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Modern sedimentation processes within the coastal zone of the Kurortny District of St. Petersburg (eastern Gulf of Finland)

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Abstract As a result of investigation carried out in 2005–2006 in the northern coastal zone of the Russian part of the Gulf of Finland the new data on geological history and modern sedimentation processes have been obtained. For the first time the side-scan-mosaic scheme of investigated area was developed. Side-scan sonar data analysis permits to distinguish some important features of the bottom structure such as glacial till ridges, dynamic sands (with ripples on the surface) zones, sand waves, erosion margins (valleys), technogenic relief and objects.

Keywords *Eastern Gulf of Finland, coastal zone dynamics, bottom relief.*

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INTRODUCTION

Kurortny District of St.Petersburg is located along the northern coast of the Gulf of Finland to the west of St. Petersburg Flood Protective Dam (Fig.1). It has a special importance as a unique recreation zone of the North–West of Russia. Sandy beaches and comfort climate caused the construction of many sanatoria, hotels and entertainment centres. Two protected natural territories – sandy beach with dunes in Komarovo village and oak park "Dubki" founded by Peter I – are situated here. The coastal erosion is one of the most urgent problems in this area. Clear understanding of the recent coastal development, that is the main objective of the study, is extremely needed for elaboration of the coast protective measurements.

Investigated coastal zone – which includes both shore and nearshore areas – has some special features of geological structure and history. It is situated in the transitional zone of the Baltic Shield and the Russian Plate. Pre–Quaternary rocks are represented mainly by Vendian terrigenous deposits and migmatite garnet-biotite gneisses displaying in erosive palaeo–valleys 100–115 meters deep. These rocks are totally covered by Quaternary deposits up to 20-40 meters thick (Spiridonov & Pitulko 2002). The history of the Baltic Sea water basin development in the late Pleistocene–Holocene as a whole is accepted by geological society (Raukas & Hyvarinen 1992). The main features of the recent coastal zone were formed during degradation of the last glacial cover and essentially transformed during post-glacial period characterized by the alteration of marine, continental and lake conditions. In spite of this fact many details of the eastern Gulf of Finland geological history such as migration of ancient coastal lines (especially below the modern sea level) are still debatable.

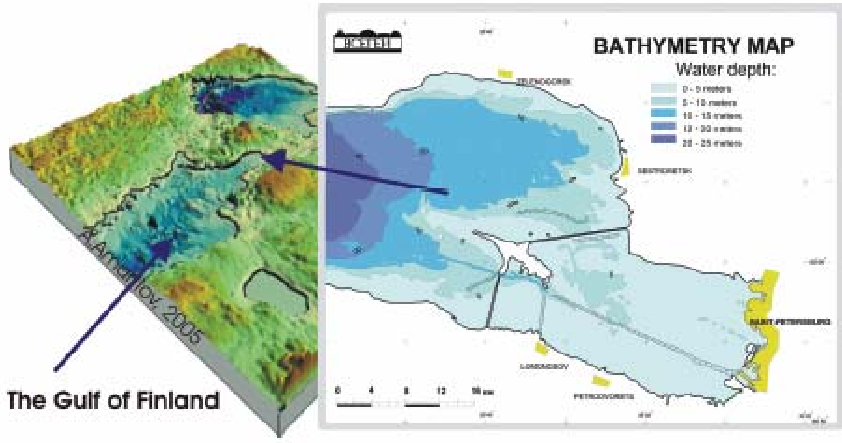


Fig. 1. Investigated area.

Since 2000 a special attention has been paid to the coastal zone dynamics processes. In 2005-2006 VSEGEI and Institute of Remote Sensing Data for Geology (NIIKAM) with the financial support of Morzashchita (Department of St. Petersburg Government) fulfilled multipurpose investigations of the northern coastal zone of the eastern Gulf of Finland (between capes Lautaranta and Dubovskoy) (Fig. 1). The study included the on-land field observations, depth measuring, sediment sampling of the beaches and near-shore sea bottom. The side-scan sonar profiling accompanied by bottom sediment sampling (box–corer and Lauri-Niemisto gravity–corer) was mostly effective and useful method for investigation of the bottom relief and distribution of the superficial sediments as Well as the study of technogenic objects. During two years more than 400 km of side-scan survey (including 100 km of repeated profiling) were carried out in the near-shore zone (water depths 2–10 m). The range of side–scan (CM-2 C-MAX.Ltd) was about 100 m, acoustic frequency 102 kHz. The distance between profiles (186 m) permits to receive continuous acoustic picture of all investigated sea bottom area. Repeated survey of three parts of near-shore zone (in front of villages Komarovo, Repino and Solnechnoye) allowed studying development of the bottom relief and sediment distribution.

As it is well-known, after the Weichselian ice sheet melting the local glacial lakes were formed in the investigated area. About 12 000 years ago they united in the Baltic Ice Lake (Raukas & Hyvarinen 1992; Spiridonov et al.1988).The most wide spread type of distal facies of the lacustrine-glacial deposits consists of varved clays (local ice lakes), laminated and homogenous brownish-grey clays (Baltic Ice Lake). In the investigated area these sediments don't differ from their analogues in the other parts of the gulf bottom. On the contrary Holocene sediments (Ancylus and Yoldia stages, Litorina and Limnea seas) are represented mainly by sands of near-shore facies. According to former VSEGEI submarine drilling data the thickness of Holocene sands in some sampling sites achieves 1.50–1.60 m. These data are partly corresponded to the palaeo-reconstructions of the Holocene coastal lines (Raukas & Hyvarinen 1992; Raukas 1994).

Nowadays the coastal zone of the eastern Gulf of Finland is characterized by a specific regime of litho– and morphodynamics caused by sharp periodic fluctuations of the sea level, seasonal ice-forming processes, intensive and various anthropogenic activities. As a result the investigated coastal zone is characterized by very complicated ("mosaic") distribution of the sediments and specific geomorphological features. It is possible to observe the alteration of the erosion and accumulation zones, different forms of dynamic accumulation, longshore sand drift, aeolian transformation, etc.

MATERIAL AND METHODS

Since 1981 the Department of Regional Geoecology and Marine Geology of Russian Research Geological Institute (VSEGEI) has carried out complex studies for State geological mapping and geoenvironmental investigations in the eastern Gulf of Finland. As a result of these works the set of geological maps of the sea-bed (maps of bedrock, Quaternary sediments, superficial sediments, etc.) were compiled at 1:200 000 scale (Spiridonov & Zhamoida 2004; Zhamoida et al. 2006).

RESULTS AND INTERPRETATION

The investigated part of the coasts of the gulf from Zelenogorsk to the Dam can be subdivided into five subtypes – moraine erosion (34% of investigated coastal zone extension), stable with periodic erosion of sandy beach (25%), sand accretion or silty-clay accumulative (38%) and technogenic (artificial) (less that 3%) (Fig. 2). Waves and along-shore currents are the most important factors controlling the lithodynamics processes. The highest waves affected the coast are observed during western and southwestern wind direction.

Each type of the coastal zone has its typical features. In erosion zone as a result of intensive sand drift in the eastern direction and sediment starvation a boulder-pebble bench is being formed both at the beach and near-shore zone. The upper part of the shoreface profile of this type is represented by a gently descending boulder-cobble bench sometimes with irregular sand spots which are not exhibited in bottom relief (Fig. 3).

At the straight coast sections with narrow sandy beaches, coastal line is more or less stable, but during Storm periods erosion processes take place here as well. During sea level rise accompanied by storm

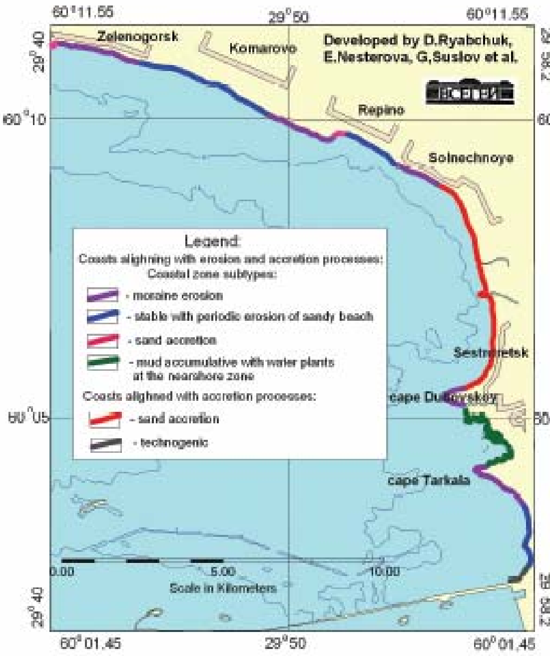


Fig. 2. Map of the coastal zone subtypes distribution (Kurortny District, northern coastal zone of the Gulf of Finland).

waves sand beaches are washed out there. The coastal slope profile is characterized by a well developed longshore sand bars at the boulder-pebble bench surface (Fig. 4).

Within the areas of sand accretion which are situated to the east of Solnechnoye village, where coastal line changes its direction from longitudinal to latitudinal – sandy beach is as wide as 100 m. In the near-shore zone both sand ridges and runnels between them are formed by fine grained sand (Fig. 5).

The measurements of the coastal slope depths have shown that the bathymetry profiles in the near-coastal zone are very much changeable and depend on hydrometeorological factors. The bathymetric profiles of the down part of the coastal slope (3–10 m water depth) are much more stable.

For submarine part of the coastal zone the main features of the sea-bottom relief and distribution of the bottom sediments were recognized, and detailed sea-bed map (scale 1:50 000) of studied area was developed. The coarse-grained sediments (boulders, pebbles, sands with gravel) are spread in the areas of submarine erosion of glacial till. It is possible to distinguish five different types of sands formed by modern erosion and accumulative processes caused by wave and current activity, and some relict sandy forms. Modern silty-clay mud is accumulated within the sea depths more than 10 m (Fig. 6). Study of the modern silty-clay mud accumulation zone has shown that the modern mud thickness has not been increasing in investigated area during the last 10-15 years. In the marginal zones of mud accumulative area modern sediments thickness has not changed, in the central part

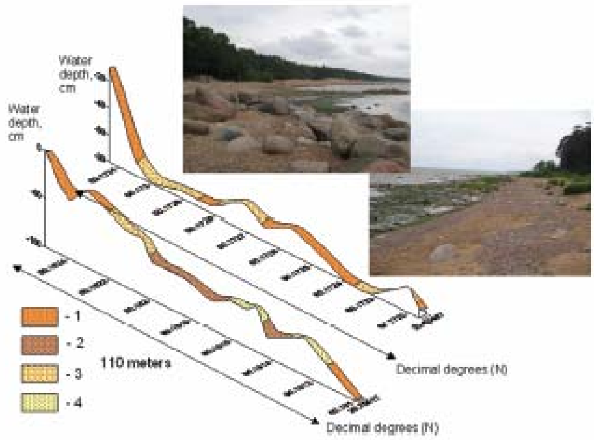


Fig. 3. Near-shore profile of erosion zone. 1 – boulders, pebbles, gravel; 2 – sands with boulders; 3 – glacial till; 4 – fine-grained sand. Photo by D. Ryabchuk, 2006.

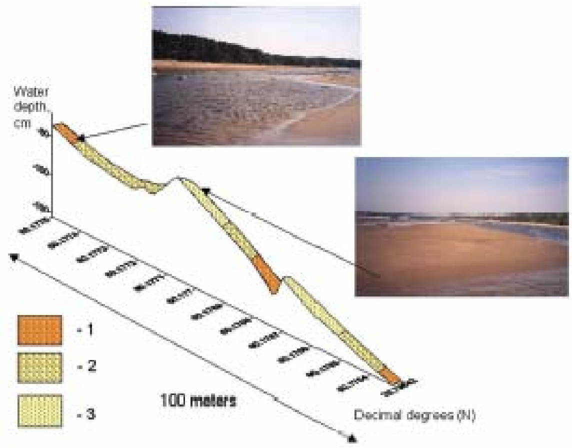


Fig. 4. Near-shore profile of transitional zone. 1 – boulders, pebbles, gravel; 2 – sands with boulders; 3 - fine-grained sand. Photo by D. Ryabchuk, 2005.

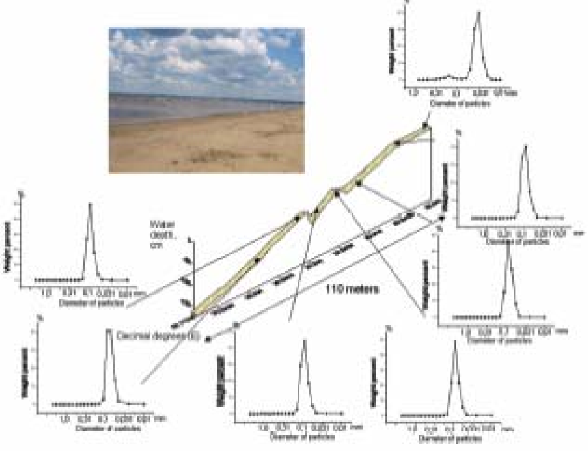


Fig. 5. Near-shore profile of accretion zone. Photo b D. Ryabchuk, 2006.

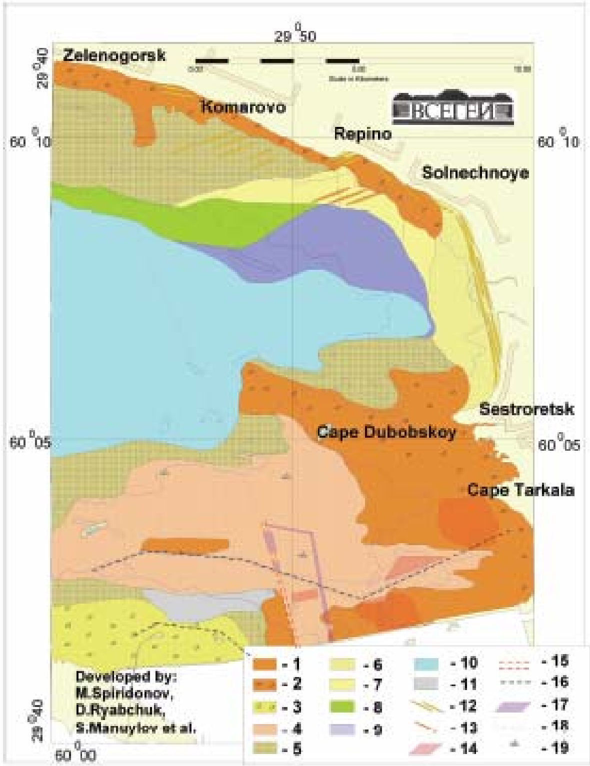


Fig. 6. Map of the bottom sediments (near-shore of the Kurortny District). 1 – sands with gravel; 2 – sands with gravel and boulders; 3 – sands with boulders; 4 – unsorted sands, mainly coarse grained; 5 – coarse to medium sands; 6 – medium to fine sands; 7 – fine sands; 8 – silty sands; 9 –clayey silts; 10 – silty-clay mud; 11 – technogenic sediments (dumping place); 12 – sand ridges; 13 – erosion valleys; 14 – technogenically transformed relief; 15 – fairways; 16 – crib-bars; 17 – areas of high accumulation; 18 – crib-bars, covered with sediments; 19 – sunken vessels.

of sedimentation basin the silty clay mud thickness has decreased during last 15 years and in some sediment cores the sandy layers have been observed. These facts allow to suppose weak erosion processes within this area. Modern sediment cores indicate a frequent changing of both sedimentological and geochemical environments.

Side-scan sonar data analysis permits to distinguish some important features of the bottom structure such as glacial till ridges, dynamic sands (with ripples on the surface) zones; sand waves, erosion margins (valleys), as well as technogenic relief and objects (Fig. 7).

The bottom surface in front of the coastal line turn (Solnechnoye village – cape Dubovskoy) (Fig. 1) has a very complicated structure. There are series of the glacial till ridges elongated from SW to NE. These ridges are interpreted as an ice margin forms (Figs. 7, 8). The till ridges location adjusts with the conception of the regional deglaciation (Raukas & Hyvarinen 1992; Usikova et al.1963; Usikova et al.1967).

In front of the Solnechnoye village a very shallow near-shore terrace covered by fine-grained well sorted sands of accretion zone (Fig. 5) is 500-600 m wide. In seaward direction the sea depth sharply increases up to 5 m (Fig. 8). The coastal line extend changing causes

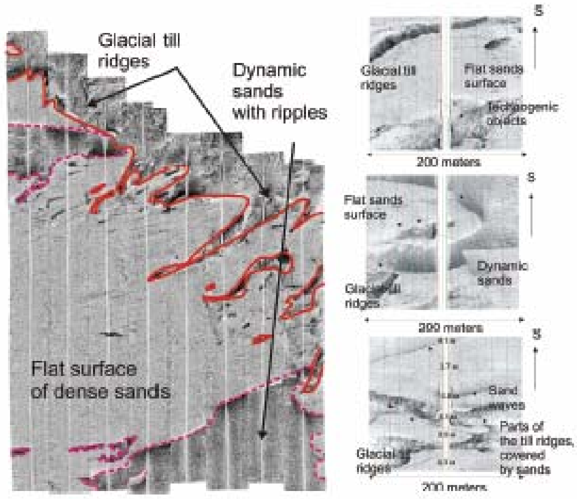


Fig. 7. Side-scan mosaic and fragments of sonograms (in front of Solnechnoye village).

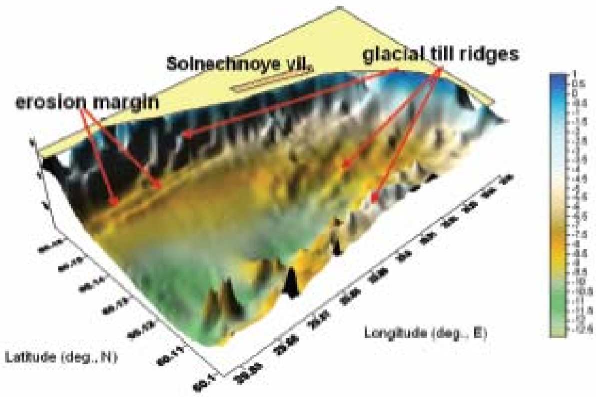


Fig. 8. Diagram of the bottom surface relief (in front of Solnechnoye village).

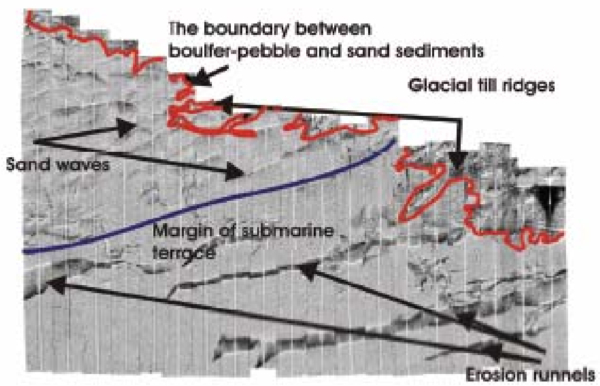


Fig. 9. Side-scan mosaic of the near-shore bottom in front of Repino and Komarovo villages (with erosion runnels, sand waves on the surface of the submarine terrace and boulder-pebble and sand sediments boundary).

the longshore sand drift discharge here, but because of near-shore bottom structure a large amount of sand material moves to the terrace foot, where the sands of

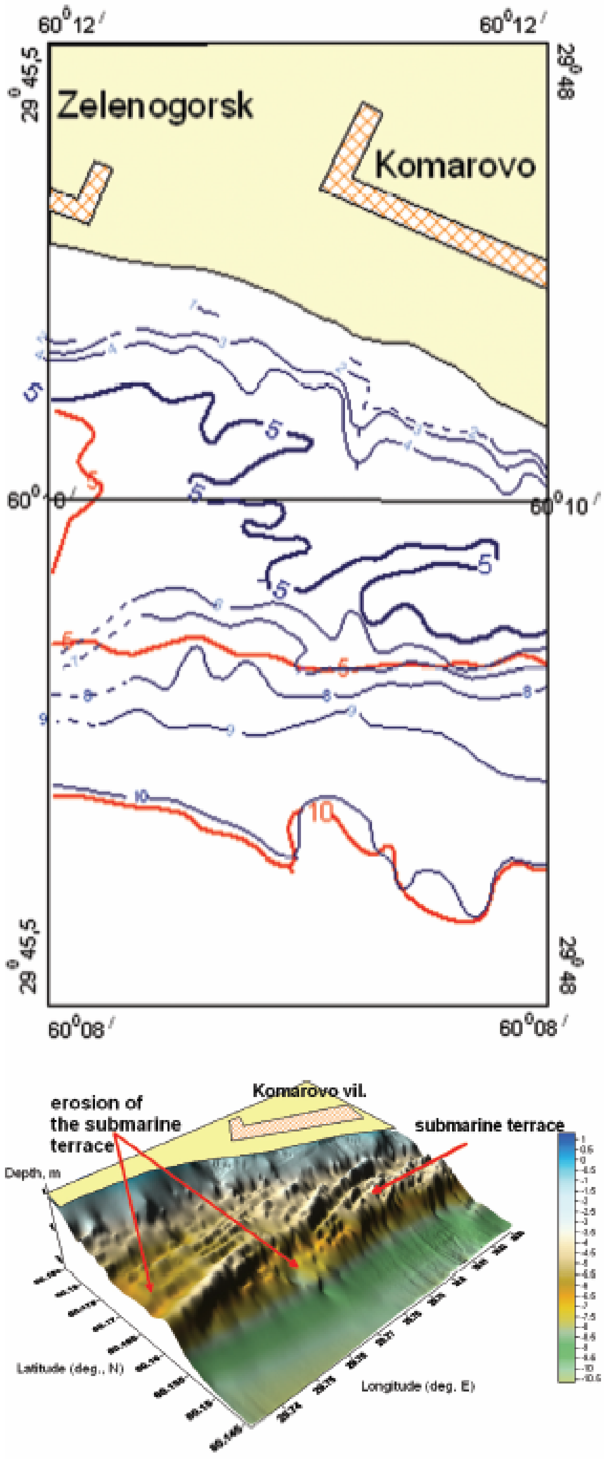


Fig. 10. Changing of the sea depths in the near-shore area as a result of the submarine terrace erosion. Red lines – isobaths of the navigational chart edited in 1989, blue lines – results of the sea depth measurements made by VSEGEI in 2005. Diagram of the bottom surface relief (in front of Komarovo village).

the same grain-size parameters can be observed (Fig. 6). The vibro-coring have shown more than 1.5 m of sand thickness. These data allow to suppose a long-term character of revealed processes.

In the next segment of the coastal zone (in front of Repino village) on the slope surface erosion runnels (troughs) (up to 30-50 cm deep) have been observed during investigations in 2005 at the depth 4 to 8 m (Ryabchuk et al. 2006) (Fig.9). Repeated survey fulfilled in 2006 has shown that these forms are very stable in spite of small relative depths. During the 2006 survey erosion runnels were traced along all coastal line. In the western part of the area they located at the sea depths from 10 to 12 m.On the surface of erosion runnels there are very distinct ripples perpendicularly orientated to the margin direction. These runnels can possible be the ways of water back-wash after extreme storms and water run-ups.

On the coastal slope in front of Zelenogorsk and Komarovo villages the system of sand ridges (sand waves) and runnels within the sea depth from 3 to 5 m was traced (Fig. 9). An important feature of sand waves is their elongation with the angle of 40-50 degrees to the coastal line in contrast to the longshore bars located in first 200-500 m from the shore. Alongshore bar system is very good visible at the satellite pictures. New data analysis permits to establish that sand waves are situated on the submarine terrace surface which locates at the sea depths about 4 m (Fig. 10).The terrace is up to 2.5 km wide and 17 km long, its foot is located at the sea depths of 8-9 meters. It is formed by medium- to coarse grained sand.

DISCUSSION

During the 2005 investigations the considerable sea depth deepening was discovered in the part of the coastal slope opposite Komarovo village (Fig. 10). Now we can conclude that the marine edge of the terrace is washing up. According to the location of the 5-m isobath, which marks terrace edge, this process has a natural origin of long duration. On the other hand underwater sand mining which took place to the west of investigated area in 1969-1992 can be supposed as one of the possible reasons of this process intensification. About 140-160 million m^3 of sand were excavated from this area. The sand were mined within the submarine terrace of Litorina Sea situated at the sea depth 6-12 meters, but because of the violation of technology the sands of nearshore zone were affected as well (Moskalenko et al. 2004).

The question of the submarine terrace age and genesis are not clear yet. It should be mentioned that the Pleistocene and Holocene ancient coastal line location on the mainland of the northern coast of the Gulf is well known (Auslender et al. 2002) as well as submarine ancient coastal line positions for many regions of the Baltic Sea (Boldyrev & Blazhchishin 1982; Uscinowicz 2003). In the same time such investigations have not been done for the shorelines existed during the Holocene regressions in the eastern Gulf of Finland.

According to the modern conception (Dolotov et al. 2001) such big accumulative bodies can be formed during slow relative decreasing of the sea water level

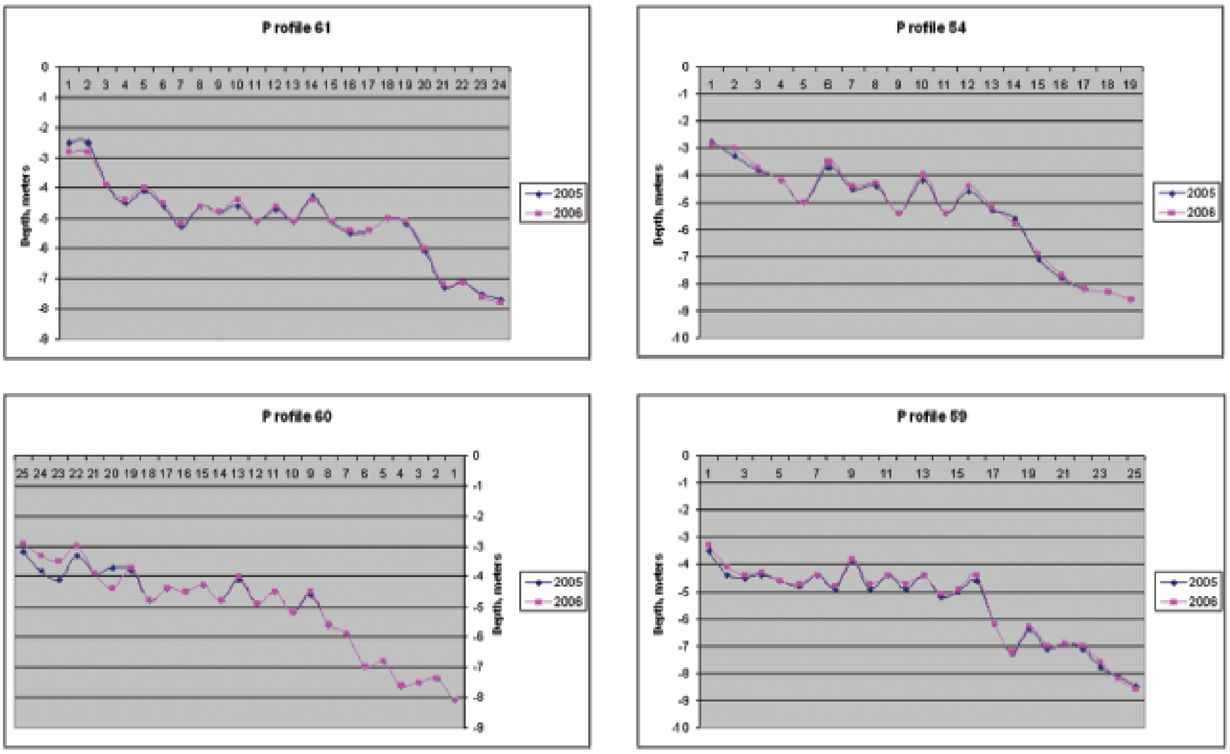


Fig. 11. Samples of repeated profiles in the sand wave zone.

and uninterrupted sedimentation with enough sand material quantity on the smooth coastal slope. It should be mentioned that to the west of investigated area (between capes Flotsky and Peschany) there is another submarine terrace with the surface situated at the sea depths of 8-12 m. During pre-exploration works with the sand prospect drilling made here by VSEGEI in 1982 and 1992, the hypothesis of the terrace formation during early Holocene sea regression was advanced. Unfortunately, there were no enough geological data for such a preposition. Besides, the terrace can be partly washed out during subsequent sea level rising.

The other possible assumption of the submarine terrace formation in front of Zelenogorsk–Komarovo village is corresponded to V.Zenkovitch (1962) scheme. In accordance with it the sand accumulative body is usually formed near the marine edge of the bench during erosion processes. In such a case the mentioned terrace could be formed during the maximum of Litorina transgression when the sea level was about 6 m higher, so the water depth above the terrace surface was about 10 m (Auslender et al.2002). The cliffs up to 40 m high were worked out at that time in glacio-fluvial sandy relief forms. But both hypotheses do not explain the sand ridges formation which are not parallel to neither modern nor ancient shorelines. Repeated survey has shown (Fig. 11) that sand waves are rather stable. So it is possible to assume their dynamic equilibrium and inconformity to the modern hydro-dynamics processes.

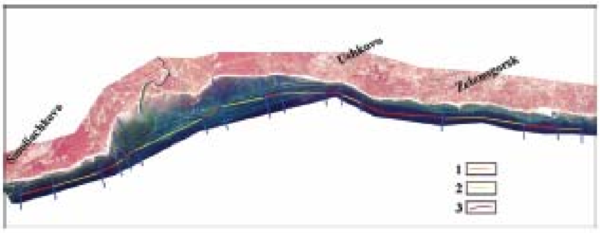
Long-term dynamics of coasts of the eastern Gulf of Finland has been studied by NIIKAM on the basis of analysis of historical materials, archive aerial photographs and modern high-resolution satellite images. From comparative analysis of large-scale aerial photographs for 1990 and high-resolution space images Quick Bird for 2005 the alteration of sites of coasts with retreating and stable coastal types has been revealed (Fig. 12). There are practically no accretive coast types – excluding small river deltas.

The comparison of the modern situation with earlier archive images from 1959 and 1982 showed that the distribution of retreat and stable coastal types have not changed, as well as the configuration of the alongshore sand ridges and sand accretion bodies formedby filling re-entrant angles to the west of the natural or anthropogenic barriers.

These facts prove the long term period of stability of the character and tendencies of the coastal-forming processes and the existence of permanent alongshore flow of sediments, oriented from west to east. The rate of shoreline retreating, as revealed from images analysis, is rather insignificant – the average value is about 0.5 m/year, maximal – up to 2 m/year (at the beach of settlement Solnechnoye).

But from the point of view of high recreation value of the beaches – it can be dangerous in any case. One of the important results of conducted investigations is the conclusion that the system of constructions for coastal protection is not effective and continuously destroying by waves.

The autumn storms rework even the widest beaches (100-140 m) in Solnechnoye and Zelenogorsk. Progressive washing up of the dunes along the Protected Natural Area in Komarovo is the most hazardous process (Pogrebov & Sagitov 2006).



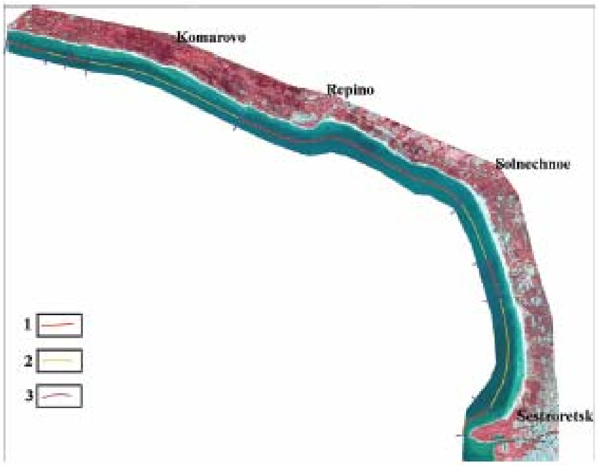


Fig. 12. Coastal zone dynamics of Kurortny District of St. Petersburg revealed from analysis of the large-scale aerial photographs from 1990 and satellite Quick Bird images from 2005 (for areas Smolyachkovo–Zelenogorsk and Zelenogorsk–Sestroretsk).

The most intensive beaches destruction was observed in Komarovo village after the storm and flooding in 11 of January, 2007. In contrast to the eastern part of the investigated coastal zone, there was no ice here yet. In such a case the ice could protect beaches against the washing up.

The beaches conditions are very threatened and the destruction of the submarine terrace margin – which can intensify the processes – is hazardous for the coast.

CONCLUSIONS

Within the investigated part of the coastal zone of the gulf from Zelenogorsk to Solnechnoye village which is characterized by latitudinal coastal line extension the erosion processes dominate. The deposits at the shore and coastal slope of the capes are represented by boulders and pebbles as a result of glacial till erosion. At the relatively straight parts of the coast in the area of Komarovo and Repino villages erosion of sandy beaches occurs. The sediment drift in the form of underwater sandy ridges has an eastern direction.

In the area of Solnechnoye village the coast line turns to the south that forms conditions favourable for sand accumulation at the coast and coastal slope. But sandy accretion and beach growing does not occur due to narrow (500-600 m width) shallow near-shore terrace. The main part of incoming sediments follows to the terrace foot.

On the coastal slope in front of Zelenogorsk and Komarovo village the terrace (2.5-km wide and 17-km long) is located.The bottom relief of terrace is characterized by the system of sand ridges (sand waves) within the sea depth from 3 to 5 m. Repeated survey has shown their stability. Taking into account their orientation it is possible to assume their inconformity to the modern hydro dynamics processes. Seaward margin of terrace is actively eroded. At the foot of terrace at the sea depths from 8 to 12 m the erosion runnels were traced. The runnels are served as the ways of water back-wash and sediment outflow after extreme storms and water run-ups.

The series of the ridges, which were interpreted as ice margin forms, were fixed in front of the coastal line turn (Solnechnoye village – cape Dubovskoy).

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