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Holocene environmental changes during transition Ancylus–Litorina stages in the Gdansk Basin, south-eastern Baltic Sea

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Abstract Two sediment cores have been obtained from the southern and eastern parts of the Gdansk Basin for lithological, geochemical and diatom analysis. The data revealed provides information about environmental changes during the transition of the Ancylus Lake to the Litorina Sea stages. The Ancylus Lake transgression and regression phases have been well traced in the diatom flora of the shallower, eastern slope of the Gdansk Depression, whereas mentioned water level changes have not been detected in the deepwater (southern) part of the basin. The Litorina Sea has been clearly defined according to geochemical, lithological and diatom analysis. The Initial Litorina Sea transition was observed as gradually increasing numbers of brackish water diatoms and higher contents of C_{org} and N in the sediments, when saline water influx reached the basin before 7600±184 cal. yr BP.

Keywords *• Diatoms • Geochemistry • Ancylus Lake • Litorina Sea • Holocene • Gdansk Basin • Baltic Sea*

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INTRODUCTION

Waters of very different salinity – completely freshwater (Baltic Ice Lake and Ancylus Lake) and marine (Litorina and Postlitorina sea) existed in the present Baltic Sea basin during the Late Glacial and Holocene. These stages of the Baltic Sea can be identified using various methods, including lithological, geochemical and diatom analysis. Mentioned methods work best for identifying lacustrine and marine deposits. The most evident boundary can be distinguished between clays of the Ancylus Lake and mud of the Litorina Sea, i.e, between sediments, accumulated in very different sedimentary and ecological environments (Gudelis, Emelyanov 1976; Emelyanov 1995).

Numerous studies gave results, that saline water of the North Sea reached the Ancylus Lake in the beginning of the Middle Ho1ocene, when the Danish Straits were formed (Andrén *et al.* 2000b; Berglund *et al.* 2005). There were several strong inflows of saline water into the lake. This period of transitional conditions was named the Mastogloia Sea stage after the diatom genus Mastogloia. However, in recent studies we find the term Initial Litorina Sea (Westman, Sohlenius 1998; Andrén *et a1.* 2000a, b; Berglund *et a1.* 2005). This term is used to describe the phase between the first marine inflows into the Baltic Sea basin and the establishment of brackish conditions of the Litorina Sea about 1000 years' later (Hyvärinen *et a1.* 1988).

Salinity of the Ancylus Lake was gradually increasing because of occasional saline water inflows at the very beginning of the Litorina Sea stage, i.e. during the Initial Litorina Sea. Salinity of the basin can be well traced by diatom analysis, where the diatom assemblage gradually shifts from freshwater (Ancylus Lake) to marine–brackish (Litorina Sea). Subsequently the freshwater diatom assemblage was replaced by marine–brackish species of the Litorina Sea.

The purpose of this paper is to clarify the transitional period of marine water inflows into the Gdansk Basin during Ancylus–Litorina stages based on diatom data. Transition from freshwater to brackish environment created special conditions in the basin (Emelyanov *et al*. 1999) and was characterized by lithological and chemical data. This paper is based on new data from two sediment cores Psd–303700–6 (depth 105 m) and PSh–4803 (depth 95 m) from the Gdansk Basin, as well as previous studies of this basin (Blazhchishin 1998; Emelyanov 2002).

MATERIAL AND METHODS

The Gdansk Basin is situated in the south–eastern part of the Baltic Sea (Fig. 1). The Late Glacial and Holocene sediments of the basin have been studied extensively during the last decades by A.L.Blazhchishin (Blazhchishin *et al*. 1991; Blazhchishin 1998), E.M.Emelyanov (Emelyanov 1995; Emelyanov 2002), E. S. Trimonis (Emelyanov, Trimonis 2002) and others (Kleimenova *et al*. 1985; Yuspina, Savukynienė 2002). It was found that sedimentation took place continuously in the central part of the basin, where the sediment sequence is most complete (for example, core AK–2682). The cores studied are of particular value for investigating transitional conditions from the Ancylus Lake to the Litorina Sea when the freshwater environment changes into marine (Emelyanov 1995; Blazhchishin 1998).

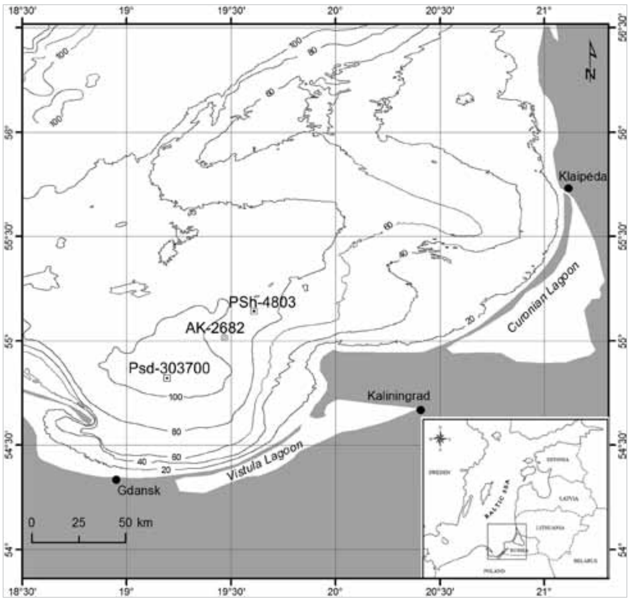


Fig. 1 Location of the studied cores in the Gdansk Basin. Bottom topography after L. Ž. Gelumbauskaitė (Ed.), 1998.

Two new sediment cores have been obtained in the Gdansk Basin for detail investigation, including the core Psd–303700–6 (an abbreviation Psd-700 for the core Psd–303700–6 is used further in this paper) taken in the southern part of the basin during the R/V "Poseidon" cruise in 2005 (led by J. Harff, IOW) arranged within the framework of the Russian–German project GISEB. The project related to modelling of spatial and temporal distribution of sediments depending on environmental changes in the Baltic Sea (Harff 2005). During the cruise several long sediment cores have been taken at the same site Psd–303700, including core Psd–303700–7. The latter core has been stratigraphically analyzed for pollen, content of bromium (Br) in pore water for the reconstruction of changes in salinity and published by Grigoriev *et al*. (2009). Cores Psd–303700–7 and Psd–303700–6 are at the same site (Table 1). The chronology of the core Psd–303700–7 has been used for the interpretation of the core Psd–303700–6. The PSh–4803 cored in the area of the eastern part of the Gdansk Depression during the R/V "Professor Shtokman" cruise is 490 cm long and its sediments consist of clay and mud. The longest core AK–2682 was obtained much earlier (Emelyanov 1995; Blazhchishin 1998).

Diatom analysis has been applied in the detailed investigation of palaeoecological conditions at the boundary of the Ancylus Lake and the Litorina Sea in cores Psd–700 (interval 0–635 cm) and PSh–4803 (interval 0–390 cm) with the additional analyses performed on: l) grain size; 2) content of CO_2, C_{org}, $Si0_{2am}$, N, Fe, Mn, Ca, Mg, P and eleven microelements and 3) mineralogy (fraction 0.05–0.0l mm).

The laboratory preparation of sediment samples for diatom analysis follows techniques mentioned in R.W.Battarbee (l986). Slides are studied under a "Nikon Eclipse E200" light microscope (magnification ×1000). Diatom species are identified using mainly the taxonomic works of K.Krammer, H.Lange–Benalot (l986–1991). The succession of the most frequent and ecologically important taxa is presented as percentages of the total sum of identified diatoms. In order to describe the palaeoecological

Table 1 Geographical location of sites. Compiled by E. Emelyanov, 2012.

Core site	Coordinates		Sea depth, m	Length of the core, cm	Thickness of Litorina silt, cm	Average V, cm/1000 years
Psd303700-6 (Psd700-6)	$54^{0}49.03'$ N	$19^{0}11.13'$ E	105	635	478	60
Psd303700-7 (Psd700-7)	$54^{0}49.03'$ N	$19^{0}11.13'$ E	105	1230	542	68
AK-2682	$55^{0}01.02'$ N	$19^{0}28.00'$ E	110	1502	341	43
PSh-4803	$55^{0}08.00'$ N	$19^{0}37.00'$ E	95	490	205	26

Note: average rate of sedimentation (V) was calculated for marine phase of Holocene. It was taken that duration of the Litorina and Postlitotrina Sea was 8000 years.

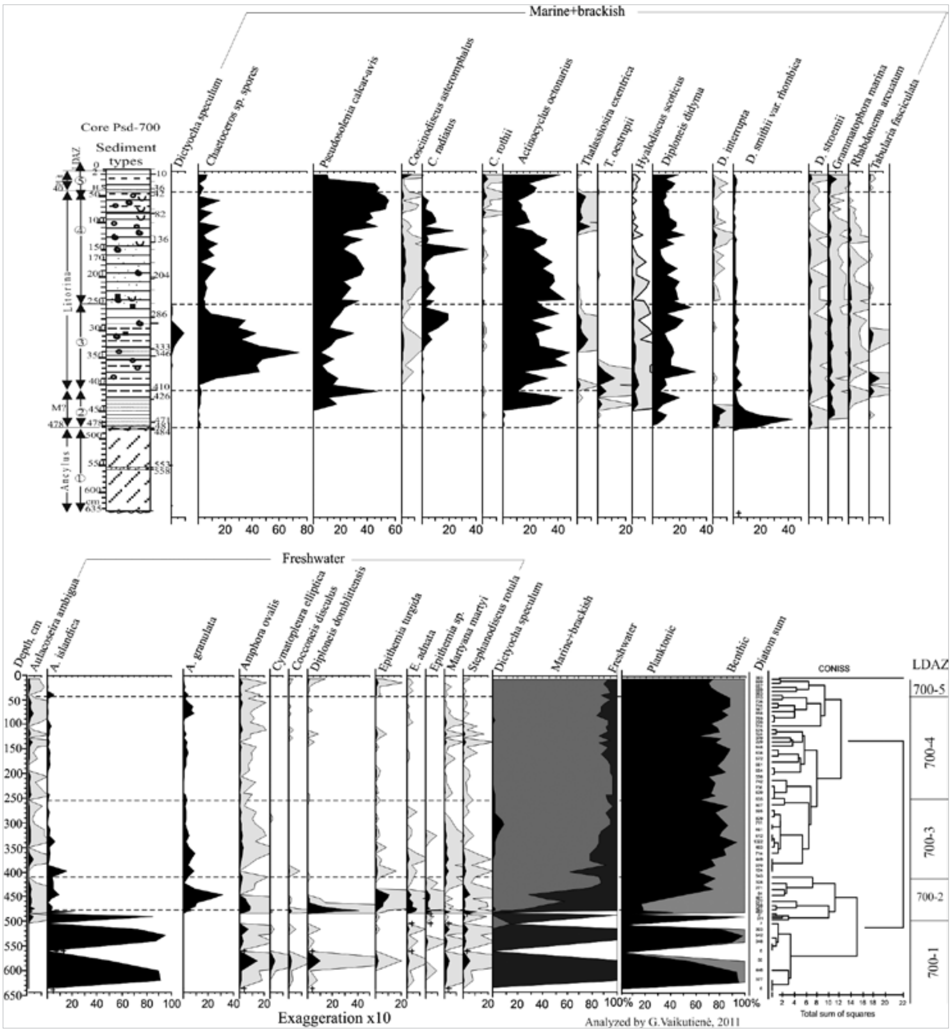
conditions of the water basin, diatom species are classified into ecological groups (Barinova *et al*. 2006; Van Dam *et al*. 1994). According to the simplified halobian system (Kolbe 1927; Hustedt 1957), the following groups of diatoms are distinguished: marine – water salinity >30 ‰ brackish – water salinity 30–0.2 ‰ and freshwater (halophilous and indifferent) diatoms. According to their habitats three groups of diatoms were distinguished: 1) planktonic – pelagic, floating; 2) benthic diatoms – bottom living and 3) epiphytic – attached to various surfaces in the shallow zone of the basin. The percentage composition of each diatom species is calculated of total diatom sum in the sample. Obtained results are presented in diagrams, using computer software “TILIA” and “TILIA&GRAPH” (Grimm 1992). Local diatom assemblages zones are grouped with the aid of cluster analysis “Connis”.

Grain size composition of sediments is analysed using pipette method (Prokoptzev 1964). Mineralogical analysis is applied only for fractions 0.1–0.05 and 0.05–0.01 mm using polarising microscope. Content of chemical components and elements is investigated using standard techniques, adopted at the Institute of Oceanology RAS, Kaliningrad and described in a particular chapter of the book (Emelyanov *et a1*. 2002). D. Eroshenko, S. Isachenko, A. Adamovich, O. Tevs and I. Klimentyeva at the Institute of Oceanology RAS have performed the analyses.

RESULTS

Core Psd–700

Five local diatom assemblage zones (further – LDAZ) have been distinguished according to changes of diatoms species composition in the core Psd–700 (Fig. 2). Peculiarities of lithology, grain size, and chemical components and elements distribution in



I. Sediment types:

1 - pelitic mud (>70% of fraction < 0.01 mm)
2 - aleuro-pelitic mud (50-70 % of fraction <0.01 mm)
3 - aleuro-pelitic mud, microlaminated
4 - fine aleuritic mud (prevailing fractions 0.1-0.01 and 0.05-0.01 mm)
5 - grey clay, aleuro-pelitic
6 - grey clay, pelitic
7 - silty (aleuritic) microlayers in the clay
8 - hydrotroilitic mud
9 - molluscs shells
10 - more than 10% of diatoms in the fractions (0.1-0.05 mm)
11 - gas craters
12 - fine (<0.3 mm) aggregates (concretions) of the hydrotroilitic mud
13 - concretions of sulfides, hard
14 - samples for the chemical analysis
15 M - beginning of (Mastogloia) transgression
16 LDAZ - local diatom assemblage zones
17 Tr - small transgressions-regressions
18 Tr - main (Litorina) transgression
19 - increased hydrodynamic activity

II. Fractions, mm

20	>0.1	23	0.01-0.005
21	0.1-0.05	24	0.005-0.001
22	0.05-0.01	25	<0.001

Fig. 2 Sediment types and distribution of dominant diatom taxa and diatom ecological groups in the core Psd–700; compiled by G. Vaikutienė, 2011. Exaggeration of species percentage (grey color) is ×10. The legend applied for the subsequent figures; compiled by E. Emelyanov, 2012.

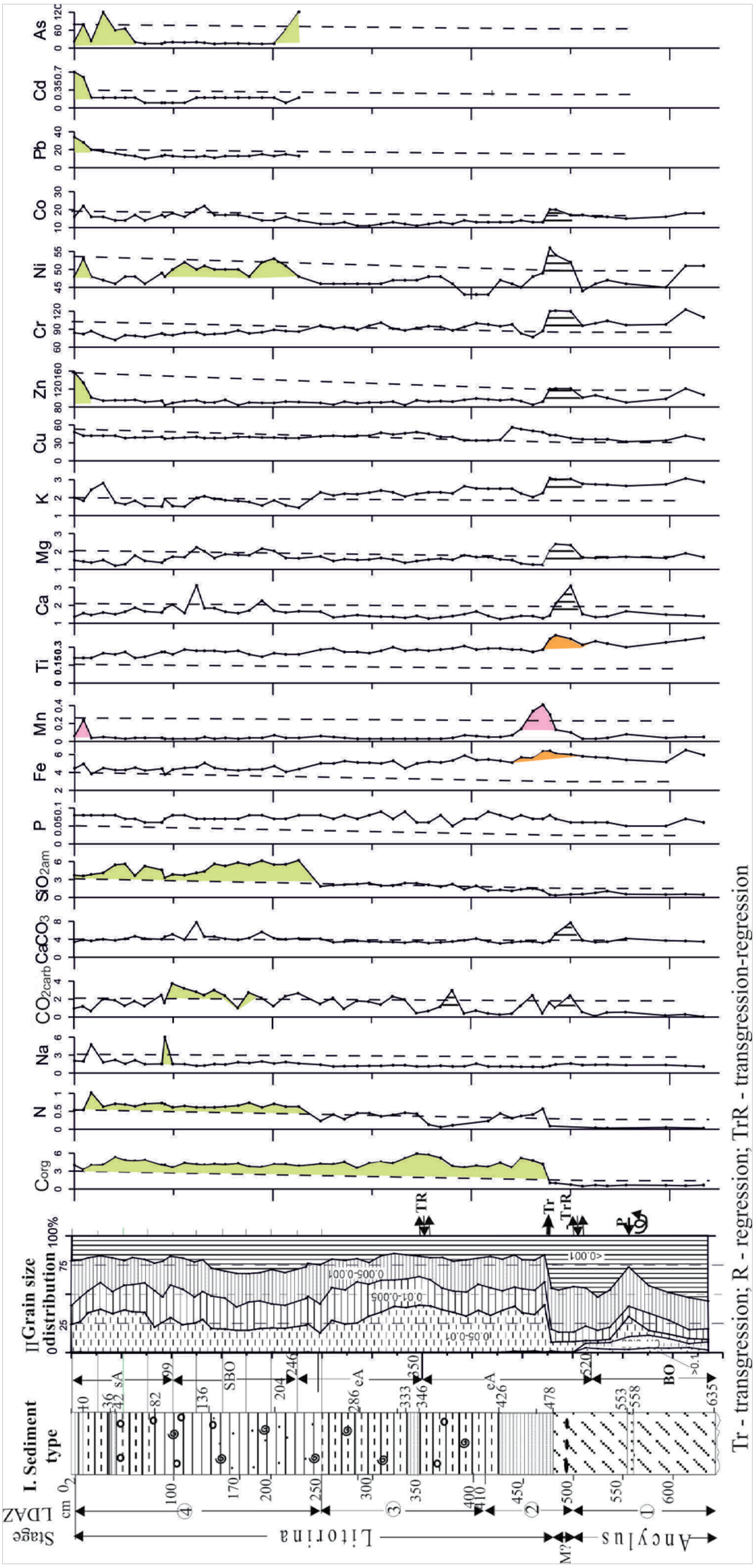


Fig. 3 The distribution of the sediment types (I), grain–size fractions (II) (in mm) and chemical components and elements in the core Psd–700; the legend see in Fig. 2. Compiled by E. Emelyanov, 2012.

sediments are described within the mentioned zones.

<u>LDAZ–700–1 (635–478 cm).</u> Planktonic freshwater diatom species (up to 90 %), especially *Aulacoseira islandica*, dominate within the zone. Benthic diatoms make up only 10 %; most common are *Amphora ovalis, Diploneis domblittensis,* and *Martyana martyi.* However, the number of diatoms abruptly decreases in the interval 558–553 cm (it is especially obvious on *Aulacoseira islandica* curve). Considerable admixture of pelitic fraction is found to be accumulated within this interval with fine auleritic (fine silty) clay turning into aleuro–pelitic mud.

<u>LDAZ–700–2 (478–410 cm).</u> Amount of freshwater diatoms decrease and brackish benthic species *(Diploneis didyma*, *D. smithii* var. *rhombica*, *D. interrupta)* appear in this zone. Brackish planktonic *Actinocyclus octonarius* becomes dominant at the top of the zone. The mud of Litorina Sea stage is coarser (increase content of fraction 0.1–0.05 mm and decrease fraction < 0.001) compared to the Ancylus clay within this zone (Fig. 3). Microlaminated Litorina mud (2.5 cm thickness layer), deposited at the beginning of the first Litorina Sea transgression consists of 14 couples of dark (clay particles and organic matter) and light (clay particles) micro–layers. Amount of iron sulphides (crystal form) makes 26.1 % and 22.2 % within fraction 0.1-0.05 mm in the layers 473–471 cm and 451–440 cm respectively.

The first Litorina Sea transgression is characterized by abrupt increase in content of C_{org} (up to 5.2 %) compared to the Ancylus clay (0.3–1.0 % C_{org}) and diatom numbers increased as well. Diatom frustule size is mainly 0.05–0.01 mm. Litorina mud possibly became coarser because of numerous diatoms in the sediment: amount of fraction 0.05–0.01 mm increases up to 40.6 % (Fig. 3). Higher content of nitrogen and SiO_{2am} is found in the mud of LDAZ–700–2 compared to the previous zone, although, amount of Ca, Mg, K, Zn and Cr decreases within this zone. Content of manganese remains higher at the bottom of the zone, but diminishes at the top of this zone (Table 2).

LDAZ–700–3 (410–250 cm). Planktonic marine and brackish diatoms *(Chaetoceros* sp. spores, *Pseudosolenia calcar-avis*, *Coscinodiscus radiatus* and *Actinocyclus octonarius)* and benthic brackish *(Diploneis didyma)* prevail within the zone. Silicoflagellata *Dictyocha speculum* makes up to 10% at the depth 300 cm. According to grain size, the mud is relatively coarse (aleuro–pelitic) and homogenous in the interval 410–368 cm. Some intervals of mud are laminated. The lamination consists of repeated 1 cm layers of greenish grey and dark grey mud. The mud becomes dark grey, micro–laminated at the depth 346–333 cm. Thickness of lamina is 0.5–1.2 mm. Dark clay layers are rich in organic matter. Content of C_{org} reaches up to 5.4–5.9 % as well as SiO_{2am} – 2.5–2.4 %, phosphorus – 0.1 % (Table 2). Fraction of 0.05-0.01 mm decreases upwards the micro–laminated mud. The mud grades into pelitic (72.0–75.4 % of fraction <0.01 mm) and homogenous starting from the depth 283 cm.

LDAZ–700–4 (250–40 cm). Amount of marine and brackish diatoms increases up to 95 % (see Fig. 2). The most common species are *Pseudosolenia calcar-avis, Actinocyclus octonarius, Coscinodiscus radiatus, Diploneis didyma, Thallasiosira excentrica.* Planktonic species dominate throughout the zone with some small decreases, when brackish benthic (mainly *Diploneis didyma*) species increase. Diatom composition is characteristic for relatively deepwater environment, stable water level and salinity.

Table 2 Content of chemical components and elements in the sediments of transitional zone between Ancylus and Litorina in the core Psd-700, Gdansk Basin (C_{org}-P in %, Cu-As in 10-4%). Compiled by E. Emelyanov, 2012.

Stage	Horizon, cm	Fraction <0.01 mm	C_{org}	N	CO_{2carb}	$CaCO_3$*	SiO_{2am}	Fe	Mn	Ti	Ca	Mg	K	Na	P	Cu	Zn	Cr	Ni	Co	Pb	Cd	As
								LDAZ - 4, Litorina mud															
Postlitorina	Min.	62.9	3.26	0.23	0.67	3.40	3.40	3.78	0.03	0.21	1.36	1.21	1.44	1.21	0.06	37	84	72	46	12	0	0.0	0
	Max.	83.4	5.30	1.02	3.73	7.78	7.78	5.05	0.24	0.28	3.11	2.23	2.81	6.03	0.08	48	157	96	53	22	34	0.7	121
	Average		4.15	0.64	4.38	4.38	4.38	4.42	0.05	0.25	1.75	1.67	1.84	1.99	0.07	40	96	83	49	16	15	0.2	34
								LDAZ - 2, Litorina mud															
Litorina	440-443	59	3.63	0.31	0.38	3.33	1.10	5.10	0.07	0.28	1.33	1.52	2.50	1.10	0.07	56	97	98	46	13	0	0	0
	449-451	64.9	5.16	0.37	1.25	3.53	1.36	5.67	0.14	0.28	1.41	1.33	2.23	1.05	0.08	53	93	83	45	14	0	0	0
	461-463	65.9	4.77	0.41	2.42	3.50	1.51	5.60	0.34	0.26	1.40	1.27	2.03	1.05	0.07	50	85	77	48	13	0	0	0
	471-473	58.7	4.19	0.57	0.43	3.20	1.17	6.33	0.41	0.28	1.28	1.26	2.26	1.02	0.07	48	92	87	49	13	0	0	0
								LDAZ - 1, Ancylus clay															
Ancylus	478-480	89.8	1.04	0.09	1.62	3.58	0.45	6.40	0.30	0.37	1.43	2.03	3.09	1.20	0.08	43	120	120	56	20	0	0	0
	484-487	90.1	1.00	<0.03	1.03	2.25	0.37	6.10	0.13	0.40	2.10	2.41	3.02	1.45	0.07	43	121	121	54	20	0	0	0
	499-502	89.8	0.74	<0.03	2.40	7.70	0.51	6.00	0.10	0.37	3.08	2.35	3.04	1.59	0.06	38	121	120	52	17	0	0	0
	511-514	81.8	0.48	<0.03	0.57	3.78	0.54	5.80	0.03	0.32	1.51	1.66	2.77	1.34	0.06	36	101	96	44	17	0	0	0

*) Calculated on Ca.

Sediments in the interval 250–82 cm are composed of pelitic, sapropelic mud, with organic matter (3.3–5.3 % C_{org}). Content of nitrogen increases significantly, up to 0.2–1.0 % (see Fig. 3). Mud is enriched with amorphous silica (3.3–6.2 %) possibly because of numerous diatom frustules in the sediments. Amount of fraction 0.05–0.01 mm increases in sediments beginning from the depth 82 cm and upwards. Mud becomes aleuro–pelitic. Sediments remain enriched in C_{org}, N and SiO_{2am} (up to 6.2 %). Very small speckles of black hydrotroilite and gas cavities are found in the mud. Smell of hydrogen sulphides and crystals of iron sulphides are characteristic for the sediments.

Numerous shells of *Macoma baltica* (1–2 cm) have been found at the depth 60–207 cm. The benthic mollusc shells possibly indicate suitable oceanographic conditions near the bottom, i.e. enriched by oxygen in the near bottom water total absence of hydrogen sulphide.

<u>LDAZ–700–5 (40–0 cm).</u> A slight decline in planktonic marine diatoms (*Rhizosolenia calcar-avis*, *Coscinodiscus radiatus* and *Thalassiosira excentrica*) and increase in brackish *Actnocyclus octonarius, Diploneis didyma, Grammatophora marina* indicate small water level and salinity decrease. Topmost (10 cm) mud turns to pelitic and contains 3.3–4.0 % C_{org}, 1.0–1.2 % CO_2, 3.6–3.7 % SiO_{2am}, 0.2 % Mn and $53*10^{-4}$ %Ni (see Fig.3).

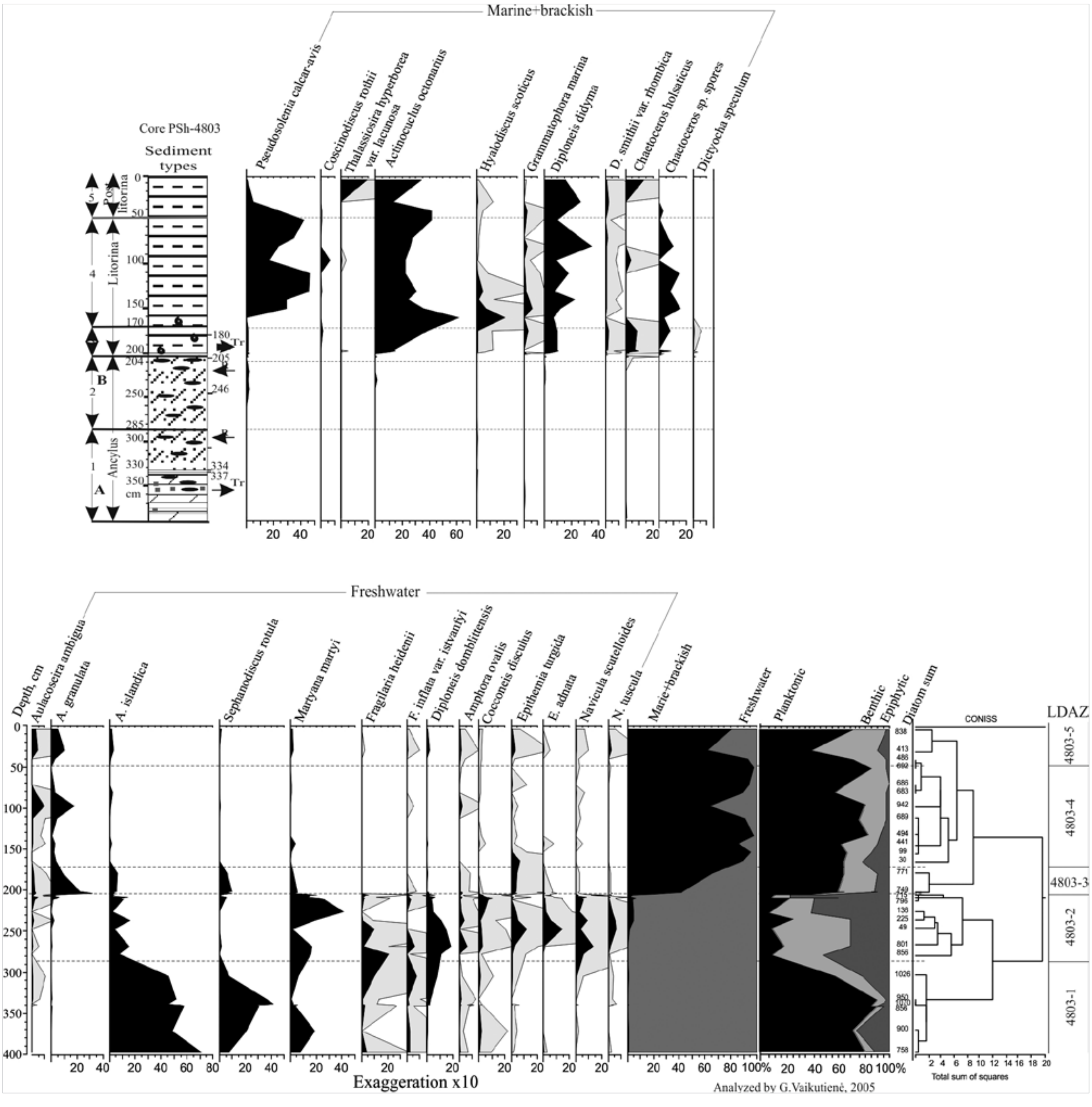


Fig. 4 Sediment types and distribution of dominant diatom taxa and diatom ecological groups in the core PSh–4803. Exaggeration of species percentage (grey color) is ×10; the legend see in Fig. 2. Compiled by G. Vaikutienė, 2005.

Table 3 Content of chemical components and elements in the sediments of transitional zone between Ancylus and Litorina in the core PSh-4803, Gdansk Basin (Corg-P in %, Li-Ag in 10-4%). Compiled by E. Emelyanov, 2012.

Stage	Horizon, cm	C_{org}	N	$CaCO_3^*$	$SiO2_в$	Al	Fe	Mn	Ti	Ca	Mg	K	Na	P	Li	Cu	Zn	Cr	Ni	Co	Pb	As	Cd	Ag
		LDAZ - 5, Postlitorina mud																						
	10-15	2.80	0.17	3.40	56.00	7.40	4.71	0.03	0.31	1.36	1.34	2.05	1.32	0.05	n.d.	38	141	116	57	16	n.d	n.d	n.d	n.d
		LDAZ - 4, Litorina mud																						
	55-66	2.91	0.05	2.75	54.00	7.67	4.55	0.03	0.28	1.10	1.24	2.04	1.10	0.05	n.d	43	110	108	50	16	n.d	n.d	n.d	n.d
	115-120	4.03	0.11	3.45	50.00	7.30	4.52	0.03	0.26	1.38	1.27	1.81	1.20	0.06	n.d	34	83	98	58	17	n.d	n.d	n.d	n.d
		LDAZ - 3, Litorina mud																						
Litorina	201-202	4.12	0.43	5.78	54.50	6.87	4.09	0.05	0.38	2.31	1.32	2.07	2.08	0.07	32	32	94	97	62	16	9	4	0.10	0.08
	202-203	3.90	0.40	4.90	54.00	7.14	4.05	0.04	0.38	1.96	1.29	2.24	2.20	0.08	31	37	92	51	60	18	8	6	0.10	0.09
	203-204	3.32	0.38	4.65	56.00	7.67	4.67	0.04	0.40	1.86	1.38	2.02	2.46	0.07	32	34	92	74	68	18	8	8	0.10	0.19
		LDAZ - 2, Ancylus clay																						
Ancylus	204-205	2.42	0.23	5.13	57.50	7.72	6.23	0.04	0.38	2.05	1.20	2.11	2.02	0.07	32	32	99	76	60	20	8	5	0.10	0.10
	205-206	2.13	0.21	5.00	58.00	7.72	5.91	0.05	0.42	2.00	1.26	2.18	2.08	0.07	34	78	97	106	80	20	8	4	0.10	0.16
	206-207	2.75	0.28	4.85	58.50	7.93	5.66	0.05	0.36	1.94	1.05	1.66	1.60	0.06	31	90	94	98	58	25	8	16	0.10	0.28
	207-208	1.78	0.20	4.20	59.00	8.15	5.88	0.05	0.40	1.68	1.29	2.37	2.14	0.07	34	75	104	118	58	20	9	2	0.10	0.11
	208-209	1.58	0.16	4.48	58.00	7.99	5.66	0.05	0.38	1.79	1.08	2.20	1.89	0.07	36	127	106	110	68	20	7	4	0.10	0.12
	245-250	1.87	0.04	3.25	58.00	8.15	5.18	0.09	0.27	1.30	1.20	2.26	1.10	0.05	n.d	56	95	121	58	18	n.d	n.d	n.d	n.d
		LDAZ - 1, Ancylus clay																						
	332-333	1.61	0.10	5.55	58.00	8.52	5.88	0.05	0.44	2.22	1.62	2.56	2.50	0.08	40	213	113	98	58	28	13	5	0.20	0.12
	333-334	1.52	0.11	5.38	56.00	8.72	5.15	0.05	0.44	2.15	1.53	2.33	2.40	0.07	38	131	118	82	62	27	11	4	0.10	0.12
	334-335	1.64	0.10	4.55	55.00	8.72	5.05	0.07	0.42	1.82	1.38	2.37	2.15	0.08	34	170	129	128	84	28	10	9	0.20	0.09
	335-336	1.73	0.14	4.88	55.00	8.46	5.42	0.08	0.43	1.95	1.32	2.68	1.95	0.09	36	127	136	128	70	18	13	13	0.20	0.22
	345-350	0.79	<0.03	3.70	59.00	8.63	5.29	0.07	0.31	1.48	1.86	2.98	1.41	0.08	n.d	53	118	140	54	18	n.d	n.d	n.d	n.d
	375-380	0.97	<0.03	5.00	55.00	7.77	6.32	0.42	0.31	2.00	2.18	2.42	1.37	0.09	n.d	50	110	116	52	25	n.d	n.d	n.d	n.d
	*) Calculated on Ca; b – bulk; n. d. – not determined.																							

Core PSh–4803

According to diatoms species composition five local diatom assemblage zones (LDAZ) have been distinguished in the core PSh–4803 (Fig.4). Distribution of grain size, chemical components and elements in sediments are described within mentioned zones.

LDAZ–4803–1 (390–285 cm). Prevalence (up to 90 %) of freshwater planktonic diatoms (especially *Aulacoseira islandica* and *Stephanodiscus rotula)* is characteristic for this zone. Freshwater epiphytic *Maryana martyi* has been found (up to 18 %) in the lower part of the zone. Content of C_{org} increases from 0.8 % to 1.6 % upwards the zone. Amount of $CaCO_3$ varies 3.7–5.6 % and A1 – 55.0–58.0 %. Somewhat high Fe (until 6.3 %), Mn (0.4 %) and Zn, Cu, Cr is observed at the depth of 380–375 cm (Table 3). Crystals of iron sulphides have been found during the examination of sediments. Unusually high (for lacustrine clay) content of manganese indicates a deficiency of oxygen in a near bottom water layer of the lake. Oxygen–enriched saline water inflows are found to cause formation of manganese hydroxides on the redox barrier in the water (Emelyanov, 1998). These hydroxides emerge on the surface film. Supposedly, hydroxides reform to the manganese carbonates (rhodochrosite) in the upper layer of the clay. These carbonates have to be very small: rhodochrosite has not been observed in the fraction 0.1-0.05 mm of the Ancylus clay.

LDAZ–4803–2 (285–204 cm). This zone is characterized by increase (up to 95%) in freshwater benthic and epiphytic diatoms *(Martyana martyi, Fragilaria heidenii, Diploneis dombittensis, Epithemia turgida, E. adnata* and *Navicula scutelloides).* Planktonic marine and brackish species *(Pseudosolenia calcar-avis* and *Actinocyclus octonarius)* appeared and reached 5 % at the top of the zone. The amount of C_{org} increases upwards from 1.6 % to 2.4 % and nitrogen – from 0.04 % to 0.3 %. Manganese content in sediments is low, only 0.04–0.1 %.

LDAZ–4803–3 (204–170 cm). Marine and brackish diatoms increase up to 80 % (especially *Actinocyclus octonarius* and *Diploneis didyma*). Number of planktonic diatoms increase also (until 65 %). Marine *Chaetoceros* sp. spores appeared. Lower part of the zone (interval 205–200 cm) is composed of fine aleuritic mud (Fig. 5). Compared to underlying clay, content of fraction 0.01–0.05 mm increases from 29.8–47.5 % to 50.3–53.5 % within this layer. Upwards, the sediments change to aleuro–pelitic mud. Mud of the zone is enriched in C_{org} (3.3–4.1 %) and nitrogen (0.4 %). Changes in grain size (from clay to mud) and increased content of organic matter can be attributed to the beginning of the first Litorina Sea transgression, when near bottom currents become more active in the Gdansk Basin.

LDAZ–4803–4 (170–50 cm). Content of marine (especially *Pseudosolenia calcar–avis)* and brackish *(Actinocyclus octonarius)* diatoms increases up to 98 %, planktonic – to 85 %. Brackish benthic *Diploneis didyma* and *Chaetoceros* sp. spores make up a significant part of total diatom sum. This zone is composed of micro–laminated sediments. The lamination is composed of <1 mm black (hydrotroilite) layers interbedded with grey mud. At the bottom of the zone (170–120 cm) mud is coarser, fraction of 0.1–0.01 mm increases up to 48 %. Fraction of 0.005–0.001 mm decreases and disappears. High content of C_{org} (up to 4.0 %) remains in the sediments (Table 3).

LDAZ–4803–5 (50–5 cm). Brackish planktonic *(Actinocyclus octonarius, Thalassiosira hyperborea* var. *lacunosa)* and benthic *(Diploneis didyma)* diatoms prevail in the zone. Planktonic marine *Pseudosolenia calcar–avis* almost disappears at the top of the zone. Increased amount of C_{org} (up to 3.49 %), zinc and chromium has been found in the mud of this zone (Table 3).

DISCUSSION

Investigation of the two cores from the Gdansk Basin revealed that sediments were deposited in the Ancylus Lake, the Litorina and the Postlitorina seas. Obtained data allows a detailed description of the Ancylus–Litorina palaeoenvironment.

Ancylus Lake

Clay of the zones LDAZ–4803–2 and LDAZ–700–1 was deposited during the Ancylus Lake transgression before 9155±163 cal. yr BP (Table 4). According to prevailing freshwater planktonic diatoms *(Aulacoseira islandica* and *Stephanodiscus rotula),* the lake was deep in the Gdansk Basin. The same species were characteristic for the Ancylus Lake transgression in the Gotland Basin (Risberg 1991; Yuspina, Savukynienė 2002; Vaikutienė 2004). Small amounts of freshwater benthic (*Martyana martyi*, *Amphora ovalis*, *Diploneis domblittensis)* diatoms indicate, that coastline of the Ancylus Lake was at a considerable distance and the numerous benthic diatoms were not transported to the Gdansk Basin by currents.

The significant decrease in freshwater planktonic diatoms and prevalence of benthic–epiphytic diatoms (*Martyana martyi*, *Diploneis domblittensis*, *Epithemia turgida*, *E. adnata*, *Navicula scutelloides*) in LDAZ–4803–2 indicate lowering of the Ancylus Lake water level. A similar diatom complex, characteristic for the regression of the Ancylus Lake, is traced in the eastern part of the Gotland Deep (Vaikutienė 2004).

Conditions became different at stations PSh–4803 and Psd–700 (see Fig. 1) due to lowering of the Ancylus Lake water level. Station PSh–4803 is in the eastern, shallower part of the Gdansk Depression. During the regression of the Ancylus Lake sedimentation of pelitic mud (LDAZ–4803–1) was replaced by aleuro-pelitic mud (the top of LDAZ–4803–1 and LDAZ–4803–2), and content of clayey particles (fraction <0.001 mm)

Table 4 Results of ^{14}C dating in the core Psd-303700-7 (Grigoriev *et al.* 2009)

Horizon, cm	Stage	^{14}C years BP	^{14}C calibrated years BP	Thickness/Age	Rate of sedimentation, mm/year
200-205	Lit.	4710 ±130	5136-4814	205/4814	0.042
258-270		5080 ±130	5574-5297	65/483	0.134
298-310		5750 ±120	6277-6013	40/(6013-5297)	0.055
377-390		6450 ± 150	7135-6779	80/(6779-6013)	0.104
480-495		7110 ± 200	7785-7417	105/(7417-6779)	0.164
620-635	A.	8520 ±130	9318-8993	-	-
1040-1060		11800 ±500	13839-12826	425/(12826-8993)	0.117

decreased from between 32.5–47.4 % to 17.3–29.2 %.

According to diatoms it is not possible to recognize the Ancylus Lake regression in the area of the core Psd–700. Oceanographic conditions remained unchanged in this deepwater area. A characteristic freshwater planktonic diatom complex is found in pelitic mud (LDAZ–700–1). However, the layer of aleuro–pelitic mud with high contents of aleuritic (0.1–0.01 mm) particles (Fig. 3) at the depth 558–553 cm indicates more intensive currents at the bottom of the 1ake. It can be related to regression of the Ancylus Lake, which caused more active terrigenous (aleuritic) material inflow into deepwater area of the1ake.

Coarser aleuro–pelitic mud in the cores represents the Ancylus Lake regression in both, the peripheral and pelagic areas of the Gdansk Basin. Water near the bottom of the lake supposedly was oxygen depleted and dissolved Mn^{2+} and Fe^{2+} were accumulated. Increased content of CO_2, Ca, Mg, Corg (up to 1.0 %) and manganese (up to 0.3 % Mn) (Table 2) at the top of LDAZ–700–1 suggests a beginning of marine water inflow into the Ancylus Lake. The waters were stratified and hydrogen sulphide was formed as indicated by lenses of hydrotroilite in the clay.

Litorina Sea

The end of Boreal and the beginning of Atlantic initiated the intrusion of marine water into the Baltic Sea basin through the Danish Straits, and it was the onset of the Litorina Sea stage. The Ancylus Lake regression has been identified only in the shallower part of the Gdansk Basin (LDAZ–4803–2), but the Initial Litorina Sea is well recognized in both, the shallower and deepwater areas of the basin according to diatoms (LDAZ–4803–3 and LDAZ–700–2). Brackish benthic diatoms *(Diploneis didyma, D. smithii* var. *rhombica, D. interrupta, Grammatophora marina, Hyalodiscus scoticus)* are characteristic for the Initial Litorina Sea, which indicate that water salinity was relatively 1ow in the Gdansk Basin. Boundary between the freshwater Ancylus Lake and the brackish Initial Litorina Sea in the shallower eastern part of the Gdansk Basin is well traced according to lithological and diatom analysis data, i.e. boundary between clay and mud (Fig. 5).

The lower boundary of Initial Litorina Sea in the deepwater southern area of the Gdansk Basin (Psd–700) has been distinguished at the horizon 478 cm according to single brackish benthic diatoms (*Navicula forcipata*, *Diploneis smithii* var. *rhombica*) found. In conformity with lithological–geochemical data, deposition of the Litorina Sea mud started at the horizon 478 cm. As it was mentioned, fine–grained (pelitic) clay shifts to coarser (aleuro–pelitic) mud in the core PSh–700 at the depth of 478 cm. Content of fraction >0.01 mm in clay increases from 12.4 % (depth 478–480 cm) to 42.3 % (depth 471–473 cm). It should be noted, that also the content of C_{org} (from 0.7 % to 4.3 %) and nitrogen (from 0 .1 % to 0.4 %) increases. Changes in diatom assemblages and increase in organic carbon content indicate an increase in primary production, related to a salinity increase

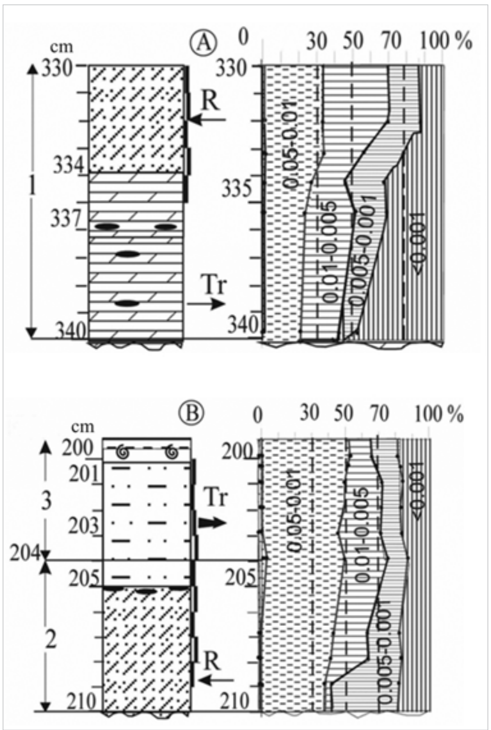


Fig. 5 Sediment types and grain size distribution of the core PSh–4803; the legend see in Fig. 2. A – the shift from transgression (Tr) pelitic clays to regression (R) aleuro-pelitic clays; B – the change of lacustrine environment (aleuro-pelitic clays) to marine environment (fine-aleuritic mud). Compiled by E. Emelyanov, 2012.

during the Initial Litorina Sea. This is also observed in the northwestern Baltic Sea and the Gotland Basin (Sohlenius *et a1*. 1996; Sohlenius, Westman 1998). Radiocarbon age of mud in the interval 480–495 cm (core PSh–700-7) is 7600±184 cal. yr BP (Table 4). The beginning of the brackish Initial Litorina Sea stage according to recorded saline water diatom floras in sediments is dated between 8900 and 10200 cal. yr BP in different areas of the Baltic Sea (Kowalczyk *et a1*. 1999; Andrén *et al*. 2000; Sohlenius *et a1*. 1996, 2001; Witkowski *et a1*. 2005). New data revealed that saline water reached the Gdansk Basin approximately before 7600±184 cal. yr BP. Evidence of this event can be an increase of C_{org} and N in the topmost part of clay (Table 2). Previous studies revealed (Emelyanov 1979, 2004) that manganese accumulates at the bottom layer of water with a deficiency of oxygen. After the new inflow (usually saline) enriched with oxygenated water, the dissolved manganese in water oxidizes and manganese hydroxides form and settle down to the bottom.

The lower boundary of marine Litorina Sea stage has been determined according to bromine in pore water studies and established at the horizon 509 cm (core Psd–700–7), when water salinity reaches 9 ‰ (Fig. 6) and becomes stable approximately 7340 yr BP (Grigoriev *et al*. 2009). According to predominating planktonic marine and brackish diatoms (LDAZ–700–3) the lower boundary of Litorina Sea stage is at 410 cm (Fig. 2), i.e. 1 m higher than distinguished on bromine data. Freshwater and

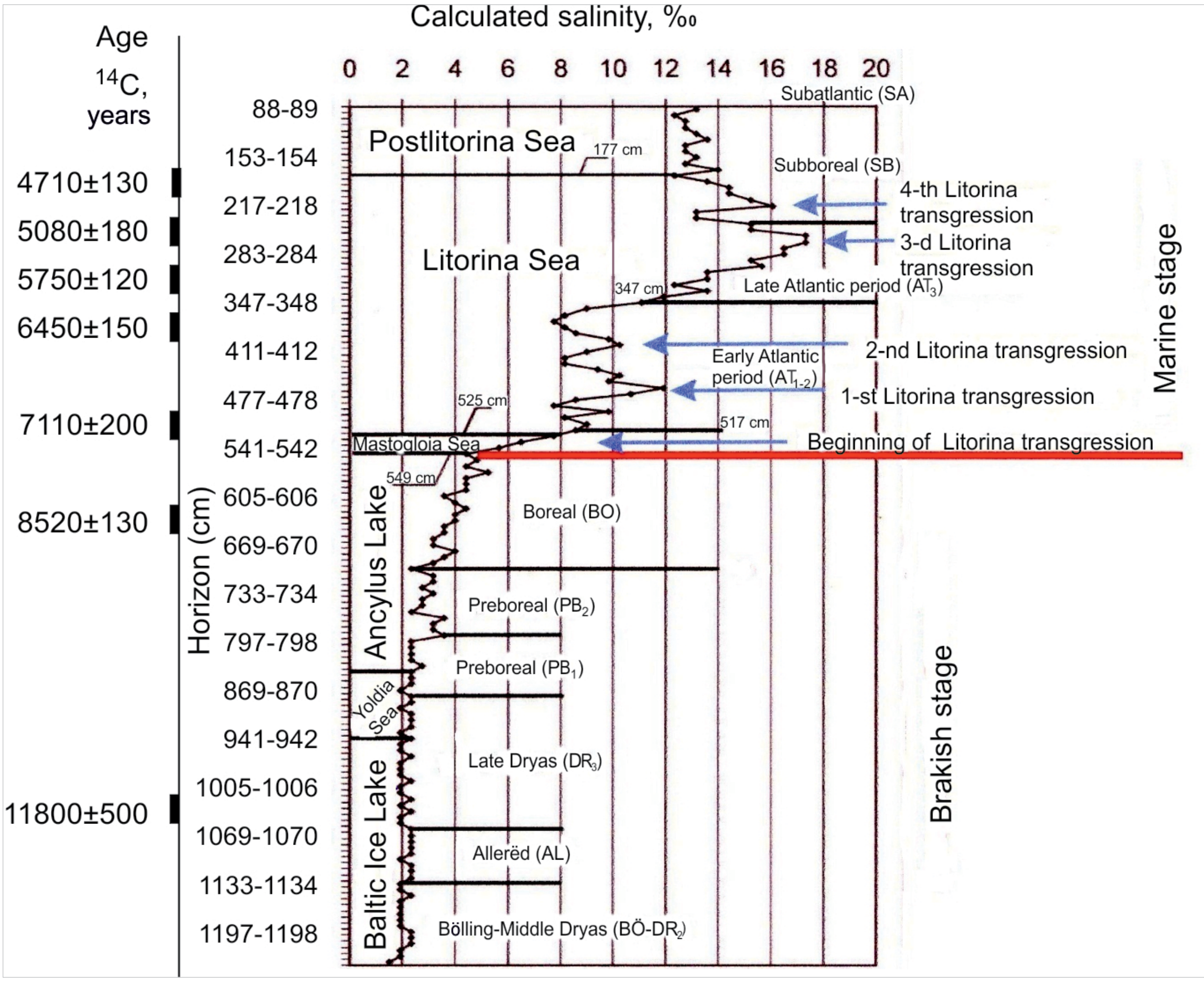


Fig. 6 The distribution of water salinity, based on bromine in pore water in sediments of the core Psd–303700–7 (after Grigoriev *et al.* 2009, with added dating). Climatic periods according to Blytt-Sernander scale (Mangerud *et al.* 1974).

only single brackish diatoms there were found at the horizon 509 cm. Only later, starting from the depth 410 cm did marine planktonic diatoms spread and we can say, that a marine environment prevailed. The lower boundary of Litorina Sea stage can be asynchronous because of methodological aspects. Diatoms represent salinity of the surface water layer in the basin, when saline water intrusions reach the upper strata of water. Possibly, the results of bromine content in the pore water reflect prior saline water near bottom inflows.

The maximum salinity of the Litorina Sea can be identified at the horizon 300 cm (LDAZ–700–3) in the core Psd–700 according to silicoflagelata *Dictyocha speculum* reaching 10 % in number. This silicoflagellata species is characteristic for the highest Litorina Sea salinity (Westman 1998). Analysis of bromine (core Psd–700–7) shows that the highest salinity of the Litorina Sea has to be 17‰ during the Atlantic optimum, approximately 5574–5297 cal. yr BP (interval 258–270 cm) (Grigoriev *et al.* 2009). Investigations of diatoms from the Darss Sill had established a maximum Litorina Sea salinity of 7–30 ‰ (Witkowski *et al.* 2005). Measurements of hydrogen isotopes indicate a 24±2 ‰ maximum Litorina Sea salinity in the Kiel Bight (Winn *et al.* 1988). Different investigations show that the highest Litorina Sea salinity in the western part of the Baltic Sea was around 17–30 ‰. We can presume that the highest Litorina Sea salinity in the Gdansk Basin has been approximately 20 ‰.

Postlitorina Sea

Topmost sediments (50–0 cm) of the investigated cores have been assigned to the Postlitorina sea stage (LDAZ–7000–5 and PSh–4803–5). Environmental changes are more distinct in the shallower area of the Gdansk Basin during the Postlitorina Sea stage. Decrease of marine planktonic and increase of brackish benthic diatoms (PSh–4803–5) indicate that water salinity and sea level slightly declined. These changes are not so evident in the deeper part of the Gdansk Basin, where marine planktonic diatoms (especially *Pseudosolenia calcar–avis)* still dominate in the Postlitorina Sea sediments. Only negligible increase in brackish benthic diatoms (Psd–700–5) indicates a small water level drop. Increase of brackish planktonic *Actinocyclus octonarius* is characteristic in both cores during the Postlitorina Sea stage.

According to measurements of Pb–210, the sediments in the interval 20–15 cm of the core Psd–700–7 had been deposited in 32±13 years (Grigoriev *et al*. 2009). Presumably, the topmost sediment layer (30–0 cm) in the core Psd–700 accumulated in 40–50 years. Sediments are enriched in zinc, lead, cadmium and arsenic mostly because of anthropogenic activity.

CONCLUSIONS

The Ancylus Lake regression can be identified according to diatoms only in the relatively shallow, eastern, part of the Gdansk Basin. However, in the southern (deepwater) part of the basin the diatom complex did not reveal significant water level decrease at the end of the Ancylus Lake stage.

The boundary between the Ancylus Lake and the Intial Litorina Sea was distinct and simultaneous according to lithological and diatom investigations. The beginning of the Litorina Sea (marine conditions) on the basis of bromine in pore water investigations was inferred earlier when compared to diatom analysis. Discrepancy arises possibly because of specificity of methods. Analysis of bromine in pore water indicates earlier inflow of saline water to the Gdansk Basin than diatoms.

The highest contents of manganese in the sediments show us the stratification of the water body due to inflows of saline water to the basin. The primary sensitive geochemical indicators of inflows are CO_2 and Ca, secondary – Ni, Co, Mn, C_{org} and N. These geochemical indicators together with diatom complexes and grain size distribution allow us to more precisely talk about inflows of the saline water into the freshwater lake.

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