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# MORPHOLOGICAL CHANGES OF THE ROMANIAN BLACK SEA ACCUMULATION COAST*

**Petre Gâştescu, Basarab Driga**
Senior researchers, Institute of Geography, str. D. Racoviţă 12, RO-70307 Bucureşti 20

**Les changements morphologiques de la côte d'accumulation de la Mer Noire dans le secteur roumain.** Le secteur roumain de la Mer Noire s'étend sur 245 km. Sous l'aspect génétique et morphologique, ce secteur peut être divisé, en grand, en deux sections, respectivement d'accumulation au nord (166 km) et d'abrasion au sud (79 km). Dans cet article, on analyse la section nordique qui correspond au front deltaïque du Danube. Bien que cette section se soit formée á la suite du processus d'accumulation qui a fermé les deux golfes – du Danube et d'Halmyris -, pourtant, à présent ont lieu des processus d'accumulation qui déterminent un avancement dans l'espace marin, ainsi qu'une abrasion avec la retraite du rivage, au détriment de la terre ferme continentale. Pour identifier les sections d'avancement et de retraite du rivage, avec les taux annuels correspondants, on a utilisé les cartes topographiques existantes pour une période de plus de 150 ans et les mesurages faits aux bornes hydrographiques pour une période de 30 ans. Les résultats obtenus ont été mis en corrélation avec les conditions spécifiques paléogéographiques et les facteurs géographiques actuels de la parti nord-ouest de la Mer Noire.

**Keywords***:* coastal zone, Black Sea, abrasion, accumulation

## Morphological and paleogeographical features

The Black Sea coastal zone in Romania stretches over 245 km, between the secondary delta of Chilia in the North (frontierline with the Ukraine) and Vama Veche locality in the South (border point with Bulgaria) (Fig. 1).

Insofar as genesis and morphology are concerned, the coastline can be divided into two sections: a lower section, of accumulation, in the North, extending along 166 km, formed of strandwalls and beaches, and a higher section in the South, long of 79 km, formed mainly of cliffs. The demarcation point between the two is Cape Midia, North of Constanța city-port (Gâştescu, 1984; Gâştescu, Driga, 1986).


**Fig. 1 Black Sea – site of our investigation**

The coastal zone in Romania consists of a continental shelf delimited by the 130 m isobath off the coast, at a distance varying between 127 km in front of Tuzla Lighthouse and 195 km in the area of the Razim-Sinoie lake complex, Gura Portiței point (Fig. 2). The area extending between the coastline and the 130 m isobath covers some 2,300 sq km, i.e. 5.5 % of the Black Sea surface.

The major morpho-hydrogeographic elements of this continental shelf are the following: the present beach, a 1–2 km – wide offshore coastal zone, the inner continental shelf directly affected by processes of water dynamic, the transitional continental shelf and the outer continental shelf bounded by the 130 m isobath (Şelariu, 1971).

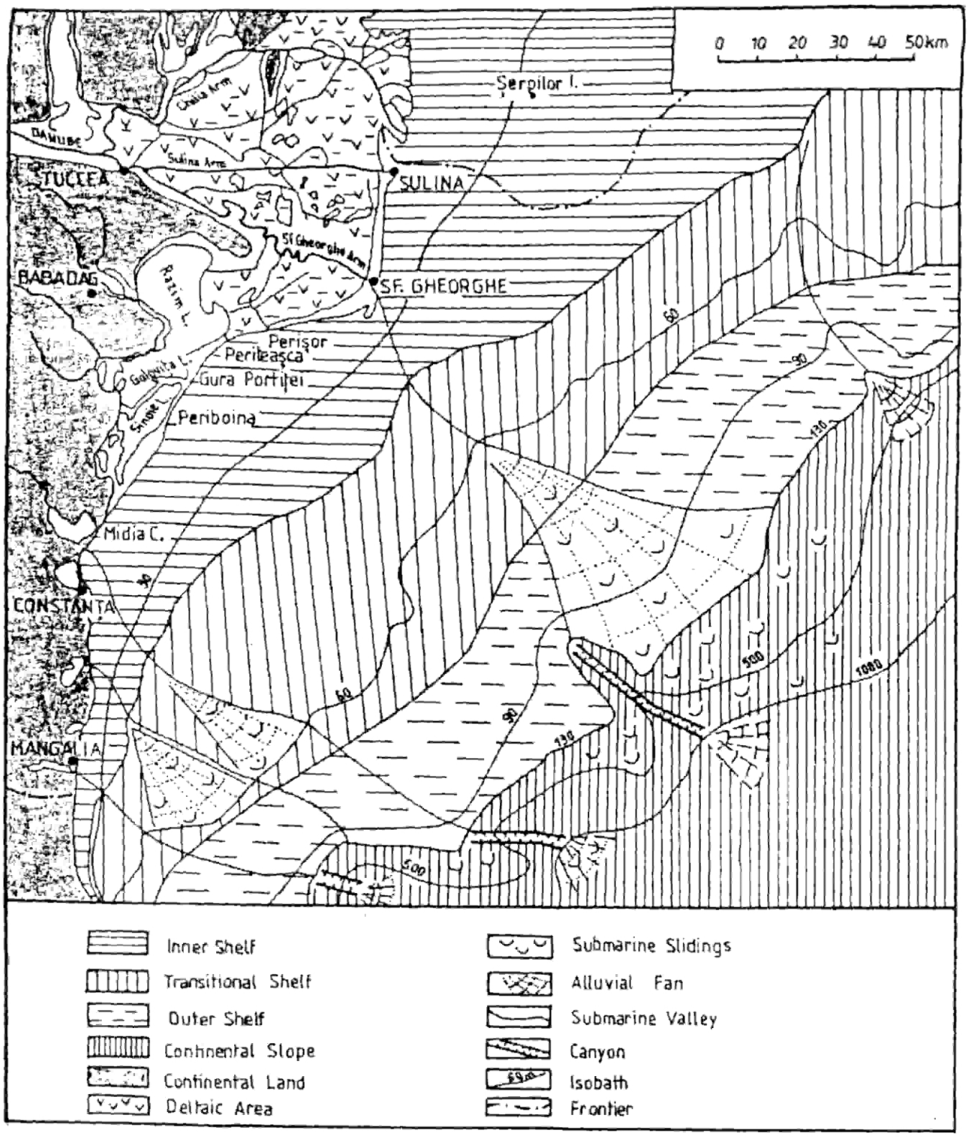
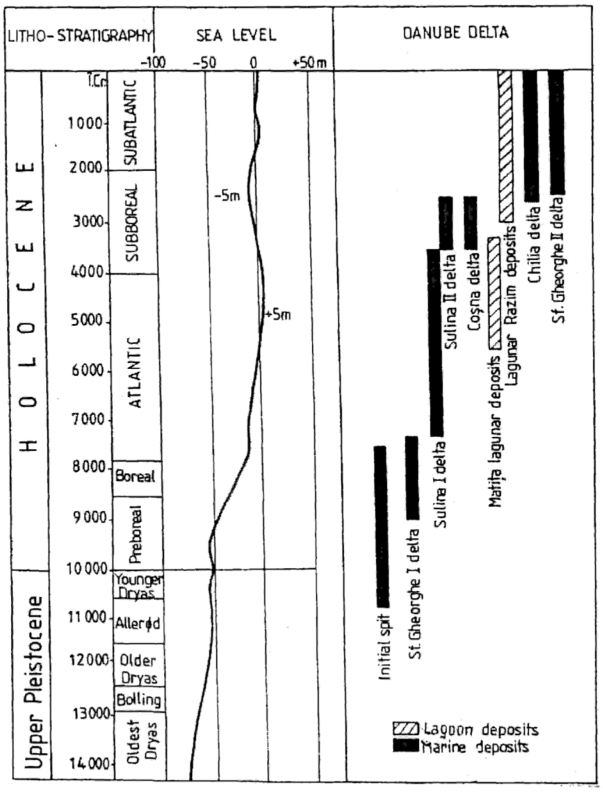



Fig. 2 *The morphological continental shelf of the Black Sea in Romania*

The coast and the continental shelf of the Romanian sectors are part and parcel of the overall evolution of the Black Sea Basin. A major regression took place in the Pleistocene (Neoxine stage), when the sea level was by 80 m lower than it is today (Fig. 3). At that time, the valleys of Dobrogea's rivers and of the paleo-Danube itself lay at depths of 40 – 80 m down the emerged shelf (Brătescu, 1942, Banu, 1969, Mihăilescu and Rogojină, 1984).

The beach barriers of the analysed coastal sector have separated two sea gulfs, one in the North, representing the Danube mouth, and the other in the South, the ancient Halmyris (Fig. 4). During the Middle Holocene, more precisely in the Late Atlantic, known as the new Black Sea stage, the Flandrian transgression which took place in this zone, led to a sea level rise of 3 – 5 m compared to the present level. The two gulfs and the mouths of limnic valleys were covered by the sea water. The processes characteristic of this phase are accumulation and the formation and consolidation of the initial Jibrieni-Letea-Caraorman spit (Fig. 4), begun during the Boreal (ca. 12,000-10,000 years BP), when the Danube Delta was emerging.

This initial spit, supplied by Ukrainian stream sediments in the North and carried South by littoral drift, was attached leaned on a few erosion outliers, remnants of the North Bugeac Plain. Behind this initial spit, almost the whole quantity of Danube-carried alluvia was deposited inside the gulf, forming the fluviatile delta in the Blocked Danube Delta phase (Panin, 1997). Next, a succession of secondary deltas came into being through the action of the three main Danube arms (Sfântu Gheorghe, Sulina and Chilia) that dissuted the initial spit; the oldest one was Sfântu Gheorghe I, followed by Sulina, Sfântu Gheorghe II, Chilia and Coşna within the perimeter of the Razim-Sinoie lacustrine complex. These secondary deltas, Sulina and Sfântu Gheorghe II, in particular, underwent intense erosion (Panin, 1983) and disappeared (Fig. 5). Nowadays, the main source of sediment supply to the beach barriers is the Danube.



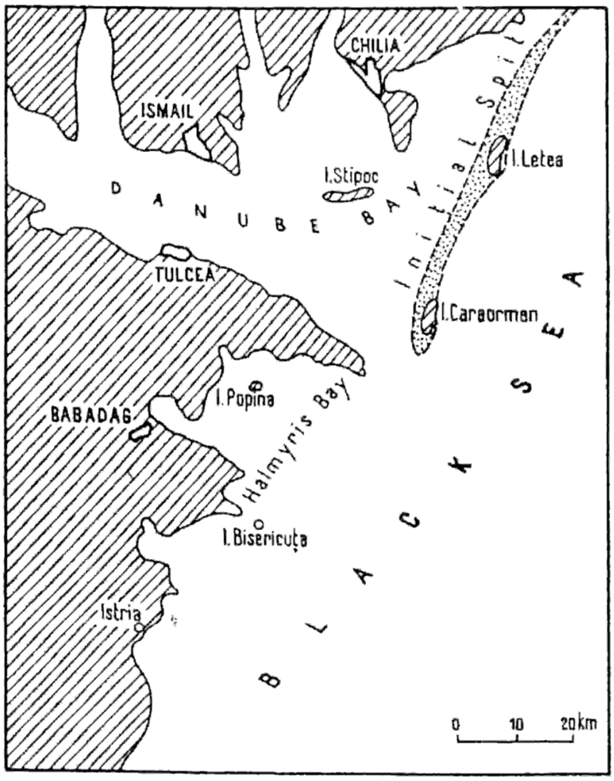




**Fig. 3 Sea level and stratigraphic scheme of the Danube Delta deposits (combined from Degens and Ross, 1972, Panin and al, 1983)**

**Fig. 4 Two isolated marine gulfs**

An analysis of measurement data (1921-1990) shows that sediment volume variations depend both on the water regime and on human interventions in the drainage basin of the Danube and in its channel bed. So, the construction of dams on the Danube's tributaries and on the river itself has led to a sharp drop in the volume of alluvia, from 67 mill.tons/year during the 1921-1960 period to a more 30-35 mill. tons/year over the past 30 years. The alluvia deficit associated with some engineering works (the Sulina and Cape Midia dams), and the slow uplift of the sea level, are factors favouring an accelerating abrasion.

The composition of Danube – carried sediments consists of quartz sands (70 % silica and 3 % heavy minerals). The alluvia pushed from the North of the Danube mouths by the littoral drifts are reacher in silica (90 %); while southwards, in the area of the beach barriers facing the Razim-Sinoie lacustrine complex they contain rather shell detritus.

## Climatic features

The masses of air travelling over the coast have a SW direction (over 60 %). There is a lower frequency, but higher magnitude of the winds, especially when blowing from the North-East. During seasonal transition, the climate on the coast is considerably influenced by the atmospheric pressure developed over the Mediterranean Sea. Hence, atmospheric fronts associated with cyclone series tend to converge towards the Black Sea Basin.

During summer, the high-pressure field situated on the Azore anticyclone ridge, brings about mild SW winds, fine, persistently sunny weather and a breeze effect. During winter, the cyclonic field that travels over the Black Sea entails storms, strong North-East winds, high waves and severe coastal erosion.

Storms associated with winds speeds > 14 m/sec. are frequently recorded during the winter. Violent storms occur when high-atmospheric pressure and thermal gradients overlap. Then, North-East winds reach even $13^o$ Bf (January-February 1962). A study of wind frequencies ( > $6^o$ Bf) reveals a decrease from the North to the South (38 % at Sulina, 17.5 % in Constanţa and under 13 % at Mangalia).

Air temperatures depend not only on the circulation of air masses and the radiative factors, but also on the specific properties of the sea waters on the land/water interface (coastal zone). The mean annual air temperature is slightly above $11^o$ C ($11.1^o$ C in the North and $11.3^o$ C in the South of the coast), averaging $12^o$ C in the adjacent sea area. Extreme values range from $37.5^o$ C (in August) to – $25.6^o$ C (in February) at Sulina (in the North) and from $36.0^o$ C to – $22.2^o$ C at Mangalia (in the South) during the same months.

Similar differences between the northern and the southern sections register also the multiannual thermal averages.

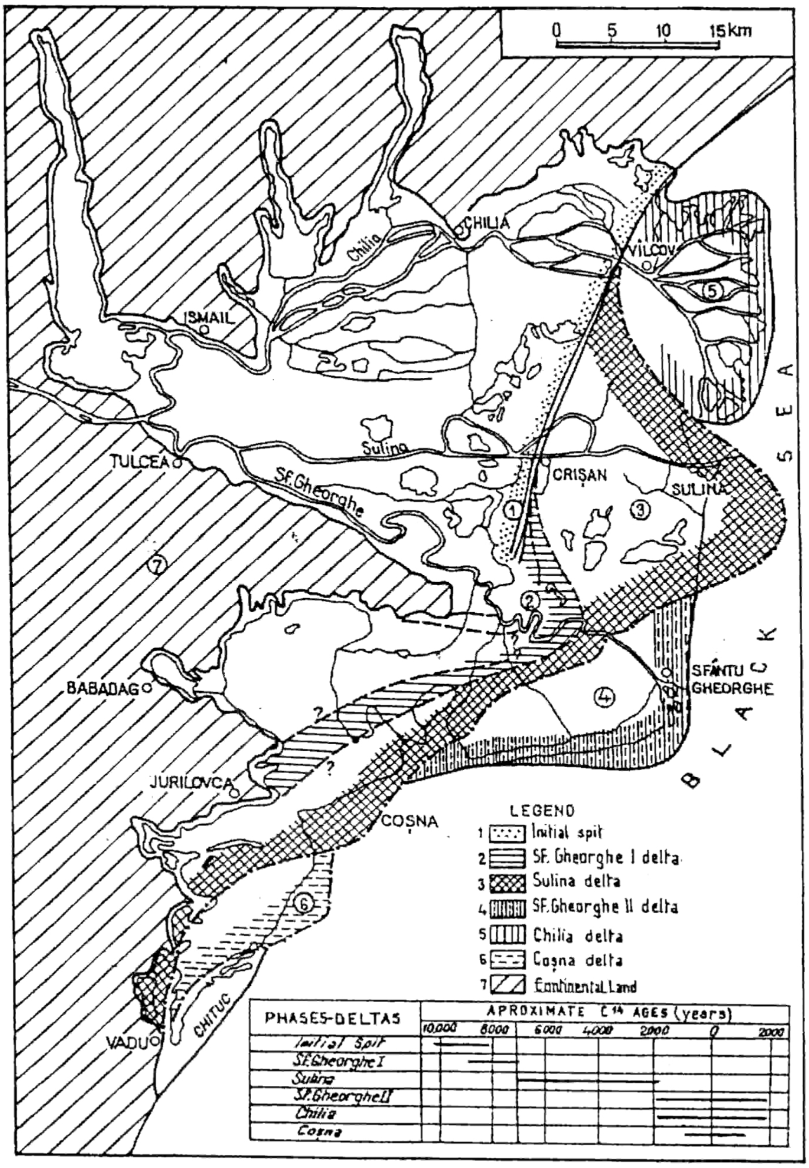



**Fig. 5 The Danube Deltas and their approximate ages (after Panin, 1983)**

## Tidal and wave regime

The sea-water in the Romanian coastal zone shows variations in level. These variations are produced by the Danube discharge (accounting for 62 % of the river water flown into the Black Sea), the atmospheric pressure, the effect of the tangential force of wind and much less by the tide (low, uneven, semidiurnal tides of 9 – 12 cm are registered in Constanța harbour) (Bondar, 1978).

According to water level registrations, high cyclic seasonal variations occur in May – June, with low values in September and October. These correlate with the discharge fluctuation of the Danube mouths.
Besides level variations, seiche-type oscillations (averaging 14 – 18 cm and lasting for $4^h$ 20') occur as well. The direction from which the wind blows also creates deregulations. During violent storms, with North-East winds blowing at a speed of over 20 m/sec., water level variations can reach 170 cm, while mean monthly amplitudes do not exceed 20 cm.

Estimations of long-term sea level changes are based on recordings made at Sulina station over a period of 130 years (beginning with 1858) and at Constanța station (beginning with 1938). These data indicate an uplift rate of 1.8 - 2.0 mm/year. Associating it with the 2 mm Danube Delta annual subsidence due to sediment compaction and regional tectonics, the difference rises to 4 mm/year, and a consequent coastal abrasion effect (Fig. 6).

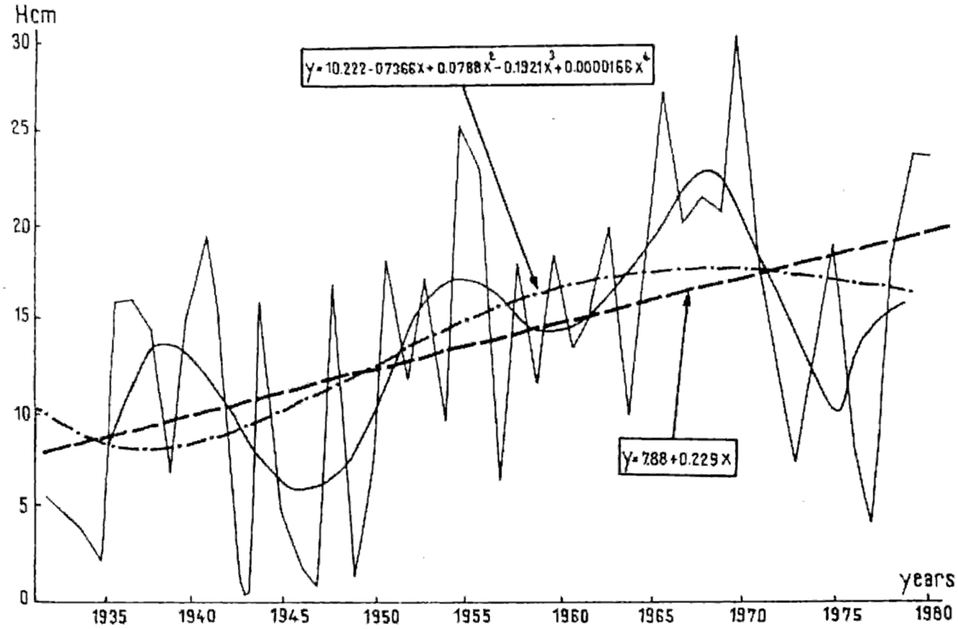



**Fig. 6 Level variation of the Black Sea – Constanţa (1933-1980)**

**The mean multiannual temperature of surface waters** close to the coast registers 12.7° C, which is 1° C in excess of the air temperature. Warm water average values in August are 23.1° C at Sulina and 22.4° C in Constanța; cold water records made in January – February show 1.9° C at Sulina and 2.9° C in Constanța. Lowest winter temperatures during the past four decades were registered in the years 1954, 1963, 1972 and 1996, with coastal waters freezing at a record low of – 3.5° C.

**Sea water dynamics**, which is involved in the morphological evolution of the coast, is dependent upon sediment transport and the waves regime.

The movement of coastal waters loaded with Danube alluvia follows in part the drift current pattern of the western section of the Black Sea; the movement of sediments is primarily related to the wave regime on the submerged coastal slopes and to the alluvial material stored. Wave pattern and distribution depend upon shoreline orientation and the submerged relief.

In the strip of coastal waters up to the 10 m isobath mean wave height is < 0.5 m, and the period 3 sec. In the same sectors, strong winds and over 2 m-high waves with 4 % frequency and period of 6 sec. may develop. With wind speeds of > 15 m/sec. and high waves, some 88 - 90 % of the alluvia discharged by the rivers are carried southward by coastal waters.

## Anthropogenic changes

Man's impact on the coast goes back to the 1850s, when the construction of piers at the mouth of Sulina Arm began. It was also in the last decades of the 19th century that corrections along Sulina Arm were made to open it for maritime navigation. The outcome was a significant higher discharge (from 7 - 8 to 19 %) and sediment transport. With the increase of sediment transport and the need to maintain the channel navigable, it became imperative to extend the Sulina mouth embankment into the sea (up to some 9 km today). At the same time, the channel was being dredged to maintain the depth required by maritime navigation over the submerged bar. The huge volume of sediment dredged (about 500,000 $m^3$/year) and discharged offshore on the submerged slope, far from the influence of shore currents, eliminates these sands from the sediment balance and accelerates coastal abrasion South of that point. The dyking pattern at the Sulina mouth reduced the circular, anticyclonic current, disturbing the ordinary transport of alluvia. In the 1850s, Constanța harbour began to be built. After 1970, a new harbour, Midia, was built and Constanța port was enlarged including a new port – Agigea – placed at the mouth of the Danube – Black Sea Canal. All these engineering works beginning with the dam built at Sulina up to the harbour and its afferent dams erected at Cape Midia, have changed the littoral drift, removed sediment from the coast the alluvia carried by the Danube and intensified abrasion.

## Method

Identifying the coastal sections subjected to abrasion and accumulation, as well as the annual accretion and retreat rates, can be achieved by comparing topographical and special maps of the studied area, eg. Map of the Russian Headquarters (1830), Map of the Danube Delta produced by the European Danube Commission (1871) and a set of topographical maps worked out by Lambert and Gauss-Krüger throughout the 1882 - 1971 interval; making periodical measurements at the landmarks planted in 1962 and studying documents that make reference to the Danube mouths since the Antiquity (Strabo, Ptolemy, Herodotus, etc.) to the present day. The data found were processed, compared and used to outline critical sectors. The aim of this paper is in principal to present the accumulation/abrasion ratio in the coastal sector between Sulina and Cape Midia, and to assess the annual rate and expansion of these processes.

## Present-day coastal morphodynamic processes in the accumulation sector (delta – lagoon coastline)

The northern coastal section (Fig. 7) is characterized by a lower shore consisting of an association of beach barriers, 80 % of which is composed of river sands. This section is characterized by an alternation of accumulation and abrasion processes, both in space (depending on the presence and orientation of different coastal sectors against the mouths of the Danube area) and in time (related to yearly seasonal variations of the Danube's solid discharge, sea level, direction and intensity of winds) (Bondar, 1983).

Since 1962, measurements have been made at beach poles (landmarks) placed between Cape Midia and Sulina harbour in order to establish distance changes on the shoreline. These measurements have provided a general picture of the evolution of this sector, affording quantitative assessments and estimates of annual coastline retreat (abrasion) or advance (accumulation). It may be seen from Fig. 7 that abrasion has prevailed over the past thirty years.

This erosion is caused by a marine minitransgression, drastic reduction of the sediments transported by the Danube and changes in the pattern of sea currents circulation in the wake of coastal engineering works. The greatest damage has been caused by dyking.

Therefore, one can find abrasion retreating sectors alternating with sectors of reduced accumulation (accretion). Sometimes, a relative temporal equilibrium between the two set in. Accumulation sectors occur as a rule right South of the Danube arms.

## Retreating sectors

***Gârla Împuțită – Câşla Vădanei levee sector*** is 20 km long and lies in the shade of the piers that extend offshore Sulina mouth. It is deprived of much of the alluvia transported both by this branch and by Chilia Arm. The shore is eroded by the waves. However, it does not benefit the sediments flown from the North that would act like a buffer. Hence beach barriers are destroyed and the waves erode the floating reed islands of the Roşu-Roşuleț lacustrine depression.

According to the topographical charts drawn up between 1884 and 1971, the mean erosion rate is 16 m/year; however, landmark measurements made over 1962-1981 revealed lower annual rates of 8 – 10 m, with maxima as high as 25 m/year in the more vulnerable parts, as shown by a short-time survey (Gâştescu, 1977, 1986).

***Ciotica-Perişor*** is a 20 km-long sector in which the coast is changing its direction (West - South-West) immediately South of the Sfântu Gheorghe mouth. This new direction, caused by the Sakhalin Island translation effect, is felt over 17 km South–westward, preventing the already meagre sediments of the Sfântu Gheorghe Arm to reach the shore. Hence, enhanced abrasion and retreat occurs here. Just like in the previous sector – Gârla Împuțită – Câşla Vădanei - , the absence of beach ridges leaves this beach unprotected for the waves. There are some places (e.g. in front of Zătonu Mare Lake where gaps in the barrier enable direct communication between the sea and the lake). Topographical data over the 1871-1971 indicate erosion rates of the order of 7.5 m/year (Gâştescu, 1979). In the West - South-western extremity of this sector, measurements conducted over a shorter time-span (1975-1981) revealed retreat values of 8 m/year.

***Leahova – Portița-Chituc***, 35 km long, stretches farther South of the Sfântu Gheorghe mouth. Since less sediments are transported alongshore, coastal abrasion is very prominent. The barrier is continually changing, moving towards the lake, which causes abrasion to affect primarily the floating reed islands or reed plots (Periboina levee).

The erosion is most prominent in the fragile Sinoie Lagoon barrier. Here, the gaps caused by waves allow the sea to flow inside. Shore erosion rates are put at 10 – 15 m/year. This fragile wall is being embanked now. Another two eroding sectors, yet less extended, are Musura Bay (6 km) North of Sulina Arm and Sakhalin Island (over 15 km long). Annual retreat rates are estimated at 5 – 10 m and 12 m, respectively. In the latter case, abrasion shows a tendency to extending westwards (Şelariu and Jianu, 1975; Gâştescu, 1977).

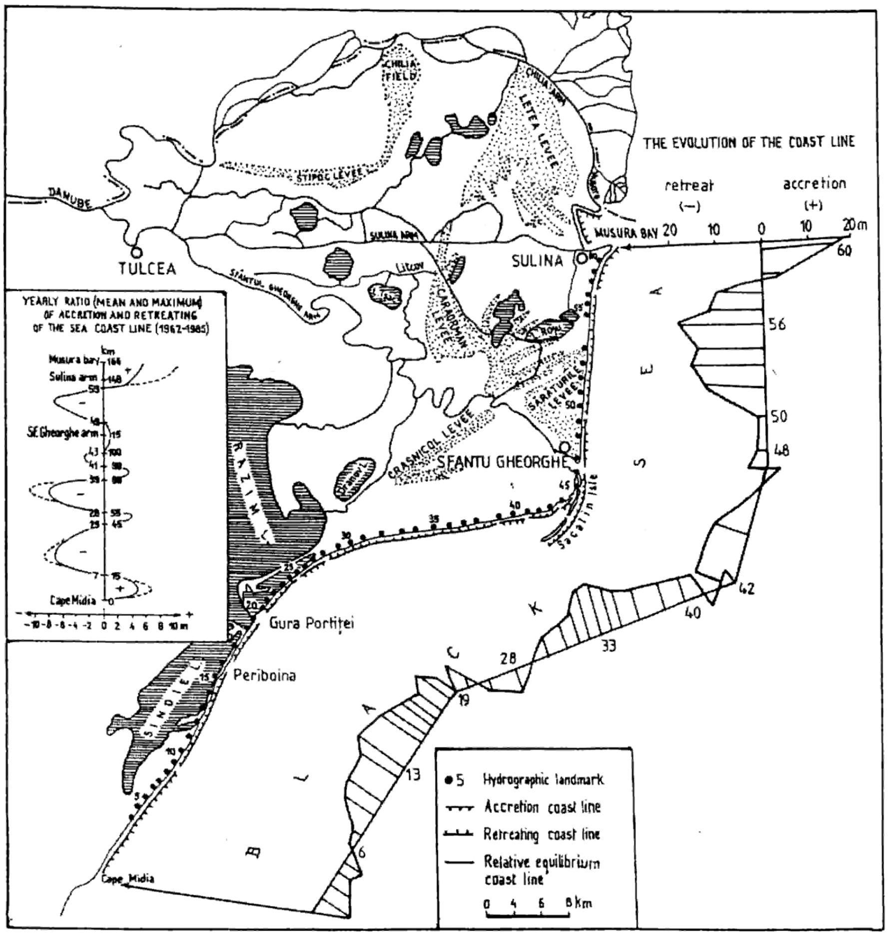



**Fig. 7 Evolution of the accumulation Black Sea coast (1962-1985)**

## Accretion sectors

***Sulina – South*** (3 km long) lies in the "shade" of the Sulina navigable channel piers. One finds here an accumulation of wave-eroded detritus carried by the western branch of the circular current that comes form Gârla Împuțita.

***The mouth area of Sfântu Gheorghe Arm*** shows a complex dynamics. Relative stability in front of Sărăturile levee, with early accumulation both on the submerged ridge (Sakhalin Island today) and through the secondary deltas in front of the Gârla de Mijloc and Gârla Turcească (secondary arms protected to the East by the alignment of the Sakhalin Island) (Gâştescu, 1979; Vespremeanu, 1983).

***Perişor – Periteasca – Pahane Rânec*** sector is situated within an arch-like area formed by a West-concaved barrier facing the Razim-Sinoie lake complex. It benefits from the alluvia transported by longshore currents from the southern part of Sakhalin Island. Accumulation of eroded materials from the adjoining sector takes places on the submerged slope of the shore. Measurements showed that the mean accumulation rate was about 8 m/year over the 1962-1975 period.

***Southern Chituc levee*** is a sector marked by the accumulation of material derived form the strongly eroded northern segment. Accumulation is enhanced due to groyne role of Cape Midia which retaining most of the sediments carried by the alongshore currents. The mean rate of accumulation, of land accretion into the sea, is gradually increasing from the North to the South (6 – 10 m/year).

To sum up we could say that the morphogenetic feature of the delta-lagoon coastline is abrasion. Nevertheless, it is of a complex nature, with remarkable mobility in time and space, some strongly eroded sectors alternating with small accumulation sectors (Table 1).

Table 1 Quantitative assessments of accumulation and abrasion processes of the Romanian Black Sea coast (1962 – 1985)

| Section | Length (km) | Type of process (km) | | | Affected area (ha/year) | | |
|---|---|---|---|---|---|---|---|
| | | Accumulation | Abrasion | Equilibrium | Accumulation | Abrasion | Balance |
| Sulina-Midia | 134 | 25 | 89 | 20 | + 34 | - 112 | - 72 |

## A study of coastal sectors with a special evolution

***The Chilia Arm Secondary Delta.*** Chilia Arm, the youngest and most active Danube branch in view of discharge and sediment transport (ca. 58 %), has in time built three successive up-to-downstream secondary deltas (Pardina, Roşca-Buhaiova, and the current, evolving delta).

The set of delta maps produced between the years 1830 and 1883 (Map of the Russian Military Headquarters, 1930; Hartley's Map, 1871; Lambert's Topographic Map Projection, 1883; Gauss-Krüger's Topographic Map Projection, 1971), have been used to determine the rate of delta accretion (m/year) along three main directions - Oceakov, Ankudenov and Staro Stambul, as well as the surface-area increase rate (sqkm/year). The tables 2 and 3 list the highest average rate along the Staro Stambul direction over the 1830-1971 interval - 101.2 m/year, with a mean value of 68.1 m/year. The surface-area (**F**) enlarged accordingly, from 78.7 sq. km in 1830 to 345.5 sq. km in 1971 (see Table 3), at a rate (**R**) of 1.89 sq. km/year (Tables 1,2). The 1992 satellite image shows a depletion of the secondary delta growth rate due to a reduced flow of sediment, the coast itself retreating between Ankudinov and the Staro Stambulsk branches (Fig. 8).

Table 2 Accretion rates of the Chilia secondary delta along three directions and mean values (m/year)

| Direction (starting from 1830) | 1856 | 1871 | 1883 | 1971 | 1830 - 1971 |
|---|---|---|---|---|---|
| Chilia – Oceakov | 23.0 | 45.7 | 70.7 | 63.8 | 50.8 |
| Chilia – Ankudinov | 43.3 | 36.6 | 82.5 | 47.0 | 52.3 |
| Chilia – Staro Stambulsk | 130.0 | 88.0 | 92.0 | 94.7 | 101.2 |
| Mean value | 65.4 | 56.8 | 81.7 | 68.5 | 68.1 |

Table 3 Chilia secondary delta. Annual rate (R sq.km/year) of surface - area increase (F sq.km)

| 1830 | 1856 | | 1871 | | 1883 | | 1971 | | 1830-1971 | |
|---|---|---|---|---|---|---|---|---|---|---|
| F | F | R | F | R | F | R | F | R | F | R |
| 78.7 | 111.4 | 1.31 | 122.2 | 0.72 | 174.4 | 4.35 | 345.5 | 1.94 | 266.8 | 1.98 |

***The Sulina mouth***. Reported problems in navigation on the Sulina Arm date back to the latter half of the 19th century. The question of navigation in the Danube mouths area became an issue after the Paris Treaty of 1856, when the European Danube Commission (EDC) was established and assigned the surveillance of navigation along the Danube arms and the execution of works to enable high-tonnage sea vessels to reach the river ports of Galați and Brăila.

Out of several variants, the Sulina Arm appeared to be the best one for maritime navigation (1865). In 1866, the EDC nominated Ch. Hartley as supervisor of the engineering works to begin at Sulina mouth and along the channel up to Sfântu Gheorghe Arm. Works ended in 1902, but the maintenance of the 7.3 m - deep arm and its mouth has continued.

Ever since Sulina mouth was chosen as a route for maritime navigation, the alluvia that keep depositing are forming a submerged bar that necessitates a lot of dredging and protection for that deep navigable channel flanked by two parallel piers; these piers have extended over 9 km if measured from the old lighthouse. The sediments deposited in front of the channel are derived from Sulina Arm, with many coming from Staro Stambul, Sulina's most active branch situated in the North. Some smaller quantities of alluvia are carried by the coastal currents along a NE - SW direction.

Before the solid sediment load of the Danube began to decrease, the mean annual volume dredged was about 470,000 tons (1894-1952), the estimated total volume amounted to 2,770,000 tons (Fig. 9).

***The Sfântu Gheorghe mouth (Sakhalin Island).*** Sakhalin Island formed in 1897 during catastrophic floods, the highest recorded by the Danube water archives ever. There is no doubt that the emergence of this island at that time, when huge amounts of alluvia were discharged, had started long before. In a study dealing with the circulation of the Black Sea waters (Ciocârdel, 1937), it was mentioned that some soundings made in front of the Sfântu Gheorghe mouth in 1854 showed the presence of two sand banks at a depth of 0.5 m below the water level.

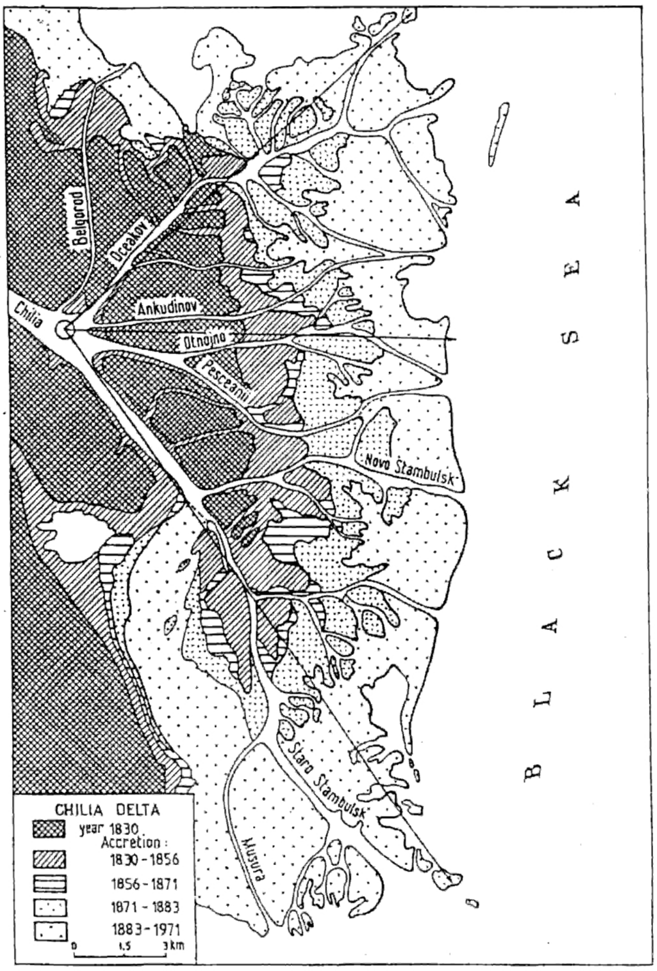



**Fig. 8 Evolution of the Chilia secondary delta between 1830-1971**

This finding was confirmed by subsequent soundings repeatedly made by Hartley after the establishment of the European Danube Commission in 1856, to choose the right arm for maritime navigation. In 1924 the island measured 10 km in length (Ionescu-Dobrogeanu, 1938). The island grows progressively, in NE-SW direction, reaching 17 km in 1991. This lengthening was caused by the sea water circulation and the deposition of sediments transported through the Sfântu Gheorghe Arm and carried by the North-East sea currents. Under wave attack, the island was drifting westwards, tending to become attached to the deltaic area, especially at its North-Eastern extremity, at the mouth of Sfântu Gheorghe Arm. According to our analysis (1977) based on cartographic documents, and to the studies carried out in the years 1991-1992, the island is indeed drifting westwards, its northern part tending to be connected with the deltaic territory. So, the forecasts made in 1977 that in 20 years' time the North-Eastern part of the island would be linked with the delta, have been confirmed. This is due to the island's westwards drift at a rate of 15.4 m/year (1910-1991) and to the eastward accretion (increase) of the Sfântu Gheorghe secondary delta at a rate of 12 m/year. In this situation the northern part of the island is linked with the delta, Gârla de Mijloc mouth is blocked, and the gulf in-between the two becomes smaller. The Sakhalin Island's evolution represents the formation of a pattern a set of levees extent in the South of Sfântu Gheorghe Arm, stretching from Crasnicol eastwards (Gâştescu, 1979) (Fig. 10).

## Conclusions

Analysing the current morphological processes of the Danube Delta and the Romanian Black Sea it appears that the coastal accumulation zone shows a slow sea level uplift at a rate of ca 2 mm/year; a sharp quantitative decrease of the Danube - derived sediments, deposited at seaside; dominance of wave action over current action; man's intervention on the on the coast by the construction and extension of the Sulina mouth piers. Therefore coastal abrasion in the studied area is by far more extended (109 km) than accumulation (57 km). The accumulation take place largely in front of the three main Danube mouths: Chilia, Sulina and Sfântu Gheorghe.

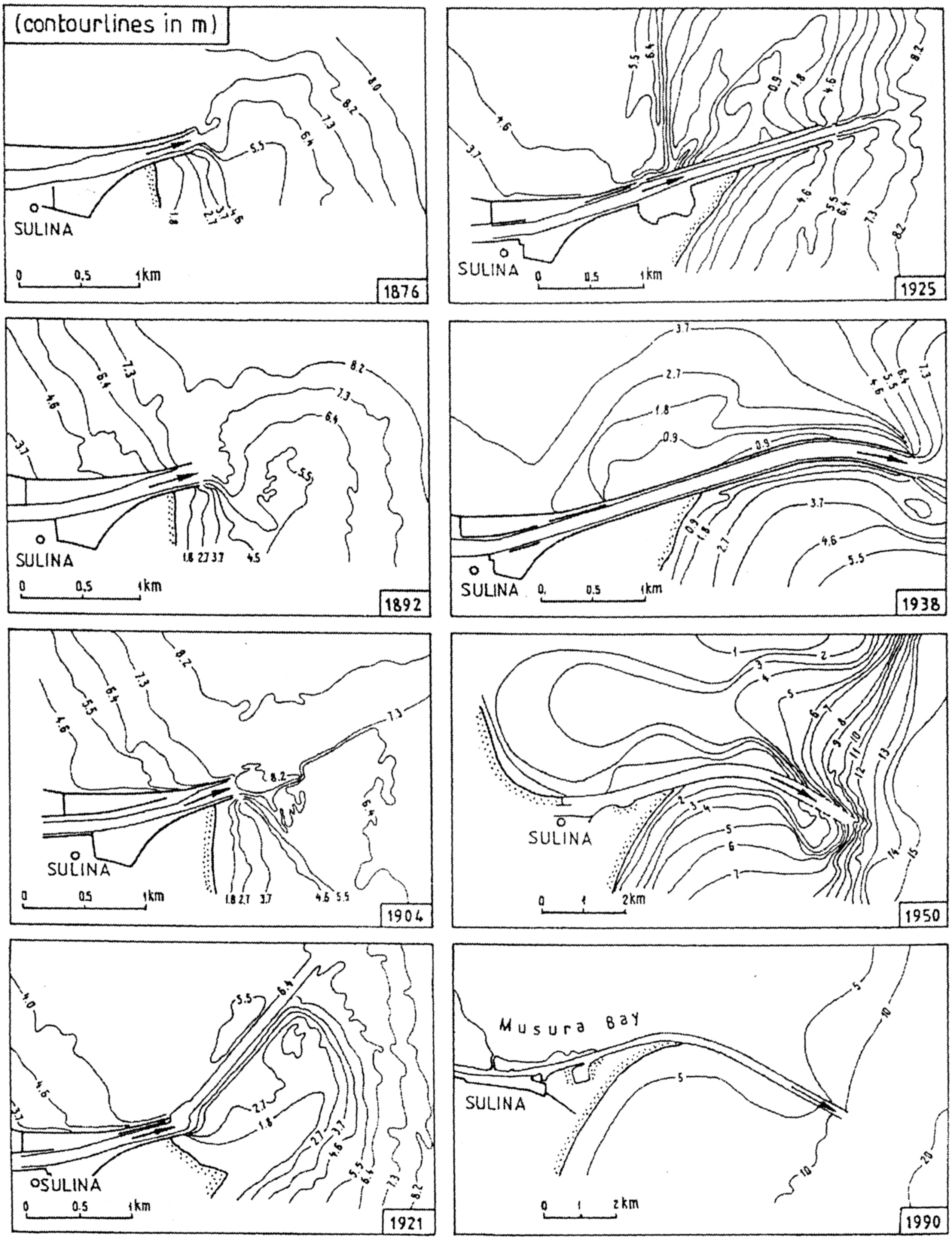



**Fig. 9 Evolution of the Sulina arm mouth between 1876-1990**

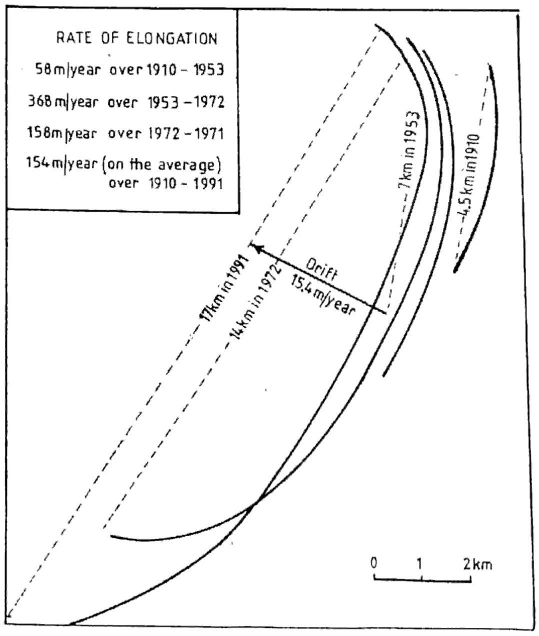



**Fig. 10** ***Elongation and east-westwards drift of Sakhalin island (over 1910-1991)***

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