



A NEW MAP OF THE NEVA BAY BOTTOM SEDIMENTS AND TECHNOGENIC OBJECTS UNDER THE RESULT OF SIDE-SCAN SONAR PROFILING

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Abstract. In summer 2004, Department of Marine and Environmental Geology of VSEGEI carried out investigations of the Neva Bay bottom surface east of the St. Petersburg Flood Protective Dam using a side-scan sonar system. The main aim of this experimental work was the creation of a new “factographical” map of bottom sediments and different types of technogenic objects. State geological surveys of the Neva Bay bottom were carried out by VSEGEI in 1987–1989. Besides, geoenvironmental investigations were conducted here in 1993–1995 and 2000–2002. As a result, a set of maps of bottom sediments based on hundreds of sampling stations (both cores and grab-sampler) were compiled. Side-scan investigations of 2004 allowed more exact recognition of the bottom sediment distribution. Furthermore, in some places new data permit to suppose that the sedimentary conditions have changed here during the last decades as a result of high technogenic load, including Flood Protective Dam influence. In summer 2004 there were a joint expedition of the VSEGEI and the Geological Survey of Finland (GTK). Altogether 10 sampling stations from the mud accumulation areas were sampled with a use of Niemisto corer. Cores were sliced in 1 cm samples and analyzed in chemistry laboratory of GTK (Finland) – gamma spectrometry for ¹³⁷Cs, ICP-AES and ICP-MS, whereupon important results about heavy metals concentration and distribution were received.

Key words: side-sonar investigations, sedimentary processes, the Neva Bay.

SUBJECT OF INVESTIGATIONS

The Neva Bay is a very interesting object for investigations because during the last decades both sedimentary and geomorphological processes have been changing here much as a result of high technogenic load, including Flood Protective Dam influence. The Neva Bay is the eastern and the shallowest and narrowest part of the Gulf of Finland. It is 21 km long and up to 15 km wide. It covers an area of 329 km², water mass volume is about 1.2 km³ (Nezhihovsky, 1988). The Bay is bordered by the Neva river mouth (from the east) and Kotlin Island and the Saint-Petersburg Flood Protective Dam (from the west). The maximum natural depths (6–7 m) of the Bay are observed in its western central part. Fairways and local technogenic depressions (former underwater sand-pit) are much deeper – up to 12–13 m. The average depth of the Neva Bay is about 3.5 m.

The most important factors affecting sedimentary processes in this area are the Neva River current and waves. Neva River discharge is the main natural source of both tractional load (65 thousand tonnes a year) and suspended material (510 thousand tonnes a year) (Nezhihovsky, 1988). Another natural supply of sediment particles is washing-out of lake-glacial and lake sediments of both bottom surface and mainland origin. All of coarse (drag) and most of fine (suspended) material of the Neva discharge is deposited within the bounds of the Neva Bay. The grain size of the surface bottom sediments becomes finer when moving westwards. As Neva current velocity decreases westwards, sands (fine- and very fine-grained), silty-sands, sandy-silts and silts of marine-alluvial origin are deposited (Fig. 1). As compared with more western part of the Gulf of Finland, silty sediments (with high content of

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0.005 to 0.05 mm particles) are more frequent. It can be explained by high content of silty particles suspended in the Neva River (83%) (Pustelnikov, 1976).

The calculated depth of wave impact upon the bay bottom is 8–12 m (Butylin *et al.*, 1991). That is why practically all its surface is under the influence of wave erosion processes.

Since the foundation of Saint Petersburg in 1703, technogenic processes have exerted considerable influence on the sedimentary environment of the Neva Bay, and this impact has been constantly growing. Naturally, the Neva Bay relief exhibit some features with the centre of its western part is its deepest area. From southern and northern coast to Kotlin Island there are some shallow water areas. In the 18th–19th centuries, some forts, the fortresses of Kronshtadt and a series of pile barriers (crib-bars) were built on these bottom eleva-

tions for defense of the Russia's capital. For navigation facilities, fairway excavation and deepening have been constantly carried out here.

Technogenic impact became most intense in the 1970s–1990s during construction of the Saint Petersburg Flood Protective Dam and very active underwater sand mining and hydro-engineering works for creation of new city territories, accompanied by excavation of large amounts of clays from the Neva Bay bottom. Nowadays, the Neva Bay is actually an “internal” bay of Saint Petersburg. Its coastal zone has a great importance from the recreational point of view. In connection with City Government's plans to build a new passenger harbour and to construct a Flood Protective Dam in the eastern part of the Bay, yearly detailed monitoring of the Neva Bay sedimentary processes becomes very urgent and important.

MATERIALS AND METHODS

Scientists from Department of Marine and Environmental Geology (VSEGEI) carried out state geological surveys of the Neva Bay bottom sediments in 1987–1989. Besides, geoen-

vironmental investigations were conducted here by VSEGEI in 1991, 1992, 1993–1995 and 2000–2002. As a result, considerable volume of information about the bottom relief, lithological

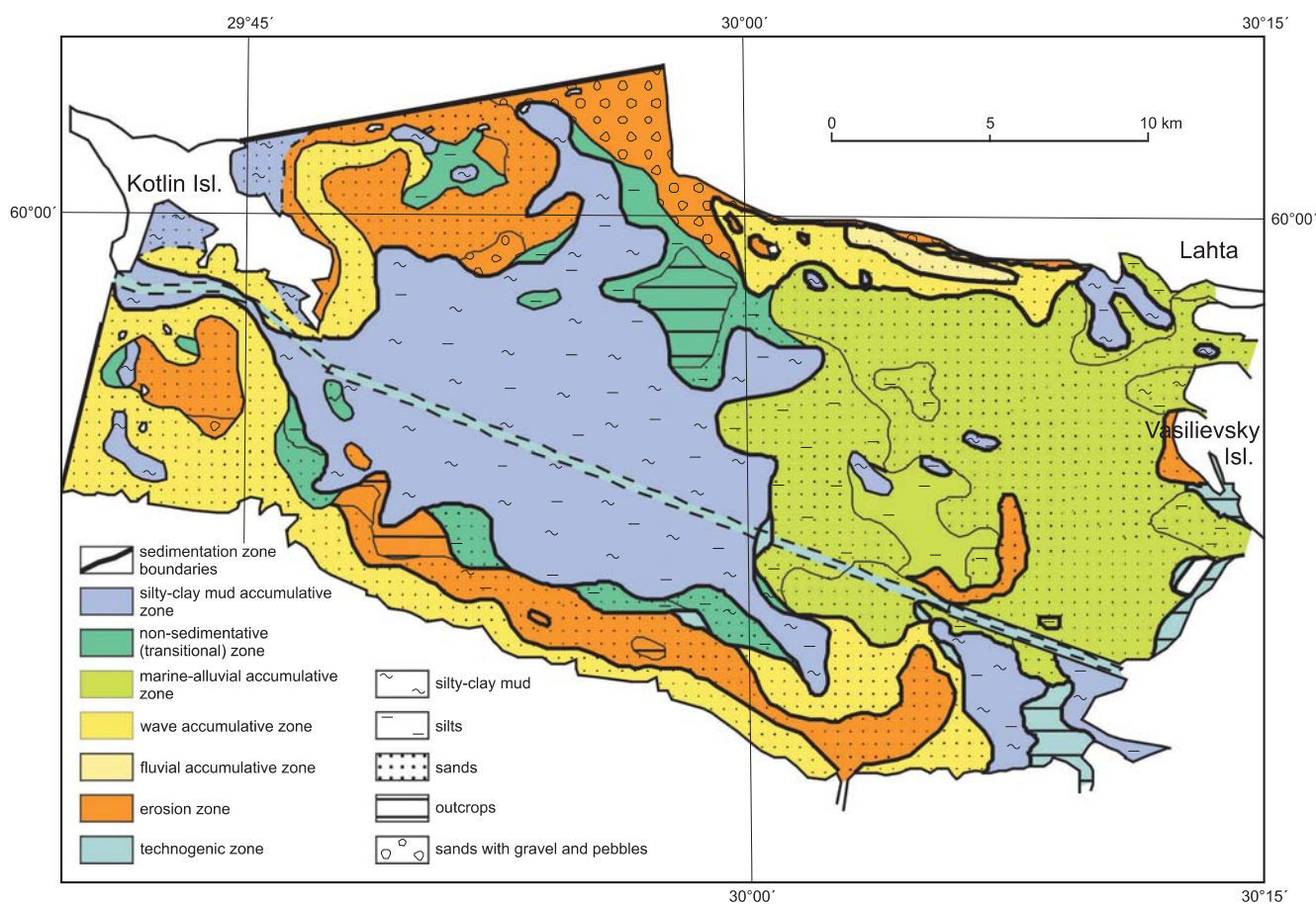


Fig. 1. Types of sedimentation zones of the Neva Bay

Developed by G. Suslov, D. Ryabchuk, E. Nesterova, M. Spiridonov and others

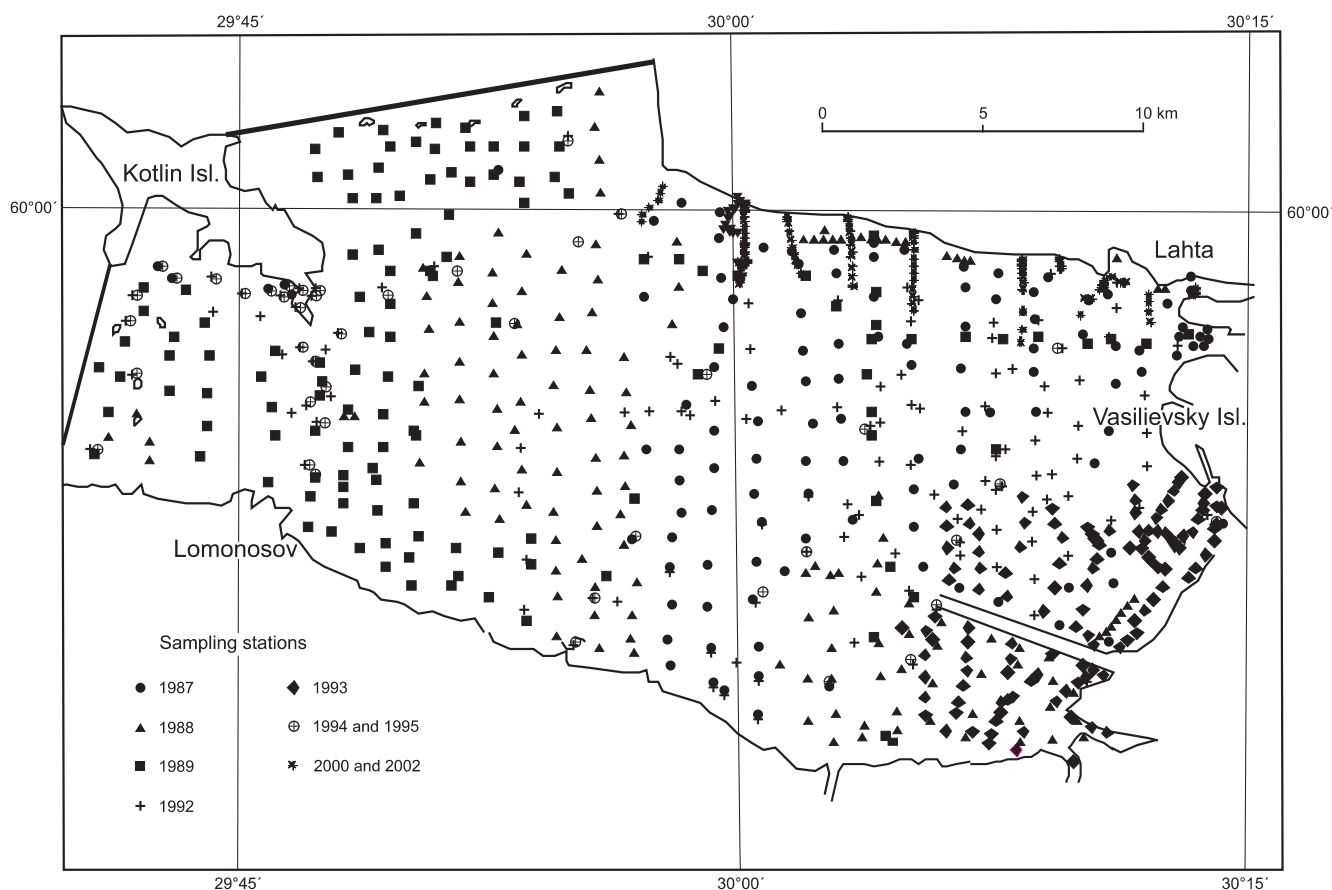


Fig. 2. Map of sampling stations carried out by VSEGEI (1987–2002)

and geochemical components and facies distribution was compiled. A set of maps of bottom sediments based on hundreds of sampling stations (both cores and grab-sampler) was also developed (Figs. 1, 2; Pitulko, Spiridonov, 2002).

In summer 2004, Department of Marine and Environmental Geology of VSEGEI carried out investigations of the Neva Bay bottom surface east of the Saint-Petersburg Flood Protective Dam, using a side-scan sonar. The development of a new map of bottom sediments and different types of technogenic objects and relief forms was the main aim of this experimental work.

The side-scan studying was executed by the CM-2 Side-scan sonar system (C-MAX Ltd.) (acoustic frequency 102 kHz, range 100 m). Sonar data were treated in MaxView V1.2 and OCTOPUS programs. As a result of side-scan study, the whole investigation area (except very shallow water zones) was covered by a sonar-profile net. Altogether, 109 sonar profiles were done (Fig. 3). The distance between each two profiles was 180 m, thus the sonar pictures overlapped. For side-scan data interpretation and bottom sediment types monitoring, 52 grab-corer sampling stations were taken.

DISCUSSION

Evolution of modern sedimentary processes of the Neva Bay is a very interesting problem. In general, stable silty-clay accumulation takes place in the eastern part of the Gulf of Finland in the bottom depressions deeper than 30 m. But in the Neva Bay, there are silty-clay accumulative zones at the depths of 4 to 6 m. During the geological survey carried out by VSEGEI in 1987–1989, such a zone was discovered and mapped in the centre of the western part of the bay. Recent muddy sediments, represented by soft homogenous clayey-silt

(0.05–0.005 mm silt particles content up to 60–65%), in some places are partly laminated because of dispersed organic material contribution. The deposits are from light to dark grey or olive grey in colour. The geochemical study suggested that mud sediments are very young, because the entire layer (40–50 cm) was homogeneous as regards chemical compounds and – from top to bottom – highly technogenically polluted. Usually, only the upper 5–10 or 15 cm of the muddy clay sediments in the depressions situated to the west of the Flood Protective Dam, are

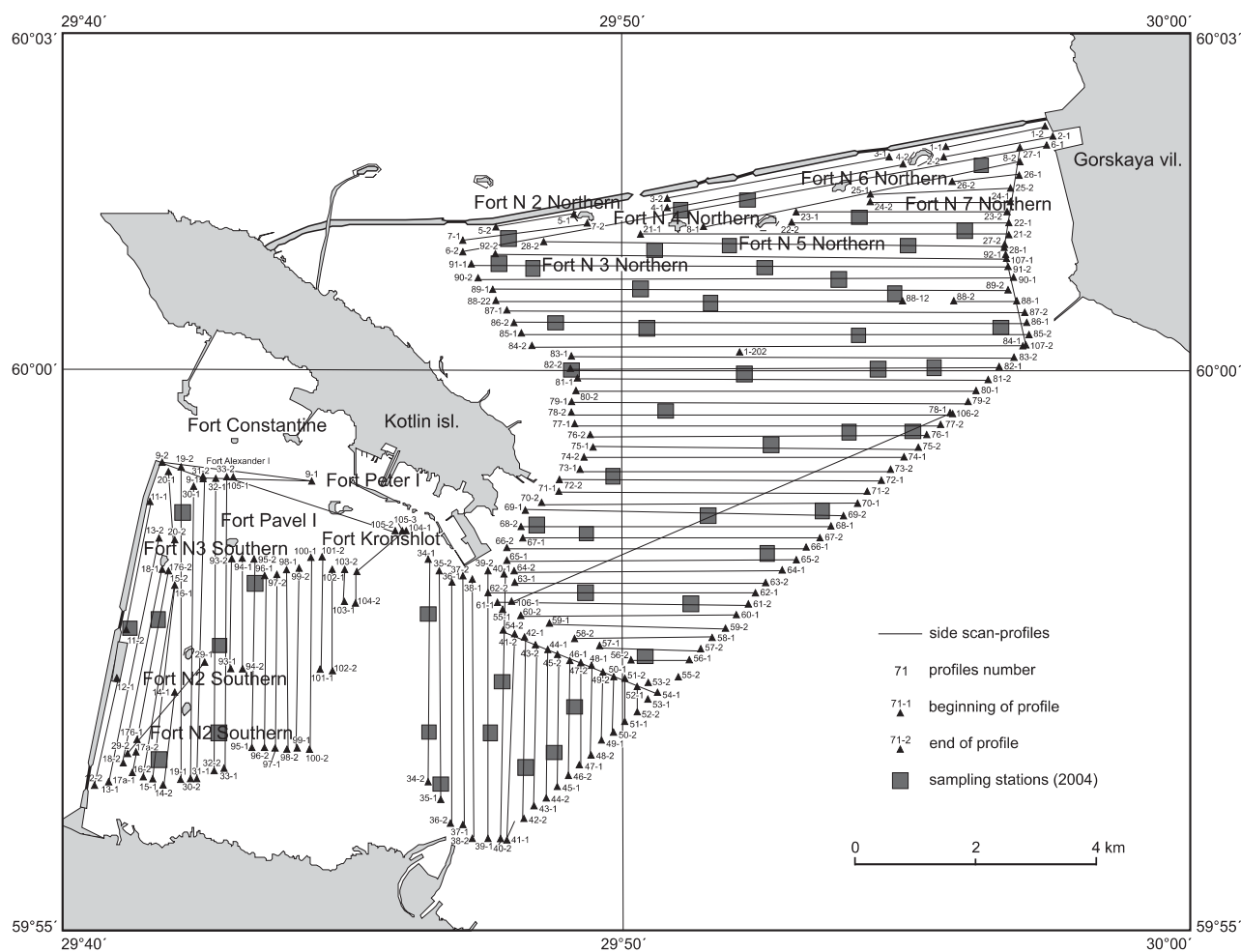


Fig. 3. Scheme of side-sonar profiles (VSEGEI, 2004)

polluted. The chemical analyses of the samples made by GTK confirmed this supposition. They revealed that pollution by heavy metals has been large or very large during the last century until our days. Only one core was long enough for good resolution of the trends in heavy metal emission to the bay. This core (05-NG-9) was 38 centimetres length and according to the heavy metal concentrations it represents some 100 years of sedimentation. At the depth of 25–26 centimetres the concentrations of heavy metals decrease rather strongly as they are approaching pre-industrial values.

The concentration curves of most of the studied metals show similar concentration trends throughout the sediment profiles. When looking at the temporal trend metals started to accumulate rather rapidly in the first half of the last century. The first metals to have reached the concentrations of strong contamination were zinc, lead and copper, probably an indication of increased base metal industry, while the very strong increase of cadmium a decade or two later indicates an increase in chemical industry.

The highest concentrations are to be found in the upper halves of the cores representing probably the time span from the 1950s almost to the end of the century. The last decade and a half has clearly been a time span of return as the concentrations of all metals have decreased significantly.

Even though the surface sediments now are clearly cleaner than during the worst days of the last century there is still a need for further decrease at least of cadmium, zinc and copper.

Very interesting data, which can help us to solve this problem, were found in the funds of State Archive of Russian Navy. Officers of the Russian Navy Hydrographic Survey made the first description of Neva Bay bottom sediments as long ago as in 1751. At the pages of vessel journals mentioned such types of sediments as sand, gravel and mud (Fig. 4) (funds of State Archive of Russian Navy, 913-1-79, p. 402). Compilation of the 18th-century data from these journals with old charts allowed establishing that in the centre of the western part of the bay (in the present-day mud accumulative zone of our maps) sandy sediments covered the bottom.

<p>11 5</p>	<p>πρωοσηδ 24. Δня снптября Потолюнаки</p>
<p>12 SSW</p>	<p>βετηρδ λεχιη Μαρμελιου πολογα οβλατια Πωδρεζα υδωδω πτυ μαυλ, βδ 3/4 εαια μπτηρμαυβ παρποπι, πολομαυ και λωδωιε σπρωμερμαυ Ζυδωι βι ναλικι μαυβ, ζζαυιβι μβ, ευ, ια σπταβλιμαυλ απομπτηρμαυβ βατταρνοβ, μαγια επρωμεροζε ζυδωιβι ναδωζοαυε υαιου μπτημβ, βετηρδ βραμειλιου πολογα πτα, διασαιε εαια σβωιελπομαυ, πποζω δωιτα εζωλα μλωδωια υδ. 5. ποττορα Πωζωιε επτο σπρωμερδ, ποζωιη μλωδωια δβιλα δωιδ μα SW. 45.00, βραπποδωιη βδ. 6. μαδεττωβδ Πωζωιη βελα Πτωμα Πποτοζωιη ρυμβ; / ποζωιη μλωδωια δωιδ δβιλα μα SW. 45.00 πποζωιη οια δβιλα υσαιωζο μα βωζοιη οπτωπρωδ Πωδρωττωιη υδ. X.</p>
	<p>25. Δня снптября Потолюнаки напорε μεση προμωταππο Μεεπεριβι μβ. βερεζο μβ. σλυεαι,</p>
<p>1 2 3</p>	<p>βετηρδ λεχιη βραμειλιου πολογα οβλατια. ποζωιη ε δβιλα οπτωαυ μα SW. 51.30 βραπποδωιη 3 1/2 βερεττα πποζωιη πδ μαυδ πβιλα Πωδρωττωιη υδ. Z. ποζωιη ελβ. δβιλα οπτωαυ μα SW. 24.00 βραπποδωιη 3. βερεττα, πποζωιη πω δρωττωιη υβαιωπυ διασαιε εαια πριεχα πτωμπτηρμα βατταρνοδ υποαυιη, πολομαυ οβαιωπτα μλωδω ναδωζοαυε υαιου μπτημβ ζυδωια δβιλα. 3 1/4. 3 1/2. 4. 4. 4 1/2. 4 1/2. 4. 4 1/2. σαφεινι ρυ ιπτω χρωμυβ ζυδωιου υαιουβ. 3. σαφεινι υβωδ πποτοζωιη 3 1/4. 2 1/2. σαφεινι ρυδωιου χρωμυβ πποζωιη οβαιωπτα ελβ. 1 1/2. βερεττα π. 1 1/2. πποτοζωιη 2 1/4. 2. 2. 1 1/2. σαφεινι ρυδ- ωιου Μελιου υαιουβ. 2 3/4. 3 1/2. 4 1/2. σαφεινι χρωμυβ οβαιωιουβ. 4. ηταρβ. 3 1/2 3. 2 1/2. σαφεινι ρυιπτω χρωμυβ οβαιωιουβ πποτοζωιη 3. 2 1/2. 2. 1 1/4. 1 1/2. 1 1/2. σαφεινι ρυδωιου Μελιου υαιουβ. 1. χρωμυβ ζυδωιου βλεπε βδ. 20. σαφεινι βεπλιεκι ναοιωμβ ρυμβ. σλιεκι μβ. υοσωμβ, ππορωττωιη υαβτωιη ζυδωια 1 1/2. 1 1/2. σα φεινι ρυδωιου υαιουβ, πριεχαυ υοιωμβ ρυε λερωιου πωδρωζωιου υαιου υρδωιου βελιχνοδ βωλινδ. μωιχρινδ πω. 4. σαφεινι βωδωιη υαιουβ υεβαλεσ φυ πο πη πωζωιη μαυδ πριεχοι ραβδ πβιλα οπτωαυ οβιλα μα SW. 51.30 βδ 3 1/2 βερετταυ οβαιωιου ζαπλια βερετταυ βδ 1 1/2. ζαυ βωλεε βλιωιουδωια ε ρωα δβιλα ναλικι εραπποδωιουβ υραβωιου υαιουβι βιχ ματαβωιουβ επωε υοιωμβ ζαβωιουβ, πποζωιη οιαυο υαιουβ υρδωιου ζυδωια 2. σαφεινι, οπτωιεζο βδ 20. σαφεινι οβλεχαυ ζυδωια δβιλα. 2. σαφεινι πποζωιη υδ, W. SW. 1 1/2. σα φεινι ρυιπτω μβιου υαιουβ, υποεχαυ οπτωαυ ρυε αυαιουβ υοιωδ ζυδωια πτωμα 2. 1 3/4. 1 1/2. 2 1/4. σαφεινι ρυιπτω υαιουβ. Μελιου 2 3/4. 2 1/2. 3 1/4 3/4. 2 1/2. 2 1/2. 2 1/2. 2 1/2. 2 1/2. σαφεινι ρυιπτω χρωμυβ, πτωιου πωζωιη ρυδωιου ρα βιλα οβαιωπτα δβιλα π. 3. βερεττα υναοζωιη λινη δβιλα βωζωιουβιη μα Πωλαττωιη, υπρωδρωττωιη υβαιωπυ ζυδωια πτωμα 2 1/2. 2 1/2. 2 1/2. 2 1/2 2 1/2. 2 1/2. 2. 1 1/2. σαφεινι ρυιπτω χρωμυβ. 1 1/2. 1 1/2. 1 3/4. σαφεινι υαιουβ. 2. 2 1/2. σαφεινι ρυιπτω χρωμυβ πποζωιη πωρωττωιη υλοσωιου μπτημβ δβιλα ναρδωιε σλι εκι μβ υοσωμβ, πποτοζωιη 2 3/4. 3. 3 1/2. 3 3/4. 3 1/2. 3 3/4. 3 1/2. 2 3/4. 4 1/4. 3 1/2. 3 1/4. 3. σαφεινι ρυδωιου χρωμυβ αμεσζωιη πτωμαυ ζυδωιου υαιουβ υτωαυ πριεχ πτωμαυ υβαιωπυ; /</p>

Fig. 4. A page from the hydrographic journal with bottom sediment description (skippers Vasily Karpov and Mathew Verhovtsev, vessel "Rak", 1751)

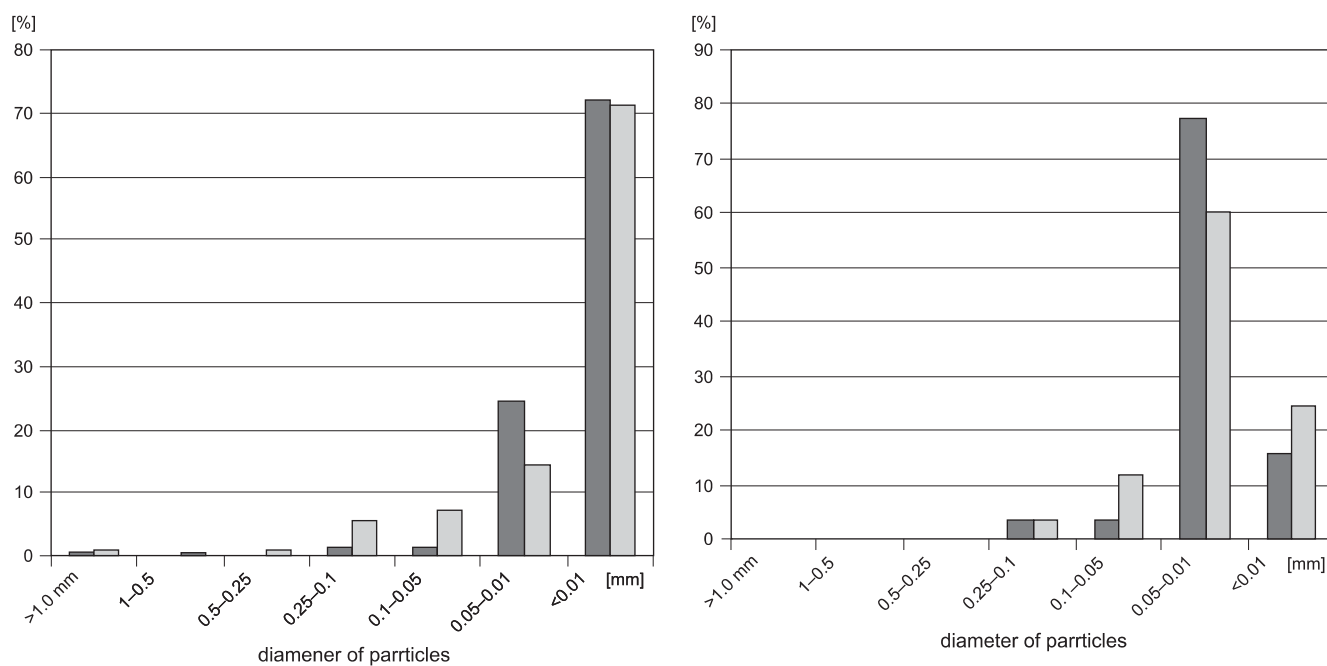


Fig. 5. Grain-size distribution of surface silty-clay mud samples

Dark grey – samples from 1923, light grey – samples from 1993–1994

The Neva Bay has always been very important for both trade and defense of Saint Petersburg. That is why hydrographic measurements accompanied by sediment descriptions have been made here practically every year since the beginning of the 19th century. All marine charts printed from 1830 to 1911 show that this part of the bottom is covered by sands.

The first scientific investigations of the Neva Bay sediments were carried out by an expedition of Professor Constantine Derugin (1920–1924) (Derugin, 1925). The expedition found silty-clayey mud in the central part of the Neva Bay. It is very important that the first grain-size analysis of the Neva Bay bottom sediments were made at that time. Comparison of these data with our analysis shows that the grain-size distribution (grain-size compound) of mud sediments had not changed until the first quarter of the 20th century (Fig. 5). One of the conclusions of the Professor Derugin's report was that the old charts and sediment descriptions were wrong. However, according to data of 1923, the silty-clay accumulative zone was at that time rather smaller (Figs. 6, 7). Thus, both analytical data and investigation of archive materials permit to conclude that the sedimentary processes in the bay have changed over the last two centuries and special conditions for mud accumulation have developed. Certainly, human-caused processes were the main factors responsible for these changes.

Furthermore, silty-clay mud sediments are discovered in artificial carriers down to the depth of 13 m near Lahta and Vasilievsky Island (Fig. 1) where underwater sand mining took place. It should be mentioned that these sediments could

be dangerous from the ecological point of view because of high content of oil and heavy metals.

Besides the natural supply of fine-grained material at the end of 1980s – beginning of 1990s, hydro-engineering works in the Neva Bay were the very important source on silty-clay material. Air-photography (Sukhatcheva, 1996) indicates that the suspended matter concentration in the upper water layers of the Neva Bay was as high as 200 mg/l – ten times more than natural. Along with the Flood Protective Dam construction it can be one of the reasons for stirring up of silty-clay accumulative processes.

In 1993, hydro-engineering works were finished in the bay and the dredge concentration increased (becoming 3–4 times less than in 1998) giving rise to a change in the sedimentary situation within the bay. A detailed monitoring study of the Neva Bay coastal zone conducted in 2000–2002 shows the existence of some alterations in facies distribution of different sediment types.

Very good results for the sedimentary processes monitoring can be received by sonar investigation accompanied by sampling. Different sediment types and their boundaries are usually very well recognizable in sonar pictures. A side-sonar scheme in Figure 8 displays a boundary between silty-clay sediments and sands with gravel, pebbles and boulders. In some cases it is possible to observe very distinct ripples on the fine-grained sand surface (Fig. 9).

Development of side-scan sonar schemes at different scales (from 1:50,000 to 1:2,000) and interpretation of single sonar profiles allow more exact location of boundaries be-

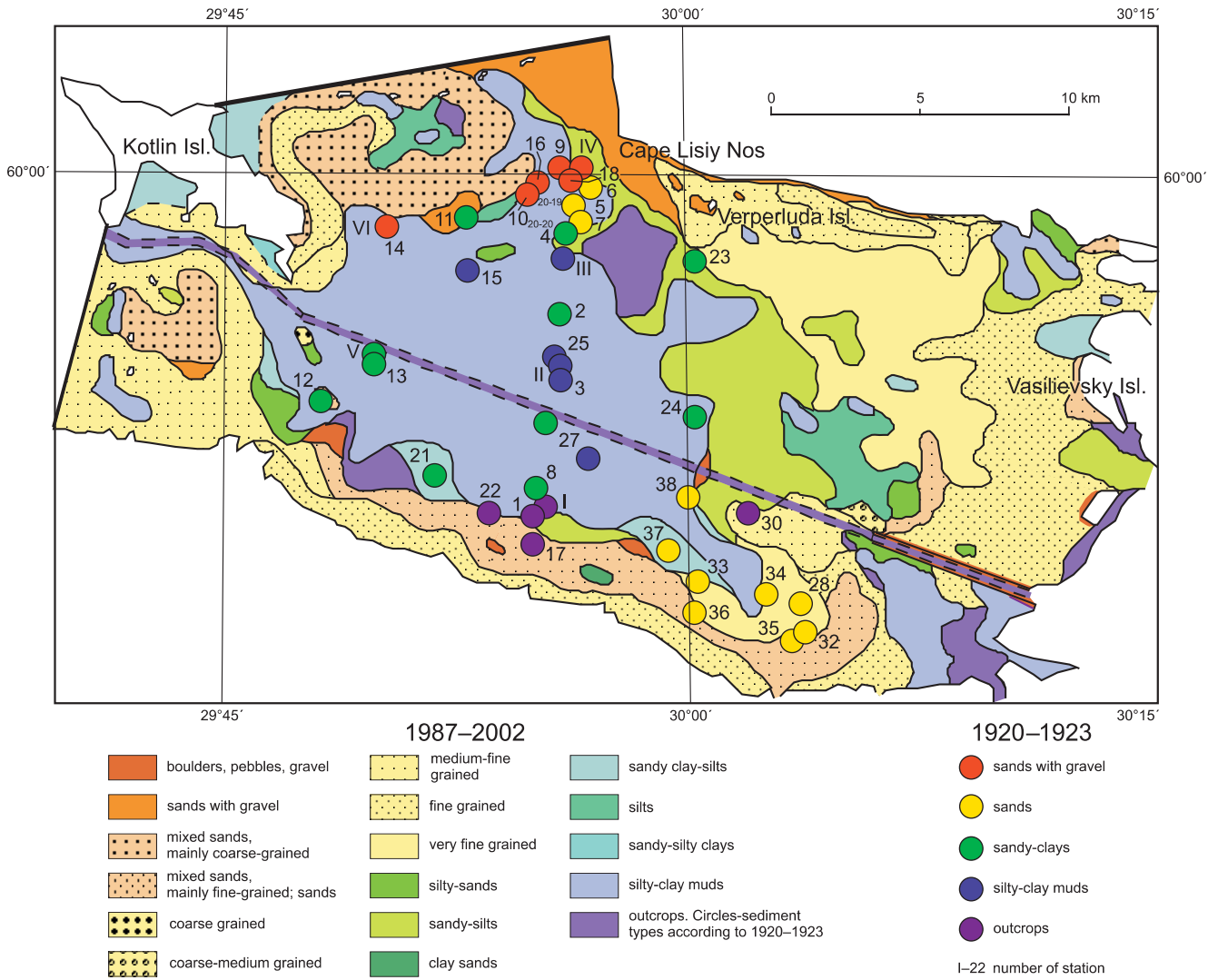


Fig. 6. Comparison of results of the 1920–1923 expedition with modern data

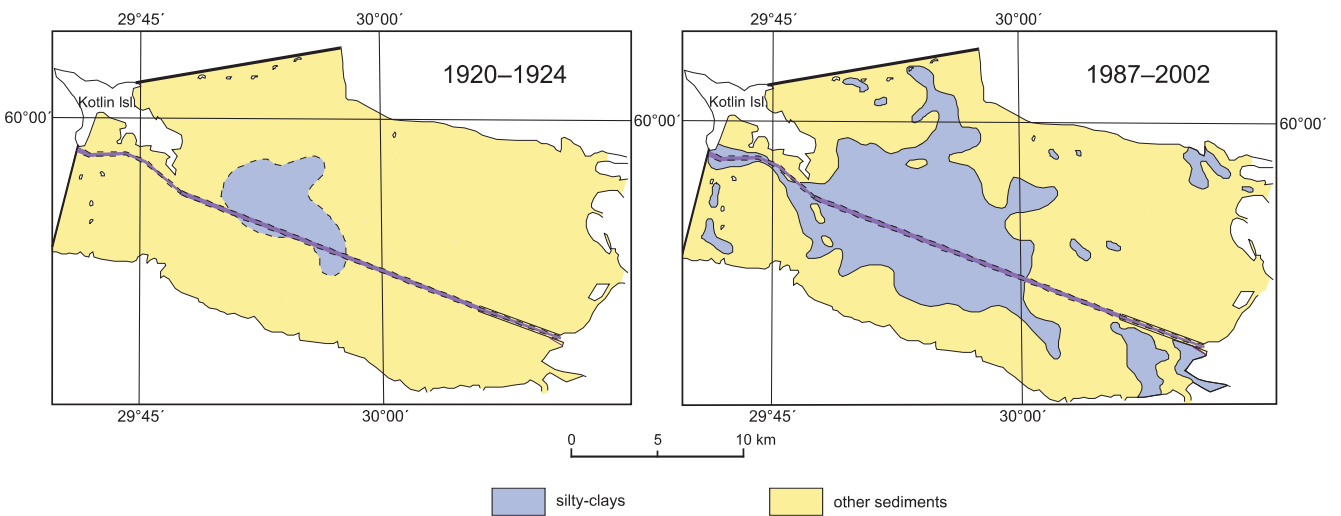


Fig. 7. Silty-clay accumulative zones according to Prof. Derugin expedition of 1920–1924 and modern data

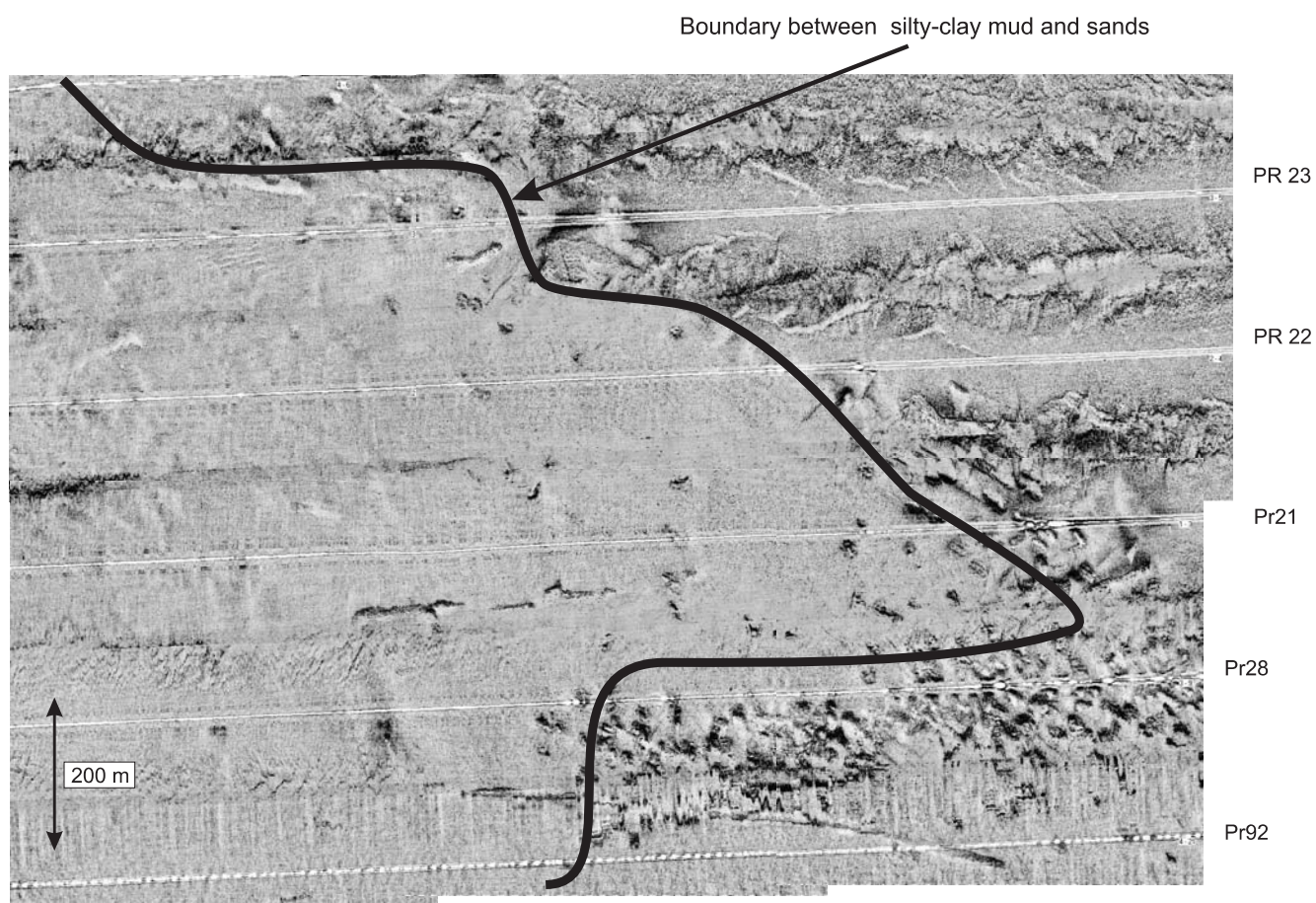


Fig. 8. Side-sonar image. Boundary between silty-clay mud and sands

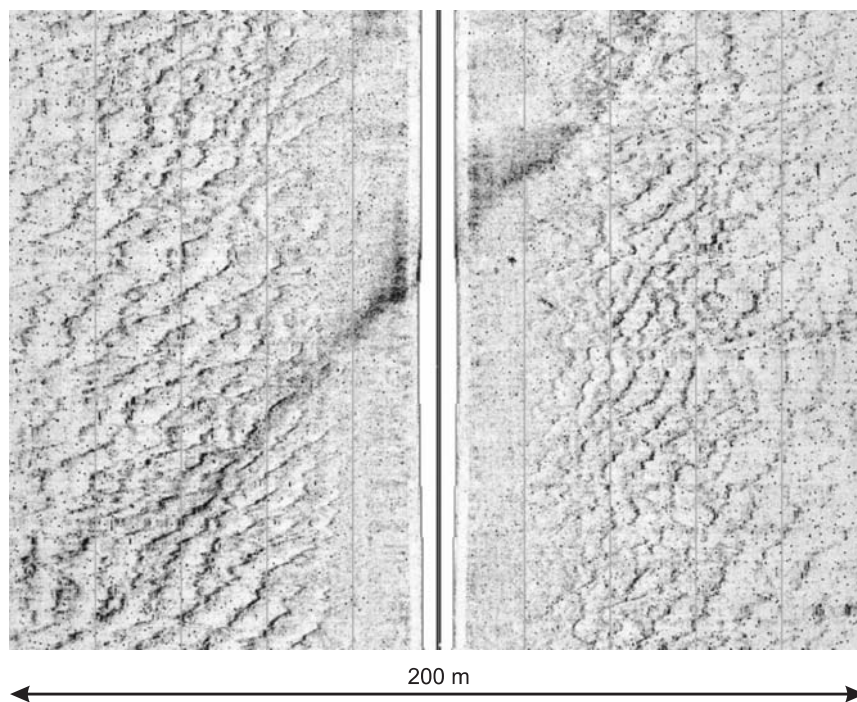
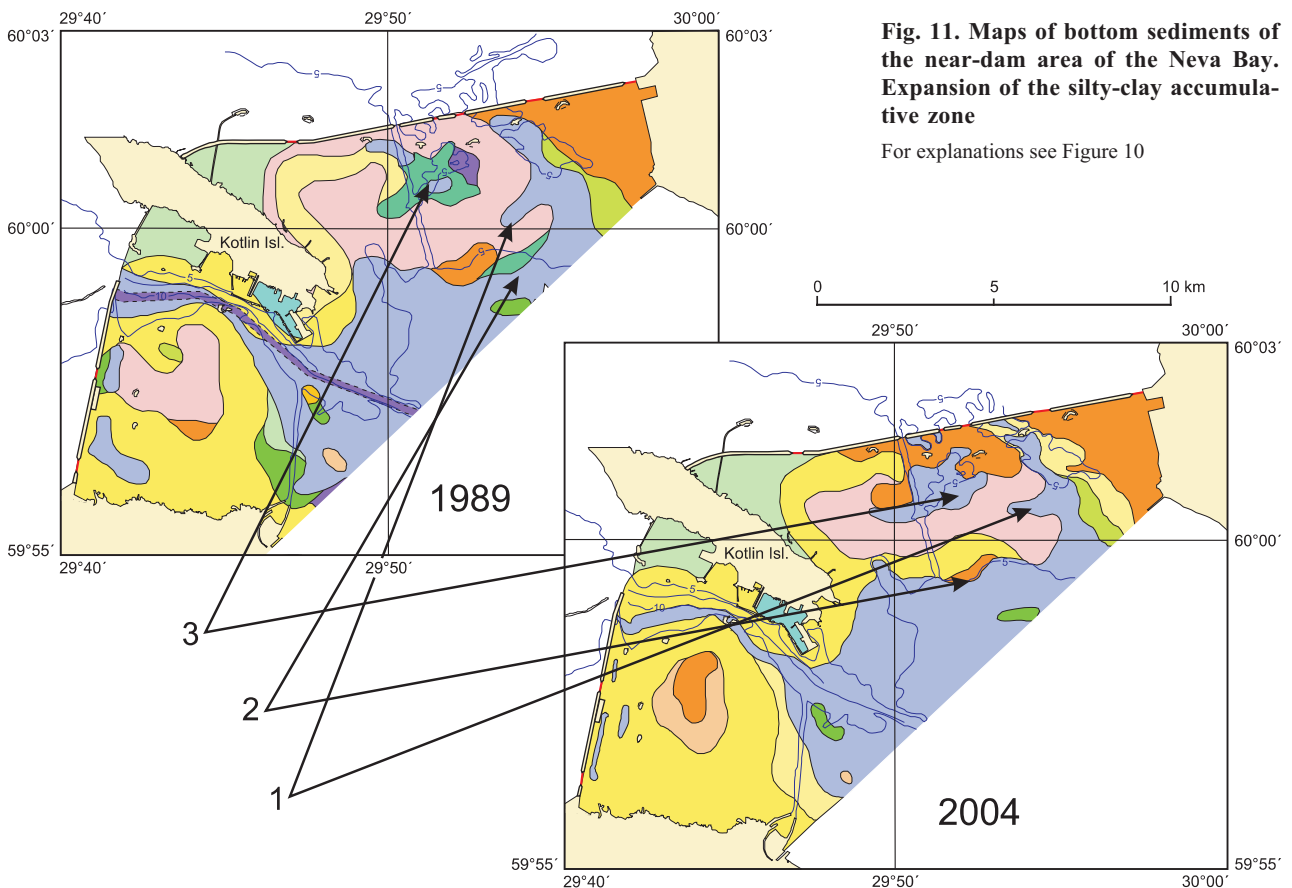
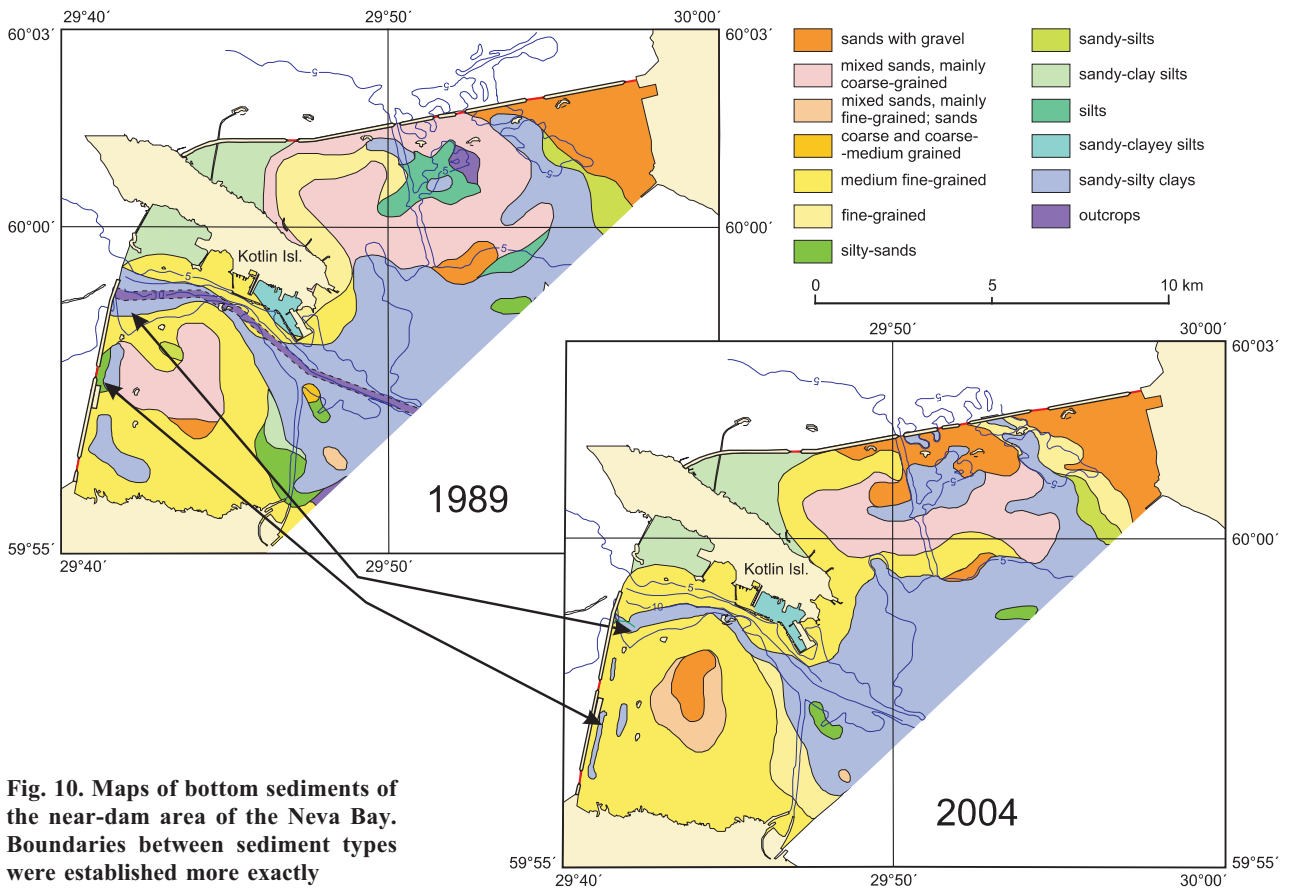


Fig. 9. Side-scan sonar image. Ripples on the fine-grained sand surface



tween different sediment types (Fig. 10). One of important results of 2004 work was a detailed bathymetric map of the study area. Along with natural relief depressions, there are a lot of local technogenic basins in the Neva Bay bottom. Sediment type's distribution (especially silty-clay mud accumulative zones) is strictly controlled by bottom geomorphology.

From the other hand, new data from some locations permit to establish that the sedimentary conditions have changed here over the last decades (Fig. 11). Some alterations in the facies zone configuration occurred in the north of the study area. Both the sonar mosaic-scheme and sampling data indicate that the silty clay accumulation zone has changed its configuration (Fig. 11, case 1) to become wider by 500–700 m (Fig. 11, cases 2 and 3). However, we can state that, as a whole, there have been no considerable alterations observed within this zone since 1987. Investigations of silty-clay mud sediments sampled with a Niemisto-corer prove that the thickness of rescent nepheloid sediments is stable as well. The maximum thickness of mud observed in 2004 (by Niemisto-corer) was 49 cm. Obviously, wave erosion prevents from silty-clay mud accumulation at the depths less than 4 m. We can also suppose that the upper mud layer can be eroded from time to time and redeposited, because one of the important features of the eastern part of the Gulf of Finland is a very significant difference in hydrodynamic conditions between the sleeve and calm

summer period and stormy autumn and winter months. As a result, in some areas even in the small technogenic depressions of the Neva Bay, stagnation anoxic conditions can be observed at the sediment surface during summer periods (e.g. upper layer of muddy clay, sampled from old underwater sand carriers near Lahta in August 2000, was quite black with abundance of dispersed organic matter and strong H₂S smell). Oxidizing conditions commonly prevail within the upper layer of the Neva Bay sediments.

During the last centuries, the bottom relief was very much transformed down to the depth of 10–13 m by crib-bars, fairways, underwater dumping sites and carriers as a result of intense technogenic activity in the bay. Plenty of cables, pipelines and sunken vessels can be observed on the bottom surface. Revealing and mapping of different types of technogenic objects was another important aim of sonar investigations. In the near-dam areas, a number of 19th-century crib-bars were discovered (Fig. 12). These areas (both south and north-east of Kotlin Island) are characterized by a very high level of technogenic load on the bottom relief. Besides crib-bars, a few carriers where ground excavations for construction of forts have taken place were also found there in the last centuries.

The most significant forms of technogenic relief of the Neva Bay bottom are fairways (Fig. 13) and waste piles (banks) created in the process of fairway deepening. Its depth reaches

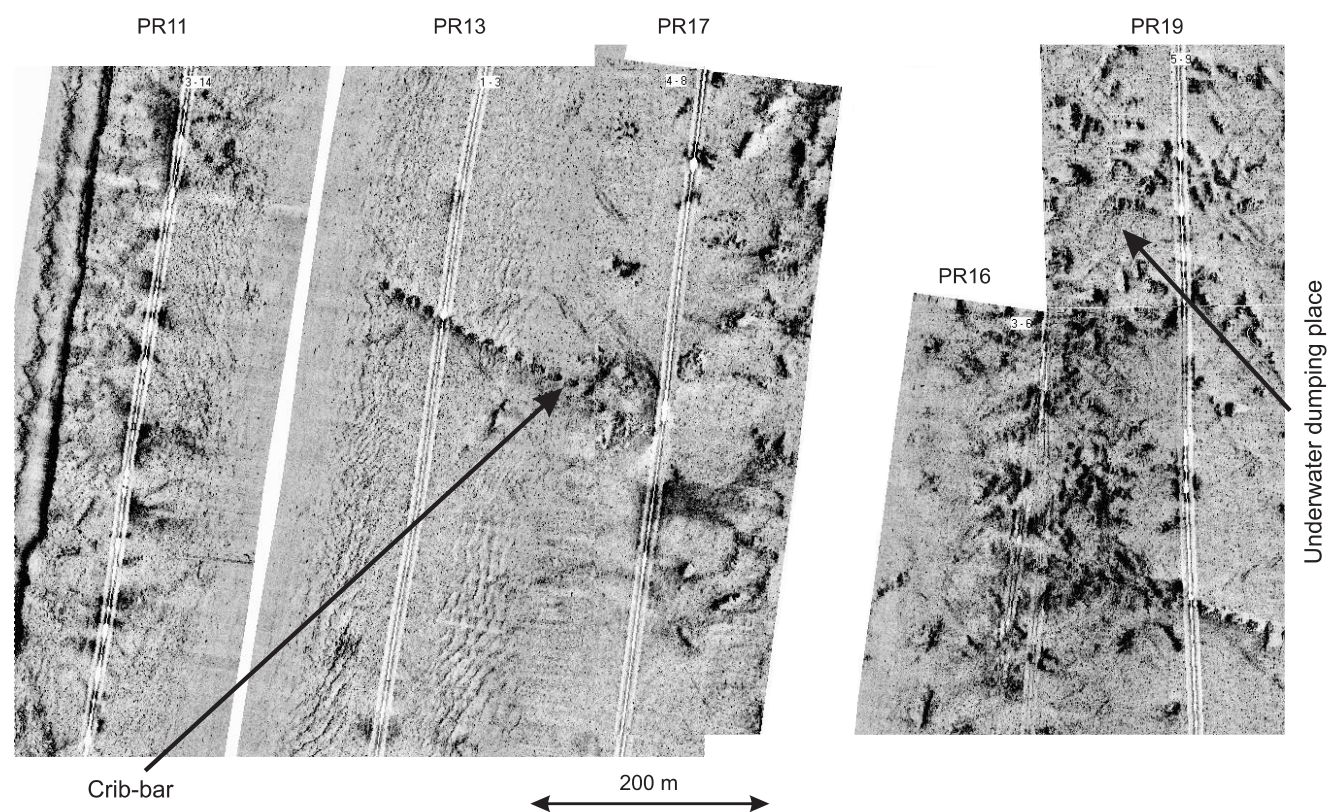


Fig. 12. Crib-bar and underwater dumping site in the side-sonar scheme

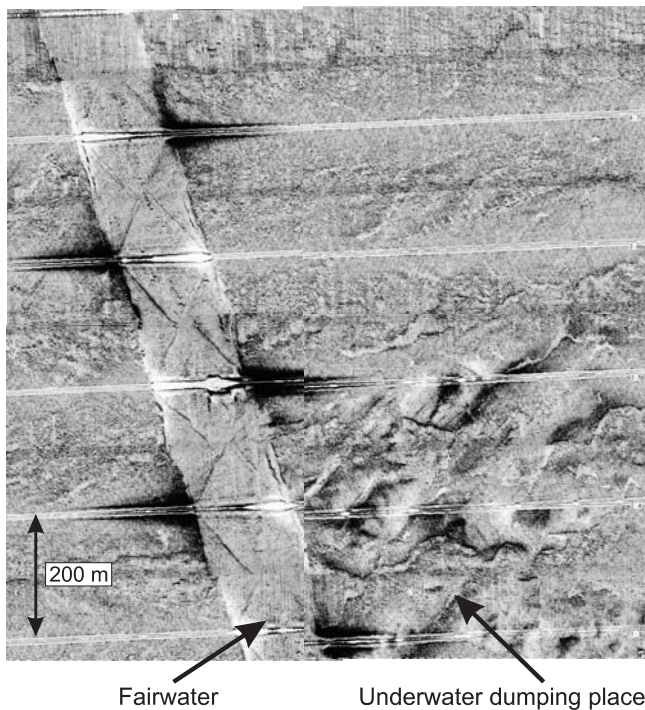


Fig. 13. Fairway in the side-sonar scheme

10–12 m. The main fairway of the Saint Petersburg Port and crossing fairways are very well visible in the sonar scheme and images east of Kotlin Island. Some of them are abandoned now, and that is why they are partly filled up with sediments. Figure 14 shows an underwater carrier of rectangular shape as a result of underwater excavation (a carrier or unfinished part of a fairway). To the east of Kotlin Island (so-called “Kronshtadt road”) the entire bottom surface is covered by fine sands and clayey silts disturbed by anchor traces. There are also technogenic objects, cables, pipe-lines and sunken vessels in this area.

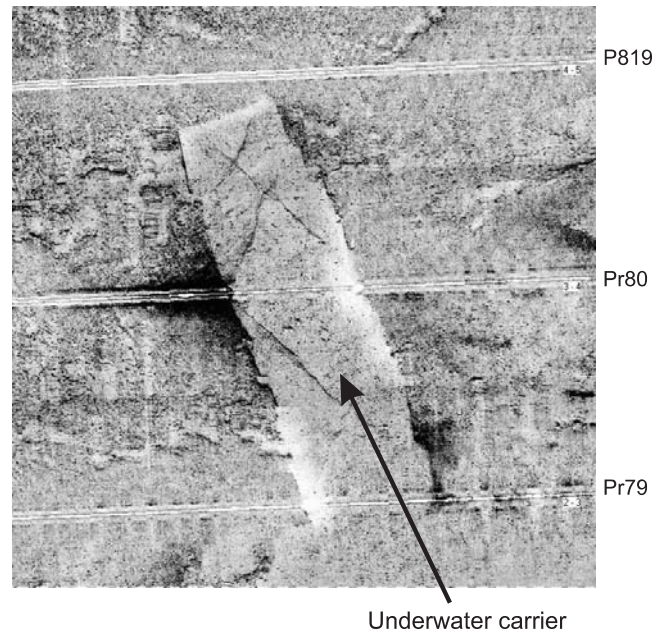


Fig. 14. Underwater carrier in the side-sonar scheme

In the northern part of the study area, there is a zone of bottom relief intensely transformed as a result of human-caused processes (Fig. 15). In sonar pictures, this zone is characterized by strong acoustic reflections resembling chaotic crossings of strait black belts. Actually, the origin of this zone is very questionable. It can be an underwater dumping site or an area of former excavations. The investigations should be continued, there are planning to carry on television observation and underwater photography of this area of the bottom surface. Using these methods can help to resolve this problem.

CONCLUSIONS

1. In summer 2004, Department of Marine and Environmental Geology of VSEGEI carried out investigations of the Neva Bay bottom surface east of the Saint-Petersburg Flood Protective Dam, using a side-scan sonar. The investigations conducted in 2004 covered the whole study area with a sonar-profile net. Altogether, 109 sonar profiles were done.

2. Comparison of side-scan investigation data with materials of state geologic survey and environmental (geoenvironmental) study, carried out by VSEGEI in the Neva Bay since 1987, allowed more exact location of boundaries between different sediment types and (in some places) permitted a suggestion that sedimentary conditions have changed during the last decades. The maximum expansion of the silty-clay accumulative zone (500–700 m) was observed in the northern part of the study area; at some places configuration of the recent

nepheloid zones has changed. However, we can state that, as a whole, there have been no considerable alterations observed within this zone since 1987. Thickness of the recent silty-clay mud sediments is stable as well.

3. Side-scan investigations of the bay bottom revealed many different types of technogenic objects (such as crib-bars, fairways, cables, pipe-lines, sunken vessels and others) and a number of zones of intense transformation of bottom relief due to human-caused processes (these zones were found as a result of creation of fairwaters and forts). Besides, a number of former underwater dumping site areas were also discovered.

4. Using side-scan profiling accompanied by bottom sediment sampling can be an important part of the water resources management

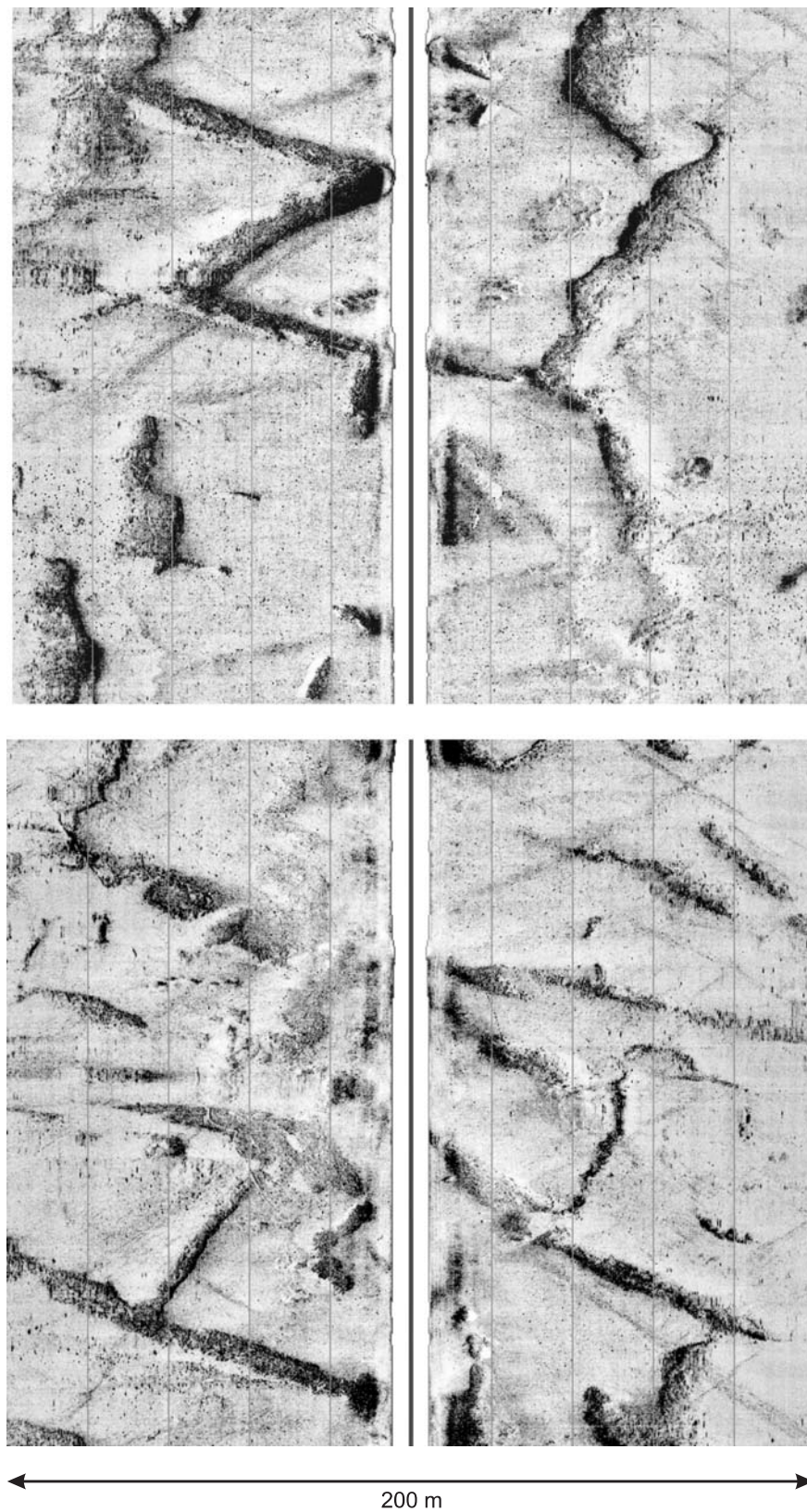


Fig. 15. Zone of intense transformation of bottom relief as a result of human-caused processes in side-sonar images

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