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HOLOCENE MARINE INGRESSIONS IN THE COASTAL ZONE OF THE POMERANIAN BAY BASED ON RADIOCARBON ASSAYS

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Abstract: In recent years, a team at the Geology and Paleogeography Unit, Marine Sciences Institute, University of Szczecin, has been performing geological, geochronological and paleogeographic surveys in (i) the Szczecin Lagoon and Świna Gate Sandbar and (ii) the estuary section of the Rega river valley near Mrzeżyno. These studies have helped to examine and identify not only the distribution of fossil marine sediments but also their lithological and sedimentological characteristics. The age of marine ingressions and regressions in the coastal zone of the Pomeranian Bay were determined using approximately 170 radiocarbon assays.

It was found that the marine ingression associated with the 'Littorina transgression' was not synchronous at these two areas. It started earlier in the Mrzeżyno area, ca. 8300-8200 cal BP. In that first phase, marine sediments developed as tightly packed sands containing a few fragments of shells. In several profiles, these deposits were separated from the bottom and top with layers of peat, thus allowing an indirect determination of their age. The next phase of ingression began about 7300 cal BP. These younger marine sediments already contained quite numerous shells of marine malacofauna, especially *Cardium glaucum*, often found in a life position.

In the area of the Szczecin Lagoon and Swina Gate Sandbar, the oldest marine ingression started as early as about 7350 cal BP. The quite clear trace is a considerably thicker series of marine sands with numerous sea shells representing marine and brackish-marine environments, including *Cardium glaucum* shells in a life position, which made it possible to identify the age and the rate of accumulation of marine sands.

Keywords: marine ingression, Baltic sea level changes, Holocene, Pomeranian Bay.

1. INTRODUCTION

The age of marine ingressions on the Polish Baltic coast has been discussed for a long time. Usually, the discussions have not been based on age determinations of marine sediments, but rather used dating of organic matter (peat, gyttja, wood fragments) underlying or covering marine layers.

The aim of this study was to determine the actual age of the marine sand layers documented in a number of locations in the coastal zone of the Pomeranian Bay (Borówka *et al*., 1999, 2002, 2005; Cedro, 2003, 2005). A conducive factor was the presence of fossil shells of *Cardium glaucum* in marine sediments, some of which were preserved in a life position. This mollusc species is particularly poorly resistant to being buried in sediments, due to its very short siphon (Wołowicz, 1991). Therefore, the radiocarbon age of the intact shells found is a *de facto* age of deposits where they were buried (taking into account the reservoir effect).

An additional factor which enabled higher dating precision is the fact that the mollusc *Cardium glaucum* has a

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short life, max. 3-4 years (Wołowicz, 1991). Hence the determination of the age of whole shells did not require taking into account the age of the mollusc.

2. STUDY AREA

The study was conducted in two test areas located on the Polish coast of the southern Baltic Sea (**Fig. 1**). The areas included the present area of Szczecin Lagoon (54º48' N, 14º20' E) and the estuary of the Rega river (54º48' N, 14º20' E).

Szczecin Lagoon has an area of approximately 665 km^2. It is a shallow freshwater body, with a natural depth not exceeding 8.5m, fed mainly by the Oder and its smaller tributaries: Ücker and Peene. The sediments filling the eastern part of the lagoon (Great Lagoon) are at max. 5 metres thick and lie on fluvial sands on lower lying glaciofluvial gravels and sands (Borówka *et al.,* 2002; 2005). The deposits in stratigraphic order are: late glacial, early and middle holocene peat and gyttjas, sands with marine fauna of *Cardium glaucum, Macoma balthica*, *Mytilus edulis, Hydrobia ventrosa* and *Hydrobia ulvae*, and then algal and silt gyttjas with lacustrine malacofauna (Borówka *et al.,* 2002; 2005).

The Rega river estuary occupies a former portion of the marginal valley, with longitudinal orientation and a general westward decline (Karczewski, 1968). The fossil bottom of the valley is a residual lag shearing interplenivistulian sand and silt sediments, and vistulian tills on the slopes. The deposits of this valley in stratigraphic order are: glaciofluvial sands and gravels, late glacial silts and clays, early and mid-holocene peats and gyttjas, sands with marine fauna from *Cardium glaucum*, *Macoma balthica* and *Mytilus edulis* separated by a layer of peat, in lateral contact with the sands in the north and lacustrine deposits in the south. This sequence is covered by mid- and late-holocene peats and then aeolian sands (Cedro, 2005; 2008).

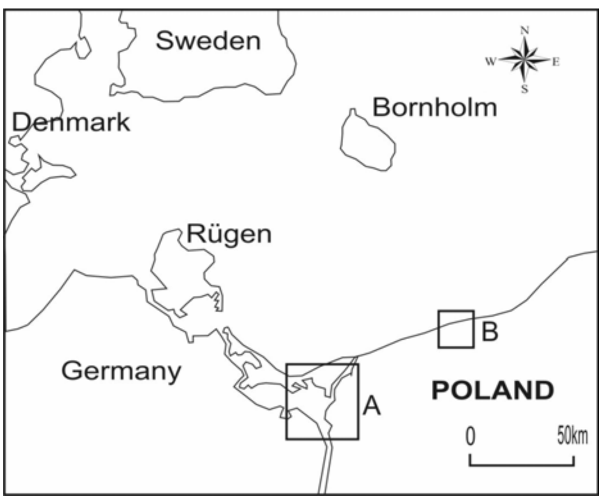

Fig. 1. *Study area A – Szczecin Bay , B – Mrzeżyno.*

3. MATERIALS AND METHODS

The materials of this research were deposits filling the aforementioned sedimentary basins. In Szczecin Lagoon they were identified using 38 vibroprobes reaching about 4 m below the present-day seabed (**Fig. 2**). In the Rega estuary 29 test drillings were performed, with depths ranging from 7.5 to 13 meters (**Fig. 3**).

From the selected vibroprobes and drillings, samples of organic sediments were collected, including *Cardium glaucum* shells, in order to determine their radiocarbon

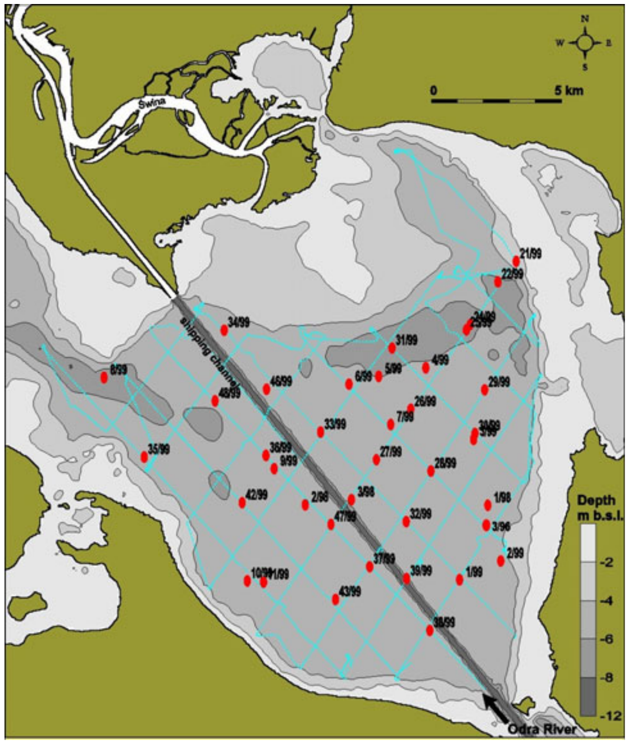

Fig. 2. *Location of sediment cores (A area).*

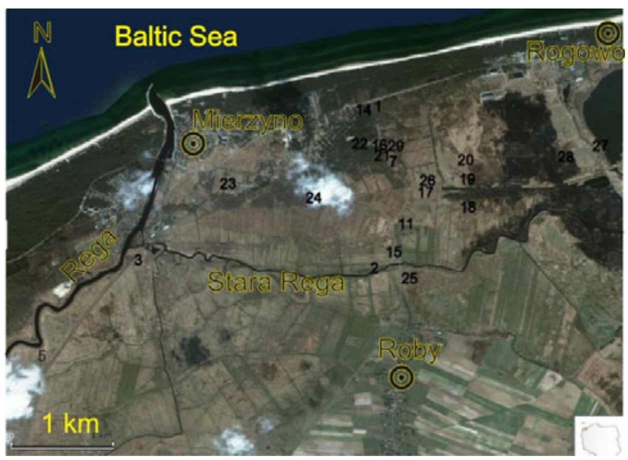

Fig. 3. *Location of sediment cores (B area).*

ages. Gyttja and peat samples were dated at the Radiocarbon Laboratory, Institute of Physics, Gliwice. The age of *Cardium glaucum* shells found in life position was determined using AMS at Poznań Radiocarbon Laboratory. The samples comprised 118 gyttja and peat samples, 7 wood samples and 70 samples of shells.

The reservoir age of *Cardium* shells was assumed as 300 years, according to values for the southern Baltic based on the Chrono Marine Reservoir Database (http://intcal.qub.ac.uk/marine/).

Calendar ages were determined using an Internet programme OxCal (https://c14.arch.ox.ac.uk, Bronk Ramsey, 2009) and calibration curve IntCal09 (Reimer *et al*., 2009) - see **Table 1** and **2**.

4. RESULTS

Szczecin Lagoon

In the area of Szczecin Lagoon, radiocarbon dating was performed on 56 samples of organic sediments and 67 *Cardium glaucum* shells. Selected results from nine geological probes are presented in **Table 1**.

Only those results which are significant for the determination of the age of marine sediments and organic deposits below them have been presented. Results of calibration for all samples are presented as frequency distribution of radiocarbon dates on calendar time scale in **Fig. 4**.

The ages of organic sediments fall in two groups, i.e., from about 15,000 until 6000 cal BP and after 3500 cal BP. The age of *Cardium glaucum* shells, showing the period of accumulation of marine sediments in the present day Szczecin Lagoon, ranges from about 7200 to 3800 cal BP (**Table 1**).

Marine sediments which developed as fine and medium sands at the bottom and silts at the top, are located mainly on limnic and swamp sediments, especially in the central part of the Great Lagoon, and on fluvial deposits in the western parts. Their base occurs at depth of -10 m to -6.5 m amsl with a thickness rarely exceeding 1.5 m.

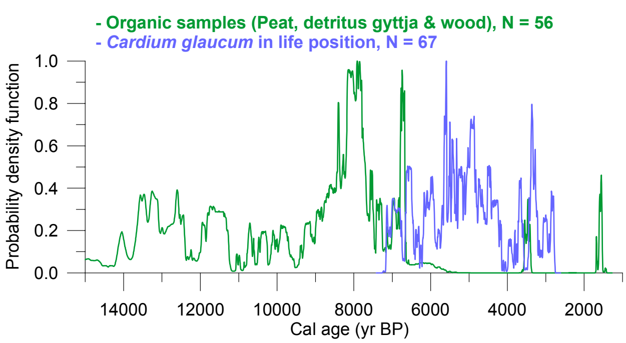

Fig. 4. *Frequency distributions of radiocarbon dates of organic and shell samples on calendar time scale. The curves were constructed by summing up probability distributions of individual dates (Option "Sum" in OxCal programme)(A area).*

Based on the results of radiocarbon age determinations presented in the **Table 1** and the example of a profile (**Fig. 5**), it can be assumed that in the area of Szczecin Lagoon the sea ingression began at the earliest around 7360 years cal BP, and at the latest about 7000 years cal BP. This is evidenced by the oldest mollusc shells derived from the bottom of the marine sediments (ZSW 78/93 - see **Table 1**), and is further supported by the results of age determinations of the youngest layers of peat and organic mud under the marine sediments (ZS 28/57 - see table). The sea lagoon lasted until about 3800 years cal BP. Based on data from profile 35/99 (**Fig. 5**) and other locations, it appears that in this relatively long period there was a continuity of marine sedimentation.

Area of the Rega river estuary

In the estuary of the Rega River, radiocarbon determinations were performed for 67 samples (**Fig. 6**) of organic sediment samples and 3 shell samples from 29 boreholes. Selected results from 8 boreholes are presented in **Table 2**.

The age of organic sediments is grouped in several classes, i.e. from 14,000 to 12,000 years cal BP, from 11,000 to 7500 cal BP to, from 7000 to 4500 cal BP and from 3000 to 1000 cal BP.

The dating results presented in the **Table 2** and the example of a profile (**Fig. 7**) show that in the vicinity of Mrzeżyno (estuary of the Rega River), the earlier phase of sea ingression occurred between 8360 cal BP and 8180 cal BP. That phase of ingression is represented by heavily packed marine sand deposits containing a few fragments of shells. They can be found at the ordinate -7 m amsl. These deposits are both underlying and covering layers of peat. The peats underlying the deposits with the aforementioned age were found in three bores/drillings, and peat covering the deposits in seven drillings. The younger layer of peat was accumulated in the period between 8180 cal BP and 7640 cal BP. On the layer at the ordinate

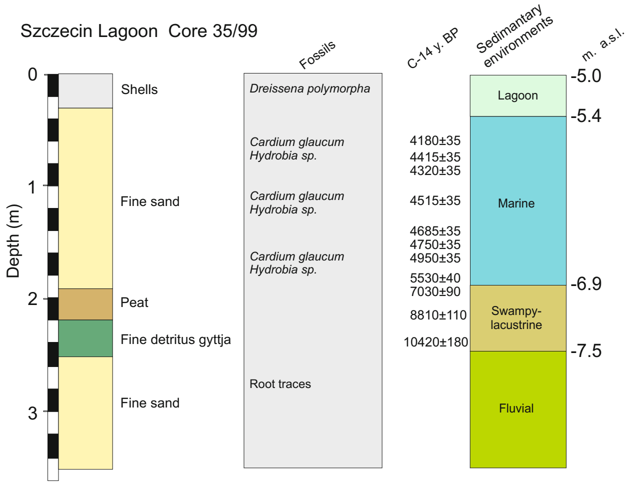

Fig. 5. *Sediment cores.*

Table 1. *Dating and calibration results.*

No	Sample name	No. of the location (core)	Type of dated sediment	Depth (meters below the terrain or sea bottom level)	Ordinate (m amsl)	Latitude	Longitude	Radiocarbon age (years ^{14}C BP)	68.2% confidence intervals Cal agerange (year BP)	Lab ID
1	2	3	4	5	6	7	8	9	10	11
1	ZS 9	9/96	organic silt	4.90-5.00	-10	53° 44' 31''	14° 30' 32''	**7250 ± 130**	7940-8200 (68.2%)	Gd-15092
2	ZS 26/56	26/99	detritus gyttja	2.75-2.80	-8.75	53° 46' 23''	14° 28' 01''	**7240 ± 120**	7950-8180 (68.2%)	Gd-15103
3	ZS 28/57	28/99	organic silt	2.80-285	-8.57	53° 45' 11''	14° 28' 41''	**6230 ± 250**	6800-7450 (68.2%)	Gd-16027
4	ZS 29/26	29/99	organic silt	1.24-1.30	-7.02	53° 46' 48''	14° 30' 25''	**7050 ± 90**	7790-7970 (68.2%)	Gd-12241
5	ZS 35/12	35/99	*Cardium glaucum*	0.52-0.56	-5.57	53° 45' 29''	14° 19' 26''	**4180 ± 35**	4800-4830 (14.3%) 4690-4770 (38.4%) 4630-4680 (15.5%)	Poz-12391
6	ZS 35/14	35/99	*Cardium glaucum*	0.60-0.65	-5.66	53° 45' 29''	14° 19' 26''	**4415 ± 35**	4950-5050 (47.6%) 4880-4940 (20.6%)	Poz-12392
7	ZS 35/18	35/99	*Cardium glaucum*	0.80-0.85	-5.86	53° 45' 29''	14° 19' 26''	**4320 ± 35**	4930-4960 (19.1%) 4840-4890 (49.1%)	Poz-12394
8	ZS 35/25	35/99	*Cardium glaucum*	1.10-1.15	-6.16	53° 45' 29''	14° 19' 26''	**4515 ± 35**	5270-5300 (11.9%) 5210-5230 (2.5%) 5060-5190 (53.9%)	Poz-12395
9	ZS 35/30	35/99	*Cardium glaucum*	1.35-1.40	-6.41	53° 45' 29''	14° 19' 26''	**4685 ± 35**	5440-5470 (15.4%) 5320-5420 (52.8%)	Poz-12396
10	ZS 35/32	35/99	*Cardium glaucum*	1.45-1.50	-6.51	53° 45' 29''	14° 19' 26''	**4750 ± 35**	5500-5590 (54.2%) 5460-5490 (14.0%)	Poz-12397
11	ZS 35/34	35/99	*Cardium glaucum*	1.55-1.60	-6.61	53° 45' 29''	14° 19' 26''	**4950 ± 35**	5640-5720 (62.4%) 5610-5630 (5.8%)	Poz-12398
12	ZS 35/39	35/99	*Cardium glaucum*	1.80-1.85	-6.86	53° 45' 29''	14° 19' 26''	**5530 ± 40**	6360-6400 (22.0%) 6280-6350 (46.3%)	Poz-12399
13	ZS 35/42	35/99	peat	1.92-2.00	-7.01	53° 45' 29''	14° 19' 26''	**7030 ± 90**	7760-7960 (68.2%)	Gd-12223
14	ZS 35/46	35/99	peat	2.15-2.20	-7.21	53° 45' 29''	14° 19' 26''	**8810 ± 110**	10060-10150 (14.0%) 9980-10050 (6.5%) 9680-9950 (47.6%)	Gd-12224
15	ZS 35/50	35/99	detritus gyttja	2.35-2.40	-7.41	53° 45' 29''	14° 19' 26''	**10420 ± 180**	12040-12560 (68.2%)	Gd-15090
16	ZS 42/6	42/99	gyttja	0.30-0.35	-6.4	53° 44' 35''	14° 22' 37''	**1670 ± 30**	1530-1610 (68.2%)	Poz-796
17	ZS 42/12	42/99	gyttja	0.65-0.70	-6.75	53° 44' 35''	14° 22' 37''	**3250 ± 40**	3520-3560 (17.1%) 3500-3510 (2.1%) 3440-3490 (35.8%) 3400-3430 (13.2%)	Poz-816
18	ZS 42/20	42/99	*Cardium glaucum*	1.00-1.05	-7.1	53° 44' 35''	14° 22' 37''	**4210 ± 35**	4810-4840 (23.8%) 4700-4760 (37.1%) 4650-4670 (7.2%)	Poz-705
19	ZS 42/21	42/99	*Cardium glaucum*	1.05-1.10	-7.15	53° 44' 35''	14° 22' 37''	**4510 ± 35**	5260-5290 (11.0%) 5210-5250 (4.5%) 5050-5190 (52.7%)	Poz-706
20	ZS 42/24	42/99	*Cardium glaucum*	1.20-1.25	-7.3	53° 44' 35''	14° 22' 37''	**5140 ± 40**	5880-5940 (45.4%) 5760-5810 (22.8%)	Poz-703
21	ZS 42/28	42/99	*Cardium glaucum*	1.40-1.45	-7.5	53° 44' 35''	14° 22' 37''	**6430 ± 45**	7320-7420 (68.2%)	Poz-702
22	ZS 42/30	42/99	detritus gyttja	1.50-1.55	-7.6	53° 44' 35''	14° 22' 37''	**6850 ± 90**	7600-7790 (68.2%)	Gd-12217
23	ZS 42/36	42/99	detritus gyttja	1.80-1.86	-7.91	53° 44' 35''	14° 22' 37''	**7320 ± 80**	8020-8200 (68.2%)	Gd-12222
24	ZS 42/41	42/99	peat	2.00-2.03	-8.08	53° 44' 35''	14° 22' 37''	**10030 ± 120**	11310-11760 (68.2%)	Gd-12214
25	ZS 42/44	42/99	peat	2.10-2.14	-8.19	53° 44' 35''	14° 22' 37''	**11450 ± 140**	13160-13440 (68.2%)	Gd-12220
26	ZSW 42/173	ZSW-042	*Cardium glaucum*	1.73	-7.13	53° 48' 33''	14° 28' 18''	**3735 ± 35**	4070-4150 (43.2%) 3990-4040 (25.0%)	Poz-28288
27	ZSW 42/232	ZSW-042	*Cardium glaucum*	2.32	-7.72	53° 48' 33''	14° 28' 18''	**6270 ± 40**	7170-7250 (68.2%)	Poz-28295
28	ZSW 57/131	ZSW-057	*Cardium glaucum*	1.31	-7.31	53° 47' 35''	14° 24' 18''	**3920 ± 35**	4290-4420 (68.2%)	Poz-28297
29	ZSW 57/237	ZSW-057	*Cardium glaucum*	2.37	-8.37	53° 47' 35''	14° 24' 18''	**6410 ± 40**	7350-7420 (45.8%) 7300-7340 (22.4%)	Poz-28304
30	ZSW 78/93	ZSW-078	*Cardium glaucum*	0.93	-6.83	53° 46' 01''	14° 25' 50''	**6460 ± 40**	7410-7430 (12.0%) 7320-7400 (56.2%)	Poz-28312

Table 2. *Dating and calibration results.*

No	Sample name	No. of the location (core)	Type of dated sediment	Depth (meters below the terrain or sea bottom level)	Ordinate (m amsl)	Latitude	Longitude	Radiocarbon age (years ^{14}C BP)	68.2% confidence intervals Cal ager-ange (year BP)	Lab ID
1	2	3	4	5	6	7	8	9	10	11
1	Trz7/16	Trz7	peat	2.75-2.80	-1.3	54º 8' 37''	15º 18' 54''	**5100 ± 140**	5962-5990(4.9%) 5660-5952 (63.3%)	Gd-15660
2	Trz7/28	Trz7	wood	4.70-4.75	-3.2	54º 8' 37''	15º 18' 54''	**7330 ± 55**	8046-8185 (68.2%)	Gd-15658
3	Trz7/38	Trz7	peat	6.20-6.30	-4.7	54º 8' 37''	15º 18' 54''	**7160 ± 50**	7941-8014 (68.2%)	Poz33390
4	Trz7/46	Trz7	peat	7.70-7.75	-6.2	54º 8' 37''	15º 18' 54''	**7680 ± 40**	8494-8516 (16.8%) 8417-8480 (51.4%)	Gd-12641
5	Trz7/74	Trz7	peat	10.95-11.00	-9.5	54º 8' 37''	15º 18' 54''	**10390 ± 220**	11960-12572 (64.7%) 11830-11875(3.5%)	Gd-15670
6	Trz19/72	Trz19	detritus gyttja	7.40-7.50	-6.4	54º 8' 23''	15º 19' 26''	**14340 ± 170**	17170-17672 (68.2%)	Gd-12833
7	Trz20/31	Trz20	peat	3.50-3.55	-2	54º 8' 28''	15º 19' 25''	**5900 ± 70**	6820-6824 (0.9%) 6639-6797 (67.3%)	Gd-15910
8	Trz20/54	Trz20	peat	5.75-5.85	-4.3	54º 8' 28''	15º 19' 25''	**7170 ± 75**	8142-8151 (2.0%) 8124-8128 (0.8%) 8095-8104 (2.0%) 7930-8050 (59.2%) 7876-7892 (4.1%)	Gd-12835
9	Trz21/34	Trz21	*Cardium glaucum*	5.70-5.80	-3.2	54º 8' 35''	15º 18' 53''	**6540 ± 40**	7424-7479 (68.2%)	Poz 20538
10	Trz21/48	Trz21	peat	7.20-7.30	-5.8	54º 8' 35''	15º 18' 53''	**7350 ± 80**	8261-8296 (10.5%) 8040-8210 (57.7%)	GdS-781
11	Trz22/32	Trz22	*Cardium glaucum*	6.80-6.85	-5.3	54º 8' 34''	15º 18' 43''	**6740 ± 40**	7640-7651 (7.8%) 7572-7622 (60.4%)	Poz 20539
12	Trz26/5	Trz26	peat	0.50-0.55	0.50	54º 8' 24''	15º 19' 10''	**1450 ± 25**	1308-1354 (68.2%)	GdS-787
13	Trz26/20	Trz26	peat	2.35-2.40	-1.4	54º 8' 24''	15º 19' 10''	**4400 ± 80**	5244-5260 (3.2%) 5224-5235 (2.2%) 5188-5214 (5.9%) 4858-5054 (56.9%)	GdS-779
14	Trz26/48	Trz26	*Cardium glaucum*	5.00-5.10	-4.1	54º 8' 24''	15º 19' 10''	**6640 ± 40**	7494-7568 (68.2%)	Poz-33389
15	Trz26/50	Trz26	peat	5.15-5.20	-4.2	54º 8' 24''	15º 19' 10''	**6775 ± 85**	7566-7692 (66.7%) 7524-7530 (1.5%)	Gd-11983
16	Trz26/56	Trz26	organic silt	5.60-5.65	-4.6	54º 8' 24''	15º 19' 10''	**9060 ± 260**	9886-10560(63.4%) 9866-9876 (0.7%) 9788-9848 (4.2%)	Gd-30180
17	Trz28/9	Trz28	peat	0.90-0.95	-0.1	54º 8' 36''	15º 20' 9''	**2270 ± 50**	2303-2345 (31.1%) 2180-2240 (37.1%)	GdS-780
18	Trz28/50	Trz28	detritus gyttja	5.10-5.20	-4.1	54º 8' 36''	15º 20' 9''	**4680 ± 80**	5546-5575 (9.2%) 5316-5474 (59.0%)	Poz-33386
19	Trz28/70	Trz28	detritus gyttja	6.70-6.80	-5.7	54º 8' 36''	15º 20' 9''	**7170 ± 50**	7946-8020 (68.2%)	Poz-33387
20	Trz28/82	Trz28	peat	7.60-7.70	-6.7	54º 8' 36''	15º 20' 9''	**6930 ± 50**	7811-7822 (5.1%) 7690-7795 (63.1%)	Poz-33388
21	Trz28/87	Trz28	wood	7.90-7.95	-6.9	54º 8' 36''	15º 20' 9''	**7370 ± 70**	8156-8315 (56.2%) 8110-8117 (1.8%) 8056-8090 (10.2%)	GdS-768
22	Trz28/93	Trz28	peat	8.35-8.40	-7.4	54º 8' 36''	15º 20' 9''	**9590 ± 290**	11294-11302 (0.4%) 10490-11288 (66.8%) 10438-10456 (0.9%)	Gd-30177
23	Trz28/103	Trz28	organic silt	9.10-9.20	-8.1	54º 8' 36''	15º 20' 9''	**11380 ± 60**	13181-13316 (68.2%)	Poz-33383
24	Trz28/113	Trz28	organic silt	9.90-10.00	-8.9	54º 8' 36''	15º 20' 9''	**11120 ± 60**	12926-13108 (68.2%)	Poz-33384
25	Trz29/10	Trz29	peat	1.1-1.15	0.4	54º 8' 36''	15º 18' 59''	**1700 ± 50**	1654-1691 (19.6%) 1547-1628 (48.6%)	GdS-766
26	Trz29/19	Trz29	peat	1.85-1.90	-0,40	54º 8' 36''	15º 18' 59''	**5630 ± 50**	6392-6466 (43.1%) 6321-6371 (25.1%)	Gd-11985
28	Trz29/57	Trz29	peat	5.7-5.75	-4,20	54º 8' 36''	15º 18' 59''	**7320 ± 120**	8260-8300 (9.0%) 8010-8212 (59.2%)	GdS-767

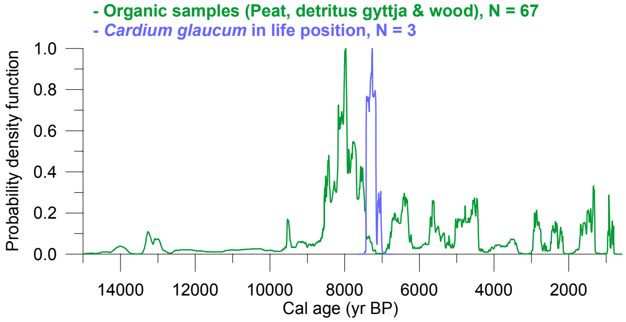

Fig. 6. *Frequency distributions of radiocarbon dates of organic and shell samples on calendar time scale. The curves were constructed by summing up probability distribution of individual dates (Option "Sum" in OxCal programme) (B area).*

around -5.5 m amsl, a younger series of marine sediments can be found containing relatively large representations of malacofauna marine shells, especially *Cardium glaucum* and *Macoma balthica*.

The age of *Cardium glaucum* shells, determining the second period of accumulation of marine sediments, occurred between 7370 and the 7150 cal BP. The oldest peat layer lying on these sediments does not exceed an age of 6740 cal BP.

Based on data from the profile (**Fig. 7**) and other locations, it can be suggested that this area experienced two brief episodes of marine sedimentation which lasted for about 180 years (the earlier one) and from about 200 to max. 600 years (the later one).

4. DISCUSSION AND CONCLUSIONS

Comparing the periods of marine deposit formation in the aforementioned sedimentary basins, it may be noted that the ingression of Baltic waters associated with the so-called Littorina transgression was not synchronous in these two areas. It started earlier in the area of Mrzeżyno (**Fig. 8**) around 8300-8200 cal BP. Deposits that developed during that first phase contained few fragments of shells, therefore it is possible that they represent the facies of washover fans forming during heavy storms on the landward side of the spit, combined with a surge of waters on the southern coast of the Baltic sea. Such fossil washover fans are known from many sections of sandbar coasts including the area of Karwia (Gajewski *et al.,* 2004) and on the southern coast of the Hel Spit (Tomczak, 1999). This interpretation is also suggested by the short-term accumulation of these deposits, not greater than 180 years. Given that their age was determined only indirectly, it cannot be excluded that they were accumulated during an even shorter period.

Analyzing the most recent literature on the ingression of the sea in the South Baltic area, clear signs can be found of marine ingression about 8300-8200 cal BP, for example in the Gardno-Łeba Costal Plain (Rotnicki, 2009). On the nearby Lithuanian coast, the first ingression occurred significantly earlier, about 8900 cal BP (Bitinas and Damušyte, 2004).

The second phase of ingression in the Mrzeżyno area started about 7300 years cal BP. These younger marine sediments already contained a considerable number of malacofauna marine shells, especially *Cardium glaucum*, often found in intravital position. This phase of ingression was also rather short, ending 6700 cal BP as is evidenced by the following geological facts:

- the presence of the oldest peat deposits about 6700 cal BP, on the marine sands,
- the presence of fluvial sediments, older than 6600 cal BP, inserted in the marine sands

In the area of the Szczecin Lagoon and the Świna Sandbar **(Fig. 9)**, the oldest marine ingression could not have begun earlier than 7360 cal BP (Borówka *et al.,* 2002, 2005), and therefore more or less at the same time as the second phase in the area of Mrzeżyno. The quite clear trace is a considerably thick series of sands with numerous shells representing the marine and brackish-marine environments (Woziński *et al.,* 2003), including the shells in life position of *Cardium glaucum* which make it possible to identify the age and the rate of accumulation of marine sands (Borówka *et al*., 2009). Geological documentation of the Szczecin Lagoon suggests that the accumulation of marine sediments continued uninterrupted until about 3800 cal BP.

That second phase of sea ingression occurred during the period of a sea level rise on the Gardno-Łeba Coastal Plain (Rotnicki, 2009). It also coincided with a distinct

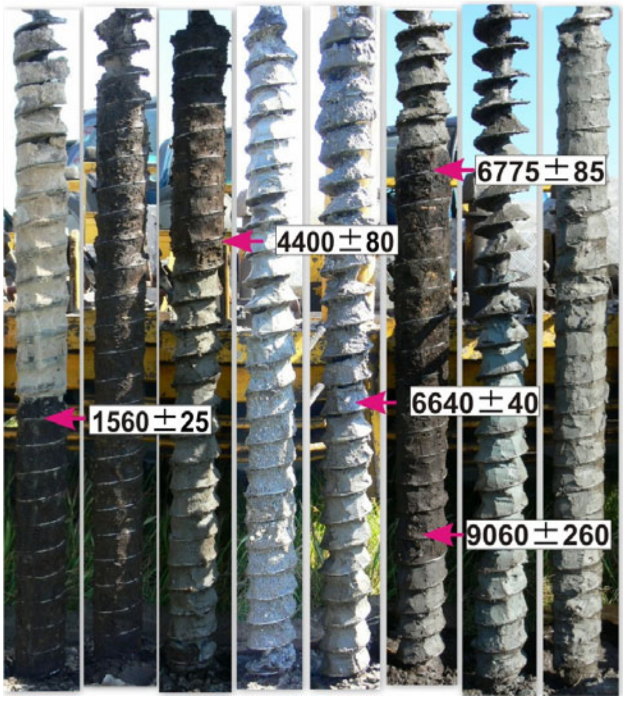

Fig. 7. *Sediment cores*

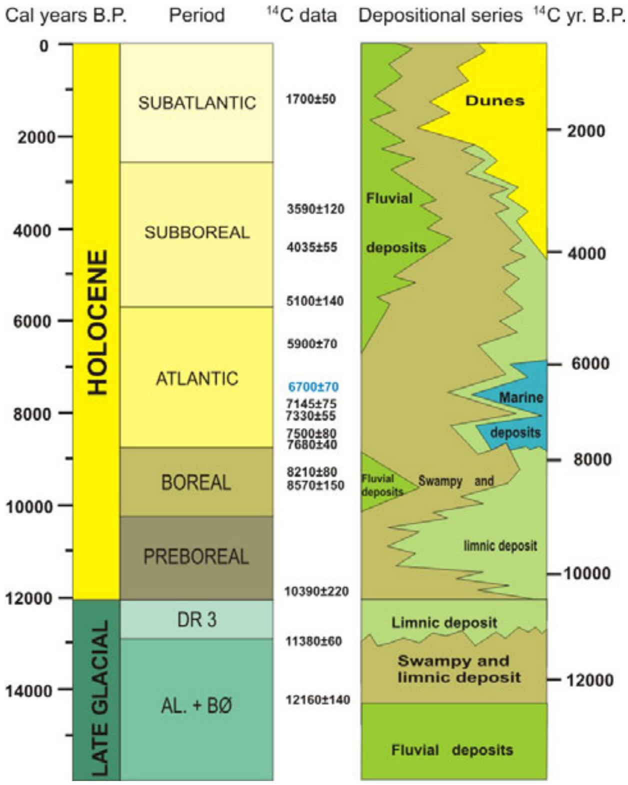

Fig. 8. *Stratigraphy of the Mrzeżyno (B area)*

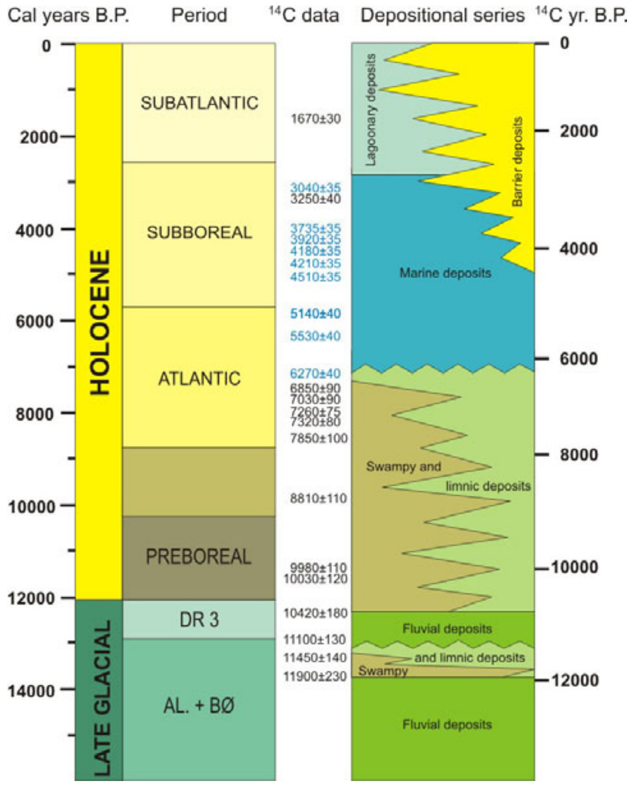

Fig. 9. *Stratigraphy of the Szczecin Bay (A area)*

rise in the level of the Baltic on the Lithuanian coast (Bitinas and Damušyte, 2004). In Lithuania, similar to the area of Mrzeżyno, that phase of sea level rise was relatively short and followed by a very clear regression which in the vicinity of Mrzeżyno resulted in the insertion of Rega river into marine sediments. Within the lagoon itself there is no clear evidence of subsequent sea regression. This is probably due to the fact that the marine works in the Szczecin Lagoon formed at a much lower ordinate compared to the area of Mrzeżyno.

It should also be noted that ingressions appeared earlier in the Gardno-Łeba Coastal Plain and in the area of Mrzeżyno, compared to Szczecin Lagoon. This was probably caused by the different bathymetric situation of the bottom of the Baltic Sea in the area adjacent to the Świna Sandbar and the Pomeranian Bay, where shallow waters occur at a considerable distance from the present-day shore, reaching just behind the northern border of the Oderbank Plateau. During the marine ingression, combined with the rising sea level, at the bottom of the Pomeranian Bay to the shore was significantly longer in comparison with the area of Mrzeżyno and the zone adjacent to the Gardno-Łeba Coastal Plain. This distance must have taken much more time to cover, hence a short-term ingression could only be observed where the 20m isobath is located near the modern coastline.

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