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Bottom sediments of the Vistula Lagoon of the Baltic Sea

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Terrigenous clastic sediments with a biogenic component are predominant types in Russian part of the Vistula Lagoon of the Baltic Sea. The following types of sediments are recognized: pebble-gravel, sand, and coarse aleurite, fine aleuritic mud and aleuro-pelitic mud. The most abundant among them are fine aleuritic mud, which cover about 45% of the lagoon bottom area, and sands of different grain size placed along the periphery of coastal zone. Distribution of granulometric fractions is a reflection of complex processes of deposition and sorting of sedimentary material. As a result, four zones of different sedimentary conditions have been recognized in the study area: estuary of the Pregel River, central and south-western zones, and Primorskaya Bight.

Vistula Lagoon, bottom deposits, sedimentation, grain size fractions.

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INTRODUCTION

As an integral result of sedimentary and environmental conditions, bottom deposits are of great interest for studying multi-component marine ecosystems, including purely sedimentological problems and understanding of other processes — geochemical, biological, geoecological. Bottom sediments can be widely used to assess the scale of technogenous impact upon coastal/marine ecosystems, recognition of qualitative content of pollutants and their transport pathways, and probable routes of natural and anthropogenous fluxes (Aibulatov & Artyukhin 1993; Anikeev *et al*. 1993; Windom *et al*. 1989, Hirschberg *et al*. 1996). Relationship between the content of chemical elements and components in sediments and their granulometric fractions, in particular the enrichment of pelitic fractions in most of pollutants, has been corroborated (Moshenko *et al*. 2001, Windom *et al*.1989). Thus, evidences about granulometric composition may be useful for understanding of regularities of accumulation of metals and organic pollutants in sediments.

Analysis of distribution of bottom sediments and their characteristics is becoming increasingly important with respect to the study of water systems, which are strongly affected by anthropogenous impact. Among such systems is the Vistula Lagoon — a shallow water estuary basin, which is situated off the south-eastern coast of the Baltic Sea and separated from it by sand bar called the Vistula Spit (Fig. 1). Its average depth is 2.7 m, maximum depth is 5.2 m; also a great many of shoals and banks with depths not more than 1 m are present in the vicinities of coasts. Water exchange with the sea is supported through the nar-

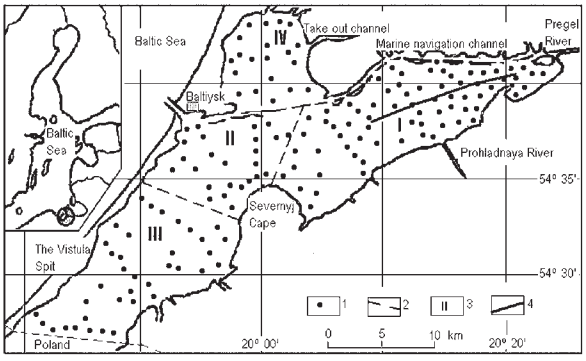

Fig. 1. Location map illustrating the regional setting of sites for sediment sampling in Russian part of the Vistula Lagoon and zones of sedimentation. 1 — stations of the bottom sediment sampling (0-10 cm), 2 – boundaries of zones, 3 — sedimentation zones: I — the Pregel River estuary; II — central zone; III — south-western zone; IV — Primorskaya Bight, 4 — the positioning of old navigable channel. Location of the Vistula Lagoon in the Baltic Sea is shown at small scheme.

row Baltic Strait, which is located near port of Baltiysk. Water surface area of Russian part of this lagoon is 472 km^2, and this is 56% of the total area (Lasarenko & Majewski 1971).

Being a transit zone for suspended matter on its way from land to sea, the lagoon plays a role of a giant trap/sedimentation basin for sedimentary material and pollutants, which are supplied, together with industrial and municipal waste waters, by the Pregel River and take out channel. At the same time, this lagoon is rich in benthos and is a good feeding place for commercial benthos-eating fish (Aristova 1966), and therefore is important for fishery. The presence of navigation channel and problems caused by its functioning, including the vicinity of port facilities, construction and re-construction of dams, forces it to undertake serious research efforts to study the present-day lagoon sedimentogenesis.

However, because of small research efforts, which have been undertaken until now, bottom deposits in Russian part of the Vistula Lagoon, have been studied insufficiently. Geological arrangement (Pratje 1936) and stratigraphy of bottom sediments in Russian part of the lagoon (Brockmann 1954) have been determined from detailed investigations carried out mainly in prewar time. Many problems of sedimentogenesis remain unclear, because there being to date no description of the sediments genetic types, their physical properties and mineral composition, and some problems were not considered at all. During the past 50 years, no generalized papers on the subject have been published.

Considering all this, since 1992, Atlantic Branch of P.P. Shirshov Institute of Oceanology (ABIORAS) has been conducting wide spectra of sedimentological investigations, including studying of bottom deposits. As a result of these investigations, some papers touching, to a degree, the problems of sedimentation have been published (Blazhchishin 1995, Blazhchishin 1998, Blazhchishin 2002, Blazhchishin & Chechko 1997, Chechko 1999, Chechko 2002, Kravchishina 2002). An attempt has been made in this paper to generalize all the available data on bottom deposits in the Russian part of the Vistula Lagoon, with the aim to recognize and describe main types of bottom sediments, and then analyze the composition and distribution regularity of main granulometric fractions.

MATERIAL AND METHODS

Data for the study have been collected during multipurpose scientific expeditions undertaken in the Vistula Lagoon and in the mouths of rivers entering the lagoon, in 1992-1999. In all, about 600 samples of bottom deposits collected by Petersen grab, piston corer (d=72mm) and Niemisto corer at 375 spatially spaced stations, have been studied (Fig. 1). Investigations cover the upper 0-10-cm layer of bottom sediments. Granulometric analysis of samples was made by using sieving and water-mechanical methods (Petelin 1967). Two parameters were used to characterize granulometric composition of sediments: Md – median particle diameter, and So — sorting coefficient, showing principal features of the sediment grain-size (Rukhin 1947).

Sediment classification was made by using the Institute of Oceanology method (Bezrukov & Lisitsin 1960), which is based on the following parameters: median-particle diameter, grain-size of the predominant fraction and its content in %. Mineral composition of sand-aleuritic fractions was analyzed by using immersion method (Logvinenko 1962): in all, 130 samples were selected for the mineralogical analysis.

RESULTS AND DISCUSSION

Main types of bottom sediments

The distribution pattern of sedimentary material entered in the lagoon and its granulometric composition depend upon a number of factors such as hydrodynamic situation, river's load, composition of bottom and coastal sediments. Differentiation of sedimentary material is strongly influenced by periodical wind-surge events. Types of bottom sediments, represented mainly by terrigenous clastic material of different grain-size with small amount of biogenic component, are a reflection of all these factors.

The $CaCo_3$ content in sands is about 1%, in coarse aleurites — 1-3%, fine aleuritic mud — 6-7%, that is a little more than the average values for the sediments of the Gdansk Bay (Pustelnikov & Musielak 1986). Content of $CaCO_3$ in silted shell is often more than 30%. Content of organic carbon (C_{org}) is minimum (0.5%) in well-sorted sands, and it is maximum (>10%) in aleuro-pelitic mud in the south-western part. Fine-aleuritic mud is the most abundant substance in this lagoon and it contains commonly about 3-5% of C_{org} (Blazhchishin 1995).

Sandy-aleuritic material of lagoon bottom sediments is composed of quartz and feldspar with notable amount of clastic carbonates, mica, and glauconite. Black ore particles, amphiboles, and minerals of epidote group dominant heavy minerals of coarse aleuritic fraction; tourmaline and disthene are also typically found in these minerals. This mineral complex is typical for glacial formations developed on Paleogene and Late Cretaceous substrate. Ferro-manganese micronodules, spherulitic siderite, pyrite and Fe phosphates represent authigenic minerals. Clayey material is composed mainly of kaolinite and hydromica with small amounts of montmorillonite and some other swelling minerals typical for the bottom deposits of the Gdansk Bay.

Regularities in distribution of fractions and types of bottom sediments, spatial distribution and composition of suspended matter (Blazhchishin 1995) related to zo-

nation of hydrodynamic parameters (Chubarenko *et al*. 1999) were analyzed that made it possible to distinguish 4 zones of different sedimentary conditions: I — the estuary of the Pregel River, II — central and III — south-western areas and IV — Primorskaya Bight (Fig. 1). In sections that follow, material will be considered in compliance with the above mentioned zones of sedimentation.

Although the basin is shallow water and semi-closed, various granulometric types of sediments — from coarse pebble gravel material with cobbles to fine aleuro-pelitic mud, are found in the lagoon. We have found that Russian part of the lagoon comprises the following types of sediments: pebble-gravel, sands, coarse aleurites, fine aleuritic mud and aleuro-pelitic mud (Fig. 2).

Comparatively small parts of the bottom surface are covered by pebble-gravely deposits, which are confined to moraine outcrops of the last glaciation. Those are usually located at small depths (1-1.5 m), frequently off capes on the southern coast. The largest area was found near the Severnyj Cape, where moraine loam experience erosion by bottom currents so that fine particles are transported away from this region. Pebbly-gravel material with a single cobblestones and small amount of varigrained sands remain at the same place.

Sands (fractions of 1.0-0.1 mm prevail), which are mainly medium- and fine-grained, cover about 30% of the bottom surface. They are composed mainly of quartz and feldspar with small amounts of glauconite and organic detritus. Sand sediments are often found along coasts (to a depth of 1.5-2 m) and in hydrodinamically active shallows, where the sediments experience continuous resuspension with the result those finer fractions are transported away from this place. These sediments are well sorted (So = 1.69-2.05), where grain-size of 0.2-0.3 mm is prevalent (see Table 1).

Coarse sands (Md = 0.52-0.55 mm) are found locally and are commonly adjacent to pebble-gravel deposits developed on a moraine. Medium sands are the more widespread materials. Large massifs of such sands (Md = 0.36-0.38 mm), which exist as migrating ridges, are concentrated on the south-eastern shallows of the estuary zone, where they are genetically connected with outwash plains on land. Continuous band of medium sands stretches along the northern coast of the estuary zone and eastern part of Primorskaya Bight. In the vicinities of the Vistula Spit, this continuity is violated by a great number of small bights where massifs of macrophytes alternate with sands, which are frequently silted and associated to young peat deposits. Sands of this dimensionality are well sorted (So is 1.60, on average). However, sorting coefficient of medium sands is worse for the western zone (1.82) than for the Primorskaya Bight, estuary and central zones (1.52-1.54). Medium sands contain from 43 to 61.2% of 0.5-0.25-mm fraction with small content of aleuro-pelitic fractions (7-9%).

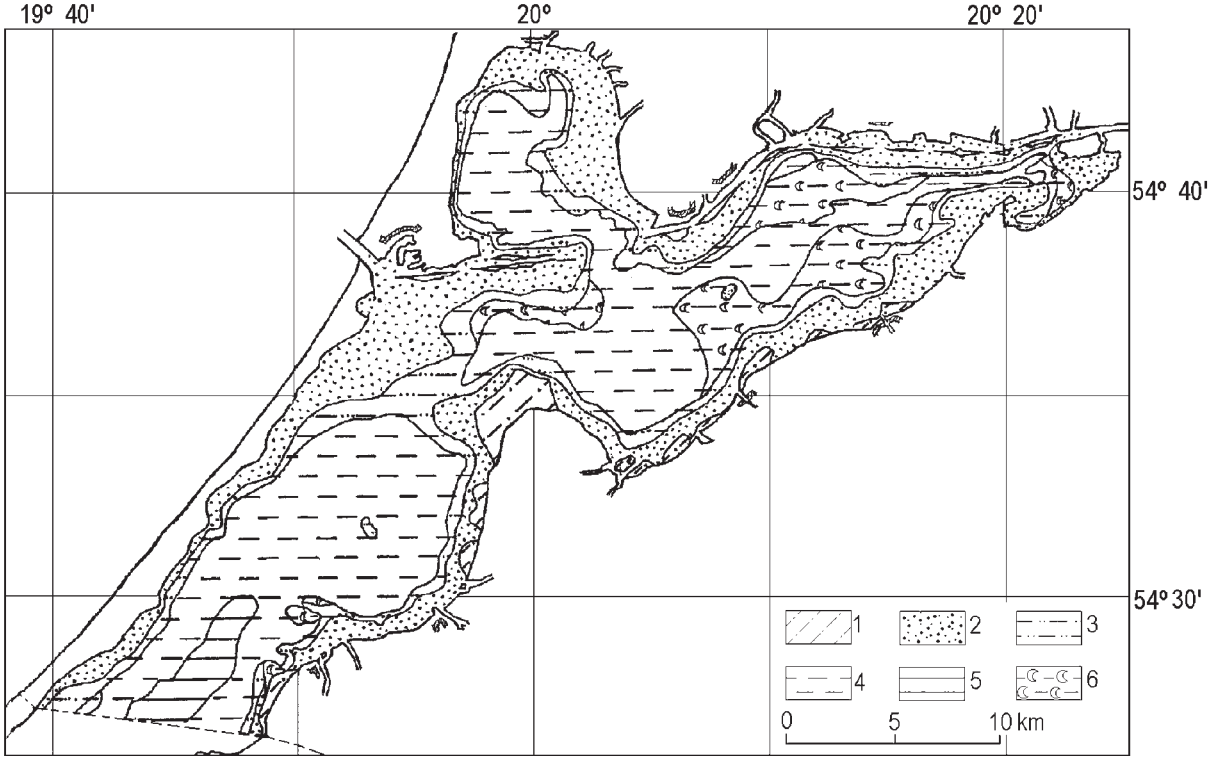

Fig. 2. Scheme of bottom sediments (0—10 cm) in Russian part of the Vistula Lagoon (according to A. Blazhchishin, 2002). Types of sediments: 1 — pebble-gravel, 2 – sand of different grain-size (1-0.1 mm), 3 — coarse aleurite (0.1-0.05 mm), 4 — fine aleuritic mud (0.05-0.01 mm), 5 — aleuro-pelitic mud (<0.01 mm), 6 — shells covered by a layer of mud or aleurite.

Table 1. Grain size composition of bottom sediments in Russian part of the Vistula Lagoon for different sedimentary zone (in %) (1.Numerator— range in composition; denominator— average content; 2. Sedimentary zones: I — the Pregel River estuary, II — central zone, III — south-western zone, IV — Primorskaya Bight).

Number of samples	Fraction. mm							Md	So	Sedimentary zone
	>1.0	1.0-0.5	0.5-0.25	0.25-0.1	0.1-0.05	0.05-0.01	<0.01			
Sand										
19	19.2-0.35 5.24	0.53-52.5 18.2	11.7-50.2 28.7	4.0-56.8 31.7	2.5-23.0 10.0	0.6-14.0 3.9	0.3-9.4 2.6	0.12-0.52 0.3	1.53-2.02 1.69	I
19	0.26-2.33 1.56	0.27-30.4 6.95	1.12-56.6 28.22	10.0-57.5 38.24	0.8-35.6 13.578	0.1-16.8 5.88	0.2-16.8 7.11	0.12-0.4 0.2	1.44-2.9 1.78	II
13	0.25-0.49 0.37	3.47-10.0 5.69	27-44.7 38.56	27.3-36 33.8	0.14-14.3 7.2	1.1-10.5 4.78	12.7-16.8 14.75	0.14-0.26 0.22	1.63-2.87 2.05	III
15	_	2.0-20 6.1	20.7-61.2 47.28	18.3-75.0 44.64	0.2-1.8 0.86	0.2-0.8 0.58	0.2-0.5 0.4	0.18-0.35 0.264	1.3-1.6 1.76	IV
Coarse aleurite										
18	0.3-17.1 2.4	0.2-2.1 1.3	0.8-11.0 5.0	8.6-12.3 10.9	38.2-52.5 42.5	13.9-34.4 26	5.8-19.1 12.1	0.053-0.071 0.063	1.41-2.24 2.04	I
13	0.35-0.6 0.475	0.58-1.0 0.76	1.39-5.8 3.16	20.2-27.8 24.7	29.8-52.5 38.4	14.0-26.7 21.03	10.7-13.4 11.6	0.061-0.07 0.065	1.39-2.4 2.01	II
13	1.5	0.3-1.25 0.78	0.8-4.2 2.08	8.0-39.2 25.96	45.5-49.6 47.7	4.3-40.4 19	2.2-5.3 3.8	0.055-0.092 0.076	1.61-1.86 1.69	III
14	_	0.5-2.5 0.95	2.0-8.3 5.83	5.0-10.5 8.675	41.92-57.4 52.9	10.1-29.9 17.13	11.6-20.67 14.85	0.062-0.065 0.064	1.3-2.4 1.675	IV
Fine aleuritic mud										
18	_	0.06-1.0 0.57	0.4-6.3 2.0	1.0-22.8 8.5	3.6-36.4 18.7	45.0-74.9 49.9	8.1-28.8 15.9	0.018-0.050 0.032	1.63-3.16 1.99	I
5	0.2	0.8	2.2	5.0	15.7	43.5	32.5	0.018	2.32	II
10	_	0.2-0.9 0.566	0.6-4.1 1.65	1.6-3.2 3.166	2.7-18.7 9.11	47.49-69.9 58.35	5.96-42.64 27.12	0.013-0.026 0.019	1.73-2.04 1.92	III
7	_	0.1-1.3 0.8666	0.5-7.7 3.233	1.0-10.5 4.333	3.36-22.9 13.153	37.0-51.98 49.13	21.2-43 29.43	0.013-0.033 0.02266	1.9-2.5 2.166	IV
Aleuritic - pelitic mud										
6	_	0.3-0.5 0.4	0.4-0.7 0.55	2.1 2.1	5.4-5.63 5.52	38.9-39.1 39	51.8-52.0 51.9	0.008-0.01 0.009	2.62-2.03 2.625	III

The largest area of fine sands (Md = 0.12—0.14 mm) is situated in the central zone just in front of the Baltic Strait and in the eastern part of the Primorskaya Bight. In estuary zone, these deposits adjoin the area of medium sands on the southeastern shallows, and single patches of fine sands were found along the Vistula Spit. These sands contain from 42 to 75% of 0.25-0.1 mm fraction which is sorted worse than medium sands (So ranges from 1.52 to 2.02).

Coarse aleurites (0.1-0.05 mm) cover about 22% of the lagoon surface. They are represented by more dispersed fractions with high mobility of particles. When in moist condition, these sediments resemble fine sands, but in dry conditions they are as cemented sediment of grey hues. In estuary and south-western zones, coarse aleurites are found as narrow band that stretches along margins of sand deposits within the depth range from 2 to 2.5 m. In the central zone, between the Severnyj Cape and Baltic Strait, fields of coarse aleurites become wider and extend deeper into sediment column, so they are found everywhere on the sea-floor where sand is absent, including maximum lagoon depths (5 m). Wide stripe of coarse aleurites has been found in the central part of the Primorskaya Bight.

Coarse aleuritic deposits are moderately well sorted (So changes from 1.3 to 2.24, or is 1.8, on average), where deposits of the Primorskaya Bight are sorted better (1.6) than those in the estuarine zone (2.04). Coarse aleurites can be readily distinguished from surrounding facies by predominant 0.1-0.05 mm fraction, which is responsible for 46% of the total sediment, in average. Main admixture in sediments of the central and south-western zone is fine sand-grained fraction, while in the Primorskaya Bight and estuarine zone it is fine aleurite fraction.

Fine aleurite mud (0.05-0.01 mm), represented by weakly consolidated watered deposits (moisture is up to 65%, in average) of dark hues, is the most widespread type of recent bottom sediments in Russian part of the Vistula Lagoon. These sediments are found over 45% of the lagoon surface and cover all deeps on the bed, except for the central sedimentary zone.

The fine aleurite surface is commonly covered by thin oxidized film of greyish-brown colour, which varies from 2 to 3 mm in thickness. Such mud contains Polichaeta, Oligochaeta, molluscs, ostracoda, and other benthos (Lasarenko & Majewski 1971, Aristova 1966, Chechko & Ezhova 1999). In some places of the Primorskaya Bight, and also in some deep drainless pits along the pathway of old navigating channel, benthos is completely absent in black mud, which have no oxidized film and are saturated with respect to H_2S.

Fine aleurite is a widespread type of sediments in regions where the effects exerted by the wave activity upon bed are diminished, therefore, wave-induced differentiation and transportation of clastic grains is insignificant, with the result that material is poorly sorted. On average, sorting coefficient is higher for this mud (So = 2.1) than for coarse aleurites. It is worth mentioning that this mud is worse sorted in estuarine zone (So = 1.63-3.16). From 40 to 74% of 0.05-0.01-mm fraction is present in fine aleurite mud. Coarse aleurite and pelitic fractions, which are admixtures, are present in the estuarine zone in nearly the same proportions. In other regions, pelitic fraction is dominant among other admixtures. Fine aleurites in the estuarine zone have larger grain size (Md = 0.032 mm) than those in other zones (Md = 0.018-0.022 mm).

Aleuro-pelitic mud is abundant only in the south-western zone, and also is found as single patches in depressions (9-11 m) of maritime navigable channel. The physical properties and association fauna of these muds are very similar to fine aleurite mud of bad sorting, 52% of which is represented by predominant pelitic fraction and Md = 0.008 mm. In general, the sediment contains less than 6% of admixture, which is represented by coarse aleurite and sand material.

Shells that are deposits made up mostly of shells of freshwater molluscs and their detritus, which are usually filled up with fine sand and silt particles, are found over fairly large areas in the estuarine zone and in the Primorskaya Bight. A layer of shells is usually 20-40 cm in thickness and is periodically exposed on the bed surface, but more frequently it is covered by relatively thin (up to 10-15 cm in the estuary, and up to 15-20 cm in the Primorskaya Bight) sediments. Shell horizon is composed of two layers: the upper layer of Dreissena time, which is made up of clastic and complete shells of freshwater mollusc *Dreissena polymorpha*, and the lower layer of Gastropoda, which is composed of small shells of freshwater molluscs *Bythnia, Valvata* (Blazhchishin 1995). The production of this shell layer is related to events involving changes of lagoon hydrology as a result of regulated flow of the Vistula River and its arm Nogat (1910-1913). As a result, water of this lagoon has become saltier and this led to mass dying of freshwater molluscs (Lasarenko & Majewski 1971).

Regularities in distribution of sedimentary material

To understand main regularities of mechanical transportation and differentiation of sedimentary material, we applied a method of Lisitsin (1966) to compile schemes of particle-size distribution for the following grades: sand (1.0-0.1 mm), coarse aleurite (0.1-0.05 mm), fine aleurite (0.05-0.01 mm) and pelite (<0.01 mm).

Clastic material (> 1 mm fraction) in the lagoon is of minor importance. In the central part of the lagoon this material is essentially non-existent, and its maximum concentrations are confined to coastal zone with depths from 1 to 1.5 m. A greatest field of this material is related to erosion of moraine in the vicinities of the Severnyj Cape. Increased contents of this material are

locally found along the southern coast and island-dams (south-western zone), separating the maritime ship channel from lagoon. In addition to products of moraine deposits dilution, benthic detritus, maximum concentrations of that are concentrated in the eastern part of estuarine zone, represents coarse clastic sedimentary material also.

The scheme of sand fraction (1-0.1 mm) distribution shows that wide deepest median areas of estuarine and south-western sedimentary zones are covered by sediments containing less than 10% of sand fraction (Fig. 3). As the distance to coast becomes smaller, content of sand fraction in the sediments increases, and in the coastal area, i.e. in the zone of wave activity, it reaches 80%, and more frequently 90%. Extraordinarily large contents of sand fraction (up to 97%) are present in the sands of the south-eastern shallow estuarine zone.

In the western part of the Primorskaya Bight, there is an area where sediments contain less than 10% of sand fraction, which is an admixture. Towards the eastern coast, which is exposed to the effects of westerly winds, which are the prevailing weather conditions in the area, sand fraction is dominant. Contents of this fraction in coastal zone reach maximum values (97-99%) not only for the bight, but also for the lagoon (Fig. 3).

Owing to high hydrodynamic activity in the central zone, fine suspended matter does not precipitate here and is carried away by currents. Sediments containing more than 10% of sand fraction are found everywhere in the area. A major portion of this zone is sand area, for which content of sand fraction is 50-80%. In the vicinities of the Severnyj Cape and eastern coast adjacent to the Baltic Strait, there are patches containing more than 90% of sand material. In general, distribution of sand shows its close relationships with hydrodynamic conditions, and characteristic deposits having maximum content of sand material mark regions of mostly intensive hydrodynamics.

When we say about distribution of aleurite material, it is worth mentioning that this material is found widely in the sediments, but the distribution of coarse aleurite is significantly different from that of fine aleurite. Coarse aleurite (0.1—0.005 mm) is found everywhere in the lagoon, but contents of large aleurite particles in the sediments range largely from 10 to 40% (Fig. 4). Single spots of their high concentrations (more than 40%) are present in all sedimentary zones, as a rule at the depths of 2.5-3.5 m. In the south-western zone, increased contents of this material are found in two locale situated just near coast.

Minimum contents of coarse aleurite in the sediments (<10%) are restricted to coastal areas of the estuarine zone and Primorskaya Bight. Content of coarse aleurite is especially low (1-3%) in sand fields of this zone, and this is evidence that these sediments are well sorted and finer particles are transported away by currents. Sediments of low contents of coarse

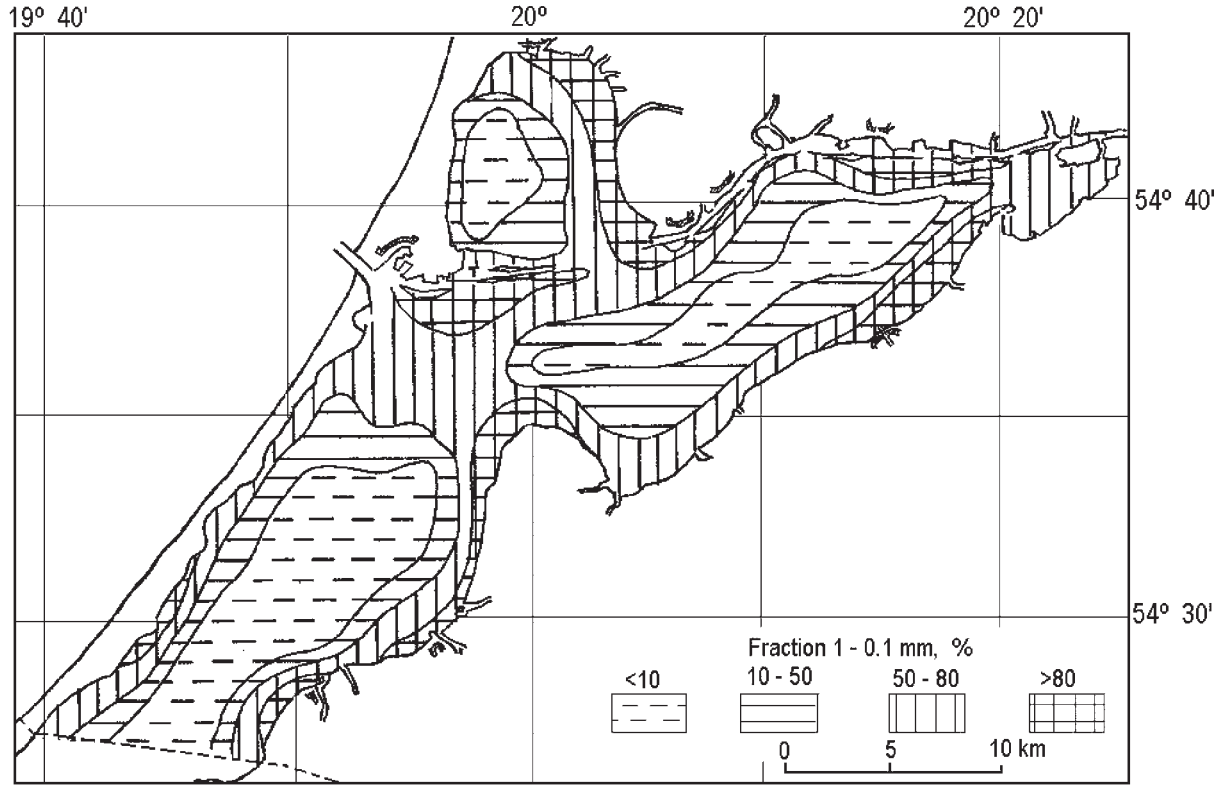

Fig. 3. Distribution of sandy (1-0.1 mm) fraction in the surface layer (0-10 cm) of the bottom sediments.

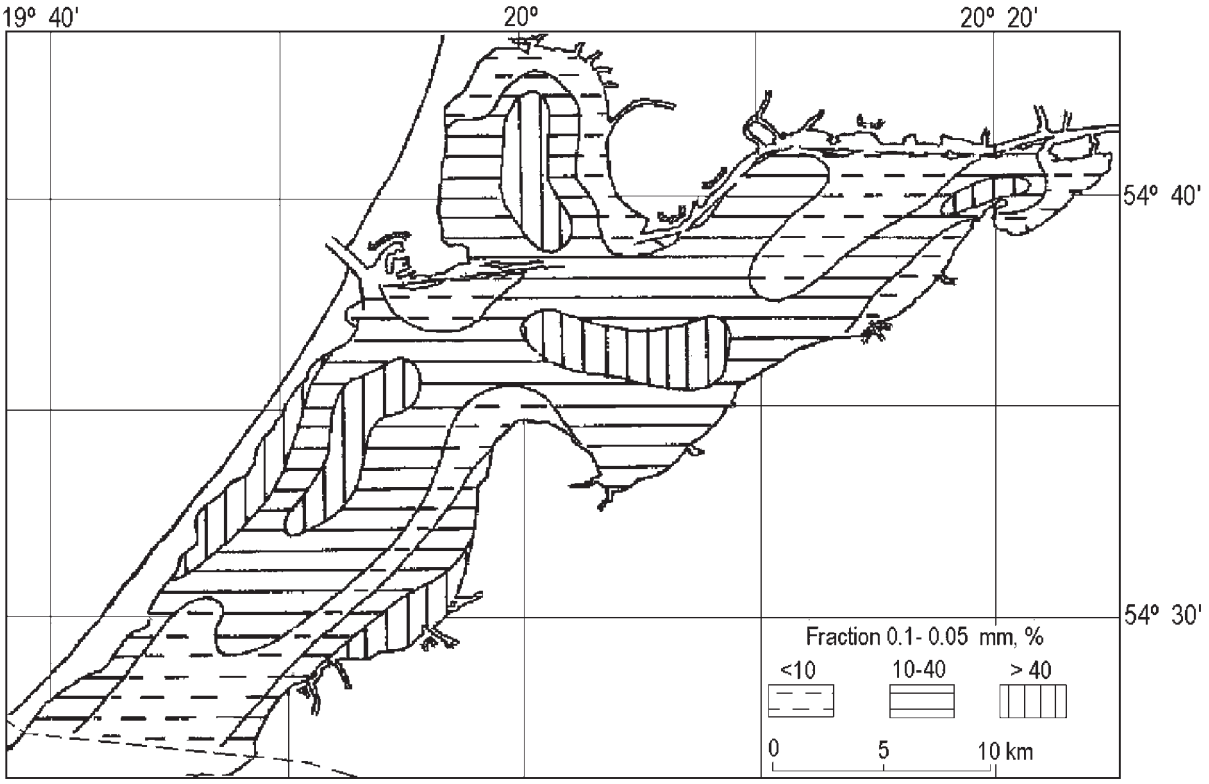

Fig. 4. Distribution of coarse aleuritic (0.1-0.05 mm) fraction in the surface layer (0-10 cm) of the bottom sediments.

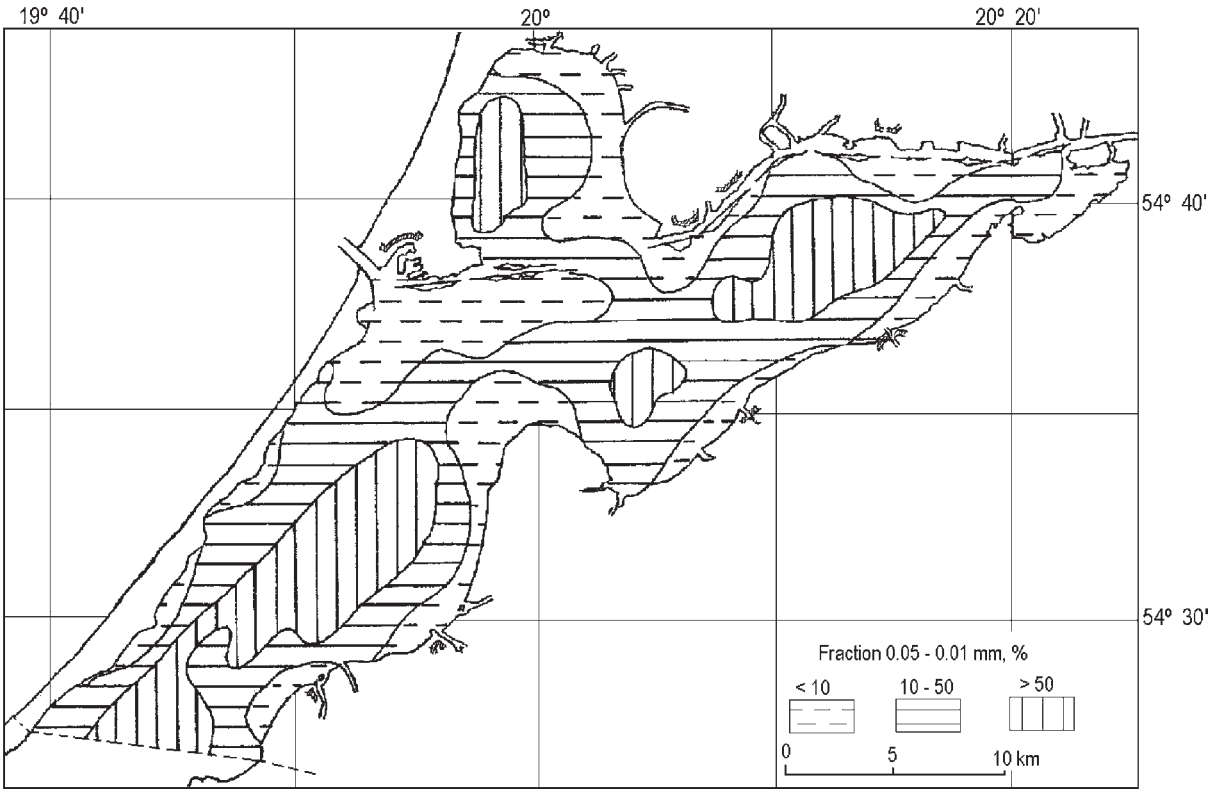

Fig. 5. Distribution of fine aleuritic (0.05-0.01 mm) fraction in the surface layer (0-10 cm) of the bottom sediments.

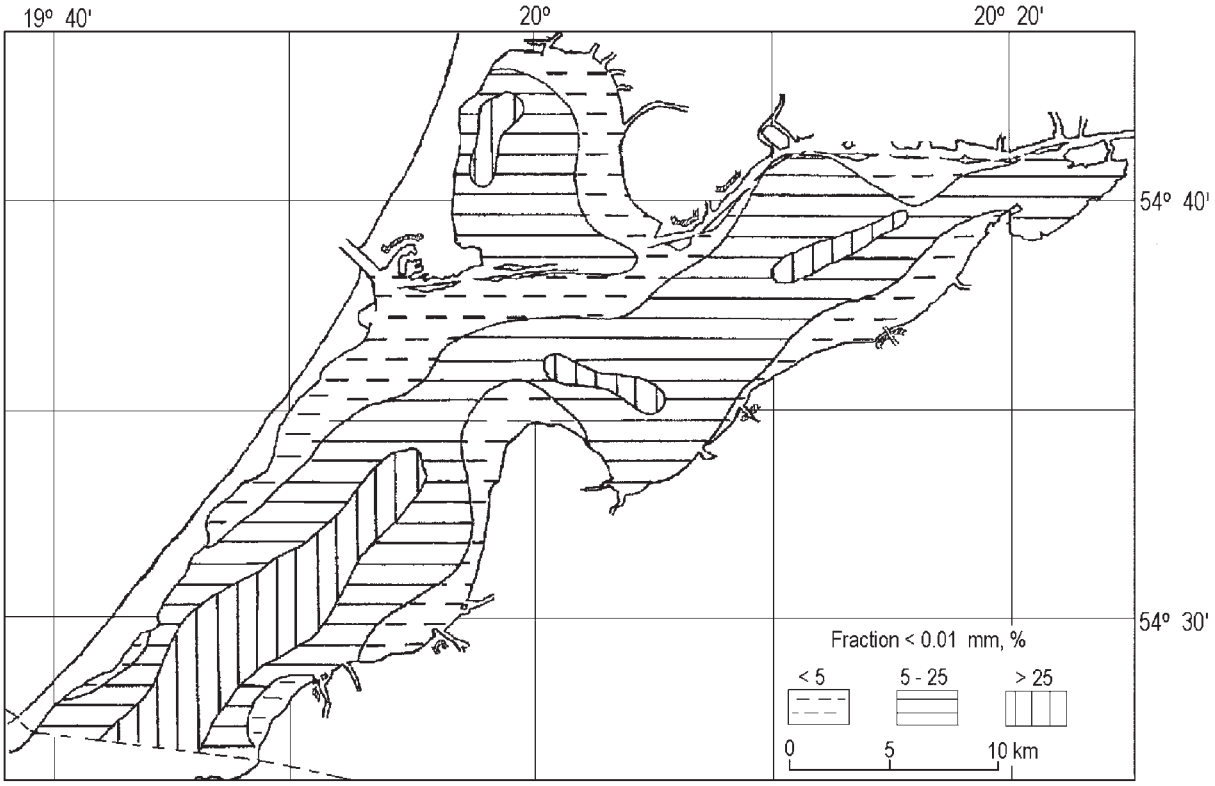

Fig. 6. Distribution of pelitic (less than 0.01 mm) fraction in the surface layer (0-10 cm) of the bottom sediments.

aleurite form a thin stripe, which extends from the Severnyj Cape throughout the whole south-western sedimentary zone. Near the Polish border, this stripe becomes wider and covers almost the entire bed surface (Fig. 4).

Sediments with minimum contents (<10%) of fine aleurite fraction (0.05-0.01 mm) form factually a continuous coastal belt, which take the form of wide field in the vicinities of the Severnyj Cape and Baltic Strait. This field is separated by narrow stripe in which sediments contain from 10 to 50% fine aleurite (Fig. 5). Areas where content of fine aleurite is the highest (>50%) are fairly large and located in median parts of estuarine and south-western zones. A small patch of such sediments is also traced in the western part of the Primorskaya Bight. Such places are absent in the central zone: precipitation of aleurite particle is, it is thought, impossible in this area because of the effects of active hydrodynamics.

Distribution of pelitic fraction (<0.01 mm), which is the finest material of the Vistula Lagoon, is consistent with the pattern described for fine aleurites (Fig. 6). The only difference is: coastal stripe of minimum (5%) or zero contents of pelitic fraction in the sediment is much wider, especially near the northern coast, than areas of its maximum contents (>25%), which cover much smaller areas. Almost all fine pelitic material is carried away from coastal zone by currents: content of pelitic fraction is locally as small as 1-5%, and in some samples collected in this area this material is absent (sand and coarse aleuritic fields).

The largest spot in which content of pelitic particles in the sediments is maximum (>25%) is found in axial part of the south-western zone, where water dynamics is the least. Single spots of such sediments are also found in the western part of the Primorskaya Bight, as well as along the pathway of old navigable channel. All this made us think that pelitic material is commonly found in the lagoon's sediments in small amounts (10-15%), and evacuation of this material by currents is probably the main reason for its low concentrations.

CONCLUSIONS

The distribution of granulometric fraction on the surface of bottom deposits has been determined, for the first time for Russian part of the Vistula Lagoon, from the analysis of a large array of data, and this is illustrated in many schemes. Further types of sediments are distinguished among terrigenous deposits: pebble-gravel, sands, coarse aleurite, fine-aleuritic mud, and aleuro-pelitic mud. Fine-aleuritic mud, covering about 45% of the studied waters, is the most widespread material among the recent bottom sediments, and varigrained sands are predominant in coastal zone. Interbeds of shells formed as a result of changes of hydrological conditions in the lagoon in 1910 are also

very typical. In such a way, one may state that this lagoon accumulates mainly aleuritic and sand material, while much of finer components is carried away from this lagoon by currents or accumulate in localized regions under quiet hydrodynamic conditions.

Analysis of granulometric composition of the recent lagoonal sediments made it possible to reveal main regularities of the distribution of clastic material typical for water basins of such a type. Hydrodynamic conditions and mineralogical composition of the sedimentary material, which is delivered from main sources such as river loads, cliff abrasion and bottom erosion explain them. Periodical wind-surge events also play an essential role.

Although size of this basin is relatively small, the sedimentation conditions are very complicated. Four zones well distinguishable by their sedimentary conditions have been recognized. In the estuarine zone, the sedimentary material distribution is influenced by the river-sea water system (the Pregel River and sea channel) as well as by the effects of wind/wave-induced resuspension of sediments. The south-western zone is predominantly accumulative, and the finest deposits of this lagoon are formed in halistatic regions. The central zone having direct relations with the Baltic Sea is mostly active in terms of hydrodynamics. Fine sediments are mostly in transit in this part of the lagoon. In the Primorskaya Bight, the sediment distribution is asymmetric. Fine silty sediments are formed in a shadow zone in the western, and sands in the eastern part of the bight, because westerly winds are prevalent. Presented data on the distribution of sediments give no exhaustive information about all aspects of the sedimentation in this water area. Nevertheless, we believe that this information will facilitate a versatile and thorough study of sedimentation regularities both in the given water body area in particular and shallow-water semi-closed lagoons in general.

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References

Aibulatov, N.A. & Artyukhin,Y.V. 1993: Geoecology of shelf and coasts of the world ocean. St.-Petersburg, *Hydrometeoizdat,* 304 pp. (In Russian).

Anikeev, V.V., Perepelitsa, S.A. & Shumilin, E.N. 1993: Assessment of contribution of anthropogenic and natural sources to the spatial distribution of heavy metals in bottom deposits of the Piotr Velikiy Bay (Japan Sea). *Geochemistry 9,* 1328-1340. (In Russian).

Aristova, G.I. 1966: Benthos of the Vistula Lagoon. *Proc. of AtlantNIRO 14*, 19-39, Kaliningrad. (In Russian).

Bezrukov, P.L. & Lisitzin, A.P. 1960: Classification of sediments in the recent basins. *Proceedings Institute of Oceanology, USSR Academy of Sciences, 32,* 3–14. (In Russian).

Blazhchishin, A.I. 1995: Geoecology of the Vistula Lagoon. *In: Problems of physical and economical geography of the Kaliningrad region.* Kaliningrad, Kaliningrad State University, 38-46 (In Russian).

Blazhchishin, A.I. 1998: Zur Geookologie des Kurischen und des Frischen Haffs. *Schriftenr. f. Geowiss. 7,* 39–57. Berlin.

Blazhchishin, A.I. 2002: The sediments of the Vistula Lagoon. *In* Emelyanov, E. (Ed.): *Geology of the Gdansk Basin, Baltic Sea.* Yantarny Skaz, Kaliningrad, 349-352.

Blazhchishin, A. & Chechko, V. 1997: Sedimentation and resuspension rates in the Vistula Lagoon. *In The Fifth Marine Geological Conf. "The Baltic", Vilnius, Institute of Geology, 17–18.*

Brockmann, Chr. 1954: Diatomeen in den Ablagerungen der ostpreussischen Haffe. *Meyniana 3,* 3–95.

Chechko, V.A. 1999: The effects of re-suspension and bioturbation during sedimentogenesis of shallow-water basin with the Vistula Lagoon of the Baltic Sea as an example. *In Geology of seas and oceans, Proceedings of 13th international school of marine geology 1*, 210-211, Moscow. (In Russian).

Chechko, V.A. 2002: Bottom sediments of the Vistula Lagoon. *In The Seventh Marine Geological Conf. "The Baltic", Kaliningrad, Atlantic Branch of P.P. Shirshov Institute of Oceanology RAS,* 25.

Chubarenko, B., Chubarenko, I. & Kuleshov, A. 1999: The results of 1994–1997 field investigations of hydrological structure and transparency of water in Russian part of the Vistula Lagoon. *In Freshwater fish and the herring populations in the coastal lagoons. Environment and Fisheries, Gdynia, Sea Fisheries Institute*, 45–59.

Hirschberg, D.J., Chin, P., Feng, H. & Cochran, J.K. 1996: Dynamics of sediment and contaminant transport in the Hudson River estuary: evidence from sediment distribution of naturally occurring radionuclides. *Estuaries 19*, 931–949.

Kravchishina M., 2002: Grain size distribution of bottom sediments in the Vistula Lagoon of the Baltic Sea. *In The Seventh Marine Geological Conf. "The Baltic", Kaliningrad, Atlantic Branch of P.P. Shirshov Institute of Oceanology RAS,* 64.

Lazarenko, N.N. & Majewski, A.L. 1971: Hydrological and meteorological regime of the Vistula Lagoon. Leningrad, Hydrometeoizdat, 279 pp. (In Russian).

Lisitsin, A.P. 1966: Processes of recent sedimentation in the Bering Sea. Moscow, Nauka, 574 pp. (In Russian).

Logvinenko, N.V. 1962: Fundamentals of method to study sedimentary rocks. Kharkov, Kharkov State University, 208 pp. (In Russian).

Moshenko, A.V., Shulkin, V.M. & Lishavskaya, T.S. 2001: Factors to control content of pollutants in coastal deposits on the sea-bed in the area nearby to the mouth of Tumannaya River. *Geochemistry 2*, 204-411. (In Russian).

Petelin, V.P. 1967: Grain size analyses of marine bottom sediments. Moscow, Nauka, 125 pp. (In Russian).

Pratje, O. 1936: Bohrungen auf den ostpreussischer Haffen. *Natur und Volk*. Frankfurt a. M.

Pustelnikov, O.S., Musielak, S. 1986: Recent sedimentation in bays of the Gdansk basin. *In Depositional processes in the Gdansk basin (The Baltic Sea),* 196-210, Moscow. (In Russian).

Rukhin, L.B. 1947: Grain size analyses of sands. Leningrad, Leningrad State University, 213 pp. (In Russian).

Windom, H.L., Schropp, S.J., Calder, F.D. et al. 1989: Natural trace metal concentrations in estuarine and coastal marine sediments of the southeastern United States. *Environmental Sciences and Technology 23,* 314–320.