POLISH GEOLOGICAL INSTITUTE
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ABSTRACT VOLUME & FIELD TRIP GUIDEBOOK

THE 13TH COLLOQUIUM ON BALTIC SEA MARINE GEOLOGY

September 12–16, 2016
Gdańsk, Poland

GDAŃSK BALTIC 2016

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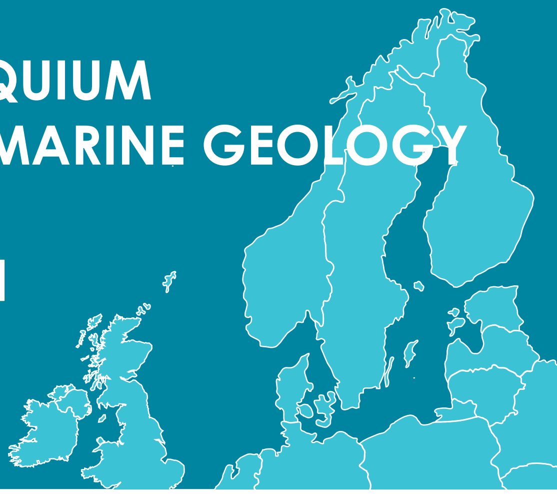

Baltic 2016

ABSTRACT VOLUME

ORAL presentations

SESSION 1

TECTONICAL FRAMEWORK AND PRE-QUATERNARY GEOLOGY OF THE BALTIC SEA

BASE QUATERNARY MAPPING AND SHALLOW FAULTS WITHIN THE SOUTH-WESTERN BALTIC SEA

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A systematic mapping of the Base Quaternary and shallow faults in the Northeast German Basin and the transition zone to the Baltic shield has not been carried out yet. The compilation of a large (*ca* 20 000 km), high-resolution, multi-channel seismic and hydroacoustic data set collected between the Bay of Kiel and the Tornquist Zone by the Universities of Aarhus and Hamburg since the late 1990s provides the unique chance to close that gap. The data were uploaded to the IHS "KINGDOM" interpretation system for depositional and structural interpretation. We primarily identified the Base Quaternary and seafloor horizons in all seismic sections. The joint interpretation of identified shallow fault systems within the Quaternary strata with deep-rooted (basement) faults published in a large number of studies will give a first idea about the driving forces, *e.g.*, plate tectonics, salt tectonics or ice-load induced tectonics. Several observations strongly suggest that fault evolution continued during the Pleistocene until today; (i) marine reflection seismic data reveal several faults that cut the unconsolidated Quaternary deposits; (ii) growth strata and divergent reflections within the Holocene deposits above the Quaternary faults as imaged by the parametric echosounder data imply recent tectonics; (ii) marine reflection seismic data clearly show that some of these faults even pierce the seafloor. A time-structure map to the Base Quaternary horizon is used to identify the location and trend of different fault systems that cut the Quaternary strata. This map demonstrates that most of the faults are trending NW–SE and other faults NE–SW and NNE–SSW. Hence, we observe a spatial correlation between the Quaternary faults (this study) and basement fault systems (literature). We explain the origin and evolution of the Quaternary faults due to the post glacial isostatic adjustment since the Last Glacial Maximum. The load of the inland glaciers pressed the lithosphere which, after the ice retreat, was unloaded and expanded over several thousand years, attaining an isostatic equilibrium. The decay of the past glaciation might have reactivated basement fault systems related to major tectonic elements in the region. Later, the recent faults were enhanced by sediments and water loads.

BALTIC SECTOR OF THE TRANS-EUROPEAN SUTURE ZONE REVISITED – FIRST RESULTS FROM THE "BALTEC" EXPEDITION (MARCH 2016)

Christian Hübscher[1], Volkmar Damm[2], Martin Engels[2], Christopher Juhlin[3], Charlotte Krawczyk[4], Ida Bruun Lydersen[3], Michał Malinowski[5], Vera Noack[2], Michael Schnabel[2], Elisabeth Seidel[6], BalTec scientific party

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In the course of RV "MARIA" S. MERIAN expedition MSM52 (BalTec) in March 2016 we imaged the Paleozoic to recent tectonic and sedimentary evolution of the southern Baltic between the North-East German Basin across the Tornquist Fan and up to the Baltic Shield east of Gotland with a unique vertical resolution.

The equipment was provided by the Federal Institute for Geosciences and Natural Resources (BGR) and consisted of 8 GI-Guns (*ca* 70 Hz mean frequency) as the source array and a 216 channel digital seismic streamer of 2700 m active length. CMP distance is 6.25 m and the fold is 54. We acquired 62 profiles having a total length of 3500 km.

Past seismic experiments across the Trans-European Suture Zone primarily targeted deep crustal structures and the Moho, or they elucidated the Post-Permian strata only. With the BalTec data we close the gap between these data sets in terms of both seismic resolution and depth penetration. We strive for an in depth understanding of the interaction between plate-, salt-, neo- and ice load induced tectonics in the different tectonic regimes between the eastern Glückstadt Graben and the Baltic Shield. Furthermore, the data represent a valuable contribution to the emerging *Geopotentials of the German Baltic Sector* (GPDO) project. Long profiles across German, Danish, Polish and Swedish territorial waters bear the potential to link geological models spatially limited by international boundaries. Since the fault systems in the Baltic continue into the hinterland the neotectonic related studies may also influence the discussions of geothermic energy, hydrogeology or CO_2 storage.

The onboard data processing carried out by the BGR has already confirmed the high scientific value of the data. Due to the short initial offset of 37 meters between the seismic source array and the active section the data image without gap the sub-surface geology from the Paleozoic strata or basement up to the seafloor. In the Kiel and Mecklenburg bays the data confirm the causative correlation between salt pillow growth and Quaternary valley evolution. A west-east striking wide-angle reflection / refraction profile in the central Bay will help to model faults in the upper crust which are related to the Eastholstein Trough and the Eastholstein-Mecklenburg Block. The nature of the West Pomeranian fault system is imaged west and east of Rügen. Several profiles across the Sorgenfrei-Tornquist and Teisseyre-Tornquist-Zone and Rønne Block elucidate the Caledonian deformation and Cretaceous inversion tectonics. The entire crustal structure of the Teisseyre-Tornquist- Zone will be derived from the recordings of the wide-angle reflections and refractions from 15 ocean bottom seismometers (OBS). Post-glacial faulting of the Baltic Shield will be studied by the analysis of north-east to south-west striking reflection seismic profiles between Hanö Bay and Gotland. During the presentation we will show first imaging and interpretation results.

FROM OFFSHORE HYDROCARBON EXPLORATION TOWARDS A 3D STRUCTURAL MODEL OF THE GERMAN BALTIC SEA AREA

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Oil and gas exploration in north-eastern Germany started in the 1950s. Different Late Palaeozoic (Devonian to Permian) and Mesozoic source and reservoir rocks have been investigated by numerous wells and 2D seismic surveys until 1990. About 750 offshore reflection profiles, measured in the 1970s and 1980s by the organisation "Petrobaltic" (a joint venture of former East Germany, Poland and the Soviet Union; Rempel 1992) together with data of four offshore wells (G14, H2, H9 and K5) are used within a research project named USO ("Untergrundmodell Südliche Ostsee") between the Geological Survey of Mecklenburg-Western Pomerania (LUNG M-V) and the University of Greifswald to create a 3D structural model of the subsurface of the southern Baltic Sea area. Major lithostatigraphic units, tectonic faults, salt pillows, potential oil reservoirs and gas storage systems will be visualized to support politicians and decision makers in underground space management. The project area is divided into an eastern and a western part, modelled separately ("USO East"; Seidel et al. 2015 and "USO West"; Deutschmann et al. 2015).

The original seismic data were partly re-processed by the Federal Institute for Geosciences and Natural Resources (BGR) during the SASO project ("Strukturatlas Südliche Ostsee"; Schlüter et al. 1997) and by the Central European Petroleum Ltd. (CEP). Up to now 86 re-processed seismic profiles in an area west of Rügen Island with a whole length of about 1500 km and 150 profiles with a total length of about 3120 km north-east of Rügen and Usedom Islands were used. After picking of important marker horizons and faults by mean of the "SeisWare" software package the Pre-Cambrian basement surface and the top surfaces of the Permian, Triassic and Jurassic sequences were gridded using Kriging. The results were compared with existing distribution and time structure maps to obtain a revised structural pattern for the investigation area. Then, the gridded marker horizons as well as tectonic structures and triangulated faults could be visualized using the "SeisWare 3D – Visualizer" or transferred into GOCAD to create a first 3D model. In a next step, the time-based horizons will be transferred into depth-based layers. Furthermore, it is planned to correlate them with geological units and structures in the adjacent Danish, Polish and Swedish part of the southern Baltic Sea region.

In addition, deep-seated structures as Mesozoic faults zones or areas of different lithological composition of Pre-Quaternary sediments will be correlated with features of the near-surface geology, *e.g.* with orientation of Pleistocene channels or young faults within the Quaternary succession. Such data are available from high resolution multichannel seismic measurements obtained from scientific studies using research vessels (Al-Hseinat & Hübscher 2014) or from soil investigations for offshore wind farm projects (Obst et al. 2015).

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SUBMARINE CANYONS AND GRAVITY FLOW ON THE WESTERN SLOPE OF THE OKINAWA TROUGH

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Slumping and gravity flowing are the most important ways of transporting sediments from upper slope to basin and their implication to slope structure in passive or active continental margins has been discussed in many papers. Okinawa Trough is a tectonically active back-arc basin. Turbidity deposits have been revealed by piston core samples. However, few papers discussed acoustic characteristics on the slumping and gravity f1owing and their deposition impact on the west slope of the Okinawa Trough. About 8000 km of high-resolution multi-channel seismic profiles and more gravity cores were collected near year in the area. Analyses of these data have shown characteristics of slumping and gravity flowing and the deposition impact on the slope. The gradient of slope and sediment supply indicates that slumping and gravity flowing deposits are extensive on the west slope. But asymmetric development in the north, south and middle part of the western slope was affected by different factors, such as depositonal rates, tectonic movements, earthquakes, tsunami and so on. Lithological analysis on core samples showed that the main lithological components of gravity flowing deposits are sand and mud. The layers of the event deposits are very thin with high frequency of occurrences vertically. Slumps distribute mainly in a belt along the through near the fault zone on the upper slope. Gravity flowing deposits distribute mainly from the lower of the fault zone to the Okinawa Trough bottom. Four types of occurrence were recognized in seismic reflection patterns: 1) undulation reflection configuration indicating sediments creeping; 2) flat sheet reflection demonstrating turbidities plain; 3) irregular reflection denoting lentoid turbidities body; 4) hummock clinoform reflection showing debris flow deposits. Multi-channel seismic profiles showed that the upper slope had been eroded heavily. The location of slumps and type of gravity flowing deposits followed certain rules. Slumping often appears the top of slope and downward the slope is the sediments creeping or debris flowing deposits. Lentoid turbidities bodies are often on the foot area of the slope, and turbidity plain appears on the bottom of the trough. In general case, slumping and gravity flowing often happen simultaneously, but in this area, gravity flowing took place more frequently. In overall, the structure of the slope was the result of serial erosion-deposition.

This project was supported by the National Natural Science Foundation of China (41576066).

STRUCTURAL ANALYSES AND CHARACTERISATION OF THE ADLER-KAMIEN FAULT SYSTEM AS PART OF THE TORNQUIST ZONE

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Analyses of the structure and evolution of complex fault systems in the southern Baltic Sea is one of the major goals of the research project USO (Untergrundmodell Südliche Ostsee) of the University of Greifswald and the Geological Survey of Mecklenburg-Western Pomerania. The project area is subdivided into a western and an eastern part regarding its position to the island of Rügen.

Offshore 2D reflection seismic lines, measured by the former organization PETROBALTIC (1970–1980s) were reprocessed in part during the SASO project in the 1990s and more recently by the Central European Petroleum Ltd. (CEP). This reprocessed lines and additional lithological and geophysical data of on- and offshore wells (especially gamma ray and sonic logs, used for correlation with important seismic reflectors) are now the major data base for structural analyses.

Besides the modelling of seismic reflectors representing lithological (and stratigraphic) boundaries, major and minor faults in between the Tornquist Zone and the TransEuropean Suture Zone (TESZ), are analysed to characterise stress fields that initiated their formation and to evaluate their poly-phase evolution. Especially the software packages SeisWare™ and MOVE™ (Midland Valley) were used for this purpose.

The NW–SE trending Tornquist Zone is subdivided into the Sorgenfrei-Tornquist Zone (STZ) and the Tornquist-Teisseyre Zone (TTZ). The formation and reactivation of faults of the TTZ crossing the southern Baltic Sea are related to Permian and Mesozoic extensional or compressional movements. The main focus was on the prominent Adler-Kamien Fault System (AKFS), which borders the TTZ to the west. Restoration analyses suggest that subsidence during the Permian was triggered by thermal destabilisation, contemporaneous to the development of the Southern Permian Basin. Vertical displacements and differences in thickness of predominantly Mesozoic sediments along the AKFS prove a synsedimentary formation of the Gryfice Graben due to continued E–W extension during the Triassic. A NE–SW compression during the Late Cretaceous triggered the reactivation of existing faults and an inversion of tectonic structures like the Gryfice Graben as part of the Mid-Polish anticline.

REGIONAL SEISMIC INTERPRETATION OF THE STRUCTURE AND STRATIGRAPHY OF THE SWEDISH SECTOR OF THE BALTIC BASIN

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A very large exploration dataset collected between 1970 and 1990 by the Swedish oil prospecting company (OPAB) has recently been made available for academic use. Although this dataset was utilized and interpreted for exploration purposes, much of the dataset remains unpublished. In recent years it has been shown that by reprocessing these seismic data a significant improvement in the final stacked image can be achieved, when compared with the original processing. Therefore these data have good potential to improve the understanding of the structure of the Baltic Basin, most notably, in the deeper parts of the Basin.

Here, we present a series of interpreted regional marine seismic profiles, detailing the structure and stratigraphy of the Swedish sector of the Baltic Basin, as well as a number of interpreted regional profiles from the island of Gotland. On these seismic profiles it is possible to interpret a series of reflections which can be used to define the stratigraphy of the Palaeozoic sequence in the Baltic Basin. In the deeper part of the basin we observe a number of faults which we interpret to be transpressional and Caledonian in age. We also observe some small scale faulting beneath the Island of Gotland. We present a series of seismic sections and structure maps which describe a region to the east of the Hanö Bay Basin, referred to here as the Outer Hanö Bay area. This area was significantly affected by transtensional faulting during the Late Carboniferous / Early Permian and was subsequently inverted during the Late Cretaceous. It is possible to map the location of carbonate mounds within the Ordovician using these seismic data. Based on the locations of these mounds we interpret areas with a deep shelf and shallow shelf depositional environment during the Ordovician. These mound structures act as hydrocarbon traps, from which small amounts of oil have been extracted in the past.

Part of this work contributes to the CGS Baltic Seed project, which has the aim to prepare a proposal for a larger EU project focusing on CGS (CO_2 geological storage) within the Baltic region. The CGS Baltic Seed Project aims to address a range of issues including the geological, legal, political and regulatory aspects of CO_2 storage within the Baltic region. The work presented here provides additional constraint on the structure and stratigraphy of the Baltic Basin, which will be used as input to a CO_2 storage atlas for the region, and to propose a plan for a potential pilot test site on Gotland.

SESSION 2

BALTIC SEA PALEOENVIRONMENTS

THE BRAKISH PHASE OF THE YOLDIA SEA – AN IMPORTANT STAGE IN THE HISTORY OF THE BALTIC SEA

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The brackish phase of the Yoldia Sea is traditionally dated to c. 11 300 to 10 950 cal. yr BP. This duration is based on the cross-correlation of several geographically spread clayvarve sequences recording fragments of this stage. Coring during the IODP Expedition 347 has provided us with a long and continuous sediment core, M0063, from the deepest basin of the Baltic Sea, the Landsort Deep, covering the entire Yoldia Sea stage. This core give us the opportunity for the first time to investigate the history, duration and development of this intriguing stage in the Baltic Sea history on a yearly resolution. We will present results from the clayvarve investigation of the varved sequence and salinity reconstruction of the brackish phase based on diatom analyses.

HOLOCENE VEGETATION CHANGES AND HUMAN IMPACT ARCHIVED IN THE BALTIC BOTTOM SEDIMENTS AT LITTLE BELT (SITE MOO59)

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The studied sediments come from five cores recovered during the Integrated Ocean Drilling Program Expedition 347 at Little Belt (site MOO 59). Sediment of the site M0059 was divided into seven lithostratigraphic units. The unit I (0–51.68 mbsf) is represented by organic rich clay while fourteen cm thick unit II consists of sandy clay. At Little Belt pollen record covers upper 53 mbsf.

According to vegetation succession compared to the terrestrial data from Lake Belau, Northern Germany (Doerfler *et al*., 2012) and radiocarbon datings the pollen record from the site MOO 59 includes the last *ca* 8000 years. It starts with dominance of *Ulmus-Tilia-Quercus* and *Corylus* forest communities. After the ulm decline (*ca* 5000–4500 years BP) *Quercus-Corylus* and *Tilia* communities dominated. Subsequently these were followed by young Holocene forests with *Fagus* and slightly later with *Carpinus*. At the same time importance of *Corylus* significantly diminished while *Quercus* remained a significant component of the forest.

The first single pollen grains of Cereals (*Triticum* type) appear around the ulm decline. At the same time for the first time were noted *Plantago lanceolata* and *Rumex acetosa* type. Continuous and in high values occurrences of anthropogenic pollen types like *Secale*, *Triticum*, *Plantago lanceolata*, *Rumex acetosa* t., and *Fagopyrum* begin around 2000 yrs BP.

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A 1000-YEAR RECORD OF THE DEVELOPMENT OF COASTAL HYPOXIA FROM THE ARCHIPELAGO SEA

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The spreading of coastal hypoxia due to anthropogenic nutrient input has adverse effects on benthic ecosystems and biogeochemical cycles, resulting in mass mortality of benthic macrofauna and release of Fe-bound P from surface sediments. Although long-term trends in the spreading of hypoxia in the offshore areas of the Baltic Sea have been widely studied, shallow coastal areas where episodic or seasonal hypoxia is enabled by thermal rather than salinity stratification, have been largely overlooked. In addition, it is still debated whether the hypoxic event during the Medieval Climate Anomaly (MCA, 950–1250 AD) in the Baltic Proper was mainly caused by intensified land use in the catchment or anomalously warm climate. In this multiproxy study, we used sedimentology, ichnology, bulk sediment geochemistry, and mineral magnetic measurements of long sediment cores to delineate bottom water redox shifts in the coastal Finnish Archipelago Sea over the past 1 000 years, encompassing the recent climatic fluctuations of the MCA, the Little Ice Age (LIA, 1350–1850 AD) and the Modern Warm Period (MoWP). The age model was constructed using ^{137}Cs and atmospheric Pb fallout as time markers together with bulk sediment radiocarbon dating.

Our preliminary results suggest oxic bottom water conditions in the LIA, whereas a decline in the bottom water oxygen concentration during the warm periods of MCA and MoWP is observed. These hypoxic events in the coastal Archipelago Sea appear to coincide with the intervals of oxygen depletion in the Baltic Proper, indicating coupling between pelagic and coastal hypoxia in the Baltic Sea. However in our coastal core, C_{org}/P and Mo/Al ratios in the MCA were significantly lower than during the MoWP, indicating less severe oxygen depletion in the M*Ca* The relatively higher bottom water oxygen concentration during the MCA is also manifested in a burrow-mottled sedimentary-fabric and a lack of magnetic enhancement in these sediments. The MoWP sediments, in contrast are characterized by unprecedentedly high C_{org}/P and Mo/Al ratios, laminated sedimentary-fabric, and magnetic enhancement possibly due to strictly anaerobic greigite-producing magnetotactic bacteria, pointing to severe hypoxia beginning in the 1950s, coinciding with the onset of intensive land use and warming climate in the Baltic Sea region. However, a slight decline in Mo/Al and Corg/P ratios since the 1970s could denote a subtle improvement of the bottom water oxygenation over the last three decades.

SOURCES OF SEDIMENTARY BIOMARKERS AND PROXIES WITH POTENTIAL PALEOENVIRONMENTAL SIGNIFICANCE FOR THE BALTIC SEA

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The Baltic Sea is a shallow, semi-enclosed and intracontinental shelf sea characterized by brackish waters, resulting from high freshwater inputs, and anoxic bottom waters in the deepest basins, allowing the preservation of sedimentary organic matter. In the present study, the most abundant, naturally-occurring lipids in surface sediments from the entire Baltic Sea and the Skagerrak area were identified and their potential sources were assigned. Together with long-chain *n*-alkanes derived from land plant leaf waxes, diploptene and branched glycerol dialkyl glycerol tetraethers (GDGTs) have a terrestrial origin, while isoprenoid GDGTs, hydroxylated isoprenoid GDGTs (OH-GDGTs), n-$C_{25:1}$, n-$C_{27:1}$ and n-$C_{29:1}$ alkenes are autochthonous lipids. The isoprenoid and OH-GDGTs are most probably derived from Thaumarchaeota and the long-chain *n*-alkenes from phototrophic organisms. Significant correlations were found between indexes based on isoprenoid and OH-GDGTs and Baltic Sea surface and bottom temperatures. The branched and isoprenoid tetraether index can be used to estimate the percentage of soil (terrestrial) organic matter in the sediments of the Baltic Sea. The distributions of C_{37}, C_{38} and C_{39} alkenones, lipids produced by certain calcifying and non-calcifying *Isochrysidales* (*Prymnesiophyceae*), may serve as proxy for tracing different water masses and, ultimately, salinity changes in the Baltic Sea. High values of the $P_{aq'}$ ratio in the northern Baltic Sea originate from the presence of both *Sphagnum* mosses in the drainage basin and submerged macrophytes, such as *Potamogeton sp*. and *Myriophyllum sp*., in the freshwater to brackish water of coastal areas. The $P_{aq'}$ ratio may thus reflect fluctuations in the regional expansion of freshwater to brackish coastal environments in the Baltic Sea. Finally, certain $C_{25:2}$ and $C_{25:3}$ highly branched isoprenoid alkenes were identified in the marine planktonic diatom *Pseudosolenia calcar-avis* isolated from the southern Baltic Sea and have a strong potential as sedimentary biomarkers for salinity. In order to illustrate the potential of these newly developed biomarkers, most of them are applied to a Holocene sediment core from the Bothnian Sea.

ENVIRONMENTAL CHANGES DURING THE LATE GLACIAL AND HOLOCENE IN THE GDAŃSK BASIN (SOUTHERN BALTIC) AS INFERRED FROM MULTI-PROXY RESEARCH

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A 12 m sediment core was taken by an international research team onboard the German RV "Poseidon" from the Gdańsk Basin (ϕ: 54°49.35 N, λ: 19°11.13 E). The following analyses were carried out: grain size distribution (141 samples), diatoms (73 samples), pollen (33 samples), AMS ^{14}C (13 bulk samples, 2 marine shells), TC, TN and TS (146 samples), TIC (104 samples), $^{13}C/^{15}N$ isotopes (28 samples), continuous XRF scanning (about 6.8 m of the upper part of the core). Additionally, seismo-acoustic data recorded in the vicinity of the coring site were analyzed.

According to biostratigraphical investigations (pollen and diatoms), the sediment core contains a record of all phases of Baltic Sea development, from early Baltic Ice Lake to Postlittorina Sea: environmental changes from Late Glacial to Late Holocene (eventually early Medieval Times) are displayed by multi-proxy-data. Amount and quality of AMS ^{14}C dates was not enough to construct age-depth model. Only very few datings correlate with pollen analyses. Some of the datings from bulk samples seem to be too old due to admixtures of older organic matter.

Most important results are:

- In general sediments are clayey (gray, locally black) in the lower part and muddy (olive gray, locally fine laminated) in the upper part of the core.
- Marine and brackish diatoms were identified in the Late Glacial clays enriched in the sandy fraction. This fact could be correlated with first drainage of Baltic Ice Lake *ca* 13 cal. ka BP and confirm earlier information about Late Glacial Yoldia Sea (Yoldia Sea I) in the Gdańsk Basin.
- Increasing silt content at the Pleistocene/Holocene transition is an eventual reference to the final drainage of the Baltic Ice Lake. The facies change coincides with the appearance of brackish and marine diatoms. This second brackish stage refers to the Preboreal Yoldia Sea (Yoldia Sea II). According to diatom and pollen data it seems that brackish conditions occurred in the Gdańsk Basin up to the late Preboreal period (planktonic brackish diatoms) or even, up to the early Boreal (benthic, brackish diatoms). This is a longer period than commonly accepted.
- The beginning of the Littorina Sea's (Mastogloia) initial stage is recorded by the appearance of benthic marine and brackish diatoms, as well as a small amount of planktonic marine species. According to pollen data it took place during late Boreal, about 9390–9110 cal. BP.
- A clear increase of benthic marine diatoms, followed by rapid increase of planktonic marine species, related to the beginning of the Littorina Sea occurred in the early Atlantic period.
- The Postlittorina Sea is marked by gradual decrease of planktonic marine diatoms with simultaneous increase of freshwater species. According to pollen diagrams this phase begun in the middle of the Subboreal period.
- In the sediments deposited since late Boreal to middle Subatlantic at least three peaks of coarser sediments were recorded coinciding with increasing amount of brackish and marine benthic diatoms indicating influxes of saltwater along with enhanced hydrodynamics.

A LONG TERM EVOLUTION OF HARMFUL SUBSTANCES INPUT INTO THE GULF OF FINLAND

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The environmental problems of the Gulf of Finland include *e.g.* eutrophication and input of hazardous substances. In this work we have used geological records to study environmental history and trends in heavy metal input in the Gulf of Finland over the past 6000 years.

We have studied sediment cores from three sites, from the western (JML), central (GF2) and eastern Gulf of Finland (F40). These sites are located in the water depths of 80, 84 and 38 meters, respectively. The short sediment cores were recovered using a GEMAX gravity corer, and long sediment cores using a piston and a gravity corer. Detailed analyses of sediments include *e.g.* inductively coupled plasma-mass spectrometry (ICP-MS), total carbon, and weight loss on ignition (LOI). The age model for these sediment cores is based on AMS ^{14}C-, palaeomagnetic-, ^{210}Pb- and ^{137}Cs dating.

Results from sediment studies indicate an anthropogenic input of harmful substances (*e.g.* lead, nickel, coppealready during the Medieval Climate Anomaly (around 950–1250 AD). Increase in heavy metal input, since 1950s until 1970/1980s, is also clearly visible in sedimentary records. Over the last decade(s) the concentrations of heavy metals have generally declined. However, seabed sediments of the Gulf of Finland still contain high concentrations of heavy metals.

This work is a part of an ongoing CISU project that is funded by Academy of Finland and Russian Foundation for Basic Research (project 14-05-91763), and former INFLOW project that received funding from the European Community's Seventh Framework Programme (FP/2007–2013) under grant agreement No. 217246 made with BONUS, the joint Baltic Sea Research and Development Programme.

ORGANIC SEDIMENTS FROM THE BURIED RIVER VALLEY RECORD LOW SEA LEVEL IN PÄRNU REGION BEFORE THE LITTORINA TRANSGRESSION

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Pärnu region in SW Estonia in the eastern coast of Gulf of Riga is characterized by slow post-glacial isostatic uplift (about 1 mm/yr) and slowly undulating low topography. Therefore even a small sea level rise can easily lead to the flooding of surrounding areas. Due to the complex deglaciation history of the Baltic Sea region, Pärnu area has been periodically submerged by the waters of the Baltic Sea and emerged on other times as terrestrial land. Therefore, transgressive deposition of water-laid sediments of the Ancylus Lake and the Littorina Sea have lead to repeated burial of organic matter layers and associated Stone Age settlement layers. So far it remains unclear if water level in Pärnu region dropped close to the present sea level or even below it before the Littorina Sea transgression. *Ca* 120-m-wide buried river valley, possibly a relict of River Pärnu, with organic infill was discovered at elevation –6 m below present water level during the fieldwork in autumn 2015. The depth of the valley is up to 4 m and it is filled with organic matter consisting of remains of plant species characteristic to wetland. The valley is buried under *ca* 7-m-thick layer of Littorina Sea coastal sands. This suggests that sea level in Pärnu region may have been several meters below zero before transgression. According to diatom analyses freshwater taxa dominates throughout the valley, but there are also some brackish taxa that possibly refers to redeposition of sediments. The results of pollen analyses refer to typical wetland environment. Preliminary results suggest that filling of the abandoned Pärnu river valley with organic matter took place between 9.5 and 8.1 cal. ka BP. Several Mesolithic stray finds, like a bird-shaped or a human-shaped statuette (dated to 8.0–7.8 cal. ka BP) are associated with this prehisoric valley. Further studies are requiered in order to clarify the development of River Pärnu during Mesolithic including its reach in the bottom of the Pärnu Bay.

STONE AGE SEAL HUNTERS AND HOLOCENE SHORE DISPLACEMENT IN HIIUMAA ISLAND, NW ESTONIA

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Hiiumaa is one of the largest islands in present-day Baltic Sea, but during its earliest occupation in Late Mesolithic only 1% of its terrain was above the sea level in the highest Kõpu area. Altogether, 15 Stone Age settlement sites, closely related with seasonal seal hunting, are known from the Kõpu area including 10 Late Mesolithic and 5 Neolithic sites. In the present study coastal landform system in SE part of the Kõpu area was investigated in order to clarify the shore displacement history of the area and its relations with early seal hunter's camp sites. Multiproxy approach was used combining sedimentary, ground-penetrating radar (GPR) and airborne LIDAR elevation data with luminescence dating. Preliminary results show two sets of coastal landforms, separated by unconformity corresponding to Ancylus Lake/Littorina Sea transition. The mean luminescence ages from Ancylus Lake set provided values 10.0 and 9.9 ka while Littorina set was dated between 6.4–3.9 ka. Both sets of landforms are characterized by several extensive seaward-dipping reflections clearly visible in GPR images. These are ground-truthed as coarser grained strata (coarse sand, gravel and some pebbles) in dominantly sandy beach deposits. Such features are suggesting their formation in active wave regime at well-exposed coast. Modelling results show that the oldest Late Mesolithic camp sites at about 7.7–7.0 cal. ka BP were established less than 100 m from the coeval Littorina Sea shoreline on the top of the older Ancylus Lake landforms. Younger, Early Neolithic and Late Neolithic sites, are located successively at lower altitudes following the shoreline displacement induced by glacial rebound.

NEW DATA ABOUT POSTGLACIAL DEVELOPMENT OF THE GULF OF FINLAND

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One of the key problems for proper understanding of deglaciation processes and regional ice-sheet oscillations in the eastern Gulf of Finland is an identification of end-moraine complexes (end-moraines, eskers, kames *etc.*) and environmental conditions of lacustrine-glacial basins. Comparing with well-known features of glacial and postglacial relief forms, located nowadays on-shore, there is still a lack of geological data about Gulf of Finland bottom.

Aiming to receive new data about regional postglacial development, the GIS analyses of bottom relief and available geological and geophysical data was undertaken; the maps of preQuaternary relief, moraine and Late Pleistocene surfaces, glacial moraine and Holocene sediments thicknesses were compiled. GIS analyses of modern relief aspect map, moraine thickness distribution and sediment cores description allowed to establish the most probable location of the end-moraine complexes.

To receive new proxy data the seismo-acoustic profiling and long core sediment sampling were undertaken. Analyses of nearshore seismo-acoustic profiling allowed to suppose occurrence of several moraines and interstadial horizons, and to find numerous glacio-fluvial relief forms within the areas of possible end-moraine development. High-resolution proxy study (grain-size, geochemical, paleomagnetic, palinological) investigations allowed to receive new data about sediment rates, near-bottom dynamics and environmental conditions of post-glacial lakes and Littorina Sea. Paleomagnetic study permitted to receive the first for the bottom sediments of Russian part of the gulf dates, characterized period of Baltic Ice Lake development.

This work is a part of an ongoing CISU project that is funded by RFBR (project 14-05-91763) and Academy of Finland, RFBR project 15-05-08169, and former BONUS INFLOW project.

SOUTHERN BALTIC DEGLACIATION AS INDICATED BY OSL DATING OF GLACIOFLUVIAL AND ICE-DAMMED LAKE DEPOSITS

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The presented results concern the first attempt of OSL dating of glaciofluvial sediments from Słupsk Bank and ice marginal lake deposits occurring on the sea bed between the Słupsk Bank and the Polish coast. Dating was applied to 22 samples of sandy-gravelly sediments from 2 glaciofluvial deltas, 11 samples of sandy-silty sediment of ice-damed lake and 10 samples of sandy sediments from 3 low ridges, related to southern range of ice-marginal lake on Gardno–Łeba Lowland. In addition, palynological analysis was performed for 22 samples from 2 sediment cores of ice marginal lake deposits.

Taking into account that the Pomeranian Phase was 17–16 ka ago (Wysota 2002, Marks 2010), Blekinge Phase 15–14 ka ago (Houmark-Nielsen, 2008), and 10Be age of the Vimmerby's moraines in southern Sweden is approx. 14 ka (Johnsen *et al*., 2009), the expected time of ice-sheet decay in the area of southernmost Baltic basin (between Polish coast and Słupsk Bank) is the period between 16 and 14 ka ago. This hypothesis is also supported by the oldest peat from the Gulf of Gdansk dated to 14 639–13 888 and 13 885–13 675 cal. years BP and from the Pomeranian Bay, dated to 14 000–13 750 cal. years BP. OSL ages of glaciofluvial deposits range from 4.11 ±0.33 to 21.3 ±2.0 ka, the ages of marginal lake deposits range from 11.93 ±0.82 to 135.0 ±12.0 ka and sandy ridges, related to southern range of ice-marginal lake range from 11.03 ±0.73 to 16.7 ±1.1 ka.

In accordance to the above assumptions and obtained results, two OSL ages of glaciofluvial deltas (14.3 ±1.2 to 15.6 ±1.2 ka), and two ages of ice marginal deposits (14.51 ±0.81 and 14.6 ±1.4) as well as five ages from low sandy ridges ranging from 14.05 ±0.79 to 15.56 ±0.98 ka indicate the most likely time of their deposition.

The dates older than mentioned above, show too little sun exposure of sediments during their deposition. The younger dates indicate that some parts of sediment were redeposited and had contact with sunlight at a later stage. It could have happened during melting of dead ice blocks, after drainage of an ice-marginal lake, or during the Baltic Sea transgression on the Słupsk Bank ca 9–7 thousand years ago. Also, it could have taken place recently, when glaciofluvial deposits were eroded and transported on seabed during storms. In the case of sandy-silts it is possible that these are the sediments of local lakes that existed in a depressions, after drainage of ice marginal lake, as also indicated by pollen analysis.

On the basis of these results it can be concluded that short stop of ice-sheet on the Słupsk Bank took place approximately 15 ka ago, during short period of climate cooling 15.1–14.8 ka BP (Alley, 2004). The Słupsk Bank Phase could be correlated with Phases of Central Skåne (16–15 ka) (Houmark-Nielsen, 2008) or Halland (ca 14.8 ka) (Lundqvist, 2002) and North Lithuanian Phase (Pirrus, Raukas, 1996).

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THE BASE OF BRACKISH-WATER MUD AS A STRATIGRAPHIC MARKER IN THE BALTIC SEA BASIN

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As is the case with many modern epicontinental seas, the early to mid-Holocene glacioeustatic ocean-level rise resulted in the marine flooding of the Baltic Sea basin. This change from a postglacial (Ancylus) lake to the present semi-enclosed brackish-water (Littorina) sea is studied here in sediment cores and seismoacoustic profiles from the major sub-basins of the Baltic Sea. In the shallow areas of the Baltic Sea, the base of the brackish-water mud is erosional and in many places covered by a thin transgressive silt-sand sheet. This erosional flooding surface becomes conformable in the deeper parts of the basin, where the base of the brackish-water mud is sharp and possibly erosional, although local gradual transitions are present. Both in the shallow and deep areas, the brackish-water mud is significantly enriched in organic matter (LOI) compared to the underlying sediments. We conclude that the base of the brackish-water mud is a robust allostratigraphic surface that is readily identifiable by the lithologic examination of sediment cores. The base of the brackish-water mud often is a strong reflector in seismic-acoustic profiles, making it a particularly useful surface for mapping and basin-wide stratigraphic subdivision.

SESSION 2.1

CLIMATE CHANGE IMPACT ON ECOSYSTEM HEALTH – MARINE SEDIMENTS INDICATORS

ASSESSMENT OF THE BIOGEOCHEMICAL SEDIMENTARY RECORD OF AN ARCTIC FJORD SYSTEM (BALSFJORD, TROMSØ, NORWAY)

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In order to assess the biogeochemical sedimentary record of an Arctic fjord system, long sediment cores were collected in Balsfjord, a narrow and undisturbed fjord located in northern Norway about 10 km south of Tromsø. Balsfjord, surrounded by mountains reaching 1500 m in elevation, is 46-km-long and 5 km across at its widest point. The fjord is narrow with limited circulation and it has a morene ridge forming an approximately 35-m-high threshold at the mouth of the fjord. Balsfjord's inner and outer basins have water depths of 130 m and 190 m, respectively. Balsfjord is characterised by comparatively low fluvial input, relatively high water temperatures and no present-day influence by glaciers.

In the current study, the history of the biogeochemical development in Balsfjord (Tromsø, Norway) was reconstructed based on the analysis of a sediment core (500 cm). Analyses were carried out using a Multi-Sensor-Core-Logger for measuring density, magnetic susceptibility, acoustic impedance, p-wave velocity, p-wave amplitude and fractional porosity. In addition, water content, TC, TOC, $CaCO_3$ content as well as grain-size distribution were analysed. Detailed profiles of geochemical element distribution were obtained using a high resolution XRF core scanner combined with photographic imaging.

The study showed clear signs of environmental changes and carbon input in this Arctic fjord system following the post glacial changes in bottom currents and transport of terrigenous material. Clear differences with the Oslo fjord region and the Gdansk deep are observed.

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INORGANIC PROXIES OF CLIMATE CHANGE IN SEDIMENTS FROM THE GULF OF GDAŃSK (POLAND) AND OSLOFJORD (NORWAY)

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Trace elements and their isotopes (TEI) have a large potential to trace rapid changes in climate related ocean processes and, thus improve our understanding of paleoceanography. The extensive use of TEI (including rare earth elements, REE) and their ratios as proxies for climatically important ocean variables is relatively new, and their relationship with marine processes is not completely established yet. TEI can be used as proxies for environmental changes in the geological past, since redox sensitive elements (such as U, Mo, V, Re, As) have a different sensitivity for oxic, anoxic and sulphidic conditions. Certain elements are enriched, while some others are depleted in sediments deposited under such special conditions.

The concentration of the extractable forms of elements was analyzed in 2 cm sections of two sediments cores (*ca* 4 m long) from the Gulf of Gdańsk (Gdańsk Depth, Poland) and Oslofjord (Bunnefjord, Norway), in framework of project CLISED (Climate change impact on ecosystem health – marine sediment indicators). The sediment samples were analyzed for chemical elements (Ag, Al, As, Au, B, Ba, Be, Bi, Ca, Cd, Ce, Co, Cr, Cs, Cu, Dy, Er, Fe, Ga, Ge, Hf, Hg, Ho, In, Ir, K, La, Li, Lu, Mg, Mn, Mo, Na, Nb, Nd, Ni, P, Pb, Pr, Pt, Rb, S, Sb, Sc, Se, Si, Sm, Sn, Sr, Ta, Tb, Th, Ti, Tl, Tm, U, V, W, Y, Yb, Zn, Zr) applying the BCR sequential extraction procedure and high resolution inductively coupled plasma mass spectrometry (HR-ICP-MS). Further, we examined the element concentrations and their ratios in relation to organic carbon, total nitrogen, stable carbon and nitrogen isotopic composition ($\delta^{13}C$ and $\delta^{15}N$), and pigments analyzed in the same samples at IOPAN, Sopot. TEI distribution, fractionation and ratios will be discussed in view of paleoenvironmental conditions that prevailed during their deposition or mobilization. This will improve knowledge on how to read the respective signals in the sedimentary records and how to interpret TEI signals in the sediment, taking into account their alterations by diagenetic processes after the deposition.

CLIMATE CHANGE IMPACT ON ECOSYSTEM HEALTH – MARINE SEDIMENT INDICATORS (CLISED)

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Studies of old Baltic Sea sediments, carried *e.g.* in framework of EU project BASYS, indicated that eutrophication occurred during the last four millennia, not only in recent times. Cyanobacteria blooms might have occurred as early as 7000 BC. Knowledge about natural toxicity of these sediments is absent, though both algal toxins could have been produced during these episodes. Aim of this project is to study climate change effects in the sedimentary record and connect it to indicators of the health of the marine environment achieved in sediments. Phytoplankton biomass and structure belong to the main indicators of the health of the marine environment. Phytoplankton population depends on climate factors, hydrodynamics and contaminants occurring in ecosystem. These organisms have an impact on the transport and fate of contaminants in the sea and in effect on pollution of this environment. Some phytoplankton strains can produce natural toxins.

The project is realized by studying sediments indicators of natural and anthropogenic toxicity in relation to different geological sediment proxies. Recent and old sediments of coastal locations of different climate, hydrology and contaminant burial history are analysed and compared: from Gulf of Gdańsk and Oslofjord/Drammensfjord as well as in the arctic region (Norway). Analysis of multi parameter sets will indicate sediment variability. During two cruises of RV "Oceania" IOPAN, Sopot in 2014, sediment cores were collected of recent sediments (0–20 cm) at 6 different locations in the Gulf of Gdańsk and 6 locations in the Oslofjord/Drammensfjord. In 2015, four deep sediment cores (from 140 till over 500 cm long) were collected from: Gulf of Gdańsk, Oslofjord, Trondheimsfjord and Balsfjord (n/Tromsø). During sediment collection the physico-chemical parameters (salinity, water temperature, oxygen content) were measured. The parameters characterizing bulk sediments like granulommetry, organic carbon, total nitrogen, stable carbon and nitrogen isotopes ($\delta^{13}C$ and $\delta^{15}N$), were analysed and ^{210}Pb and ^{14}C dating was done. Besides that the geological proxies *i.e.* pigments (chloropigments and carotenoids), diatoms and cyanobacterial toxins were determined, as well as 69 elements.

Chloropigments, *i.e.* chlorophyll-a is a commonly accepted marker of plant biomass, chlorophyll-b – of green algae, higher plants and chlorophylls-c of diatoms, dinoflagellates, red and brown algae, respectively. Chlorophyll-a derivatives are indicators of post-depositional conditions, grazing, freshness of material, decomposition by microorganisms. The chloropigment content in recent sediments reflects primary production, sedimentation rate, hydrology and post-depositional conditions. The recent sediments collected were characterized by various chloropigment content, the most rich were those collected from the Deep of Gdańsk and inner Oslofjord, locations where anoxia occurred due to restricted water exchange. The long core from the Deep of Gdańsk (P116) consisted mainly from silty/clay sediments. Maxima of chloropigments in the core prove that warm periods with higher eutrophication than nowadays occurred in the past four millennia.

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CAROTENOIDS IN THE GULF OF GDAŃSK SEDIMENTS AS EUTROPHICATION AND CLIMATE PROXIES

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Carotenoids are a large group of natural compounds, which are ubiquitous in the environment. They are abundant in freshwater and marine organisms: plants, algae, bacteria and zooplankton. Already in water column and later in sediments they undergo different reactions. Additionally, the pigment pool is supplemented or modified by herbivores. Because of that carotenoids are used as valuable chemotaxonomic markers of plankton in water column and proxies in sediments. They differ in stability and, due to that, carotenoids in marine sediments are indicators, not only of organic matter sources but also pre- and post-depositional conditions. As a result of development of various chromatographic techniques in the last thirty years, the quantitative studies of these compounds has been reported, mainly for water column as well as for recent sediments, though their variety and differentiated stability still make their quantitative analysis in sediments a real challenge.

This work presents a concentration and distribution of selected carotenoids in recent (6 cores 0–20 cm) and deep (1 core, up to ~400 cm) sediments of the Gulf of Gdańsk. The sediments were collected and analysed in framework of CLISED project. The Gulf collects waters of the Wisła (Vistula), the largest Polish river and the second largest river flowing into the Baltic. It is a highly eutrophic area of high primary production and high sedimentation rate. The Deep of Gdańsk (the deepest part of the Gulf of Gdańsk) collects autochthonic particulates, those introduced by the Wisła waters and those formed as a result of flocculation in the freshwater/seawater mixing zone. All these make the Gulf of Gdańsk an interesting area for studying the processes governing sedimentation in a transitional area where carotenoids are very good proxies. Just after collection the sediments were frozen and kept in such a state until analysis in land laboratory. After extraction, carotenoids were analysed using high performance liquid chromatography (HPLC-DAD).

There were selected the parent carotenoids, markers of the main phytoplankton groups occurring in the Baltic: fucoxanthin as a marker of diatoms, diatoxanthin (diatoms and dinoflagellates), alloxanthin (cryptomonads), lutein (green algae), zeaxanthin, canthaxanthin and echinenone (cyanobacteria), and β-carotene (most algae, marker of primary production). Concentrations of carotenoids were compared with those of chlorophylls-a, -b and -c in the same sediment samples. Carotenoids in recent and deep sediments can be used as equal or better than chloropigments indicators of average primary production in adjacent waters. The results were discussed in relation to environmental conditions and physico-chemical parameters characterizing sediments, such as organic carbon, total nitrogen, grain size, stable carbon and nitrogen isotopes ($\delta^{13}C$ and $\delta^{15}N$).

HISTORY OF CYANOBACTERIAL BLOOMS IN THE BALTIC SEA APPLICATION OF CHEMICAL AND GENETIC MARKERS IN THE ANALYSIS OF SEDIMENTS

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In the reconstruction of life and processes in marine ecosystems, the application of biomolecules, including DNA, pigments, lipids, carbohydrates and proteins, has become more common. Good molecular markers are characterized by high stability and their occurrence is restricted to a specific group of organisms or environmental conditions. Of the compounds, DNA is the most informative structure, however, due to low persistence, its use is problematic.

In the current study, the history of the brackish water cyanobacterium, *Nodularia spumigena*, was reconstructed based on the analysis of 2 cm sections of the sediment core (400 cm) collected from Gdańsk Deep (Station P116) in the southern Baltic Sea. Nodularin (NOD), a cyclic pentapeptide, was used as a chemical marker unique for *N. spumigena*. Sediment samples (2 g) were extracted in 75% methanol, and after purification on C18 SPE cartridges, analyzed using liquid chromatography combined with tandem mass spectrometry. For molecular analysis, *mcy*E and *nda*F genes involved in the biosynthesis of cyanobacterial peptides, microcystins and nodularins, were selected as the target sequences. To improve the quality and increase the quantity of the DNA isolated from sediment samples (0.5 g), the conditions for clean-up and PCR procedures were optimized.

Nodularin was detected in all analyzed samples. The lowest concentrations of the peptide were determined in the most recent (0.2–0.4 ng/g dw) and the oldest (0.1–0.2 ng/g dw) sediments. Peaks in nodularin content, suggesting the most intensive blooms of the cyanobacterium, were recorded in sections 170–180 cm (64.6–292.5 ng/g dw). High concentrations of NOD (approx. 40 ng/g dw) was also in sections 122–124 cm, 106–108 cm and 90–92 cm. The analyzed *nda*F gene sequences were detected in different sections of the sediment core, and confirmed the presence of NOD-producing *N. spumigena*.

The maxima in NOD concentrations correspond with the warmer climate periods in the history of Europe, while the drop in NOD content between sections 78–80 cm and 76–78 cm can be attributed to the Little Ice Age. The obtained results confirmed the decisive role of temperature in bloom development of the Baltic cyanobacteria. The studies also showed for the first time high value of nodularin as chemical marker of environmental changes in the Baltic Sea.

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DIATOMS IN RECENT AND DEEP SEDIMENTS OF THE GULF OF GDAŃSK (SOUTHERN BALTIC)

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Diatoms, a basic component of microflora occurring in various water habitats, are very sensitive to environmental changes. Among others, salinity and trophy conditions influence on the floristic spectra of diatom assemblage. Therefore, the diatom taphocoenose can be used as a valuable tool for ecological reconstructions in the past. In the Late Holocene paleohydrological conditions of the Gulf of Gdańsk, the open bay of the southern Baltic Sea, were shaped by various factors. Amongst regional factors, major role played inflows of marine/brackish waters in Littorina and Post-Littorina stages, which were connected to climatic fluctuations in Subboreal and Subatlantic chronozones. Moreover, changes of environmental status were forced by local factors, amongst which input of riverine waters is one of the most important. In the last decades transport of large amounts of nutrients, organic matter and pollutants by Vistula River resulted in eutrophication and degradation of the Gdańsk of Gulf.

Fossil and recent diatom flora preserved in sediments of various parts of basin was analysed within the framework of CLISED project (Climate Change Impact on Ecosystem Health – Marine Sediments Indicators). The material studied consists of six short cores (length of 10–20 cm) collected with a Niemistö core sampler and one long core (length of 384 cm) with a vibro-corer.

Samples for diatom analyses (*ca* 0.3–2.0 g dry sediment) were prepared following the standard procedure for diatom observation under light microscope (Battarbee, 1986). To estimate the concentration of siliceous microfossils per unit weight of dry sediment (absolute abundance), a random settling technique was used (Bodén, 1991). The diatoms were divided into groups according to their biotype, salinity and trophy requirements. The content (in percentage) of all ecological groups were counted in the core.

Four diatom assemblages zones (DAZ) were distinguished in long core P116. P116-A *Thalassionema nitzschioides* DAZ (384–322 cm) related to marine stage of the Baltic sea development – Littorina Sea. Two next zones are corresponded to brackish-water stage of Post-Littorina Sea *i.e.* P116-B *Actinocyclus octonarius–Chaetoceros* RS DAZ (322-210 cm) and P116-C *Actinocyclus octonarius –Pseudosolenia calcar-avis* (210–40 cm). Finally, P116-D *Thalassiosira levanderi* DAZ (40–0 cm) were distinguished in the top of the core. This diatom taphocoenosis occurred also in all short cores. The abundance of eutraphentic and pollution-tolerant small-sized planktonic forms was noted in the near-bottom sediments of the Gulf of Gdańsk. This community is characterized by the occurrence of *Cyclostephanos dubius, Cyclotella atomus, C. caspia, C. meneghiniana, Stephanodiscus hantzschii, S. medius, S. neoastraea S. parvus. Thalassiosira levanderi* and *T. lacustris*. Noteworthy are visible changes in the frequency of these anthropogenic species, which show the close relationship to the distance from mouth of the Vistula River.

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SESSION 3

COASTAL PROCESSES

POST-GLACIAL SEISMIC ACTIVITY ON THE SOUTH-EASTERN COAST OF THE BALTIC SEA

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For many years the south-eastern coast of the Baltic Sea, as well as the whole Eastern Baltic Region, had been considered as a low seismic activity area. This opinion has changed significantly after a few earthquakes that occurred on the junction of the XX–XXI centuries. Despite a great number of new data about the present and historical (*i.e.* last millennium) earthquakes, the question about palaeoseismicity of the region during the recent geological past (*i.e.* starting from Late Glacial and during the entire Holocene) still remains an open issue.

There were two main reasons that the Eastern Baltic Region seismic activity has not been adequately assessed: 1) a priori prevailing opinion that the region is of a very small seismic activity due to its geological structure (that is a stable part on the Eastern European Craton); 2) lack of experience and skills to identify reliably traces of the past earthquakes.

During the last decade, based on the results of geological surveys and critical analysis of some previous scientific publications, an assumption about possible presence of palaeoseismic deformations in the Baltic Sea south-eastern coast was made. It was observed that in the number of previous publications the palaeoseismic deformations were attributed to the particular structures triggered by other geological processes: permafrost, slope processes, glaciotectonism, activity of living organisms, soil-forming processes, *etc.* All this led to overestimation of the settled opinion about seismic stability and gave rise to talks about strong earthquakes and their induced geological processes: 1) soil liquefaction; 2) tsunamis; 3) large landslides.

The soil liquefaction structures (palaeoseismic deformations) have been determined in a number of localities along the whole south-eastern coastal zone (*i.e.* a few kilometers-wide belt) of the Baltic Sea: in the lower reaches of the upper terrace of the Šešupė River (Kaliningrad Oblast of the Russian Federation), in the Ventės Ragas exposure (eastern coast of the Curonian Lagoon, Lithuania), Juodikiai sand quarry (Lithuania), in the Baltic Sea cliffs at Jūrkalne and Sārnate (Latvia).

The marine diatoms in the peat layers near Būtingė (Lithuanian-Latvian cross-border area) or inside the freshwater lagoon sediments near Nida (Curonian Lagoon) were interpreted as salt water invasions, possibly caused by the tsunami waves. The sand interlayer in the peat thickness of the Svencelė bog (eastern coast of the Curonian Lagoon) could also be linked with tsunami event. The landslides of about 360 meters long (this scale of landslide is not characteristic of the south-eastern Baltic area) on the old Littorina Sea cliff, north of Klaipėda, could be as a result of strong earthquake. Unlike the case of palaeoseismic deformations, the evidence of tsunamis traces as well as large landslides caused by earthquakes on are still under discussion and needs more detailed investigations in future.

SHORT-TERM BEACH CHANGES CAUSED BY DIFFERENT HYDRODYNAMIC CONDITIONS ALONG DZIWNOW SPIT DUNE COAST

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This research focuses on a comparison of changes caused by different hydrodynamic conditions along a dune coast of Dziwnow Spit. The studies were carried out along two 2-km-long sections of the southern Baltic coast, from which one section is a natural coast and the other is a protected area. Several real-time kinematic (RTK) GPS surveys were carried out from June to December 2012. The surveys included cross-shore profiles measured from the dune foot to a water depth of 1 m. The profiles were spaced at constant 100 m intervals. In addition, offshore wave data and water level data were collected. Using statistical method of Ward's hierarchical cluster analysis, three groups of hydrodynamic conditions were identified, and these groups had different effects on the coast. The group 1 represents values of significant wave height <1 m, the group 2 is characterized by the occurrence of 2–3 weak storm events with significant wave heights of 1.4 to 1.9 m. The group 3 includes 1 to 5 storm events with significant wave heights of 1.5 to 2.4 m. The coastal changes that occurred along the natural and protected sections of the coast were analyzed using two parameters: shoreline displacement and volume changes. Additionally, the net, total and maximal value and mean of shoreline displacement and beach volume changes were calculated.

The analysis confirms that both natural processes of erosion and accumulation take place with relation to the location of the shoreline displacement and the volume changes in all groups of hydrodynamic conditions on both the natural and protected coast. The proportion of these changes depends on the hydrodynamic conditions and the type of the coast. The studies proved that the coast protection system, in form of groynes, increases the shore dynamics during the occurrence of hydrodynamic conditions classified as groups 1 and 2. The protective function of the system is demonstrated by the increased accumulation at the shoreline, resulting in positive volumetric changes. However, during the occurrence of the most severe conditions, *i.e.*, group 3, the groynes no longer fulfill their protective function and contribute to an increase in the erosion values of both the shoreline location and the volume of the beach, relative to the natural coast.

Moreover, the correlation coefficient between shoreline displacement and volume changes was estimated for the aforementioned groups for both the natural and protected coasts. The coefficients exhibit stronger correlation for the natural coast: group 1 R = 0.82, group 2 R= 0.75 and group 3 R = 0.80, than for the protected coast: group 1 R = 0.79, group 2 R = 0.74 and group 3 R = 0.61.

TEMPORAL AND SPATIAL DISTRIBUTION OF THE VOLUMETRIC CHANGES OF THE SOUTHERN BALTIC SEA COAST IN 2008–2012 BASED ON DTM FROM AIRBORNE LASER SCANNING

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In terms of presently occurring climate changes – an increase of number and intensity of storm events observed within the southern Baltic Sea and a general deficiency of sediments in the coastal zone – the determination of the accurate volumes and spatial distributions of change occurring on the coast through the application of state-of-the-art techniques (such as ALS) will allow more precise determination of the volume of sediment taking part in sediment balance. This is of particular importance for broadly defined coastal safety.

In response to this need, the aim of this study was to determine the magnitude and both: spatial and temporal distribution of the coast changes (included the dune, the active surface of the cliff and the beach) based on digital terrain models (DTM) generated from ALS point clouds. Application of this technology permitted precise assessment of the magnitude and spatial patterns of coastal volume changes over selected time intervals to be made. The obtained results were discussed in terms of hydrodynamic factors driving the changes as well as in view of geological and geomorphological settings. Four series of airborne laser scanning data derived consecutively using the following scanners: LMS–Q560i Riegl (31.08.2008), TopEye SN 741 (30.11.2009), LMS–Q680i Riegl (21.03.2011) and LMS–Q680i Riegl (28.09.2012) were used. In case of analysis of ALS data derived by means of various scanners, attention must be paid to proper pre-preparation of the geodata. In order to make a credible comparison between individual years available, preprocessing should concern both the horizontal (X, Y) and the elevation (Z) adjustments of point clouds as well as the selection of points which represent the ground.

Investigated area, almost 80-km-long section of the Pomeranian Bay of the southern Baltic Sea, includes dune coast composed of Holocene marine and Aeolian accumulation sediments, mainly sands and also some sections of cliff coast, composed of unconsolidated Pleistocene sediments, mainly glacial till and sands. A comparison of generated DTMs allowed to determined the magnitude and spatial and temporal distribution of the volumetric coastal changes and showed high spatial and temporal diversity in sediment distribution along investigated area.

MONITORING OF COASTAL EROSION OF THE ORŁOWO CLIFF (GULF OF GDAŃSK, SOUTHERN BALTIC SEA)

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Cliffs, depending on their geological an hydrogeological setting, are particularly susceptible areas for shift of a fragile coastal equilibrium which results in irreversible cliff destruction due to hydrodynamical and meteorological factors. The Orłowo Cliff is a threefold marginal zone between Kępa Redłowska morainic upland and the Gulf of Gdańsk – southern Baltic Sea. Since the Atlantic period (mid-Holocene) the upland has been affected by considerable erosional factors resulting in dynamical reshaping of the coast, during Littorina transgression from *ca* 7000–6500 cal. years BP. Kępa Redłowska sediments represent two geological epochs: Miocene and Pleistocene. Miocene outcrops within Orłowo Cliff are represented by silts, quartz sands with brown coal dust and brown coal. In general, the Pleistocene sediments consist of glacial tills and boulders as well as glaciofluvial sands, silts and gravels. Moreover, composition of each part of the cliff – northern, central and southern – differs considerably.

The applied methodology revealed different cliff top retreat ratios for the central part of the Orłowo Cliff – the Orłowo Headland, its surroundings and cliff's southern part. The highest erosion rates occurred within a colluvium of a slump situated between 81.30–81.37 kilometre of the coast and in case of the Orłowo Headland (*ca* 5 meters). The acquired results imply high spatiotemporal variation of cliff erosion ratio. Zones impacted by mass wasting processes (slumps, rockfalls) demonstrate significantly higher erosion than the rest of the cliff. Large scale analyses enabled a delineation of an old dichotomous slump, located between 81.15 and 81.37 kilometre of the Polish coast. Therefore a spatial extent of the Orłowo Cliff requires correction. Based on LiDAR data analyses, and on-site verification, the Orłowo Cliff ranges from 81.15 up to 82.08 kilometre.

Spatial extent of the former Kępa Redłowska was determined based on a range of the boulder field across Gulf of Gdańsk inshore in the cliff foreground. Up to a point, the extent of boulder fields demonstrates a high correlation with 8 m bsl isobath. Kępa Redłowska during the Atlantic period extended eastwardly from a few hundreds of meters up to over a kilometre. In consequence, an overall Kępa Redłowska mean erosion rate since the mid-Holocene in Orłowo Cliff region has equalled *ca* 0.10–0.15 m/yr. Within the last century (1908–2015) its destruction rate increased up to *ca* 0.25 m/yr. Latest results of multitemporal LiDAR imaging (MLI) revealed mean erosion (of cliffs' central and southern part) equalling *ca* 0,4 m/yr. Volume of sediment delivered to the inshore totalled *ca* 6200 m^3.

APPLICATION OF SATELLITE INTERFEROMETRY FOR IDENTIFICATION OF THE VERTICAL GROUND MOVEMENTS IN THE POLISH BALTIC COASTAL AREA

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Presented material includes results gained from realization of the Polish Baltic case study within the "SubCoast" project UE – FP 7. SubCoast was a collaborative project aimed at developing a GMES-downstream service for assessing and monitoring subsidence hazards in coastal areas around Europe. It is firmly rooted to the GMES Service Element "Terrafirma" (www.terrafirma.eu.com) which provides the ground motion hazard information service, distributed throughout Europe via national geological surveys and other institutions. One of the primary aims of Subcoast project were analysis of vertical ground movements, potentially causing geohazards in the coastal areas. To reach this goal Interferometric Synthetic Aperture Radar (InSAR) data were obtained. For the Polish Baltic Coast, ERS archive radar data were processed in order to provide Permanent Scatterer InSAR (PSI) results. A description of the methodology, the final results and the analysis of the satellite interferometric data with respect to the geological conditions were presented. A total of 78093 PS points are detected measuring velocities between –24,08 and +25,85 mm/year with a mean of –0,61 and a standard deviation of 1,29 mm/yr. It should be noted that 90% of all points (70520) have velocity rates between –2 and +2 mm per year. Therefore, in general the study area should be considered as stable. For the Polish coasts most of the area proved to be stable. However, there are a few small areas where multiple PS exceed the stable values. In particular the area of the Gdynia–Gdańsk agglomeration is characterized by values of about plus five millimeters per year, which may be related to groundwater level changes. Other observed anomalies are associated with small subsidence, probably related with local soil conditions. nevertheless some local deviations up to –15 mm per year of movement were found. In addition, the relationship between slow ground movements and changes in the ground water level was presented. The new innovative product – Dynamic DEM (DDEM) was demonstrated. The deformation model defined by the Subcoast project normally needs to be created by merging InSAR, satellite navigation (GNSS), optical leveling and/or gravimetry measurements. Elaboration of DDEM enable more effective comparison between PS and tectonic features. The comparison of PS data (Deformation rates on regular grid 100 × 100 m, derived from the quadtree decomposition by Ordinary Kriging) with tectonic zones indicated additional argument for existence of the low rate tectonic activity. Majority of the discontinuities oriented NNW–SSE and ENE–WSW create system of blocks, which separates areas characterized by different ground motion (uplift and subsidence). The results of the geological interpretation demonstrated that the examples of movements detected by PSI include subsidence linked to deformation of engineering constructions, compaction of organic or weak soils, and eolian accumulation or deflation processes of the sand dunes.

COASTLINE CHANGE OF THE BALTIC SEA AND ITS DRIVING FORCES

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For modern management of the coastal zones – their protection and economic use – scenarios explaining the effect of natural and anthropogenic forcing are becoming indispensable. The reliability of those scenarios is determined by the extent to which the different driving forces of coastal morphogenesis are reflected in the multi-scale process models. Prior to planning any coastal engineering activities, the natural driving forces and their interaction have to be analyzed. For the Baltic Sea there have five natural driving forces to be considered: Glacio(hydro)-isostatic adjustment, climatically induced eustatic sea-level rise, wind-driven sea-level change, wind-waves and eolian forces shaping the subaerial part of a coastal zone. These forces act on different scales – spatially and temporally – and have to be analyzed separately before superposing in a complex modeling approach. Instrumental data are to be combined with decoded proxy-data from dated sedimentary records in order to cover time-spans from annual seasons to the millennia. The geological compartments along the Baltic coastlines respond differently to relative sea-level change and the action of hydrographic and eolian forces: The surface of the glacio-isostatically continuously uplifting Proterozoic crystalline rocks of the Fennoscandian Shield, just emerge because of permanent marine regression. At the gently uplifting southern Gulf of Finland and the Estonian Baltic Sea Islands and coast, Paleozoic sediments are exposed to wave-driven erosion and sediment transport dynamics forming steep cliffs – the typical "Klint" coast. The subsiding southern and south-eastern Baltic shores consist mainly of Quaternary soft sediments and are morphologically shaped by permanent transgression and eolian and hydrographically induced sediment dynamics. Because of dominating westerly winds, sediment alongshore transport is mainly west–east (northeast) directed and has led to the typical alternation of glacial till cliffs – serving as sediment source – and sandy beaches and spits – the sinks in the interplay between erosion and accretion. In particular the „Subsiding South" of the Baltic Sea needs management strategies for sustainable coastal protection. Morphodynamic models in particular for local areas sensitive to erosion need to consider regional sediment balances. At the moment we are far from a regional sediment budget for the southern and eastern Baltic Sea. To get closer to this target we have to join our forces interdisciplinarily and internationally. We need a close cooperation between sedimentologists, oceanographers, climatologists, and coastal engineers. A main role in the interdisciplinary debate plays the harmonization of spatial and temporal scales. Local studies have to be linked by regional models in order to realize a vision: regional sediment source-to-sink models for the Baltic Sea.

SPECIFIC CONDITIONS OF THE ACCUMULATION OF HEAVY MINERALS IN THE COASTAL SEDIMENTS OF THE GULF OF RIGA, SOUTH-WESTERN ESTONIA

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In south-western Estonia, shorelines along the Baltic Sea have been rather stable for a long period of time, which are dependent on tectonic conditions. Tectonic uplift in the Baltic Sea area was uneven. The duration and the culmination of the transgressions in northern, southern, and central Baltic were different. During the transgressions in Estonia the shoreline was stable due to the moderate uplift of the Earth´s crust, causing favourable presumption for the separation of heavy minerals.

The goal of this study was to discover regularities in terms of heavy mineral composition varieties through transgressive and regressive changes of the sea level, influence of wind activity, storms, and alongshore sediment movement. Besides, heavy mineral concentrations (HMC) were used as a tool to understand and interpret accumulation processes and explain high radioactivity levels in the study area. During fieldworks in south-western Estonia were collected samples from 16 sites from Pärnu town to Ikla in Estonian/Latvian border. Altogether 49 samples in the fractions of 125–250 µm, 100–150 µm, and 63–100 µm were analysed using immersion method. Changes in the sea level and the coastal erosion pattern result mainly from glacioisostatic and climatic factors. High concentrations of heavy minerals are found in ancient beach sediments. Besides, there are some findings of HMC in aeolian formations on the contemporary seashore, resulted from storm erosion and wind activity, which reflect changes in the frequency and intensity of these processes in the past. The largest concentrations of heavy minerals have been found in Littorina Sea transgressive sediments (some 7600 BP) in the Lemme – Piiskopi area (extremely high in Lemmeoja up to 83.7% of heavy minerals). The averaged heavy mineral content in sandy-silty fractions in the whole investigated area from Pärnu to Ikla is high, over 5%. Differences have been identified in sedimentation during transgressive and regressive phases in the relative sea level history. In the course of the sea's invasion into the tectonically stable areas, intensive mechanical and mineral differentiation of the sediments took place, causing an accumulation of heavy minerals. The transgressive phases were more intensive, causing sediments reworking and heavy mineral concentrations (HMC).

IMPACT OF CATASTROPHIC EVENTS ON THE COASTAL DEVELOPMENT OF THE GULF OF GDAŃSK – CASE STUDY OF THE WISŁA ŚMIAŁA MOUTH

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Many parts of the south-eastern Baltic coast are threatened with systematically progressing erosion. An increasing process of destruction affecting the coastal area refers not only to the Hel Spit and Jastrzębia Góra coast, but also to the region of the mouth of the Wisła Śmiała. Episodically repeated catastrophic storms are the major threat to the areas lying in the immediate proximity to the sea.

The studied part of the Gulf of Gdańsk costline is an area where backshore is covered by an anterior dune, vegetaded in many places. Its maximum height reaches 23 m at Górki Wschodnie. That it is most unlikely to sea waters to be able to encroach upon the Żuławy Delta Plain through such a natural barrier.

Increasing coastal erosion has been observed at the mouth of the Wisła Śmiała since the 1960s. The spit and then a breeding-ground of waterbirds at the Ptasi Raj Lake will soon be encroached by the sea and probably lost for ever unless the degradation of the narrow dune belt is restrained. There have already been overflows of sea-waters from the gulf into the lake during storms when sea-level rose by 1.5 m. As soon as waves erode chutes in the sand, the spit will turn into a number of islets which then will be washed away.

Sobieszewo Island, separated by a stone dike from the Ptasi Raj Lake, is human made. It is likely that the occurring changes have led to restore the original state. The river mouth, which is the entrance to the port of Gdańsk–Górki Zachodnie. Has been shallowing due to a deposition of sand by sea-currents. Simultaneously, the stone breakwater has been being broken and the coastline retreated. The nature reserve and the whole mouth of the Wisła could be saved by restoring the spit. One of the methods is to pile up the sand excavated from the port entrance area.

It is inferred from the analysis of the maps of the mouth of the Wisła Śmiała which have been produced over the last seventy-year period that the coastline changes appear to have been a continuation of the phenomena taking place in the southern Baltic, particularly the Gulf of Gdańsk.

The bottom sediment transport in the region of the mouth of the Wisła Śmiała is generated by waves and sea-currents. It results in both an accreation or retreating of the coastline and a sanding-up of the mouth.

A transport towards the north-west and north predominates on the eastern side of the river mouth, mainly due to storm wind action. The eastern coast is controlled by the break-water and the dike running to Górki Wschodnie. On the western side a transport towards the west prevails. The total balance of sanding-up is 40 000–59 000 m^3/a.

The above-presented facts show a natural tendency of the coast to have been slowly returning to the position from before 1840.

TENDENCY OF SEA LEVEL CHANGES IN THE SOUTH-EASTERN BALTIC BY TIDE-GAUGE OBSERVATIONS OF LAST 150 YEARS

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The aim was to analyze the tendency of water level changes in the coastal zone of the south-eastern Baltic (including the Vistula Lagoon), considering this site as an element of the Baltic Sea watershed cascade. We used available data on annual sea level at the tide gauge stations of Russia, namely, Baltiysk and Kronstadt, at which long-term measurements were carried out during 1840–2005. For comparison we have used the data for Klaipeda (1901–2005), Liepaja, Ventspils, Tallinn (1901–1990 for all three points), as well as data for measuring points in the Vistula Lagoon, Curonian Lagoon. All data were referred to the Baltic Reference System (Kronstadt).

The absolute value of mean annual water level in Kronstadt is permanently higher than in Baltiysk, but gradual reduction of this difference from the middle of the XIX century to the end of the XX-th (from 20 to 5 cm) is obviously detected from measured data. It could be a consequence of significant land subsidence in the south-eastern part of the Baltic coast and/or uplift in the Gulf of Finland.

A steady positive trend in the water level variations was revealed; its magnitude varies significantly depending on the time period. In general, during the 100–150 year period, the rate of the sea level rise (SLR) in the lagoons and coastal areas of the Baltic Sea (1.7–1.8 mm per year) is close to the SLR rate in the World Ocean. At the end of the 20th century, the rate of the SLR in the lagoons and marine areas became stronger (up to 3.6 mm per year in the Vistula Lagoon and up to 2.3 mm per year in the sea) and exceeded the SLR rate.

Correlation between the average annual water levels in different points of the eastern shore of the Baltic (Russia, Lithuania, Latvia, Estonia) for the period 1901–1990, calculated after deduction of the linear trends, is characterized by the correlation coefficient in the range 0.86–0.96. It allows to hypothesize that inter-annual variations are caused mainly by one forcing factor for whole eastern part of the Baltic. Dependence on Western Atmospheric Transfer from the Atlantic Ocean was verified.

The result presented mostly rises the questions than gives the answer. Additional analysis of the mean values of sea level from the tide gauges of Baltiysk, Kronstadt, Klaipeda, Liepaja, Ventspils and Tallinn was averaged over the thirty-year intervals for 1901–1990. Data showed the significant lifting in the sea level from Baltiysk to Klaipeda during whole period. The results of the comparison showed that for Baltiysk, Pionersk, Klaipeda, Kronstadt the rate of SLR experienced a permanent increase from the end of the XX century to beginning of XXI, especially in Baltiysk (8 mm/year, 1991–2005). In whole for the period 1901–1990 it was found that according to observations the rate of SLR was negative in Tallinn (–0.2 mm/year) and the annual mean sea level was the most stabilized in Ventspils (trend was about 0).

MONITORING AND ANALYSIS OF CLIFF COLLAPSES TO EVALUATE THE GEOHAZARD POTENTIAL OF THE STEEP BALTIC SEA COAST IN NE GERMANY

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The 377-km-long Baltic Sea coast of Mecklenburg-Western Pomerania is divided into shallow and steep sections. Steep cliffs up to 118 m in height are exposed along 25 sections with a total length of about 140 km (StALU Rostock 2009). They suffer from erosion by the sea and are liable to partial and large scale collapses. Coastal retreat has been studied using historical maps, photogrammetric measurements and laser scanning. The long-term mean erosion rates is about 0.35 m/a. In detail, the erosion rate varies and can reach extreme values as reported from cliffs east of Rostock (Rostocker Heide: 1.20 m/a) and on Usedom (Streckelsberg: 0.90 m/a).

Due to several larger cliff collapses in 2005 on Rügen (*e.g.* Lohme landslide: 100 000 m^3; Obst, Schütze, 2006) the Geological Survey of Mecklenburg-Western Pomerania started in cooperation with the BGR Hannover and the Universities of Greifswald and Tübingen a project of mapping and monitoring of landslides and rock falls along the 25 km long coast of Jasmund peninsula (*e.g.* Günther, Thiel, 2009). Since that, the landslide inventory data base for all steep cliff sections has been steadily increased and comprises now about 600 records of recent cliff collapses and historical events of the last 100 years.

Each record gives information about the location, type and size of landslide and their relationship to geomorphological features (cliff height, slope) and geological properties (bedding, lithological composition, thickness, jointing, porosity *etc.*). Besides, other factors as vegetation, distance to springs and sliding activity are noted. All these data are incorporated in the GIS register of the LUNG. Together with monitoring results using airborne and terrestrial laser scanning techniques they provides users with easy access to landslide information, raises awareness of landslide causes, and will help prevent injury or property damage.

The landslide inventory database was used to create a first geohazard information map for the coast of Jasmund peninsula in scale 1:10 000 (Schütze, Obst, 2011). It shows locations of known landslides and classified areas susceptible to debris flows. This cliff section exhibits the highest number of collapses (220 records) due to its height and complex geological structure comprising soft and intensely jointed Cretaceous chalky limestones and Pleistocene glacial deposits of till, sand, silt or clay. Both stratigraphic successions were glaciotectonically deformed together during late Weichselian ice advances that resulted in tight folding and shearing of the Pleistocene and thrusting and more open folding of the Cretaceous sediments.

Furthermore, leaflets and information boards initiated and financed by the Geological Survey transfer knowledge about the geology of cliff sections, coastal processes and potential risks of landslides (Obst, Schütze, 2012; Schütze, Obst 2013). The effects of geohazards can be minimized, if the broad public as well as politicians and decision makers know the triggers and impacts of cliff collapses.

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EXTREME WAVE EVENTS (EWE) IN THE MIDDLE PART OF THE POLISH BALTIC COAST IN THE LIGHT OF LEGENDS, HISTORICAL RECORDS AND GEOLOGICAL DATA

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There are records of unusual catastrophic events in the chronicles: "The Baltic Sea holds its own weather, which has no connection with the weather on land. Sometimes a submarine storm occurs in the Baltic Sea. Under a clear and calm sky, thunder can be heard rolling along the Pomeranian coast, and dead or half-dead marine or coastal fish are thrown onto land. The local people call that phenomenon the Sea Bear (Seebaer)" (Brüeggemann, 1779).

We present the results of the geological investigation carried out along the Southern Baltic coast near the towns of Mrzeżyno, Kołobrzeg and Darłowo, Poland, where two historical extreme wave events (EWE) were recorded on the 8th of September in 1497 and the 1st of March in 1779. The aim of the study was to verify historical information about peculiar waves at the Southern Baltic coast.

The first stage of the research focused on finding potential EWE layers and identifying their inland extent, morphology and thickness. As Morton *et al*. (2007) indicated, these features can serve as criteria to distinguish EWE layers left by tsunami waves from storm deposits. Two sand layers separated by a very thin bed of peat were found near Mrzeżyno and Darłowo. The boundary between them is clearly defined by organic deposits (peat), while the organic deposits below the lower layer are underlain by lacustrine silts (Darłowo). ^{14}C dating of samples taken from the organic deposits underlying both layers confirmed that they are related to events from the 15th and 18th centuries.

The shape of the top and bottom boundaries of these layers follows the palaeotopography. The maximum inland extent of the lower layer is 1400 m in Mrzeżyno and 700 m in Darłowo, while the upper one stretches up to 400 m from the coast. Their thickness varies from several centimetres to 40 cm (average of 20 cm).

No such layers were recorded in the study area near Kołobrzeg, mainly due to the large distance between the coast and the town centre as well as significant reworking of the near-surface in the urban area. Combined geological and archeological analysis confirmed the catastrophic inundation to the level of 5.0 m above the sea level.

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MODELS OF LAND UPLIFT AND GLACIAL ISOSTATIC ADJUSTMENT IN NORTHERN EUROPE

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Glacial isostatic adjustment (GIA) is the dominating geodynamical process in northern Europe leading to a maximum absolute land uplift of about 1 cm/year near the Swedish city of Umeå. In contrast, the areas of the southern Baltic and North seas are subsiding due to the collapse of the peripheral bulge. Both effects have enormous impact on coastal changes and thus on society and economy, especially in view of current sea-level change which may increase subsidence or decrease uplift, depending on the location.

The Nordic countries have developed and are frequently updating land uplift models for usage in the national geodetic surveys. We present currently used models as well as further efforts for the development of high precision and high resolution land uplift and GIA models which can also help in past, present and future sea level research. This includes most recent results for land uplift/subsidence and sea-level change of the Baltic Sea.

IMPACTS OF WAVESTORMS ON THE EASTERN SHORES OF THE BALTIC SEA IN DIFFERENT COMBINATION WITH SEA LEVEL HEIGHT: STORMS ULLI IN JANUARY 2012 AND ST JUDE IN OCTOBER 2013

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The energy of extreme storms and their impact on shores is exponentially larger than that of moderate storms. However, depending on the combination of forcing factors, some extreme storms may leave significant and lasting marks on the shores while others remain nearly unnoticed based on the observed shore changes. Consequently, there is a crucial need to understand the relationships between met-ocean parameters of extreme storms, corresponding shore processes and geomorphic coastal changes.

The study was carried out in the West Estonian Archipelago – in an active region in terms of both geomorphic and hydrodynamic processes. The study analyzes the meteorological parameters, hydrodynamic conditions and resulting shore changes caused by two extreme storms, characterized by similar meteorological parameters but quite different sea-level and surge conditions – storm Ulli, January 2012 with high sea level and storm St Jude, October 2013 with relatively low background sea level. The aim of the study was to analyse the effects of storm and sea-level combinations on shore processes on the eastern coast of the Baltic Sea.

The wave parameters were instrumentally measured by RDCP and simulated by wave models (SMB, SWAN). The shoreline and topography changes were recorded before and after the storm by RTK-GPS device. Simultaneous experiments with painted sediments were carried out to analyze the sediment transport patterns and wave impacts on the swash zone and on the seabed.

Storm Ulli (January 2012, 1h-sustained wind speed reached 20 m/s, gusts 28 m/s) had the greatest impact in terms of maximum sea-levels and wave parameters among all the storms during the 2011/2012 season. Starting from the pre-elevated background sea level, local storm surge height finally reached 1.2 m, nearshore wave heights were up to 4.2 m and on-site wave run-up reached 3.22 m. High waves combined with elevated sea level caused extensive erosion on the active shores exposed to the prevailing wind direction while rapid accumulation was recorded on the leeward shores. Slight changes were recorded on the sea bottom. The storm St Jude (October 2013, 1h-sustained wind speed reached 23 m/s, gusts 33 m/s) was the strongest storm of the 2013/2014 season. However, the sea-level remained below 0.8 m, while nearshore wave heights reached 5.2 m and wave run-up was 2.9 m. Despite record-high wave heights, only minor changes were registered in the shoreline position and cross-shore profiles. At the same time, the painted sediments placed on the sea-bottom at 2 to 6 m depths moved up to 20 m towards the shore. The coastal slope and the seabed showed signs of extensive erosion.

We may conclude that extreme storms accompanied with high sea-level leave significant marks on the shores while the impact of extreme storms with low sea-level remain modest. Such storms with low sea-level bring up additional material to the swash zone, possibly stabilizing the shore system and building small ridges that act as natural protection against subsequent storm impacts occurring at elevated sea-levels.

LANDSLIDES TYPOLOGY AND PROCESSES IN THE CLIFFS OF NORTHERN POLAND

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Coastal areas have always played a special role for economical, political or social reasons. Therefore, the special attention should be paid to the risks arising from a specific contact of the marine environment and land, where among all types of coasts the greatest risk is related to cliffs, within which landslides of varying range, nature and genesis can be developed.

Landslide processes are generated by a number of interrelated factors, such as geology and geomorphology, hydrological and hydrodynamical conditions, and finally climatic phenomena and human activities. These factors, in various combinations, lead to the development of mass movements which, through constant development are becoming a significant problem. The characteristic of these phenomena and attempts to prevent their development are particularly difficult in complex geological conditions, which can include alternate occurrence of cohesive and non-cohesive rocks, as well as glaciotectonic deformations.

Such conditions can often be found on the Polish Baltic coast. Intensive geodynamic processes have been reported particularly in relation to the region of Pobrzeże Kaszubskie (vicinity of Jastrzębia Góra–Rozewie–Chłapowo). Taking into account the above factors the several types of landslides can be distinguished in the cliffs within the so-called Kępa Swarzewska, especially on the stretch between Jastrzębia Góra and Władyslawowo city. In the course of field work based on geological and landslide mapping at least 3 types of landslides can be identified:

- Type I: simple ground landslide developed in unconsolidated rocks, predominate by fine fractions (sand) while the slip surface is relatively shallow. Such landslides are very common phenomena, basically around whole Polish coast.
- Type II: landslides developed in homogeneous and undisturbed rocks, for example – loams, clays, sands. Examples of this type of landslides are multiple forms developed mainly on the stretch approximately between 132.25 and 133.50 km and 128.50 and 129.50 km of coastline.
- Type III: complex landslides in which the movement and displacement of rock masses occurs in complex geological and hydrogeological conditions. The complexity of factors can be determined by glacitectonic, discontinuity of rock layers and thrust zones. Slip surface occurs at considerable depths, and sometimes several slip surfaces can be distinguished. These types of landslides are located in the vicinity of Jastrzębia Góra and Rozewie.

In relation to all of the above types the prediction of their formation is extremely difficult. Even if we have long-term observations, variable over time the mass movement are difficult to interpret. It is clear that the changes are continuous, but occurs with varying intensity. Proper recognition of the types of mass movement could be crucial in the establishing the appropriate methods to prevent their development.

SESSION 4

ENVIRONMENTAL ISSUES AND PRACTICAL APPLICATIONS

METHODOLOGY OF SUBMARINE GROUNDWATER DISCHARGE RESEARCH, PUCK BAY, POLAND

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The presence of a contact zone between marine waters and groundwater in the coastal zone was well known for a long time, problems with drainage and sea encroachment, despite steady progress in the diagnosis are still not well understood. A number of research papers on this subject has already been taken, thanks to the development of new research methods expanding their scope and finding out more detail information is now possible.

The aim of this study is to locate the SGD – submarine groundwater discharge in the bottom of the Bay of Puck and establish conditions for drainage. The study involved inner part of the Puck Bay and the rim of land consisting of the coastal belt of the Kashubian Coast plateau.

Implementation of the task was possible using the methods of classical hydrogeology and analysis in the field of geographic information systems (GIS). Potential outflows of fresh water in the Puck Bay is determined by analyzing satellite images, which develop in the ArcGIS helped to get a thermal picture of research area. A clear temperature anomaly pointed to a place for installation divers that were periodically measuring parameters such as water temperature and salinity. As a result, it was possible to confirm the presence of SGD in the bottom of the sea.

In the context using new research techniques regarding the measurement of sediments filtration attempt to use apparatus called filtometer that was constructed at the Institute of Physical Geography and Environmental Sciences, University of Adam Mickiewicz in Poznań. Hitherto, bottom filtrometer used in the hydrogeological measurements intended for determining spot rate of filtration of water from the water reservoir to the ground. The device has been developed in such a way that allows to determinate the intensity of the drain water from the aquifer. Preliminary results of SGD research allowed to establish relationships between fresh groundwater and the sea and the separation zones of groundwater drainage.

Discussed research issue in the field of submarine hydrogeology is extremely important for the formation of the Puck Bay ecosystem. Confirmation of the effectiveness of the work that presents a new measuring techniques will help in the next stage of research on balancing the flow of groundwater, the designation of drain zones and obtaining samples of underground water for its quality tests.

SPATIAL AND TEMPORAL POLLUTION PATTERNS IN WESTERN BALTIC SEA SEDIMENTS

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The semi-enclosed Baltic Sea is surrounded by nine highly industrialised countries and therefore under strong anthropogenic pressure. Apart from direct impact by commercial use (fishery, maritime traffic and constructions), industry and agriculture are still the main sources of contamination through river discharge and air pollution. Based on geochemical analyses of surface sediments (mapping) of the German EEZ and short sediment cores from the Mecklenburg Bight and Arkona Basin, we aim at a regional characterisation of the present environmental situation and a reconstruction of the historical development.

Here we present sedimentary trace metals (*e.g.* Hg, Cd, As, Pb) and contents of organic pollutants (PCB´s, PAH´s), which provide insights into the pollution history since pre-industrial times. Our data suggest temporary storage of contaminants from the former highly polluted Oder River in the Oder Lagoon for decades before entering the Pomeranian Bight and further transport NW to the Arkona Basin and/or NE to the Bornholm Basin. Other pollution sources are dumping sites appearing as hot spots surrounded by aureoles of contaminated material. Two hot spots are situated in the Mecklenburg Bight near Lübeck and at the western edge of the Arkona Basin, where industrial waste from a smelter and presumably military waste from World War II was dumped in the 1960s and during/shortly after the war (Leipe *et al*., 2005, 2013), respectively. Although both basins are the most important deposition areas for fine-grained muds and associated substances, it is currently unclear whether contaminants remain buried on longer time-scales because sediment mixing by bioturbation, hydroturbation, and bottom trawling continuously interferes with sediment accumulation. While some pollutant patterns allow historical reconstructions, several profiles are strongly mixed but are at least suited for inventory calculations.

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MODELLING AND EXPERIMENTAL ANALYSIS OF POTENTIAL FEASIBILITY TO PROTECT THE MARINE SHORE OF THE SOUTH-EASTERN BALTIC BY OFFSHORE DISPOSAL OF THE DREDGING MATERIAL

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Material of dredging disposed in offshore dumping sites may be included in the lithodynamics turnover of the sediments in the coastal zone and be used for coastal protection. The report overviews the results of modeling analysis made for three dumping sites in the Kaliningrad Oblast and the results of experiment of dispose the dredging material in one of this site near the entrance to the Vistula Lagoon. In numerical analysis three dumping sites located at the south-eastern part of the Baltic Sea (Kaliningrad Oblast) at shallow depths are considered (Sokolov, Chubarenko, 2016). The first one is located to the south of the Vistula Lagoon inlet in front of a permanently eroded open marine shore segment. The second one is located to the north of the Vistula Lagoon inlet, and is used now for disposing of dredged material extracted from the Kaliningrad Seaway Canal. The third dumping site is located near the northern shore of the Sambian Peninsula to the east of the Cape Gvardeijski and assigned for disposing the dredged material extracted from the fairway to the Pionerskij Port located nearby. A numerical hydrodynamic-transport 3D model (MIKE) was used to model sediment transport under different wind actions.

Demonstration disposal at the first site is presented. Changes of sediment distribution resulting from a demonstration disposal of clean fine sand at depths of seven to nine metres opposite the eroded segment of the shore are examined (Chechko *et al*., 2015]. Experimental study and supplementary numerical modelling analysis of sediment transport for different winds showed that the disposed material is transported northward or southward alongshore depending on the onshore wind direction, and almost none of it is stored at the shore slope. Only the offshore winds are favourable for accumulating sediments near the shore, but winds in these directions have low probability of repetition. The demonstration disposal and numerical modelling results demonstrate that the only way to use the dredged material to protect the eroded shore near the inlet of the Vistula Lagoon is to dispose it directly onto the beach and not into the shallow water nearby.

The first location (to the south of the Vistula Lagoon inlet) looks very ineffective for potential protection the shore nearby. At the other hand, the second and particularly the third locations are favorable for transport of disposed material to the shore.

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TRANSPORT AND FATE OF TERRYGENIC MATTER IN PRODELTA OF VISTULA RIVER (GULF OF GDAŃSK, BALTIC SEA)

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The River Vistula with mean water discharge 1080 m^3/s is the second largest supplier of fresh water and terrigenous matter to the Baltic Sea. The impact of this river on the Baltic coastal system and the fate of the sediment delivered to the Gulf of Gdańsk are not well understood. Also the scale of input and distribution of the Suspended Particulate Matter (SPM) from Vistula are not fully recognised. Spatial transport patterns, settling, deposition and accumulation of the sediments were studied at the Vistula prodelta in different seasons from January 2012 to May 2013. Range of distribution and composition of SPM with distinction for Particulate Inorganic Matter (PIM) and Particulate Organic Matter (POM) were also verified. $\delta^{13}C$ composition in surface water, material from sediment traps and surface sediments were examined in terms of organic matter sources identification. The concentration of suspended matter in the water column was measured with optical methods, the sedimentation rate was determined with sediment traps, and the sediment accumulation rate was estimated using ^{210}Pb dating. The water samples collected from the Niskin Bottles and sediment traps were vacuum-filtered onto pre-weighed filters and then concentration of SPM, PIM, POM were estimated. Also $\delta^{13}C$ composition of the POM were measured with an Isotopic Ratio Mass Spectrometer IRMS.

The following results and regularities were observed as conclusions of researching campaign:

- During the average water levels on the Vistula, the typical hypopycnal flows of brackish layer took place. This system favours the slow mixing of river and marine waters, leading to further distribution of SPM in Gulf of Gdańsk. However, in most cases, total or partial mixing of brackish and marine water was noted at a distance of approx. 10 km from the river mouth.
- Analysis of the SPM concentration in surface waters of the Vistula prodelta during different seasons showed a high correlation with the river flow. Highest concentrations of suspensions were observed especially during high river discharges and stronger winds. During low discharges in the Vistula, delivery of PIM and POM was limited to the prodelta only.
- The high concentrations of SPM in Vistula water resulted in the rapid particles falling out from the water surface layer in the prodelta region, and thus a high rate of deposition in the area.
- Analysis of $\delta^{13}C$ in the surface waters of the Gulf of Gdansk showed a satisfactory correlation with river discharge. Only during marine phytoplankton blooms a significant increase in $\delta^{13}C$ were observed. However, the values of $\delta^{13}C$ for surface sediments indicated the predominant share of mixed (terrestrial and marine) organic matter with a slight predominance of marine POM in outer prodelta.
- Grain size data of the surface sediments and the sedimentation in water column for the period of the storms indicated intense redeposition of surface sediments within prodelta and sediment transport to deeper basin.
- The sediment accumulation rates in Vistula prodelta is lower than the suspensions sedimentation measured with sediment traps thanks to sediment redeposition and its further near bottom transport during the storms.

COUPLED MANGANESE AND TRACE METAL CYCLING IN THE DEEPS OF THE BALTIC SEA

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The Landsort Deep and Gotland Basin in the central Baltic Sea are well known for considerable sedimentary enrichments in Ca-rich Mn carbonates ($MnCO_3$). The environmental conditions favouring pronounced formation of $MnCO_3$ are, however, still under debate. Previous conceptual models include oxygenation of sulphidic bottom waters enriched in dissolved Mn due saline inflows from the North Sea but also on-going $MnCO_3$ precipitation under sulphidic bottom water conditions (Huckriede, Meischner, 1996; Lenz *et al.*, 2015). Our comparison of water column time series of O_2 and H_2S covering the last 60 years with well-dated sediments from both basins suggests long-lasting hypoxic but non-sulphidic bottom waters as an important prerequisite for exceptional $MnCO_3$ presence. Because the hypoxic but still O_2-containing bottom waters prevent the escape of reduced Mn into the open water column, enhanced deposition of Mn-oxides (MnO_x) at the sediment-water interface likely promotes the transformation of MnO_x into $MnCO_3$. Intense Mn cycling close to the sediment surface further affects sedimentary trace metal (TM) inventories via scavenging (Dellwig, *et al.*, 2010). In accordance with TM signatures of redoxcline-derived MnO_x particles, TM enrichments in $MnCO_3$ layers strongly differ from those observed in sapropelic sediments deposited during stagnation periods. While Mo is highly enriched in both Fe sulphide- and Mn-rich layers, Se and U sequestration is favoured during stagnation periods with sulphidic bottom waters. In contrast, Co, Sb, and especially W are tightly related to Mn cycling. These TM signatures also appear in pre-industrial Mn layers precipitated during the Medieval Climate Anomaly and the Holocene Thermal Maximum and differ substantially from typical sapropels formed *e.g.* in the Holocene Black Sea.

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LANDSCAPES MAPPING ON THE GDANSK-GOTLAND SILL

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The Russian part of the south-eastern Baltic Sea has been heavily threatened during last years by commercial and leisure human activities, including fisheries, dredging, tourism, *etc*. This causes severe pressures on vulnerable marine habitats and natural resources. Geological mapping provide the basis for development of marine landscape maps for areas with little or no biological information (Al-Hamdani *et al.*, 2007, BALANCE project).

The high-resolution landscape maps are developed for the coastal zone of the Russian part of south-eastern Baltic Sea which is covered by detail geophysical surveys. In contrary, the Gdansk-Gotland sill situated in off-lying sea is poorly studied. This sill is the bottom rise up to water depth 70–90 m. Here are extremely reduced sedimentation rates, lower than in adjacent Gdansk and Gotland Deeps. We present a new data of geoacoustical surveys of the Gdansk-Gotland sill carried out in 2015–2016.

The field investigations included side-scan and high-resolution bathymetry surveys by Benthos C3D, acoustic profiling by Knudsen Chirp Portable 3212 of 28–40 and 80–140 kHz, sediment grub sampling. The grain-size analysis of sand and gravel was made by dry sieving according Wentworth scale. The grain-size of muds was obtained with the laser diffraction particle size analyzer Shimadzu SALD 2300 on bulk sediment samples. The Folk classification diagram was used for identification of sediment types. The ArcGis software was used for data post processing. The archive data were used for the geological mapping as well.

The Gdansk-Goltland sill is represented by sculptured relief and very complicated patchy sediments distribution. The bottom surface is compounded of coarse-grained till outcrops partly covered by the Baltic Ice Lake and Ancylus Lake deposits. The undulating till surface is clearly expressed. The high diversity of the bottom landscape types according BALANCE project approach are identified on study area.

New bottom relief features were identified. The extended chaotic furrows (ploughmarks) of 1 m depth and up to 10 m width in most cases filled with thin layer of mud were discovered. Most of furrows are V- or U-shaped stepped depressions and they can be attributed to the action of icebergs scouring. Icebergs from Scandinavian Ice Sheet were expanded in the Baltic Ice Lake.

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SAND WAVES ON THE SOUTHERN BALTIC BOTTOM

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The bottom of the southern Baltic Sea contains sand ridges with different sizes and character (Rudowski *et al.* 2008, Kubacka *et al.* 2016). The ridges form isolated bedforms or series. Registered among these were series of rhythmically aligned forms, with wavelengths ranging from several metres, through tens of metres, up to even hundreds of metres, and heights ranging from tens of centimetres to several metres. Each series is either a megaripple (wavelength up to 10 m) or a sand wave (wavelength over 10 m). The series occur primarily on sandy plains over 20 m in depth, and are usually composed of medium-grained sands.

Several examples of such sand waves on the bottom of the Polish Exclusive Economic Zone are provided. The study used material obtained from research conducted at the Marine Institute in Gdańsk as part of other specialist tasks. The material presented in the study constitutes an important foundation for a discussion on the conditions for and time and method of their formation as well as for an assessment of environmental conditions, including conditions pertaining to the exploitation of resources and marine engineering infrastructure. Such forms have been reported to occur in tide seas (Ashley 1990), where they are considered to be caused by tide currents, and in fluvial environments. Since the origin and development of Baltic sand waves remain undetermined, further specialist research is needed.

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THE OCCURRENCE OF MAGNETIC AND GEOCHEMICAL ANOMALIES IN EXTERNAL DELTA SEDIMENTS OF THE VISTULA RIVER CROSS-CUT

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The Vistula River Cross-Cut is an artificial channel between Przegalina and Świbno villages. The excavation of this new riverbed, finished in the 1895, is undoubtedly the biggest investment for the permanent flood protection in the Vistula River Delta. This is also considered to be the one of the most radical and the most important hydrographical changes in the modern history of the Vistula River. The channel is about 3000 m long, 400 m wide and its depth is up to 10 m.

The results of this study is to determine the scale of changes in terms of the quality of Gdansk Bay bottoms located in the estuary area of the Vistula River Cross-Cut, with the usage of modern magnetic techniques. The samples of sediments were subjected to magnetic analysis, *i.e.* the measurement of magnetic susceptibility by means of MS2 Barington, the magnetic susceptibility gauge equipped with magnetic detectors MS2B or MS2F, and chemical analysis, *i.e.* examination of heavy metals. The magnetic techniques is rely upon the measurement of low-field and specific magnetic susceptibility, as well as upon calculated frequency correlation between magnetic susceptibility and the constitution of heavy metals and oil-derivative substances in the samples of examined sediments.

Based on the studies, was defined the impact of techno or geogenic factors in the sediments of the Vistula River estuary zone based on the characteristics of an easy to measure geophysical gauge of marine environment pollutions, which thus can be widely ractised in seas and oceans monitoring.

This study was financed by the Polish National Science Centre (grant DEC 2012/07/B/ST10/04080, 2013-2016).

FIBERBANKS IN THE NORTHERN BALTIC SEA – EXTENDED KNOWLEDGE OF AN ANTHROPOGENIC SEDIMENT

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Anthropogenic fiber banks and fiber-rich sediments are present along the coast of Northern Sweden as a result of deposited waste from the forestry and pulp and paper industries during mainly the 20th century. These organic-rich sediments are oxygen-poor and thus unfavorable for biota. In addition they may contain high levels of toxic pollutants that could spread and negatively affect the surrounding aquatic environment.

Eleven coastal zones and five lake and river areas with suspected fiber banks were investigated during 2015–2016 by the Geological Survey of Sweden (SGU) in cooperation with concerned regional authorities.

Field work was carried out using SGU's research vessel "Ocean Surveyor" and the smaller vessel "Ugglan" along the coast, and "Ugglan" alone in lacoustrine environments. Preliminary results indicate that fiber banks and/or fiber-rich sediments occurred in all, but three of the investigated areas.

The project is on-going and the investigations will result in a thorough description of the fiber sediments in terms of spatial distribution, estimates of volumes and their content of a wide range of pollutants. A more precise definition of the terms "fiber banks" and "fiber-rich sediments" will also be formulated. Furthermore a risk classification will be made using a recently developed method that includes geological phenomena, known to increase the risk for re-mobilization of pollutants, such as submarine landslides, land uplift that causes negative shore-line displacement, increased wave abrasion *etc.*

The goal of the project is to have a list of prioritized fiber banks in terms of need for remediation.

The project is managed by the County Administrative Board of Gävleborg and financed by the Swedish Agency for Marine and Water Management. The project is a continuation of the investigations previously carried out by SGU in the County of Västernorrland, which were reported in 2014: *http://resource.sgu.se/produkter/sgurapp/s1416-rapport.pdf*. The risk classification method mentioned above is developed by the County Administrative Board of Västernorrland and the consultant company Golder Associates.

SEABED DYNAMICS OF THE SOUTHERN MIDDLE BANK (SOUTHERN BALTIC)

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The Southern Middle Bank is a shallow sea area located *ca* 90 km north from the middle part of the Polish coast and the same distance to the southeast of the Swedish coast near Blekinge and Kalmar.

The test field having dimensions of 3 × 9 km is located in the south-eastern part of the Southern Middle Bank. The water depth within the test field is generally between 16 and 26 m. The area was investigated using seismoacoustic (boomer) and side-scan sonar (SSS) profiling (range 2 × 250 m). In total, 81 km of profiles were collected (full coverage by side scan mosaic) and 5 sediment cores were taken using a 6-m-long vibrocorer.

The analyses of core samples included determinations of grain size distributions, mineral-petrographic composition (fraction 1.0–0.5 mm), content of caesium-137 (^{137}Cs) as well as accelerator mass spectrometry (AMS) ^{14}C and optically stimulated luminescence (OSL) dating.

The SSS records revealed a range of large-scale bedforms (sand waves, megaripples). The distances between sand-wave crests varied between *ca* 5 m and *ca* 15–20 m. Crests are asymmetric with lengths ranging from dozens of meters to 100–150 m, generally straight or slightly curved. There are also lunate sand waves with distances between them reaching *ca* 10 m. These large-scale bedforms are built of medium and fine sand. Smaller bed forms, transitional size megaripples built of coarse sand and fine gravel, have crest lengths reaching *ca* 40 m with distances between crests of *ca* 0.8 to 1.0 m. In both cases, determination of regularity in crests orientation is not possible because of the large diversity of its directions. Measurements of ^{137}Cs in sediment cores indicated that at least *ca* 1 m of sand and 0.2 m of fine gravel (<32 mm) was redeposited during the last 70 years.

The OSL ages of the sediments range from 0.47 ±0.06 to 8.98 ±0.68 ka. Among 27 dates, 12 are in the range of 7.03 ±0.51 to 8.98 ±0.68 ka. This corresponds well with the time of the sea transgression into the Southern Middle Bank. The glaciofluvial deposits were in contact with the sunlight during their redeposition in shallow water which resulted in optical bleaching. Sediments of younger age could have come into contact with the sunlight after the transgression, and also recently when they were redeposited during storms. Sediment samples dated by the OSL method for 4 to 8 ka contain shells dated for 1758 and 1771 AD. The presence of ceasium-137 in the sand with the OSL ages between 4 and 7 ka also indicates contemporary erosion, redeposition and, in result partial bleaching.

The results of the investigation carried out in the Southern Middle Bank confirm large-scale erosion and redeposition of glaciofluvial deposits during the marine transgression as well as reveal contemporary high seabed dynamics built by sand and even sandy-gravel.

The research was funded by the National Science Centre, Poland (project No. 2011/03/B/ST10/05822).

GEOLOGICAL MAPS OF THE GULF OF FINLAND SEA BOTTOM AS A BASIS FOR ASSESSING THE STATE OF MARINE ENVIRONMENT

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The principle target of the frame directive of the European Union marine strategy is to preserve the good condition of the sea areas or reach it by 2020. The SedGoF project (Assessment for ecosystem-based management of marine environment on the basis of the sea bottom and sediments of the Gulf of Finland) was carried out for reaching the strategy goals. The main aim was to compile a data model on the Gulf of Finland sea bottom and its environmental state and to give an assessment accordingly.

The assessment was reached trough the following activities:

- Compilation of digital geological maps;
- Definition of sedimentation areas;
- Choosing adequate sampling and monitoring sites;
- Gathering of new data during marine expeditions (eight expeditions, at least 800 sediment samples, 2,500 km of geophysical profiles);
- Analysis of micro- and macroelements, age definition of sediments;
- Comparative analysis of element content in the sedimentary sequence in regard to background content and assessment criteria valid in various;
- Giving an assessment.

Digital geological maps of the Estonian Exclusive Economical Zone of the Gulf of Finland were compiled for the bedrock, quaternary cover, geomorphology and geological resources. Supplementary fieldwork was conducted with geophysical profiling and with selecting appropriate accumulation areas for sampling. These map layers provide an essential addition in the dataset for spatial planning of the use of the Gulf of Finland. In addition, the maps form the basis for periodical monitoring of the environmental state of the sea bottom.

The project is financed by the financial mechanism of European Economic Area, supported by Norway, Iceland, and Liechtenstein. The project goal is to contribute to reaching a good environmental state of Estonian seas and inland waters.

SEDIMENT AND CARBON ACCUMULATION ALONG THE SOUTHERN COAST OF FINLAND

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The southern coast of Finland is a mosaic of hundreds if not thousands of islands, peninsulas and bays, which also are reflected in the seabed of the coast. The sea floor is composed of a patchy and fragmented mosaic of mainly quite small basins separated from each other by thresholds of islands, peninsulas or submarine ridges. This affects transport and near bottom currents such that deposition of suspended particles is restricted to certain areas only.

Linear sediment accumulation rates along the southern coast of Finland have been found very varying, with rates from less than 0.5 cm/a to values of nearly 3 cm/a, and mass accumulation rates from 0.5 kg/m^2/a to 8.8 kg/m^2/a. The sediment accumulation rates have been observed to be higher in shallower water in coastal sheltered or semi-sheltered bays and lower in off shore areas more distant from land.

Total carbon concentrations vary from 0.3% to 20.1% and measured carbon accumulation rates from 20 g/m^2/a to 355 g/m^2/a. The highest carbon concentrations are usually found in deeper water with some distance from the coast, while the highest carbon accumulation rates are normally found in the coastal shallow basins where also sediment accumulation is observed to be strongest.

CONSEQUENCES OF UNDER-WATER MINING TRANSFORMING NATURAL SEDIMENTATION CONDITIONS IN THE EASTERN GULF OF FINLAND

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For many years the aggregates (sand and sandy-gravel mixtures) are extracted from the bottom of the eastern Gulf of Finland mainly within near-shore sand terraces formed in Early-Middle Holocene during Littorina Sea regressions. Study of the areas of sand under-water mining using side-scan sonar and seismic acoustic profiling allowed finding numerous technogenic depressions with relative depth up to several meters. It was supposed that these bottom relief forms have to be filled in by surrounding sand. But sediment sampling within these depressions near the northern coast of the gulf showed accumulation of laminated silty-clayey mud layer more than 50 cm thick. It may be stated that even in conditions of active wave processing in coastal zone, restoration of sand deposits within the former underwater quarries does not take place. Study of Cs^{137} distribution in the sediment core with Chernobyl peak fixing allowed to determine high sedimentation rate (up to at least 1.2 cm/year).

Resembling situation was found within the area, where in 2006–2008 "PetroTrans Ltd." carried out an experimental underwater extraction of ferromanganese concretions using dredge pump vessel "Lauwer". Totally, it was extracted about 60 000 tonnes of concretions. The area of underwater mining was investigated in 2012–2015 using side scan sonar and multibeam echosounding profiling, as well as underwater video-observations and sediment sampling. Within the trenches (0.5–1.0 meter depth) left by mining vessel, conditions of sedimentation were markedly changed. Former slow or almost zero clastic sediment accumulation accompanied by concretions growth within this area was changed by intense silty-clayey mud accumulation. The thickness of silty-clayey mud surface layer suggests abnormally high (up to 1–1.5 cm/year) recent sedimentation rate. Spheroidal concretions (up to 1 cm diameter) and their debris are rare and mainly found buried in the sediments at a depth of 5–10 cm. Lack of microconcretions and smoothed surface of buried concretions indicate that the concretions at present do not grow. Concretions are conserved or, more likely, dissolved. This supposition is confirmed by geochemical data. Comparison of the geochemical structure of concretions sampled within the area of underwater mining and outside it allowed to identify their noticeable difference. It can be assumed that this was a result of selective removal of elements from dissolving concretions. Thus, the concretions remaining after underwater mining as a result of change of sedimentation conditions have become a secondary source of contamination of bottom sediments. It is possible to predict further dissolution of concretions buried in the sediment and their subsequent formation at the periphery of the areas of modern silty-clay mud accumulation after the trenches left by the dredger will be filled by sediments and sedimentation equilibrium will be restored.

CHARACTERISTICS OF LABILE SEDIMENTARY ORGANIC MATTER EN ROUTE FROM SOURCE TO SINK AREAS IN THE SOUTHERN BALTIC

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Organic matter plays an important role in the marine environment and is an essential component in the carbon cycle of shelf seas. Although quantitatively it is a minor component, organic matter has an influence on properties of sea water (*e.g.* it conditions colour of seawater, modifies the exchange rate of gases through the atmosphere – seawater interface, and sets up redox conditions) and processes occurring in sea water (*e.g.* absorption of substances by biota, regeneration of nutrients). The properties of the bulk organic matter depend on the proportion of the autochthonous *vs* allochthonous and labile *vs* stabile fractions. Both the former and the latter may change spatially and temporally between and within individual basins.

Origin and stability of sedimentary organic matter in the Baltic Proper were the aim of the presented study.

Elemental composition (C, N) and stable carbon isotopes ($\delta^{13}C$) were measured in order to quantify the origin, concentration and composition of sedimentary organic matter in both the shallow and depositional areas of the Baltic. The contribution of organic matter originated from land sources *vs* marine sources was calculated using the end member approach. Labile fraction of the bulk organic matter was assessed by measuring total organic matter in the course of 410 days long storage

The obtained results, indicate that the contribution of the autochtonous organic matter fraction is the largest in the near shore, shallow sediments (58.7–72.8%), while in the sediments of the depositional areas it is the lowest (54.3–58.3%). Furthermore organic matter in the sediments of the study area shows progressive depletion of the labile fraction in the transect from coastal, shallow areas (spread along the southern coast) to depositional ones (Gotland and Bornholm Deeps).

IS GLOBAL WARMING A REALITY OR JUST A POLITICAL HOAX?

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The global average temperature has been rising since the Little Ice Age (15th to 18th century) and that is a fact. That the rate (speed) of this temperature rises up is according to the IPCC unprecedented (= never seen before) is, however, a matter of debate and hardly a fact. The paradigm seems to be that this rise is mainly due to human-made emissions of CO_2 following the increasing use of fossil fuels in the wake of industrialization and urbanisation.

But really, is the increase in atmospheric CO_2 the villain that must be stopped by all available means? A questionable consensus seems to have evolved within the "green" meteorological community insisting that a continuing rise in temperature will lead to increasing catastrophic weather events (heat waves, floods, storms, *etc.*), but...

As geologists we should all be fully aware that global temperatures, or more precisely climates, have varied between hot and cold and dry and humid conditions through most of our Earth's history. This we know because a multitude of signs of drastic climatic changes have been observed in geological records.

The closure of the Panama isthmus between the Pacific and Atlantic oceans some 3 million years ago seems to coincide with the onset of a long series of ice ages and intervening interglacials. Where does the Milankovitch theory of ice ages fit in?

During the present interglacial and more specifically the Holocene climatic optimum (7–8000 yrs ago) was obviously warmer than today with even northern Greenland free of ice. Still even the polar bears survived the warmer and partly ice free climate.

In more recent times we know that the "global" climate was amiable during the Roman-Period but miserable during the following Dark Ages (early medieval 500–800 AD). The Medieval Warm Period (1000–1400 AD) was at least as warm as that of today. This again was followed by climatically difficult times during the Little Ice Age 1400–1800 AD. Fortunately the next centuries saw a marked warming leading to increased human activity and well-being through growth of industrialisation and urbanisation.

So why would the present climate similar to the warm periods of the past be something exceptional? Present increase in atmospheric CO_2 can not be the cause because ice core data shows that varying concentrations of this gas does not regulate global temperature but on the contrary this minor gas crucial for life as we know it, follows (not causes) changes in temperature with a delay of hundreds of years.

So what has changed during the past decades to cause the present global warming hysteria? The simplest answer is POLITICS and naturally BIG MONEY. In this reality scientific debate in search of alternative (improved) knowledge is not allowed if you want to stay alive.

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ABSTRACT VOLUME

SESSION 1

TECTONICAL FRAMEWORK AND PRE-QUATERNARY GEOLOGY OF THE BALTIC SEA

CHALLENGES FOR THE INTERPRETATION OF THE ”BALTEC” EXPEDITION DATA (MARCH 2016) – A DETAILED LOOK AT THE ZECHSTEIN LAYER OF THE MECKLENBURG BAY (SOUTHERN BALTIC SEA)

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New high resolution multi-channel seismic data was acquired in the course of RV "MARIA" S. MERIAN expedition MSM52 (BalTec) imaging the sedimentary and tectonic inventory of the southern Baltic Sea between the North-East German Basin across the Tornquist Fan to the Baltic Shield east of Gotland. We used a 216 channel streamer with a small initial and a maximum offset of 2725 m, which allows gapless imaging from Paleozoic strata up to the seafloor for the first time. Previous seismic surveys in limited areas with deep target horizons or with focus on Permian to Caenozoic strata are only of low vertical resolution. In contrast, the new BalTec data reveal both deep penetration and optimum vertical resolution of the sedimentary basin fill due to the seismic source array which comprised eight GI-Guns. We point to special challenges of data processing such as multiple suppression and model building. On the basis of the Zechstein salt in the Mecklenburg Bay we will exemplify how the processing influences interpretation. As part of the widespread profile net acquired during the expedition, the seismic interpretation will be of great benefit to decipher the sedimentary and tectonic evolution of the Mecklenburg Bay. A first onboard processing already allows for the interpretation of the top and the base of the Zechstein salt. Using one salt pillow imaged by a single seismic profile as an example, we discuss challenges and problems in the interpretation of the Zechstein horizon. We show how the results of a detailed seismic velocity analysis may improve the image quality. Furthermore, the seismic velocities can also be an indicator for the lithology. Finally, these velocities are needed to convert the seismic data from time to depth. The new data will be used to bridge still existing gaps in stratigraphic interpretation across the Baltic Sea. For future work these interpretations will help to extend a subsurface model of the North German Basin to the German sector of the Baltic Sea.

SESSION 2

BALTIC SEA PALEOENVIRONMENTS

THE BRAKISH PHASE OF THE YOLDIA SEA – AN IMPORTANT STAGE IN THE HISTORY OF THE BALTIC SEA

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The brackish phase of the Yoldia Sea is traditionally dated to c. 11 300 to 10 950 cal. yr BP. This duration is based on the cross-correlation of several geographically spread clayvarve sequences recording fragments of this stage. Coring during the IODP Expedition 347 has provided us with a long and continuous sediment core, M0063, from the deepest basin of the Baltic Sea, the Landsort Deep, covering the entire Yoldia Sea stage. This core give us the opportunity to for the first time investigate the history, duration and development of this intriguing stage in the Baltic Sea history on a yearly resolution. We will present results from the clayvarve investigation of the varved sequence and salinity reconstruction of the brackish phase based on diatom analyses.

A SUBMERGED MESOLITHIC LAGOONAL LANDSCAPE IN THE BALTIC SEA, SOUTH-EASTERN SWEDEN – EARLY HOLOCENE ENVIRONMENT RECONSTRUCTION AND SHORE DISPLACEMENT BASED ON A MULTIPROXY APPROACH

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Remains of a submerged landscape are found at Haväng in the Hanö Bay, south-eastern Sweden, containing organic-rich sediments, wood remains and archaeological artefacts. The submerged landscape stretches almost 3 km from the present coastline down to depths of at least 20 m b.s.l. The landscape was formed during two low-water phases of the Baltic Basin, the Yoldia Sea (11 700–10 700 cal. BP) and the Initial Littorina Sea (10 200–8 500 cal. BP). The inner part of the landscape, formed during the Initial Littorina Sea stage, is the focus of this study aiming at reconstructions of the local environment and shore displacement during the Early Holocene, and the nature of human exploitation of the area during the Mesolithic. A 3-m-long sediment sequence was sampled at 8 m b.s.l. and was analysed for pollen, diatoms, organic and inorganic elements, which was explored in the context of highly detailed Multibeam echo sounding bathymetry of the area and surveillance and sampling of archaeological artefacts by experienced divers. The sediment sequence represents a stable and productive lagoonal environment, with an unusually high accumulation rate, dated to *ca* 9100–8600 cal. BP. The diatom data show a weak, but definite brackish signal throughout the sediment sequence. The uppermost meter of the sequence reflects a destabilized environment as seen in the diatom assemblages and element composition. The destabilization is interpreted as a response to an increased brackish influence due to the approaching coastline during the Littorina transgression. Stationary fishing constructions, dated to 9100–8400 cal. BP, have been found throughout the area, which indicate extensive lagoonal and riverine fishing activity in the area, something previously not seen during the Mesolithic in Sweden. Findings of elk and red deer bones and antlers with slaughter marks, and a unique pick axe of elk antler indicate use of terrestrial resources. The local shore displacement is characterized by rapid water level changes, as the Ancylus transgression reached a maximum of 2 m b.s.l., followed by the Initial Littorina Sea low-stand at 12 m b.s.l. The Haväng site shows the potential of submerged landscapes as palaeoecological source materials and demonstrates the importance of coastal resources near river mouths for Mesolithic communities.

TRACING ENVIRONMENTAL CHANGES IN THE BALTIC SEA COASTAL ZONE DURING THE LAST 2000 YEARS

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The Baltic Sea is an ecosystem suffering heavily from eutrophication manifested in changed biodiversity, cyanobacterial blooms, decreased secchi-depth and increased sea bottom hypoxia.

This ongoing project aims to increase our understanding of how climate change and human impact have affected the Baltic Sea. Our focus is on how the distribution of hypoxia and the nutrient loading in the coastal zone have varied during the last 2000 years. This time frame comprises two periods with extensive areal distribution of hypoxia in the open Baltic Sea. The first time period 1000–700 years BP corresponds to the medieval climatic anomaly and coincides both with an increase of water temperature and a suggested increase of human population. The second time period from 1950 to present caused by eutrophication has led to a rapid expansion of hypoxic sea bottoms, and the Baltic Sea now constitutes one of the largest hypoxic areas worldwide.

In the coastal zone, in contrast to the open Baltic Sea, data on long-term trends of hypoxia are lacking. In order to increase our understanding of human impact on the Baltic Seas ecosystem, coastal sites should be more carefully studied as land-based human activities will probably influence the coastal zone first, before the effects are registered in the open Baltic Sea.

Laminated sediments are used as a proxy for hypoxic events, and diatom analysis followed by statistical analyses using transfer functions, will be used to reconstruct historical nutrient levels. Further, we will compare results from the coastal zone with the open Baltic Sea in order to explore if there is a synchronicity in registered environmental changes.

Several sediment cores have been sampled along a selected part of the Swedish east coast using piston and gravity corers. These cores are being studied using a multi-proxy approach. Lithologies, age models and sedimentation rates will be presented together with results from diatom analysis and geochemical analyses including total organic carbon content (TOC), C/N-ratio, stable nitrogen ($\delta^{15}N$) and carbon isotopes ($\delta^{13}C$).

MIDDLE AND LATE HOLOCENE CLIMATE FORCING ON THE OPEN BALTIC SEA: A DIATOM STRATIGRAPHICAL INVESTIGATION FROM IODP EXPEDITION 347 SEDIMENT CORE M0063 LANDSORT DEEP

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This project aims to investigate the role of climate-driven processes on the open Baltic Sea from the Middle Holocene up to the present. The objectives are to determine the history, timing and duration of Middle and Late Holocene Baltic marine inflows and its implications for changing salinity and to reconstruct the Holocene historical record of ice cover in the open Baltic Sea. The emphasis will be on identifying triggers and timing of high primary productivity events and the return to low productivity during the Littorina Sea in high resolution, and to assess the relative importance of natural climate forcing versus anthropogenic forcing on environmental change of the Baltic Sea.

During IODP Expedition 347 "Baltic Sea Paleoenvironment", a sediment core with extremely expanded laminated Middle and Late Holocene sequences from Landsort Deep, the deepest subbasin in the Baltic Sea basin, has been retrieved. Diatom stratigraphy, using both relative and absolute abundance, and micro fabric analysis of the sediments will be used to reconstruct environmental changes during the Holocene and to investigate climatic and oceanographic mechanisms behind these changes.

Preliminary diatom abundance results from the Littorina Sea to the present of the Landsort Deep core will be presented. An age model based on bulk sediment radiocarbon dates has been established. These results will guide us on which sequences to carry out high resolution analysis.

Future plans include collaboration with the UPPBASER project to investigate whether there exists a synchronicity or not between the recorded environmental changes in the coastal sea and the open Baltic Sea. Furthermore, collaborations with IODP Expedition 347 Science Party Members working on other sites and proxies, will result in a comprehensive high-resolution reconstruction of Holocene climate-driven processes in the Baltic Sea.

SESSION 3

COASTAL PROCESSES

GEOPHYSICAL MONITORING LANDSLIDE IN JASTRZĘBIA GÓRA CLIFF USING ELECTRICAL RESISTIVITY TOMOGRAPHY (ERT)

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In recent years greatly increased the use of geophysical methods in the study of landslides. Extremely useful method in the diagnosis of landslides is the Electrical Resistivity Tomography ERT. With it, you can interpret the structure of landslides and assess the depth of occurrence of the slip zone. There were chosen active landslides located on 134 km of coastline, which had been activated during the spring of 2010. Studies conducted with using terrestrial laser scanning TLS in 2010 showed withdrawal edge of the cliff about 10 m and land loss of 4000 m^3 (Kramarska *et al*, 2011). Measurements ERT monitoring landslides were made along a section with a length of 300 m between spring 2013 and autumn 2014 (twice a year – in spring and autumn). Schlumberger system was used. Inversion measurements were performed using the Geotomo Company software RES-2DINV. Time-laps inverson method for comparative analysis of the results was used. Modeling shows a percentage decrease in the value of resistance in two zones of the landslide. Reducing the resistance value indicates an increase hydration and further activation of landslide movement.

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HOLOCENE COASTAL ZONE DEVELOPMENT OF THE EASTERN GULF OF FINLAND: FIRST RESULTS OF GEOARCHAEOLOGICAL RESEARCH

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Interdisciplinary geoarchaeological approaches offer new opportunities for studying the geological history and paleogeography of the eastern Gulf of Finland coasts. Based on proxy marine geological and coastal geoarchaeological studies (*e.g.* off-shore acoustic survey, side-scan profiling and sediment sampling, on-shore ground-penetrating radar (GPR SIR 2000), levelling, drilling, grain-size analyses and radiocarbon dating and archaeological research) detailed paleogeographical reconstruction for three micro-regions – Sestroretsky and Lahta Lowlands and Narva-Luga Klint Bay – were compiled. As a result of geological-geomorphic high resolution modelling the new models of Holocene geological development of the eastern Gulf of Finland were received. Investigations have shown that lagoon systems, separated from the sea by sand accretion forms – spits and bars – were wide spread in the eastern Gulf of Finland coasts during Holocene. GIS relief analyses and interpretation of its results basing upon general trends of recent lithodynamics processes allowed to reveal the succession of relict coastal form development during Holocene.

Model calibration and verification used results of proxy geoarchaeological research. Results of archaeological studies helped to reconstruct paleoenvironment of the Holocene coastal zone and to date the "barren" geological formations, *e.g.* coastal accretion bodies. On the other hand, based on predictive geological and geomorphological models of the coastal systems formation, during archaeological expeditions several new sites of Neolithic – Early Metal Epoch were found (Sosnovaya Gora 1, Kuzemkino 4-6, Kurovitzy 2-6). New archaeological findings confirmed hypothesis of Holocene development of study area.

Research was supported by RFBR projects 14-05-91763, 15-05-08169, and 15-06-05548.

INFLUENCE OF THE GLACIAL ADVANCE ON THE GEOLOGICAL STRUCTURE OF THE WESTERN SUBMARINE COASTAL SLOPE OF THE SAMBIAN PENINSULA (KALININGRAD REGION)

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Most detail geological and geophysical surveys were carried out offshore Sambian Peninsula in mid-1960s. Echo-sounding, seismic-acoustic profiling, bottom and vibro-corers sampling were performed during research cruises of RV “Professor Dobrynin”. A.I. Blazhchishin using these data traced the submarine cliffs formed by the Paleogene and Cretaceous rocks and compiled geological map of the submarine coastal slope of the Sambian Peninsula. In particular, usage of vibro-corers data allowed him to map distribution of amber-bearing deposits.

New geophysical data were obtained by A.P. Karpinsky Russian Geological Research Institute and Immanuel Kant Baltic Federal University in 2007-2015. Sediment imaging and bottom microrelief mapping were performed using side-scan sonar (CM2, C-MAX Ltd. UK) profiling accompanied by echo-sounding (HydroBoxTM, SYQWEST, USA). Seismic profiling was carried out using 0.2–5.0 kHz boomer sub-bottom profiler GEONT–HRP (Spectr-Geophysika Ltd., Russia). The signal penetration depth was varied depending on geological properties and achieved 30–35 m (40–50 ms).

The geophysical model of the submarine coastal slope of the Sambian Peninsula was developed using more than 130 km of seismic data. The model shows that the northern part of the investigated area is characterized by monoclinal geological structure with incline to the southeast. The flank of outcropping sedimentary rocks forms submarine cuesta with well-known cliffs along the submarine Sambian slope. Local flexure of the Paleogene rocks was fixed in the middle part of the submarine slope near Yantarny. The cause of deformation could be glacial tectonic movements due to advancing of the Pleistocene Scandinavian ice-sheet. The flexure located near large end-moraine ridge is known as Yantarny Bank. Southward from this flexure it is possible to trace fairly distinct acoustic border which is interpreted as erosion surface of Paleogene bedrock. The overlain deposits are represented by Late Pleistocene moraine, the Holocene marine sands and anthropogenic dumping sediments.

The correlation between the offshore seismic-acoustic data and onshore boreholes of mining survey in the vicinity of Yantarny gave opportunity to suggest that the almost the amber-bearing layer (so called “Blue Earth” of the Prussian Suite) was totally destroyed by glacial erosion of the submarine coastal slope deeper than 2–3 m. A remnant of this layer might be preserved only to the south from Yantarny. However, this layer is covered by more than ten meters of the Quaternary deposits. However, presented conclusions based upon geophysical modeling can be confirmed only by offshore drilling.

Processing and interpretation of geophysical data was financed by the Russian Scientific Fund (grant 14-37-00047). The work was supported by the Russian Foundation for Basic Research (grant 16-35-50131).

SESSION 4

ENVIRONMENTAL ISSUES AND PRACTICAL APPLICATIONS

GROUND PENETRATING RADAR PROFILING IN THE COASTAL ZONE OF NARVA BAY

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The ground penetrating radar (GPR) system is geophysical technique that based on the theories of electromagnetism. During the survey, the measured data is saved by means of wave amplitude *vs* the Two Way Time (TWT), which is the time consumed by the ray from the transmitter to the object and back to the receiver again. The GPR's capabilities and information flow make its application participate in many problems related to the bowels of the Earth and the environment such as the engineering geophysics, the study of the near surface geology, the underground water and the archaeological prospecting. More than 25 kilometers of ground penetrating radar profiles were made by Marine Geology and Regional Geoecology department of VSEGEI under a grant 15-05-08169 of Russian Foundation For Basic Research during 2015 year. The Subsurface Interface Radar model 2000 (SIR 2000, produced by GSSI) with 70 MHz antenna was used to collect data. The antenna with odometer was towed by car on a dirt road with a speed up to 20 km/h. The number of scans per meter was 5. Trace recording duration was 300 microseconds and it permitted to obtain information from depths up to 12 m. RADAN program was used to process the records, standard filters and procedures have been applied. The series of horizons of erosion and glacial deposits were captured and tracked on the records. Information about their location and configuration will clarify geological history of the region in Late Pleistocene–Holocene.

EMODNET GEOLOGY – SEABED SUBSTRATE AND SEDIMENTATION RATE DATA FROM EUROPE'S SEAS

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The European Union's (EU) Marine Strategy Framework Directive targets to achieve Good Environmental Status (GES) of the EU's marine waters by 2020. However, it has been acknowledged that the poor access to data on the marine environment is a handicap to government decision-making, a barrier to scientific understanding and a break on the economy. The effective management of the broad marine areas requires spatial datasets covering all European marine areas. As a consequence the European Commission adopted the European Marine Observation and Data Network (EMODnet) in 2009 to combine dispersed marine data into publicly available datasets covering broad areas.

Currently EMODnet is in the second phase of development. EMODnet assembles data, data products and metadata from several marine themes/disciplines. Geology is one of the EMODnet themes. The 2nd phase of the EMODnet Geology project started in 2013 and it will run for 3 years. The partnership includes 36 marine organizations from 30 countries. The partners, mainly from the marine departments of the geological surveys of Europe (through the Association of European Geological Surveys – EuroGeoSurveys), have aimed to assemble marine geological information at a scale of 1:250 000 from all European sea areas (*e.g.* the Baltic Sea, the Barents Sea, the North Sea, the Iberian Coast, and the Mediterranean Sea within EU waters). In comparison to the urEMODnet project (2009–2012) the data is more detailed and aims to cover much larger area.

The data will be essential not only for geologists but also for others interested in marine sediments like marine managers and habitat mappers. A 1:250 000 GIS layer on seabed substrates has been delivered in the EMODnet Geology data portal, in addition to an updated 1:1 million map layer from the previous phase (2009–2012). The data was compiled and harmonised from several datasets, which were heterogeneous as the European sea areas have been mapped according to national standards. The project adopted a shared hierarchy of seabed substrate classes that is a modified presentation of the Folk triangle. A confidence assessment has been applied to identify the information that underpins the geological interpretations.

SMARTSEA – GULF OF BOTHNIA AS RESOURCE FOR BLUE GROWTH

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Blue growth is a long term strategy of the European Union (EU) to enhance the sustainable growth of the maritime sector. Our surrounding seas have been drivers for the European economy for a long time, but still they have a great potential for further harnessing of natural resources and economic growth. Especially if the growth can be achieved in an environmentally sustainable way, benefits are obvious. It has been recently estimated that improvement of the state of the Baltic Sea would until 2030 create 900 000 jobs in the whole Baltic Sea area, mainly in Blue Tech, tourism, real estate and building businesses (Dahlgren *et al.*, 2015).

However, coastal seas already experience multiple stressors like off-shore construction, pollution, eutrophication, shipping, over-fishing, and climate change. In order to obtain sustainable Blue Growth, it is necessary to localize and assess the current maritime activities, estimate their growth potential, and investigate their present and future effects on each other and on the environment.

The purpose of the SmartSea project is to support the growth of commercial marine activities in the Gulf of Bothnia region. The Gulf of Bothnia is an essential resource in terms of fish farming and wind power, for example, and it is also possible to make use of the geological natural resources of the gulf.

Moreover, the rapid growth of the commercial marine activities and the consequences of the climate change may lead to conflicts between the different activities and harm the marine ecosystem of the Gulf of Bothnia. The SmartSea project aims to identify these risks and find solutions for the sustainable use of the sea.

SmartSea is one of the projects the Strategic Research Council of the Academy of Finland has selected for its newly founded "Climate-Neutral and Resource-Scare Finland" research programme. The project will last for six years (2015–2020) and its funding totals nearly 8 million euros. The project involves close to 40 researchers from eight different institutions: the Finnish Meteorological Institute (coordinator), the Finnish Environment Institute, Natural Resources Institute Finland, Geological Survey of Finland (GTK), VTT Technical Research Centre of Finland, the Universities of Helsinki and Turku and the Swedish Meteorological and Hydrological Institute (SMHI).

THE RECOGNISION OF THE RESOURCE BASE OF SAND AND GRAVEL AGGREGATE IN THE POLISH MARINE AREAS

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To achieve the objective set out in the title of the project the four areas of interest in various parts of Polish sea areas were set. As a result of work on the geological map of the Baltic Sea, this fields were considered to be a potential supply areas of sand and gravel.

During the years 2013–2015 the geological studies were carried out at Kołobrzeg 1, Kołobrzeg 2, Ławica Słupska – E, Ławica Stilo fields. The geophysical investigation (multi beam echosounding, sidescan sonar) and geological work (vibrocores, grab samples) allowed a detailed diagnosis of the geological structure at the bottom of the areas and have demonstrated a high degree of differentiation in relation to primary Baltic seabed geological map.

A characteristic feature of Kołobrzeg 1 and 2 fields is a small thickness of marine sands and outcrops of tills, which in the field of Kołobrzeg 1 occupy up to 24% of the study area (20 km^2).

Ławica Słupska – E field is characterized by the presence of minor sand and gravel glaciofluvial deltas. In turn, Ławica Stilo field is characterized by wide spread of marginal lake deposits. However in both cases the mentioned sediments are covered by thin layer of marine sand.

There are large areas where the thickness of marine sediments is less than 30 cm on each investigated field.

The obtained results allowed to verify the boundaries of areas considered to be prospective for the occurrence of sand and gravel deposits. The studies revealed the existence of small isolated fields of sand and gravel within the areas of Kolobrzeg 1 and 2 and Ławica Slupska – E. They were also determined fields of fine and medium sands in all the studied areas. They may state as a reserve of material beach nourishment.

Data obtained were entered into a NEPTUNE marine database, which is part of the Central Geological Database.

ENGINEERING GEOLOGY MAP OF THE POLISH PART OF THE BALTIC SEABED

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The aim of developing the *Engineering geology map of the Polish part of the Baltic seabed* is to illustrate at the general scale (1:500 000) the geological complexity of the Baltic seabed in context of the properties determining its use by the building industry. There is a great need for such a map, also at more detailed scales, due to intensive development of communication network between the countries of the European Union, especially considering development of the trans-European Baltic-Adriatic Corridor.

The map will facilitate general planning decisions with regards to developing new transport and energy infrastructure including power lines and pipelines. Furthermore, there is a demand for the general picture of engineering geology of the area for construction of offshore drilling platforms, coastal defenses such as underwater revetments (for example geopipes) and other marine facilities. Thus, it is clear that such map is necessary to secure future sustainable development of the seabed, also in terms of environmental protection.

This map can be prepared as a preliminary stage for developing engineering geology maps at more detailed scales which will present geodynamic conditioning with a much greater accuracy.

Because the hydrodynamic processes have a great impact on the engineering geology of seabed, they are the primary criterion for dividing it into regions. Intensity of hydrodynamic processes such as waves and water currents directly reflects water depth, therefore three areas associated with water depth are distinguished, *i.e.* up to 10.0 m (zone I), between 10.0 and 30.0 m (zone II) and deeper than 30.0 m (zone III).

Sediments in each of these zones can be divided based on the following engineering geology criteria:

- Clay mineral content (cohesive, incohesive);
- Depositional environment (including glacial, fluvioglacial, marine, lake, fluvial, deltaic, eolian);
- Geological age which reflects the level of their consolidation (Miocene, Pleistocene, Holocene to recent).

The above criteria combined with depth of water determine different conditions for construction industry.

The thickness of the Quaternary sediments building the seabed across the whole study area varies from 1.3 m to approximately 200 m. However locally, better ground conditions are expected where the Pleistocene deposits have a thickness below 5.0 m being directly underlain by the bedrock of Silurian or Cretaceous age.

INTERPRETATION OF SEABED MORPHOLOGY BASED ON STATISTICAL ANALYSIS OF MULTIBEAM ECHOSOUNDER BATHYMETRIC MEASUREMENTS AT SOUTHERN BALTIC SEA

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Multibeam echosounders measure bathymetry of water reservoirs with accuracy of even a few centimeters, enabling high resolution images of the bottom. Processing and analysis techniques of Digital Terrain Model were developed vigorously over the past few decades. Treating a set of bathymetric points with irregular surface as stationary process terrain model can be subjected to a series of calculations specific to signal processing. Statistical spectral and fractal techniques appear to be irreplaceable to describe the surface (Wilson, *et al*., 2007; Cazenave, *et al*., 2008). Parameters such as standard deviation, slope, aspect, curvature and power spectral density are useful in the analysis and description of various features of the floor space.

This work focuses on analysis of statistical parameters calculated for the digital model of the bottom of the Baltic Sea near Rowy harbor. The Area of study is about 1 km^2 and is located about 1.5 km away from the shore. Digital terrain model with resolution of 25 cm was analyzed. In the central part of the study area the outcrops of clays are the large moraines protruding above the surrounding surface of slope. There are numerous boulders and gravels, which are often present in a diverse material of tills. In the valleys and hollows of the study area, modern sands with small thickness are deposited.

Describing the surface by statistical parameters allows for a detailed analysis of the morphology and recognition of the physical processes that occurs in the study area. Presented results of calculations of distribution of parameters were achieved in a window moving across the bathymetric map. Gradient and slope calculated for the Rowy area show the amount of elevation changes over the area of the moving window, where the statistics are calculated. The maximum values are achieved on the slopes of ridges and valleys of tills.

The study area has a complicated geomorphological structure. Accurate measurement of the bottom bathymetry made using multibeam echosounder allows to distinguish and recognize the small bottom forms such as megaripples. On the image of bathymetry are also visible single rounded boulders and whole covers rocks and gravels. Registration of such a small bottom forms is possible only using high resolution hydroacoustic devices. Previously presented parameters allows for a detailed analysis of the morphology of the sea bottom. They are particularly useful for the classification of areas in the lithological, morphological and ecological terms.

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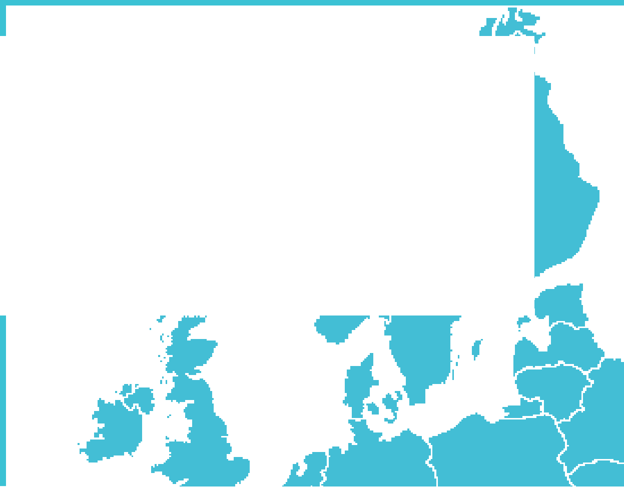
BALTIC 2016



Baltic 2016

FIELD TRIP GUIDEBOOK

The Baltic 2016 – The 13th Colloquium on Baltic Sea Marine Geology

September 16th, 2016, Field Trip to Vistula Spit and Żuławy Region

8.00: start of the Field Trip – Gdańsk, Targ Rybny 1 (parking in front of Hilton Hotel)	
8.00–8.30: transit	
8.30–10.20: Stop 1 – WESTERPLATTE (Gdańsk)	
	Vistula Delta – an outline of the geology and development
	Origin and development of Vistula River mouth in Gdańsk
	Sightseeing
10.20–11.00: transit	
11.00–11.45: Stop 2 – VISTULA RIVER MOUTH (Świbno – Mikoszewo)	
	Origin and development of recent Vistula River mouth
11.45–12.15: transit	
12.15–13.15: LUNCH (restaurant in Kąty Rybackie)	
13.15–13.30: transit	
13.30–14.20: Stop 3 – COAST OF THE GULF OF GDAŃSK (Przebrno)	
	Age of dunes on Vistula Spit as indicated by OSL dating
14.20–14.30: transit	
14.30–15.10: Stop 4 – COAST OF THE VISTULA LAGOON (Przebrno)	
	Peat bogs and fossil soils of the Vistula Spit
	Relative water level changes in the Vistula Lagoon
15.10–15.30: transit	
15.30–16.30: Stop 5 – THE HIGHEST DUNE "Wielbłądzi Garb" and COAST OF THE VISTULA LAGOON (Krynica Morska)	
	Origin and development of the Vistula Spit
16.30–18.00: transit to Gdańsk	
18.00: end of the Excursion – Gdańsk, Targ Rybny 1 (parking in front of Hilton Hotel)	

STOP 1
WESTERPLATTE (GDAŃSK)

Vistula Delta – an outline of the geology and development

Szymon Uścinowicz

Vistula (Wisła) Delta Plain (Żuławy region) is situated north of Poland on the southern coast of the Baltic Sea. It covers an area of *ca* 1800 km^2 and is cut off from the Gulf of Gdańsk by the Vistula Spit. The delta stretches at an altitude ranging from about 10 m a.s.l. where the Vistula branches into two main streams, to 1.8 m b.s.l. in its north-eastern part (Fig. 1). The highest elevations reaching 11.4 and 14.6 m a.s.l are related to small "morainc islands" emerge above deltaic sediments. Progress in the seafloor exploration, and particularly the wide use of seismoacoustic profiling has led to recognition the submerged part of the Vistula Delta in the Gulf of Gdańsk (Ejtminowicz 1982). The submerged part of the delta extends from the shoreline to *ca* 60–65 m b.s.l. and cover the area of *ca* 700 km^2.

Fig. 1. Vistula Delta

Palaeodepositional surface of deltaic sediments in the southern inland part is built of till and fluvioglacial sand of the last glaciation whereas sediments of the Eemian sea dominate in the northern part of the Delta while tills and glaciofluvial occur only locally. The relief of palaeodepositional surface is almost entirely erosive. The lowest erosive surface of the inland part of the Delta lies about 35 m b.s.l. Thickness of the deltaic sediments in the inland part of the delta varies from *ca* 2 m to *ca* 35 m (Fig. 2) (Mojski 1988). According to Mojski (1988) fossil Vistula channels are incised down to the level of about 25 m b.s.l in southern part and to about 35 m b.s.l. in northern inland part of the delta. The oldest peat dated by ^{14}C method reveals the age of 13 350–12 910 cal. years BP whereas the lowermost, situated *ca* 21.5 m b.s.l., was formed in the period of 11 535–10 620 cal. years BP.

The submerged part of the Vistula delta is built of two units mostly consisting of sandy sediments exhibiting large-scale progradational structures. The lower (older) unit lies at a depth of 30–35 and 60–65 m m b.s.l. The thickness of the deposits reaches 20–35 m. Surface of this unit shows numerous traces of later erosional incisions reaching down to about 45 m b.s.l.

The upper unit lies at a depth of 20 and 35 m b.s.l. and its sediments are up to 10 m thick. In addition to a predominance of sand deposits, the geological structure of the submerged part of the Vistula delta also features numerous depressions (palaeolakes and palaeochannels) filled with organic sediments (Fig. 3).

There is only a little information about the age of submerged part of the Vistula Delta and also, there is no attempts to build an integrated model for inland and submerged parts of Vistula delta development.

The Vistula was able to form its delta in the Gulf of Gdańsk not earlier than 15 000–14 500 years ago, what is the beginning of Baltic Ice Lake in this area. According to palinological data distal part of lower unit was formed at the break of Preboreal and Boreal periods. There is no datings for upper unit. Incisions in the inland and submerged parts of the delta could be related most probably to the first and the second drainages of Baltic Ice Lake. Since the middle Atlantic period, when Vistula Spit occupy its present position, the Vistula delta has started to evolve primarily as an interior delta. This is suggested by the age of peat deposits covered by the sediments of the Vistula Spit and Vistula Lagoon (Mojski 1988, Uścinowicz 2003).

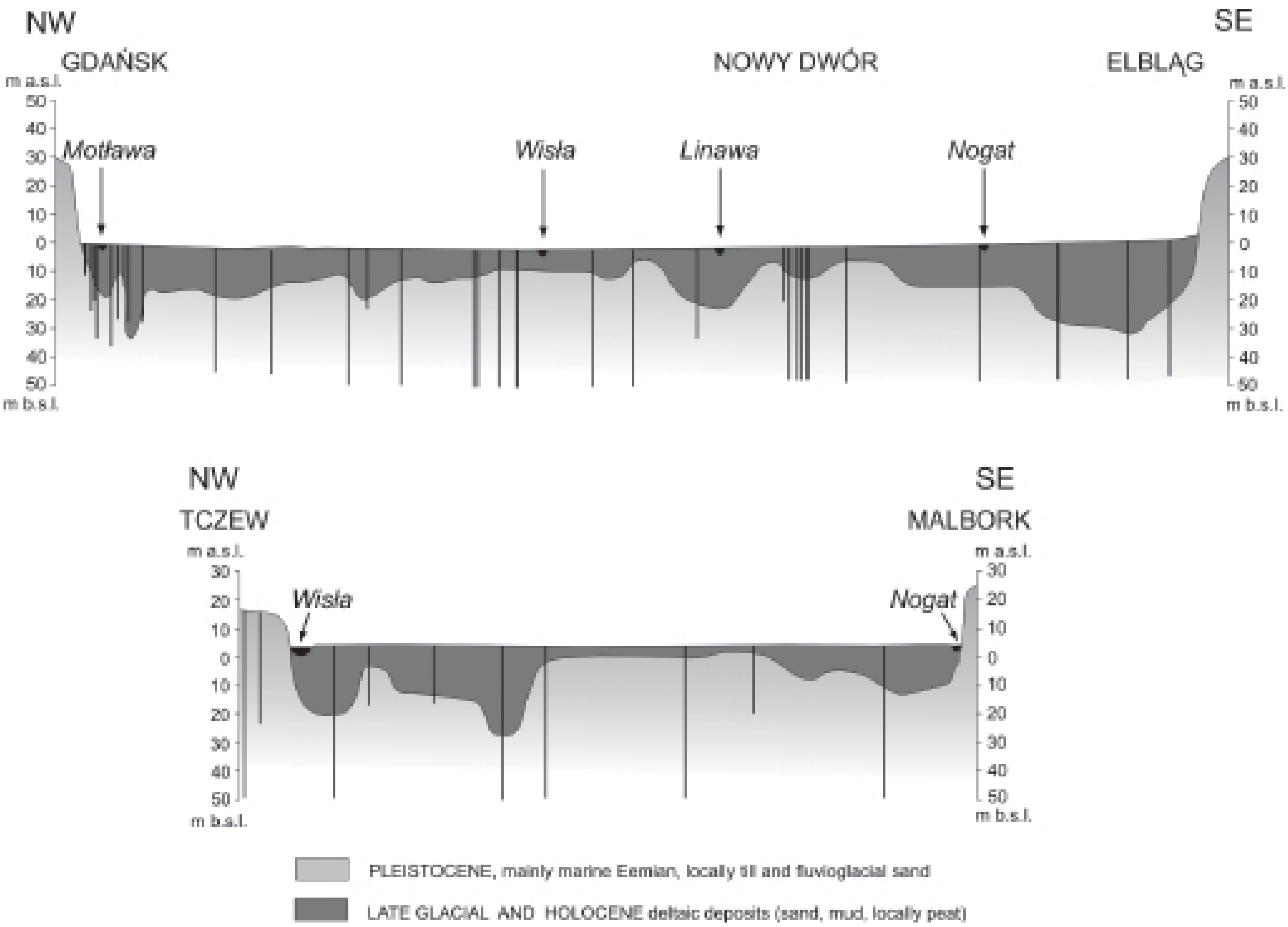


Fig. 2. Geological cross-section of the inland part of Vistula Delta (acc. to Mojski ,1988, simplified)

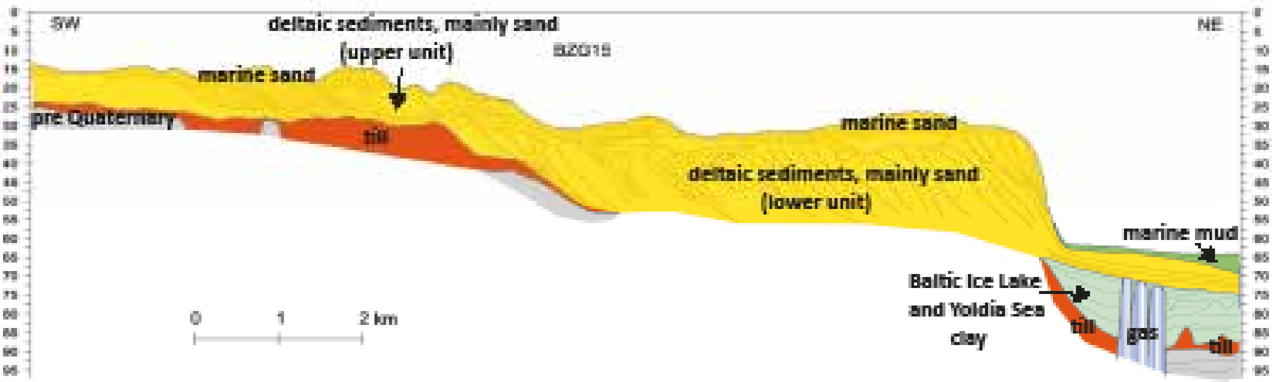


Fig. 3. Geological cross-section of submerged part of Vistula Delta (acc. to seismoacoustic data)

In the late Atlantic, Sub-Boreal and Sub-Atlantic periods the Vistula Spit was undoubtedly broken on numerous occasions by the waters of the Vistula, which drained into the Gulf of Gdańsk either directly or indirectly via the Vistula Lagoon. River-mouth fans similar to those we can see today without doubt developed at the points where the Vistula entered the Gulf of Gdańsk. During the historical times three outlets of Vistula river existed (Fig. 4). Before 1840 Vistula river flowed into the sea via Gdańsk. At the end of January 1840 the new mouth was naturally formed *ca* 10 km east from Gdańsk. Since 1895 most of the water discharge and all sediment transport has reached the Gulf through artificial channel *ca* 20 km east from Gdańsk.

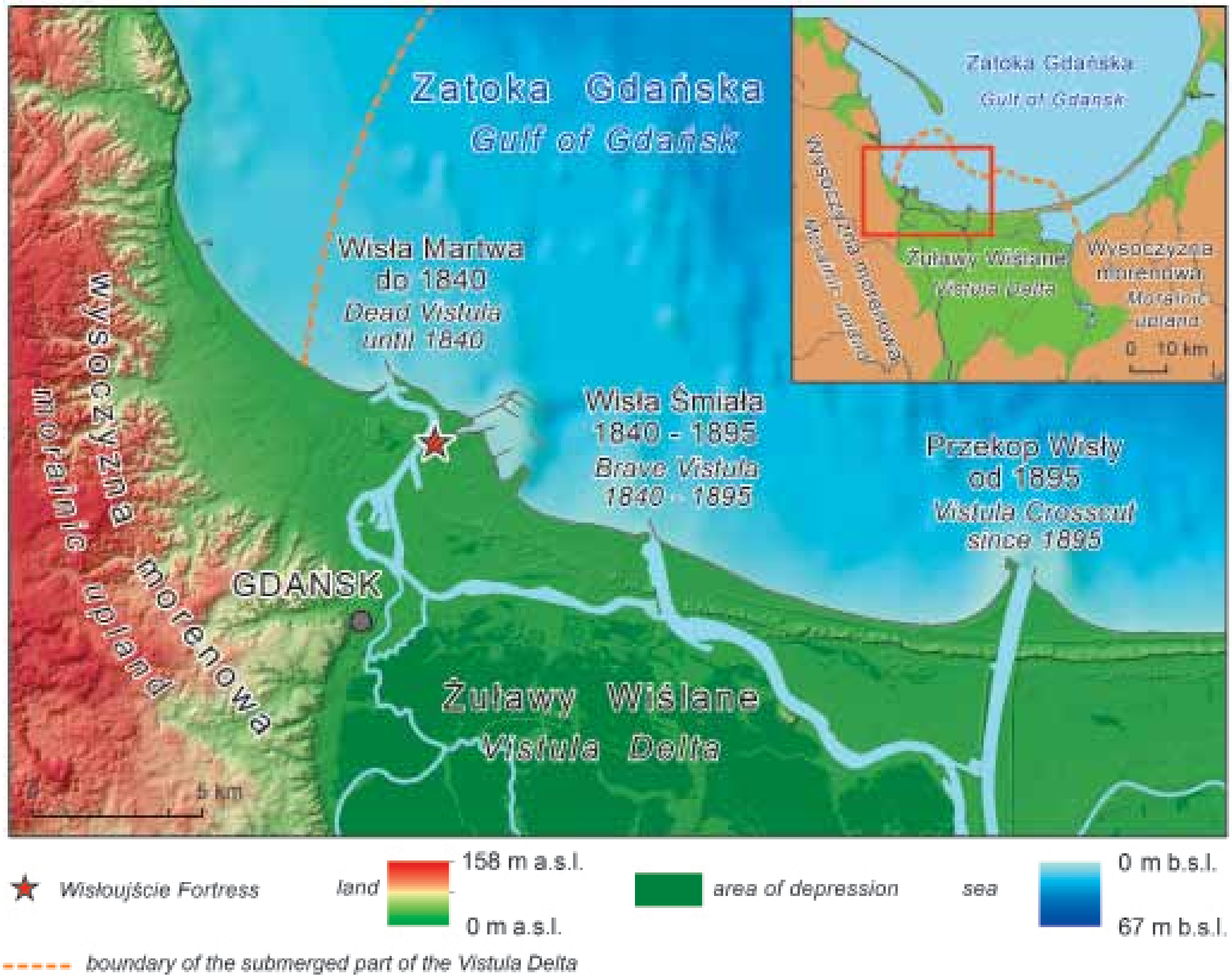


Fig. 4. The outlets of the Vistula River in historical times

Origin and development of Vistula River mouth in Gdańsk

Wojciech Jegliński

The present-day shape of the southwest coast of the Gulf of Gdańsk is largely attributable to the emergence and evolution of the Vistula mouth in this region. The earliest known mouth of the river into the sea was located near Gdańsk, where extensive fan had been formed up until 1840 (Fig. 4).

According to Jegliński (2013) the top of the depositional palaeosurface of this fan lies at a depth of 3–14 m b.s.l. and slopes slightly to the northeast. The alluvial fan deposits mostly overlie sediments of the Littorina and post-Littorina Seas, represented mainly by fine and medium-grained sands. The age of marine mollusc shells found in these sands ranges from 4467 to 2342 cal. years BP. Locally, the marine sand cover is discontinuous, and the material of the mouth fan of the Gdańsk Vistula rests directly on silty-clay or less often on organic and sandy deltaic sediments of the Atlantic period which was radiocarbon dated to 8789 and 7089 cal. years BP (Fig. 5).

The river-mouth fan has a dual structure. It is made of prodelta sediments and overlying sediments of the delta front (Fig. 5). The sediments of the prodelta and delta front contain marine and freshwater mollusc shells as well as brackish-water and freshwater diatoms indicating diverse fluvial and marine depositional environments. The prodelta is represented primarily by clayey-silt material as well as silty-sandy and, sporadically, sandy mate-

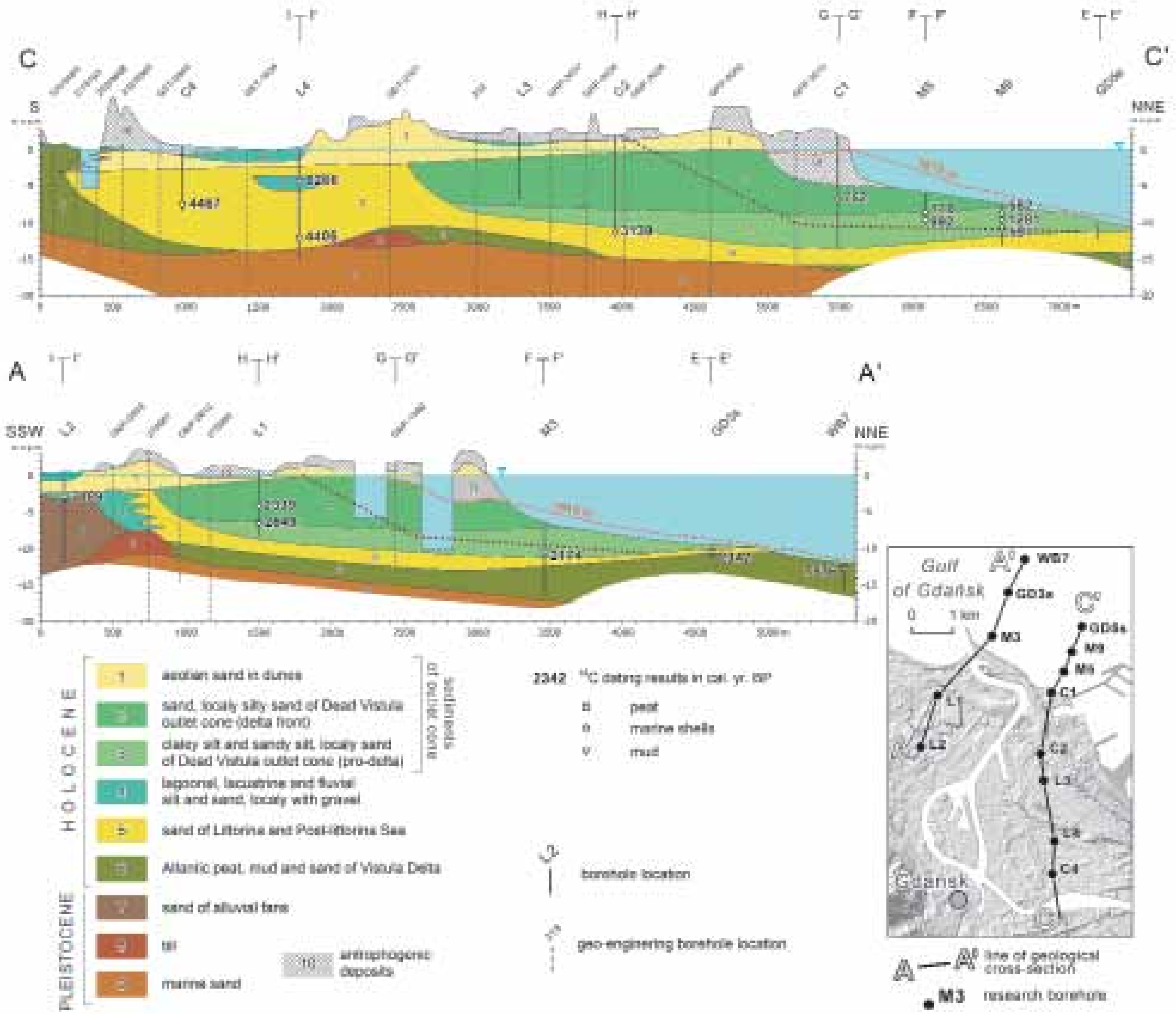


Fig. 5. Geological cross sections

rial. The surface of the top of this layer is slightly and unevenly inclined eastwards at a depth ranging from around 6 m to 9 m b.s.l. Radiocarbon age of the prodelta deposits, determined from the shells contained within these sediments, yielded ages of 3058 and 582 cal. years BP. The delta-front deposits are represented chiefly by fine and medium-grained sands with a lesser proportion of silty sands. Small local intercalations of silty-clayey sediments are also noted. Radiocarbon analysis of shells present within the delta-front sediments yielded dates between 2339 and 143 cal. years BP. The terrestrial portion of the river-mouth fan sediments is overlain by aeolian cover. Optically stimulated luminescence (OSL) dating of the stabilisation of individual dune ridges yielded dates of 3950 to 1161 years (Fig. 6).

Around 7000 years ago the sea reached the level *ca* 8 m lower than its present day state, and marine ingression in the Żuławy region (present day inland part of the Vistula Delta) attained its maximum extent, forming a small embayment in the region of Gdańsk (Fig. 7). Subsequently, despite a further rise in sea level, the marine embayment gradually filled up with sandy sediments carried in great quantities along the shore mostly from the east, as evidenced by the accumulation of Sambian amber within these deposits. Around 3000 years ago, with the sea level around 1.5–2.0 m lower than at present, the embayment became entirely filled up with marine sand, and the evened shoreline slowly moved towards the open sea (Fig. 7). The increase in land area (caused by the shoreline shifting seawards) left its mark on the terrain surface in the form of a sequence of successive generations of coastal dune ridges evidencing the development of this stretch of coastline (Fig. 7) (Jegliński, 2011, 2013). It can be assumed that during this period the Vistula would

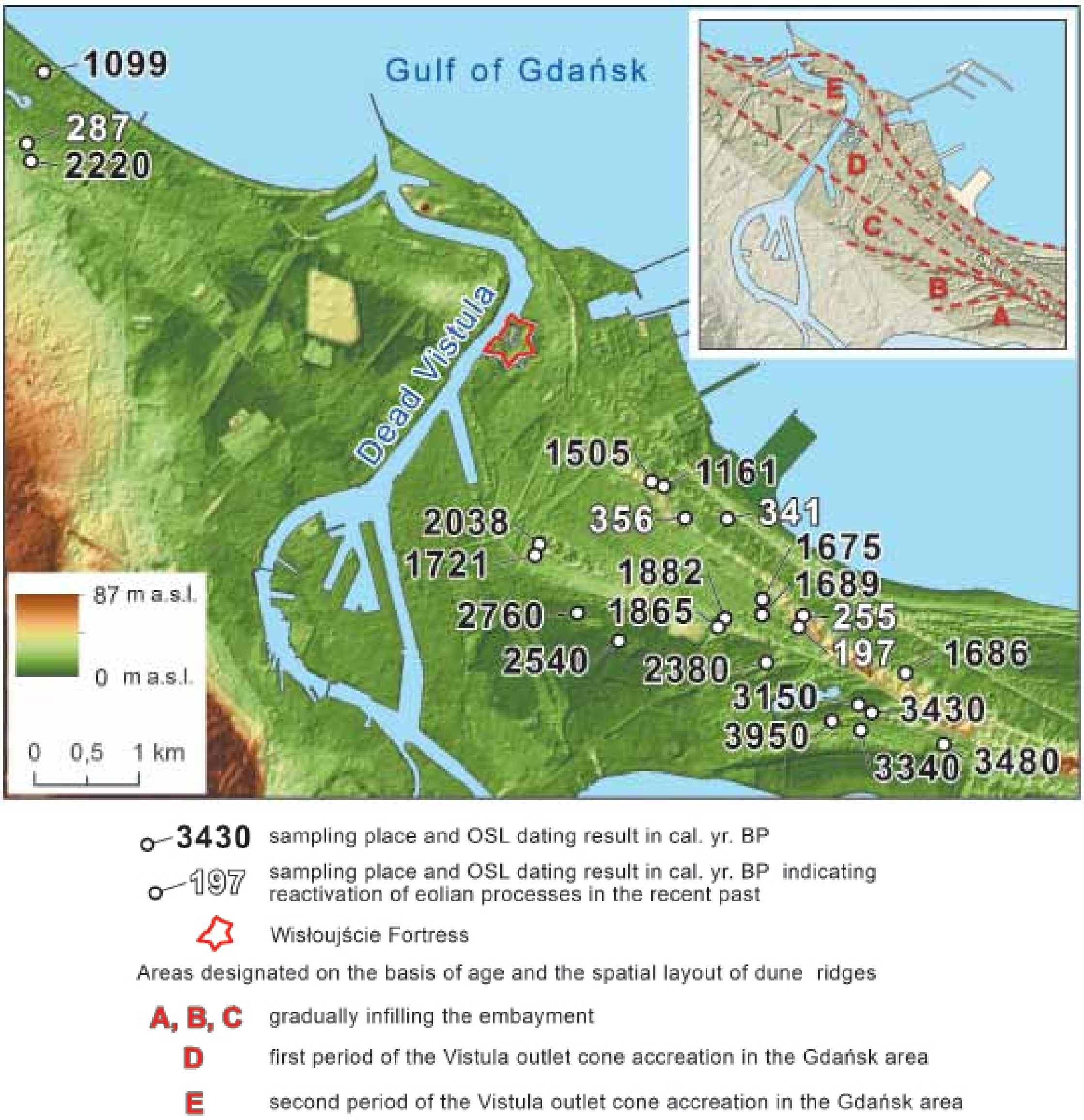


Fig. 6. Dune ridges dated by OSL method (Jegliński, 2011; 2013)

have had multiple branches distributing river water throughout its delta. However, there is no evidence suggesting that any of them emptied directly into the sea within the region under discussion.

Around 3000–2500 years ago the Vistula formed a new mouth in the Gdańsk region (Fig. 7). This period is indicated by the youngest ^{14}C dates obtained from shells found in marine sands and the oldest dates obtained

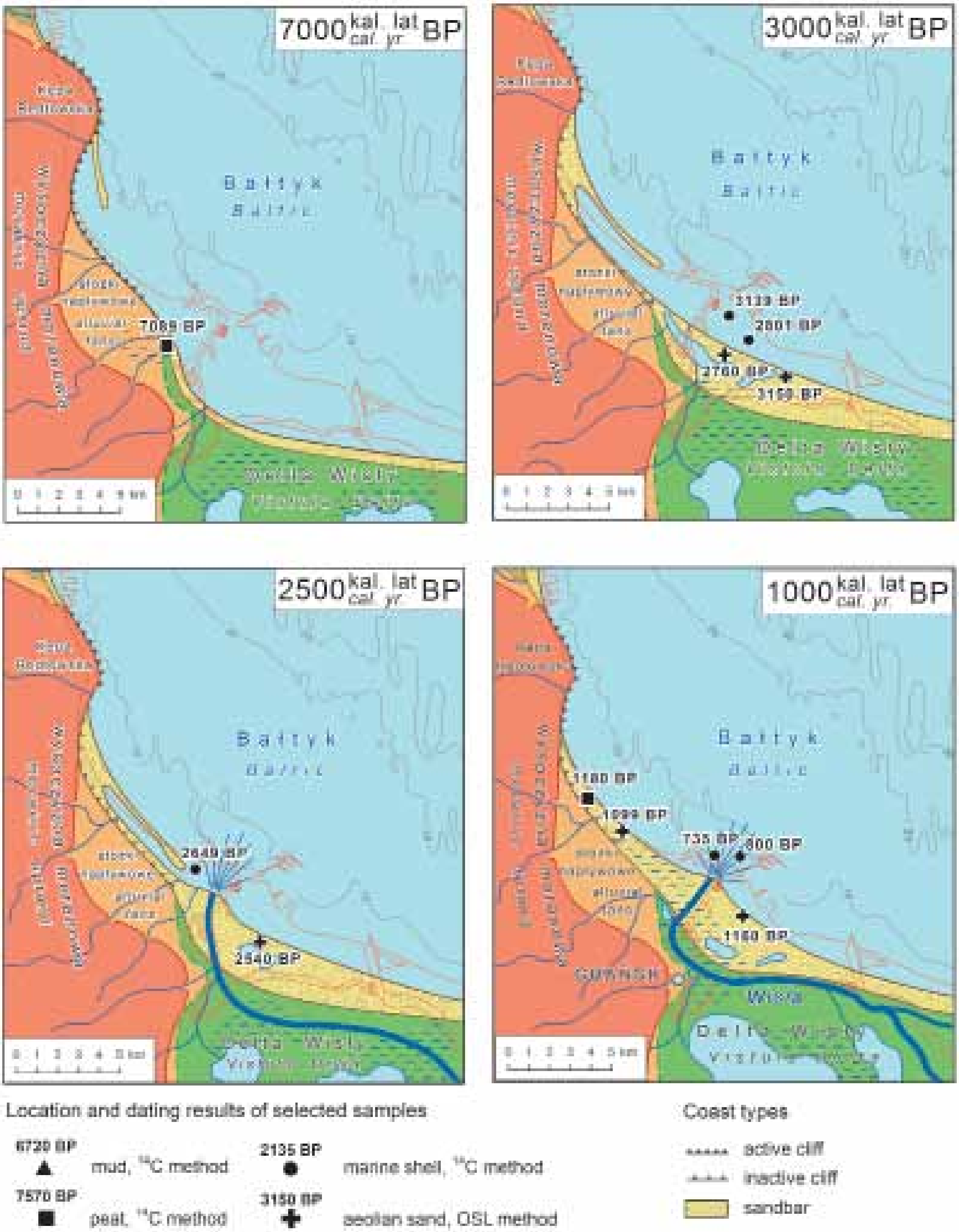


Fig. 7. Palaeogeographical sketch maps of the southwest coast of the Gulf of Gdańsk

from shells found in the overlying layer of silty-sandy sediments of the prodelta, as well as by the OSL dates obtained from the chain of dunes which lie on the landward boundary of the alluvial fan of the Gdańsk Vistula. Having formed a mouth near Gdańsk, the accumulation of the Vistula's alluvial fan continued over the next 1000–1500 years. This is evidenced by the date of stabilisation and spatial layout of successive dune ridges and by the age of shells recovered from the sediments of the river-mouth fan. During this period approximately 96 800 000 m^3 of clastic material was deposited at an average rate of around 60 000–100 000 m^3 per year. Around 1500 years ago a period of stagnation began in the development of the alluvial fan. The period lasted 700–1000 years. The hiatus in aggradation and stabilisation of the shoreline position were conducive to the formation of an extensive dune ridge. The unchanging position of this ridge over the centuries is attested by OSL dating of aeolian sands which produced a range of dates from 1505 to 1099 years, and by the fact that at the end of the 15th century the dune ridge in question_was still located in the immediate vicinity of the shoreline. It was at this time when a lighthouse and the defences of the Wisłoujście fortress were built. The period of stagnation came to an end around 1000–700 years ago. This is indicated not only by the age and shape of the coastal dunes, but also by radiocarbon dates of 752 to 582 cal. years BP obtained from analysis of marine shells found in sandy sediments of the delta front. Historical records suggest that the mouth of the Dead Vistula (Martwa Wisła) reopened around the year 1300. During the second phase of aggradation approximately 82 000 000 m^3 of clastic material was deposited at an average rate of 100 000–150 000 m^3 annually. The growth of the alluvial fan at the mouth of the Gdańsk Vistula came to an end in 1840 when the Vistula formed a new mouth known as the Brave Vistula (Wisła Śmiała). In the latter half of the 19th century, after a section of the river between the Brave Vistula and Gdańsk Vistula had been cut off by sluices, an intensive ongoing process of marine erosion began, the extent of which encompasses the coastal zone of the Westerplatte region. This resulted in the lowering of the seabed, in some places as much as 4 m, and the amount of sediment in the alluvial fan decreasing of around 10 000 000 m^3 (Fig. 7).

STOP 2
VISTULA RIVER MOUTH (ŚWIBNO–MIKOSZEWO)

2

Origin and development of recent Vistula River mouth

Dorota Koszka-Maroń

The canal length of 7 km was dug in 1893–1895 to shorten and straighten the Vistula riverbed, thereby protecting the Vistula delta and Gdańsk against flood. The new outlet of Vistula River to the sea was opened 31st of March 1895. Within 16 hours after opening, the water washed out 2 million m³ of sand to extend the cross-cut bed from 50 to 300 m. Within six months, this volume increased to 9 million m³, and at the end of 1895 it reached 17 million m³ (Makowski, 1995). Detailed geodetic and bathymetric surveys have been done every year since the beginning of the work to present days (Fig. 8).

The development of the Vistula mouth fan was analysed on the basis of the selected digitally generated bathymetric plans. 3-D models of the Vistula mouth region were created for the years: 1894, 1906, 1933, 1953, 1970, 1990 and 2000 (Fig. 9). The fan's substratum was determined on the basis of the bathymetric map of the 1894 bottom configuration, *i.e.* one year before the new mouth was opened. In 1894, the underwater coastal slope descended to a depth of 15 m over a section of 1500 m, which gave an average bottom gradient of 1:100.

In 1906, the volume of the river-mouth cone was 21.6 mln m³ and the average rate of sediment accumulation over the 11 years was 1.96 mln m³/yr (Fig. 10).

In 1933, the river-mouth cone contained 71.17 mln m³ of material, while the average rate of sediment accumulation over the period 1906–1933 was 1.81 mln m³/yr.

In 1953 the volume of material in the river-mouth cone reached to 98.3 mln m³. The average rate of sediment accumulation for period between 1933 and 1953 fell to 1.39 mln m³/yr.

In 1970 sediments volume in the river-mouth cone grew to 112.18 mln m³. The average rate of sediment accumulation during the period 1953–1970 dropped to 0.82 mln m³/yr.

In 1990 the volume of the deposit accumulated in the river-mouth cone reached 129.6 mln m³ and an average accumulation rate during the period 1970-1990 slightly increased to 0.87 mln m³/yr.

In 2000, 105 years after the opening of the Vistula Cross-cut, volume of sediments accumulated in the river-mouth cone reached 133.39 mln m³.

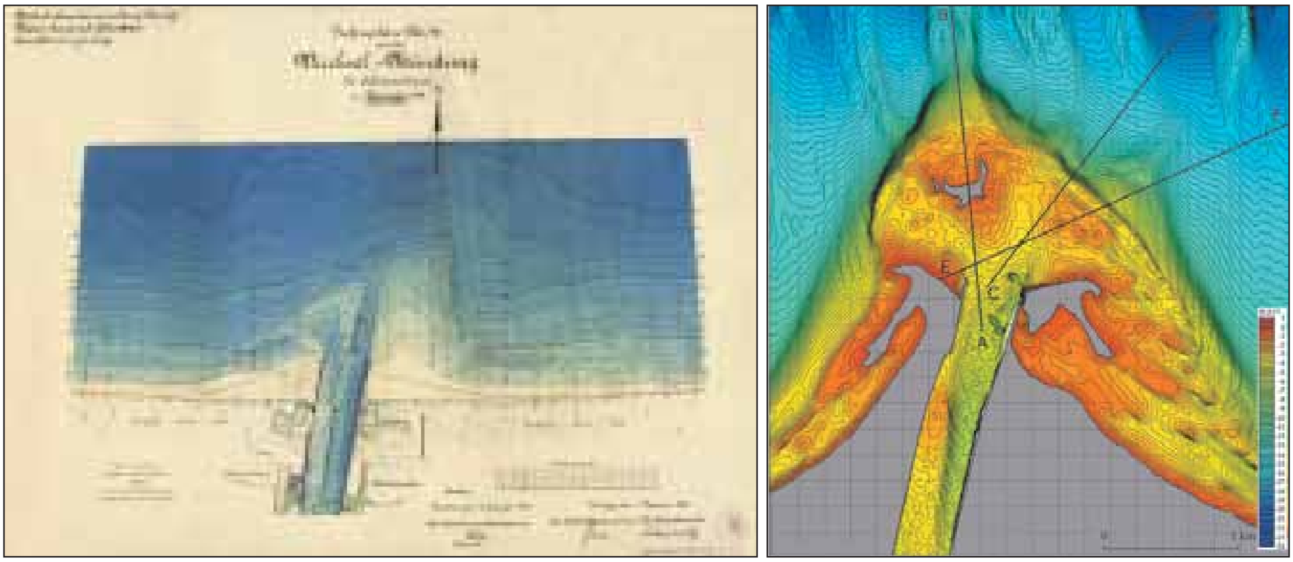


Fig. 8. Bathymetric maps of the Vistula River outlet cone; 1914 (on the left) and 2014 (on the right – after Wróblewski et al., 2015)

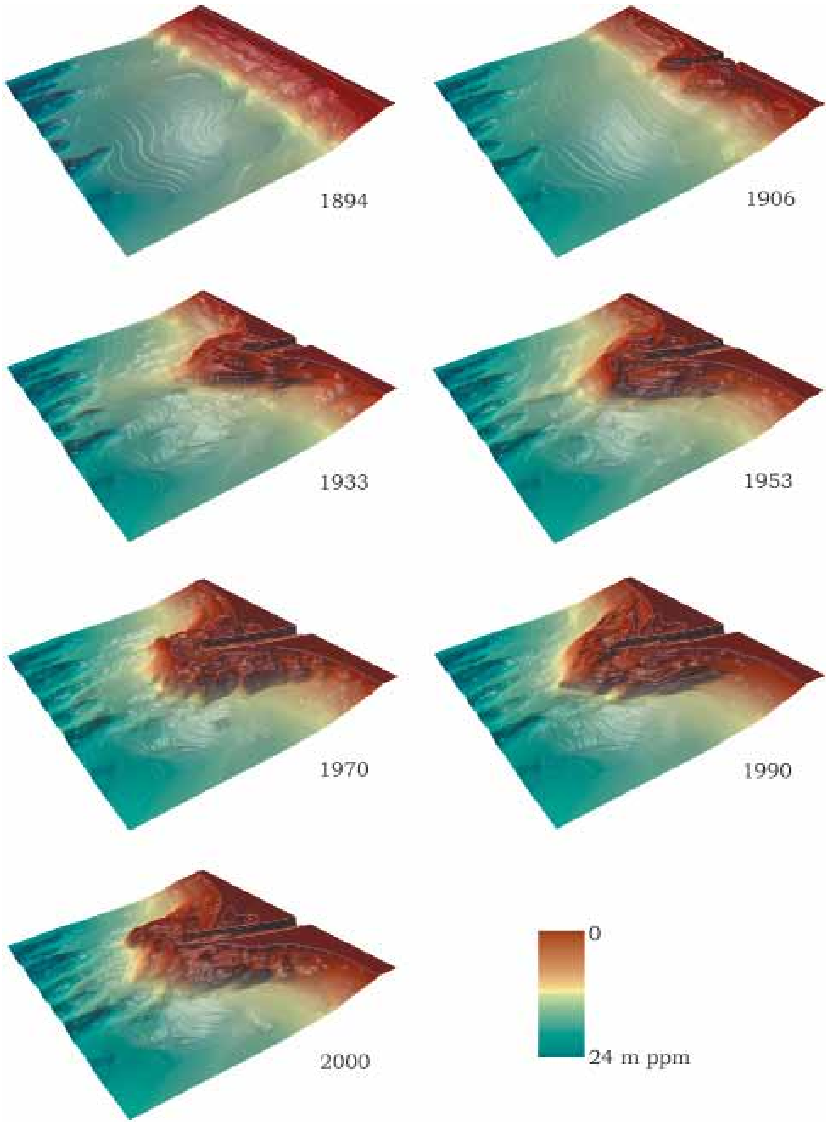


Fig. 9. 3D models of the Vistula river outlet cone

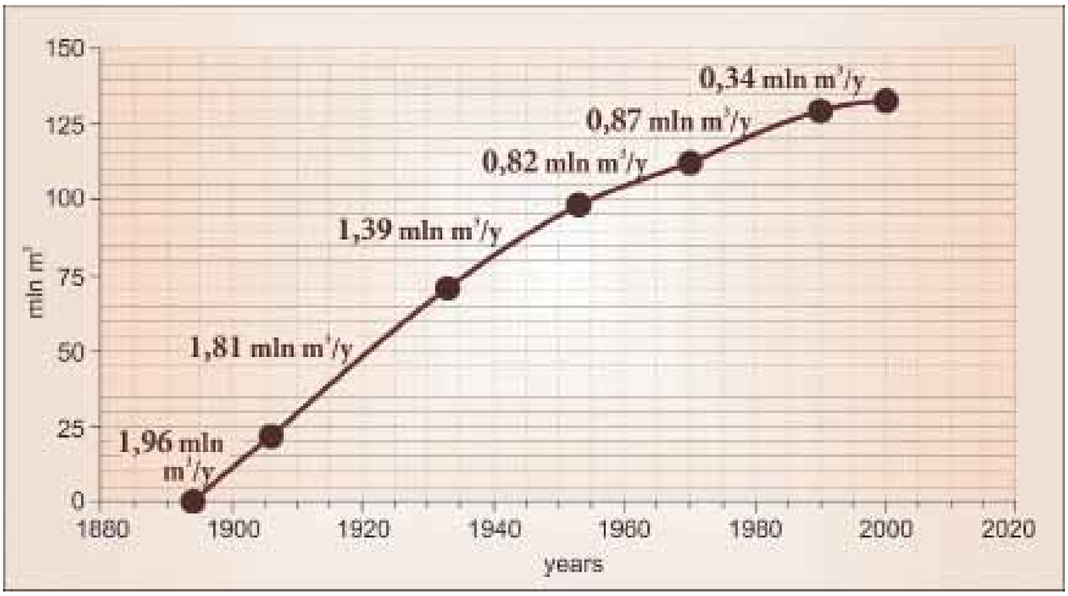


Fig. 10. The rate of accretion of the Vistula river-mouth cone

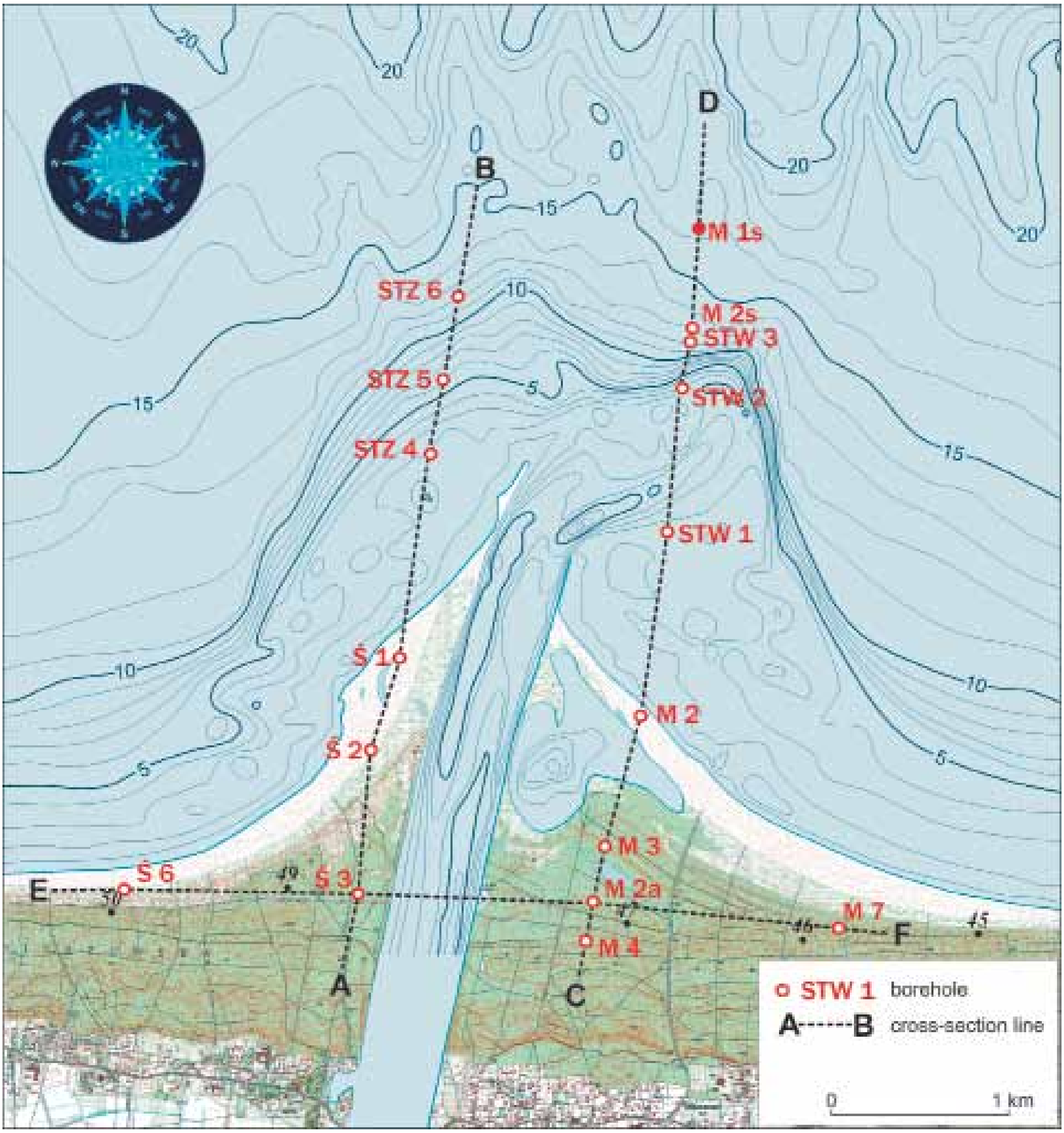


Fig. 11. Drilling sites and cross section lines

Between the years 1990–2000, an average accumulation rate clearly decreased to 0.34 mln m^3 per year, whereas average accumulation rate over the 105 year period, *i.e.* 1895–2000, was *ca* 1.27 mln m^3/yr.

The internal structure of the Vistula river outlet cone is recognized basing on 11 sedimentary cores with a length from 13 to 30 m (Fig. 11). Following analyses were done: grain size distribution (370 samples), heavy minerals (52 samples), $CaCO_3$ content (30 samples), malacofauna (252 samples).

Based on the similarity analysis (cluster analyses) of the individual granulometric types of the Vistula mouth fan sediments and the correlation between the granulometric fractions, two lithofacies have been distinguished in the sediment of the Vistula river-mouth cone. The lithofacies are subdivided into two subfacies each (Fig. 12, 13):

- X-I subfacies: clayey silt with admixture of sand,
- X-II subfacies: fine-grained sand with admixture of silt,
- Y-I subfacies: medium-grained sand,
- Y-II subfacies: coarse-grained sand.

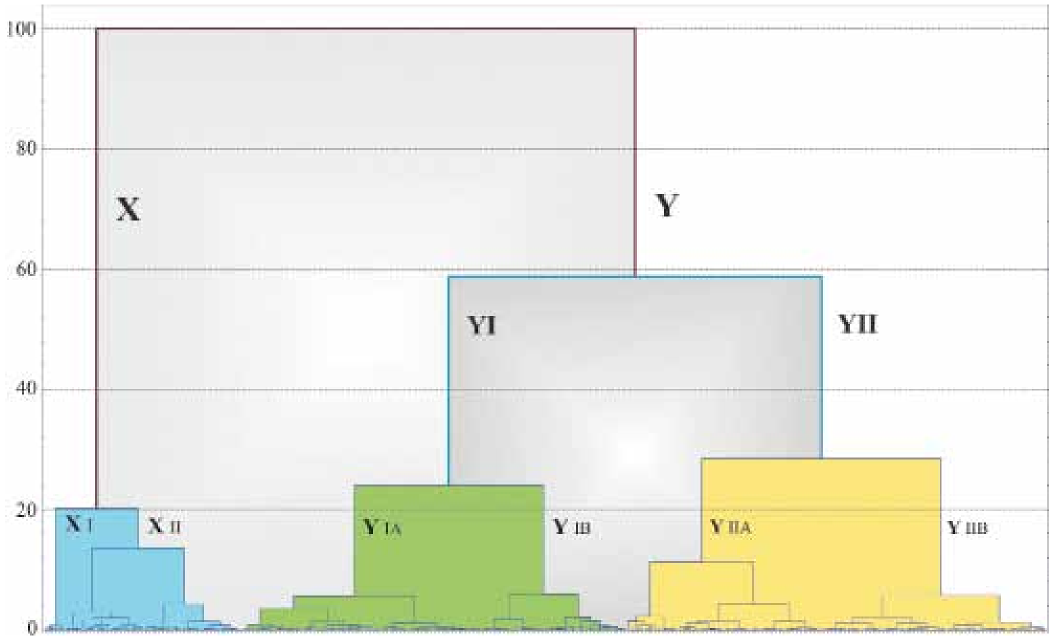


Fig. 12. Dendrogram of sediments of the Vistula river outlet cone

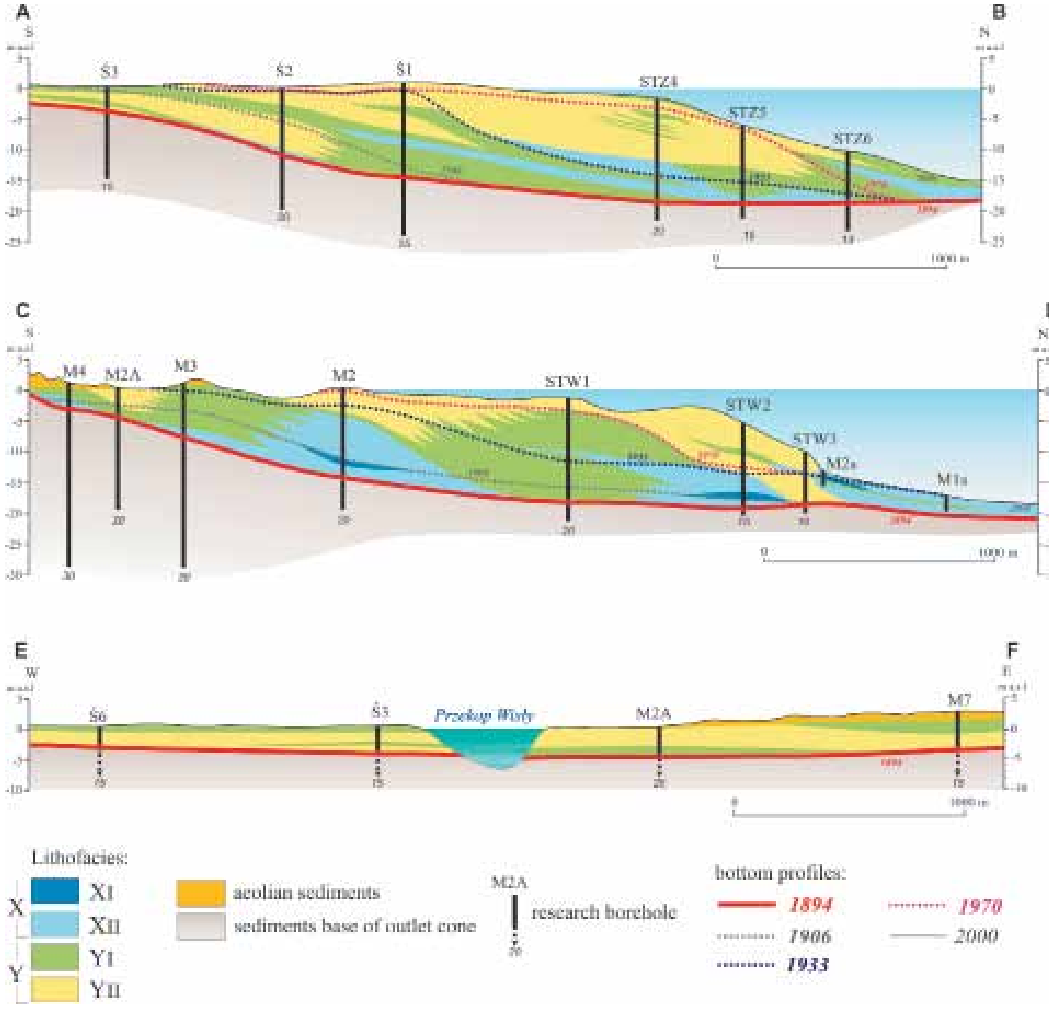


Fig. 13. Lithofacies of the Vistula river outlet cone

	§ 3	§ 2	§ 1	STZ 4	STZ 5	STZ 6	foreground cone
2000			YII	YI	YII	YI	YI
1970		YII	YII	YII	YII	YI	XII
1933		YII	YII	YI	YI	XII	
1906	YII	YII	YI				

	M 4	M 2A	M 3	M 2	STW 1	STW 2	STW 3	M 2s	M 1s (foreground cone)
2000				YII	YII	YII	YII	XII	XII
1970				YII	YI	YII	XII	XI	XII
1933			YI	YII	YI	XII	XII	XI	XII
1906	XII	YI	YI	XI	YI	XII			

Fig. 14. Horizontal sequences of the lithofacies on western side (on left) and eastern side (on right) of river bed

Horizontal and vertical sequences of lithofacies have been recognized on the base of analyses of the cross sections (Fig. 13). Horizontal sequences (along the timelines the bottom surface in a given year according to bathymetric plans) are variable (Fig. 14) however, most common is transition from lithofacies Y to lithofacies X and the model horizontal sequence is as follow:
Y-II (coarse-grained sand)→ Y-I (medium-grained sand)→ X-II (fine-grained sand →X-I (clayey silt).
The vertical sequences are also variable (Fig. 15) nevertheless, here most often the transitions are as follow (Fig. 13): **substratum → X-II (fine-grained sand) → Y-I (medium-grained sand) → Y-II (coarse-grained sand)**. The characteristic feature is that the transition from substratum to subfacies X-I has not been found however, these subfacies occur within the alluvial fan (Fig. 13). It could indicate that fine-grained particles are accumulated only locally and episodically within the alluvial fan. Most often, shortly after deposition they are eroded and transported far away outside the cone, if they are not covered quickly by coarser sediments.

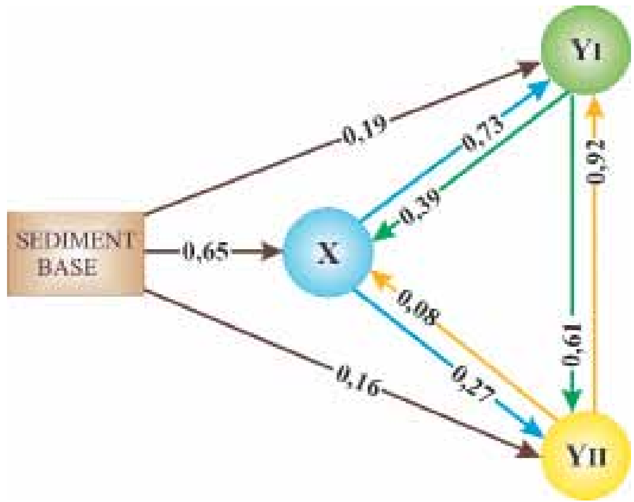


Fig. 15. Vertical sequences of the lithofacies

The lithofacies analysis of the Vistula river outlet cone revealed a classic model (Walther 1894) of horizontal and vertical sequences of the lithofacies.

STOP 3
COAST OF THE GULF OF GDAŃSK (PRZEBRNO)

Age of dunes on Vistula Spit as indicated by OSL dating

Wojciech Jegliński, Szymon Uścinowicz

The dating of dune sands from the Vistula Spit using the OSL method was made for 12 samples. Samples for dating were taken from excavations of approx. 1–1.5 m depth located at the foothill or on the slopes of windward side of dunes. Eight sampling sites were located in the section across the Vistula Spit in the Przebrno area and covered all generations of dunes, two stations were located on the brown dunes located on the border of Żuławy Wiślane (Vistula Delta) between Mikoszewo and Junoszyn and one site was set in the area of Kąty Rybackie (Fig. 16).

The OSL dating method results showed that the age of the dunes of the Vistula Spit (the time of their stabilization) is in the range from 7250 to 303 years B.P. The oldest dates obtained for the low dunes, heights relative approx. 2 m, in the part of the Spit adjacent to the Żuławy Wiślane (sites Prz_10 and Prz_11) and the Vistula Lagoon region in Przebrno area (sites Prz_2 and Prz_9) (Fig. 17). The age of these dunes ranged from 5610 to 7250 years. The oldest age obtained for the dune located approx. 610 m from the shore of the Vistula Lagoon in Przebrno. All of these dunes have well developed podzolic soil profile. The dune from the site Prz_10 have also a fossil soil and therefore, due to both the morphology and the profile of soil, can be classified into brown dunes. A slightly different situation occurs in the case of the dunes in Przebrno closest to the shore of the Vistula Lagoon (site Prz_1). Despite a well-developed soil profile, and even the occurrence of fossil soil, they are different in shape and size of the typical brown dunes. Reaching a height of up to about 10–12 m above the sea level is considerably higher than the brown dunes. Also the dating results around 4960 years indicates that it has been stabilized later than the rest of dated brown dunes.

Sand dunes located north from the brown dunes, rising the most on the height of 10–30 m and a maximum of 49.5 m. In the literature they are referred as the yellow dunes, they are diverse in terms of size and the formation level of the soil profile. Age of dunes with a height of ridges rising to 10–15 m above sea level, with a well developed soil profile, amounts to 5280 and 4120 years on section Przebrno (sites Prz_3 and Prz_4) and to 5960 years in Kąty Rybackie, where apart from a well-developed contemporary soil there is also a fossil soil (Prz_12 site) (Fig. 18). The highest sand dunes in the north of Przebrno rising up to a height of 30–35 m, were dated in 2 loca-

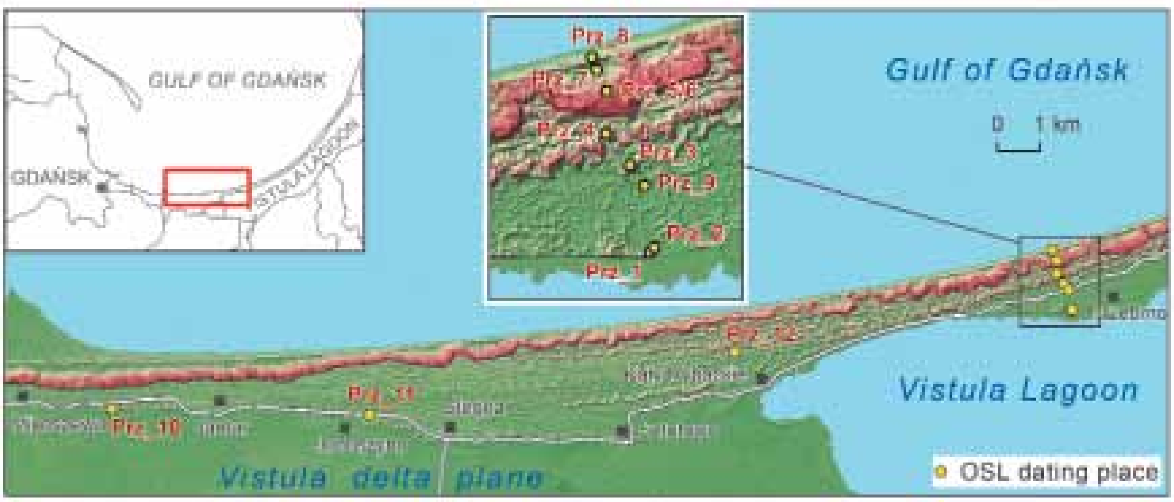


Fig. 16. Location of dunes dated by OSL method

Fig. 17. Sampling sites and the results of OSL dating (in the upper row, from the left side, sites: Jantar (Prz_10), Junoszyno (Prz_11), in the bottom row from the left side: Przebrno_1 (Prz_1), Przebrno_2 (Prz_2), Przebrno_9 (Prz_9)). Photo by S. Uścinowicz

tions. From the excavations located in the central part of the windward slopes of the dunes, 2 samples were collected which age was 511 and 439 years. At the foot of this dune (from the north, windward side) one more sample was collected and dated to 2084 years. These results indicate that the highest dune ridge on the Vistula Spit was formed in the period between 4000 and 2000 years ago and that the slopes and tops of the dunes were still active approx. 500–400 years ago.

The youngest date was obtained for the site Prz_8 located approx. 100 m from the beach on a dune with a height of around 10 m. Dune is situated between the contemporary front dune with a height of approx. 3 m undercutting by storm surges, and on the other side the highest dune in this part of the Spit (sites Prz_7 and Prz_5/6). Age of the dunes is 303 years BP.

The results shed a new light on the development of the Vistula Spit. On the Spit, as in other parts of the southern coast of the Baltic Sea, due to the degree of development of the soil profile, 3 generations of dunes occur: brown, yellow, and white ones. This sub-division based on the degree of podzolisation of the dunes on southern Baltic coast were established by Keilhack (1912).

The formation of these dune generations attributed to specified dune-generation phases – periods of intense aeolian activity (Tomczak, 1990, 1995; Fedorowicz *et al.*, 2009, 2012). The sequence of OSL dates within section Przebrno shows the constant development of the Spit and the formation and stabilization proceses of the following dune ridges. These results also indicate not only much older period of formation of brown dunes than was pointed by Tomczak (1995), but also the earlier formation of the yellow dunes than was determined by Fedorowicz *et al.* (2009, 2012).

The OSL dating was performed at Institute of Physics – Centre for Science and Education, Silesian University of Technology, Poland

Fig. 18. Sampling sites and the results of OSL dating (in the upper row, from the left side, sites: Kąty Rybackie, Przebrno_3, Przebrno_4, in the bottom row from the left side: Przebrno_5/6, Przebrno_7, Przebrno_8). Photo by S. Uścinowicz

STOP 4
COAST OF THE VISTULA LAGOON (PRZEBRNO)

Peat bogs and fossil soils of the Vistula Spit

Grażyna Miotk-Szpiganowicz

Peat bogs of the Vistula Spit, located in the depressions between brown dunes, were dated earlier in two locations in Sztutowo (Tomczak, 1990, 1995). The radiocarbon age obtained was: 3920 ±60 and 3160 ±50 years BP (4427–4282 and 3449–3345 cal. years BP, respectively). Recently, peat bogs from the vicinity of Kąty Rybackie and Przebrno have been investigated more in details. For both locations samples from the lower parts of the deposits were analyzed palynologically as well as ^{14}C AMS dating was done (Fig. 19).

Przebrno peat bog

Przebrno site is situated about 250 m northworth from the Vistula Lagoon, in the wide depression between low dune ridges, at the level of 0.2 m a.s.l. The thickness of peat is about 1.5 m. Sample from the base of the deposit was dated with ^{14}C AMS method. Lower part of the core, about 20 cm long, was palynologically investigated (Fig. 20). The peat bog near Przebrno developed on a sandy substratum. According to the results of palynological expertise, the beginning of its formation could be correlated with the older subboreal period (Fig. 21). It's indicated by the pollen spectrum composition with low concentration of elm (*Ulmus*), occurrence of mistletoe (*Viscum*) as well as lack of hornbeam (*Carpinus*) and beech (*Fagus*) pollen grains, which are typical for younger subboreal period. Domination of alder (*Alnus*) and hazel (*Corylus*) is an evidence for predominance of local factors in vegetation. Palynological interpretation has been confirmed by radiocarbon date from the deposit base level: 1.48–1.50 m (1.28–1.30 m b.s.l.) which stays for 4540 ±35 years BP (5158–5123 cal. years BP).

Fig. 19. Location of investigated peat bogs (the crosses)

Fig. 20. Coastal peat bog near Przebrno. Photo by S. Uścinowicz

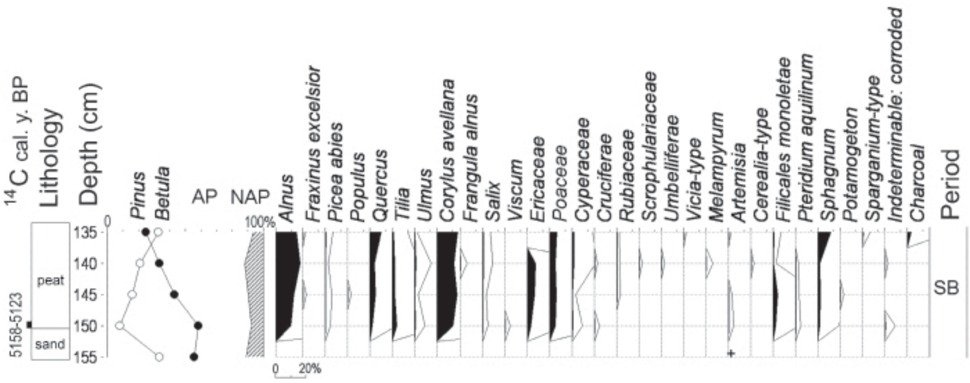


Fig. 21. Simplified pollen diagram of the lower part of the core from coastal peat bog near Przebrno

Kąty Rybackie peat bog

Kąty Rybackie site is located in a distance of about 1 km to the north-east from Kąty Rybackie village. The peat bog's level is about 0.7 m a.s.l. It is situated in the depression between dune ridges, which rise up to 8–11 m a.s.l. The thickness of peat is 1.45 m. Palinological analysis were carried out for the lower, about 25 cm long part of the core section. ^{14}C AMS dating was done for a sample taken from the bottom of the deposit.

The results of palynological investigations revealed, that during initial phase of the peat-forming process, there were forests growing in the vicinity, with a significant role of pine (*Pinus*) and oak (*Quercus*). Of minor importance were elm (*Ulmus*) and lime (*Tilia*). More wet habitats were occupied by communities with alder (*Alnus*) and hazel (*Corylus*). Small quantities of herbaceous plants suggest predominance of oligotrophic, unstable sandy dune habitats, unfavorable for flora growing (Fig. 22).

Fig. 22. Peat bog near Kąty Rybackie. Photo by S. Uścinowicz

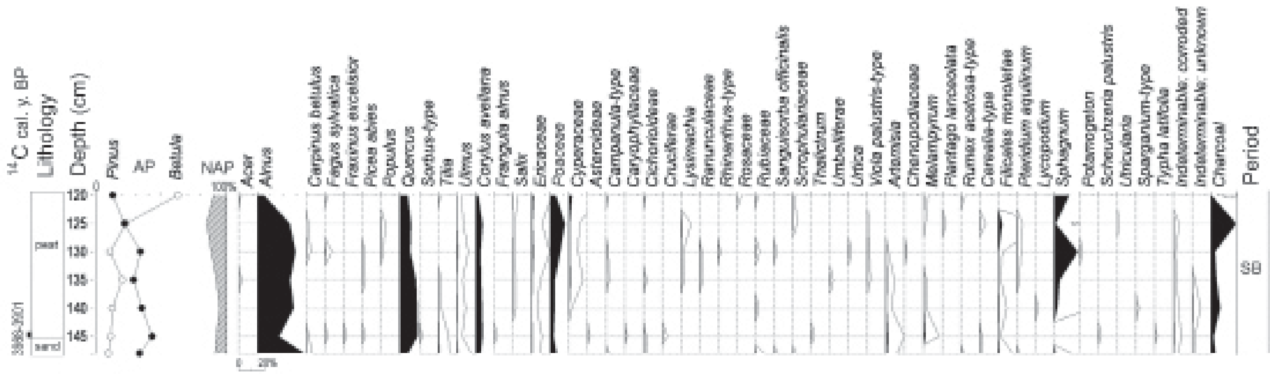


Fig. 23. Simplified pollen diagram of the lower part of the core from peat bog near Kąty Rybackie

Presence of singular hornbeam (*Carpinus*) and beech (*Fagus*) pollen grains in the deposit indicates, that the peat bog formation process was initiated in the subboreal period, probably around 3500 years BP. This is the time, when both mentioned species started to appear in the area. (Ralska-Jasiewiczowa *et al.* 2004, Latałowa *et al.* 2004). This conclusion has been confirmed by radiocarbon age from the depth 1.43-1.45 m (0.73–0.75 m b.s.l.) which stays for 3645 ±35 years BP (3988–3901 cal. years BP).

In the pollen diagrams visible share of *Artemisia* is noted, the ruderal species preferring nitrogen rich conditions. Also singular grains of cereals (*Cerealia)* as well as *Melampyrum* – species related to mid forest pasturage appear. These indicate the agricultural activity in the direct vicinity of the site. Evident shift in vegetation is marked in the palynological spectrum at the depth of 125 m. There are noticed: decrease in alder (*Alnus*) and hazel (*Corylus*) representations, distinct drop of peat mosses (*Sphagnum)* curve, appearance of percentage concentrations of fern (*Filicales)* as well as significant increase in charcoals (Fig. 23). Individual grains of plantain (*Plantago lanceolata)* which is indicatory for pasturage are also observed. Such changes indicate both: distinct drainage of habitats as well as significant influence of anthropogenic factor. Occurrence of *Utricularia* may suggest the presence of holes with water after peat exploitation.

Fossil soils in the dunes of the Vistula Spit have so far been dated by radiocarbon method at three sites (Tomczak, 1990). The organic matter from well-developed podsolic soils covered with younger aeolian deposits and modern soil was dated. The age of the fossil soils ranged from 1210 ±60 to 460 ±60 years BP (Tab. 1), which correspond to the younger part of the Subatlantic period.

In recent years, 3 new sites of fossil soils have been localized for which palynological analysis was carried out (Fig. 24, 25).

In all the studied sites well developed fossil podsolic soils with a clear orszty level (level with a high content of ferric compounds) were investigated. Termination or interruption of soil-forming processes was associated with fires as evidenced by the sudden appearance of charcoals and large quantities of corroded pollen grains in sediments (Fig. 26, 27, 28). One such event was recorded at the site of Kąty Rybackie (Fig. 28), two events at Mikoszewo site (Fig. 26), and three events at Junoszyno (Fig. 27). Fires caused the levels of humus preserved only in residual form, and sometimes they have numerous small sandy interbeddings (Junoszyno site – Fig. 27), what demonstrates the instability of habitats also in the period preceding fire.

Table 1.
Radiocarbon age of fossil soils from the Vistula Spit (acc. to Tomczak, 1990)

Site/sample No.	Coordinates		Sample altitude m b.g.s.	^{14}C y. BP	cal. y. BP (68.2%)	cal. y. BP (95.4%)	Lab. code
	φ	λ					
Sztutowo-Muzeum 2	54°20.0´	19°09.2´	0.5–1.0	1140 ±90	1151–968	1276–920	Gd – 2736
Stegna 1/1	54°19.7´	19°09.8´	1.27–1.30	460 ±60	546–460	560–425	Gd – 5302
Komary F	54°20.1´	18°54.0´	1.20–1.40	1210 ±60	1185–1061	1276–1046	Gd – 1661

Fig. 24. Location of palinologically investigated fossil soils

Palynological spectra of the samples from the top of the levels of eluviation and illuviation consists mainly of alder pollen grains (*Alnus*) and ericaceous plants (*Ericaceae*), with less percentage of birch (*Betula*), lime (*Tilia*), oak (*Quercus*), elm (*Ulmus*), hazel (*Corylus*), hornbeam (*Carpinus*) and beech (*Fagus*). The amount of pollen grains of pine (*Pinus*) is variable and clearly increases in the periods between fires, what is distinctly noticeable especially in the diagram of the Junoszyno site (Fig. 27).

The majority of analyzed sediment samples, especially in the preserved parts of the humus levels contained the pollen grains of plants related to the human impact, such as *Artemisia*, goosefoot family (*Chenopodiaceae*) and sorrels (*Rumex acetosa, R. acetosella*), ribwort plantain (*Plantago lanceolata*) also cereals (*Cerealia*), small amount of wheat (*Triticum*), rye (*Secale*) and cornflower (*Centaurea cyanus*). The increase of the significance of these species in the pollen spectra occurred after successive fires (Fig. 26, 27, 28), what proves their anthropogenic background. The results of palynological analysis showed that the analyzed fossil soils developed during the Subatlantic period. It is evidenced by the overall palynological picture indicating the existence of forest assemblages with a predominance of alder (*Alnus*) with only a small percentage of other deciduous trees. The composition of plant communities was also under the influence of habitat conditions. However, the presence of pollen grains of rye (*Secale*) and cornflower (*Centaurea cyanus*), species associated with corn-growing, is also a proof that the analyzed fossil soils at Mikoszewo and Junoszyno sites (Fig. 26, 27) were developing probably even in the younger part of the Subatlantic period. Only the fossil soil at Kąty

Fig. 25. Fossil soils (from left to right: Mikoszewo, Junoszyno and Kąty Rybackie site). Photo by S. Uścinowicz

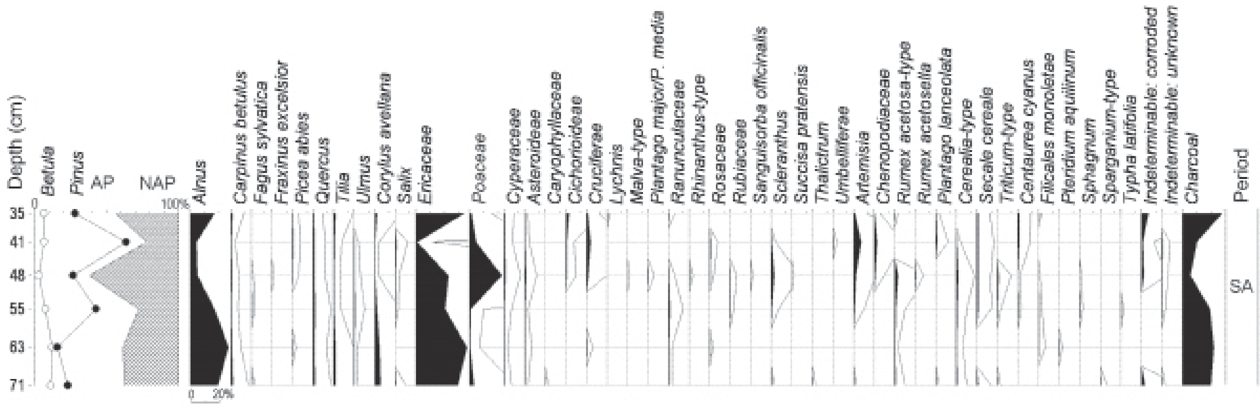


Fig. 26. Simplified pollen diagram of the fossil soil in Mikoszewo site

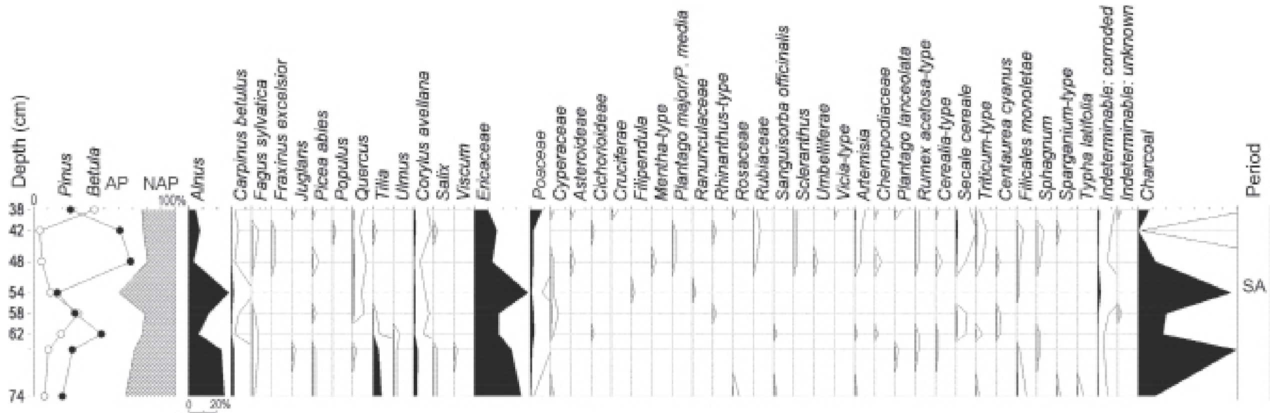


Fig. 27. Simplified pollen diagram of the fossil soil in Junoszyno site

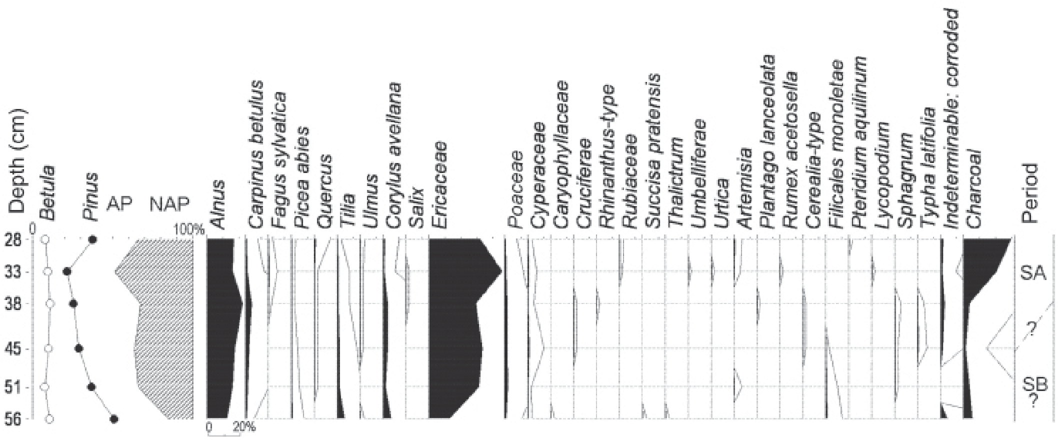


Fig. 28. Simplified pollen diagram of the fossil soil in Kąty Rybackie site

Rybackie site (Fig. 28) seems to be older. It probably began to develop in the older part of the Subboreal period. It is indicated by significantly higher than in other sites the percentage of hornbeam (*Carpinus*) and the subsequent appearance of beech (*Fagus*) in forest communities (Fig. 28). There is also fewer of pollen grains related to human activity. Primarily, there is a lack of species indicated the cultivation of rye (*Secale* and *Centaurea cyanus*).

Relative water level changes in the Vistula Lagoon

Szymon Uścinowicz

The relative sea-level change curve was constructed based on the analyses of 103 radiocarbon dates (upon samples of: peat – 64, wood – 4, limnic gyttja – 5, lagoon mud – 10, shells within marine sands and lagoon mud – 20). Calibration of conventional radiocarbon dates into calendar years BP was accomplished with OxCal (Bronk, Ramsey, 2009), using IntCal09 calibration curve (Reimer *et al.*, 2009). The reservoir effect was included while obtaining of shell dates using "Marine'04" calibration curve along with Delta_R = –120 ±60 years local correction.

Distribution of dated samples (peat, wood, gyttja, mud, shells) against the current sea level (Fig. 29, 30) enables determination of the mean water level of Vistula Lagoon (VL) and the Gulf of Gdańsk. It was lower than nowadays, and equalled:

m b.s.l.	years BP
14.0–14.5 m	8000
8.0–8.2 m	7000
4.0–4.2 m	6000
2.6–2.8 m	5000
2.0–2.2 m	4000
1.6–1.8 m	3 000
1.0–1.2 m	2000

Information recorded in the coastal peat bogs, indicate a presence of water level oscillations connected with climatic cycles apart from long-term trend of sea-level rise. Maximum $\delta^{13}C$ content together with an increased amounts of brackish diatoms, pollen of aquatic plants, and especially presence of *Pediastrum* coenobia, imply sea-water ingressions into coastal peat bogs.

The 1st evident $\delta^{13}C$ maximum of Łąki Różańskie peat core (ŁR 0) obtained from SE Vistula Lagoon coast, occurs 4.50–4.25 m deep (4.34–4.09 b.s.l.), which formed *ca* 7000–6800 cal. years BP, according to age/depth model (Fig. 30). The same depth range visible at the pollen diagram demonstrates *Pediastrum* increase, which may indicate elevated water level within the peat bog. According to a curve of water level rise, surface of the peat bog at that time could be found *ca* 3.0–2.5 m above the water level in the Vistula Lagoon (Fig. 29, 30, 31). Therefore, this is low probability that this is 1st VL water ingression into the peat bog. However, it could be also interpreted as a result of catastrophic storm flooding.

The 2nd evident $\delta^{13}C$ maximum (Fig. 31) of ŁR 0 peat core occurs 4.0–3.85 m deep (3.84–3.69 m b.s.l.) and was dated to 6500–6350 cal. years BP, when the mean water level of the Vistula Lagoon was only *ca* 1.5–1.0 m lower than the former peat bog surface. However, sediments of the above age lack *Pediastrum*. Since 6500–6000 cal. years BP the Łąki Różańskie peat bog was developing under direct influence of VL waters. Increased levels of *Pediastrum* coenobia correlated with more or less evident $\delta^{13}C$ maximums can be found within the intervals of: 6200–6100; 5400–5300; 5000–4900; 4600–4500; 4100–4000; 3600–3500; 3000–2900 and 2000–1900 cal. years BP (Fig. 30). An assumption of frequent storm surge ingressions of VL water into the peat bog needs to be made. Correlation of paleotemperatures curve with $\delta^{13}C$ and *Pediastrum*

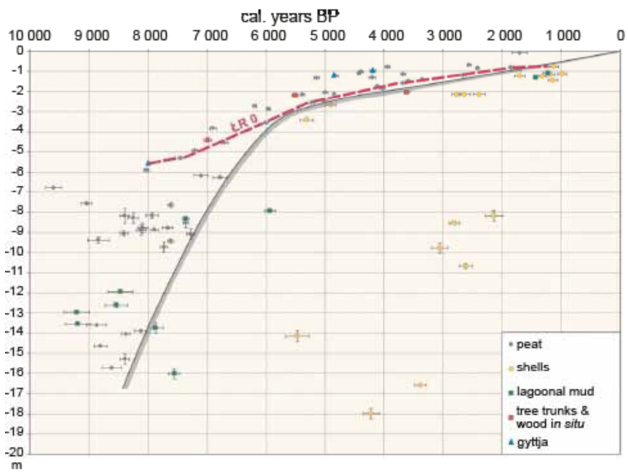


Fig. 29. Relative water level changes in the Vistula Lagoon and position of peat core ŁR 0

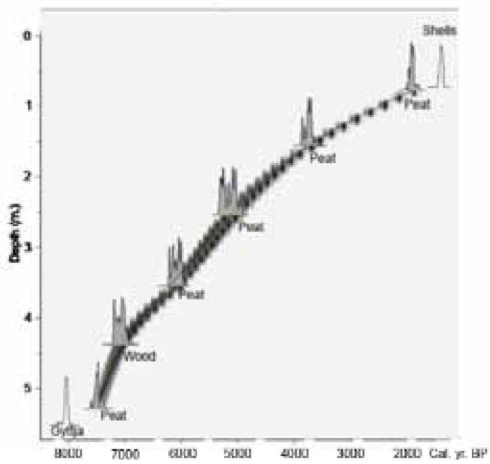


Fig. 30. Age/depth model of the core ŁR 0

indicate that increased and more frequent storm surges occurred during climate cooling periods. Their frequency equalled *ca* 400–500 and 900–1000 years.

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Analyses of δ^{13}C done by M.O. Jędrysek & A. Trojanowska (Wrocław Uniwersity).

Palynological analyses done by J. Zachowicz (Polish Geological Institute – National Research Institute)

Age-depth model for core ŁR 0 done by T. Goslar (Poznań Radiocarbon Laboratory).

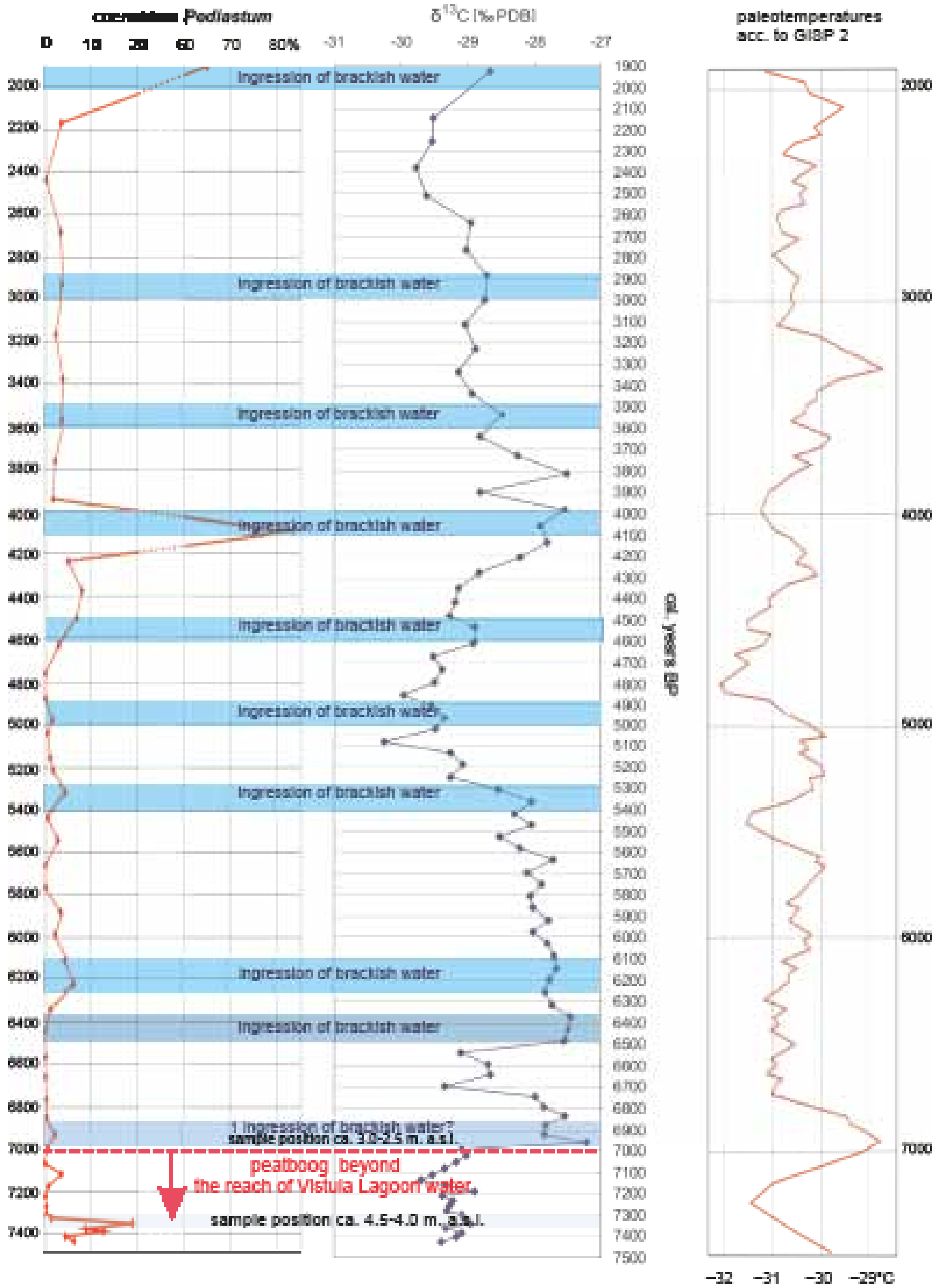

Fig. 31. Water level oscillations in Vistula Lagoon as inferred from changes of coenobium Pediastrum and δ^{13} in coastal peat bog (core ŁR 0) compared with paleotemperatures acc. to GISP 2 (Alley, 2004) ve water level changes in the Vistula Lagoon and position of peat core ŁR 0

STOP 5
THE HIGHEST DUNE "WIELBŁĄDZI GARB" AND COAST OF THE VISTULA LAGOON (KRYNICA MORSKA)

5

Origin and development of the Vistula Spit

Szymon Uścinowicz, Wojciech Jegliński, Grażyna Miotk-Szpiganowicz

Compilation of dune OSL dating with age of organic sediments (mainly basal peat) of Vistula Spit substrate, age of shells collected from the spit sands and age of peat bogs situated between dune ridges allowed to create the Vistula Spit development model (Fig. 32).

The first period of the Vistula Spit development is related to the transgression of the southern Baltic Sea in the early Atlantic when the sea level rose at a rate of approx. 6 mm/yr. The Vistula Spit was probably low and narrow barrier, often broken down during storms, migrating with the rise of water level in the land direction. The Vistula Spit as a transgressing sandy barrier had developed until approx. 7000 years ago. At that time there was a slowdown in the rate of sea level rise and processes of erosion and accumulation became balanced. As a result, the transgressing barrier evolved gradually into a stationary barrier. The period of Vistula Spit transgression is determined by the youngest radiocarbon dates of sediments (peat and organic mud) that occur in the spit substrate. The age of these sediments is between 8456–8332 and 7658–7460 cal. years BP. They lie at the depth of approx. 15 m b.s.l. in the area of Krynica Morska and Przebrno (see map). About 20 kilometers west of Przebrno, in the area of Jantar and Komary, these deposits occur at the depth of approx. 9.5–8.5 m b.s.l. and their age ranges from 7796–7670 to 7318–7133 cal. years BP.

The age of the oldest dunes (approx. 7000–6000 years) advanced the furthest to the south and southeast sets the period of converting the transgressing barrier into the stationary. At that time also dunes located to the south and southeast in the area of the current Vistula Lagoon probably existed (Fig. 32). However, in later periods they were eroded due to the Lagoon water level rise. This is indicated by the occurrence of extensive and thick sandy platforms along the Lagoon coast between Przebrno and Piaski.

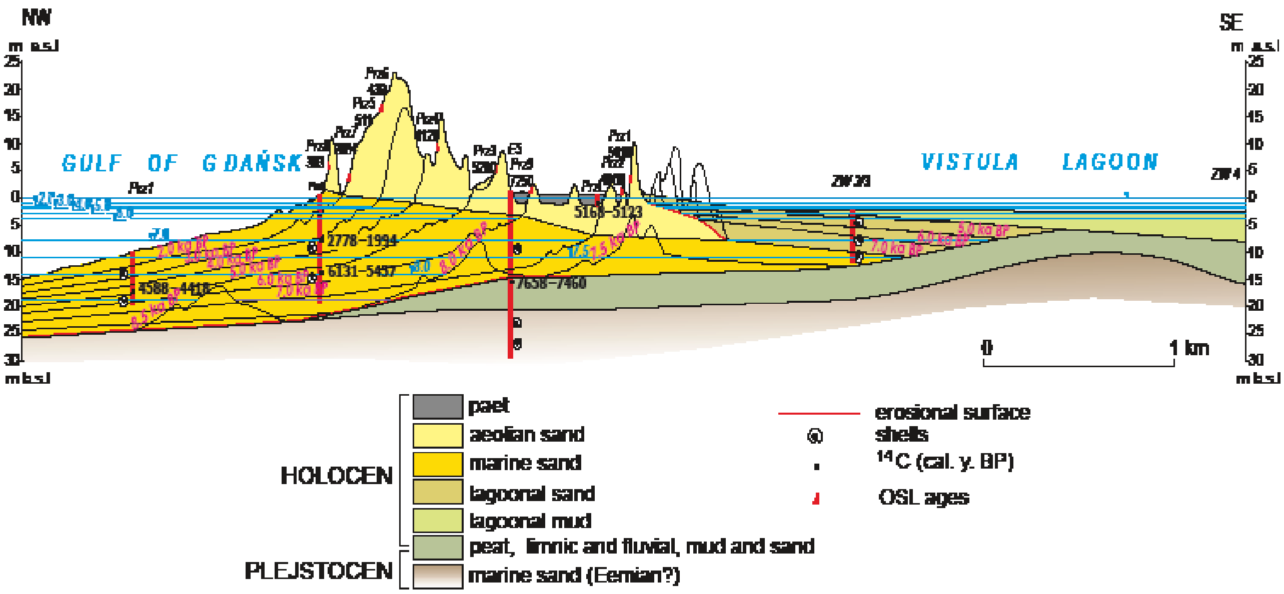

Fig. 32. Development of the Vistula Split

About 6000–5000 years ago a period of progradation of the Vistula Spit began. This is indicated by both the youngest OSL dates that define the stabilization of sand dunes on the Lagoon shore (5910 and 4960 years ago) and the oldest ^{14}C dates of peat (5168–5123 cal. years BP) that mark the beginning of development of peat bogs in depressions between dune ridges. At that time on the sea side underwater slop of the spit the intensive accumulation of sand occurred as evidenced by the oldest date from marine shells (6131–5475 cal. years BP) currently located approx. 13.5–14.5 m below the surface of the beach (Fig. 32). The time of the transition of the Vistula Spit from stationary into prograding phase coincides with a clear slowdown in the sea level rise throughout the southern Baltic. The water level rise in the Vistula Lagoon in the period of 8000–7000 years ago equalled approx. 6 mm/yr, and approx. 4mm/yr between 7000–6000 years ago. About 6000–5000 years ago the water level rise significantly slowed down to 1.5 mm/yr. More or less stable supply of the material from eroded coast of Sambia Peninsula, the western coast of the Gulf of Gdańsk and from the Vistula River mouth with a clear slowdown in the rate of sea-level rise enabled approx. 5000 years ago the initiation of intensive processes of sand accumulation in underwater coastal zone and beaches first and then, the intensive development of increasingly high dune ridges and, as a consequence, the shoreline translocation towards the sea.

Together with the formation and stabilization of the consecutive dune ridges also, the successive peat bogs between dune ridges formed. One of them is the peat bog in the area of Kąty Rybackie located at the level of approx. 0.7 m a.s.l. in the hollow between the dune ridges of a height of 8–11 m a.s.l. During 3000 years (5000–2000 years ago) the Vistula Spit was extending fast due to accumulation of sand on the underwater slope of the spit and the beach. This is proved by increasingly younger age of the shells of *Cerastoderma* sp. and *Macoma* sp. occurring close to modern bottom surface (Fig. 32) and the formation of a new high dunes. According to OSL dating the highest dunes (so-called yellow) exceeding a height of 30 m a.s.l. were formed between 4000 and 2000 years ago (Fig. 31). The highest parts of the dunes were periodically transformed by wind as indicated by younger dates. In the past 2000 years the youngest dunes located closest to the modern shore formed. They were repeatedly reshaping by wind as evidenced by numerous OSL dates younger than 1000 years (Fedorowicz *et al.*, 2009; 2012).

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