioni, Kelkit are forming thick delta fans.

### 3) *Sediments in the Romanian Sector*

In the Romanian sector, the Danube water flow delivers an annual sediment discharge of about 31.680 x $10^6$ $m^3$ sediments into the Black Sea, 54,000,000 t, representing 84% of the total river sediment input. They consist of silt, clay and sand, with a grain size of up to 1.5 mm. The specific sediment discharge of this river is 38,8 $m^3/km^2$ [3].

In the relatively wet periods as 1940-1941, 1955, 1967 and 1980, the Danube River sediments played a major role in the Black Sea sediment-genesis, but between these intervals their importance dropped sharply [12]. During the last two decades the Danube solid runoff is within 40-50 x $10^6$ t/year [21]. The time period with large and small sediment run-off from the Danube is repeated every 22 years.

During the last four decades, the sediment run-off of the Danube decreased constantly in time, due to natural and man-made causes. The man-made causes led to a reduction in sediment supply, due to the construction of an important embankment and hydrotechnical works on the course of the Danube and its main tributaries. As a consequence of the dam building on the riverbeds, there has also been a decrease of the sediment discharge to the Black Sea from the Danube hydrographic basin [3].

The variation in the large volume of sediments delivered by the Danube to the Black Sea produced some annual oscillations in the distribution of the sediments in the littoral zone, with effects on the coastal morphological balance and sea water transparency. The decreasing trend of the sandy sediments input of the Danube into the Black Sea had negative effects on beaches, causing erosion. Following this process, the grain-size distribution and the mineral composition of the beaches were radically changed, due to the increase of the organogenic composition of sand and to the presence of broken marine shells and snails [3].

## IV. Erosion

The sediments discharging from rivers into the sea should be considered as a result of the process of erosion. Data on river sediments from different sources most often include only the suspended load. That is why observations on bed load have been conducted only in very few cases [41].

The western Black Sea coast, especially the Romanian coast has been affecting by high rates of erosion, especially in the last several decades; 22 $km^2$ of beaches have been lost in the last 40 years.

The erosion has affected especially the south Romanian coastline, where important beach losses were registered. Erosion processes are more intense during winter, when storms are more frequent and stronger. Storms have induced deficits of beaches sediments. They are less frequent during the summer and their intensity is weaker; however, the beaches do not restore completely and consequently the sedimentary budget remains negative. The natural driving forces -wind, waves and currents- combined with anthropogenic impact on the coast, result in increased beach erosion. In addition, temporary sea level rise due to wind set up and mainly in winter contributes to the erosion process [4].

The coasts are mainly sandy beaches directly exposed to wave action. The waves impacting the western coasts of the Black Sea and especially the open coasts of Romania are very energetic due to the long fetch in the southwest direction [20].

The important reduction of sediment fluxes from wind and waves generating near-shore currents associated with the coastal sediment transport, sea level rise and climatic changes are the significant causes of coastal erosion in the last few decades.

Hydrotechnical works on the Danube and its tributaries resulted in serious decrease of Danube sediment load, imposing negative consequences on the littoral sediment balance. In addition, hydrotechnical and harbour works intercept the longshore drift, leading to a decrease of the littoral sediment budget and acute erosion. Different types of protection works have been built in the southern part of the coast, most affected by erosion [5].

**Causes and effects**

- The rectification of Sulina branch of the Danube Delta and extension of jetties 8 km seaward determined a constant migration of sediment discharging points to areas of larger depths (>15 m). However, this sediment load has a big role in replenishing coastal sand bars from the southern part of the coast, from Mamaia to Vama Veche.
- The seaward extension of the jetties for navigation purposes created a sediment trap for the sediments discharged through Chilia branch, contributing to a secondary delta of Chilia branch north of Sulina.
- The Sahalin Island, a naturally formed littoral sand bar and Midia, Constanta South – Agigea, Mangalia harbour dikes disturbed the natural direction of the longshore drift, having negative effects both on the littoral sediment budget and the shoreline.
- Sea level rise and intensification of hydrodynamic factors contribute to the erosion phenomenon [6].

Significant erosion occurred in the northern part of the Romanian coastal zone (Danube Delta Biosphere Reserve) [37], where in certain places the sea water enters 200–400 m into the beaches. In the southern part, the erosion is 1- 3 m/year. Even with such a small rate of erosion, its impact is bigger due to the destructive risk on the civil buildings. On the other hand, the existing shore protection structures were seriously affected by destructive factors.

## V. Conclusions

The variation in the volume of sediments delivered by the Danube to the Black Sea has produced oscillations in their distribution in the littoral zone.

The decreasing sediment trend had negative effects on beaches, causing a predominant process of erosion that changed the grain-size distribution and the mineral composition of the beaches due to the increase of the organogenic composition of sand and to the presence of broken marine shells.

The erosion has affected especially the south Romanian beach, where important beach losses were registered. The conditions of the existing shore protection structures were seriously affected by destructive factors.

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