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# The Curonian Lagoon bottom sediments in the Lithuanian water area

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Distribution and composition of the Curonian Lagoon (Kuršių Marios) bottom sediments in the Lithuanian water area are analysed on the basis of geological mapping data from more than 750 sites. A new map of bottom sediments was compiled. It differs from previously published ones in greater detail, more accurate localization of sediment types and in some other elements. Surficial bottom sediments of the Curonian Lagoon are heterogeneous. Clastic (clastogenic) sediments are intensively accumulating now and participate in formation of the surficial bottom layer almost in the whole lagoon. The main types are: medium sand, fine sand, coarse silt and fine silty mud. Biogenic sediments are represented by mollusc shells and peat. Shell detritus as a conspicuous constituent is included in the composition of other types of sediments. Glacigenic sediments are represented by boulders, pebbles, gravel and till outcrops resulting from the erosional activity of currents.

*Bottom sediments, grain–size, sand, silt, mud, distribution, shell deposits.*

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## INTRODUCTION

The Curonian Lagoon (Kuršių Marios) is one of the biggest lagoons (1584 km$^2$ area) of the Baltic Sea separated from it by a narrow (0.5–4 km) sand bar. A 12 km long and 0.4–1.5 km wide straits make its only link with the sea. Such geographical situation predetermines the character of sedimentation in the lagoon. Nemunas River is the main source of sediments with annual output making up 600–700 thousand t. (Pustelnikovas 1998). The sedimentary matter distribution in the comparatively shallow lagoon (the average depth is 3.8 m) is also greatly dependent on the Nemunas water stream which exceeds the water volume of the lagoon itself by about 3.6 times (Repečka *et al*. 1980, Gailiušis et al. 1996). About 3.2 mm sediments deposited annually in the zones of mud accumulation (Pustelnikovas 1998). The composition of mud is predetermined by the type of sediment input and its differentiaton due to water dynamics in the basin.

Recent accumulation processes and the main features of the sedimentary environment have been investigated in many studies (Gelumbauskaitė 2002, Gudelis 1955, 1958, 1998, Gulbinskas 1994–1995, Jokšas *et al.* 1998, Kabailienė 1967, 1997, Kunskas 1978, Pustelnikovas 1997, 1998, Pustelnikovas, Gulbinskas 2002, Repečka *et al*. 1980, etc.). Some maps of the Curonian Lagoon bottom sediments are available. They represent information about bottom sediment types is obtained in different time slices of the last century (Pratje 1931, Gudelis 1959, Gulbinskas 1994–1995, Galkus, Jokšas 1997, Pustelnikovas 1998).

A very small depth, an active water dynamics and intensive sedimentation in the lagoon generate considerable changes in sediment distribution patterns during rather short time spans. Therefore, the previously published maps differ from each other and don't reflect the actual situation. It should be emphasized that the previously published maps were based on insufficiently accurate methods applied for geographical location of sampling sites. Owing to this the spatial distribution boundaries of sediment types do not always coincide with the actual situation. In order to avoid the influence of these factors the production of a new, more accurate sediment map had to be preceded by more detailed mapping surveys.

## METHODS

The data for the map of the Curonian Lagoon bottom sediments were collected in 1998–1999 within a framework of the Baltic Sea geological mapping programme (scale 1:50 000) ordered by the Lithuanian Geological Survey (programme supervisor Prof. A.Grigelis).

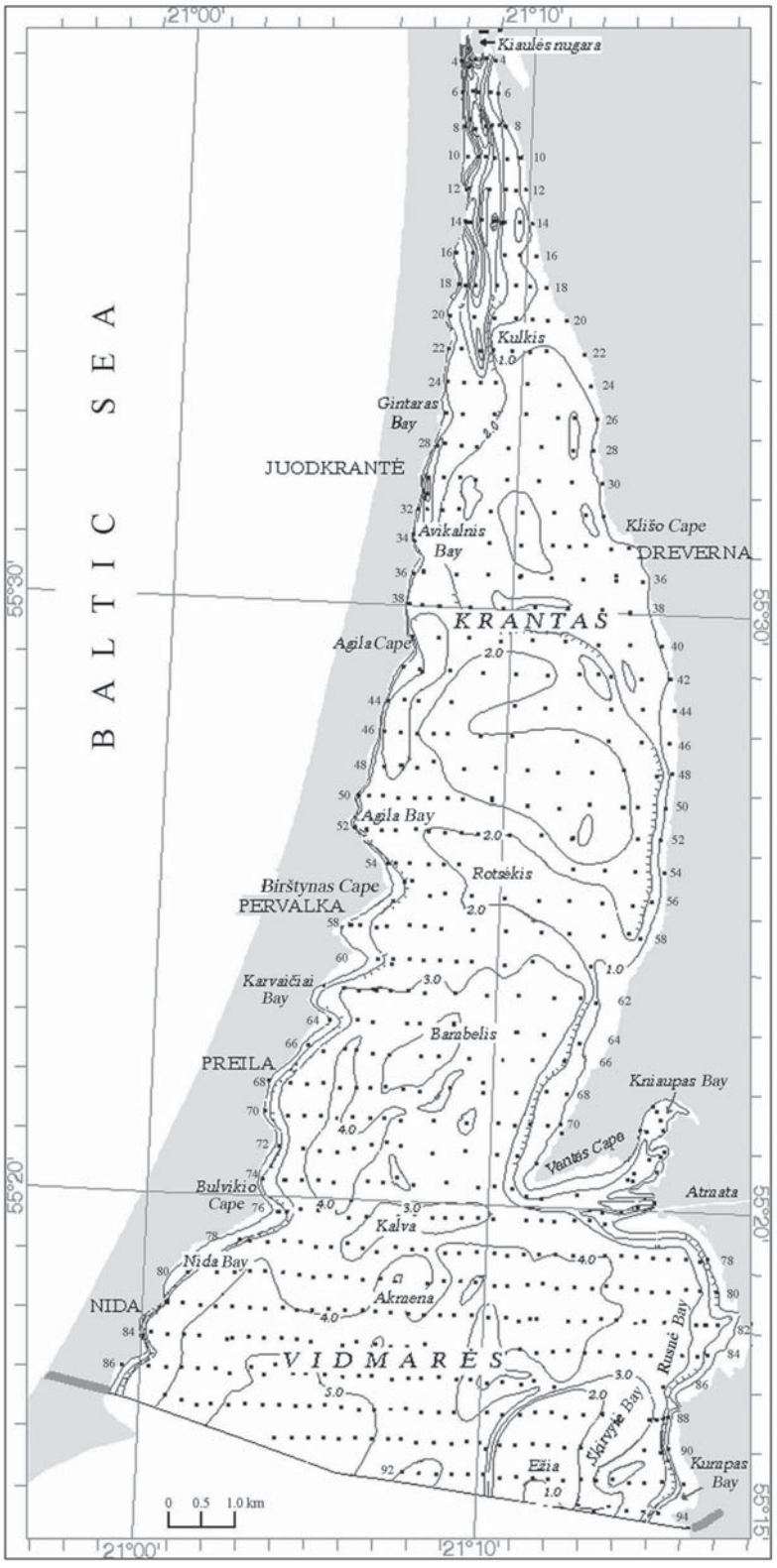


Fig. 1. Location of sites for geological mapping.

The mapping survey included 410 km$^2$ Lithuanian water area of the Curonian Lagoon. Bottom sediment samples were taken from more than 750 sites (Fig. 1). The geographical coordinates of the sites were determined by GPS. A new map was compiled using the results of grain–size analysis of the collected samples. Bathymetric data and names of the bottom relief forms of the Curonian Lagoon were taken from published works (Gelumbauskaitė 2002, Gulbinskas, Žaromskis 2002).

The types of bottom sediments were distinguished on the basis of the decimal granulometric classification system according to the dominant fraction and median diameter (Md) of particles (Bezrukov, Lisitzin 1960). The latter is the decisive index for the naming of the sediment types (Table 1). Often two or three fractions are quantitatively comparable with the main, i.e. dominant, fraction. When these fractions (not dominant) make up more than 30%, the sediment subtypes may be distinguished. This helps to reveal local differences of sediment composition.

## RESULTS AND DISCUSSION

### Distribution patterns of sediment types

According to this investigation actually almost the whole bottom of the Curonian Lagoon is covered by recent sediments. The relict glacigenic sediments occur only locally. They are exposed as small fields of boulders with pebbles and gravel accumulations overgrown by mollusc colonies (Fig. 2). Earlier such outcrops were found on the Akmena and Kalva banks and other bottom elevations in the Curonian Lagoon (Gulbinskas 1994–1995). During this survey boulders, pebbles and gravel were found on the slope of the Akmena Bank at a depth of 4.8 m (Fig. 3), southwest of the Ventė Cape – at a depth of 2.3 m and shallower.

Table 1. Grain–size classification of clastic bottom sediments.

| Type of sediment | Median diameter (Md), mm | Prevalent fraction | Name of prevalent fraction |
|---|---|---|---|
| Boulders | 1000–100 | | |
| Pebbles | 100–10 | | |
| Gravel | 10–1 | | |
| Coarse sand | 1–0.5 | 1–0.5 | coarse sand |
| Medium sand | 0.5–0.25 | 0.5–0.25 | medium sand |
| Fine sand | 0.25–0.1 | 0.25–0.1 | fine sand |
| Coarse silt | 0.1–0.05 | 0.1–0.05 | coarse silt |
| Fine silty mud | 0.05–0.01 | 0.05–0.01 | fine silt |

A deficiency of recent clastogenic sediments was recorded in the shallow eastern nearshore areas of the lagoon where fine sand in the bottom surface south of the Klišas Cape is locally interrupted by small areas of peat sapropel and peat at a depth of 1.1–1.7 m. Here the aquatic landscape of the Curonian Lagoon merges into a coastal raised bog landscape (Žaromskis 1989–1990). In deeper lagoon areas (2.2 m) such peat bed is covered by a sand layer of about 10–14 cm thickness (sites in the eastern part of Profile 46, Fig. 1).

Bottom areas covered with bio- or tanatocoenoses predominated by *Dreissena polymorpha* were distinguished. Shell deposits (more than 50% of mollusc shells and their detritus) are mostly found in the Vidmarės – the middle part of the lagoon: they occupy greater areas at a depth of 3–4 m whereas slightly deeper (4.5–5.1 m) such areas are smaller (Fig. 3). Shell deposits are mostly up to 20–30 cm thick and have almost no terrigenous grains (Fig. 4). The transition from shell deposits to adjoing fine sand or silty mud is varying – from consecutive with a gradually increasing portion of sand and silt to a rather abrupt and very pronounced one. On account of this it is possible to distinguish areas of sandy or silty shell deposits.

Sandy shell deposits were traced at a depth of 2.1–3.3 m on the slope of the Bambelis Elevation, which in its main part is covered by fine sand and also at the Vidmarės bottom. An area of sandy shell deposits was detected in a hollow southeast of Nida (deeper than 5 m).

Fig. 2. Pebble from site 80/15, depth 4.8 m.

Silty shell deposits were found in the eastern part of the Vidmarės where an area of shelly bottom extends south–westward from the Ventė Cape. The same sediment type occupies small areas in the Nemunas aqual delta and on the bottom surface close to the Ežia Shallow at a depth of 2.8 m.

The greatest part of the Curonian Lagoon bottom is covered by recent clastogenic sediments: medium sand, fine sand, coarse silt and fine silty mud (Fig. 3).

Medium sand occupies a large area in the northernmost part of the lagoon where at a depth of 1–4.2 m a sand belt more than 5 km in length and 500–700 m in width extends southward from Kiaulės Nugara isle along the central part of the lagoon. Some larger areas of medium sand are situated only in the western part of the lagoon where in some places they are almost directly linked with the sand dunes of the Curonian Spit (Kuršių Nerija) – the main source of sand. Areas of medium sand accumulation are arranged in an almost continuous belt south of the Agila Bay. The sand actually is accumulated between the coastline and the steep foreshore slope at a depth of approximately 2–2.4 m. In some places (the Nida Bbay) it goes down slightly deeper – to 3.7 m.

Medium sand occupies small bottom areas in the western nearshore area of the lagoon south of the Agila Cape, in the Vidmarės (Ežia Shallow, Akmena Bank) at a depth 1.3–4.6 m and in front of the Atmata mouth (Fig.3).

The greatest part of the bottom in the northern part of the Curonian Lagoon is covered by fine sand. It forms the background to smaller areas of other sediment types. In the western nearshore part of the lagoon fine sand is separated from the coast by a belt of medium sand or silty sediments whereas in the eastern nearshore region fine sand approaches the dynamic coastline. Fine sand accumulation is not limited by the lagoon's depth. A relatively smaller area is occupied by fine sand in the Vidmarės however even there it represents the main type of recent sediments.

Coarse silt is distributed on the bottom surface following two patterns – in areas of irregular size or in belts, which separate fine silty mud from sand sediments. The largest areas of coarse silt are found in the eastern part of the Vidmarės. One of them is extending from the Rusnė Bay till the depth of 4.8 m. This area has a complicated form. Parts of it are covered by fine sand and shell deposits. The second area is situated between the steep slope of the Kumpas Bay and the Ežia Shallow at a depth of 2.1–4.2 m. Besides, coarse silt occupies a greater part of the Kniaupas Bay at a depth of 1.4–2.2 m. In the western part of the Vidmarės coarse silt accumulates in the deepest hollow – at a depth of 5.2–5.8 m. Small bottom areas with coarse silts are particularly situated in the western nearshore part of the lagoon.

Three large areas with fine silty muds were distinguished in the western part of the lagoon. These

areas are separated from sands by narrow belts of coarse silt sediments. The mentioned areas are: the nearshore region north of the Agila Bay, the lagoon slope between Karvaičiai Bay and Bulvikis Cape and the southwestern region in the Vidmarės in front of Nida (Fig. 3). Fine silty mud is accumulating in these areas at a depth of 2–3.9 m, 3–4.5 m and 3.3–5.7 m, respectively. Many small areas where recent fine silty mud is accumulating abound at a depth of 1.3–5.4 m in the Vidmarės and in the western part south of the Avikalnis bay.

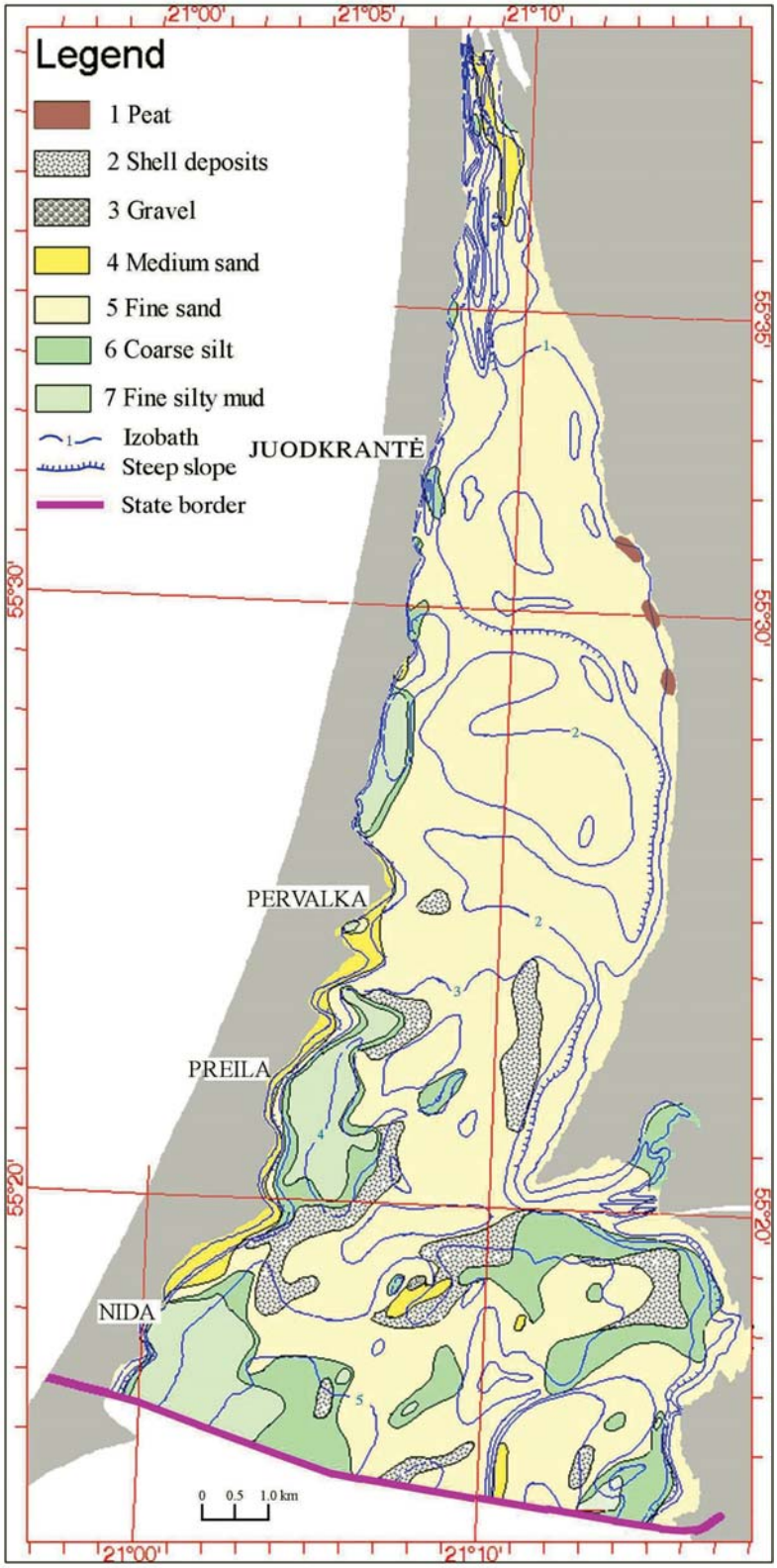


Fig. 3. The Curonian Lagoon bottom sediments. 1– peat, 2– shell deposits, 3– gravel, 4– medium sand, 5– fine sand, 6– coarse silt, 7– fine silty mud.

## Composition of bottom sediments

According to grain–size composition the clastogenic sediments in the lagoon belong to four main types: medium sand, fine sand, coarse silt and fine silty mud.

The quartz medium sand is greenish grey, grey to yellowish, yellow and even brownish. Sand fractions (1–0.1 mm) make up 97.8% of the average sediment composition. The dominant fraction is medium sand (0.25–0.5 mm) – 58.97% (Table 2). Because the portion of gravel and silt–clay particles is very small the medium sand is best sorted – $S_o$ is 1.28. Sediment sorting or standard deviation was calculated using graphic method formula (Trask 1930). According to the mineral composition the medium sand nearshore the Curonian Spit has more heavy minerals than the sand of the blown dunes and distinctly differs from the medium sand which is accumulating in the Nemunas aqual delta, i.e. in the southeastern part of the investigated area (Gulbinskas 1994–1995). From the point of view of granulometric composition the medium sand in different parts of the lagoon also varies.

The medium sand of the northern part of the lagoon (south of the Kiaulės Nugara isle) is worse sorted (1.32) than the average value because this part of the lagoon has a relatively small portion of the main medium sand (only 48%) and comparatively greater portions of other sand fractions (coarse sand – 9.45% and fine sand – 37.63%). This part even comprises of gravel (2.68%) and more than elsewhere

Fig. 4. Shells *Dreissena polymorpha* from site 82/29, depth 3.8 m.

silty–clayey fractions – 2.23%. The median diameter of the sand is 0.29 mm.

The medium sand fraction is obviously the dominant one (66.88%) and is considerably higher than the average value of the lagoon sediments (Table 2) in the medium sands nearshore the Curonian Spit – the largest area of medium sands. This fraction is followed by fine sand fraction (28.45%), whereas the total of sand fractions is 98.97%, thus implying a good differentiation of sand from other particles (actually from silt and clay because grains coarser than sand are absent). The Md of medium sand is 0.31 mm, whereas the sorting ($S_o$) is 1.28.

The medium sand in front of the Atmata mouth in the subaquaeous part of the Nemunas delta is relatively finer than nearshore the Curonian Spit. The Md of sediments is 0.29 mm because coarse sand grains are almost absent (only 0.48%), whereas the portion of fine sand is relatively higher (37.34%) with a decreasing amount of the main medium sand fraction (60.5%). The sorting of the sand is good – 1.27. The granulometric composition of medium sand accumulating in the Ežia Shallow is comparable to the latter one. The yellowish quartz sand there is slightly finer (Md is 0.26 mm) whereas the sorting is better (1.13). Presumably this is accounted for by a stronger impact of wave differentiation because the sand in this area is deposited at a depth of 1.3–1.7 m, whereas at the Atmata area medium sand is accumulating deeper – down to a depth of 4.4 m.

The medium sand exposed in a small area in the central part of the Vidmarės (Akmena Bank) differs conspicuously in terms of its granulometric composition. The Md of the sand is the greatest one – 0.4 mm, because the portion of the coarse sand fraction is high (34.67%) and the portion of medium sand is only 39.72%. The fine sand fraction makes up 23.93%, silt – 1.68%, whereas clay particles and gravel are absent. The sorting is much worse (1.61) compared to the average value (Table 2). This kind of granulometric spectrum implies that the sediment sources and factors predetermining their accumulation are considerably different from the ones, which predetermine the recent medium sand accumulation in the lagoon. Presumably, the medium sand at the bottom surface is associated with relict pebble–gravel and till deposits found in the adjacent areas. Clay particles are absent what implies the redistribution processes to be rather active at this depth (3.6–4.2 m).

Thus, the differences of the granulometric composition of medium sand in the mentioned bottom areas are caused by recent sedimentation conditions and existing more than one source of sedimentary matter.

The quartz fine sand is from yellowish, greenish or grey to brighter yellow or brownish. South of the Birštvynas Cape latitude, i.e. where the amount of shells at the bottom surface is greater, in the Vidmarės particularly, the sand colour is considerably darker – from dark grey to even black. The sum of all sand fractions in the fine sand is smaller (93.57%) than in the medium sand, whereas the dominant fine sand fraction makes up 76.37% (Table 2). The fine sand is well sorted – the average sorting value is 1.296.

The main sources of sand – the Curonian Spit and the Nemunas drift – predetermine the grain–size of sediments in almost the whole bottom surface of the lagoon. In the western nearshore area, where the sand of blown dunes is accumulating, the fine sand is most often separated from the coastline by a belt of medium

Table 2. Average grain-size composition of most important bottom sediment types in the Lithuanian part of the Curonian Lagoon.

| Sediment type | Number of samples | Depth, m | Fraction, mm | | | | | | | | | Md, mm | So |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Aver. Limits | >1 1-0.5 | 0.5- | 0.25 0.25- | 0.1 0.1- | 0.05 0.05- | 0.01 0.01- | 0.005 0.005- | 0.001 | <0.001 | | |
| Medium sand | 33 | 2.0 0-7.6 | 0.81 | 6.07 | 58.97 | 32.76 | 0.84 | 0.3 | 0.03 | 0.06 | 0.01 | 0.301 | 1.28 |
| Fine sand | 424 | 2.7 0.6-6.4 | 0.12 | 4.06 | 12.76 | 76.37 | 4.44 | 1.64 | 0.26 | 0.19 | 0.14 | 0.184 | 1.30 |
| Coarse silt | 69 | 3.0 1.3-5.2 | 0.03 | 1.51 | 1.91 | 15.62 | 58.43 | 17.41 | 2.11 | 1.75 | 1.23 | 0.078 | 1.55 |
| Fine silty mud | 69 | 3.8 1.3-5.4 | 0.14 | 0.67 | 1.55 | 4.42 | 18.14 | 59.24 | 7.25 | 4.65 | 3.94 | 0.034 | 1.9 |

sand whereas the fine sand actually everywhere comes close to the shore in the eastern part of the lagoon. The Md of the fine sand is the same as the average of the lagoon (0.18 mm) in the subaqueous part of the Nemunas delta at a depth of 0.7–3.4 m. The portion of fine sand is slightly higher (79.83%) what accounts for a better sorting than the average (1.277).

North of the Ventė Cape in the nearshore area (depth 1–2.2 m) the Md of sediments remains the same (0.18 mm) but the portion of the fine sand fraction increases to 89.31% accounting for a considerably better sorting index (1.16). The same patterns of grain–size variations – relatively increasing fine sand fractions, decreasing Md and improvement of sediment sorting – can be followed up nearshore (at a depth of 0.6–2.1 m) till approximately the Kulkis elevation where the 2-m isobath abruptly moves away from the coastline.

The fine sand area in the northern part of the lagoon between the Kiaulės Nugara isle and the Gintaras Bay is divided into two parts by a belt of medium sand. The Md of fine sand is 0.2 mm in the eastern part of this area whereas it is 0.16 mm in the western one. This difference is related to a considerably greater portion of coarse and medium sands and a smaller portion of silts and clays in the eastern part of the lagoon. The portion of the fine sand fraction in the eastern part is smaller than the average value in the lagoon (70.43%).

The granulometric composition of fine sand in different morphological bottom areas is also variable. The Vidmarės and Bambelis stand out for the smallest portion of the fine sand fraction – 67.59% and 65.75% respectively. The fine sand in the Vidmarės contains relatively greater amounts of coarser sand grains, however owing to a greater depth (3.2–5.1 m) and more active accumulation of silty and clayey particles the Md of the fine sand is 0.19 mm. It differs little from the sands accumulating in the subaqueous part of the Nemunas delta and the Skirvytė Bay. Yet the sorting of the sand of the Vidmarės is obviously worse ($S_o$ is 1.42).

According to its main indices the fine sand of the Bambelis is very similar to the fine sand of the Vidmarės, though the sorting of the sand is there even smaller ($S_o$ is 1.46) and the Md equals to 0.2 mm. The portion of the coarse sand fraction composed of shell detritus is relatively high (11.85% on average).

The Kalva Bank (depth is 2.2–3.3 m) between the Vidmarės and Bambelis is covered by fine sand, which Md is 0.2 mm. Its sorting index (1.18) is considerably better than in the adjacent bottom areas. The Md of the Ežia fine sand is 0.2 mm and the sorting – 1.23. Its granulometric composition differs from the Vidmarės sand in that it contains more fine sand fractions and from the Skirvytė Bay sand by considerably less silt and clay fractions and better sorting. These differences imply the influence of water dynamics on sedimentary matter differentiation depending on the depth.

The fine sand covering the Rotsėkis Elevation surface (depth 1.5–2.1 m) is distinguished for a high portion of fine sand fraction (90.37%), which is the greatest as in the adjacent eastern nearshore area. The Md is 0.18 mm, the sorting index $S_o$ is the best one – 1.15. The fine sand occupying the central part of the lagoon north of the Rotsėkis Elevation has a smaller portion of the fine sand fraction. Yet the Md is almost the same and the sorting is rather good.

Thus, the analysis of granulometric composition of fine sand revealed that its Md follows a regular pattern of increase moving away from the Nemunas delta and the eastern nearshore area approaching the middle part of the lagoon. The best-sorted sand occupies the Rotsėkis and the adjacent nearshore region, the worst sorted covers the Vidmarės and Bambelis, where sedimentary matter from the above mentioned two main sources is accumulating. Shell detritus plays an important role in the granulometric composition of sand.

The coarse silt is greyish green, in rarer cases – yellowish green. The main coarse silt fraction makes up to 58.43% on the average in this type of sediments. However this fraction usually is more abundant (up to 62–68% on average) in the largest occurrence areas of coarse silt – in the eastern part of the Vidmarės and the Kniaupas Bay. The sum of sand fractions in the silt makes up 19.04% on average, the portion of thin-dispersed particles (<0.05 mm) is slightly higher – 22.5% (Table 2). The Md of the sediments is 0.078 mm. In general the grain–size of coarse silt is rather variable: the Md ranges from 0.056 to 0.09 mm. This is predetermined by the position of this type of sediments among other types, especially when the coarse silt is an intermediate type. For example, the coarse silt in the hollow south of Juodkrantė is sandy and its Md is 0.09 mm.

The coarse silt occupying a large bottom area in the eastern part of the Vidmarės has a clearly dominant coarse silt fraction (62.09%). The Md is 0.078 mm, the sorting ($S_o$) is 1.48, i.e. the latter is slightly better than the average value for this type in the lagoon. A coarse silt of comparable composition is accumulating in the Kniaupas Bay (Md is 0.073 mm) and east of the Ežia Shallow closer to the shore. Its Md is 0.068 mm, whereas the sorting is the best for this type of sediments – $S_o$ is 1.39.

In a large area of the western part of the Vidmarės where coarse silt mud is distributed around the field of fine silty mud, widespread southeast from the Nida Cape, the coarse silt is characterized by a relatively small portion of the coarse silt fraction (54.8%) but a considerably greater portion of fine silt. The Md is 0.066 mm, the sorting $S_o$ is close to the average value – 1.58.

The fine silty mud is greenish grey almost everywhere, only sometimes – yellowish or yellowish grey (in the southwestern corner of the Vidmarės). The fine silt fraction makes up 59.24% on average in

this type of mud. The portion of finer material (<0.01 mm) is smaller than that of sand or coarse silt. The Md is 0.034 mm, the sorting 1.9 (Table 2).

The granulometric composition of fine silty mud is also rather variable especially there where this type of sediments occupies very small bottom areas. In large areas of fine silty mud its composition is more uniform though not always. North of the Agila Bay at a depth of 2–3.9 m the dominant fraction of fine silty mud (0.05–0.01 mm) accounts for less than the average value for the lagoon (58.16%) owing to a higher sum of sand and coarse silt fractions. The Md is 0.035 mm, the sorting – 2.036.

The mud occupying a large bottom area in the southwestern corner of the Vidmarės at a depth of 3.3–5.7 m has a clearly dominant fine silt fraction (63.88%). The Md is 0.031 mm, whereas the sorting is better than the average for this type of sediments – 1.79. A similar pattern may be observed in the depression east of Preila, where the fine silty mud distributed at a depth of 3–4,5 m has comparable values of the main indices. Moreover visually this greyish green mud is comparable in all investigated sites.

## CONCLUSIONS

The new map of the Curonian Lagoon bottom sediments is a considerably more accurate representation of localization and distribution patterns of genetic and lithological types of sediments and peculiarities of recent sedimentation conditions.

The formation of recent bottom sediments in the northern part of the lagoon is predetermined by the distribution of sedimentary matter from the main known sources – the Nemunas drift and the Curonian Spit and depends on the lagoon's water dynamics. The surficial bottom sediments of the Curonian Lagoon in the Lithuanian waters are of different genesis:

(a) clastogenic, which are intensively accumulating and participate in the formation of the surficial bottom sediment layer almost in the whole lagoon;

(b) biogenic, which are represented by mollusc shells and peat. Biogenic detritus as a conspicuous constituent (10–30%) is included in the composition of other sediments. When the portion of shells is 30–50% the subtypes of shell sand and shell coarse silt are distinguished;

(c) glacigenic, which are represented by pebble, gravel and local till outcrops exposed by nearbottom current action. The wind–wave impact may exist also (Chubarenko *et al*. 2002).

The most intensive recent accumulation is characterized by clastogenic sediments: medium and fine sand, coarse silt and fine silty mud. The larger part of the bottom is occupied by sand: in the western nearshore part of the lagoon the medium sand has accumulated as a result of eolian activity (from blown dunes) whereas the central and eastern parts are dominated by the Nemunas drift material – fine sand. The smallest Md of the fine sand is characteristic of the subaqueous part of the Nemunas delta and the eastern nearshore region. It is gradually increasing towards the central part of lagoon and is responsible for the formation of the subtypes of shell sand.

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