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CHRONOSTRATIGRAPHY OF CALCAREOUS MIRE SEDIMENTS AT ZAWADÓWKA (EASTERN POLAND) and THEIR USE IN PALAEOGEOGRAPHICAL RECONSTRUCTION

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Abstract: **Holocene evolution of the cupola spring mire at Zawadówka is presented, which is located in the borderland of the Lublin Upland and Volhynia Polesie (E Poland). Based on the results of sedimentological, malacological, geochemical analyses, and AMS radiocarbon dating, four main sedimentation stages are distinguished, which were associated with regional variability of humidity and temperature in the last 10 ka BP and with human activities in the last 200 years.**

1. INTRODUCTION

Calcareous mires form a unique group of water-swamp geosystems, in respect of both their geology and ecology. They are characterized by the occurrence of highly carbonate peat layers separated by biogenic deposits with lower content of calcium carbonate; reaction of the whole bed is distinctly alkaline (Dobrowolski, 2000), which causes individual floristic character of calcareous mires (Buczek and Buczek, 1993). Cupola spring mires are their special variety supplied with groundwater in point outflows, generally of ascending nature. They usually form raised knolls, up to several metres high and 10-20 m in diameter. They are composed of layers of strongly decomposed reed and sedge fen peat separated by slightly consolidated calcareous tufas, which macroscopically often resemble calcareous gyttja (Kovanda, 1971; Succov, 1988). As carbonates are a very important indicator of humidity and temperature changes (their deposition course is closely connected with the environment conditions), beds of such mires are excellent for the detailed palaeoenvironmental studies (Dobrowolski *et al.*, 2002; Pazdur *et al.*, 2002).

In the Lublin Upland and Volhynia Polesie (E Poland), calcareous mires frequently occur in the bottoms of karst depressions (**Fig. 1**). Among them, cupola spring mires are also found. Five sites have been registered in this area till now. Chronostratigraphy of all these cupola spring mires is well recognized (Dobrowolski *et al.*, 1999 and 2003).

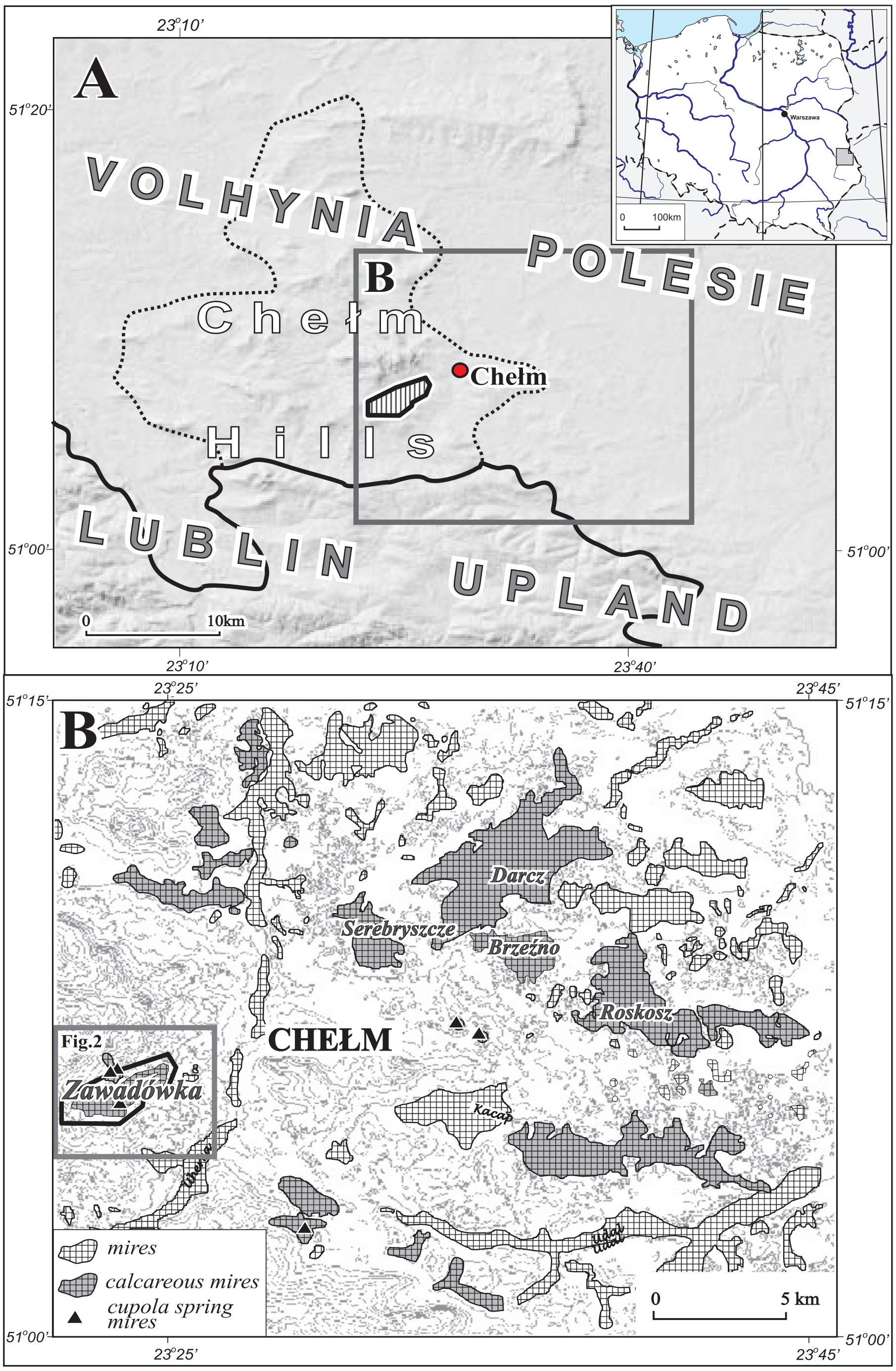

Fig. 1. Situation of the examined site against the background of: A – digital model of relief in eastern Poland (after Gawrysiak, 2004); B – hypsometric sketch of Chełm environs with location of mire geosystems (after Dobrowolski, 2000).

2. STUDY SITE

Zawadówka site (51°06'50"–51°08'00"N; 23°22'50"–23°25'20"E; 190-210 m a.s.l.) is located in the eastern, marginal part of Chełm Hills region (**Figs 1 and 2**). In regional divisions of Poland, this area is included to the Lublin Upland (Chałubińska and Wilgat, 1954; Maruszczak, 1972) or to the Volhynia Polesie (Kondracki, 2000). Karstified, Upper Cretaceous carbonate rocks (chalk, marly limestone, marls) are commonly exposed here. In some places they are covered by the Miocene sands and quartzitic sandstones, the Pleistocene glaciogenic deposits from the Saalian Glacial (tills and glaciofluvial sands and gravels), and the Holocene peats and muds (**Fig. 2**). Groundwater circulation here is controlled mostly by an orthogonal system of faults and joint fractures (NW-SE/NE-SW) cutting the Upper Cretaceous rocks. Fissured chalk forms the regional aquifer, generally with a free groundwater table. However, groundwater is confined in places because a clayey residuum of the carbonate rocks overlies the water-bearing horizon. This situation results in the occurrence of ascending spring in the floor of the karst depression and in the formation of the cupola spring mire. Zawadówka cupola spring mire (51°07'40"N; 23°23'45"E; 208 m a.s.l.) is situated in the central part of broad peaty plain filling a large karst depression (**Fig. 2**). It covers the area of about 800 m² forming a distinct peat-tufa cupola, oval-shaped in planar section, raised about 1.5 m over the plain. A small spring reservoir (limnokren – *sensu* Thieneman, 1926, *vide* Starmach *et al.*, 1976), surrounded by *Phragmites* community, occurs on the top of cupola. Water of the ascending spring (discharge about 1 dm^3/s) is temporarily retained in this reservoir.

3. MATERIAL AND METHODS

Geological and palaeomorphological situation of the whole bed of calcareous mire was recognized on the basis of 82 geological borings, situated in 16 sections perpendicular to the axis of the form (**Fig. 2**). The cupola was examined in detail (8 borings). For chronostratigraphic and palaeogeographic considerations two counterpart cores (numbers 75 and 75a) of an undisturbed structure from the top of cupola were taken. Detailed malacological (Zaw-75a), sedimentological, geochemical analyses, and AMS radiocarbon dating (Zaw-75) were carried out for these cores. Samples for dating were selected from the lithofacial key horizons representing main peat sedimentation cycles.

Sedimentological analysis

Macroscopic lithofacial analysis of the core was made. The Troels-Smith method was used for description of the deposits (**Table 1**). The thickness of the bored deposits was 5.5 m, of which 5 m is composed of biogenic-carbonate deposits. Bottom part of the core consists of clayey weathered chalk which changes upwards into dark-grey organic clay, overlain by a series of strongly decomposed reed-sedge peat, in places with inserts of moss peat. The whole peat core is enriched with calcium carbonate and zones of its increased concentrations (several centimetres thick interlayers of silty calcareous tufa) are distinctly visible. Facial variability of the deposits gives a readable record of palaeohydrological evolution of mire, and also evidences the changes of moisture-temperature conditions.

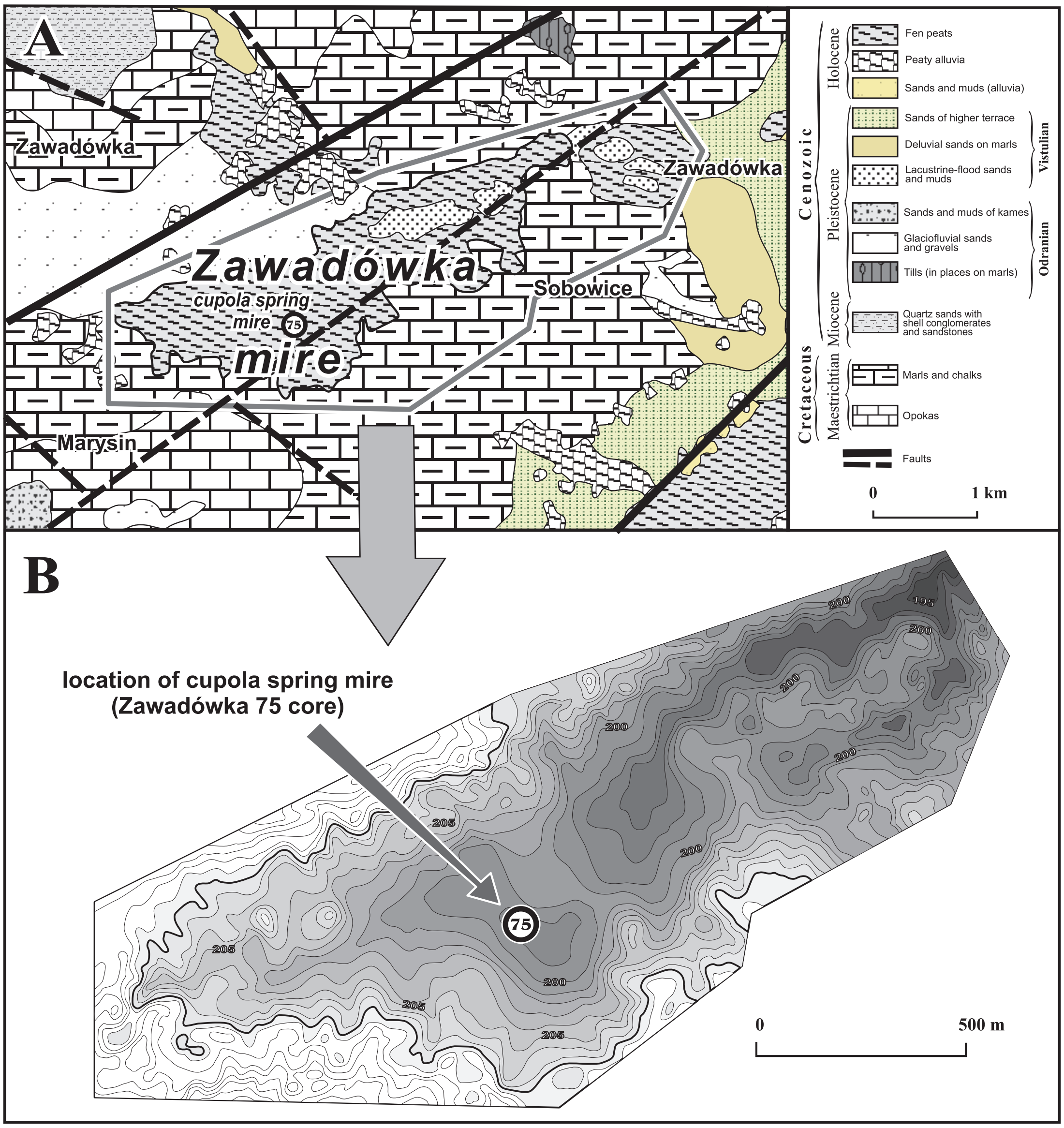

Fig. 2. Geological structure of the area surrounding the examined site: A – map of surface deposits (after Harasimiuk et al., in print); B – hypsometric sketch of the rock surface under the organic deposits in the Zawadówka mire (after Głaz, 1999 and Dobrowolski et al., 2003).

Table 1. *Description of the deposits from Zaw-75 core according to Troels-Smith (1955).*

Depth (m)	Description	T-S formula
0.00 – 0.10	Reed peat, slightly decomposed	$Th^1$4, Ld+, Lc ++, nig.3, strf.0, elas.3, sicc. 2
0.10 – 0.18	Reed peat, medium decomposed	$Th^2$4, Lc ++, nig.2, strf.0, elas.3, sicc. 2, lim. sup. 0
0.18 – 0.38	Reed peat, medium decomposed, with amorphous calcium carbonate (silty calcareous tufa)	$Th^2$2, $Tb^2$1, Lc1, nig.1, strf.1, elas.3, sicc. 2, lim. sup. 0
0.38 – 0.48	Reed-sedge peat, medium decomposed, with inserts of moss peat and dispersed amorphous calcium carbonate (silty calcareous tufa)	$Th^2$3, $Tb^2$1, Lc ++, nig.3, strf. 0, elas. 3, sicc. 2, lim. sup. 1
0.48 – 0.90	Reed-sedge peat, strongly decomposed	$Th^3$4, nig.3, strf. 0, elas. 3, sicc. 2, lim. sup. 0, [part. test. (moll.)]
0.90 – 3.13	Reed-sedge peat, medium decomposed	$Th^2$4, nig.3, strf. 0, elas. 3, sicc. 2, lim. sup. 0, [test. (moll.)]
3.13 – 3.23	Reed-sedge peat, very strongly decomposed, with amorphous calcium carbonate	$Th^4$2, Lc 2, nig.1, strf. 3, elas. 2, sicc. 2, lim. sup. 0, [part. test. (moll.)]
3.23 – 3.28	Reed-sedge peat, very strongly decomposed	$Th^4$3, Lc 1, nig. 2, strf. 3, elas. 2, sicc. 2, lim. sup. 1
3.28 – 3.34	Reed-sedge peat, very strongly decomposed, with amorphous calcium carbonate	$Th^4$2, Lc 2, nig.1, strf. 3, elas. 2, sicc. 2, lim. sup. 0, [part. test. (moll.)]
3.34 – 3.38	Reed-sedge peat, very strongly decomposed	$Th^4$3, Lc 1, nig. 2, strf. 3, elas. 2, sicc. 2, lim. sup. 0
3.38 – 3.53	Reed-sedge peat, very strongly decomposed, with amorphous calcium carbonate (silty calcareous tufa)	$Th^4$2, Lc 2, nig.1, strf. 3, elas. 2, sicc. 2, lim. sup. 0
3.53 – 3.68	Reed-sedge peat, very strongly decomposed	$Th^4$3, Lc 1, nig. 2, strf. 3, elas. 2, sicc. 2, lim. sup. 0, [test. (moll.)]
3.68 – 3.71	Reed-sedge peat, very strongly decomposed, with amorphous calcium carbonate (silty calcareous tufa)	$Th^4$2, Lc 2, nig.1, strf. 3, elas. 2, sicc. 2, lim. sup. 0, [test. (moll.)]
3.71 – 3.80	Reed-sedge peat, very strongly decomposed	$Th^4$3, Lc 1, nig. 2, strf. 3, elas. 2, sicc. 2, lim. sup. 0, [test. (moll.)]
3.80 – 4.00	Reed-sedge peat, very strongly decomposed, with amorphous calcium carbonate (silty calcareous tufa)	$Th^4$2, Lc 2, nig.1, strf. 3, elas. 2, sicc. 2, lim. sup. 0, [part. test. (moll.)]
4.00 – 4.40	Reed-sedge peat, very strongly decomposed	$Th^4$3, Lc 1, nig. 2, strf. 2, elas. 2, sicc. 2, lim. sup. 0, [test. (moll.)]
4.40 – 4.72	Reed-sedge peat, very strongly decomposed, with inserts of moss peat	$Th^4$2, $Tb^3$1, Lc 1, nig. 2, strf. 2, elas. 2, sicc. 2, lim. sup. 0, [part. test. moll.)]
4.72 – 4.88	Reed-sedge peat, very strongly decomposed	$Th^4$3, Lc 1, nig. 2, strf. 2, elas. 2, sicc. 2, lim. sup. 0, [test. (moll.)]
4.88 – 5.00	Reed-sedge peat, very strongly decomposed	$Th^4$3, Lc 1, nig. 2, strf. 2, elas. 2, sicc. 2, lim. sup. 0, [part. test. (moll.)]
5.00- 5.28	Reed-sedge peat, very strongly decomposed, with single pieces of wood	$Th^4$3, Lc 1, nig. 2, strf. 1, elas. 2, sicc. 2, lim. sup. 0, [part. test. (moll.), *trunki*]
5.28 – 5.45	Organic clay, with sedge and reed detritus	Ag3, $Th^4$1, Lc++, nig.1, strf. 0, elas.0, sicc.2, lim.sup.0
5.45 – 5.50	Weathered chalk	As3, Ag1, Lc++, nig.1, strf.0, elas.0, sicc.2, lim.sup.0

AMS radiocarbon dating

The chronology of events is based on the AMS radiocarbon dating of the peat series with the highest contents of OM which evidence the main cycles of organic sedimentation. Radiocarbon dating of peat samples provided the most reliable ages in palaeostudies in times when only the counting (conventional) technique of ^{14}C was available. The development of the accelerator mass spectrometry (AMS) technique allows radiocarbon dating of C-containing material that is not as rich in C as peat (bulk sediments) or does not occur in large quantities (macrofossils). A reduction in sample size (ca 1000 fold) brought about by the AMS technique opened the whole new chapter of chronological approach in palaeostudies. In the case of peat samples AMS ^{14}C dating allows dating of identified plant fragments or fine fraction to avoid contamination caused by younger rootlets penetrating older peat layers.

Samples of peat were disintegrated in a weak acid (0.5 M HCl) and base (0.1 NaOH) solution (room temperature) and washed through a 0.5 mm sieve to separate macrofossils. Only peat sections, which were still not thoroughly decomposed contained sufficient amount of macrofossils. Fine Fraction (FF; smaller than 32 μm) was separated for one of the samples (depth 505-510 cm) along with the fraction ≤ 0.5 mm and macrofossils. Chemical acid-alkali-acid (AAA) pre-treatment was applied in addition to the first treatment described above. Macrofossils were treated with warm (65°C) weak acid (0.5 M HCl) for ½ hr, and then another ½ hr with warm base (0.1 M NaOH). At the end warm acid step was applied for 15 min to remove potential contamination with modern CO_2 during the alkali step.

Dry samples (ca 2 to 3 mg C) were placed in pre-heated Vycor (quartz) tubes together with CuO and silver powder, sealed under vacuum and combusted for 2 hrs in 950°C. A mixture of graphite and cobalt is produced in the reaction of CO_2 and H_2 with cobalt powder as a catalyst. The cobalt is pre-cleaned in a pre-treatment procedure (Hajdas *et al.*, 2004). The gases are heated to 625°C and water that is produced as well is frozen out during the whole reaction in a water trap. The reaction is completed in 2 to 3 hrs. Samples are pressed into copper targets and measured with standards and a blank (zero ^{14}C content). Each sample is analyzed for at least 30 minutes (standard precision of ca 5 per mil). The reduction system of the AMS facility at the ETH/PSI and the procedures are described by Hajdas *et al.* (2004) and at the web page www.radiocarbon.ch.

Geochemical analysis

Geochemical analysis was carried out for 55 samples taken from the core (Zaw-75) every 5 cm (18 compounds were determined in each sample, i.e. 990 subsamples were analysed). Organic matter (OM) content was determined as the percentage of loss-on-ignition by igniting of subsamples at 550°C for four hours. The amount of $CaCO_3$ was determined using standard Scheibler method modified by Lityński (*vide* Lityński *et al.*, 1976). Acidity (as pH) was measured from $CaCl_2$ (0.01 M) suspension of peat. Macroelements (Na, K, Ca, Mg, Fe) and microelements (Mn, P, Sr, Cu, Zn, Pb, Ni, Co, Cr, Cd) were analysed using the AAS (*Atomic Absorption Spectrophotometry*) technique after the removal of organic matter and digestion at 180°C of mineral matter with a mixture of hydrofluoric, nitric, and perchloric acids.

Malacological analysis

A total of 19 samples (Zaw-75a/1 – Zaw-75a/19) were collected from the profile of the borehole at 0.25 m thick intervals[1]. The sediment was washed in order to separate the complete mollusc shells and any identifiable fragments. Standard methods of malacological analysis as described by Ložek (1964) and Alexandrowicz (1987) were used.

4. RESULTS

AMS radiocarbon ages of the analyzed samples are presented in **Table 2**.

Figure 3 shows the ^{14}C ages calibrated sequence model of OxCal plotted against the INCAL98 calibration curve. Only the age of FF appears younger than expected by 2500 years but the three other samples are consistent with the whole stratigraphy. The weighted mean value of these three ages was used for calibration. In the case of the FF sample the contamination source is not quite clear however it is certain that the sample is older than this FF age. Therefore this outlier was omitted from the final chronology of Zawadówka mire.

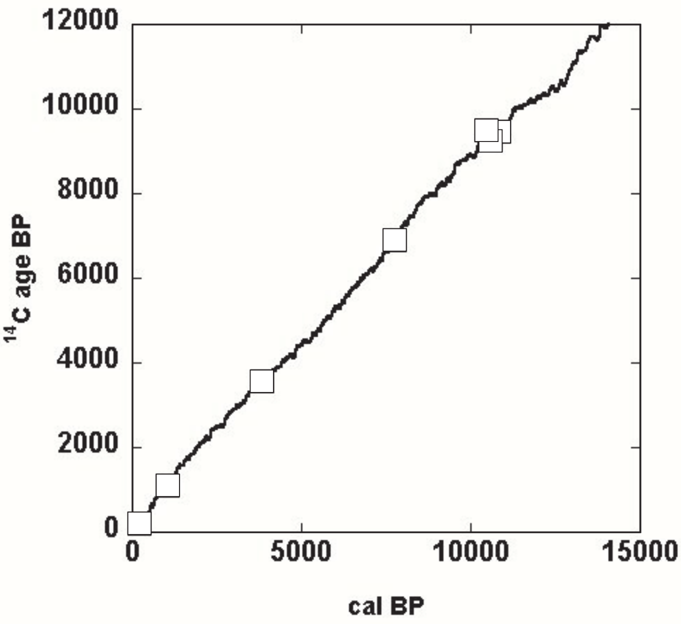

Fig. 3. ^{14}C *ages calibrated sequence model of OxCal.*

Sedimentological analysis

Based on the lithofacial variability of deposits, four main sedimentation stages can be distinguished, which are chronostratigraphically correlated with the following periods (**Fig. 4**): I) Preboreal (PB-2 phase) – mid Atlanticum (including AT-2 phase); II) mid AT-2 phase – end of Atlanticum; III) Subboreal – mid SA-3 phase; and IV) last 200 years. Within each stage, sedimentation cycles can be distinguished (21 cycles altogether), which stress the changes of deposition. They are also reflected in the vertical distribution of main geochemical features and molluscan associations (**Figs 4, 5** and **6**).

Table 2. *Results of AMS radiocarbon dating. Calibrated ages were obtained using INTCAL98 data set (Stuiver et al., 1998) and the sequence model (Bayesian procedure) within the OxCal calibration program (Bronk Ramsey, 1998 and 2001).*

Sample	Depth (m)	ETH number	Material	^{14}C Age (BP)	$\delta^{13}C$ (‰)	Cal Age, 95.4% conf. intervals (cal BP)
Zaw-75/1	0.40-0.45	26705	peat/macrofossils	215±45	-25.8±1.2	0-440
Zaw-75/2	1.00-1.05	26706	peat/macrofossils	1100±50	-29.4±1.2	920-1170
Zaw-75/3	2.95-3.00	26707	peat/macrofossils	3560±45	-22.7±1.2	3690-3980
Zaw-75/4	4.20-4.25	26708	peat/macrofossils	6910±55	-18.9±1.2	7610-7920
Zaw-75/6	4.95-5.00	26710	peat/macrofossils	9495±85	-18.1±1.2	10,280-10,680
Zaw-75/7	5.05-5.10	26711	peat/macrofossils	9275±60	-21.5±1.2	10,420-10,740
Zaw-75/8	5.05-5.10	26712	Fine Fraction<32μ	7710±70	-28.9±1.2	Outlier
Zaw-75/8	5.05-5.10	26712	Fraction: 32 to 50μ	9555±75	-33.1±1.2	
Zaw-75/8	5.05-5.10	26712	peat/macrofossils	9440±60	-23.2±1.2	
Zaw-75/8	5.05-5.10	26712	peat/macrofossils	9470±70	-28.4±1.2	
Zaw-75/8	5.05-5.10	26712	Weighted mean of macrofossils and 0.5 mm Fraction	9480±40		10,580-11,070

[1)] *Malacological analysis was supported by Grant 3PO4F 015 24 from State Committee for Scientific Research.*

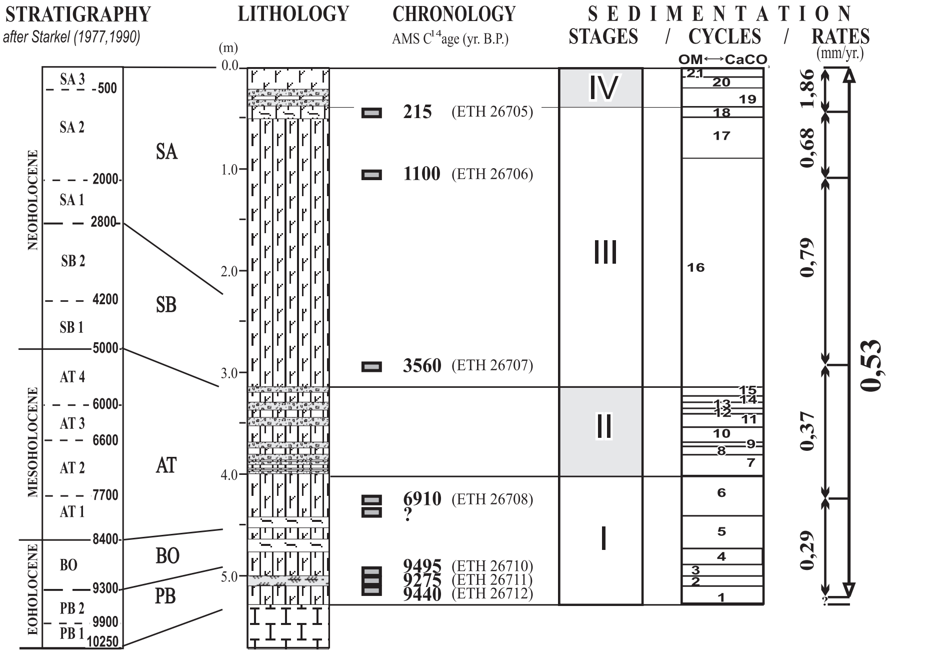

Fig. 4. Chronostratigraphical and sedimentological characteristics of the deposits from Zaw-75 core.

Stage 1 (9.9-6.6 ka BP; 5.45-4.0 m) was characterized by a specific equilibrium state between the contents of organic (peat) and carbonate (calcareous tufa) material. It was associated with activation of the ascending spring, formation of an initial peat cupola, and existence of limnokren at its top, that is spring reservoir which temporarily retained water. The mean rate for the vertical peat-tufa increment was slow enough (*ca* 0.3 mm·yr^{-1}).

Stage 2 (6.6-5.0 ka BP; 4.0-3.13 m) was the main stage of tufa deposition associated with activation of chemical denudation in the catchment under the conditions of warmer and more humid climate. The increased content of $CaCO_3$ implies higher activity of the ascending spring supplying the mire. In this stage the deposits accumulated at an average rate of *ca* 0.4 mm·yr^{-1}.

Stage 3 (5.0-0.2 ka BP; 3.13-0.38 m) was characterized by distinct decrease in humidity and temperature in the catchment; the spring discharge was considerably reduced, low amount of amorphous calcium carbonate was dispersed in peat; limnokren disappeared almost completely and helokren developed (it means that peat cupola became swampy), and oxidizing conditions changed into reducing ones; this is evidenced not only by geochemical indicators but also by the sudden transformation of water malacofauna association into terrestrial one. The organic deposition was probable impeded at the beginning of the Subboreal period (hiatus in SB-1 phase?), though the average rate of peat accumulation in this stage was rather high (*ca* 0.7 mm·yr^{-1}).

Stage 4 (0.38-0 m), that is the last 200 years, when the ascending spring supplying the mire was active again, and the content of calcium carbonate in biogenic deposits abruptly increased (tufa layers occur in peat). The increment of peat-tufa was very rapid (*ca* 1.85 mm·yr^{-1}). These phenomena were probably conditioned not only by a relatively more humid climate but also by human activities, that is deforestation of the catchment area.

Geochemical analysis

The lithology of the cupola spring mire at Zawadówka is reflected in the variability of the geochemical features of the deposits, as geochemical boundaries usually correspond with distinct lithological boundaries. It concerns especially those elements which are the main chemical components of deposits and determine the nature of geochemical environment in the studied area, that is Ca, P, Fe, K, and Na.

On the basis of the relation between the contents of individual elements, two main geochemical zones and eleven minor geochemical sub-zones can be distinguished in the profile (**Fig. 5**). The older of these two main zones (I) corresponds to the time interval from PB to the end of AT. Calcium carbonate plays an important role in this zone. Its average content exceeds 50% (with the maximum reaching 80%). Therefore, the contents of elements composing carbonates, i.e. Ca, Sr, and Mg, are enhanced in this part of the profile. The percentages of Fe and Mn are also high, while those of Na, K, and P are rather low (**Fig. 5**). Four sub-zones (a-d) distinguished within the geochemical zone I correspond to the cyclicity of tufa-peat sedimentation, and reflect distinct variability of macro- and microelement concentrations. Proportions between the contents of calcium carbonate and organic matter ($CaCO_3$/OM ratio), considered in a stratigraphic context, give us very important information not only about lithological variability of deposits. Taking into account the geological structure of the area, we can also estimate the rate of chemical denudation in the mire basin, and so the intensity of the karst processes. The $CaCO_3$/OM ratio is used as an indicator of moisture and temperature changes in the Holocene. The younger geochemical zone (II), which corresponds to the time interval from the beginning of SB to the present time, is characterized by the considerably higher content of organic matter (50% on

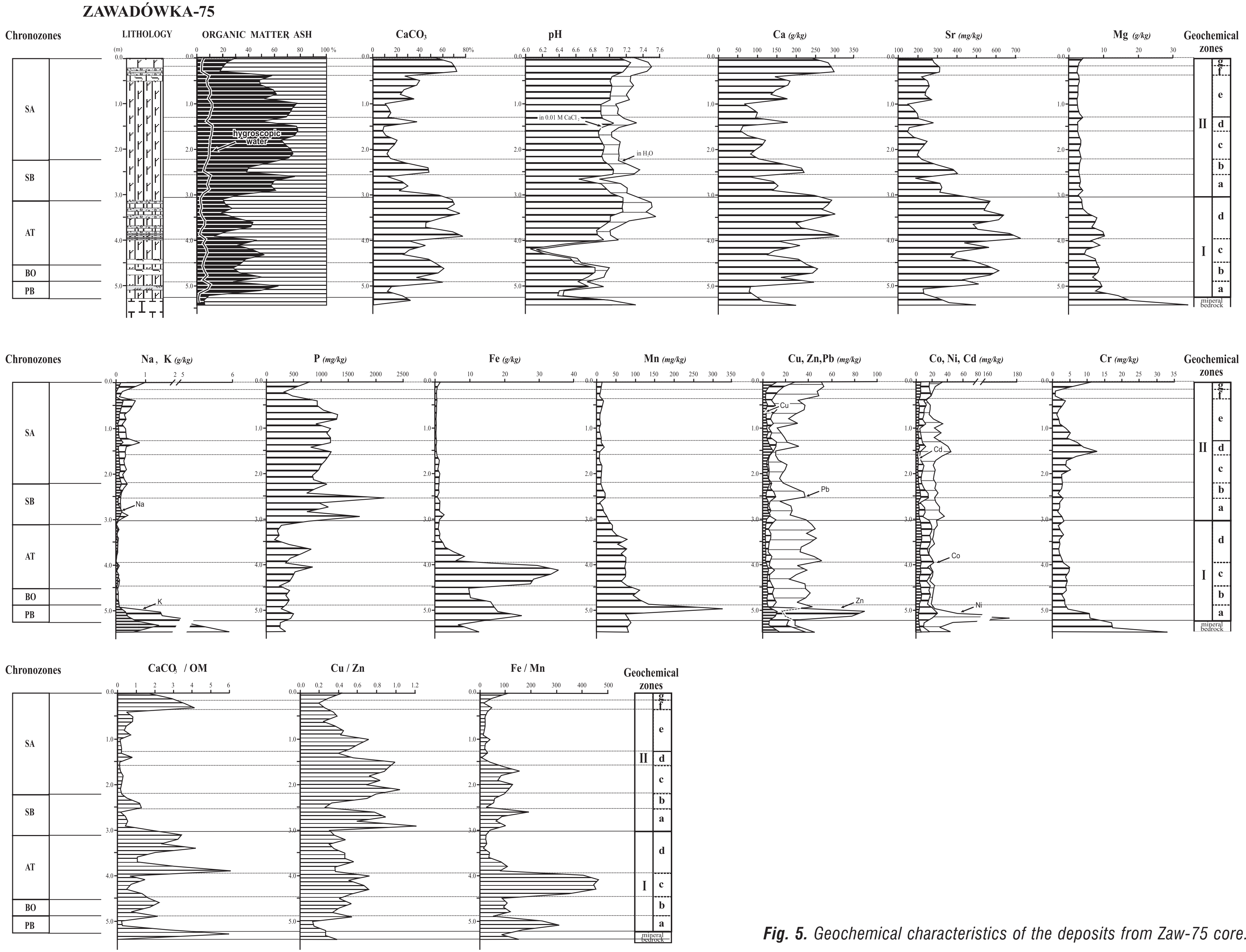

Fig. 5. *Geochemical characteristics of the deposits from Zaw-75 core.*

the average, max. to 80%), and the enhanced percentages of Na, K, and P (**Fig. 5**). The redox indicators (Cu/Zn and Fe/Mn) show that an essential change of depositional environment occurred between SA and SB, i.e. oxidizing conditions transformed into reducing ones, evidencing a considerable change in water supply to the mire. Fluctuations of the vertical distribution of the main elements allow us to distinguish seven geochemical sub-zones (a-g) in this zone (**Fig. 5**).

The results of the geochemical analysis are the basis for the following palaeogeographical interpretation. The phases of a rather dry climate are evidenced by: 1) rise in the organic material content, 2) decrease in the calcium carbonate percentage, 3) increase of redox indicators. The phases of climate moistening are recorded as: 1) increase of the $CaCO_3$/OM ratio, and 2) relatively low values of redox indicators.

Malacological analysis

Biogenic and carbonate deposits forming the cupola spring mire at Zawadówka contain numerous molluscan shells which occur in all layers of the profile. The number of taxa in any sample varied between 5 and 19, while the number of specimens varied between 6 and 200 (**Fig. 6** N). The whole population of 1803 specimens comprises 29 species, including 19 taxa of land snails, 7 of aquatic ones, and 3 of bivalves. Five groups of species have been distinguished in individual malacological spectrum (MSI): woodland (F), open-country (O), mesophilous (M), hygrophilous (H), and water (W). Two-component and triangular diagrams illustrate the differentiation of the fauna and interpretations of environmental changes (**Fig. 6**).

Two different types of molluscan communities may be distinguished in the described profile. The first is present in the lower interval (5.20 - 3.00 m) (Zaw-75a/1–7) (**Fig. 6** S) and the assemblage is relatively rich (**Fig. 6** N) being dominated by aquatic molluscs (snails and bivalves – ecological group W) representing up to 97% of the total (**Table 3; Fig. 6** MSI). Species which inhabit small, shallow water bodies with rich plant vegetation are the main component of this fauna. Numerous shells of *Valvata cristata* (Müll.), *Lymnaea peregra* (Müll.), *Lymnaea turricula* (Held), and *Lymnaea truncatula* (Müll.) are present. Land snails are the supplementary component of this assemblage. They are mainly represented by taxa typical of the moist habitats such as mires or swamps (ecological group H): *Carychium minimium* Müll., *Succinea putris* (L.), accompanied by single specimens belonging to the remaining ecological groups (F, O, M) (*Euconulus fulvus* (Müll.)), *Nesovitrea hammonis* (Ström) and some others. The occurrence of cold-tolerant species (*Vertigo geyeri* Lindh. and *Pisidium obtusale laponicum* Cless.) is a very interesting feature of this part of the profile.

The second assemblage is found in the upper part of the profile (3.00 – 0.00 m) (Zaw-75a/8 –19) (**Fig. 6** S). A rich and differentiated fauna is dominated by land snails (**Table 3; Fig. 6** N, MSI). The main components of the community are hygrophilous species (ecological group H): *Carychium minimum* Müll., *Succinea putris* (L.), and species of wide ecological tolerance (group M): *Euconulus fulvus* (Müll.), *Nesovitrea hammonis* (Ström), *Cochlicopa lubrica* (Müll.), and slugs of *Limacidae*. These are supplemented by open-country taxa (*Vallonia pulchella* (Müll.), *Vallonia costata* (Müll)), and woodland species (*Vitrea*

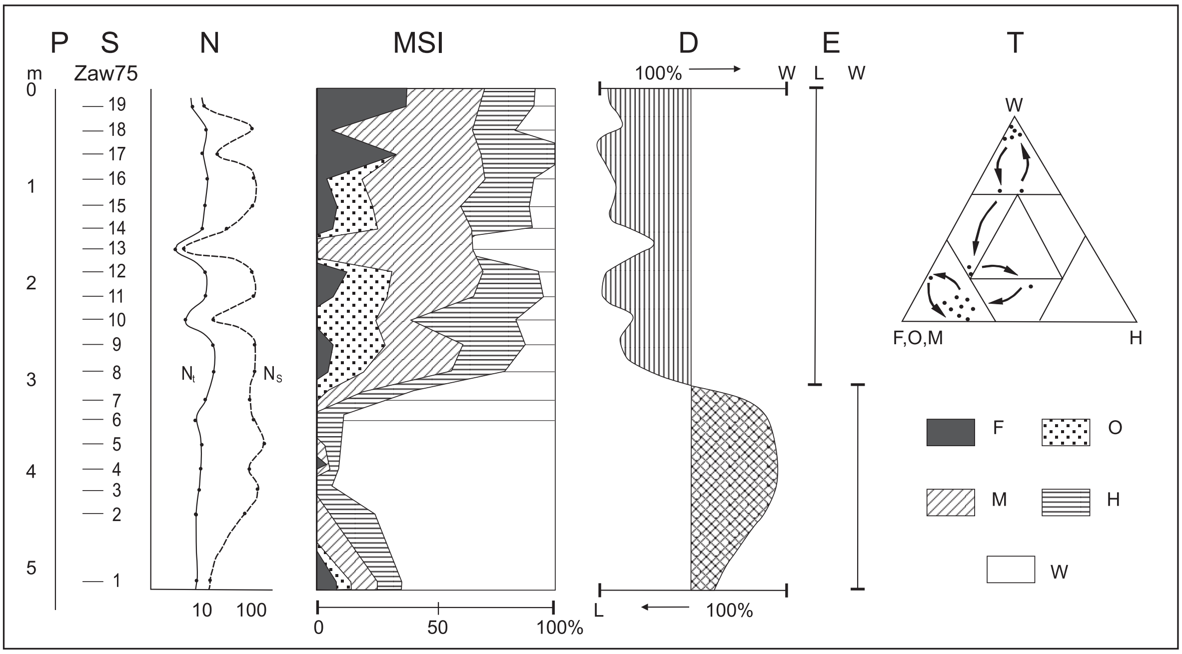

Fig. 6. *Malacological composition of the cupola spring mire at Zawadówka (Zaw-75a): P – profile, S – samples, N – number of species (N_t), and specimens (N_s), MSI – malacological spectrum of individuals, F – forest (woodland) species, O – open-country snails, M – mesophilous taxa, H – hygrophilous species, W – water molluscs, D – two-component diagram, L – land snails, W – water molluscs, E – environment, T– triangular diagram.*

Table 3. *Malacofauna of the cupola spring mire at Zawadówka (Zaw-75a): E – ecological group, F – forest (woodland) species, O – open-country snails, M – mesophilous taxa, H – hygrophilous species, W – water molluscs, number of specimens:* ***1*** *– 1-3,* ***2*** *– 4-10,* ***3*** *– 11-32,* ***4*** *– 33-100.*

		Zaw-75a																		
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**
E	**TAXON**	5.15-5.40	4.50-4.75	4.25-4.50	4.00-4.25	3.75-4.00	3.75-3.50	3.25-3.50	3.00-3.25	2.75-3.00	2.50-2.75	2.25-2.50	2.00-2.25	1.75-2.00	1.50-1.75	1.25-1.50	1.00-1.25	0.75-1.00	0.50-0.75	0.25-0.50
2	*Vitrea crystalline*	1							2	3		2	3		2	2	2	1		1
2	*Bradybaena fruticum*								1	1			1					2	1	1
3	*Perforatella bidentata*																	2		1
5	*Truncatellina cylindrica*																	1		
5	*Vertigo pygmaea*								2	1					2	1	1			
5	*Pupilla muscorum*	1																		
5	*Vallonia costata*								3	2		3	3			2	2			
5	*Vallonia pulchella*				1				2	3	2	3	3		2	2	2	1		
7	*Cochlicopa lubrica*	1						1	3	3		2	2		2	3	3	2	1	1
7	*Punctum pygmaeum*									1							1			
7	*Nesovitrea hammonis*					1		1	2	2	1	2	2	1	2	1	1	1		1
7	*Limacidae*		1		1		1	2	2	2	1	3	3	1	2	2		1	1	1
7	*Euconulus fulvus*				1	1		1	2	2		2	1	1			2			
8	*Carychium tridentatum*								3			2	2			3	3	1	1	
8	*Succinea oblonga*	1				1		1												
8	*Vertigo angustior*								2	3		3		1	1	2	3	1	1	1
9	*Carycium minimum*	1	1	2	2	1	2	3	3	3	2	3	3		2	3	2	2	1	2
9	*Succinea putris*		2			1	2	1	2	2	2	3			1	2	2	2	1	
9	*Vertigo genesii*					2		2	1	2		2	2							
10	*Valvata cristata*	2	3	4	3	4	4	3	2								1			
10	*Bithynia tentaculata*			2		3	1													
10	*Lymnaea peregra*	1	3	3	3	3	3			2										
10	*Lymnaea turricula*		3	4	3															
10	*Lymnaea truncatula*			3	2	4	3	3	3	3	2	2	2	1	2	3	2		1	1
10	*Planorbis planorbis*																1			
10	*Anisus contortus*		2	1	2	2														
10	*Pisidium milium*			3																
10	*Pisidium obtusale*																1		1	
10	*Pisidium obtusale lapon.*	1	3	3	3	3	3	1	2											

crystallina (Müll.), *Bradybaena fruticum* (Müll.)). Water molluscs typical of the temporary water bodies occur sporadically (*Lymnaea truncatula* (Müll.)). Single shells of *Vertigo geyeri* Lindh. have been found in the lower part of this profile.

The composition and structure of the molluscan communities reflect environmental changes. According to radiocarbon data, the start of organic and carbonate deposition was in the Preboreal period. The fauna from the lower part of the profile (5.40-3.00 m) represents deposition in small, shallow but permanent water bodies which have a rich plant vegetation surrounded by swamps or water meadows (**Fig. 6** D, E, T). Species of wide climatic tolerance and euryecological molluscs prevail. Cold-loving taxa such as *Vertigo geyeri* Lindh. or *Pisidium obtusale laponicum* Cless. may be regarded as glacial relicts. The first form is still extant in the southern part of Belarus (Wiktor, 2004). The upper interval (3.00 – 0.00 m) denotes deposition in the Subboreal and Subatlantic periods. Certainly, the fauna which has a dominant content of land snails is representative of this phase. Molluscan communities represent open and relatively wet habitats (**Fig. 6** D, E, T). This process was probably connected with gradual groundwater lowering. In the uppermost part of the profile the occurrence of bushes, probably alderwood, is notable. Similar malacological sequences have been described from other localities in the Western Polesie (Alexandrowicz *et al.*, 1994; Alexandrowicz and Żurek, 1996; Dobrowolski *et al.*, 1999).

5. CONCLUSIONS

The main palaeogeographical conclusions resulting from the analyses of calcareous mire at Zawadówka are as follows:

– The mire started to develop in the younger Preboreal period (PB-2) as soligenous mire supplied with ascending groundwater in point outflows; it was developing during the whole Holocene independently on a large surrounding fen which filled a karst depression. The formation of the mire was induced by a complete transformation of groundwater circulation after degradation of permafrost (activation of ascending springs on tectonic faults).

- Evolution of the mire was characterized by cyclic organic and carbonate (tufa) sedimentation associated with the Holocene fluctuations of humidity and temperature.
- A high discharge of ascending spring supplying the mire, resulting in the permanent existence of spring reservoir (=limnokren) at the top of peat knoll, persisted probably from the beginning of PB-2 phase till the end of the Atlantic period.
- Distinct deterioration of humidity and temperature conditions at the beginning of the Subboreal period caused reduction or even temporary cessation of ascending spring activity, decrease in the rate of organic material increment, and radical reduction of carbonate deposition. A stratigraphic hiatus of several hundred years corresponds probably to the boundary of AT and SB phases.
- The ascending spring had a relatively low discharge from the beginning of the Subboreal period till the end of SA-2 phase with several rather short episodes of increased activity. The limnokren probably totally declined and was transformed into helokren. It is confirmed by the transformation of water malacofauna association into terrestrial one, and by a considerable increase in organic material content in relation to $CaCO_3$ content.
- In the latter part of SA-3 phase (last 200 yrs), the intensification of carbonate deposition occurred again. It can be expected that it was conditioned not only by the change of climatic conditions but also by human impact on water conditions (deforestation).
- The most intensive deposition of calcareous tufas, similarly as in other sites of cupola spring mires in this area, is correlated with the climatic optimum of the Atlantic period (initial stages of AT-3 and AT-4 phases) and the youngest Subatlanticum.

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