FOREWORD

The publication "GEO-ECO-MARINA" is launched by the Romanian Centre of Marine Geology and Geoecology as a necessity, with the aim of communicating some of the results generated by this three years old institute and other institutions to a wider audience. It is the first issue thought to be a Report Series.

Improving scientific understanding of natural and, why not, social processes relating to man's interactions with his near environment - the Danube Delta - Black Sea ecosystems, providing information useful to decision making on resource use, promoting the conservation of genetic diversity as an integral part of coastal zone management, enjoying the efforts of scientists, policy makers and local people in problem-solving ventures, mobilising resources for field activities, strengthening of regional cooperative frameworks. These are some of the generic problems expected to be reflected in the new publication of RCGGM.

The first issue comprises the papers presented by the Romanian scientists at the workshop "Global Changes upon the Deltas. Case studies: Rhone Delta and Danube Delta" held in the Danube Delta (October 2-10, 1995), with an international participation (France - IFREMER, Ukraine - Odessa State University, Germany - Hamburg University). The workshop was organised with the full support of Ministry of Research and Technology and in cooperation with the Black Sea University and IFREMER - France.

A publication, especially a scientific, professional one is a great responsibility. I am convinced that the commitment of the RCGGM is a challenge of all the scientists carrying out researches, making measurements and observations on geology, sedimentology, geochemistry, palaeontology, ecology and paleoecology etc., in the macro-geo-ecosystem Danube River - Danube Delta - Black Sea and, why not, a challenge of the scientists studying other river-ocean systems.

We are ready to give all our scientific results included in Scientific Reports, long time kept for limited circulation, to scientific community and to civil society for their wise use.

At the start of this publication, after only three years of existence of its publisher - RCGGM, my sincere wish is success to GEO-ECO-MARINA and long life.

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IMPACT OF GLOBAL CHANGES ON GEO-ENVIRONMENTAL AND COASTAL ZONE STATE OF THE BLACK SEA

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Abstract: The Black Sea had experienced very drastic environmental changes during its Quaternary and recent geologic evolution, which brought a suite of changes in the coastal area state and position, river water and sediment discharge, and mainly in fresh versus marine conditions of the seawater. The most spectacular changes of coastal zones occured in the north-western part of the Black Sea, the shallowest region with a very wide continental shelf and important river derived sediment inputs. Nowadays, the Black Sea coastal zone is affected by very strong degradation as a result of the geological and historical tendency, combined with the slow present-day sea level rising, the decreasing of the river sediment input and the increasing influence of anthropogenic littoral structures. Sectors with natural tendency of progradation become unstable, main resort beaches are eroded and the coastal ecosystem is stressed.

Key words: sea level changes, water input, sediment input, sediment drift, coast line migration.

1. General evolution trend

The Black Sea - a back-arc basin, a remnant of the Paleo-Tethys Ocean, with a very eventful geological history - had experienced very drastic environmental changes during its Quaternary and recent geologic evolution. It is generally accepted that in the Black Sea the depositional regime oscillated between marine and lacustrine as a result of temporary linkage to or cut-off from the Mediterranean Sea. Such linkages and cut-offs were controlled by sea level fluctuations associated with glaciations and deglaciations. It also appears that during the Chaudian (Cromerian, about 0.4 to 0.75 m.y ago) a rapid subsidence of the Black Sea occurred and chemical sedimentation was replaced by terrigenous deposition (Degens et al., 1986).

The relative sea level changes were acting as a major factor governing the geo-environmental state of the river-ocean systems, as well as of the coastal sea zones. The depositional and environmental model for these processes can be imagined as follows (Weimer, 1990; Wong et al., 1994): During the highstands, the deltaic region is far removed from the shelf edge and represents the depocenter for much of sediment input. The slope and basin are sediment-starved, characterised by prevalent hemipelagic deposition. As the sea level begins to fall, the delta (depocenter) progrades towards the shelf edge. Rapid deltaic sedimentation leads to overpressuring in the prodelta and slope sediments, resulting in sediment failure and canyon formation. The canyons become connected to the incised valleys through retrograde erosion, so that fluvial-derived sediments are transported directly into deeper waters. At sea level lowstands, deep sea fan systems become the main site of deposition. As sea level rises to a highstand, the deltaic system as depocenter and the littoral zone gradually retreats landward. The incised channels begin to be filled by finer material and hemipelagic sedimentation prevails again in the slope and deep basin area. Moreover the lowstands of the sea are periods of a very high relief energy and consequently of very active erosion on the continent and high sedimentation rate in the sea. The lowstands being linked to the glaciations correspond to the maximum mobilisation of water in the ice caps, so the highest erosion and sedimentation rate occurs at the beginning of ice melting.

In the specific case of the Black Sea, the lowstands are also phases of fresh or brackish water and of active vertical circulation with complete oxygenation of water masses and disappearance of euxinic conditions.

According to this scenario the drainage basin of the Black Sea, its system of tributaries and their water and sediment input, has changed many times and very drastically. For example, the River Danube, the main river of the Black Sea drainage system, during the lower Quaternary debouched into the Dacian Lake, filling it progressively with sediments. The lake was, probably, separated from the Black Sea basin by a low relief barrier (-50 ÷ -60 m under the present-day sea level) placed at the western boundary of the marine Danube Delta Plain (the location of the so named "initial spit Letea-Caraorman"). Only the drastic drops of the sea level related to glaciations led during these climatic events to a massive discharge of the lake waters towards the remnant Black Sea. The River Danube together with the Carpathian rivers have completed the filling up of the Dacian Lake probably by the end of Karangatian transgression (Eemian - about 100 - 65 ky ago). The Danube, as a definitely constituted river, reached the Black Sea in the upper Pleistocene - during probably the Post-Karangatian regression. At that time the water and sediment input of the Danube was directed beyond the shelf-break into the continental slope and deep-sea area, the depocenter being represented by the deep-sea fan complex. Consequently the strictly deltaic environment has set up after this phase and migrated landward concomitantly with the beach line at the rise of the sea level in the Surozhskyan interstadial. The last Würmian glaciation and drop of the sea level till about -100 m shifted again the depocenter offshore the shelf break into the Danube deep-sea fan complex area. This event occurred approximately 18 k.y ago, and since 15 k.y the sea level rose continuously but not homogeneously till the Holocene, about 8 k.y ago when the level almost reached the present day mark.

These major geoenvironmental changes brought a suite of changes in the coastal area state and position, river water and sediment discharge and mainly in fresh versus marine conditions of the seawater by the setting up the linkage with the Mediterranean Sea.

2. Changes in river water and sediment input

The highest water and sediment input of the river system occurred at the beginning of ice melting episodes, at the transition between glacials and interglacials. At the same time, the lowest base level (sea level) is obviously always determining the strongest erosional energy.

Within the Black Sea basin, the Würmian (Neoeuxinian) glaciation and low stand of the sea level is marked by very strong erosion of older Quaternary deposits in the river valleys and deltaic areas (Panin, 1974). The bed of the deltaic bodies, corresponding to this climate event consists everywhere of gravely, pebbly and coarse sandy deposits substantiating the high erosional energy of this period of time.

Since about 12 K.y (latest Neoeuxinian and Holocene) the deltaic conditions were set up, at least in the present day Danube Delta area (Panin et al., 1983), and the changes of water and sediment input have been controlled by limited climate and sea-level stand changes during Holocene time.

In the last three-four decades the anthropic activities had a significant impact on the river water and sediment discharges. If the Black Sea, on the whole, responds very slowly to changes in water balance because its volume (530,000 km^3) is incomparably bigger that the amount of annual river runoff (about 350 km^3/y.). On the contrary the regions close to river mouths as the NW shallowest part of the Black Sea, the Sea of Azov and the near Kerch Strait zone are highly susceptible to environmental changes in response to man-induced modifications of river runoff. The mentioned areas are characterised by the most high river water input. The changes referred to the thermohaline structure, circulatory patterns, gaseous regime, bioproductivity and biodiversity.

A short analyse of the Black Sea Northern tributaries runoff in the last decenies shows the following:

The River Danube. No significant changes of the Danube water discharge can be pointed out. In opposition a major change of sediment discharge of the river occurred after the damming of the valley at Iron Gate in 1970. At the Danube mouth zone the river sediment input dropped by 35-40 %.

The Ukrainian rivers. Very strong changes of Ukrainian rivers (Dnieper and Dniester) runoff began with the development of post-war water management projects established within the former Soviet Union. Starting in the early 1950s, numerous reservoirs were built up on the rivers to produce hydroelectric power: on the Dnieper the total storage capacity of these reservoirs lakes is 43,6 km^3, on the Dniester - 4.1 km^3. The hydroenergy programme was basically completed in the early 1970s. Approximately at the same time, the river water has been massively used for irrigation of the southern lands of Ukraine. The increasing of the evaporation, the growth of industrial, agricultural and municipal water consumption have brought a dramatical decrease of the river water discharge into the Black Sea.

The Sea of Azov tributaries. The same water crisis is reported for the rivers Don and Kuban. The impact of the reduction of annual river runoff on the Sea of Azov is stronger than the other Black Sea regions, due especially to its limited volume.

Table 1. Reduction of annual river water input into the Black Sea (north-western and Northern coasts) as a result of economic activities (after Tolmazin, 1985).

Rivers	Mean annual water discharge Q(km³/yr.)	Reduction of Annual Discharge for Average Flow Conditions					
		1971-1975		1981-1985		1991-2000	
		km³	% of Q at the mouth	km³	% of Q at the mouth	km³	% of Q at the mouth
I. North-Western Black Sea - Ukrainian Rivers							
Dnieper	53.5	13.0	24.0	28.0	52.0	38.0	71.0
Dniester	9.3	1.9	20.0	3.7	40.0	5.8	62.0
II. Sea of Azov tributaries							
Don	27.9	5.4	19.0	7.6	27.0	12.0	43.0
Kuban	13.4	4.3	39.0	5.4	49.0	7.2	65.0

The former Soviet Union planners had had the intention to cut the connection of the Dniester and Dnieper estuaries and the Black Sea. The construction of the dam separating the Dnieper estuary of the sea has been scheduled to start in 1985 and to be completed by 1993. At the same time they had planned the re-routing of about 16 - 23 km³ water/yr. from the Danube along the sea coast trough a canal, and the first part of it (Danube-Sasyk) was already under construction in 1985. A project for complete separation of the Sea of Azov and the Black Sea was also widely discussed in 70s and received strong financial and so-called scientific support.

The implementation of all these projects by the year 2000 should lead to the reduction of the river water input into the Black Sea by 50 - 70 km³ per year, that should have a very significant effect mostly in the productive 75 m upper layer across the sea. The political and economic crisis of the former Soviet Union had stopped the above mentioned projects (Tolmazin, 1985).

Shimkus and Trimonis (1974) suggested that almost all the sediment input from the rivers of the NW part of the Black Sea (Danube, Dniestr, Dnieper, Southern Bug) is led to the abyssal plain trough the canyons corresponding to these rivers (for example Viteaz canyon for the Danube River). The more recent studies has showed that the Danube-borne sediments are drifted southward all along the Romanian and Bulgarian continental shelf and dumped down to the abyssal plain into the near-Bosphorus region and only a very small part of the sediment input of the NW-rn rivers is directly discharged into the corresponding canyon system.

On the contrary, the Caucasian and Anatolian river sediment input is almost entirely discharged through multiple canyons into the deep part of the Black Sea. For the Caucasian coast, a large scale redistribution of sediments supplied to the coastal zone took place during the last five or six thousand years. Initially there existed two long-range sediment drifts along the north-west and south-east sandy-pebbly shores of Caucasus and especially of Georgia. Both were directed towards the mouth of river Rioni where the coast supported an intensive progradation. Almost the same progradation was evidenced at promontories near the mouths of other rivers of the Caucasus coast. These promontories have crossed the very narrow shelf and the sediment drift were trapped by the numerous canyons of the region and directed towards the deep Black Sea (Zenkovich, 1962; Kiknadze, 1995).

The Black Sea mass budget and hydrochemical structure depend on the exchange through the Bosphorus with the Mediterranean basin. Recent estimates of the average fluxes at the Black Sea end of Bosphorus are: approximately 300 km³/yr. (10,000 m³/s) for the inflow into the Black Sea and about 600 km³/yr. for the outflow from the Black Sea (Özsoy et al., 1993), the difference being of the same order as the total river water input into the Black Sea. The Bosphorus underflow introduces 0.6 million t sediments per year into the Black Sea, while the amount of sediments transported by the out-flow towards the Sea of Marmara is 13 million tons/y.

The mixing processes of the Mediterranean water within the Black Sea appear to be an important element contributing to the Black Sea interior balances and implicitly to its environmental state. The Mediterranean water first spreads onto the shelf and becomes diluted by entraining the overlying Cold Intermediate Water. Then, descending the continental slope, the anomalous water generates a pattern of intrusions and secondary circulation up to a depth of 500 m, aided by the double diffusive instability of the Black Sea interior. This, in turn, sets up a larger scale vertical circulation of the interior, contributing to the mixing across the halocline. Intrinsic properties of the Mediterranean and Intermediate Cold waters are thus transported in three dimensions, and occur simultaneously with the transport of shelf-derived materials into the interior. Instability in the Black Sea currents enhances the transport of materials from the basin periphery into the interior through fluctuating components of cross-shelf exchanges. A bottom convection layer of several hundred meters thickness is driven by geothermal heat fluxes. The slow but efficient convective motions homogenise the bottom properties across the basin. The deep vertical structure is dominated by the convective layer interface and double diffusive fluxes (Özsoy et al., 1995).

It is obvious that in the past the boundary mixing processes were not the same as to day. First of all, during the lowest stands of the sea no Mediterranean effluent penetrated the Black Sea, later on when the sea level rise began and the Mediterranean inflow was settled up, at the beginning the mixing processes were weaker, the Cold Intermediate Layer being at that time unexisting. Only when the sea level reached high enough stands for CIL generation, the mixing processes and by this geoenvironmental state of the Black Sea became closer to the present day ones.

3. Coastal zones changes

The most spectacular and evident changes of Black Sea coastal zones occurred in its NW part - the shallowest region of the sea with a very wide continental shelf and important river derived sediment inputs.

The best known is obviously the Danube Delta area. As mentioned above, the deltaic conditions were settled here during the Quaternary, when the Danube started flowing into the Black Sea basin. The important Quaternary changes of the sea level strongly influenced the Danube Delta and adjacent coast line evolution. The Würmian regressions, and mainly that of the Neoeuxinian stage of the Black Sea (the minimum was placed at about 18,000 - 15,000 y BC), when the sea level lowered to about -130 m, brought about the intense erosion of the delta deposits. Probably much of the old Quaternary deposits were thus removed. One can still recognise deposits assigned to the Karangatian and Surojskian stages (Würmian interstadial), located East of the Letea-Ceamurlia-Caraorman line, preserved behind some erosion relics of the predeltaic relief. The Danube Delta edifice (with a thickness of tens to 300-400 m of detrital deposits) was therefore formed mainly during the Upper Pleistocene (Karangatian, Surojskian, Neoeuxinian) and especially the Holocene. The present-day geomorphology of the Danube delta plain expresses the interaction of the river and the sea during the Holocene (Panin, 1974, Panin et al., 1983).

During the lowest Neoeuxinian Black Sea water level (at -130 ÷ -150 m) the shore line was situated at the continental shelf break, and can be evidenced by a number of paleo-beach ridges, sometimes associated with paleo-cliffs. At that time, the deltaic depocentre moved to the shelf edge, being located near the Viteaz canyon head (approximately 44° N, 33° 10'E) and in the deep-sea Danube fan system. A complex system of, more or less meandering, buried channels can be observed on the continental shelf at 50-75 m depth interval. In the following about 10,000 y the sea level has risen till nearly present day level and the mean shore line retreatement might be considered of about 10 m/y. This movement was not continue, with accelerations and stagnations, marked by a number of intermediate paleo-beach lines which can be pointed out at the depth of 70-80 m, 50-60 m, 30-35 m, 25-27 m.

As regards the tendency of coast line migration during the Holocene time within the so called Northern Unit of Romanian littoral, represented by the Danube Delta coast, we can point up the following main phases (Panin, 1983, 1989) (Fig.1):

1. During the period 11,700 - 8,000 y BP the coast line within the Northern unit was represented by the "Letea-Caraorman initial spit", located at about 25-30 Km Westward the present coast line;

2. At the southern end of this spit the first delta of the River Danube ("Sf. Gheorghe I Delta") was formed (9,000 - 7,200 y BP) by the first Danube distributary - the Paleo-Sf.Gheorghe branch. In about 2,000 y period of time the Delta Sf.Gheorghe I has prograded seaward by about 8 Km;

3. In the following phase, as the Paleo-Sf.Gheorghe distributary was partly filled up and its delta became partially eroded, the new Danube's distributary - Sulina, which was formed at that time, took over more and more water and sediment discharge and started forming its own delta - the "Sulina Delta". Its development was slow at the beginning, the shape of the delta being controlled entirely in this period by the waves and the littoral drift. The later increase of water and sediment discharge of the Sulina distributary determined a rapid progradation and the lobate shape of Sulina Delta, with three and then five distributaries. The development of "Sulina Delta" took place during the 7,200 - 2,000 y BP period. The maximum

progradation of this delta into the sea, when its front has surpassed the present-day shore line by 10-15 Km, and the "initial spit" shore by 30-35 Km, coincides with the Phanagorian Regression when the sea level was at -2 - -4 m mark. Starting with that phase the Danube sediment input has actively participated to the feeding of the beaches situated southward the mouths zone of Danube's distributaries.

4. At the same time (3,500 - 1,500 y BP) in the southern part of the delta area, a little secondary delta - the "Cosna-Sinoie Delta", was formed by a secondary distributary named Dunavăt. Its front line was surpassing the present shore line at least by 5 Km.

5. The next phase (2,000 y BP - present) coincides with the present-day sea level rising. By then the Sulina distributary was partly clogged and the Sulina Delta gradually

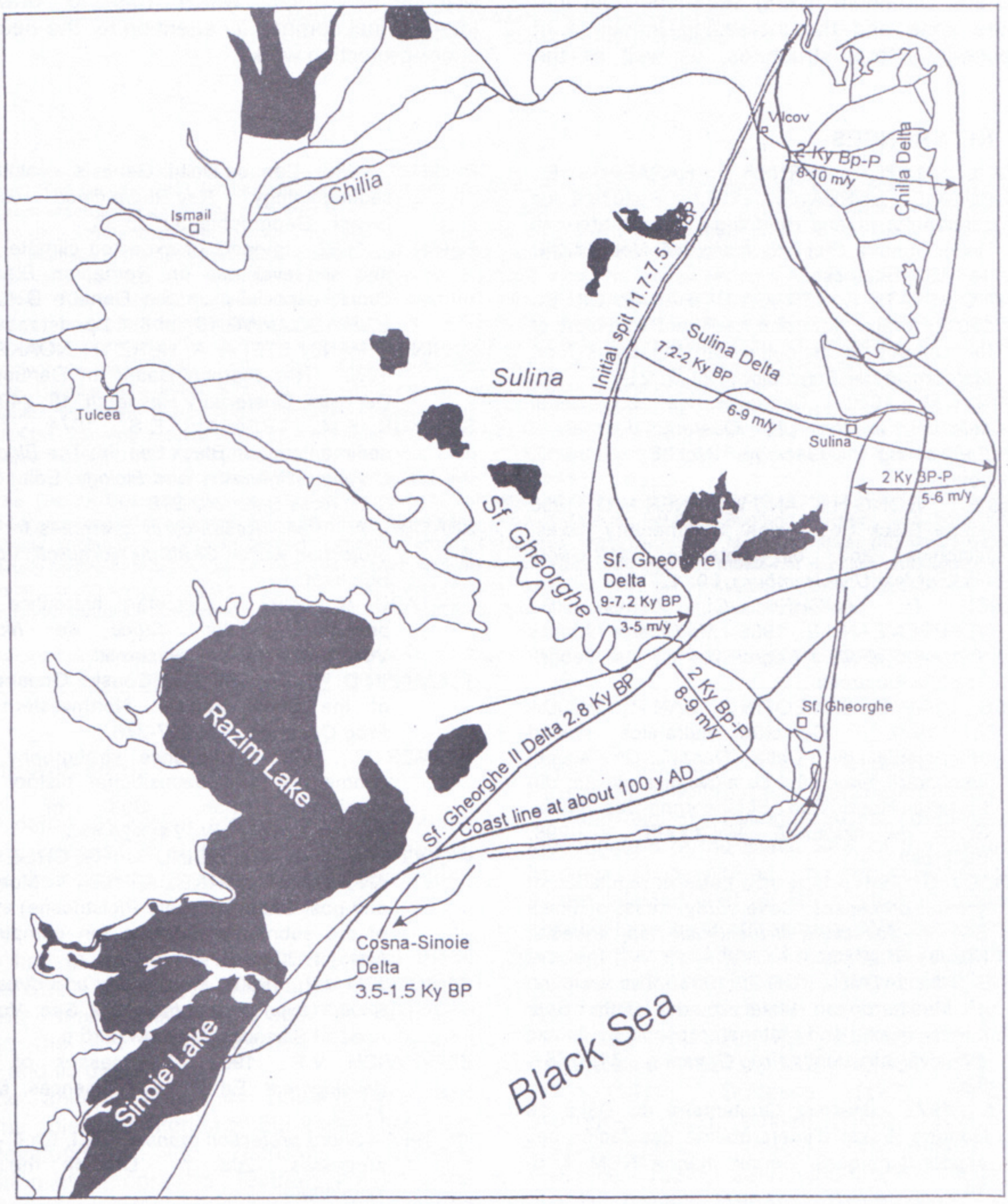

Fig.1 - Evolution of the Danube Delta in Holocene and correspondant changes in coast line position

eroded, while the Chilia distributary in the North and Sf.Gheorghe one, in the South, built up their own deltas: "Chilia Delta" and respectively "Sf.Gheorghe II Delta". During 2,000 y they have prograded by 16-18 Km, while Sulina Delta coast line regressed by about 10-12 Km.

The same process of erosion and coast retreatment (by few Km) has been recorded at the "Cosna-Sinoie Delta" within the Portita-Periboina sector of the littoral zone.

The above described geological and historical tendency, combined with the slow present-day sea level rising, the decreasing of the river (mainly the Danube and Ukrainian rivers) sediment input into the shore zone and the increasing influence of anthropogenic littoral structures, as well as the morphological characteristics of different sectors of the coast generate very strong degradation of Black Sea coastal zone. Sectors with natural tendency of progradation become unstable and regressive, main resort beaches are eroded loosing tourist and balneologic interest, the coastal ecosystem is hardly stressed. It is obvious that one of the main goals of any Environmental Rehabilitation Plan in the Black Sea region is to establish an efficient Integrated Coastal Zone Management Plan which has to draw the international community attention to the necessary shore-protection works.

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