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FOREWORD

Herewith, on behalf of the Conference Committee, we have the pleasure to welcome all participants to the **Proceedings of the Fifth Marine Geological Conference "the Baltic".** The Conference was held on October 6-11, 1997 and was focused on current research in Marine Geoscience in the Baltic area. Traditionally, the Marine Geological Conferences—The Baltic—are arranged biyearly, since 1987. The previous conferences were held in Parainen, Rostock, Sopot, and Uppsala.

The Conference has continued to strengthen professional links between the researchers in marine geology in the Baltic Sea area. The goal of the Conference achieved was to present and discuss research results—increasingly growing during the last decade—to enrich the knowledge, and to stimulate future research as well as the international co-operation.

The Conference papers—talks or posters, submitted by authors, are compiled in these Conference Proceedings as the BALTICA Special Publication 12. Both oral and poster presentations have dealt with very broad aspects of bedrock geology, Quaternary, Holocene, sedimentology, coastal geology, geochemistry, new research technologies and geoinformatics. It seems, however, that the main focus was devoted to the recent Baltic Sea history; state of the art for its different basins; and prediction of future development, either harmful or beneficial for people and for the environment.

Many colleagues have helped in completing of the Proceedings, and in the Conference organisation as well. We are especially grateful for opinions received from paper reviewers. Sincere thank is expressed to the members of the Conference Committee and staff of the Department of Baltic Marine Geology for their sufficient efforts that made the Conference and Geological excursion course successful.

The Conference Committee acknowledges with gratitude the support for this Conference granted by the Lithuanian National Committee of Geologists, the Lithuanian Science and Studies Foundation, the Open Lithuania Fund and the European Association of Geoscientists and Engineers—Programme for Association and Co-operation in Earth Sciences (EAGE-PACE) Foundation.

The Baltic—the Fifth Marine Geological Conference was organised by the Lithuanian Institute of Geology in co-operation with the Lithuanian Academy of Sciences, the Vilnius University, the Lithuanian Institute of Geography and the Geological Survey of Lithuania. The Conference Committee is happy to close its own duty with this publication.

Welcome to the Conference Proceedings!

Editor Algimantas Grigelis

Vilnius, September 1999

Correlation of Tills from the South-Eastern Baltic Sea Bottom and Nearshore Boreholes

Albertas Bitinas,
Marijonas Repečka
and Laimdota Kalnina

Bitinas, A., Repečka, M. & Kalnina, L. 1999: Correlation of tills from the South-Eastern Baltic Sea bottom and near shore boreholes. *Baltica Special Publication 12*, 5-10. Vilnius ISSN 0067-3064

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Stratigraphic correlation and identification of tills is one of the most important problems of geological mapping of the South Eastern Baltic Sea (Lithuanian sector, Šventoji—Klaipėda aquatory) and surrounding offshore area (northern part of Lithuanian Maritime region). Stratigraphic correlation of tills from the SE Baltic Sea bottom and near shore boreholes was carried out on the basis of results of geochemical investigations and data of morphological analysis of hornblende grains. Stratigraphic subdivision of till sections in boreholes and grouping of till samples from the sea bottom surface as well as stratigraphic correlation between boreholes till layers and sea bottom sample groups was completed using factor and cluster analysis. Stratigraphic interpretation of correlated geological strata was performed taking into consideration additional information, such as results of OSL dating and paleobotanical investigations of intermorainic deposits. It has been found that Saalian tills prevail in the geological sections of Quaternary deposits of Lithuanian Maritime region and dominate on the Baltic sea bottom surface of the northern part of the Lithuanian sector.

Keywords: Baltic Sea, sea bottom, borehole, till, geochemical investigations, hornblende, stratigraphic correlation, factor analysis, cluster analysis.

INTRODUCTION

The problem of stratigraphic identification of Quaternary deposits existed during the whole period of the Baltic Sea bottom investigations. Visual colour comparison, physical-mechanical properties (density) or geological bedding conditions served as main criteria for stratigraphic subdivision and correlation of Pleistocene tills during geological mapping of the Baltic Sea at a scale of 1:500 000 (Grigelis 1991; Repečka et al., 1993). The problem of stratigraphic correlation of tills of the South Eastern Baltic Sea was started to be solved only in the last decade. The investigations of petrographic composition of tills (Gaigalas et al. 1987; 1997) and rounded hornblende grains studies (Majore et al. 1997) were the first steps in this direction.

Stratigraphic subdivision and correlation of Quaternary deposits, especially Pleistocene tills, was one of the most complicated problems that had been solved during large scale (1:50 000) geological mapping of the SE Baltic Sea bottom (Šventoji—Klaipėda aquatory of the Lithuanian sector) and neighbouring offshore area (Northern part of Lithuanian Maritime region). Traditionally palynological analysis of interglacial deposits and petrographic examination of gravel part of tills are used for such purposes at first. However, it was impossible to use palynological analysis because interglacial deposits have not been detected in the investigated region. Analysis of results of petrographic investigations of tills in the East Baltic and Lithuanian Maritime region (Gaigalas et al. 1987; 1997) shows that petrographic composition greatly varies in the same till layer because of different reasons, so this method of investigation is not very effective. On the other hand, the till samples from the sea bottom surface have been taken only by grab and they contain relatively small amount of sediments, so it limited the possibility to use such method of investigation as petrographic analysis of gravel part of tills as well. Thus, stratigraphic correlation of tills from the sea bottom and near shore boreholes was carried out on the basis of results of geochemical investigations and data of mineralogical analysis - morphological studies of hornblende grains.

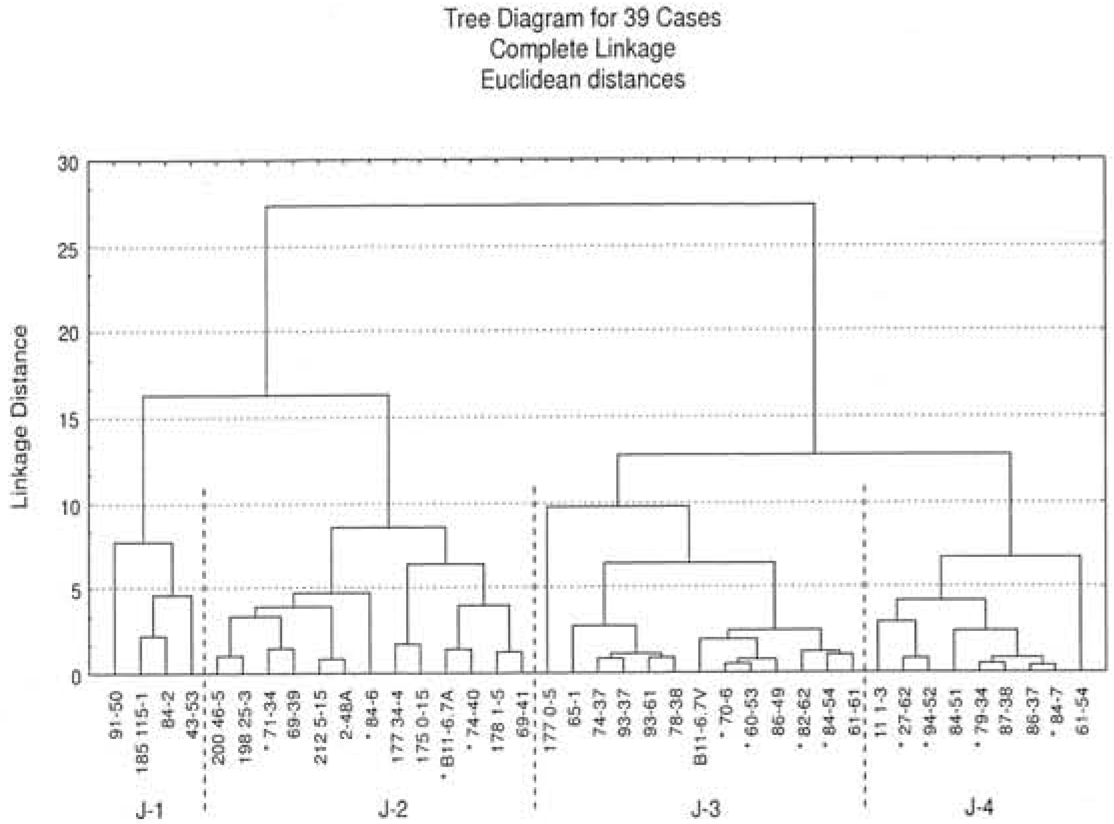

Fig. 1. Clustering of till samples from the Baltic Sea bottom according to geochemical composition. The number of sampling station with an asterisk means that mineralogical investigations have been done here as well. J-1, ..., J-4 are indexes of sample groups according to author's interpretation

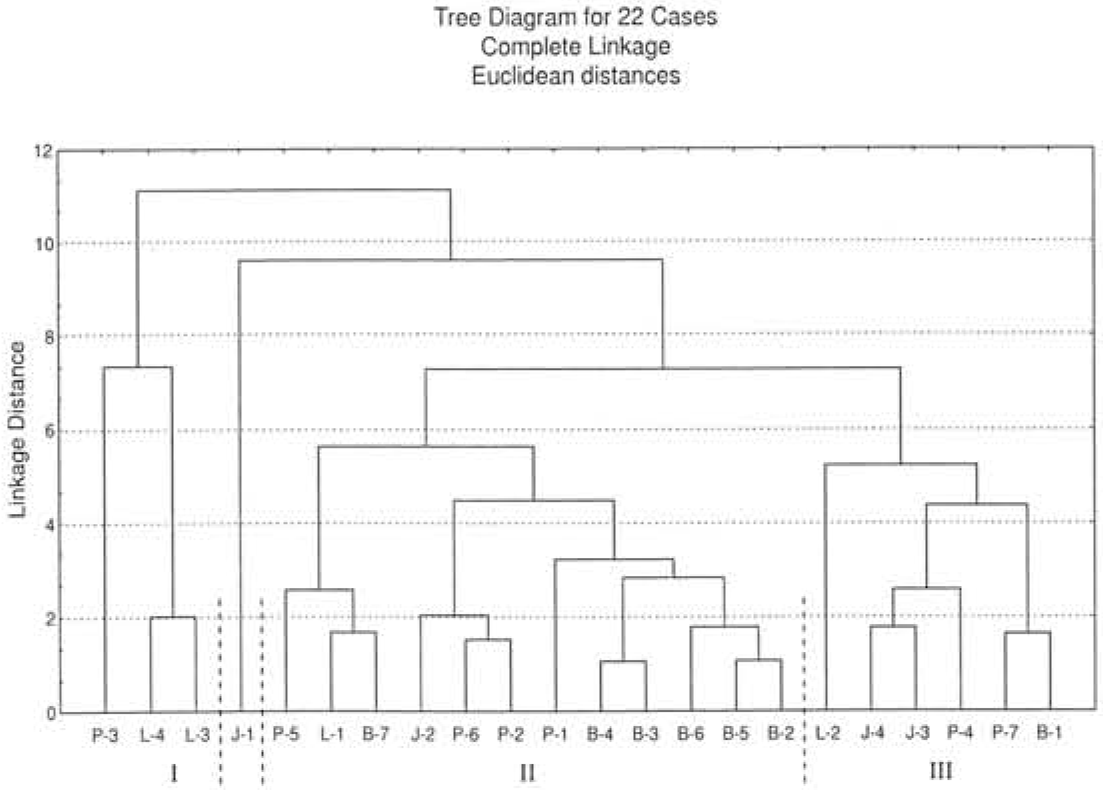

Fig. 2. Clustering of till sample groups from the Baltic Sea bottom surface and till layers from offshore boreholes according to geochemical coefficients. I, II and III mark different geochemical types of tills according to author's interpretation

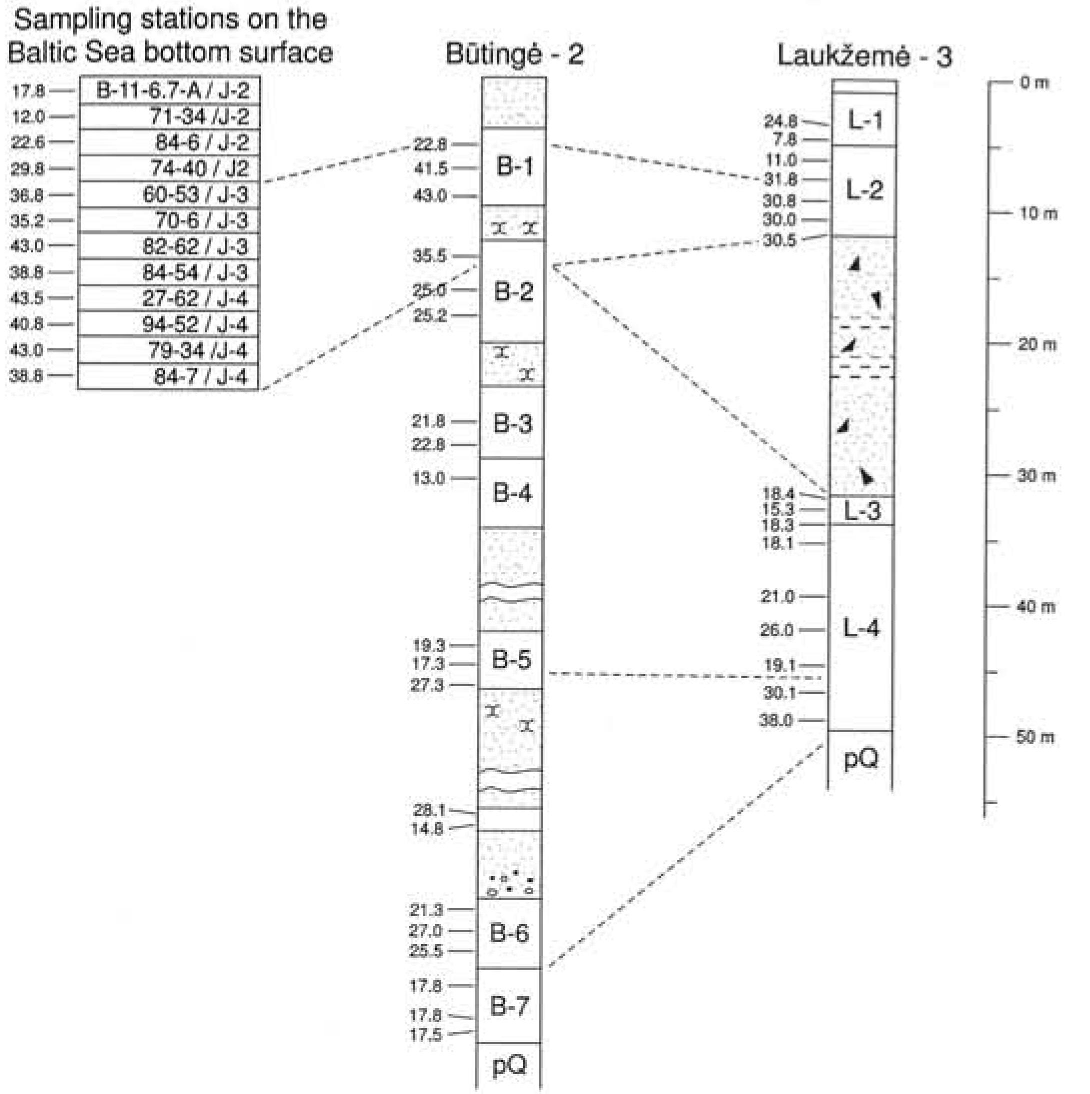

Fig. 3. Correlation scheme of till strata. 1 - group of till samples from the Baltic Sea surface and its index; 2 - till layer from offshore borehole and its index; 3 - intermorainic deposits: sand or sand with organic admixtures, silt, clay; 4-6 - different geochemical types of till (I, II, and III) according to the results of clustering in Fig. 2. A, B, C, D and E are indexes of correlated till strata

METHODS OF CORRELATION

Geochemical investigations (whole rock ICP analysis) of fine grained part of tills (less than 1 mm) have been carried out in the samples of 3 offshore boreholes (218 samples, Būtingė-2, Laukžemė-3 and Purmaliai-5 boreholes) and sea bottom surface (39 samples) in Canada, ACME Analytical Laboratories LTD. Morphological properties and total amount of well-rounded hornblende grains (fraction Ø 0.25-0.1 mm) in 36 till samples from Būtingė-2 and Laukžemė-3 boreholes, as well as in 12 till samples from the sea bottom surface were examined at the same time in Riga, Latvia University by L.Kalnina.

Stratigraphic subdivision and correlation of till layers have been done according to results of geochemical investigations first of all. Method of subdivision and correlation of glacial deposits had been used previously for analogous purposes in the other regions of Lithuania (Bitinas 1993). According to this method, the interpretation of different geological facts has been combined with results of the mathematical-statistical treatment of geochemical data. The samples of tills from the sea bottom surface were subdivided into four relatively homogenous groups according to chemical composition using cluster analysis (Fig. 1). Analogous separation of relatively homogenous till layers have also been done in the geological sections of boreholes using factor analysis. Till sections of boreholes were subdivided into four (Laukžemė-3) to seven (Būtingė-2 and Purmaliai-5) till layers. After that, the number of geochemical coefficients (SiO_2/Al_2O_3, SiO_2/CaO, Al_2O_3/Fe_2O_3, Al_2O_3/MgO, Al_2O_3/K_2O, K_2O/Na_2O, MgO/TiO_2, CaO/Al_2O_3, CaO/MgO, CaO/Fe_2O_3) have been calcu-

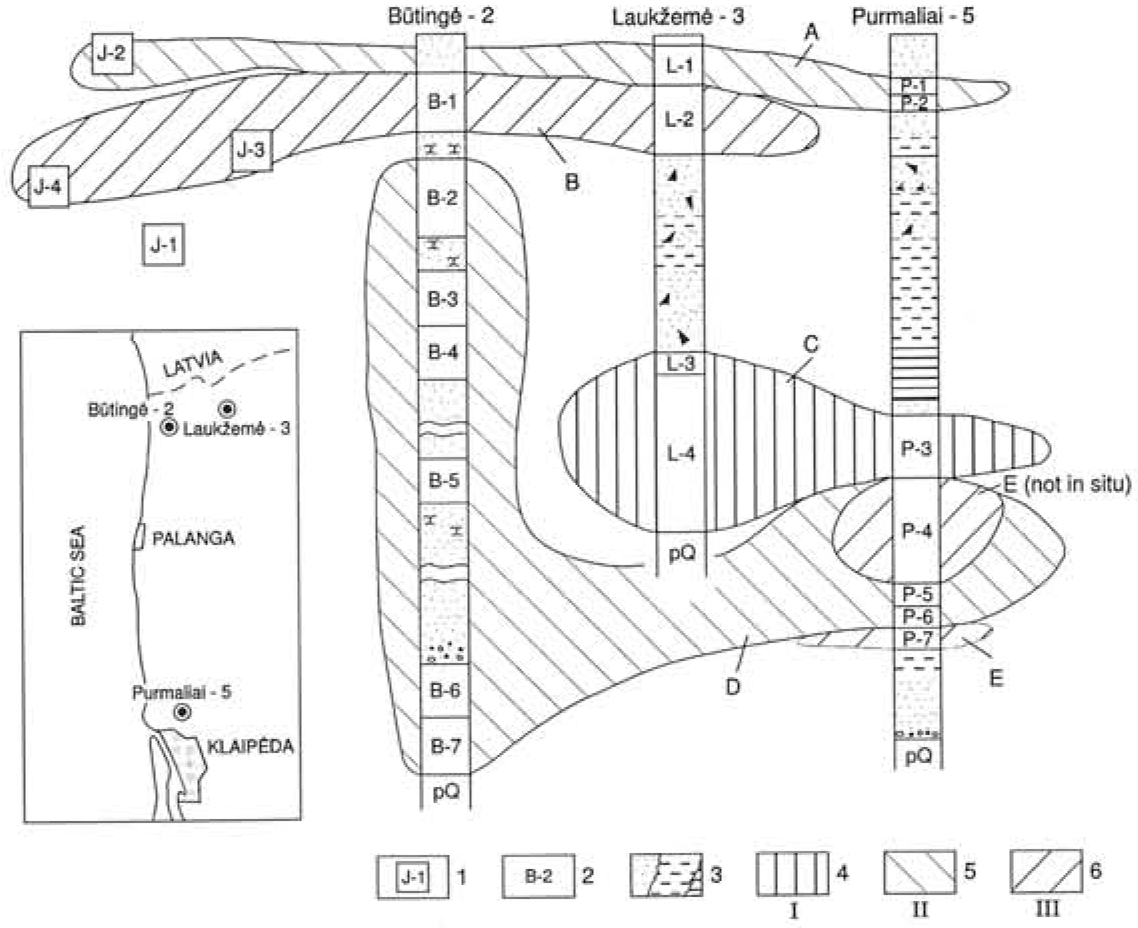

Fig. 4. Amount of well-rounded hornblende grains (in %) in tills and possible version of correlation of the till strata. Sampling stations on the Baltic Sea bottom surface: the number of station / dependence to sample group according to clustering in Fig. 1

lated for each till layer of boreholes and each sample group of the sea bottom surface. Single till samples in borehole sections with anomalous geochemical composition (reflecting crust of weathering, floes, etc.) have not been included in this calculation. In the next step of investigations previously calculated geochemical coefficients for all till layers or sample groups were compared to each other using the cluster analysis (Fig. 2). The correlation scheme of geological bodies (till strata) have been made on the result of such clustering (Fig. 3). According to the geological logic of strata formation (not possible to correlate strata crosswise) five till strata belonging to three different geochemical types of tills were pointed out. It is evident that one group of till samples from the sea bottom surface (J-1) is outside correlation. Relatively higher amount of Al_2O_3, Fe_2O_3, MgO, Na_2O and lower concentration of SiO_2 as well as a bigger amount of the pelitic particles (less than 0.01 mm) are characteristic of this group. Such geochemical and granulometric composition may reflect local till, rich in Pre-Quaternary sediments.

The scheme of correlation of tills according to data of examinations of well-rounded hornblende grains (Fig. 4) is very similar to the correlation scheme of till strata created according to data of geochemical investigations. The highest concentration of well-rounded hornblende grains (more than 30%) have been fixed in the till samples of the sea bottom surface, that belong to groups J-3 and J-4 according to data of geochemical investigations (Fig. 1). Similar high amount of well-rounded hornblende grains are characteristic of till layers of boreholes: B-4, L-2 and lower part of L-4. Thus, it is possible to correlate samples from groups J-3 and J-4 as well as till layers B-2 and L-2 (as according to data of geochemical investigations, Fig. 3). Four remaining till samples from the sea bottom surface (B-11-6,7-A, 71-34, 74-6 and 74-40) have lower amount of well-rounded hornblende grains and belong to group J-2 (Fig.1), that previously had been correlated with till layers L-1, P-1 and P-2 (Fig. 3). Data of mineralogical investigations do not contradict to such correlation, because the content of well-rounded hornblende grains is very similar in the samples from group J-2 and till layer L-1 (Fig. 4). The correlation of other till samples according to concentration of well-rounded hornblende grains is more problematic.

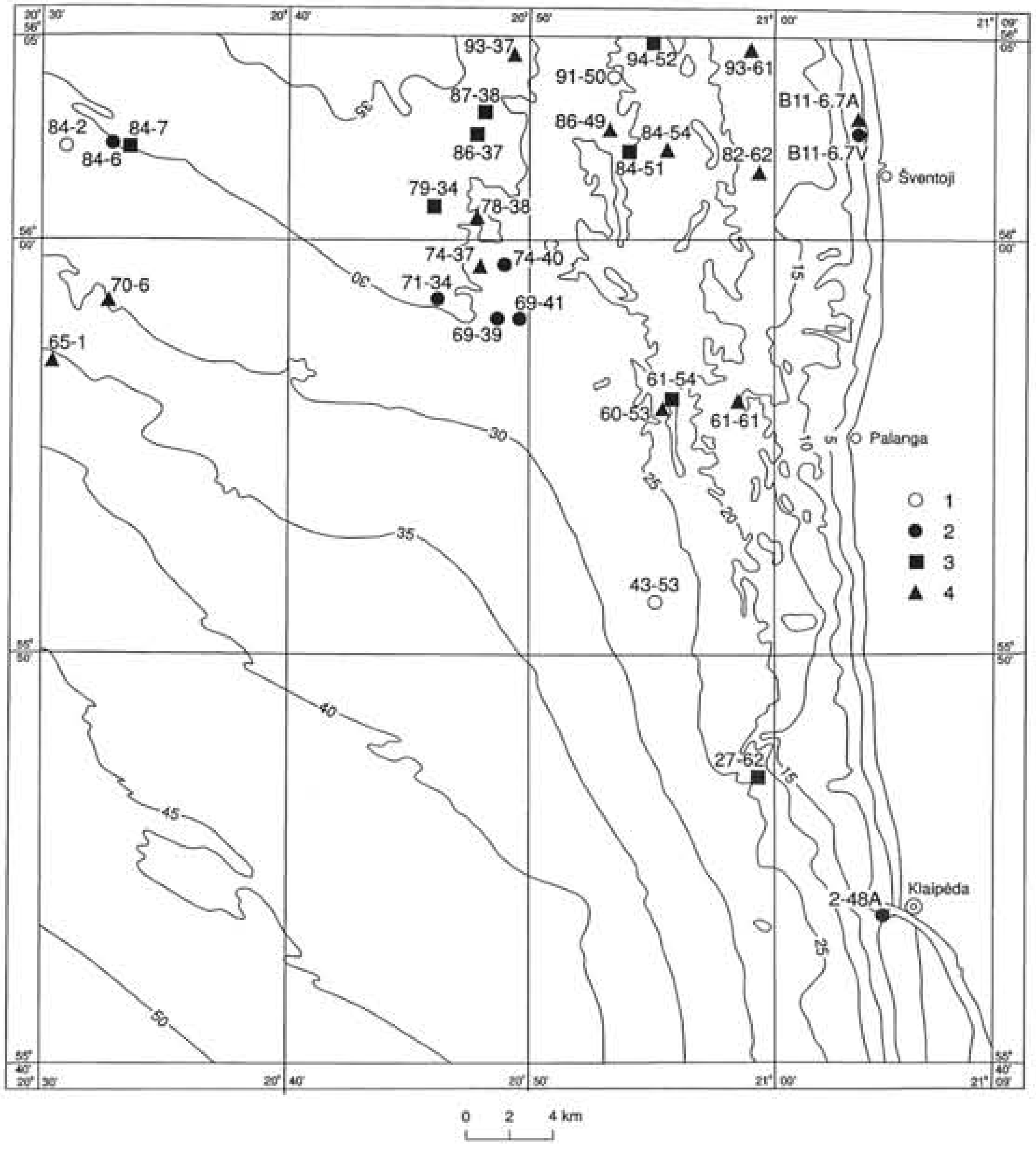

Fig. 5. Dislocation of till sampling sites on the Baltic Sea bottom surface, their numbers and groups of samples are given according to the results of clustering in Fig. 1: 1 - J-1; 2 - J-2; 3 - J-3; 4 - J-4. Some sampling sites are beyond the limits of the indicated area

It is possible to conclude that presented correlation scheme of till strata created on the basis of geochemical investigations has been confirmed on the results of mineralogical examination. Thus, stratigraphic correlation of tills is supposed to be more or less reliable, and the correlated till strata (Fig. 4, strata A, B, C, D and E) represent glacial deposits of different glaciations, stadials or oscillations.

STRATIGRAPHIC IDENTIFICATION OF TILLS

According to the data of geochemical investigations of tills it is possible to correlate separate till layers, but it is very difficult to decide about the age of these deposits. The results of morphological investigations of hornblende grains are more suitable for this purpose. It has been observed that amount of well-rounded hornblende grains in the East Baltic region and surrounding areas of Russia and Belarus vary in different tills: from 6 to 22% for Weichselian (Wurmian) till; from 28 to 37% for Saalian till and from 11 to 18% for Elsterian (Mindelian) till (Ulst & Majore 1964; Majore et al. 1997). In accordance with these data the uppermost till stratum A (Fig. 4) could be correlated with the Weichselian till. The till stratum B belongs to Saalian till because of the highest amount of well-rounded hornblende grains. The lower till strata C and D most probably belong to Saalian till as well because the amount of well-rounded hornblende grains increases to 27.0% (B-6) or 38.0% (L-4). Thus, strata B, C and D are as stadial or phasial Saalian tills. Such conclusion is supported by results of optically stimulated luminescence (OSL) dating of intermorainic deposits. According to OSL dating and the results of paleobotanical investigations, the sandy deposits between till layers L-2 and L-3 in Laukžemė-3 borehole also between P-2 and P-3 in Purmaliai-5 borehole (Fig. 4) were formed in a freshwater interstadial basin approximately 140-160 kBP. It is characteristic that concentration of well-rounded hornblende grains in till strata C and D vary in relatively large scale - from 13.0 to 38.0%. It may be associated with a big amount of Elsterian sediments (lenses, floes) in these Saalian till strata. The Elsterian till may be distinguished only in Purmaliai-5 borehole (till layer P-7), but we have no data of mineralogical investigations from this geological section. According to presented stratigraphic interpretation the uppermost Saalian till prevails on the surface of the sea bottom (Fig. 5). The younger Weischselian till must have been eroded during reiterative transgressions of the Baltic Ice Lake and the Litorina Sea.

The distribution of till samples, distinguished by cluster analysis (Fig. 1), depends on the sea bottom surface relief (Fig. 5). The till samples of group J-1 spread in the depths of 26-29 metres (average 27.5 m). The till samples of group J-2 located in the depths of the 26-34 metres (average 31 m) are found in the local areas. The till samples of groups J-3 and J-4 are spread at the two sea depth levels: about 34 m - lower level and 22-25 m - upper level. The till samples of separate groups differ in granulometric composition. The till samples of group J-2 contain about 40% of pelitic particles (less than 0,01 mm) and represent silty loam. The amount of the pelitic particles in the J-3 and J-4 groups of till samples vary from 21 to 44% but their average amount is 29 and 24% accordingly. These till samples represent the sandy loam. Thus, the granulometric composition of till probably has an influence on its geochemical composition. On the other hand, the regularities between geochemical composition of till and sea depth may be attributed to different parts of the same till stratum with different granulometric and geochemical composition and exposed at different levels on the sea bottom surface.

CONCLUSIONS

The results of geochemical investigations and mineralogical examination (analysis of well-rounded hornblende grains) of Pleistocene tills together with mathematical-statistical data treatment enabled to solve the problem of stratigraphic correlation and identification of Quaternary deposits in the South Eastern Baltic Sea bottom and surrounding offshore areas. It has been established that Saalian tills prevail in the geological sections of Quaternary deposits of the Lithuanian maritime region and dominate on the surface of the Lithuanian sector of the Baltic Sea bottom. The Weichselian till covers this part of the sea bottom only fragmentarily. The regularities between geochemical, mineralogical, granulometric composition of tills on the sea bottom surface and depth of the sea have been detected as well. The methods of investigations mentioned above are worth using in continuation of geological mapping or other investigations in the SE Baltic Sea and neighbouring land areas.

ACKNOWLEDGEMENTS

Presented investigations served as a composite part of geological mapping of Šventoji—Klaipėda aquatory in the Lithuanian sector of the Baltic Sea and northern part of Lithuanian maritime region on a scale of 1:50 000 that have been carried out in parallels and finished in 1997. Both these projects were financed by Geological Survey of Lithuania. The authors are sincerely grateful to colleagues who worked together during marine expeditions and field investigations, helped to prepare drawings and corrected the English text.

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Geotechnical Properties of the Baltic Sea Bottom Sediments (Lithuanian Nearshore Zone)

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Marijonas Repečka

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Engineering geological research of bottom sediments of the Baltic Sea near shore zone of Lithuania has been done. Grain size, physical and mechanical properties of bottom sediments have been determined.

Keywords: The Baltic Sea, bottom sediments, grain size, sand, moisture content, density, void ratio.

INTRODUCTION

The research of physical properties of various age and genesis of bottom sediments and rocks was being done before (Sviridov 1980). The speed of sound spreading was defined in these sediments (Sviridov 1977). These results were applied in geophysical research of the Baltic Sea bottom. Physical properties of the clayey bottom sediments in the South Eastern Baltic were determined (Lukoševičius & Marcinkevičius 1977). The data published show that clayey sediments of different age are in the diagenesis stage and at a very low degree of lithification. Dehydration and consolidation of sediments is caused by gravity powers. The physical properties and their changes were investigated in the mapping area during geological mapping of the Baltic Sea bottom surface. The geological mapping on a scale of 1:50 000 of the Baltic Sea bottom was done for the first time. The bottom sediments make up a water-saturated substance. The bottom sediment samples may be of a slightly disturbed structure, and they physical properties change when the samples are taken. All samples were taken by Van-Veen grab and these changes were approximately the same for each sample.

METHODS AND MATERIAL

Engineering geological research of the Baltic Sea bottom has been carried out together with geological investigations in 1994-1995 years. 110 sediment samples were taken from the sea bottom surface. The moisture content (W), density (r), particles density (r_s), void ratio (e), and mechanical properties of sediments (angle of internal friction, cohesion and deformation modulus) were determined at the Vilnius University laboratory. Grain size distribution were determined at the Institute of Geology by LST-1445, 1995. Other properties were determined according to the USSR standards. LST-1445 is a new Lithuanian soils engineering geological classification (Dundulis 1997). It is based on ISO and EUROCODE-7 recommendations. According to grain size sandy sediments can be presented in four groups with the following particle size: 60-2.0; 2.0-0.06; <0.06 and <0.002 mm (calculated from fraction <0.06 mm) (BS 1377,1990).

According to predominating fraction, sandy sediments consist of coarse, medium and fine sand.

DISCUSSION

Grain size distribution. Sandy sediments of different grain size are wide-spread in the mapping area (Fig.1). Fine sand contains 95-99% of particles with grain size ranging in 2-0.06 mm and 1-5% grains smaller than 0.06 mm particles. The particles of the same size are

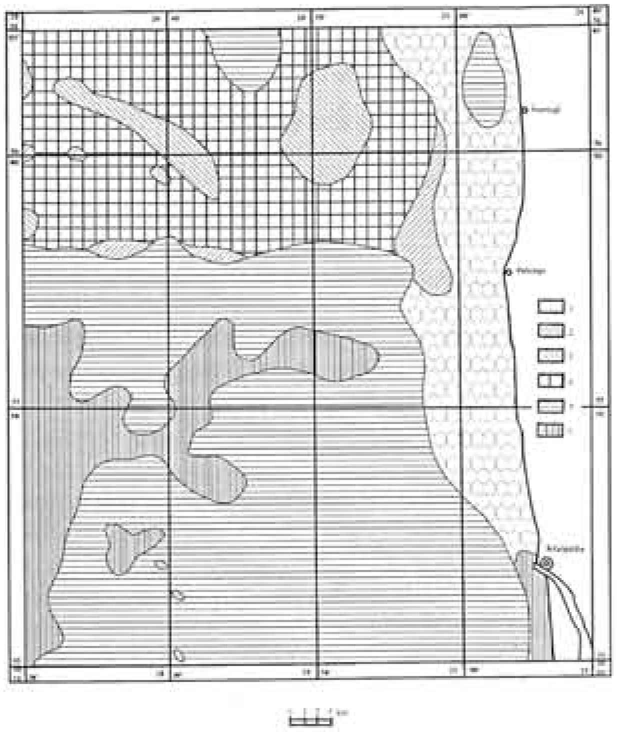

Fig. 1. Engineering geological scheme of Baltic Sea sediments: 1 - sandy gravel, very gravely and gravely sand, 2 - coarse sand, 3 - medium sand, 4 - fine sand, 5 - silty sand, 6 - very silty sand

Fig. 2. Moisture of bottom sediments (%): 1 - <20, 2 - 20-25, 3 - 25-30, 4 - 30-35, 5 - >35

present in medium sand, with the main fraction of 0.2-0.6 mm. About 5% particles (< 0.06 mm) are silty sand and very silty sand, and 5% particles (2 - 60 mm) are gravel and coarse sand. Fine sand is spread in northern part, silt and very silty sand are spread in the central and southern area, whereas gravel sand occurs in the near-shore zone.

Physical condition of sediments. The moisture content (W), density (r), particles density (r_s) and void ratio (e) were determined in the laboratory. On the ground of void ratio the sediment density was calculated. If $e<0.60$, soil is dense, at $e = 0.60\text{-}0.80$ it is medium dense, and at $e> 0.80$ it is loose. Fine sand is medium dense, its moisture content ranges in 21.2-27.7%, density varies within 1.94-2.09 g/cm^3, particle density - 2.50-2.71 g/cm^3. Medium sand is dense, moisture content ranges in 21.3-9%, density - 2.05-1.83 g/cm^3, particle density - 2.50-2.71 g/cm^3. Fine sand is characterized by minimum void ratio, where silty sand has maximum ratio. These results enable us to assert void ratio increase in finest material and decrease in coarse material. The sandy sediments of the Baltic Sea bottom surface are statistically monolithic. The statistical parameters of main physical properties are shown in Tables 1, 2 and 3.

Mechanical properties of bottom surface sediments. The shear test was applied for determination of angle of internal friction and cohesion and odometer test - for deformation modulus in the laboratory. Angle of internal friction of fine sand ranges from 29° to 45°, cohesion - 2-7 KPa. Angle of internal friction of silty sand is the largest - from 22° to 31°, cohesion - 1-19 KPa. According to the odometer test compressibility of sand is low.

Physical properties obtained by lithological investigation. The moisture content of bottom sediments ranges from 20 to 35% (Fig. 2). The density of bottom sediments exceeds 2.0 g/cm^3 in sand spread in the fields of pebble and gravel, 1.9-2.0 g/cm^3 in the near-shore zone, and 1.7 g/cm^3 in the coarse aleurite (Fig. 3). Void ratio increases from sand to coarse aleurite from 35 to 60% (Fig. 4). The physical properties are directly related to the grain size of bottom sediments. Distribution of these bottom sediment properties in the near-shore area is of the same character as the engineering geological types of the sediments.

CONCLUSIONS

The research results were applied for estimation of sediment strength in the mapping area. Hard and firm sediments seem to be distributed in the northern part and more loose and week in the central and south ar-

Table 1. Statistical values of fine sand

Physical value	Number of sample	Max value	Min value	Average value	STDEV	VAR
Moisture content (W), %	14	27.7	21.2	25.17	1.95	0.08
Density (ρ), kg/cm^3	14	2.09	1.94	1.98	0.04	0.02
Void ratio (e), %	14	76	60	68	0.05	0.07
Particle density (ρ_s) kg/cm^3	14	2.71	2.9	2.67	0.05	0.02

Table 2. Statistical values of silty and very silty sand

Physical value	Number of sample	Max value	Min value	Average value	STDEV	VAR
Moisture content (W), %	35	44.9	24	33.9	5.2	0.16
Density (ρ), kg/cm^3	35	2.09	1.75	1.9	0.098	0.0516
Void ratio (e), %	35	126	61	88	0.146	0.166
Particle density (ρ_s) kg/cm^3	35	2.67	2.54	2.61	0.036	0.0138

Table 3. Statistical values of medium and coarse sand

Physical value	Number of sample	Max value	Min value	Average value	STDEV	VAR
Moisture content (W), %	19	27.7	9.0	23.1	4.5	0.195
Density (ρ), kg/cm^3	19	2.09	1.83	1.98	0.05	0.03
Void ratio (e), %	19	76	53	65	0.06	0.097
Particle density (ρ_s) kg/cm^3	19	2.71	2.50	2.657	0.043	0.016

Fig. 3. Porosity of bottom sediments (%): 1 - <35, 2 - 35-40, 3 - 40-50, 4 - 45-50, 5 - 50-55, 6 - 55-60, 7 - >60

Fig. 4. Density of bottom sediments (g/cm^3): 1 - <1.7, 2 - 1.7-1.8, 3 - 1.8-1.9, 4 - 1.9-2.0, 5 - >2.0

eas of the South-Eastern Baltic. These sediments are characterized by a high void ratio and water saturation. There are many problems in investigation of sea bottom sediments. Some new equipment for investigation of bottom sediments in natural occurrence is necessary.

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Sub-Quaternary Surface of the South-Eastern Baltic Sea

Leonora-Živilė Gelumbauskaitė

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The sub-Quaternary surface in the south-eastern Baltic Sea has been analysed on the basis of geological mapping on a scale of 1:50 000. The study area stretches along the Lithuanian coast between the settlement of Šventoji and Klaipėda city at the depths of 0-40 m. Seismic profiling data have been used for an information about the bedrock morphology and geology. The Quaternary cover has also been taken into consideration in the article. Two structural-denudational surfaces are reshaped by paleochannels, as the highest levels of the sub-Quaternary peneplain in the south-eastern Baltic Sea have been identified. The influence of tectonics on the sub-Quaternary surface and Quaternary deposits is described and their possible interralationship discussed.

Keywords. Sub-Quaternary surface, tectonics, Quaternary deposits, paleochannels.

INTRODUCTION

The sub-Quaternary surface of the south-eastern part of the Baltic Sea, as an area of the Central Baltic Sea, reflects all the basic features of the Phanerozoic tectogenesis and geological distribution of the geological basin (Grigelis 1995). The sub-Quaternary peneplain can be started to form in the Oligocene, when marine basin, due to regression, retreated from the eastern Baltic land and the south-eastern Baltic Sea area.

N.I.Sviridov and others (1976), N.I.Sviridov and V.M.Litvin (1983), M.Mordanov (1975), and A.Šliaupa (1998) worked with the sub-Quaternary topography on the onshore and offshore of the south-east Baltic area. Majority of these investigations revealed a system of buried paleoincisions. The schematic maps separately for this area were compiled by the authors. More detailed map of the bedrock topography for the study area was compiled by M.Mordanov (1975). A structural terrace at the depths of -50 -40m, reshaped by the incisions reaching -100, -110m and going down south-westwards, is exposed on this map.

MATERIAL AND METHODS

Seismic profiling was performed by Latvesta - Latvian geophysical company - and joint Lithuanian-Swedish (Lithuanian Institute of Geology and Stockholm University) expeditions (Fig. 1). The data of the sub-bottom structure were collected by an analogue single seismic reflection equipment. Latvesta used 500 Hz and 10 kHz records, which were displayed on graphic records. During Lithuanian-Swedish survey, the signals were filtered on side, and two 250-500 Hz records (stacked and unstacked version) were displayed on the precision graphic records at 0.5 sec. intervals.

The seismic profiles were interpreted with respect to the following seismic units: I - Holocene (homogenous and/or laminated mud, silty sand, clay of Postlitorina, Litorina, Ancylus and Yoldia stages); II - laminated and homogenous glaciolacustrine clay and sand; III -Pleistocene till, IV - top boundaries of the sub-Quaternary surface.

During Lithuanian Swedish seismic profiling new data were obtained for the Late Paleozoic and Mesozoic sedimentary bedrock and seismostratigraphy. The unit boundaries consist of discontinuity surfaces fixed by strong reflection. The units are correlated with the borehole and core available for the study sea area and the mainland as well. This analysis has resulted in two maps: one of the morphology in the bedrock composed by Triassic and Jurassic sedimentary rocks; and another of the Quaternary thickness.

IDENTIFICATION OF BEDROCK SURFACE

The recent seafloor topography shows the submarine coastal zone that, going offshore, passes to less-steep hilly relief and abraded till plain (Fig. 1).

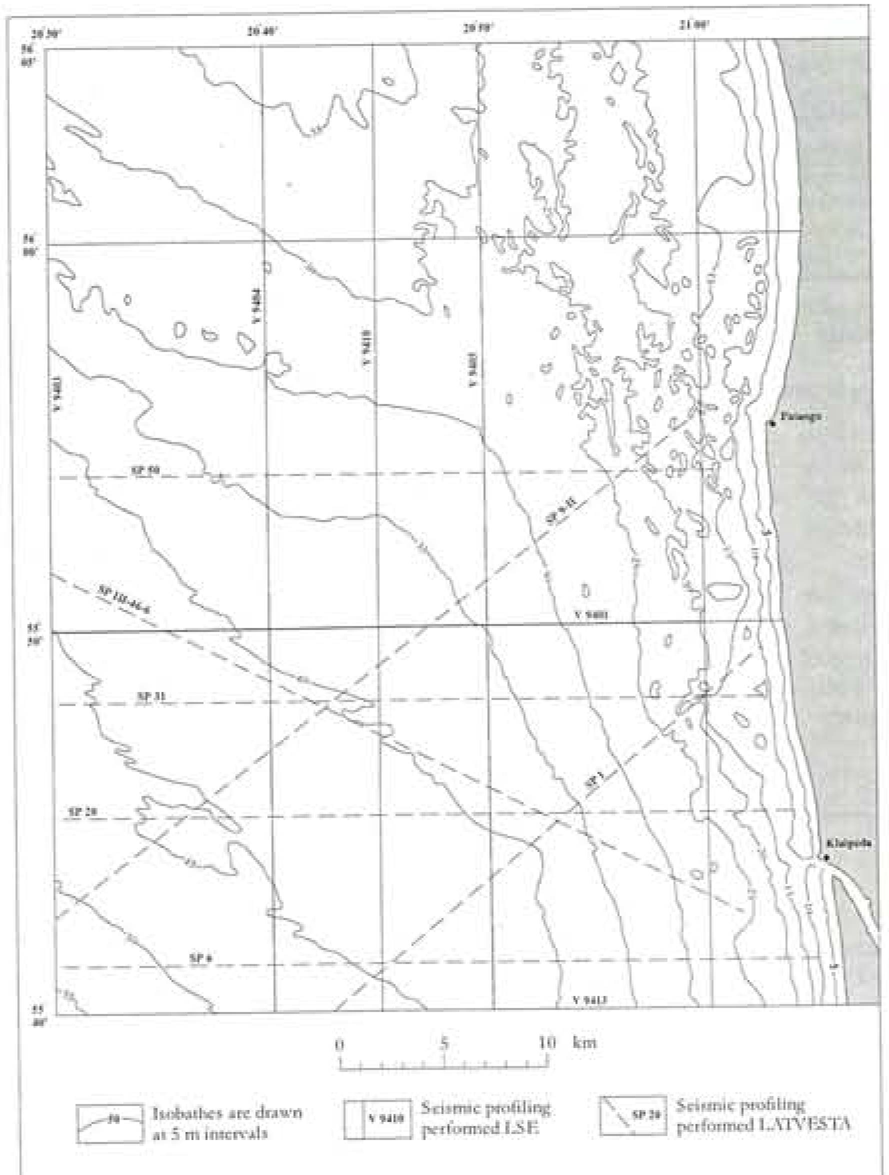

Fig. 1. Location map of the seismic track lines. The isobathes of present bottom topography drawn at 5 m intervals

The new reconstructed sub-Quaternary topography contains two denudational levels at 65-50 and 45-35 m b.s.l., slightly tilted south-westwards (Fig. 2). A scarp, approximately 15 m high, separates lower and upper levels, making up two terraces. These terrace surfaces exhume Triassic and, in some places, Jurassic sedimentary rocks.

The ridge, oriented from north-west to south-east towards the shore, exists at the higher terrace level, and only rare bedrock hills rise at the lower level. A gentle scarp of the lower terraces descends southwards until 75 m b.s.l. Going to the northern edge of the study area, more steep 10 m high scarp of the upper terraces of descends into isolated depression and at the foot reaches only 55 m b.s.l. The bedrock topography along the submarine coastal zone goes down towards ashore and only at the latitude of Klaipėda is separated by a ridge belonging to the higher terrace.

The paleoincisions are imprinted in the peneplain topography. The sub-Quaternary channels are concentrated in the southern part of the area. Paleochannels are inserted in this surface to the depths from –68–78 m to –98 m below NN, and they are generally V-shaped. The buried drainage systems with the same depths are recorded in the coastal land area (Šliaupa 1998). Regarding forms, depths and infillings of the channels they can be closely conformed with drainage system south-westwards.

Data on bedrock topography and the development of the sub-Quaternary peneplain have also been taken into interpretation of thickness and depositional forms of the Quaternary cover. The Quaternary is very uneven, and its thickness varies from 5 to 40 m. The maximum thickness is distinguished in the submarine coastal zone, and minimum one – at the ridges of higher and lower terraces and at the scarps. Quaternary deposits are thicker in the south-western part, too. The Quaternary of higher thickness along the nearshore zone, in the present topography, is expressed by less-steep hilly relief, or is visible as a till plain where Quaternary is less than 15 m thick on the tops of sub-Quaternary peneplain (Figs. 1 and 3).

DEVELOPMENT OF THE SUB-QUATERNARY SURFACE

The morphology and development of sub-Quaternary surface reflects the special features created during both pre-Late Permian and pre-Quaternary continental periods in this region (Grigelis 1995). The sub-Quaternary surface was formed during Late Paleogene-Neogene after retreat of the sea from the south-eastern and southern parts of the Baltic landmass. At the end of Neogene, the area rose up, and processes of denudation and erosion were activated. The river valleys network might have taken place there with its erosion base being Polish-German basin. At the beginning of the Pleistocene, the sub-Quaternary surface was affected extensively by glaciers. Pleistocene glaciers renewed the Neogene peneplain, exarated pre-Pleistocene and incised fresh valleys, as well as created depositional forms (Gelumbauskaitė & Grigelis 1995).

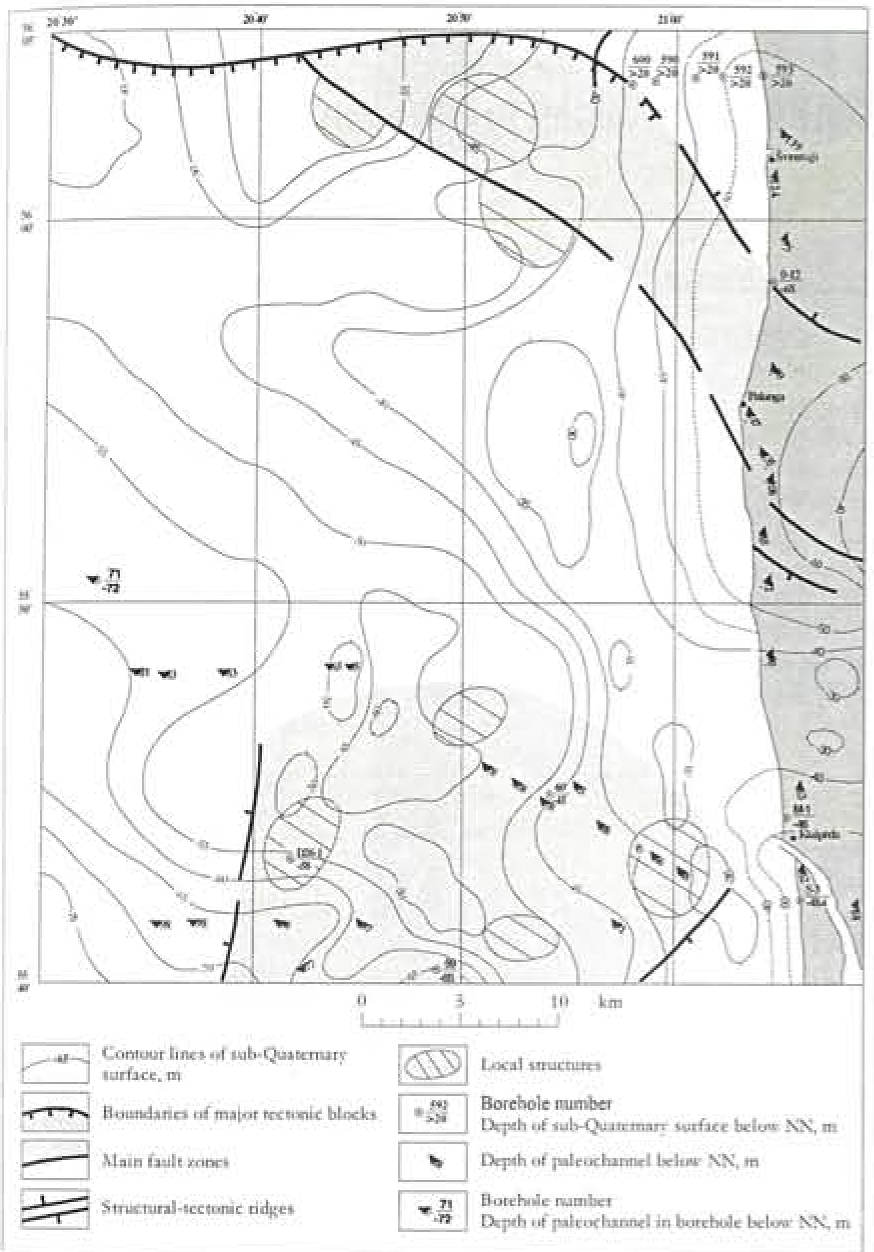

Fig. 2. Morphology of the sub-Quaternary surface of the south-eastern Baltic Sea. Contours drawn at 5 m intervals; tectonic sketch map after K.Sakalauskas et al. (1998)

Reconstructed sub-Quaternary peneplain seems to be mainly structural–denudational in its origin. Analysing seismic profiles with tectonic setting of the study area Hercynian disjunctive structure can be detected in the surface of the pre-Quaternary peneplain. The interrelationship does exist between main fault lineaments and sub-Quaternary morphology. On the risen central area, the West Nida and Telšiai faulting zones protrude on the ridges (Fig. 2; Sakalauskas & Suveizdis 1990). The West Nida structural tectonic ridge, including local deformation, is clearly expressed in the sub-Quaternary morphostructure. The Telšiai main fault zone, oriented from north-west offshore to south-east onland, is weakly expressed in the sub-Quaternary topography. The north-western edge of this faulting zone bordering major tectonic blocks is emplaced in the northern slope of the higher terrace ridges.

The relationship between Quaternary thickness and sub-Quaternary morphology seems to be existing too. The Quaternary is less than 15 m thick at the sub-Quaternary peneplain ridges, i.e. it reaches 14 m in the borehole D26-1, and is only 10 m thick in the borehole 60 (Majore et al., 1997). It can be noted that sedimentation pattern has been modified by tectonics during and after the Quaternary glaciations.

CONCLUSIONS

Analysis of the deformations of sub-Quaternary surface of the south-eastern Baltic Sea shows that the described parallelisms are not merely accidental.

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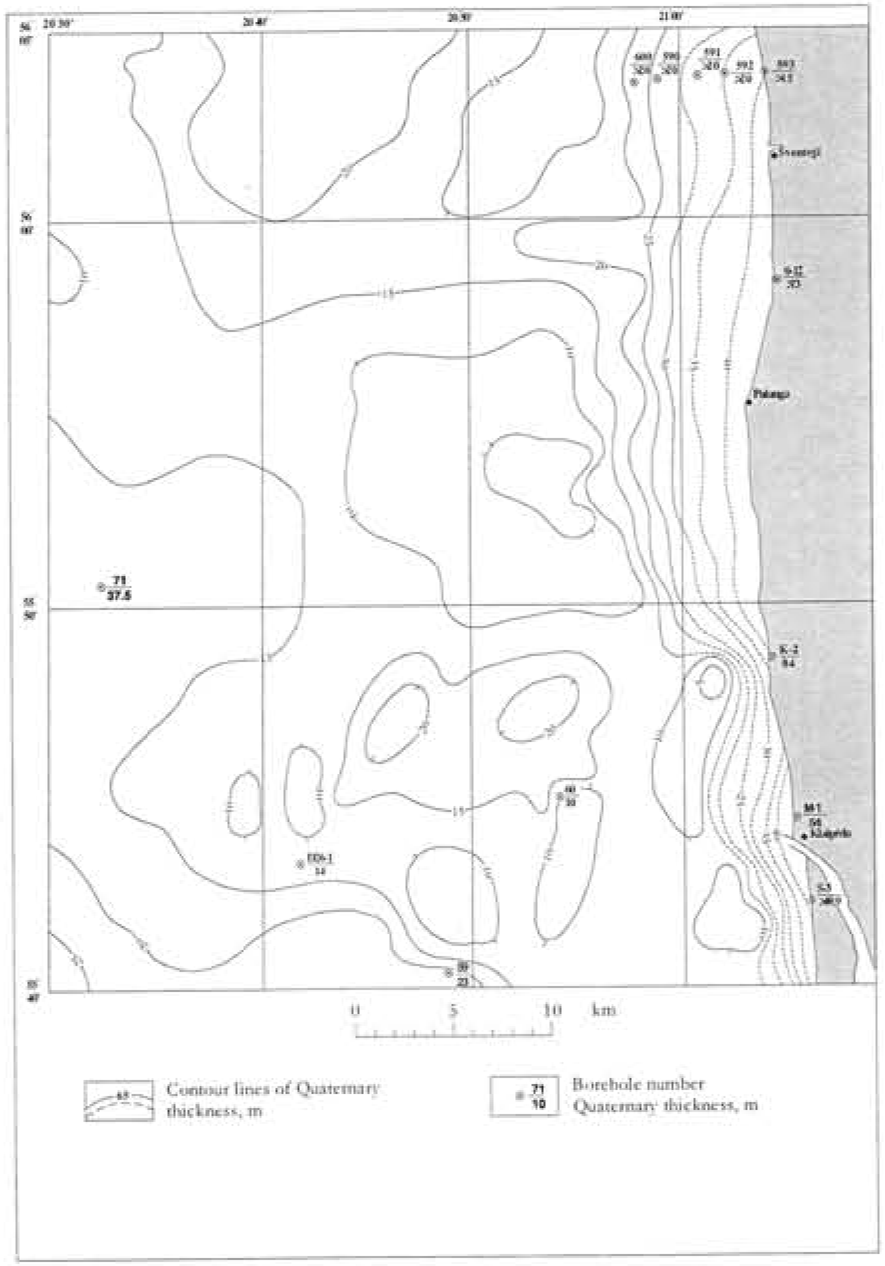

Fig. 3. Quaternary thickness of the south-eastern Baltic Sea. Contours drawn at 5 m

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Stratigraphic Units of Late Paleozoic and Mesozoic Bedrock of the Baltic Sea

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The article displays preliminary data of the lithological-stratigraphical subdivision of Upper Permian-Mesozoic bedrock exposed at the pre-Quaternary surface of the south-eastern Baltic Sea. Geographically, the area of investigation stretches along offshore the Latvian-Lithuanian coast in the north from 56°30' N, between 18°50'-21°05'E, as far as the Sambian Peninsula and Gdansk Bay in the south. The principal seismostratigraphic subdivision of the Permian-Cretaceous sequence is presented, and the reflecting boundaries, typical features and "signature" of distinguished seismic units are characterised.

Keywords: South-eastern Baltic Sea, seismic stratigraphy, bedrock, Late Paleozoic, Mesozoic.

INTRODUCTION

The upper part of the sedimentary cover in the south-eastern and southern Baltic Sea is composed of Late Paleozoic and Mesozoic sedimentary rocks (Fig. 1). The time interval embraces the Early Alpine tectonical cycle. Generally, thickness of the whole Alpine sedimentary complex, deeping southwards from Klaipėda Bank to Gdansk bay, varies from 200 to 1600 m (Grigelis 1991; Marek & Grigelis 1998). Not so much is studied on a bedrock geology and tectonics of the study area (Dadlez 1993; Grigelis 1995; Grigelis & Norling 1999; etc.).

Present stratigraphic subdivision of the south-eastern Baltic bedrock is still based on rare marine drillings made in 1977-1984 (boreholes D-1, D-5, D-6, C-7, C-8, C-9). A simple stratigraphic subdivision has been used before, by distinguishing separate geological systems only (Sviridov 1883, 1991). Permian-Mesozoic stratigraphy framework and consequently regional geological maps constructed in the end of 80-ties were based on the episodically performed geophysical research and marine drillings data (Grigelis 1993). Some labour to study Upper Devonian-Permian structural features and seismic stratigraphy on the eastern side of the Baltic Sea (mainly, Latvian waters - Floden 1980), as is noted (Grigelis 1991, pp. 169, 182), was not professional due a lack of basic knowledge of the East Baltic Devonian-Permian geology.

New data for the whole Paleozoic and Mesozoic sequence of the central Baltic were obtained in 1993-1995 by seismic reflection profiling performed by Latvian company Latvesta and by Lithuanian-Swedish expeditions on R/V Vėjas (Grigelis & Floden 1994; Kovalenko 1994). The first data were presented at the Baltic Stratigraphic and Baltic Marine Geology Conferences (Sopot, 1993; Uppsala, 1995; Tallinn, 1996; Vilnius, 1997).

OVERVIEW OF SEISMIC SURVEYING DATA USED PREVIOUSLY

Different modifications of seismic prospecting used within the central and southern part of the Baltic Sea allowed distinguishing sequences of different stratigraphic range. Their exposures have been traced under the sub-Quaternary surface of the sea floor (Sviridov et al. 1976; Floden 1980; Grigelis 1991, 1993).

In the central and south Baltic, the Paleozoic and Mesozoic layered sections comprise several strong reflecting boundaries, many of which are acoustic screens. Subsiding under the acoustically permeate strata, they are traced to the maximum depth, and can serve as reference boundaries in case of stratigraphic correlation and subdivision of sedimentary complexes (Sviridov, in Grigelis /ed./ 1991).

DATA BY *LATVESTA* AND *VĖJAS* EXPEDITIONS, 1993-1995

The upper part of sedimentary cover in the south-eastern Baltic is so far not completely investigated. Con-

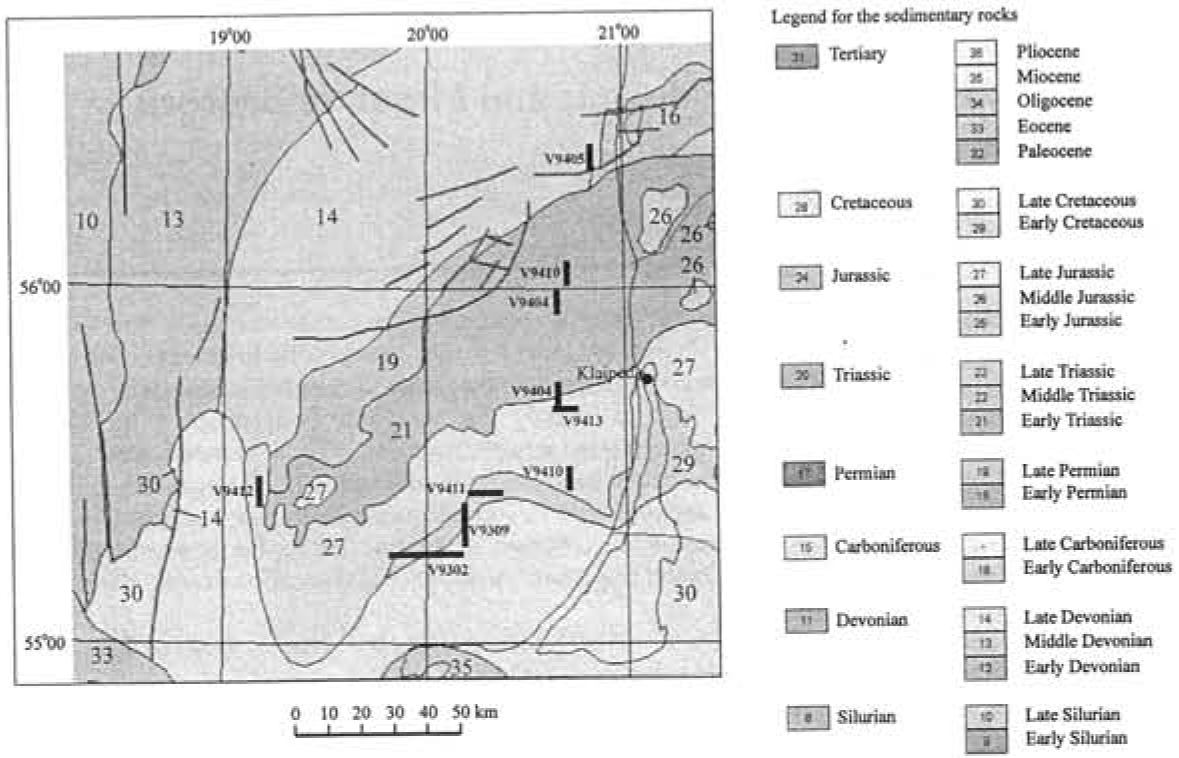

Fig. 1. The south-eastern Baltic Sea: the area of investigation is displayed on the Geological Map of the Baltic region (after A.Grigelis, 1999; generalised). Location of used seismic profiles is marked: SP - Latvesta, 1993; V - R/V Vėjas, 1993-1995 (see Figs. 2-12). On the figures 2-12: upper part - seismic record; lower part - geological interpretation; means of seismic reflectors - see Table 1; w.l. - water level; b.s.l. - below sea level

tinuous seismic reflection profiling performed during Latvesta (Lithuanian-Latvian) and R/V Vėjas (Lithuanian-Swedish) expeditions in 1993-1995 aimed to investigate in detail the geological structure of this area. The particular interests were given to the Middle-Late Paleozoic and Mesozoic bedrock structure and Quaternary development.

The field methods described in Grigelis and Floden (1994) include echosounding, seismic reflection profiling and geological sampling, all using high resolution satellite navigation systems. The base-net of N-S profile lines has a spacing about 10' of latitude degrees, i.e. 10.25 km. The base-net is supplemented by a sparse net of E-W profiles and some densely profiled areas to highlight certain structural features. The Lithuanian R/V Vėjas (Marine Research Center, Klaipėda), was appointed for the expeditions.

The continuous seismic reflection profiling (CSP) is performed for about 8000 km. An analogue single-channel seismic reflection equipment (Stockholm University), based on a PAR-600B airgun, was used. The instrumentation has the larger part of its acoustic energy restricted to within the frequency interval 100-1000 Hz which is sufficient for penetration of around 500 m in the present sedimentary bedrock. The reflected waves are filtered at the interval 250-500 Hz, and recorded on a precision graphic recorder. The data received belonged both to the Lithuanian Institute of Geology in Vilnius, and Stockholm University.

The initial seismic interpretation of the results is partly done at present time. It includes correlation of seismic reflectors in the N-S and E-W direction followed by seismostratigphic correlation with onshore and offshore drillings, as well as analysis of paleotectonics and other structural features. The profiles shot in the area between Gotland and the Latvian-Lithuanian coast have revealed new information on the geological framework and on the Paleozoic to Quaternary stratigraphic succession of the area. In the central part of the investigated area, when depth of seafloor is over 100 m, reflectors representing different lithological changes or discontinuity surfaces are abundant (see Figs. 9, 10 and 11).

SEISMOSTRATIGRAPHIC SUBDIVISION

The seismostratigraphic subdivision is based on structural features and lithology, which reflect environment conditions. Seismic boundaries and unconformity surfaces in most cases coincide with the boundaries between structural and stratigraphic units of a certain rank; therefore, dividing the sedimentary cover they are accepted as the "stratigraphic frame". Using the above features, the lithological complexes simultaneously with the unconformity-bounded surfaces and strong reflecting boundaries are correlated with the lithological stratigraphic sections in adjacent onshore wells, such as Palanga-318, Vydmantai, Klaipėda-1, Nida-1, Rusnė-1, which improved the accuracy of the interpretation (Grigelis 1991; Grigelis & Kadūnas 1994; Kepežinskas et al. 1996). The approximate thickness of the above complexes is determined with regard to the mean layer velocity values.

Correlation of stratigraphic boundaries in plan is favoured both by the constant reflection pattern of seismic sections, and the coincidence of the strike of these boundaries with linear forms of sub-Quaternary relief, i.e. steep slopes and escarpments.

PRESENTATION OF RESULTS AND DISCUSSION

The interpretation of Mesozoic as well as Late Paleozoic has been based on distinct angular unconformities recorded in the seismic sections. The unconformities represent breaks in sedimentation, and they separate the stratigraphic units of contemporary sedimentation. The tentative geological identification of seismostratigraphic units is based on the comparisons with the onshore geology of the Lithuania mainland.

It is essential to note that interpretation of seismic research data obtained in 1993-1995 is limited by some specific geological (and technical) conditions making serious difficulties to trace distinguished reflectors through the area studied:

- shallow and very shallow waters (<30 m), when record is covered by multiple reflections;
- deeply eroded pre-Quaternary rock surface, when record data fix some depositional relics only;
- fragmentary recorded seismic signature when seismic signal is dispersed due to some uncertain reasons and this does not allow to trace distinguished reflectors in the whole area with distribution of certain sediment units.

Table 1. Mean values of layer velocities in lithological-stratigraphic complexes of the Baltic Sea (after Sviridov 1991, modified)

Age of complexes	Layer velocity, m/s
Cambrian	2750
Ordovician	3500
Silurian	3000
Devonian & Carboniferous	2500
Permian	2200-5000
Triassic	2350
Jurassic	2100
Cretaceous	2000
Paleogene-Neogene	1950
Quaternary	1700-1850
Water layer	1438-1446

Late Permian

The sequence of strong parallel reflectors just above the eroded Upper Devonian surface is interpreted as equivalent to the lower part of Zechstein Werra Cycle, with typical seismic signatures (from base to top): P1 (supposed) - as limestones or dolomites; P2 - close and hard limestones and dolomites with silica concretions; P3 - carbonate beds with parallel reflectors (Fig. 2).

The unit P2 is deeply affected by paleokarst in the eastern part of the area. This unit becomes thicker and the seismic signature changes southwards forming the structure interpreted as a barrier reef.

The unit P3 is distinguished only in the shallower northern part of the barrier reef. The Late Permian seismic units mentioned above gradually become thinner and finally disappear in south-western direction. The uppermost part of the Upper Permian (Stassfurt, Leine cycles) are present south-westwards of the area studied.

Thickness of Upper Permian as recorded reaches over 25 m.

Early Triassic

Seismic units T1 and T2 are distinguished. They are interpreted as the lower Early Triassic sequence of argillaceous rocks, presumably equivalent to the Purmaliai Group.

Table 2. Principal stratigraphic subdivision of the Upper Paleozoic-Mesozoic of the south-eastern Baltic Sea

Stratigraphy			**Environment**	**Seismic unit**
Upper Cretaceous	Maastrichtian-Campanian-	Galinga Formation Bebras Formation	Marine	[not studied]
	Santonian-Coniacian-Turonian	Brasta Formation	Marine	**K2**
	Cenomanian	Labguva Formation	Shallow marine-nearshore zone	**K1** } **K1.2**
Lower Cretaceous	Albian	Jiesia Formation		**K1.1**
Upper Jurassic	Volgian-Kimmeridgian	Tarava and Girdava Formations	Shallow marine	[not studied]
	Oxfordian	Ąžuolija Formation	Marine	**J4**
Middle Jurassic	Callovian	Skinija Formation	Shallow marine	**J3**
		Papartinė Formation		**J2**
	Bathonian	Skalviai Group (upper part)	Brackish water basin	**J1**
Lower Triassic		Nadruva Group	Continental basin	[not studied]
		Purmaliai Group		**T2** **T1**
Upper Permian	Z4 Leine and Z3 Aller cycles	Aistmarės and Prėglius Formations	Lagoonal-shallow marine	[not studied]
	Z2 Werra cycle	Naujoji Akmenė Fm.	Shallow marine	**P3**
		Sasnava Formation		**P2**
		Kalvarija Formation		**P1** [not studied]

Unit T1 is characterised by rather weak regular reflectors; becoming disrupted northwards in the investigated area, where the unit may be partly eroded (Fig.3). Seismic unit T1 is referred to the lowermost Nemunas Formation.

Unit T2 is interpreted as equivalent to the Early Triassic Palanga Formation. The unit is composed of rather weak, irregular reflectors of limited lateral extension forming typical transparent seismic signature (Fig. 4). The irregularities of reflectors appear to be more accentuated in the northern and western part of the present area. The different seismic signatures as well as the presence of thin layers with local extensions in the upper part of unit, indicate the distinctive changes of lithology in the unit.

Thickness of Lower Triassic in records varies around 50 m.

The Middle-Upper Triassic and Lower Jurassic are absent in the present area.

Middle-Late Jurassic

Seismic unit J1 is interpreted as terrigenous sediments equivalent to the upper part of Skalviai Group of the Middle Jurassic age. It is expressed by extremely weak reflectors, which create an almost transparent seismic signature (Fig. 5). The unit is deeply eroded by glacial activities.

Seismic unit J2 is interpreted as representing the Middle Callovian sandy carbonate rocks typical for the onshore Papartinė Formation. It is composed of almost horizontal layering having several strong reflectors (Fig. 6). The unit is consistent with the maximal transgression to the north-western direction.

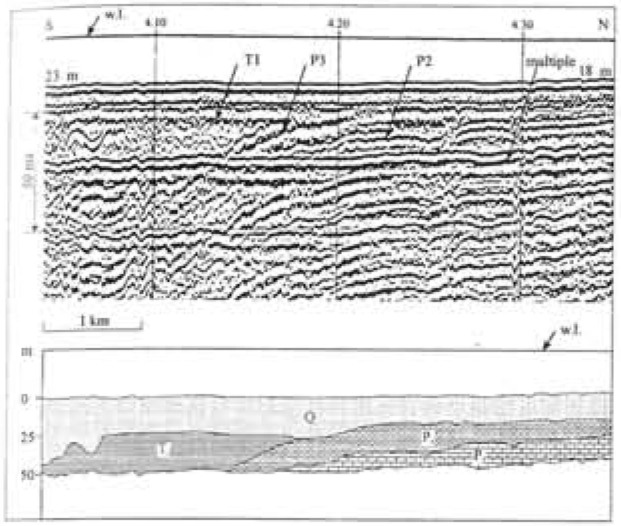

Fig. 2. Interval 4.04-4.35 of the seismic profile V9405, seismic units P2, P3 and T1. Angular unconformity is recorded between Upper Permian carbonate and Lower Triassic argillaceous clasts

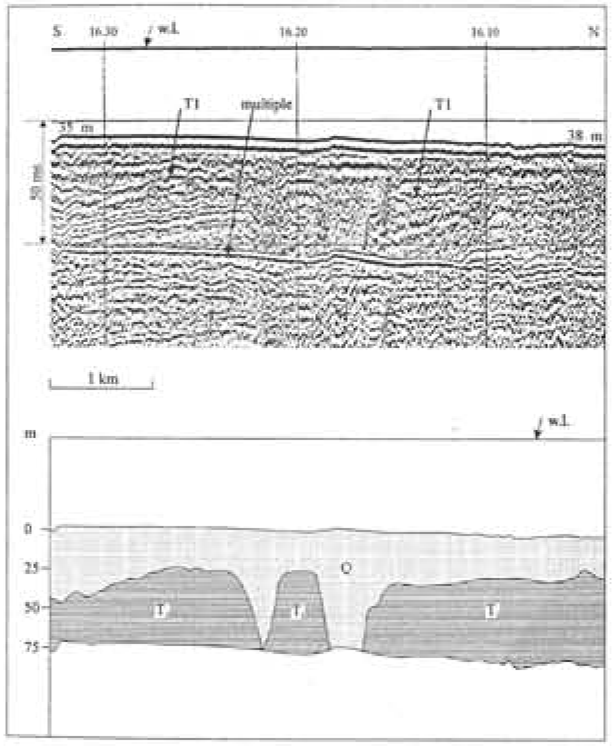

Fig. 3. Interval 16.06-16.33 of the seismic profile V9410. Deeply eroded T1 seismic unit surface

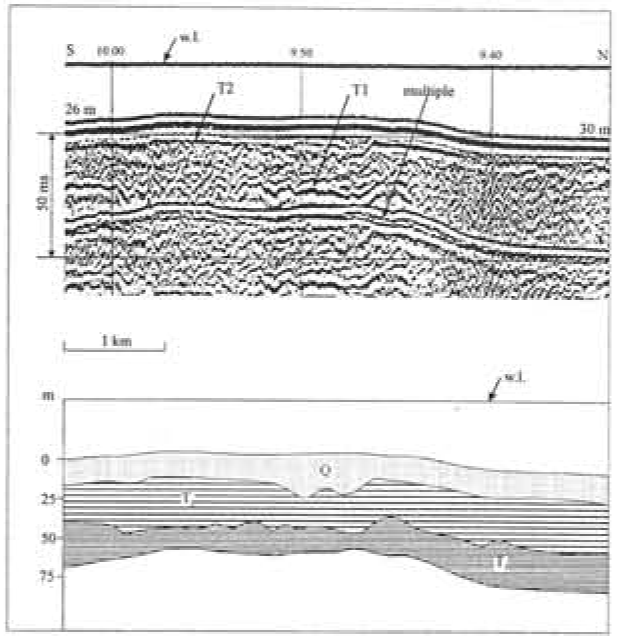

Fig. 4. Interval 9.34-10.02 of the seismic profile V9404. Strong reflector T1 in Lower Triassic sequence is interpreted as T1/T2 seismic units boundary

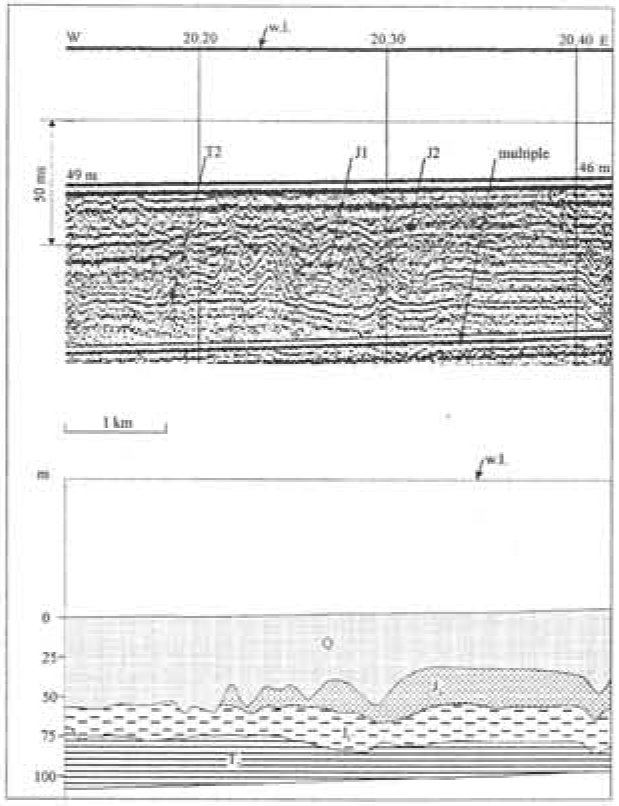

Fig. 5. Interval 20.13-20.42 of the seismic profile V9413, seismic units T2, J1 and J2. Lower Triassic argillaceous sequence (T2, weak reflectors) is covered by weakly layered Middle Jurassic terrigenous rocks, J1 and J2 seismic units

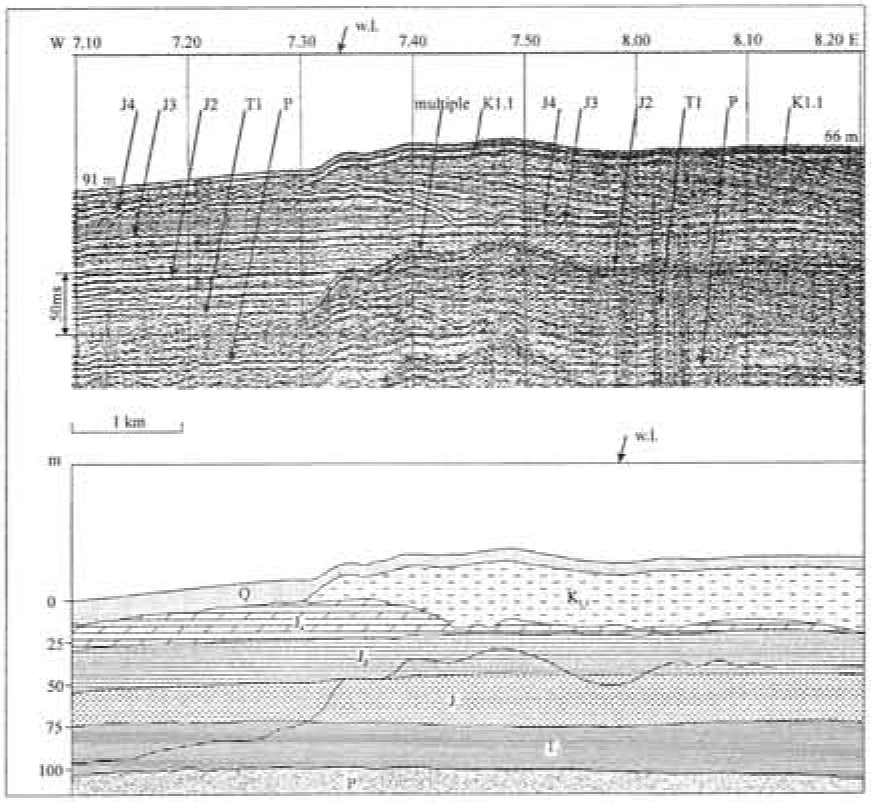

Fig. 10. Interval 7.10-8.20 of the reference seismic profile V9302 representing deep penetration in the central part of study area. Seismic units are distinguished: P, T1, T2, J2, J3, J4, K1.1

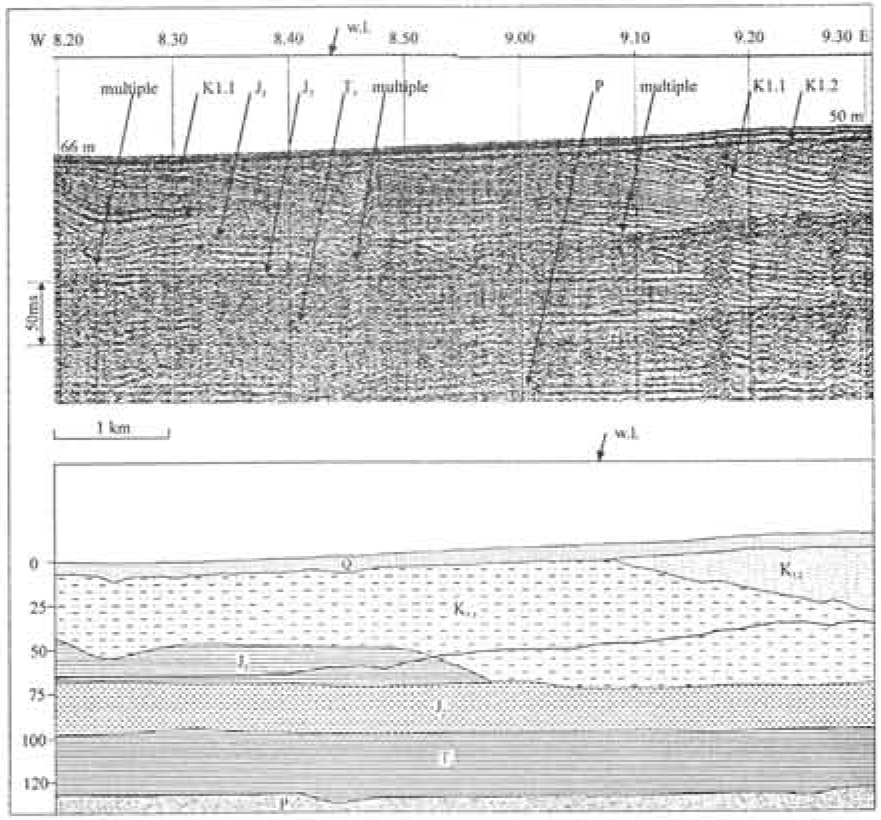

Fig. 11. Eastward continuation of the reference seismic profile V9302, interval 8.20-9.30, demonstrates thick layered sequence of seismic units K1.2 and K2

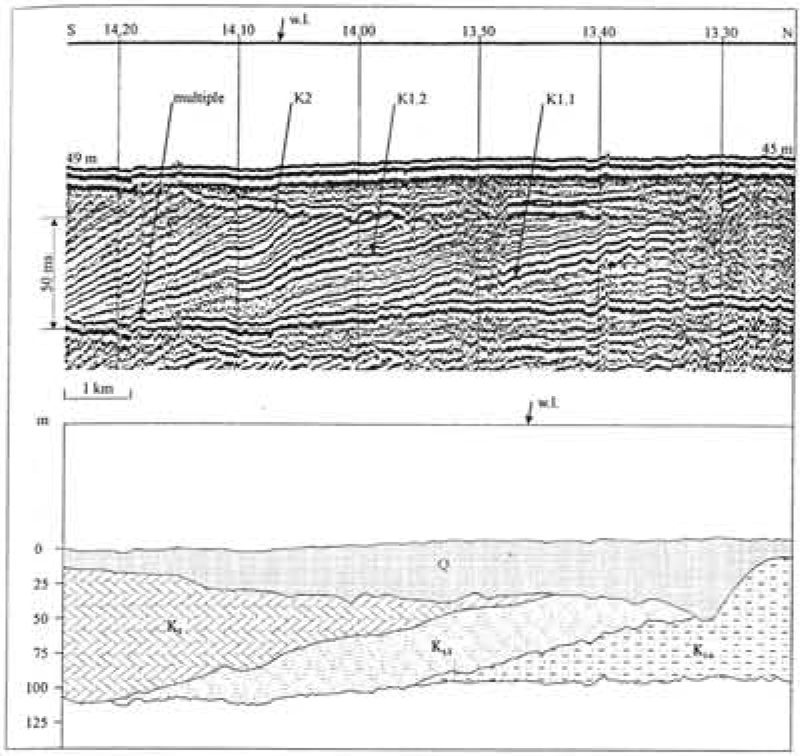

Fig. 12. Interval 13.24-14.24 of seismic profile V9309 shows transition between seismic units K1.1, K1.2 and K2

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Role of Storms in Formation of Turbulent Sea Currents in the Near-Shore Zone

Vladimir Gritsenko and
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The given paper aims to study the process of formation of suspensive currents in the coastal zone under stormy conditions by means of numerical models. Model calculations have confirmed validity of proposal, according to which extremely high values of mixing coefficient in the zone of storm impact are of crucial importance for the process of formation of turbidity currents. In particular, it has been shown that under chosen conditions the formation of quasi-stationary suspensive water takes place indeed. Besides, formation of bottom currents is also possible. Thus, mixing in coastal zone under stormy conditions is a necessary condition for formation of back currents penetrating into water column below the transition layer.

Keywords: turbidity flow, turbulence, nonhomogeneity mixing coefficient, stratification, storm mixing, near-bottom current

INTRODUCTION

A number of authors (Aibulatov 1990; Sviridov 1997; Antsiferov et al. 1978; Pykhov & Dachev 1981) have found that during storms the return and discontinuity currents are formed in shallow water areas of the Baltic Sea; they play a considerable role in transportation of sedimentary material from the coastal zone to the high sea. Indeed, seismo-acoustical and geomorphological data show that shallow water bottom and slopes are covered by network of erosive channels, which serve for transportation of suspensive material from shoal to deep regions, forming along its path accumulative bodies - accumulative fans and channel banks. Large part of shallow water area and slopes (in the zones of storm impact - above pycnocline) is eroded and covered by coarse grain material. All this testifies the occurrence of intensive near-bottom currents participating in formation of erosive-accumulative bottom forms. At the same time, generation of turbidity flows in shallow water is of pulsating and sporadic nature (Pykhov 1976; Leontyev 1981). Seemingly, this is associated with saturation capabilities of coastal water, where transportation of suspension to a deeper areas occurs. Physical nature and mechanisms of such return and discontinuity currents are not clear yet. On the basis of facts one may only conclude that during storm in the zone of wave impact saturation of coastal water with suspended material takes place. This water does not spread over bottom, despite its larger density, if compared to that of the off-sea water masses, but it is accumulating, sometimes to large volumes. Finally, storm-induced bottom currents are characterized by considerable erosive capabilities (Pykhov, Dachev & Kosyan, 1980; Antsiferov et al. 1978; Sviridov 1997) and, therefore, it could be reasonable to explain all these facts from generalized point of view.

This paper aims to investigate influence of mixing processes in the coastal zone on formation of suspension flows under the stormy conditions. It is clear that it is impossible to perform an analytical investigation of the above mentioned processes in full size, i.e. to make records and solve the differential equations preserving physical idea. Implementation of laboratory and field experiments is also problematic. That's why studies on formation suspensive flows under the stormy conditions have been carried out by means of numerical model.

MODEL

Formulation of model equations will allow to propose that flow of inviscid and non-homogeneous fluid is turbulent and non-stable. Buoyancy forces are known to suppress the vertical turbulent exchange on the interface between two water masses, differing in density (Monin & Yaglom 1971). That's why for modeling turbulence inside a suspensive current the notion of effective viscosity was used (Monin & Yaglom 1971; Anuchin & Gritsenko 1985) and it was assumed to be equal to zero. The larger density of water layer, formed under the influence of wind, was also assumed to result from the occurrence of passive impurity (suspension). Discontinuity or return currents are characterized by small (normally to velocity vector) values. This made us possible to come to conclusion about horizontal homogeneity of current in transverse direction. Use of physical variables and establishment of pressure boundary conditions are rather problematic (Roache 1976). Transition to variables of vorticity-streamfunction-density ($\omega-\psi-\rho$) gave us equations applied as a basis for numerical model of vertical movements in stratified fluid (Anuchin & Gritsenko 1985; Gritsenko & Sivkov 1997):

$$\frac{\partial\omega}{\partial t}+u\frac{\partial\omega}{\partial x}+w\frac{\partial\omega}{\partial z}=\frac{g}{\rho_0}\frac{\partial\sigma}{\partial x}+\nu_T\Delta\omega\ , \tag{1}$$

$$\frac{\partial\sigma}{\partial t}+u\frac{\partial\sigma}{\partial x}+w\frac{\partial\sigma}{\partial z}=D_T\Delta\sigma, \tag{2}$$

$$\Delta\psi=\omega \tag{3}$$

$$\frac{\partial c}{\partial t}+u\frac{\partial c}{\partial x}+w\frac{\partial c}{\partial z}=D_T\,\Delta c, \tag{4}$$

where *u* and *w* - velocity components along axis *x* and *z*, correspondingly; **g** - gravity acceleration; ρ_0 - characteristic density of fluid; t - time; $\omega=\partial u/\partial z-\partial w/\partial x$ – vorticity; ψ - streamfunction; $u=\partial\psi/\partial z$, $w-\partial\psi/\partial x$, ρ – density of intrusion; $\sigma=\rho-\rho_0$ - variaton of density; $\nu_T=\nu_0+\nu_{ef}$, $D_T=Sc\cdot\nu_T$ - turbulent viscosity and diffusion; ***Sc*** Schmidt number; ν_{ef} - effective turbulent viscosity; ν_0 -molecular coefficient of viscosity; Δ - Laplace operator; axis *x* is oriented horizontally; axis *z* is oriented upwardly, starting from bottom; **c** - tracer concentration (suspension), transported by fluid. Tracer is auxiliary model parameter and is used for tracing suspensive material of bottom currents.

Discrete computer model equations to describe the distribution of density stratified flow were obtained by means of the second difference scheme (Roache 1976). Finite-difference analog of Poisson equation (3) was solved by means of iterative relaxation method. All model fields were given on the net with dimension of 201 x 21 . Characteristic scales of currents under consideration were as follows: $h_0=10$ m , $u_0=5$ cm/s , $\Delta\rho_0=0.001$ g/cm^3 (Pykhov & Dachev 1981; Sviridov, Sivkov & Christiansen 1995; Antsiferov et al. 1978). In all model space at the initial moment of the time the vertical velocity is assumed to be equal to zero. To consider saturation of coastal zone with suspensive material we assumed the occurrence of dispersive source of corresponding water mass on the entire left border of the model space, where the effluent velocity U_0 was assumed to be equal to 0.5 cm/s.

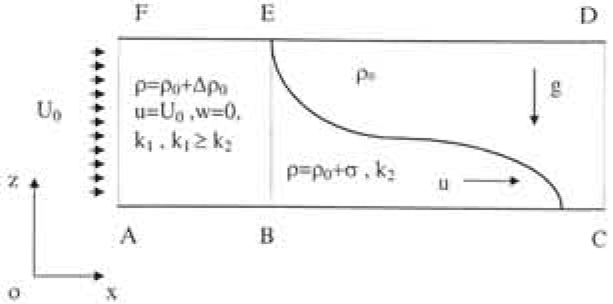

Fig. 1. General diagram of problems, being considered in the paper: ABCDEF - geometry of the model space; AF - inlet into the model space; CD - outlet from the model space; ρ - density, U_0 - speed of inflowing bottom gravity current; ρ_0 - density of fluid filling up the model space; **oxz** - coordinate system; g - gravity acceleration vector; $\rho=\rho_0+\sigma$ - density of water in bottom layer, k_1 and k_2 - coefficients of viscosity ; u - speed of bottom current

The initial model conditions (t=0, $0\leq z\leq 1$) were given (Fig.1) as following:

$$\rho=\begin{cases}\rho_0+\Delta\rho_0\ , \text{ if } 0\leq x\leq 1\\ \rho_0\ , \qquad\quad \text{ if } 1<x\leq 10\end{cases} \tag{5}$$

$$u=\begin{cases}U_0\ , \text{ if } 0\leq x\leq 1\\ 0\quad\ , \text{ if } 1<x\leq 10\end{cases} \tag{6}$$

$$c=\begin{cases}1\quad , \text{ if } 0\leq x\leq 1\\ 0\quad , \text{ if } 1<x\leq 10\end{cases} \tag{7}$$

$$\nu_{ef}=\begin{cases}k_1\cdot\nu_0\cdot c\quad , \text{ if } 0\leq x\leq 1\\ k_2\cdot\nu_0\cdot c\quad , \text{ if } 1<x\leq 10\end{cases} \tag{8}$$

The above mentioned correlations show that in the model space the square $\{0\leq x\leq 1;\ 0\leq z\leq 1\}$ has been used for description of the initial volume of suspensive water formed in the zone of wave action. Mixing coefficient k_1 is also specific for this space and might be chosen in a way to satisfy extremely high (stormy) mixing of water in the coastal zone. Coefficient k_2 is used for parametrization of turbulent exchange in bottom flow outside wind influence zone.

Model boundary conditions were as follows: on the left side of model space (*x=0*)

$$u=U_0\ ,\ \rho=\rho_0+\Delta\rho_0 \tag{9}$$

on the right side of model space (*x=10*)

$$\frac{\partial u}{\partial x}=0,\ \ \frac{\partial\rho}{\partial x}=0,\ \ \frac{\partial\omega}{\partial x}=0 \tag{10}$$

On the upper ($z=\mathbf{1}$) and lower ($z=\mathbf{0}$) boundaries of model the conditions on fluid non-passage and sliding were prescribed (Anuchin & Gritsenko 1985; Gritsenko & Sivkov 1997), thus, allowing to escape consideration of viscous interaction between flow and bottom, which is not the purpose of the given paper.

CALCULATIONS

Besides the determined characteristic values of velocity, length and density drop the first series of calculations were done with mixing coefficient $\mathbf{k}_1=6\ \mathbf{cm^2/s}$. Analysis have shown that dispersive source of suspensive water located on the left border of the model space always generates bottom flow. However, simple consideration of suspension effect in coastal zone of wind influence is insufficient for estimation of cold water accumulation even in the case of occurrence of an initial "reserve" of suspensive water at the start moment of time (see Fig. 2, the upper diagram). Note that at the ordinary flow parameters quick plumbing (collapse) of heavier water mass takes place. Fig. 2 shows three successive phases of this process. This peculiarity was supported by observations during experimental amber extraction in the area of Sambian Peninsula and in other places of the Baltic Sea (Aibulatov 1990; Sudolskiy 1991; Simpson 1982).

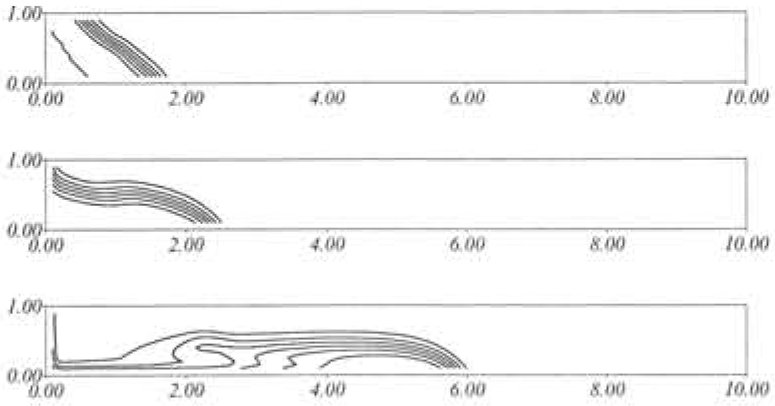

Fig. 2. Successive phases of distribution of discontinuity current in the model space. Quick compression of coastal water volume in a vertical is clearly seen. Isolines of excessive density $\sigma=(\rho-\rho_0)/\Delta\rho_0$ in figure run consequent (up from bottom) on the following values: { 0.1 ; 0.25 ; 0.4 ; 0.55 ; 0.7 ; 0.85 }

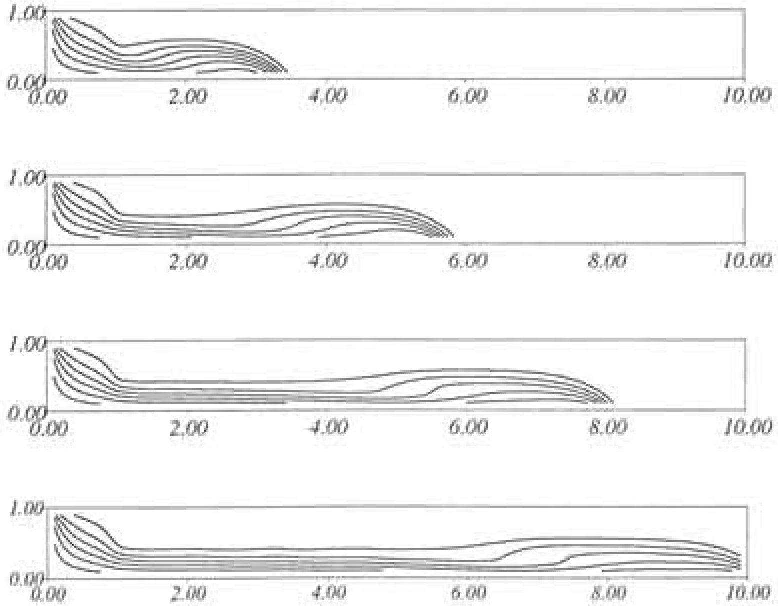

Fig. 3. Successive phases of discontinuity current distribution in the model space. Volume of suspensive water is clearly seen in the left part. Isolines of excessive density $\sigma=(\rho-\rho_0)/\Delta\rho_0$ in figure run consequent (up from the bottom) on the following values: { 0.1 ; 0.25 ; 0.4 ; 0.55 ; 0.7 ; 0.85 }

The second series of calculations was based on assumption about strong spatial non-homogeneity of turbulent mixing coefficient in the water area under consideration. Evidently, in the zone of active storm mixing, a characteristic scale of velocity fluctuation might be equal to amplitude of breaking waves, becoming as large as 1 m/s (Pikhov, Dachev & Kosyan 1980; Antsiferov et al. 1978). It is also clear that in this case the process of spreading of initial volume of slope water will be much slower in comparison with the above considered case. To parametrize the effect of storm mixing, in the second experiment we have chosen viscosity coefficient $\mathbf{k}_1=300\ \mathbf{cm^2/s}$ characteristic only of the intensive wind mixing zone (located in the model in square $\{0\le\mathbf{x}\le1;\ 0\le\mathbf{z}\le1\}$). In the rest of the model space mixing coefficient was taken depending on situation. In particular, when suspensive near-bottom jet leaves mixing zone, running down sloping bottom, the effective viscosity coefficient have been assumed to be ordinary ($\mathbf{k}_2=6\ \mathrm{cm^2/s}$), which is far from an extreme storm value .

Successive calculations support validity of assumption that extremely large mixing coefficient in the zone of storm impact is of crucial importance for formation of turbidity flows. Consecutive phases of discontinuity development or return current shown in Fig. 3 testify that under proposed conditions in the coastal zone the quasi-stationary near-bottom currents are formed indeed. At the same time, in coastal area, the source of suspensive water remains existing, and this is in full correlation with field observations in many seas (Sukhodolskiy 1990; Aibulatov 1990; Pikhov & Dachev 1981). Thus, extremely large (stormy) mixing in coastal zone is a necessary condition for formation of discontinuity or return suspensive currents penetrating in the area below transition layer. Note that value $\mathbf{k}_1=300\ \mathrm{cm^2/s}$, chosen proceeding from physical compatibility to numerical solution, is satisfactorily in concordance with field data (Sukhodolskiy 1991).

Finally, having left the zone of intensive storm mixing, the suspensive current is transformed into a near-bottom current with a high and stable stratification. In so doing, vertical fluctuations (as well as vertical mixing) on the upper boundary of current will be suppressed by buoyancy forces (Simpson 1982). The transformation of homogeneous turbulent current into the near-bottom current with a complex anisotropic structure of fluctuations takes place. Inside the near-bottom current, where stratification is small or absent, during a certain period of time the high level of turbulence exists. As a result, the most probable scenario of process development is as follows: firstly, after G.I. Barenblatt (1982), fetch of near-bottom current and growth of stress should have taken place. This may only intensify erosive role of near-bottom current and secondary saturation of current with suspensive material, providing thus growth of life time and distance of the near-bottom current spreading. Calculations support validity of at least two first phases of the process: formation of stable source of suspensive sloping bottom water and near-bottom suspensive current as it is.

CONCLUSION

The given work has proved, first of all, that an extremely high values of mixing coefficient are necessary for accumulation of quasi-stationary volume of suspensive water in the wave impact zone. All calculations and comparisons carried out allow to suggest the phenomenological model of formation of discontinuity and return currents under stormy conditions. The model compares quite well the available experimental data.

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Distribution and Composition of Bottom Sediments on the Underwater Slope at the Lithuanian Coast of the Baltic Sea

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Main types of bottom surface sediments on the underwater slope of the Lithuanian coast are found to be boulders with pebbles and gravel, sands and silts. Coarse clastic sediments are related to the exposures of till deposits, whereas fine sands and silts are mostly formed under recent sedimentation conditions. The chemical composition of sandy sediments is typical of the geochemical background in the south-eastern part of the Baltic Sea.

Keywords: underwater slope, bottom sediments, grain-size, chemical composition.

INTRODUCTION

The underwater slope at the Lithuanian coast of the Baltic Sea (nearshore) as a part of the entire coastal zone lies between the dynamic shoreline and the depths of 20-30 m, where waves and wave currents still affect the bottom relief and load transport (Dolotov 1989; Gudelis 1993). The geological structure of the bottom and its palaeogeographical development have determined heterogeneity of the Lithuanian coastal zone. Two morphogenetic types of the coastal zone are distinguished: the coast of Kuršių Nerija (Curonian) Spit (from Nida to Klaipėda) and the continental coast (from Klaipėda to Būtingė) (Gudelis 1992, Kirlys & Janukonis 1993).

The nearshore of the continental coast is separated from the deeper part of the sea by glacial plateau. Bottom relief is of abrasive-accumulative type with relicts of old abrasion forms here (Gelumbauskaitė & Litvin 1990). Formation of recent bottom sediments takes place at very different depths: from 0 to 20-27 m, but in some places - only up to 4 m. The underwater slope at the coast of Curonian Spit is notable for a relatively smooth accumulative relief (Gelumbauskaitė 1993). Bottom sediments distributed here were formed recently under the influence of currents and sedimentary matter outflow from the Kuršių Marios (Curonian) Lagoon.

The new data on bottom sediment distribution and composition on the underwater slope of the Lithuanian nearshore are discussed in the article.

METHODS

The data used in this paper were collected during the state geological survey on the scale of 1:50000 (1993-1995) and subsequent investigations of the nearshore carried out in 1996-1997. The investigation area covers the nearshore of the northern part of the Curonian Spit and mainland coast - between the dynamical shoreline and the depths of 20-30 m. The field investigations embraced bottom echo-sounding and sediment sampling. Echosounder "Fish Finder Model-1060A" (frequency 200 kHz) has been used. Accuracy of depth measurements was 1%. The investigation profiles were spaced every 500 m. The bottom sediments were sampled by Van Veen grab and taking into consideration the morphological peculiarities of the bottom relief, but at space intervals less than 500 m. The location of profiles and stations was recorded using the GPS "Shipmasters 5310".

Grain-size of the bottom surface sediments (interval 0-3 cm) was analysed using sieving and complex pipette-sieving methods. The granulometric types of bottom sediments were distinguished according to Wentworth (1922) and Shepard (1969) classification: sand (2-0.063 mm), silt (0.063-0.004 mm) and clay (<0.004 mm). The chemical composition of bottom

sediments was determined by the following methods: coulonometric - CO_2 and TOC (accuracy of measurements - 0.03%), spectrometric - P, Ti, Mn (0.01%), Ca (0.5%), flameless atomic absorption - Hg (10 ppb), atomic absorption Pb, Ni, Co, Cr (10 ppm), Cu, Zn, Li, Rb, Cd (5 ppm), Fe, Na, K, Mg (0.1%).

DISTRIBUTION OF BOTTOM SEDIMENTS

The material composing the bottom sediments in the studied area is rather heterogeneous: boulders, pebbles, gravel, mixed sand and silt (Fig. 1). Washed out from the till relict deposits and carried out from the Curonian Lagoon it is transported by a longshore sediment flow. This sedimentary material differs in origin, and under the impact of hydrodynamic factors forms the lithological types of bottom sediments of variable grain-size composition: (1) boulders (pebbles, gravel), (2) coarse- and medium-grained sand, (3) fine sand, and (4) silt.

Boulders (pebbles and gravel). Their distribution is related to the exposures of till deposits. In many cases the surface of tills is strongly eroded and covered with coarse clastic material: boulders, pebbles and gravel. The variable in size material is distributed on the sea floor in a mosaic pattern. Boulders prevail, but the areas of mixed sand, pebbles and gravel occur among them. The diameter of boulders rarely exceed 30-40 cm, however, some blocks reach 6 m. Their surface is covered with the colonies of *Mytilus* and *Balanus* molluses.

Coarse- and medium-grained sand. It is mostly related to the relict deposits. Sands particularly abound at the foot of plateau of the Šventoji-Būtingė aquatory and also are found at the depths up to 2 m in the environs of Klaipėda and Olando Kepurė cliff. The increase in grain-size of the sand in these areas of the underwater slope is related to the deficiency of transported sedimentary matter due to the impact of Klaipėda port jetties and coast abrasion.

Fine sand. It constitutes almost all recent bottom sediments accumulating in the nearshore. We can get more information about the regularities of their sedimentation from the data about the distribution of median diameter (Md) (Fig. 2). The dominating Md of sands in the surf zone till 4-10 m is 0.25-0.16 mm. Depending on the bottom inclination, amount of sediments and dominating longshore sediment flow the underwater sand bars develop. In the studied area we can distinguish three nearshore parts with Md of sands in greater depths changing unevenly: the nearshore of the Curonian Spit, Klaipėda-Šventoji, and Šventoji-Būtingė slopes.

Silts. Their accumulation in the nearshore is related to the wastewater unloading into the sea and drift from the Curonian Lagoon (Gulbinskas & Gaigalas 1997). The sedimentary matter from these sources settles

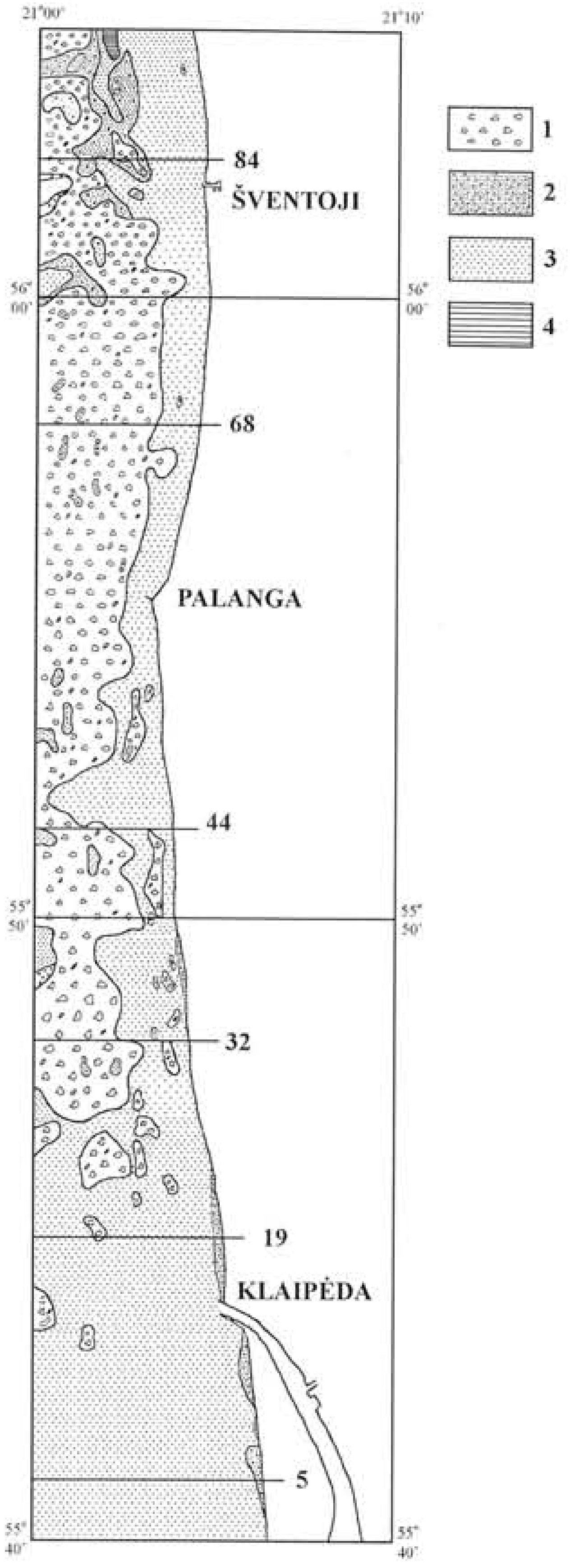

Fig. 1. Lithological types of bottom surface sediments: 1 - boulders (>64 mm) and gravel (64-2 mm), 2 - coarse-grained (2-0.5 mm) and medium-grained (0.5-0.25 mm) sand, 3 - fine (0.5-0.063 mm) sand, 4 - silt (0.063-0.004 mm)

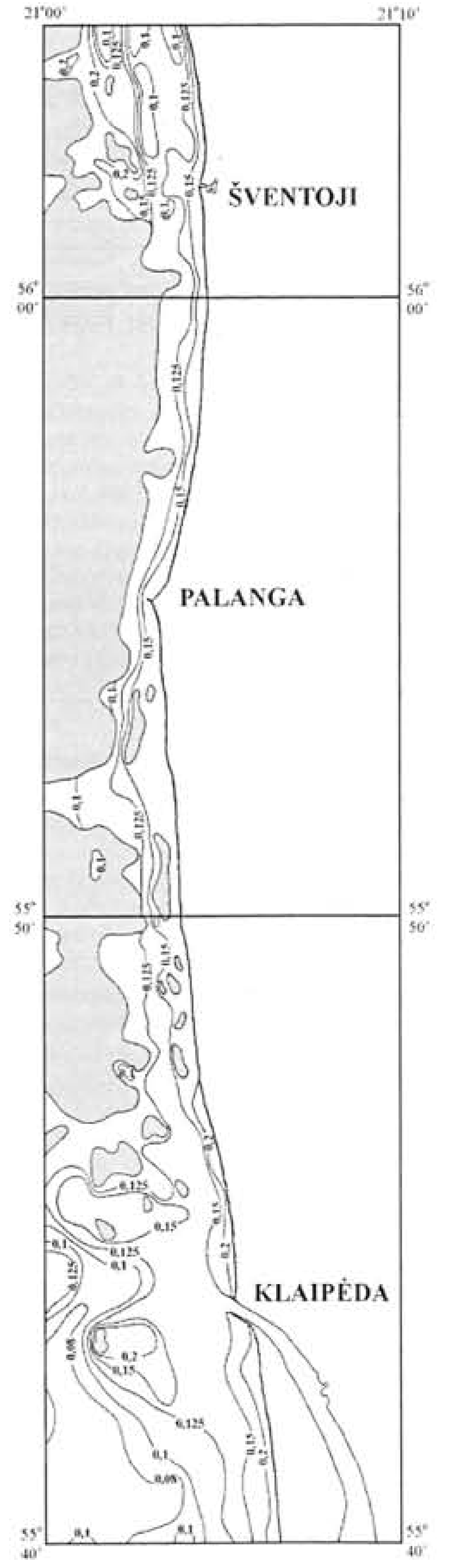

Fig. 2. Md (mm) of bottom surface sediments

down on the substratum of variable lithological composition and forms a 30-40 cm thick unstable layer of silty mud. Its development and time of existence greatly depends on the hydrodynamic conditions. The wastewater is discharged into the sea in the Šventoji-Būtingė aquatory at the depths of 16-18 m. In this area the silty muds accumulate. The patches of silty sediments from the Curonian Lagoon can be traced at the depths of 13-16 m, about 10 km northwards from the Klaipėda Strait mouth.

GRAIN SIZE AND CHEMICAL COMPOSITION

Fig. 3 demonstrates the changeability of grain-size composition of bottom sediments in various parts of the underwater slope. In the Curonian Spit nearshore the sands gradually get finer and turn into silts (Fig. 3, profile 5). The formation of bars is obvious till the depths of 8 m. The composition of bottom sediments includes a considerable amount of medium- and even coarse-grained sand. Further on - till the depths of 20 m - the underwater slope is a concave in profile, the content of 0.25-0.125 mm fraction sharply decreases, whereas the content of 0.125-0.10 mm fraction remains stable. At the depths of 20-30 m the composition of sediments is rather stable and represents a smoothened flat bottom relief.

In the Klaipėda-Šventoji area the grain-size composition of sand, beyond the surf zone and till the contact zone with the relict deposits, remains rather stable. However, in the northern direction the sediments on the underwater slope get finer. The dominating fraction in profiles 19 and 32 is 0.25-0.125 mm, 0.125-0.1 mm - in profiles 44 and 64, with the fraction 0.1-0.063 mm gaining weight. Very distinct changes of grain-size composition in some places are related to the exposures of relict deposits (profiles 19 and 44), which at the depths of 10-15 m (profiles 32, 44 and 68) represent the bottom surface in the considered slope. In the environs of Šventoji (profile 84) the active accumulation of sand till the depth of 17 m considerably increases the content of fraction 0.25-0.125 mm. In the deeper part the fine sand is deposited on the coarser relict deposits.

The given examples reveal that the differences of the distribution regularities of recent bottom sediments in the studied coastal zone largely depend on the distribution of relict deposits, bottom relief and impact of hydrotechnical constructions (Gulbinskas 1995).

The chemical composition of bottom sediments was evaluated by comparison of geochemical characteristics (Table 1) of three main areas (Klaipėda, Palanga and Šventoji) situated northwards from the mouth of the Curonian Lagoon. All samples represent fine sands (Md - 0.125-0.09 mm) taken from the depths of 14-20 m.

Table 1. **Chemical composition of the bottom surface sediments (0-3 cm)**

Elements and components		Klaipėda area (21)*	Palanga area (8)	Šventoji area (5)
TOC	%	0.24-5.45 2.04	0.14-3.05 1.19	0.11-0.26 0.2
$CaCO_3$		2.50-25.66 10.21	2.41-17.1 7.44	1.91-4.41 3.43
Fe		0.85-3.65 1.94	1.1-3.13 2.0	0.96-1.0 0.98
Mn		0.01-0.15 0.05	0.03-0.11 0.07	0.02 0.02
K		0.83-1.47 1.14	0.65-1.63 1.14	0.75-0.99 0.88
Na		0.3-1.05 0.58	0.30-0.95 0.50	0.28-0.35 0.31
Ca		0.86-6.43 3.28	0.88-5.18 2.46	0.97-1.37 1.41
Mg		0.20-1.10 0.58	0.25-1.32 0.57	0.25-0.29 0.27
Ti		0.14-0.33 0.23	0.11-1.38 0.53	0.18-0.37 0.25
P		0.03-0.14 0.07	0.04-0.11 0.07	0.05 0.05
Cu	ppm	<5-39 18	<5-21 11	5-6 5
Zn		13-174 68	20-130 50	21-32 26
Cr		<10-60 37	<10-72 40	10-50 23
Ni		<5-58 29	<5-87 24	5-10 8
Co		<5-27 13	7-22 13	5-10 7
Li		<5-40 17	<5-32 12	5 5
Rb		28-136 68	22-120 62	30-46 37
Pb		<10-108 22	<10-122 35	<10 <10
Hg	ppb	<10-79 26	<10-79 30	31-72 41

* Number of studied samples
Limits of concentration values are given in numerator, average values - in determinator

The maximum concentrations of many chemical elements were recorded in the Klaipėda area. Their main source is, presumably, the drift from the Curonian Lagoon. In the dominating direction (S-N) of sediment matter transportation a general tendency of decreasing content of chemical elements can be observed. Mercury is an exception because its highest average concentrations occur in the Šventoji area. Such situation has been observed before (Pustelnikovas 1994) and accounted for by the wastewater discharge. The maximum values of some elements (Mg, Ti, P, Cr, Ni, Co, Rb, Pb) are rather widely distributed over the Klaipėda and Palanga areas. Throughout the whole slope between Klaipėda and Šventoji the accumulation of thin-dispersed sedimentary matter (main accumulator of chemical elements) is unstable and its distribution is very fragmentary. Under the changing lithodynamic situation this material is re-suspended and transported to other places of accumulation. This may act as an important factor in the formation of local (but temporary) geochemical background.

In general the concentrations of chemical elements and components in the sands of nearshore zone are similar to those in other parts of Southeast Baltic Sea (Emelyanov 1987,1996, Repečka et al. 1997).

CONCLUSIONS

The distribution of bottom sediments and variations of grain-size composition in the studied nearshore of the Lithuanian coast is generally determined by the exposures of relict deposits (boulders, pebbles, gravel and mixed sands), recent processes of sedimentation (medium- and fine sand) and impact of hydrotechnical constructions.

In the areas of recent accumulation only the sands (>0.063 mm) accumulate permanently. The accumulation of silts and muds bears an episodical character. It depends on the season, duration of stagnant hydrodynamic regime and technogenic factors (wastewater discharge).

The differentiation of the grain-size composition of bottom sediments on the underwater slope moving from south to north varies depending on the lithodynamic properties of different parts of the nearshore. Three parts can be distinguished: slope of the Curonian Spit -

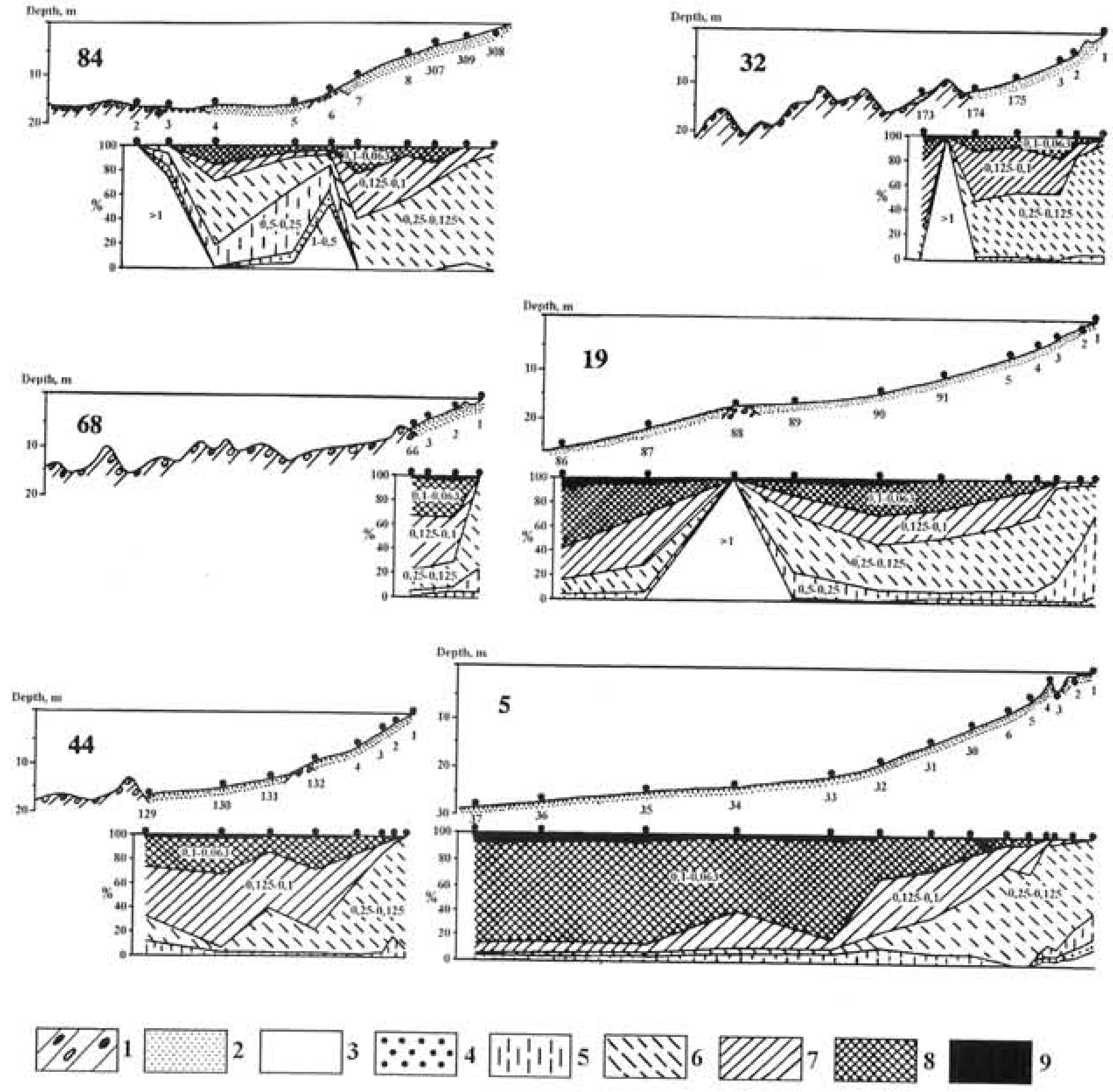

Fig. 3. Morphological profiles on the underwater slope and grain-size of sediments (location of profiles are shown in Fig. 1). Sediment types: 1 - tills, 2 - sands. Grain-size composition: 3 - >1 mm, 4 - 1-0.5 mm, 5 - 0.5-0.25 mm, 6 - 0.25-0.125 mm, 7 - 0.125-0.1 mm, 8 - 0.1-0.063 mm, 9 - <0.063 mm

accumulative; Klaipėda-Šventoji - transitional-accumulative-erosive; Šventoji-Būtingė - accumulative-transitional.

The distribution of chemical elements and components in the sandy sediments is typical of the geochemical background of the Southeast Baltic Sea. Larger deviations of concentrations are determined by local changes of sedimentation conditions in each individual area of the nearshore.

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Metal Distribution in the Sediments of Kuršių Marios Lagoon, Lithuania

Kęstutis Jokšas

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Bottom sediment samples from the northern part of the Kuršių Marios Lagoon were investigated for Pb, Zn, Cu, Cd, Cr, Hg, and total organic carbon(TOC). The content of TOC in the bottom sediments of the northern part of Kuršių Marios Lagoon varies from 0.01 to 7.9%. The lithological type of sediments determines the distribution of Cu, Cr, Zn, Pb and Hg and affects in the least the concentrations of Cd. The maximum concentrations of most metals are observed in the sediments of Klaipėda strait and in the fine-grained Kuršių Marios Lagoon bottom sediments. A particularly good correlation coefficient was determined for Hg and Cu (0.85), Hg and Zn (0.86), Hg and TOC (0.8), TOC and Cu (0.75) and TOC and Zn (0.75).

Keywords: Kuršių Marios Lagoon, bottom sediments, metals, total organic carbon.

INTRODUCTION

The Kuršių Marios Lagoon is a fresh shallow basin (average depth is 3.8 m) separated from the Baltic Sea by Kuršių Nerija Spit and connected with it only through a narrow Klaipėda strait. Its water level depends on marine water level oscillations, wind force and direction and yearly distribution of river runoff among which Nemunas must be distinguished. The water in the lagoon changes throughout the year for 3.5 times (Rainys 1978).

The present article is devoted to the northern part of the Kuršių Marios Lagoon which is included into Lithuania's territory and makes approximately one third (413 km^2) of the total (1584 km^2) lagoon area. The greatest depth exceeding 4-5 m is observed in the central and southern parts of the investigated area and only the Klaipėda strait is artificially deepened till 14 m (Fig. 1).

METHODS AND MATERIAL

Sediment samples for metal analysis were taken in September 1996. Surficial (0-3 cm) bottom sediments were taken with a Van Veen sampler and from deeper layers (up to 50 cm) with gravity corer of a 50 mm diameter with a plastic insert (Niemistö 1974). The sediment cores were sliced into 1 cm subsample slices. 84 bottom sediment samples were investigated for Pb, Zn, Cu, Cd, Cr, Hg, and total organic carbon(TOC). For metal analysis the solution of strong acids ($HClO_4$, HNO_3, HCl, HF) (total digestion method) were used. The content of trace elements was determined by the method of atomic absorption. Mercury was determined using the cold vapour reduction-aeration method (Hatch and Ott 1968). Total carbon was analysed by Leco type analyser. TOC was obtained from difference between the total and carbonate carbon values (Hedges and Stern 1984).

DISCUSSION

A major part of the investigated area is covered with fine-grained sandy sediments which form mainly under the influence of sedimentary matter carried into the Kuršių Marios Lagoon by the Nemunas River. In the mentioned zone the transition of thin-dispersed sedimentary material into the Baltic Sea takes place. In the composition of sand the fractions 0.25-0.1 mm dominated. Their content varies from 58.2 to 97.5 %. The content of thin-dispersed particles (< 0.063 mm) in this sand does not exceed 3 % (Fig. 1).

In some bays and embayments as well as lowerings of the bottom muddy sediments develop due to weak

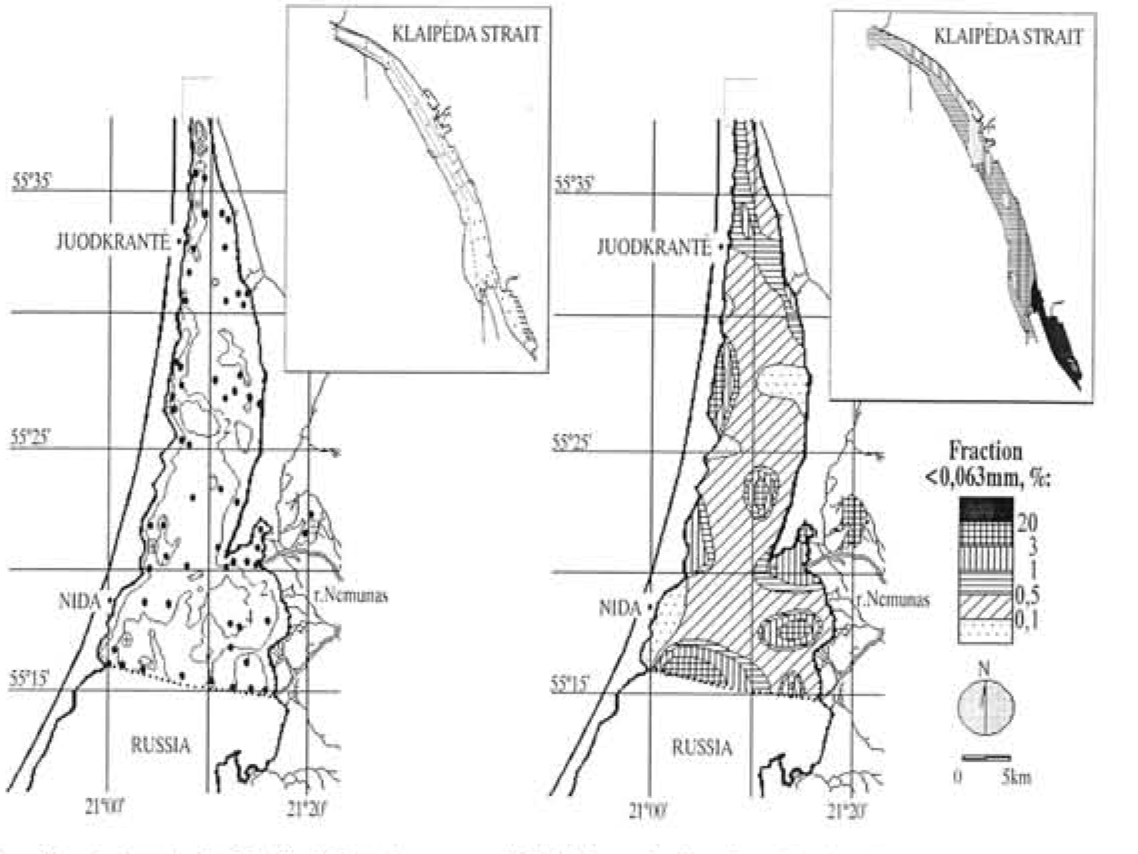

Fig. 1. Sampling stations in the Kuršių Marios Lagoon and Klaipėda strait. Fraction of under 63 mm particles in the surface (0-3 cm) layer of bottom sediments

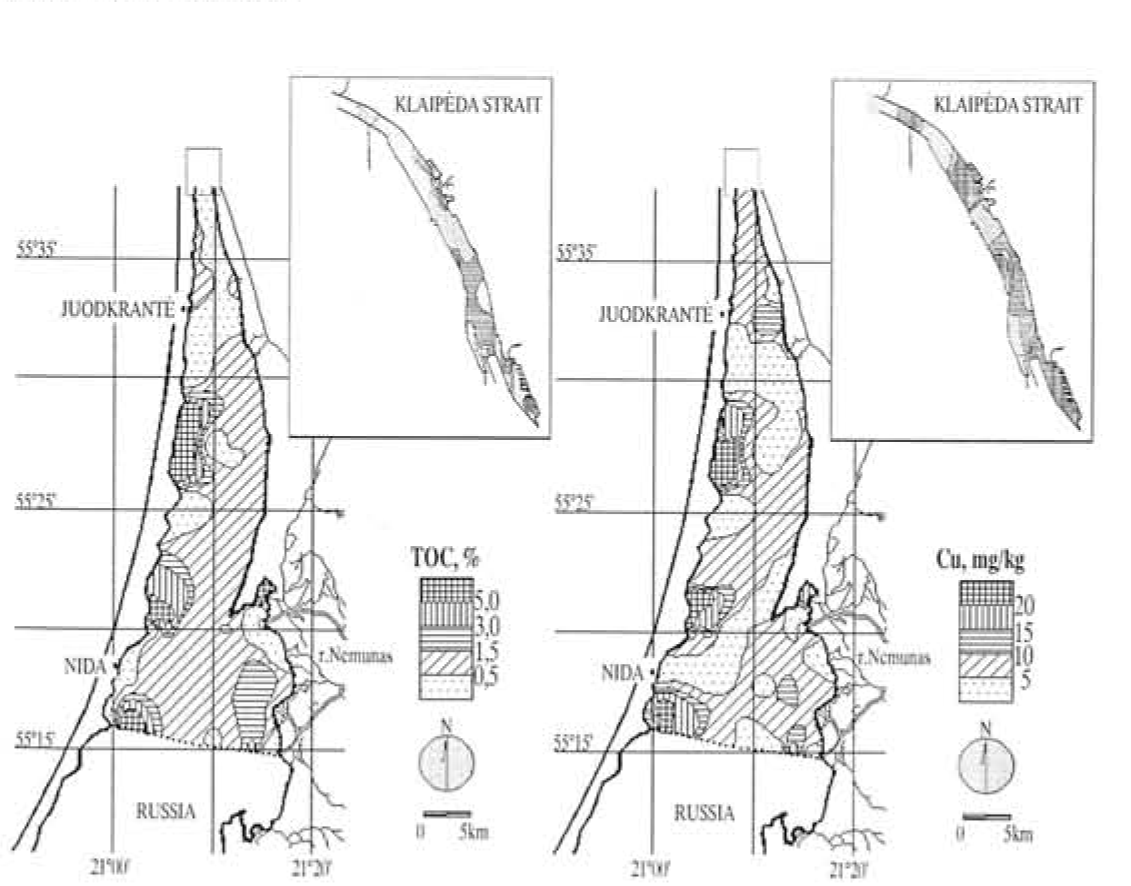

Fig. 2. Distribution of total organic carbon (TOC) and copper (Cu) in the surface (0-3 cm) layer of bottom sediments

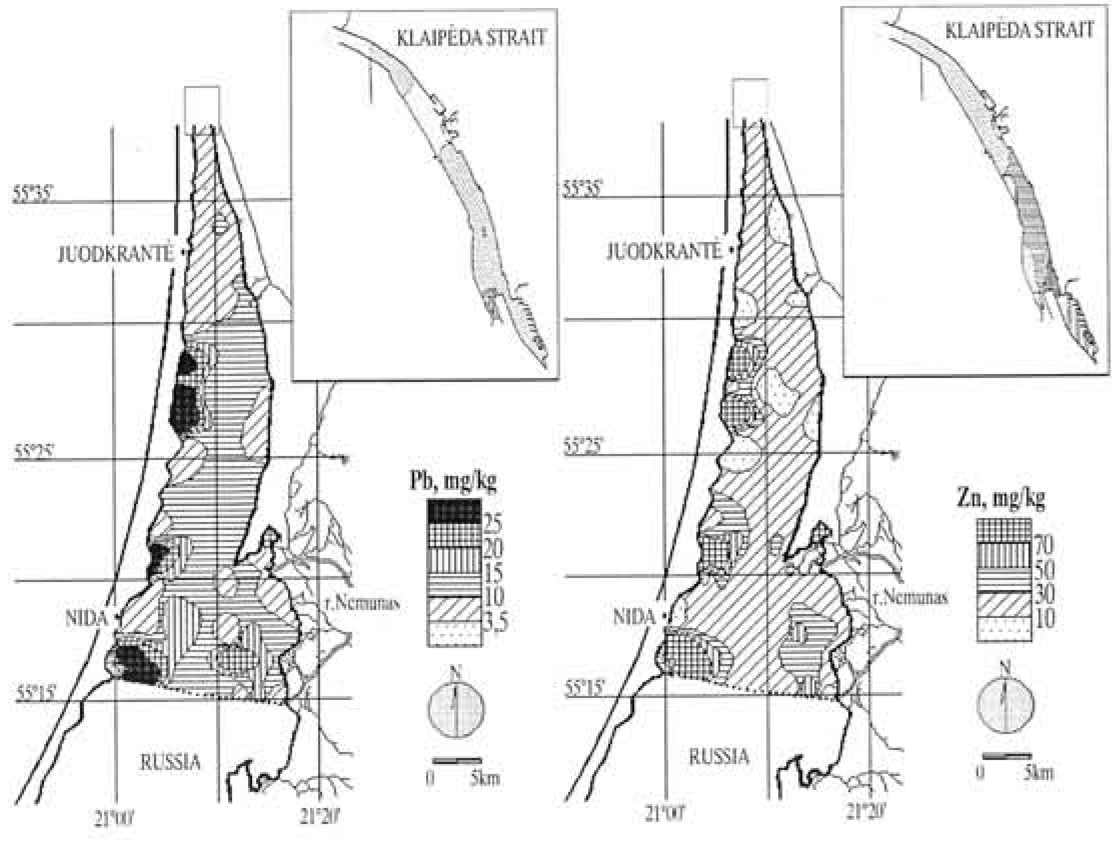

Fig. 3. Distribution of lead (Pb) and zinc (Zn) in the surface (0-3 cm) layer of bottom sediments

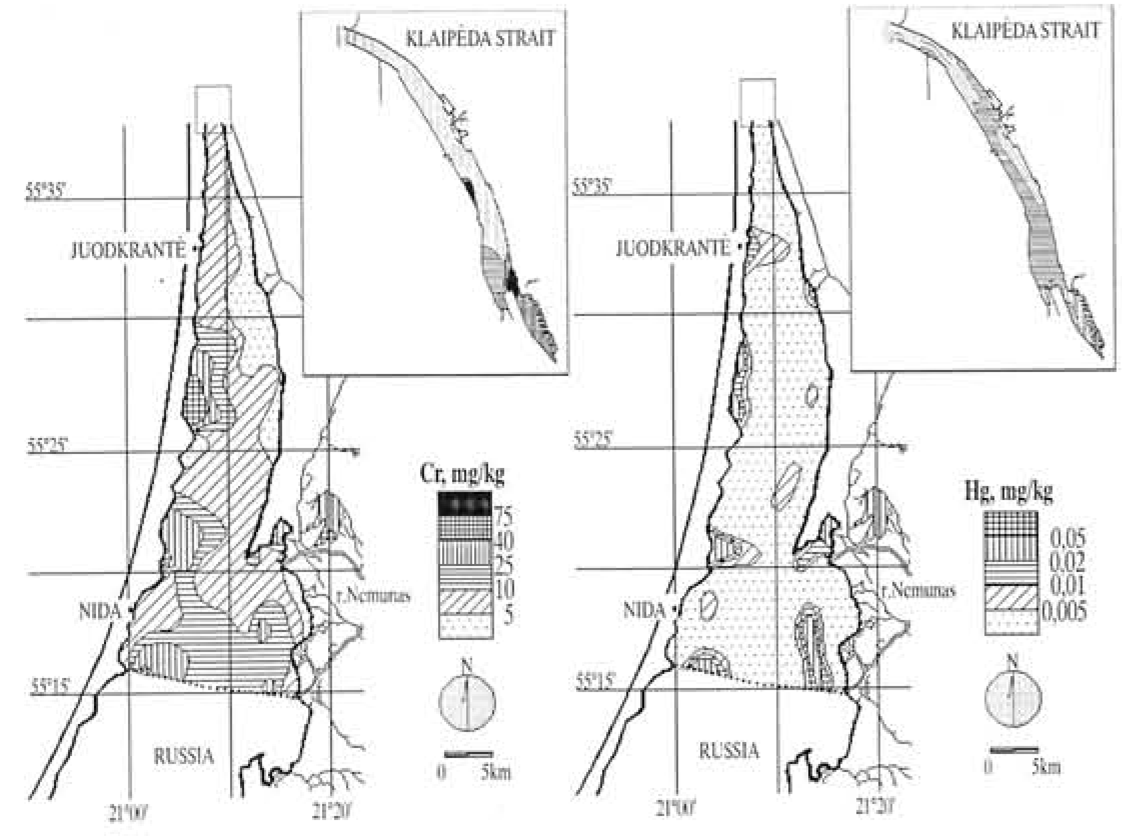

Fig. 4. Distribution of chromium (Cr) and mercury (Hg) in the surface (0-3 cm) layer of bottom sediments

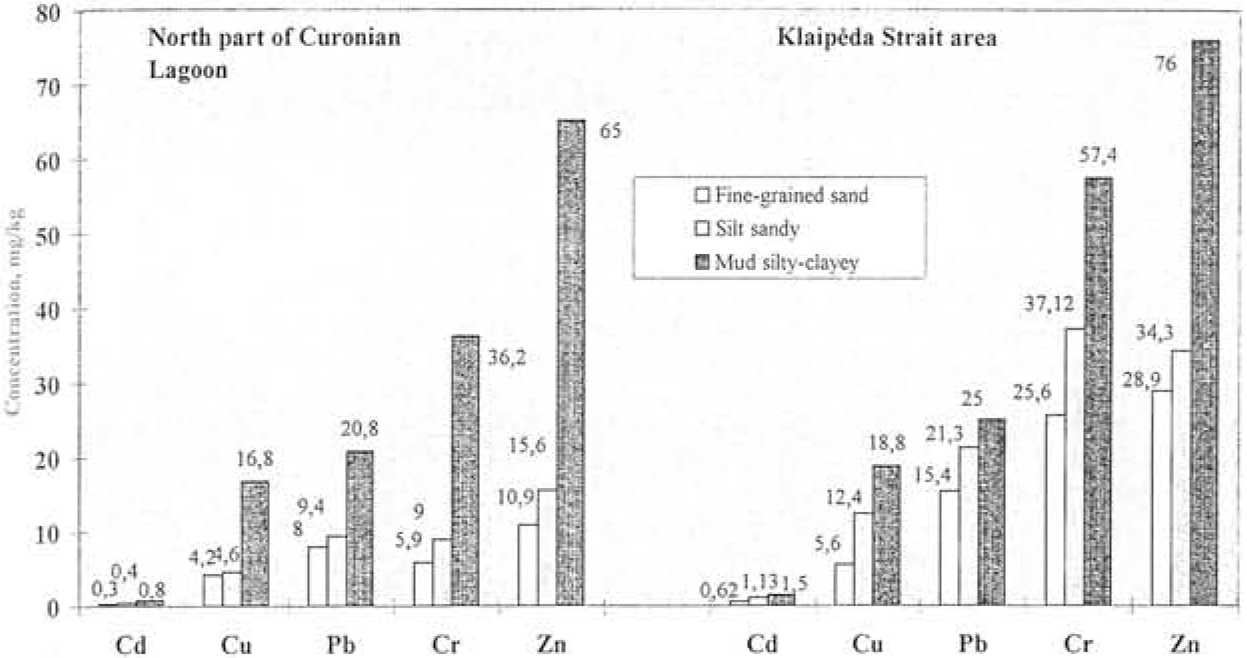

Fig. 5. Average amount of metals in different types of bottom sediments in the Northern part of Kuršių Marios Lagoon and Klaipėda Strait

hydrodynamics. They are in most cases composed of dark grey mud, silty -clayey with organics, and small shell detritus.

Investigation data revealed that maximum concentrations of most metals occur in muddy sediments, whereas, minimal - in medium and fine grained sands. The amount of metals under natural conditions is in direct proportion to the content of thin-dispersed sedimentary material consolidated in the sediments (Figs. 1, 2, 3 and 4). It also depends on the granular and genetic composition of this material, morphology of particles, consistency, degree of organic matter destruction, etc.

The content of TOC in the bottom sediments of northern part of Kuršių Marios Lagoon varies within 0.01 to 7.9% (Fig. 2). The average content of TOC in the medium-grained sand is 0.14 %, fine-grained - 0.5%, silty sand sediments - 0.6% and mud silty-clayey sediments 4.4. In the areas of mud accumulation the concentration of TOC is maximum in the surface layer of bottom sediments and gradually decreases with depth. Particularly high values of correlation coefficient exceeding 0.75 were determined between TOC and Cu, and TOC and Zn

As sandy sediments prevail in the northern part of Kuršių Marios Lagoon the concentrations of metals are not high there. In the areas of muddy sediment distribution the concentrations of metals increase (if compared with sands) from 1.5 to 9.0 times. The lithological type of sediments determines the distribution of Cu, Cr, Zn, Pb and Hg and affects in the least the concentrations of Cd. Metals are closely interrelated.

The results obtained revealed that the maximum concentration of mercury in the northern part of Kuršių Marios Lagoon (excluding the Klaipėda strait) is 0.033 mg/kg. The increased concentrations are observed in mud silty-clayey sediments and only in small bays closer to the shore and further from the main stream of Nemunas water falling into the Baltic sea (Fig. 4). Almost throughout the northern part of Kuršių Marios Lagoon the concentration of mercury does not exceed 0.01 mg/kg.

The correlation coefficient between Hg and TOC (0.8) revealed that there exists a direct link between their concentrations. Particularly good correlation coefficient was determined for Hg and Cu (0.85), Hg and Zn (0.86). This may prove their common ways of getting into the bottom sediments.

Sediments most highly enriched with metals are observed in the Klaipėda Strait. The sedimentary matter coming from the Kuršių Marios Lagoon abundantly settles down in the lagoon— sea barrier zone (Jokšas 1996). Together with the highly polluted sedimentary matter coming from the Klaipėda port and town it constitutes the most highly polluted bottom sediments in the whole Lithuanian sector of the Baltic Sea. Investigations revealed that the sediments of Klaipėda strait are particularly highly enriched with Zn, Cr, Pb, Cu, Cd and Hg (Fig. 5). In the fine-grained sand the concentrations of Cu, Pb, Cd, Zn and Cr are higher from

1.3 to 4.5 times, whereas, in mud silty-clayey sediments - from 1.1 to 2.3 times. The increased metal concentrations are obvious in sands which, if compared to the northern part of Kuršių Marios Lagoon, is related with the increase of thin-dispersed sedimentary material (< 0.063 mm) in certain types of sediments and anthropogenic pollution of the area. In the Klaipėda strait the concentration of mercury, if compared with the northern part of lagoon, increases twice.

The distribution of metals in the columns of bottom sediments bears a rather complicated character. In the upper layer of sample cores the increase of concentrations of some metals (Cu, Zn, Cr) can often be observed. The fluctuations of concentrations in deeper horizons is related with the increase of TOC, changes of lithological composition of sediments. In deeper horizons (depth 5-15 cm) of sediment sample cores of the northern part of Kuršių Marios Lagoon a slight increase of Pb, Cu, Ni concentrations can be observed. This could be accounted for by an active anthropogenic pollution 10-15 years ago when industry and agriculture functioned rather intensively. In the sediment layer up to 50 cm in depth the traces of bioturbation can often be observed.

CONCLUSIONS

Generalizing we should point out that in the sediments of the northern part of the lagoon the maximum concentrations of most metals are observed in the fine-grained fractions of bottom sediments which accumulate in local lowerings of relief, bays and embayments, where water hydrodynamics is weak. The concentrations of Cr and Zn in sediments are closely related with the content of TOC in the sediments. In the Klaipėda strait area, where active mixing of fresh and salty water and intensive economic activity take place, the concentration of metals in sediments increases if compared with the northern part of Kuršių Marios Lagoon.

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Buried Quaternary Channels in the Southern Baltic Sea North of Rügen Island, Germany: Distribution and Genesis

Udo Jürgens

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Reprocessing and reinterpretation of seismic-reflection records enabled previously poorly documented seismic velocity anomalies in the uppermost reflections north of the island of Rügen to be more accurately characterized. They are interpreted as due to a channel system formed during the Quaternary. The channels are not reflected in the morphology of the sea floor. They trend mainly NE–SW, with an apparent depth of about 10 to 50 ms TWT, and are mostly between 500 and 1000 m wide and vary in cross-section. The channel system covers an area of about 625 km^2. Their genesis was possibly influenced by uplift movements of the Arkona block. The channels were most probably eroded in front of the ice sheet due to the drop in base level in the North Sea area during the Pleistocene.

Keywords: Quaternary channels, southern Baltic Sea, seismic records, reprocessing, interpretation.

INTRODUCTION

Between 1975 and 1987, several seismic reflection surveys were carried out for hydrocarbon exploration in the German sector of the Baltic Sea by PETROBALTIK, a consortium formed by the former socialist riparian nations to the Baltic Sea. The seismic lines had a total length of about 16,000 km and were arranged on a regular grid with a spacing of between 1 and 2 km.

The PETROBALTIK records from the area north of Rügen Island (Fig. 1) show a pattern of near-surface seismic anomalies documenting locally increased travel-times in the map of the base of the Cretaceous (Wegerdt et al. 1994). The anomalies must be regarded as real and have been interpreted as indicating a channel system of Quaternary age.

Precise analysis of these shallow anomalies was considerably complicated by the fact that the original seismic arrays were aimed at Permo-Carboniferous and older rocks, the targets of the exploration campaign, which are located at considerable depths. At that time, frequencies > 62.5 Hz were suppressed during recording, and processing was of course focused on deep horizons.

REPROCESSING

North of Rügen Island, water depths range in 10–40 m, the sonic velocity in the water is 1500 ms^{-1} and the sonic velocity in the uppermost sediments assumed to be 1900 ms^{-1}. The normal seismic array used a distance of 160 to 240 m from the shot-point to the first group of hydrophones. Under these conditions, the wave reflected by the sea floor, the direct wave from the shot-point to the first group of hydrophones, and the refracted waves from the uppermost sediments arrived almost at the same time. Therefore, the invariable bundle of reflections is seen in the seismic records at a travel time of about 150 ms (TWT) as an apparently irresolvable mixture of waves (see Fig. 2, bottom).

The research project "Structural Atlas of the Southern Baltic Sea (SASO)" (Schlüter et al. 1997) undertook the reprocessing of PETROBALTIK's seismic

Fig. 1. Location map

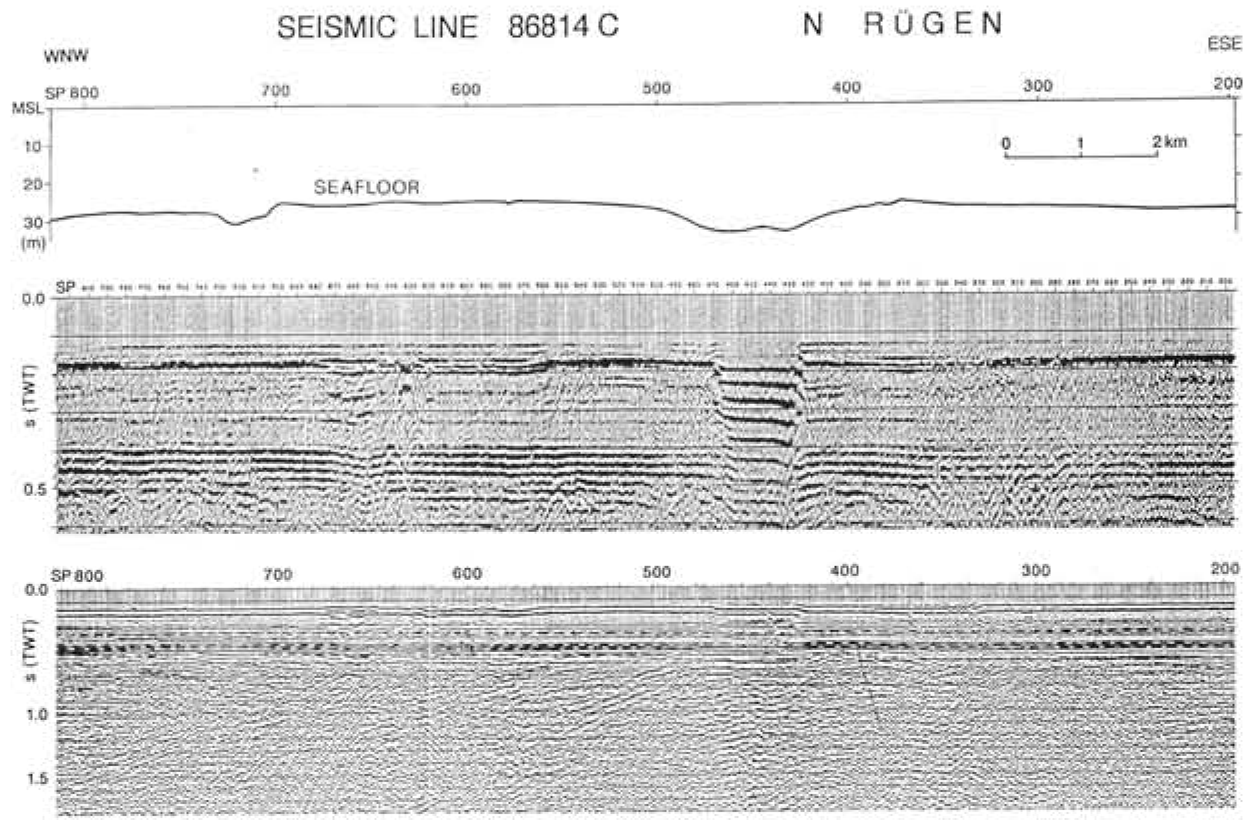

Fig. 2. Comparison of original and reprocessed seismic lines. Top: echosounder record showing open channels. Middle: reprocessed line with near-shot traces only. Bottom: original Petrobaltik seismic line

data with the objective of improving the resolution at short travel-times and interpreting the anomalies. A number of profiles were selected and only the traces from the geophone nearest the shot-point were used. Altogether, 256 km of seismic profiles from the area of the anomalies were reprocessed, i.e. a total of 158 km of WNW-ESE lines and 98 km of NNE-SSW lines.

After reprocessing, the extent of the anomalies and the morphology of the lower boundary of the anomalous features were interpreted with reasonable accuracy. Due to a low degree of resolution of commercial seismic records, however, internal structures can hardly be distinguished. In the echosounder record (Fig. 2) for profile 86814C (location see Fig. 4), the sea floor distinctly shows recent channels caused by currents, as well as sand ridges. Between shot points 675 and 565 and between 470 and 430, the profile processed by PETROBALTIK (Fig. 2, bottom) displays diffuse anomaly patterns in the uppermost reflection band that are interpretable only with difficulty. The reprocessed version (Fig. 2, middle), however, provides better resolution. The travel-time anomaly between shot points 470 and 430 can be seen to be due to an open channel of recent age. The apparent "graben structure" on the seismic profile is purely a reflection of the morphology of the sea floor.

The anomaly located further to the west, however, does not correlate with any particular morphological feature on the sea floor. In the western part of the anomaly, the increased travel-time is most distinct and is accompanied by an increase in travel time with depth. This can be seen as an increasing amount of sag with depth (more clearly visible in Fig. 3) within the bundle of reflections between 0.4 and 0.5 sec (TWT) around the base of the Cretaceous.

This anomaly is interpreted as an erosional structure filled with low-velocity sediments. Since in this region the Quaternary deposits overlying this buried channel may be about 50 m thick and may consist of high-velocity material such as till (Lemke 1994), the travel time difference must be due to the presence of channel fill with a very low velocity, possibly slightly consolidated mud. It is feasible that these sediments contain gas, which further reduces the sonic velocity; gas has already been demonstrated in the western part of the Baltic Sea, e.g. in the Eckernförde Bay, and is also known to occur in surface sediments of the Arkona Basin (Lemke 1994). However, the presence of gas remains unknown because so far no core samples have been taken of the sediments in the channels. It should be mentioned that the anomalies on the seismic records from those parts of Kiel Bay in which gas-bearing mud occurs (Hinz et al. 1971) show a close similarity with those on the profiles described here.

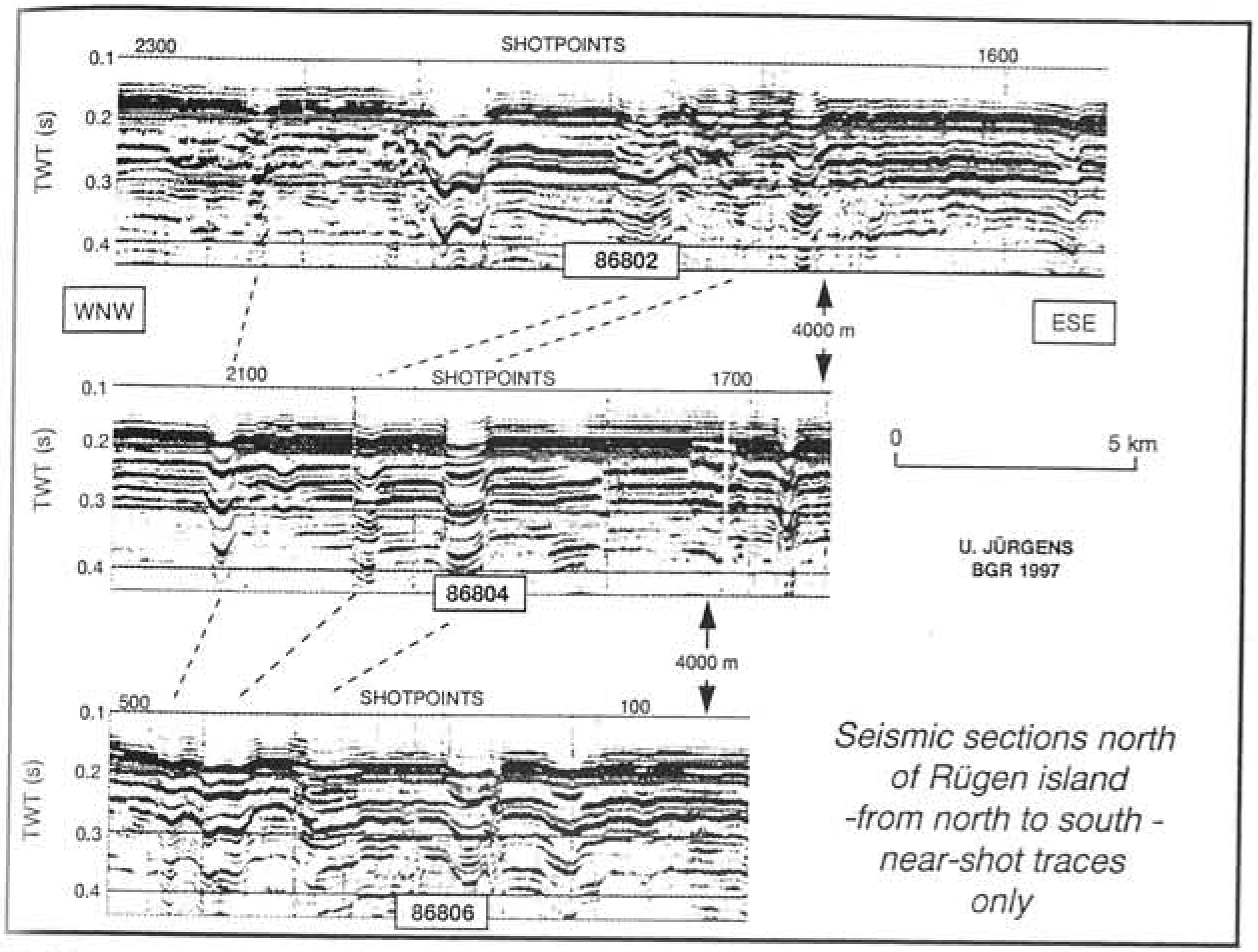

Fig. 3. Range of variation of the travel-time anomalies interpreted as Quaternary glacial channels. Explanation in the text

DESCRIPTION OF CHANNELS

The morphological variability of the travel-time anomalies interpreted as buried Quaternary channels becomes obvious in the three parallel, WNW-ESE profiles which are almost perpendicular to the channels (see Fig. 3; location of profiles shown in Fig. 4). The intermediate profiles used for correlation are not shown.

An increase in travel-time difference with depth is typical of the channels. The cross-sections of the channels vary from symmetrical tub shaped (86804: center), box shaped (86804: SP 2100), funnel shaped (86804: east of SP 1700) to asymmetric (86802: center). Channels showing two troughs separated by a ridge (86802: west of center, 86806: in the west) are common. To investigate the anomalous travel-time, which must correlate with channel depth and/or thickness of the mud, the travel-time difference was determined at a depth of 0.2 sec TWT. Values of 10–50 milliseconds (Fig. 4), which were determined this way, are an indirect indication of the presence of a comparatively thin fill. This corresponds to the depth of the known Weichselian channels, which are partly open, rather than to the Elsterian channels known from northern Germany, some of which are several hundred meters deep. The channels were mapped via travel-time anomalies on the southern margin of the Arkona Basin (see Fig. 4) in a water depth which varies from 25 m in the southern part of the study area to 47 m in the north. In an area of about 25 x 25 km (625 km²), the channels, which are mostly connected with each other, generally trend NE–SW, but some trend N–S and some E–W. Narrow, relatively long channels prevail in the SW, W and N, shorter and wider forms are dominant in the E and SE. In the west and north of the study area the channeled part of the sea floor ends abruptly, whereas in the eastern part the channels seem to become more and more disjointed until they disappear altogether eastwards. This pattern of distribution may indicate the existence of a subsurface block tilted towards the NW. Single channels may be more than 20 km long, and are generally 500 to 1000 m wide, but are occasionally up to 2000 m wide. The channels often display a curved course and sometimes an undulating thalweg.

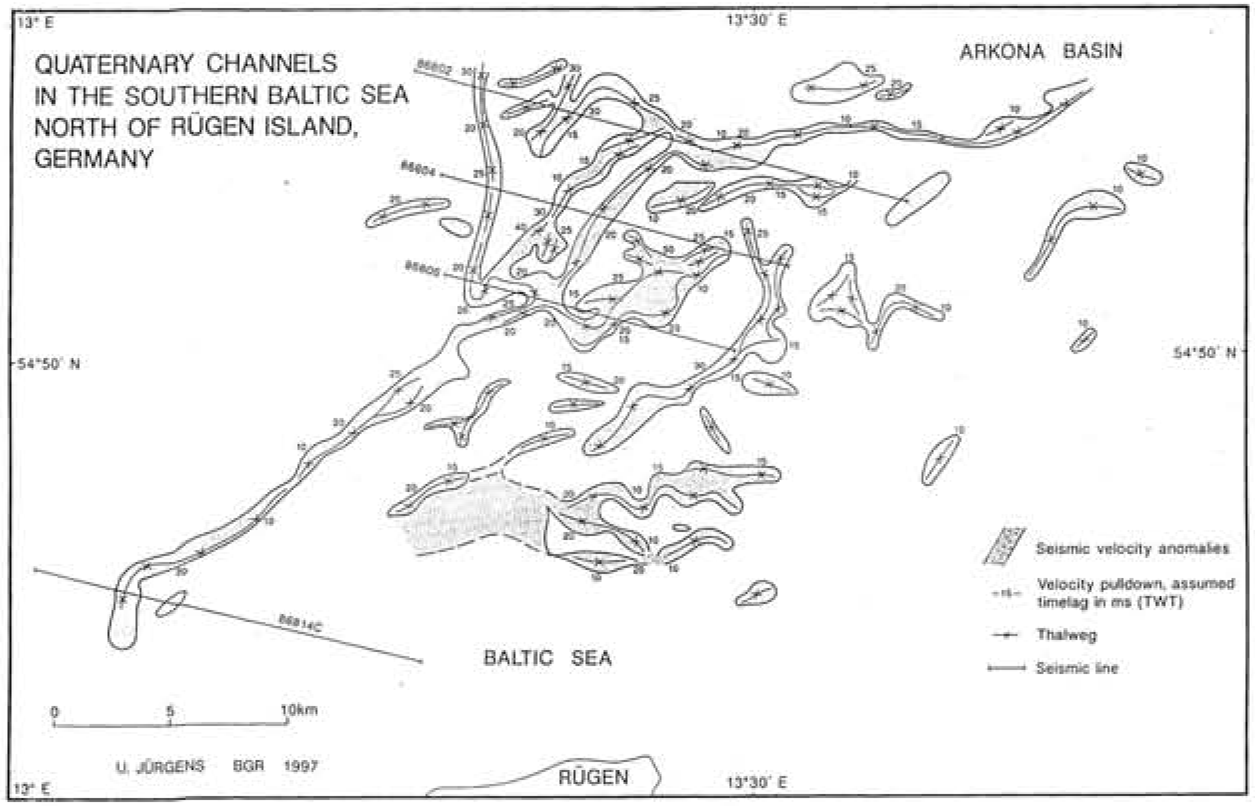

Fig. 4. Map of shallow seismic anomalies (buried channels) showing travel-time differences in ms (TWT)

MODE OF FORMATION

In analogy to other areas in northern Europe, this anastomosing channel system is interpreted as a glacial feature. These long, overdeepened channels were eroded by meltwater streams which cut into the probably permanently frozen ground, into Quaternary deposits and - in the deepest parts - into the Cretaceous sediments beneath. This took place beyond the front of the ice sheet, probably rather early in glacial times, i.e. during the Elsterian. The type and age of the sedimentary fill are still unknown. The general course of the channels (NE–SW) agrees with the pattern known from the mainland; however, the other directions present indicate the existence of a more variable drainage system. The channels were possibly formed at different times. The undulating channel floor is interpreted as being partly due to the melting of dead ice beneath the channel, which left deep depressions. The comparatively undisturbed shape of the edges of the channels makes it improbable that the initially open channels were filled with ice and/or were overridden by the ice sheet.

The fact that the channels occur in a restricted area suggests that their formation and preservation were controlled by tectonics . The channels are situated on a highly uplifted part of the Arkona block (Schlüter et al. 1997). At least the western and northern boundaries of the area in which they occur correlate with faults at the base of the Cretaceous. Differential neotectonic movements of the Arkona block clearly played an important part in the formation and preservation of the channel system. Outside this closely restricted area, no channels or travel-time anomalies of this kind can be demonstrated by seismic methods in the area around Rügen Island. However, similar channels can be observed on Rügen Island and southwest of it on the mainland.

DISCUSSION

In northern Germany and adjacent areas, Quaternary channels are important aquifers. Particularly during the last few decades, several drilling programs have been carried out as a result of the steadily increasing demand for water. Consequently, our knowledge of the trends of the channels, their locations and sedimentary fill has improved considerably (e.g. Kuster & Meyer 1979, Hönemann et al. 1995). From the very beginning, the distribution and shape of the channels suggested a connection between their genesis and the glaciation of northern Europe. Similar channels are also very frequently found near the former margin of the ice sheet in England, in the North Sea, as well as in eastern Europe. Often, the fill consists of lacustrine to glaciolacustrine deposits of Elsterian age overlain by sediments belonging to the Holstein Interglacial (Kuster & Meyer 1979). Therefore, most of the known channels in northern Germany, some of which are up to 400 m deep (Reeßeln and Hagenow channels near the River Elbe) are inferred to have been formed during the Elsterian glacial period. Some younger glacial channels are also known.

The prevailing direction of the channels in the German sector of the North Sea is N–S to NW–SE (Schwarz 1996); in NW Germany they run predominantly N–S (Kuster & Meyer 1979), and in NE Germany mostly NE–SW (Hönemann et al. 1995, Schwab & Ludwig 1996). These directions suggest that they were formed by meltwater from the ice sheet.

In northern Germany and adjacent areas, the channels are inferred to be of subglacial origin (Kuster & Meyer 1979), meaning that water under excess pressure has eroded non-frozen ground below the glacier. The very irregular channel floor, which is often undulating along its course, is said to be incompatible with a fluviatile origin except at the northern margin of the central German uplands (Mittelgebirge).

Various theories have been proposed to account for the orientation of these channels, e.g., they tend to follow reactivated faults (Schwab & Ludwig 1996), or the peripheral sinks of salt domes (Kuster & Meyer 1979).

CONCLUSIONS

The Quaternary channels have been described (Bjerkeus et al. 1995) from the western, central, and eastern parts of the Baltic Sea. They differ in their morphology and fill; different modes of origin have been inferred including fluviatile, periglacial and subglacial, and they have been assigned to three different glacial periods.

The channels described from the southern part of the Arkona Basin north of Rügen Island fit into this regional picture. The fact that these channels occur in an isolated area is probably due to isostatic movements which caused differential lifting and lowering of the lithosphere during the Pleistocene - and then possibly with particular intensity. This also applies to the inferred shallowness of the channels. Meltwater draining from the ice sheet eroded the channels probably during a phase of uplift. It should be borne in mind that, during the Pleistocene, the base level (the North Sea and N. Atlantic) dropped more than 100 m due to the general fall in sea level. During a subsequent phase the channels were filled. The depth and direction of the channels (Fig. 4) suggest that the underlying Arkona block was subject to tilting. The channels and their fill are overlain by Late Pleistocene deposits; thus, no direct morphological evidence of their presence is visible on the sea floor. High-resolution studies such as shallow seismics and core drilling are necessary to characterize these channels more precisely.

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Late Weichselian Palaeo-Environmental Conditions in the Kattegat, South-Western Sweden

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The marine Late Weichselian Kattegat began at about 15,000 BP when the ice left northern Denmark and sea water entered the Kattegat Basin. At about 14,000 BP the ice front reached the Swedish west-coast. Between 13,500 BP and about 12,200 BP icebergs from the south, containing sedimentary clasts, were transported into the Kattegat. At about 12,700 BP the outflow from the Baltic Ice Lake water through the Öresund Strait increased, which affected the hydrography in the Kattegat, especially the surface water. From this date to about 10,300 BP the fresh water drainage of the Baltic Ice Lake water was substantial into the Kattegat, which created arctic to boreo-arctic environmental conditions with brackish salinity. The environmental conditions changed at about 11,000 BP in the beginning of the cold Younger Dryas period, when cold sea water flowed into the Kattegat at the bottom from the Atlantic Ocean, whereas the surface water was still affected by an outflow of Baltic Ice Lake water. At 10,500 BP the water temperature increased, especially in the southern part of the Kattegat. The shift of the Baltic Ice Lake outlet to the northern part of the Billingen Mountain at 10,300 BP changed the hydrography of the Kattegat. Freshwater from the Baltic basin mainly flowed out north of the Kattegat via the Skagerrak to the Norwegian Sea, so that the salinity and the surface water temperature in the Kattegat increased.

Keywords: Benthic foraminifera, the Kattegat, Late Weichselian, Billingen Mountain, Öresund Strait, Baltic Ice Lake

INTRODUCTION

Late Weichselian marine sediments formed during the deglaciation are widespread in south-western Sweden, where the former Kattegat extended eastward in over the glacially depressed landscape. Sediment-loaded meltwater flowed into the sea, where clay and silt particles deposited with a relatively high accumulation rate in a glaciomarine environment. Glacial varved clays, in particular close to the ice front, were accumulated in the eastern and southern Kattegat. Non-varved glacial marine clays were deposited, upon the varved deposits in positions more distal from the ice. After deglaciation erosion of exposed sediment and redeposition of fine-grained sediments occurred. The drainage shift of the outflow from the Baltic Basin from the Öresund Strait to Billingen Mountain at 10,300 BP (Björck 1995) marks a natural end of the Late Weichselian hydrographic pattern in the Kattegat. The aim of this paper is to interpret the palaeoenvironment in the Kattegat during 14,000 BP to 10,300 BP period highlighted by four palaeogeographic maps. These maps are based mainly on shore level displacement data and biostratigraphical interpretations of the marine fine-grained sediments. The biostratigraphical division is interpreted from foraminiferal and diatom analyses and radiocarbon dating.

SETTINGS

The present Kattegat forms a large estuary between the Skagerrak and the Baltic Sea (Fig. 1). The Kattegat is relatively shallow with a mean water depth of 26 m. The Baltic water regulates the surface water in the Kattegat, which normally forms a stratified water column with the Skagerrak water as a bottom water current (Stigebrandt 1983). The halocline is generally located at a depth of 10 to 20 m in the Kattegat. The salinity is about 30 to 34‰ in the bottom water whereas the salinity of the surface water becomes substantially lower towards the south, ranging between 15 and 30 ‰ (Stigebrandt 1983).

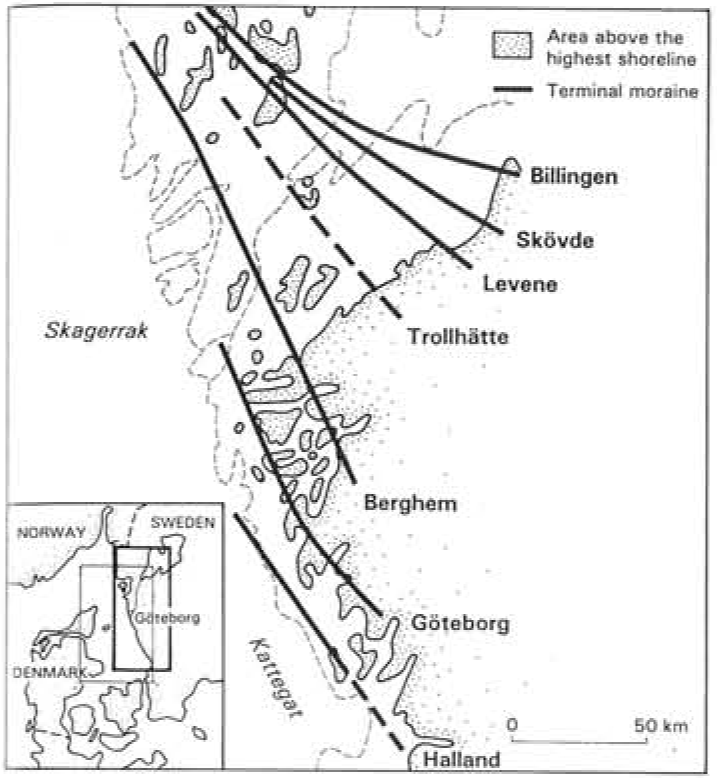

Fig. 1. Main moraines in south-western Sweden and the area above the highest shoreline. The inset map shows; the square to the right - the position of the figure, the square to the left - the position of the palaeogeographic maps. Redrawn from Klingberg 1998

The Late Weichselian Kattegat was formed when the ice left northern Denmark and the sea water entered the Kattegat Basin (Knudsen *et al.* 1996) at about 15,000 BP or before c. 14,600 BP according to Rickard (1996). About 1000 years later, about 14,000 BP, the southernmost part of Halland county in Sweden, was ice free (Lagerlund & Houmark-Nielsen 1993). The Swedish west-coast was successively deglaciated north-eastwards. During the deglaciation moraines were formed; the Göteborg moraine, which is dated to 12,800 - 12,600 BP (Berglund 1979; Påsse 1986), the Berghem moraine (12,400 BP, Berglund 1979), the Trollhätte moraine (11,800 BP, Fredén 1988), the Skövde-Levene moraine (11,000, Fredén 1988) and the Billingen moraine dated to 10,250 BP (Fredén 1988) (Fig. 1). The marine sediments are found on land (e.g. Klingberg 1998.; Bergsten 1994), and at the sea floor in the Kattegat (e.g. Nordberg 1989; Bergsten & Nordberg 1992).

SHORE LEVEL DISPLACEMENT

In central Halland the regression of the sea level can be illustrated by the shore level displacement curves from Falkenberg. Here the highest shoreline was about 65 m above sea level and about 100 m in the area of Göteborg (Påsse 1987). During the deglaciation the highest shoreline was developed at about 60 m above the present sea level at Vendsyssel, in the northernmost part of Denmark (Rickard 1996).

METHODS

Sediment cores were taken on land in Halland county, and off shore in the Kattegat. For the study of the palaeo-oceanography of the Kattegat, lithostratigraphy, foraminifera, pollen, diatoms as well as stable oxygen and carbon isotope analyses performed on the foraminifera were used (Klingberg 1998). Radiocarbon dating using the AMS-methods was performed on mollusc and foraminifera shells. Those datings were supported by pollen analyses (Klingberg 1998).

PALAEO-OCEANOGRAPHIC INTERPRETATIONS

The results from the shore level displacement data and the biostratigraphical investigations have been used for the construction of the palaeooceanographic maps. The time-slices are from Klingberg (1998) and chosen in order to show the environmental conditions during: 14,000 - 13,500, 13,500 - 12,200, 12,200 - 11,000, and 11,000 - 10,300 BP.

14,000 - 13,500 BP

During this period the Kattegat was relatively wide in an east-westerly direction (Fig. 3). During this period the ice margin was at sea long entire the Swedish coast. Debris was transported into the Kattegat by icebergs originating from the ice along the Swedish west-coast. The oldest Late Weichselian fine-grained sediments in the southern Kattegat are varved clays or silt laminated clays (Bergsten & Nordberg 1992; Påsse 1992). More commonly, are sediments deposits in more distal positions from the ice and which are homogenous, relatively stiff, blue-greyish or brown clay (Påsse 1990). The meltwater flowed into the Kattegat from the melting ice in Halland county and from the ice in the area of the Öresund Strait. The amount of freshwater later became gradually larger, which lowered the salinity in the surface water in the southern Kattegat. The inflow of sea water as a bottom water current was substantial. Arctic conditions and brackish salinity are reflected by foraminifera.

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Sediment Erosion and Deposition in the Western Part of the Gulf of Finland

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Crustal uplift following deglaciation of the Baltic Sea still alters the sedimentary environment in the western Gulf of Finland exposing former active accumulation areas to erosion. The suspension and redeposition of older material can have a substantial effect on the quality of recent sediments used for marine environmental monitoring. The magnitude of this diluting effect is being evaluated from interpreted acoustic profiles acquired from the westernmost part of the Gulf of Finland. The older resuspended material participates in the formation of recent sediments. However, preliminary results indicate great temporal and spatial variability in the sedimentary processes active at the studied sites. The amount of redeposition will be evaluated for different subareas.

Keywords: acoustic profiling, recent sediments, sediment redeposition, Gulf of Finland, Baltic Sea.

INTRODUCTION

The northernmost Europe, including the Baltic Sea basin, was covered by a continental ice sheet during the Weichselian. In the course of deglaciation the combined effect of land uplift following the crustal unloading (melting of the ice sheet) and fluctuations in sea level the sedimentary environment experienced many changes. Especially in the northern Baltic Sea where the abating crustal uplift is still being felt, variations in wave exposure and current patterns influence the distribution of sediment on the sea floor. Formerly active sedimentary basins can be exposed to erosion, and nondeposition areas can experience even rapid sediment accumulation.

The eroded and redeposited older material may have a diluting effect on sediments being currently deposited in the deep basins. The addition of unpolluted older sediment should be heeded when estimating the environmental impact of anthropogenic contaminants entering the marine system. The redeposition of older sediments may also affect the results of dating methods and lead to erroneous dates. The environmental role of redeposited material on the quality of recent sediments is being studied at the Geological Survey of Finland.

METHODS

Subbottom profiler and echosounding data from the westernmost part of the Gulf of Finland (Fig.1) is used for the evaluation of the effect of redeposited material on the total amount of sediment being deposited in sedimentary basins. The estimation is based mainly on the interpretation of the acoustic profiles, which were aquired from the transect area between Hanko, Finland and Osmussaar, Estonia surveyed during the Basys (Baltic Sea System Study) cruise of r/v Petr Kottsov in September 1996. A GeoChirp subbottom profiler together with a shipboard DESO 25 echosounder have been used for acoustic imaging of the seafloor features. The GeoChirp subbottom profiler uses the chirp technology. In contrast to the short single frequency pulse used in convential subbottom profilers, a broad band frequency coded source pulse is transmitted and the received echoes are match filtered. This technique provides both high penetration and high resolution.

Because the tow depth of the Chirp-profiler transceiver, "fish", varied during the survey, DESO echosounding profiles were used to determine the actual water depth of the interpreted Chirp-profiles. To calculate the water depth, a calibrated sound velocity of 1435 m/s was used. In calculations of sediment thickness a sound velocity of 1600 m/s was used for glacial clays and silts, and a value of 1500 m/s for transitional clays and postglacial muds.

The interpretation of the acoustic profiles will be verified by dating different lithostratigraphical units in sediment cores taken from the area in July 1997. Paleomagnetic dating and microfossil analyses are being carried out, and the results will be published later, together with ^{14}C-datings.

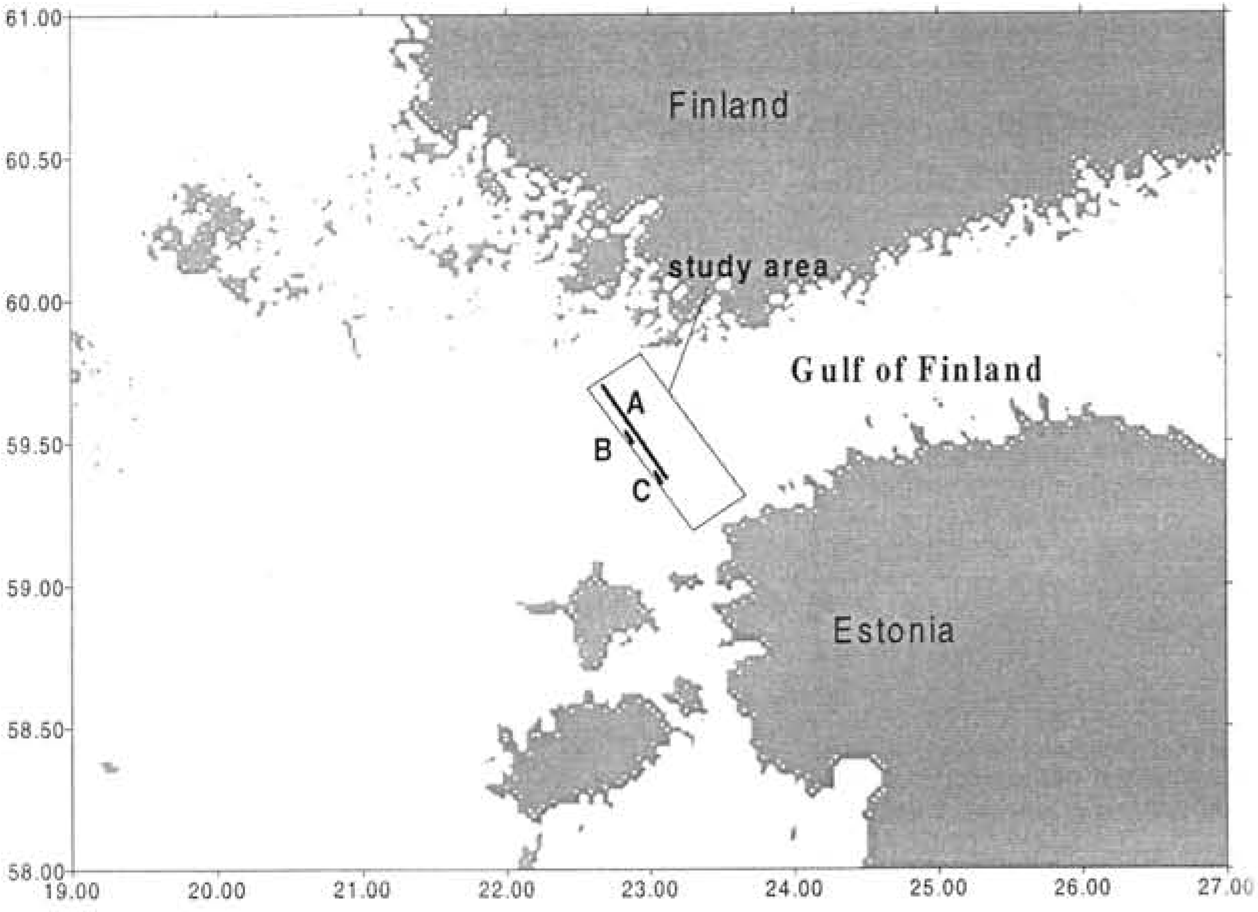

Fig. 1. Study area and location of the Chirp-profiles referred in the text as A, B, and C

INTERPRETATION OF SEDIMENTARY UNITS

Ignatius et al. (1981) proposed a stratigraphic model for the Baltic Sea basin consisting of three major lithological units: "glacial clay and silt", "transition clay", and "postglacial mud". In GeoChirp-profiles these units can be identified. Litorina and recent sediments are defined as postglacial muds. According to Winterhalter (1992) the most recent muds often differ acoustically from underlying, more compact sediments. In this study this boundary was not visible, probably due to continuous input of reworked older sediment. A clear acoustic reflector separates Litorina sediments from Ancylus clays (Winterhalter 1972, Ignatius et al. 1981, Nuorteva 1994). Below the transitional Ancylus and Yoldia sediments the glacial clays and silts deposited in the Baltic Ice Lake show a characteristic pattern of internal reflectors in Chirp-profiles. The lowermost, fourth interpreted unit, "hard bottom", consists of till and bedrock, which cannot be separated from each other in GeoChirp-profiles.

Sedimentation processes are ruled by several factors; wind-induced waves, bottom currents, bottom topography, amount of suspended material etc. Fluctuations in the sea level have influenced the sedimentary environment of the study area. Assuming the water depth to be the main factor controlling sedimentation, a schematic presentation of past sedimentary environments was constructed after an interpreted Chirp-profile. (Fig. 2). As the water depth is gradually decreasing in the study area due to vertical crustal uplift, a similar presentation could be prepared to describe future sedimentary environments. According to Gubler et al. (1992) the rate of recent uplift is 2-3 mm/year at the mouth of the Gulf of Finland.

Table 1. **Distribution of the sea floor deposits at the site A (see Fig. 1 for location)**

Sea floor mbwl	Litorina / recent mud %	Ancylus / Yoldia clay %	Glacial clay and silt %	Bedrock / till %
<70	20.1	11.3	46.0	22.6
70-90	44.3	21.7	33.2	0.8
>90	92.2	3.9	3.9	-

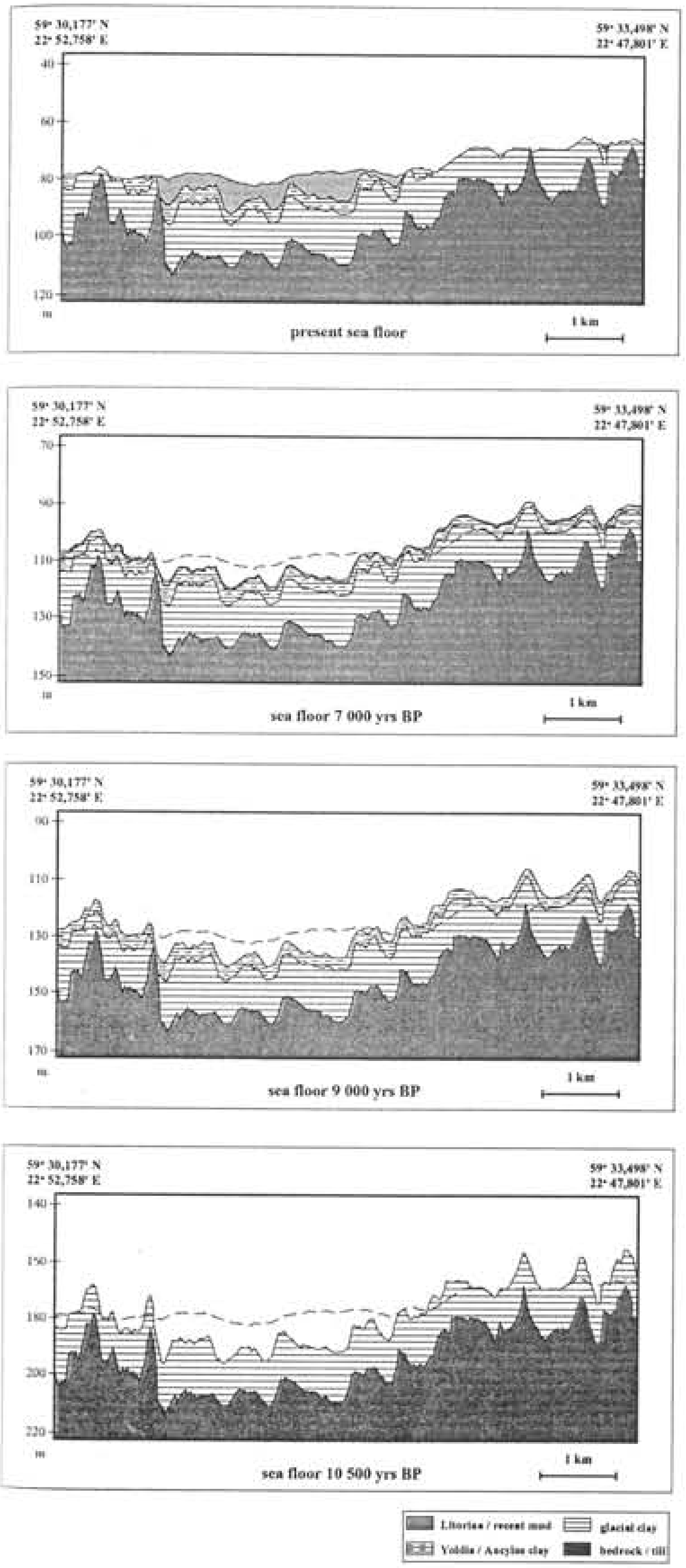

Fig. 2. A schematic representation of past events in the study area, compiled after an interpreted Chirp-profile (the uppermost chart). The dashed line represents the present seafloor at 64-81.5 m below present sea level

RESULTS AND DISCUSSION

Results of interpreted Chirp-profiles from area A (Fig. 1) show, that on the sea floor <70 m below the water level (mbwl), postglacial sediments are only preserved in sheltered depressions (Table 1). In areas with water depths in excess of 90 m, Litorina and recent mud cover 90% of the sea floor.

Wind-induced waves prevent active sedimentation in an open-sea environment at water depths <70-90 m. In Nuorteva's (1994) study area in proximity to the coast in the western part of the Gulf of Finland the thickness of postglacial sediments increases rather uniformly with increasing water depth until the depths are over 70 m, when a decrease can be noticed. Also in this study, in the investigated site A (Fig.1), the average thickness of Litorina and recent muds first increases with depth, but in depths over 70 m a decrease can be observed (Fig. 3). This decrease can probably be attributed to a decreasing storm wave induced resuspension of older sediment in water depths over 70 m. It is evident, that near bottom currents influence locally the accumulation of mud deposits. These currents also have an erosive effect on older sediments, especially on transitional clays and postglacial gyttja clay. Glacial clays and silts seem to be more resistant to erosion than younger deposits.

In an interpretation of a 2 km long Chirp-profile (site B in Fig. 1) with an average water depth of 78.5 m, most of the sea floor is covered by postglacial sediments (Fig. 4). The average thicknesses of interpreted units are: glacial clays and silts 16.7 m; transition clays 4.2 m, and postglacial deposits 6,4 m. An estimated amount of erosion of glacial clays is 6 %. Another 2 km long interpretation further south (site C in Fig.1) shows more erosional features, even if the waters are deeper (Fig. 5). In this area the mean thickness for glacial clays and silts is 11.5 m, for transition clays 2.9 m, and for postglacial deposits 2.8 m. The amount of erosion of glacial clays is estimated to be over 14 %.

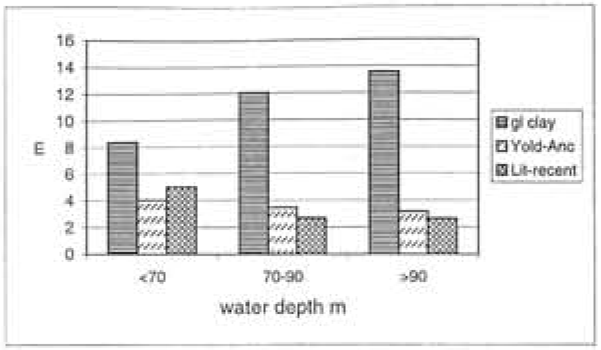

Fig. 3. The thickness of interpreted sediment units in relation to water depth (area A in Fig.1)

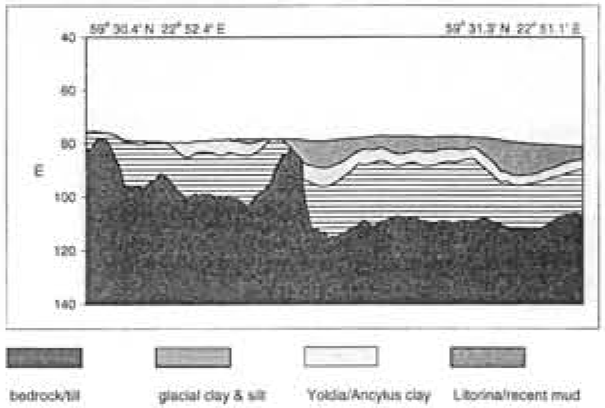

Fig. 4. An interpreted 2 km long Chirp-profile (area B in Fig. 1)

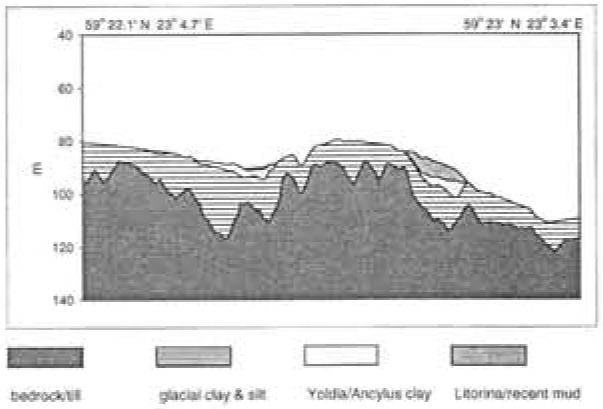

Fig. 5. An interpreted 2 km long Chirp-profile (area C in Fig. 1)

These preliminary results indicate, that the sedimentary environment of the Baltic Sea is quite variable, even in a relatively small area as the mouth of the Gulf of Finland. It is obvious, that similar differences in sedimentation have occurred during earlier phases of Baltic Sea history. Due to the variability of the sedimentary environment, including the dynamics and the availability of erodable material, the study will be divided into subareas according to their sedimentary characteristics. The amount of erosion of glacial and transitional sediments and their later redeposition will be evaluated separately for each subarea. This evaluation will be based on available knowledge of surrounding bathymetry, bottom near current patterns and distance to erodable sediments. The ultimate goal being an estimate of the environmental effects of reworked older material in currently accumulating deposits.

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Pre-Quaternary Faults Below the Greifswalder Bodden (SW Baltic Sea) and Their Correlation with Structures Near the Sea Bottom (Project SASO II)

Manfred Krauss, Peter Mayer and Holger Wirth

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The Greifswalder Bodden (GBO) is situated approximately in the central part of the Vorpommern Fault System. In its surroundings there are the penetrations of salt water (salty ground-water, salt spring) and of heavy hydrocarbons to the surfaces, which are bounded to pre-Quaternary faults. The question is whether such endogenous processes have influenced or are still influencing the deposits of the GBO and the adjacent Baltic Sea. On base of about 1000 profile-km of reprocessed industrial CDP-seismic data the structure in the pre-Quaternary underground of the GBO (project SASO II) is reinterpreted. It is clear the faults are extent through the Cretaceous deposits towards the base of the glacial deposits. The morphology and the distribution of the GBO sediments seem to correlate with the underground faults.

Keywords: Seismic, SW Baltic Sea, pre-Quaternary faults, Quaternary sediments

GEOLOGICAL SITUATION

The Vorpommern Fault System has been generally mapped in 1960-1980 within the context of oil exploration in Lower Zechstein sediments (depths about 2500 m). Seismic and drilling data revealed a system of palisade-like NNW-SSE strike faults, which arrange the Mesozoic formations structurally as dip-slip faults and Y-grabens, with salt activations being partially involved (Wegner 1964, Beutler & Schüler 1978, Beutler 1979, 1982, Reinhardt 1993) (Fig. 1).

The formation of the VPFS happened as a result of extensive stress impulses during the Middle Keuper (Old Kimmeridgian event) and towards the end of the Jurassic (Young Kimmeridgian event). This was the same regional stress situation that caused the so called Saxonic Tectonic in all of North Germany. But there was a special tectonic situation at the northeasternmost margin of the North German Trough in the area of the Transeuropean Fault and near the Tornquist Zone. Further reactivation of the faults took place in connection with Laramic events (Uppermost Cretaceous to Palaeocene), but in this time due to compressive stress. Regionally this resulted in the final formation of the Tornquist Zone with inverse high structures as well as to the uplift of the Grimmen Wall.

Faults due to Laramic events (with Tertiary deposits missing) extend locally to the base of Pleistocene sediments. Thus, they may have influenced the glacial and Baltic Sea sediments structurally and by material influx (salty water, gases) up to the surface. The ascent of salty water and higher hydrocarbons through glacial sediments up to the surface is known from the surrounding area of the Greifswalder Bodden. An example for this is the extraction of salt from springs in Slavonic time and later with the Christianization here at this location the foundation of the Cistercian monastery Hilda (1199) and the foundation of Greifswald (1250). Faults with ascended salt water and springs at the surface, salt extraction and its trade were the cause of the foundation of Greifswald.

The connections with the faults of the pre-Quaternary structure and the structural situation inside the glacial sediments are, however, still unknown. The thickness of the glacial complex from 40 to 200 m and its division in till and sand layers is known in regional overlook by drillings. But the kind of water ascent through the till layers and the water movement inside

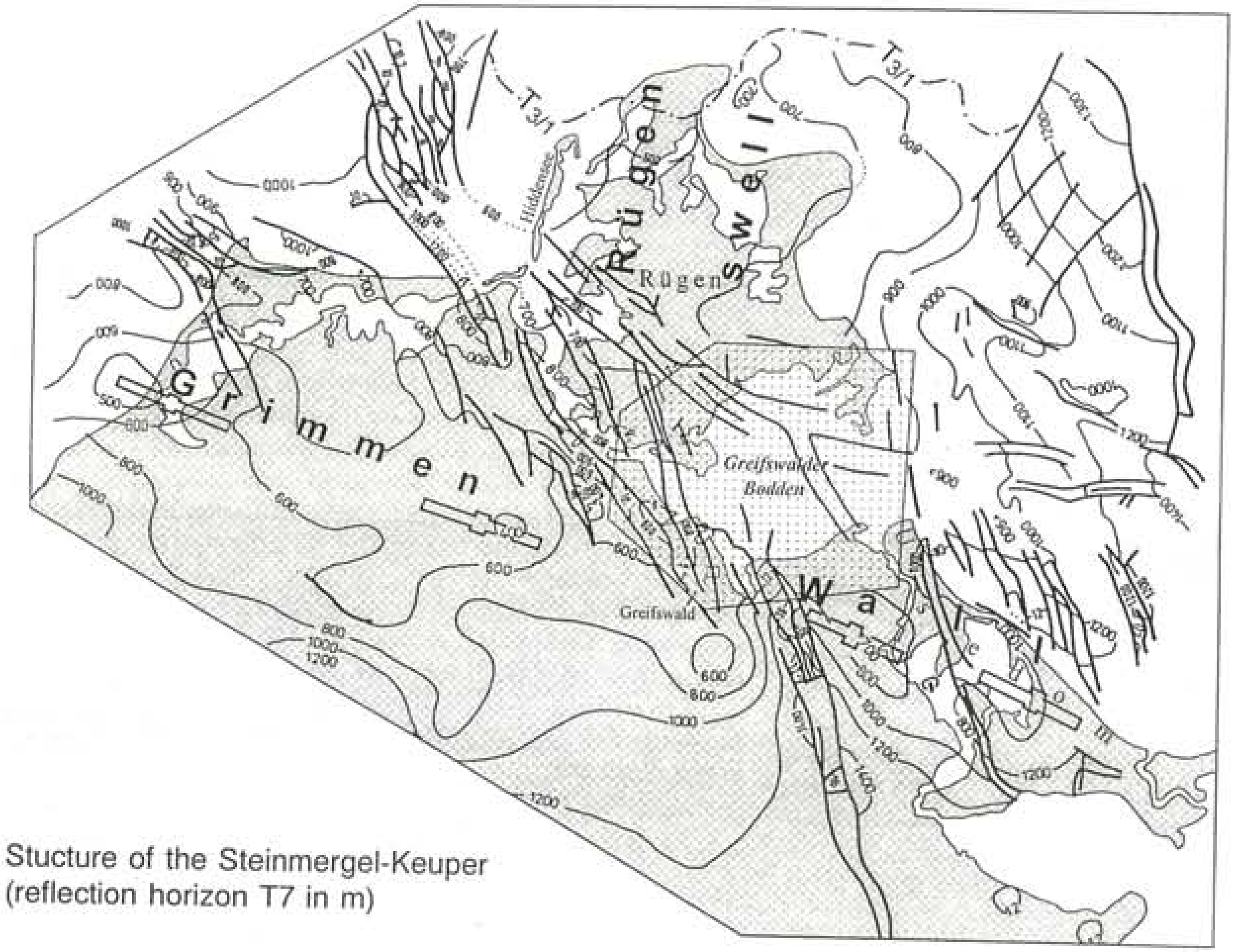

Fig. 1. The Vorpommern-fault system in the northeasternmost part of Germany and the adjacent Baltic Sea and the location of the SASO II-project. Structure of the Steinmergel-Keuper (reflection T7)

the sand layers there is not known due to lack of drilling and near-seismic data. This is the content of a future project. The first step for solving this problem is to delineate the structure up to the surface of the Cretaceous sediment complex, respectively up to the basis of the Quaternary glacial complex.

TARGET AND PRECONDITIONS

The investigations of the project „Struktur Atlas Südliche Ostsee, Teil Greifswalder Bodden" (SASO II) are aimed at mapping the structure of the Mesozoic sediment complex in the Greifswalder Bodden and its surroundings including the adjacent Baltic Sea and tracing it as far as possible to the Quaternary basis. The base of these investigations is the reprocessing and reinterpretation of older seismic and drilling data.

In the area of the Greifswalder Bodden and its surroundings there are about 2 000 km of CDP-seismic data of the oil exploration, which have been recorded since 1970 in more than 30 separate projects by means of on-shore, shallow water and off-shore techniques. Field and interpretation methods, i.e., hardware and software have been continuously developed since. Therefore, there were no uniform conditions for a reprocessing of the data (Mayer et al., in this volume).

Reprocessing and interpretation of the seismic data have been complicated by seismic effects of sub-bottom low-velocity layers (peat, gas-saturated mud). Echograms on the GBO lines, Boomer seismic data ‚as well as shallow wells could be used for mapping of the sediments (Fig. 6). Furthermore, there are about 20 oil wells drilled in the surrounding area in 1960s and 1970s, which can be used for interpretation. In the GBO area, however, a direct connection of seismic horizons is possible only in 2 wells in the southwesternmost part. The correlation of the horizons on the lines is very difficult because of large faults and time deformation of reflections due to low velocities beneath the sea bottom (gas saturated mud).

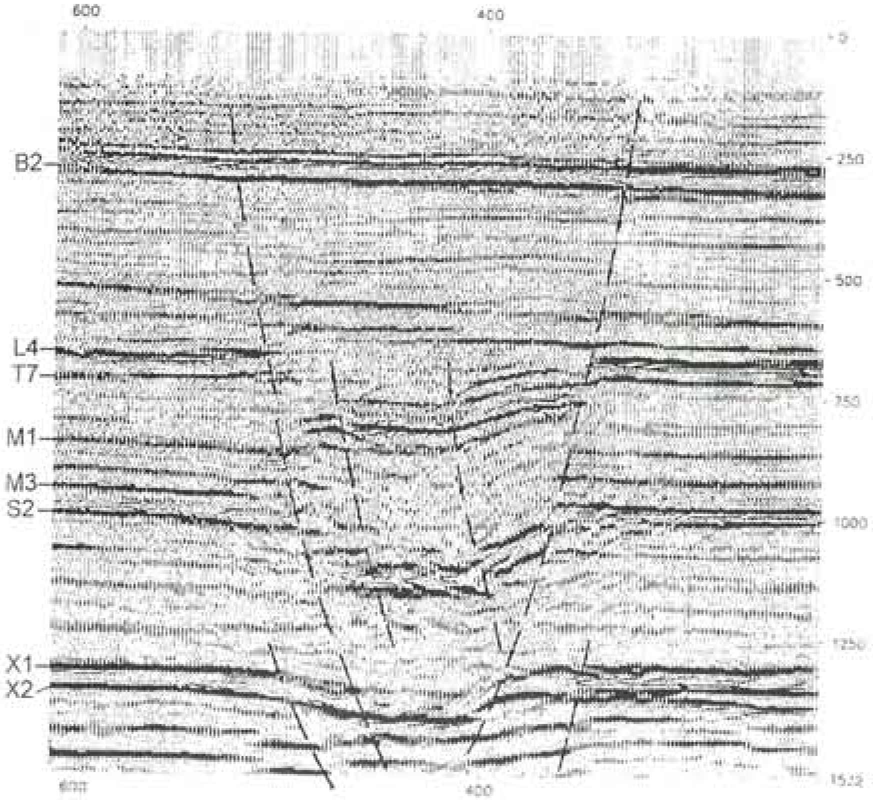

Fig. 2. Migrated time section line A with Freest fault

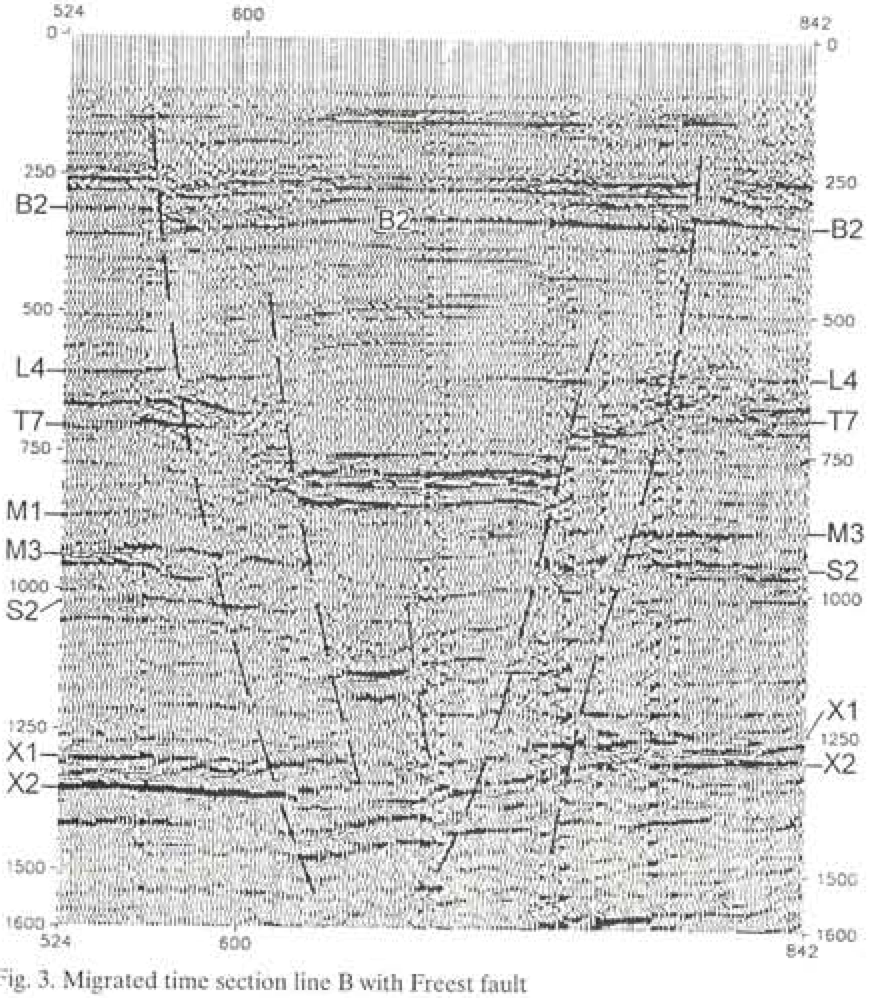

Fig. 3. Migrated time section line B with Freest fault

PRELIMINARY GEOLOGICAL RESULTS

- For the interpretation of more than 1000-km reprocessed field data (Mayer et al., in this volume) the computer-assisted interpretation system CHARISMA has been used.
- To delineate the structure of the Mesozoic sediment complex in the target area of the project the following seismic reflection horizons had to be correlated: B2 (Upper Cretaceous base), L4 (Lias base), T7 (Upper Keuper transgression), M3 (Muschelkalk base), S2 (Rhoethian base), X1/X2 (Triassic base).
- The pre-Quaternary structure in the area of the Greifswalder Bodden is divided through SSW-NNE and WNW-ESE orientated fault zones with dip-slip amplitudes up to several 100 m in the Triassic-Lias horizons. The main structural element is the Samtens Fault Zone in the northern part. At this E-W to WNW-ESE orientated, several 100 m wide graben zones are leading into the other NNW-SSE orientated fault zones (Fig. 5). There are also two elements: the Freest Fault Zone in the eastern part and the Greifswald-Gristow-Poseritz Fault Zone in the western part of the investigation area. The faults are partly single dip-slip faults, partly graben systems with dip-slip amplitudes of several 100 metres. The faults are fading partly listric into the Zechstein salinar, partly steep cross cutting. The grabens are sharp outlined and inside divided by smaller faults (Fig. 2).

The faults are reactivated by compressive Laramic activities during Uppermost Creta-

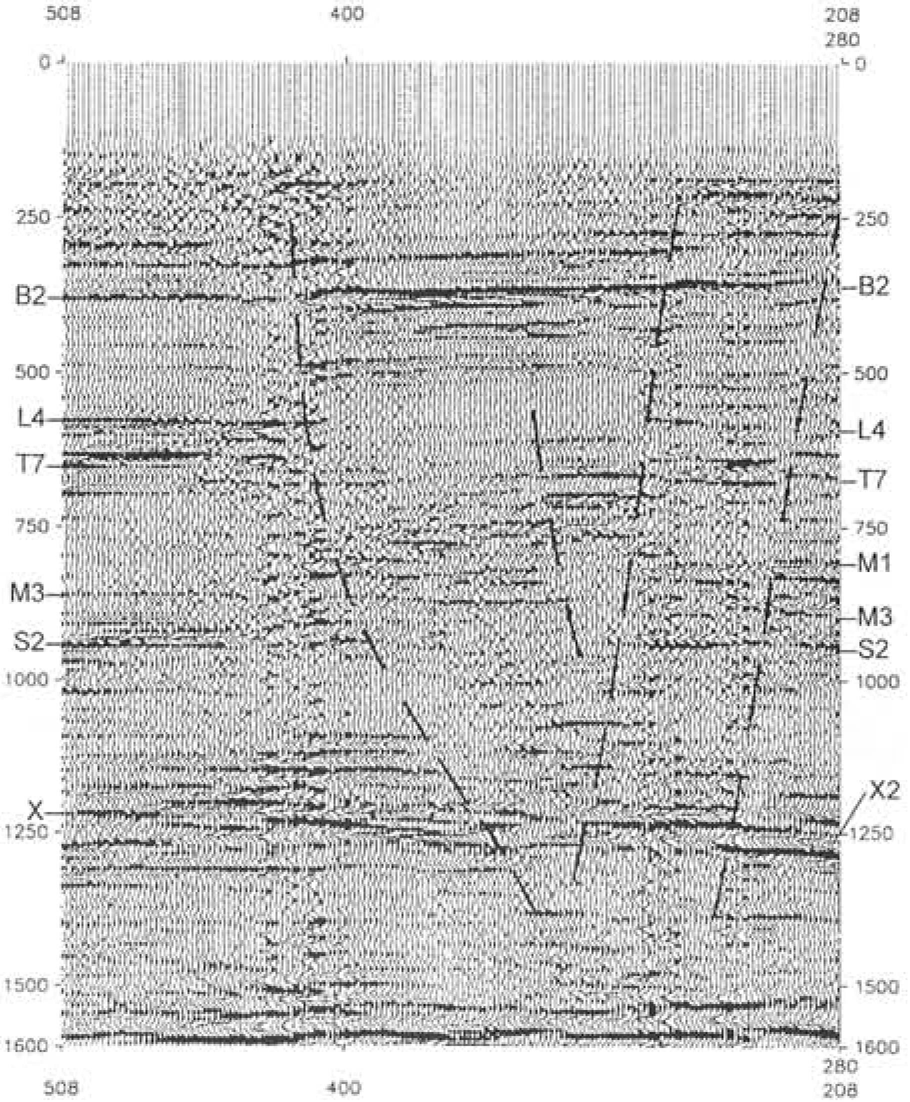

Fig. 4. Migrated time section line C with eastern Samtens fault

ceous to Palaeocene time with movement amplitudes up to several 10 m. These fault reactivations took place in the context with the uplift of the Grimmen Wall. There are Cretaceous sediments missing in the recent stratigraphic profile (Fig. 5). In this area the Quaternary glacial sediments are lying directly on clearly disturbed Liassic sediments.

The seismic horizons at the base Upper Cretaceous (B2) either are likewise clearly disturbed or there are horizon flexures and wave shape distortion as features of small dislocations (Fig. 2-4). This proof was firstly possible on base of reprocessed seismic data. The faults extend (with Tertiary deposits missing) towards the base of the glacial deposits.

- The interpretation of BOOMER-seismic profiles allows the representation of the sediment distribution in the GBO with fine sand, silt and mud (Fig. 6). Mud rich in gas and peat primarily are situated in formerly glacial stream channels. The thickness of mud does not exceed 3-4 m. The mud-peat layers cause a large quality and correction problem. Due to high gas content, a strong absorption of seismic energy and seismic quality is diminished (Mayer et al., in this volume). Therefore thickness of underlying peat complexes can not be recorded.

In some regions there are indications of correlation between underground faults and morphological and sedimentological surface anomalies. For instance the channels are partly concurrent in direction and position with the underground faults (Fig. 6).

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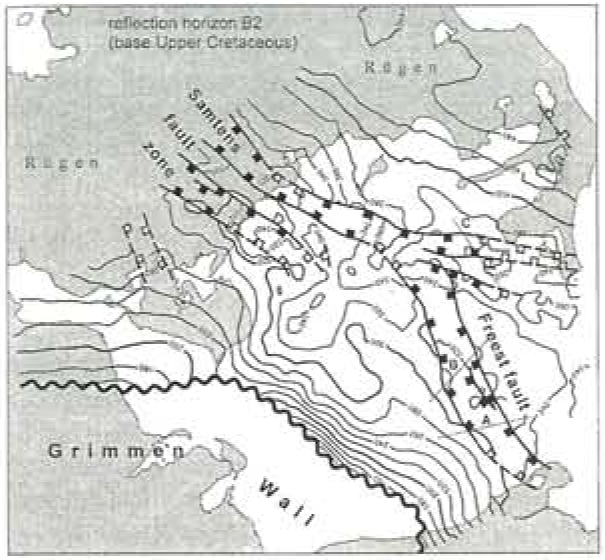

Fig. 5. Isochrone map Upper Cretaceous base (refection horizon B2): (a) certain fault with small amplitude, (b) questionable fault, (c) subcrop line B2, (d) position of the migrated time section Fig. 2-4

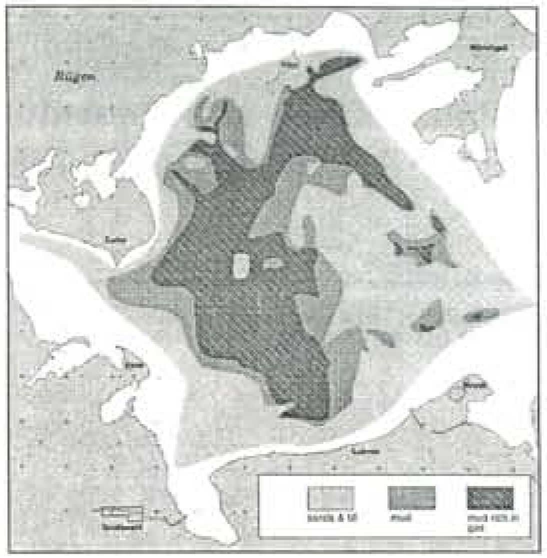

Fig. 6. Sediment distribution on base of near-seismic (BOOMER-) data in the area of the Greifswalder Bodden

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Variability of Recent Sedimentation Rates in the North Central Basin of the Baltic Sea

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Five sediment cores from a small area within the North Central Basin, Baltic Sea, were dated by Pb-210 with subsequent Cs-137 verifications. Closely spaced cores yielded similar unsupported Pb-210 depth curves. Radioactivity curves with depth (both Pb-210 and Cs-137) vary only when the very fine surface sediment top layer (sediment fluff) has been disturbed or even removed.
The dating of the sediment slices was found to be straightforward and few errors are introduced during sample preparation processes. The real errors in the dating process occur during core recovery and core slicing.

Keywords: Pb-210 dating, non-destructive gamma spectrometry; variability, central Baltic Sea.

INTRODUCTION

The paleoenvironmental studies presently being conducted in the deep basins of the Baltic Sea (Baltic Sea System Study, BASYS, EU Marine Science and Technology project) include also studies on the most recent sediments. By doing this changes in sedimentation caused by possibly human activity and also climatic and other environmental changes can be coupled and compared to what is preserved in the record of past sediments, i.e. in the deep (> 1 m) parts of long cores. A pre-requisit of all surface sediment studies is to make sure that the sedimentation in place has not been disturbed by human or bio-activity changing the surface sediment characteristics significantly. One way of checking whether the upper 50 cm of the sediments has been disturbed would be visual or X-ray inspection outlining structures caused by disturbances of the above mentioned activities. A check method is also non-destructive Pb-210 dating based on dried sediment discs (0.5 or 1 cm thick). By following the natural radioactive (Pb-210) and the anthropogenic (Cs-137) tracers with sediment depth, and modelling these data, one is able to construct a verified sedimentation history. The high-resolution dating through the radioactivity depth profiles then also gives the possibility to predict inhomogeneities in the recent sedimentation record.

In the present contribution, we focus on 5 short (Niemistö type) cores from the North Central Basin (NCB) of the Baltic Sea. Special emphasis is on the variability of the dating of closely spaced sediment cores with some varying topographic relief. Because dating is often conducted with varying instrumentation, a comparison between instruments is also included. Finally, this investigation aimed also at the outlining of uncertainties in connection with the dating by following critically the whole process of Pb-210 dating.

SETTING AND METHODS

All the cores are from a BASYS-7 cruise with R/V Kottsov (Harff & Winterhalter 1996) conducted in 1996. Characteristic data for the cores (position and water depth) are compiled in Table 1. Some of the core positions (2NC5 and 2NC6, and 2NC3 and 6NC2) are only a few hundred meters apart (Fig. 1).

The cored sediments have been described by Larsen (1996). Accordingly, black fluffy mud of about 5 cm thickness covers otherwise olive grey clayey mud at depth. Several black sulfidic spots suggest burrowing of the sediments. At varying depths below 70 cm, a finely laminated stiff mud is observed, which then grades into grey homogeneous mud. This layer has been named "Viking layer" because of its reported age of about 1500 years B.P (T. Andrén, Stockholm University, personal communication).

All the cores were sliced into 1 or 0.5 cm sections at the home laboratory, some 3 weeks after cruise termination. The slices were freeze dried and filled into containers with a thin PVC foil at the bottom. The radioactivity measurements were carried out with ultra-low background (remotely positioned preamplifiers) Ge(Li) detector systems (e.g. Kunzendorf et al. 1996; Kunzendorf & Christiansen 1996; Kunzendorf & Christiansen 1997). Detector shielding was by 8 cm present-day lead and 2 cm old lead sandwiched with 5 mm Cu. Data recording was via PC. Each sample was counted for 1 day and besides the total Pb-210 (46.5 keV) and the Cs-137 (661 keV) activities, a number of other natural and anthropogenic radioisotopes were determined. By doing this, supported Pb-210 activities were estimated directly from Ra-226 or Pb-214. Unsupported Pb-210 was calculated by subtracting the amount of supported from the total Pb-210. Errors introduced by the subtraction operation were usually about 10%. A relatively simple constant rate of supply (CRS) model (e.g., Appleby & Oldfield 1992; Robbins 1978) was used for the calulation of age/depth expressions. Basically, a numeric technique was applied to calculate the total unsupported Pb-210 in the core using bulk density estimations (obtained from the dry weight of the slice divided by the (wet) volume of the slice).

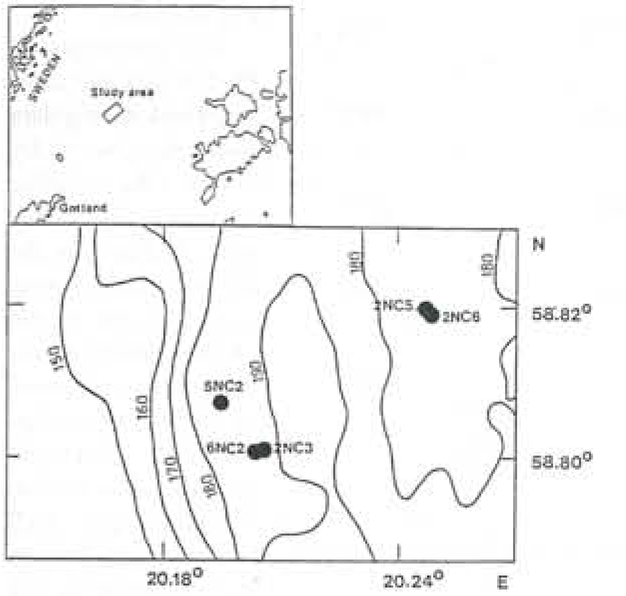

Fig. 1. Sampling stations in the North Central Basin (NCB) of the Baltic Sea. Isolines are given in metres

Table 1. **Characteristics of the sediment coring stations**

Core	Coordinates		Water depth
2NC3	58.80099°	20.20537°	192.70 m
2NC5	58.82028°	20.24635°	174.10 m
2NC6	58.81925°	20.2489°	174.50 m
5NC2	58.80723°	20.19242°	187.10 m
6NC2	58.80067°	20.20367°	188.90 m

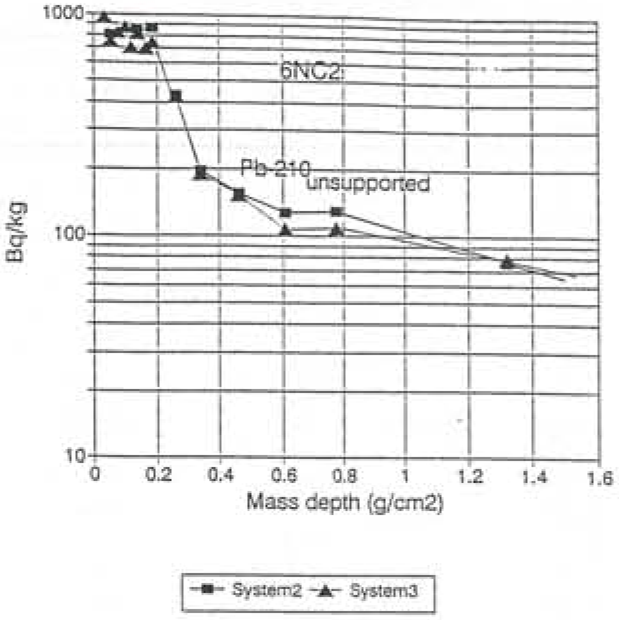

Fig. 2. Comparison of unsupported Pb-210 vs. mass depth curves generated with two different dating instrumentations

DATING RESULTS AND DISCUSSIONS

Because the core measurements were carried out by differing instrumentations with their own physical parameter characteristics (efficiencies, energy resolution etc.) the dried sediment slices of core 6NC2 were counted with two different instrumentations to check the variability within instruments. The resulting unsupported Pb-210 activities plotted against mass depth (g cm^{-2}) are shown in Fig. 2. The obtained curves are more or less identical suggesting that the radiometric profiles are independent of use of instrumentation.

In general, the measured Pb-210 activities are very high, sometime exceeding 1000 Bq/kg. High activities are usually connected with the fluffy layer. This suggests that the very fine particles more or less contain all the radioactivity. Fine particles are supposed to react agressively in the deep basin, due to their large surface area catching increased amounts of Pb-210 (and Cs-137) containing particles.

Cores 2NC5 and 2NC6, and 2NC3 and 6NC2 were taken only a few hundreds of meters apart (see Fig. 1). Indeed there are slight differences in the unsupported Pb-210 curves of cores 2NC5 and 2NC6 (Fig. 3) but the more visible difference is in the curves of 2NC3 and 6NC2. While the differences between cores 2NC5 and 2NC6 can be explained by mainly a slightly varying detector system respons (difference in magnitude of unsupported Pb-210), the deviation of 2NC3 core curve compared to core 6NC2 can only be explained

Table 2. **CRS modelling of the cores**

Core slice (mm)	2NC5	2NC6	Pb-210 Age (year B.P.)	5NC2	2NC3		6NC2
0-5		1995			1996		
5-10		1993			1995		
0-10	1994			1994			1995
10-15		1990			1993		
15-20		1987			1990		
10-20	1991			1991			1993
20-25		1984			1987		
25-30		1981			1984		
20-30	1989			1989			1990
30-35		1977			1978		
35-40		1975			1973		
30-40	1986			1986			1987
40-45		1972			1968		
45-50		1970			1965		
40-50	1983			1983			1984
50-55		1967					
55-60		1964					
50-60	1979			1979	1958		1981
60-65		1960					
65-70		1957					
60-70	1976			1976	1945		1977
70-75		1951					
75-80		1943					
70-80	1972			1972	1923		1971
80-85		1934					
85-90		1924					
80-90	1967			1967	1882		1965
90-95		1914					
95-100		1908					
90-100	1960			1960			1959
100-110	1951		1951			1952	
110-120	1939		1939			1944	
120-130	1925		1925			1933	
130-140	1903		1904				
140-150	1865		1865				

by loss of fluffy material on top of the core. A reasonably good agreement of both curves would be obtained by "adding" about 0.7 g cm^{-2} mass on top of 2NC3.

By comparing the unsupported Pb-210 curves of all the cores as one group (see Fig. 3, 2NC3 not plotted), it is obvious that there is little influence of water depth on the shape of the curves. While the eastern cores (2NC5 and 2NC6) were taken at a topographical elevation at about 174 m which compares with water depths of about 185 m for the 3 western cores, the unsupported Pb-210 curves show little variation. The slight differences observed are usually in the uppermost part of the core caused presumably by a minor loss of material, and in the lowermost part of the cores variation being explained by variable detector response (background). In summary, the curves within subareas are often nearly identical and also the slight variation between the two areas are minor. If any differences at all are observed these are most likely explained by the occurrence or absence of the unstable fluffy layer on top of the cores. This problem is even more addressed through the Cs-137 data where activities vs. mass depth are plotted in Fig. 4 for cores 2NC5 and 2NC6. Although the shape of the curves is almost identical, it is obvious that core 2NC6 lacks the uppermost portion because the activity is significantly lower in its top section.

Using unsupported Pb-210 data and measured bulk density data (bulk density = dry weight of the slice/slice volume) the cores were all dated by the constant rate of supply model. In the model calculations each sediment slice is compared to the total unsupported Pb-210 rate in the entire core section. Estimated ages of all the measured core slices using this model are given in Table 2. As can be seen there is good agreement in the chronology of cores 2NC5, 5NC2 and 6NC2 down to about 10 cm depth. Agreement with cores 2NC3 and 2NC5 is not too good below 4 cm core depth and this must be ascribed to the loss of surface material in these cores leading to total unsupported Pb-210 rates that are too low.

CONCLUSIONS

The dating of 5 short sediment cores from a small deep sedimentary basin of the Baltic Sea allows us to conclude the following:

(1) Closely spaced surface sediment cores from the North Central Basin area of the Baltic Sea yield similar unsupported Pb-210 depth curves.

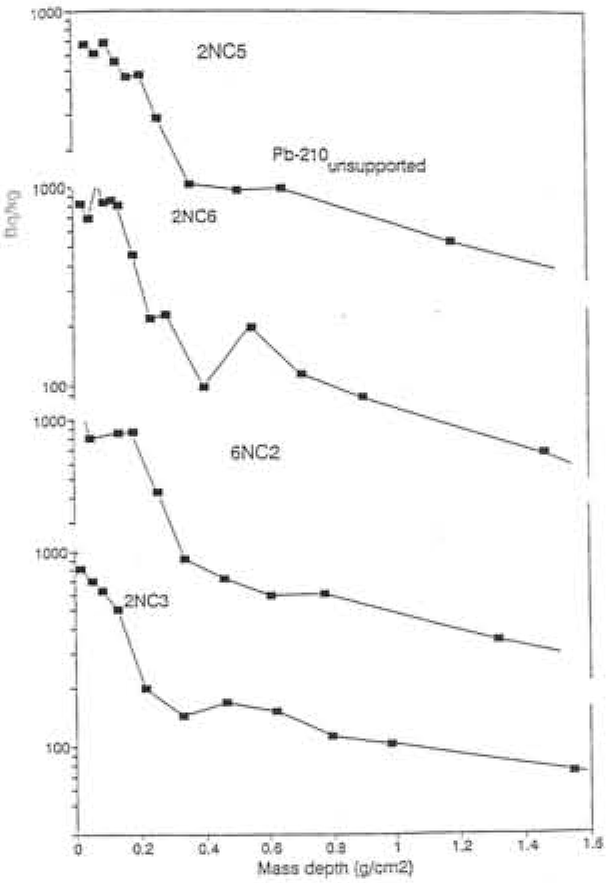

Fig. 3. Unsupported Pb-210 vs. mass depth of closely spaced cores 2NC5 and 2NC6, and 2NC3 and 6NC2

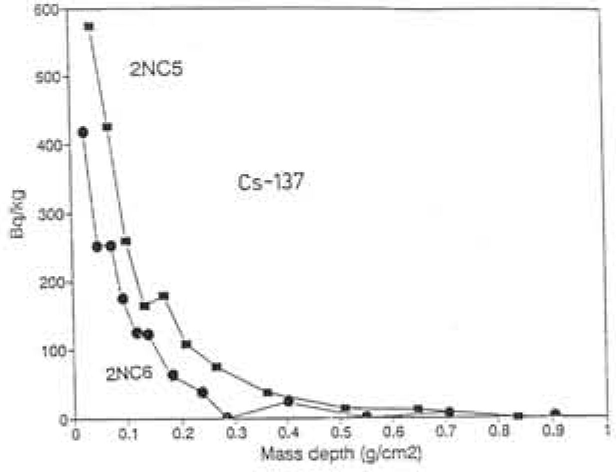

Fig. 4. Cs-137 vs. mass depth for cores 2NC5 and 2NC6

(2) Variation of radioactivity curves (both Pb-210 and Cs-137) is only found when the very fine surface sediment layer (sediment fluff) has been disturbed or even removed.

(3) Because of the varying thickness of the fluffy surface layer more than one sediment core is required for the determination of the recent chronology of the surface sediments.

The dating of the sediment slices is straightforward and introduces few errors during sample preparation processes. Being non-destructive, the measurements can be repeated on the same sample material and from tests it is concluded that uncertainties judged by repeated measurements are low, usually below 5%. The real errors in the dating process are introduced by the core recovery and the slicing. Through the coring process, core penetration may not be strictly vertical, i.e. not perpendicular to sediment layering, leading to increased sedimentation rates. Such errors can only be eliminated by multiple coring at the same coring station. As regards the slicing, some material is removed through the normal slicing process using professional slicers. This error is therefore regarded minor compared to the core penetration problems.

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No Indication of a Deeply Incised Dana River Between Arkona Basin and Mecklenburg Bay

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It is generally believed that beginning at its maximum highstand level the Preboreal-Boreal Ancylus Lake was drained by the Dana River via Kadet Channel, Fehmarn Belt and Great Belt. One missing link in this concept is an indication of the Dana River valley in the area between Arkona Basin and Kadet Channel. Joint Danish, Polish and German studies including shallow seismic surveys, sediment sampling, paleobotanical investigations and radiocarbon dating have been carried out in this region since 1989.
The results do not confirm the former existence of an incised Dana River draining the Ancylus Lake at the predicted course to a depth level of 32 m below present sea level. On the contrary, there is a Pleistocene threshold of 23 m below present sea level being inconsistent with the expected course and depth level of the Dana River.

Keywords: Baltic Sea, Holocene, Paleogeography, Ancylus Lake.

INTRODUCTION

The Ancylus Lake with its water level fluctuations has been one of the most fascinating and enigmatic subjects in Baltic paleogeographical research. Especially the Ancylus Lake highstand, the following regression and the outlet channels of this giant freshwater lake gave rise to several different hypotheses. The recent state of knowledge was summarized by Björck (1995). About 9,500 a BP isostatic uplift of south central Sweden started to produce up-damming of the water level in the Baltic basin. In the southern Baltic, where the isostatic uplift had either ceased or even turned into submergence, it resulted in a substantial transgression. Numerous suggestions on the maximum highstand level in the southern Baltic region during this transgression have been published. Kolp (1965) proposed a value of 20 m below present sea level (bsl) according to findings in the Darss Sill area. Kolp (1986) and Kliewe & Janke (1982) suggested a highstand level of 8-12 m bsl while Björck (1995) estimated a level of about 20 m bsl.

A still wider range of values has been suggested regarding the regression rate of the Ancylus Lake after its maximum highstand. Kessel & Raukas (1979) reported an Ancylus Lake level lowering of 25 m. A value of 13-15 m was published by Alhonen (1979) and Gudelis (1979). Eronen (1988) found 20 m in his studies while Svensson (1991) and Björck (1995) suggested 8-10 m.

According to Björck (1995) the regression of the Ancylus Lake was due to gradual down-cutting in the Darss Sill area, i.e. to the incision of the Dana River valley between 9,200 and 9,000 BP. The course of the Dana River was suggested to be coincident with the Kadet Channel, Fehmarn Belt and Great Belt implying a buried continuation from Kadet Channel to the Arkona Basin. However, only little information was available about this c. 35 km wide transition area. Therefore, Björck (1995) recommended a detailed seismic survey to detect the course of the Dana River here. Such a survey combined with sediment sampling, pa-

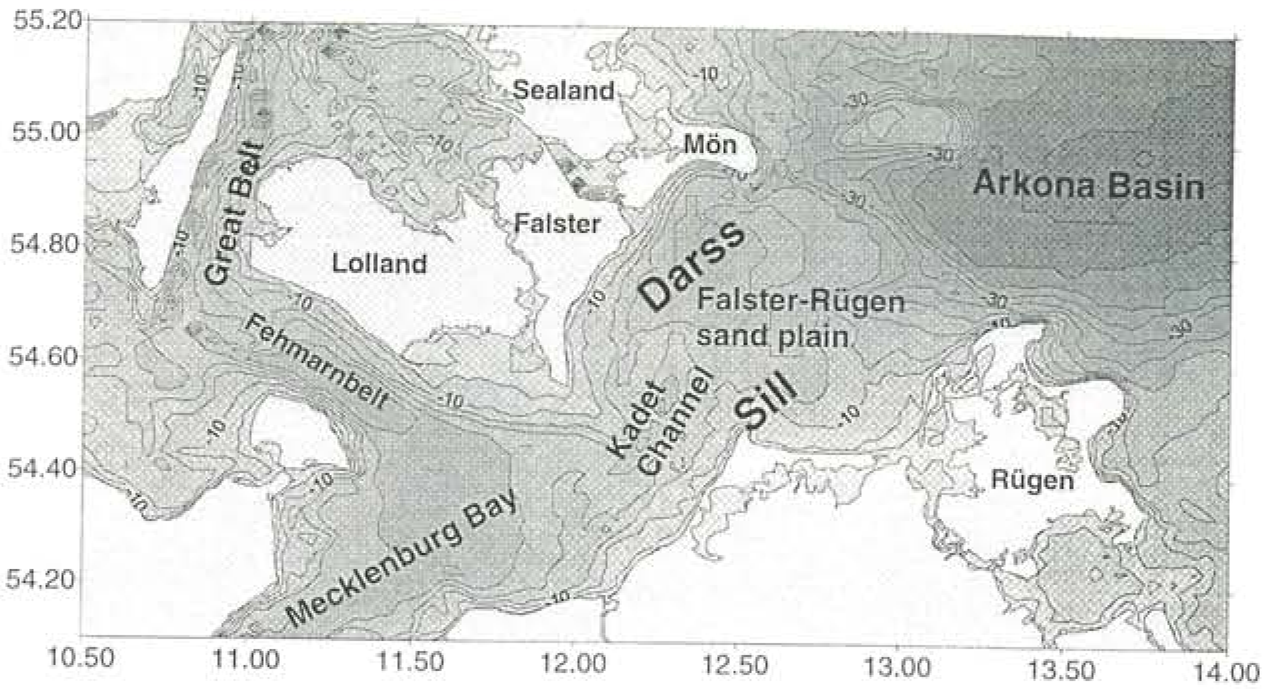


Fig. 1. Regional setting with main bathymetric features (bathymetry after Seifert & Kayser 1995)

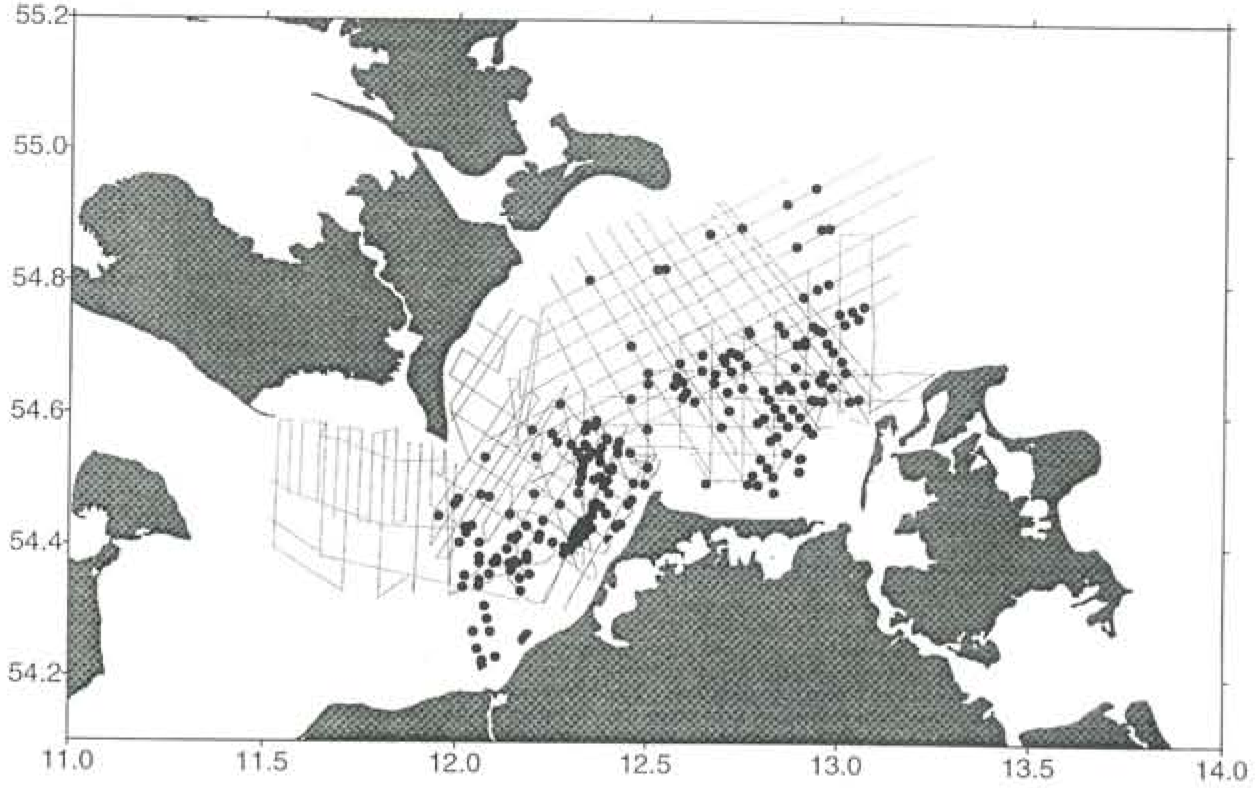
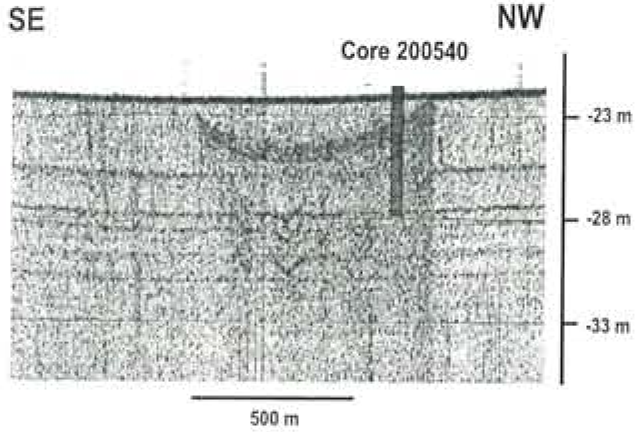
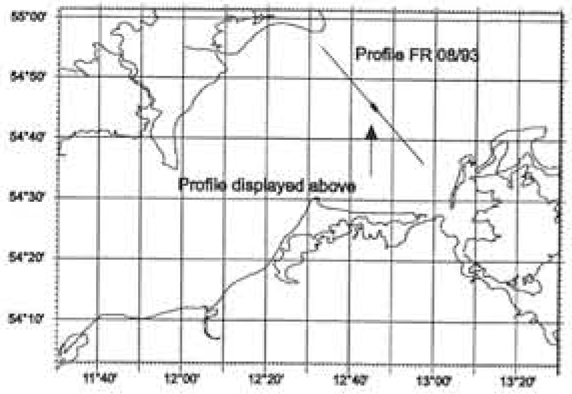


Fig. 2. Seismic grid and vibrocoring sites





leobotanical investigations and radiocarbon dating was carried out in a joint Danish, Polish and German study since 1989.

METHODS

A shallow seismic survey and sediment sampling were carried out onboard the research vessels "A.V. Humboldt", "Professor Albrecht Penck" and "Marie Miljø". The seismoacoustic equipment used in this study included a Boomer (Uniboom, 0.8-16 kHz), a subbottom profiler (ORE, 3.5 kHz), Datasonics and Geoacoustics CHIRP (1-10kHz) and a dual frequency echosounder (DESO 25, 15 and 210 kHz). Sediment samples were taken by a 6 m vibrocore device. Navigational data were provided by differential GPS and the Sercel Syledis system with an accuracy of within 10 m.

A number of cores were subsampled at selected levels for radiocarbon dating and analyses of macro- and microfossils, in order to obtain further information on the age and depositional environment of the sediments. The samples were dated either by conventional ^{14}C-dating at the Dating Laboratory of the Danish National Museum and GEUS, or by Accelerator Mass Spectrometry (AMS) ^{14}C-dating at the Institute of Physics, Aarhus University, following the method described by Heinemeier & Andersen (1983).

For more detailed information on the seismic interpretations, macrofossil- and diatom analysis and radiocarbon dating we refer to earlier publications (Jensen & Stecher 1992, Jensen et al. 1997, Lemke and Kuijpers 1995, Lemke et al. 1997).

200540 (FR A 7500/21)
54°43.483 N / 12°45.956 E
Water depth = 21.80 m

0-30 cm: Fine sand, light olive gray, many shells of *Macoma*

30-259 cm: Fine sand, light olive gray, homogeneous, coarse plant particles, no shells

259-322 cm: peat gyttja, brown, with sandy laminae, AMS-C14-Dating on remains of *Meryanthes trifoliata*, *Scirpus lacustris* and *Pinus sylvestris* gave an age of **9810 +- 75 a BP**

322-336 cm: Gyttja, greenish- to olive gray, fine laminated

336-342 cm: Fine sand, silty, light olive gray

342-487 cm: Silt - --> silty clay, a little lighter than above, fine plant remains

487-542 cm: clayey silt, light olive gray, AMS-C14-Dating on remains of *Salix herbacea* at 487-505 cm gave an age of **12180 +- 100 a BP**

542-598 cm: clayey silt with humic particles, light olive gray, high carbonate content , AMS-C14-Dating on remains of *Betula nana* and *Salix herbacea* gave an age of **12700 +- 110 a BP**

Fig. 3. Core 200540 with dated plant remains

SETTING

The area between Kadet Channel and Arkona Basin is part of the Darss Sill which acts as a major hydrographic threshold between the central Baltic Sea and the Kattegat at present. As the sea bottom is formed mainly by sand in this part of the Darss Sill it was called "Falster-Rügen sand plain" by Kolp (1965). The recent threshold depth is 17 m bsl (see Fig. 1). More detailed data are presented in Lemke (1992, 1994), Lemke et al. (1994) and Jensen et al. (1996).

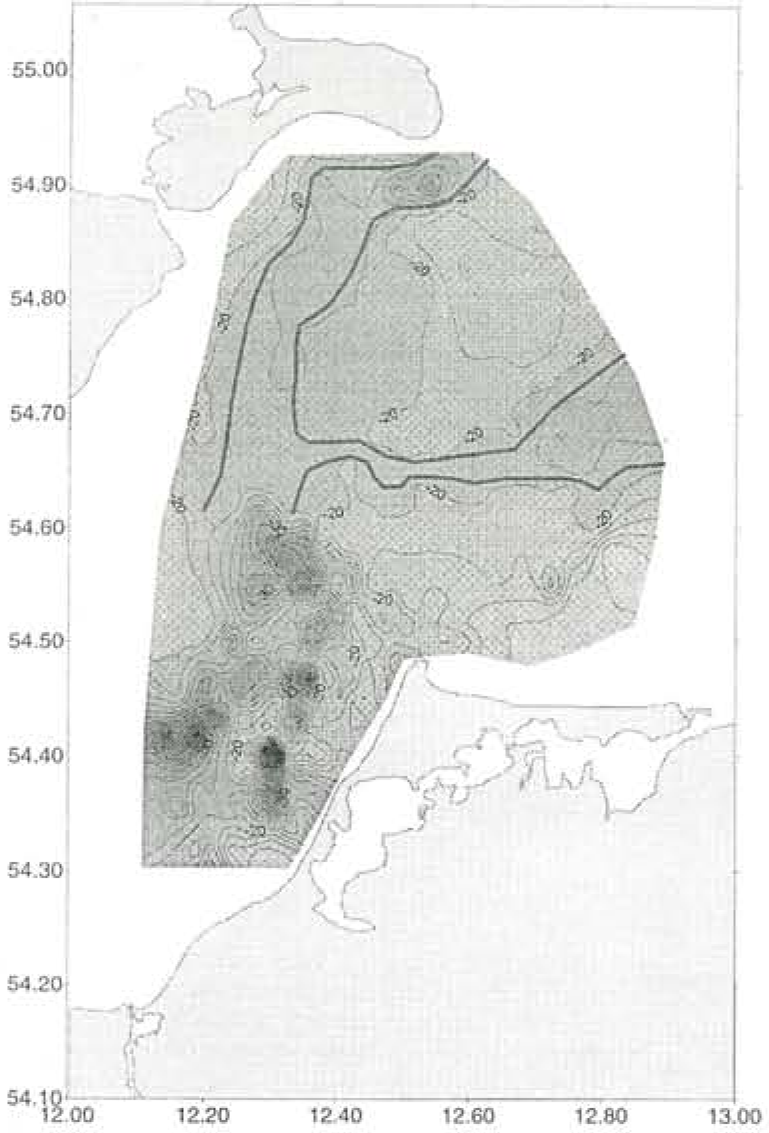


Fig. 4. Pleistocene surface at the Darss Sill in m below present sea level, solid lines indicate the course of shallow channels

RESULTS

During the seismoacoustical surveys a shallow subbottom reflector was identified nearly over the entire area. Usually, this reflector was detected some decimetres below the sea bottom. Locally however, the overlying bed thins out completely so that the reflector forms the sediment's surface. Lithologically, the upper bed consists of fine to medium sand with marine shells. The reflector described above forms the upper boundary of another fine sand type. This sand is rich in fine dispersed carbonate and contains no marine fossils. Fine humous particles are common.

The minimum age of the sand was determined by dating of organic infillings within shallow channels incised in the sand. A detritus gyttja was dated to 9,660 ± 145 BP (K 6343) by conventional radiocarbon dating, and plant remains within such a layer gave an age of 9810 ± 75 BP (AAR 2639) by using the AMS technique. Within the sand itself two datings could be gained from remains of *Betula nana* and *Salix polaris*. The ages were 12,180 ± 100 BP (AAR 3040) and 12,700 ± 110 BP (Fig. 2). Together with findings in the Arkona Basin and Mecklenburg Bay (Jensen et al. 1997) these datings confirm a late glacial age of the sands below the fragmentary thin marine sediment cover.

A map of the late glacial sand's upper boundary (Fig. 3) clearly shows a Pleistocene threshold at a recent level of 23 m bsl east of Kadet Channel.

DISCUSSION AND CONCLUSIONS

Assuming a Dana River valley as proposed by Björck (1995), one had to expect a buried valley with a minimum depth of 32 m bsl, as it is known from the Kadet Channel. The infill of this valley would have to be of late Boreal or younger age.

As shown above, the deepest incisions in the Pleistocene sands do not go beyond 23 m bsl. Actually, Boreal deposits were found in these channel structures. They consist, however, of calcareous gyttjas reflecting a rather quiet lacustrine or paludal depositional environment (Bennike et al. in press) . Similar Boreal deposits of local lake, mire or swamp origin are found at several places in the Darss Sill area.

Furthermore, if the Dana River would have drained the Ancylus Lake via the Kadet Channel for a time span of several hundreds of years, a prograding system was likely to have developed in the southwestern Kadet Channel exit. Interpretations of seismic data from this area show no indications of such a prograding system.

Further results of this study which will be presented elsewhere (Jensen et al. in prep.) indicate a maximum highstand level of the Ancylus Lake at 18 m bsl. Considering the following regression of at least 8-10 m (Svensson 1991, Björck 1995), the Pleistocene threshold northeast of Kadet Channel must have prevented a lake level lowering of more than 5 m. Thus, any further drainage must have happened elsewhere.

According to Björck (1995), the Ancylus Lake became level with the sea after the regression. This implies necessarily a connection between the Kattegat and the Ancylus Lake. As the Pleistocene threshold is much too high to maintain this connection via the Darss Sill, it has to be looked for the link in another place. Without such a connection in a different locality, a new transgression in the Darss Sill area would have occurred. However, there is no indication for this.

Therefore, it has to be stated that the Dana River in the previously predicted course and depth level is not verifiable.

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Reprocessing Results of Older Seismic Oil Exploration Data from the Area of the Greifswalder Bodden (Project SASO II)

Peter Mayer, Friedrich Zenker,
Holger Wirth and
Manfred Krauss

Mayer, P., Zenker, F., Wirth, H. & Krauss, M.1999: Reprocessing results of older seismic oil exploration data from the area of the Greifswalder Bodden (Project SASO II). *Baltica Special Publication* 12, 71-73. Vilnius, ISSN 0067-3064

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In the framework of the project SASO II (Struktur-Atlas Südliche Ostsee) there were CDP-seismic oil exploration data from the area of the Greifswalder Bodden (north-eastern part of Gernmany) reprocessed. The target of the project is to reconstruct the Cimmerian-Laramic structure in the above mentioned area. For this reason it was necessary to increase the resolution and the signal/noise ration of the older seismic processing results. Hereby, the main problems were the wave-form distortion caused by gas-saturated mud on the subbottom, as well as the superimposition of low frequency and low velocity noise. Therefore, the seismic reprocessing technique mainly was designed for a careful prestack processing. The given result examples demonstrate the quality improvement reached by the seismic reprocessing.

Keywords: Seismic, reprocessing, prestack processing, Greifswalder Bodden, NE Germany, Vorpommern fault system.

PROJECT SASO II TARGET

The target ofthe SASO II project - as a part of SASO (Struktur-Atlas Südliche Ostsee) - is to reconstruct the Cimmerian-Laramic structure beneath the eastern Boddens of Vorpommern using existing older industrial seismic field data. Presently, the main activity of the SASO II project is centred on the area of the Greifswalder Bodden (north-eastern part of Germany).

SEISMIC FIELD DATA

The data acquisition (72 CDP-seismic lines, 560 km) was performed by standard marine seismic technology (towed hydrophone streamer) on extremely diffcult conditions (water depth 5...8 m, busy shipping traffic and fishing, partly mud-covered sea bottom). The parameters of data acquisition (1986/87) and former data processing (1987) were designed for oil and gas exploration of the Permian (TWT > 1.5 s) and, therefore, non-optimal for the target of the SASO II project (high seismic resolution for TWT up to 1.5 s).

Parameters of data acquisition:

CDP-geometry:	Hydrophone group spread -160...-1310 m, 24-fold CDP-coverage, shot point interval 25 m;
Energy source:	VAPORCHOC, octojet, tow depth 2 m;
Streamer:	24 groups of 48 hydrophones each, group distance 50 m, tow depth of the streamer 3...5 m:
Data recording:	Sample rate 4 ms, frequency filter 18 ... 62.5 Hz.

SEISMIC DATA QUALITY ANALYSIS

The 1987 data processing does not satisfy the quality requirements of the SASO II project (see Fig. 1) because of

- a low frequency filtering in data acquisition,
- non-optimal prestack processing of the single records, and

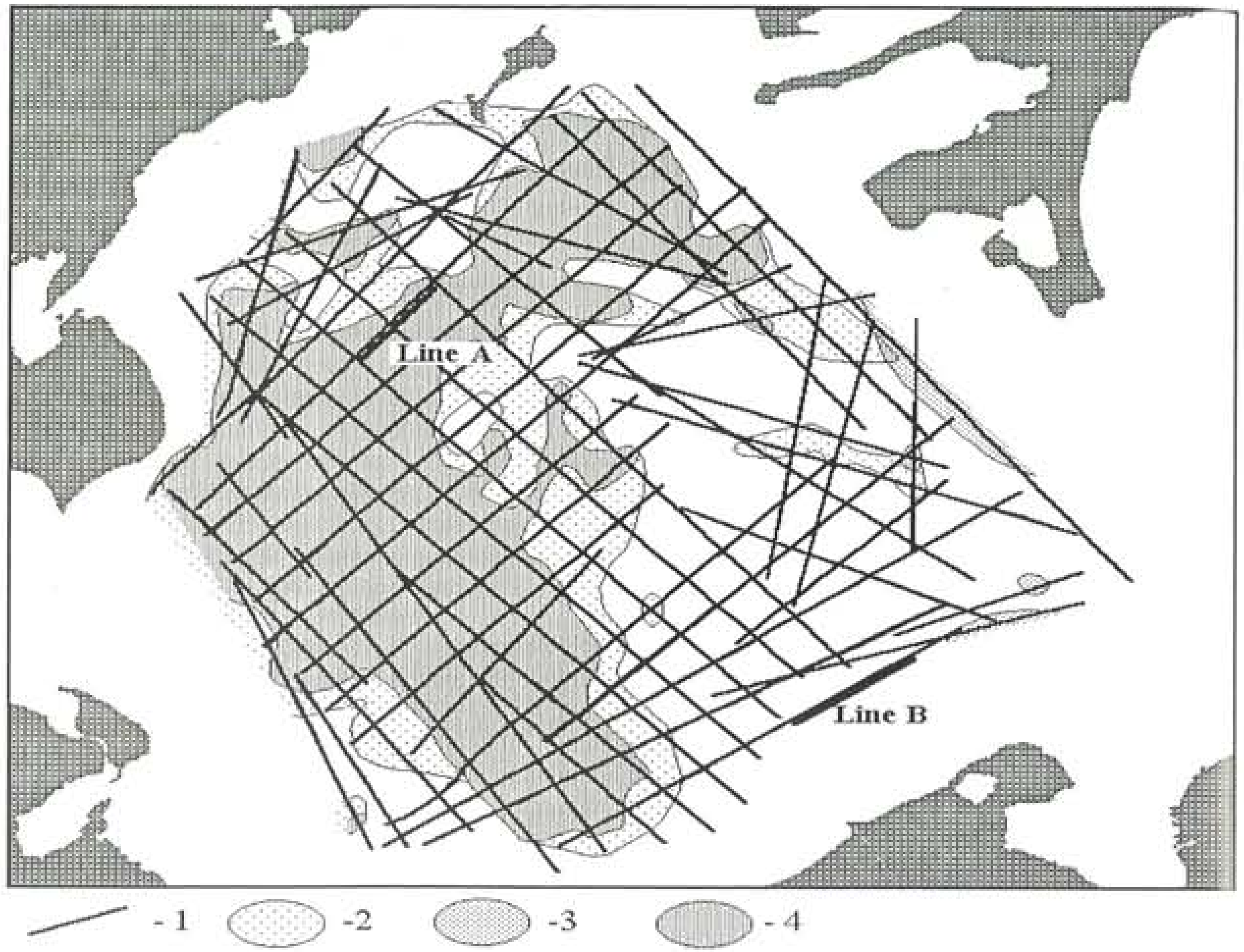

Fig. 1. Schematic map of seismic quality and mud distribution from sediment echograms in the area of the Greifswalder Bodden: 1- seismic and sediment-echographic lines; 2 - mud covering without diminishing of seismic quality; 3 - no mud covering, diminished seismic quality; 4 - mud covering and extremely diminished seismic quality

- narrow low frequency band-pass filtering before and after stack were applied.

For designing optimal seismic reprocessing parameters, as the first step, a detailed quality analysis of seismic data was caried out using:

- field records of each shot point,
- non-processed records of the shot point nearest traces as well as
- sediment echograms simultaneously recorded on the seismic CDP lines.

The schematic map in Fig. 1 in connection with the seismic examples shows that there are two facts diminishing the seismic quality: ;

- In mud-covered areas neither on the single field records of the shot points nor on the non-processed records of the shot point nearest traces it is possible to recognize any useful seismic energy;
- In the whole investigation area, a strong low frequency and low velocity coherent noise (6...8 Hz resp. ± 1500 ...1700 m/s) is superimposed to the useful seismic energy.

DATA REPROCESSING RESULTS

In close co-operation with the members of the project group SASO II (Institut für Geologische Wissenschaften der Universität Greifswald) the seismic data reprocessing was carried out by the Gesellschaft für Geowissenschaftliche Dienste Leipzig mbH (GGD) using the seismic system ProMAX (6.2). The main target of the data reprocessing was to increase the signal/noise ratio and the seismic resolution in the TWT-interval up to 1.5 s. The optimal reprocessing parameters were determined after detailed processing tests mainly centred on the prestack processing (VAPORCHOC signature deconvolution, wide-band frequency - wave-number - filtering, predictive minimum-phase deconvolution)

The given examples demonstrate the quality improvement reached by the seismic data reprocessing of the above mentioned field data. Due to higher vertical and horizontal seismic resolution of the migrated time sections and obvious correlation of relevant reflection horizons, the boundaries and the detailed structure of faults can be reliably mapped. This is a necessary precondition to achieve the most important premise of the oriject: Delineation of the Structure of the Vorpommern Fault System in the Area of the Greifswalder Bodden.

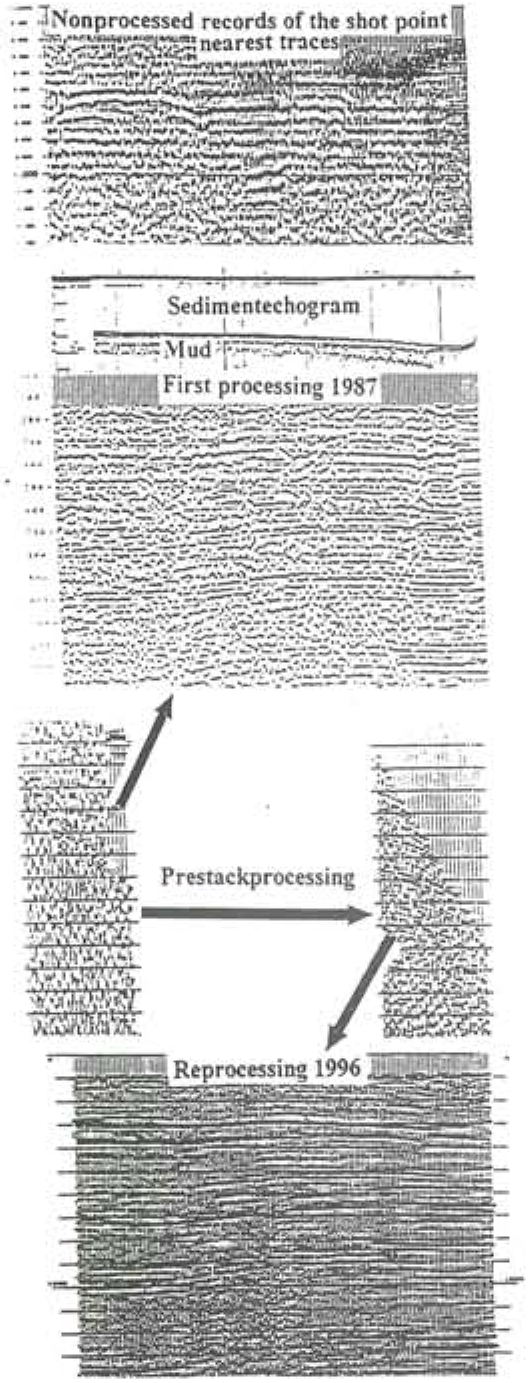

Fig. 2. Example for quality improvement by reprocessing of industrial seismic field data from the area with mud covered sea bottom (Line A, see Fig. 1).

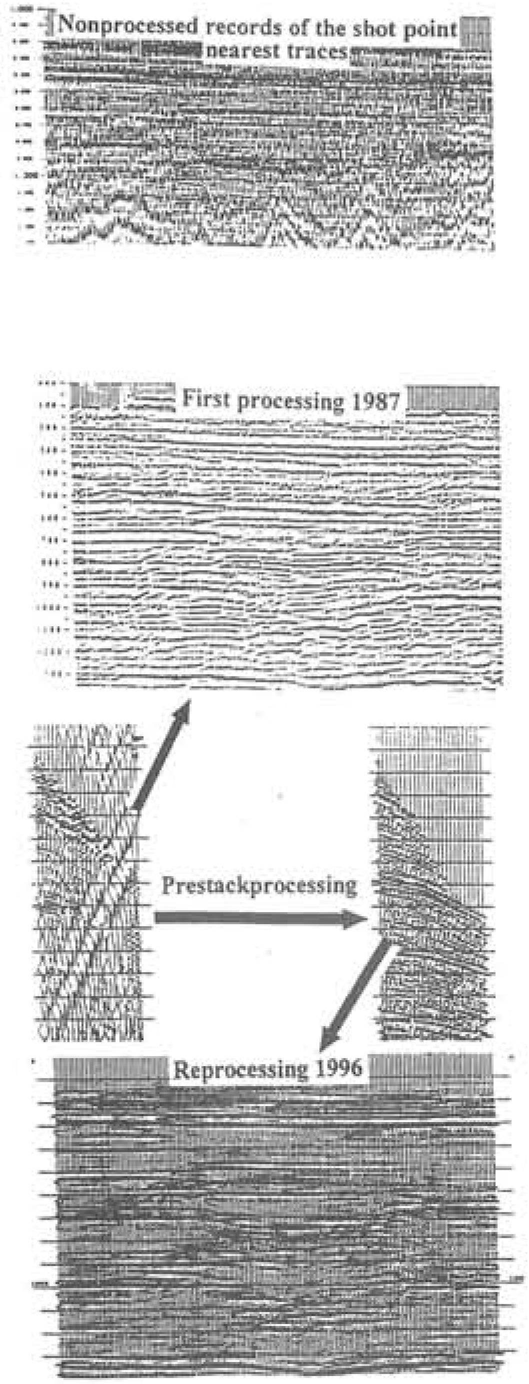

Fig. 3. Example for quality improvement by reprocessing of industrial seismic field data from the area without mud covering of the sea bottom (Line B, see Fig. 1).

ACNOWLEDGEMENTS

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Glaciofluvial Deposits in the North-Eastern Baltic Proper

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Glaciofluvial deposits have been recorded at several locations in the north-eastern Baltic Proper. The investigated area extends from the Estonian Islands Hiiumaa (Dagö) and Saaremaa (Ösel) in the east to some 100 km westwards. The investigations of the area were performed using a single channel seismic reflection profiler. Glaciofluvial deposits occur on top of the Late Weichselian till in the vicinity of two prominent, ENE-WSW directed escarpments, namely the Ordovician-Cambrian clint in the northern part of the area, and the Silurian clint in the central part of the area. The glaciofluvial formations found in the clint zones have locally been interpreted as possible eskers, whereas those in the foreclint area, in all likelihood, consist of a mixture of glaciofluvial and glaciolacustrine deposits.

Keywords: glaciofluvial deposits, continuous seismic reflection profiling, northeastern Baltic Proper.

INTRODUCTION

Our understanding of the bedrock as well as of the Quaternary deposits of the Baltic Sea has considerably improved since the initiation of seismic investigations. Such investigations were conducted in the western part of the Baltic Sea already in the beginning of 1960s by the Marine Department of the Institute of Geology, Stockholm University (Flodén 1975a, 1980). In the eastern part of the Baltic Sea systematic seismic profiling began in 1970 (Litvin et al. 1974). A review of the marine geological research on the Estonian Shelf is given by Lutt and Raukas (1993). The first results of systematic seismic profiling in the eastern Baltic Proper, conducted within the frames of joint marine geological projects between Stockholm University and various Geological Institutions in the Baltic States since 1991, have been published (Noormets 1994; Flodén et al. 1994; Tuuling et al. 1995; Bjerkéus et al. 1995).

Glaciofluvial deposits occur on, as well as below the upper, Late Weichselian, till layer. This paper is focused on the distribution and morphology of glaciofluvial deposits laid down ontop of the Late Weichselian till in the northeastern Baltic Proper.

DATA ACQUISITION

The present investigation is essentially based on c. 4400 km of seismic profiles (Fig. 1). These continuous seismic reflection data were collected in the frames of joint marine geological projects between the Department of Geology and Geochemistry, Stockholm University, the Estonian Geological Survey, Tallinn, and the Institute of Geology, Tallinn. During 1991 to 1995 the seismic equipment operated by the Stockholm University was used on board of various vessels. The single channel seismic equipment consisted of an air gun transmitter and a 20 m long hydrophone eel for the detecting of impulses reflected from different layers below the sea bottom. Registered signals were then forwarded through analog input to the graphic recorder. They were displayed on a special paper in the form of continuous profiles. Recorded frequency bands were 250-500 Hz for the bedrock and 450-900 Hz for the Quaternary deposits. Water depths were recorded by a 33 kHz ATLAS echosounder. Detailed description and use of this equipment is given by Flodén (1975b, 1981).

Location of the vessel was noted in 20 min. intervals in 1991 and in 10 min. intervals in the following years by the use of a RAYTHEON Global Positioning System (GPS) Navigator. The precision of the GPS equipment was c. +/- 50 m at the time of this investigation.

GENERAL GEOLOGICAL BACKGROUND

The bedrock in the explored area consists of Precambrian crystalline basement in the north. Southwards the basement is successively overlain by a cover of Cambrian, Ordovician and Silurian sedimentary bedrock towards the south (Lutt & Raukas (eds.) 1993; Flodén 1980; Winterhalter et al. 1981). The most distinguished geomorphological features which have influenced the glacial and glaciofluvial, as well as the postglacial deposition in the area are the two extensive, ENE-WSW directed, bedrock escarpments. These are the Ordovician-Cambrian clint in the northern part, and the Silurian clint in the central part, of the investigated area (Fig. 1). Martinsson (1958) has discussed the origin and structure of these escarpments in the Baltic Sea. The two plateaus in the area, namely the Ordovician plateau in between the two clints, and the Silurian plateau south of the Silurian clint have comparatively flat bedrock topographies. The bedrock surface in the area of investigation has a gentle dip towards southwest by c. 12 m per 10 km.

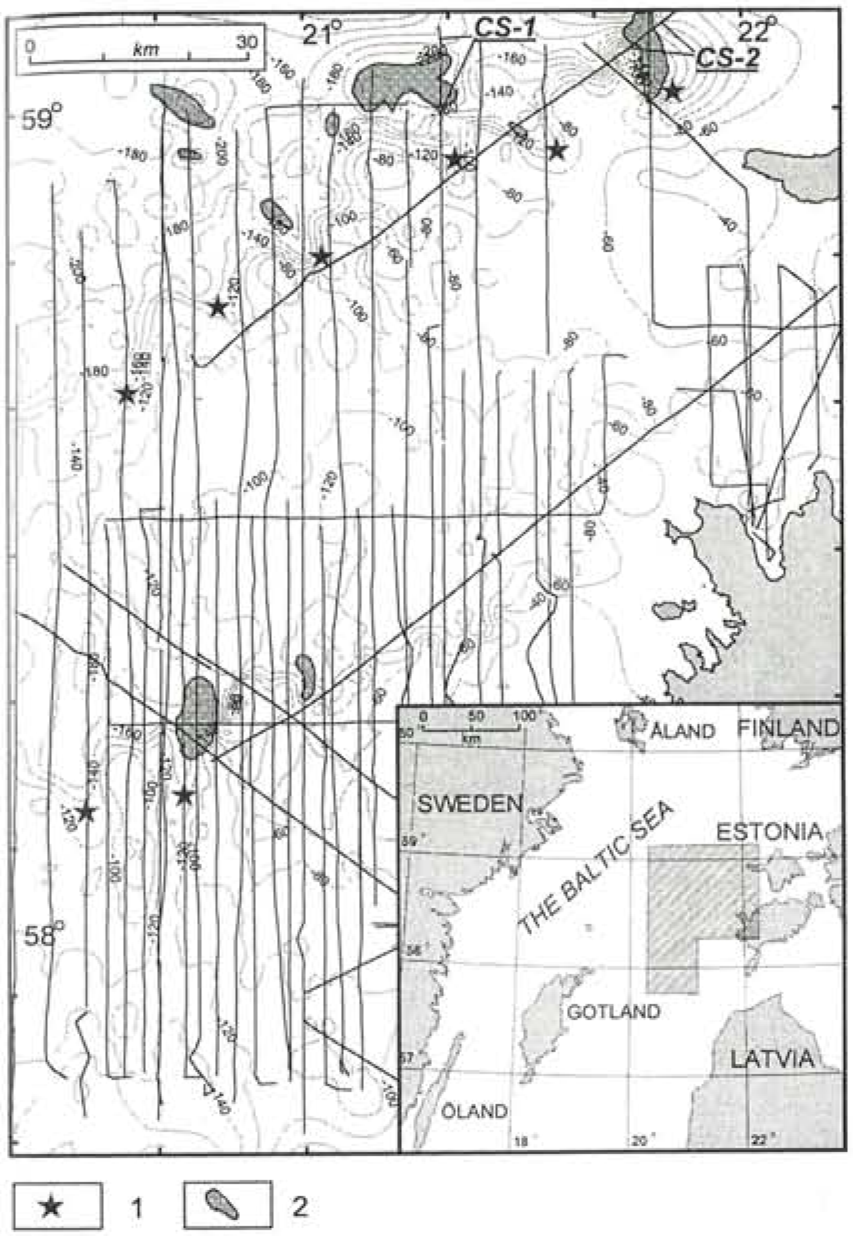

Fig. 1. Location of the seismic lines, and cross-sections CS-1 and CS-2, presented on Figs. 2 and 3 respectively. The bedrock topography is presented by isolines with 20 metres intervals below sea level. 1- troughs; 2- glaciofluvial deposits

GLACIOFLUVIAL DEPOSITS

The glaciofluvial deposits have been differentiated mostly on the basis of their seismic pattern. Different grain sizes and lithologies cause greater scattering of the seismic energy within the glaciofluvial deposits as compared to within the beds above and below. This results in a "lighter" seismic pattern and rather distinctive upper and lower boundaries of the glaciofluvial deposits in the seismic profiles. Lamination can often be distinguished within glaciofluvial deposits, too (Figs. 2 & 3).

The morphology of the glaciofluvial landforms varies from layers with uniform thicknesses, covering several square kilometres, to high ridges with sharp crests (Figs. 2 & 3). The former morphological variety is characteristic to the areas of low altitude in front of the Ordovician-Cambrian and Silurian clints, while the latter occurs generally within the troughs in the Ordovician-Cambrian clint zone. Thick sequences of glacial deposits, filling deep depressions in the bedrock surface, often contain layers of glaciofluvial deposits, too. Laterally the glaciofluvial deposits seem to have rather variable shapes, such as round, elongated, and irregular. The shape of any single formation was not possible to map in detail because of the sparse spacing of survey lines in the Ordovician-Cambrian clint zone (Fig. 1). The glaciofluvial deposits are usually covered by complexes of late- and postglacial glaciolacustrine and marine deposits.

In the central part of the investigated area the glaciofluvial deposits occur in connection with a trough cut into the sedimentary bedrock. The trough cuts through the Silurian escarpment and is filled with a complex sequence of glacial and postglacial deposits. The sequence of Quaternary deposits in the trough is locally over 70 m thick and contains layers of

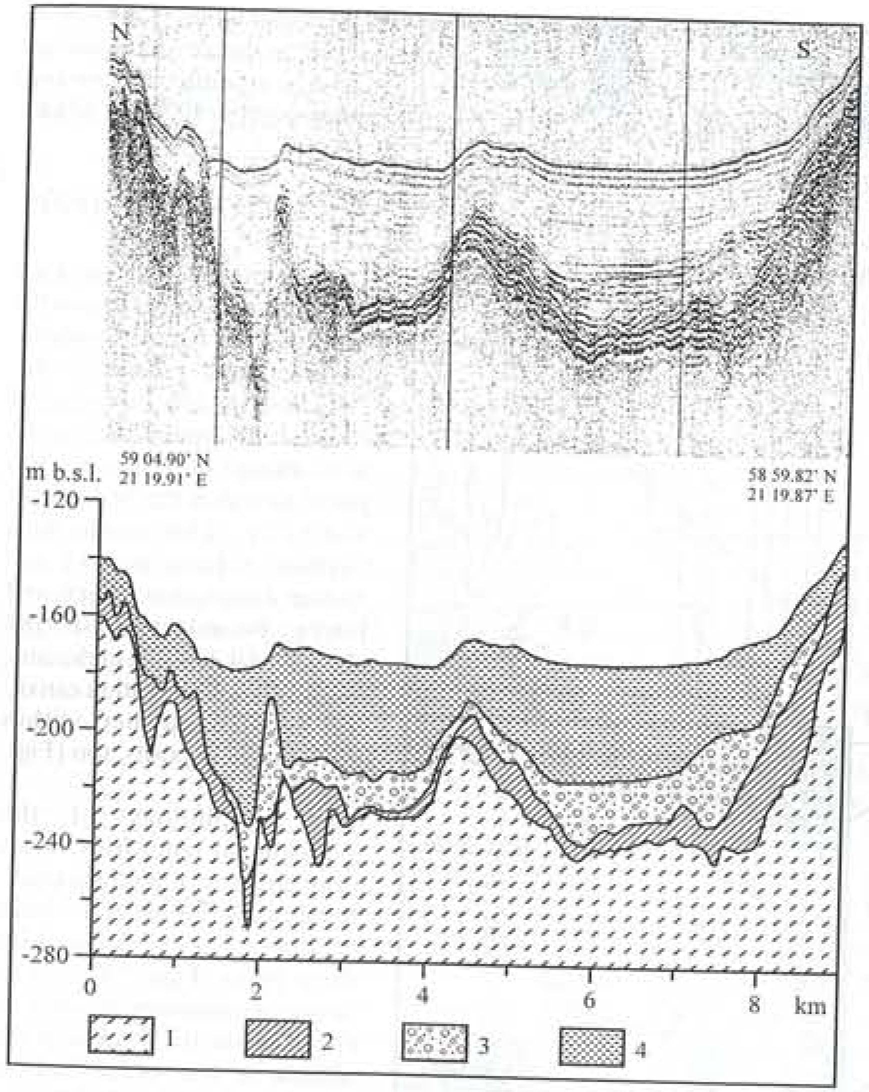

Fig. 2. Cross-section 1. 1- sedimentary bedrock (unidentified); 2- Late Weichselian till; 3- glaciofluvial deposits; 4- late- and postglacial glaciolacustrine and marine deposits. For the location of cross-section see Fig. 1

glaciofluvial deposits. South of the Silurian clint the glaciofluvial deposits have not been recorded on the Late Weichselian till.

DISCUSSION

Glaciofluvial formations with distinct crests have mostly been recorded in the troughs cut into the Ordovician-Cambrian clint, whereas in the foreclint area these deposits have the form of layers with comparatively uniform thicknesses. However, several troughs were recorded, particularly in the Ordovician-Cambrian clint zone, where these deposits are filling depressions in the subjacent topography.

The glaciofluvial deposits found in the foreclint area were probably laid down in a glacioaquatic environment near the ice margin. Thus, these deposits consist very likely of a mixture of glacial, glaciofluvial and glaciolacustrine deposits i.e. were laid down in water, rather than by water, ponded partially in front of the ice margin and partially under the floating ice margin.

The ridges with sharp crests are rather well preserved. This suggests that the glaciofluvial deposits were laid down in passive ice sheet conditions near the ice margin (Hoppe 1961). Since the entire clint complex is of a erosional origin, the troughs mentioned earlier were very likely cut into the bedrock during the advancing stages of the ice sheet or even during the preglacial period (Martinsson 1958). Thus, the meltwater, issuing from beneath the ice sheet during the recession, was obviously concentrated along already existing pathways, and the subglacial meltwater channels most likely coincided with the troughs cut into the clint. That would explain the occurrence of glaciofluvial deposits along the troughs.

The formation of glaciofluvial ridges with sharp crests may be explained by an accumulation of deposits along the steep ice-walled channels, possibly subglacially. Many studies have pointed to the possibility of such a mechanism with similar landforms created as a result (Hoppe 1961; Tanner 1932). Considering the above mentioned these glaciofluvial ridge landforms could well be eskers or, according to Flint (1928), esker-like crevasse fillings.

CONCLUSIONS

The submarine glacial landforms left by the vanishing last ice sheet allows us to draw some general conclusions regarding the glacial sedimentary environment at the Ordovician-Cambrian clint zone during the Late Pleistocene. Thus, the ice seems to have been generally passive at the marginal zone during the formation of the esker-like formations. The lack of a continuous belt of glacial formations suggests that no long term halt of the glacier margin occurred along the clint zone during the recession of the ice sheet. The few landforms with considerable dimensions which were recorded there, were formed most likely in the marginal ice crevasses by glacial marginal and/or subglacial melt water streams, or in the water ponded front of the ice margin and partially also under it.

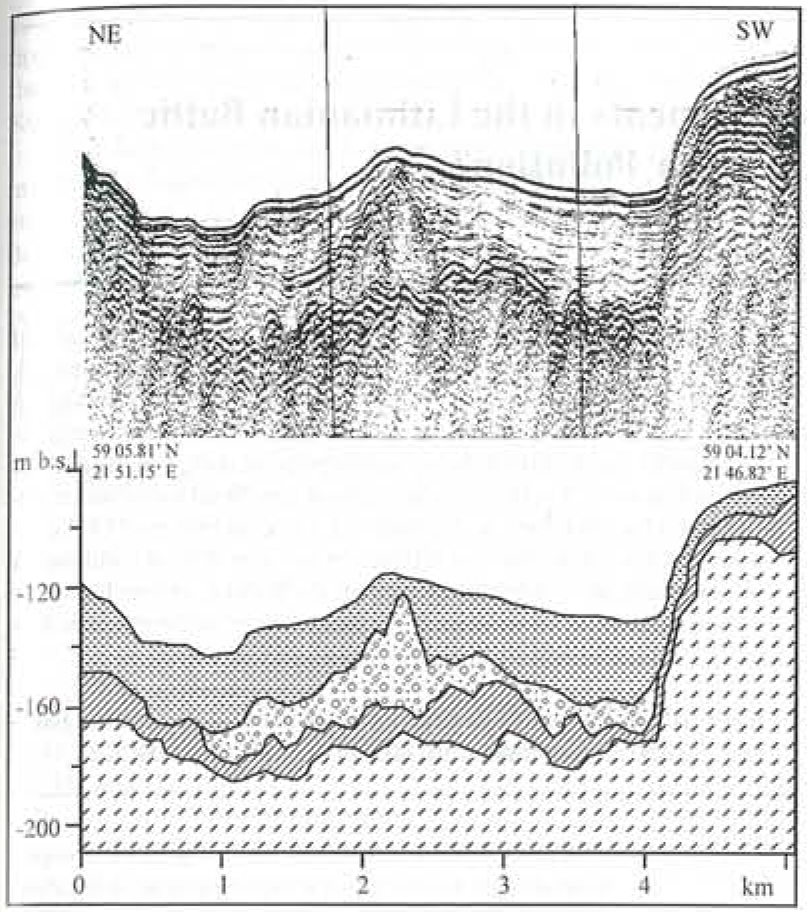

Fig. 3. Cross-section 2. For the location and legend of cross-section see Figs. 1 and 2 respectively

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Geochemical Anomalies of Elements in the Lithuanian Baltic Coastal Zone - Natural Origin or Pollution?

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The results of sedimentological–geochemical investigations carried out in 1975–1996 in the lagoon of Kuršių Marios (Curonian Lagoon), the sand spit of Kuršių Nerija (Curonian Spit) and environs of Būtingė and Klaipėda oil terminals are generalised. The level of environment pollution, ratio of natural–anthropogenic components of sedimentation, as well as the consequences of unrefined waste water discharge on the environment are analysed. The distribution of 18 chemical elements determined for different types of sediments and media of environment enables to distinguish the natural and technogenic sedimentation areas and reveal the local role of anthropogenic factors in the anomalies of the Lithuanian nearshore.

Keywords: Lithuanian coastal zone, geochemical anomalies, natural–antropogenic components, lagoon of Kuršių Marios.

INTRODUCTION

Heavy metals (HM), hydrocarbons (HC), organic compounds (OC), and other components identified by chemical analysis in marine and continental media are often attributed to toxic representatives of pollution.

However, in the process of sedimentation and turnover, both natural and anthropogenic analogues of HM, HC and OC take place. In determining their total content and presenting it is a purely anthropogenic product many researchers make tendentious conclusions. Recommendations leading to groundless and non-objective administrative decisions are usually suggested. What is the real state of affairs?

The dependence of formation of the chemical composition on the lithology of rocks, content of organic matter, water mineralisation, changes in sedimentation conditions and other factors determines the development of two main state forms: lithogenic (LG) and reaction capable (RC) in the process of sedimentogenesis and their redistribution during differentiation of sedimentary matter. The dominating state forms differ with different elements (Monin & Lisitsin 1983, Lukashev1986, Pustelnikovas 1992).

Are soils and sediments polluted? Does the content of investigated components reflect the natural anomalies, which recorded the trends of past and present exogenic processes in the course of late geological history? An attempt is made to answer these questions in this work, which generalises the investigations carried out in the aqua- and continental landscapes of Lithuanian nearshore of the Baltic sea in 1975-1996.

The analysis of natural and anthropogenic components in aqua-landscapes is widely represented (Gudelis & Pustelnikovas 1983, Pustelnikovas & Nesterova 1984, Pustelnikovas 1992, 1993, 1994a,b, 1995a,b, 1996, 1998). The samples were analysed by the methods of spectrometry, gas chromatography and macro-chemistry. The results obtained enabled to make recommendations for revision of nature protective standards for HM and HC (Pustelnikovas 1994 b, 1995 b).

COMPARATIVE CHARACTERISTICS OF THE TOTAL AND STATE FORMS OF ELEMENTS

The characterisation of total element content was done for the Baltic Sea basins (Kuršių Marios and Vistula lagoons, Gulf of Riga and Gulf of Finland) with different climatic conditions, hydrological regime, geological structure and biological productivity, and for the polar Hornsund fjord (Pustelnikovas 1992,1998).

These comparisons revealed the decisive role of natural – geochemical factors of sedimentation environment in quantitative and qualitative changes of elements.

The state form of elements in the sediment thickness can reflect their background level in the pre-industrial period and its changes in the times of intensive human activity. The investigation of 14-m thickness of Quaternary sediments in the Gdansk Bay (Lukashev 1986) revealed that actually throughout the geological history of the sea the ratio between the lithogenic and reaction capable forms of Mn and Cr remained stable, prevailed by RC (58 – 64 % - for Mn) and LG (72 – 87% - for Cr) forms. Even the background concentrations of these elements in many cases exceed those in the surface layer of recent sediments of the lagoon Kuršių Marios.

The ratio between RC and LG forms of 6 elements in different chains and sediment types of the barrier zone Nemunas – Kuršių Marios - Baltic Sea clearly demonstrates their geochemical nature. The basic sedimentation medium was represented by the Baltic Sea Proper, whereas, deposits - by the marine Holocene clay. For Mn, Ni, Zn and Cu the prevailing state form is RC, whereas, for Co and Cr – LG (Pustelnikovas 1994b, 1995a,b, 1998).

The total content of HC in the Klaipėda strait-port – if compared with their negligible concentration (0.3 – 6.3 mg/g) in other investigated sectors of sedimentation – show 50–60–fold increase, and their technogenic constituent makes as much as 65–70%. The natural material and untreated city wastes accumulate in the strait. The zones of natural and technogenic sedimentation were distinguished (Pustelnikovas 1996). In the latter, where stagnant conditions prevail, the content of elements is anomalous. Thus, the concentrations of Cu, Zn, Pb, and Hg are by 2.5-12 times higher if compared to those in the zones of natural sedimentation, whereas hydrocarbons (HC - oil products) - by as much as 40 times. The natural (biogenic) HCs do not exceed 35%. Notwithstanding the huge anthropo-pressure we cannot yet speak about the scale of actual pollution, because not all anthropogenic sediments are toxic.

Bearing in mind the most intensive human activity during the last 30–40 years and the still shorter period of material changes and conversion of forms, we may judge about the relation of pollution with the most unstable state forms (water soluble and organic–mineral - OM). They are composed of elements sorbed from the water by suspensions or plants or contained in the organisms and their facies.

A cyclic distribution of the organic-mineral form of macroelements in the 115 cm sediment thickness of Kuršių Marios lagoon was determined. Its content slightly decreases towards the surface. Depending on genetic link of elements the relative content of OM form ranges from 0-0.3 (Ti, Fe) to 8.4-21.2 (Mn, Zn)%. The relation of this form with the natural sedimentary matter is obvious. The OM form of HM, on the contrary, can be with reservation related with the anthropogenic substance. This is especially true for Zn and Cu, though the content of Zn (%) in its total concentration is not high. The content of OM form of Zn, Cu, Cr, Ni and Co increases towards the surface (Pustelnikovas 1994b).

The contents of OM form of elements in different basins of Eastern Baltic reveal their lower concentrations in Kuršių Marios than Vistula lagoon (2.6-30) or Gulf of Finland (3.1-40 times). Having compared the ratio between this form and total content of elements we can speak only about minimal pollution of sediments. Their low concentrations are also observed in the Baltic Proper (Pustelnikovas 1992). The obvious increase of OM form of elements in the barrier zones may be a result of human activity.

COMPARATIVE GEOCHEMICAL CHARACTERISTICS OF BACKGROUND AND POLLUTED AREAS

The range of pollution in continental- and aqua-landscapes should be determined by comparing background levels of analysed parameters with their factual state in various sites of the basin, sediment types and areas with different anthropogenic load.

The main comparative geochemical data are given in Table 1. They include Neogene and Quaternary (Pleistocene and Holocene) deposits and recent sediments, as well as marine and beach sediments, which are often effected by human impact areas, such as oil terminal and railway, port aquatory, and other natural-anomalous lithological objects.

All concentrations of elements in the natural sediments (Table 1, I) are within the limits of various rock and lithosphere object Clarks. Among these sediments natural-anomalous objects stand out with high quantities of organic and carbonaceous matter. They have extreme concentrations of all investigated elements, exceeding the background values by 2-150 (and even more) times (Table 1, II).

Abrupt trends are often determined not by anthropogenic causes but rather by geochemical properties of elements, sorptive capacity of containing object and environmental conditions of their formation.

If compared with the background contents of these elements in clean sediments their concentrations in technogenically-anomalous varieties are 2-7-fold (sometimes even 15-fold) higher (Table 1, III). However, they are by far lower than contents of all elements in natural-anomalous objects - which is, actually, not related with the environment pollution. In the zone of technogenic sedimentation of the Klaipėda Strait, where pollution is obvious, the concentrations of many elements, if compared with the Kuršių Marios lagoon, are from 3-15 (Fe, Cr, Zn, Mn) to 34-45 (Hg, Cu) times higher (Table 1, IV). However, this is less than in the sedimentary matter of the estuary of the Sheldt River draining the pollutants of France, Belgium and Netherlands (Zwolsman, Berger & Eck 1993).

The comparison of the data in Table 1 with the content of elements in the continental deposits and marine sediments, of Lithuanian coastal area in the existing and projected industrial units, reveals anomalous increase in concentrations of elements certain coastal

Table 1. **Comparison of element contents in the Neogene and Quaternary deposits, recent Kuršių Marios Lagoon sediments and surrounding areas (average contents are given according to Pustelnikovas 1998)**

Sediments	Elements (average contents)							
	%		ppm					
	Fe	Mn	Cu	Zn	Cr	Ni	Co	Pb
	I. Background deposits							
Sand (Neogene)	1.29	0.008	6	14	48	17	8	n.i.
Peat (Holocene)	1.54	0.030	17	36	34	17	5	"
Sand lagoonal, fill-up (Pilkopa)	0.81	0.020	13	13	46	20	4	"
Beach sand, marine part of Kuršių Marios lagoon	0.96	0.021	8	14	44	14	8	<10
The same (lagoon part)	0.77	0.020	7	9	41	14	6	"
Eolian sand, forest dunes of Melnragė	0.44	0.011	12	7	40	30	3	<10
Morainic till, Klaipėda strait	1.19	0.030	16	52	57	n.i.	21	16
	II. Background - anomalous objects							
Buried soil, Vistula spit	3.78	0.148	40	172	140	70	32	n.i.
Rotten timber (>120years old)	5.64	0.080	760	780	264	286	28	"
Mix of sand & plankton, Rybatchy beach	13.40	0.760	24	88	142	28	40	80
	III. Technogenic - anomalous deposits							
Beach sand, marine part of Kuršių Nerija spit	1.14	0.015	12	83	46	31	13	<10
The same, lagoon part	4.74	0.260	13	34	63	16	15	30
Soil Klaipėda OT area	1.25	0.030	21	115	25	14	3	24
Till morainic, technogenous sedimentation zone of the Klaipėda Strait (TSZ)	2.30	0.470	24	76	39	n.i.	4	7
	IV. Recent sediments of Kuršių Marios lagoon							
Average value in layer 0-5 cm	1.60	0.043	17	52	49	29	23	n.i.
The same in layer 0-10 cm, Klaipėda port gates	1.50	0.050	24	52	44	23	15	"
The same through the strait	1.51	0.039	77	131	54	22	12	44
Sand and silt in TSZ	3.28	0.295	28	156	81	n.i.	5	17
Mud thin silty in the strait TSZ	4.01	0.750	757	287	119	"	6	26

localities, medium concentrations in the Kuršių Marios lagoon and highest - in the fine-grained silty muds of the Klaipėda Strait technogenic sedimentation zone. These values mirror only the local pollution of the areas of enterprises and port. This is evident also in the outlet zone of untreated Palanga wastes. A high level of pollution of the untreated wastes reveals the comparison of sediments of lagoon and HC-polluted wastes of Mažeikiai industrial complex and the analysis of treated wastes outlet areas (Pustelnikovas 1998). The high efficacy of mechanical and biological treatment becomes clear in the cleaning process.

The comparison of all mentioned data with their Clark values in different objects of lithosphere, other basins of Baltic Sea and World Ocean reveals that in most cases the concentrations of elements of the investigated areas are within Clark values. These values are exceeded only in natural-anomalous sediments, soils of various polluted areas and technogenically effected beach sands. They are also exceeded in the zone of technogenic sedimentation in the Klaipėda Strait. The pollution in the mentioned zone, as well as in the soils of the areas of enterprises is obvious. Its scale (judging by the content of OM form), is not large and represents no hazard for marine ecosystem (with the exception of Klaipėda Strait).

For determination of the scale of pollution it is of primary importance to ecologically interpret the concentrations of organic pollutants. So, the mean values (background) of HC in the zone of natural sedimentation are 10-21.9 mg/g, the extreme concentrations in the zone of technogenic sedimentation of the Klaipėda Strait exceed them by 100-1000 times. These values are similar to those recorded in the areas of extreme pollution of Klaipėda oil terminal (KOT) and Pauostė railway station (RWS), where an obvious pollution with heavy oil products is recorded. The extreme contents of HC (75-88%) are composed of their technogenic varieties. Whereas, up to 80% of background content of HC in the sediments of lagoon is composed of biogenic HC including 71% of allochthonous analogues (Zareckas 1989). The treatment of municipal-industrial wastes from Mažeikiai industrial complex reduces the content of HC 10-fold. The burning out 600-1000°C of collected slime reduces their content to the minimum - 0.02μg/g.

CONCLUSIONS

The anomalies in the Lithuanian coastal area reflect the consequences of natural process, but not solely the anthropogenic impact and scale of pollution. Further analysis of toxicity of element forms and anthropogenic OC (benz(α)pyrene, chlororganic compounds, PCB, etc.) will determine the level of actual pollution. The comparative data reveals that ecological and hygienic hazard is represented by the Klaipėda Strait-port, industrial and transport objects, emergency outputs and untreated water drainage into the water basins. These hotbeds of pollution require special attention while developing infrastructures of port and town.

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Some Geochemical Features of Postglacial Clay Sediments in the Archipelago Sea, Finland

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In this study geochemical characteristics of postglacial and late-glacial clays was evaluated. Data were gathered using acoustic-seismic surveys and sampling. All subsamples were analysed after leaching with both strong and weak solvent by ICP-MS equipment and Leco-analyzer. Heavy metal content and the proportion of weakly bound elements is generally highest in surface layer of recent gyttja. Average concentrations were similar to those found elsewhere in the Baltic Sea. However, Pb, Cu, Zn, Sr and P concentration in the most recent gyttja was well above background values. Human influence could be detected in V, Ni, Na, Mg, Ca and K concentrations. Extraordinary low concentration of some element was found in the upper Litorina clay.

Keywords: marine sediments, clay, gyttja, geochemistry, Holocene, Baltic Sea, Archipelago Sea, Finland

INTRODUCTION

The aim of this study was to evaluate the geochemical character, and changes therein, of postglacial and late-glacial clays on the sea-floor in the Archipelago Sea area, SW-Finland. Data from sea-floor sediments were gathered using continuous seismic profiling, echo-sounding and side-scan sonar images. Sampling sites were chosen based on the interpretation of these profiles. Four samples were taken on a nearly north-south transect with a vibro-hammer corer (Fig. 1). All geochemical analyses were made from separate subsamples by aqua regia extraction (18 element), and by weak extraction using 1M ammonium chloride (12 element). The elementary concentration was determined using ICP-MS equipment and Leco-analyzer (C_{tot}). 33 subsamples in total were analyzed.

SAMPLE DESCRIPTIONS

Sample 19/94 (Fig. 2) is from a strait (water depth 10 m) next to a little fish farming plant. The soft recent top-layer of the gyttja sediment was dark greenish gray and the lower part of the unit was olive gray. Underlying the quite homogeneous gyttja unit was a layer of residual sand. It was underlain by Ancylus clay unit, divided into a bluish gray and nearly homogeneous upper part and a lower part consisting of olive gray clay with sulphide-layers. Sample 22/94 (Fig. 2) was taken from a wide and elongated basin in a water depth of 48 m. The sample contained the entire length organic matter. The upper part of the olive gray recent/subrecent gyttja showed faint layering. A ^{14}C-age of 2280±80 BP (Su-2588) was measured from plant remnants from a depth of 94-95 cm in the core. There was nearly homogeneous and more grayish subrecent clay between 150 cm and 231 cm. Some fish bones (*Cadus morhua*) was found in depths 158 cm, and the result of ^{14}C-dating from fish bones gave an age of 3300±65 BP (Ua-10983). The rest of sample 22/94 consisted of light olive gray Litorina clay with faintly layered or laminated texture. Sample 37/94 (water depth 48 m) is from a wide basin. The core consisted of a olive black gyttja top-layer, of laminated and grayish olive gyttja below it, and it was underlain a few centimetres thick lower contact zone with muddy residual sand (Fig. 2). Underlying the recent unit was grayish olive Litorina clay containing thick layers of organic matter in its homogeneous upper part. But, the lower part of Litorina unit consisted of laminated clay without organic interlayers. Weakly laminated Mastogloia clay contained rather small spots of grease-like matter together with brittle sulphide grains. The rest of core 37/94 consisted of Ancylus clay with very dense monosulphide staining and/or layering with some sulphide grains also in the upper part of unit. Sample 43/94 (water depth 48 m) was taken from a small basin in the outer margin of the Archipelago. Its upper part consisted of about 70/80 cm thick recent gyttja unit (Fig. 2). The topmost part of the recent unit consisted of very soft and homogeneous olive black mud. Underlying this mud was stiffer, olive gray, recent gyttja with faint layering. There was lots of organic matter and a sand interlayer in the upper part of the subrecent gyttja/clay unit. The lower part of the subrecent unit was light olive gray in colour and showed almost homogeneous texture with numbers of thin layers of sand. The lower end of this core-sample is assumed to represent Litorina clay unit. This light olive gray clay was laminated and it contained visible organic matter.

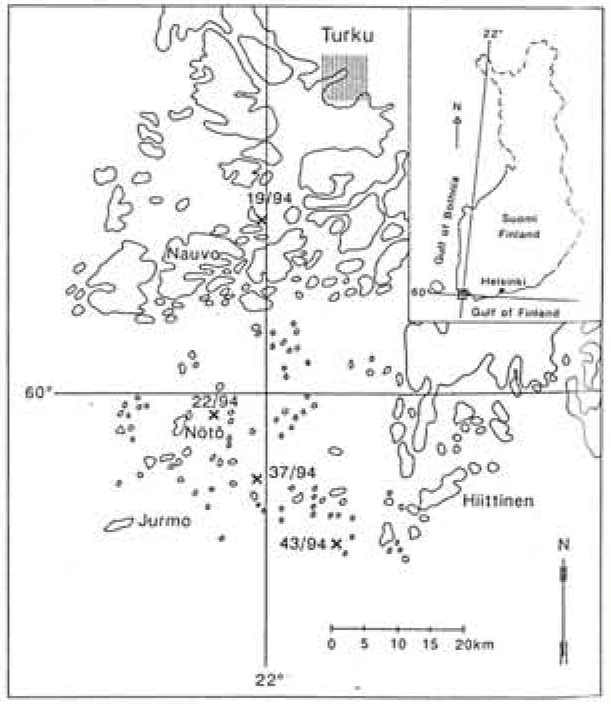

Fig. 1. Sampling sites and location of study area on the Archipelago Sea

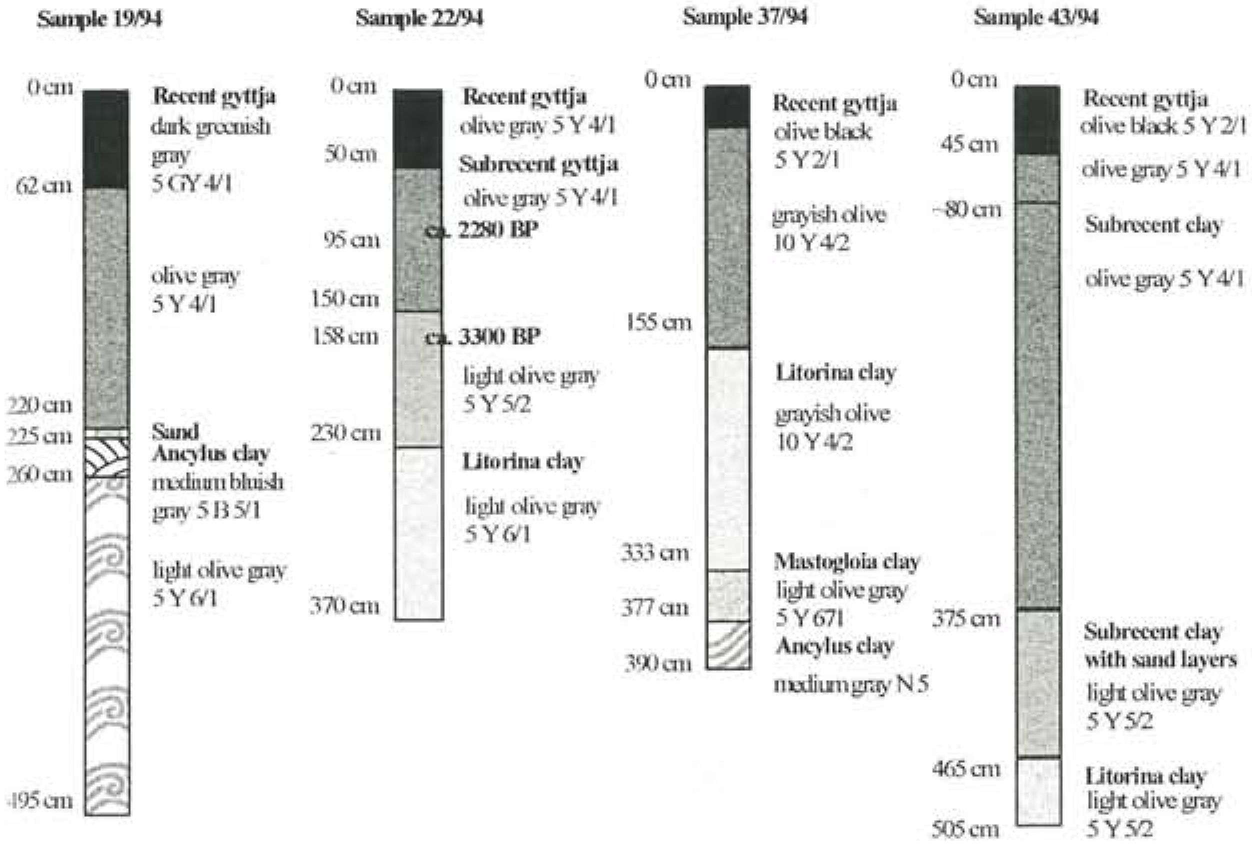

Fig. 2. Core sections from the Archipelago Sea; with stratigraphical notes. The colour codes used were according to Goddard (1984)

GEOCHEMICAL RESULTS

The chemical assay data refers to aqua regia extractable portion unless stated otherwise. The concentration of aluminium and iron decreased downward from recent gyttja to the upper part of Litorina clay (Table 1). In the lower part of the Litorina sequence, in the Mastogloia clay and in the Ancylus clay, the amount of Al (3-4%) and Fe (4-4.5%) was similar to the values in recent gyttja. Magnesium (1.2-1.4%) and potassium (0.9-1.1%) concentration was at the same level in all units except in the upper Litorina and subrecent clays (Table 1). Calcium was distributed evenly in the samples and its concentration was generally 0.4-0.5%. The average concentration of sodium (0.3-0.5%) was comparable to calcium in Ancylus, Mastogloia and Litorina clays (Table 1), but sodium concentration increased

Table 1. **The average concentrations of element in the sediments from the Archipelago Sea. Element concentrations were analysed after leaching with aqua regia solvent by ICP-MS equipment, and C_{tot} by Leco-analyzer**

Sediment	Al %	Fe %	Ca %	Na %	K %	Mg %	S %	C %	Mn ppm	P ppm	Ti ppm	Sr ppm	Cr ppm	V ppm	Ni ppm	Co ppm	Pb ppm	Cu ppm	Zn ppm
Recent, toplayer	3.3	4.0	0.5	0.9	1.0	1.3	1.1	4.7	375	1039	1660	50	64	72	41	15	44	37	159
Recent, lower part	3.0	3.7	0.4	0.6	0.9	1.2	1.1	3.2	353	870	1658	38	59	68	38	15	19	23	101
Subrecent	2.7	3.5	0.5	0.5	0.8	1.1	1.1	2.9	382	852	1532	36	53	62	35	14	15	23	87
Litorina, upper part	2.1	2.8	0.4	0.3	0.6	0.8	0.9	1.2	298	780	1307	24	41	49	25	11	12	14	64
Litorina, lower part	3.1	3.8	0.5	0.5	1.0	1.2	1.2	1.8	574	809	1788	32	60	71	37	15	17	20	93
Mastogloia	3.3	3.8	0.5	0.4	1.0	1.3	1.0	1.8	450	811	1840	32	63	76	39	16	20	23	94
Ancylus	3.6	4.5	0.4	0.4	1.1	1.4	0.5	0.5	390	719	1937	34	68	80	43	17	19	24	109

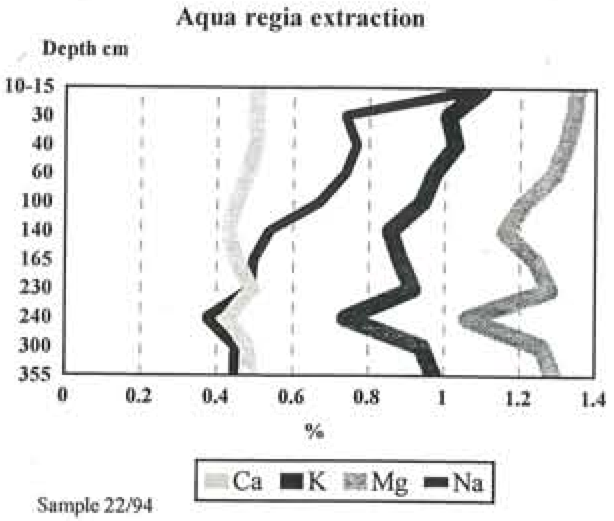

Fig. 3. Generally, the concentrations of calcium, potassium, magnesium and sodium were higher in the recent top-layer; shown e.g. in sample 22/94

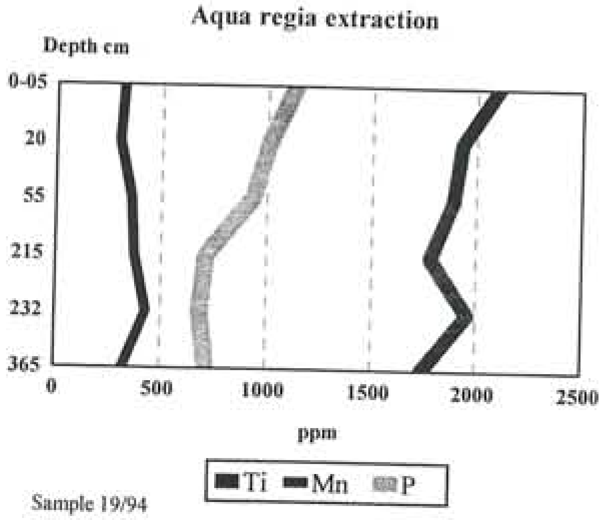

Fig. 4. Manganese concentrations were on a similar level in all stratigraphical units. There were usually more phosphorus, but occasionally also titanium (e.g. sample 19/94) in the recent sediment than elsewhere

compared to calcium in subrecent and recent sediment (Fig. 3). Manganese concentration was generally 400±100 ppm (Fig. 4), but one twice as high Mn value from sample 37/94 affected the average value for the lower part of Litorina clay (Table 1). Generally, there was more Ti in Litorina, Mastogloia and Ancylus clays than in subrecent and recent gyttja/clay (Table 1). However, there was more titanium in the top-layer of sample 19/94 than in the older sediments (Fig. 4). The average concentration of phosphorus was 800±100 ppm (Fig. 4), but its concentration increased to over 1000 ppm in recent sediment (Table 1). The average concentration of strontium increased from 30±5 ppm in Litorina and older clays to 50 ppm or even higher in the most recent gyttja (Fig. 5, Table 1). There was always more vanadium than chromium, and the average concentration for vanadium was 50-80 ppm and for chromium 40-70 ppm (Table 1). The concentration of nickel 35±5 ppm and cobalt 11-17 ppm varied in very narrow limits (Table 1). Lead, copper and zinc concentration for recent/subrecent gyttja differed remarkable from amounts found in Litorina, Mastogloia and Ancylus clays (Fig. 6). The background concentration of lead was usually 15±5 ppm in the study area, but there was twice as much lead in the recent gyttja (Table 1). Copper behaved similar to lead, but occasionally its concentration began to rise already in the upper part of the subrecent unit. On the average, the background concentration for copper was 20±5 ppm and for zinc 90±25 ppm (Table 1). Cadmium concentration (0.5-0.7 ppm) exceeded the reliable detection limit of 0.3 ppm for the method used only in the topmost part of the recent gyttja. The concentration of C_{tot} inreased remarkably from the level in the Litorina unit towards the top surface (Table 1). Sulphur concentration varied generally within the same concentration limits in the different sedimentary units. Easily extractable concentrations for Na, Zn, B, Mg, Si and Sr was higher in recent gyttja than in the older sediments (Table 2). Furthermore, there was generally some easily leachable Ca, K, P and V in the recent top-layer. Barium behaved reversely and its easily extractable proportion was generally lower in the recent gyttja than in older sediments. Occasionally, easily extractable Al, Fe, Ni, Co and Zn was detected in Litorina clay. The concentration of easily extractable manganese varied widely.

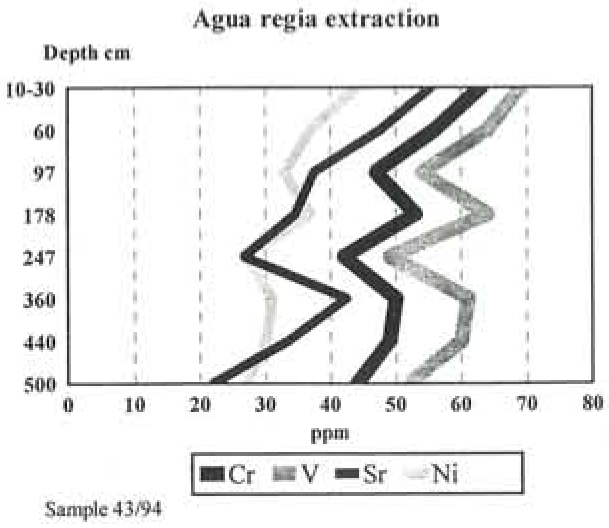

Fig. 5. Chromium, vanadium, nickel and strontium concentrations were higher in the recent gyttja in the sample 43/94

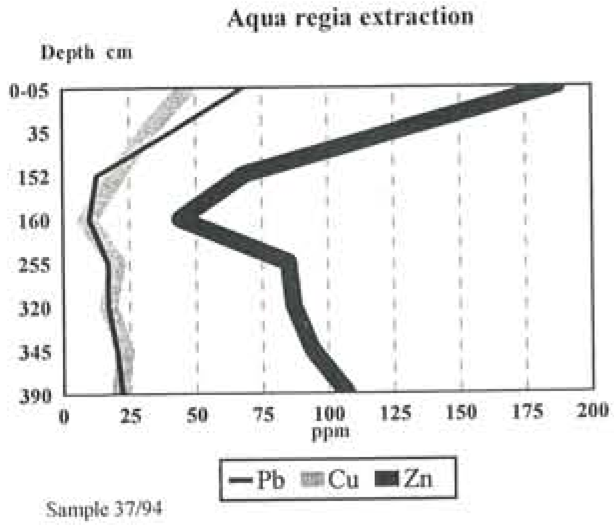

Fig. 6. Human impact on the geochemistry of recent sediment was shown in the concentrations of lead, copper and zinc; e.g. sample 37/94

DISCUSSION

Geological factors control the Al and Fe concentration as noted by their identical behaviour both in strong and weak extraction. In aqua regia dissolution, the element pairs K and Mg as well as Cr and V behaved identically (Figs. 3 & 5), but in weak extraction these pairs break up, and there was in proportion more Mg and V in the recent gyttja (Table 2). Anthropogenically produced elements usually have a weaker bond in sediments as compared to the natural geologically derived proportion of elements (e.g. Salomons & Förstner 1984, Räisänen & Hämäläinen 1991). Hence, it could be assumed that human impact is shown in recent gyttja as easily extractable proportion of Na, K, Ca, Mg, Si, P, Sr, B, Zn and V. But the concentration of easily extractable elements has been increasing since the early subrecent time for many element. The comparison of easily vs. aqua regia extractable concentration of elements (Tables 1 & 2) proved that natural geological factors (e.g. sediment compaction) affected Na, K, Ca, Mg, Si and B concentrations. Human impact was clear for Pb, Zn, Cu and Sr, but faint for V and P in the recent top-layer. Heavy metal concentrations in the Archipelago Sea sediments were comparable to the means found elsewhere in the Baltic Sea (e.g. Niemistö & Voipio 1981, Enckell-Sarkola et al. 1989 and Rantataro 1996). However, the Pb and Cu concentration was 1.5-2.0 times higher, and Zn and Sr concentration was 0.5-1.5 times higher in the recent top-layer than the background concentrations found in the study area (Tables 1 & 2). Na, Mg, Ca and K concentrations were within the limits of natural geological variation, but evidently also these were slightly affected by human activities (cf. Verta et al. 1989). The striking decrease of nearly all element concentrations in the upper Litorina clay (Table 1) could be attributed to a change in the sedimentation rate over the whole Archipelago Sea area.

CONCLUSION

In the Archipelago Sea area, the glacial clay sequence is overlain by at least four geochemically different gyttja/clay units. The oldest unit consisted of Ancylus clay, Mastogloia clay and the lower part of Litorina clay, with a rather uniform concentration of major, minor and trace elements (Table 1), is proposed to represent the aqua regia extractable background concentration

Table 2. **The average concentrations of element in the sediments from the Archipelago Sea. Element concentrations were analysed after leaching with weak solvent, 1M ammonium chloride, by ICP-MS equipment**

Sediment	Ca	Na	K	Mg	B	Ba	Mn	P	Si	Sr	V	Zn
	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
Recent, toplayer	1550	7115	1234	2178	8.9	14	46	> 4.0	69	27	> 0.8	3.2
Recent, lower part	1204	4670	1014	1625	7.3	16	35	< 4.0	65	20	~ 0.8	0.4
Subrecent	1623	4162	982	1327	6.2	17	18	< 4.0	53	18	< 0.8	~ 0.2
Litorina, upper part	775	2327	627	723	~ 3.5	24	16	< 4.0	41	10	< 0.8	< 0.2
Litorina, lower part	1203	3828	969	1223	5.2	20	78	< 4.0	55	14	< 0.8	2.9
Mastogloia	1070	3030	836	861	< 3.0	58	24	< 4.0	60	12	< 0.8	< 0.2
Ancylus	1060	3433	1053	1057	< 3.0	37	27	< 4.0	40	13	< 0.8	~ 0.2

for the Archipelago Sea area. The only exception was the low concentration of sulphur and C_{tot} in Ancylus clay. A remarkable decrease was shown in the upper part of the Litorina clay, where element concentrations were generally 30-40% lower than elsewhere. The third unit consisted of subrecent clay together with the lower part of recent gyttja. In this group most of the element concentrations showed background levels. However, there were some differences compared to the underlying sediments, as a clearly increasing concentration of sodium, C_{tot}, strontium, boron and occasionally zinc and copper. The recent topmost gyttja was geochemically remarkably dissimilar to all the underlying sediments. The difference was observed both by strong and weak extraction. The easily extractable elements are abundant in recent gyttja top-layer for Ca, K, Mg, Na, Si, Sr, P, V, B and Zn. In the aqua regia leach, there was generally more Pb, Zn, Cu, Sr and P in the upper part of recent gyttja than elsewhere. The topmost part of recent gyttja contained 0.5-0.7 ppm of cadmium. Higher concentrations of Pb, Zn and Cu were observed in recent top-layer everywhere in the Archipelago Sea, but the concentration of V, Cr and Ni increased also near the Gulf of Finland. Based on two ^{14}C-datings, the average sedimentation rate has been 0.4-0.6 mm/year during the last 3000 years in the middle part of the Archipelago Sea.

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Distribution of the Eemian Sea in North-Eastern Europe

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The article deals with the distribution and duration of the Eemian Sea in vast areas of North-Eastern Europe. Formation of Pleistocene deposits in this area was strongly affected by numerous glaciations and sea level fluctuations. In the complicated history of the area the Eemian deposits, accumulated during the isotope Stage 5e, serve as an excellent key horizon for palaeogeographical and stratigraphical conclusions. On the other hand, ESR dates on marine mollusc shells in the range from 71,500 to 120,000 years allow to assume that the Boreal Sea, an analogue of the Eemian Sea in Northern Eurasia, occupied much longer time interval than it may be expected on the basis of the researches conducted in the Western countries.

Keywords: Age, Eemian transgression, Boreal Sea, ESR dating, mollusc shells, palaeoclimate.

INTRODUCTION

Besides local sources of pollution, in the near future, human society will have to face global hazards, the most important of which at present are the changes in carbon dioxide concentration in the atmosphere and the impairment of the ozone layer leading to a global warming of the climate. The so-called "greenhouse effect" will give rise to several undesirable phenomena, including shifting of climate zones, displacement of air masses, melting of glaciers and a rise in ocean level. The growth of the concentration of CO_2 expected by the beginning of the 21st century may trigger a rapid rise in atmospheric temperature and, correspondingly, a rapid rise in ocean level which, according to different specialists, will range from a few decimetres to several metres.

The Eemian interglacial, the warmest among interglacials, furnishes a good basis for palaeoclimatic conclusions and speculations for the future. The palaeogeographic reconstructions provide evidence (Gerasimov & Velichko 1982) that during the Eemian interglacial climatic maximum mean July temperature over the Baltic was much the same as at present. However, in January it was several degrees higher. The climate was more humid; the mean annual precipitation over the southern part of the Eemian Sea was 200-500 mm and over its northern part approximately 100 mm higher than at present. Therefore, depending on local and regional factors differences from the present will display a great variability. This means that good knowledge of the environments in the past is needed to draw reliable conclusions. One of the topical problems is estimation of contours of the Eemian (Boreal) Sea, because the sea had a great impact on the regional climate.

STUDY AREA AND CORRELATION METHODS

The study area covers the northeastern part of Europe. In particular detail we studied the eastern part of the White Sea coast: Arkhangelsk Region, Kanin Peninsula and Kolguyev Island (Fig. 1). The results together with the materials from the Baltic States, St. Petersburg area, Kola Peninsula and Siberia allow to draw some conclusions about the distribution and age of the Eemian (Boreal) Sea.

Continental and marine beds of the Eemian interglacial have been identified in the study area at more than a hundred sites. Abundant spore and pollen data, synthesized by Grichuk (1989), suggests a pronounced latitudinal zonal development of the plant cover. In the area under consideration the main difference as compared to the present situation was the absence of tundra. Differences in forest composition between then and now are due to both the higher temperatures and the effect of marine transgressions. As mentioned above great environmental shifts are to be expected in the future as a result of climatic changes due to human activities.

The correlation of the sections is mainly based on palynological data. Seven assemblage zones (M_2-M_8)

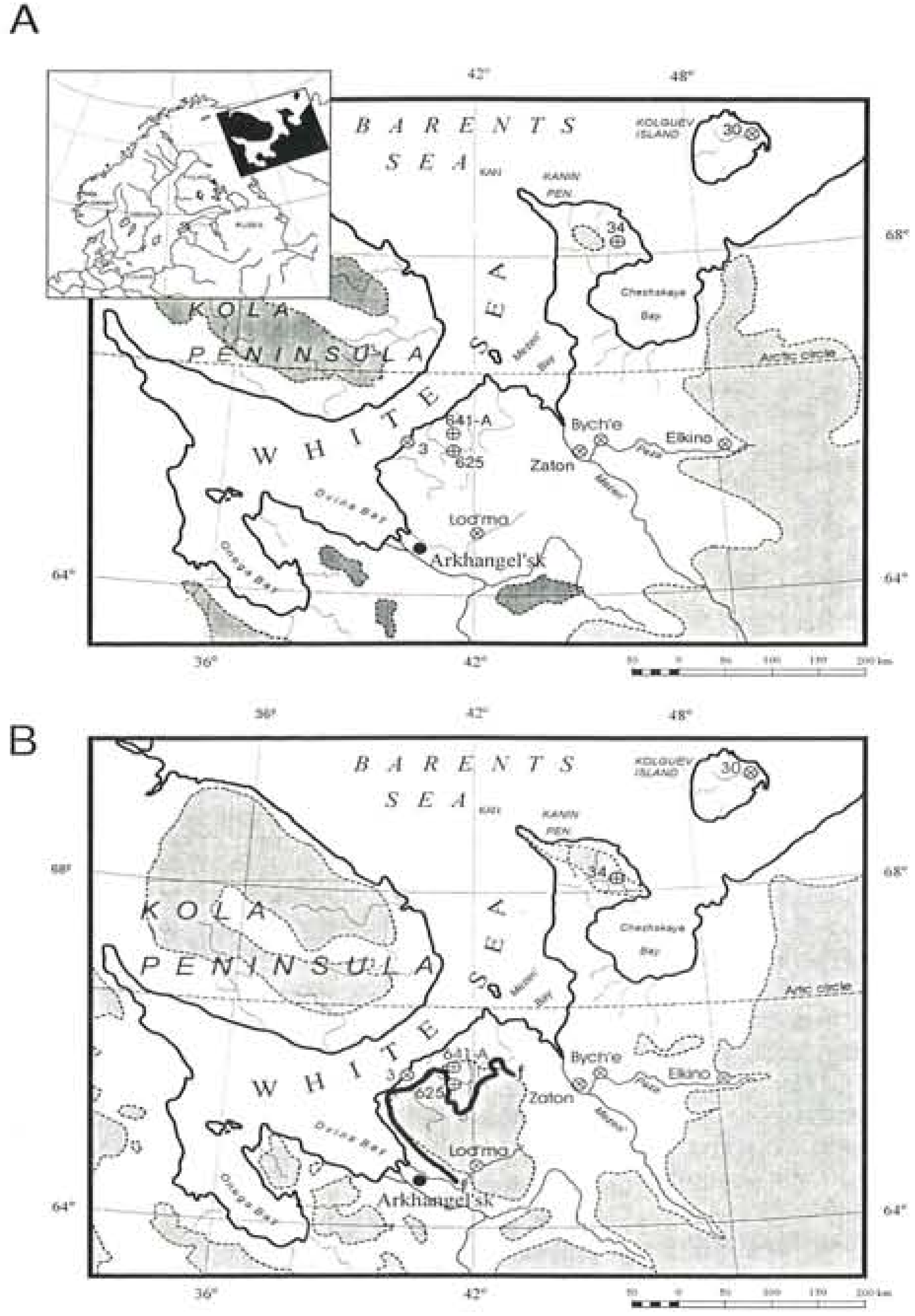

Fig. 1. Location of investigated sites in the White Sea basin: ⊕ - boreholes, ⊗ - outcrops. Dotted line shows distribution of the Boreal Sea (A - after Lavrova 1961, B - after Devyatova & Loseva 1964, Devyatova 1982; thick line (f-f) marks a shore-line after Forrström et al. 1988)

of wide geographical and temporal (*ca.* 60 ka) extent (Grichuk 1961, 1989 a.o.) have been established for the last interglacial. However, several geographical variations require establishment of local and regional stratotypes, as well as compilation of local and regional stratigraphic schemes.

The following pollen zones (c-i after Jessen & Milthers 1928, M$_2$-M$_8$ after Grichuk 1961) from bottom to top are more or less distinct in the study area (Grichuk 1961, 1989):

c($_{M_2}$) - birch and pine with an admixture of spruce;
d($_{M_3}$) - pine and birch with an admixture of oak, elm and hazel;
e($_{M_{4a}}$) - pine with an admixture of oak and elm, appearance of hazel;
fα($_{M_{4b}}$) - oak and elm, the lower maximum of hazel;
fβ($_{M_5}$) - linden with abundant oak, elm and hornbeam, the upper maximum of hazel;
g($_{M_6}$) - hornbeam with an admixture of linden, oak, elm, hazel and spruce;
h($_{M_7}$) - the upper maximum of spruce with an admixture of broad-leaved trees;
i($_{M_8}$) - pine with an admixture of spruce and birch.

However, the palynologically studied sections alone do not provide sufficient evidence for solving problems related to the distribution of the Eemian Sea, because due to glaciotectonic effect in the glaciated areas the Eemian beds of the same age are known from different absolute heights. For instance, at Rybatskoye and Sinyavino on the Gulf of Finland's coast synchronous Eemian marine beds occur at the depths of 5-45 metres below sea level, while in the Mga section they are at a height of 10 metres and in Krasnoselskoye section (on the Karelian Isthmus) at a height of 12 metres above sea level. The Eemian layers are at their deepest on the Island of Prangli (-61 to -75 m) and in the mouth of the Luga River (-50 to -60 m). Such great variations in depositional conditions for similar deposits with the same pollen zones with no doubt cannot be explained by sedimentary facies only.

For more reliable conclusions we need sections beyond the maximum distribution area of the last glaciation, but often those sections have not been palynologically studied or their correlation is hampered by the high content of redeposited pollen and spores.

To obtain chronological data on marine deposits in this area we have applied ESR technique to determine the ages of mollusc shell remains embedded in different marine deposits. The ESR-dating method is based on direct measurements of the amount of radiation-induced paramagnetic centres created by natural radiation resulting from radioactivity in the shell itself and from the environment. The presence of paramagnetic carbonate centres in mollusc shell substance can be detected by means of the ESR spectrometry. The concentration of the centres correlated with the shell's age can be determined from the ESR signal intensity. The signals are absent in modern shells, but increase in intensity as a function of the total radiation dose absorbed by the shell over the time of burial. The ESR method used can cover a time range from a few hundred to about a million years BP (Molodkov 1988, 1989).

CORRELATION OF THE EEMIAN AND BOREAL SEA DEPOSITS

In the Western Europe, the Eemian period hypothetically correlates with the stage 5e of the deep-sea record, which is dated roughly between 125 and 115 ka (Shackleton & Opdyke 1977). Several methods, including the counting of annual layers in fresh-water sediments (Müller 1974), suggest the duration of about 10,000 years for the Eemian interglacial period, however, to our mind it may be considerably longer, comparable with the duration of Eemian and Boreal transgressions in the North-Eastern Europe.

Correlations with pollen diagrams of Western Europe, Karelia and White Sea basins show that the Boreal transgression lasted probably longer than that of the Eemian Sea (Lavrova 1961). The Boreal Sea level was subject to recurrent fluctuations and during the last interglacial (*sensu lato*) the shorelines changed considerably. The first lowering of the shoreline corresponds to the pollen zone M$_2$. Regressive stages lasted up to the beginning of M$_{4a}$, however, the main part of the zone correlates with the maximum of the transgression. The period, synchronous with the zones M$_{4a}$- M$_8$ is characterized by general regression, pulsatic in character (Devyatova 1982). The stability of the climate during the Eemian interglacial has recently been questioned by many scholars (Robertsson 1997 a.o.).

The interglacial marine fauna of the Boreal Sea was much richer in species than the present-day fauna of the same region. It contained a lot of thermophilous boreal (*Cyprina islandica* L., *Littorina littorea* L., *Capulus hungaricum* L., *Mytilus edulis* L., *Cardium fasciatum* Mont., *C. echinatum* L., *Macoma baltica* L., *Astarte sulcata* Da-Costa, *A. borealis* Chemn., *Lucina borealis* L.) and boreal-lusitanian and lusitanian (*Nassa reticulata* L., *Bittium reticulatum* Da-Costa, *Cardium edule* L., *C. fasciatum Mont.*, *C. paucicostatum* Sow., *Anomia straita* Broc.) species (Devyatova 1982; Lavrova 1961 a.o.). Those thick-walled mollusc shells are extremely good objects for the ESR-dating.

In the eastern peripheral area of the Fennoscandian Shield we dated tens of shells. These can be firmly grouped into two marine events which probably occurred about 120,000 to 71,500 years ago and around 46,000 years BP, respectively (Table 1).

The first event coincides with the Boreal Sea which was more or less simultaneous with the Eemian Sea in Western Europe. The datings of *ca.* 46 ka support the opinion expressed by many geologists that deposits of the Byelomor transgression, the second huge Late Pleistocene transgression which took place in the Early or Middle Valdai (=Weichselian), occur in this region.

The longer duration of the Boreal Sea compared with the "short" (*ca.* 10 ka) last interglacial, correlated to oxygen isotope substage 5e, can be explained by the hydrodynamic activity of the warm Nordcap Current, a branch of the Gulf Stream responsible for intensive intrusion of Atlantic waters into the Polar-Arctic seas. During the Boreal transgression, the whole Arctic experienced significant warming, January temperatures were by 4-8°C higher than at present. This suggests a far more powerful inflow of warm Gulf Stream water into the Arctic which would have resulted in highly reduced sea ice cover in the Arctic Ocean for a long time.

CONTRADICTIONS IN THE DISTRIBUTION OF THE EEMIAN AND BOREAL TRANSGRESSIONS

In the Eastern Britain, Eemian interglacial marine terraces are at their highest - about 7 metres above the present-day sea level. The depth of the marine Eemian sediments surface below the present-day sea level ranges from 5 m in Belgium to 8 m in the western and 13 m in the northern part of the Netherlands. In Lower Saxony on the German North Sea coast, it is at a depth of 7-9 metres, and at a depth of 5 metres in western Schleswig-Holstein (Streif 1990; Zagwijn 1983). At least 80% from the general sea-level rise in NW Europe was due to the eustatic sea level change, and only 20% was caused by tectonic subsidence, isostatic movements or some other causes (Strief 1990). This means that the amplitudes of the transgression-regression cycles result mainly of worldwide eustatic processes. It is generally concluded that sea levels at *ca.* 125 ka BP were 5-15 metres higher than nowadays (Shackleton & Matthews 1977).

Table 1. **Some ESR dating results on shells from the White Sea basin marine deposits**

Sample	Species	Locality (see Fig. 1)	Depth, m	Ages, ka
173-095	*Hiatella arctica*	34	25.0	72.9 ± 7.4
174-095	*Cyprina islandica*	34	25.0	87.8 ± 8.5
175-095	*Pecten islandicus*	34	25.0	96.2 ± 9.1
Mean age		34	25.0	**85.6 ± 9.6**
177-095	*Hiatella arctica*	625	5.4	75.6 ± 7.3
178-095	*Hiatella arctica*	641-A	20.0	77.2 ± 7.8
179-095	*Astarte borealis*	641-A	20.0	86.7 ± 8.8
180-095	*Astarte elliptica*	641-A	20.0	92.0 ± 9.2
Mean age		641-A	20.0	**85.3 ± 6.1**
187-095	*Cyprina islandica*	3	13.0	71.5 ± 6.0
189-095a	*Hiatella arctica*	Lod'ma	15.0	41.1 ± 3.8
189-095b	*Hiatella arctica*	Lod'ma	15.0	43.0 ± 4.0
190-095	*Modiolus modiolus*	Lod'ma	15.0	47.5 ± 4.3
191-095	*Mytilus edulis*	Lod'ma	15.0	53.4 ± 5.0
Mean age		Lod'ma	15.0	**46.3 ± 4.7**
136-051	*Cyprina islandica*	30	4.0	100.0 ± 10.0
132-051	*Cyprina islandica*	30	10.0	111.0 ± 9.0
135-051	*Hiatella arctica*	30	16.5	120.0 ± 8.0

This is difficult, however, to reconcile with the data obtained from the areas in the north of Eurasia. Here the waters of the Boreal transgression which, as already noted, was almost identical with the Eemian transgression, dashed farther onto the mainland along the deep ancient valleys, forming ingressive sounds - estuaries, and overflooding low areas between rivers. This transgression led to the formation of large epicontinental basins, such as the White Sea, Petchora, West Siberian and the Taymyr. Abrasional benches and terraces, formed during the transgression maximum, are, due to the uneven tectonic uplift, traceable at different elevations, 160-175 m in the eastern part of the Kola Peninsula, 150 m on the Kanin Peninsula, 120 m in the northern Timan, 410-420 m on the Island of Novaya Zemlya, 100-150 m on the West Siberian Lowland, 180-270 m on Taymyr. The thickness of deposits frequently reaches 80-100 m, in the West Siberian basin they are up to 130-150 m thick (Lavrova 1961).

In the former Soviet Union there were two basically different viewpoints as to the contours of the Eemian Sea and the sounds connecting it with the Atlantic Ocean. According to Grichuk (1982), the Baltic Sea basin was connected with the North Sea via the Skagerrak, Kattegat and Danish Sounds through the present lake system of Vänern and Mälar in Central Sweden and the area of the current Kiel Canal on the Jutland Peninsula. Like Lavrova (1961), he assumes a connection between the Eemian and White Sea basins through the system of shallow sounds and the lakes Onega and Ladoga.

According to the second reconstruction, the contours of the Eemian Sea closely coincided with the Litorina Sea limit and, therefore, could have been linked with the ocean only via the Skagerrak, Kattegat and Danish sounds. Transgressive waters would have inundated the Lake Ladoga depression, small areas at the Vistula and Narva River mouths, and the ancient Neva River valley (Blagovolin et al. 1982).

Resolving the question concerning a connection with the White Sea is of principal importance. If no connection existed, the hydrological regime for that part of the Eemian Sea which is now the Baltic Sea, changed during the course of the interglacial in a way similar to the Holocene (Flandrian) transgression. If the connection did exist - the situation must have been fundamentally different from that in the Holocene.

In the field, this problem was investigated in most detail by Lavrova (1961 a.o.) and Devyatova (1982 a.o.). The reconstructions of other researchers, including interesting compilations of Grönlund (1991), Forrström et al. (1988 a.o.), in the White Sea area are mainly based on published sources. But, what is interesting, according to our data the reconstructions by Forrström seem most realistic. Our results obtained in the eastern part of the White Sea coast (Fig. 1, Table 1) allow to assume that the big island, shown by Devyatova (1982) probably did not exist, at least in these limits.

It means that in spite of a great number of well-studied sections, the present knowledge of the Eemian Sea distribution is still incomplete. The information at our disposal is still too modest to provide a basis for a prediction of future environments as a result of global anthropogenic effect.

CONCLUSIONS

The record of the transgression cycle of the Eemian interglacial period is rather complete in many localities of the study area. The fauna and flora in marine deposits indicate climatic amelioration during the Eemian transgression from Arctic and Subarctic towards considerably higher temperatures than at present. Water levels at, or close to the climatic optimum of the Eemian interglacial should have been higher than at present, but the concrete numbers are not yet clear especially within the whole isotope Stage 5. The factual data from Western Europe and Siberia are not easy to compare because of the different neotectonic situations.

During the isotope Stage 5, in the White Sea coast at least one glacial advance is assumed (Zubakov 1992). Oxygen isotope records imply at least two-fold sea-level lowering of around -55 m during this time interval (Shackleton 1987). At the same time, no interruption of marine sedimentation in the sections studied was observed in the range from 120,000 to 71,500 years. It allows to assume that the Boreal Sea has occupied this area during much longer time interval than it may be expected from the duration of the Eemian interglacial correlated to deep sea substage 5e only. As a result, the stratigraphic correlation between different marine and terrestrial deposits found in this region and in western and eastern areas, and even the temporal extent of marker marine horizon is becoming rather complicated.

In the study area, after the Eemian (Boreal) transgression was also the second huge marine (Byelomor) transgression which probably took place in the Middle Weichselian (Valdai).

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Quaternary Sediments on the Bottom Surface of the South East Baltic Sea

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Various types of sediments were distinguished at different sea depth levels. These levels may be correlated with the stages of geological development of the Baltic Sea. The modern sedimentation zone is in the shallow and deep part of the sea. Lag sediments are spread between these zones of sedimentation. Pleistocene till and Baltic Ice Lake clay with overlying coarse sediments of mixed grain size at the lower part of slopes and separate elevations showed, that in Holocene time there were near bottom currents, which created nonsedimentation conditions.

Keywords: Pleistocene till, Baltic Ice Lake clay, bottom sediments, sedimentation zone, sea depth levels, South East Baltic Sea.

INTRODUCTION

The bottom relief, hydrodynamic conditions and changes of sea level in Holocene have a significant influence on distribution of sediments in the Baltic Sea. The sedimentation of shallow zone and deep sea areas, as well as abrasion-zero sedimentation (transit) zones with a characteristic complex of sediments are distinguished at the modern bottom surface (Repečka 1994, Repečka et al. 1997). The intensive, but diverse sedimentation conditions at the sea deeps formed lag sediments. Pleistocene till and Baltic Ice Lake clay occur on the slopes and plateau surfaces. The coarse sediments lie on the bottom surface of the near shore zone, where abrasion processes are predominating in active hydrodynamic conditions. There is different sand in the shallow zone of sedimentation. The shallow zone of accumulation processes ends at the depths of 8-10 m, and the transit or zero sedimentation zone begins. Different grain size sediments at 25-45 m and more depths are attributed to the accumulation and abrasion zones of the earlier stages of geological development of the Baltic Sea. These sediments have no direct hydrodynamic relationship with the modern shallow zone. Mixed grain size sediments are spread at different Baltic Sea levels. There were active hydrodynamic conditions during whole Holocene and only 3-5cm thick layer of sandy sediments was accumulated. The Pleistocene till and Baltic Ice Lake clay occur (are exposed) on the bottom surface areas.

The grain size of bottom sediments reflects the hydrodynamic activity, peculiarities of bottom relief and sea level changes. It is important to reveal changes in grain size at different sea depth levels and to define hydrodynamic conditions of the time, when bottom sediments were formed in these regions. It enables to determinate the paleogeographical conditions at the moment of sedimentation processes.

Understanding of modern sedimentation processes, with exception of transit (zero sedimentation) and abrasion zones, is important for bottom sediment matter spread, as well as for technogenical load migration and concentration. The sediments of different genesis (lithogenous, organogenous and technogenous) are accumulating in the zones of active sedimentation processes. The peculiarities of sedimentation processes are important for understanding of environmental processes and determination of final concentration regions.

METHODS AND MATERIAL

The bottom sediment samples were collected during the Lithuanian-Swedish expeditions in 1993-1995 by grab Van Veen, Niemistö and gravity corers. More than 200 samples were taken in the South East Baltic Sea (Grigelis & Floden 1994). Also the material of geological mapping in scale 1:200 000 carried out by J. Šimėnas (1989) was used for studies of sediments at different sea levels. Grain size of bottom sediments was determined by a sieving shaker 'Analizette 3' in the Department of Baltic Marine Geology, Institute of Geology. The pelitic sediments have been analyzed by pipette method (Petelin 1967). The stations cover the whole South East Baltic area (Fig.1). Main stations are used for compiling of profiles, crossing the Gotland and northern part of Gdansk deeps. Seven profiles of W-E direction and two from south-west to north-east illustrate distribution of different particles of bottom sediments across the deeps (Figs. 2 and 3).

DISCUSSION

Distribution of different types of sediments and their fractions is shown in cross sections 1-9 (Figs. 2 and 3). Pelitic mud is spread locally in the Gotland Deep and in the deeper parts of the SE Baltic Sea. The sea depths here range from 120 to 250 m. Coefficient of uniformity of these sediments is 2.2 by Trask. It shows a high degree of differentiation of sediment particles. The pelitic mud of near lag sediments and on the slopes has poor uniformity coefficient (So 3.2-4.14). There is an influence of coarse sediment fractions in these regions.

Aleuritic- pelitic mud is spread on the bottom of basin deeps and on the lower part of slopes. These sediments have a higher amount of coarse particles and poor uniformity coefficient. There is an influence of bottom relief, distance from sources of sedimentary particles supply and hydrodynamic activity in the environment of this region. The main cause of bad sorting of aleurite-pelitic mud is an influence of coarse (> 0,05mm) and subcolloid (< 0,001mm) particles. For this reason sorting coefficient of aleuritic-pelitic mud is worse than that of pelitic mud. The sorting coefficient of coarse sediments is better, because the amount of pelitic particles decreases and diameter of sediment

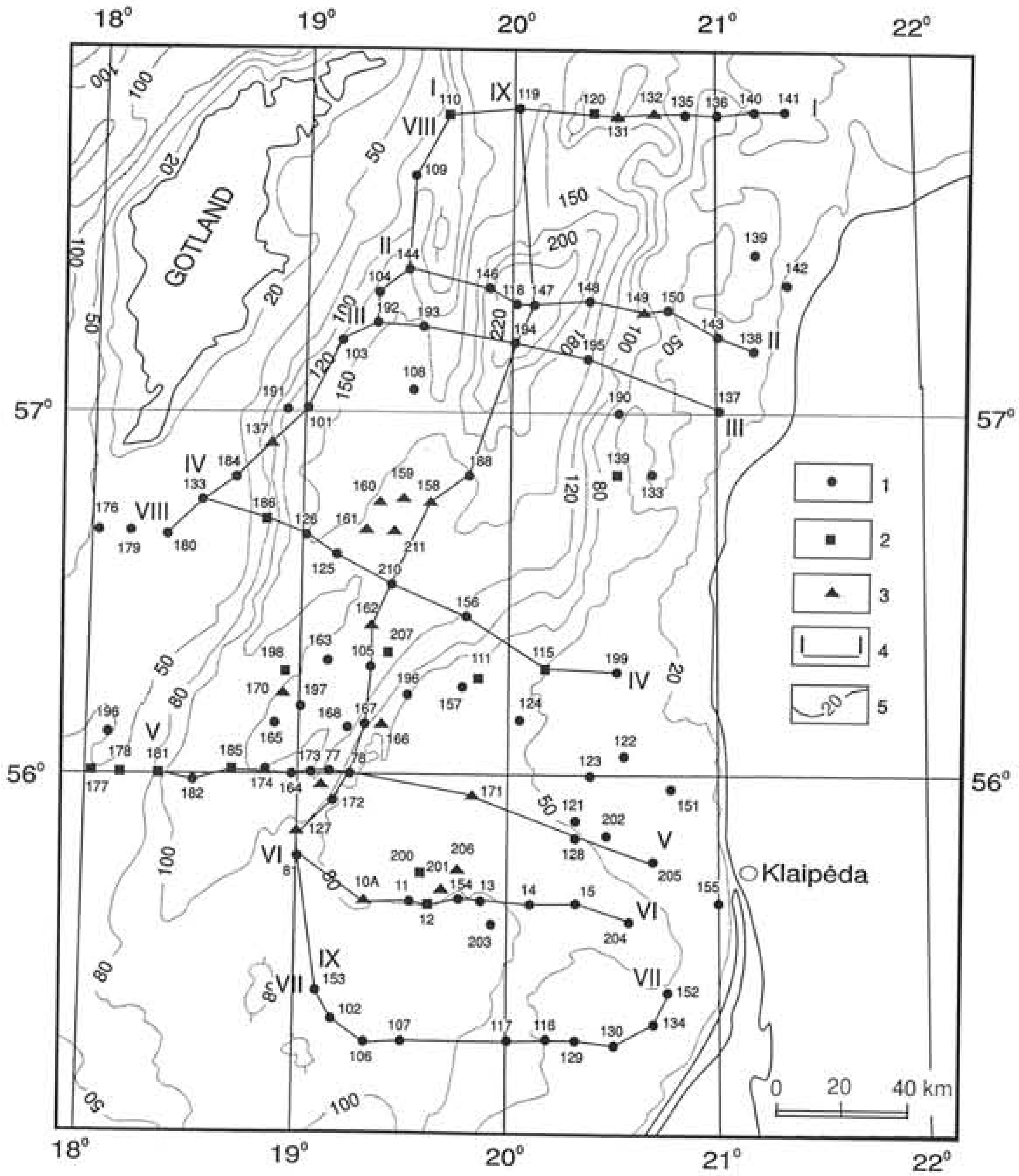

Fig. 1. Distribution of Quaternary sediments on the bottom surface of the South East Baltic Sea: 1 - Holocene sediments, 2 - Baltic Ice Lake clay, 3 - Pleistocene till, 4 - profiles and their Nos., 5 - isobathes, m

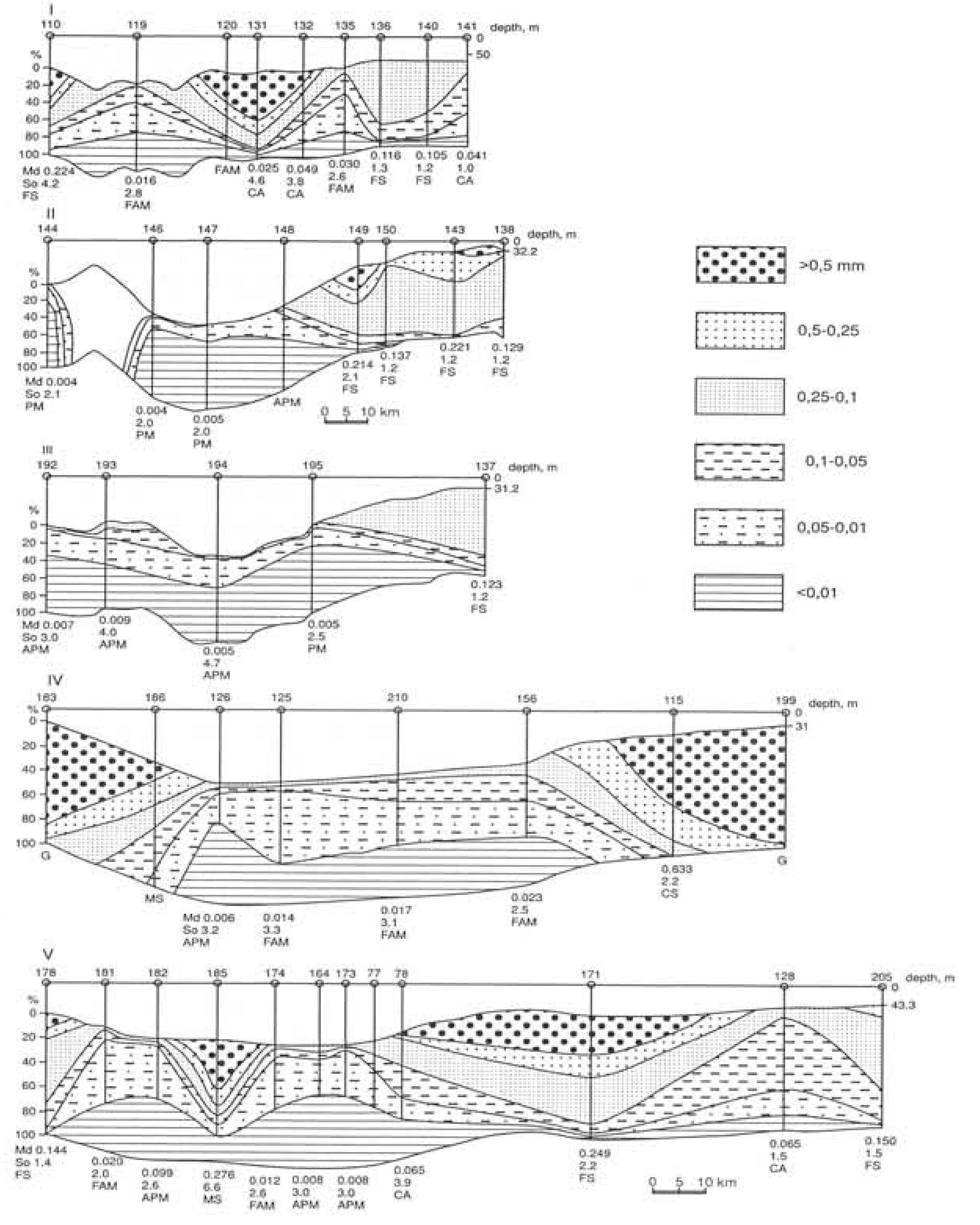

Fig. 2. Distribution of fractions (%) in bottom sediments of 1 -5 profiles: **Types of bottom sediments:** G- gravel (10-1mm), CS- coarse sand (1-0,5mm), MS- medium sand (0,5-0,25mm), FS- fine sand (0,25-0,1mm), CA- coarse aleurite (0,1-0,05mm), FAM- fine aleurite mud (0,05-0,01mm), APM- aleurite-pelite mud (50-70% < 0,01mm), PM- pelitic mud (>70% <0,01mm). Md-median diameter mm, So- coefficient of uniformity by Trask

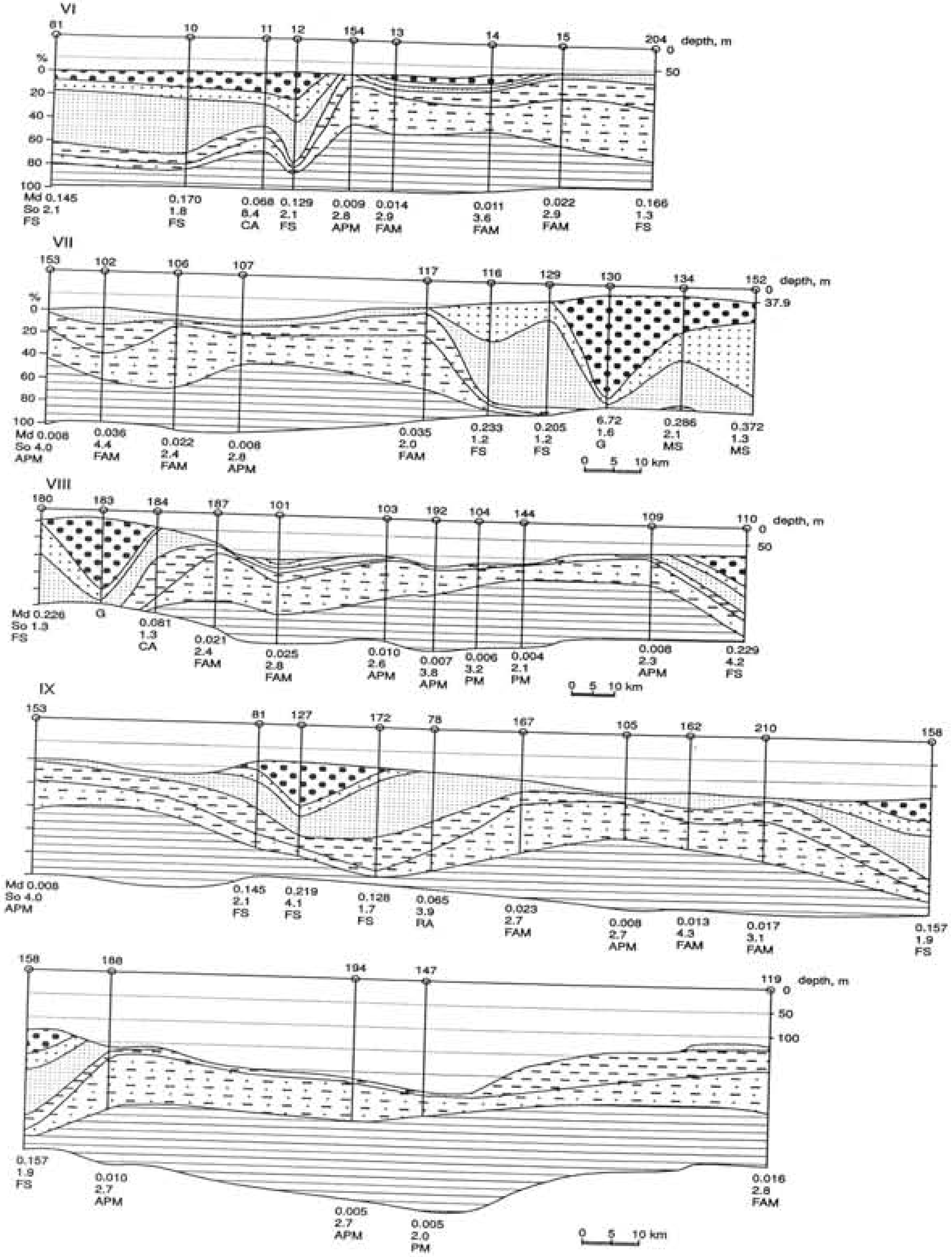

Fig. 3. Distribution of fractions (%) in bottom sediments of 6-9 profiles. For types of bottom sediments see Fig. 2

forming particles remains small. The average uniformity coefficients of fine aleurite mud, coarse aleurite, fine sand are 2.5, 1.5, and 1.3 by Trask, respectively. There are poorly sorted lag sediments of these types. The average uniformity coefficients of these sediments are 2.8, 5.2, and 2.4, correspondingly.

Various types of bottom sediments are spread at different sea depth levels (Fig. 4). Gravel and coarse sand are spread locally in the present near shore zone. Fine sand is widespread in the near shore zone. First level for gravel, coarse and medium sand is at the 24-26 m (average) sea depths. First level for fine sand and coarse aleurite is at the 16 m sea depth. The second level of the same types of the sediments is at the depths of 34, 39, 35, 33 and 42 m. Third level is at the sea depths of 46, 47, 53 and 52 m, correspondingly. Fine sand is spread at two lower levels - 64 and 83 m depths. Distribution of coarse sediments at deeper levels of sea bottom may be considered as that of sediments formed at the earlier stages of development of the Baltic Sea, when sea level was lower (Gudelis 1997). These levels may correspond to the Litorina, Yoldia Sea and Baltic Ice Lake stages.

Fine aleuritic, aleuritic-pelitic and pelitic muds are accumulating at the depths of 65, 74, and 89 m (average of the upper boundary of accumulation). The Pleistocene sediments on the bottom surface occur at the same sea depth, where non-sedimentation conditions are in Holocene. Glacigenous till on the bottom surface is spread at the sea depths of 57, 67, and 81 m, whereas the Baltic Ice Lake clay - at 66 and 84 m (average levels).

The mixed grain size sediments are spread at different levels of sea depth. Their upper level is the same as for the Pleistocene till and the Baltic Ice Lake clay on the bottom surface. The fine sand also is spread at these levels (64 and 83 m). These sediments may be lag material of the abrasion processes of the Pleistocene till. The variability of these sediments depends on hydrodynamic conditions of the environment. Modern pelitic sediments are accumulating at these levels too. There is no clear relation between the sea depth and different grain size of mixed sediments. These sediments occurring above the Pleistocene till are at a higher level, than those overlying the Baltic Ice Lake clay. There are areas of modern pelitic sediments on the bottom surface next to the mixed sediments areas. It shows that the active hydrodynamic conditions are at the bottom surface covered by mixed sediments. The 3-5cm thick bed of coarse mixed grain size sediments were accumulating on the bottom surface during the whole Holocene time.

Pleistocene till and Baltic Ice Lake clay are widespread on the bottom surface. These sediments are covered only by few centimeters thick bed of coarse mixed grain size sediments in some areas. These areas are on the slopes at the sea depths of 50-130 m and on separate elevations. Modern pelitic sediments are spread in the deeper part and coarse sediments in the shallow part of the sea. The mixed sediments were accumulating during the whole Holocene time. There were active hydrodynamic conditions at the bottom surface since Pleistocene time, and these sediments were covered by coarse grain size mixed sediments. Grain size of bottom sediments on the surface shows, that in some regions the near bottom currents are available. The coarse sediments are formed by strong stream and near the border the sediments are more finer (Figs. 2 and 3). More intensive currents may be in the region of the stations Nos. 131, 149, 185, 12, 110, 127, and 158. There is a poorly sorted sand on the bottom surface of these stations.

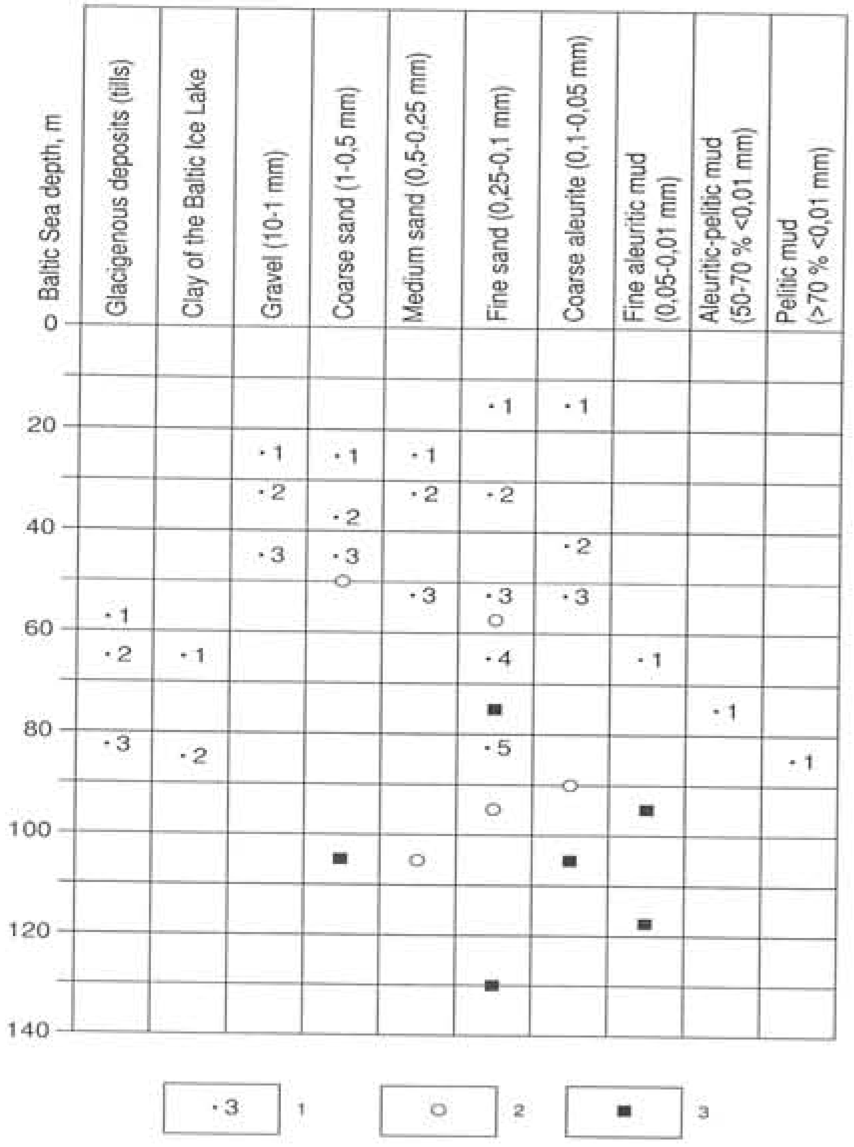

Fig. 4. Spread of bottom sediments at the different sea depth levels.
1- average spread levels of different sediment types, 2- the same of mixed sediments, occurring Pleistocene till, 3- occurring over the Baltic Ice Lake clay

CONCLUSIONS

There are modern sedimentation zones in the near shore and the deep part of the SE Baltic Sea. The coarse sediments are spread in the near shore zone and pelitic sediments in the deep part. The lag sediments are spread at different sea depths between the shallow and deep zones of sedimentation.

There are the following different sea levels fixed for various types of bottom sediments: gravel - 26, 34, and 56 m (average levels); coarse sand - 26, 39, and 47 m; medium sand - 24, 35, and 53 m; fine sand -16, 33, 52, 64, and 83 m; coarse aleurite -16, 42, and 52 m. The lower level of fine sand is found in the accumulation zone of pelitic sediments. The mixed grain size sediments are spread at different sea depth levels. Mixed fine sand occurring on the Pleistocene till is spread at the sea depths of 57 and 92 m and occurring on the Baltic Ice Lake clay - at the 75 and 130m. The different levels of sediments spread may be attributed to the different stages of geological development of the Baltic Sea.

Distribution of Pleistocene till and Baltic Ice Lake clay with coarse mixed grain size sediments on their surface shows the action of the near bottom currents at the lower part of slopes and separate elevations. The more intensive near bottom currents may be available in the region of the following stations Nos.131, 149, 185, 12, 110, 127, 158. This conclusion needs to be proved by further works.

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General Features of the Sub-Quaternary Relief of the Baltic Sea in the Latvian Economic Zone

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The Eastern Gotland Depression, Latvian submarine Plateau and Latvian—Gotland Slope are the large (regional) forms of the sub-Quaternary surface in the Latvian economic zone of the Baltic Sea. The mesoforms - such as the Eastern Gotland Trough, Eastern Gotland Basin and the Northern Slope with Northern Swell - are distinguished in the Eastern Gotland Depression. The individual elevations (Klaipėda, Rietumliepāja, etc.) separated from each other by small depression (Klaipėda-Rietumliepāja, etc) are widespread mesoforms in the area bedrock surface of the Latvian submarine Plateau. Besides them, there occur the deep depressions - Ziemupe-Ovīši and Liepāja also. The numeral burried palaeovalleys and palaeocannels are characteristic element of the sub-Quaternary surface. The floor of them reach the altitudes to -320 m.

Keywords: sub-Quaternary surface, depressions, elevations, palaeovalleys, Latvian economic zone.

INTRODUCTION

The sub-Quaternary relief separately for the area of the Latvian economic zone of the Baltic Sea is described and discussed for the first time (Fig. 1). Before the Quaternary cover of the Latvian zone had been investigated irregularly. However, available data allowed to draw the schematic map reflecting the features of the bedrock surface. The materials published by I. Danilāns (1973), Z. Meirons et al. (1974), H. Brio & V. Alexandrov (1980), M. Repečka et al. (Ed. A. Grigelis 1991), M. Bjerkéus et al. (1994) and Ž. Gelumbauskaitė (1995) have been used as well. Many important results about the Quaternary cover were obtained by I. Timovejev, F. Kovalenko, A. Samburg, V. Barashkov, L. Bolotov and their colleagues, which studied the different areas of the Latvian economic zone in 1971-1985.

BASIC FORMS OF SUB-QUATERNARY RELIEF AND THEIR DISTRIBUTION

The maritime areas of the Western Latvia characterizing by the bedrock surface with altitudes lower of sea level belong to the eastern outside part of the Baltic Depression (Danilāns 1973, Meirons et al. 1974, Segliņš 1987).

Two general different levels (steps) of the sub-Quaternary relief are clearly distinguished in the observed area of the Baltic Sea: a higher one with altitudes from 0 m to -80-90 m and lower one from -140-150 m (southern part) to -270-280 m (northern part). The first of them is the bedrock surface (socle) of the recent Latvian submarine plateau (Klaipėda-Ventspils, Bjerkéus et al. 1994, Gelumbauskaitė 1995). This level characterizes a wide zone of the Baltic Sea along the Latvian shoreline. A width of this zone is varying from 50 km (in its northern part) to 100 km (southern part). The second level reflects the bedrock surface of the Eastern Gotland Depression. The both regional forms mentioned are separated from each other by a steep slope (Latvian-Gotland Slope). The slope and both areas divided by it are of regional significance and strongly marked in sub-Quaternary surface. Slope height varies from 40-50 m (in its southern part) to 100-120 m (northern part). Another steep slope is stretches on outside the limits of the Baltic Depression in the Kurzeme maritime area between Ventspils and Ziemupe and is traced south-westwards on the sea. The height of this slope reach to 30-40 m.

The recent Gotland Depression is subdivided into the Western Gotland and the Eastern Gotland Depressions, the Gotland Deep, the Klint and the South Klint Banks (Gelumbauskaitė 1995). The Eastern Gotland Depression, the Gotland Deep and the northeastern part of the South Klint Bank are located in the area of the Latvian economic zone, with the rest situated in the area of Sweden.

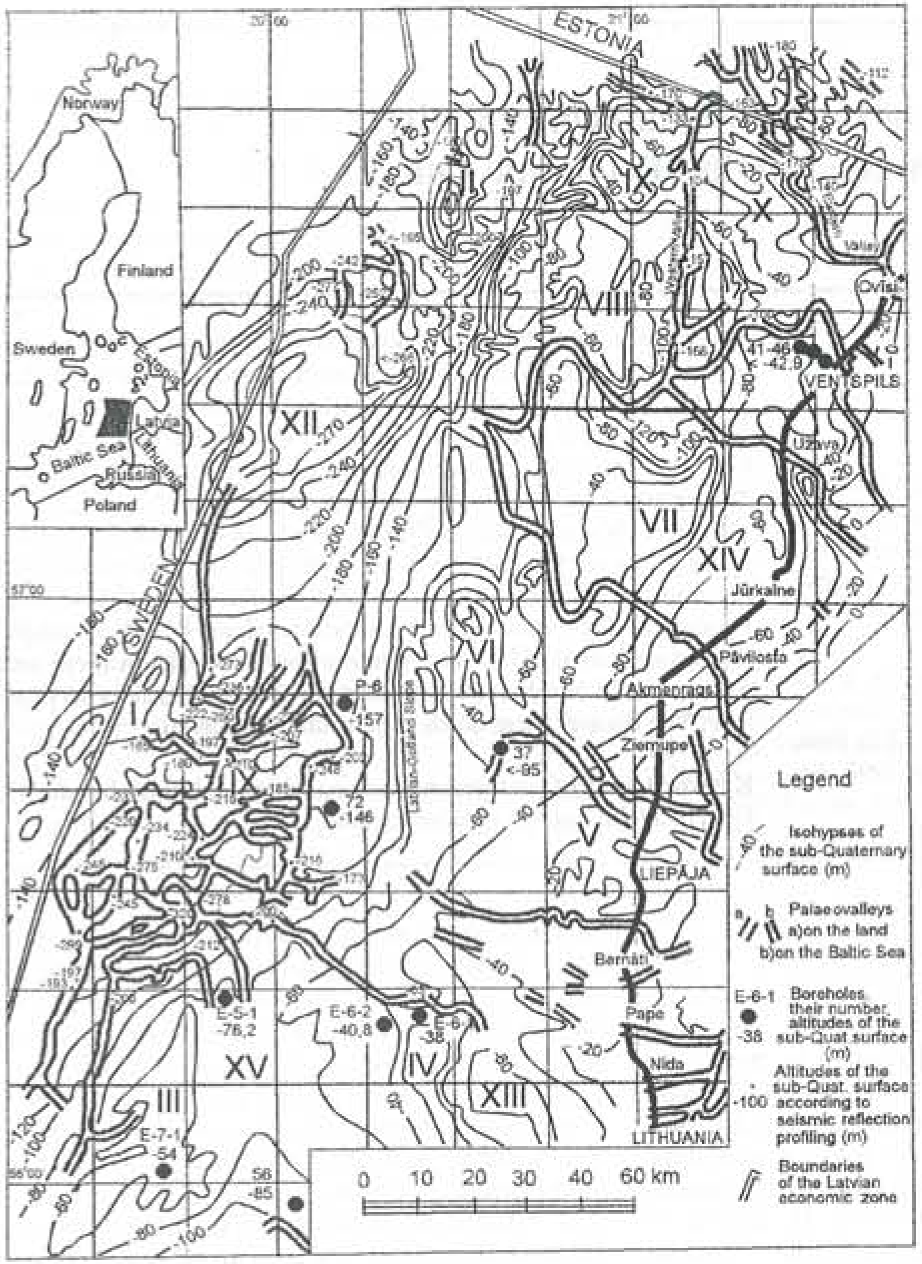

Fig. 1. Sub-Quaternary surface in the Latvian economic zone of the Baltic Sea. Elevations: I - South Klints Bank Swell (after Gelumbauskaitė 1995), II - Northern Swell, III - Klaipėda, IV - Rietumliepāja, V - Austrumliepāja, VI - Akmeņrags, VII - Pāvilosta-Užava, VIII - Ventspils, IX - Rietumovīši, X - Austrumovīši; Depressions: XI - Eastern Gotland Trough (after Gelumbauskaitė 1995), XII - Eastern Gotland Basin (after Gelumbauskaitė 1995), XIII - Liepāja, XIV - Ziemupe-Ovīši, XV - Klaipėda-Rietumliepāja. The investigated area of the Baltic Sea is marked by a black quadrangle

The southern and northern parts are distinguished in the bedrock relief of the Eastern-Gotland Depression. The southern part is named as the Eastern Gotland Trough (Gelumbauskaitė 1995) and occupies the space between elevations of bedrock surface in both as the Latvian submarine Plateau (eastern) and as well as the South Klint Bank (western). It floor has a northward inclination and lies at the depths with altitudes from -130-140 m to -160-170 m. There is a dense network of palaeovalleys observed in this area. Their floors reach the marks to -250-300 m and below. It is very difficult to distinguish he palaeovalleys from palaeoincisions. Presence of deep incisions there was reported by Bjerkéus et al. (1994) and Gelumbauskaitė (1995) as well.

The Eastern-Gotland Trough goes northwards into the Eastern Gotland Basin (Gelumbauskaitė 1995), which controls deeper part (the Gotland Deep) of the Eastern Gotland Depression. The Basin is of a kettle shape with plain floor at the absolute marks of -260-270 m. This Basin north-eastwards goes over to the Northern Slope of the Depression. The Northern Swell prolonged in meridian direction is drawn on this slope. Its dome parts have altitudes of -120 m and more. The Western and the Eastern valley-like depressions stretched in meridian direction are located on both sides of the Northern Swell. Their southward surfaces are expanded and flowed together with the Eastern Gotland Basin. The palaeovalleys along valley-like depressions have the marks of floors from -180 m to -280 m.

Basic forms of the sub-Quaternary surface on the area of the Latvian submarine Plateau are the individual elevations separated from each other by relatively small depressions, deep depressions, valley-like depressions and the palaeovalleys.

The Klaipėda and the Liepāja elevations with altitudes of the bedrock surface above -60 m and -40 m are located in the southern part of the total basement of the submarine Latvian Plateau. The saddle-like depressions between these elevations are observed. These forms on the bedrock surface correspond to the forms of the bottom topography (Klaipėda Plateau, Liepāja Plateau, Klaipėda-Liepāja Saddle, Bergman & Timofejev 1972, Timofejev et al. 1974, Veinberga et al. 1986). There are the Western-Liepāja (altitudes -35 m and more) and the Eastern-Liepāja (altitudes to 20m and 0 m) elevations distinguished on the bedrock surface. The both Liepāja elevations are separated by meridian elongated Liepāja Deep Depression (altitudes to -60 m).

Further northwards from the bedrock surface area described there are the large Akmeņrags and Pāvilosta-Užava elevations situated. Their surfaces have the absolute marks to -40 m and more. The Ventspils (to -60 m and more), the Western-Ovīši (to -30 m) and the Eastern-Ovīši are also elevations separated by different depressions located in the northern part of the basement of the submarine Latvian Plateau. Enumerated forms of the bedrock surface control the features of the bottom topography.

The Ziemupe-Ovīši Deep Depression clearly is drawn in the structure of the palaeorelief in the central and northern parts of the Latvian submarine Plateau. The existence of that Depression was forecasted by the analysis of the Quaternary cover (Emelyanov et al. 1975). The Depression stretches in meridian direction and is large in size - to 100 km long and to 30 km wide. The floor of it lies at the absolute marks of -60-80 m and less (southern part) and -100-120 m and less (northern part). Its south-eastern and eastern parts occur on the area of the Kurzeme maritime, but northern part - on the area of the Baltic Sea.

The deep palaeovalleys are observed on the sub-Quaternary surface of the submarine Latvian Plateau. They present an extension of deep palaeovalleys, known on the bedrock surface in adjacent land areas (Meirons et al. 1974). Their separate fragments and sections have been found in the coastal (nearshore) zone by geologists F. Kovalenko, A. Samburg, V. Barashkov and L. Bolotov. The palaeovalleys cross the area of the submarine Latvian Plateau in northern, north-western and western directions. The Western and the Eastern valleys traced in meridian direction are located on both sides of the Eastern-Ovīši Elevation. The Eastern Valley is notable for complicated contours and branching. It is about 40 km long and 2-6 km wide. The bottom of the Eastern Valley lies at the altitudes of -160-180 m. Probably this valley is an extension of a palaeovalley, known near Ovīši on land. The Western Valley crosses the saddle-like depression located between the Western and the Eastern-Ovīši Elevations and farther southwards stretches as far as to the middle of the Akmeņrags-Ovīši Deep Depression and along the depression between the Pāvilosta-Užava and the Ventspils elevations. The length of the Western Valley is about 100 km and its width is 2-3 km. The floor reaches the absolute marks of -160-170 m and even less. The palaeovalleys pra-Venta, pra-Užava, Aizpute etc., known in Kurzeme (Meirons et al. 1974) seen to be joined with the Western Valley in the Baltic Sea. The palaeovalleys of more southern region of Kurzeme across the Baltic Sea towards the southern part of the Eastern-Gotland Depression.

CONCLUSION

In general, the sub-Quaternary surface is lowering in the direction of inside regions of the Baltic Sea (from 0 m to -270 m). Its relief is uneven and notable for complex combinations of above described various forms. The relief of the sub-Quaternary surface of the Latvian submarine Plateau is of more complicated structure. The bedrock surface forms are clearly reflected in the bottom topography.

Numerous buried palaeovalleys (to -320 m) are typical for the sub-Quaternary relief. The incisions crossing the Latvian-Gotland Slope are reflected in the bottom topography.

The bedrock relief of the Latvian economic zone in a general plan correspond to the sub-Quaternary surface of Western Kurzeme, which both are similar in stretching and density of palaeovalleys network. According to Eberhards (1975) the area of Western Kurzeme clearly differs from adjacent regions of Latvia by features of the observed network of palaeovalleys. The meridian orientated network of palaeovalleys is located in the inside part of the Baltic Sea in the area of the recent Eastern Gotland Depression on the sub-Quaternary surface. The network seems to be of a common transbaltical significance.

The origin of the sub-Quaternary relief is the subject of independent discussion. However, it confidently can be recognized that general features of the sub-Quaternary relief in the Latvian economic zone of the Baltic Sea have been formed during the pre-Quaternary time. The Quaternary deposits filling the part of Akmeņrags-Ovīši Deep Depression located on the coast are of Elsterian, Holstenian, Saalian and Weichselian ages (Konshin et al. 1970, Danilāns 1973). The Elsterian, Saalian and Weichselian ages are attributed to the Quaternary tills found by borehole 37 in the palaeovalley in the Baltic Sea (Majore et al. 1997).

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Biostratigraphic Traits of the Nemunas Submarine Valley Sediments

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The sediments of PSh 2583 core taken in the Nemunas submarine valley were analysed by palynological and diatom methods. Pollen analysis data were used for description of the Late Glacial and Holocene stratigraphy. Variations of diatom species composition were used for determination of water salinity and level changes in the investigated area.

Keywords: palynology, diatoms, Baltic Sea stages, pollen spectrum.

INTRODUCTION

The buried Nemunas delta and valley in the south-eastern part of the Baltic Sea have already been mentioned before by A. Basalykas (1961), M. Kabailienė (1967), R. Kunskas (1970), L. Lukoševičius (1975), Ž.Gelumbauskaitė (1991), and V.Gudelis (1993). It is recorded in echograms, geomorphological maps, sample cores of bottom sediments. In 1989, during the 24th cruise of R/V "Professor Shtokman" (Atlantic Branch of Institute of Oceanology RAS), the PSh 2583 core was taken on the Curonian (Kuršių)–Sambian plateau at the point 55°33'25" N and 20°35'31" E, water depth 66 m (Fig. 1). The length of core is 4.65 m. The lithological composition of sediments is the following: from 0 to 82 cm depths - grey-greenish to grey silt; 82-109 cm - greenish grey aleurite; 109-139 cm - grey silt; 139-354 cm - grey silt with interlayers of coarse silt and black patches of hydrotroilite; 354-465 cm - grey clay (with patches of hydrotroilite at the depth of 354-375 cm) with sparse interlayers of aleurite.

METHODS

The samples for palynological and diatom investigations were taken at 10 cm intervals. For microscopic analysis of pollen they were treated using separation and acetolysis methods (Kabailienė 1979). Carbonates in sediment samples for diatom analysis were dissolved in diluted hydrochloric acid (10% HCl). Repeatedly washed sediments were boiled in 10% sodium hydrophosphate solution. Organic material was destroyed by heating in hydrogen peroxide (15% H_2O_2). The clay particles were eliminated by repeated washing after 2 hours settle, careful decanting, until the water mixture was colourless and clean. Gravity solution (specific weight 2.6) was used for separation of diatoms. Slides were produced with the help of mounting medium Naphrax (index of refraction 1.74) (Miller & Florin 1989). Pollen and diatom diagrams were compiled using the "Tilia" software. Percentage of spores and pollen was calculated from the bulk quantity of trees, shrubs and herbs. Percentage of diatoms was calculated only in those slides where the number of diatoms was about one hundred or more. For determination of palaeogeographical conditions the species of diatoms were divided into two ecological groups. One group was distinguished according to halobian system: marine (>30‰ salinity), brackish (30-0.2‰ salinity) and freshwater. The other ecological group - according to the life-form: planktonic, benthic (bottom-living), epiphytic (attached) (Miller & Florin 1989).

DATA ANALYSIS

The spores and pollen are well preserved in all samples. However, their frequency in different periods varies. The highest concentration was observed in the sedi-

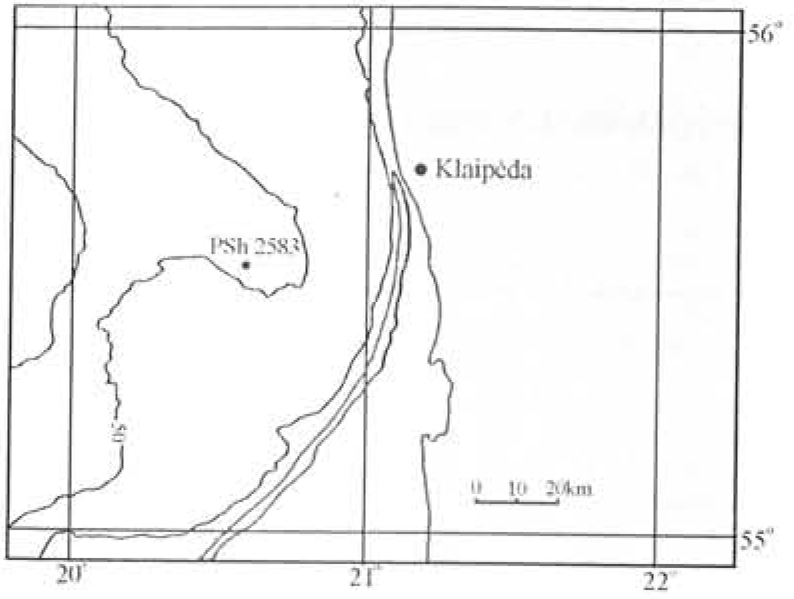

Fig. 1. Location of the core PSh 2583

ments of Litorina Sea and Postlitorina Sea, the lowest - in the sediments of Late Glacial and Yoldia Sea. The spore-pollen spectrum of these sediments abound in redeposited forms, which can be easily distinguished from those deposited *in situ*. They differ in their form, structure, colour and are often mineralised. The redeposited pollen were brought from Mesozoic, Palaeozoic but mainly from Paleogenic and Neogenic layers. Their frequency in samples sometimes reaches 40% of the total content of pollen. The spores and pollen synchronic to sediments are light greenish and well preserved. Among the redeposited ones the pollen of trees and shrubs abound, namely Pinaceae, Betulaceae, Fagaceae, *Tilia sp.*, *Ulmus sp.*, Taxodiaceae, Juglandaceae, *Castanea*, Ericaceae sp., *Rhus sp.*, *Nyssa sp.*, *Ilex sp*. The frequency of spores is also rather high: *Cyathea*, *Anemia*, *Gleichenia*, *Lygodium*, *Extratriporopollenites*. All of them are included in the pollen diagram into the column of unidentified and redeposited ones (Fig. 2). Similar frequencies of redeposited pollen are described also in cores taken from other parts of SE Baltic Sea, particularly near the Sambian peninsula where an intensive abrasion of pre-Quaternary steep slopes has taken place (Kleymenova & Khomutova 1981, Lukoševičius & Savukynienė 1981, Stelle et al. 1976). In the core of Nemunas submarine valley the redeposited spores and pollen are found through the pre-Litorina sediment stratum. The pre-Litorina sediments stand out in the diatom diagram (Fig. 3), where the content of diatoms varies in slides from different depth markedly. The data of palynological and diatom studies make it possible to reconstruct the course of sedimentation in the Nemunas submarine valley in the Late Glacial and Holocene. It was difficult to determine the boundaries of Yoldia and Ancylus stages, particularly on the basis of diatom data in this sample core. For this reason the determination of age of these sediments was mostly based on the palynological data.

The Baltic Ice Lake clays deposited in the Nemunas submarine valley were found at the depth of 354-465 cm. In the pollen spectrum of these sediments the tree pollen (70-85 %) prevailed. However, the frequency of herb pollen was also rather high (20-30%): *Artemisia sp.*, Chenopodiaceae, Poaceae, Cyperaceae. Among trees *Pinus* and *Betula* (a considerable part composed of *B. sect. Nanae*) prevail. Isolated pollen of *Picea abies*, *Alnus sp.*, *Salix*, etc. were traced. The spectrum abounds in representatives of periglacial flora: *Ephedra sp.*, *Dryas oct.*, *Selaginella selaginoides*, *Botrychium boreale*, *Lycopodium dubium*. Spores of *Sphagnales* and Polypodiaceae were found but only few. However, in the interlayer 415-425 cm the concentration of pollen increased. *Pinus* and *Betula sect Albae* prevail in the spectrum, isolated *Alnus* and *Picea* were found. Among herbs the pollen of *Artemisia*, Chenopodiaceae decrease, whereas, Poaceae and Cyperaceae slightly increase. The described spectrum of spores-pollen corresponds the Alleröd chronozone, whereas, the ones above and below - the chronozones of Older and Younger Dryas respectively. The content of diatoms in the described interval is small and uneven at different samples. However, in general, the freshwater diatoms prevail (*Aulacoseira islandica*, *Opephora martyi*, Epithemia sp.). The Baltic Ice Lake was a freshwater one but rather shallow, which was testified by the presence of epiphytic species. At the depth of 400-410 cm the representatives of brackish species *Actinocyclus ehrenbergii* were found but only few. We may assume that the water level of Baltic Ice Lake oscillated, and some marine water got into the lake. The input of marine water into Baltic Ice Lake was proved also by the analysis of diatoms from deep water depressions (Kabailienė et al. 1978, Blazchishin et al. 1991, Kabailienė 1995).

During Yoldia Sea stage grey silt sediments were deposited in the Nemunas submarine valley. They are found at the depth of 310-354 cm. These sediments still abound in redeposited spores and pollen from older Neogenic and Paleogenic layers. The pollen of *Pinus* and *Betula sect Albae* prevail in the palynological complex. Among herbs the pollen of *Artemisia*, Chenopodiaceae decrease, whereas, Cyperaceae, Asteraceae, Rosaceae and others herbs increase. A gradual increase of Polypodiaceae spores may be observed. However, isolated spores of *Selaginella selginoides*, *Botrychium boreale*, *Lycopodium annotinum* etc. can be still found. This pollen spectrum corresponds to the Preboreal chronozone.

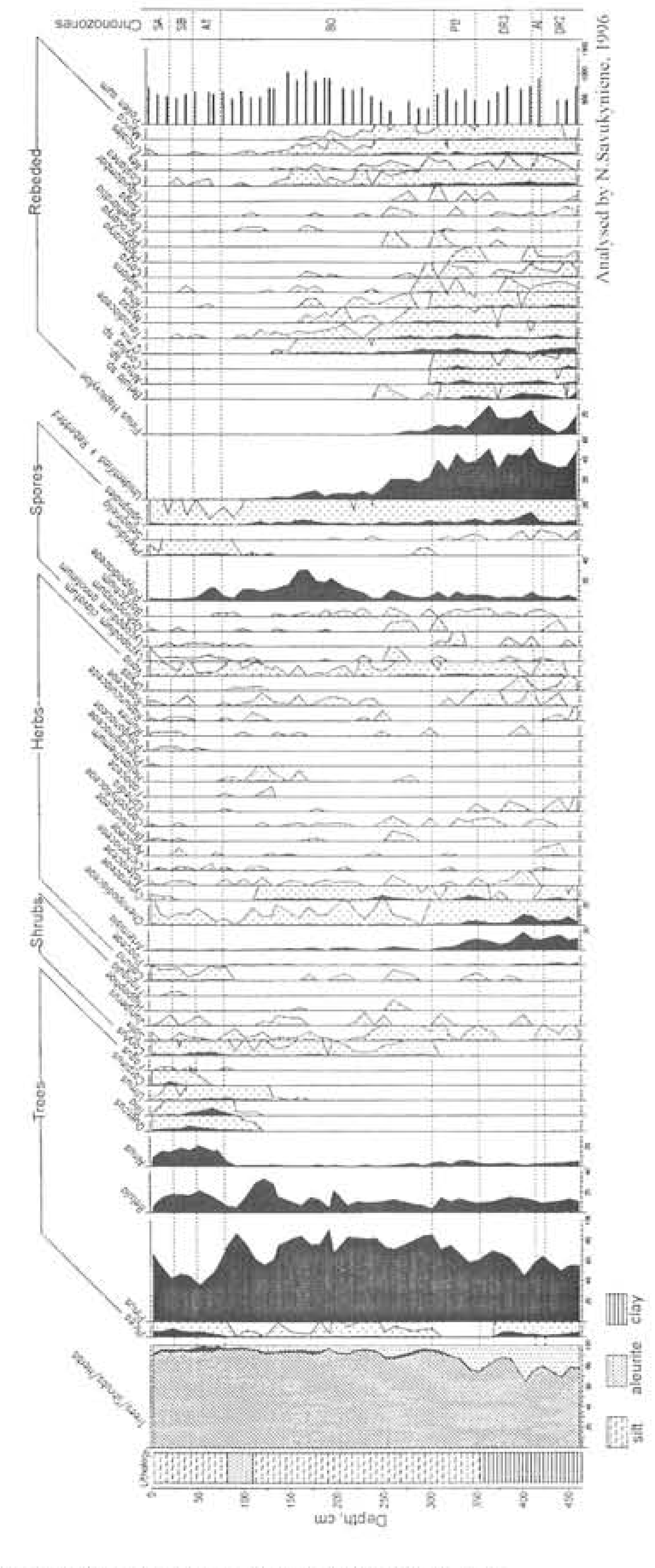

Fig. 2. Pollen composition in the core PSh 2583 sediments

Freshwater species *Aulacoseira islandica* and *Fragilaria inflata* dominate in the interval 354-220 cm. Among the brackish species only isolated diatoms were found. It is difficult to define the stage of the Baltic Sea in this interval (Yoldia Sea or Ancylus Lake). According to diatom data it could be Yoldia Sea with almost fresh water. *Fragilaria inflata* is halophilous (diatoms which can live in slightly brackish water) species and it is dominating in mentioned interval. However, according to pollen data Ancylus Lake sediments were defined in the depth 80-310 cm.

The thickest sediment layer (80-310 cm) was deposited in the Nemunas submarine valley during the Ancylus Lake stage. The pollen complex corresponds to the Boreal chronozone. In the first part of spectrum (200-245 cm) the curve of *Pinus* gradually rises, whereas, the curve of *Betula* falls down. The pollen of *Alnus* and *Corylus*, *Picea*, *Ulmus*, *Tilia* were found but only few. The number of herbs pollen and spores became less in comparison with the second complex. In the second half of the spectrum (80-200 cm) there is an abrupt fall of *Pinus* and rise of *Betula* pollen and, particularly, Polypodiaceae spores (up to 40%). Among herbs there were small contents of Cyperaceae, *Artemisia*, Poaceae pollen and individually *Helianthemum*, *Ephedra*, Cichoriaceae, Cariophyllaceae, *Dryas oct*. pollen, *Lycopodium clavatum*, *Pteridium*, *Botrychium boreale* spores. The content of redeposited spores and pollen decreases (up to 5%).

The sediments in the interval 80-220 cm were almost empty of diatoms. The absence of diatoms it is difficult to explain. Perhaps diatoms could not be preserved due to high rates of sedimentation and reduction conditions reflected by hydrotroilite.

The Litorina Sea stage is represented by a layer of 50-80 cm thick bottom sediments. *Pinus* in the pollen spectrum decreases till 40%, whereas, the content of *Alnus*, *Ulmus*, *Quercus*, *Tilia*, *Corylus* increases. The curve of *Picea* is stable rising. Herbs, pollen and spores were found to be not plentiful. The spectrum corresponds to the Atlantic chronozone.

The Postlitorina stage is represented by a 50 cm layer. Therefore, it is rather difficult to distinguish the Subboreal and Subatlantic stages. However, the distinct

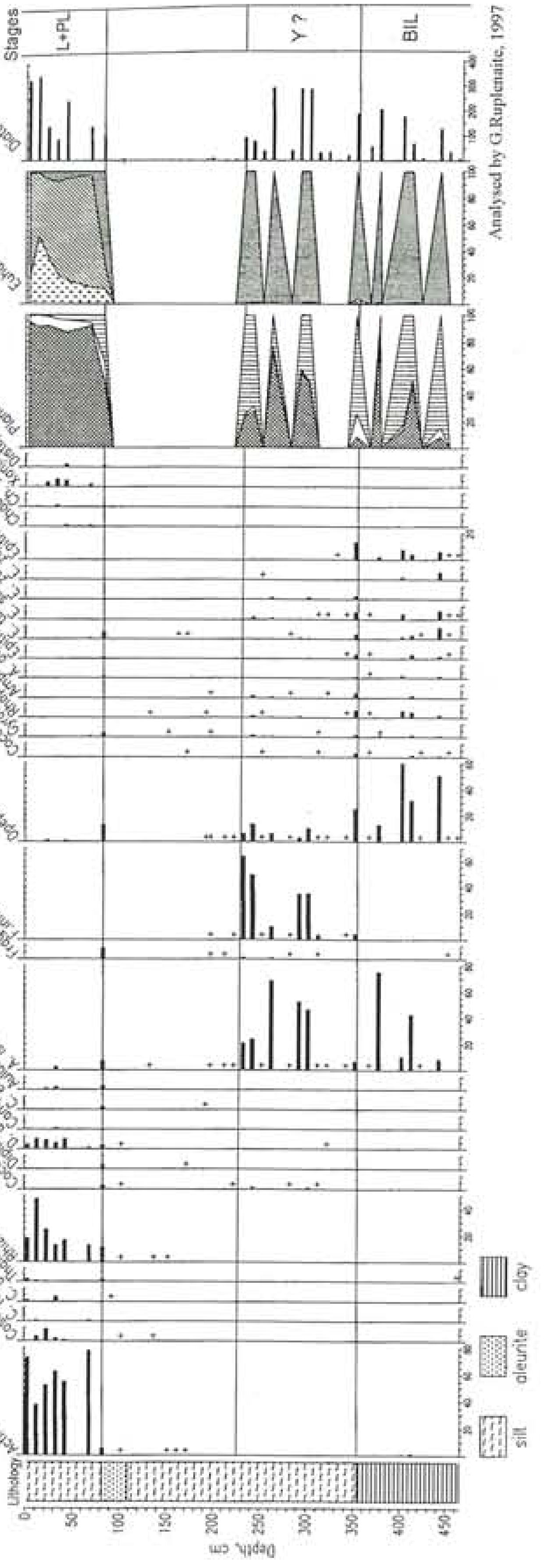

Fig. 3. The main diatom species found in the core PSh 2583 sediments

fall of *Ulmus*, *Tilia*, *Corylus* pollen curves allow to distinguish the beginning of Subboreal, whereas, the maximum of *Picea*, *Carpinus* and increase of herb pollen - show the boundary between them. The sediments from the mentioned period contain colonies of green algae (*Pediastrum boryanum*).

In the diatom diagram the whole upper interval (80 cm) of sediments is attributed to Litorina and Postlitorina. At the depth of 85 cm there appears the mezohalobous littoral species *Actinocyclus ehrenbergii* and euhalobous *Rhizosolenia calcar-avis*, the number of freshwater species decreases. At the mentioned depth (85 cm) water salinity started gradually increase. During the Litorina Sea stage *Actinocyclus ehrenbergii, Rhizosolenia calcar-avis, Diploneis didyma* dominated. The dominance in planktonic species revealed that water level was rather high and stable. The depth of 15 cm stands out for the fact that the content of euhalobous increases there - mostly as a result of the increase in *Rhizosolenia calcar-avis*. According to the palynological distribution this might have been the increase of Postlitorina Sea marine water salinity. Above the mentioned depth the salinity decreases again.

CONCLUSIONS

The high concentration of redeposited pollen in sediments of the Baltic Ice Lake and Yoldia Sea stages testifies an intensive abrasion of underwater morainic step slopes, promontories and transportation of sedimentary matter.

The most intensive sedimentation took place in pre-Litorina period. In the sediments from this period the content of diatoms was not high and at different depths ranged widely.

The sediment thickness dated to Litorina and Postlitorina stages is small because formation of the Kuršių Marios Lagoon changed the sedimentation conditions in the Nemunas submarine valley area.

The Litorina and Postlitorina diatom flora is abundant. The euhalobous and mesohalobous species prevail. In the Postlitorina stage short-term increase of water salinity took place.

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Heavy Metals in the Sediments of the Gulf of Riga both in the Shallow Coastal Zone and the River Mouths

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The obtained results revealed the highest levels of Hg, Cd, Pb, Cu, Zn, and Mn in the sediments of the Daugava River in comparison to the sediments of the Lielupe and Gauja rivers, but the level of Ni reached maximum in the sediment of the Lielupe River. The maximum levels of heavy metals were often observed in the sediments of the shallow coastal zone in the stations near the river mouths. The levels of Hg, Pb, Cu, Ni, and Mn are higher along the Vidzeme coast than those of the Kurzeme coast. This is associated with local pollution. Each heavy metal has seasonal changes that differ in the shallow coastal zone of the Gulf of Riga and river mouths.

Keywords: heavy metals, river mouths, shallow coastal zone of the Gulf of Riga.

INTRODUCTION

The aim of this study is to determine the concentration of Hg, Cd, Pb, Cu, Zn, Ni, and Mn in sediments in the river mouths and in the shallow coastal zone of the Gulf of Riga, which is one of the most endangered areas, since unique sand beaches are widely used for recreation. The coastal line of unique sand beaches is under the impact of three large river estuaries - Daugava, Lielupe and Gauja. The presence of Riga city and port, the Jurmala resort and other densely populated areas also have an important role. All this adds to the pollution of the Gulf of Riga and practically needs to be studied.

The results of our investigation of Hg,Cu,Zn,Mn.and Fe in the sediments of the coastal zone (1988-1992) are partly published (Kulikova 1995; Seisuma, Kulikova & Legzdina 1996).

Originality of the Gulf of Riga is that 82% of freshwater runoff is contributed by three biggest Latvian rivers - Daugava, Lielupe and Gauja - falling into its southern part. Daugava alone gives 65% of its runoff (Pastors 1988). According to geological and geomorphological structure and hydrodynamic conditions, the Gulf of Riga is divided into 5 zones: the coastal area, the upper part of the submarine coastal slope, the lower part of the submarine coastal slope, the upper part of the Gulf's bed and the lower part of the sea bed. The coastal area incorporates the narrow belt of land (beach) and the shallow water (to 7 m) part of the submarine slope. The width of this zone is up to 2 km. In the shallow water part of the coastal zone the overturning of the crest occurs, it is the zone with maximum energy of waves. In this zone, the roughness reaches the sea bottom and prevents accumulation of the clay and silt particles. There the main part of the sediment drift goes (Stiebrins & Valing1996). The sediment of the coastal area consists of varied grained sand.

MATERIALS AND METHODS

The width of the Daugava mouth is about 700 m. Three sampling sites were used in the Daugava mouth - right side (depth 3-4m), left side (4-5m) and a middle site (depth-12m). The mouth-bed consists of gravel and varied grained sand covered with mud. The width of the Lielupe mouth is about 600 m. Two sampling sites were used in the Lielupe mouth - right side (depth 4 m) and left side (depth 4). The mouth-bed consists of gravel and varied grained sand with detritus. The width of the Gauja mouth is about 100 m. One sampling site (depth 2 m) was used in the Gauja mouth - a middle one. The mouth-bed consists of varied grained sand. The concentrations of heavy metals were determined monthly at 7-13 stations off the Kurzeme (Jaunkemeri, Kauguri, Melluzi, Dubulti, Majori, Bulduri, Lielupe, and Bulli) and Vidzeme coast (Vecaki, Garciems, Gauja, Saulkrasti, and Skulte) in the surface layer (0-3 cm) of the sediments at 1m depth in 1988-1989 and in sediments of the river mouths of Daugava, Lielupe and Gauja in 1994 and 1996 (Fig. 1). In the recent years (1992, 1995) the concentrations of heavy metals were determined in separate stations of the coastal area and months.

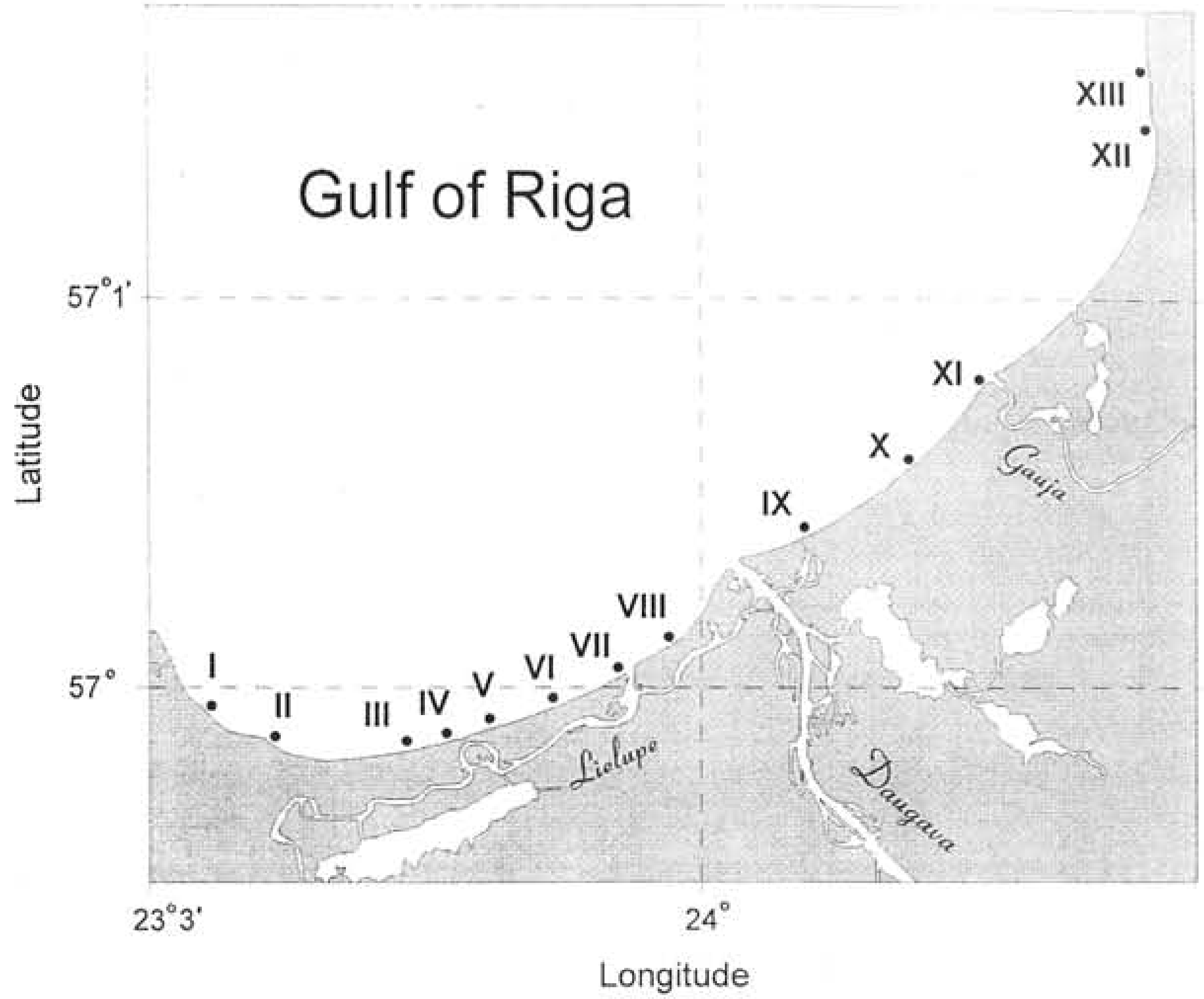

Fig. 1. Location of sampling sites: I - Jaunkemeri, II - Kauguri, III - Melluzi, IV - Dubulti, V - Majori, VI - Bulduri, VII - Lielupe, VIII - Bulli, IX - Vecaki, X - Garciems, XI - Gauja, XII - Saulkrasti, XIII - Skulte

Van Veen grab was used for sediments in the Gulf of Riga and in the rivers. The samples were stored frozen until they were dried at 80^0C in 48 h and homogenized in an agate mortar in the laboratory.

Cd, Pb, Cu, Zn, Ni, and Mn were extracted from sediment samples with concentrated HNO_3 and assessed by atomic absorption spectrophotometry. Hg was extracted from sediments by a mixture of concentrated H_2SO_4, HNO_3 and HCL (Seisuma & Legzdina 1995; Kulikova 1995). Measurements were performed by AAS-1 (Carl Zeiss) and by FIMS-Flow Injection Mercury system (Perkin Elmer). The error of analyses is estimated to be about 10-15%.

RESULTS AND DISCUSSION

The level of heavy metals in the sediments of the Daugava, Lielupe, Gauja river mouths differ significantly (Table 1, Figs. 2 and 3). Higher content of mercury is found in the sediments of the Daugava mouth and consequently lower in Lielupe and Gauja. The variations in river runoff are shown in the seasonal variations of mercury in the sediments. In May in all cases the concentrations of mercury are higher (except, left side in the Daugava) than in July. Similar to Hg, higher content of Cd, Pb, Cu and Zn was in the sediment of the Daugava mouth than in comparison with the sediments of Lielupe and Gauja. Content of Ni was higher in the sediment of the Lielupe river mouth. The content of Mn was higher in sediments of the Daugava and Gauja than in the sediments of the Lielupe. On the Daugava there is Riga city with many plants and ports. The sediments of the Daugava mouth consist of finer particles that absorb metals better than the sediments of the Lielupe and Gauja mouths. The left side of the Daugava is characterized by more intensive industrial influence than the right side. This input produced elevated concentrations of Hg, Cd, Pb, Cu, and Zn in the sediments of the left side of the Daugava. The seasonal changes of heavy metals in the sediments are observed in all mouths of the rivers. Par-

Table 1. **Level of heavy metals (mg/kg dry wt) in the sediments of the Daugava, Lielupe, and Gauja rivers in 1994**

Station	Month	Hg	Cd	Pb	Cu	Zn	Ni	Mn
Daugava	May	0.036	0.80	12.0	9.62	30.11	19.99	84.66
left side	July	0.076	0.689	14.44	4.89	20.11	7.33	146.0
	Oct	0.080	0.888	12.66	11.44	24.89	7.11	149.3
right side	May	0.013	0.622	4.88	3.80	7.91	16.66	83.78
	July	0.095	0.311	7.78	3.24	14.11	9.78	114.9
	Oct	0.031	0.355	4.66	2.44	10.67	7.11	56.22
middle	May	0.118	0.844	12.44	19.38	53.11	14.67	88.22
	July	0.091	0.444	8.22	6.22	16.34	10.45	97.11
	Oct	0.051	0.155	4.44	3.44	10.44	8.00	62.88
Lielupe	May	0.022	0.555	8.00	5.89	14.53	21.11	78.88
left side	July	0.039	0.466	7.11	4.78	20.89	14.45	69.56
	Oct	0.042	0.422	9.33	4.44	12.67	7.11	76.22
right side	May	0.016	0.466	4.22	4.15	8.39	20.89	27.78
	July	0.023	0.200	4.22	2.56	9.55	11.11	20.44
	Oct	0.087	0.133	3.33	2.44	2.11	11.00	11.11
Gauja	May	0.018	0.255	4.19	2.20	5.17	9.23	86.41
middle	July	0.033	0.222	3.77	2.29	4.33	5.33	88.22
	Oct	0.006	0.244	4.88	3.00	5.56	9.55	120.4

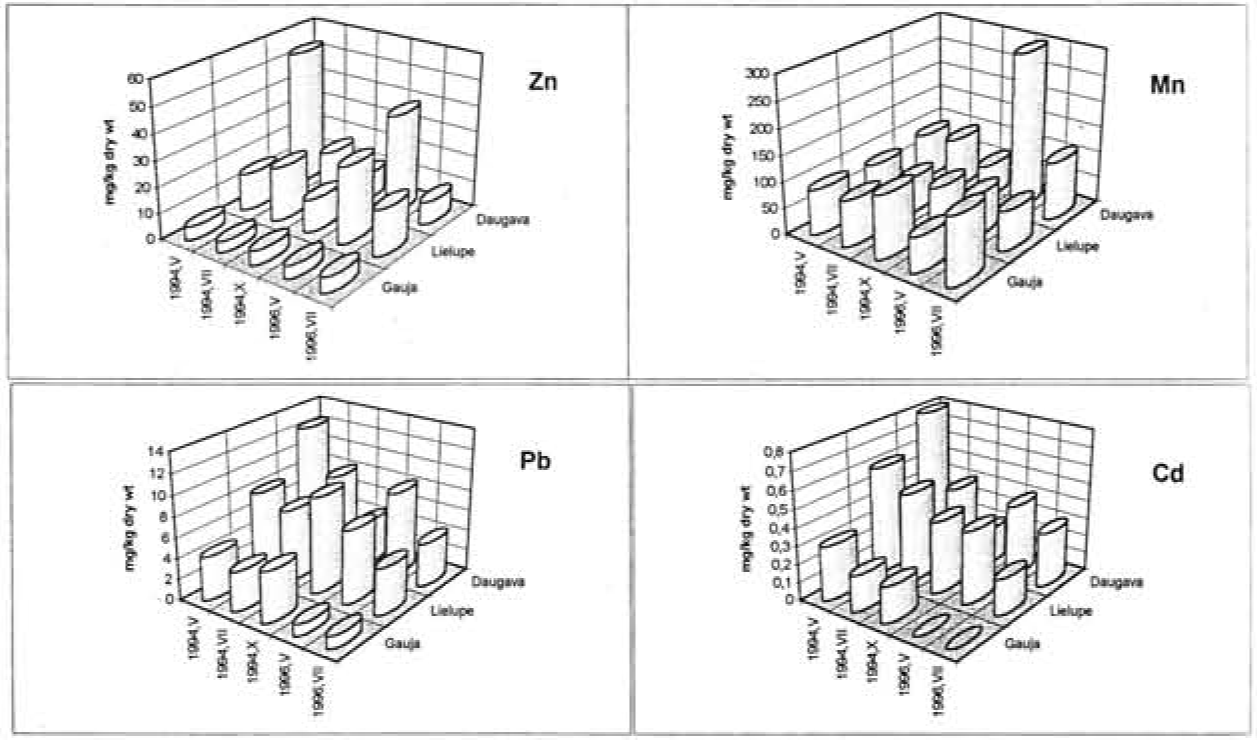

Fig. 2. Concentrations of heavy metals in the bottom surface sediments of the river mouths of the Gulf of Riga

ticularly high concentrations of Cd, Pb, and Zn are observed in spring in the sediment of the mouth of Daugava. Obviously, it is connected with snow that was thrown out on the Daugava in winter. There are yearly fluctuations in the concentrations of heavy metals in the river mouth sediments as well (Fig. 2).

The shallow coastal zone of the Gulf of Riga as a unique sand beach is widely used for recreation. The analyses of Hg, Cd, Pb, Cu, Zn, Ni, and Mn levels in bottom sediments are carried out at the depth of 1 m at thirteen stations from Jaunkemeri to Skulte (Figs. 1, 4-6).

Cu is a metal which is mostly brought in the Gulf from the largest rivers of Latvia (Daugava, Lielupe and Gauja). The concentrations of Cu differ with stations and from year to year (Fig. 4). In 1992 the concentrations in the sediments of all stations had a tendency to decrease. In the stations Bulli and Vecaki, which are near the estuary of the Daugava River, we observed higher concentrations of Cu than in stations a great distance away from river estuaries, for example, Melluzi and Kauguri. The increase of Cu concentrations in Saulkrasti is related to local pollution of the town. Zn is also a metal, which is mostly brought in the Gulf from the largest rivers of Latvia (Andrushaitis et al. 1995).

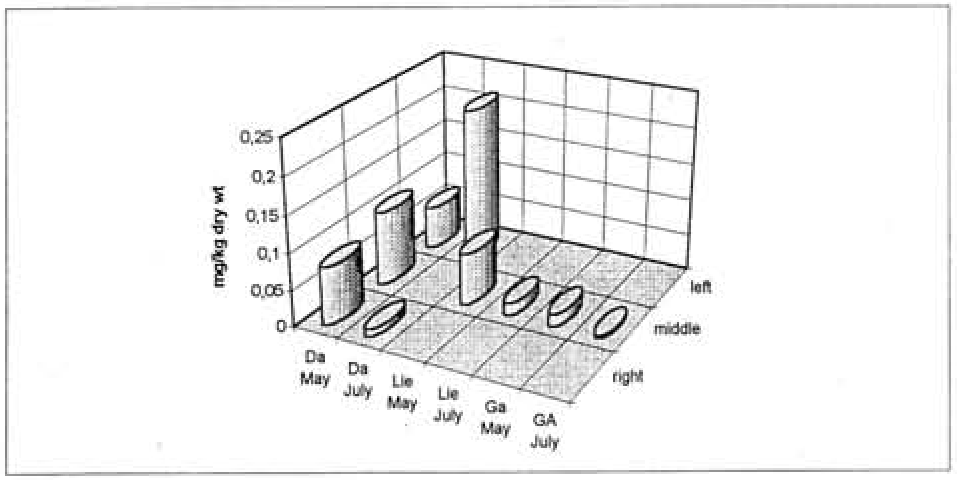

Fig. 3. Level of Hg in sediments of Daugava (Da), Lielupe (Lie), Gauja (Ga) in 1996

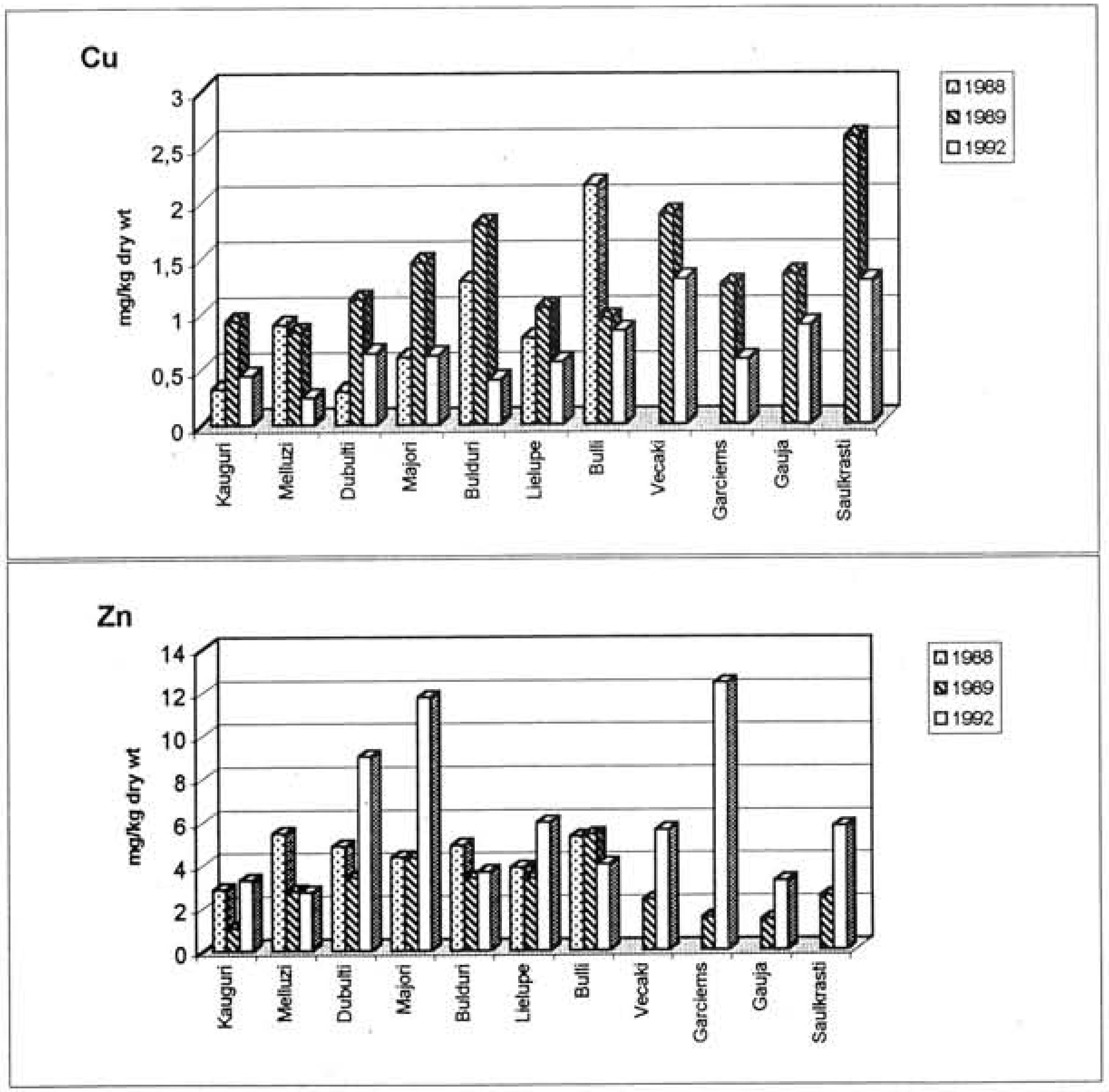

Fig. 4. The level of Cu and Zn in sediments of Jurmala at the depth of 1 m in July of 1988, 1989, 1992

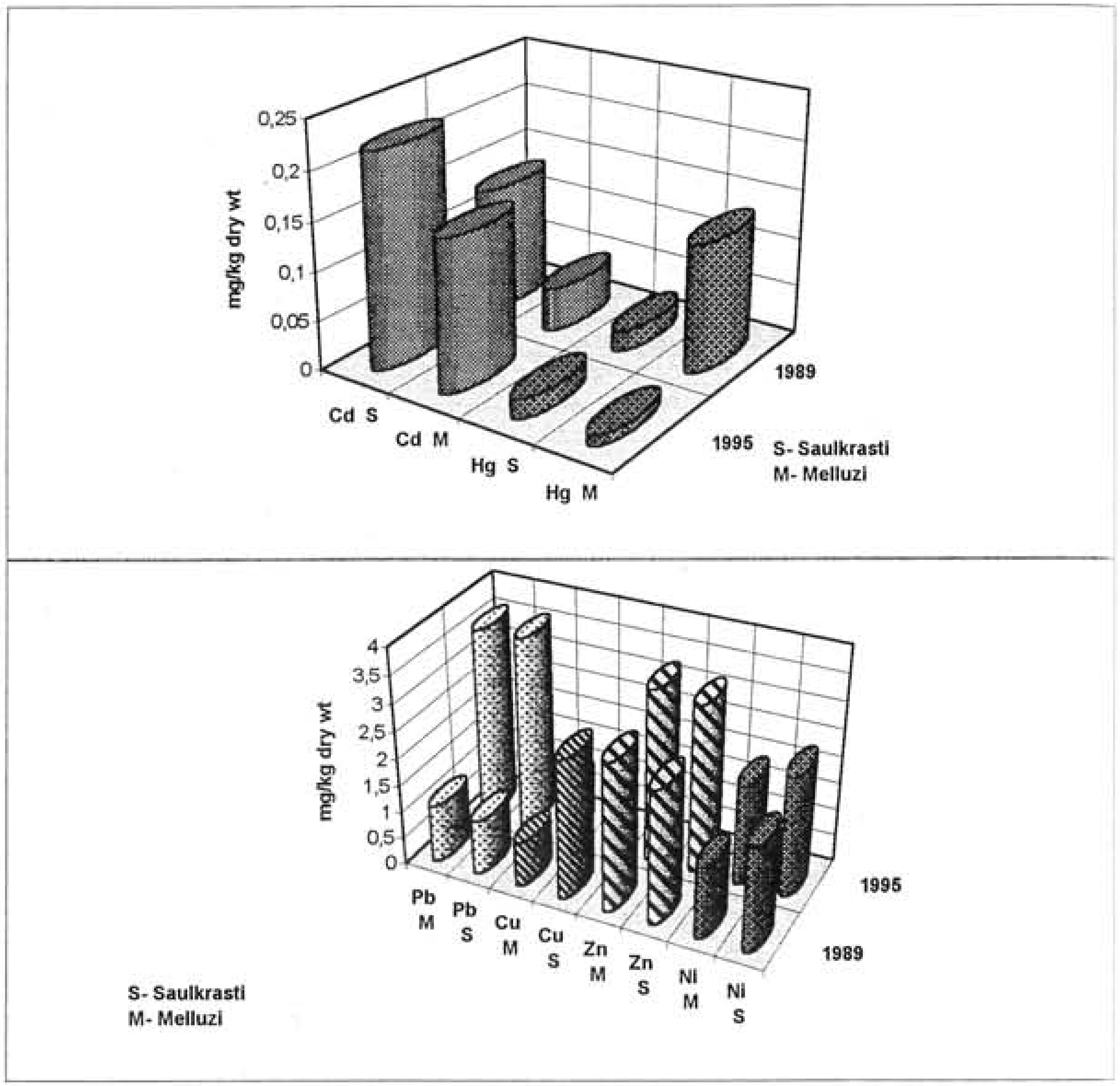

Fig. 5. Concentrations of heavy metals in sediments of Melluzi (M) and Saulkrasti (S) in July, 1989, 1995

The concentrations of Zn like those of Cu differ with stations and from year to year. In 1992 the concentrations of Zn, in comparison with those of Cu, had a tendency to increase in the sediments, particularly in Dubulti, Majori and Garciems stations. These stations are situated in the areas of most intensive recreation. Moreover, the increase was obviously connected with local pollution, as it can be seen by the results of July in Fig.4.

The concentrations of Hg, Cd, Pb, Ni and Mn differ with stations and from year to year (Figs. 5 and 6). In contrary to Hg and Cu, the highest concentrations of Cd, Pb, Zn, Ni and Mn were in 1995 in comparison with 1989. In 1989, the sediments of Melluzi and Saulkrasti contained Mn at the concentrations of 12.4 and 30.3 mg/kg dry weight, but in 1995 - 61.6 and 86.7 mg/kg dry weight. Sediments of shallow coastal zone show the highest concentrations of Pb in spring (April and May) and the lowest in summer (July and August). All through the year there is a difference among Pb concentrations in the stations. In Jaunkemeri, which is far from the Daugava River estuary, there are the lowest concentrations of Pb in the sediments. In Bulli, which is near the river mouths, the concentrations of Pb in the sediments are higher than in Jaunkemeri. In Saulkrasti, due to the local town and a highway along the seaside , there are the highest concentrations of Pb in the sediments. Levels of other metals also have seasonal changes. In total, the whole recreation zone 1 m deep from Jaunkemeri to Skulte has very varied concentrations of heavy metals in sediment, while an intensive abrasion in this shallow area has a strong impact on it.

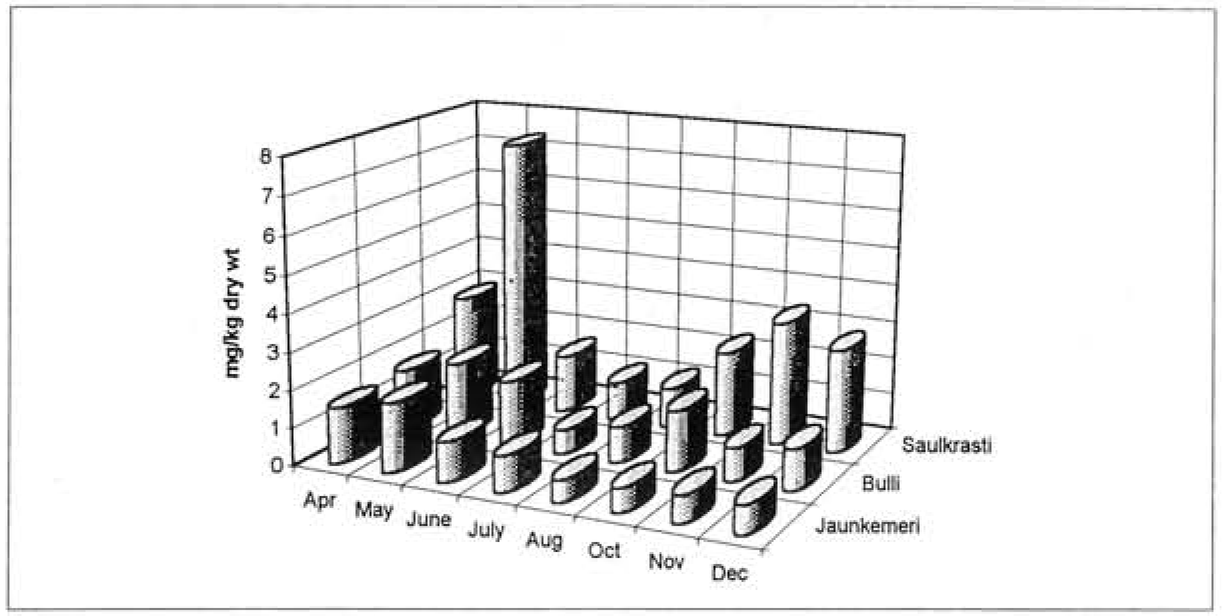

Fig. 6. The level of Pb in the bottom sediments of the recreation zone 1 m deep in 1989

In July 1989 we compared the levels of investigated metals in the sediments of the Kurzeme coast (mean concentration for the stations of Jaunkemeri, Kauguri, Melluzi, Dubulti, Majori, Bulduri, Lielupe, and Bulli) and the Vidzeme coast (mean concentrations for the stations of Vecaki, Garciems, Gauja, Saulrasti, and Skulte). In contrary to Zn (1.93 mg/kg) and Hg (0.01 mg/kg) the level of Pb (1.17 mg/kg), Cu (1.56 mg/kg), Ni (1.73 mg/kg), and Mn (19.65 mg/kg) are higher in the sediments of the Vidzeme coast in comparison with the Kurzeme coast (Zn-3.06,Hg-0.12, Pb-0.98, Cu-1.14, Ni-1.4, and Mn-13.03 mg/kg). The level of Cd (0.12) is similar in both regions. Similar situations were observed for all metals in July of 1992 as well .Concentrations of heavy metals in the sediments along the whole recreation zone of Kurzeme and Vidzeme coasts do not exceed MPL (Maximum Permissible Level) in the year of investigation (Report 1985).

CONCLUSION

The concentrations of all heavy metals in surface sediments at 1 m depth in the shallow coastal zone of the Gulf of Riga (Vidzeme and Kurzeme coasts) and in the river mouths do not exceed the norms typical for unpolluted bottoms. The fact that Cd, Pb, Cu, Zn, Ni and Mn concentrations were higher at the stations near the river mouths, was obviously related to the discharge of the Daugava, Lielupe and Gauja waters into the Gulf of Riga. This is particularly expressed for Pb, Cu, Zn and Mn, which enter the seas via rivers. Concentrations of Cd, Pb, Cu, Zn, Ni and Mn in sediments of river mouths exceed those of the shallow coastal zone in the Gulf of Riga at 1 m depth from 3 to 10 times. The sediments of the Daugava mouth have the highest concentrations of all the heavy metals, particularly Hg, Pb and Zn. The concentrations of all heavy metals in the coastal and river mouth sediments undergo seasonal and yearly fluctuations.

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XRD Analysis of Heavy Minerals in Bottom Sediments of the Baltic Sea

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Jolita Apanavičiūtė

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Evaluation of composition and content of heavy mineral fraction derived from bottom sediments of the Baltic Sea, using a new XRD method of analysis, instead of the microscopic one, is described. Realisation of this method is illustrated by semiquantitative analysis of heavy fraction samples from the Lithuanian nears-shore zone of the Baltic Sea.

Keywords: XRD analysis, heavy minerals, mass absorption, radiation, diffraction, garnet, amphibole, almandine, tremolite, ilmenite, magnetite, zircon, rutile, epidote.

INTRODUCTION

It is the first attempt to apply XRD method for analysis of heavy minerals in the XRD laboratory of the Institute of Geology (diffractometer DRON-2.0, Cu_α radiation), instead of usual method of analysis by means of polarising microscope. The merit of XRD method is that there is a possibility to find out percentage of each individual mineral, but not the mineral group as in the microscopic method. The XRD method enables determination of minerals, with their content exceeding 3-5% in a sample. However, this method does not allow to find amorphous minerals, like some oxides and hydroxides, and those which make only some grains in a fraction. It is a fault of the method. As far as it has been established by evaluation of results of microscopic analyses, the average content of amorphous oxides and hydroxides, as well as other minerals "invisible" in diffractogram, is about 10%. So, the total sum of identified minerals in diffractograms of analysed samples is likened to 90 per cent, and content of each mineral found in a fraction is calculated from this sum. In heavy fraction of bottom sediments of the Baltic Sea the minerals of amphibole, epidote and garnet groups, also ilmenite, magnetite, rutile and zircon are relatively abundant (Blazhchishin 1976) and may be found by XRD method.

METHODS

The XRD semiquantitative analysis is based on the following theoretical propositions of X-rays diffraction by a sample: (1) picture of diffraction, i.e., disposition and intensity of peaks in diffractogram characterises a crystalline matter and is obtained independently on other compounds available in a sample; (2) intensity of diffraction peaks of a mineral in a mixture is proportional to its concentration.

On the grounds of these propositions, all methods of XRD quantitative and semiquantitative analysis come to determination of mineral concentration in a mixture according to dependence established theoretically or by experiment between intensity I_i of diffraction maximum and content c_i of a mineral. Since an intensity of diffraction maximum depends on a number of factors, the establishment of precise analytical dependence of intensity on concentration in most cases is a complicated task.

The methodology of XRD quantitative analysis is described in a number of publications (Alexander & Klug 1948; Copeland & Bragg 1958; Peter & Calman 1964; Bezjak 1961; Nechvolodov 1936; Zevin & Zav'yalova 1974; Hardy & Tucker, 1986 and other).

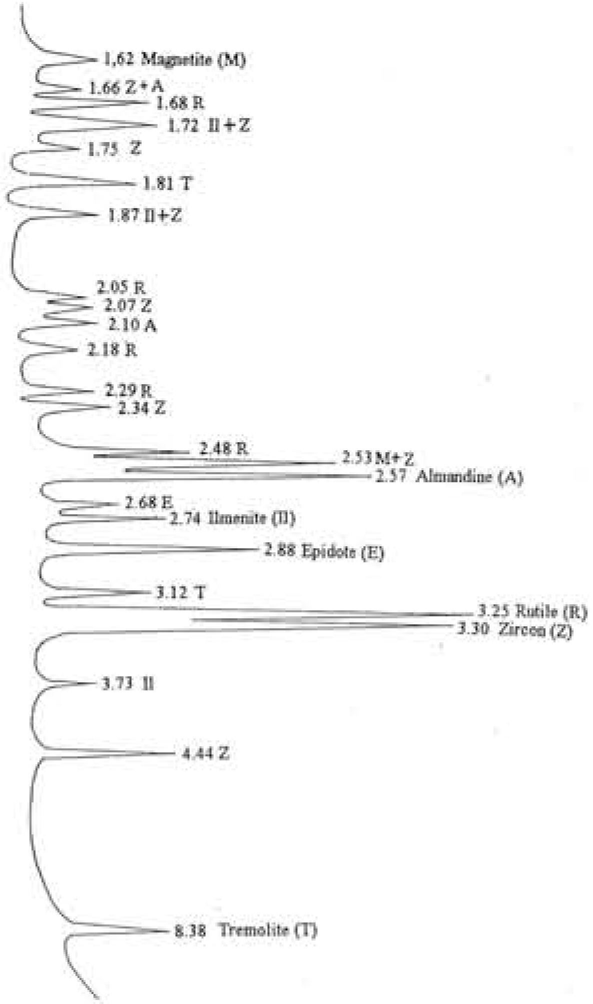

Fig. 1. Diffractogram of standard mixture of heavy minerals

The diffraction maximum of integral intensity of i-phase under determination, the volume concentration of which is v_i, theoretically is expressed by the formula:

$$I_i = k_1 k_2 k_{3i} A(\Theta;\mu) v_i dV, \qquad (1)$$

where $k_1 = \dfrac{e^4}{m^2 C^4}$ - coefficient, which depends on physical constants: e and m - charge and mass of electron, C - light velocity; $k_2 = \dfrac{I_0 \lambda^3}{32 \pi R}$ - coefficient, which depends on conditions of experiment: I - intensity of primeval X-ray beam, λ - x-ray wave length (Å); k_{3i} - coefficient, which depends on structure of analysed crystalline phase and is equal to

$$k_{3i} = \frac{1+\cos^2 2\Theta_i}{\cos\Theta_i \bullet \sin^2\Theta_i} M_{hkl} \left|F_{hkl}\right|^2 N_i^2, \qquad (2)$$

where Θ - Bragg's angle, M_{hkl} - multiplier of recurrence, $[F_{hkl}]^2$ - structural factor, N_i - amount of elementary lattices in volume unit, A(Θ;μ) - multiplier of absorption, m - linear coefficient of X-rays absorption, v_i - volume concentration, dV - element of sample volume.

The expression (1) determines dependence of diffraction maximum on all main characteristics of analysed matter and position of maximum and enables to establish relation between values I_i and v_i.

The intensity of reflection by sample, thickness of which is dx, would be as follows:

$$dI_i = k_1 k_2 k_{3i} v_i \frac{U_0}{\sin\Theta} e^{\frac{-2\mu x}{\sin\Theta}} dx, \qquad (3)$$

where $\dfrac{U_0}{\sin\Theta}$ - irradiated surface of sample, U_0 - section of primeval X-ray beam at axis of goniometer, $\dfrac{2x}{\sin\Theta}$ - path of incident and diffracted rays in sample.

After an integration of formula (3) from 0 to ∞ we shall receive:

$$I_i = k_1 k_2 k_{3i} v_i U_0 \frac{1}{2\mu} \qquad (4)$$

In this case the multiplier of absorption $A = \dfrac{1}{2\mu}$.

If concentration is defined by weight (c_i), the change from volume to weight concentration may be expressed by formula:

$$c_i = v_i \frac{\rho_i}{\rho}, \qquad (5)$$

where ρ_i and ρ - density of i-phase and sample, respectively. Substituting v_i in formula (4) for its expression from formula (5), we shall receive:

$$I_i = k_i \frac{c_i}{\rho_i \mu^*} = k_i \frac{c_i}{\rho_i \sum_{i=1}^{n} c_i \mu_i^*}, \qquad (6)$$

where $k_i = \dfrac{\rho}{2} k_1 k_2 k_{3i} U_0$ - constant coefficient for concrete phase and conditions of experiment, $\mu^* = \mu/\rho$ - coefficient of mass absorption of X-rays by sample, μ_i^* - coefficient of mass absorption by i-phase, n - amount of phases in sample (Zevin & Zav'yalova 1974).

In a general case an intensity of analytical peak of a phase under determination is quite complex function of its concentration and, in addition, depends on concentration of the rest phases of a sample as well. Even in the case when an effect of micro absorption is inessential, the equation

$$I_i = k_i \frac{c_i}{\rho_i \mu}, \tag{7}$$

where I_i - intensity of reflection, k_i - coefficient, constant for certain phase and conditions of experiment, ρ_1 - density of i - phase in a sample, c_i - weight content of component in a sample, m - mass absorption of the total sample, allows the simple solution only in some cases because the mass absorption coefficient

$$\mu = \sum_i \mu_i c_i \tag{8}$$

is settled by complete phase composition of the sample (Zevin & Zav'yalova 1974).

In the complete analysis of n-phase system which contains n crystalline components, the concentration of all available phases in a sample is determined using the following formula:

$$\sum c_i = 1 \tag{9}$$

There are two following cases possible: 1) with overlapping peaks and 2) system with free analytical peaks. The first case is more complicated.

The authors of this paper have had a purpose to apply the XRD method of analysis in the more simple (2nd) case and have used the formula

$$c_i = \frac{1}{1 + \sum\limits_{r \neq i}^{n} \frac{S_{ri}}{\beta_{ri}}} \tag{10}$$

for determination of content of every component or i-phase, where $S_{ri} = \frac{I_r}{I_i}$ - ratio of intensities of analytical diffraction peaks, and $\beta_{ri} = \frac{\beta_{ro}}{\beta_{ri}} k_{ri} = \frac{I_{ro} k_r}{I_{io} k_i}$, which is obtained from analysis of two-phase homological artificial mixtures where ratio of intensities of components main peaks I_{ro}/I_{io} is multiplied by coefficient k_{ri}.

In the equation (10) the summing up by all r, except r = i, is carried out.

If to designate the $\frac{1}{c_i} - 1$ by p_i, the equation (10) might be expressed in the following form:

$$p_i = \sum_{r \neq 1}^{n} \frac{S_{ri}}{\beta_{ri}} \tag{11}$$

In the case of three-phase system the equations (5) will be following:

$$\begin{aligned} p_1 &= \frac{S_{21}}{\beta_{21}} + \frac{S_{31}}{\beta_{31}} \\ p_2 &= \frac{S_{12}}{\beta_{12}} + \frac{S_{32}}{\beta_{32}} \\ p_3 &= \frac{S_{13}}{\beta_{13}} + \frac{S_{23}}{\beta_{23}} \end{aligned} \tag{12}$$

On the ground of theoretical basis, presented above, the authors of this paper have worked the method of XRD analysis by making of artificial mixtures of minerals, with their weight concentration known in advance. The calculation of β_{rio} has been carried out using intensities of two-phase homological artificial mixtures, as standards (Table 1).

Table 1. Values of β_{rio}.

Ro	io						
	A	T	I	M	Z	R	E
A	1	0.55	0.96	2.49	0.65	0.33	1.92
T	1.83	1	0.88	5.78	0.42	0.63	3.09
I	1.04	1.14	1	3.29	0.59	0.66	2.71
M	0.4	0.17	0.3	1	0.27	0.2	0.37
Z	1.54	2.39	1.7	3.72	1	1.85	4.23
R	3	1.58	1.51	5.13	0.54	1	2.96
E	0.52	0.14	0.37	2.71	0.24	0.34	1

Then the values of relative intensities S_{ri} of mineral peaks in diffractogram of analysed standard sample (artificial mixture) are calculated (Table 2). The intensities of following peaks of minerals in diffractogram (Fig. 1) have been used: almandine (A) - 2.57, tremolite (T) - 8.38, ilmenite (I) - 2.74, magnetite (M) - 1.62, zircon (Z) - 3.30, rutile (R) - 3.25 and epidote (E) - 2.88Å.

Table 2. Values of S_{ri}.

R	i						
	A	T	I	M	Z	R	E
A	1	3.29	2.35	4.26	0.82	0.79	2.88
T	0.3	1	0.71	1.3	0.25	0.24	0.88
I	0.43	1.4	1	1.81	0.35	0.34	1.23
M	0.23	0.77	0.55	1	0.19	0.18	0.68
Z	1.22	4	2.86	5.19	1	0.96	3.5
R	1.27	4.17	2.98	5.41	1.04	1	3.65
E	0.35	1.14	0.82	1.48	0.29	0.27	1

The obtained results of calculation of minerals concentration (p_i) using system of equation(12) have been normalised by division of real values of each mineral (p_r) into calculated from diffractogram (p_c) values and by calculation of coefficients k_{ri} (Table 3).

Table 3. Values of k_{ri}.

R	i						
	A	T	I	M	Z	R	E
A	1	4.08	1.55	0.78	1.89	0.78	1.2
T	0.25	1	0.38	0.19	0.46	0.19	0.29
I	0.65	2.64	1	0.5	1.22	0.51	0.78
M	1.28	5.24	1.98	1	2.43	1.01	1.54
Z	0.53	2.16	0.82	0.41	1	0.42	0.64
R	1.27	5.2	1.97	0.99	2.41	1	1.53
E	0.53	3.4	1.29	0.65	1.57	0.65	1

Then the β_{rio} of each mineral ratio is multiplied by their coefficients k_{ri} respectively, and values β_{ri} are obtained (Table 4).

Table 4. Values of β_{ri}.

R	i						
	A	T	I	M	Z	R	E
A	1	2.4	1.49	1.94	1.23	0.26	2.3
T	0.46	1	0.33	1.1	0.19	0.12	0.9
I	0.68	3.01	1	1.65	0.72	0.34	2.11
M	0.51	0.89	0.59	1	0.66	0.2	0.57
Z	0.82	5.16	1.39	1.53	1	0.78	2.71
R	3.81	8.22	2.97	5.08	1.3	1	4.53
E	0.43	0.48	0.48	1.76	0.38	0.22	1

The final calculation of mineral content of the standard sample, which contains almandine - 20%, tremolite - 15%, ilmenite - 10%, magnetite - 10%, zircon - 20%, rutile - 10% and epidote - 15%, is presented below:

$$p_A = \frac{S_{TA}}{\beta_{TA}} + \frac{S_{IA}}{\beta_{IA}} + \frac{S_{MA}}{\beta_{MA}} + \frac{S_{ZA}}{\beta_{ZA}} + \frac{S_{RA}}{\beta_{RA}} + \frac{S_{EA}}{\beta_{EA}} =$$

$$= \frac{0.3}{0.46} + \frac{0.43}{0.68} + \frac{0.23}{0.51} + \frac{1.22}{0.82} + \frac{1.27}{3.81} + \frac{0.35}{0.43} =$$

$$= 0.65 + 0.63 + 0.45 + 1.49 + 0.33 + 0.81 = 4.36$$

p_T=6.41
p_I=9.43
p_m=9.77
p_Z=4.33
p_R=9.4
p_E=6.1

Using the formula (10) expressed by p:

$$c_i = \frac{1}{1+p}, \tag{13}$$

the following percentage of each mineral has been obtained:

Almandine	$C_A = \frac{1}{1+p_A} = \frac{1}{1+4.36} = 18.7\%$
Tremolite	$c_T=13.5\%$
Ilmenite	$c_I=9.6\%$
Magnetite	$c_M=9.3\%$
Zircon	$c_Z=18.8\%$
Rutile	$c_R=9.6\%$
Epidote	$c_E=14.1\%$
Total sum	**93.6%**

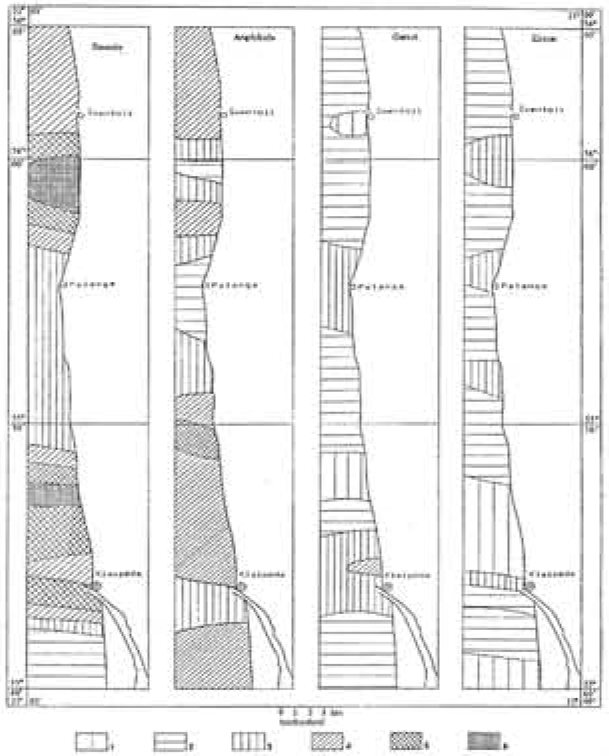

Fig. 2. Distribution of heavy minerals: ilmenite, amphibole, garnet, and zircon (weight per cent) in sediments of Lithuanian near-shore zone (fraction 0.25-0.1 mm): 1 - 5-10%, 2 - 10-15%, 3 - 15-20%, 4 - 20-25%, 5 - 25-30%, 6 - 30-35%

The allowed error of results is from 2 to 10% (Zevin & Zav'yalova 1974). The obtained results satisfy the requirements and the calculated β_{ri} be used for XRD analysis of samples containing the same association of minerals.

RESULTS

Fourteen samples of heavy fraction (0.25-0.1 mm) derived from bottom sediments (sand and silty sand) of the Lithuanian near-shore zone of the Baltic Sea stretching from the Lithuanian State frontier with Latvia in the north to the city of Klaipėda in the south have been analysed by XRD method worked out by the authors of this paper. The analysed samples have been collected during field expeditions by r/v "Vėjas" financed by the Geological Survey of Lithuania.

The results of analysis show that the content of ilmenite is most changeable (ranges from 10.8 to 32.0%). The least its content is found near the coastal zone of Kuršių Nerija and the most concentration is observed with the segment of, approximately, 10 km of length from the Klaipėda sea channel northwards, as well as between the towns of Palanga and Šventoji (Fig. 2), the sediments relatively are finer.

The minerals of amphibole group in most cases are distributed on the contrary to ilmenite (Fig. 2). The content of amphiboles ranges from 13.2 to 26.4%. the least their content is near the town of Palanga, near the Klaipėda sea channel and between Palanga and Šventoji. The most content is observed between Klaipėda and Šventoji. Its average content is about 15-20%.

The minerals of garnet group (almandine) make 10-15% of heavy fraction on most part of studied area. The increase of their content to 20.7% is observed only near Klaipėda, and decrease to less than 10% - northwards from Klaipėda and near Šventoji (Fig. 2).

The content of zircon makes 6.6-16.8% of heavy fraction. This mineral is confined to the coarse - sandy - fraction, but its distribution is rather monotonous (Fig. 2). The most its content is found near the Klaipėda sea channel and on some little areas between Klaipėda and Šventoji.

The other 3 minerals: magnetite, rutile and epidote are found too, but their content is rather small, seldom it exceeds 5%. Thus, they are not shown in the map.

CONCLUSIONS

The XRD method of analysis is more objective than by means of polarising microscope because does not depend on skill of analysed.

Distribution of heavy minerals in bottom sediments mostly depends on their grain size. Minerals of amphibole and garnet groups are related to coarse sediments (sand) and ilmenite and magnetite - to fine sediments. Zircon is indifferent to grain size and is deposited near its source area. Most concentrations of epidote and rutile are confined to fine sand of shallow zone. The obtained results of XRD analysis of heavy minerals in the Lithuanian near-shore zone of the Baltic Sea and their distribution correspond to different zones of lithological composition of bottom sediments which are known from previous works of marine lithologists.

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Sedimentary Matter Fluxes between the Curonian Lagoon and the Baltic Sea

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The intensity of sedimentary matter fluxes and their grain-size composition in the Klaipėda Strait are discussed. According to 1994-1997 data the most intensive sedimentary matter fluxes were in action during fall or spring in the port gate area and western passage of the Curonian Lagoon (Kuršių Marios). The grain-size composition of sedimentary matter flux depends on their intensity. Grain-size are changing from fine silty mud up to fine sand.

Keywords: Klaipėda Strait, sediment flux, grain-size, year seasons.

INTRODUCTION

Solving the problem of sedimentary matter circulation between the Baltic Sea and the Curonian Lagoon (Kuršių Marios) from the sedimentological point of view the Klaipėda Strait is particularly important. It is the only way by which the fluxes of water and sedimentary matter from Nemunas and Curonian Lagoon get into the Baltic Sea. In order to improve our knowledge about the mechanism of the circulation we completed the following tasks: (1) evaluation of spatial and temporal changes in intensity of sediment fluxes in the Klaipėda Strait, (2) determination of composition of transported material and features of its changes.

The Klaipėda Strait is 12 km long. Its width near the port gates is 385 m, whereas in the southern part - where it joins the Curonian Lagoon - it reaches almost 1500 m. The water outflow from the lagoon into the Baltic Sea is 26.5 km³/year, the volume of reverse flow is about 5.1 km³. According to the averaged long-term data the ratio between these two water flows makes slightly over 5. The ratio of sedimentary matter is likely to be similar. Due to abrupt and strong changes of hydrometeorological situations in the strait the essential changes in current velocities and directions occur (Gailiušis et al. 1992). This results in permanently changing migration of sedimentary matter too. Besides, the sediment fluxes are strongly affected by human activity in the Klaipėda harbour.

METHODS AND MATERIALS

The exchange of sedimentary matter between the Curonian Lagoon and the Baltic Sea was repeatedly evaluated and its balance calculated on the basis of determination of suspension concentrations by the method of filtration (Pustelnikov 1983, Galkus 1995, etc.). Beginning with 1994 we used sediment traps for investigations of sedimentary matter fluxes. They are made of plastic tube. Their diameter is 14 cm, height - 1.2 m, collecting area - 154 cm².

The sediment traps were installed 3 m above the bottom in 9 sites of the strait (Fig. 1). The exposition time differed usually lasting for a few days. Such measurements were carried out 4 times per year at different seasons. From some to some hundred grams of sedimentary matter was collected in this way. The intensity of sedimentary matter flux (g/cm²/day) and grain-size composition of sediments were determined. The same methods as for bottom sediments have been applied.

INTENSITY OF FLUXES

The seasonal intensity of sediment fluxes in the Klaipėda Strait is rather variable (Fig. 2). The year 1994 stood out among others for very intensive fluxes in the port gate aquatory, central part of the strait and, particularly, western passage of the Curonian Lagoon (G-7). The intensive transport of sedimentary matter from the Curonian Lagoon caused the increased quantity of sediments throughout the strait with the exception of its isolated inlets (G-9). The high intensity of sediment transport in the port gate aquatory, undoubtedly, was also determined by marine sediments, because water dynamics was active not only in the strait but in the sea nearshore, as well as a result of stormy conditions. During later observations no sediment fluxes of such intensity were recorded any more. Intensive sediment fluxes in the port gate aquatory were recorded in the winter and spring of 1995, the fall of 1997, whereas in other seasons the intensity usually would not exceed 1000 g/cm²/day (see Fig. 2).

A rather variable intensity of sediment fluxes in different seasons was observed also in the western passage of the Curonian Lagoon. It is less variable in the central part of the strait (G-3, G-4) and eastern passage, with a minimum flux registered in the Malkų Bay (G-9) (see Fig. 2). The Malkų Bay is rather well isolated. Its hydrodynamical environment is relatively calm, whereas the supplies of sedimentary matter are rather limited. For this reason the intensity of sediment fluxes in all seasons is very low. An appreciable intensification of fluxes was observed in the spring and summer of 1995. However, the causes were rather evident - intensive dredging works were carried out in the strait. For the same reasons the quantity of sedimentary matter was increased also in some other places of port fair-

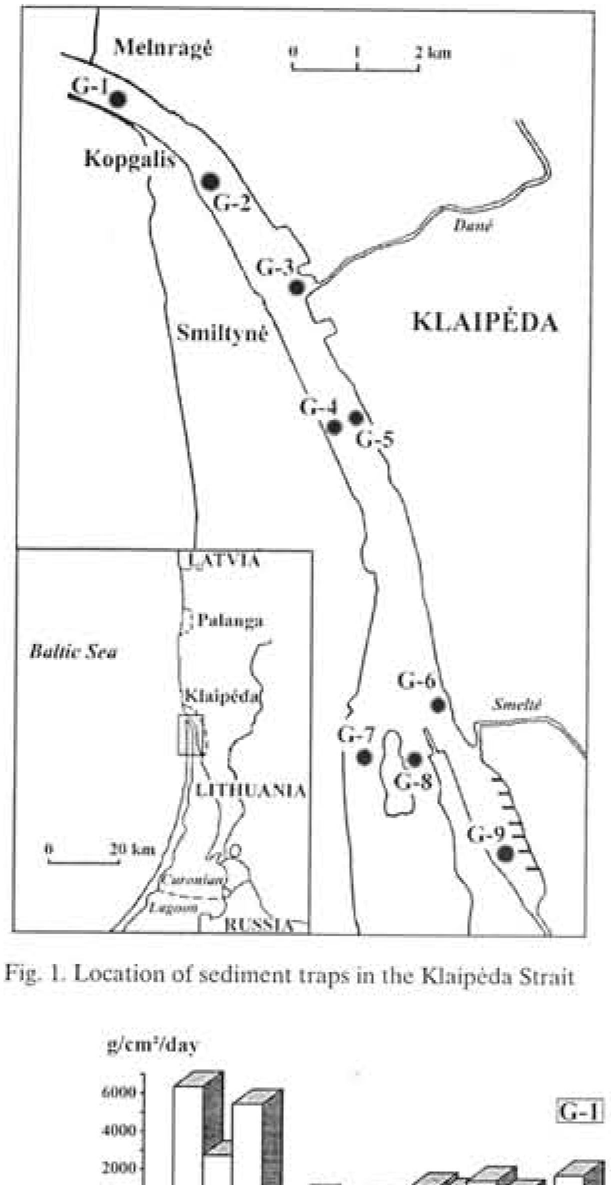

Fig. 1. Location of sediment traps in the Klaipėda Strait

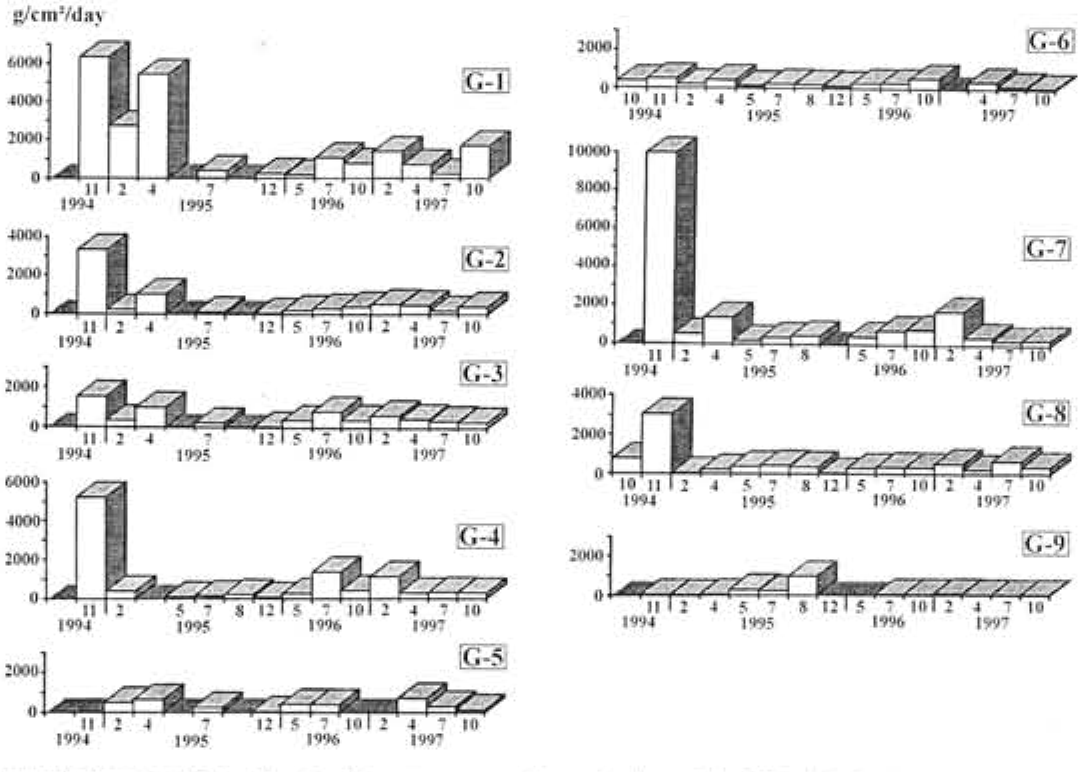

Fig. 2. Seasonal changes of intensity of sedimentary matter fluxes in sites of the Klaipėda Strait (from G-1 up to G-9). Numbers below the histograms indicate months and years of measurements

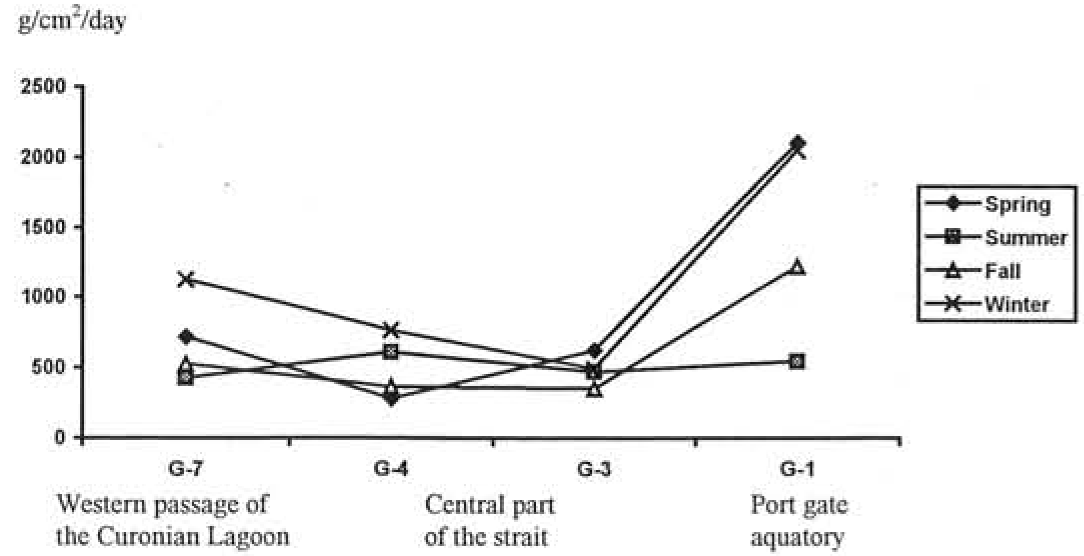

Fig. 3. Seasonal changes of average values of sediment fluxes intensity alongside the Klaipėda Strait

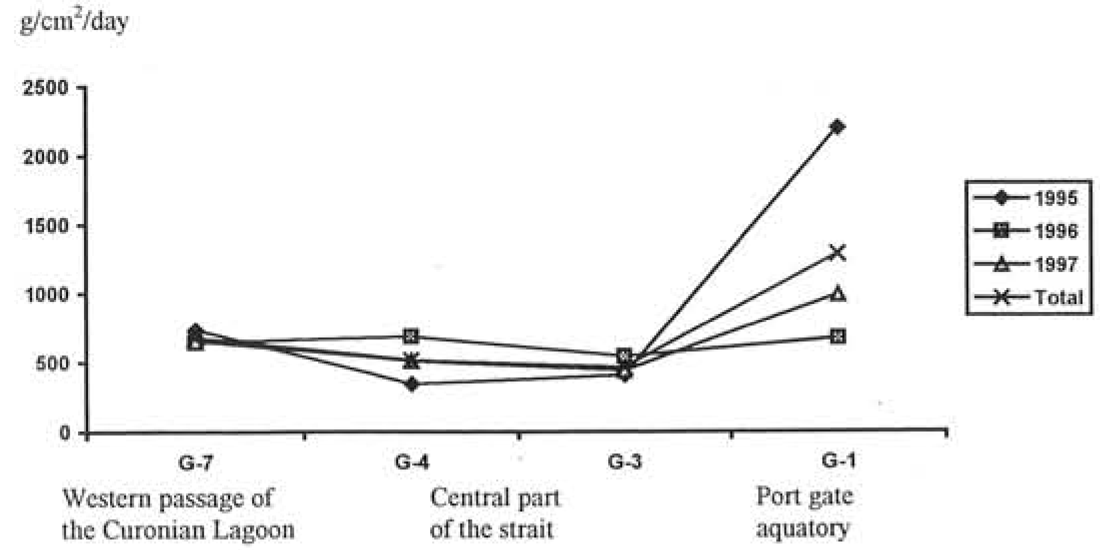

Fig. 4. Averaged data of sediment fluxes intensity in 1995-1997 alongside the Klaipėda Strait

way (G-3 and G-4). In the close vicinities of harbour embankments (G-5, G-6) sedimentary matter fluxes are rather low, like in Malkų Bay.

So, judging by the data obtained a more intensive sediment transport takes place in the western passage and port fairway (see Fig. 2). The comparison of average values of sediment flux intensity in different seasons of 1995-1997 revealed a distinct tendency of their decrease moving from the Curonian Lagoon passage (G-7) towards the central part of the strait. In the port gate aquatory the intensity again distinctly increases (Fig. 3).This tendency is reflected by the averaged data of three years (Fig. 4). This is related with accumulation of part of material on the way of transport. Reaching port gate aquatory the sediment transport intensifies as a result of marine sedimentary matter carried by sea waves and currents.

In the larger part of the year the sediment fluxes are directed from the Klaipėda Strait towards the sea in correspondence with the general hydrological situation of the environment. However, under the changing hydrometeorological conditions the water mass and sedimentary matter transport may also change. Such changes take place many times per year and create situations for rapid accumulation of sedimentary matter. The more intensive the fluxes the higher, evidently, the rates of sedimentation in the strait.

GRAIN SIZE COMPOSITION

Sediment fluxes comprise variable clastic material which includes the types of sediments from fine silty mud (Md = 0.01-0.05 mm) to fine sand (Md = 0.1-0.25 mm). The most coarse material represented by coarse silt (Md = 0.05-0.1 mm) and fine sand occurs in the port gate aquatory more often. In the grain-size spectrum of sediments one or two fractions stand out clearly, whereas the contents of other fractions are usually negligible. The maximum Md reaches 0.14 mm, the sorting is very good. Such composition corresponds to the marine yellowish-grey fine sands which accumulate in the mentioned area. Therefore, large part of sediments, without doubt, is carried by marine currents.

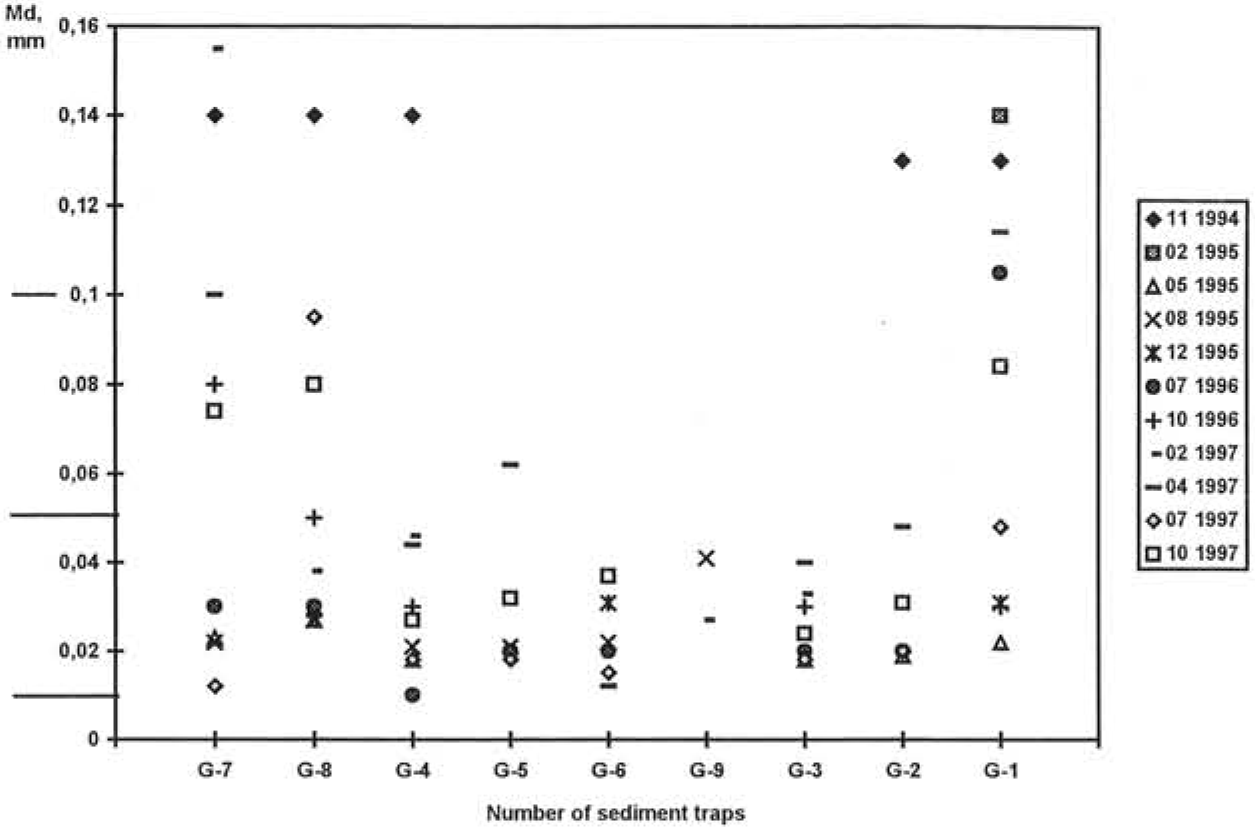

Fig. 5. Median diameter (Md) of sedimentary matter at different time of the year (1994-1997 data) in the Klaipėda Strait sites

The sedimentary matter transported in the Curonian Lagoon passages has wider spectrum of grain-size types - in the western passage in summer fine silty mud is transported, in other seasons - silt and sand; in the eastern passage, where the intensity of fluxes is lower, sand was transported only in fall, whereas in other seasons - only fine silty mud and silt (Fig. 5).

Fine silty mud prevail in the main part of the strait (sites from G-2 to G-5). Some coarser transported sedimentary matter is observed in spring (G-5), whereas sand has been met during fall (G-2 and G-4).

Most stable grain-size composition of sediments in different seasons is observed in the eastern part of the strait and closed aquatories (G-6, G-9), where fine silty mud prevails (Fig. 5). Its grain-size almost does not respond to the changes of hydrodynamic regime in the strait and depends only on the source of sedimentary matter. In one case (G-6) the main source of sedimentary matter is represented by the waste water outlet, in another (G-9) - it is the local bay (including its bottom) material.

The available data makes it possible to assert that changes of grain-size composition in different areas of the strait reflect the changes in intensity of fluxes. The content of coarser fractions in the transported sedimentary matter increases when the sediment fluxes become more intensive, whereas in weak fluxes fine silt and clay fractions prevail. This is proved by changes of Md of transported material during different seasons (Fig. 5).

CONCLUSIONS

The most intensive fluxes of sedimentary matter develop in the western passage of the Curonian Lagoon and port gate aquatory. The intensity of sediment transport is seasonally changeable, the most changes occur in fall and, sometimes, spring.

The accumulation of sedimentary matter in the Klaipėda Strait is closely related to the frequency of changes in hydrological situation, resulting in alterations of water flow directions. Under the conditions of abrupt decrease in water flow velocity there occurs mass accumulation of transported material in local bottom areas. This phenomenon takes place in all seasons and such processes increase the rates of port filling up.

The grain-size composition of transported sediments ranges from fine silty mud to fine sand. The changes of grain-size are determined by the intensity of fluxes - the higher the intensity of fluxes the larger the content of transported coarse-grained fractions; the lower the intensity - the relatively higher the content of thin-dispersed particles.

ACKNOWLEDGEMENTS

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The Ancient Shorelines of the Latvian Coast and Their Dynamics

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The shore formations and topography forms in the area of the Latvian Coast are described and basic conditions of their origin are characterized. The formations of the Baltic Ice Lake Stages are observed in more detail. This belongs to the shorelines of $B\ gl_{I}$, $B\ gl_{II}$ and $B\ gl_{IIIa}$, $B\ gl_{IIIb}$, $B\ gl_{IIIc}$ Stages. The outlines over major area of these basins have uneven contours along of which abrasion and accumulative shore formations take place. The along shore drift is of a local character, and important role in the formation of shorelines is played by transverse littoral drift. The shorelines of the Ancylus Lake and the Litorina Sea stages from known Holocene stages of the Baltic Sea occur at the surface of the Latvian Coast only. The shore formations of the Litorina stages are represented by typical large lagoons and beach barriers with dune swells. The along shore drift stretching from the Sambian Peninsula to the region of the head of the Gulf of Rīga was of dominant significance for shoreline formation during the Litorina Sea stages.

Keywords: shore formations, abrasion scarps, ledges, accumulative terraces, bars, spits, beach barriers, dune ridges, lagoons, bays, prominences, shorelines, Latvian Coast, Baltic Sea.

INTRODUCTION

The Latvian Coast is characterized by wide spreading of various shore formations connected with different stages of the Baltic Sea, such as the Late and the Post Glacial time (Fig. 1.). A systematical study of the Coast was begun by Grīnbergs (1957), and afterwards it was carefully studied by other Latvian researchers also. The investigations of the Coast are proceeding further now. The types of shore forms and the conditions of their origin have been ascertained.

REGIONAL DISTRIBUTION OF THE SHORE LINES

Shorelines of different stages of the Baltic Sea have been traced by Grīnbergs (1957), first of all.

Shore formations of the Litorina Stages are situated nearest to the modern sea outline. They are represented mainly by sandy sediments of beach barriers, spits, accumulative terraces and lagoon sediments, as well as the dune ridges and massifs. Large lagoons, in the lowest parts of which occur the relict lakes, characterize the shore zone of these stages. The shore formations and relief forms of the Litorina stages are wide spread in the area of the Coast in Latvia. They are absent in the middle area of the Eastern Coast of the Gulf of Rīga and in small area of the Coast of the Baltic Sea (region Pāvilosta) only.

The older shore formations - of the Ancylus Lake Stage - are known at the surface of the northern part of the Kurzeme Peninsula only, and they are represented by aggradation terraces, dune swells, abrasion scarps, etc.

The oldest shorelines of the Baltic Sea in the Coast of Latvia are represented by formations of the Baltic Ice Lake stages. They are most widely spread and constitute the border between the Coast and the area, where glacial forms of relief occur.

SHORE FORMATIONS OF THE BALTIC ICE LAKE STAGES

The five shorelines of the Baltic Ice Lake ($B\ gl_{I}$, $B\ gl_{II}$, $B\ gl_{IIIa}$, $B\ gl_{IIIb}$, $B\ gl_{IIIc}$) are observed in the area of the Latvian Coast. The shoreline altitudes range from 5 to 55 m and the southeastward inclination (Grīnbergs 1957) and are represented by abrasion scarps, bars,

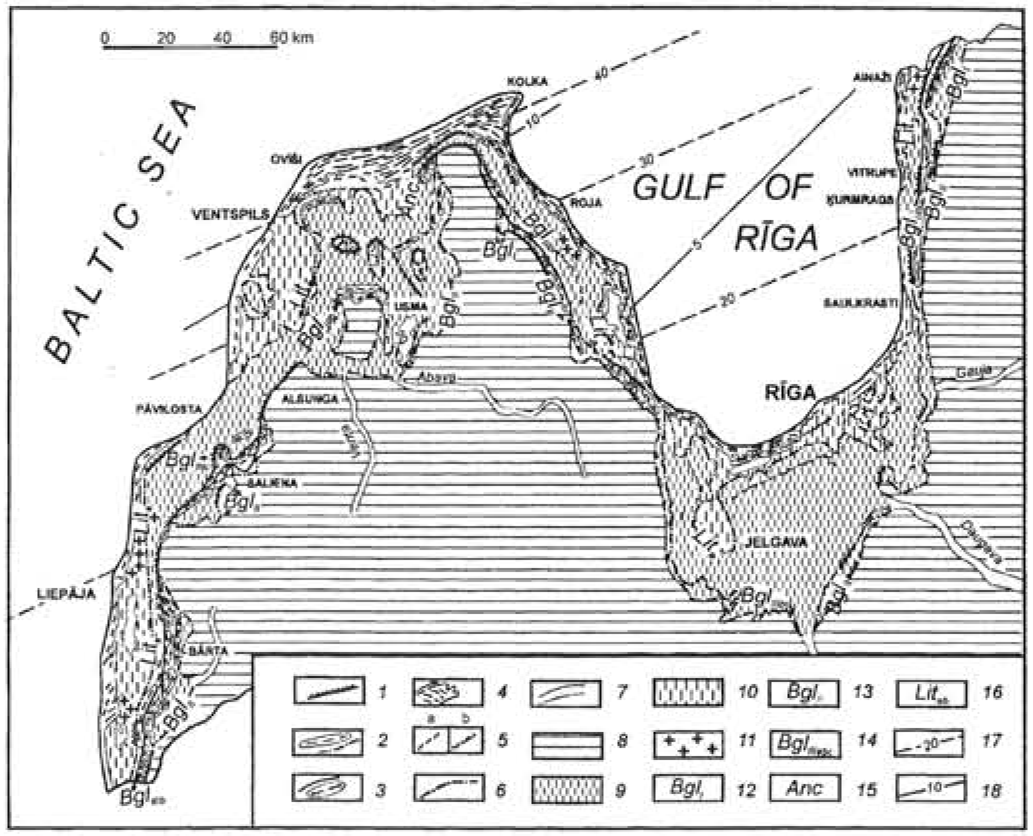

Fig. 1. Geomorphological map of the coast of Latvia. 1 - abrasion scarps and cliffs, 2 - bars, 3 - aggradation terraces, 4 - spits, 5 a - dune barriers, 5 b - shore represented by steep slopes of hilly glacial topography with no marked traces of the wave activity, 6 - faintly defined shore, 7 - valleys of the largest rivers with terraces in the lower courses correlated with old shorelines of the Baltic Sea, 8 - area of distribution of glacial formations, 9 - abrasion-accumulation plain of the Baltic Ice Lake, 10 - accumulation plains of the Ancylus Lake and the Litorina Sea, 11 - concentration of boulders on the coast, 12-14 - indexes of the Baltic Ice Lake shorelines, 15 - index of the Ancylus Lake shoreline, 16 - index of the Litorina Sea shorelines, 17 - isobases of the B gl$_{IIIb}$ basin shoreline, 18 - isobases of the Lit$_{a}$ basin shoreline

spits, shore dunes, etc. The shores of B gl$_{II}$ and B gl$_{IIIb}$ occur in all places, but the others are of fragmentary occurrence only. The transgression stages of the Baltic Ice Lake are marked by shorelines of B gl$_{I}$ and B gl$_{II}$ stages. Amplitudes of changes in levels of these basins in the region of Labrags reached 29 m (for the basin B gl$_{I}$) and 26 m (for the basin B gl$_{II}$) (Veinbergs 1986). Amplitude of the transgression B gl$_{II}$ in the region Grobiņa reached 19 m (Grīnbergs 1957). The shorelines of B gl$_{III a}$, B gl$_{III b}$ and B gl$_{III c}$ phases were formed and connected with the momentary rising in level of the general regressing basin of B gl$_{III}$ Stage.

The Baltic Ice Lake is characterized by numerous shallow large bays and a prominence in the common shore contour. The Bays - Usma, Saliene, Bārta, etc. were formed in the places of previous glaciodepressions (ice lobes) and Late Glacial ice-dammed basins.

A larger Usma Bay of the Baltic Ice Lake appeared in the place of previous Venta-Usma Ice Lobe and the Late Glacial ice-dammed Venta-Usma Basin. The varved clay of ice-dammed basin spread in the region of Usma, but the sandy deposits there are known in a lager part inside general area of this basin.

Shore laid sandy sediments (thickness to some m) in the Usma Bay of the Baltic Ice Lake were originated in the result of wash up again as the deposits of previous ice-dammed basin and as well as the till. The ancient Venta and Abava rivers were flowed into the Usma Bay and had been characterized by the considerable accumulation of alluvial material in their valleys at the time of primary stages of the Baltic Ice Lake. The entrance of the alluvial material in the bay in great quantity took place during of the regressive B gl$_{III}$ Stage only. The largest thickness of river-bedded alluvial deposits is observed at the VII terrace of the Abava River. This terrace is attended with the shoreline of B gl$_{I}$ Stage in the Usma Bay. The younger VI terrace is attended with the shoreline of B gl$_{II}$ Stage and is distinguished by the thickness of the alluvium deposits to 7 m only. The alluvium deposits of this terrace has the structure of constrative type (Lamakin 1948). The terraces V, IV, III of the Abava River valley are connected with shores of B gl$_{IIIa}$, B gl$_{IIIb}$, B gl$_{IIIc}$ and are characterized by less thickness of the alluvium deposits than at the terrace VI.

The Venta River mouth during the time of the Baltic Ice Lake was located near Kuldīga. The terrace VI of the Venta River is distinguished by larger thickness of the river bedded alluvium and correspond to the shore line of B gl$_{II}$, when the transgression of the Baltic Ice Lake took place. The terraces V and IV conform to shorelines of B gl$_{IIIa}$ + B gl$_{IIIb}$ and B gl$_{IIIc}$.

The islands, such as Pope, Puze, Āmele and Ugāle had been situated inside area of the Usma Bay and had been exposed by intensive abrasion. The north-western, northern and north-eastern parts of the Pope Island were experienced by most intensive abrasion starting with B gl$_{I}$ Stage. The sand-gravel deposits had been originated in the result of abrasion in these area and the large spit in the south-western part of island was formed. The accumulation and abrasion took place here during following stages of the Baltic Ice Lake too.

The shore formations in the southern and south-eastern parts of the Usma Bay are marked not clear in relief.

Large shore accumulation forms occur in north-eastern area of the Usma Bay near the western end of the high scarp Zilie Kalni. They are represented by spits, bars and etc. The Zilie Kalni scarp was being washed out during all stages of the Baltic Ice Lake. Here the shore accumulation of sediments during B gl$_{I}$ Stage did not take place. All material had been replaced down the submerged slope. The bar was formed during B gl$_{II}$ Stage, but the spits near Nivēja - at the time of B gl$_{IIIa}$ and B gl$_{IIIb}$. Along shore displacement of the sediments from Zilie Kalni to west and south directions took place at these times.

The Saliene Bay originated in the place of previous of the Apriķi Ice Lobe and Late Glacial ice-dammed Apriķi Basin. The deposits of this basin are represented by clay. The entering drifts to the Saliene Bay from land not happened. The sediments of the Bay formed in the result of wash out of the Last Glaciation till only. The origin of the shore formations connected as with along shore and as well as with transversal to shore transportation of the sediments. The transversal to shore transportation of the sediments was dominated. Small spits occur in the north-eastern and south-western parts of the Bay, which are stretched from the Alsunga-Kāpasciems and Grobiņa-Vērgale abrasion prominences of the shore. The shore of B gl$_{II}$ Stage is represented by separate abrasion scarps observed in the top of Bay (NW and SW from Saliene). The shorelines of regressive B gl$_{III}$ Stage are marked by small accumulative sandy terraces and dune swells.

The Bārta Bay occurred in the place of previous relative small the Bārta Ice Lobe and the Late Glacial ice-dammed Upper-Bārta Basin. The sandy sediments transporting by rivers of glacial melting waters had been deposited in this ice-dammed basin. The part of sandy sediments was transported to the bay by the Bārta River also. The II, III, IV terraces of the Bārta River are connected with shore lines of B gl$_{II}$, B gl$_{IIIb}$ and B gl$_{IIIc}$.

The transverse littoral drift took place in all the contours of the Bārta Bay during B gl$_{II}$ Stage and because at that time the sandy gravel bars and accumulative terraces there were formed. The along shore transportation of the drift took place during of B gl$_{IIIa}$ Stage. The Grobiņa spit was formed in the northern area of the Bārta Bay. The three large spits supplying oneself by clastic material from abrasion the Rucava prominence of shore were originated in the southern part of the Bay. The eolian accumulation had been typical for shoreline during B gl$_{IIIc}$.

The shorelines of the Baltic Ice Lake in the area of the Kurzeme Coast of the Gulf of Rīga are distinguished by the relative rectilinear and smoothed outline and represented by abrasion scarps, bars and accumulative terraces. A small bay had been formed in the region of Tiņģere during B gl$_{I}$ and B gl$_{II}$ stages only. The shallow bay was situated near Dursupe at the time of B gl$_{II}$ Stage too. The small spits are observed in this section.

The transversal transportation drift took place in the area of the Vidzeme Coast of the Gulf of Rīga at the time of the Baltic Ice Lake. The shorelines in this area are characterized by the most straightened contours and are represented by series of large bars and accumulative terraces also.

A large shallow Elgava Bay of the Baltic Ice Lake had been developed in the area to southern of the recent head of the Gulf of Rīga. There are the sandy deposits of this basin, which lies above varved clay of the ice-dammed basin. The shores of the Elgava Bay are marked not clear in topography. They are observed in some sections only and are represented by not high ledges (Salaspils, Smārde-Mežamuiža, Zālīte) and small accumulation terraces and dune swells (Pabaži). The shore forms are known in the area of the Elgava Bay and they belong to B gl$_{II}$, B gl$_{IIIb}$ and B gl$_{IIIc}$ stages of the Baltic Ice Lake.

HOLOCENE SHORELINES OF THE BALTIC SEA

Holocene formations and forms of topography connected with the shorelines of the Ancylus Lake (Anc) and Litorina Sea (Lit$_{a}$, Lit$_{b}$) Stages of the Baltic Sea. The shore formations of the Yoldia Sea had been appeared in finish of the Baltic Ice Lake regression and are known at the submerged slope of the Latvian Coast (Grīnbergs 1957) and studied very a little until. The abrasion ledges and the spit of the Yoldia Sea Stage are located on the Klaipéda Plateau and have the altitudes above -50 m (Bergman & Timofeyev 1972, Raukas 1994, Bjerkéus et al. 1994).

The shore forms of the Ancylus Lake occur in the northern part of the Kurzeme Peninsula. Their altitudes range from 12 to 17 m a. s. l. The shoreline of this basin is characterized by meandering outline. The separate bays and shore prominences are observed in the contours of shore. The shorelines abrasion Irbes-Krauja prominence is situated near Slītere. The shallow small bays existed to south-western from this prominence in the region of the Irbe River. The relatively large bay had been located in the region to southern from Lake Būšnieku Lake around Ventspils also. Here is observed a large Ventspils lagoon that was developed from Yoldia to Litorina time (Grīnbergs 1957, Jinoridze et al. 1967).The shores in this part of the Ancylus Lake basin are not clearly marked in topography. They sometimes are represented by separate not high ledges and small accumulation terraces.

The Ancylus Lake shore formations in the area of north-western Coast of the Gulf of Rīga are traced by high dune swell, which are stretched south-eastwards from the Irbes-Krauja region to Roja.

The shore zone of the Litorina Sea in the western Coast of the Kurzeme in general plan is characterized by occurrences of large lagoons - such as Nida, Pape, Liepāja and Ventspils, as well as the abrasion Pāvilosta-Jūrkalne section and by the large accumulation prominence in the top of the Kurzeme Peninsula also. The numeral beach barriers and dune ridges separating the lagoons from sea are the typical shore forms. The resent relict lakes (Pape, Liepāja, Būšnieku) preserved in the area of these palaeolagoons. The lagoon shore formations in the Western Coast of the Kurzeme are not clearly marked in topography. Usually they are represented by small breaks at the recent surface. Not high ledges are observed in Pape and Ventspils lagoons and the accumulation terraces in Ventspils Lagoon only.

The accumulation prominence observed in the top of the Kurzeme Peninsula is about 60 km a long and 10-12 km a wide. It is the unique formation of series shore forms. The accumulation terraces of different levels with the shore swells and dune swells at their surface wide spread inside area of this accumulation prominence. The origin of the accumulation prominence took place at the time of Lit_b and Lit_a stages (Veinbergs 1979).

The formation of beach barriers, which, as mentioned above, are typical for the Litorina Sea stages was closely connected with the East-Baltic along shore drift (Knaps 1966). This along shore drift starting from Sambian Peninsula and stretching to the top of Kurzeme Peninsula and further had been distributed along western shore of the Gulf of Rīga to the region at the head of the Gulf of Rīga (Lit_a), but it had been distributed to the Kolka Cape at the time of Lit_b only. A common meridian-orientated large beach barrier is stretching along the lagoons of Nida, Pape and Liepāja. The large beach barrier was formed in the area of the section from Pāvilosta to Ventspils also.

Typical characteristic features of shore formations for the time of the Litorina stages are observed in the Western and Southern coasts of the Gulf of Rīga also. Large lagoons with relict lakes, such as Engure, Kaņieru, Babīte, etc., beach barriers, swells and dune ridges are important in the structure of the Litorina shore zone as in the Kurzeme Coast of the Gulf of Rīga, as well as at the head of the Gulf of Rīga. Here the lagoons occupied a large part of the coast area. The shore swells and dune swells occur at the surface of beach barriers and their heights are gradually lowering westward to the sea , hence, their formations con be considered to be connected with slow lowering of the sea level (Ulst 1957, 1961).

Two along shore drifts existed in the Eastern Coast of the Gulf of Rīga during Litorina Stages. One of them had been stretched from Tūja to the head of the Gulf of Rīga and another - from Tūja to the Pärnu Bay. These streams with transversal transportation of drift together formed shore accumulative terraces with shore swells and dunes at their surface. The shore formations of the Litorina stages in the Eastern Coast of the Gulf of Rīga occur in the southern and northern parts only. In the southern part of the Eastern Coast they continue the formations, which are known in the Coast of the head of the Gulf of Rīga, and are represented by accumulative terraces, bars and dune barriers. The accumulative terraces with swells at their surface occur in the northern part of the Eastern Coast of the Gulf of Rīga in the section from Ainaži to Vītrupe.

CONCLUSION

The combination of various formations is characteristic feature for each shoreline of the Latvian Coast.

With respect to the feature of the Baltic Ice Lake there was no general along shore drift, but only separate local along shore drifts had been developed. The transversal shore transportation of sediments had been dominating during the time of the Baltic Ice Lake. Therefore large spits and beach barriers are absent and, basically, bars and accumulative terraces spread among accumulative forms. The bays and prominences took place in the shore contours.

Probably the meandering shore contours could be at the Yoldia Sea and the Ancylus Lake time also.

Widely distributed shore formations of the Litorina Sea distinguish the shore zone in the area of the Coast by numeral occurrences of large lagoons and large accumulative forms, such as beach barriers with dune swells and large accumulative terraces with shore and dune swells. The formation of the Litorina Sea shores in the Western Kurzeme Coast and partly in the Eastern Kurzeme, as well as in the head of the Gulf of Rīga Coast was closely connected with regional Eastern Baltic along shore drift, but in the Eastern Coast of the Gulf of Rīga influence of this regional drift not took place. Here the transversal shore transportation of sediments had been dominated and besides that local two along shore drifts had been existed too.

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