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Palynology of Late Pleistocene varved clays from ice-dammed lakes at Lębork and Złocieniec (north-western Poland) – preliminary results

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Abstract

Samples collected from Late Pleistocene varved clays of the Vistulian (Weichselian) glaciation exposed at Lębork and Złocieniec (Gardno and Pomeranian phases, respectively) yielded palynological contents that are related to the different lithologies composing the varves. The dark-coloured clay units contain very small amounts of palynological material. The lighter-coloured, much thicker coarser units yielded large amounts of organic particles consisting of predominantly palynodebris of terrestrial plants, sporomorphs and aquatic palynomorphs. The latter include fresh-water and marine phytoplankton..

All particles were presumably washed out from the pre-Quaternary basement or from erratic material. This is indicated by the dinoflagellate-cyst assemblages, which represent Cretaceous and Palaeogene taxa. The large amounts of organic particles in the light-coloured layers indicate high-energy meltwaters streams, which washed them out, transported them and deposited them in ice-dammed lakes. The barren layers and those with lower amounts of organic particles were deposited during calm, presumably winter, periods, when the energy of the meltwater streams was much lower.

Keywords: palynology, varved clays, palaeoenvironment, Weichselian, Pleistocene, NW Poland

1. Introduction

The term ’varve’ expresses a couplet of lithologically different units formed mainly by settling from suspension during the changing seasonal conditions (De Geer, 1912). Originally, this term referred to glaciolacustrine deposits, but later its meaning was extended to any two-layer rhythmic sediments deposited in a lake or marine environment (e.g., Bradley, 1931; Stokes, 1964; Calvert, 1966).

The varves under study here represent finely laminated clastic sediments deposited in proglacial lakes that originated at the front of a melting glacier. A typical varve consists of a light-coloured lamina settled during summer, and a dark-coloured clay unit deposited during winter time (De Geer, 1912). The former is usually much thicker and consists, in addition to clay, of coarser material, including silt or fine sand. The differences in grain size reflect unequal depositional conditions of seasonal character related to the higher energy of meltwater streams during summer (e.g., Merta, 1978). The coarser fraction of the summer laminae may represent traction and/or hemipelagic (including aeolian) deposition, whereas the clays of the winter laminae are almost entirely of hemipelagic origin (e.g., Merta, 1978, 1986; Brodzikowski & Van Loon, 1991). Some

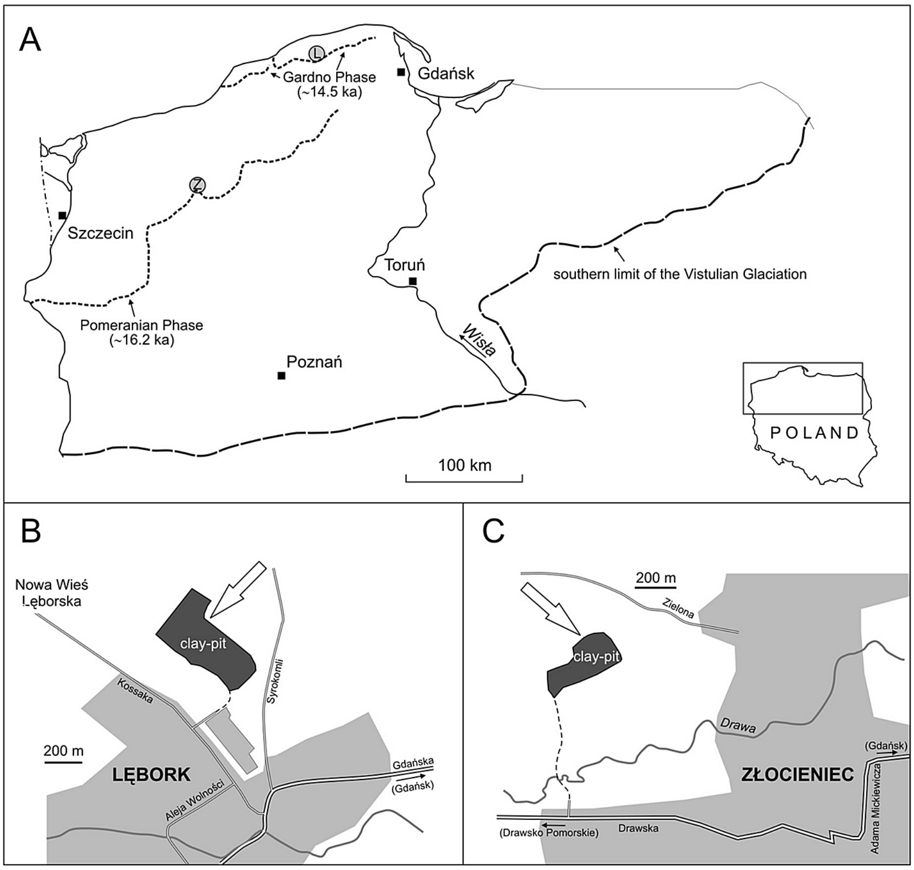

Fig. 1. Location of the Lębork and Złocieniec sites. **A –** Maximum extent of the Vistulian (Baltic) glaciation (after Marks, 2005), and the Pomeranian and Gardno phases (after Kozarski, 1986) at Lębork (L) and Złocieniec (Z); **B –** Location of the clay-pit at the northern outskirts of Lębork (sampling place arrowed); **C –** Location of the clay-pit west of Złocieniec (sampling place arrowed).

authors, however, suggest a more complex origin of varves; they might depend on changing palaeoenvironmental and palaeogeographic conditions (e. g., Brauer et al., 1999).

1.1. Objectives

The present study was aimed at the reconstruction of the conditions in the ice-dammed lakes in north-western Poland during the latest phases of the Vistulian glaciation. Their locations provide the opportunity to do so for lakes that existed at the margin of a retreating glacier.

A second objective was to evaluate the meaning of the differences in palynological content between the dark- and light-coloured laminae. Theoretically, they should reflect different environmental and sedimentological conditions related to the annual seasonal changes. Both winter and summer units of successive varves exposed at Lębork and Złocieniec (Vistulian glaciation) have therefore been preliminary studied for their palynological content. Results of similar studies on varved sediments were published recently by several authors, e.g., Goslar et al. (1999), Merkt & Müller (1999) and Ralska-Jasiewiczowa et al. (2003), but these studies focused on younger strata, or on sediments deposited under different environmental conditions.

1.2. Geological context

The Vistulian (Weichselian) glaciation was the last glaciation that covered the northernmost part of Poland (Fig. 1A). It started some 114 ka ago following the Eemian climatic optimum. The main glaciation phase of the Vistulian glaciation took place between approx. 32 and 12 ka ago (Lindner, 1984). The subsequent deglaciation includes several phases: the ice-dammed lake deposits under study here are related to the two youngest ones, i.e. the Pomeranian and Gardno phases (Fig. 1A). During the Gardno Phase, the glacier finally left the territory of Poland: this event was dated by thermoluminescence as 12.8–12.75 ka (Fedorowicz et al., 1985, see Lindner, 1992).

2. Material

Varved clays have been sampled from two locations at Lębork (see Rachlewicz, 2010) and Złocieniec (see Paluszkiewicz, 2010). These two sites comprise deposits from ice-dammed lakes at the front of a retreating Vistulian glacier.

2.1. The Lębork material

The Lębork succession is associated with the Gardno Phase (Fig. 1A), when meltwaters flowed through the Reknica and Kiszewa river pre-valleys into an ice-dammed lake located some 10–12 km south-east from the glacier margin (Morawski, 1989; Rachlewicz, 2010). The succession of varved clays is 16 m thick and has an age between 11–14 ka, based on thermoluminescence dating of the under- and overlying deposits (Morawski, 1990, 1998). The outcrop studied here is located in the northern part of the Lębork clay-pit (Fig. 1B); it shows a varved clay that consist of rhythmically bedded clays and silts. The dark clay (winter) layers are 1–2 cm thick. The light-grey to blackish summer layers are thicker, up to 4–6 cm. They show a distinct subordinate lamination (Fig. 2). No bioturbation has been observed.

Three samples from this site have been collected (Table 1). Samples L2w and L3s represent a single varve rhythm; sample L2w is a thin ′winter′ lamina, whereas L3s has been taken from the overlying ′summer′ lighter-coloured unit (Fig. 2). Sample L1 represents a silt-enriched, presumably ′summer′ lamina.

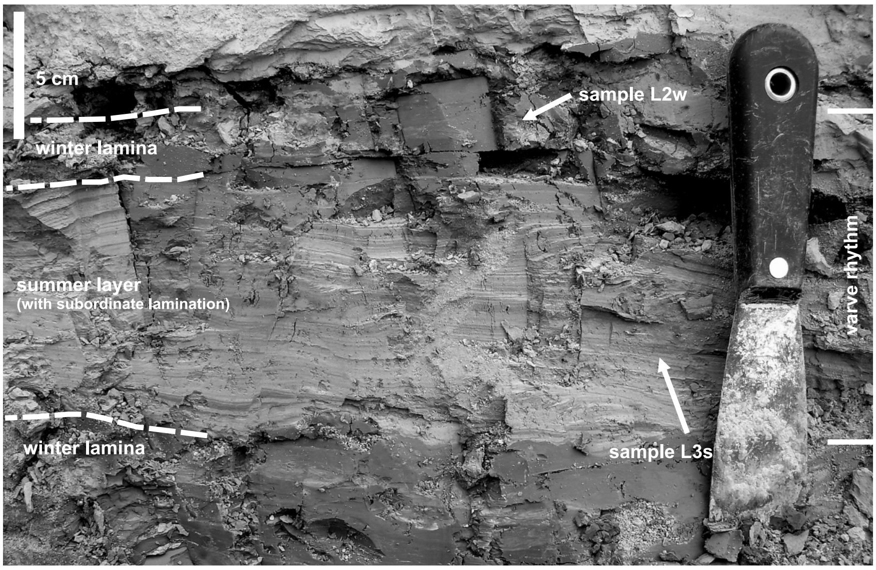

Fig. 2. Varve succession format Lębork and sample location.

Table 1. Description of the samples.

Location	Sample	Lithology	Estimated age	Glaciation – phase	
Lębork	L1	black highly calcareous clay with fine silt laminae	14–11 ka	Vistulian (Weichselian) glaciation	Gardno phase
	L2w	black homogenous, highly calcareous clay			
	L3s	grey highly calcareous clay with light-grey silt laminae			
Złocieniec	Z1w	black homogenous, calcareous clay	17–14 ka		Pomeranian phase
	Z2s	grey, calcareous clay with lighter silt laminae			
	Z3w	black homogenous, calcareous clay			
	Z4a	grey, calcareous clay with lighter silt laminae			

2.2. The Złocieniec material

The Złocieniec site is located in the Drawsko Lake District. Outcrops of the varved clays are exposed in a local clay-pit (Fig. 1C). The exposed fine-grained deposits are associated with the Pomeranian Phase of the Vistulian glaciation (e.g., Karczewski, 1985; Fig. 1A). The majority of clastic material was supplied to the Złocieniec ice-dammed lake by a river system running from a glacier margin located to the north-west (Paluszkiewicz, 2010). Its succession consists of three complexes, as distinguished by Paluszkiewicz (2004). The varved clays (up to 16 m thick) are underlain by sands of 1 m thick and overlain by silty strata (up to 7.5-m thick) representing the final stage of the ice-dammed lake. Rhythmical bedding, similarly as in Lębork, consists of thicker laminated summer layers, and dark clayey (winter) layers of only 0.5–1.5 cm thick (Fig. 3; see also Paluszkiewicz, 2004, 2010). No bioturbation has been found.

Four samples from two successive varve rhythms have been sampled for the present study (Table 1). Samples Z1w and Z3w represent black (when wet) clays of ′winter′ laminae, whereas samples Z2s and Z4s have been collected from silt-dominated ′summer′ laminae.

3. Methods

The samples were processed in the Micropalaeontological Laboratory of the Institute of Geological Sciences, Polish Academy of Sciences, Kraków. The applied standard palynological procedure included 38% hydrochloric-acid (HCl) treatment, 40% hydrofluoric-acid (HF) treatment, heavy-liquid ($ZnCl_2$+HCl; density 2.0 g·cm^{-3}) separation, ultrasound for 10–15 s and sieving at 10 μm on a nylon mesh. No nitric-acid (HNO_3) treatment was applied.

The quantity of rock processed was 20.0 g for each sample. Thin sections were made from each sample using glycerin jelly as a mounting medium. The rock samples, palynological residues and slides are stored in the collection of the Institute of Geological Sciences, Polish Academy of Sciences, Kraków.

4. Results

The samples from the Lębork site yielded qualitatively similar palynofacies (Fig. 4A). They are dominated by palynodebris (dark-brown phytoclasts, black phytoclasts, woody particles, and infrequent cuticles: Fig. 5E, G-I, K); sporomorphs are common (mainly bisaccate pollen grains: Fig. 5A-D). Sample L1 contains the highest ratio of amorphous particles (Fig. 5J). Aquatic palynomorphs are represented by marine dinoflagellate cysts (reworked: see Section 4.1; Fig. 6E-R, V) and fresh-water algae (e.g., *Botryococcus*, *Pediastrum*: Fig. 7). The latter are relatively rare, being strongly dispersed by palynodebris particles.

In contrast, the samples differ significantly in a quantitative sense: sample L3s contains a much larger amount of palynological organic

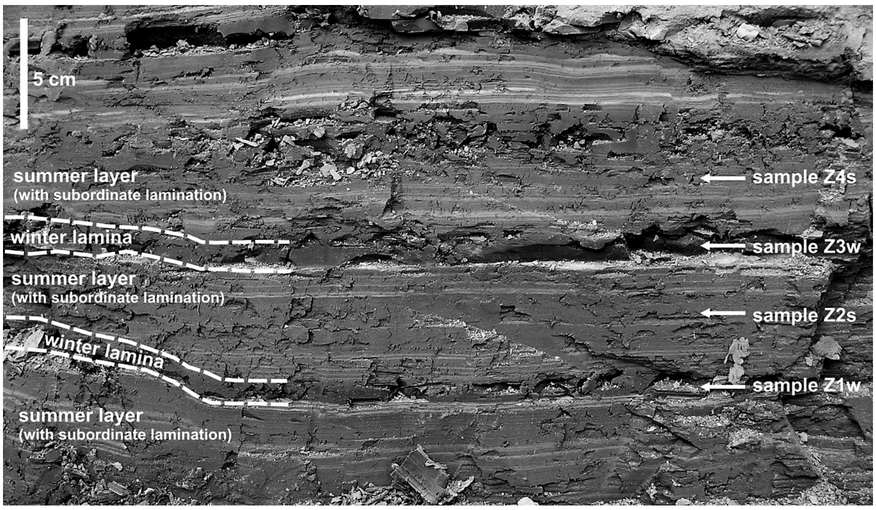

Fig. 3. Varve succession at Złocieniec and sample location.

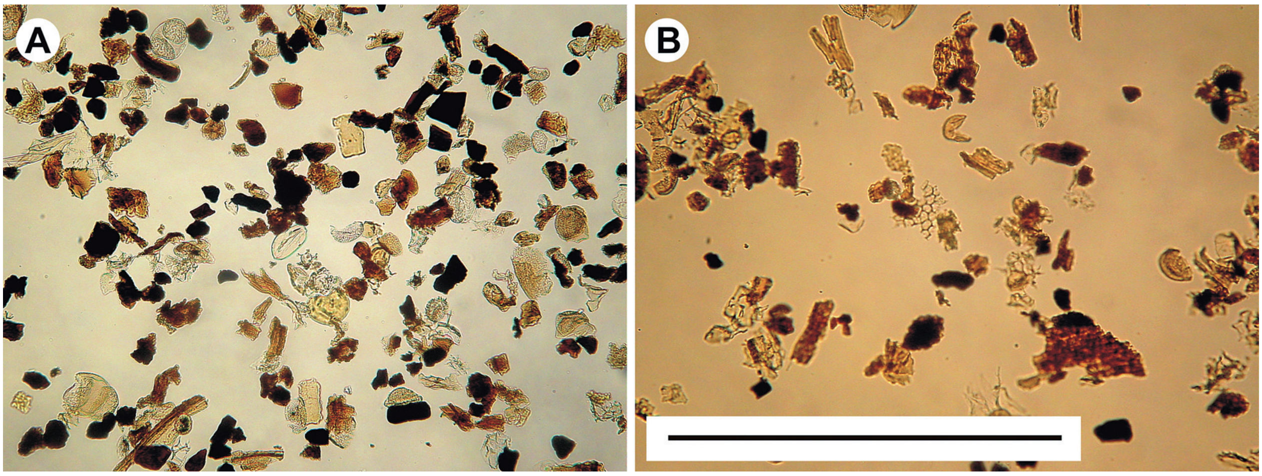

Fig. 4. Palynofacies of the varved clays from Lębork (A) and Złocieniec (B).
A – sample L3s; **B –** sample Z2s. Scale bar at B is 0.5 mm and refers to both microphotographs.

matter than the underlying sample L2w. Dinoflagellate cysts are well preserved; they are pale-coloured and show an intact wall structure. However, they are frequently mechanically torn-off, so that they commonly occur as fragments only.

Much more diverse are the samples from Złocieniec. The samples representing thin black (winter) laminae (Z1w and Z3w) contain virtually no palynological material: only very rare dark-brown phytoclasts are present. The samples representing summer laminae, Z2s and Z4s (Fig. 4B), yielded a completely different palynological content. Their palynofacies consists of large amounts of palynodebris, which includes cuticles (Fig. 5F), dark-brown phytoclasts and woody particles, and sporomorphs and aquatic palynomorphs. The latter are up to a few percent and are represented mainly by the fresh-water alga *Pediastrum*. Dinoflagellate cysts, similarly to those from Lębork, are considered as recycled (see Section 4.1; Fig. 6A-D, S-U). All palynomorphs are pale-coloured, and their wall structure is intact. This refers especially to the delicate *Pediastrum* specimens, which frequently are complete. Dinoflagellate cysts are frequently preserved as isolated fragments only.

4.1. Dinoflagellate cysts

All samples that contain palynological material yielded also organic-walled dinoflagellate cysts (Fig. 6). They are relatively common, and are particularly frequent in the samples from Lębork. The cysts from this site amount to a few percent of their palynofacies. However, all specimens are pre-Quaternary. Most frequent are the Cretaceous specimens *Odontochitina* sp., *Exochosphaeridium* sp., *Epelidosphaeridia spinosa*, *Palaeohystrichophora infusorioides*, *Isabelidinium* sp., *Surculosphaeridium*? sp., *Oligosphaeridium complex*, *Cerbia* sp. and *Pseudoceratium*? sp. Less frequent in the Lębork material are Palaeogene specimens represented by *Operculodinium centrocarpum*, *Wetzeliella* sp., *Charlesdowniea columna*, *Dinopterygium cladoides*, *Homotryblium* spp., *Corrudinium incompositum*, *Dapsilidinium* sp., *Cordosphaeridium* sp., *Enneadocysta pectiniforme*, *Areosphaeridium diktyoplokum* and ?*Rhombodinium* ?*perforatum* (incomplete specimen). Several other specimens range from the Late Cretaceous to the Palaeogene; these are represented by *Spiniferites ramosus*, *Areoligera* sp., *Achomosphaera* sp., *Impagidinium* sp., and some peridinioid species of *Alterbidinium*.

The Złocieniec 'summer' samples contain dinoflagellate cysts that represent Palaeogene taxa only (the 'winter' samples are barren). The following taxa have been identified: *Deflandrea* sp., *Homotryblium tenuispinosum*, *Homotryblium* sp., *Lingulodinium machaerophorum*, *Distatodinium paradoxum*, *Operculodinium* sp., *Cordosphaeridium* sp., *Wetzeliella* sp., *Adnatosphaeridium multispinosum*, *Areosphaeridium diktyoplokum*, and long-ranging taxa including *Spiniferites ramosus*.

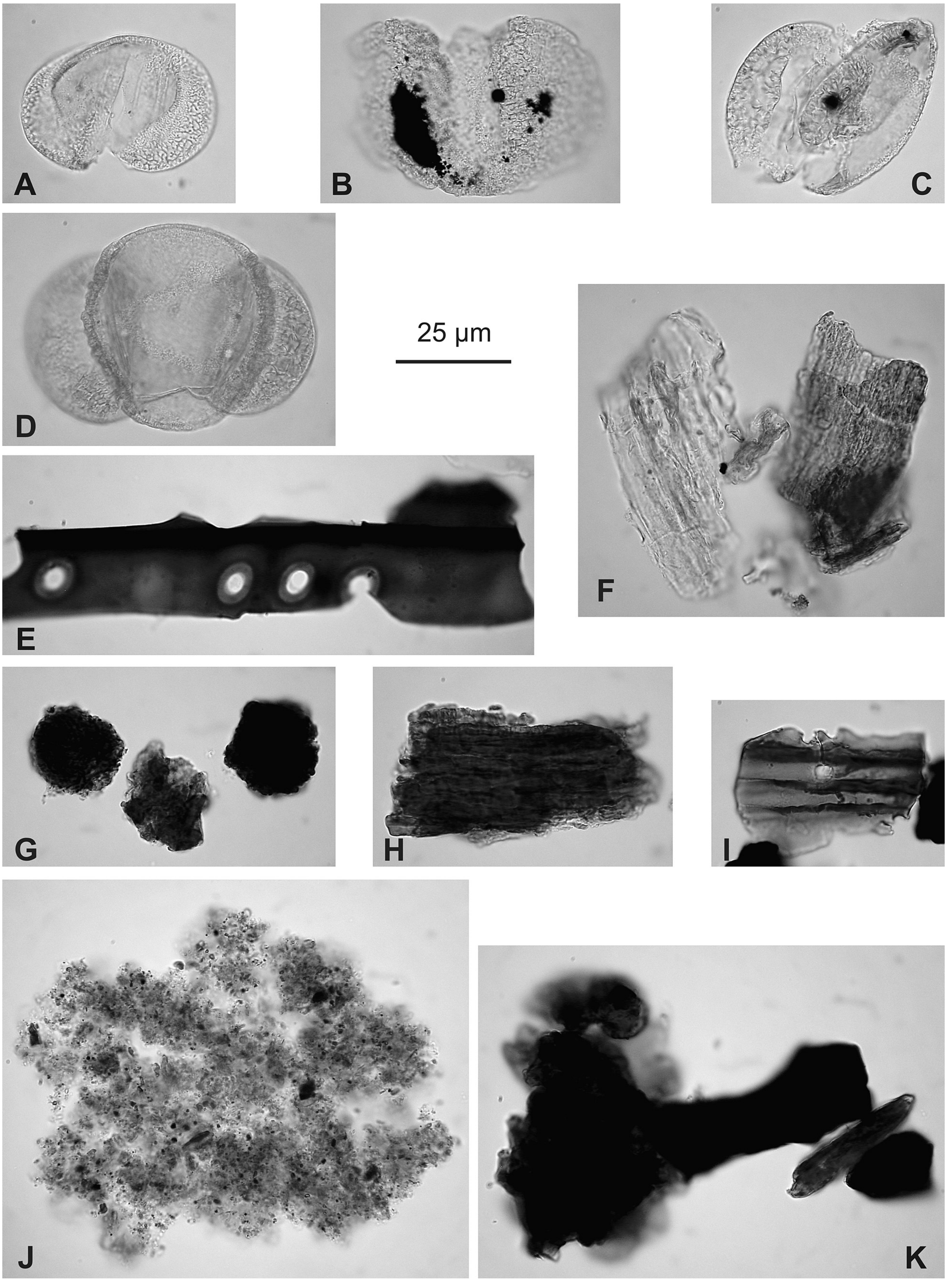

Fig. 5. Phytoclasts and sporomorphs from the varved clays at Lębork and Złocieniec.
A-D: Bisaccate pollen grains (L1); **E:** Wood particle (L1); **F:** Cuticle remains (Z2s); **G:** Dark-brown phytoclasts (L1); **H:** Wood tissue (L1); **I:** Cuticle (L3s); **J:** Structureless (amorphous) organic matter (L1); **K:** Dark-brown phytoclasts (L1).

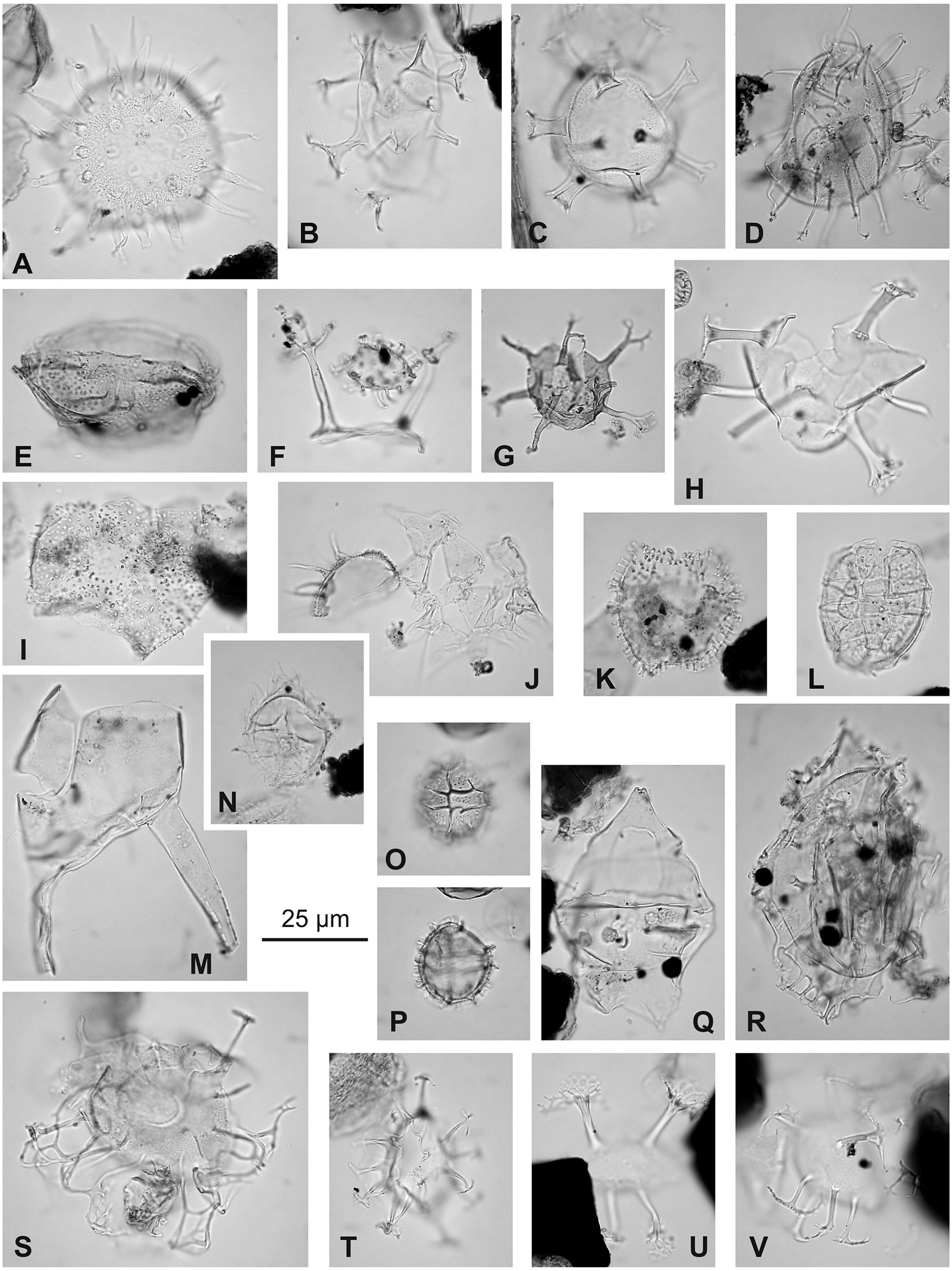

Fig. 6. Reworked Cretaceous and Palaeogene dinoflagellate cysts from the varved clays at Lębork and Złocieniec.
A – *Lingulodinium machaerophorum* (Z2s); **B –** *Distatodinium paradoxum* (Z2s); **C –** *Homotryblium tenuispinosum* (Z2s); **D –** *Operculodinium* sp. (Z4s); **E –** *Dinopterygium cladoides* (L1); **F –** Fragments of two unidentified dinoflagellate cysts (L1); **G –** *Surculosphaeridium*? sp. (L1); **H –** *Oligosphaeridium*? sp. (L1); **I –** *Cerbia*? sp. (L1); **J –** Fragment of a dinoflagellate cyst (left) and *Pediastrum* sp. (right; L1); **K –** *Epelidosphaeridia spinosa* (L3s); **L –** *Alisocysta* sp. (L1); **M –** *Odontochitina* sp. (L1); **N –** *Palaeohystrichophora infusorioides* (L3s); **O-P –** *Corrudinium incompositum* (same specimen, various foci; L3s); **Q –** *Isabelidinium* sp. (L3s); **R –** *Charlesdowniea columna* (L1); **S –** *Adnatosphaeridium multispinosum* (Z2s); **T –** *Spiniferites* sp. (Z4s); **U –** *Adnatosphaeridium diktyoplokum* (operculum; Z4s); **V –** *Enneadocysta pectiniforme* (L3s).

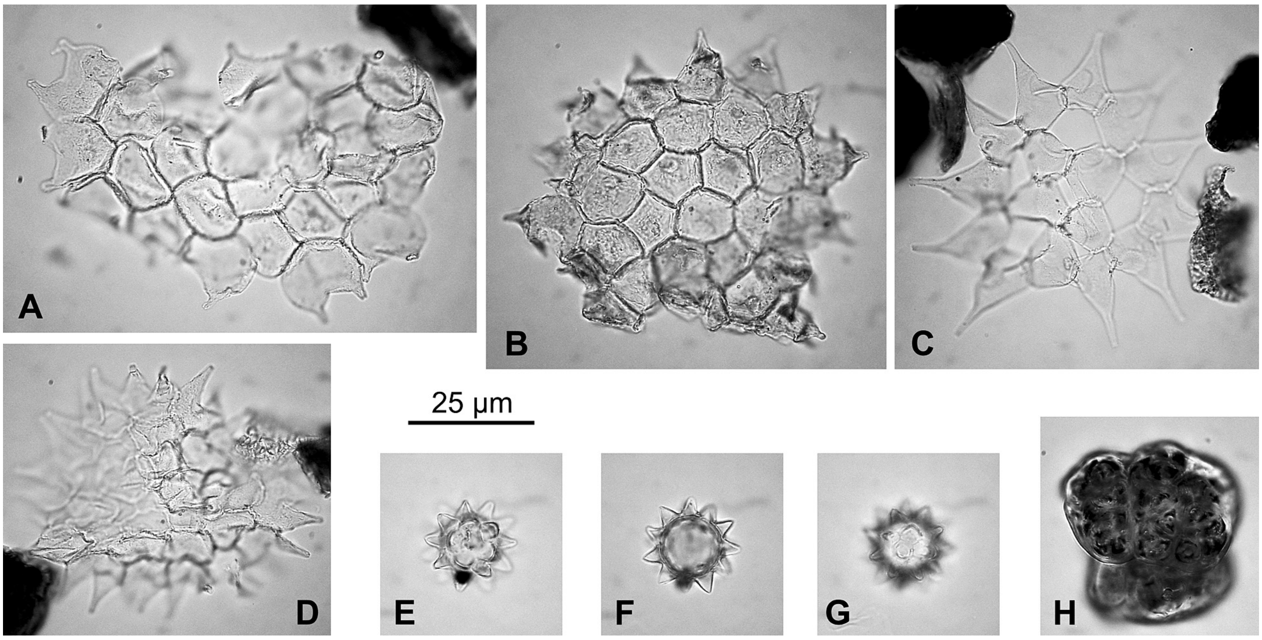

Fig. 7. Fresh-water algae from the varved clays at Lębork and Złocieniec.
A–D: *Pediastrum* spp. (A, B: L1; C, D: L3s); **E–G:** *Cystidiopsis* ?*conicus* (same specimen, various foci; L1); **H:** *Botryococcus braunii* (L1).

5. Interpretation

5.1. The origin of the palynological material

The occurrence of recycled dinoflagellate cysts suggests that at least part of the organic particles is not *in situ* but comes from reworked pre-Quaternary strata. It is not possible to estimate whether the bulk of the organic particles, especially phytoclasts, has also been reworked or that it is *in situ*. Analysis of other palynomorphs found in the studied material supports, however, the hypothesis that all palynological material in the varved clays may have been reworked. This regards in particular the fresh-water Chlorococcales represented by *Botryococcus* and *Pediastrum*. *Botryococcus*, an extant green alga of the order Chlorococcales, has a long stratigraphical range, going back into the Palaeozoic (Batten & Grenfell, 1996). The specimens from the study material have most probably been reworked, since recent *Botryococcus* has its widest distribution in fresh-water reservoirs of temperate and tropical regions (Batten & Grenfell, 1996). Hence, its presence in an ice-dammed lake during a glaciation phase is rather dubious. The same refers to the extant colonial Chlorococcales genus *Pediastrum*, which frequently occurs in samples from both study sites; it is especially frequent at the Złocieniec site. This genus is known from the Cretaceous to the Holocene; recent species inhabit fresh-water habitats, usually with a high nutrient availability (Batten, 1996a). This suggests that *Pediastrum* has also been reworked.

Although the above data and considerations do not prove that the Chlorococcales have been reworked, they support the thesis that they have been, indeed, together with the marine dinoflagellate cysts, from Palaeogene, respectively Cretaceous, rocks by meltwater streams. *Botryococcus*, *Pediastrum* and *Cystidiopsis* are known from Palaeogene strata of northern Poland; they were reported from the Late Eocene of the Pomorska Formation by Grabowska (e.g. 1996a,b, *in* Grabowska & Ważyńska, 1997), but *Pediastrum* is also known from the Neogene of the Polish Lowlands (Grabowska, 1996c).

The dinoflagellate cysts from the varved clays at Lębork and Złocieniec show at least two ages. An older assemblage dates from the latest Albian-Cenomanian, as indicated by the co-occurrence of *Palaeohystrichophora infu-*

sorioides (latest Albian-Early Maastrichtian), *Epelidosphaeridia spinosa* (latest Albian-Cenomanian) and *Isabelidinium* sp. (Late Albian-Early Maastrichtian; stratigraphic ranges after Costa & Davey, 1992; and after Stover et al., 1996). These Cretaceous dinoflagellate cysts were presumably reworked from the sandy Late Albian deposits that are known from northern Poland (see, e.g., Cieśliński & Jaśkowiak, 1973a,b); they must have been exposed, washed out and redeposited in the varved clays at Lębork. It cannot be excluded, however, that some Cretaceous strata were embedded in an ice-raft and thus were transported from higher latitudes. Several isolated erratic blocks of Cretaceous material are known from glacial deposits in northern Poland (Cieśliński & Wyrwicka, 1973).

The Palaeogene dinoflagellate cysts from both sites represent Late Eocene species. This dating is based on the occurrence of a poorly preserved *Rhombodinium perforatum*, and on the co-occurrence of *Enneadocysta pectiniforme*, *Areosphaeridium diktyoplokum* and *Corrudinium incompositum*. This suggests that the Palaeogene dinoflagellate cysts were derived from the Pomorze Formation or its coeval equivalents (see Piwocki, 2004). Similar conclusions were drawn by Paluszkiewicz (2008), who – on the basis of the morphological analysis of quartz grains from the ice-dammed lake near Pyrzyce (Pomerania Phase of the Vistulian glaciation; Szczecin Lowland, NW Poland) – stated that they are genetically associated with marine Tertiary deposits. Also Górska (2006) suggested that at least part of the material building glacial deposits of the Pomeranian phase in NE Germany are derived from eroded Tertiary strata.

5.2. Depositional model of the organic particles

Although only few samples were studied, the difference between summer and winter layers, which is especially pronounced in the Złocieniec varves, is well visible. The quantitative and qualitative variations in the organic matter content reflect seasonal cycles. Summer layers contain a large amount of organic particles that in majority, if not completely, were eroded from the substratum or from erratic blocks by meltwater streams. The winter layers, in contrast, contain no palynological material (i.e. organic particles larger than 10 μm) as in Złocieniec, or they contain smaller amounts than the summer layer (Lębork). This points at increased meltwater activity during summer, leading to intensive reworking of pre-Quaternary strata and subsequent deposition of their organic fraction in low-energy ice-dammed lakes. During cold seasons, in contrast, the erosional capability of the water decreased significantly and/or the surface of the ice-dammed lake was covered with ice.

No evidence of autochthonous phytoplankton appearances has been found. All freshwater forms (mainly *Pediastrum* and *Botryococcus*) seem recycled from Palaeogene rocks. This suggests that the ice-dammed lake was not inhabited by fossiliferous phytoplankton. Interestingly, the increased supply of organic matter to the lake basins during summer did not lead to the development of rich benthic biotas, of which the activity could have been preserved as ichnofossils. Both the Lębork and the Złocieniec varves show no sign of bioturbation (see Figs 2 and 3). The lack of fossil traces of benthic animals may result from inconvenient bottom conditions caused by the high sedimentation rate (especially during summers) and by the low temperature and stagnant conditions during winters. The latter factor may have caused a low-oxygen or even anoxic condition at the bottom.

The structureless organic matter found in sample L1 (Fig. 5J) may result from bacterial decay of organic matter under anoxic conditions (see Tyson, 1987; Batten, 1996b). Merta (1980) noted some arthropod, bivalve and presumably gastropod traces in varved deposits of the Warszawa glacial lake (Pleistocene), indicating that the bottoms of at least some ice-dammed lakes were inhabited. However, this lake was situated much more to the South, and it was interpreted by Merta (1980) as an extraglacial lake, of which the environmental conditions were fairly different from those in the ice-dammed lakes at Złocieniec and Lębork.

6. Conclusions

Because the results of the present study are based on a few samples only, conclusions must be treated as preliminary. Despite this, they agree well with interpretations of data from previous investigations of varved glacial deposits. The high concentration of organic particles in the summer layers confirms that these layers accumulated by settling during periods of increased ablation and drainage of glacial deposits or the substratum, and by supply of material that the meltwaters eroded to the ice-dammed lakes. Winter laminae, in turn, represent sediments deposited in ice-covered basins with stagnant water and a very slow sedimentation rate (e.g., Merta 1978, 1986). Anoxic-dysoxic bottom conditions could appear during winters.

The occurrence of Cretaceous and Palaeogene dinoflagellate cysts shows that sediments of these ages were reworked and re-deposited as varved clay at Lębork and Złocieniec. This partly confirms the interpretation of Paluszkiewicz (2008), who suggested a Tertiary origin of the quartz grains in the varves of the Pyrzowice ice-dammed lake. Possibly all organic particles from the deposits under study, including fresh-water phytoplankton, were derived from the pre-Quaternary substratum and/or erratic blocks.

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References

Batten, D.J., 1996a. Colonial Chlorococcales. [In:] J. Jansonius & D.C. McGregor (Eds): *Palynology: principles and applications* 1, 191–203. American Association of Stratigraphic Palynologists Foundation, Dallas, Texas.

Batten, D.J., 1996b. Palynofacies and palaeoenvironmental interpretation. [In:] J. Jansonius & D.C. McGregor (Eds): *Palynology: principles and applications* 3, 1011–1064. American Association of Stratigraphic Palynologists Foundation, Dallas, Texas.

Batten, D.J. & Grenfell, H.R., 1996. *Botryococcus*. [In:] J. Jansonius & D.C. McGregor (Eds): *Palynology: principles and applications* 1, 205–214. American Association of Stratigraphic Palynologists Foundation, Dallas, Texas.

Bradley, W.H., 1931. Non-glacial marine varves. *American Journal of Science* 22, 318–330.

Brauer, A., Endres, C. & Negendank, J.F.W., 1999. Lateglacial calendar year chronology based on annually laminated sediments from Lake Meerfelder Maar, Germany. *Quaternary International* 61, 17–25.

Brodzikowski, K. & Van Loon, A.J., 1991. Glacigenic sediments. *Developments in Sedimentology* (Elsevier, Amsterdam) 49, 674 pp.

Calvert, S.E., 1966. Origin of diatom-rich, varved sediments from the Gulf of California. *Journal of Geology* 74, 546–565.

Cieśliński, S. & Jaśkowiak, M. 1973a. Kreda dolna. Synekliza perybałtycka i wyniesienie mazursko-suwalskie. Alb [Lower Cretaceous. The peri-Baltic Syneclise and the Mazury-Suwałki Elevation. Albian]. [In:] S. Sokołowski (Ed.): *Budowa geologiczna Polski, Vol. I: Stratygrafia, Part 2: Mezozoik*, 551–552.

Cieśliński, S. & Jaśkowiak, M. 1973b. Kreda górna. Niecka szczecińska i monoklina przedsudecka [Upper Cretaceous. The Szczecin Trough and Fore-Sudetic Monocline]. [In:] S. Sokołowski (Ed.): *Budowa geologiczna Polski, Vol. I: Stratygrafia, Part 2: Mezozoik*, 586–592.

Cieśliński, S. & Wyrwicka, K., 1973. Osady kredy górnej w krach lodowcowych [Upper Cretaceous rocks in the ice-drift blocks]. [In:] S. Sokołowski (Ed.): *Budowa geologiczna Polski, Vol. I: Stratygrafia, Part 2: Mezozoik*, 640–644.

Costa, L.I. & Davey, R.J., 1992. Dinoflagellate cysts of the Cretaceous System. [In:] A.J. Powell (Ed.): *A stratigraphic index of dinoflagellate cysts*. Chapman & Hall, London, 99–153.

De Geer, G., 1912. A geochronology of the last 12,000 years. 11th *Congres Géologique Internationale*, *Comptes Rendues*, (Stockholm 1910), 241–253.

Fedorowicz, S., Rosa, B. & Sylwestrzak, J., 1985. Wiek TL moren gardzieńskich [TL age of the Gardno Phase end moraines]. [In:] *Sympozjum Paleogeografia Niziny Gardzieńsko-Łebskiej*. Gdańsk.

Goslar, T., Bałaga, K., Arnold, M., Tisnerat, N., Starnawska, E., Kuźniarski, N., Chróst, L., Walanus, A. & Więckowski, K., 1999. Climate-related variations in the composition of the Lateglacial and Early Holocene sediments of Lake Perespilno (eastern Poland). *Quaternary Science Reviews* 18, 899–911.

Górska, M., 2006. Wybrane cechy teksturalne glin lodowcowych i osadów wodnolodowcowych fazy pomorskiej północno-wschodnich Niemiec [Some textural features of till and fluvioglacial deposits of the Pomeranian Phase in north-eastern Germany]. *Przegląd Geograficzny* 78, 69–89.

Grabowska, I., 1996a. Gromada Chlorophyta [Division Chlorophyta]. [In:] L. Malinowska & M. Piwocki (Eds): *Budowa geologiczna Polski, Vol. III: Atlas skamieniałości przewodnich i charakterystycznych, Part 3a: Kenozoik, Trzeciorzęd, 1: Paleogen*, 387–391.

Grabowska, I. 1996b. Incertae sedes. [In:] L. Malinowska & M. Piwocki (Eds): *Budowa geologiczna Polski, Vol. III:*

Atlas skamieniałości przewodnich i charakterystycznych, Part 3a: Kenozoik, Trzeciorzęd, 1:Paleogen, 391–392.

Grabowska, I., 1996c. Chlorophyta. [In:] L. Malinowska & M. Piwocki (Eds): *Budowa geologiczna Polski, Vol. III: Atlas skamieniałości przewodnich i charakterystycznych, Part 3a: Kenozoik, Trzeciorzęd, 2: Neogen*, 774–778.

Grabowska, I. & Ważyńska, H., 1997. Badania palinologiczne i fitoplanktonowe osadów trzeciorzędowych Pobrzeża Gdańskiego i z Bałtyku [Palynological and phytoplankton studies of Tertiary deposits of the Gdańsk Coast and the Baltic Sea]. *Biuletyn Państwowego Instytutu Geologicznego* 375, 5–41.

Karczewski, A., 1985. Typy morfogenetyczne form strefy marginalnej fazy pomorskiej w obszarze tzw. Lobu Parsęty na Pojezierzu Szczecineckim [Morphogenetic types of the glaciomarginal forms of the Pomeranian Phase at the Parsęta Lobe extent in the Szczecinek Lake District]. *Sprawozdania PTPN* 101, 29–32.

Kozarski, S., 1986. Skale czasu, a rytm zdarzeń geomorfologicznych Vistulianu na Niżu Polskim [Timescales and the rhythm of Vistulian geomorphic events in the Polish Lowland]. *Czasopismo Geograficzne* 62, 2–6.

Lindner, L., 1984. An outline of Pleistocene chronostratigraphy in Poland. *Acta Geologica Polonica* 34, 27–49.

Lindner, L., 1999. Plejstocen [Pleistocene]. [In:] L. Lindner (ed.), Czwartorzęd. Osady, metody badań, stratygrafia. Wydawnictwo PAE, Warszawa, p. 466–613.

Marks, L., 2005. Pleistocene glacial limits in the territory of Poland. *Przegląd Geologiczny* 53, 989–993.

Merkt, J. & Müller, H., 1999. Varve chronology and palynology of the Late Glacial in Northwest Germany from lacustrine sediments of Hämelsee in Lower Saxony. *Quaternary International* 61, 41–59.

Merta, T., 1978. Extraglacial varved deposits of the Warsaw ice-dammed lake (younger Pleistocene), Mazovia Lowland, central Poland. *Acta Geologica Polonica* 28, 241–272.

Merta, T., 1980. Arthropod and mollusk traces in varved clays of central Poland. *Acta Geologica Polonica* 30, 165–173.

Merta, T., 1986. Varve sedimentation in extraglacial ice-dammed lakes. *Acta Geologica Polonica* 36, 325–336.

Morawski, W., 1989. Morfogeneza Niziny Łebskiej i Pradoliny Łeby między Lęborkiem a Łebą [Morphogenesis of the Łeba Lowland and the Łeba Pradolina between Lębork and Łeba]. *Studia i Materiały Oceanologiczne* 56, 163–170.

Morawski, W., 1990. *Objaśnienia do szczegółowej mapy geologicznej Polski, 1:50 000, arkusz Lębork* [Explanation to Geological Map of Poland, 1:50 000, sheet Lębork]. Wydawnictwa Geologiczne, Warszawa, 80 pp.

Morawski, W., 1998. Late Glacial Lębork ice-dam lake. *INQUA Commission on Glaciation, Field symposium on glacial geology at the Baltic Sea coast in northern Poland, Excursion guide*, 87–88.

Paluszkiewicz, Re., 2004. Warunki sedymentacji osadów rytmicznie warstwowanych w zastoisku złocienieckim na Pojezierzu Drawskim [Depositional conditions of rhythmically stratified sediments from the Złocieniec proglacial lake in the Drawsko Lakeland]. *Poznańskie Towarzystwo Przyjaciół Nauk, Prace Komisji Geograficzno-Geologicznej* 34, 101 pp.

Paluszkiewicz, Re., 2010. Stanowisko 6: Złocieniec. Zastoisko złocienieckie [Site 6: Złocieniec. Złocieniec ice-dammed lake]. [In:] J. Rotnicka, W. Szczeciński, K. Skolasińska, R. Jagodziński & J. Jasiewicz (Eds): *Teraźniejszość kluczem do przeszłości: współczesne procesy sedymentacyjne i ich zapis kopalny*. IV Polska Konferencja Sedymentologiczna (POKOS'4), (Smołdzino 21–26.06.2010), Streszczenia referatów i posterów, Przewodnik do wycieczek, 185–187.

Paluszkiewicz, Ry., 2008. Cechy osadów pyrzyckiego zbiornika glacilimnicznego jako wyraz zmieniających się warunków środowiska depozycyjnego [Features of the Pyrzyce glacilacustrine deposits as a result of variable conditions of the sedimentary environment]. *Poznańskie Towarzystwo Przyjaciół Nauk, Prace Komisji Geograficzno-Geologicznej* 38, 160 pp.

Piwocki, M., 2004. Paleogen [Palaeogene]. [In:] T.M. Peryt & M. Piwocki (Eds): *Budowa geologiczna Polski, Vol I: Stratygrafia. Part 3a: Kenozoik, Paleogen, Neogen*. Państwowy Instytut Geologiczny, Warszawa, 22–71.

Rachlewicz, G., 2010. Stanowisko 1: Lębork. Zastoisko lęborskie [Site 1: Lębork. Lębork ice-dammed lake]. [In:] J. Rotnicka, W. Szczuciński, K. Skolasińska, R. Jagodziński & J. Jasiewicz (Eds): *Teraźniejszość kluczem do przeszłości: współczesne procesy sedymentacyjne i ich zapis kopalny*. IV Polska Konferencja Sedymentologiczna, 175–176.

Ralska-Jasiewiczowa, M., Goslar, T., Różański, K., Wacnik, A., Czernik, J. & Chróst, L., 2003. Very fast environmental changes at the Pleistocene/Holocene boundary, recorded in laminated sediments of Lake Gościąż, Poland. *Palaeogeography, Palaeoclimatology, Palaeoecology* 193, 225–247.

Stokes, W.L., 1964. Eolian varving in the Colorado Plateau. *Journal of Sedimentary Petrology* 34, 429–432.

Stover, L.E., Brinkhuis, H., Damassa, S.P., de Verteuil, L., Helby, R.J., Monteil, E., Partridge, A.D., Powell, A.J., Riding, J.B., Smelror, M. & Williams, G.L., 1996. Mesozoic-Tertiary dinoflagellates, acritarchs and prasinophytes. [In:] J. Jansonius & D.C. McGregor (Eds): *Palynology: principles and applications* 2, 641–750. American Association of Stratigraphic Palynologist Foundation, Dallas, Texas.

Tyson, R.V., 1987.The genesis and palynofacies characteristics of marine petroleum source rocks. [In:] J. Brooks & A.J. Fleet (Eds): *Marine petroleum source rocks*. Geological Society, London, Special Publication 26, 47–67.

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