

THE BLACK SEA COASTAL ZONE – AN OVERVIEW

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Abstract. The total length of the Black Sea coastline is over 4 400 km and belongs to 6 states: Bulgaria, Turkey, Georgia, Russian Federation, Ukraine and Romania. The proposed zoning of the Black Sea coastal zone evidences 17 main sections characterised by different geology and morphology, as well as specific littoral water circulation, sediment drift systems and sedimentary budget. These zones belong to three main morphodynamic categories: (1) low, accumulative coasts mostly related to the rivers mouth zones (mainly sandy complex barrier beaches with strong longshore sediment drift systems); (2) Erosive coasts within lowstanding plateaux and plains, with active cliffs with very narrow beaches in front of the cliffs; (3) Mountainous coasts, with cliffs, marine terraces, land slides, sometimes with sandy or gravely beaches. An overview of the coastal erosion in the Black Sea and of factors controlling these erosional process is given. The threats to the coastal zone generated by global changes and anthropogenic pressure are analysed. The most vulnerable sections of the Black Sea coastal zone exposed to environmental risks are presented and analysed.

Key words: Coastal zone; coastline erosion; littoral sediment drift; global changes; anthropogenic pressure; environmental risks and vulnerability

1. PRESENT-DAY STATE OF EROSION

1.1. INTRODUCTION, GENERAL SETTING

The Black Sea is one of the largest enclosed seas in the world, covering an area of about 4.2×10^5 km²; the maximum depth of the sea is 2,212 m and the total volume of water - 534,000 km³. Most of this water (the 423,000 km³ that lies below a depth of 150-200 m) is anoxic and contaminated with H₂S. The Black Sea drainage basin covers more than 2 million km²; more than 160 million people live in this area. The largest rivers flowing into the sea are the Danube, the Dniester, the Dnieper and the Don. The River Danube is the most important European waterway flowing 2,857 km across the continent from the Schwarzwald Massif in Germany down to the Black Sea. Its water discharge into the Black Sea is about 200 km³ of water/year. The Danube drainage basin extends on 817,000 km², more than 15 countries sharing this catchment area.

1.2. THE BLACK SEA COASTLINE

The total length of the Black Sea coastline is over 4 400 km and belongs to 6 states: Bulgaria, Turkey, Georgia, Russian Federation, Ukraine and Romania. The large variety of geomorphologic types of these coasts corresponds to different geological environments surrounding the Black Sea.

The Black Sea coastal zone can be divided in 17 main zones characterised by different geology and morphology, as well as specific littoral water circulation, sediment drift systems and sedimentary budget (Fig. 1, Table 2).

In a more general approach the Black Sea coast zone could be subdivided into three main morphodynamic categories, with very specific characteristics and behaviour:

1. **Low, accumulative coasts** mostly related to the main rivers mouth zones. This type of littoral zone consists of sandy complex barrier beaches with strong longshore sediment drift systems; these zones are generally characterised by isostatic adjustments of overloading by rapid accumulation of sediments (subsidence).

To this type belongs, first of all, the Danube Delta with a very exposed to erosion littoral of about 240 Km; then within this type must be considered partly the unit River Dnieper liman - Karkinit Bay (total length of about 618 Km), specifically the Kinburn spit - Dolgyi Island section (~20 Km) and Tendra spit - Dzharlygatch Island section (~137 Km). The Taman - Anapa section of about 200 Km long (of which 66 Km are the Anapa spit) represents mainly an accumulation of sediments brought by the River Kuban few hundred years ago, and could be allocated to the same first type of coasts. Further to the South, the mentioned type is present within the Kolkhida (Rioni) Lowland where the rivers Chobi, Rioni,

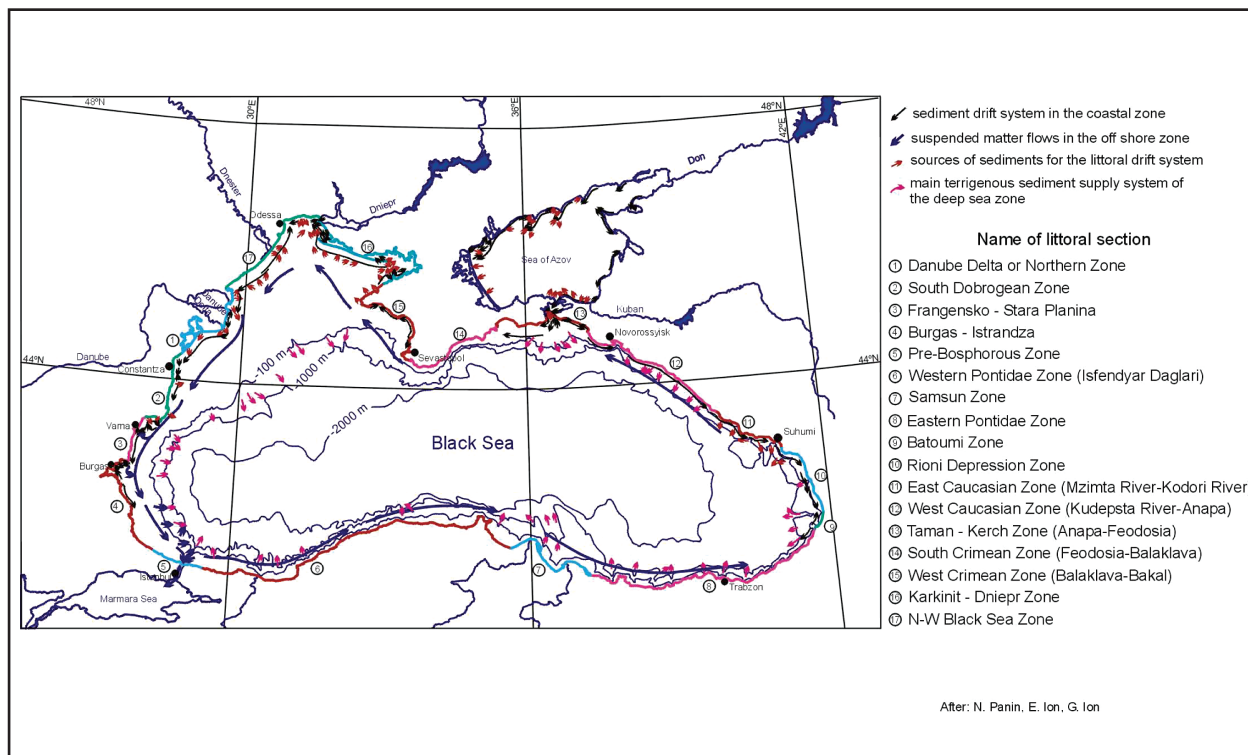


Fig. 1 Zonation of the Black Sea Coastal Zone - Sediment movement systems

Inguri and Supsa have built up their deltas. On the Turkish coast there are the deltas of Kizilirmak, Yesilirmak and Sakaraya rivers, and finally, in Bulgaria, sandy accumulative beaches are related mainly to the rivers Diavolska, Kamchya, Provadyiska and Batova, summing about 100 Km. The accumulative coasts of Anapa section, Kolkhida Depression, the deltaic sections on the Turkish and Bulgarian coasts are located within or nearby zones of high relief energy, relatively strong sediment nourishment and general uplifting tendency, so their equilibrium state is not yet very strongly affected.

2. **Erosive coasts within lowstanding plateaux and plains**, with active cliffs in loess and loess-like deposits, sometimes underlain by older deposits as Pontian limestones, Meotian clays and Sarmatian lumachelles, with very narrow beaches in front of the cliffs. To this type of coasts could be distributed the North-Western unit of the Ukrainian coast zone. This unit extends from the Northern limit of the Danube Delta (of the Kilia secondary delta) to the town of Ochakov (Western limit of the Dniepr liman), summing 232 Km. The Southern unit of the Romanian coastal zone (Cape Midia - Vama Veche at the Bulgarian border - about 75 Km long), as well as the Northern part of the Bulgarian coast, from the Romanian border to Caliacra Cape (about 50 Km long) belong to the same type of littoral.
3. **Mountainous coasts**, with cliffs, marine terraces, land slides, sometimes with sandy or gravelly beaches.

This type of coasts is generally subject to isostatic and orogenic uplift.

To this type belong the coasts of Crimea, Caucasus, Pontides, Strandza and Staro Planina Mountains, as well as of Frangensko and Avrensko plateaux.

1.3. COASTAL EROSION IN THE BLACK SEA. FACTORS CONTROLLING THE EROSIONAL PROCESS

The coastal erosion in the Black Sea represents one of the main environmental concerns of the riparian countries. The erosion is controlled by:

- **Global and natural factors.** The Black Sea coastlines erosion is strengthened as everywhere in the World Ocean by the global changes and the general sea level rise. The coast erosion will depend on the synergetic effect of factors controlling the littoral processes (meteorological regime, wave energy regime, water circulation, sediment supply and drift etc.), global changes and the consequent modification of the energetic level of the coastal sea, general sea level rise and regional characteristics as shoreline morphology, elevation and geologic constitution, subsidence or/ and neotectonic regime.
- **Anthropogenic factors.** The coast zone erosion and the state of the coastal sea ecosystems are strongly affected by the anthropogenic activities, the effect of which is added to the impact of natural factors. The anthropogenic changes of large rivers hydrologic characteristics (water and especially sediment supply, regularisation of floods

etc.), men-made littoral structures as breakwaters, dykes, groins, harbours etc. which are modifying the littoral circulation cells, the uncontrolled use of beach sand, dredging of sand too close to the beaches or within the river mouth bars and many other activities are causing an enhancement of coastal erosion and endangering of the coastal ecosystems.

The first category of coasts described in the Chapter 1.2 (*Low, accumulative coasts*) is the most influenced by the global changes, specifically by the sea level changes and by the changes in the river sediment inputs. The decreasing of sediment supply and changes in littoral sediment drift due to anthropogenic activities (river damming, hydro-technical regularisation, littoral structures etc.), especially when the sandy beaches are low, added to the rising of the sea level and the increasing of littoral sea energy could determine in certain conditions a very active and almost continuous recession of the beach line (up to 20 m/y, as it happens in some sections within the Danube Delta littoral). This process is causing land losses, environmental changes and economic degradation of the coastal zone. If the region represents the coastal zone of an important delta which plays an essential role in the normal structuring and functioning of ecosystems, any changes of delta/sea interaction zone environments could be fatal and irreparable.

The second category of coasts described above (*Erosive coasts within lowstanding plateaux and plains*) could be also affected by erosional processes but the rates of coastline regression do not reach the same values as within the first category (only 1-2 m/y). In this case the erosion affects mostly the narrow beaches in front of the cliffs. The environmental transformations are not so important and consequently the economic losses are much lower.

The third type of coasts (*Mountainous coasts*) is the least affected and transformed by the erosional processes. Generally, the littoral of this type is constituted of consolidated rocks, resistant to the eroding process. In front of such rocky littoral there are no beaches or they are very narrow and coarse grained (coarse-grained sand and pebbles). If the development of tourism is intended one has to build up artificial beaches and pertaining protection structures as wavebrakers, groins etc. In this case one could affirm that the only economic concern is the maintenance of these artificial beaches.

2. THREATS TO THE COASTAL ZONE GENERATED BY GLOBAL CHANGES AND ANTHROPOGENIC PRESSURE

Taking into consideration the above mentioned observations, it clearly appears that the most vulnerable sections of the Black Sea Coastal Zone belong to the first type (*Low, accumulative coasts*) described in the chapter 1.2. Among the coast zone sections referred to this type the Danube Delta is the most significant and important.

The Danube Delta is located 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 km² of which the lower, marine delta plain represents ca. 1,800 km². 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 within the Romanian territory.

The marine delta plain is a very low area with marshes, lakes and numerous old beach-ridges (very elongated, narrow and extremely low altitude sand bodies), which in certain zones generate, by juxtaposition, accumulative littoral bodies (the main of them are Letea, Caraorman and Sărăturile) with limited dune fields and the highest altitudes within the delta territory (+12.4 m in the Letea Formation, and +7 m in the Caraorman Formation). About 20.5 % of the Danube delta-plain represents areas with negative relief, *i.e.* with an average level below the Black Sea - Sulina reference system, about 54.5 % of the Danube delta plain consists of areas having altitudes between 0 and 1 m above the sea-level, and 18 % with altitudes between 1 and 2 m.

In front of the Danube Delta, the North-Western Black Sea continental shelf is very large (over 100 km wide). This part of the sea receives the discharge of some of the largest rivers from the Central and Eastern Europe – the Danube with a water discharge of about 200 km³/yr and the Ukrainian rivers (Dnieper, Southern Bug and Dniester) contributing about 66 km³/yr.

The present-day longshore sediment drift system off the Danube Delta area is directed towards the South (see Table 2, Fig.2). It is induced by the predominant winds, which are from the North and North-East and the most frequent wind waves recorded also from NE corresponding to the prevailing wind direction. The average maximum heights of wind waves in front of the Danube Delta reach 7.0 m. The energy of storm waves reaches important values (to 12,242 kWh/m, recorded on February 17, 1979), but generally the energy value is about 2 000 kWh/m (Spătaru, 1984). The storm surges from N, NE, E and SE direction induce water level rises to 1.2 – 1.5 m. The tide in the Black Sea has an average period of 12h 25' and amplitudes of only 7 – 11 cm (Bondar *et al.*, 1973; Sorokin, 1982). The general relative sea-level rise in the delta-front area (at Sulina gauge) is estimated at 3.7 mm/a, of which subsidence accounts for 1.5 – 1.8 mm/a (Bondar, 1989).

In such natural conditions, for the Danube Delta the main factors of risk are the river flooding and the littoral beach barrier flooding by the sea. The climate changes and the related sea level rise represent also elements of risk.

2.1. RIVER FLOODING

Flooding events in the Danube Delta occur when the water discharges of the Danube River are over 10,000 m³.s⁻¹. According to existent records, catastrophic floodings in the Lower Danube section took place in 1845, 1853, 1888, 1895, 1897, 1907, 1914, 1919, 1924, 1932, 1940, 1941, 1944, 1947, 1954, 1955, 1956, 1958, 1962, 1965, 1970, 1970, 1975, 1980, 1981,

1988, 2005. Statistic analysis of the data set for 161 years (1840 – 2000), concerning the average annual water discharges of the Danube River, shows that, at the delta apex, were recorded over 89 flooding events. According to the existing data-sets, the flooding events with discharges of 10,000 – 11,000 m³.s⁻¹ along the Lower Danube section have a mean repeatability of occurrence of two years (Bondar *et al.*, 2000).

For an easier assessment of the river water level and its influence on the delta territory a special measure unit, named *hydro-degree*, has been defined: a hydro-degree represents one tenth of the highest water level at a given point. The table below demonstrates the impact of flooding on the Danube Delta territory by showing the non-flooded areas at different stages of rising of the Danube water level.

Table 1 Non-flooded areas of the Danube Delta at different water levels of the Danube River

Geomorphological categories	Non-flooded area (ha)			
	Lowest waters 3 hydro-degrees	Low waters 4 hydro-degrees	Ordinary waters 5-6 hydro-degrees	Highest waters 10 hydro-degrees
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
Old littoral accumulative bodies, of which:	26,215	23,811	21,410	10,000
Letea (max. altitude +12.6 m)	12,710	12,185	11,660	7,915
Caraorman (max. altitude +6.5 m)	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

2.2. LITTORAL BEACH BARRIER FLOODING BY THE SEA

The present sandy beach barrier along the Danube Delta Front is very low (+0.7 to +1.5 m) (Fig. 1a). The lowest sections are: Girla Imputita-Cisla Vadanei (about 15 Km long, corresponding to the inter-beach ridge depression Rosu-Lumina), Ciotic-Perisor (20 Km long, corresponding to the Zatoane Depression) and Portita-Periboina (about 20 km, the present-day beach barrier bordering the lagoon complex Razim-Sinoie). These sections represent the most vulnerable zones of the delta coastline to the flooding by the sea.

To the natural high degree of risk the anthropogenic pressure is added. In the last 20-25 years, the River Danube sediment supply diminished severely as the Iron Gates I and II barrages have been constructed: measurements and computations show that the present day sediment discharge dropped by almost 40 % and the real sediment load brought nowadays by the Danube into the Black Sea does not exceed 40 million t/y, of which not more than 10-12 % is sandy material taking part in the littoral budget of the delta front zone. The effects of this misbalance added to the impact of

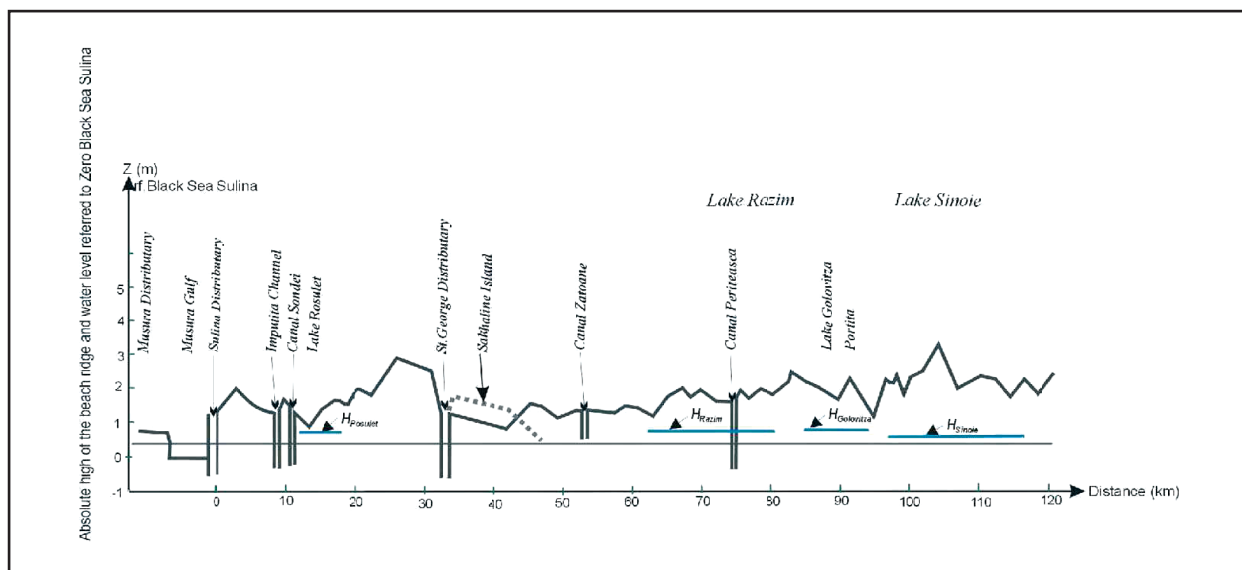


Fig. 1a The profile of the beach ridge along the Danube Delta front between the Ukraine-Romanian border (Musura distributary mouth) and Cape Midia

other anthropogenic structures and to the rise of the sea level and the increased energy of the coastal sea bring about a very active erosional process of delta-front beaches.

2.3. RISKS AND IMPACTS OF CLIMATE CHANGE AND SEA LEVEL RISE

2.3.1. Impacts on rainfall and water flow and water 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 of at least 10% of the river flow. This decline combined with a decrease of water energy by the rising of the base level would substantially lower the fresh water input into the sea.

Lesser and more erratic precipitation will reduce the groundwater recharge and will misbalance 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 precipitation and of 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.

2.3.2. Impacts of global changes and sea level rise on the Danube Delta territory and on the 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 cumulated 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 anthropogenic 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 shows (Panin, 1992):

- a rise of 20 cm of SL will produce a decrease of water discharge by 10% at a free water table slope of 1.143 cm/km and by 26% at a slope of 0.54 cm/km (at the lowest water level), the current velocity will decrease by 12% and 28.6 %, respectively 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 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 50%, respectively.

The reduced fresh water input would influence the general salinity of the Black Sea especially when the general SL will rise continuously. This would involve a greater supply of saline Mediterranean water by the bottom Bosphorus 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 of at least 3-4 hydro-degrees. This means that 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 met 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, in the Ciotic - Perisor section and in the Portita-Periboina zone (corresponding to the lagoon complex Razim-Sinoie), even if here the beach barrier is at present protected by a setback line of embankments limiting losses of beach material by over-washing.

Table 2 The Black Sea coasts zoning and description

Zone	Section	Length Km	Characteristics, description	Observations on sediment feeding and littoral drift system
1. Danube Delta or Northern Zone of Romanian Coastal Zone	2	3	4	5
	~240.0 km long General description: Low, accumulative, mainly sandy coast Two sub-zones: 1. Coastal zone between the main distributaries of the Danube Delta: Kilia, Sulina and St.George 2. Coastal zone of Danube Delta lagoon system			The River Danube is the main source of sediments for the littoral drift system. After the damming of the Danube River at the Iron Gates (Iron Gates 1 in 1970 and Iron Gates 2 in 1983) the sandy supply of the beaches by the river dropped by ~40%. The sediment drift oriented to the South
	1. Kilia (Chilia) Delta	75.0	Progradational trend near the main distributaries of the Kilia Delta. The Kilia distributary sediment discharge represents almost 50% of the total sediment discharge of the Danube River. The natural lengthening of the Kilia distributary and anthropogenic changes occurred along the Danube River and within the delta territory the Kilia sediment supply dropped and the Kilia Delta shape is slowly changing from a lobe to a cusped-like delta (in the neighbourhood of the main distributaries).	
	2. Baia de Nord (Baia Musura) - Musura Bay	12.0	At the beginning of our era - strong erosion; At present: the erosion is stopped, tendency of clogging and transformation in a lagoon by forming of a spit at the entrance into the bay.	The sediment drift oriented to the South at the mouth of the bay. The spit closing the Musura Bay is formed of sandy sediment load of the Stary Stambul distributary of the Kilia Delta.
	3. Sulina beach	6.0	Before the nineties, accumulation of sediments; At present, the accumulation is slacked under anthropogenic impact.	Local, eddy-like Northward sediment drift, due to the Sulina 8 Km long jetties
	4. South Sulina - Gârla Imputita - Căsla Vădanei	16.0	Present-day strong erosion (up to 15-20 m/yr); During the last 2 K.yr. erosion of Sulina Delta - the retreat of the coast line was over 10-15 Km	Southward Danube borne sediment drift
	5. Căsla Vădanei - St.George distributary mouth	15.0	Present-day strong to moderate erosion; At the Southern end of the section, nearby the distributary mouth weak erosion or stationary state; The section corresponds to the littoral accumulative formation Sărăturile, formed by juxtaposition of numerous old beach ridges.	Southward littoral drift of sediments
6. Sakhalin island	18.0	An arcuate lateral bar, extending to SW by 300-600 m/yr, migrating also Westward by over-washing	Very strong South-Westward drift of Danube borne sediments	
7. Secondary delta of St.George distributary - Ciotic	~12.0	The secondary St.George delta has three distributaries: St.George (Kedrulez) - the continuation of the main course of the distributary, the Sereдне arm, the smallest, almost clogged and the Gârla Turcului arm. Active progradation as a result of accumulation of sediments supplied by the distributaries of the St.George secondary delta in the shadowed by Sakhalin island area	The Gârla Turcului and the Sereдне distributaries mouth zones are characterised by homopicknal flows into shadowed by Sakhalin island area	

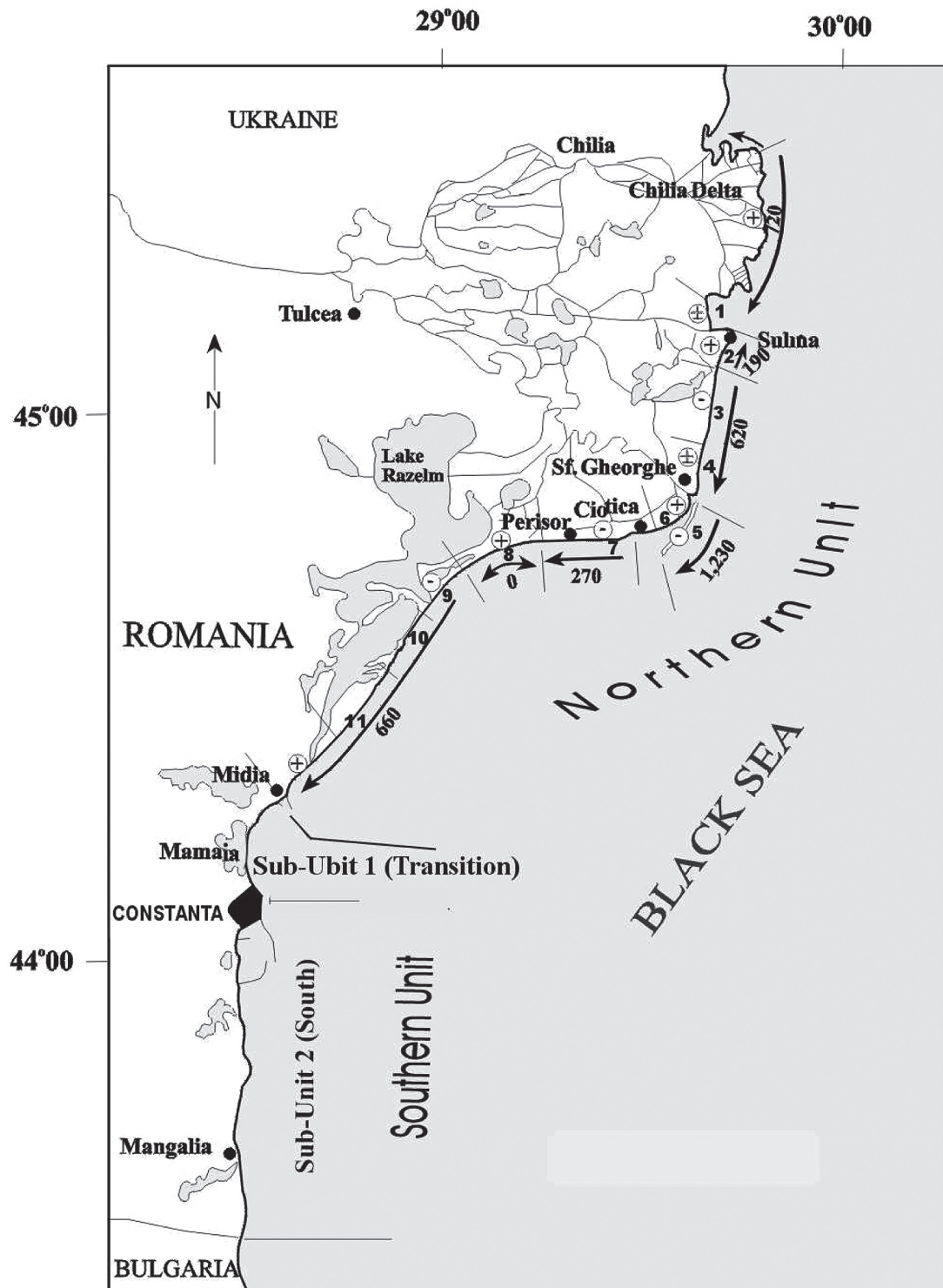


Fig. 2 Romanian Black Sea coast and the longshore sediment transport model (for the Danube Delta coast zone - Northern Unit). Sediment drift (arrows) and transport rates in thousand of cubic meters per year (figures by the arrows). Circled + and - represent advancing and retreating sections, respectively (after Giosan *et al.*, 1997)

1	2	3	4	5
	8. Ciotic – Perisor	18.0	Strong coastal erosion; significant lack of terrigenous material, the beaches are formed predominantly by organogenic detritus (mainly hashed shells).	Southward unsaturated drift of sediments
	9. Perisor – Peritesca	12.0	The section corresponds to the littoral accumulative formation Perisor; almost stationary state of the coastline	Southward active littoral drift of sediments
	10. Peritesca – Chituc Nord	30.0	The section represents a beach barrier limiting the Danube Delta lagoons Razim and Sinoie to the sea; this section is characterised by a strong erosion and a very active sediment transfer.	Active Southward littoral drift of sediments
	11. Chituc	26.0	The section corresponds to the littoral accumulative formation Chituc; strong to moderate erosion and active sediment transfer	Strong Southward drift of sediments
II. South Dobrogean Zone	~ 175 km total length. General description: Erosional coast, with active cliffs and narrow beaches at the feet of cliffs or small beach barriers separating lagoons from the sea			Negative sedimentary budget, local littoral cells
	1. Cape Midia - Cape Singol	~ 22 km	The section represents a transition from the Northern accumulative zone to the Southern Dobrogean sensu stricto zone, characterised by predominantly active cliffs; the section is characterised by large littoral beach barriers located in front of fossil cliffs, limiting lagoons or littoral lakes.	Local littoral cells of sediment circulation; general drift system remains oriented to the South; strong anthropogenic impact – the Midia harbour wave breakers disturb the littoral drift system.
	2. Cape Singol - Vama Veche (Romanian- Bulgarian border)	~ 60 km	Active cliffs with barrier beaches limiting lagoons. The cliffs are formed of loess formation laying on Sarmatian lumachelles.	Local littoral cells of sediment circulation; General sediment drift system remains oriented to the South. The beaches are formed mainly of organogenic material – shell debris.
	3. Vama Veche - Cape Kaliakra	~ 50 km	Same characteristics as the previous section - active cliffs with barrier beaches at the Black Sea tributary rivers mouth. Two subsections: (1) Cape Sivri (Sivri Burun) – Cape Shabla (Sabla) with low cliffs mainly in loess formation, small lagoons at the mouth of rivers and sandy beaches; (2) Cape Shabla – Cape Kaliakra, the cliffs become higher towards the Cape Kaliakra (up to 60 m height), the cliffs are formed of limestone.	Local littoral cells of sediment dynamics; from Cape Shabla Northward to Cape Sivri the drift is oriented to the North, with local convergent or divergent cells. From Cape Shabla to the Cape Kaliakra the general sediment drift system remains oriented to the South. Local differently oriented cells are evidenced.
	4. Cape Kaliakra - Balcic	~30 km	Almost the same characteristics as the previous section, but without beaches - active cliffs and massive landslides. The coastal relief is higher (up to 120 m at Kavama and 220 m North of Batova river). Accumulative beaches of sandy sediments only at the mouth of Batova River (the sand is supplied by the Batova river).	The general littoral drift is oriented Westward, parallel to the coast, with local littoral cells. The first subsection Cape Kaliakra-Kavama is characterised by weaker drift, while the Kavama-Balcic subsection has a stronger Westward drift. The lack of sediments doesn't allow beaches to form.
	5. Ekrene	~ 10 km	The Batova River represents the limit between Dobrogean Plateau and Frangensko Plateau. The altitude of the relief in the coastal zone is higher, up to 290 m. Massive landslides. There are sandy beaches in the Northern part of the section.	Along the Frangensko Plateau a Northward oriented weak drift of sediments with local differently oriented cells. The beaches of Albena resort are formed by convergent supply from the Batova River and from the material resulted from the erosion of Frangensko Plateau coast.

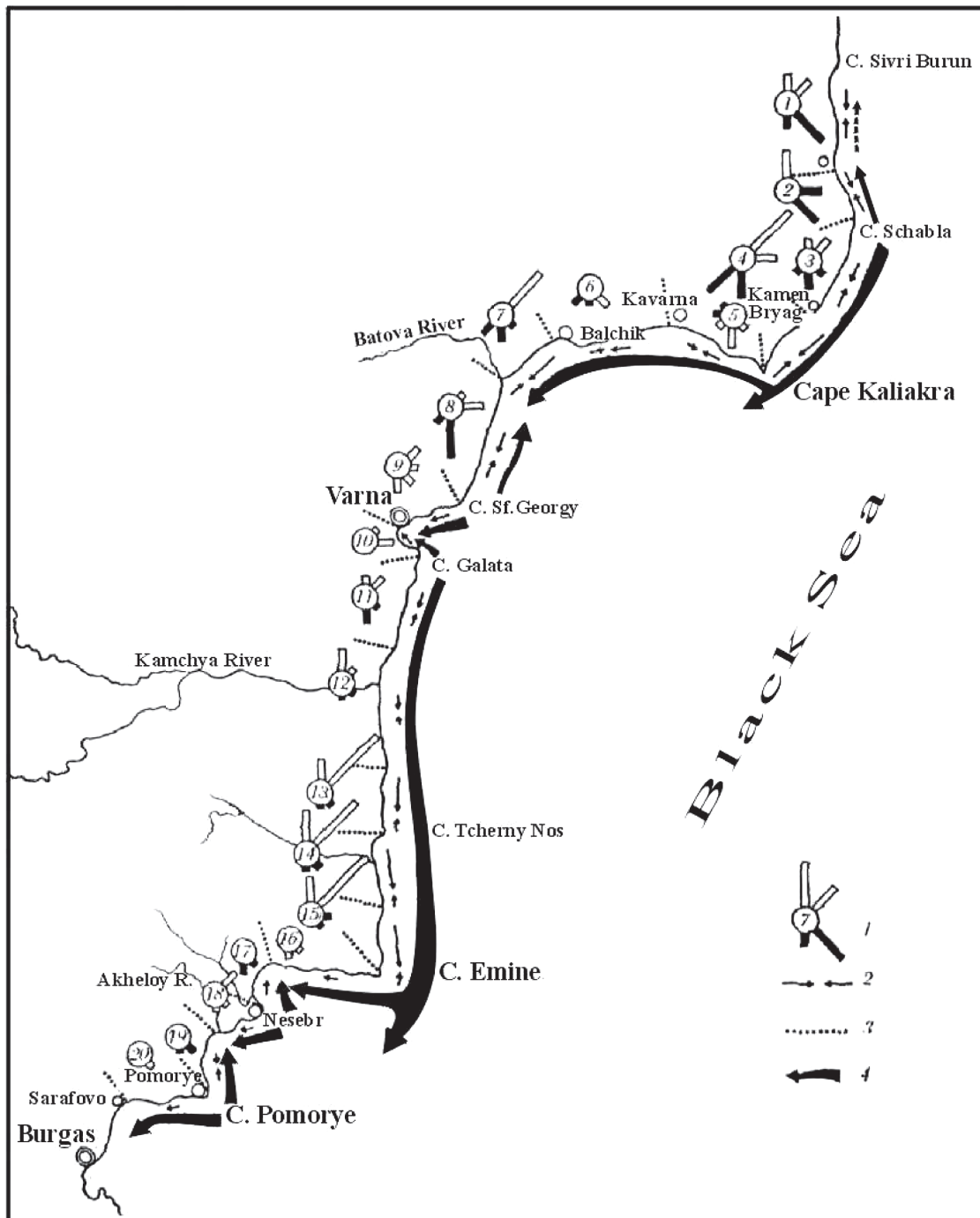


Fig. 3 Schematic representation of the littoral drift system of sediments on the Bulgarian section of Black Sea Coast (after Aksenov *et al.*, 1979). Legend: 1 - rosette diagram of the energy components in different sections; 2 - alongshore components of the energy fluxes; 3 - limits of computation sections; 4 - resultant of the alongshore energy fluxes and littoral sediment drift

1	2	3	4	5
<p>III. Frangensko - Stara Planina</p>	<p>1. Frangensko Plateau coast 2. Varna bay 3. Lower Kamchia 4. Kamchia River - Cape Emine. Two subsections: (1) Kamchia-Cape Tcherny, (2) Stara Planina Mountains coast Cape Tcherny-Cape Emine</p>	<p>~ 10 km ~ 10 km ~ 18 km ~ 40 km</p>	<p>Abrasive coast with marine terraces and massive landslides. Very small, mainly artificial beaches The Varna bay is located at the mouth of Provadyiska River that represents the limit between Frangensko and Avrensko plateaux. The section is limited by the Cape St. George (Sv. Georgi) at the North and the Cape Galata at the South. Between the Cape Galata and the mouth zone of the Kamchia river the coastal zone relief has altitudes of 100-130 m; marine terraces and landslides occur. South of the Kamchia River until the Cape Tcherny (first subsection) the largest beaches on the Bulgarian coastal zone are located. In the second subsection, between Cape Tcherny and Cape Emine, the coast is characterised by land slides, terraces and small beaches. Within this second subsection starts the Stara Planina Mountains. The Nesebar section extends from the Cape Emine to the Cape Nesebar. The Stara Planina Mountains coast continues along this section. The capes are formed of hard Neogene rocks. Coasts cut in ancient metamorphic complexes, Jurassic and Cretaceous rocks, Paleogene and Quaternary deposits. The subsection C. Nesebar-C. Pomorye is characterised by strong abrasion with small accumulative beaches within small gulfs. The subsection C. Pomorye-C. Sozopol corresponds to the Burgas bay sensu stricto and is influenced by negative neotectonic movements of the Burgas synclinorium. This is expressed by the occurrence of lagoons - Atanasovsko, Burgas, Mandrensko. This section is limited to the North by the River Tchukalya and to the South by the River Dyavolska. The coastline is very sinuous with small promontories and gulfs where small beaches are formed. Some terraces are also present. Coasts in Mesozoic-Cenozoic rocks, mainly granites, diorites, syenites. The section starts at the Dyavolska River, includes the Bulgarian-Turkish border on the Rezovska River and continues until Karaköy. The coastline is parallel to the axis of the Istrandza synclinorium. The section is characterised by rocky capes and small gulfs with limited beaches. More than 75% of the length of the section is cliffy.</p>	<p>Northward oriented weak drift of sediments with local differently oriented cells The littoral drift is convergent from the limiting capes (St. George and Galata) to the centre of the section. The drift is supplying enough material for creating a positive trend of coastline evolution - the advancement of the coastline goes up to 1 m/yr. The general drift system has a Southward direction, with differently oriented local cells. The Kamchia River sediment supply is almost equally distributed to the North and to the South. The general drift system has a well expressed Southward direction. The beaches are formed of the Kamchia River sediment supply as well as of the sediments brought by small permanent or temporary streams. The littoral sediment drift is oriented Westward. The Cape Emine protects this section and large beaches could be formed: Sunny Coast beach with coastal dunes up to 11 m high, Nesebar gulf. The littoral drift system is influenced by the high sinuosity of the coastline. The system in the C. Nesebar-C. Pomorye subsection is convergent to the middle of the gulf. In the C. Pomorye-C. Sozopol subsection similar convergent to the center of Burgas bay drift system is reported. The general drift system is oriented Southward. Local cells generated mainly by the coastline shape The general drift system is oriented Southeast-ward. Local cells generated mainly by the coastline shape (small bays and capes).</p>
<p>IV. Burgas-Istrandza</p>	<p>1. Nesebar section 2. Burgas bay. Two subsections: (1) Cape Nesebar-Cape Pomorye, (2) Cape Pomorye-Cape Sozopol 3. Mednoridsky plateau coast 4. Istrandza Mountains coast</p>	<p>~ 40 km ~ 115 km ~ 60 km ~ 85 km</p>	<p>The general drift system is oriented Westward. The Cape Emine protects this section and large beaches could be formed: Sunny Coast beach with coastal dunes up to 11 m high, Nesebar gulf. The littoral drift system is influenced by the high sinuosity of the coastline. The system in the C. Nesebar-C. Pomorye subsection is convergent to the middle of the gulf. In the C. Pomorye-C. Sozopol subsection similar convergent to the center of Burgas bay drift system is reported. The general drift system is oriented Southward. Local cells generated mainly by the coastline shape The general drift system is oriented Southeast-ward. Local cells generated mainly by the coastline shape (small bays and capes).</p>	<p>The general drift system is oriented Westward. The Cape Emine protects this section and large beaches could be formed: Sunny Coast beach with coastal dunes up to 11 m high, Nesebar gulf. The littoral drift system is influenced by the high sinuosity of the coastline. The system in the C. Nesebar-C. Pomorye subsection is convergent to the middle of the gulf. In the C. Pomorye-C. Sozopol subsection similar convergent to the center of Burgas bay drift system is reported. The general drift system is oriented Southward. Local cells generated mainly by the coastline shape The general drift system is oriented Southeast-ward. Local cells generated mainly by the coastline shape (small bays and capes).</p>

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V. Pre-Bosporus zone	1. Karacaköy - Bosporus (European side - Rumeli)	~ 45 km	Coasts formed in Cenozoic sedimentary rock complexes that are easily eroded and supply sandy sediments to beaches and littoral dunes (ex. Karaburun dunes). The coastline is almost straight.	The general drift system oriented to the ESE
	2. Bosporus - Sile (Asian side - Anadolu)	~ 40 km	West Pontian synclinorium. The shelf has an average width of 19 km	
VI. Western Pontidae zone (İsfendiyar Dağları)	1. Sile - Cape Kefken	~ 60 km	Mesozoic and Quaternary deposits	
	2. Sakaraya River mouth (Cape Kefeken- Cape Baba)	~ 115 km	Coasts formed of Quaternary (alluvial, terraces), Paleogene, Mesozoic and Paleozoic deposits	
	3. Zonguldak section (Cape Baba - Cape Kerempe)	~ 160 km	Cretaceous-Eocene flysch and volcanic rocks. Very narrow and steep shelf (average width of 7 km)	
	3. Hosalay section (Cape Kerempe - Sinop)	~ 130 km		
VII. Samsun zone	1. Kizilirmak River Delta section (Sinop - Samsun)	~ 150 km		
	2. Yesilirmak River Delta section (Samsun-Unye)	~ 120 km		
VIII. Eastern Pontidae zone	1. Ünye - Cape Yasun	~ 45 km		
	2. Cape Yasun - Harasit River - Cape Fener	~ 175 km		
	3. Trabzon section (Cape Fener - Kemalpaşa)	~ 230 km		
IX. Batoumi zone		41.0		
	1. Chorokh River Delta - Kakhaber Plain	19.0	Sediment supply to the coastal zone from the Chorokh River	Littoral drift of sediments directed to the SW; The sediment discharge of the Chorokh River is partly discharged into the deep sea zone through three main canyons situated in front of the river delta.
X. Rioni Depression zone	2. Batoumi - Kobuleti	22.0	Section of marine abrasion	Sediment littoral drift towards the North till Supsa River mouth
		115.0	Low, straight coast, with important input of sediments from the rivers debouching in this zone	Littoral drift of sediments with variable directions; Numerous canyons capturing a part of sediments
	1 Kobuleti - Supsa River	10.0	Very narrow shelf	Northward littoral drift; in front of Supsa River there is a very active canyon.
	2. Supsa River - Poti (Inguri River Delta)	24.0	Accumulative sandy coast	Southward littoral drift; there is a canyon in front of the Southern distributary of the Inguri River Delta
	3. Poti - Chobi River mouth	19.0	Accumulative sandy coast	Northward littoral drift
	4. Chobi River - Inguri River Delta	23.0	Accumulative sandy coast	Southward littoral drift; a canyon in front of Inguri River mouth
	5. Inguri River-Ochamchire	39.0	Accumulative sandy coast	Strong Southward littoral drift.

1	2	3	4	5
XI. East Caucasian zone (Mzimta River - Kodori River)	186.0 km long General description: Erosional coast with deltaic progradational sections at the river mouths 1. Skurdza gulf – Ochamchire 2. Kodori River Delta 3. Sukhumi bay 4. Gumista River Delta 5. Gudauta section 6. Bzyb River Delta and Pitsunda Cape	24.0 15.0 19.0 10.0 50.0 24.0	Erosional coast Accumulative coast, sandy and gravelly beach material Low clayey coast, Kelasuri River supplies a limited amount of sediments Accumulative coast, sandy and gravelly beaches Erosional predominantly clayey coast with slumps Sandy-gravelly beaches affected by strong erosion especially within the Pitsunda Cape	Southward littoral drift; fine sandy material migrates inversely to the North. South-Eastward littoral drift South-Eastward littoral drift of sediments, partly captured by a very active canyon located in front of Kodori River South-Eastward littoral drift South-Eastward littoral drift; a canyon in front of Gumista river mouth Strong South-Eastward littoral drift Strong South-Eastward drift of mostly coarse-grained sediments The Bzyb River sediment supply is predominantly discharged towards the deep sea zone through the Acula Canyon located at a few hundred meters offshore the Bzyb River mouth.
XII. West Caucasian zone (Kudepsta River - Anapa)	286.0 km in length General description: Bay-like in the North, aligned abrasive coast composed of relatively resistant rocks (flysch series) in the South 1. Kudepsta River - Matzesta River 2. Sochi section 3. Mamayka River - Loo River 4. Loo River - Ashe River 5. Ashe River - Tuapse 6. Tuapse - Aderba River section, subdivided into : 6.1. Kodosh Cape – Gryaznov Bay; 6.2. Gryaznov Bay – Guavga Cape; 6.3. Sandy Bay 6.4. Dzhubga Bay - Chugovkopas Cape 6.5. Chugovkopas Cape – Idokopas Cape 6.6. Idokopas Cape – Aderba River	21.0 23.0 11.0 13.0 12.0 43.0 23.0 87.0	Erosional coast with cliffs Accumulative sandy-gravelly beaches Abrasive coast Abrasive coast with significant anthropogenic impact Curved abrasive coastal line with sudden beach width variations Almost straight abrasive coastline Abrasive coast, sediment deficit Mostly abrasive curved but stable coastline; The subsection Gryaznov Bay - Guavga Cape is a bay; The subsection Sandy Bay is an accumulative one; Ancient terraces are commonly present.	South-Eastward littoral drift South-Eastward littoral drift South-Eastward littoral drift South-Eastward littoral drift South-Eastward littoral drift; the littoral drift starts at Ashe River Mouth Section with deficit of sediments No littoral drift in this section

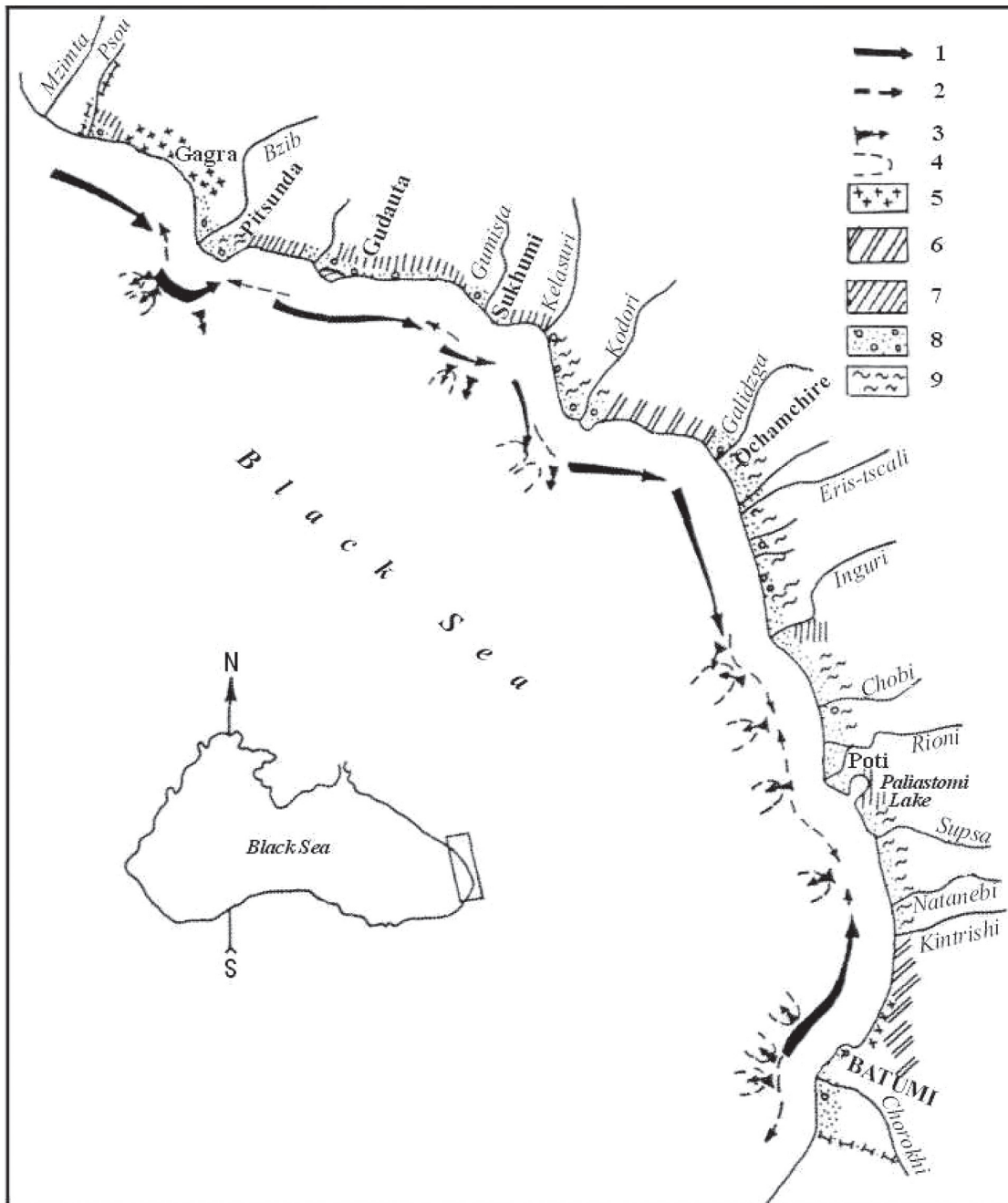


Fig. 4 Schematic map of the litoral sediment drift system in the Black Sea Coastal Zone of Georgia (after Kiknadze, 1993)
 Legend: 1- Longshore sediment drift direction and relative capacity; 2 - Direction of fine grained sediments migration; 3 - Partial loss of sediments towards the deep sea through canyons; 4 - Canyon heads; 5 - Cliffs in hard rocks (metamorphic and eruptive); 6 - Cliffs in conglomerates, sandstones, marls, schists; 7 - Soft rock and flat relief; 8 - Non-consolidated deposits (pebbles, gravels, sands) forming beaches, terraces, coastal dunes; 9 - Lacustrine and lagoon deposits.

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	<p>7. Aderba River - Myskhako Mountain section, subdivided into: 7.1. Aderba River -Cape Thick 7.2. Gelendzhik Bay 7.3. Cape Thin-Doob Cape 7.4. Novorossiysk Bay</p>	66.0	Abrasive coast formed by relatively resistant rocks (flysch series), with two major bays of structural origin; In certain sections there are hanging valleys.	Variable littoral drift
	<p>8. Sudzhuk Spit - Anapa section subdivided into: 8.1. Myskhako Mountain -Cape Utrish 8.2. Cape Utrish - Anapa</p>	30.0	Ancient landslides coast; abrasive coast in flysch series rocks	
<p>XIII. Taman- Kerch zone (Anapa - Feodosia)</p>	<p>210.0 km in length. Straightened, abrasive coast composed of loose rocks, in certain sections lagoons with barrier beaches</p>	66.0	Accumulative coast in the Eastern part and abrasive in the Western one	Westward drift in front of the Panagia Cape; Eastward drift in front of lagoons and of the Anapa spit
	<p>1. Taman section, subdivided into : 1.1. Anapa spit 1.2. Salty Lagoon - Zhelezny Rog Cape 1.3. Zhelezny Rog Cape - Panagia Cape 2. Kerch strait and peninsula, subdivided into: 2.1. Kerch strait 2.2. Cape Takil - Opuk Mountain 2.3. Opuk Mountain – Chauda Cape 2.4. Feodosia Bay</p>	144.0	Straightened complex coast in Cape Takil - Cape Chauda subsections; Alternating erosional and accumulative zones within the Feodosia Bay	Northward drift in the Kerch strait; Westward drift from the Cape Takil to the Feodosia
<p>XIV. South Crimean Zone (Feodosia - Balaklava)</p>	<p>221.0 km in length.</p>	<p>General description: mountainous, abrasive coast with gulfs</p>		
	<p>1. Feodosia - Cape Voron, subdivided into: 1.1. Feodosia - Cape Kiik Atlama 1.2. Koktebel Bay 1.3. Karadag subsection 1.4. Meganom Penins. 1.5. Sudak Bay 1.6. Sudak Bay - Cape Voron</p>	79.0	Very complex erosional coast, consisting of rocks with different resistance (for ex. the subsection Karadag is formed by volcanic rocks); The beaches are small and formed mainly by pebbly and gravely material.	

1	2	3	4	5
	<p>2. Cape Voron - Castel Mountain, subdivided into: 2.1. Cape Voron - Cape Tchaban Kale 2.2. Cape Tchaban Kale - Kuru - Uzen River 2.3. Kuru - Uzen River - Castel Mountain</p> <p>3. Castel Mountain - Balaklava Bay, subdivided into: 3.1. Castel Mountain - Cape Ayu Dag 3.2. Gurzuf Bay 3.3. Yalta Bay 3.4. Cape Ay -Todor - Kuchuk Koy 3.5. Kuchuk Koy - Batil.Lagoon 3.6. Batil.Lagoon - Balaklava</p>	<p>43.0</p> <p>99.0</p>	<p>Straightened abrasive coast in rocks of the Tavrik Formation</p> <p>Eosional coast with landslides (Castel Mounts - Kuchuk Koy sections), olistolithes and accumulations of blocks (Kuchuk Koy - Batil.Lagoon) and nonabrasive cliffs and slopes</p>	
<p>XV. West Crimean zone (Balaklava - Bakal)</p> <p>283.0 km in length</p> <p>General description: abrasive coasts in Neogene formations. Straightened and complex coast in tectonic depressions, in the South-Eastern section with gulfs</p>	<p>1. Balaklava - Sevastopol section, subdivided into: 1.1. Balaklava Gulf - Kersones Cape; 1.2. Kersones Cape - Sevastopol</p> <p>2. Sevastopol - Evpatoria section, subdivided into: 2.1. Bay of Sevastopol- Lukull Cape 2.2. Cape Lukull-Kizil Yar 2.3. Kizil Yar - Evpatoria</p> <p>3. Tarkhankut Peninsula section subdivided into: (1) Donuzlavskoye Lake (2) Donuzlavskoye Lake - Tarkhankut Cape (3) Karadzhiinskaya Bay (4) Tchernomorskaya Bay (5) Yarylgatchskaya Bay (6) Cape Karamrun - Bakal</p>	<p>42.0</p> <p>78.0</p> <p>163.0</p>	<p>Abrasive and ingressive coast in resistant rocks</p> <p>Straightened, abrasive coast in the Southern part of the section; Straightened, complex coast in the Northern part; Coast with lagoons in Kizil Yar - Evpatoria subsection</p> <p>Abrasive coast, with accumulative low sections and sometimes ingressive gulfs * Subsection 3.1. Evpatoria-Donuzlavskoye Lake - low, accumulative, with lagoons; * Subsections 3.2. and 3.6. (the two capes) - abrasive; * Subsections 3.3 and 3.4 - ingressive, with submerged valleys and spits at their mouths</p>	<p>Eastward littoral drift, only in the E, close to the Sevastopol gulf</p> <p>Eastward littoral drift in front of the Eastern coast of Tarkhankut Peninsula, especially in the subsection 3.2. Tarkhankut Cape - Donuzlavskoye Lake</p>

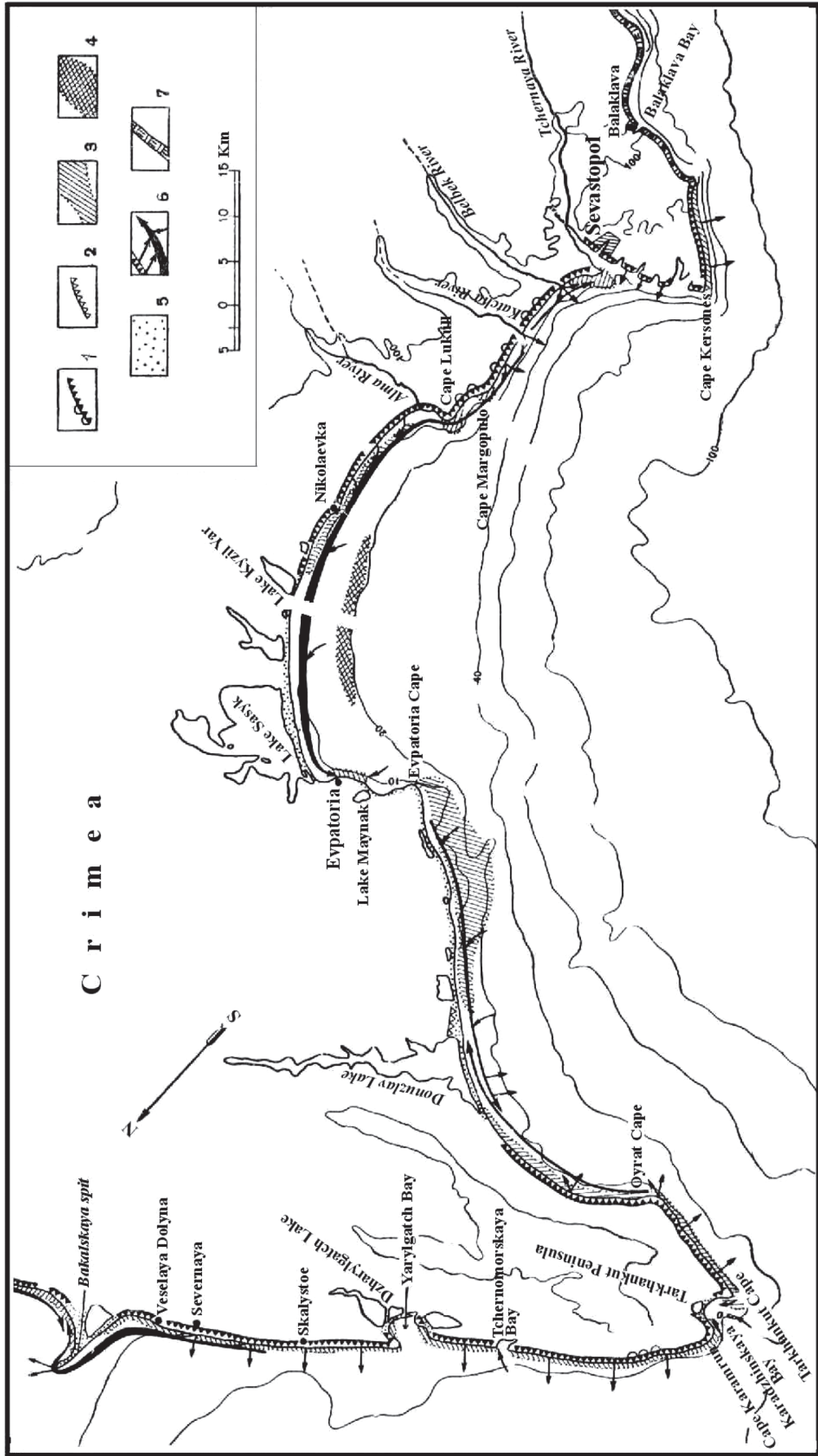


Fig. 5 Coastal zone morphology and sediment dynamics in the Western Crimea region (after Zenkovich, 1960)
 Legend: 1 - active cliff and landslides; 2 - fossil cliff; 3 - bench (outcrops of older deposits in the nearshore zone); 4 - lithified deposits; 5 - accumulative littoral bodies; 6 - littoral sediment drift system and its feeding by erosion of coast or of the bottom (the thickness of the arrow corresponds to the intensity of the drift); 7 - non-abrasive cliffs and slopes

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<p>XVI. Karkinit - Dniepr zone</p> <p>618.0 km in length</p> <p>General description: Abrasive and, in certain sections accumulative coast, with large gulfs or lobate-shaped contour</p>	<p>1. Karkinit Bay section, subdivided into:</p> <p>1.1. Bakal Spit</p> <p>1.2. Crimean side of the Karkinit Bay</p> <p>1.3. The landward end of Karkinit Bay</p> <p>1.4. Dzharylgatch Bay</p> <p>2. Dzharylgatch – Tendra section subdivided into:</p> <p>2.1. Dzharylgatch spit</p> <p>2.2. Novo-Alekseevka - Zeleznyi village</p> <p>2.3. Tendra spit (seaward side)</p>	<p>312.0</p> <p>134.0</p>	<p>Abrasive coast in clayey formations - accumulative coast in the 3.1. subsection</p> <p>A system consisting of two long spits, separated by an abrasive subsection</p>	<p>Northward littoral drift in the Bakal spit subsection (3.1) Southward and then Northward drift in front of subsection 1.2</p> <p>Strong Westward littoral drift in front of the Tendra spit; Eastward drift from Zeleznyi village to the end of the Dzharylgatch spit</p>

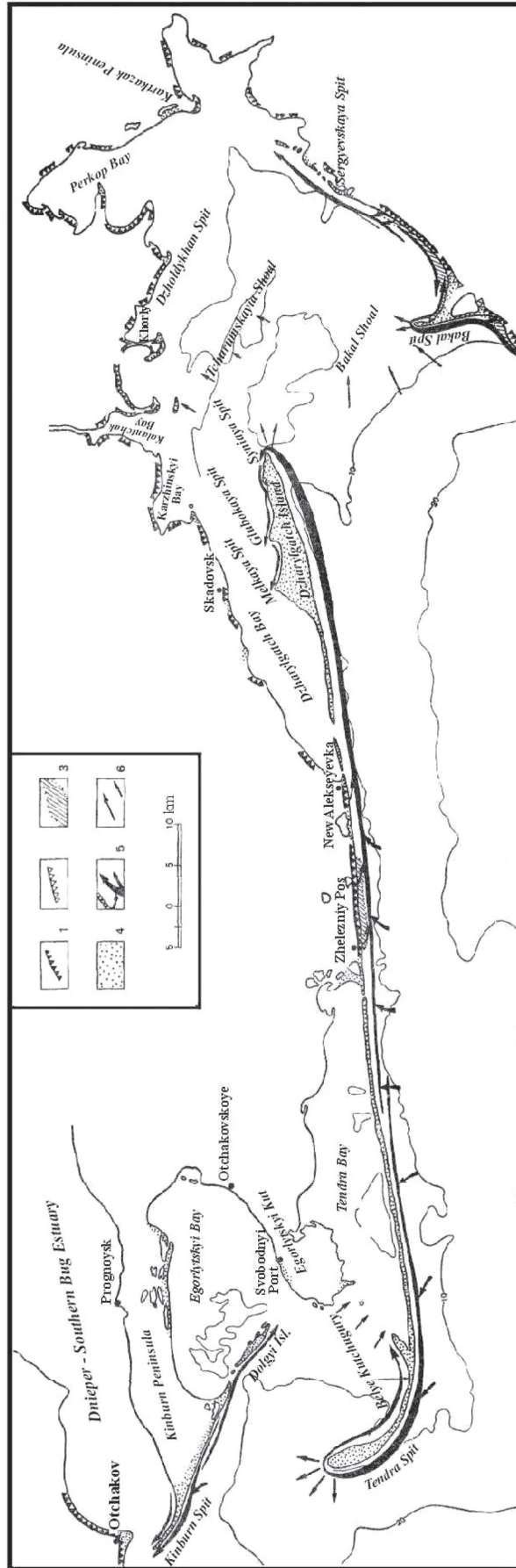


Fig. 6 Coastal zone morphology and sediment dynamics in the Dnieper-Karkinit section (after Zenkovich, 1960)

Legend: 1 - active cliff; 2 - fossil cliff; 3 - bench (outcrops of older deposits in the nearshore zone); 4 - accumulative littoral bodies on the coast; 5 - littoral sediment drift system and its feeding by erosion of the coast or of the bottom (the thickness of the arrow corresponds to the intensity of the drift); 6 - supply of sedimentary material to the underwater accumulative ridges (shoals) or its discharge to the deeper zones

1	2	3	4	5
	<p>3. Tendra Bay – Kinburnskaya Spit, subdivided into: 3.1. Tendra Bay 3.2. Egorlytzkiy Kut Peninsula 3.3. Egorlytzkiy Bay 3.4. Island Dolgyi 3.5. Kinburnskaya Spit and Peninsula</p>	172.0	<p>Predominantly accumulative coast with large gulfs and long spits: * 3.3. subsection - accumulative coast; * 3.4. subsection - “independent”, separated, accumulative spit; * 3.5. subsection - a long spit and an erosive zone</p>	Westward littoral drift in front of Kinburnskaya spit; Eastward drift in front of Island Dolgyi
<p>XVII. NorthWestern Black Sea zone</p> <p>233.0 km in length General description: from Otchakov to Zhibrieny - straightened, complex coast, with lagoons</p>	<p>1. Otchakov - Odessa Bay section, subdivided into: (1)Otchakov - Cape Adzhyask (2)Cape Adzhyask - Cape North-Odessa (3)Odessa Bay</p> <p>2. Odessa town section (Cape Bolshoy Fontan Cape – Odessa Port)</p>	77.0	<p>Accumulative coast with lagoons and landslides: Subsection (1) - complex abrasive and accumulative coast; Subsection (2) - abrasive coast with landslides; Subsection (3) - accumulative coast from the Cape Odessa North to the port of Odessa (~7.5 km in length); it is a large barrier beach limiting the lagoons Kuyalnik and Hadjybay, concave in shape.</p>	<p>North-Eastward drift in the Western part of the section and South-Eastward drift in its central part; in the Cape Adzhyask - Otchakov subsection Eastward drift</p>
	<p>3. Bolchoy Fontan Cape - Dniestr Lagoon, subdivided into: (1)Bolshoy Fontan Cape – Sukhoy Lagoon subsection (2)Sukhoy Lagoon – Dniestr Lagoon subsection</p>	12.0	<p>Abrasive coast with cliffs and large landslides. The landslides affect all the succession of deposits constituting the cliffs: Pontian limestones, Meotian marls and Quaternary loess formation. The relief of the coastal zone presents three to five terraces formed by sliding of large blocks of deposits mentioned above</p>	<p>North-Eastward drift. The drifted material is brought by the littoral drift system from the coastal section placed to the South. This material is represented by fine to medium sands.</p>
	<p>4. Dniestr Lagoon – Zhebriany section, subdivided into three subsections: (1) Dniestr Lagoon – Budaki village; (2) Budaki – Cape Burnas (3) Cape Burnas – Zhebriany village</p>	44.0	<p>Abrasive coast with cliffs and lagoons: The subsection 1 - cliffs in Pontian limestones, Meotian clays and Quaternary loess deposits. Sometimes important landslides affecting all the succession of deposits occur. The subsection 2 is formed of cliffs in loess deposits (sometimes with land slides and incisions cut by temporary torrents) at its Northern part and of a spit limiting the Dniestr lagoon at its Southern end. The spit can be divided in three parts: the Northern part (~4 km long and 0.7 km wide), the middle part (~4 km long) and the Southern segment (~2.5 km long). Between the central and Southern parts lies the only inlet into the lagoon (Tzaregradskiy inlet, water depth about 5 m).</p>	<p>Strong North-Eastward littoral drift; the sedimentary budget is supplied by the erosion of ancient onshore and near-shore and cliff deposits. The drifted material is represented by medium to coarse sand and small pebbles supplied by the bottom and littoral erosion of older deposits.</p>
	<p>~ 100 km</p>	<p>Straight coastline oriented to SWS. The coast is formed by loess deposits, gently deepening to the South. The section is characterised by the existence of abrasive cliffs and large lagoons. The three subsections mentioned in the column 2 can be described as follows: Subsection (1) – spit limiting the Dniestr and Budaki lagoons; Subsection (2) - abrasive coast with cliffs in loess deposits; Subsection (3) – sandy spit limiting large salty lagoons Burnas, Alibei, Shagany, Kunduk. The Southern end of the subsection is formed of juxtaposed littoral bars constituting an accumulative formation.</p>	<p>Strong South-Westward littoral drift supplied by the erosion of ancient nearshore deposits and by the abrasion of cliffs</p>	

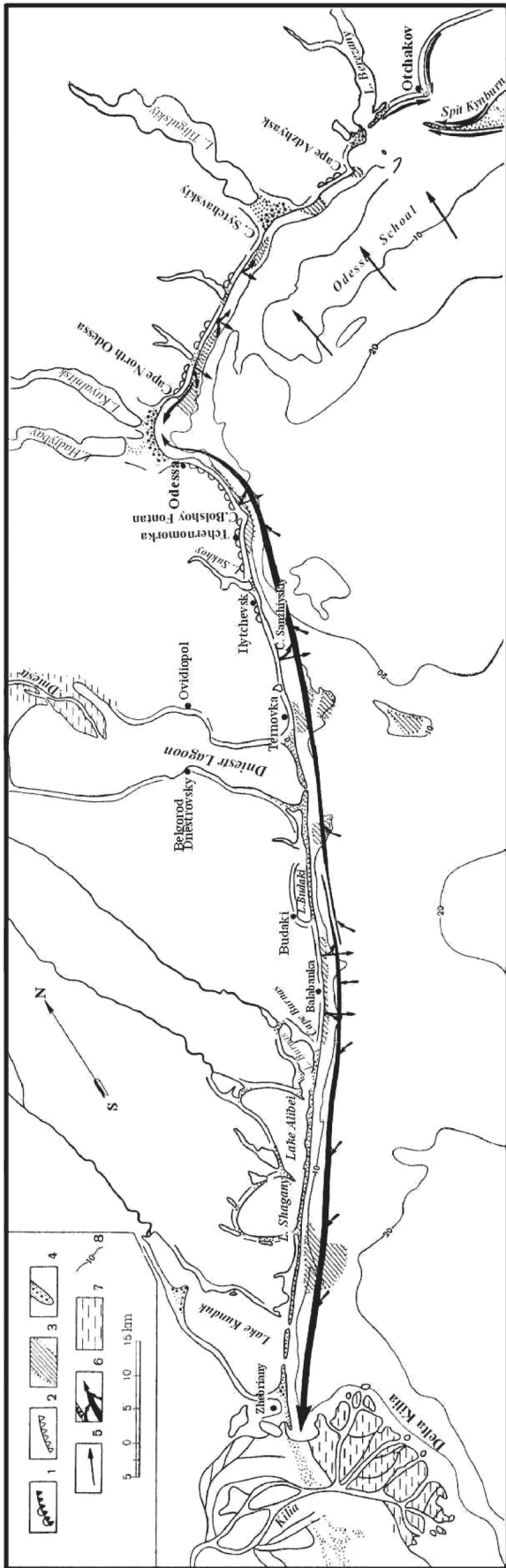


Fig. 7 Coastal Zone Morphology and Sediment Dynamics within the Dnieper mouth zone - the Danube Delta section (after Zenkovich, 1960)

Legend: 1 - active cliff and landslides; 2 - fossil cliff; 3 - bench (outcrops of oifer deposits in the nearshore zone); 4 - accumulative littoral ridges and beach ridges; 5 - supply system of material eroded from the bottom to underwater accumulative ridges; 6 - littoral sediment drift system and its feeding by erosion of the coast or the bottom (the thickness of the arrow corresponds to the intensity of the drift); 7 - delta area; 8 - contour lines in m.

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