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LACUSTRINE CHALK DEPOSITION IN LAKE KRUKLIN (NE POLAND) AS A RESULT OF DECALCIFICATION OF THE LAKE CATCHMENT

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Abstract

Lacustrine chalk is very common in post-glacial lakes of northern Poland. In the deposit of Lake Kruklin (NE Poland) carbonates occur as a layer 2–3 m thick. Samples for laboratory studies were collected from three profiles in SW part of the deposit. Mineral composition of the sediments was determined using differential thermal analysis (DTA) and thermogravimetry analysis (TGA), while the age was determined on the basis of pollen analysis. The sediment profiles represent an age of early Holocene. Calcite is the major component of lacustrine chalk. It forms small crystals (<10 μm), sometimes grouped in aggregates, or present as bioclasts.

Calcium carbonate precipitated from lake water. Chemical weathering of glacial and fluvioglacial material of the lake catchment is the main source of ions, transported to the lake mainly by groundwater. Formation of the Kruklin lacustrine chalk deposit must have required 300–350 kg of dry weight calcium carbonate to be carried away from each square meter of the lake catchment. If only top one-meter layer of glacial sediments had been decalcified, it should have contained 13–22 percent of calcium carbonate. The results of petrographic analysis show this value to be possible.

Key words: Kruklin Lake, lacustrine chalk, decalcification, Holocene, NE Poland

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INTRODUCTION

Lake sedimentation is the most common genesis of Holocene continental calcareous sediments. Other processes, like formation of caliche or calc-sinter, have minor significance. Lacustrine chalk is deposited by precipitation of calcium carbonate. This process depends on many physical, chemical and biological factors.

Gyttja and calcareous chalk occurs and is being mined commonly in northern Poland. 83 million tons of resources at over 50 deposits have been documented. There are numerous deposits without full geological documentation and supposed reserves of chalk are 15 times greater (Alexandrowicz 1986).

There are many classifications of holocene lacustrine carbonates. The most important is based on the content of calcium carbonate. Therefore lacustrine chalk may be defined as a sediment with calcium carbonate as the main component (over 75–80% of dry mass). Another factor is the content of organic versus detrital matter (mainly quartz). Calcareous sediments composed mostly of detrital parties are classified on the basis of their granulometric composition (*e.g.* calcareous silt, calcareous sand *etc.*).

Composition of lacustrine carbonates is commonly expressed to air-dry mass of sample. However, major component of lacustrine chalk is water. Water-content is the key factor for physical and chemical properties of sediments (*e.g.* Dobak, Wyrwicki 2000). Unfortunately, its significance is very often disregarded and its content not examined. Sediments described in this paper contain up to 90% of water.

Among numerous sites with lacustrine chalk deposits, the Lake Kruklin deposit is one of few, where the chalk occurs at the surface. In other sites, deposits are being exploited from below water level and are not easily available for detail studies.

Calcium carbonate, the major component of chalk, is supplied from the catchment of a lake. It is transported via surface and groundwater. In Mazury Lake District calcium carbonate, originally contained within glacial and fluvioglacial sediments, is mobilized by meteoric water decalcifying uppermost part of these sediments.

The purpose of this paper is to assess the value of decalcification of the catchment needed for the Kruklin deposit to have formed.

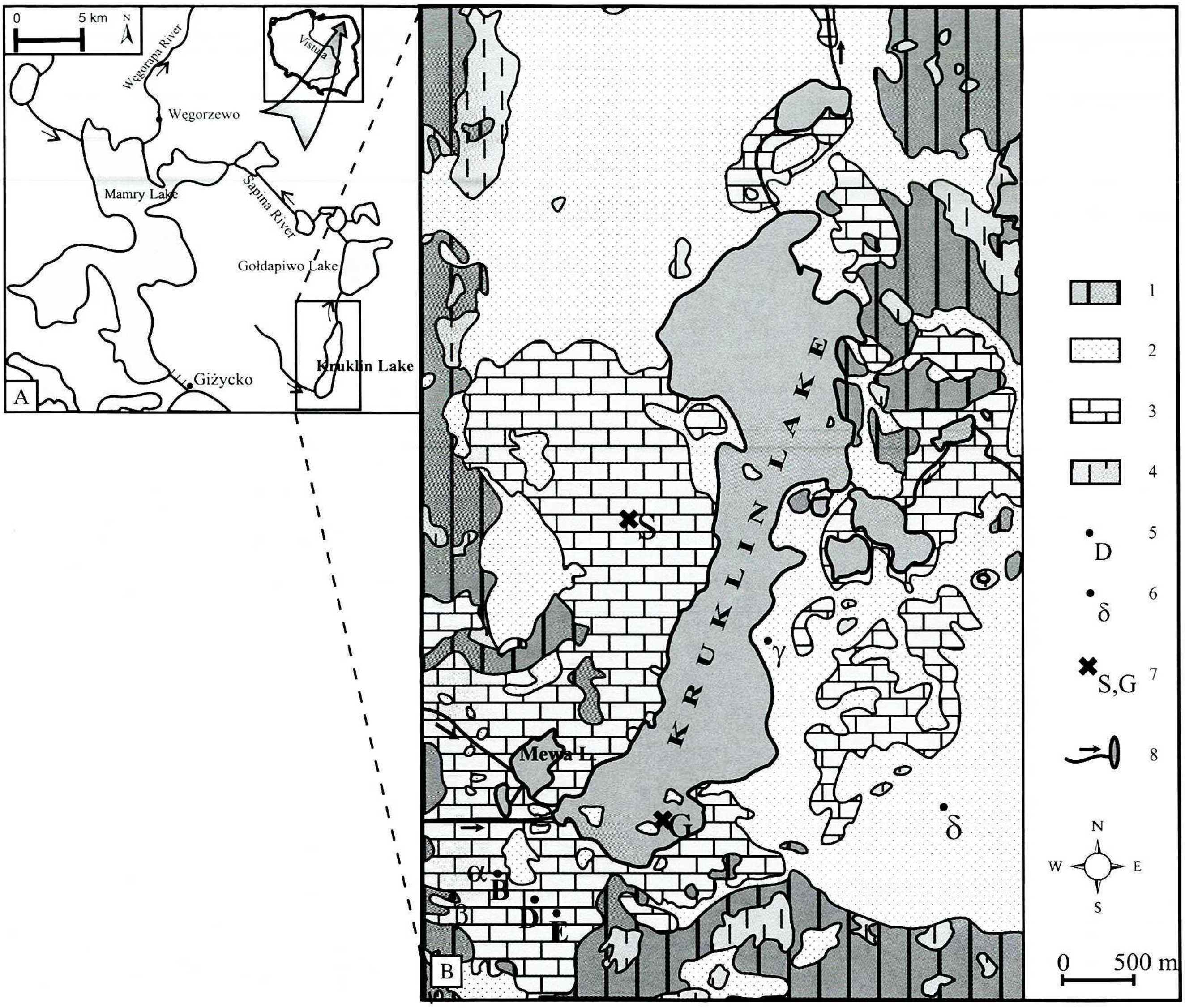

Fig. 1. **A** – Location of the study area in the Masurian Lake District; **B** – Geological map of Kruklin Lake surroundings (after Stasiak 1963): *1* – till, *2* – sand and gravel, *3* – gyttja and lacustrine chalk, *4* – peat, *5* – profile of study, *6* – location of sample for petrographic analysis, *7* – location of former study sites (S – Stasiak 1963, G – Czeczuga & Gołębiewski 1969), *8* – lakes and streams.

GEOGRAPHICAL AND GEOLOGICAL SETTINGS

Lake Kruklin lies in the Masurian Lake District, 10 km east of Giżycko (Fig. 1A). It is fed by a stream, which drains small lakes from the east and by a drain ditch from the west. Originally, the lake had no outflow. Between 1841–1851 it was connected with Lake Gołdapiwo (in the north), so the lake level dropped artificially by 6.3 m (Srokowski 1945). This caused unique conditions to study lacustrine chalk deposits, due to that the deposit is very well explored (Stasiak 1963, 1966, Czeczuga, Gołębiowski 1969, Czepiec 1997). Today, the lake belongs to Pregoła river basin and is connected with Pregoła by Sapina river, Mamry Lake system and Węgorapa river

At present the lake is 5000 m long, 1300 m wide with an area of about 320 ha. The lake is elongated in a northerly direction. It is composed of two basins. The northern basin is wider and deeper with a maximum depth of 25.1 m, while the average water depth is 4.9 m (Czeczuga, Gołębiowski 1969). The average water level is at 120 m a.s.l. The lake has a complex shoreline with a number of bays of different size. It is seasonally connected with Mewa lake (Kożuchowskie lake), where a natural reserve has been established. The bottom of Kruklin lake has numerous sand and gravel islets.

The geological map (Fig. 1B) was drawn in 1:25000 scale, based on the geological map by Stasiak (1963) and verified by own field studies. Geology of the Kruklin lake surroundings is closely related to Vistulian ice sheet regression stages. Kruklin lake, like many other lakes of the region, lies in a small lobe of a former ice sheet.

METHOD OF STUDIES

The field work was carried out in the summer of 1998 and 1999. Samples of lacustrine chalk were collected in the SW part of the deposit, from three pits (B, D, E in Fig. 1B). Profiles from the pits were sampled in 10 and in 20 cm inter-

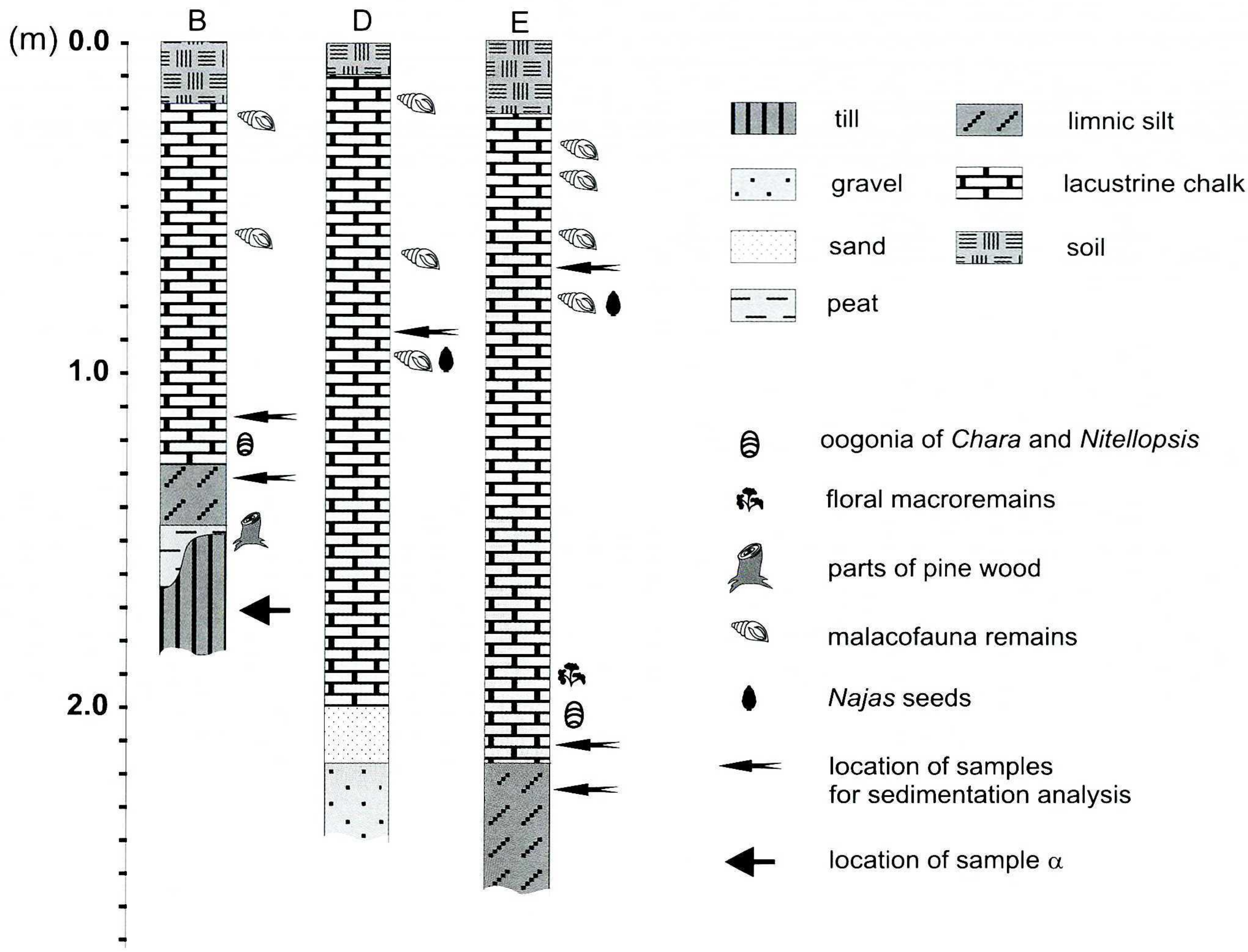

Fig. 2. Profiles of lake sediments from SW part of Kruklin deposit.

vals as cubes with 10 cm side length. In the laboratory, determination of the mineral composition and pollen analysis were made.

The method developed by Kenig (1998) was used for petrographic analysis of glacial and fluvioglacial material. The samples for the petrographic analysis were derived from four sites (α, β, γ, δ on Fig. 1B). The sample α comes from till at the base of profile B (Fig. 2), the sample β comes from an islet of till southwest of profile B, and the samples γ and δ come from fluvioglacial deposits east of the lake. Petrographic composition of gravel (5–10 mm in diameter) from each sample was analysed using >300 grains. Quantitative ratios of the petrographic components were calculated (sedimentary rocks to crystalline rocks + quartz, crystalline to carbonate rocks and non-resistant to resistant rocks) and compared to the ratios determined for till horizons in the Mrągowo Lake District (Kenig 1998).

Mineral composition of investigated lake sediments was determined by a means of differential thermal analysis (DTA) and thermogravimetry analysis (TGA). Samples from every "cube" of air-dried sediment were ground in a mortar. Parameters of analyses (10°C/min, 20–1000°C) were set on the basis previous studies (Webb & Kruger 1970, Smykatz-Kloss 1974, Wyrwicki 1988). The sedimentation analysis of several samples was carried out and the granulometric composition was determined. High contents of organic matter were removed by H_2O_2 treatment. After that a standard DTA was started. Rules of interpretation of derivatograms were given in the papers by Smykatz-Kloss (1974) and Wyrwicki (1988).

Samples for pollen analysis (1cm^3) were collected from every 20 cm of the profile E (Fig. 2). The slides were prepared according to the standard procedure (Berglund, Ralska-Jasiewiczowa 1986). Pollen identification and counting were carried out by Dr Krzysztof Bińka (Institute of Geology, University of Warsaw). Results are recorded in a pollen diagram prepared with *Tilia 2.0 b* software.

SEDIMENTS OF KRUKLIN DEPOSIT

Lithology and stratigraphy

Kruklin lake sediments lie directly upon till or fluvioglacial sands and gravels. Peat with parts of pinewood is found at some places at the bottom of lake sediments. This peat was described by Stasiak (1963) and dated by ^{14}C at Alleröd stage. Thickness of the peat stratum is not uniform and reaches a maximum of 0.2 m.

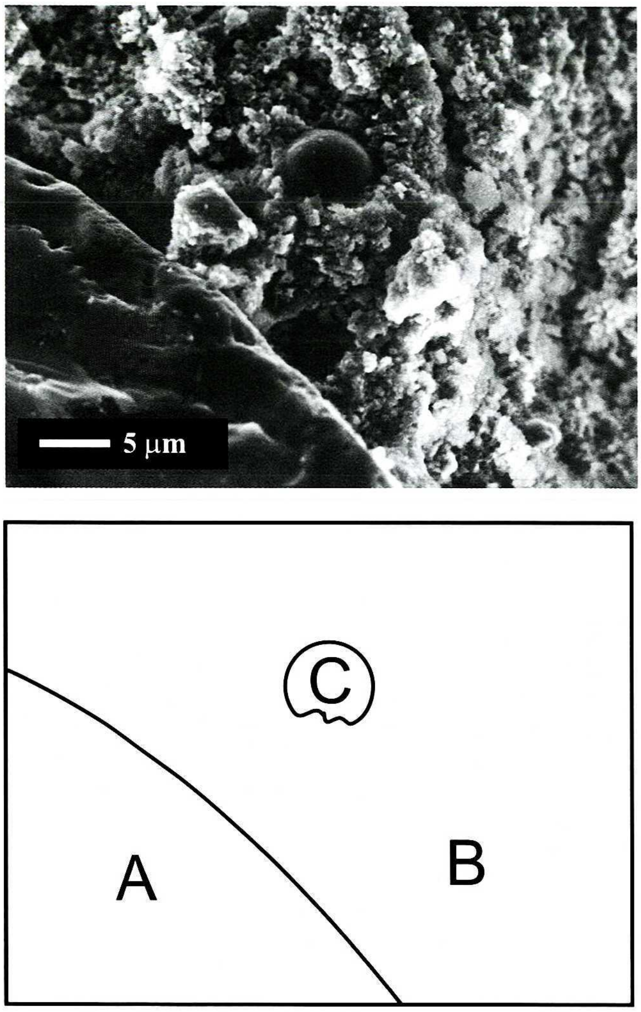

Fig. 3. SEM pictures of lacustrine chalk sample (profile B, depth 0.5–0.6 m): A – quartz grain, B – calcite crystals, C – pyrite.

A typical profile of Kruklin Lake sediments (Fig. 2) starts with grey-blue quartz clay (<1 m thick) at its base. The clay is overlain by carbonate sediments with a thickness of up to 2 m. These sediments have light grey laminae at the bottom. The carbonate sediments are composed of small calcium carbonate aggregates which disintegrate in distilled water within 48 hours. In a fraction greater than 63 μm, calcium carbonate aggregates, bioclasts, grains of quartz, opaque minerals and organic detritus occur. SEM photos of sediment samples (Fig. 3) show very small size of calcite crystals. The dominant animal remains are molluscs, which are the main component of sediment in some parts of profiles. *Gyraulus* and *Valvata* shells and *Bithynia* opercula predominate among gastropods. Shells of *Pisidium* and a terrestrial snail *Succinea* were discovered in profile D. Gastropoda shells sometimes form continuous layers several centimetres thick. Floating shells of gastropods must have been swept into an ancient bay and then deposited forming layer. All malacofauna is precisely characterised by Czepiec (1997). Assemblages of Ostracoda from Kruklanki (northwestern part of the Kruklin deposit) are being studied. Remains of Cladocera were present in samples prepared for pollen analysis. Floral macroremains are represented by slightly decomposed parts of *Chara* "footstalks" and "leafs" and *Typha* leafs. In the western part of the Kruklin deposit, numerous rhizomes of *Typha* were found. Oogonia of *Chara* and *Nitellopsis* are common in lower parts of the profiles. Frequency of oogonia decreases towards the top of the profiles, where *Najas* seeds are common.

Many cracks are observed, which intersect calcareous sediments. These cracks, 1.5 m long, 5 cm wide and narrowing towards the bottom are filled with humus, derived from overlying soil. Therefore, it is assumed that they opened after soil formation caused by drying of deposits due to lowering of the water level.

Overall thickness of lake sediments in the outcrops studied by author is less than 3 m. In the southern part of the present-day lake, thickness of lake sediments is less than 6 m (Czeczuga, Gołębiowski 1969) and in the western part of the deposit it is <8 m (Stasiak 1963).

Analysis of pollen diagram (Fig. 4) enables the author to distinguish four pollen zones. The first zone is characterised by significant content of herb pollen and traces of thermophilous trees. Pollen of *Pinus* (>50%) and *Betula* (>25%) are dominant. Among genus *Betula*, dwarf *Betula nana* species is the most abundant. Pollen of willow are infrequent. General pollen content is lower than in the other zones. These features indicate cold and dry climate and presence of open tundra-steppe communities. The second zone is characterised by a decrease of herb pollen number. Among trees pine and birch (with *B. nana* no more observed) are still dominant with frequencies similar to each other. Significance of *Ulmus* (elm) and *Corylus* (hazel) gradually grows. Characteristic feature of the third zone is the domination of *Corylus*. It indicates restoration of the forest species structure. The content of *Alnus* (alder) pollen starts to increase, probably related with banks of rivers and lakes. More significant are thermophilous trees (*Tilia*, *Quercus*). The last zone was distinguished by decrease of *Corylus* and increase of thermophilous tree pollen. *Pteridium* appears, which indicates milder climate conditions related to the Holocene optimum. *Viscum* and *Hedera* pollen are still absent.

Pollen diagram was compared to that published by Stasiak (1963) and to regional correlation (Berglund et al. 1996). The first distinguished zone in profile E represents Younger Dryas, the second one – Preboreal, the third – Boreal and the fourth – early part of Atlantic stage. Sediments of the later part of Holocene are absent. Moreover, the bottom stratum of peat in profile B, is similar to that observed by Stasiak (1963) and dated to Alleröd.

Mineral composition

Mineral composition of sediments (Fig. 5) varies along the profile. Calcium carbonate is the main component (over 80% dry weight) of the carbonate sediments. Samples from limnic silt and sand are composed mainly of thermally inactive substances, mostly quartz. In carbonate sediments quartz is accessory and reaches only 30% in bottom parts of the sediments.

Results of granulometric analyses are shown in Table 1. Fraction >60 μm consists mostly of calcite aggregates. The

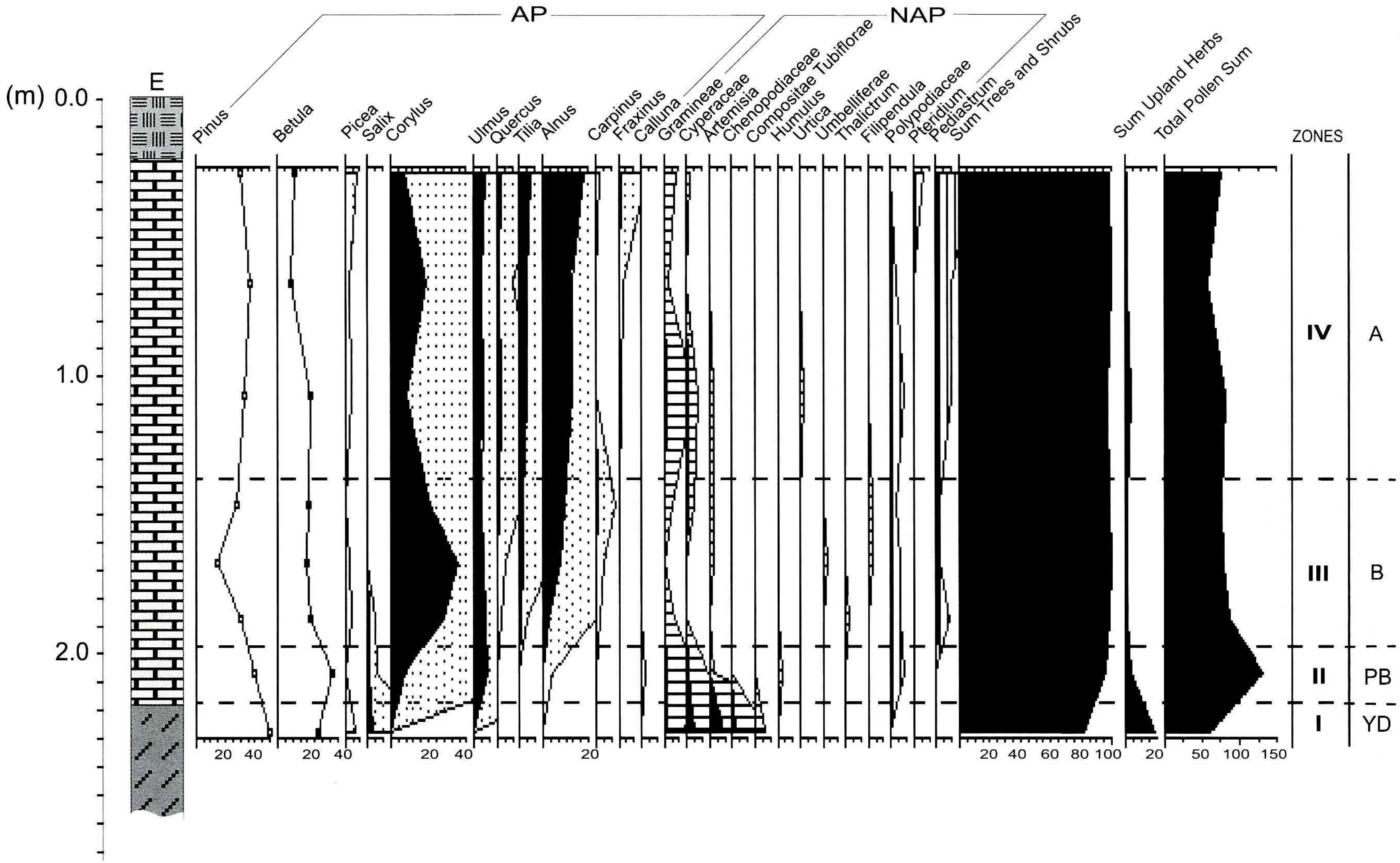

Fig. 4. Pollen stratigraphy for profile E. YD – Younger Dryas, PB – Preboreal, B – Boreal, A – Atlantic. For key to stratigraphic symbols see Fig. 2.

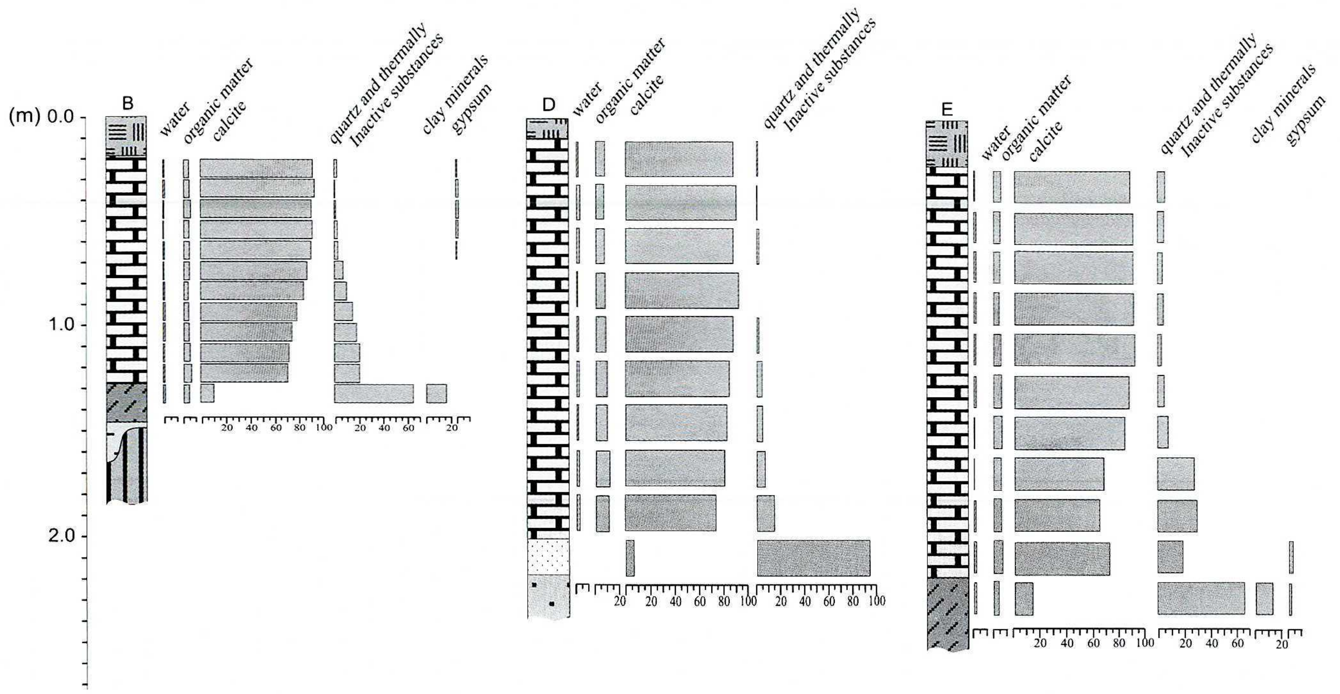

Fig. 5. Composition of studied sediments (in % of dry mass). For key to stratigraphic symbols see Fig. 2.

bottom sediments can be classified as clayey silt (according to Shepard 1954). The dominant fraction in bottom parts of profiles is 10–60 μm. Content of clay fraction (<2 μm) is higher in the upper parts of profiles. Granulometric composition of lacustrine chalk is diverse. A great deal of fraction over 60 μm is related with calcite aggregates and organic remains (mainly shells and/or its parts). Regardless of sediment type and depth, all samples have similar content of the fraction 2–10 μm (28.1–35.5%). In many samples after hydrogen peroxide treatment, organic matter is still detected by DTA-TGA. Moreover, new substances appear, probably resulting from oxidation of original sediment components. They could be amino acids and humid acids, which were adsorbed on the surface of calcite crystals (Hakansson, Jansson 1983). Therefore they must have avoided oxidation by H_2O_2 and "evaporated" from crystals' surfaces, than burned and produced exothermic effect on derivatogram.

Table 1

Granulometry of the Kruklin Lake sediments
(*italic – samples of limnic silt*)

Sample (name of profile; depth)	**Percent of fraction**				
	>60 μm	10-60 μm	5-10 μm	2-5μm	<2 μm
Kruklin B; 1.1-1.2 m	14.6	40.5	16.5	15.9	12.5
Kruklin B; 1.3-1.4 m	*3.9*	*35.7*	*13.8*	*14.7*	*31.9*
Kruklin D; 0.8-1.0 m	32.4	13.9	11.3	16.8	25.6
Kruklin E; 0.6-0.8 m	30.9	13.8	11.3	18.4	25.6
Kruklin E; 2.0-2.2 m	19.8	30.0	18.6	16.9	14.7
Kruklin E; 2.2-2.4 m	*4.3*	*38.0*	*18.5*	*13.3*	*25.9*

DEGREE OF CATCHMENT DECALCIFICATION

Processes leading to formation of calcareous gyttja and lacustrine chalk are very fast and efficient. Occurrence of these deposits at many sites proves that these processes have been common at given geological, morphological, climatic and hydrological conditions. Precipitation of calcium carbonate is the last stage of its circulation in catchment area. Mechanism of lacustrine chalk sedimentation involves also processes related to mobilization and transport of calcium carbonate to a basin.

The contemporary precipitation in northeastern Poland has the average content of calcium ions 3.3 mg/l (Felter 1999) and pH from 3.4 to 8.3 with an average 5.5 (Małecka 1991). Carbon dioxide concentration of meteoric water is in equilibrium with atmospheric CO_2, and gradually increases during water seepage through the soil, due to CO_2 coming from decomposition of organic matter. Dissolution of carbonates is most intensive directly below the soil zone and weakens in deeper zones. High concentration of Ca^{2+} in the uppermost level of groundwater (88.4 mg/l on average – Felter 1999) results from such a process. Increase of hydrostatic pressure downwards an aquifer causes successive dissolution of carbon dioxide (Petelski, Sadurski 1987) and further

Table 2

Petrographic indicators for glacial and fluvioglacial sediment samples from the Kruklin Lake surroundings (location of sites shown in Fig. 1B): O/K – ratio of sedimentary rocks to crystalline rocks and quartz, K/W – crystalline to carbonate rocks, A/B – non-resistant to resistant rocks

Symbol of sample (number of examinated grain *n*)	**O/K**	**K/W**	**A/B**
α (*n = 362*)	2.23	0.59	1.48
β (*n = 323*)	2.63	0.39	2.40
γ (*n = 381*)	2.26	0.48	1.89
δ (*n = 440*)	1.97	0.55	1.63

calcium carbonate dissolution. Dissolved calcium carbonate migrates with water, which can supply lakes through underwater springs. Such outflow of water is followed by a sudden decrease of pressure and CO_2 solubility. The excess CO_2 escapes to the atmosphere. If lake water is saturated with calcium ions, the decrease of carbon dioxide is balanced with precipitation of calcium carbonate. Ions, which were not precipitated, can be exported from the basin with surface and underground water.

Global reserves (documented and supposed) of the Kruklin deposit exceed 12 million tons of dry mass with an average calcium carbonate content 86% (Stasiak 1966). Calculation of the degree of decalcification within the catchment was done under the following assumptions:

1. Total area of lake drainage (over 43 km^2) was calculated on the basis of topographic maps 1:25000.

2. The eastern part of the lake catchment area has been excluded, because there are many small basins where sedimentation of calcium carbonate still occurs. Consequently, area which was decalcified encompasses 33 km^2.

3. As the lake drainage area represents a closed system, there is no lateral water exchange with other areas.

Given these assumptions, calculated amount of calcium carbonate, which was removed from the catchment, corresponds to 300–350 kg/m^2. It should be noticed, however, that decalcification occurred mainly in the aerobic zone. Volume density of glacial and fluvioglacial material varies strongly from 1600 kg/m^3 for loose sands up to 2250 kg/m^3 for semi-coherent sandy loam and moraine loam. Therefore, these rocks should contain at least 13% (loose sands) to 22% (semi-coherent sandy loam and moraine loam) of calcium carbonate, if only the top one-meter layer was decalcified. Petrographic analysis and calculated ratios for glacial and fluvioglacial deposits (Tab. 2) indicate carbonate content up to 70%. Two indicators in sample β document even higher carbonate content. In sample δ low value of O/K indicator documents impoverishment in sedimentary rocks. It should be noticed that this sample comes from fluvioglacial sands, where sedimentary rocks (especially carbonates) could have been weathered and washed away. According to petrographic analysis, amount of calcium carbonate calculated for glacial and fluvioglacial rocks of the lake surrounding is probable.

CONCLUSIONS

Formation of Kruklin chalk deposit resulted from decalcification of the catchment. The degree of that decalcification is calculated as 300–350 kg/m^2. Given the estimation of calcium carbonate content in the catchment sediments available for decalcification, it is concluded that only a small part of carbonate material has been dissolved, washed out and formed chalk deposits.

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