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DEVELOPMENT OF THE SOUTHERN COASTAL ZONE OF THE EASTERN GULF OF FINLAND (FROM LEBYAZHYE TO THE ST. PETERSBURG FLOOD PROTECTIVE DAM)

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Abstract. In July–September 2004 and April 2005, the specialists of the Department of Marine and Environmental Geology of All-Russian Geological Institute (VSEGEI) conducted field studies of the coastal zone of the Gulf of Finland from thesouthern alignment of the St. Petersburg Flood Protective Dam to Lebyazhye. The basic purpose of the studies is the analysis of coastal zone dynamics. Along the southern coast of the Gulf of Finland from Lebyazhye to the Dam, three different coastal dynamics zones were identified: (1) flat accumulative shore with aquatic plants, (2) erosion zone and (3) zone of modern sand accumulation. Along-shore sand drift in the eastern direction was also determined. Alongside with routine observations, the comparative analysis of space photography images of the study area, carried out during last 20 years, allowed finding out that as a result of intense eastward sand transfer, as mush as 80 metres of sand accumulative bodies have been eroded since 1982 near the village of Izhora. To the west of a small river, a 230-metres long sand split has been formed since 1982.

Key words: sand drift, coastal zone dynamics, southern coastal zone of the Gulf of Finland.

SUBJECT OF INVESTIGATION

Part of the coastal zone under consideration is situated at the southern coast of the Gulf of Finland from the southern alignment of the Saint Petersburg Flood Protective Dam to Lebyazhye. It extends over a distance of 14 km.

Along the western segment (2 km) of subaerial part of the coastal zone, glacial-fluvial sands with gravel form a terrace, up to 7 metres high. Over the next 3 km, the shore becomes very flat and lake-glacial deposits are exposed here. The eastern part of the coast is composed of Holocene sand bodies. Along the subaqueous part of the coastal zone, lake-glacial deposits (varved lamination of silts and clays and Baltic Ice Lake clays) are observed at the bottom surface (Amantov *et al*., 2002).

The underwater coastal slope is very flat and shallow here. At a distance of 1 km from the shoreline, the water depth is just 0.8–1 metres. Average inclination of the underwater coastal slope is about 0.001–0.0015.

Coastal zone dynamics of the zone under study is very active. According to many observations (Raukas, Hyvarienen, 1992) made during the 1970s and 1980s in the environs of Lebyazhye and Bolshaya Izhora, the processes of coast destruction have become essentially stronger. Some scientists suggest that the main reason of this phenomenon is increasing storm activity and repetition rate of extreme storms both in the Gulf of Finland and across the whole Baltic Sea (Raukas, Hyvarienen, 1992). Now the problem of coastal zone dynamics has a special importance because of completion of Saint Petersburg Flood Protective Dam construction and possible alteration of litho-dynamic processes to both east and west of it.

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MATERIALS AND METHODS

In 1990–1992, geological surveys have been carried out (52 sampling stations) by VSEGEI in subaqueous part of the analysed coastal zone. As the result, a set of geological maps was made (Amantov *et al*., 2002).

In July–September 2004 and April 2005, the specialists of the Department of Marine and Environmental Geology of VSEGEI carried out marine investigations (72 grab-corer sampling stations) and land surveys. The basic purpose of the studies is analysis of coastal zone dynamics processes. The study of shoreline changes was integrated by repeated beach surveys, topography charts and air photo and satellite photo analysis of shoreline changes in the study area. Binding of sampling stations was carried out by GARMIN – GPS 128. Grain size composition of sand sediment was studied by making a 21-fraction sieve analysis (AS 200 "Retsch" analyzer).

DISCUSSION

Most of the nearshore bottom surface is covered by fine- and medium-fine grained sands (Fig. 1). According to their origin, littoral zone sands can be divided into two groups. From the coastal line to a depth of 2–3 metres, 40–50 cm of very well-sorted wave deposited sand is observed. Further upper 10–20 cm of the bottom sediment is represented by erosion zone sands, and below there is an outwashing surface of varved Pleistocene clays (Fig. 2). Special grain-size distribution features characterize both the types of surface sands.

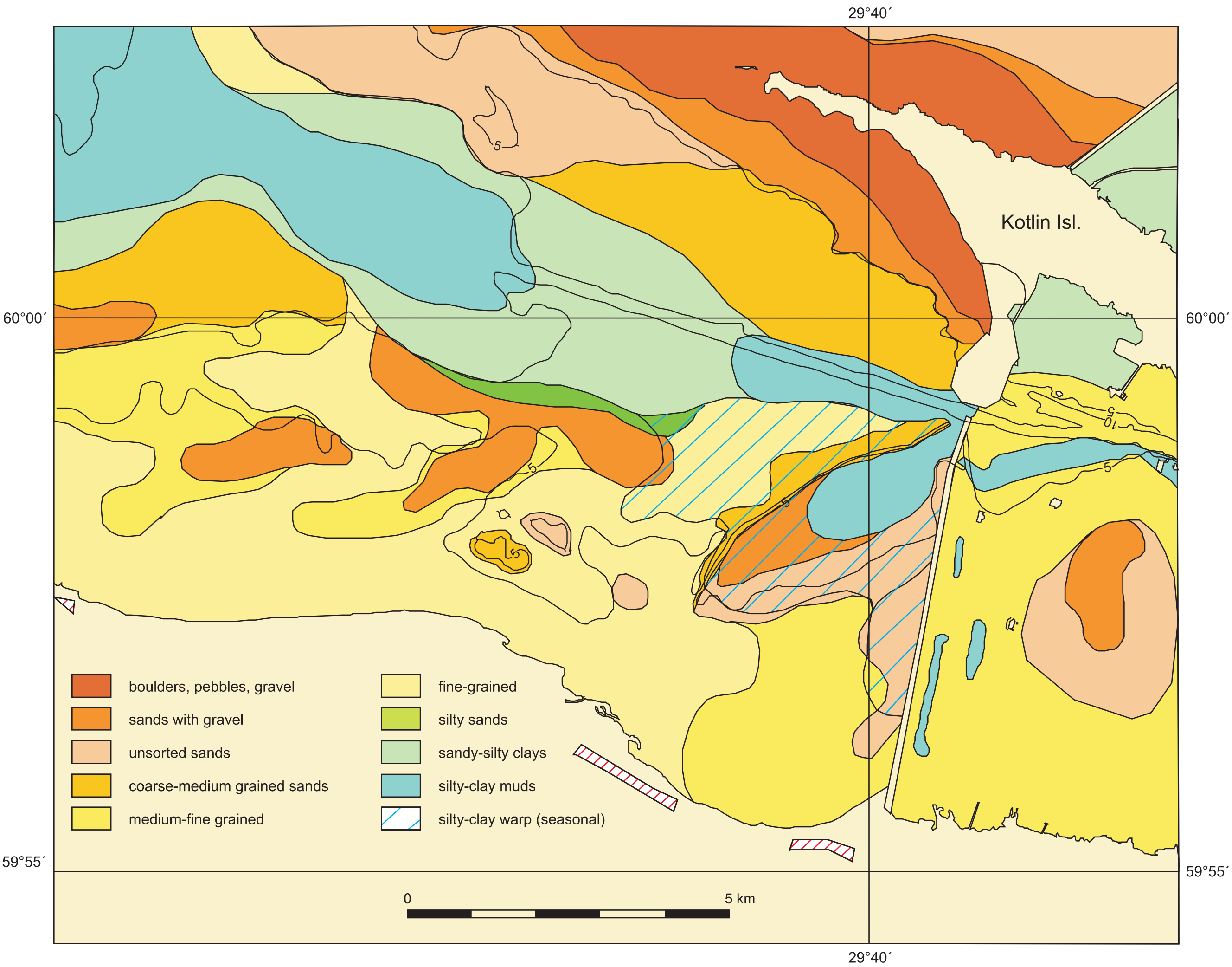

Fig. 1. Map of bottom sediments of the subaqueous southern coastal zone, the Gulf of Finland

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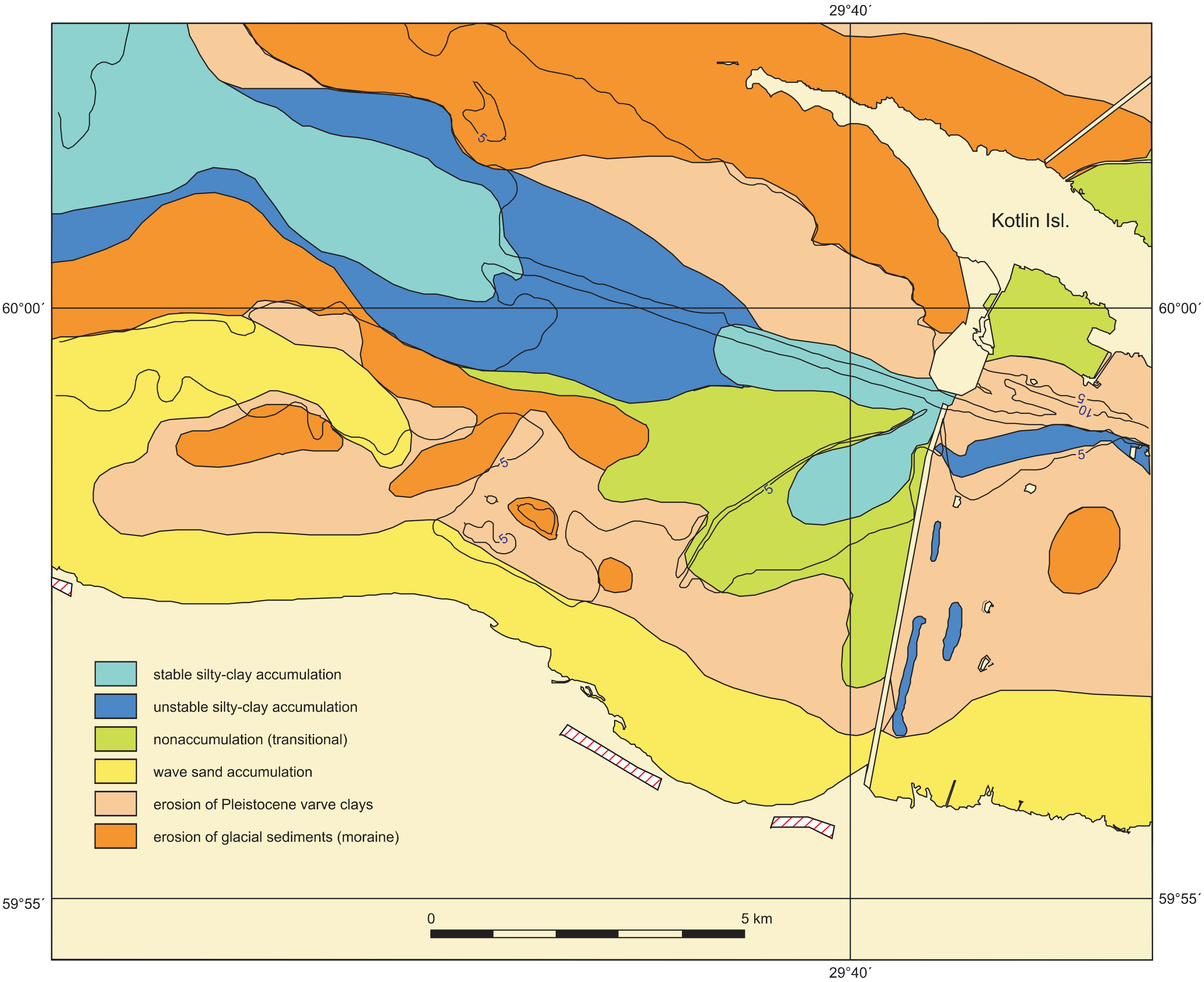

Fig. 2. Types of sedimentation zones of the subaqueous southern coastal zone, the Gulf of Finland

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Southern coastal zone of the Gulf from Lebyazhye to the Dam can be subdivided (from west to east) into three types – erosion, sand accumulative and artificial types of coastal zone dynamics (Figs. 3, 4). However, it should be mentioned that just some areas of the coastal zone can be classified as typical erosion or accretion zones. Over most of the coast, litho-dymanic processes are very complicated and they significantly change depending on seasonal fluctuations of the wave and see-level regime.

There are three different types of erosion zone (Figs. 3, 4). In its western part, a very large difference in hydrodynamics of the sleeve are observed and there are calm summer periods and stormy autumn and winter months with frequent water level rises (floods). During autumn and winter, erosional processes are very active here, so a terrace forms in coastal Quaternary deposits (glaciofluvial sands with gravel), The cliffs are up to 3–6 metres high. However, in summer periods, the shallow underwater costal slope is covered by aquatic plants, which block the coast destruction. As a result, temporary silty-clay accumulation takes place here (Fig. 5A).

In the second part of erosion zone, the shore is very flat. Here, a washing of outcropping Quaternary clays takes place on the beach (Fig. 5B). The underwater coastal slope is steeper in comparison with the other parts of the coast, and the surface of washing-out sediments is covered by 2 to 20 cm of sands.

In the next part of erosion zone, a narrow sand beach is eroded (Fig. 5C). Using the Patrick MacLaren methods (MacLaren, 1985), grain-size distribution investigation of 15 near-coastline surface sands shows the existence of sand drift in eastern direction.

Mac Laren estimated by experiments that there are two possible ways of grain-size parameters, changing if sand drift (transport) exists:

1. Sediment becomes finer, better sorted, asymmetry more negative;

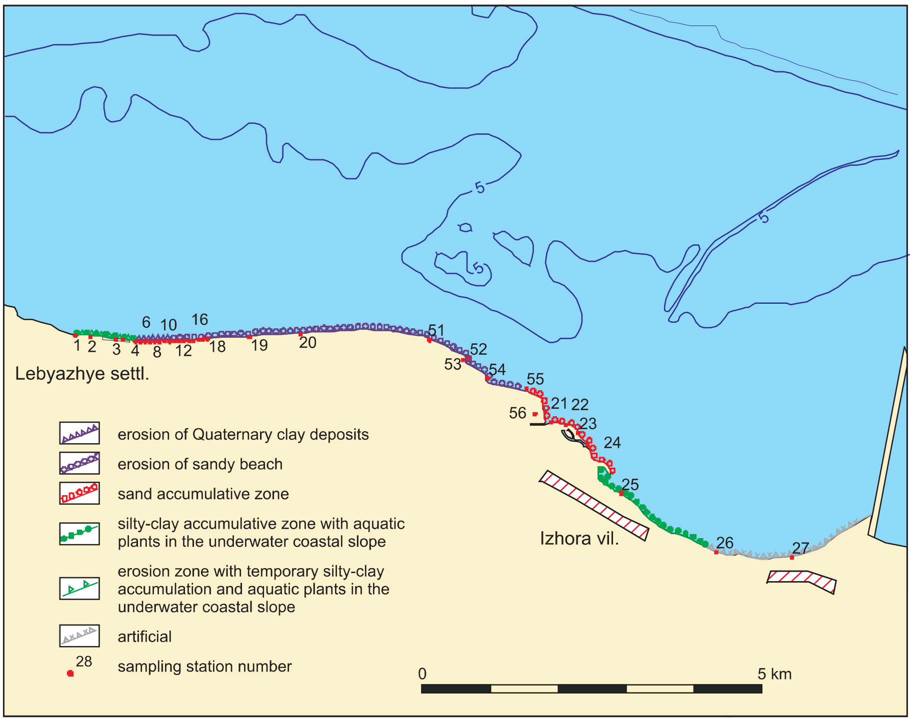


Fig. 3. Types of the southern coastal zone, the Gulf of Finland

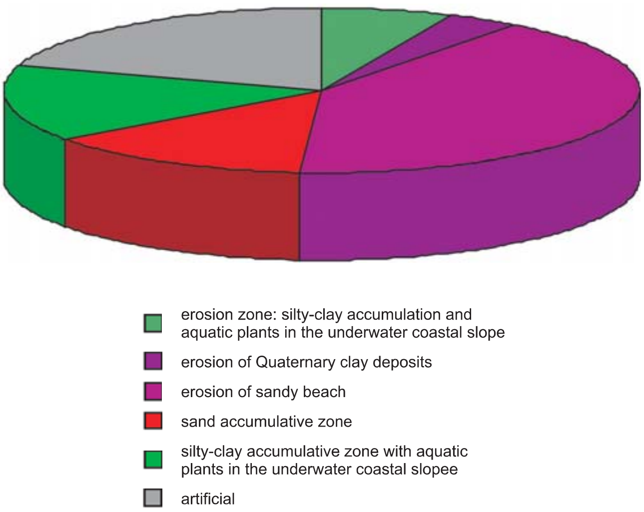


Fig. 4. Distribution of southern coastal zone types (from Lebyazhye to the Dam; 2005)

2. Sediment becomes coarser, better sorted, asymmetry more positive (MacLaren, 1985).

Sand drift transport existence is determined by the formula (**1**):

$$Z = \frac{x - Np}{\sqrt{Npq}}, \text{ where } N = \frac{n^2 - n}{2} \text{ (MacLaren, 1985)}$$

n – number of samples,

x – quantity of cases of grain-size parameters alteration in concordance with two possible for sand transport existence variants,

p = 0.125 (coefficient probability),

q = 1 – p = 0.875.

Sand drift direction exists with significance level 0.05, if Z >1.645 (**2**), and with significance level 0.01, if Z >2.33 (Spiegel, 1961). The method can be used if number of samples along suggested transport direction is higher than 8.

According to this method, for sand drift direction definition, 15 samples of surface sands were taken from the near-shoreline zone of the coast segment where erosion of Quaternary clays was proved. Samples were taken with the interval of 65 metres along the beach (sampling stations No 4–18). Then, Ma, So and A coefficients were calculated for each sample using a 21-fraction sieve grain-size analysis. Grain size parameters for samples 04-4–04-11 are shown in Table 1.

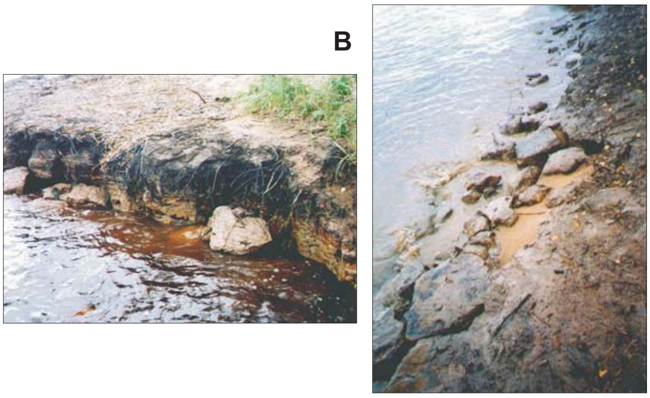
As the coastal line extends from east to west, calculations of grain-size parameters alteration were made for both directions (Table 2).

Thus, only one from these four possible cases corresponds to the formula (2). For the eastern trend (sediment becomes finer, better sorted, asymmetry more negative) Z = 2.76, i.e. Z >1.645. That means that there is eastward sand drift transfer with significance level 0.01.

Considering in series by the same way grain-size parameters for next 6 samples, taken in direction from west to east, we can observe, that coefficient Z is growing (Table 3), it is in all cases greater then 2.33. It confirms the conclusion of eastward sand drift in the near-shore zone.

A

B



C

D

Fig. 5. Photographs of different coastal zone types

A – erosion zone: silty-clay accumulation and aquatic plants in the underwater coastal slope; B – erosion of Quaternary clay deposits; C – erosion of sandy beach; D – artificial

Table 1

Grain size coefficients for samples 04-4–04-11

N	Sample number	Ma (γ-scale)	So	A
1	04-4	3.20	3.04	–0.14
2	04-5	2.24	2.56	0.34
3	04-6	5.45	1.61	–1.02
4	04-7	6.17	1.10	1.17
5	04-8	5.57	1.66	–0.48
6	04-9	5.26	1.36	0.00
7	04-10	5.55	1.20	0.13
8	04-11	5.09	1.47	–0.72

Table 2

Definition of sand transfer direction after MacLaren method

	Eastern trend	Western trend
1. Sediment become coarser, better sorted, asymmetry more positive	$N = 28$ $x = 8$ Z = 0.86	$N = 28$ $x = 0$ Z = 0
2. Sediment become finer, better sorted, asymmetry more negative	$N = 28$ $x = 8$ Z = 2.75	$N = 28$ $x = 0$ Z = 0

Table 3

Results of sand transfer direction definition for 15 samples after MacLaren method

Sample number	N	x	Z
8	28	8	2.75
9	36	11	3.28
10	45	13	3.32
11	55	16	3.72
12	66	21	4.76
13	78	22	4.19
14	91	26	4.62

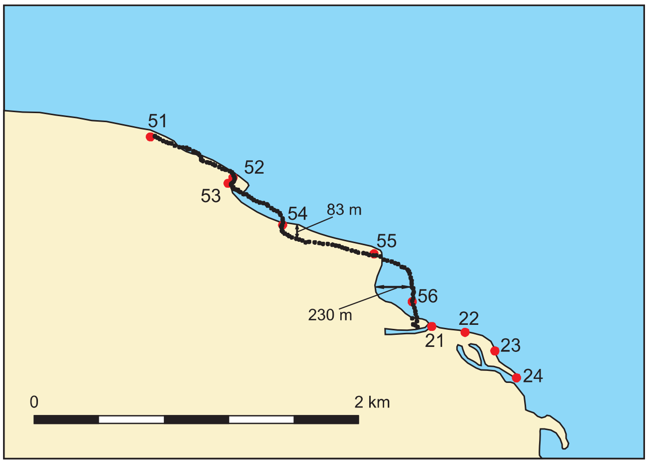


Fig. 6. Changes in the coastal zone line since 1982

Yellow area – coastal line according to map edited in 1982, black spots – spring 2005 GPS survey results

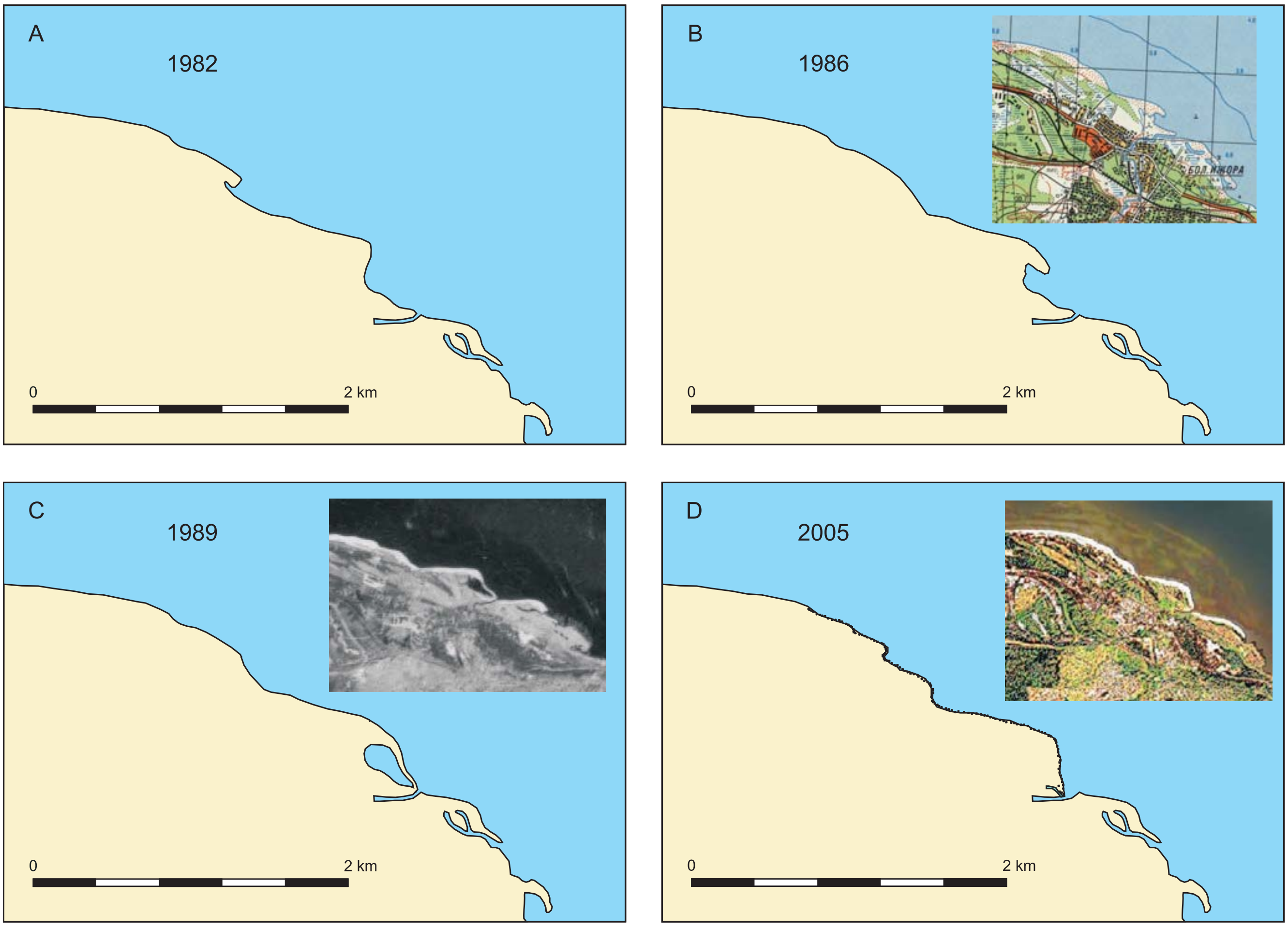


Fig. 7. Sand body transformation processes since 1982, from charts (A), air-photos (B) and satellite photography analysis (C), and GPS survey results (D)

In the next segment of the coast, there is a zone of erosion of sand accumulative bodies. For a long time, accumulative sand bodies (spits) of different forms and sizes were formed here as the result of intense sand drift in the eastern direction. The existence of such sand bodies could be seen even in old maps of this region. However, investigations of air photography images (Research Institute of Satellite and Air Photography Methods (NIIKAM) showed that from 1975 to 1990, as much as 60–70 m of sand beach were eroded in some parts on the coast in this area, and several accumulative sand spits were washed out over the distance of 500 metres. These processes are continuing now. Long-time coastal line changes could be reconstructeded from maps and air- and space-photography analysis. Figure 6 illustrates the coastal line changes between 1982 (yellow colour – a topography chart) and 2005 (black points – GPS survey results). Configuration of sand bodies varied (eastern part of sand body migrated over a distance of up to 230 metres, maximum erosion is about 80 metres).

Mechanism of long-term coastline changes can be established by topography charts, and analyses of air-photo and satellite images (Fig. 7). Figure 7A shows a smooth curve of the coastal line (topography chart, 1982); Figure 7B – the beginning of sand spit growth and lagoon formation (topography chart, 1986); Figure 7C – formation of a narrow sand bridge between the spit ridge and the river delta, the lagoon is closed (air photography, 1989); Figure 7D – the sand spit is quite wide, the lagoon is dry (satellite photo and field GPS study, 2005). In the images (taken in April 2005) shown in Figure 8, the newly formed sand body and the former lagoon – now a dry low space overgrown with grass and shrubs – can be seen at the eastern border of the sand spit.

A comparison of observations from different seasons allows recognition of the erosion mechanism, sand drift and growth of the eastern part of sand bodies. The most intense coast erosion and sand transfer processes take place during storm waves caused by westerly and northwesterly winds. In the calm summer period, most segments of the coast are straight, the curves in the points of erosion are smooth and beach slopes are flat. After stormy autumn and winter months, new small-scale erosion sites can be observed on the straight segments of the coast. These pictures illustrate the processes – straight coastal line (October 14, 2004) and new erosion curve at the same place (April 22, 2005) (Fig. 9).

Fig. 8. Eastern border of sand accumulative body (1) and former lagoon (2)

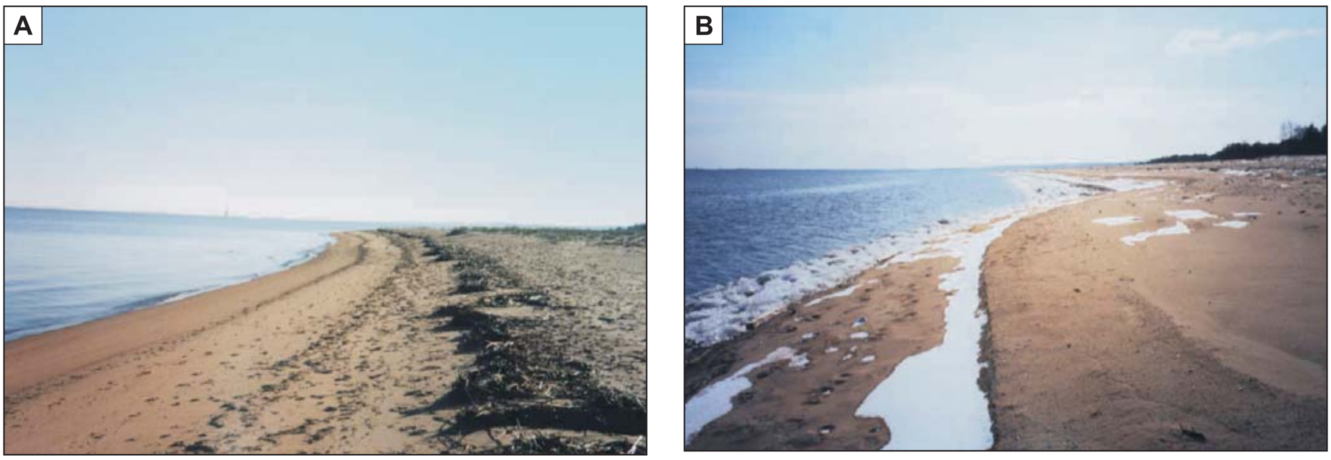


Fig. 9. Erosion "curve" formed during stormy winter periods

A – October 2004; B – April 2005

To the east of a small river mouth, modern accumulative bodies are forming now. In small “lagoons” between them there are a lot of aquatic plants. This place is important from the biological conservation point of view. During our summer works, we observed many species of birds in this area, some of them are rare and registered.

The eastern part of the coastal zone under study (near the Dam) is artificial (Fig. 5D).

CONCLUSIONS:

1. On the southern coast of the Gulf of Finland from Lebyazhye to the Dam, three different coastal dynamics zones were identified: (1) flat accumulative shore with aquatic plants, (2) erosion zone and (3) zone of modern sand accumulation.

2. Along-shore sand drift in the eastern direction with significance level 0.01 was established by the MacLaren method (MacLaren, 1985).

3. As a result of intense eastward sand transfer, as mush as 80 metres of sand accumulative bodies were eroded near the village of Izhora. To the west of a small river, a 230-metres long sand split was formed since 1982.

4. The most intense coast erosion and sand transfer processes take place during storm waves caused by westerly and northwesterly winds. In the calm summer period, most segments of the coast are straight, the curves in the points of erosion are smooth and beach slopes are flat. After stormy autumn and winter months, new small-scale erosion sites can be observed on the straight segments of the coast.

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