Sedimentation and geochemical anomalies in the Klaipėda strait: natural origin or human impact?

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The present article contains investigation results obtained and compiled by the author during the last 15 years. From the geoecological positions they generalize the data on suspensions, sediment fluxes and sediments in the Klaipėda strait area.

In this 6.23 km^3 sedimentation area the natural and technogenic sedimentation zones as well as input, transit, output and accumulation sectors are distinguished.

The input of particulate sedimentary matter (suspensions) from the Kuršių Marios lagoon into the Klaipėda strait is 561.8 thous. t, of them 58.3 thous t. accumulate on the bottom of the technogenic zone. In the strait (port) gate area 746.4 thous. t of sedimentary matter (suspensions and sediment fluxes) are accumulated, including 242.9 thous. t of marine sediment fluxes and 503.5 thous. t of suspension output from the strait to the Baltic Sea. The geochemical anomalies are forming only in the technogenic sedimentation area. They are conditioned by the interaction of natural and human impact factors, but anomalous contents of elements are accumulated only in fine silty and silty-clayey muds. The total form of chemical elements in many cases does not serve as a pollution index. Pollution should be related only to the toxic forms of elements. Among them we must distinguish the element state forms, the lithogenic form being natural, and the reaction-capable forms as a potentially anthropogenic component of chemical elements.

The data obtained allow to recommend the element state forms for investigation of the actual (toxic) level of pollution and for revision of the present concept of pollution.

Keywords: geochemical anomalies, suspensions, sediment fluxes, sedimentation

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INTRODUCTION

As an interface between fresh and salty water, the Klaipėda strait area performs the function of a geochemical barrier concentrating many hydrological, sedimentological, biological, anthropogenic and other factors. The aggregate action of these factors complicates the ecological situation of the strait and frequently exerts a negative effect on the recreational conditions in the coastal area around the port.

The hydrodinamic regime is one of the major factors in the formation of geochemical anomalies in the bottom of this area. It conditions the migration pattern of sedimentary matter, which depends on the velocity and direction of currents. It is natural that sediment fluxes are often predetermined by morphometric changes of the bottom occurring as a result of coast reconstruction and dredging of the surrounding water areas. The mentioned activity is reflected in sedimentary matter accumulation, intensification of various chemical processes and silting up of some port areas. The latter factors in turn affect the dredging works and soil dumping in the sea and on the land. Therefore, the assessment of the outcomes of Klaipėda port and marine entrance channel deepening to the depth of 14 m must be based on the analysis of the scale of sediment accumulation and the chemical composition of sediments.

The Klaipėda strait water asea includes an area of 6.23 km^2 (Klaipėdos..., 1996). Its length between the port gates in the north to the Kiaulės Nugara island is 12 km, whereas the width varies from 1.5 km (at the island) to 0.4 km at the entrance into the Baltic Sea. The Kiaulės Nugara island, overgrown with macrophytes and sandy, separates the strait from the northern part of the Kuršių Marios lagoon dividing it into the western (deeper) and eastern (more shallow) branches. The Smeltė peninsula is situated between the latter and the continental (eastern) coast of the strait. The eastern part of the peninsula has a small closed backwater – Malkų Bay. The bay represents a closed part of the area which is 1.6 km long and 300–500 m wide. The drainage of Klaipėda strait water into it is particularly limited. The north-eastern part of the bay embraces the mouth of a small river, the Smeltė. The Danė River falls into the strait 5 km from the port gates. Through these arteries – excluding the natural constituents – the partly biologically cleaned sewage water from Klaipėda is drained.

A 11–14 m deep and 100–110 m wide navigation channel runs along the western part of the strait-port area. It represents an artery for 26.5 km^3 of annual discharge of the Nemunas and other small rivers and atmospheric precipitation into the lagoon.

The Klaipėda strait is a sophisticated hydrosystem with pulsating fluxes of energy, sediment migration and exchange of biomass between the freshwater Kuršių Marios lagoon and the salty Baltic Sea. This area of extreme sedimentation conditions concentrates a multitude of natural factors – grain-size differentiation, variations of sedimentary matter migration forms, and periodic input into the strait of marine water with sedimentary matter. The velocity of outflowing currents reaches 0.2–0.25 $m \cdot s^{-1}$ (during spring floods it even exceeds 2 $m \cdot s^{-1}$). Similar speeds are characteristic also of the inflowing marine water. According to B. Gailiušis (Klaipėdos uostas..., 2000, 37–48), the marine water inflow lasts about 74 days and by even >60 cm rises the water level in the strait. It increases the input of salty water (12–15%) and silty marine sediments, abounding in sandy and aleurite fractions, into the lagoon. The annual input of marine water makes 5.954 km^3.

The present article is designed to answer the question how this sophisticated hydrosystem affects the formation of geochemical anomalies in the Klaipėda strait area. Different aspects of these processes have been discussed or generalized in a few works that appeared in the last 5 years (Pustelnikovas, 1998; Kuršių marios..., 1998; Klaipėdos uostas..., 2000; Lapinskienė, Pustelnikovas, Želvytė, 2002; Pustelnikovas, 2002).

RESEARCH METHODS, SECTORS OF SEDIMENTARY AREA AND MIGRATION OF SEDIMENTARY MATTER

Long-term investigation data on the Klaipėda strait (Pustelnikovas, 1998; Klaipėdos uostas..., 2000; Trimonis, Gulbinskas, 2000) enabled to distinguish 9 monitoring stations which since 1995 have been used for composite research works aimed at solving scientific-technological problems (Fig. 1). These stations reflect different sedimentation aspects of the Klaipėda strait geochemical barrier complicated by anthropogenic activity. On this basis the natural (NSZ) and technogenic (TSZ) sedimentation zones have been distinguished.

The natural sedimentation zone is the main artery into the sea. This zone includes the navigation channel and extends from the marine ferry station to the KLASCO quays. Further in the north it includes the entire strait (Fig. 1, I). In many cases sediments fail to accumulate in the bottom of this zone, because strong water flows carry the matter into the Baltic Sea.

The technogenic sedimentation zone is situated in the eastern part of the strait. It is far from the main flow of water and sedimentary matter. It includes the areas of trade and fishing ports, shipbuilding yards, landing-stages and backcreaks. The stagnant and semi-aeration conditions prevail in these areas (Fig. 1, II). These areas receive nonpurified city wastewater and abound in building and navigation wastes. Navigation resuspends and redistributes the sedimentary matter.

Sedimentation processes in these zones are obviously affected by sedimentary matter input during frequent marine water rises and geochemical factors of element differentiation predetermined by marine water invasion.

The Klaipėda strait is a sedimentary matter transit zone. The permanent marine water rise and variable hydrodynamics in sedimentation zones complicate the sedimentation processes. Therefore, different sectors of sedimentary matter migration should be distinguished in the strait (input, transit and ac-

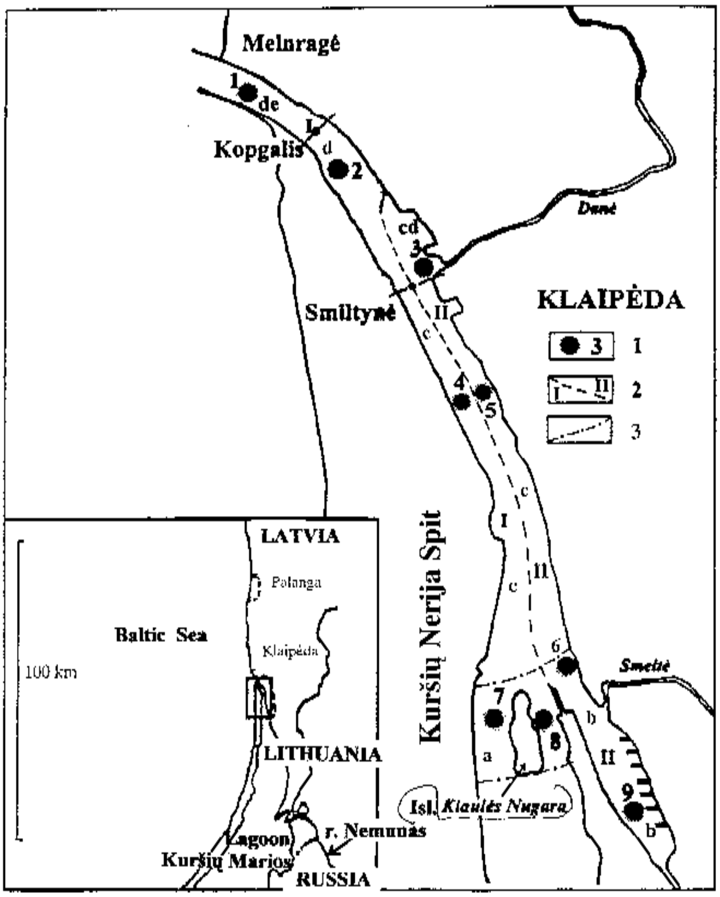

Fig. 1. Situational map of suspended sedimentary matter investigations in the Klaipėda strait: *1* – station No; *2* – sedimentation zones and their boundaries: I – natural, II – technogenic; *3* – migration zones and their boundaries: input (*a*), accumulation (*b*), transit (*c*), output (*d*), fresh and salty water mixing subzone (*e*) in the port gate area

1 pav. Suspenduotos nuosėdinės medžiagos tyrimų schema Klaipėdos sąsiauryje: *1* – stoties Nr.; *2* – sedimentacijos zonos ir jų ribos: I – gamtinė, II – technogeninė; 3 – migracijos zonos ir jų ribos: *a* – prietakos, *b* – akumuliacijos, *c* – tranzito, *d* – nuotėkio, *e* – gėlo ir sūraus vandens susimaišymo pazonė uosto vartuose

cumulation, output, and evident mixing of fresh and salty water).

The inflow sector is represented by branches on the both sides of the Kiaulės Nugara island through which the Nemunas water with sediments penetrates into the strait. The sedimentary matter further migrates into the transit sector or settles down in the Malkų Bay or its premises. The input sector represents the southern part of the natural sedimentation zone (Fig. 1, Ia). The transit sector includes the area between the marine ferry station and quays of KLASCO company. It is composed of the areas of natural and technogenic sedimentation zones (Fig. 1, I–IIc). The output sector is the most narrow strait segment north of the Klaipėdos Nafta terminal (partly this sector includes the areas north of the Danė mouth). In this sector, active mixing and sedimentation of freshwater matter and marine sediments take place (Fig. 1, I–II, cd, d, de). From there the sedimentary matter migrates into the Baltic Sea or (under the impact of extreme water rise) together with marine sediments accumulates in the transit sector (partly even in the Malkų Bay). In this sector three subzones can be distinguished: actual output (end of the transit zone, st. 3, Fig. 1, I–II, cd), a zone of weak mixing of fresh and salty water (st. 2, Fig. 1, Id) and a zone of strong mixing (st. 1, Fig. 1, I de). The first of them accumulates the freshwater flow matter remaining after part of it has settled down in the transit-input sectors (within the limits of NSZ and TSZ). This zone includes the northern part of the NSZ and partly TSZ.

Accumulation of especially thindispersed matter takes place in the accumulation sector under the effect of bottom hydrodynamics and complicated geochemical processes. Such accumulation can be observed in the transit and output sectors including both sedimentation zones. The sedimentation process is particularly active in the Malkų Bay area.

The analysis of sedimentation and migration conditions, agents and scale was based on the standard methods of bottom sediments, particulate matter and sediment flow analysis described in detail in previous works (Pustelnikovas, 1998; Salučka, Trimonis, 1998; Pustelnikovas, Salučka, 1999; etc.). The samples were taken by bathometers, sediment traps, dredges and gravity cores.

Sedimentary matter migration, differentiation and accumulation in the distinguished areas of the Klaipėda strait as well as the factors conditioning the variability of sediments in such a small sedimentation area as the Klaipėda strait are described in the ecogeochemical interpretation of bottom sediments (Trimonis, Gulbinskas, 2000), suspended matter (Pustelnikovas, Salučka, 1999) and sediment fluxes (Salučka, Trimonis, 1998) analysis.

2. GRAIN-SIZE COMPOSITION OF BOTTOM SEDIMENTS AND TURNOVER OF SEDIMENTARY MATTER

According to the previous data, the input of sedimentary matter from the lagoon into the Baltic Sea makes 424 thous. t or 31.5% of the total input into the lagoon. This process is predominated by biogenic (22.8%) matter. Part of terrigenous suspended particles carried into the sea makes 25.8% of the input of terrigenous and only 8.7% of the total input of sedimentary matter into the Kuršių Marios lagoon. The settling rates of this matter vary. The rates of sedimentation estimated by the ^{210}Pb method vary in different lagoon depressions within 2.5–3.6 mm · year^{-1}, making the average of 3.2 mm · year^{-1}. The preliminary rates of sedimentation observed by the author in the pit area of a marine ferry were even 30 cm · year^{-1} as a result of a difficult hydrological situation, geochemical barrier effect, and resuspension caused by navigation and port dredging (Результаты…, 1989). It is interesting to find out the factors predetermining the huge sedimentation rates in the strait. Let us have a look at the new detailed investigations.

The grain-size composition of Klaipėda strait bottom sediments, the distribution and the chemical composition of their lithotypes depend on the sedimentary matter input from the northern part of the Kuršių Marios lagoon, marine sediment transport and accumulation in the lagoon, regular bottom dredging and input of technogenic wastes. This is reflected in the scheme of grain-size types (Gulbinskas, 1994, Trimonis, Gulbinskas, 2000). The scheme demonstrates an obvious prevalence of coarse-grained clastic (silty and sandy) composition in the western part of the strait (Fig. 2). In the area of the strait (port) gates prevails fine sand with patches of medium sand, pebble and gravel. In this area the invasion and accumulation of marine sediments is obvious. The southwestern part of the strait is also predominated by sandy sediments. The percentage of silty particles increases southwards.

The eastern part of the strait (between the northern boundaries of KLASCO and the southern shore of Malkų Bay) is a distribution zone of fine silty and silty-clayey mud with patches of silty sand. In this area the human impact on sedimentation processes is obvious. Thus, in a small sedimentation area variable conditions facilitate the formation of different accumulation areas of the following sediment

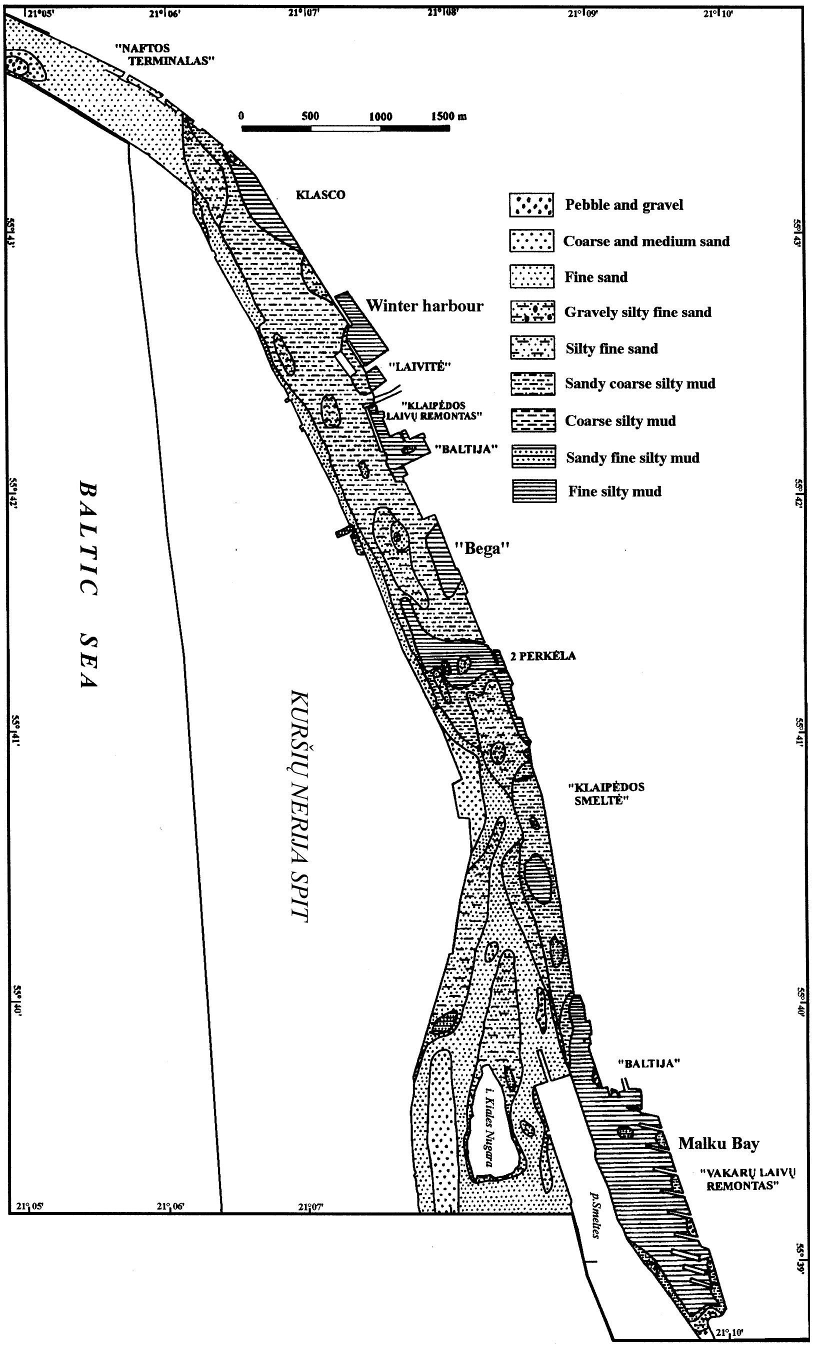

Fig. 2. Distribution of bottom sediments in the Klaipėda port water area: *1* – gravel and different grain-size sand; *2* – fine sand; *3* – silty fine sand; *4* – coarse silt; *5* – silty mud; *6* – silty-clayey mud

2 pav. Dugno nuosėdų pasiskirstymas Klaipėdos uosto akvatorijoje: *1* – žvirgždas ir įvairaus grūduotumo smėlis, *2* – smulkus smėlis, *3* – smulkus aleuritingas smėlis, *4* – stambus aleuritas, *5* – auleuritinis dumblas, *6* – aleuritinis-pelitinis dumblas

Table 1. **Average composition of grain-size types of sediments dredged from the Klaipėda strait area (according to "Žuvininkystė…, 1996)**
1 lentelė. **Klaipėdos sąsiaurio gilinimo metu iškastų nuosėdų granuliometrinių tipų vidurkinė sudėtis (pagal „Žuvininkystė…, 1996)**

Sediment type	Fractions, mm			
	>1	1–0.1	0.1–0.01	<0.01
Fine sand	0.8	93.3	5.9	–
Silty fine sand	0.3	75.4	23.7	0.6
Coarse silt	0.5	31.7	52.4	15.4
Fine silty mud	0.3	9.5	67.6	22.6
Till	3.4	20.2	48.2	28.2

types: coarse clastic (>2 mm) material residual "isles", medium and fine sand, silty sand, sandy coarse and fine silt and silty-clayey muds.

On the basis of average grain-size composition of soils dredged from the strait the sediments accumulating in the strait area are divided into five major groups (Table 1). Taking into account the specific features of technogenic sediments and the character of sedimentation, zones of natural and technogenic sedimentation (types) and sub-zones (subtypes) of abrasion-neutral and accumulation have been distinguished (Pustelnikovas, 1995).

The subtypes reflect sediments of different composition, sedimentation conditions and technogenic level. Their chemical composition is variable.

3. MIGRATION AND DISTRIBUTION OF SEDIMENTARY MATTER IN SEDIMENTATION ZONES

Sedimentary matter gets into the sedimentation area (zones) of the strait from two main natural sources: from the Kuršių Marios lagoon (suspensions are dominant) and from the Baltic Sea (sediment fluxes). (Of course, we cannot exclude the source of anthropogenic matter whose debatable levels are obviously lower than those of the first two). The sedimentary matter coming from these sources is heterogeneous; their heterogeneity is reflected in the sediment types and their grain-size and chemical composition.

The first source provides silty (0.1–0.01 mm) and clayey (<0.01 mm) particles, but during spring floods the part of fine sand (0.25–0.1 mm) considerably increases. The matter from the second source is predominated by fine sand. The anthropogenic source is characterized by a highly thindispersed and even colloidal composition.

It is important to know the distribution patterns of suspensions and sediment fluxes in extremely different sedimentation zones.

Data of Table 2.1 show that in the natural sedimentation zone the long-term average of suspension concentrations is 20.9 mg · l^{-1} and their seasonal variations are within 16.5 (summer) and 35.4 (spring) mg · l^{-1}. The spring average (the highest) is about 2.1 times the average of each of the rest seasons. The annual concentration average of the technogenic zone (17 mg · l^{-1}) is by 19% (1.23 times) lower than in the natural zone. The average values for each season are respectively lower.

The presented data reveal neither the migration patterns of sedimentary matter nor the scale of sedimentation in the strait. These questions can be highlighted by analysis of seasonal variations of sediment fluxes (particulate matter) intensity (Table 2). Its long-term average is 833 g · cm^{-2} · day^{-1}, but seasonal variations are huge – the maximum values exceed the minimum ones 4.3 times. These seasonal averages are obviously conditioned by sediment flow in the natural zone. In all seasons it is 3.5–4.8 (in summer 1.6) times higher than in the technogenic zone (Fig. 3). Chemical elements of natural and technogenic origin migrate in the general composition of sedimentary matter. Huge total amounts of se-

Table 2. **Long-term seasonal variations of suspension concentrations (mg · l^{-1}) and sediment fluxes (g · cm^{-2} · day^{-1}) in sedimentation zones**
2 lentelė. **Suspensijų kiekio (mg/l) ir nešmenų srauto (g/cm^2 per parą) daugiametė sezoninė kaita sedimentacinėse zonose**

Season	Average in the strait	Including sedimentation zones		Ratio
		Natural (NSZ)	Technogenic (TSZ)	NSZ: TSZ
1. Concentration of suspensions, mg · l^{-1}				
Winter	14.8	16.9	12.7	1.33
Spring	30.4	35.4	24.7	1.43
Summer	15.4	16.5	14.1	1.17
Autumn	16.5	17.2	15.6	1.10
Long-term average	19.6	20.9	17.0	1.23
2. Intensity of sediment fluxes, g · cm^{-2} · day^{-1}				
Winter	486	710	205	3.5
Spring	1185	1826	382	4.8
Summer	314	377	236	1.6
Autumn	1347	2075	439	4.7
Long-term average	833	1220	318	3.8

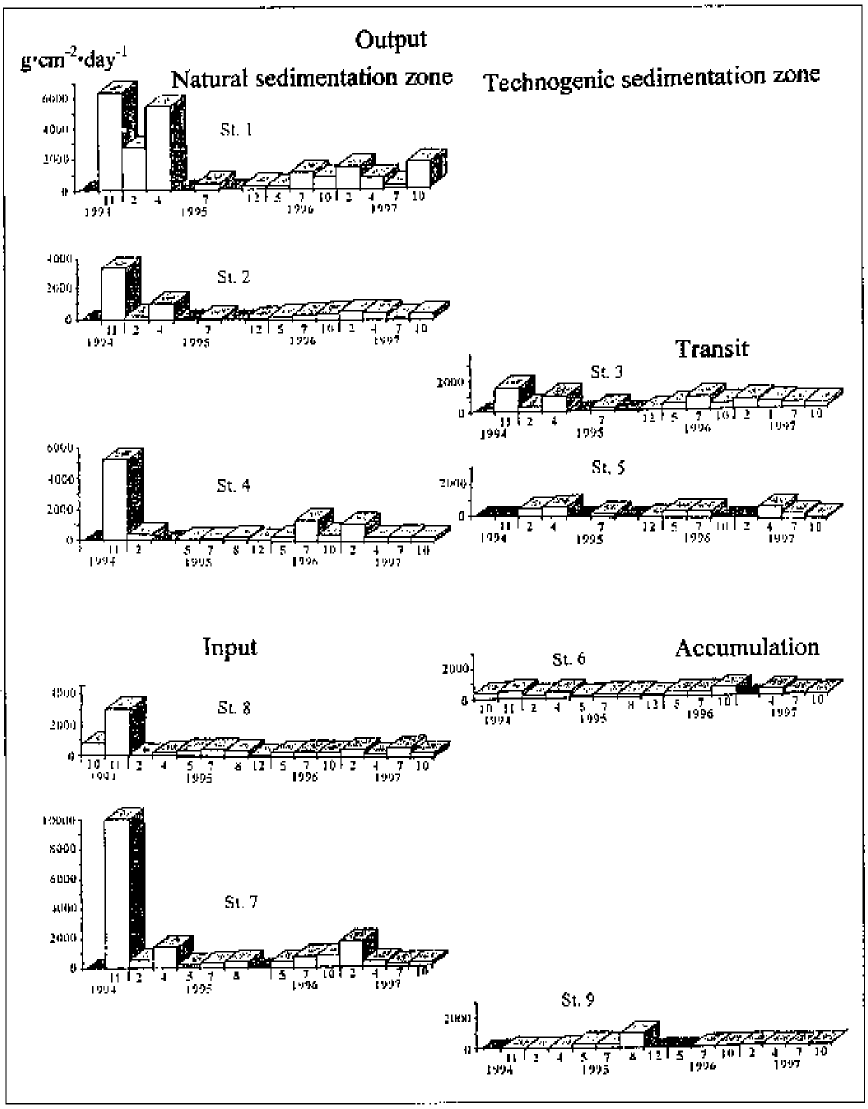

Fig. 3. Intensity of sediment fluxes (g · cm^{-2} · day^{-1}) in the natural and technogenic sedimentation zones and input, transit, accumulation and output migration sectors of sedimentary matter

3 pav. Sąnašų srauto intensyvumas (g/cm^2 per parą) gamtinėje ir technogeninėje sedimentacijos zonoje bei nuosėdinės medžiagos prietakos, tranzito, akumuliacijos ir nuotėkio sektoriuose

dimentary matter, its extremely thindispersed composition, and anomalous concentrations of chemical elements serve as a basis for supposing their possible toxicity and ecological implications in the areas of dredged soil dumps (Žaromskis, Gulbinskas, 1996; Gulbinskas, 2000).

In order to elucidate the actual ecological situation, it is necessary to determine the amounts of sedimentary matter transported into the sea and the amounts that remain in the Klaipėda strait. In other words, it is necessary to know the balance of sedimentary matter in the strait. This can be done through investigations of migration processes of this matter.

4. MIGRATION AND ACCUMULATION PATTERNS OF SEDIMENTARY MATTER

Migration patterns of suspensions and sediment fluxes in the mentioned sectors are listed in Table 3. A comparison of the amounts of long-term suspensions (mg · l^{-1}) and sediment flux intensity (g · cm^{-2} · day^{-1}) in different migration sectors – without going into more detailed generalizations (they have been done in the works: Pustelnikovas, Salučka, 1999; Salučka, Trimonis, 1998; Lapinskienė et al., 2002) – revealed their diminishing values from the input (a) to the output (d) sectors (in cd sub-zone in particular) and a considerable increase in the port gate area (e), *i.e.* in the sub-zone of fresh water output and salty water input mixing (Fig. 1, Table 3). These values are subject to seasonal variations but in the mixing zone they are slightly lower than in the input zone. The lowest concentrations of suspensions and sediment flux intensity in the accumulation sector (b) as well as the grain-size composition of sediments and hydrodynamic regime provide a convincing evidence of extremely thin-dispersed sedimentary matter accumulation in the bottom of the technogenic sedimentation zone. A considerable increase (up to 20–25%) of its content in the mixing sub-zone (e) enables to predict the invasion of marine sediments into the strait. The rate of invasion and the amounts of accumulating sedimentary matter can be revealed by its balance calculations (Table 4).

5. SEDIMENTATION RATE AND GEOCHEMICAL ANOMALIES IN THE SURFACE LAYER (0–5 CM) OF SEDIMENTS

Long-term variation analysis of suspension and sediment flux intensity has revealed an obvious accumulation of sedimentary matter in the Klaipėda strait.

Table 3. **Migration of suspended and sediment flux matter**
3 letnelė. **Suspensijų ir nešmenų srauto medžiagos migracija**

Season	Migration sectors					Relation a:b:c:d:e
	Input (a)	Accumulation (b)	Transit (c)	Output (d)	Head (mixing) zone (e)	
	1. Concentration of suspensions, mg · l^{-1}					
Winter	13.9	12.1	17.4	16.4	19.4	1:0.87:1.25:1.18:1.40
Spring	34.2	20.3	33.7	26.1	34.2	1:0.59:0.99:0.76:1
Summer	16.8	13.8	14.6	15.8	15.3	1:0.82:0.87:0.94:0.91
Autumn	17.7	16.2	15.7	17.4	23.1	1:0.91:0.89:0.98:1.31
Many years mean	21.2	15.8	20.9	19.0	23.0	1:0.75:0.99:0.90:1.08
	2. Intensity of sediment fluxes g · cm^{-2} · day^{-1}					
Winter	661	107	395	348	1441	1:0.16:0.60:0.53:2.18
Spring	2574	180	449	620	2850	1:0.07:0.17:0.24:1.11
Summer	395	137	340	399	391	1:0.34:0.87:1.01:0.99
Autumn	2188	220	1116	787	2932	1:0.10:0.54:0.36:1.34
Many years mean	1455	169	558	536	1765	1:0.12:0.38:0.37:1.21

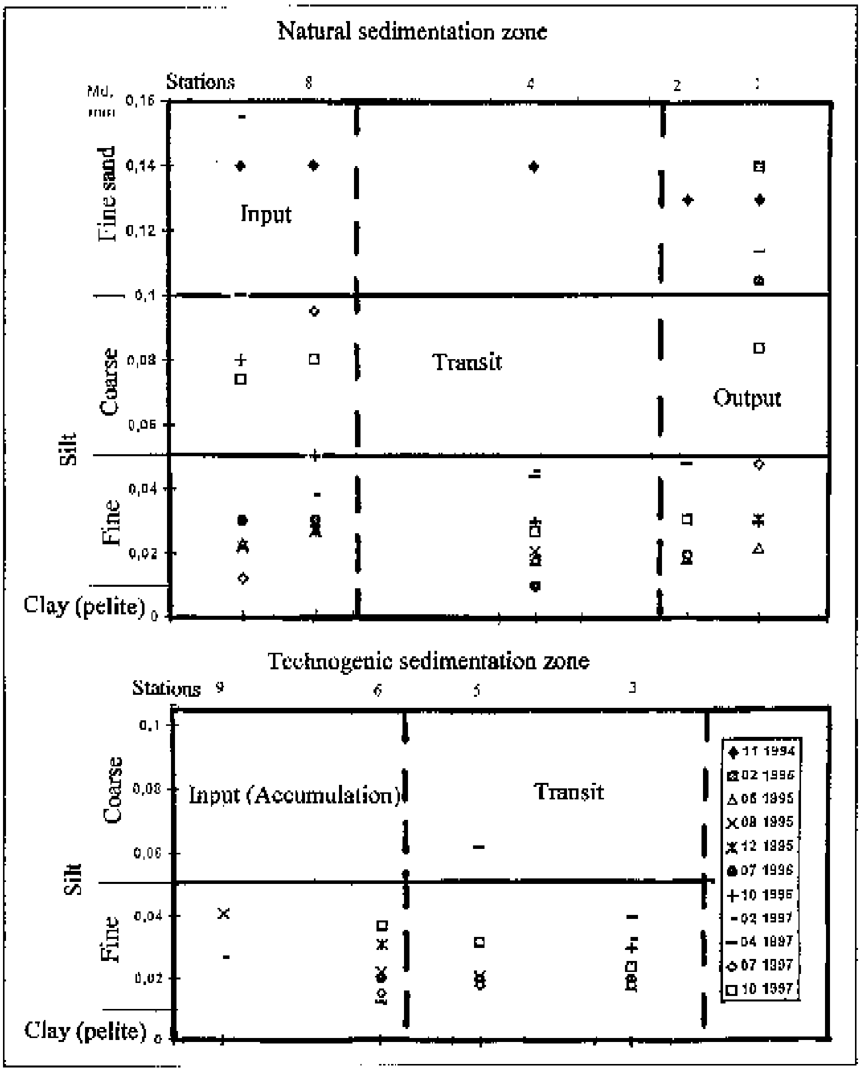

Fig. 4. Grain-size composition of sediment fluxes in sedimentation zones and migration sectors
4 pav. Sąnašų srauto granuliometrinė sudėtis sedimentacijos zonose ir migracijos sektoriuose

The annual accumulation of sedimentary matter in the strait is calculated by interpolation. The balance calculations were based on the following data:

- freshwater output into the strait (V) – 26.5 km^3
- marine water input into the lagoon (V_1) – 5.954 km^3 (Klaipėdos uostas..., 2000).
- concentration of suspensions in the input sector (m_1) – 21.2 mg · l^{-1} (thous. t · km^{-3})
- concentration of suspensions in the output zone – interface of transitory sector and mixing area (m_2) – 19 mg · l^{-1} (thous. t · km^{-3})
- concentration of suspensions in the fresh and marine water mixing sub-zone (m_3) – 23 mg · l^{-1} (thous. t · km^{-3}),

where:

✓ the amount of sedimentary matter (Q_1) coming from the northern part of lagoon makes:

$Q_1 = V \cdot m_1 = 26.5 \cdot 21.2 =$
$= 561.8$ thous. t

✓ the output of sedimentary matter from the strait (Q_2) is:

$Q_2 = V \cdot m_2 = 26.5 \cdot 19 =$
$= 503.5$ thous. t

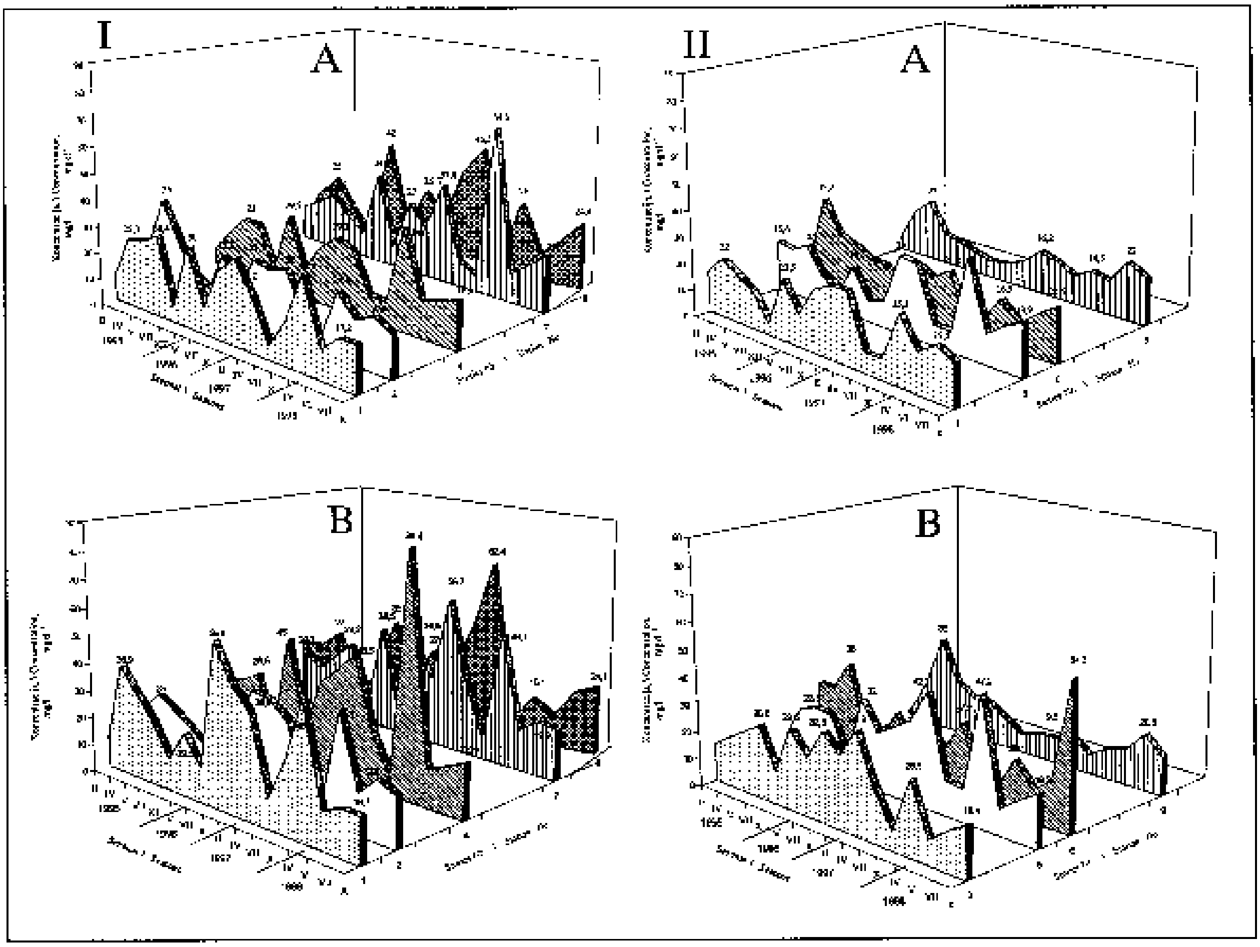

Fig. 5. Blockdiagrams of seasonal suspension distribution in Klaipėda strait in the stations of natural(I) and technogenic (II) sedimentation zones. Water layers: surface (A), nearbottom (B)
5 pav. Sezoninio suspensijų pasiskirstymo blokinės diagramos Klaipėdos sąsiaurio gamtinės (I) ir technogeninės (II) sedimentacijos zonose. Vandens sluoksniai: *A* – paviršinis, *B* – priedugninis

Table 4. **Balance of sedimentary matter of the Klaipėda strait, thous. t · year^{-1}**
4 lentelė. **Nuosėdinės medžiagos balansas Klaipėdos sąsiauryje tūkst. t/metus**

Input	Output	Accumulatiom	Head (mixing) zone	Marine sediments
$Q_1 = V \cdot m_1$	$Q_2 = V \cdot m_2$	$Q_S = Q_1 – Q_2$	$Q_3 = (V + V_1) \cdot m_3$	$Q_{ms} = Q_3 – Q_2$
26.5 · 21.2 = 561.8	26.5 · 19.0 = 503.5	561.8–503.5 = 58.3	(26.5 + 5.954) · 23.0 = 746.4	746.4–503.5 = 242.9

The difference

$Q_S = Q_1 – Q_2 = 561.8–503.5 = 58.3$ thous. t

reveals that 58.3 thous. t of sedimentary matter accumulate mainly in the technogenic sedimentation zone (Q_S) of the strait.

When the concentration of suspensions in the marine water input sub-zone increases to 23 mg · l^{-1}, the total amount of suspensions becomes

$Q_3 = (V + V_1) \cdot m_3 = (26.5 + 5.954) \cdot 23 = 746.4$ thous. t.

This value (746.4 thous. t) can be taken as an annual summary amount of sedimentary matter output from and input into the lagoon. The difference (Q_{ss}) between the amounts of sediments,

$Q_{ss} = Q_3 – Q_2 = 746.4–503.5 = 242.9$ thous. t,

may be preliminarily taken as the annual amount of marine sediment input into the strait.

The difference between the new and old (see Section 1) data shows an increase of sedimentary matter output into the sea (503.5–424.0 = 79.5 thous. t). How this can be accounted for? Firstly, the investigations have become more detailed, and more seasonal data on the strait are available. On the other hand, the influence of climatological-hydrological factors on the increasing suspension levels in the basin cannot be excluded. In order to revise the previous balance calculations (Pustelnikovas, 1983; Galkus, 1993) and to develop new prognostic models for Kuršių Marios lagoon, it is expedient to carry out a long-term seasonal investigation along the whole geochemical barrier sector from the lower Nemunas to the Baltic Sea. The Klaipėda strait as the most important sector of this barrier requires separate balance calculations.

On the example of chemical composition variations of bottom sediments (Table 5) we can analyse the distribution of natural-anthropogenic anomalies and try to interpret it from the geoecological point of view, as well as to preliminarily determine the contribution of the anthropogenic factor in the formation of the absolute values of these anomalies. A generalized analysis of composite investigations has been presented in the latest work (Lapinskienė et al., 2002).

The data of Table 5 show that the concentrations of almost all chemical elements in the NSZ are on the same level as in the northern sedimentation area of the Kuršių Marios lagoon. Their values do not exceed the values in Holocene and glacial deposits of the catchment basin (Table 6) (Pustelnikovas, 1998).

The chemical composition of sediment types reflects the dependence of element concentrations on the content of thindispersed sedimentary matter (Емельянов, 1998). It is natural that as a result of human economic activity the technogenic sedimentation zone includes extreme geochemical anomalies where element concentrations are a few and even tens of times higher than in the natural zone (Table 5). Yet, even in this case we cannot unambiguously assert their anthropogenic origin, because the technogenic zone is predominated by stagnant conditions – the bottom sediments are not aerated. Besides, as has been mentioned in Section 3, 58.3 thous. t of thindispersed lagoon matter accumulate annually mainly in this zone. Water rises facilitate intensive water mixing and thus change the oxidation-reduction and pH conditions, increasing the salinity up to 3‰. Under these conditions the elements convert from dissolved to colloidal-suspended form, *i.e.* chemical sedimentation occurs and considerably increases the concentration of elements in the extremely thindispersed bottom sediments. Unfortunately, these processes in the Klaipėda strait have not yet been investigated, and thus it is difficult to determine the ratio between the natural and the anthropogenic constituents. Judging from the pollution classes of soil and concentrations of pollutants (Klaipėdos uos-

Table 5. **Average concentrations of elements (total form) in sedimentation zones of Klaipėda strait and in grain-size types of sediments (based on the data from "Nemuno baseino…", 1991, Jokšas; 1996 and on individual data of the author)**
5 lentelė. **Vidurkinis elementų kiekis Klaipėdos sąsiaurio sedimentacinėse zonose bei genetiniuose nuosėdų tipuose (pagal „Nemuno baseino…, 1991; Jokšas, 1996 ir autoriaus duomenis)**

Elements	Measuring units	Sedimentation zone			Sediment types						
		Northern part of Kuršių Marios lagoon	Klaipėda strait		NSZ			TSZ			
			NSZ	TSZ	Sand	Coarse silt	Till	Sand	Coarse silt	Fine silty mud	Till
C org	%	1.8	1.5	3.2	–	–	–	–	–	–	–
Fe	„	1.4	0.77	1.84	0.67	0.85	1.19	3.15	3.40	4.01	2.30
Mn	„	0.05	0.019	0.048	0.01	0.02	0.03	0.29	0.30	0.75	0.47
Cu	10^{-4}% (ppm)	17	10	105	3	10	16	29	26	757	24
Zn	„	70	31	172	16	38	52	140	171	287	76
Co	„	12	11	13	–	–	–	–	–	–	–
Ni	„	33	16	25	–	–	–	–	–	–	–
Cr	„	64	42	58	37	46	57	74	88	119	39
Li	„	19	9	13	–	–	–	–	–	–	–
Pb	„	14	9	62	8	10	16	–	–	–	–
Cd	„	–	1.3	1.5	–	–	–	–	–	–	–
Hg	10^{-6}% (ppb)	80	12	31	–	–	–	–	–	–	–
Oil products	10^{-4}% (ppm)	25	23	508	21	94	9	790	2012	4597	15

Table 6. **Comparison of average total quantities of elements in various genetic objects of land, water basin and biota**
6 lentelė. **Bendro elementų formų kiekio pasiskirstymas įvairiuose sausumos, vandens ir biotos genetiniuose objektuose**

Place	Object	Elements							
		Percent		ppm (10^{-4}%)					
		Fe	Mn	Cu	Zn	Cr	Ni	Co	Pb
Lagoon Kuršių Marios	Sediments (0–10 cm)	1.3	0.050	17	52	43	21	12	50
Gulf of Finland (east part	Sediments (0–10 cm)	5.8	0.660	48	195	136	79	49	n.i.
Vistula lagoon	Sediments (0–10 cm)	2.5	0.033	30	107	66	50	20	12
Hornsund fjord	Sediments (0–10 cm)	4.2	0.038	28	92	93	66	42	68
Sambian peninsula	Sand (Neogene)	1.3	0.008	6	14	48	17	8	n.i.
Kuršių Marios Lagoon	Peat (Holocene)	1.5	0.030	17	36	34	17	5	n.i.
Forest dunes of Melnragė (Kaipėda)	Eolian sand	0.4	0.011	12	7	40	30	3	<10
Vistula spit	Burried soil	3.8	0.148	40	172	140	70	32	n.i.
Kuršių Marios Lagoon	Rotten timber (>120 years old)	5.6	0.080	760	780	264	286	28	n.i.
Spit Kuršių Nerija (Rybachy beach)	Mix sand-blue-green algae	13.4	0.376	24	88	142	28	40	80
Klaipėda Oil terminal	Soil	1.3	0.030	21	115	25	14	3	24
Klaipėda strait (NSZ)	Till	1.2	0.030	16	52	57	n.i.	21	16
Klaipėda strait (NSZ)	Sand and silt	1.5	0.050	24	52	44	23	15	n.i.
Klaipėda strait (TSZ)	Sand and silt	3.3	0.295	28	156	81	n.i.	5	17
Klaipėda strait (TSZ)	Till	2.3	0.470	24	76	39	n.i.	4	7
Klaipėda strait (TSZ)	Mud fine silty	4.0	0.750	757	287	119	n.i.	6	26

tas…, 2000) and taking into account the average element concentrations in sedimentation zones (Table 5), we may draw a conclusion that only the concentration of HC (oil products) in all types of sediments of the technogenic zone corresponds to the class of highly polluted soils. Analysing the distribution of HM (heavy metals), we see that polluted and highly polluted soils include fine silty muds (Cu). The concentrations of Zn and Cr are those characteristic of slightly polluted soils. What areas are occupied by these sediment types? What is the toxicity level of these (and other) elements? What concentrations of natural elements reach this zone from the input area in the form of suspended matter flows? What is the ratio between the lithogenic (natural genesis) and hydrogenic-reaction-capable (potentially anthropogenic) element forms in the sediments of this zone? Answers to these questions alone do not allow a straightforward assertion of the high rates of pollution in this zone and in the Klaipėda strait. The patches of polluted and highly polluted soils in this area presented in (Klaipėdos uostas…, 2000) most probably can be associated with the mixing of sediments during soil dredging and loading.

Data presented in this work indicate that geochemical anomalies in the Klaipėda strait locally occur only in TSZ and reflect the impact of natural and anthropogenic constituents. This is not enough to prove the popular conception of global pollution. It is necessary to carry out targeted investigations of the actual (toxic) level of pollution.

CONCLUSIONS

1. The annual input of sedimentary matter into the Klaipėda strait reaches 561.8 thous. t, of which 58.3 thous. t accumulate mainly in the bottom of the technogenic zone and 503.5 thous. t are transported into the Baltic Sea.

2. Sea water rises obviously increase the amount of sedimentary matter in the port gate area to 746.4 thous. t, including 242.9 thous. t of marine sediment input into the strait.

3. According to the impact of natural and anthropogenic factors the natural and technogenic sedimentation zones can be distinguished. Geochemical anomalies occur only in the latter one.

4. The chemical element distribution depends on the sediment types. The highest concentrations of all investigated elements are accumulated in fine silty muds.

5. Anomalous element concentrations in fine-grained silty muds of the technogenic sedimentation

zone are a result of the interaction between natural and anthropogenic factors. Their actual ratio is to be established in the future. Geochemical anomalies in this zone cannot be regarded as purely anthropogenic.

6. Element state forms investigations are necessary for determination of the actual (toxic) level of pollution. The previously established levels should be revised.

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SEDIMENTACIJA IR GEOCHEMINĖS ANOMALIJOS KLAIPĖDOS SĄSIAURYJE: GAMTINIS VEIKSNYS AR ANTROPOGENINIS POVEIKIS?

S a n t r a u k a

Pateikiamas darbas apibendrina autoriaus ir kitų mokslininkų duomenis, gautus per pastaruosius 15 metų. Klaipėdos sąsiaurio suspensijų, suspenduotų nešmenų srautų ir dugno nuosėdų tyrimų rezultatai analizuojami iš geoekologinių pozicijų.

Šiame 6,23 km^2 nuosėdų kaupimosi plote išskiriamos gamtinės ir technogeninės sedimentacijos zonos bei nuosėdinės medžiagos prietakos, pernešimo (tranzito), nuotėkio ir akumuliacijos sektoriai.

Su Nemuno nuotėkiu iš Kuršių marių į sąsiaurį patenka 561,8 tūkst. t nuosėdinės medžiagos (suspensijų), iš kurios net 58,3 tūkst. t (> 10 %) nusėda technogeninės sedimentacijos zonos dugne. Uosto vartų rajone susikaupia 746,4 tūkst. t medžiagos (suspensijų ir suspenduotų nešmenų), iš kurios 242,9 tūkst. t (apie 33%) sudaro jūrinės sąnašos ir 503,5 tūkst. t – suspenduotų medžiagų nuotėkis iš sąsiaurio į Baltijos jūrą. Geocheminės anomalijos randamos tik technogeninės sedimentacijos zonoje. Jas sąlygoja gamtinių ir antropogeninių veiksnių sąveika, bet anomalūs elementų kiekiai paplitę smulkiaaleuritiniame ir aleuritiniame-pelitiniame dumble. Cheminių elementų formų suma dažniausiai nėra užterštumo rodiklis. Su užterštumu sietinos tik toksinės elementų formos. Iškyla būtinybė nustatyti elementų būsenos formas: litogeninę (gamtinę) ir judrią (hidrogeninę) – potencialiai antropogeninę cheminių elementų dedamąją.

Pateikti duomenys padeda išaiškinti faktinio (toksinio) užterštumo lygį ir įtvirtinti šiuolaikines užterštumo sampratas.

Олегас Пустельниковас

ОСАДКОНАКОПЛЕНИЕ И ГЕОХИМИЧЕСКИЕ АНОМАЛИИ В КЛАЙПЕДСКОМ ПРОЛИВЕ: ЕСТЕСТВЕННЫЙ ФАКТОР ИЛИ АНТРОПОГЕННОЕ ВЛИЯНИЕ?

Р е з ю м е

В настоящей работе приводятся данные автора и других исследователей, полученные в течение последних 15 лет. Результаты анализа взвеси, взвешенных наносов и донных осадков Клайпедского пролива обобщаются с геоэкологической точки зрения.

Седиментационная область пролива площадью в 6,23 км^2 включает в себя зоны естественного и техногенного осадконакопления, а также секторы поступления, перемещения (транзита), выноса и аккумуляции осадочного вещества.

В пролив из Куршского залива (Куршю-Марёс) в составе стока р. Нямунас поступает 561,8 тыс. т осадочного материала (взвеси), 58,3 тыс. т (>10%) которого оседает на дно зоны техногенного осадконакопления. На выходе из пролива (портовые ворота) накапливается 746,4 тыс. т материала (взвесь и взвешенные наносы), 242,9 тыс. т (около 33%) которого составляют наносы морских отложений и 503,5 тыс. т – сток взвешенного материала из пролива в Балтийское море. Геохимические аномалии встречаются лишь в зоне техногенной седиментации. Они обусловлены взаимодействием естественного и антропогенного факторов, но аномальные количества элементов сосредоточены в мелкоалевритовых и алеврито-пелитовых илах.

Суммарная (общая) форма химических элементов в большинстве случаев не является показателем загрязнения. Последнее ассоциируется лишь с токсическими составляющими элементов. Это приводит к необходимости определять формы состояния этих составляющих: литогенная форма представляет естественную (природную), нетоксическую, а гидрогенные (подвижные, реакционноспособные) формы – потенциально антропогенную составляющую химических элементов.

Представленные данные позволяют рекомендовать анализ фактического (токсического) уровня загрязнения и нормализовать понятия о его масштабах в настоящее время.