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Sandy deposits study offshore Lithuania, SE Baltic Sea

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Abstract The growing demand of sand needed for beach nourishment works and limitations concerning land-won aggregates has initiated the offshore exploration of the sand deposits in Lithuania. The first attempt to extract the sandy aggregates in Lithuanian marine zone was performed in 2008. Taking into account the several stages of the Baltic Sea development, the former coastal formations are the potential sand sources. Using the complex of modern geophysical–geological methods such as side scan sonar, multi–beam echo sounder, sub–bottom profiler; supported by the results of geological investigations such as vibro–coring and Van Veen sampling, the exploration of the offshore marine aggregates became the auspicious research priority in the Lithuania. Two offshore sites—Būtingė in the northern part and Juodkrantė–Preila in the southern part of Lithuanian marine zone have been investigated for the potential sand sources. According to the preliminary paleogeographic interpretation based on the relevant literature and occasional direct findings the relicts of the former shore line formation (Būtingė area) and sandy bars (Juodkrantė-Preila area) of Litorina Sea transgression–regression stage have been identified and seems to be promising sand resources for the future beach nourishment works.

Keywords *Baltic Sea, relict sandy deposits, marine aggregates, beach nourishment, vibro–coring, seismo–acoustic profiling.*

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INTRODUCTION

Importance of marine sand and gravel aggregates as a mineral resource has increased in the EU during recent years. More than 45 million m^3 of sand and gravel are extracted annually from the northern European continental shelf alone (ICES 2005). The production is bound to increase further to supply the material needed for the construction of the planned projects of coastal infrastructure (Mesdag, Schuttenhelm 2000; Phua *et al*. 2004; Van Dalfsen 2004), and the replenishment of the eroding European beaches (Selby, Ooms 1996; Humphreys *et al*. 1996; Eurosion 2003). Many countries around the Baltic Sea treat the marine sand and gravel aggregates as an important source of the mineral material needed for the beach nourishment and replenishment works (Harff *et al.* 2004). Lithuania is still not in the list of those. Recently, in 2008, the first dredging activities in order to extract the available sand aggregates have been initiated. The growing coastal erosion and related demand of sand needed for beach nourishment works as well as environmental limitations while using land-won aggregates forces to look for the relevant resources offshore.

The origin of the SE Baltic marine sand and gravel deposits is related to the glacigenic sedimentary processes of Late Quaternary and later re–sedimentation of those. Modern re–sedimentation is the consequence of climatic and sea level changes during Holocene (Gudelis 1976; Punning 1982; Blazhchishin 1984, 1998a; Björck 1995; Kabailienė 1999). Sediments of periglacial river systems, terraces, point bars and fans as well as drowned beaches and barrier islands are the main sources of sand (Bitinas, Damušytė 2004; Blazhchishin 1998b; Lukoševičius, Gudelis 1974). Especially the latest mentioned drowned beaches and barrier islands are of the particular interest, as they are characterised by relatively well sorting and resistance to abrasion, which makes them ideal for beach replenishment (Bates *et al.* 1997). Therefore, sediments preliminary recognized as old shoreline formation (in Būtingė area on the Klaipėda–Ventspils plateau) and relicts of the drowned sandy bar of Litorina Sea transgression–regression stage (Juodkrantė–Preila area on the Curonian–Sambian plateau) have been chosen for further investigations and evaluation of potential sand resources. The main purpose of the studies carried out was the potential sand aggregates exploration and, if relevant, identification of suitable places of sand excavation. The detail paleogegraphic and/or sedimentation reconstruction of chosen formations was not possible due to the insufficient accuracy of chosen equipment settings (e.g. lower vertical resolution of seismic devices, low penetration of drilling), determined by specific (sand extraction oriented) objectives of the study.

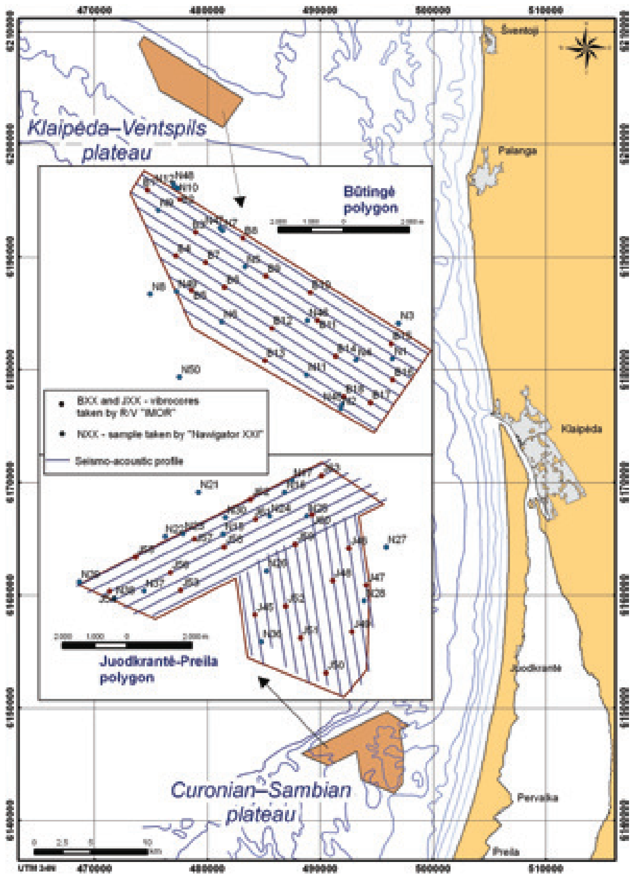

Fig. 1. Study sites. Compiled by N. Blažauskas, 2008.

MATERIAL AND METHODS

Būtingė site, covering the area of ~ 42 km^2, is located on the slope of south–eastern part of Klaipėda–Ventspils plateau. Juodkrantė–Preila site, occupying the area of ~ 55 km^2, is situated on the slope of north–eastern part of Curonian–Sambian plateau (Fig. 1). Two research campaigns (in 2005–2006) on Polish research vessels "Nawigator XXI" and R/V "IMOR" have been organized in these two areas. The geological–geophysical investigations of the sea floor at the sea depths of 19–48 m have been carried out. The geological structure of sea bottom and sediments composition was investigated using vibro–coring and sediment sampling (using Van Veen grab sampler). Totally, 52 samples of the surface sediments (0–10 cm of uppermost layer) were taken (15 in Būtingė and 37 in Juodkrantė–Preila site). Additionally, 39 vibro–cores of maximum length of 3.3 m (20 in Būtingė and 19 in Juodkrantė–Preila site) were picked up.

The geophysical investigations have been carried out in 30 profiles (10 in Būtingė and 20 in Juodkrantė–Preila site). Detail sea bottom bathymetry was achieved using RESON multi–beam echo sounder (working at frequency of 455 kHz). Also examination of the sea floor sub–bottom structure (up to 5–10 m below the surface) was made using seismo-acoustic sub–bottom profiler OreTech 3010S (working at frequencies of 3.5–14 kHz) and the "acoustic shadow" based sea floor photography was made after hydro-acoustic side–scan sonar imagery survey using EdgeTech DF 1000 sonar (working in dual frequency 100 kHz and 500 kHz). Grain–size composition of bottom sediments was determined by laboratory sieving method. Eighteen fractions (ranging from >2.5 mm to <0.05 mm) were distinguished. Type of sediments was determined according to the median diameter (Md) and the range of prevailing particle size (using the decimal classification system). Simultaneously, some of sand samples were examined in order to reveal their mineralogical composition.

RESULTS OF GEOLOGICAL AND GEOPHYSICAL INVESTIGATIONS

The results of sea bottom morphology studies (prepared after multi–beam echo sounder data), examples of sea floor morphology modelling, identification and distribution of distinguished litho-complexes (according to side scan sonar mosaic and lab analysis of sediment samples), the results achieved while modelling the geological structure of the sub-bottom, spatial correlation of the distinguished litho-complexes (using sub–bottom profiling records and core material), quality and volume of the sand resources are presented in this chapter.

JUODKRANTĖ–PREILA SITE

Two underwater hilly structures (bars?) surrounded by the relatively flat area have been detected after compiled sea floor morphology model (Fig. 2). Two 4–5 m high hills extending to the south-northern and south-western-north-eastern directions have been identified.

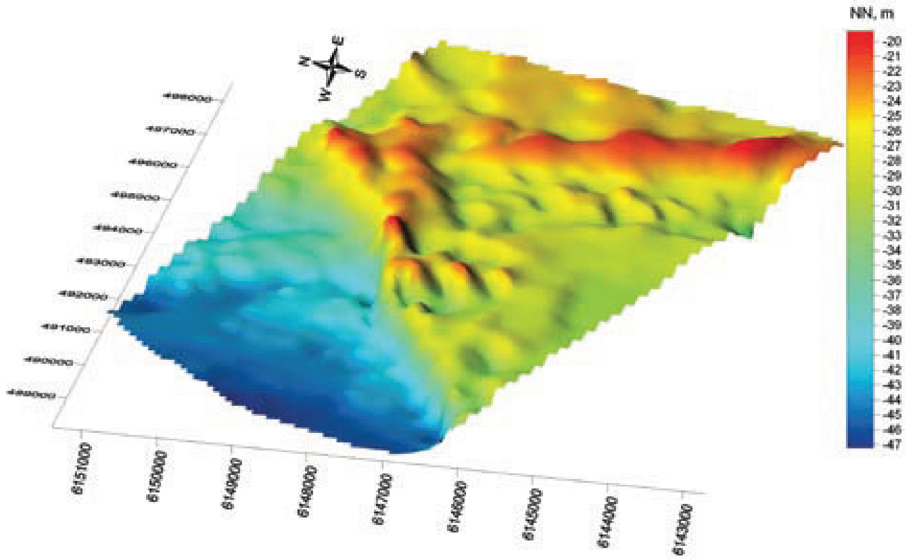

Fig. 2. Sea floor elevation model of the Juodkrantė – Preila polygon. Compiled by N. Blažauskas, 2008.

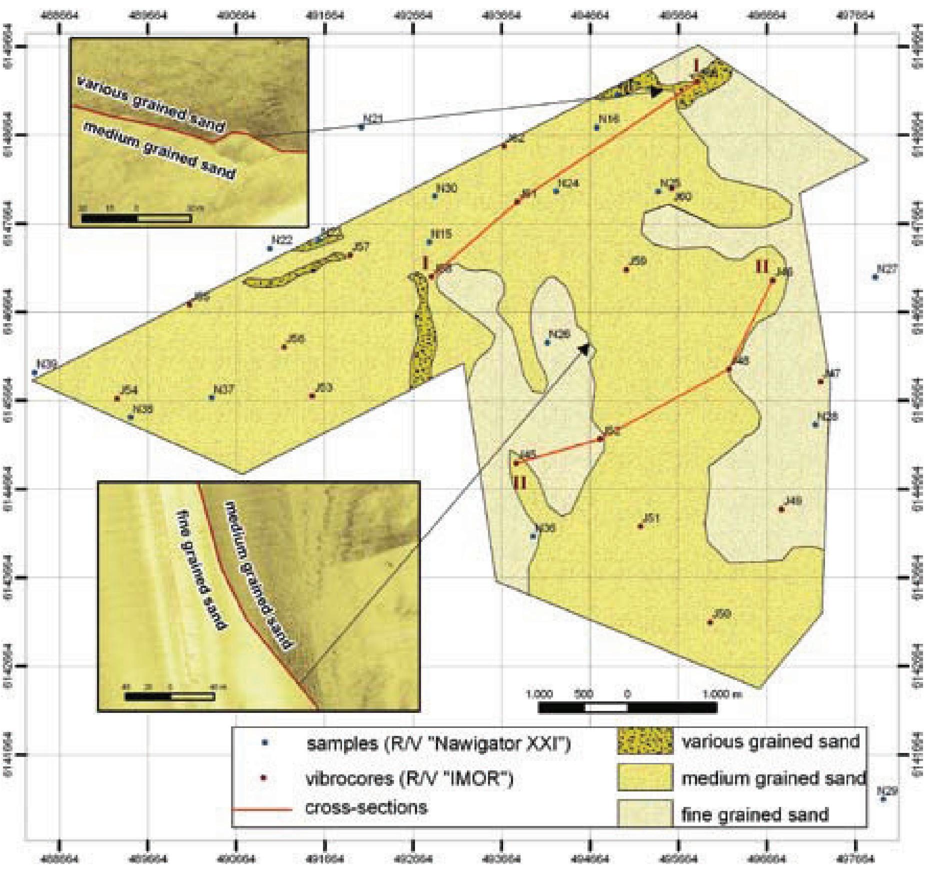

Fig. 3. Sediment distribution in the Juodkrantė–Preila polygon. Compiled by N. Blažauskas, 2008.

The certain difference of the surface structure has been recognized in the acoustic picture of these morphological features (Fig. 3). Deeper part of the research area—the flats are characterised by smoother acoustic picture usually determined by monotonous fine grained sediments, while acoustic signal reflection from the bars surface is more intensive and gives quite rough acoustic picture, due to coarser material and visible ripple marks of small and medium scale. The differences between the particular parts of the acoustic picture are determined by the lithological variations of the bottom sediments mainly. This was later on confirmed by geological sampling and grain size distribution analysis.

Three main litho-complexes were distinguished in the area after lab analysis of the collected sediment samples (Fig. 3). The deeper part of the area is represented by well sorted ($S_o < 1.3$) grey and yellowish grey fine grained sand. According to the grain size analysis of samples of stations J47 and J 49, the amount of the sand particles of 0.16-0.25 mm diameter is 44–45 %). This is a prevailing type of bottom surface sediments also composing the underwater slope of the Curonian spit. The second litho-complex is composed of light yellowish, often greyish yellow, well sorted (S_o 1.2–1.6), mainly homogeneous medium grained sand with relicts of fine shells (*Macoma baltica*, in rarer cases *Cardium edule, Mya arenaria*). The prevailing diameter of the sand grains is 0.25-0.4 mm. The average percentage of medium grained sand analysed in most of the stations (J50, J51, J53, J54, J55, J59, J60) is 32-50 %. The distribution of these sediments almost precisely outlines the contour of the sandy bars. The third litho-complex is represented by coarse grained sand (Md 0.59–0.67 mm; S_o 1.3–1.7) locally situated in the small bottom areas at the depths of 20–28 m. This is light yellow and brownish tint or grey sand, which contains different portions of shells or shell detritus. The results of grain size distribution of the surface sediments shows that fine and medium grained fractions predominate in the sand. The highest amount (>50 %) of fine grained sediments (0.1–0.25 mm) are present near shore in the southern part of the region at the depth of 20–25 m and in the northern part at the depth of 35–40 m. The highest amount of medium grained sediments (0.25–0.5 mm) was detected in the central part of the region—composing the sandy bars. The highest concentration of coarse grained sand (0.5–1.0 mm) was observed locally in the northern part of hilly bottom zone. Amount of silt material (particle size 0.1–0.01 mm) in the surface sediments is quite small.

The main task of the sea bottom deep structure investigations was recognition of quality and quantity of sandy sediments potentially suitable for beach nourishment. This has determined the methods and settings (vertical resolution and penetration) of the chosen equipment. Most of the seismo–acoustic profiles showed quite monotonous internal structure of the sub-bottom sediments—almost no distinct stratification, no strong reflections pointing to substantial changes in lithology (at least down to the maximum penetration of seismo acoustic signal). Only in few seismo–acoustic profiles and two vibro–cores (J46 and J52) the bottom of the upper most layer has been reached.

The uppermost layer (0–10 cm) identified in section J46 is composed of recent yellowish fine grained sand (29% of particles with diameter of 0.315–0.25 mm; 26.5 % of 0.315–0.4 mm diameter) with small content off marine shells. Down to the 277 cm the lamination of fine sand (with small admixture of coarse grained silt) of changing colour (yellowish grey to dark grey) and different amount of marine mollusc shells was observed. The clear change in lithological sequence was identified at the 277 cm depth—the 22 cm thick layer of grey coloured dense silt passing to bellow laying brownish black gyttja was assumed to be the bottom boundary of above deposited (10–277 cm interval) sandy sediments complex. The

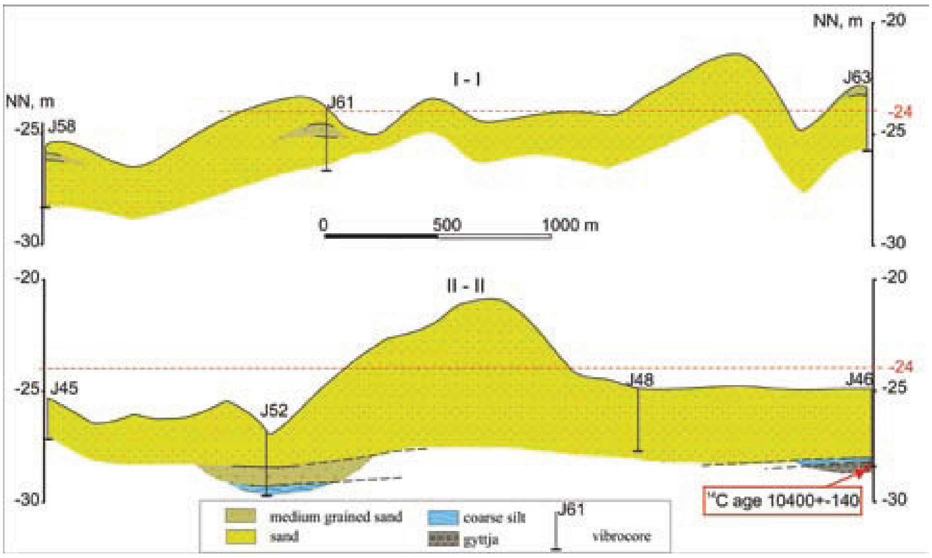

Fig. 4. Geological cross-sections of Juodkrantė–Preila polygon (sections location on Fig. 3). Compiled by N. Blažauskas and D. Michelevičius, 2008.

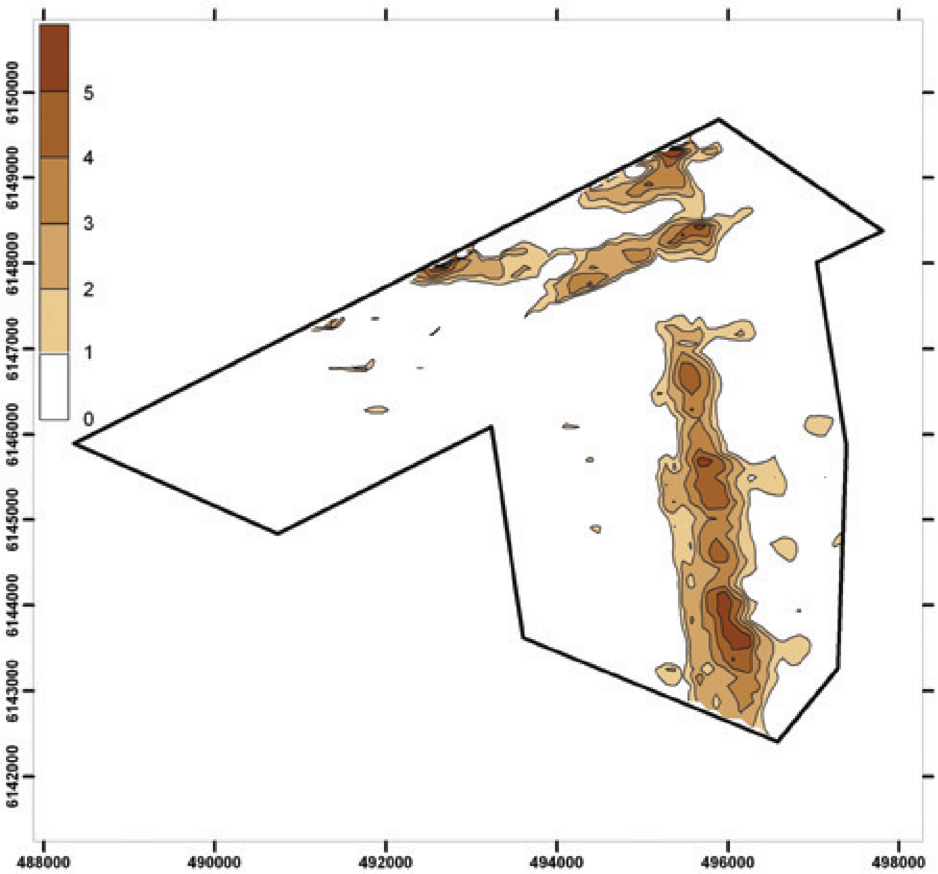

Fig. 5. Thickness of sandy sediments in Juodkrantė–Preila polygon. Compiled by N. Blažauskas and D. Michelevičius, 2008.

similar boundary of various grained sandy sediments complex and silt was identified in section J52 at the 280cm depth

The strong reflections in seismo–acoustic records allowed tracing the spatial extension of identified layers while vibro–cores give the understanding of lithological composition. Thus we have recognized the upper most part of the sequence as heterogeneous sandy (inter-layering of fine, medium and various grained sand) sediments down to the depth of 5–10 m below the bottom surface (depending on penetration of seismo–acoustic device). The chosen seismic method did not allow identifying minor variations of sandy sediment composition determined in the cores by visual description and further confirmed by analytical results. The deeper architecture of the sea bottom and correlation (lateral and vertical) of the distinguished litho-complexes made according to the results of seismo–acoustic data interpretation and ground trouthing using vibro–cores data description is presented in Fig. 4.

According to the applied methodology, developed in order to evaluate the suitability of the "borrowed" sand in terms of grain size distribution (Krumbein, James 1965), recommendable mean diameter (Md) of the sand used for the beach nourishment works in Lithuania, shouldn't be finnier than 0.25 mm. The performed investigations suggest that the most relevant sand resources are concentrated in the above mentioned sandy bars. The bars are composed of more than 3 m thick, almost monotonous and homogeneous, layer of medium grained sand. The Md parameter of the sand varies from 0.23 to 0.46 mm, yet sand grains with diameter smaller than 0.25 mm are very rare and occur only in thin intervals. Additionally, as required by the methodology described by James (1975), the sorting index of the "borrowed sand" was evaluated. Result: sorting index S_o index is quite good (relevant) and equals to 1.2–1.6. The mineral composition of the sand is quite uniform. Quartz is the main constituent and reaches 94–96%. The feldspars amount in few percents (4–5%), while garnets, hornblende and magnetite–ilmenite dominate among the heavy minerals.

Evaluating the morphological conditions of the area, composition of the sediments and distribution of the most suitable sand, the sandy bars were recommended for the further sand extraction works (Fig. 5). As the bottom boundary of the sandy body was not completely (in all sections and seismo–acoustic recordings) revealed using both remote (sub-bottom profiling) and geological (vibro–coring) methods, the 0 ("bottom") level for volumetric calculations of the sand deposit was considered to be at the level of 24^{th} isobath (Fig. 4). It was calculated that in the two main areas above the 24^{th} isobath (5.04 and 2.6 km^2) is possible to excavate respectively 7.97 and 3.61 million m^3 of sand.

Būtingė site

Būtingė area is characterized by eroded, unevenly ridged surface (Fig. 6), gradually deepening in the NE direction (down to 30 m depth). This ridge was the main target for the sand deposits exploration. The complex surface of the research area was scanned using acoustic side scan sonar. The different parts of sea floor image have been distinguished after the acoustic mosaic compilation and interpretation. Zones of high intensity reflection and rough structure were identified as glacigenic diamicton sediments, located in the NW part of the polygon.

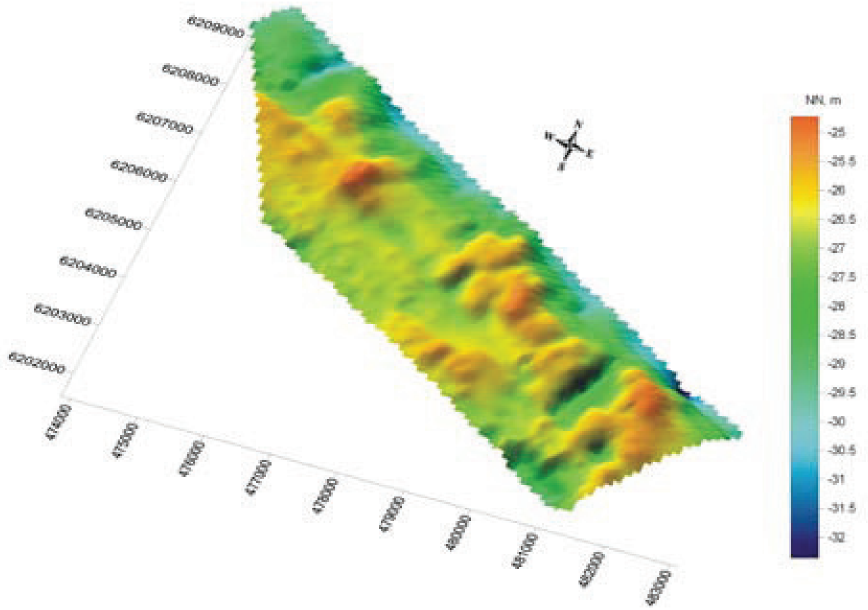

Fig. 6. Sea floor elevation model of the Būtingė polygon. Compiled by N. Blažauskas, 2008.

These were also recognized using geological sampling of the area (Fig. 7). Loam of brown colour, gravel and boulders of the Last Glaciation, were recognized in sites N6 and N49 as well as in vibro–cores B4 and B5. The main part of the research area is covered by fine and medium grained sand (10–19% of 0.5-1 mm; 35–63% of 0.5–0.25 mm and 13–40% of 0.25–0.1 mm diameter particles), giving the smoothest picture in the acoustic photograph of the sea floor surface. The medium grained (Md 0.26–0.41 mm), well sorted

(So 1.3) sand is situated in the central part of the area at the depths of 26–27 m while fine grained (Md 0.17–0.25 mm, So 1.2) sand is present in the deeper parts of the investigated site. The third distinguished litho-complex is represented by mixture of various grained sand, gravel and pebbles, moderate to very poorly sorted (So 1.6–2.3).

Performed interpretation of seismo–acoustic profiling has revealed the deeper architecture of the sea floor structure (Fig. 8). It is clear that the sandy sediments are deposited on the eroded till surface (loam). Due to the slight NE directed inclination of till surface the loam has not been often reached while vibro–coring. Even though, remotely detected (records of sub bottom profiling) lower boundary of the sand layer has facilitated the volumetric calculations of the amount of promising sand resources.

The general thickness of the sand sediments is 1–2 m, maximum value do not exceed 4 m (Fig. 9). Taking into account the general aim of the investigations, e.g. exploration of potential sand resources, only the medium grained sand (Md 0.2–0.4, So 1.3) meeting the quality requirements addressed to the "borrowed" sand for Lithuanian beach nourishment works have been evaluated. The mineral composition of the sand is quite uniform. Quartz is the main constituent and reaches 93.2–96%. The feldspars amount in small percentage (~4%), while garnets, hornblende and magnetite–ilmenite prevail among the heavy minerals. Assuming that after potential exploration of the sand deposit the thickness of the left in situ sand layer shouldn't be less than 0.5 m, the volume of the sand resources has been preliminary calculated. The final conclusion—in the area of about 10 km^2 around 15 million m^3 of sand can be excavated.

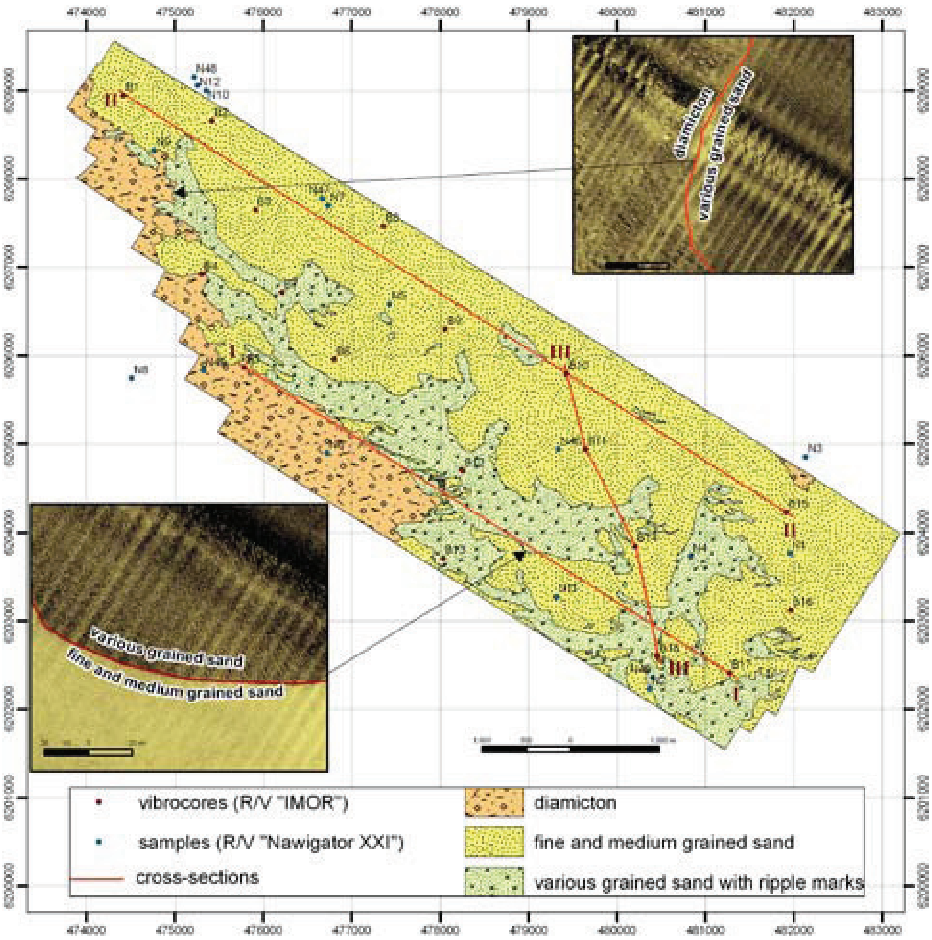

Fig. 7. Sediment distribution in the Būtingė polygon. Compiled by N. Blažauskas, 2008.

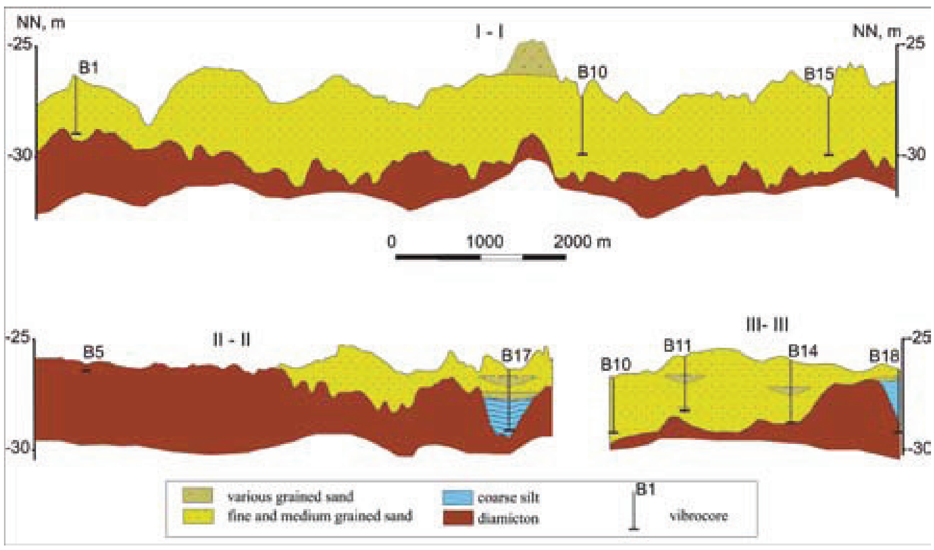

Fig. 8. Geological cross-sections of Būtingė polygon (sections location on Fig. 7). Compiled by N. Blažauskas and D. Michelevičius, 2008.

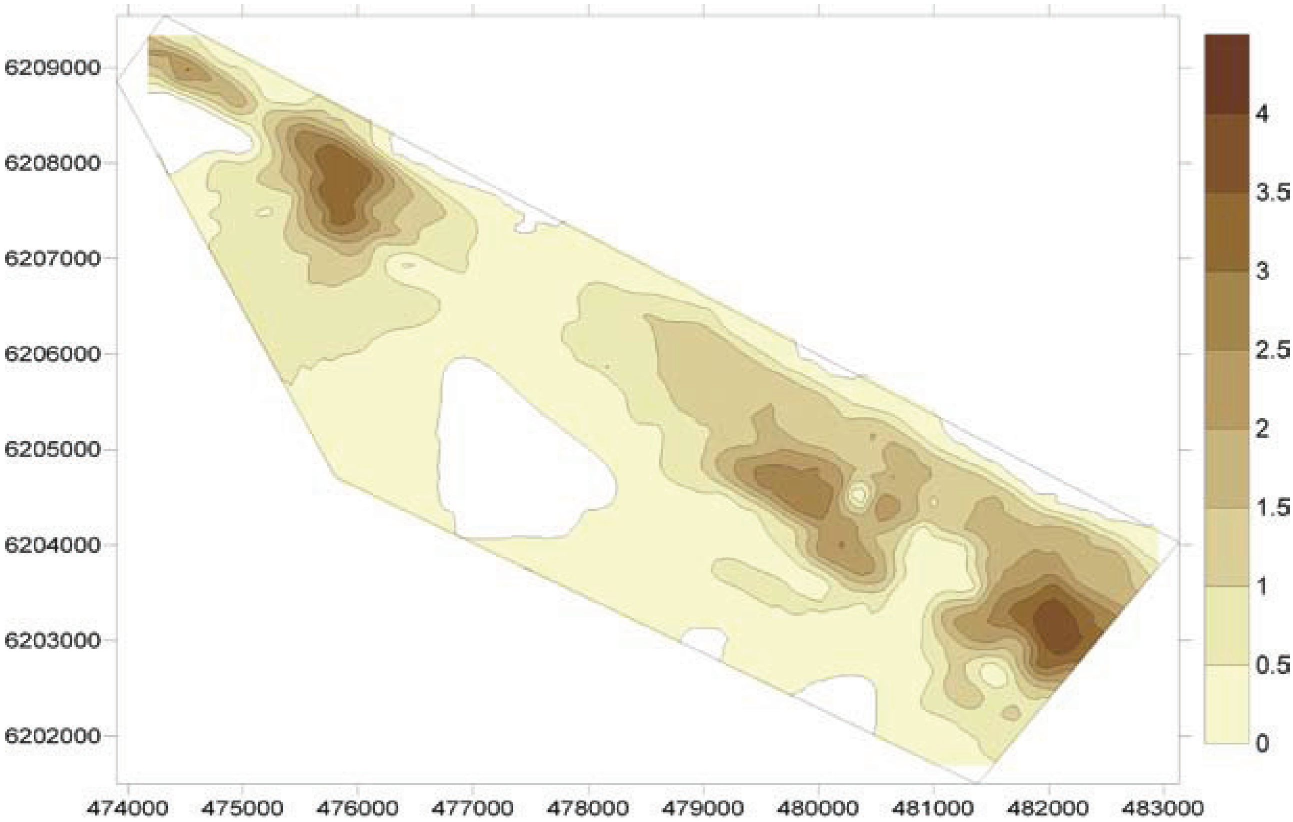

Fig. 9. Thickness of sandy sediments in the Būtingė polygon. Compiled by N. Blažauskas and D. Michelevičius, 2008.

DISCUSSION

It seems that palaeographic conditions for exploration of potential offshore sand deposits, if properly applied and reconstructed, could be very promising approach for the South Eastern Baltic marine aggregates. Theoretically, the relicts of former coastal formations fit the best the quality requirements for the recent beach nourishment works. There are known several stages of Baltic Sea development (Gudelis 1976, 1998; Blazhchishin 1984, 1998a; Eronen 1988; Kabailienė 1999). The maximums of transgressions and regressions were determined based on the seismic and age determination data (Gelumbauskaitė, Šečkus 2005): Baltic Ice Lake maximal transgression refers to +6 m NN, Yoldia maximal transgression to –55.5 m, Ancylus maximal transgression to –5.5 m, Ancylus regression to –46.5 m, Litorina L_1 transgression to 26.5 m, L_2 maximal to +5.0 m, L_3 and PostLitorina to +2.0 m of recent water level. These levels are reflected as abrasion or abrasion–accumulation terraces bounded by cliffs and troughs of the underwater slope. There are certain geological, geophysical and geomorphologic evidences that during the Late Postglacial and beginning of the Holocene (Yoldia–Ancylus stages) part of the underwater slope in the SE Baltic was above the present sea level (Lukoševičius, Gudelis 1974; Blazhchishin 1998b). This has directly affected (surface erosion) the morphology of the morainic ridge in the Būtingė polygon. Such situation could last until the first stage of Litorina transgression. The shore line relicts of this transgression have been identified at the depths of 28–30m.

It was already known that large sand massifs on the surface of the western part of Curonian–Sambian plateau and central and southern parts of the Curonian spit are related to transgression–regression cycles. It is assumed that submerged beach developed during the Ancylus regression and first phase of the Litorina transgression 8–7 thousand years ago (Blazhchishin *et al*. 1982). The same origin of the bars in Juodkrantė-Preila area can by suspected. Especially when silt and brownish black gyttja found in section J46 (sea depth 24.8 m) have been dated. The ^{14}C age of coarse silt layer containing gyttja (277–322 cm) is 10400±140 years BP. These are the oldest observed sediments in the central part of the study area. It probably means that overlying sand layers could be accumulated only after the end of the Baltic Ice Lake stage.

The evidences of the fluctuations of the sea water level are also well visible in the Būtingė area. According to the above mentioned levels of transgressions and regressions of Baltic Sea development, the research area was above the water level during the Ancylus transgression. This was also confirmed by the sedimentary pattern observed in the core (site B12) and identified diatoms of fresh water (Ancylus Lake?). The frequent interlayering of the various grained sand, gravel and pebbles (vibro–cores B7, B6, B12) can by related with the intensive erosion of the glacigenic deposits (till) under the low water conditions close to the existed shore zone. Therefore, in order to find the most relevant sand deposits it is expedient to get acquainted with the paleogeographic history of the sea during the mentioned period.

Many countries are considering the beach nourishment as an effective and environmentally friendly tool. The environmental impact, especially in the sand, needed for these activities, extraction sites, is one of the main issues. In order to ensure that exploration of the marine sand in the Juodkrantė-Preila polygon will not cause considerable negative effect, especially on the sensitive near shore zone of Curonian spit, the comission led by prof. A. Grigelis, the chairman of Geosciences section of Lithuanian Academy of Science, was established by Government of Republic of Lithuania. By the decision of the Commission (dated 2007-06-12) concerning the sand extraction from the offshore deposit and beach nourishment was positive, stating that neither negative effect on environment nor sediment dynamics on the near shore zone will be made.

On the other hand, marine sand amount in the open sea is several times bigger than available onshore. According to the information concerning land born sand and gravel resources certified by Lithuanian Geological Survey, there are 5 working and 12 explored sand deposits in the coastal zone with total available amount of about 13.7 million m^3. In comparison, only in these two sites the total volume of the explored sand is more than 25 million m^3.

CONCLUSIONS

According to the numerous geophysical and geological investigations carried out during last decade, the beginning of the sandy deposits formation in the SE Baltic could be identified with the Ancylus Lake stage. The sandy deposits in the SE Baltic do not compose the huge continuous bodies, i.e. are locally situated and structures particular morphological features.

In the case of Būtingė, the 2-3 m thick fine and medium grained sandy layer is situated on the slope of glacigenic ridge at the depths of 26-30 m. The amount of the suitable for beach nourishment medium grained sand is calculated to be around 15 million m^3.

The extraction of the sandy bars of the Juodkrantė-Preila area could give additionally 11.6 million m^3. The average thickness of the sand varies from 1-2 m in Būtingė to 3-4 m in Juodkrantė-Preila polygons. It is obvious that using the up-to-date geophysical-geological methods in the relatively small marine areas quite huge amount of the sand can be found.

Acknowledgements

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