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The rivers of the Black Sea

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This document presents the result of a study of the discharge of river water and river load into the Black Sea. The volume of river water and load is investigated by individual river, by region and in total over the whole sea. The data used here came from hydrometric observations, field studies and calculations.

This book is intended for Black Sea researchers - geographers, geologists, hydrologists and oceanologists.

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Introduction

The Black Sea, or the Euxine Sea or Pontus Axeinus as it was known in antiquity, is one of the cradles of civilisation. The history of mankind is deeply rooted in its shores. It has always been a lodestone for travellers and researchers because of its strategic position and the richness of its natural resources. The Euxine Sea was well known to the peoples of the eastern Mediterranean littoral. The first records we have of the Pontus Axeinus date back to the 5th century BC. The voyage of Jason to Colchis is described with a fair degree of verisimilitude in the myth about the Argonauts, which began in the 13th–14th centuries BC, and there is a description of the Euxine Sea in Homer's Odyssey. Herodotus, Strabo and Ptolemy have left us a host of meticulously collected information, and a detailed description of the shores and estuaries can be found in Polybius' Histories (201–120 BC) (6, 109, 115).

Proper hydrographic study of the Black Sea was begun at the end of the 18th century. The first accurate charts of the entire sea were drawn up in 1825–36 by Captain Mangarani, and Black Sea navigational directions were published in 1851. Comprehensive studies of the Black Sea, its shores and waters, were begun in the second half of the 19th century (43,115).

The Black Sea is now one of the most studied of all the marine basins on our planet. This has engendered a requirement for more precise data from additional research such as the balance between water and river load, sediment formation and a wide range of other subjects. The situation has been made more complex in recent years by the ever-increasing level of pollution, with its links to the outflow of water and river load from the surrounding landmass.

Interest in the Black Sea stems not just from its strategic position and the biological richness of its waters. It is also of great economic significance internationally. The economic role of the Black Sea has increased over recent years since, after the disintegration of the Soviet Union, six Black Sea littoral countries (Bulgaria, Georgia, Russia, Rumania, Turkey, Ukraine) reasserted their interest in these waters. Of prime importance to the Black Sea economy is the transportation of cargo, locally and as part of the ancient Silk Route, and the production and transportation of oil. The need to transport oil has driven the recent expansion of the existing ports and there are plans for new ports to be built.

There are many industrial and military sites located around the Black Sea. Moreover, the Black Sea was, in the recent past, an important resort and holiday destination - a fact which must not be lost sight of. While this role diminished throughout the 1990s, the Black Sea resorts and recreational areas have once again begun to attract tourists.

The international Black Sea Economic Cooperation Area (BSEC), comprising the six littoral States and Azerbaijan, Albania, Armenia, Greece and Moldova, was set up in 1992 to exert some control over these complex economic issues.

All these circumstances give support to the conclusion that a new approach to Black Sea issues is necessary, one which will entail meticulous study of the sea's biology, all the more urgent now as human life has more and more negative impact on the already poor ecological condition of the sea.

This new raft of work will attempt to quantify the amount of river discharge — water and load — disgorging into the Black Sea. Much is expected from a study at this level. The aggregate amount of fresh water entering the sea is still known only approximately; precise information is long overdue. New data from hydrometric observations and research over recent years has enabled more precise figures to be calculated for the amount of river water entering the Black Sea; these calculations have included the effect of artificial control of the flow.

River load is the factor least studied, in the Black Sea as in other regions. There are other associated issues here, too, such as erosion of riverbanks, artificial beach formation, pollution of the sea etc. These issues are particularly topical now, when shoreline retreat, caused by a decreasing amount of bank-forming deposits, has become irreversible, and are played out against a background of observable increase in the ocean levels worldwide, with pollution in the Black Sea already reaching threatening level. Accurate quantitative assessments of river load reaching the sea are also necessary for any proper research into current sediment formation processes on the sea bottom.

It must also be remembered that the virtually locked water basin of the Black Sea is many ways similar to an ocean, especially in the relation between river load distribution and deposition. Given its more favourable conditions and the less extensive scope of work involved, the Black Sea can be regarded as a natural laboratory (110).

In recent years, with ‘new times’ entering the political situation, the spirit of new times has entered the Black Sea research arena, too, and investigations have become international in character. A Black Sea Regional Committee (BSRC) was set up in 1996 under Unesco’s Intergovernmental Oceanographic Commission, tasked with coordinating and intensifying scientific research on the Black Sea. One of its key projects (pilot project 2: Black Sea sediment fluxes) conducts research into flows of river load into the sea, and our document is part of this project.

1. River-estuary-sea: a unified natural system

> All the rivers run into the sea
> yet the sea is not full
> unto the place from whence the rivers come
> thither they return again.
> *Ecclesiastes*

All rivers flow into oceans, seas and lakes. The inflow of fresh water back into a water basin completes the regular hydrologic cycle. This process has continued ceaselessly for billions of years and will continue while our planet still exists.

The hydrologic cycle begins with evaporation from the surface of the ocean, replenishing atmospheric humidity. Water vapour condensation is followed by precipitation, initiating surface runoff. Precipitation also feeds soil- and groundwaters which then contribute to river formation. The total volume of the hydrosphere is currently 1.5 billion km^3. Ninety-four percent of this volume is concentrated in the oceans of the world, 4 % is derived from subsurface water, 1.6 % is locked in polar ice and 0.15 % is vapour in the atmosphere. Surface fresh water only accounts for 0.25 % of the hydrosphere, or 360 000 km^3. Lakes occupy 278 000 km^3, surface humidity accounts for 81 000 km^3 and 1 200 km^3 is concentrated in river channels. While river channels hold an apparently small volume of water at any one time, the process of water exchange within their bounds is in effect uniquely and extremely active. These channel flows are replaced on average every 11 days — six times more active than the oceans or subsurface waters (56).

The rapidity of this hydrologic cycle means that channel flows process almost 33 times as much water and rivers deliver around 38 830 km^3 fresh water a year to the oceans of the world. (56). A further 3 000 km^3 comes from polar ice (52) and subsurface water contributes 2 400 km^3 (42) to the oceans. In total, the flow of fresh water from the landmass to the Ocean is 44 230 km^3, with the flow in internal (closed) areas boosting this to 45 060 km^3 a year (56).

The hydrologic cycle is a global phenomenon and the process is to a large extent dependent on our planet's physical and geographical features. Even though moisture and water are distributed unequally around the globe, due to the heterogeneity of natural conditions, the hydrologic cycle is ubiquitous and uninterrupted, albeit moving at varying pace, and every droplet of water in the hydrosphere is an integral part of it. To quote Lvovich, 'All waters are conjoined not only in the sense of origin but under the constant action of the hydrologic cycle' (56, p 16).

Along with their water content rivers pour out detrital material into the seas and oceans in the form of sediment load, the result of a complex process of denudation. Along the whole course of a river, from its source to its mouth, the flowing water breaks up, transports and accumulates fragments of rock and ground. Compared with the hydrologic cycle the erosion and deposition process works discretely, in a complex and tight-woven relationship with local natural conditions. The entire face of the Earth as we see it today can be said without exaggeration to be the result of the action of flowing water.

Rivers, as the principal agent of denudation, transport the product of rock pulverisation from higher areas to lower altitudes, with the key processes of erosion and deposition occurring along the whole length of the river. The detritus (products of erosion) finally accumulates in the seas and oceans, initiating the formation of sedimentary facies. Sediment load from rivers is the main contributor of solid material to the ocean. A P Lisitsyn (59) considers that solid load represents 73.1 % of the terrigenous sedimentary material involved in ocean sedimentation. Of the remaining fraction of the load thus discharged from the landmass to the sea, 12.7 % is made up of dissolved substances, 6.4 % is aeolian-derived and 1.9 % the products of abrasion. The work carried out by other researchers is in broad agreement with these statistics on sediment load; Makkaveev (65) calculates the ratio of sediment load at 72.3 %.

Opinion is still divided however on the exact quantity of river load reaching the Ocean. Wildly differing estimates are put forward by various authors, with figures fluctuating between 12.7 billion tonnes and 51.1 billion tonnes a year (see Table 1.1). Research undertaken since 1960 has produced more coordinated results which vary between 15.0 and 21.7 billion tonnes a year.

Table 1.1

Annual discharge of sediment load from rivers into the world ocean: estimates put forward by different authors

Author	Year	Sediment load, billion t/year	Discharge volume per unit of area, t/km^2-year
R. H. Kunen (128)	1950	32.4	314
G. V. Lopatin (62)	1952	12.7	124
I. Gilluly (123)	1955	31.8	315
D. Pechinov (81)	1959	24.2	238
F. Fournier (122)	1960	51.1	570
S. A. Shumm (135)	1963	20.5	200
G. N. Holeman (125)	1968	18.3	180
M. I. Lvovich (55)	1974	21.7	180
A. P. Lisitsyn (59)	1974	18.53	180
V. V. Alekseev, K. I. Lisitsyna (72)	1974	15.7	151
G. A. Safyanov (89)	1978	21.3	207
J. Milliman (131)	1981	16.0	150
N. I. Makkaveev (65)	1981	17.0	165
J. Milliman, R. Meade (132)	1983	15.0	150
J. Milliman, G. Syvitsky (133)	1992	20.0	187
A. P. Dedkov, V. I. Mozzherin (26)	2000	15.5	158

Milliman and Meade (132) write that in the second half of the 20th century there was a significant decrease in the amount of sediment load discharged into the ocean due to sedimentation of controlled rivers in reservoirs. They estimate the load to be no greater than 15 billion tonnes a year. Of this amount, 13.5 billion tonnes is suspended material carried along by the rivers and about 1.2 billion tonnes is tractional (bed) load which is brought to the ocean by flood water (71, 132). Milliman and Syvitsky (133) calculate that, under natural conditions (without the effect of reservoirs in the flow line) the total sediment load discharged into the ocean would be 20 billion tonnes a year.

It is important to remember that sediment load has two components: the first is the natural component, formed through erosion under natural conditions, and the second is anthropogenic, the result of increased erosion and sediment load due to human activity, primarily agriculture. According to Milliman (71), it can be argued that 2600 years ago (before land cultivation developed) all the rivers of the world together transported less than 7 billion tonnes suspended and tractional solid material to the ocean.

Now, according to the UN's Food and Agriculture Organisation, around 30 % of the planet's land is used for pasture and cultivation and these processes have changed the natural vegetation mainly in areas which were predominantly covered with forest. Dedkov and Mozzherin (26) believe that as a result of this the contribution to the total sediment load discharged into the ocean (15.5 billion t/year) attributable to the anthropogenic component is 9.5 billion t/year (61.3 %) while the natural component supplies 6.0 billion t/year (38.7 %).

The river load is not discharged evenly around the world. More than 95 % of the outflow into the ocean is in the northern hemisphere and the greater proportion of this is from the rivers of the Asian continent. The Ganges, Brahmaputra and Huanghe and Yangtse alone supply 25 % annually of the total load mass. Sediment load is extremely zonal in nature. In northern latitudes, between 20° to 30°, more than half the inflow is alluvial. Most of the load is discharged into the Indian and Pacific oceans.

During its course from land to sea a proportion of fluvial deposits lodges in the coastal zone of the seas and oceans where it forms littoral and marine deposits or coastal load. The coastal zone itself is a margin area between land and sea where the interchange between them occurs. The upper boundary of the shore zone is usually taken to be the line reached by the uprushes of the worst storms and the lower boundary is the isobath or submarine contour line where wave motion ceases to have an effect (44, 61).

The shores of the ocean and the seas have developed out of the play between four main biogeographical interfaces of the Earth: the lithosphere, hydrosphere, atmosphere and biosphere. The dynamic of their interplay on the formation and changing nature of coastal zones has in turn been encouraged or limited by the background of geographical features such as the nature of the contiguous land, the fall of a submarine slope or even the latitude in which the zone lies. Different types of coastline emerge, depending on the dominance of one of the main factors (44). In recent decades a new factor, the anthropogenic factor, has come into play, with an ever-increasing role.

Accumulative coastlines are built up by the deposition of littoral and marine sediment. If the load is of river origin the shores are alluvial and accumulative. The formation of this type of coastline is the result of local action, the rivers carrying sand, gravel and pebbles offshore in the estuary and wave action dispersing this alluvium along the coast. Alluvial accumulative banks are widely found in temperate latitudes. They are formed in localities where there is a large number of small rivers whose sediment load is not large enough for delta formation and the wave factor is responsible for distributing the alluvial material along the coastline. An outstanding example of this is the Black Sea, with the overwhelming majority of its shores conforming to this pattern.

In general, the coastal zone is a filter for material coming to the ocean from the land; it is a holding area where terrigenous material is retained for subsequent processing or long-term storage, gradually feeding it out to other zones (61). In this process river mouths have a major role to play. They are the river-sea frontier where alluvial material is differentiated and graded into coastal (littoral-marine) and ocean (pelagic).

Fluvial alluvium reaches the river mouth as suspended and tractional load, the mode of dispersal entirely dependent on the particle size of the load itself. Usually bedloads, almost in their entirety, become coastal. Suspended loads of large particle size may also become coastal and this is often the case with mountain rivers. Division of loads between coastal and marine is usually by particle size; particles larger than 0.25 mm are beach-forming and found on steep pebble banks while particles larger than 0.1 mm are found on sand banks. The information on river loads presented in various sources in the literature almost always focuses on suspended loads, as regular observation of bedloads is only carried out in certain individual cases and there have been significantly fewer observational studies carried out on bedload than on suspended load.

The loads discharged in estuaries are then exposed to the effect of marine factors. There are now two zones of sediment accumulation, a wave coastal sediment accumulation zone and the non-wave coastal sediment accumulation zone (79). Dolotov (40) identifies three dynamic types in modern littoral-marine deposition on a shallow shelf, corresponding to three facial zonalities: firstly, the outer, offshore, zone of the submarine coastal slope; secondly, a zone of submarine bars, ridges and linear depressions; and thirdly, the beach or shore zone.

Large-particle alluvium derived from bedload and large suspended particles form the submarine alluvial fans and foredeltas. Usually fresh river water transporting large quantities load in suspended form does not mix with sea water but flows out over the surface in a 2–3 m layer. Fluvial fresh water, even saturated with load, is always lighter than sea water. The Inguri and Rioni rivers are examples of this. At maximum turbidity, the density of the water in these rivers is 1 006 kg/m3 while the density of the undiluted sea water at the mouth is 1 017 kg/m3 (54).

In the marine area, after the river flow has lost contact with the bottom, the bed load continues to push forward, partly as a result of inertia but mainly due to wave action. The suspended load separates out of the river flow as ‘sandy rain’. The particle size of this ‘rain’ and its vigour are always greater the closer the precipitation occurs to the river mouth. Once out at sea, the river flow delivers only silty and pelitic non beach-forming particles. In tideless seas, however, solid substances are usually transferred by wave and current action as has been shown by studies of hydrogenic transport of sedimentary material.

The river loads thus accumulated along the littoral form continental or coastal deposits while the finer component of the discharge, not coastal in terms of its hydraulic profile, is carried out over a larger area and becomes part of the marine sediment formation process.

Typically, each river carries to the coastal zone marker rock found only at its own drainage basin. This makes it easier to establish boundaries for the distribution of discharge load by each individual river (48).

To sum up, we can conclude that river sediment load plays a decisive role in the formation of alluvial and accumulative shores. The amount of suspended matter, and hence the process of sediment formation in the deeper parts of the sea, is a function of the discharge load. Coastline formation and marine sediment formation are likewise dependent on the adjacent landmass, and rivers, which furnish the sea’s coastal zone with the product of rock disintegration and destruction, are the arterial link between land and sea.

In a word, fluvial valley, river mouth, coastline and sea are all part of a single yet complex arrangement in nature. The river-estuary-sea system has therefore to be examined as a unified natural system - an organic whole.

2. Natural features of the black sea coastline

Lying between Europe and Asia, the Black Sea is one of the most interesting and singularly unique areas of the ocean. Its basin is asymmetric and the rivers that flow into it shape the dramatically different natural conditions of two continents. The sea itself covers a total area of 423 000 km^2 while the basin it represents draws on an area covering 2.5 million km^2 (109).

Its north-eastern shores are the margins of mountain spurs which reach down from the Caucasus to the sea while its eastern coast borders the Colchis Depression and its south-eastern shores meet the Lesser Caucasus range. In the south, the Anatolian coastline fringes the Pontic Mountains. The western coast delineates the boundary of the Balkan peninsula and in the north the sea laps the steppes of the East European Depression.

The Black Sea coast of the Caucasus runs over 725 km from the Taman peninsula (Cape Panagia) to the border between Georgia and Turkey, slightly south of where the Chorokhi enters the sea. Vertical zonality is the dominant feature here in the Caucasus region of the Black Sea basin. The relationship between climate and hydrology is clearly marked, as it is between other natural features and the high altitudes of the area. The highest point in the Black Sea basin is here; in the heights above the Inguri, Mount Shkhara rises to 5 068 m.

There are six regions in this area of the Black Sea basin, easily identifiable in terms of physical geography: (1) the smaller heights of the northwest Black Sea Caucasus; (2) the middle ranges of the Black Sea Caucasus; (3) the high peaks of the west and central Caucasus; (4) the foothills of the Greater Caucasus; (5) the Colchis Depression; and (6) the western part of the Lesser Caucasus (15).

The climate in the Caucasian lowlands is humid and subtropical, gradually becoming subnival with altitude and nival at higher levels, in the 'top storey' of the snow and ice cover.

There are great contrasts in the geographical distribution of precipitation because of the complexity of the relief and the proximity of the sea. In general there is a marked increase in precipitation from north to south (Anapa 452 mm, Novorossiisk 724 mm, Tuapse 1 264 mm, Sochi 1 490 mm, Sokhumi 1 530 mm, Poti 1 831 mm, Anaseuli 2 330 mm, Batumi 2 685 mm). Precipitation also increases with altitude. More than 3 000 mm fall around the upper courses of the Bzyb, 3 000 mm in the headwaters of the Inguri and 2 000 mm feed the high waters of the Rioni. Not far from Batumi, on Tsiskara (Mtirala), 4 519 mm precipitation a year falls at an altitude of 1 210 m. This is the wettest spot in the entire Black Sea basin (14, 96).

The Black Sea Basin rivers can be divided into three categories:

(1) large rivers which rise high in the mountains, with a catchment area of more than 1 500 km^2 and an average annual flow of more than 100 m^3/second (Bzyb, Kodori, Rioni and Chorokhi). The Inguri also belonged in this category before it was artificially controlled;
(2) rivers of average size with their sources in the spurs of the Caucasian and Meskheti ridges, with a water catchment area of 100 to 1 500 km^2 and an average annual flow of 5 to 50 m^3/second (Pshchada, Vulan, Shapsukho, Tuapse, Ashe, Psezuapse, Shakhe, Sochi, Mzymta, Psou, Khashupse, Khipsta, Aapsta, Gumista, Kelasuri, Madjarka, Mokva, Galidzga, Okumi, Khobi, Supsa, Natanebi, Kintrishi, Chakvistskali);
(3) Small rivers with a catchment area of 50 to 100 km^2 and an average annual flow of less than 5 m^3/second (Mezyb, Dzhubga, Tu, Nebug, Agoi, Dagomys, Matsesta, Khosta, Kudepsta, Zhove-Kvara, Besleti, Tumush, Korolistskali etc.).

Apart from these, there are within the boundaries of the Caucasus a great many rivers draining into the Black Sea whose catchment area is less than 50 km^2 and whose loads and discharge have little impact on the sea's major systems.

Large alpine rivers are usually swollen in the Spring and this is the time of year they bring down the greatest quantity of river load. These floods are caused by thaw waters combined with rain from seasonal peak precipitation. In addition to the Spring spate, rivers of average size often have major floods in the autumn-winter period. When swollen, they sweep more than half the annual amount of load down to the river mouth and offshore; the rest of the load comes down with the autumn and early winter floods. For the small rivers, especially in the Colchis Depression, high water levels are not typical. It is usually rainwater flooding that drives along the load in these rivers, and only in small quantities. In contrast to the rivers of the Colchis Depression the small mountain rivers often produce flash flooding in the Spring when their high water levels carry along around half the annual amount of load.

Altitudinal zonality can be clearly seen, too, in the way runoff water forms and rivers are fed. The runoff layer increases with altitude. Alpine rivers are fed from different types of sources, but predominantly from snow and ice runoff. The melt water component often represents 35–45 % of the water draining into these rivers while the rainwater component is 20–30 %. Rivers rising in mountain ranges of medium altitude are also fed from a variety of sources, though, in this case, predominantly from rainwater runoff (45–65 %), the proportion of thawed snow waters never being more than 15–25 % in these rivers. Small rivers in the Depression are mainly fed by rainwater (70–85 %). Snow water may, however, be an important source of runoff draining into small alpine rivers (14, 28).

There is a significant rise from north to south in unit discharge, from 6–7 litre/second·km^2 to 70 litre/second·km^2. The runoff layer also increases with altitude; in the Colchis Depression the unit discharge is less than 25 l/sec·km^2 while in the headwaters of the major rivers it is greater than 60–70 l/sec·km^2. An exception is the Adjara, where the discharge in several of its gorges does not vary, or only decreases slightly, with altitude (14, 28).

Both the morphology and the dynamics of the river channel affect the flow's transport of load and deposition at sea. The river channel is itself shaped and determined by a complex system of natural phenomena constantly flowing through the river's entire catchment area. Indeed, river channel processes are just as subject to zonality as other natural phenomena (64, 107, 108).

The way the river channel formation changes along the length of a river is most clearly seen in alpine rivers, where the source is at the altitude of the snow and ice zone and the mouth is at sea level. In alpine conditions, with the rivers transecting every natural zone and terrain, the conditions which govern the river load transport and river channel formation also change. Given the huge differences in the processes occurring in mountain and lowland rivers, river channels can be classified into three types: alpine, subalpine and lowland (4, 64). Chalov (107) has subdivided alpine rivers into river channels with developed alluvial forms, with undeveloped alluvial forms and ones with cataracts and waterfalls (broken water).

River channel processes and the movement of river load in alpine rivers are more complex and diversified than in lowland rivers. The main difference is the high kinetic activity of alpine flows, the undulation of floodwaters and the commensurability of the depth of flow and particle size in the fluvial deposits. In lowland rivers arenaceous bedloads are usually transported as bottom layers. In alpine rivers, however, when river flow is very fast, there is a 'flat phase' in the transport of load. As the gradient of the slopes decreases and the rate of flow in the channel slows down, alluvial ridges (dunes and antidunes) composed of large-particle size pebbles start to form. Another factor in this process is that the various forms of load transport are by nature temporary and change with season and with the drive produced by high water levels. Load transport also vary with river size (34, 107, 108).

All possible types of river morphology and dynamics are to be found in Western Transcaucasia, due to the clearly defined zonality of the natural phenomena and the huge drops in distance via cascade and waterfall. Even though catchment areas are relatively small, all the main features of river channel morphology and dynamics (slopes, flow rates, volume of water, flood-plain formation etc.) change along the length of the rivers. The Rioni, for example, stretching for 327 km from source to mouth, changes from being a high-altitude alpine river with cascades and cataracts to a typical lowland river.

In the ridges of the Caucasian ranges bordering the Black Sea, the rivers come down from the mountains from different absolute altitudes, with, in the majority of cases, a variation of between 100 and 200 m, depending on the orography of the basin. The river channels fall steeply to the mountain apron; at their headwaters the drop is usually steeper than 100 metres per kilometre, in the middle ridges it varies between 30 and 80 metres per kilometre and once the river has shot out of the gorges the downward gradient is reduced to 0.5–5 metres per kilometre.

While the cataract-waterfall (broken water) type of river channel is broadly typical of the headwaters of these rivers, it also features lower down in the middle ranges and even near the coastline (Matsesta, Mekhadyr, Zhove-Kvara, Gagripsh etc.). The high kinetic energy of the flow in these rivers transports the product of rockfall and scree without difficulty. Alpine rivers with undeveloped alluvial forms are usually found in the upper courses of all the major rivers, they generally occupy the least area. Alpine rivers with developed alluvial forms are usually restricted to the middle ranges but may form these channels close to the sea. Subalpine channels are a typical feature of the foothills and are often encountered in the coastal zone.

While channel process characteristics are not constant but change with the season and the time of year, the general features of the channel, dependent as they are on the local relief of the terrain, are retained.

The various characteristics of river channel processes have a significant effect overall on the discharge of river load into the sea, particularly on the dynamics of the process in the coastal zone; volume and particle size is a factor of their force and intensity. Thus, the altitude and slope of the adjacent landmass have a significant impact on the morphology of the shoreline and marine deposition, an impact regulated by change in channel processes along the whole length of the river.

The southern, Turkish, coastline of the Black Sea ranges over 1 450 km and stretches across two continents. This area can be divided into three regions, in terms of its physical geography:

(1) the coastal North Anatolian Highland province, stretching parallel to the coast for 1 150 km from the frontier with Georgia to the Sakarya river;
(2) the lowlands of the Kocaeli peninsula, from the Sakarya to the Bosporus (140 km);
(3) the hilly terrain of the Çatalca peninsula, or Eastern Thrace, the European part of Turkey, from the Bosporus to the Bulgarian border (160 km).

The North Anatolian Highlands which stretch along the coast of the Black Sea are not a continuous chain and are cleft in several places by deep valleys running parallel to the coastline. Only the deltas of the Yesil-Irmak and the Kizil-Irmak and the Ince Burun peninsula (Sinop promontory) level out, in the middle of the region, into wide coastal plains. These ranges are further subdivided into the Eastern Pontic (from the Chorokhi to the Kizil Irmak, a distance of about 590 km) and the Western Pontic (from the Kizil Irmak to the Sakarya, about 560 km) (23, 67).

The Northern Anatolian Highlands form an important climatic boundary. Humid air masses in the west and north shed their moisture on the sea-facing slopes which are completely covered right up to 2000 metres with forest and scrub, with grassy meadows above them (67). At the extreme eastern end, in Lazistan, the climate is humid and subtropical, as in Colchis. The amount of precipitation decreases from east to west (Rize - 2532 mm, Trabzon - 863 mm) (96). After Trabzon, the climate gradually becomes a more Mediterranean type of subtropical. The Harsit can be considered the boundary of this zone.

The stretch from the Chorokhi to the Harsit, 260 km of coastline, abounds with rivers. Around thirty of them have a catchment area of more than 100 km^2, though no more than 500 km^2. Among the largest are the Abivice, Firtina, Kolopotamus, Karadere and Degirmen. Due to the high humidity level they carry a lot of water, their unit discharge rate being 20 l/sec·km^2, on average. They are mostly fed by snow and rainwater, and from April to the end of June water levels are not very high. Heavy rains can cause peak flooding, often in the autumn-winter period. Rainwater flooding is so frequent an occurrence that low water discharge is not a significant factor.

The river basins have steep slopes, and river channels, even close to the sea, are more alpine in character, with developed alluvial forms. In the mountains, all the rivers have many cataracts and waterfalls.

The largest river in the Eastern Pontic Mountains is the Harsit, with a catchment area of 3 500 km^2. In its lower course, near the sea, its current is slow, sand predominates in its floodplain and its channel could be classified as subalpine.

To the west of the Harsit the mountains gradually reduce in height and wide valleys frequently spread out between them. While the total annual precipitation in Giresun is 1 374 mm, to wards the west this figure falls to 730 mm at Samsun (23, 96).

The rivers in this region (such as the Yaglidere and Melet-Irmak) have large basins, up to 1 000 km^2 in area, but their water levels are not high and their unit discharge is less than 10–15 l/sec·km^2. They are fed by snow and rainwater. In addition to high levels in the spring, there is frequent strong flooding throughout the entire year, most often in the autumn-winter period. In the mountains, cataracts and waterfalls are typical of the river channels while near the sea the channels become subalpine. In general, zonality in the Eastern Pontic Mountains is vertical, as can be seen in the formation of discharge and load, in channel formation processes and in the transport of alluvium.

The western extremity of the Eastern Pontic Mountains is the birthplace of one of Turkey's major rivers, the Yesil-Irmak, 519 km long with a catchment of 36 129 km^2. The river rises in the Tozanli Mountains, where cataracts and waterfalls form its river channel. Emerging from the mountains, the river flows through a wide valley. Here the river channel is 200–300 m wide and its bottom is composed of sand and pebbles. In the lowlands the river divides into separate branches with sandy channels and in this area too there are many artificial drainage canals. The river load has formed a large delta plain with marshy fringes. In its lower course the rates of flow are very slow and the river here seems typical of a lowland plains region. Offshore in the delta, there are sandy shoals and banks.

The Kizil-Irmak, 1 355 km long with a catchment area of 78 646 km^2, is the largest Turkish river flowing into the Black Sea. It rises in the Kizil Dagi, deep in Anatolia. Starting as a typical alpine river it gradually becomes a river of the plains and lowlands, where its main course is 100-300 m wide and its bottom sandy. It is peppered with many islands, has low banks and an arenaceous or muddy bottom. Its discharge is rigorously controlled. It reaches the sea near Bafra, through a wide coastal plain. At sea, near its mouth, there are well-defined underwater shoals.

Compared with the Eastern, the Western Pontic Mountains are more rounded, divided in many places by wide valleys. Annual precipitation increases to the west (Sinop 754 mm, Inabolu 1 300 mm, Zonguldak 1 330 mm) (67, 96). This is an area of many small rivers which fall separately into the sea. The largest of them are the Kodjacai and the Hoja-Irmak, with basins spreading over 1 000 km2. Their unit discharge is around 10 l/sec·km^2. In winter water levels are high but in summer the smaller rivers dry out.

The largest river in the region is the Filyos, 228 km long with a catchment of 13 156 km^2, which rises in the Köroglu Mountains. Flooding is typical of the river, especially in the autumn. In its lower reaches the river flows peacefully through a wide level valley. The river bed here is about 100 m wide, branching, with many sandy islands scattered in it.

After the Filyos we reach the start of the Kocaeli peninsula which is lowland in character with gradually rising uplands, never higher than 442 metres. The climate here is one of comparatively mild winters (6°C), a significant amount of precipitation (more than 800 mm a year) and frequent humid winds off the sea (23, 67). To the west, the terrain gradually drops and several small rivers enter the sea here. Unit discharge in this region is 10 l/sec·km^2.

The Sakarya, 824 km long, with a catchment area of 56 504 km^2, flows through the Adapazari plain and reaches the sea near Karasu. The unit discharge of this river is less than 3.15 l/sec·km^2. As it crosses the plain, the river channel is 100–200 m wide, with low banks and gentle curves. Further on, before the Bosporus, there are several small rivers which flow into the sea, the largest of these being the Riva, with a catchment area of 880 km^2. On nearing the sea the Riva produces a wide sandy floodplain. The channel here is around 100 metres wide, with low banks and gentle curves, and only the occasional steep escarpment (23, 67, 116).

After the Bosporus, in Eastern Thrace's hilly peninsula of Çatalca, the climate becomes drier and the landscape changes to steppe, with low mountain ranges in the north-west. The Istranca gradually rise and expand towards the Bulgarian frontier. There is a watershed along these mountains, between the Black Sea, the Aegean and the Sea of Marmara. Several small rivers, with insignificant discharge, feed into the Black Sea in this region.

The major rivers in the Turkish part of the Black Sea Basin (Kizil-Irmak, Yesil Irmak and Sakarya) and several of the middle-sized rivers (Riva, Karasu, Gyulyuk) are under pressure from the impact of human activity. Intensive management of the rivers (controlling flow with reservoirs and using water for irrigation and power) began in the 1950s and by now about 15 different kinds of dams have been built along these rivers and more are planned (141).

On the western, Balkan, coastline of the Black Sea the climate is of a continental Mediterranean type. In Bulgaria, five different regions can be delineated, from south to north, in terms of their geography and physical features: the Istranca, Burgas, Stara Planina, Varna and Dobrogea coastlines (7, 10). The amount of precipitation decreases from south to north (Tsarevo 682 mm, Burgas 553 mm, Varna 502 mm) (96).

In Romania, the low limestone plateau of Dobrogea occupies the stretch of land between the lower course of the Danube and the Black Sea. Its central part is the lowest and the Tulcea plateau rises in the north west, with its highest point at Tsutsuyat (459 m). Total annual precipitation is 350–400 mm (Constanta 400 mm, Sulina 365 mm) and the maximum amount of precipitation falls in June, the minimum in February (96).

Other major rivers on this western coastline of the Black Sea are the Camcea and the Velika but their discharge is tightly regulated and used in water distribution systems and cultivation. All the other rivers are small (catchment areas of less than 500 km^2) and their waters come from the low hills of Istranca, Stara Planina and the eastern part of the Danubian lowlands which are not very humid. The outflow of water at the river mouths is not significant and the unit discharge is no more than 4 $l/sec \cdot km^2$. In the northern part, after the Batova river, the terrain changes to karst and there are hardly any constant water courses.

A typical feature of the western coastline of the Black Sea is the number of 'limans' (lagoons and embayments) with many smaller rivers draining into them (91).

The main feature of the north-western part of the Black Sea is that it has so many major rivers pouring into it, rivers which have their source far away from the sea, in the Alps, the Balkans, the Carpathians and east European Platform.

The magnificent delta of the Danube opens up in the northern part of the Romanian coastline. The delta occupies an area of 5 640 km^2, the river basin covers 817 000 km^2 and the length of the river is 2 860 km. The river has its source in the region of the Alps, in the Schwarzwald mountains and flows through eight countries to the sea. From its source to the region of Vienna (970 km) it is an alpine river; from there to Turnu-Severin (950 km) it gradually becomes a lowland river and then for another 940 km it flows along as a clearly identifiable river of the plains (19, 74, 75, 76).

In contrast to the Danube, the major rivers of Ukraine do not fall directly into the sea. They flow into limans through which they eventually reach the Black Sea (41, 58).

The Dniester, 1 441 km long with a catchment area of 72 100 km^2, starts in the Carpathians at an altitude of about 900 metres. The headwaters can be classified as alpine, and the channel has developed alluvial forms. After the town of Galich the river becomes lowland in features. The river has the Dnestrovskaya and Dubosarskaya hydroelectric plants on its banks, and acts as reservoir for them. Many lakes have been created in its tributaries and throughout the whole basin water is withdrawn from the river channel in large volumes. Gravel has traditionally been taken from the Dniester bed for building materials — in

Moldavia alone 1.5 million m^3 alluvium is removed every year (87).

At 155 km from its mouth the river divides into the Dniester proper and its left branch, the Turunchuk. The Dniestr flood plains, a flat marshy delta system, begin close to the river mouth. The Turunchuk draws off 51 % to 69 % of water discharge and 25 % to 79 % suspended load. Bedloads continue in the Dniester. Reservoirs and quarrying for building materials have a huge impact on the characteristics of the river, and the amount of river load and its particle size has decreased many times over. In its lower reaches, the channel contains mostly fine (30 %) very fine (45 %) particle size sands. The average particle size decreases further down the river to 0.19–0.12 mm (87).

The Southern Bug, 857 km long with a catchment area of 63 700 km^2, runs into the Bug liman, Its basin lies between the Podolsk and the Cis-Dneprian Uplands (Pridneprovskaya vozvyshennost) and its lower courses flow through the steppes of the Black Sea lowlands with its Quarternary loess-like loams where the river channel is generally a wide, straight flood plain, only cutting into Neogene limestones in its lower reaches. River loads are composed of silts and sands and the river mouth is muddy silt. The floodplains are the bottom surface of a former liman, composed of clays (87).

The basin of the river Ingul, 341 km long with a catchment area of 9 700 km^2, is generally spread over the Cis-Dneprian uplands (Pridneprovskaya vozvyshennost). The river channel is regulated by low pressure dams. In its lower reaches, in the Black Sea lowlands, the Ingul channel first runs through free and forced meanders and then loses itself in flood plains for 50 km. Channel-forming loads comprise silts and sands and at the river mouth, near the Bug liman, the loads are silty (87).

The Dnieper, 2 285 km long with a catchment area of 503 000 km^2, rises in the Valdai Hills (Valdaiskaya vozvyshennost), its headwaters at an altitude of 253 m. The river cuts through zones of mixed and deciduous forest in the north, forest and steppe in the central part and steppe in the south. Typically, the rivers in the Dnieper basin are fed by snows while to the south the proportion of feed water from subsurface sources increases. A large part of the river discharge comes from spring flooding. River load is not particularly large, and at the river mouth turbidity is 0.5–1.0 kg/m^3. Due to the flatness of the Dnieper basin and its geological structure, channel-forming loads tend to be arenaceous (87).

The Dnieper and the rivers in its basin are heavily regulated and used intensively in water supply management and cultivation. The river is only free in its upper reaches and at its mouth. It is quarried in many places for building materials (87).

The Dnieper channel (downstream of the Kakhovskaya Power Station) is relatively straight and 500–600 metres wide. The Dnieper delta begins below the confluence of the Ingulets, near the Dnieper liman. Here the river channel divides into a complex branching network. The Dnieper and Bug limans together form the Dnieper-Bug Liman (41, 58).

In addition to these major rivers the steppe here in the northern Black Sea region is home to the basins of many smaller rivers, the largest of these being the Tiligul. A large proportion of the discharge of these rivers is due to spring flooding. In August nearly all the rivers dry out partially or completely. All the rivers flow into coastal salt lakes (Sasyk, Alibey, Shagani etc.) separated from the sea by narrow spits. For this reason these small rivers in the northern part of the Black Sea do not play a role in the processes discussed here (114, 137).

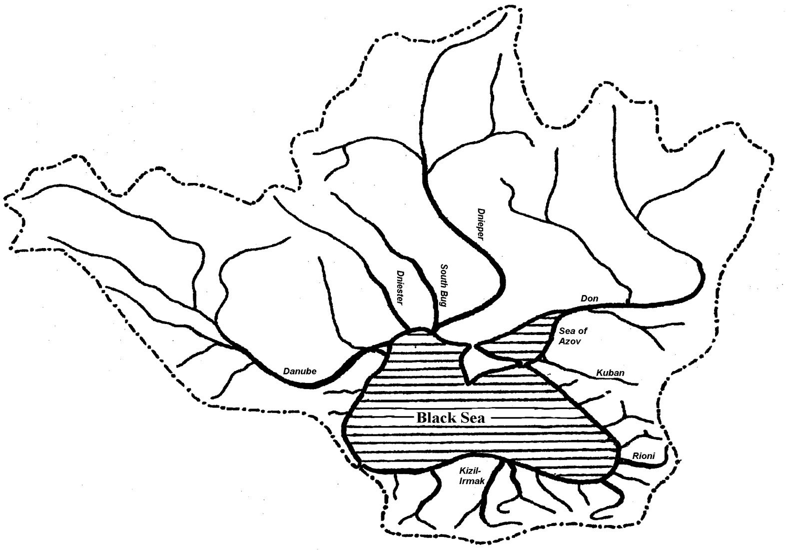
The Crimean Peninsula can be divided into three main areas in terms of its geographical and physical characteristics: (1) South or mountainous Crimea; (2) the steppes and plains in the central and northern parts of the Crimea; and (3) the Kerch Peninsula with its hilly terrain (9). There is no river discharge from the steppe and the Kerch Peninsula into the Black Sea. Small rivers rising on the steep slopes of the Crimean mountains reach the sea only along the west and south Crimean shoreline, a stretch of less than 250 km.

The climate in the Crimea is mild and gentle, particularly on its 220 km long south coast. Even though the mountains here are not very high the zonality of their slopes is noticeably alpine. Annual precipitation in the mountains fluctuates between 500–1 000 mm while in the lowlands it is never more than 300–600 mm (96). Rivers are fed by snow and rainwater, predominantly by rainwater, and there is therefore an immense fluctuation in water levels, with many water courses drying up in the summer. Unit discharge ranges between 0.4 l/sec·km^2 and 12 l/sec·km^2 (25).

The flow and channel-forming features of the Crimean rivers are typical of alpine watercourses. For almost their entire length their channels, of boulder alluvium, are interrupted by waterfalls or cataracts. Channel-forming loads are composed of gravels and shingles which, being texturally unstable, are rapidly pulverised. Mudflows occur periodically in the basins of some of these rivers. Before reaching the sea, rivers associated with resorts are canalised and turned into concrete ditches and raceways. The Crimean rivers are used intensively for water management and cultivation and many of them are regulated by small reservoirs (87).

Considering the natural conditions of the Black Sea basin as a whole, it has to be reiterated that the river load and discharge of the Black Sea rivers take shape under completely diverse natural and climatic conditions. The vertical and horizontal zonality of the basin's natural features is clear-cut.

Black Sea Basin Figure 2.1



3. Coastline and estuaries

As discussed earlier, the sea coast and the submarine slope together make up the coastal zone, an area of constant interaction between land and sea (44, 46). The river estuary is an important element and integral component of the coastal zone; apart from being a link between river and sea and being part of channel formation processes, it is also a player in a system where all the basin's complex erosion and deposition processes are deployed. The particular combination of coastal zone features and wave behaviour also play an important part in the formation of estuaries (73).

The Black Sea has a comparatively uneven shoreline. The northwest and west coasts are the most broken; here too are the huge bights of the Odessa Bay and the Karkinit Gulf. Along the Caucasian shore the Novorossiisk Bay is the largest. The Turkish coastline has the gulf at Sinop, the Samsun Bay and the Vona, and the bay of Igneada on the coast of Turkey in Europe. The largest bays on the western shoreline are at Burgas and Varna. The largest peninsula is the Crimea, together with the Kerch Peninsula, while in the south the Ince Burun and Yasun are the largest peninsulas. The Black Sea has hardly any islands; the largest are Zmeinyi, or Fidonisi, Berezan and Kefken (82, 95, 109, 138).

The overall length of the Black Sea coastline is 4 125 km. The longest stretch is the Turkish coast (1 450 km), then the Ukrainian (1 330 km), Russian (410 km), Bulgarian (380 km), Georgian (315 km) and Romanian (240 km). More detailed figures for distances along the Black Sea coastline are given in Table 3.1 below. These distances were measured on a 1:200 000 chart; the shores of the limans were not included in the overall length, as river factors are, we believe, dominant in those basins and it would introduce an imbalance to apply them to marine systems.

Table 3.1 **Morphometric characteristics of the Black Sea coastline**

		Length of shore, km
RUSSIA	Cape Panagiya to Anapa	70 km
	Anapa to Utrysh Head	18 km
	Utrysh Head to Myskhako Head	34 km
	Novorossiisk Bay (Myskhako Head to Doob Head)	35 km
	Doob Head to Tonkii Point	14 km
	Gelendzhik Bay (Tonkii Point to Tolstyi Point)	12 km
	Tolstyi Point to Arkhipo-Osipovka	50 km
	Arkhipo-Osipovka to Tuapse (Kadosh Head)	57 km
	Tuapse (Kadosh Head) to the mouth of the Kudepsta	102 km
	Mouth of the Kudepsta to the Psou	18 km
	Total in Russia	**410 km**
GEORGIA	Psou to the Bzyb	38 km
	Bzyb to the top of Pitsunda Bay	12 km
	Top of Pitsunda Bay to the Khipsta	15 km
	Mouth of the Khipsta to the Gumista	38 km

	Mouth of the Gumista to the Besleti	10 km
	Mouth of the Besleti to the Kodori	25 km
	Mouth of the Kodori to the Inguri	67 km
	Mouth of the Inguri to the Natanebi	57 km
	Mouth of the Natanebi to the Çoruh	43 km
	Mouth of the Chorokhi to the frontier with Turkey	10 km
	Total in Georgia	**315 km**
TURKEY	Frontier with Georgia to the Harsit	260 km
	Mouth of the Harsit to the Yesil-Irmak	225 km
	Mouth of the Yesil-Irmak to the Kizil-Irmak	105 km
	Mouth of the Kizil-Irmak to the Filyos	410 km
	Mouth of the Filyos to the Sakarya	150 km
	River Sakarya to the Bosporus	140 km
	Bosporus to Rezovo	160 km
	Total in Turkey	**1 450 km**
BULGARIA	Rezovo to Talaskara Point	100 km
	Burgas Bay (Talaskara Point to Pomorie Point (Pomoriiskii mys)	60 km
	Pomorie Point to Cape Kaliakra	170 km
	Cape Kaliakra to the frontier with Romania	50 km
	Total in Bulgaria	**380 km**
ROMANIA	Frontier with Bulgaria to the Sfintu Gheorghe delta arm of the Danube	190 km
	Danube Delta (within Romania)	50 km
	Total in Romania	**240 km**
UKRAINE	Frontier with Romania to Perekopskii Zaliv (Perekop Bay)	610 km
	Crimea (top of Perekop Bay to Takil Head	720 km
	Total in Ukraine	**1 330 km**
	Total for the entire Black Sea	**4 125 km**

In the north-east part of the Black Sea the impressive Caucasus range starts at Taman and runs parallel to the coast for 450 km. In many places its spurs reach down right to the sea itself. The coastline here runs south-east and after the town of Ochamchire it turns to the south and parts company with the mountains along the flank of the Colchis Depression. In the north-east of the region, a long-ranging flysch massif trends towards the sea. Coasts here are graded, apart from the Novorossiisk to Gelendzhik stretch which is cut into by deep bights (43, 143).

The Russian Black Sea coastline is 410 km long and is intersected by a multiplicity of rivers and watercourses. Their water levels tend to be low, especially in the north-western part and the loads they bring to the sea do not impact the ongoing abrasion process. Given this, the coast here can be classified as a graded-abrasion type. The first classification of the coastal zone in this region was carried out in 1958 by V P Zenkovich (43) whose work was updated in 1993 by N A Aibulatov (143). These authors identified seven separate regions: (1) the abrasion coast of the Taman peninsula; (2) the Anapa coastline; (3) the landslip coast from Anapa to Mount Myskhako; (4) the bay region of Novorossiisk and Gelendzhik; (5) the abrasion coastline from the river Aderba to Tuapse; (6) the region from Tuapse to Kudepsta where river alluvium is available to longshore drift; and (7) the abrasion coast of the river Mzymta's deltaic bar.

Today this coastline is densely populated and is under heavy pressure from human activity. For its whole length it is eroded and reinforced with dikes and armoured with other types of coastal protection. Dikes have even been built in the enclosed Gelendzhik Bay where a magnificent sandy beach was built up artificially in 1971. The port of Sochi has had a particularly damaging effect on the area, diverting the sediment load further to the south, in the area of the popular resorts, and giving rise to intensive erosion of coasts as well as vigorous landslide processes (127).

In the north-western part of the Russian shoreline the estuaries of the smaller rivers have clearly been dominated by marine factors. Alluvial material has only accumulated close to the mouths of mountain rivers which discharge fairly large particle-size material during flooding. The rivers in the south — the Tuapse, Psezuapse, Shakhe and Sochi — bring down sediment in such quantities that during the spring flood season small bars can appear at the river mouth which are then associated with longshore drift. In natural conditions, this drift is no more than 30–35 000 m^3/year.

After the Mzymta estuary fluvial behaviour begins to dominate coast formation. Large delta bars are created by alluvial deposits and these break up the coast into a series of independent regions. River deposits also shape contemporaneous longshore drift. Indeed, this Georgian shore on the Black Sea's east littoral is an excellent example of accretion coastline built up from river alluvium.

According to A G Kiknadze (48), three major episodes occurred in the development of this Georgian coastal zone since the beginning of the Holocene epoch. In the first half of ancient Black Sea time, the coast was mainly composed of rias, and long gulfs penetrated up through the valleys of the major rivers. The estuaries soon changed to landmass as most of the river loads, precipitating out in these long fjords, never reached the sea. As the gulfs filled up with alluvium the shore evened out and became more gradual and rounded. River discharge which reached the offshore formed two vigorous and extensive longshore drifts which thrust towards the centre of Colchis. Shore deposits were moved by the energy of the prevailing westerly waves. These two trends sediment movements together with the discharge from the Rioni enabled the infilling of the gulf in what is now the Colchis Depression. By the time the sea level was stabilising (5 000–6 000 years ago) a large quantity of river sediment had formed an intricate pattern of delta bars and promontories and the coastal zone was divided up into several dynamic systems each with its own feed sources and areas of sediment loss.

Thus the relief, morphology and contemporary dynamics of the coastal zone in Georgia are predetermined by the abundance of river load, by the prevailing westerly wave pattern and the overall geological structure. The transition zone between the Caucasus and the Black Sea basin is marked by high tectonic activity and it is entirely probable that major stripping occurred here during the Pleistocene since there is no shelf along most of the coastline (43, 48).

There is a 20 km wide shelf, the Gudauta Bank, along the coastline between Pitsunde Bay and the city of Sokhumi. There is another narrow shelf near the town of Ochamchire. The fairly narrow Colchis Shelf which varies between 10 and 15 km wide is carved up by submarine canyons associated with the estuaries of the Inguri, Rioni and Supsa. Submarine canyons are also found near the estuaries of the Bzyb, Kodori and Chorokhi and near the headland at Batumi.

Within the borders of Georgia, a length of 315 km, the Black Sea littoral is divided into eight independent dynamic coastal systems identifiable as separate longshore. Those in the northern part — the North-west, the Bzyb, the Myusser-Khipsta, the Gumista and the Kodori — all trend to the south. The Chorokhi drift travels north while the Colchis dynamic system, where the Rioni discharge flows out in both directions, does not favour a constant direction. Two subsystems can be identified in the Myusser-Khipsta drift: cliff abrasion is an important player in the area of the Myusser highlands but further along the drift relies completely on alluvial sources. At present the coastal drifts of the Kodori and Chorokhi systems are interrupted by harbour moles and they are developing as individual and separate subsystems. The Colchis dynamic system is also divided in two by the port of Poti (48).

Modern coastline systems in the eastern Black Sea are increasingly impacted by anthropogenic interference in the natural dynamic. One result in the coastal zone is serious depletion of beach-forming sediment, with the shore eroded and in retreat. Dikes, breakwaters, buttressing walls, blocks and tetrapods, which have long been deployed to reinforce the coastline, not only disrupt sediment transportation behaviour but also cause severe bottom abrasion and erosion.

More changes are anticipated in the central Colchis zone in the near future when the building of a new terminal at the mouth of the Khobi and the reconstruction work in Poti harbour will lead to the coastline reshaping itself. Between the encircling installations of these two ports, for a length of 8 km, there will be vigorous accretion of sediment brought down by the Rioni. The sudden excess of sediment will enable the landmass to extend itself even in case of the possible sea level increase.

In the decade from 1981 to 1991, shores along the Georgian coast and, from 1987 onwards, parts of the Russian coast were protected by building up artificial beaches. Bargeloads of pebbles, gravel and sand were brought to the shore zone for this, and these new beaches had their own regenerating effect on the interchange between land and sea (49).

The particle size of beach deposits is usually, however, entirely dependent on the type of bedload contributed by the rivers. In the north-west sector of the Caucasus region the beaches are sandy. Further south, at Tuapse, pebble begins to predominate and the beaches in Abkhazia and Ajaria are pebble. Towards Colchis, particle size decreases and in the areas where the Inguri, Rioni and Supsa reach the sea, river load forms gently sloping, sandy beaches. In the transition zone at the estuaries of the Okumi and Natanebi beaches are gravel, for a short extent, due to the type of river sediment.

Thus beach deposits reflect, through their particle size, the nature of the terrain and relief of the hinterland (particularly when sloping) and the morphodynamics of the river channels.

The river estuaries along the Caucasian coastline of the Black Sea tend to vary widely in their physical size and in the thickness of alluvial deposits and display great diversity in the hydrological and morphological processes occurring there. The dynamic of accretion shores, the number of them and their stability is affected by delta and estuary conditions.
In studies of alluvial and accumulative marine shores, it can be helpful to classify river estuaries in terms of the scale of their impact on the shore. When this approach is applied to the Caucasian coastline three main groups can be identified:

(1) estuaries where the volume of load reaching the sea is several times greater than the capacity of the longshore drift. This type of estuary is predominantly the result of river factors. The major rivers of the Georgian coastline fall into this group - the Çoruh, Rioni and Kodori (until dammed for the hydroelectric power station the Inguri also belonged to this group);
(2) rivers where the volume of load is the same as the capacity of the longshore drift. There may be variations from year to year, with one factor more dominant than the other, depending on the intensity of marine processes or the abundance of river sediments but in the long term, over a long period of years, the effect of river and marine processes can be considered to be of equal importance. Rivers in this group are the Bzyb, Gumista, Mzymta and Psou;
(3) rivers where the volume of load is considerably less than the vigour of the longshore drift. Their estuaries are always formed by the dominating marine factors.

In the first case the balance of river load is always positive. With the second type, looking at a cross-section over many years, the estuary offshore is seen to be balanced. With the third group the volume of river load is insufficient in the majority of cases to maintain a balance.

In the humid, subtropical climate of the eastern Black Sea landmass flash floods typically occur simultaneously in a group of small rivers in relative proximity, as they drain the winter rains from wide-ranging territories. In these cases the alluvial material deposited over a large area of the offshore is a significant player in maintaining a stable regime along the shore line.

Rivers depositing major sediment loads in the sea and forming banks are, in the overwhelming majority of cases, rivers with a single mouth. These river loads are not deployed in the formation and development of delta systems but are involved in longshore drift. The terrigenous material brought down by the river is, in full or in part, entirely dependent on particle size, drawn by wave motion into longshore drift and is distributed in the direction of the drift over a certain distance. In contrast to the rivers which form a broad and extensive delta, the Black Sea rivers which flow down from the Caucasus create large delta bars due to the transverse attack of the waves. In such cases a promontory accumulating coarse discharge loads begins to extend in the prevailing wave direction; this is in effect similar to the formation of a delta but the sediment is transported alongshore. The only river on the Caucasus coast to carve out a double-branched delta is the Rioni, where wave processes are dominant and wave attack is at right angles to the shore. The interplay of natural conditions in the new mouth of the Rioni has in less than 10 years produced a delta similar to the older one in shape and size.

Estuary formation in those rivers of the Caucasus which flow into the Black Sea cannot be regarded as an independent and isolated process as the estuaries here are formed by contemporaneous fluvial and basinal regimes. The coarser bank deposits usually accumulate offshore in the estuary as a submarine fan. They can take on entirely different shapes depending on the amount of discharge and wave action. In periods of intense wave action the loads are involved in longshore drift and become littoral-marine deposits.

On reaching the sea, all the rivers of the Caucasus form submarine fans of varying size. During spring flooding, large and medium-sized rivers create bars of considerable size. With the onset of rainwater flooding, medium-sized and small rivers can build up bars at any time of year, though this occurs most often in the autumn-winter period.

Estuarine shoals which build up every year in the coastal zone of the Caucasus can be classified as a fluvial-basinal type of bar: they build up when water levels are high and are completely destroyed by wave processes in low water periods (73). The impact of marine or river factors depends on storm activity during the year and the amount of water in the river. River factors generally tend to play a greater role in large and medium-sized rivers: for example, bars are thrown up in the spring when sea storm activity is minimal. The formation of bars in the estuaries of small rivers as a result of rainwater flooding is greatly dependent on marine factors, where the rainy season coincides with storms and where the jet of water flowing from the river is not very forceful. At times of severe flooding (1–2 % probability) mountain rivers only transport coarse material. Boulders of 0.5 metres in diameter are deposited offshore and small bars shaped like promontories appear in the estuaries (Chakvistskali, Korolistskali, Mekhadyr etc).

On the whole, the formation and dynamics of estuaries and shores along the Georgian coastline of the Black Sea are dominated by river factors as the bulk of bank-forming sediment is brought down by the rivers during the spring, with high water levels, when there is no storm activity.

Submarine canyons are a feature associated with rivers and abundant discharge from them. They occur frequently in the eastern part of the Black Sea. There is a concentration of them, either as groups or as a series of isolated canyons, between the estuaries of the Mzymta and the Çoruh. The crests of most of these canyons lie at depths of 15–25 metres. Several of them cut into the coastal zone, where they begin to slope steeply at 6–10 metres. The crests of all the canyons lie in a Holocene unit and in contemporary silt, sand and pebble deposits. While slope angles generally vary between 6–20º, sheer escarpments also occur, the gradient of lateral declivities can be 45º, and there are individual occurrences of vertical walls. Offshore, the canyons run out to depths of more than 1 000 m (57, 60, 68, 70, 89).

While it is difficult to be specific about the genesis of these submarine canyons, their origin and contemporary dynamics are undoubtedly dependent on a multiplicity of fluvial processes.

Irrevocably swallowing up part of the river discharge, they exert an effective braking action on the deposition of coastal sediment. Their effect is cyclical and depends on storms over the sea and the amount of fluvial discharge penetrating offshore. When there is a superfluity of river discharge and insignificant transportation along the coastline, river load is lost in the canyons. In counterpoint to this, when river discharge is low and longshore drift is particularly active, canyon processes have no impact.

Thus the determining factor in shaping the coastal zone and submarine slope of the eastern shores of the Black Sea is the abundance of alluvial material. The presence of rivers discharging large amounts of coarse sediment into the sea produces a qualitative shift in the morphology of the coastline. Alluvial and deltaic plains, fluvial terracing, flooded deltas, longshore drift and the whole interrelated system of formation associated with river load — all these factors indicate that the most important feature of coastal zone development in the eastern part of the Black Sea is deposition of river load. This process is long-established and the shore is built out so much that the shelf overlaps it (43).

The southern, Turkish, shores of the Black Sea are precipitously steep. The North Anatolian Mountains (the East and West Pontics) extend for 1 150 km along the coastline. For almost the entire extent the coastline presents abrasion and denudation landforms (particularly in the east) and abrasion shores with high, precipitous cliffs. Along the coastline fringed by the North Anatolian Mountains there are alternating sequences of rocky headlands and wide bays shallowly cut into the landmass, and there are many submarine and surface cliffs known as kekurs.

Even though the Turkish coastline is intersected with a multiplicity of rivers with a substantial volume of discharge, the coast has not acquired an alluvial relief and there is no extensive longshore drift.

In the eastern part of this coast, in Lazistan, many small mountain rivers debouch into the sea, carrying coarse sediment offshore. Their estuaries are shaped predominantly by fluvial processes and some short, local pebble beaches extending for 1–2 km are derived from them. Natural conditions do not encourage longshore drift. There are no coast-facing storms, there is a dearth of river sediment, there are many rocky promontories and there are many harbour structures and coastal reinforcements

Further to the west, the coast retains its elevated profile but is less rugged. In river discharges, sand begins to predominate over coarser material. Small constructional plains appear near the estuaries and shoals occur offshore. Small bays are encrusted with narrow ‘pocket beaches’.

In the middle of the Turkish coastline the Yesil-Irmak and Kizil-Irmak have created wide constructional plains reaching far out to sea, almost to the edge of the shelf. In the lowland area, the Yesil-Irmak divides into many branches and reaches the sea through them. The Kizil-Irmak debouches into the sea through a single main channel, with some unimportant branching; the river channel is broken up by sandy islands. Both rivers have islands in their estuaries, near the coast, and the outer edges of their deltas are fringed with wide sandy beaches.

Along the West Pontic ranges, the coastline is less broken up than in the east. The shoreline is elevated and steep, in places precipitous. There are many rocky promontories, and some stretches of sandy or pebble beaches. The majority of the rivers are small — alpine or subalpine. Occasionally small constructional plains have formed where rivers flow into the sea and low shore banking has occurred here.

In their lower reaches, the major rivers of the region, the Filyos (Yenice) and the Sakarya, have shaped out wide accumulative valleys where they flow peacefully and carry along predominantly sandy loads. They branch near their mouths, forming channels 100-200 m wide. The banks are straight and low and sandy beaches have built up near the estuaries. Dunes run parallel to the bank, and freshwater marshes and lakes lie between them.

The Black Sea coast of the Kocaeli peninsula is an embayment, straight, steep and denuded. There are fewer rivers here, the largest being the Riva, with its basin covering 880 km^2. Near its mouth the current is slow, the channel composed of fine sands and up to 100 m wide.

In eastern Thrace (the Çatalca peninsula) the shores are high, the result of abrasion. Small rivers with low discharge volumes, have no impact on coastal development processes. The largest river in the region, the Kanlidere, falls into the coastal lake of Terkos and has no direct link with the sea.

In general, the Turkish coasts of the Black Sea run straight, for most of their length, have no deep bights into the landmass and are not protected from northerly or north-westerly storms. Like all other Black Sea coastlines, these southern ones are subject to erosion and retreat, leading to a proliferation in massive stone coast reinforcement installations along almost the whole length of the Turkish coastline.

The entire extent of the Bulgarian coastline (380 km) is dominated by banks formed by abrasion and landslip, mainly as a result of marine processes and wave action. Over half the entire length is composed of escarpments and cliffs, varying between 1–20 and 60–90 metres in height. Frequent tremors and earthquakes and underground water all contribute to the landslip process. About one third of the Bulgarian shoreline is beach, of varying width (17, 24, 46, 93, 112, 119, 134).

The total volume of friable material removed by waves during cliff erosion and destruction amounts annually to 1 344 100 m^3 (17, 93). In addition to the products of abrasion, the rivers contribute constructional sediment, though in insignificant amounts. The Bulgarian coastline has, in addition to these abrasion shores, some more localised stretches of deposition, for instance near the city of Varna (24). Overall, the Bulgarian coastline experiences a dearth of accretion sediments and is receding. Various strategies are employed to reduce coastal abrasion: building dikes and groynes, armouring with boulders and employing other coast reinforcement techniques. In some places the shoreline has been built up with artificial beaches.

The estuaries of most of the rivers in Bulgaria are lagoons inundated by the sea and blocked by bars; they have their own hydrological processes, typical for semi-enclosed or almost totally isolated bodies of water. Many river valleys near the mouths are hollowed out deeper than sea level (91). In the contemporary behaviour of these estuaries marine factors predominate and as a result, during low water periods, the rivers of the Strandja coast become limans as longshore drift sweeps over their estuaries.

The magnificent delta of the Danube, one of the largest rivers in Europe, occupies a significant part, 240 km, of the Black Sea coastline in Romania. The origins of the Danube date back 5 000 years, when a vast arm of the sea began to fill up with river sediment and river channels emerged in the interior. At the top of the delta the river divides into two branches, the Kiliya (115 km long) and Tulcea (17 km long). At the river mouth the Kiliya arm, which lies entirely within Ukraine, forms its own complex branching delta with many streams. The Tulcea arm separates into two branches, the Sfintu Gheorghe (109 km long) and the Sulina (69 km long), both in Romania. At the end of the 19th century 70 % of the flow was through the Kiliya arm but a reduction in flow was observed at the beginning of the 20th century; at present 59 % of the overall flow passes through this arm and this figure is due to fall in the next 10–15 years to 56–57 % (74, 75, 76).

Since the 1930s, as delta progradation has slowed down and the number of branches decreased, the rugged sea margin of the Kiliya delta has gradually levelled out and sandy beaches have become established. For almost two centuries now, too, delta development has been forcefully disrupted by anthropogenic factors (74, 75, 76).

Lagoon embankments stretch south from the Danube delta. River sediment from the Danube entering the sea through the Sfintu Gheorghe are washed without meeting any obstruction as far as Constanta and this section of the coastline, around 120 km long, owes it origin and development to the delta formation dynamics and behaviour of the Danube. The Razelm, Golovica and Sinoe, lagoons separated from the sea by longshore drift, are relics of the old Danube delta. South of Constanta, onward movement of the sediment is halted by a submarine platform and headlands, while harbour structures and coastal protection have been a bar to sediment transport in this direction since the end of the 19th century. In general, though, river load from the Danube, even in small quantities, reaches as far as Cape Kaliakra.

In the southern part of Romania, due to the dearth of river discharge, the coastline suffers abrasion. Shuisky has identified 10 separate abrasion sectors of coast, of an overall length of 51 km (139).

At present, the Black Sea coast of Romania is under heavy pressure from human activity. To protect the shore from erosion and recession, dikes and other types of coastal engineering have been built (140).

The north-west part of the Black Sea is a lacustrine coast. All the landmass adjacent to the littoral is lowland steppe while the marine sector and its shores lie within platform structures where the water is shallow and the sea bottom is graded. Over the vast expanse from the Danube delta to the southern shores of the Crimea, natural conditions — geology, climate, geomorphology, hydrology, landscape — are generally similar. Zenkovich has identified several subregions in this coastal zone: (1) a lacustrine shoreline from the Danube delta to the Dnieper-Bug Liman; (2) lobate coasts from the Dnieper liman to the top of the Karkinit Gulf; and (3) the abrasion shores of the West Crimean province (43).

The sea coast between the Danube and the Dnieper-Bug Liman lies in the South Ukrainian and Moldavian plateau. The adjacent shelf is broad, with shallow waters. The coast is interspersed with many limans and lagoons. Part of the coast between the Dniester liman and Odessa is delineated by high cliffs, with a ubiquitous tendency to landslip. The Odessa bay itself is an area of deposition. Further on towards the Dnieper liman the coastline is the product of abrasion and landslip while, continuing on to the Karkinit Gulf, the shoreline is low and characterised by long sandy spits, wide lagoons and sandy swells. The abrasion coast of the Tarkhankut peninsula is composed of horizontally bedded limestones. Here high cliffs rise locally to 150 m (113, 114). The lowland shore of the West Crimean province is also formed by abrasion and it is flecked with submerged marshes and salt lakes (43).

A feature typical of the morphology of the north-western part of the Black Sea is the almost ubiquitous interlinking of accumulation formations with deep-rooted abrasional elements. Abrasion features occupy about 30 % of the extent of this shoreline, accumulation formations spread over 36 %. The remaining stretches behave in a relatively stable way. A tendency to erosion is currently observed in the accumulative formations even along these stable shorelines. Accretion of coastal sediment is only noted in places where longshore drift is active, that is, in individual bays and in the distal extremities of sandbars and spits. Abrasion products are the main source of the detrital material reaching the coastal zone in this region. Abrasion of benches results in 19 million t/year of terrigenous detritus, abrasion of cliffs yields a further 13.7 million t/year and deposits of crustacea add 8.6 million t/year (113, 114, 137).

In present times the natural development of the coastal zone in the north-west part of the Black Sea is hampered by the numerous harbours and port structures in the area as well as by coastal engineering installations. Here are the major ports of Ilichevsk, Odessa and Yuzhnyi. In the Odessa area alone 23 km of coast line, or 10 % of the total length of this coast, is reinforced with coastal protection. In addition to a network of dikes, more progressive methods are now being introduced, such as the creation of artificial beaches (114).

In this vast province stretching from the Danube to South Crimea, all the rivers and the relatively large short-lived streams and watercourses flow into limans which formed when the low-lying areas of the river valleys and balkas (the local small, flat-bottomed valleys) were inundated and submerged. Simultaneously with flooding, the level of the native bottom dropped and there was a shift in banks and river mouths. At present the majority of the limans are cut off from the sea by continuous solid sand bars. Only limans into which major rivers debouch (such as the Dniester and Dnieper-Bug) have preserved a direct link to the sea and are mostly freshwater basins.

The region at the mouth of the Dniester is a floodplain and the estuary contains a triangular delta with two branches. The flatland is broken up by river channels, oxbows and many lakes. The Dniester liman, with an average depth of 1.5 m, covers 508 km^2. It holds

0.733 km^3 and is 43 km long along its long axis and varies in width between 4.2 and 12.0 km. The Tsaregrad arm which links it to the sea is 370 m long and 220-300 m wide (41, 58, 74, 98).

The combined Dnieper-Bug Liman is complex in delineation and structure. Its overall area is more than 1 000 km^2 and distance from the Dnieper delta to the gateway to the sea is 63 km. Its maximum width is around 15 km and the volume of water it contains is 4.24 km^3. Its average and greatest depths are 4.4 m and 12 m respectively. The Bug liman is 42 km long and 2-8 km wide (41, 58, 74, 98).

The complex Dnieper delta contains more than 50 islands and over 200 lakes and basins. Its overall area is 303 km^2 (41, 58, 74, 98).

The Bug liman is fed by the Ingul as well as the south Bug. Both of these rivers have well-developed single-branch estuaries.

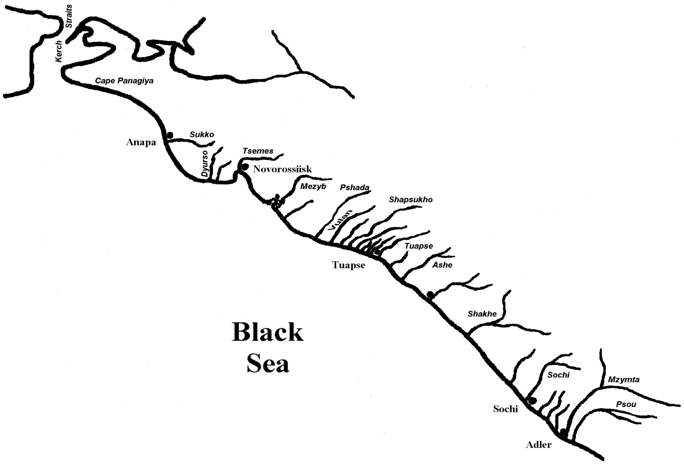
The southern coast of the Crimean Peninsula, from Balaclava to Feodosia, is 220 km long and is one of the most picturesque of the Black Sea coastlines. The shoreline is fringed by high mountains whose steep slopes sink straight into the sea. Because of the number of different geological structures found here, the coast is extremely varied. The entire shoreline of southern Crimea is made up of alternating rocky promontories and small semicircular bays watered by alpine rivers and skirted by pebble and gravel beaches. Near the shore the marine landscape has many kekurs, both above and below water. To the east, the mountains are less high and become more gentle with wide valleys. The climate is drier and becomes steppe-like.

The Crimean shore descends to a great depth. Fluvial alluvium falls deep and there are hardly any alluvial formations in the coastal zone. There is no longshore drift here, but the coastline is active with landslips and subsidence. The coastal zone of this South Crimean province can be classed as mountainous with a coastline formed by abrasion and embayment (43, 129).

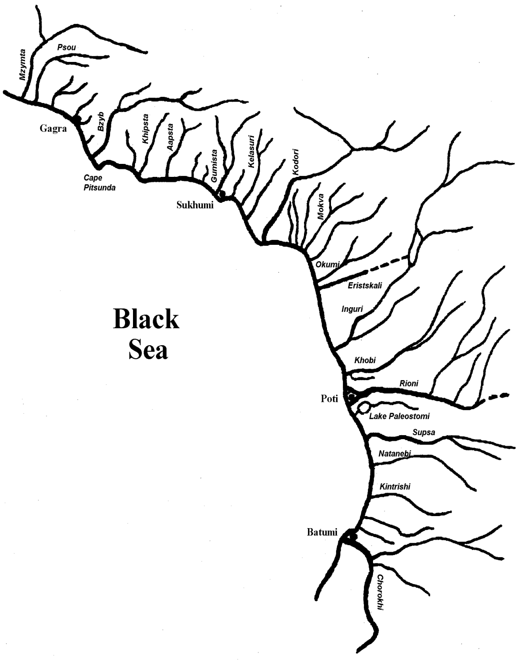
The Kerch-Taman stretch of the Black Sea coast has no river network and is bisected by the Kerch Straights which connect the Azov and Black Seas. Here the coast is composed of flattened, established shorelines built up with unstable rock. There are small limans and lagoons (43).

With this circular tour of the Black Sea's coastal zone completed, we can say that the entire system of basin, coast and estuary is uniquely heterogeneous. This is of course quite natural, as both the coastline and the estuaries vary in origin and their individual development is derived from the interaction of the sea and the entire natural system of the contiguous landmass.

Rivers of the Russian coastline Figure 3.1



Rivers of the Georgian coastline Figure 3.2



Rivers of the eastern part of the Turkish coastline Figure 3.3

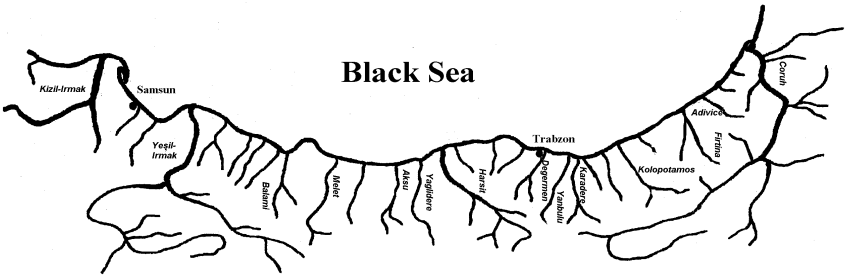


Figure 3.4 **Rivers of the western part of the Turkish coastline**

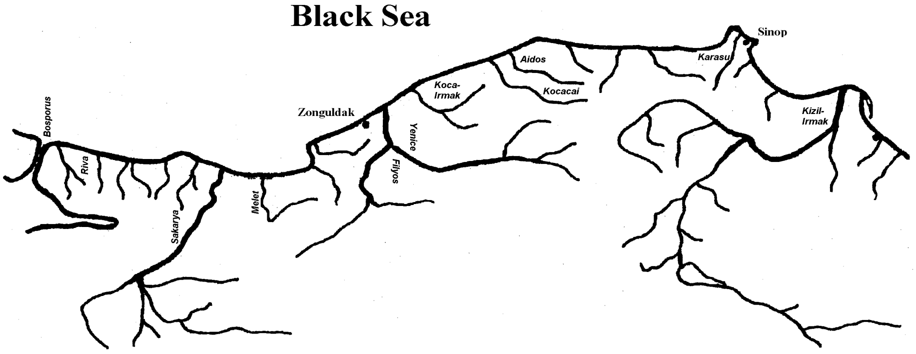


Figure 3.4 **Rivers of the Bulgarian coastline**

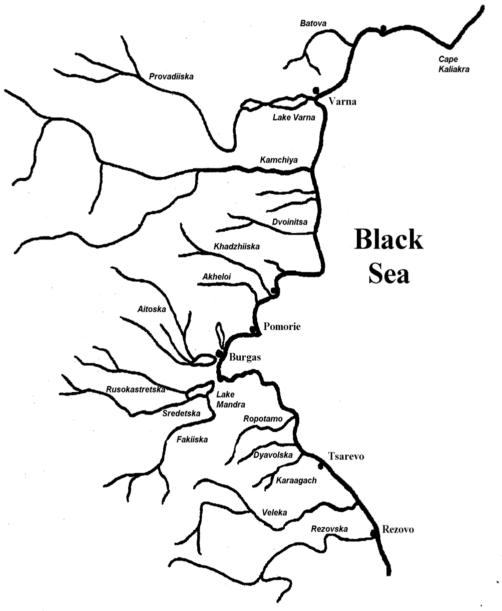
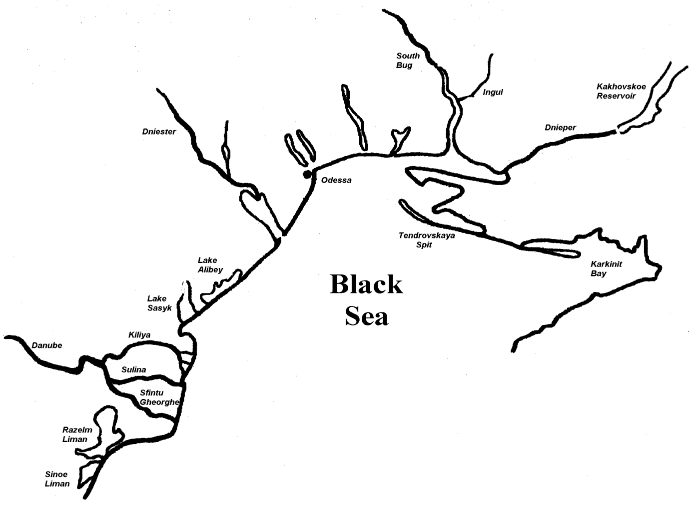
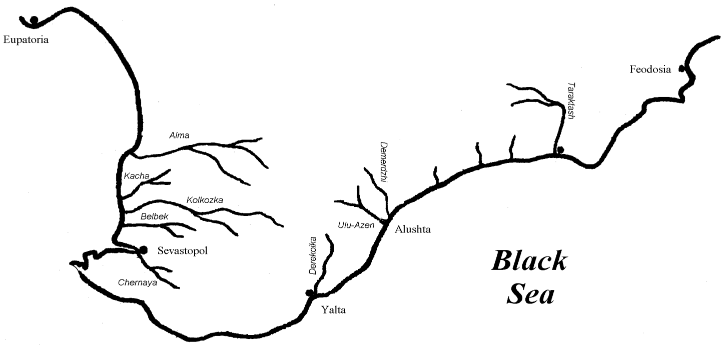


Figure 3.6 **Rivers of the north-western coastline**



Rivers of the Crimea Figure 3.7



4. Volume of river discharge into the Black Sea

There are about one thousand rivers that flow into the Black Sea and they are all markedly different, both in terms of water level and extent of basin. The overwhelming majority of them are small rivers and barely 500 of them are any more than 10 km long. There are also many seasonal, short-lived watercourses. Major rivers, with a catchment area greater than 10 000 km^2, number only 10. Their water levels fluctuate greatly; the maximum unit discharge of their surface flow is greatest in the humid subtropical climate of Ajaria (60–70 l/s·km^2) and smallest in the western and northern regions of the sea (1–2 l/s·km^2).

The rivers of the Black Sea basin have not all been studied to the same extent. Long-term hydrological observations are available for the majority of rivers in the former Socialist grouping, while the sets of data available for the rivers along the Anatolian coastline are sporadic and static observations of some of the major rivers were begun only recently. Existing sets of data on the total discharge of fresh water into the Black Sea conflict with each other and figures vary between 294 k^3 a year and 474 km^3 a year (5, 20, 74, 82, 94, 95, 109, 142).

Since the regions adjacent to the Black Sea also vary enormously in the way the discharge is formed, the rivers themselves can be discussed and classified in terms of their own individual features and by region and country.

A large number of small and middle-sized rivers fall into the sea along the Caucasian littoral. The size of their basins increases towards the south, as the main watershed ridge of the Caucasus moves away from the sea. Only the outflow of rivers with basins larger than 50 km^2 has been calculated, since the outflow from smaller rivers is insignificant and they only have a local impact within their estuaries. The outflow from Caucasian rivers is calculated from data based on regular hydrometric observations of the river (22, 85) and by the generally accepted method for calculating outflow in mountainous countries, based on establishing a link between river discharge and altitude. Results from previous studies were also used (14, 18, 53, 90, 100, 102, 103, 104).

In the north-eastern part of the sea, constantly flowing watercourses are found south of the town of Angara. Along the Russian shore here, the majority of rivers flowing into the sea are small ones, the largest of these being the Mzymta. The annual discharge of most of the rivers is less than 0.15 km^3. The Pshada, Tuapse, Ashe, Psezuapse and Sochi supply 0.3 km^3 water to the sea, 80 % of this during the winter and spring seasons (53, 103, 104), since the rivers are mostly fed by rainwater. The Mzymta, however, contributes 1.5 km^3 a year, and has very high water levels in the spring and early summer, from snow thawing in the mountains.

The rivers in the north-eastern part of the sea are little affected by anthropogenic changes. Their water is of course used for water supplies and other needs within the economy but non-recoverable losses are not very great and there is no accurate data for them.

The overall amount of discharge into the Black Sea from rivers in Russia is 6.5 km^3 a year (including the small rivers). Detailed figures for these rivers are given below, in Table 4.1.

Larger rivers flow into the sea in its eastern part, and the unit discharge here is incomparably higher. The overall volume of river water discharge into the Black Sea from Georgia (including small rivers) is 46.0 km^3. Of this, almost three quarters comes from the major rivers: Bzyb (3.79 km^3), Kodori (4.17 km^3), Eritskali Canal (the conduit for the canalised and controlled Inguri) (3.15 km^3), Rioni (13.37 km^3) and Chorokhi (8.71 km^3). The most important of the medium-sized rivers are the Psou (0.606 km^3), Gumista (1.051 km^3), Mokva (0,571 km^3), Galidza (0.928 km^3), Inguri (1.247 km^3 once controlled), Khobi and Tsivi together (1.895 km^3), Supsa (1.581 km^3), Natanebi (0.773 km^3) and Kintrishi (0.527 km^3). Detailed figures for river discharge from Georgia are given in Table 4.2. Since

Outflow of rivers along the north-eastern littoral: Russia Table 4.1

River	Area of basin, km²	Average altitude of basin, m	Outflow Average annual outflow, m³/s	Outflow Unit discharge, l/s·km²	Outflow Annual volume, km³
Succo	89.2	180	0.69	7.7	0.022
Dyurso	53.7	190	0.45	8.4	0.014
Ozereika	52.5	150	0.35	6.6	0.011
Tsemes	82.6	130	0.51	6.2	0.016
Mezyb	194	200	3.86	19.9	0.122
Dzhankhot	49.0	230	1.14	23.3	0.036
Pshada	358	310	9.82	27.4	0.310
Vulan	278	240	6.36	22.9	0.200
Dzhubga	100	140	1.52	15.2	0.048
Shapsukho	303	210	7.03	23.2	0.222
Nechepsukho	225	150	4.59	20.4	0.145
Tue	59.1	210	1.36	23.0	0.043
Nebug	73.3	320	2.53	34.5	0.080
Agoi	91.8	330	3.39	36.9	0.107
Tuapse	352	335	12.8	36.3	0.404
Shepsi	57.5	310	1.93	33.5	0.061
Ashe	282	570	12.4	43.9	0.390
Psezuapse	290	700	15.4	53.7	0.486
Shakhe	553	890	36.8	66.5	1.161
Dagomys	103	200	2.06	20.0	0.065
Sochi	296	720	16.1	54.3	0.508
Matsesta	67.5	306	2.28	33.8	0.072
Khosta	93.5	410	4.90	52.4	0.155
Kudepsta	87.1	347	3.39	38.9	0.107
Mzymta	885	1 309	49.5	55.9	1.562

we have used new results of observations, the results given here differ slightly from those published by us in previous studies.

As well as omitting the small rivers, Table 4.2 does not show the bog rivers of Colchis, due to their low water levels. These are the Gagida (F = 270 km²), Churiya (F = 296 km²) and Pichori (F = 406 km²). The Gagida and Churiya each discharge 0.03 km³ annually. The Pichori flows into the coastal lake of Paleostomi which also receives several other small bog rivers. Lake Paleostomi is joined to the sea by the Maltakva, a man-made canal, and the total outflow here is around 0.05 km³ a year. A typical bog river is the Tsivi (F = 254 km²) which flows into the Khobi a kilometre upstream of its estuary. Its annual discharge is 0.416 km³ and is included in the total discharge for the Khobi.

Several rivers in West Georgia are controlled by reservoirs and utilised in the production of hydroelectricity. However, control has not had any significant impact on the Rioni or Gumista, and the total average annual discharge is unchanged. In the Inguri estuary, however, the average annual outflow of water has decreased since 1976 from 165 m^3/sec to 39.5 m^3/sec. This change has not significantly affected the overall situation in the Colchis area of the Black Sea as the waters of the Inguri are channelled into the Eristskali, supplying 3.15 km^3 annually. There have also been changes in the central part of Colchis; in 1939 the mouth of the Rioni was diverted further north to Poti and in 1959 part of its discharge was diverted back into its old channel.

The rivers in the eastern part of the Black Sea are also used for irrigation and water supplies. Overall, in West Georgia little water is lost irreversibly to water utilisation, up to 2-3 km^3 a year on average.

We have to point out here that the data we obtained for river discharge in Russia and Georgia are in broad agreement with previous findings, especially the results of studies by L. A. Vladimirov, N. I. Kochetov, O. I. Khalatyan, I. I. Kherkheulidze, G. N. Khmaladze etc., and fall easily within the accuracy limits. Only one indicator for the rivers in the Caucasus, 35 km^3, put forward in the monograph entitled ‘The Black Sea’ (109), is markedly different, showing a much lower figure than the others.

The rivers of the Turkish Black Sea basin are less well studied by hydrometric observation than the others, and a significant proportion of the data for overall average discharge has been obtained by calculation and differs significantly from other figures (23 km^3; 25 km^3; 29.4 km^3; 32.4 km^3; 35.8 km^3; 40.6 km^3; 43.96 km^3, 46.5 km^3) (86, 109, 116, 124, 133). All these calculations have also included the Chorokhi (Çoruh); this river accumulates most of its waters in Turkey but its mouth is in Georgia.

Table 4.2 **Outflow of rivers along the eastern littoral: Georgia**

River	Area of basin, km^2	Average altitude of basin, m	Outflow		
			Average annual outflow, m^3/s	Unit discharge, l/s·km^2	Annual volume, km^3
Psou	421	1 110	19.2	45.6	0.606
Khashupse	200	1 210	9.5	47.5	0.300
Zhove-Kvara	72	1 520	6.11	84.8	0.193
Bzyb	1 510	1 570	120	79.5	3.79
Mchishta	169	720	7.71	45.6	0.243
Khipsta	166	1 220	9.76	58.8	0.308
Aapsta	243	670	10.8	44.4	0.341
Gumista	576	1050	33.3	57.8	1.051
Besleti	81.5	340	3.53	43.3	0.111
Kelasuri	220	1 280	13.2	60.0	0.416
Majarka	114	408	5.1	44.7	0.161
Kodori	2 030	1 680	132	65.0	4.170
Tumish	62.2	174	1.64	26.3	0.052
Dgamysh	120	350	4.32	36.0	0.136
Tskhenistskali	61	171	1.61	2.64	0.051
Mokva	336	700	18.1	53.9	0.571
Galidzga	483	880	29.4	60.9	0.928
Okumi	265	520	14.5	54.7	0.458

Eristskali Canal			100		3.15
Inguri	4 060	1 840	39.5 165*	 40.6*	1.247 5.207*
Khobi	1340	560	60.1	44.8	1.895
Rioni: north delta south arm	13 400	1 084	305 119	31.6	9.62 3.75
Supsa	1 130	970	50.1	44.3	1.581
Natanebi	657	830	24.5	37.3	0.773
Kintrishi	291	835	16.7	57.4	0.527
Chakvistskali	172.6	740	12.5	72.4	0.394
Korolistskali	55	500	3.8	69.1	0.200
Chorokhi (Çoruh)	22 100	1 530	276	12.5	8.71

* before control

We have calculated the outflow of Turkish rivers into the Black Sea on the basis of existing data, the available literature (86, 116, 124, 133), use of analogies and data on precipitation. For the larger rivers, data is available from recent projects by Turkish researchers based in most cases on results from field studies (116). As mentioned before, the majority of the major rivers in Turkey are controlled to a very large extent, are used for energy production and irrigation and are under heavy anthropogenic pressure. All these factors affect the calculations. The total volume of discharge into the Black Sea from Turkish rivers with their controlled conditions amounts to 38.0 km3 (not including the Chorokhi and Veleka). More than half of this outflow is from the major rivers, the Yesil-Irmak, Kizil-Irmak, Filyos (Yenice) and Sakarya (see Table 4.3).

Almost one third of the Black Sea basin discharge from Turkey originates in the subtropical region, at the edge of the eastern part and the area between the Chorokhi and the Yesil-Irmak. The area of this interfluve is typically 24 000 km^2, in all 10.5 % of the total area of the Black Sea basin in Turkey. This region can be divided climatically into two subregions: the extreme eastern part from the Chorokhi to the Harsit, with its humid subtropical climate, and the region from the Harsit to the Yesil-Irmak with a Mediterranean-type subtropical climate. The Harsit itself is the largest river in this region (its basin extends over 3 500 km^2) and it contributes around 1.10 km^3 water to the sea each year. In the stretch from the Chorokhi to the Harsit basin, about 30 small rivers flow into the sea. The largest of these are the Kolopotamos, Firtina, Istila, Degirmen and Fol. The area of their basins fluctuates between 200 and 500 km^2. The total annual discharge from this subregion is 5.70 km^3. West of the Harsit, as far as the Yesil-Irmak, around 20 medium and small rivers fall into the Black Sea. The largest of these are the Yaglidere, Aksu, Melen-Irmak and Curi-Irmak (area of their basins being 1 000–2 000 km^2). The total annual discharge in this subregion is 4.50 km^3. Towards the west the unit discharge gradually decreases, and the basins of the Kizil-Irmak and Sakarya, which rise in the arid regions of central Anatolia, have particularly low levels of surface discharge.

In the plains area of the Turkish littoral (the Kocaeli peninsula and Çatalca) there are fewer rivers. Small rivers and short-lived watercourses fed mainly by rainwater predominate. The overall discharge into the sea in the stretch from the Filyos to the Bulgarian frontier (not including the Sakarya) is 2.60 km^3.

A substantial proportion of the controlled flow of rivers in Turkey is used for irrigation and other water needs, and the Kizil-Irmak, Yesil-Irmak, Riva, Karasu, Güllük and Abdal suffer from significant irreversible losses. Many small and medium-sized rivers are used for the same purposes. The total volume of irreversible losses can be up to 3–5 km^3. In natural conditions, the volume would have been around 42 km^3 a year.

Table 4.3 **Outflow of rivers along the southern littoral: Turkey**

River basins	Area of basin, thousand km^2	Average altitude of basin, m	Precipitation mm/year	Unit discharge $l/s \cdot km^2$	Annual discharge, km^3
From the Çoruh to the Harsit	9.5	(800)	1400	19.0	5.70
Harsit	3.5	900	(1 000)	10.0	1.10
From the Harsit to the Yesil-Irmak	11.0	(800)		13.0	4.50
Yesil-Irmak	36.1	650	500	4.65	5.30
From the Yesil-Irmak to the Kizil-Irmak	2.5	(300)		12.0	0.95
Kizil-Irmak	78.6	810	400	2.38	5.90
From the Kizil-Irmak to the Filyos	9.9	(350)		10.0	3.10
Filyos (Yenice)	13.1	700		7.0	2.90
From the Filyos to the Sakarya	3.6	(300)		10.0	1.15
Sakarya	56.5	430	450	3.15	5.60
From the Sakarya to the Rezovska	4.8	(200)	700	9.60	1.45

Along the western littoral, in Bulgaria, rivers with low water levels flow into the sea. The largest of these are the Veleka and the Kamchiya supplying 0.267 km^3 and 0.607 km^3 respectively. The Kamchiya is controlled by several dams and is used to supply the water needs of the large cities of Varna and Burgas, and its discharge is therefore much reduced. Water is also taken from the Veleka (16, 17, 81). Detailed figures for Bulgarian rivers flowing directly into the sea are given in Table 4.4 (7, 10, 16, 17, 25, 118).

The Bulgarian littoral is lacustrine, with many lakes and limans which are connected to the sea either directly or partially (91). The rivers flowing into these basins are nonetheless, even if only to an insignificant extent, involved in the process of feeding fresh water into the Black Sea.

The Fakiiska, Sredetska, Rusokastrenska and several other small streams flow into Lake Mandra, near Burgas Bay. Their total annual discharge is 0.260 km^3. The Chakrliika and Aitoska, with an annual discharge of 0.03 km^3, flow into Lake Burgas. The Provadiiska and Devnya, with a combined annual discharge of up to 0.30 km^3, flow into Lake Beloslav which is a continuation of Lake Varna and is joined to it by a canal (10).

Table 4.4 **Outflow of rivers along the southern littoral: Bulgaria**

River	Area of basin, km^2	Average altitude of basin, m	Outflow		
			Average annual outflow, m^3/s	Unit discharge, $l/s \cdot km^2$	Annual volume, km^3
Rezovska	183.4		0.79	4.30	0.025
Veleka	995	362	8.76 9.41*	9.45*	0.276 0.296
Karaagach	224.3		0.96	4.28	0.030
Dyavolska	133.2		0.57	4.28	0.018
Ropotamo	248.7	201	1.17	4.70	0.037

Akheloi	141.0		0.61	4.33	0.019
Khadzhiiska	355.8	230	1.53	4.30	0.048
Dvoinitsa	478.8		2.06	4.30	0.065
Perperidere	58.2		0.25	4.29	0.008
Shkorpilovska	78.7		0.34	4.31	0.011
Kamchea	5 358	327	19.2 27.7*	 5.17*	0.607 0.873*
Kranevska	84.5		0.36	4.26	0.011
Batova	338.8	252	0.73	2.15	0.023

* before control

In Bulgaria, therefore, the annual river discharge directly into the sea is 1.2 km^3; if the discharge from rivers flowing into coastal lakes is included, the total is 1.8 km^3. Up to 0.5 km^3 is removed annually and not returned.

In Romania, it is mainly, in fact, only short-lived streams and watercourses which flow into the sea. The biggest river in the Black Sea basin is the Danube, one of the most studied and observed of rivers. The Danube was first mentioned by Herodotus (484–425 BC) and at various times the delta has been observed from 94 hydrometric posts (6, 19). Despite this, sets of data on river discharge are inconsistent. The majority of authors consider current annual discharge, over the long-term, to be 6 300–6 500 m^3/sec (19, 25, 74, 75, 76, 131, 132, 133). According to Romanian authors (117) over the last 150 years the Danube's average long-term discharge into the sea has been 196.9 km^3 a year (6 238.5 m^3/sec). Even though the load is not subjected to particularly heavy anthropogenic impact, around 15 km^3 water is still lost to non-return use. In natural conditions there are only slight fluctuations and at present a high water level phase is gradually moving to a low water level phase (76).

The Danube's discharge is divided, at the top of the delta, between the Kiliya and the Tulcea arms. The Kiliya is in Ukraine and the Tulcea is in Romania. The Tulcea splits into the Sulina and the Gheorghe arms. There are partial deltas in the Kiliya and Gheorghe estuaries. Given this multiple subdivision, it is difficult to estimate the volume of water entering the Black Sea from the Danube. It would however seem correct to take the annual discharge for the Danube as 6 300 m^3/sec and the volume of water as 200 km^3.

In Ukraine, the major rivers - the Dniester, Southern Bug, Ingul and Dnieper — flow into coastal limans. The courses of these rivers are controlled by a great many reservoirs and they are under heavy anthropogenic pressure. These rivers pour 55.5 km^3 annually into the coastal limans. The Dnieper alone supplies 43.5 km^3 of this and control of its flow has reduced its discharge by 18 %. In recent times the Dniester outflow has also been reduced by 11 %. In natural conditions the major rivers of Ukraine would feed 66.0 km^3 fresh water into the Black Sea (Table 4.5) (58, 74, 98).

In addition to the major rivers, some small rivers (the Tiligul etc.) feed into the coastal salt lakes in the north-western part of the Black Sea but the volume of their discharge is so small that it has no effect on marine coastal behaviour.

The discharge of Crimea's small rivers is heavily controlled; the water is utilised for economic needs and the total annual discharge is less than 0.3 km^3 (Table 4.6) (25).

Thus the flow of river discharge into the Black Sea is dependent on geographical zonality and on average the rivers feed 348 km^3 fresh water a year into the sea. Of this, 86 % is contributed by ten major rivers: the Danube 200 km^3 (57.5 %), Dnieper 43.5 km^3 (12.5 %), Rioni 13.37 km^3 (3.8 %), Dniester 9.1 km^3 (2.6 %), Chorokhi 8.71 km^3 (2.5 %), Kizil-Irmak 5.90 km^3 (1.7 %), Sakarya 5.60 km^3 (1.6 %), Yesil-Irmak 5.30 km^3 (1.5 %), Kodori 4.17 km^3 (1.2 %) and Bzyb 3.79 km^3 (1.1 %).

Table 4.5 **Outflow of rivers along the north-western littoral**

River	Area of basin, km²	Outflow		
		Average annual outflow, m³/s	Unit discharge, l/s·km²	Annual volume, km³
Danube	817	6300	7.71	200
Dniester	72.1	288 320*	4.4*	9.1 10.2*
Southern Bug	63.7	69	1.1	2.2
Ingul	9.7	18.5	1.9	0.60
Dnieper	503	1375 1683*	3.3*	43.5 53.0*

* before control

Discharge can be allocated by country and region, as follows: annually from Russia 6.5 km³ river water (1.9 %), from Georgia 46.0 km³ (13.2 %), from Turkey 38.0km³ (10.9 %), and from Bulgaria 1.8 km³ (0.52 %). The Danube supplies 200 km³ (57.5 %). The rivers in Ukraine contribute 55.5 km³ (15.9 %) and the rivers in the Crimea supply 0.3 km³ (0.08 %).

These figures represent volumes discharged when the rivers are controlled and their waters utilised. Under natural conditions the outflow would be more than 381 km³.

Table 4.6 **Outflow of rivers: Crimea**

River	Area of basin, 1000km²	Average altitude of basin, m	Outflow		
			Average annual outflow, m³/s	Unit discharge, l/s·km²	Annual volume,
Alma	633	500	1.40	2.2	0.044
Kacha	110	800	1.32	12.0	0.042
Kokozka	836	910	1.17	1.4	0.037
Belbek	270	730	2.16	8.0	0.068
Chernaya	47.6	730	1.47	31.0	0.046
Derekoika	49.7	730	0.48	9.8	0.015
Ulu-Azen	64.8	610	0.56	8.7	0.017
Demerdzhi	53	460	0.13	2.4	0.004
Taraktash	153	340	0.06	0.4	0.001

* before control

By far the largest volumes flow into the Black Sea during the spring high water levels. River discharge is also subject to significant variation and cyclical fluctuation and there are instances of exceptionally high floods when volumes are many times greater than the average long-term figures. For example, maximum outflows for the Rioni were 2 850 m³/sec in 1895, 5 484 m³/sec in 1922, 3 000 m³/sec in 1933, 4 650 m³/sec in 1982 and 4 500 m³/sec in 1987 (51).

In the geological and historical past outflow volumes fluctuated between wider limits than they do now. Judging by the paleomeanders in various geographical zones, flood flows could have been 10–20 times greater than they are now. In the second half of the Holocene epoch there were, according to the Blytt-Sernander sequence, three main, dramatically different, climatic periods. The Atlantic period, 7 500–5 000 years ago, was governed by a warm and humid climate. In the Subboreal period, 5 000–2 500 years ago, the climate was predominantly warm but dry, while the Subatlantic period was cool and damp (106).

Depending on climatic conditions, flows into the Black Sea obviously reached a maximum during the middle Holocene, in the Atlantic period. In a warm and humid climate, and with intensive thawing of the ice cover and the mountain glaciers, volumes of river flow could have been many times greater than present ones. This is also evidenced by the intensive rate of rise in level of the Black Sea, which reached a maximum between the 2nd and 1st centuries BC (27, 47, 92). At that time the volume of river discharge was so great that in all probability it contributed to the appearance of the ancient Babylonian and Biblical stories of a ‘world flood’. Later, in the Subboreal period, when the climate was warm and dry, levels of river flow would have been lower. With the onset of the Subatlantic period approximately in the 5th century BC, the age of climatic optimum ended and the climate tended to become cooler and wetter. At this time the Black Sea was in a state of Fanagorian regression (3-5 metres lower than at present) (27, 47), undoubtedly linked with low water levels in the rivers.

After this regression there was a rise in levels in the first centuries AD and by the fifth century AD levels were approximately as they are now (27, 47). In the early Middle Ages there was a brief climatic improvement, a ‘little climatic optimum’ period, which was superseded in the 13th century by a ‘Little Ice Age’. During all this time there were no significant fluctuations in the sea level, if anything there was a slight tendency to a fall in level, this continuing until the middle of the 19th century (47, 92). Throughout this entire period there were evidently no significant changes in river discharge and water levels in the rivers were close to present figures.

At the end of the ‘Little Ice Age’, for about 100 years, the level of the Black Sea showed a tendency to slow though stable rise. From the 1940s to the 1970s the level was relatively stable. Now, with global warming, there has been a marked increase in the rate of rise.

5. Freshwater balance of the Black Sea

The water balance of the Black Sea has been studied many times but each time the results obtained have disagreed with other sets of data (Table 5.1). It is certainly the case that different aspects of the water balance are subject to significant cyclical fluctuations and changes, but the variations are generally not brought about by any inaccuracy in the original data. Neither would it be correct not to take into account the ingress of underground water.

Even today there is still no accurate data on the volume of the underground flow into the Black Sea. The research conducted by I. S. Zektser and G. P. Kalinin, I. S. Zektser et al, and R. K. Kliege (42, 50, 72) indicates that underground discharge to the ocean fluctuates on average between 2 % and 5.7 % of the fluvial discharge; the proportion of discharge from the continent of Europe into the Atlantic Ocean and the Mediterranean is 6.9 %, while the figure for Asia is 4.2 % (50). Discharge into the Black Sea from underground sources could therefore be considered to be about 5 % of surface inflow - a minimum of 17 km^3 water. Thus a combined total volume of 365 (348 + 17) km^3 fresh water reaches the Black Sea from the adjacent landmasses, and it is this figure we can use in calculations for the balance of Black Sea water.

A major component of the sea's balance is precipitation. In recent years observations have been made out at sea and their results offer a more accurate reflection of the true volume of precipitation falling onto the surface of the Black Sea. According to the Reference book on the Black Sea climate (1974) the annual precipitation averages 518 mm while more recent data, with corrections, gives this figure as 562 mm (28 km^3/year) (20, 82).

Thus, in modern-day conditions, with river control and managed use of river water, the annual volume of fresh water reaching the Black Sea is 603 km^3, or 0.11 % of the total volume of the sea. In natural conditions this figure would be 636 km^3.

With these figures, the figures for the volume of exchange of water through the Bosporus with the Sea of Marmara can also be adjusted and made more precise. For the Sea of Azov, though, the current through the Kerch Straights has no constant direction, with the result that data for this interchange can often be contradictory (74, 84).

In the balance compiled by T. S. Bondar, E. N. Altman and V. I. Reshetnikov (5, 20, 82, 142), input exceeded output by 2–3 km^3, the explanation for this being the rise in sea level (4.7–5.0 mm a year). In fact, the rise in level in the Black Sea parallels eustasia in the world ocean, brought about by the impact of global warming, caused by the greenhouse effect, on the climate. In this case, we have to bear in mind that the major player in the rise of sea levels in the Black Sea is not river discharge and precipitation but the heat-density expansion of the upper 120–140 m biologically active layer (density static factor). This factor in sea level rise is thought to be 70 % (51, 83, 130) and has resulted in the last 20–25 years in a sharp increase in the rate of rise, which in the eastern part of the sea has reached around 1 cm a year (fig. 5.1).

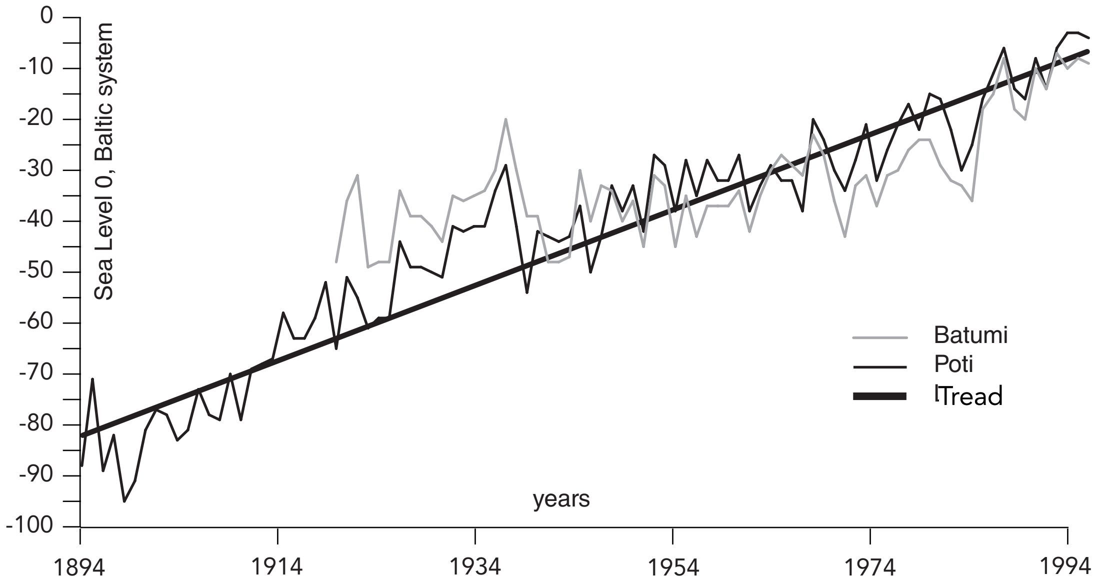
The annual ingress of river discharge affects seasonal fluctuations in sea level. Maximum levels are recorded in June and July, at the end of the spring high waters, and the lowest levels are in November.

In the light of the above conditions we can conclude that the research conducted so far on the Black Sea water balance has now to be revisited and revised; indeed this area will continue to be the subject of research and revision.

Water balance of the Black Sea: data from various authors (5, 20, 82, 94, 109, 142) Table 5.1

Author	Input (km^3/year)					Output (km^3/year)			
	River discharge	Atmospheric precipitation	Inflow from Sea of Azov	Inflow from Bosporus	Total	Evaporation	Outflow to Sea of Azov	Outflow to Bosporus	Total
Shpindler (1896)	474	220			694	232		416	648
Merz (1928)	328	231		193	752	354		398	752
Sverdrup (1942)	328	240		192	760	363		397	760
Zenkevich (1947)	320	145		202	667	319		348	667
Rozhdestvenskii (1953)	340	280		195	815	240		575	815
Leonov (1960)	309	230	95	193	827	365	70	392	827
Bruevich (1960)	350	225		175	750	350		400	750
Barenbeim (1960)	340	120	59	193	712	280	34	398	712
Solyankin (1963)	346	129	53	176	704	332	32	340	704
Ozturgut (1971)	352	300		249	901	353		548	901
Rozhdestvenskii (1971)	294	254	38	229	815	301	29	485	815
Serpoianu (1973)	336	120	53	123	632	340	32	260	632
Pora, Oros (1974)	294	254	38	229	815	301	29	485	815
Fonselius (1974)	320	230		200	750	350		400	750
Bondar (1986)	364	119	50	203	736	332	31	371	734
Unloata (1990)	352	300		312	964	353		612	965
Altman (1991)	338	238	50	176	802	396	33	371	800
Reshetnikov (1992)	353	225	22		600	370		227	597

Changes in the level of the Black Sea at Batumi and Poti, over 100 years Fig. 5.1



6. River loads discharged into the Black Sea

The overwhelming bulk of land-derived material reaching the Black Sea is delivered by the rivers as sediment load. Despite the topical urgency and the significance of information about this subject, the sediment load of the Black Sea basin has not been researched in all regions to the same level and in some areas this specific topic has hardly been studied at all. This means, of course, that the data we have for the overall total amount of load being delivered into the closed reservoir of the Black Sea and then being distributed onwards are not reliable.

Generally speaking, river load is the least studied hydrological element. This is largely because of the complex nature of its formation and the difficulties involved in measuring it. The movement and transport of load occur discretely, only in particular hydraulic conditions. Further, the ways solid substances are transported constantly vary throughout the whole length of all the rivers, from source to mouth, and the processes of erosion and accretion occur everywhere. Active accumulation of alluvial material commences with a fall in the river's carrying capacity, near the mouth and in the shore zone, but the main mass of the load still accumulates in the final basin — the seas and oceans — where it plays a role in the process of contemporary sedimentation.

The formation of contemporary deposits in the shore zone, on the shelf and in the ocean is one of the most important natural processes on Earth. The main stage in the process of sedimentation is the ingress of terrigenous material to the water basin, yet it is this that is the least studied process, whether as a qualitative assessment or as a quantitative relationship (97).

In contrast to river load, the ingress and distribution of deposits in the sea is much more complex. Even though water, after various 'vicissitudes', may eventually reach the sea and continue to be part of the cycle, part of its load may be forever held captive in the reservoirs of controlled rivers, or used industrially. Even after reaching the sea, the sediment may accumulate in land-locked bays and limans; rarely does it reach the sea from there. Often bottom sediments, extremely important for the shore zone because of their particle size, are carried out irrecoverably to great depths along the sediment channels of submarine canyons.

The most reliable data on the ingress of river load to the sea are those for the rivers of the Caucasus. In addition to regular hydrometric measurements over a long period of time, this region has also been the focus of more specialised research (8, 12, 13, 18, 28-39, 53, 54, 63, 66, 69, 70, 77, 80, 84, 88, 90, 100, 102, 103, 104, 107, 108, 121, 126).

In the north-eastern part of the Black Sea, within Russia, 930 000 m^3 river load (including the smaller rivers) reaches the sea. As previously mentioned, sediment is graded naturally by particle size in the estuaries and shore zones; a certain proportion remains close to the shore and creates coastal deposits (littoral-marine sediment) and the finer solid particles are carried out to the open sea and gradually settle out onto the bottom, thus taking part in the contemporary sedimentation process. Of the 930 000 m^3 sediment, 320 000 m^3 is littoral and the remaining 610 000 m^3 is marine.

In this region the amount of load increases from north to south. Up to the Tuapse the discharge from small rivers is insignificant and they have only a local impact on the shore, and in general the Tsemes debouches into the closed Novorossiisk Bay. After the Tuapse, the shoreline has been created by pebble drift and is interrupted in places by coastal defences and the port of Sochi (43, 142). The largest amount of sediment is brought to the sea by the Shapsukho, Tuapse and Psezuapse, and the largest river in the region, the Mzymta, contributes 158 000 m^3 load, of which 60 000 m^3 is littoral and 98 000 m^3 marine (Table 6.1).

In the north-eastern part of the Black Sea, river load is obviously inadequate for maintaining the stability of the coastline. To the north, the Tuapse is involved in a heavy abrasion process while to the south, on the beaches formed by accretion and accumulation, there is a shortage of coastal sediment. Along the whole length of the Russian coastline the shores are protected with huge defensive installations; this in itself aggravates the situation regarding the shore zone.

Human activity, economic and industrial, has a negative impact on the quantities of fluvial and coastal sediments. The disruption of the natural balance of loads is worsened by non-return water use, control of water courses, extraction of sediment, improper bank reinforcement etc.

Overall, the absolute amount of river load in this region has not been reduced to a very great extent by anthropogenic intervention. In natural conditions the rivers of Russia might contribute around one million m3 load to the Black Sea.

The amount of river load increases markedly in the eastern part of the sea, in Georgia. The overall amount is over 11 100 000 m^3 and of this 4 300 000 m^3 remains in the coastal zone

River load: rivers of the north-eastern littoral, Russia Table 6.1

River	River discharge			Coastal deposits, thousand m^3/year	Marine deposits, thousand m^3/year
	Thousand t/year	Thousand m^3/year	m^3/km^2-year		
Succo	12.3	6.83	76.6	3.0	3.83
Dyurso	1.32	0.77	14.3	0.5	0.27
Ozereika	7.40	4.1	78.1	1.8	2.3
Tsemes	11,3	6.3	76.3	2.0	4.3
Mezyb	67.2	37.3	192	13.5	23.8
Dzhankhot	20.5	11.4	232	4.0	7.4
Pshada	56.8	33.4	93.2	14.0	19.4
Vulan	59.0	32.8	118	12.0	20.8
Dzhubga	30.5	16.9	169	4.5	12.4
Shapsukho	113	62.8	207	15.5	47.3
Nechepsukho	87.7	48.7	216	12.5	36.2
Tou	24.8	13.8	233	4.5	9.3
Nebug	42.3	23.5	320	8.0	15.5
Agoi	56.0	31.1	339	9.0	22.1
Tuapse	111	65.0	184	17.0	48.0
Shepsi	31.4	17.5	304	5.5	12.0
Ashe	57.0	33.5	118	15.5	18.0
Psezuapse	91.5	53.8	185	20.0	33.8
Shakhe	211	124	224	45.0	79.0
Dagomys	44.5	24.7	240	8.0	16.7
Sochi	101	59.5	201	20.0	39.5
Matsesta	31.3	17.4	258	6.0	11.4
Khosta	31.5	18.5	197	8.0	10.5
Kudebsta	38.2	21.2	243	6.0	15.2
Mzymta	258	158	376	60.0	98.0

and 6 800 000 m^3 is carried out to the open sea. In this region the particle size is typically larger than in river sediments in Russia. In Abkhazia and Adjara, fluvial detrital material is of larger particle size than in other regions round the sea. Of the total amount, over 90 % of the load discharged into the sea comes from the larger rivers, the Bzyb, Kodori, Inguri, Rioni and Chorokhi (Çoruh) (Table 6.2).

Along the Georgian coast large river loads contribute to eight independent longshore drifts which move towards the centre of Colchis where the Rioni delta spreads out (48).

At maximum spring high water levels, the fine dispersion component of the suspended load in the rivers is here dispersed over large areas. The suspended matter may be carried as much as 15-20 km from the shore. In the area where the Chorokhi (Çoruh) has a direct impact, where load concentrations in the surface layer of the sea can be as much as 1 000–2 000 g/m^3, sediment can be transported further north, for almost 50–60 km. Suspended loads from Abkhazian rivers travel south; here the turbidity is 100–300 g/m^3 (Bzyb) and 300–500 g/m^3 (Kodori). In Colchis (where the Rioni flows into the sea) turbidity varies between 1 000 g/m^3 and 1 500 g/m^3.

A major counterbalance to this, in the Georgian sector of the sea, are the submarine canyons along which around 2 000 000 m^3 large particle size loads are carried to great depths. The greatest amount of beach-forming sediment is swallowed up by the Chorokhi canyon, and under natural conditions losses could be as much as 1 800 000 m^3 a year, while 100 000 m^3 is lost to the Kodori canyon. Smaller amounts disappear into the Bzyb, Rioni and Supsa canyons. In addition to these estuarine canyons, loads also disappear into lateral canyons. Landslips have several times been observed in Batumi Canyon, when an excess of river load accumulating near the mole in Batumi port has slipped into the canyon at the slightest push. The volume of a single loss may be in excess of 50 000 m^3. Shore sediments are lost in the submarine canyons of the Pitsundi (‘Akula’ — the shark) and on the steep slopes of the headland itself. It must be remembered that canyon activity is cyclical in nature. Where there is excess of river alluvium and weak longshore drift the canyons capture part of the beach-forming material. When the reverse holds, when the amount of alluvium is reduced and longshore drift is more active, the canyons play a lesser role (31, 39).

In Georgia, due to the way river load is regulated by reservoirs and other industrial installations, the natural dynamic of the river load is severely disrupted. Control of river flow was begun some time ago, in the 1930s. Use of river water for irrigation and utilisation of river load has been going on for centuries.

Hydroelectric power stations have been built on the banks of the Rioni and its tributaries - the Rioni(1933), Gumati(1958), Ladzhanuri (1962) and Vartsikhe (1971). While the Rioni, Ladzhanuri and Vartsikhe power stations have had little impact on the flow of river load, the construction of the Gumati power station has had some considerable effect on the Rioni. Since 1958 river load has almost halved. Extraction of sediment and exploitation of river bed quarries for sand (up to 15 % of the load) has also led to loss of river sediment in the estuary. With the filling up of the Gumatskoe reservoir with alluvium, in the 1980s, river load reached previous levels (before the river was controlled) (88). Since the beginning of the 1990s there has been a trend in the Rioni for a decrease in the amount of river load, probably due to cyclical fluctuation.

With the construction of the arch-shaped dam for the hydroelectric station on the Inguri, the volume of river load at the estuary has decreased by 83 %. The construction of the Sokhumi power station has also had a negative impact on the load in the Gumista. Even though the upper reaches are scoured, 51 900 m^3 alluvium was accumulated in the reservoir at East Gumista between 1948 and 1964 (13), and the river load at the mouth was reduced by 20-25 %. At present, in the river Gumista, there has been almost total regeneration of the amount of river discharge and its natural dynamic. In addition to these rivers, there has also been some regulation of flow in the Adzharistskali, Abasha, Bzhuzha (tributary of the Natanebi) and Zheobse (tributary of the Khashupse) etc.

The exploitation of river bed quarries for inert materials and direct extraction of sediment from river beds have had an enormously negative impact and deleterious effect on the natural dynamic of river loads. These practices still continue, whether legally or illegally. One inert materials plant, 7 km from the mouth of the Chorokhi (Çoruh), has been operating since 1972 and has extracted 600 000 m^3 of large particle alluvium from the river bed. Near the village Sadzhevakho, 50 km from the mouth of the Rioni, up to 500 000 m^3 sand and gravel have been extracted each year. Extraction from the Kodori has reached 150 000 m^3. Small amounts of alluvium have been extracted almost everywhere. This has had a particularly deleterious effect on small rivers where occasional, one-off extraction has sometimes exceeded the annual volume of sediment load, and this has of course severely affected the dynamic of the river course. At the beginning of the 1990s, with the collapse of the Soviet Union and the economy, extraction volumes fell sharply. By the end of the century however, volumes began to rise again. In 1997–98, for example, 40 000 m^3 of alluvium were removed from the Supsa for the construction of an oil terminal.

In the near future major changes can be expected at the mouth of the Chorokhi (Çoruh) and along the coastal zone of Ajaria, due to flow control measures in Turkey. Dams are already being built at Muratli (30 km from the mouth), Borça (40 km from the mouth), and higher up the Artvina there is the dam at Deriner (67 km from the mouth). For almost 10 years now there has been a steady trend towards a reduction in the quantity and particle size of the sediment. Once construction is complete (planned for 2005), the flow of river load will virtually come to an end. The sediment loads of the Machakhela and Adzharistskali are insignificant (the volume of large shore deposits is less than 80 000 m^3 from both rivers); these rivers are now filling up the troughs left by river bed quarrying and hardly reach the sea any more. All these factors intensify the existing erosion rate. If appropriate measures are not taken, waves will soon wash away the heavily populated area between the mouth of the Chorokhi (Çoruh) and Batumi.

Changes are also expected at the mouth of the Khobi where a new oil terminal is being built. The port is to be situated in the estuary of the river where it will act as a brake to the flow of river alluvium and discharge of river loads to the sea will be reduced to virtually zero.

One of the ways industry affects river load behaviour is diversion of flow and change in location of the river mouth. For example, the Inguri was diverted into the bed of a small river, the Eristskali, thus providing the flow for the hydroelectric station. Moreover, river loads tend to remain in the Inguri's Jvarireservoir and clear water runs into the Eristskali (60).

In 1939, to protect Poti from flooding, the mouth of the Rioni was diverted north of the town. As a result a heavily populated urban area of around 300 hectares was washed away while to the north, over a period of 30 years, a new delta formed and the landmass was extended by 800 hectares. By the 1980s the shore had grown to such an extent that the shoreline azimuth had changed, the coastal dynamic had been restructured and discharge from the Rioni had begun to travel north. At present, there is an accumulation process taking place along the stretch of coastline between the mouths of the Rioni and Khobi and the shore is increasing fast.

Flow regulation and industrial activity has had a particularly strong impact on coastal sediment

River load: rivers of the eastern littoral, Georgia Table 6.2

River	River discharge			Coastal deposits, thousand m^3/year	Marine deposits, thousand m^3/year
	Thousand t/year	Thousand m^3/year	m^3/km^2-year		
Psou	158	90.8	215	38.0	52.8
Khashupse	80.5	46.0	230	23.8	22.2
Zhove-Kvara	53.7	30.7	426	15.3	15.4
Bzyb	767	445	295	133	312
Mchishta	20.2	11.7	69.2	2.2	9.5
Khipsta	34.4	19.7	119	11.0	8.7

Aapsta	37.7	21.6	88.8	9.5	12.1
Gumista	264	153	265	46.0	107
Besleti	12.0	6.85	84.0	2.5	4.35
Kelasuri	84.2	48.5	220	27.4	21.1
Madzharka	15.9	9.05	79.3	5.0	4.05
Kodori	1 295	754	371	362	392
Tumush	3.35	1.9	30.5	0.85	1.05
Dgamysh	9.0	5.1	42.5	1.85	3.25
Tskhenistskali	3.35	1.9	31.1	0.8	1.1
Mokva	46.8	27.5	81.9	8.3	19.2
Galidzga	94.7	54.6	113	21.6	33.0
Okumi	34.5	19.7	74.5	7.2	12.5
Eristskali Canal	-	-	-	-	-
Inguri	450 2 700*	260 1 500*	385*	78.0 490*	182 1 010*
Khobi	221	130	97.0	40.0	90.0
Rioni -north delta	3 390	1 990	264	610	1 380
Rioni - south delta	2 630	1 550		450	1 100
Supsa	246	143	126	46.0	97.0
Natanebi	146	84.9	129	36.2	48.7
Kintrishi	22.3	12.6	43.2	6.9	5.7
Chakvistskali	19.0	10.6	61.4	8.5	2.1
Korolistskali	8.30	4.6	83.6	3.5	1.1
Chorokhi (Çoruh)	8 440	4 920	222	2310	2610

* before control

behaviour and on the shore zone overall. Indeed, populated and agricultural areas have been washed away. Port development and the construction of ill-thought-out coastal defences have also had a negative impact on coastal dynamics.

Taking an overall view of the inflow of rivers into the Black Sea within the borders of Georgia, we can note the following points. The Black Sea coastline of Georgia is one of the few places where we can clearly see the relationship between river discharge, the shore zone and contemporary marine deposition. The formation of river load and its transformation into littoral and marine deposits occurs against a background of human effort - active industrial endeavour- and the waiting depths of submarine canyons, all disrupting the natural cycle of river load balance.

Overall for the Georgian sector of the Black Sea the structure of the annual balance of river load looks as follows. Around 2.0 million m^3 of river load settles in reservoirs and does not reach the sea and around 1.0-1.5 million m^3 of alluvium is extracted from river bed quarries. Of the 11.1 million m^3 of river load which reaches the sea, 2.3 million m^3 of beach-forming sediment remains in the shore zone and is involved in the formation of beaches, 2.0 million m^3 large particle deposits move out to great depths along the channels of submarine canyons and 6.8 million m^3, being very fine particles, are carried away from the coastal zone and take part in contemporary marine deposition processes.

It is important to note that this behaviour structure may vary, with significant fluctuations in volumes; in other words, the differences between maxima and minima can vary enormously. Maximum deviation from the average long range figure, for river loads entering the sea, may be 2.2, while for longshore drift it may be 4.0 and 3.8 for wave equivalent force (36).

We have already said that river sediment in the Caucasus has been studied on many occasions and that much has been published on this subject. This is indeed the case but the results often diverge and are not in agreement with each other (in contrast to the situation with fresh water studies). This is primarily due to the complex process of formation and movement of load, the lack of measuring instruments and the paucity of databases, which means that, effectively, most results are obtained by calculation and do not necessarily reflect the true nature of load movement.

In contrast to many studies our results are based on observations in the field and direct measurements in rivers and in the sea. Indeed, it was the underestimation of the marine factor and the fact that a significant proportion of river sediment accumulates in offshore flats that led to overestimated results. Similarly, the role of the smaller rivers in contributing deposits to the sea cannot be overstated.

The inflow of load to the sea is a complex and diverse process and any study of it must take into consideration the influence of fluvial, estuarine and marine factors as well as the specific geographical factors of the coastal zone. In modern conditions anthropogenic factors must also be included. Only such a multilateral approach can produce results which reflect the actual situation as closely as possible.

The Black Sea rivers of Turkey are under heavy anthropogenic pressure. Dozens of large and small dams and reservoirs have been constructed along them. Their flow is controlled and the water used in hydroelectricity schemes, for industrial and other needs and for improvement and reclamation programmes. The natural course of fluvial alluvium transport is therefore completely altered. Studies are further complicated by the paucity and inaccessibility of data.

A quantitative analysis of the river loads in Turkish rivers was carried out using the results of research by Hay, Milliman and Syvistsky, and Algan and co-authors, and existing data on sediment load (72, 116, 124, 131, 132, 133). Wide-ranging use was made of known methods for calculating slope denudation and sediment load. For major rivers, as with river load, the results of the latest research by Turkish experts were used (116).

Today, Turkish rivers flowing into the Black Sea deliver 8 000 000 m^3 of load, of which

River load: rivers of the southern littoral, Turkey Table 6.3

River basins	Sediment load		
	Thousand t/year	Thousand m^3/year	m^3/km^2·year
From the Chorokhi to the Harsit		(750)	(80)
Harsit		(300)	(85)
From the Harsit to the Yesil-Irmak		(850)	(75)
Yesil-Irmak	330 12 500*	195 7 350*	205*
From the Yesil-Irmak to the Kizil-Irmak		(175)	(70)
Kizil-Irmak	440 16 700*	260 9 800*	125*
From the Kizil-Irmak to the Filyos		(600)	(60)
Filyos (Yenice)	3 700	2 170	170

From the Filyos to the Sakarya		(220)	(60)
Sakarya	3 800 4 600*	2 230 2 700*	50*
From the Sakarya to the Rezovska		(250)	(50)

* before control

4 855 000 m^3 (60.7 %) is from the Yesil-Irmak, Kizil-Irmak, Filyos (Yenica) and Sakarya. A substantial amount of alluvium is carried out to sea by middle-sized rivers in the eastern part of Turkey and the sediment load of these rivers is expressed in terms of the erosion coefficient. From the Chorokhi to the Harsit the total volume of river load is 750 000 m^3, the Harsit itself producing 300 000 m^3, while the stretch from the Harsit to the Yesil-Irmak contributes 850 000 m^3 (Table 6.3).

Of the total amount of alluvium a certain proportion undoubtedly remains in the coastal zone and forms littoral-marine deposits. Approximate calculations suggest that at present around 2–3 million m^3 of river load is involved in shore formation within Turkish borders. Marine sediments make up 5.6 million m^3.

Due to control and industrial use of river sediment the amount of load has decreased many times over in the major rivers, particularly the Yesil-Irmak and Kizil-Irmak (by more than 97 %) and the Sakarya (by more than 19 %). The decrease has been particularly severe with large-particle size bottom sediments which are now entirely deposited in reservoirs and are hardly ever to be found downstream of the dams.

Control and intensive utilisation of the rivers in Turkey's Black Sea basin started in the upper reaches, and up to the 1980s disruption in the behaviour of river sediment in the estuaries was insignificant. However the construction of dams brought about reductions in the amount of sediment load reaching the sea: the Hasan-Uruglu and Suat-Uruglu were built on the Yesil-Irmak in 1981, the Altinkaia in 1988 and the Derbent in 1991 on the Kizil-Irmak, not far from the sea. It is expected that in the near future there will be a reduction in sediment load in the Sakarya estuary when three more dams are built. In addition to the dams on the major rivers, there are also plans to control the flow of middle-sized rivers such as the Karasu and Lori (141). At the present time, more than 17 million m^3 of sediment is captured in reservoirs in the major rivers of the Turkish Black Sea basin. Under natural conditions the sediment load reaching the Black Sea from rivers in Turkey would be a minimum of 25-26 million m^3.

The rivers in Bulgaria do not have well-developed carrying capacity properties. The flows of the largest of them, the Veleka and Kamchiya, are controlled and the amount of load is reduced by 17 % and 59 % respectively. Due to water utilisation, the amount of load discharged by the Khadzhiiska and the Batova is reduced by 27 %, compared with the zonal indicator. The Fakiiska, Sredetska, Aitoska and Provadiiska debouch into coastal lakes and reach the sea through them, their loads not being transported further then these lakes (7, 10, 16, 17, 25, 118).

In all, the rivers in Bulgaria transport about 450 000 m^3 load to the sea. The bulk of this load is of small particle size and no more than 50 00–100 000 m^3 remains in the shore zone, forming beaches. Under natural conditions the rivers of Bulgaria would contribute 850 000 m^3 of sediment load to the sea.

To the north of the Batova, as far as the Danube delta, short-lived watercourses and streams do not make any contribution.

Despite the fact that the Danube is one of the most studied rivers in Europe, figures for the amount of sediment load brought down it to the sea vary considerably. According to Rumanian writers, over the last 155 years the average amount of river load has been 54.06 million t/year (117). Of this amount around 9–12 % is bottom sediment which settles out in the delta offshore in the estuary and takes no part the process of marine deposition (76).

River load: rivers of the western littoral, Bulgaria Table 6.4

River	Sediment load		
	Thousand t/year	Thousand m^3/year	m^3/km^2·year
Rezovska	17.4	10.2	55
Veleka	65 78*	38.2 45.9*	46*
Karaagach	21.3	12.5	55
Dyavolska	12.7	7.5	56
Ropotamo	23.6	13.9	56
Akheloi	13.4	7.9	55
Khadjiiska	33.8 46.0*	19.8 27.0*	75*
Dvoinitsa	45.5	26.7	56
Perperidere	5.5	3.3	57
Shkorpilovska	7.5	4.4	56
Kamchiya	462 1122*	272 660*	123*
Kranevska	8.0	4.7	55
Batova	35.4 48.0*	20.8 28.2*	83.2*

* before control

At present, sediment load from the Danube is showing a tendency to decrease. There was a marked reduction after 1960. In the past, the annual volume of river load was 80–85 million t/year but this has fallen to a present level of 50–55 million t/year (19, 74, 75, 76). Precise figures produced by Mikhailov in 1921-70 put river load at 67.7 million t/year, and after the construction of a series of reservoirs the figure fell to 42.2 million t/year (74). According to new research by Mikhailova and Levashova the total figure for the Danube's suspended and bottom sediment at the top of the delta in the period from 1921 to 1960 was 87.8 million t/year while in the period from 1961 to 1998 it was 51.2 million t/year (78).

The major rivers of Ukraine are controlled and the total amount of alluvium is reduced by 45 %. The rivers debouch into wide limans where around 1 500 000 m^3 of sediment load is deposited (25, 41, 58, 74, 98, 133), and only a negligible amount of load reaches the sea — approximately 160–170 000 m^3 (Table 6.5).

The figures for river loads in the small rivers of the Crimea (75 000 m^3) are given in Table 6.6 (25).

River load: rivers of the north-western littoral Table 6.5

River	Sediment load		
	Thousand t/year	Thousand m^3/year	m^3/km^2·year
Danube	51 200 87 800*	30 000 50 000*	61.2*
Dniester	1 730 2 500*	1 000 1 500*	20.8*
Southern Bug	200	120	1.9
Ingul	126	75	7.8
Dnieper	800 2 100*	470 1 250*	2.5*

* before control

To sum up, on average 52.2 million m³ of sediment reaches the Black Sea every year as river load. Of this, up to 11.7 million m³ is, in terms of its particle size, bank-forming and its littoral-marine deposits create beaches. Around 2.0 million m³ of coastal load is carried off to great depths through the canals of submarine canyons and about 40.5 million m³ of fine-grained sediment is pelagic, of a size to take part in the contemporary process of sedimentation in the deeper parts of the sea although, while described as pelagic, the bulk of it (over 90 %) settles out in the shelf zone, not more than 15-20 km from the shore. These volumes of load reach the sea under conditions of river flow control and water utilisation; under natural conditions (without reservoirs) the total amount of sediment load would be at least 95.0 million m³.

Over the course of a year unequal river loads are brought to the sea. All the major rivers have huge spring high water levels, when the bulk of the load is transported. The small rivers have autumn-winter flooding, but the absolute amount of load is not large and these rivers do not play a significant role in the process of marine deposition. It must also be remembered that the volume of load also varies considerably from year to year. Load variation coefficients for large rivers can reach 0.6-0.9 and for small rivers can be higher still. The particle size of the alluvium also varies but this depends on the whole on the dynamic of the banks. The particle size distribution of marine deposits varies insignificantly.

In the geological and even historical past, the amount of sediment load varied considerably, depending on climatic conditions. In the Pleistocene and the beginning of the Holocene epochs there was apparently less suspended material in the Black Sea basin rivers and in the world as a whole, as can be seen from the absence of land cultivation. The history of cultivation in the Black Sea basin starts in the Mesolithic age, at the beginning of the Holocene epoch, but areas of worked land were extremely small and their impact on erosion processes was negligible. Slow and stable growth in cultivated land areas continued up to the Middle Ages. A big jump in this rate in the Black Sea lands was due to the introduction of maize, this rise continuing into the 17th century. Felling increased and pastureland was opened up to a maximum extent in the second half of the 20th century.

Table 6.6 **River load: rivers of the Crimea**

River	Sediment load		
	Thousand t/year	Thousand m³/year	m³/km²·year
Alma	44.3	24.6	38.8
Kacha	12.1	6.72	61.1
Kokozka	25.9	14.4	17.2
Belbek	32.4	18.0	66.6
Chernaya	0.57	0.32	6.72
Derekoika	2.78	1.54	30.9
Ulu-Azen	6.48	3.6	55.5
Demerdzhi	4.66	2.58	48.6
Taraktash	2.65	1.47	9.6

The genesis of large bottom sediments is less affected now by the ploughing up of the land; and the amount of load has more to do with climatic conditions, exogenous processes and other natural phenomena. In the Black Sea basin sediment load reached its maximum in the middle Holocene epoch, in the Atlantic period (7 500–5 000 years ago), together with maximum flow. This is connected with the disappearance of the last major ice cover and the sharp decrease in alpine glaciers. As the ice retreated, vast areas of fluvioglacial deposits were formed. Rock, broken up and pulverised, filled gorges, valleys and floodplains. The high flood levels of river flow augmented the carrying capacity of the rivers and the amounts of large-particle material carried along must have been significantly greater than today. The large quantity of fluvial sediment in that period give grounds for believing that the alluvial-accumulative banks of the Black Sea were, on the whole, formed at the end of the Atlantic period, about 5 000 years ago.

In the Subboreal period (5 000–2 500 years ago), with its warm and dry climate, figures for river flow were much lower, and the circumstances were not conducive to increases in carrying capacity. With the onset of the Subatlantic period, approximately the 5th century BC, with its cool and damp climate, water levels were not very high and, as with flow, the figure for sediment loads was not very high. Evidence of these low volumes of load can be found along the shores of the Black Sea; in the 5th century AD several towns and villages situated immediately beside the sea were submerged, most probably because the lack of deposits in the coastal zone was a contributory factor in erosion of the shores, along with a rise in sea level.

From the early Middle Ages to the second half of the 19th century, during the ‘little climatic optimum’ and the ‘Little Ice Age’, the level of the Black Sea was relatively stable, as can be seen from the absence of major changes in water level in the rivers. It seems that the amount of load entering the sea was also stable and on average much the same as today. It was in this period that the Black Sea acquired its present contours.

In addition to climatic conditions, a major role in the formation of large amounts of bottom sediments is played by erosion processes which occur in river basins, especially in their mountainous regions. Since natural phenomena (earthquakes, landslides, mudslides, catastrophic floods etc) have always been normal phenomena in mountainous regions, rivers could on occasion have delivered quantities of solid matter many times larger than today’s volumes. This can be seen from many major accumulation and accretion forms both under water and on land. It must also be remembered that sedimentation processes have always been incomparably more intensive on the floor of the Black Sea basin than on the floor of the Atlantic Ocean (109).

Sedimentation processes on the sea bottom did not occur identically at the various stages in the development of the Black Sea depression. At low levels, and if there were no shelf, the bulk of the sediment load did not remain close to the shore but was carried out to the open sea. One factor all stages had in common was the dominant role of land-derived sedimentation in the sedimentary process and its heterogeneous role in various regions of the sea (111). The rate and particular characteristics of the sedimentation process and the composition and distribution of the bottom sediments depended on the natural phenomena which occurred on land and in the basins of individual rivers, as it was the rivers which were the main agents delivering land-derived material from the land to the sea.

In addition to sediment load, the rivers and underground watercourses flowing into the Black Sea carry dissolved substances which have a major role to play in contemporary deposition.

The research work of Aibulatov (1, 2) indicates that in the Black Sea the actual formation of major longshore drift deposits (the direction and size of which are governed by the profile of the coastline, the contour of the shelf and the prevailing current) is directly linked to river discharge. In general, the direction in which fine particle size sediments are distributed follows longshore drift. The alluvium load from each major river or individual region has its own area of distribution and it is in these areas that deposition of these loads takes place.

Thus coastal processes and contemporary sedimentation are entirely dependent on the adjacent landmass. Rivers are the arteries which link the land to the sea, delivering to it products of erosion and denudation. Given this, the River-estuary-sea system has to be considered a unified natural system, and sediment load, the estuarine and lithodynamic processes of the coastal zone, and contemporary processes of sediment formation in the seas and oceans all have to be studied as a whole and simultaneously.

Conclusions

The Black Sea basin and the sea itself form a single unified natural system. The rivers form a link between the land mass and the sea, supplying the marine reservoir with water discharge and output from erosion and denudation. As a result, the RIVER-ESTUARY-SEA chain can be regarded as a unified natural system.

Rivers with an average annual discharge of 348 cubic kilometres of fresh water drain into the Black Sea. 86% of this outflow comes from ten major rivers:

Table A

Danube	- 200 km^3	(57.5%)
Dnieper	- 43.5 km^3	(12.5%)
Rioni	- 13.37 km^3	(3.8%)
Dniester	- 9.1 km^3	(2.6%)
Çoruh	- 8.71 km^3	(2.5%)
Kizil Irmak	- 5.90 km^3	(1.7%)
Sakarya	- 5.60 km^3	(1.6%)
Yesil Irmak	- 5.30 km^3	(1.5%)
Kodori	- 4.17 km^3	(1.2%)
Bzyb	- 3.79 km^3	(1.1%)

The breakdown of discharge by state and region is as follows: the volume of water entering the sea each year from Russia is 6.5 km^3 (1.9%), from Georgia 46.0 km^3 (13.2%), from Turkey 38.0 km^3 (10.9%) and from Bulgaria 1.8km^3 (0.52%). The Danube supplies the sea with 200 km^3 water (57.5%). The major rivers of the Ukraine contribute 55.5 km^3 (15.9%) of water to the sea and the rivers of the Crimea 0.3 km^3 (0.08%).

These amounts are discharged into the sea from rivers which are controlled and managed for various purposes. Under natural conditions the discharge would have been more than 381 km^3.

In addition to the surface discharge, at least 17 cubic kilometres of fresh water reaches the Black Sea from underground sources. Precipitation contributes another 238 km^3 (562 mm precipitation).

Thus the annual volume of fresh water entering the Black Sea (river water plus precipitation plus underground sources) is on average 603 km^3. Under natural conditions, without human interference, this figure would be 636 km^3.

With the water 52.2 million cubic metres of river load enters the sea every year. Of this, 11.7 million m^3 form banks and continental deposits, as beaches, and 40.5 million m^3 reach deeper waters and are involved in current sedimentation processes (mainly within the confines of the continental shelf). This amount of river load enters the sea from rivers that are controlled and managed in various ways. Under natural conditions the overall quantity of river load discharged would be at least 95.0 million cubic metres.

Underwater canyons currently contribute their own form of adjustment to the discharged load, and around 2 million cubic metres of large-scale shore sediment are carried along these outflow channels to greater depths.

In today's conditions (and allowing for flow control) the greatest amount of river load comes from the Danube, with 30.0 million cubic metres. The Chorokhi contributes 4.92 million m^3,

Table B **River load distribution by region, in million m³**

Region	Current river load volume			River load volume before flow control
	Total	Shoreline	Marine	
North-eastern part	0.93	0.32	0.61	1.00
Eastern part	11.1	4.30	6.80	14.5
Southern part	8.00	2.50	5.50	25.5
Western part	o.45	0.10	0.35	0.85
Danube	30.0	3.00	27.0	50.0
North-western part	1.66	1.50	0.16	3.00
Crimea	0.075	0.025	0.050	0.09
Total	**52.2**	**11.7**	**40.5**	**94.0**

the Rioni 3.54 million m^3, the Sakarya 2.23 million m^3, the Filyos 2.17 million m^3 and the Dniester 1.00 million m^3.

The inflow of river water and load into the Black Sea is very diverse in nature and depends on the natural conditions on the adjacent land mass and of the sea itself. The entire process is also subject to prevailing geographical zonal conditions

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