GLOBAL CHANGES, SEA LEVEL RISING AND THE DANUBE DELTA: RISKS AND RESPONSES

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Abstract. The Danube Delta is one of the largest deltas in Europe (~5800 km^2) and represents the Upper Pleistocene-Holocene and present-day depocentre of the River Danube. The recent Delta development started at ~11,700 yr. BP and includes 5 main phases when different lobes had progradations (up to 10 m/a), sometimes followed by regressions (4-6 m/a). Consequently to the shortage of Danube-borne sediment supply, due mainly to the dams building, strong erosion processes affect the Danube Delta coast zone (shoreline recession up to 20 m/a), except very limited sections where the sedimentary budget is still in equilibrium. In response to the expected future sea level rise, the regression of beaches will obviously continue all along the Danube Delta coast (mean coast recession estimate to 3 to 5 m/a.). Despite of a not very critical value of the sea level rise, the impact on the shore zone will be quite strong due to combined effect of the level rising, wind set-up, shortage of beach sediment feeding and anthropic pressure on the coast area. The sea-level rise of more than 20-30 cm (as it is forecasted for 2020-2030) will significantly affect the Danube water and sediment discharge within the delta front. At the same time a rise by 20-30 cm will flood the lowest areas within the coastal zone and will enhance the flood risks on the entire delta territory.

Résumé. Le Delta du Danube est un des plus importants de l'Europe (~5.800 km^2) et représente le centre de dépôt des sédiments du Danube pendant le Pléistocène Supérieur, le Holocène et l'actuel. Le développement du delta actuel a commencé il y a ~11.700 ans et peut être sous-divisée en 5 phases pendant lesquelles les différents lobes deltaïques ont eu des progradations en moyenne jusqu'à 10m/an, parfois suivies de régressions de 4-6 m/an. Comme conséquence à la diminution de l'apport des sédiments du Danube, due principalement à la construction des barrages sur le fleuve, presque l'entière zone côtière du Delta est affectée par de fortes érosions (retrait de la côte jusqu'à 20 m/an) à l'exception de quelques secteurs limités ou l'équilibre sédimentaire est encore préservé. La montée prévue du niveau de la mer va déterminer la continuation du recul du trait de la côte sur tout le front du delta (estimé à une valeur moyenne de 3-5 m/an). L'effet cumulé de la montée du niveau de la mer, des surcotes dues aux tempêtes, de la diminution des apports sédimentaires et de la pression anthropique sera assez important. La montée du niveau de la mer de 20-30 cm vers 2020-2030 pourra influencer d'une manière significative les décharges sédimentaires du Danube dans la zone côtière, certaines zones basses du delta près de la côte seront submergés, ainsi que les risques des grandes inondations sur tout le territoire du delta seront augmentés.

Key words: Danube Delta, Black Sea, coastal zone, shoreline, erosion, sea level, global changes, sediment load, sedimantary budget, environmental risk.

1. INTRODUCTION

The Black Sea is the largest land-locked sea: total area 4.2x10^5 km^2, maximum depth 2.212 m, water volume 547.015 km^3, bellow the depth of 150-200 m the deep water is anoxic and contaminated with H_2S. The Black Sea is connected to the Mediterranean Sea only through a rather narrow and shallow Bosphorous-Dardanelles system of straits. The past changes of the Black Sea level, which have occurred in Quaternary, driven by the global glaciations and deglaciations, followed up to a certain limit the World Ocean level changes. When the general sea level was lower than the Bosphorous sill (32-34 m) the further variations of the Black Sea level were determined by specific regional conditions without being coupled to the ocean changes.

The Black Sea drainage basin covers more than 2 million km^2. The main river-sea geo-system of this basin is the River Danube - Black Sea one. The River Danube as one of the end-terms of this system, is the most important European waterways flowing 2,857 km across the continent from the Schwarzwald Massif in Germany down to the Black Sea. Its drainage basin extends on 817,000 km^2, more than 15 countries sharing this catchment area.

The second term of the system is the Danube Delta, situated in the north-western part of the Black Sea, between 44° 25' and 45° 30' N and between 28° 45' and 29° 46' E. The delta plain covers an area of about 5,800 km^2 of which the lower, marine delta plain represents ca. 1,800 km^2. The Danube Delta shoreline is about 240 km long, of which about 75 km represents the coastline of Kilia Delta and belongs to Ukraine and 165 km is on Romanian territory.

The other end-term of the system is the Black Sea, which was shortly presented above.

2. HISTORICAL TREND OF THE DANUBE DELTA COAST LINE MIGRATION

The deltaic conditions were established 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 its coastline evolution. The Würmian regressions, and especially that of the Neoeuxinian stage of the Black Sea (the minimum at about 18,000 yr. BC), when the sea level lowered to -130 ÷ -150 m, brought about the intense erosion of much of the older Quaternary delta deposits. One can still recognise some remnants of these older deposits (assigned to Karangatian and Surojskian), preserved behind some relics of the predeltaic relief. The present-day Danube Delta edifice (tens to 300-400 m thickness of detrital deposits) was therefore formed mainly during the Upper Pleistocene (Karangatian, Surojskian, Neoeuxinian) and especially during the Holocene (Panin *et al.*, 1983).

The development of the Danube Delta during the Holocene time is marked by the following main phases (Panin *et al.*, 1983; Panin, 1989, 1998) (Fig.1, 2):

1. "Letea-Caraorman initial spit" phase (11,700-7,500 yr.BP): the coastline was represented by a spit located at the entrance into the "Danube Gulf" at about 25-30 km West of the present delta shoreline;

2. The first delta of the River Danube - "St. George I Delta" was formed by the first Danube distributary - the Paleo-St. George branch in the 9,000-7,200 yr. BP period. In about 2,000 yr. the Delta St. George I has prograded seaward by about 8 km;

3. The following phase (7,200-2,000 yr. BP) is represented by the development of a new distributary - Sulina and its deltaic lobe - "Sulina Delta". The maximum progradation was of 30-35 km from the "initial spit", the delta-front advanced beyond the present-day shoreline by 10-15 km.

4. At the same time (3,500-1,500 yr. 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 prograded at least by 5 km offshore from the present shoreline.

5. The next phase (~2,800 yr. BP - present) is represented by the formation of two new deltaic lobes: "Kilia Delta" in the North, built up by a new Danube distributary - Kilia, and "St. George II Delta" in the South, corresponding to a reactivation of the St. George distributary. By then the Sulina distributary was partly clogged and the Sulina Delta gradually eroded. Thus, during the last ~2,800 yr. the new lobes have prograded by 16-18 Km, while Sulina Delta coast line regressed by about 10-12 km. The same process of erosion and coast regression (by few km) has been recorded at the "Cosna-Sinoie Delta" within the Portita-Periboina section of the littoral zone.

3. PRESENT-DAY STATE OF THE DANUBE DELTA COASTAL ZONE

3.1 Processes and dynamic factors controlling the delta coastline morphology and development

a. River Danube water and sediment input

The following table characterises the River Danube water and sediment discharges during 1840-1990 period at the entrance into the delta territory (Bondar *et al.*, 2000).

Table 1 Main characteristics of the River Danube water and sediment discharges

Characteristic values	Water Q	Sediment discharge R
Mean multiannual discharge	6,283 m^3/s (198.3 $km^3/yr.$)	1,737 kg/s (54.8 M t/yr.)
Mean annual maximum discharge and date	9,420 m^3/s in 1941	4,780 kg/s in 1871
Mean annual minimal discharge and date	3,160 m^3/s in 1863	224 kg/s in 1990
Maximum daily discharge and date	20,940 m^3/s in 07.1897	
Minimum daily discharge and date	1,350 m^3/s in 10.1921	

The sediment discharges presented in the Table 1 resulted from a mediation of values measured before and after Iron Gate I and II dams building. The average annual suspended sediment discharge before the dams building was 2,140 $Kg.s^{-1}$ (67,5 millions t/yr), out of which sandy alluvia ca. 10% (Almazov *et al.*, 1963; Stançik *et al.*, 1988).

After 1970, consequently to the building of Iron Gates I dam (Km.942,95 from the Black Sea) and, especially after the Iron Gates II (Ostrovul Mare) dam (Km.864) building in 1983, the sediment discharge decreased catastrophically (Fig. 3): at present, one can estimate that the Danube total average sediment discharge could not be larger than 35 - 40 million t/yr., out of which less than 4 million t/yr. is sandy material (Panin, 1996). This is the only amount of sandy sediments contributing yearly to the littoral zone sedimentary budget, which since 1970 became strongly uncompensated. It is also obvious that the present day coarse sediment load (bed load) of the Danube originates mainly in the sediments eroded from the river bottom.

b. Meteorological factors - wind system

The western and north-western areas of the Black Sea basin are zones of active atmospheric circulation, being situated at the interference of the routes of Atlantic and Polar, Mediterranean and Euro-Asian air masses. Thus, winds exceeding 2 m/s are recorded for 80-90% of a year, winds exceeding 6 m/s for 30-55% and those exceeding 11 m/s for 4-15%. Prevailing winds are from the northern sector (40-50%); the northern winds are also the strongest. The frequency and duration of storms from the northern sector are clearly predominant (more than 55%).

c. Sea level and subsidence

The Delta is situated in an area of high mobility of the Earth crust, repeatedly affected by strong subsidence

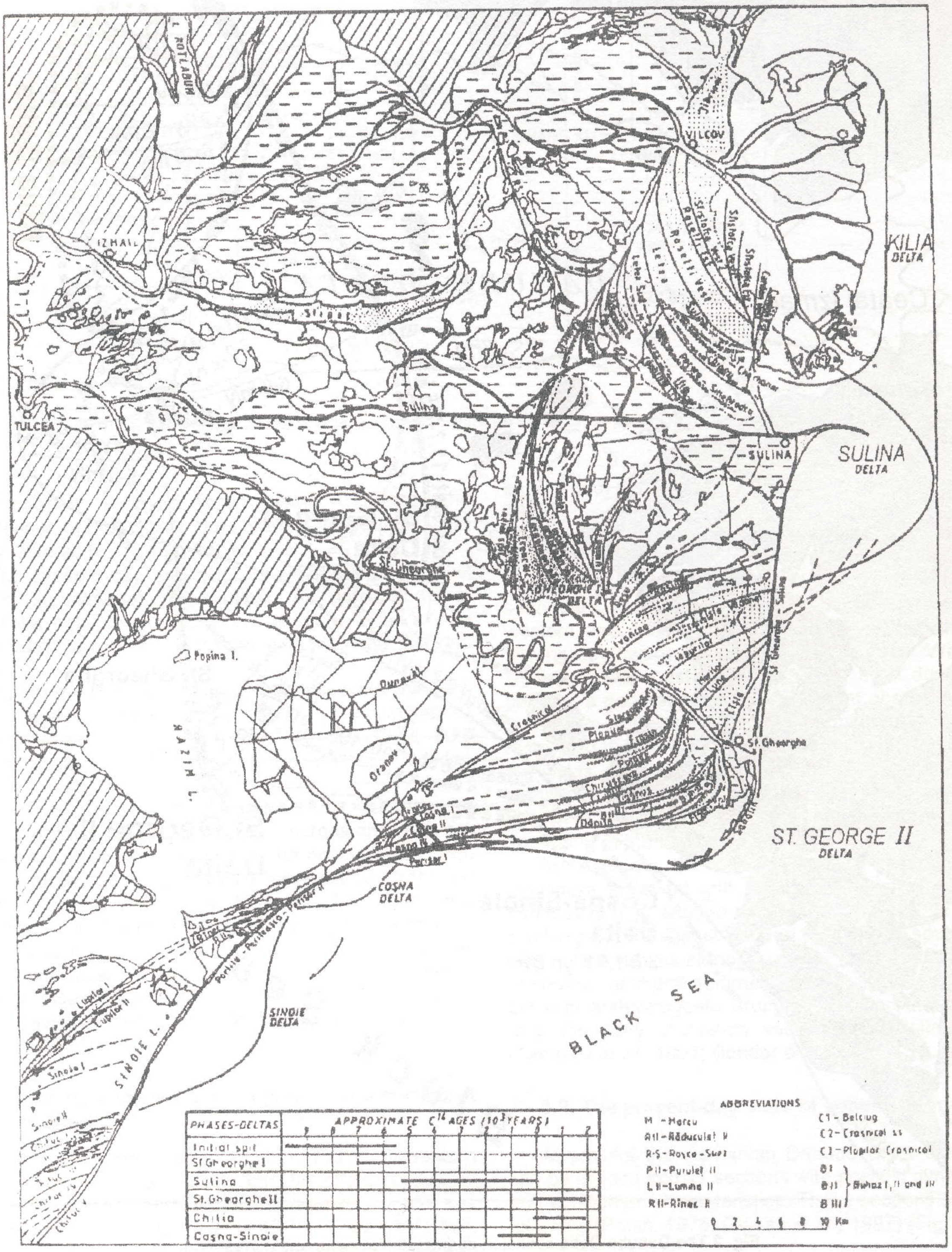

Fig. 1 The Danube Delta geomorphologic-sedimentologic structure. The map outlines the main sets of beach ridges and the phases of delta development during the Holocene.

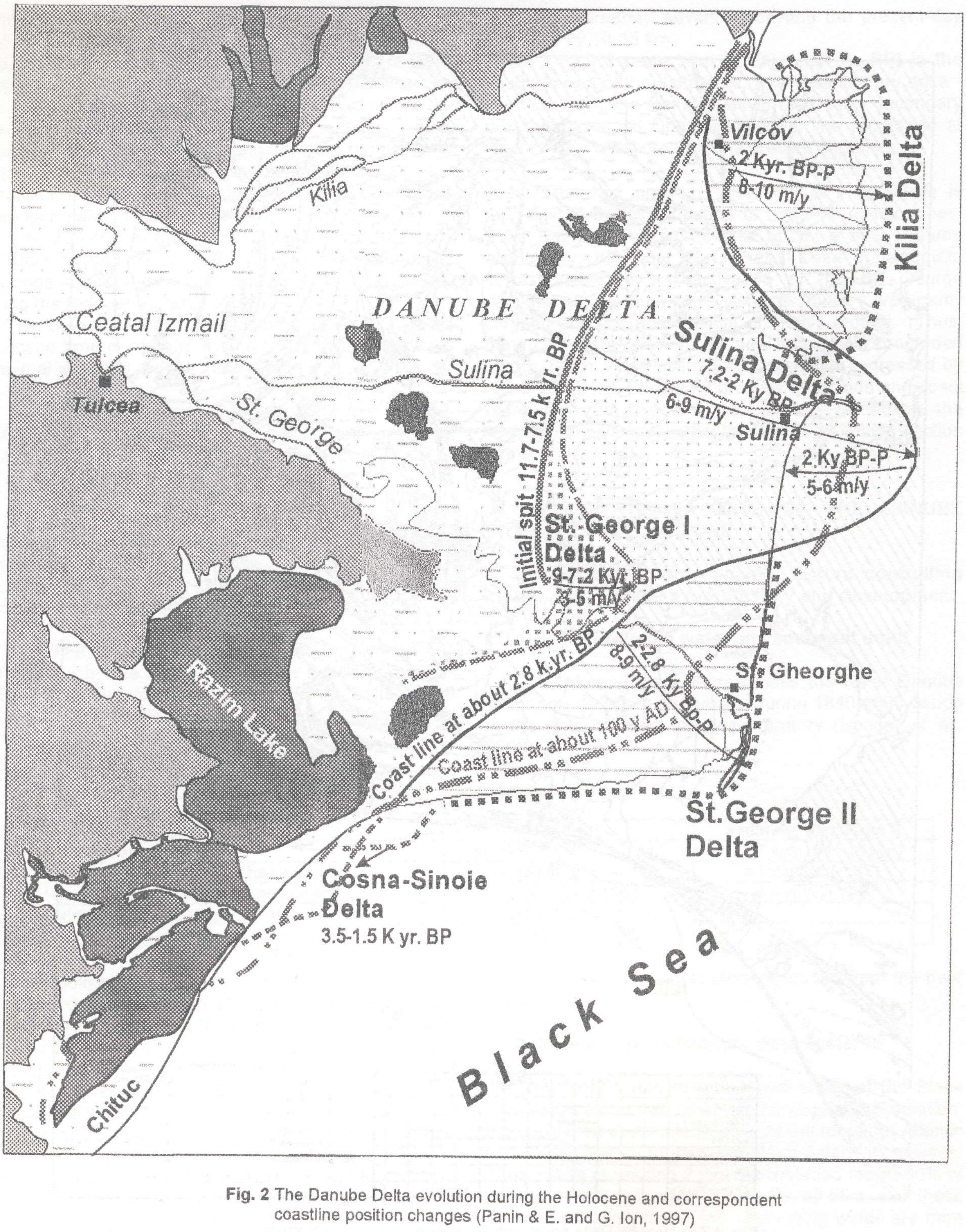

Fig. 2 The Danube Delta evolution during the Holocene and correspondent coastline position changes (Panin & E. and G. Ion, 1997)

and important sediment accumulation. At present the subsidence of the coastal zone nearby the Danube Delta is appreciated to 1.5-1.8 mm/yr.

The present-day variations of the Black Sea level depend on seasonal, multiannual or eustatic changes of sea water balance as well as on the deformation of free water surface under the influence of different external forces.

During the last century the maregraphic observations have shown the tendency of rising by 1.5-4 mm/year of the relative sea level (2.595 mm/yr. - Selariu, 1972; 3.73 mm/yr. at Sulina, 2,67 mm/yr. at Constantza - Bondar, 1989).

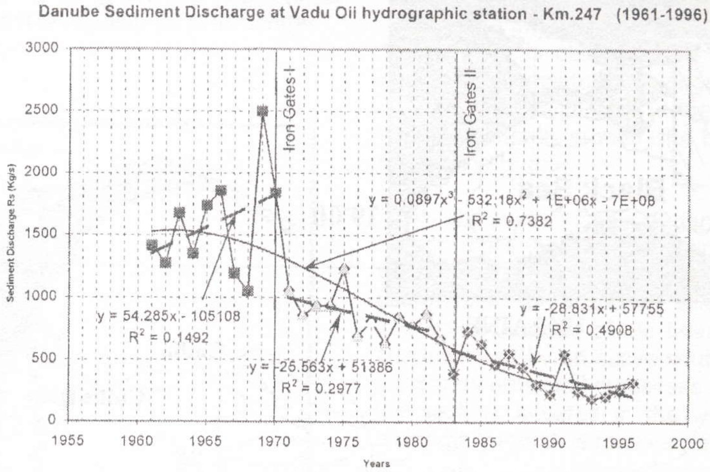

Fig. 3 The River Danube mean annual sediment discharge variation at Vadu Oii hydrographic station (Km 247).

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Amongst the short-term deformational oscillation of the sea water surface seiches, wind surges and tides are to be mentioned. The seiches in the north-western and western areas of the Black Sea have periods from few minutes to 13 hours and amplitudes from few centimetres to 2.0 m. The storm surges from northern, north-eastern, eastern and south-eastern directions induce sea level set-up of up to 1.2-1.5 m. The tide in the Black Sea has insignificant values (amplitudes of 7-11 cm, average period of 12.25 h) (Bondar *et al.*, 1973; Sorokin, 1982).

d. Waves, currents and longshore sediment drift system

The wave regime in the western and north-western parts of the Black Sea basin can be characterised as follows (Cristescu, Diaconu, 1980): tranquil (smooth) sea (waves below 0.2 m) represents 49.1% of the whole bulk of data concerning the waves, wind waves - 33% and swell, 17.9%. The most frequent wind waves are recorded along NE direction, corresponding to the prevailing wind direction, while from east are recorded almost 40% of swell waves. The mean and maximum heights of wind and swell waves (5.2 m at Constantza, 7.0 m at Sulina at the jetties end) are higher for the eastern direction for which the wind fetch is maximum. The energy of storm waves reaches important values: e.g. on 17-th of February 1979 there was a storm characterised by 12,242 kWh/m, while usually the energy is of approximately 2,000 kWh/m (Spătaru, 1984, 1992).

The atmospheric circulation and other hydrological and morphological factors determine in the Black Sea a general cyclonic water circulation with numerous secondary and smaller scale eddies. In the north-western and western areas of the sea, this current, is flowing southward towards the Bosphorous. Within the Danube Delta coastal area, there is, even during quiet periods, a generally southward current characterised by 5-50 cm/s velocity depending on the water supply of rivers and the Coriolis Force. In addition to this current, the winds, of different velocity and stability, generate a complex current system generally roughly corresponding to the wind direction, influencing the direction and spreading of the river jet-like wedge.

As regards the Danube Delta seashore, the longshore sediment drift is directed towards south. Its intensity is high enough to transport the coarse-grained discharge of the Danube many tens of km south of the distributary mouths along the shore. Local perturbations of southward littoral sediment movement are induced by different anthropogenic structures built on the shoreline (e.g. the eddy circulation south of the Sulina jetties) (Almazov *et al.*, 1963; Bondar *et al.*, 1973).

3.2. The present-day state of coastal degradation

At present the Romanian Danube Delta coast zone can be divided into 11 sections with specific dynamic and equilibrium characteristics. These sections are the following (Panin, 1976; Giosan *et al.*, 1997) (Fig. 4):

1. Baia de Nord or Baia Musura (Northern Bay or Musura Bay), situated north of Sulina distributary, 12 km long, with a very low, marshy coast. A tendency of clogging by the sediment input of Kilia distributary is reported.

2. Sulina section, South of Sulina distributary, about 8 km long, with a complex barrier beach, fed by the eddy-like current generated by Sulina jetties, as well as artificially, with the sand dredged from the port of Sulina.

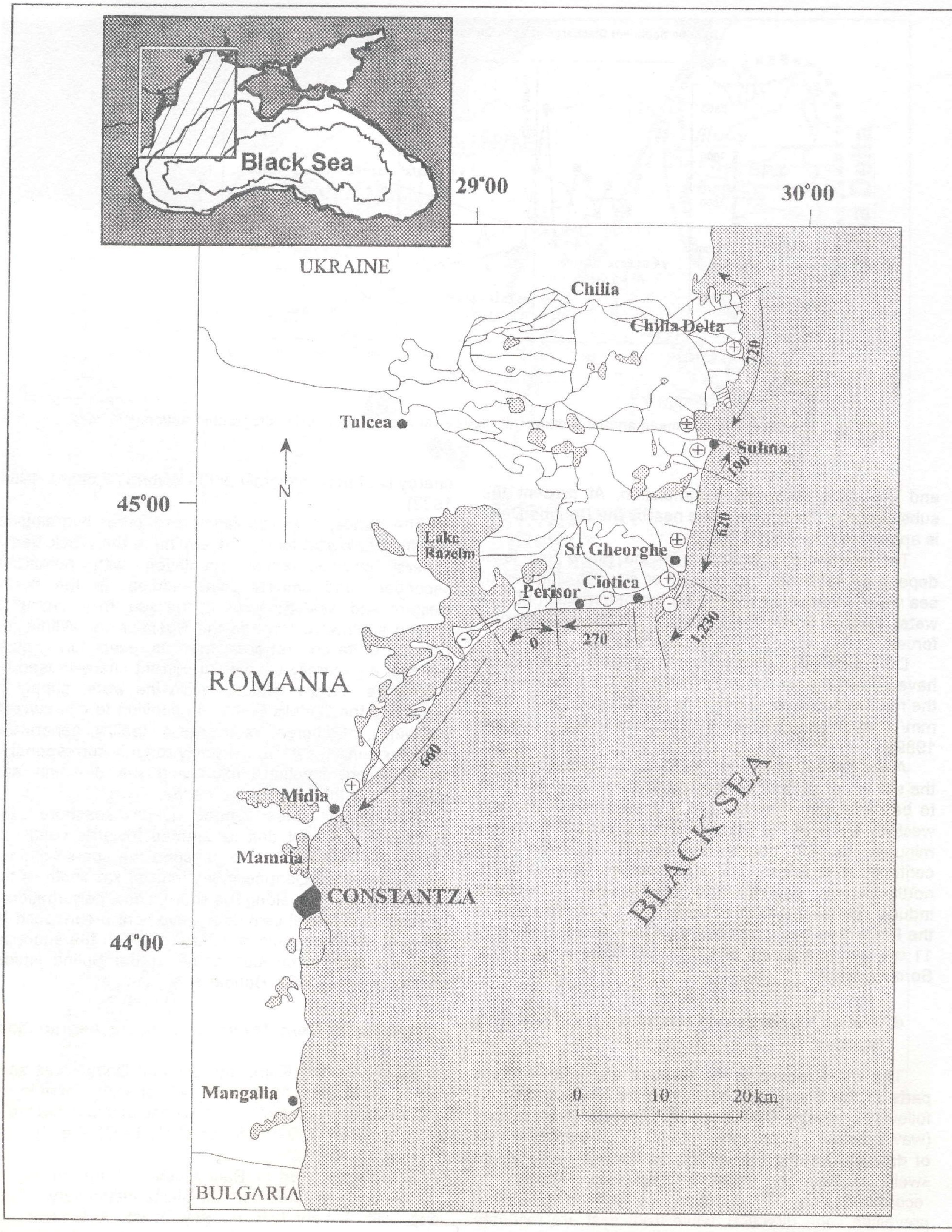

Fig. 4 Romanian Black Sea coast and the longshore sedment transport model for the Danube Delta coast. The sections described in the text are shown on the figure (numbers 1 to 11). Sediment drift (arrows) and transport rates in thousands of cubic meters per year (figures by the arrows). Circled + and - represent advancing and retreating sections respectively (after Giosan *et al.*, 1997).

This sector is slowly prograding near the jetties (in its northern part) and is almost in equilibrium in its central and southern parts (Fig.5).

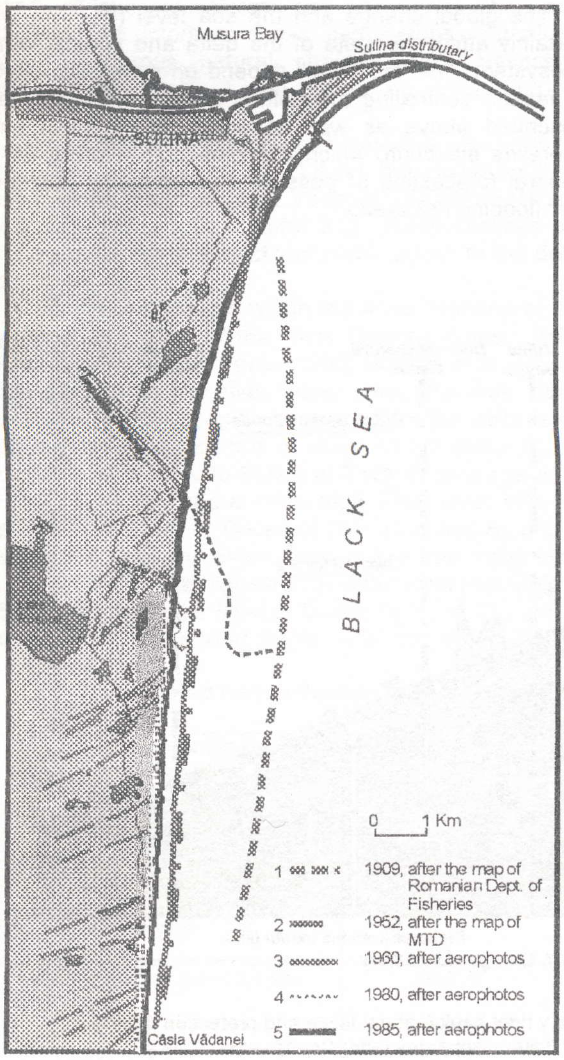

Fig. 5 The evolution of the coastline of the Danube Delta Front in the Sulina -St.George section during the last century

The Sulina jetties, in accordance with the initial project of Charles Hartley from the European Danube Commission (Hartley, 1862; Rosetti et Rey, 1931), set up in 1856, were intended to facilitate the navigation and to protect the mouth of the navigable canal of the Sulina arm from the Kilia-born sediments, drifted southward by the littoral current along the shore. The jetties went on building since 1858, reaching in 1980 a length of about 8 km. These jetties are breaking the southward longshore drift of sediments brought into the littoral zone by the Kilia distributary. Additionally they are taking off from the sediment littoral budget the sediment input of the Sulina arm by carrying it too far and too deep from the shoreline. The jetties are creating a large eddy-like littoral circulation cell, which strongly influences the distribution of the sediments all along the coast south of jetties.

3. Gârla Imputita - Câsla Vădanei section, more than 15 km long, is characterised by negative sedimentary budget and unsaturated longshore current (under the Sulina jetties influence). In the last 25 years, the coast was permanently eroded, the beach regression being of 5 - 30 m/yr (Fig.5).

4. The section Câsla Vădanei-St. George distributary mouth, more than 13 Km long, represents the present beach line of an ancient littoral accumulative body (Sărăturile), composed by the juxtaposition of a very impressive number of old beach-ridges. The section is characterised by an active southward sediment drift and temporary erosional processes. Only the southern end of the section, situated in the vicinity of the St. George distributary mouth is relatively stable.

5. Sakhalin Island section, a lateral arcuated bar, lying South of St. George distributary mouth, is fed principally by the St. George sediment input. The first reference about the Sakhalin Island is given by Spratt's maps and European Commission of the Danube documents after the exceptional 1897 flood. The island is continuously lengthening, nowadays being of about 17 km long. At the same time the island is migrating onshore by overwashing: in certain years the onshore movement was up to 70 m (Fig. 6).

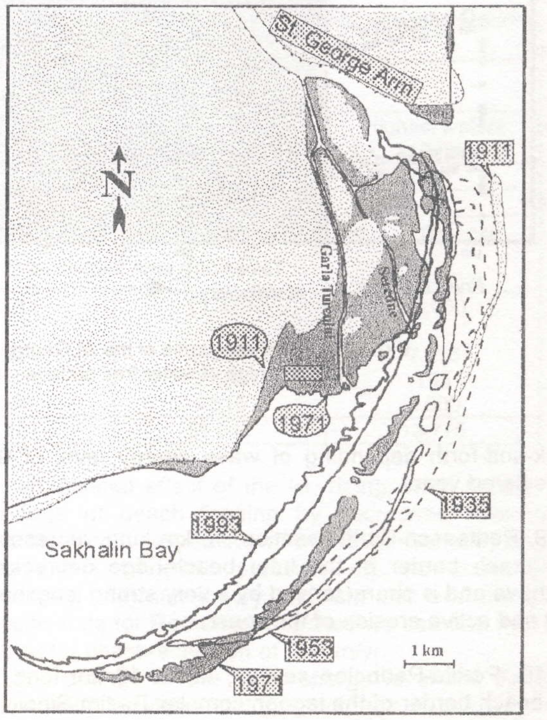

Fig. 6 Evolution of the modern St.George Delta and Sakhalin barrier island (from Giosan *et al.*, 1997).

6. The secondary St. George delta section, being shadowed by the Sakhalin Island, is the beneficiary of very special, energetically quiet conditions. The distributaries of this delta are: the main arm is St.

George (Kedrilles), the secondary arm, named Câinelui, divided into Seredne and Turcului distributaries. The St. George secondary delta front is prograding and is characterised by very fine-grained sediments.

7. Ciotic-Perisor section, about 20 km long, is subject of very strong erosion (10-20 m/yr.) and a very negative littoral budget of sediments. The coastline regressed since 1950 more than 500 m and, thus, lakes as Zătonul Mare became bay opened towards the sea, after quite entire destruction of a narrow barrier beach.

8. Perisor-Periteasca section corresponds to the littoral accumulative body Perisor. The coast line of this section is almost stable, suffering 5-10 m movements back-and-forth depending of wave energy level of the considered year.

9. Periteasca-Portita section, 15 km long, represents the beach barrier of the inter beach-ridge depression Leahova and is characterised by a very strong longshore drift and active erosion of the coast.

10. Portita-Periboina section, about 18 km long, is the beach barrier of the lagoon complex Razim-Sinoie. It is subject of a strong erosion and intensive southward longshore sediment drift. The section is protected by a setback line of embankments limiting losses of beach sand by overwashing.

11. Chituc section, about 20 km long, is a littoral accumulative body built up with the material eroded from the Cosna-Sinoie Delta. The coastline of this sector is temporarily eroded and is characterised by strong longshore drift of beach sediments.

4. IMPACTS OF CLIMATE CHANGE AND SEA LEVEL RISE ON THE ROMANIAN DANUBE DELTA SHORELINE

The global change and the sea level (SL) rise will certainly affect the state of the delta and coastal zone ecosystem. The impact will depend on synergetic effect of factors controlling the deltaic and littoral processes described above as well as on the delta plain and shoreline elevation, which can give us the basis for a general forecasting of possible environmental changes and flooding risk areas.

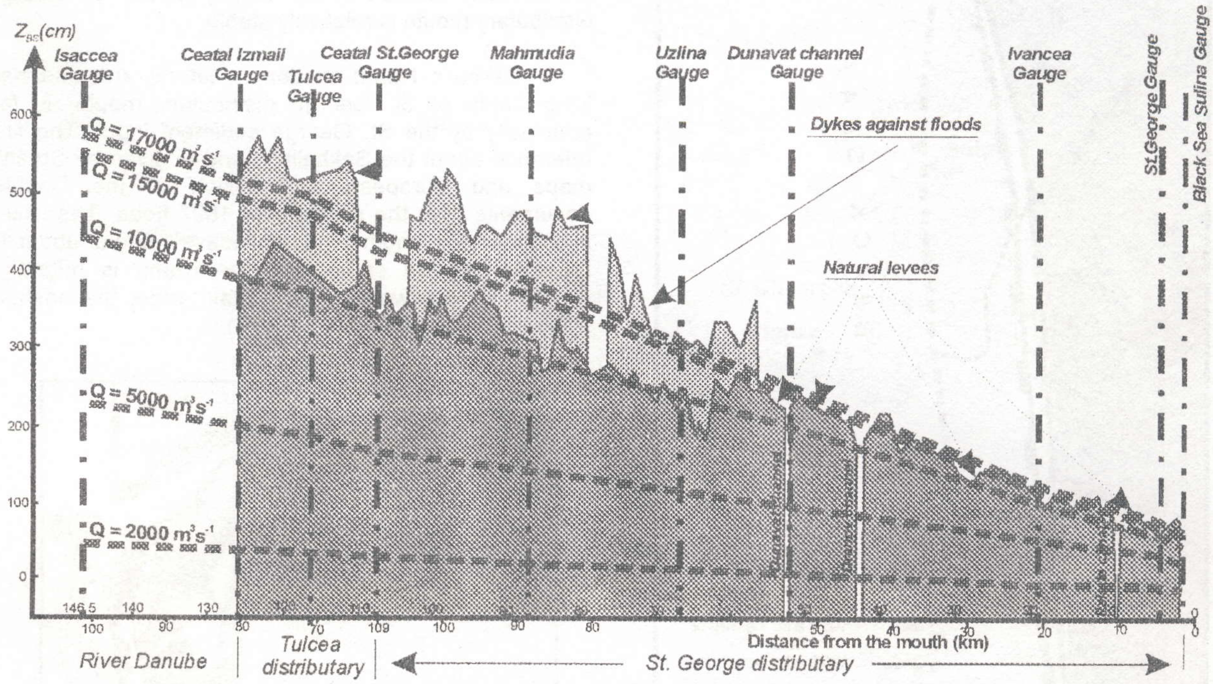

Fig. 7 Longitudinal profile of the St.George distributary right bank (natural levee and protection dykes) and the high of water free surface at different water discharges (after Bondar *et al.*, 2000).

4.1. Danube Delta Plain and sea shore zone hypsometry

The marine delta plain is a very low area with marshes, lakes and numerous old beach ridges, which in certain zones generate, by juxtaposition, large accumulative littoral bodies (the main of them are Letea, Caraorman and Sărăturile) (Fig.1). The interdistributary and inter beach-ridge depressions are lying only a few cm above (and sometimes even below) the SL, while the beach ridges have altitudes of few tens of cm to 1.7 m above the sea level. The only more elevated zones of the marine delta plain are the above mentioned accumulative bodies, with mean heights of about 1.0 - 1.5 m, and in certain places with dunes reaching altitudes up to 12 m.

In the fluvial delta plain one notes as more elevated morphological elements the fluvial natural levees and some old lacustrian spits (e.g. Stipoc). For example, the natural levees heights are starting near the river mouth at +20-30 cm above SL, and finish at +450 cm above SL at the delta apex (Ceatal-Izmail) (Lepsi, 1942, Bondar *et al.*, 2000) (Fig.7). The interdistributary depressions (as Fortuna-Papadia, Matita-Merhei, Uzlina-Gorgova, Dranov, Rosu-Lumina etc.) are characterised by an infinity of lakes of different size and depth. The water inflow/outflow into/from these depressions is realised trough numerous natural channels and crevasses, artificial canals and, at high waters, by overflowing the natural levees.

The present-day sandy beach barrier is also very low (the upper berms at +0.7 - +1.5 m), the lowest sections being: Gârla Imputita-Câsla Vădanei, Ciotic-Perisor and Portita-Periboina (see chapter 3.2). These sections are at the same time, the most vulnerable zones of the delta coastline.

The free water table within the delta depends of the hydrological regime of the River Danube (Lepsi, 1942; Almazov *et al.*, 1963; Panin, 1992; Bondar *et al.*, 2000). At the mean lowest river water level, the free water surface is slightly deeping seaward from the delta head (Ceatal Izmail), where it is at about 44 cm above SL, to Tulcea at 39 cm and to Sulina at 0 cm: its average slope is of 0.54 cm/km. At the mean high water level, with the height of the water at Tulcea of 293 cm above SL and at Sulina of 49 cm, the mean slope of the free water table is 3.3 cm/km. At the highest river water level (recorded in 1897), with the water level at Ceatal Izmail of 531 cm, at Tulcea of 477 cm and at Sulina of 81 cm above SL, the mean slope of the free water surface within the delta territory has a value of 5.35 cm/km (Fig. 8).

For an easier appreciation of the river water free table within the delta territory one define the so named "hydro-degree", representing one tenth of the highest water level at a given point along the river course. Consequently, the hydro-degree has different values for different zones of the delta and along the river as follows (Lepsi, 1942): Sulina - 8.1 cm, Vilcov - 10 cm, Tulcea - 47,7 cm, Isaccea - 54,2 cm, Galati - 64,4 cm, Brăila - 69.3 cm. The table 2 points out the non-flooded area at different levels of the River Danube water.

4.3. Impacts on rainfall and water flow and resources

In accordance with the generally accepted models the most important changes in the climate would be the northward shift of climate zones, the lengthening of summer at the expense of other seasons, the changes of winter cyclonic patterns etc.

The models show that the increase of the mean temperature by 1.5°C in these conditions will determine a decline with at least 10% of the river flow and this fact combined with a decrease of water energy by the rising of the base level will substantially lower the fresh water input into the sea.

Table 2 Non-flooded areas within the Danube Delta at different levels of the river water (after Lepsi, 1942 with modifications)

Geomorphologic Categories	**Non flooded area (ha)**			
	Lowest waters 3 hydro-degrees	Low waters 4 hd	Ordinary waters 5-6 hd	Highest waters 10 hd
Natural fluvial levees	19,757	15,343	9,850	-
Lacustrine spits	3,005	2,607	2,210	30
Present day barrier beach	2,400	2,390	2,380	1,800
Geomorphologic Categories	Non flooded area (ha)			
Littoral accumulative bodies, of which:	26,215	23,811	21,410	10,000
- Letea (max.+12.6 m)	12,710	12,185	11,660	7,915
- Caraorman (max.+6.5m)	5,540	4,565	3,590	165
- Saraturile	5,465	4,990	4,515	2,000
TOTAL	72,542	62,131	51,045	13,775

Lesser and more erratic precipitation will reduce the groundwater recharge and will disbalance the fresh versus marine water equilibrium. Despite an increased need for irrigation water, the average storage in the reservoirs will fall as a consequence of decreased river flow and participation and increased evapo-transpiration. Reduction of rainfall during the hot summer period might cause deficiency in soil moisture, thus degrading soil structure and fertility and finally affecting the agricultural production.

4.2. Impacts on the Danube Delta territory and coastal zone.

In response to the forecasted for 2020-2030 SL rise with 20-30 cm, the regression of beaches will, obviously, continue all along the north-western and western Black Sea coast. Despite a not critical value of SL rise, the impact on the shore zone will be strong enough because of cummulated effect of the SL rising, wind set-up, the shortage of beach feeding by decreased river-borne sediment input (especially of the River Danube) and, of course the anthropic pressure on the coast area. According to Bruun theory and formulas and using the specific data for Romanian beaches we can find average values for coast recession of 3-5 m/yr.

The change of the base energy level will diminish significantly the water and the sediment discharge of the Danube River. A very rough model of the SL rise impact on the Danube water and sediment discharges within the delta territory shows (Panin, 1992) that a base-level rise by 20-30 cm can be significant (inducing reductions larger than 10%) only for free water table slopes less than 1.1 cm/km (at a river water level of two hydro-degrees). The perturbations produced by the base-level rising could be shortly presented as follows:

- a rise of 20 cm of SL will produce a decrease of water discharge by 10% at a free water table (FWT)

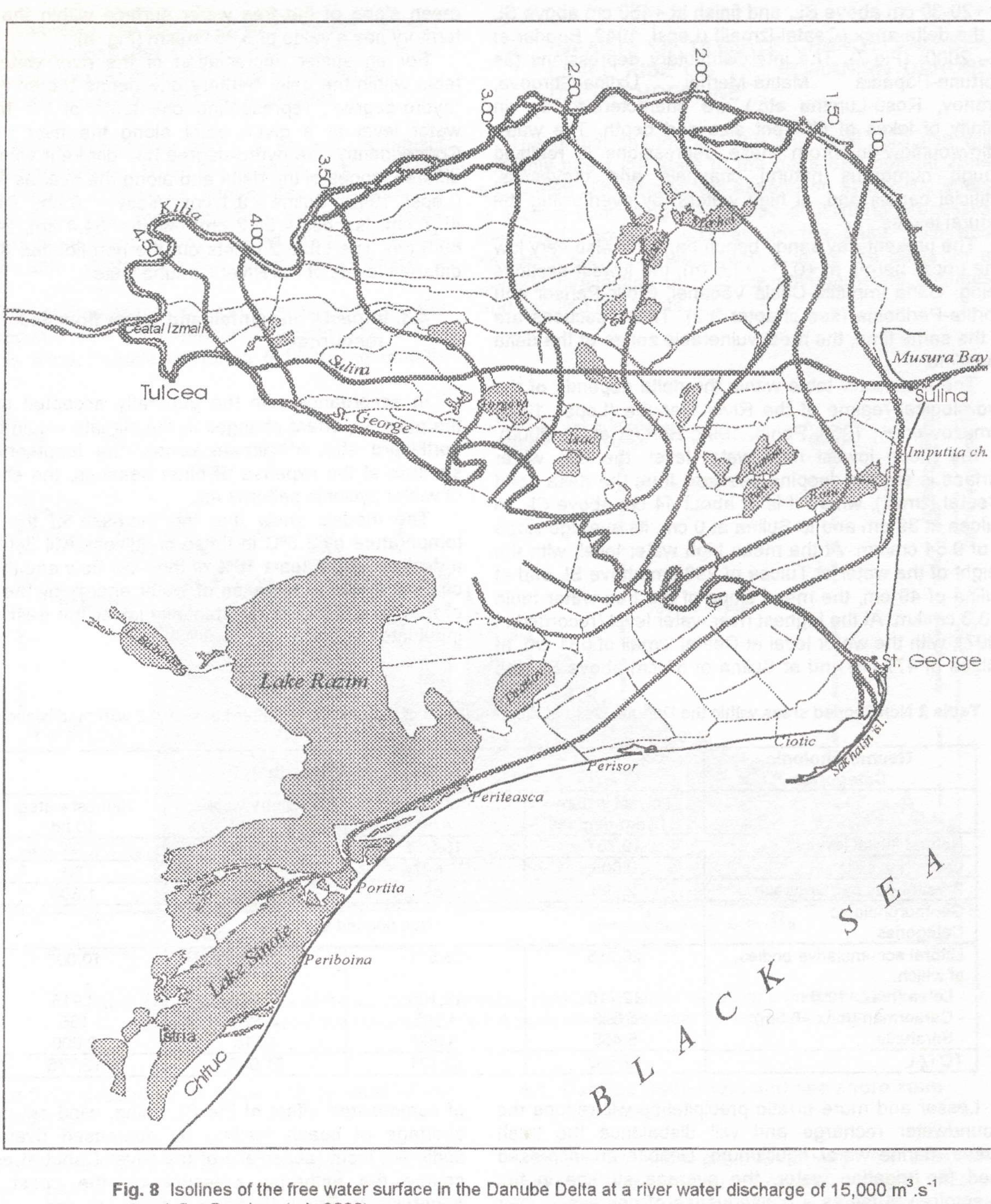

Fig. 8 Isolines of the free water surface in the Danube Delta at a river water discharge of 15,000 $m^3.s^{-1}$ (after Bondar *et al.*, 2000).

slope of 1.143 cm/km and by 26% at a FWT slope of 0.54 cm/km (at the lowest water level), the current velocity will decrease by 12% and respectively 28,6 % and, correspondingly its sediment transport capacity will decline;

- a rise by 30 cm of SL will produce a decrease of the water discharge by 16% for a FWT slope of 1.143 cm/km and by 47% for that of 0.57 cm/km. The mean current velocity will decrease by 19% and respectively 50%.

The reduced fresh water input would influence the general salinity of the Black Sea especially when the general SL will rise continuously. That involve a greater supply of saline Mediterranean water by the bottom Bosphorous current and a decrease of the thickness of the less saline superficial layer of the Black Sea.

At the Danube distributaries mouth zone the penetration of the salt wedge deeper upstream into their course will create a significant disturbance in the processes of transfer of bed-load to the mouth bar and further to the littoral zone. The diminished sediment input would induce a greater deficit in the sedimentary budget of the littoral zone.

As regards the deltaic shore, a rise of SL by 20-30 cm corresponds to an equivalent river water rise with of at least 3-4 hydro-degrees. This means that a very extended area of the delta nearby the shore zone would be flooded and also greater flood risks on the entire delta territory will occur (Panin, 1992).

The deltaic coast will be reshaped by marine processes, but in the more vulnerable sections as Gârla Imputita-Câsla Vădanei, Ciotic-Perisor and Portita-Periboina conditions will be gathered to transform the corresponding intradeltaic depression or lagoon areas into bays. Such risk is greater in the Gârla Imputita - Câsla Vădanei section which corresponds to the Rosu-Lumina interdistributary depression and Ciotic-Perisor section and lesser in the Portita-Periboina zone (corresponding to the lagoon complex Razim-Sinoie) where the beach barrier is at present protected by a setback line of embankments limiting losses of beach material by overwashing.

REFERENCES

ALMAZOV A.A., BONDAR C., DIACONU C., GHEDERIM VETURIA, MIHAILOV A.N., MITA P., NICHIFOROV I.D., RAI I.A., RODIONOV N.A., STĂNESCU S., STĂNESCU V., VAGHIN N.F., 1963, Zona de vărsare a Dunării. Morfografie hidrologică, 396 p., Ed. Tehnică, Bucureşti.

BONDAR C., STATE I., ROVENTA V., 1973, Marea Neagră în zona litoralului românesc. Monografie hidrologică. IMH, 516 p., Bucuresti.

BONDAR C., 1989, Trends in the evolution of the mean Black Sea level. Meteorology and Hydrology, **19**, 2, 23-28, Bucuresti.

BONDAR C., 1993, Secular evolution of some components of the hydrological Danube regime and of the mean level of the Black Sea. Proc. World Coast Conf., 891-893.

BONDAR C., BUTĂ CARMEN, HARABAGIU ELENA, 1994, Variation and trend of the water, sediment and salt runoff for the Danube River at the inlet in our country, during the period 1840-1992. XVII-th Conf.of the Danube Countries on Hydrological Bases of Water Management, Budapest, 5-9 Sept.,1994, 671-676.

BONDAR C., N. PANIN, G. NICCOLINI, 2000, The Danube Delta Hydrologic DataBase and Modelling. In Final Report EC: "Fluxes of greenhouse gases in the north-western region of the Black Sea coastal zone: Influence of the Danube River System", 35 p., Romania-Italy.

CRISTESCU T.M., DIACONU V., 1980, Energy aspects of the wind profile structure over the wave field. Cercetări Marine, **13**, 17-25, Constanta.

GIOSAN L., BOKUNIEWICZ H., PANIN N., POSTOLACHE I., 1997, Longshore Sediment Transport Pattern along Romanian Danube Delta Coast. Geo-EcoMarina, **2**, 11-24, Bucharest.

HARTLEY CH.A., 1862, Description of the Danube and of the works, recently executed at Sulina Mouth. Proc.Inst.of Civil Engineering, London.

LEPSI I., 1942, Materiale pentru studiul Deltei Dunării. I, Bul. Muz. Regional Bassarabia, **10**, 94-325, Chisinău.

PANIN N., 1976, Some aspects of fluvial and marine processes in the Danube Delta. An. Inst. Geol. Geophys, **50**, 149-165, Bucuresti.

PANIN N., 1989, Danube Delta. Genesis, evolution and sedimentology. Rev. Roum. Géol. Géophys. Géogr., Ser.Géographie, **33**, 25-36, Bucuresti.

PANIN N., 1992, Impacts of expected climate changes and sea-level rise on Romanian Black Sea shore, especially on the Danube Delta area. In: Implications of Climate Change in the Black Sea Region , Editor: Macram Gerges, UNEP (Oceans and Coastal Areas Programme Activity Centre) WG.,**19**/ contribution 8, 1-11, Istanbul.

PANIN N., 1996, Danube Delta. Genesis, evolution, geological setting and sedimentology. Geo-Eco-Marina, **1**, 7-23, Bucharest.

PANIN N., 1998, Danube Delta: Geology, Sedimentology, Evolution. Ass. Sédimentologistes Français, **65**, Fontaibleau.

PANIN N., PANIN STEFANA, HERZ N., NOAKES J.E., 1983, Radiocarbon dating of Danube Delta deposits. Quaternary Research, **19**, 249-255, Washington.

ROSSETTI C., REY F., (eds), 1931, La Commission Européenne du Danube et son oeuvre de 1856 a 1931. Imprimerie Nationale. Paris. 499 p.

SELARIU O., 1972, Asupra oscilaţiilor de nivel ale Mării Negre la Constanţa. Stud. Cercet. Geogr. asupra Dobrogei, Soc. St.Geogr., Fil. Constanţa

SOROKIN I., 1982, The Black Sea. Ed. Nauka Acad. Sc. USSR: 216 p., Moskva.

SPĂTARU A., 1984, Research Programme for Coastal Protection Works. Hydraulics Research, **XXX**, 159-214, Bucuresti.

SPĂTARU A., 1992, Cercetări hidraulice pentru protecţia plajelor. Studii de hidraulică, **XXXIII**, 299-314, Bucureşti.

STANCIK A., JOVANOVIC S. *et al.*, 1988, Hydrology of the river Danube. Perioda Publ. House: 271 p., Bratislava.