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STUDIES OF YOUNGEST LACUSTRINE SEDIMENTS IN THE HIGH TATRA MOUNTAINS, POLAND

INTRODUCTION

The present study is a summary of the first results of lacustrine sediment investigations carried out within a Polish-Swedish joint research programme during 1988—1989 in the Polish Tatra Mountains. The lacustrine sediments in the Polish Tatra Mountains have been studied during the last 30 years. In 1974—78 expeditions of the Warsaw University were led by Prof. J. Kondracki (Series in Geography, 1984, ed. Warsaw University Press). Sediment cores, 2—3 m thick, were taken from lakes in the Gąsienicowa valley as well as in the valley of Five Polish Lakes. The deposits in the different lakes have the same general character. The upper most part (ca 1 m) contains gyttja with 15—30% organic content. Below the gyttja the sediments are mainly built up by minerogenic material with less than 5% of organic content. The boundary between the two different layers is very distinct. Two radiocarbon dates from the boundary zone are available, 10 100 ± 140 BP (ITA 1005) and 9900 BP ± 120 BP (ITA 1006) (Wicik 1979, 1984).

AIMS AND STUDY AREA

The aim of this study is twofold as it is focused on both paleogeographical reconstructions of Late Glacial and Holocene environmental changes as well as upper Holocene slope process activity reflected in the lacustrine sediments. This paper is focused on the youngest lacustrine sediments. During the field studies sediment cores were taken from Czarny Staw Gąsienicowy Lake and Zielony Staw Gąsienicowy Lake.

Bigger lake — Czarny Staw Gąsienicowy — is surrounded by steep alpine cliffs, rocky slopes and talus slopes. The lake is located 1621 m above sea level. Its maximum depth is 51 m. Bathymetry of the lake

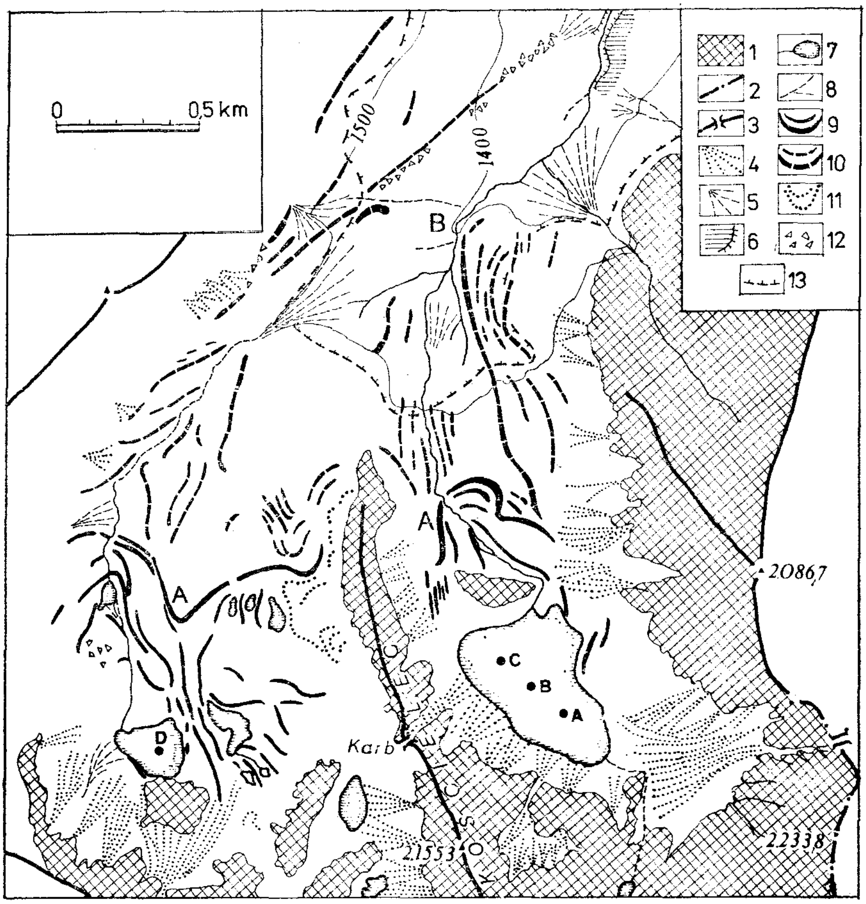

Fig. 1. General geomorphological map of upper Gąsienicowa valley, showing the location of the lakes Czarny Staw Gąsienicowy (A, B, C sampling points) and Zielony Staw Gąsienicowy (D sampling point). 1 — rockwall or rocky slope, 2 — summit, 3 — pass, 4 — talus cone, 5 — alluvial cone, 6 — terrace, 7 — lake, 8 — episodical stream, 9 — moraine ridge, younger generation (A), 10 — moraine ridge, older generation (B), 11 — rock glacier, 12 — block field, morainic, 13 — upper timberline

Ryc. 1. Szkic geomorfologiczny górnej części doliny Gąsienicowej pokazujący położenie Czarnego Stawu Gąsienicowego (miejsca poboru prób A, B, C) i Zielonego Stawu Gąsienicowego (próba D). 1 — ściany i stoki skalne, 2 — wierzchołek, 3 — przełęcz, 4 — stożek usypiskowy, 5 — stożek napływowy, 6 — terasa, 7 — jezioro, 8 — potok okresowy, 9 — wały morenowe młodsze (A), 10 — wały morenowe starsze (B), 11 — lodowiec gruzowy, 12 — pola blokowisk, 13 — górna granica lasu

show that the bottom basin has the shape of a deep longitudinal trough. During periods or events of intense slope process activity, the surrounding slopes supply sediments to the lake. Therefore, these sediments should be possible indicators of past and present geomorphic processes in the nearest surroundings of the lake basin (Fig. 1 and 2).

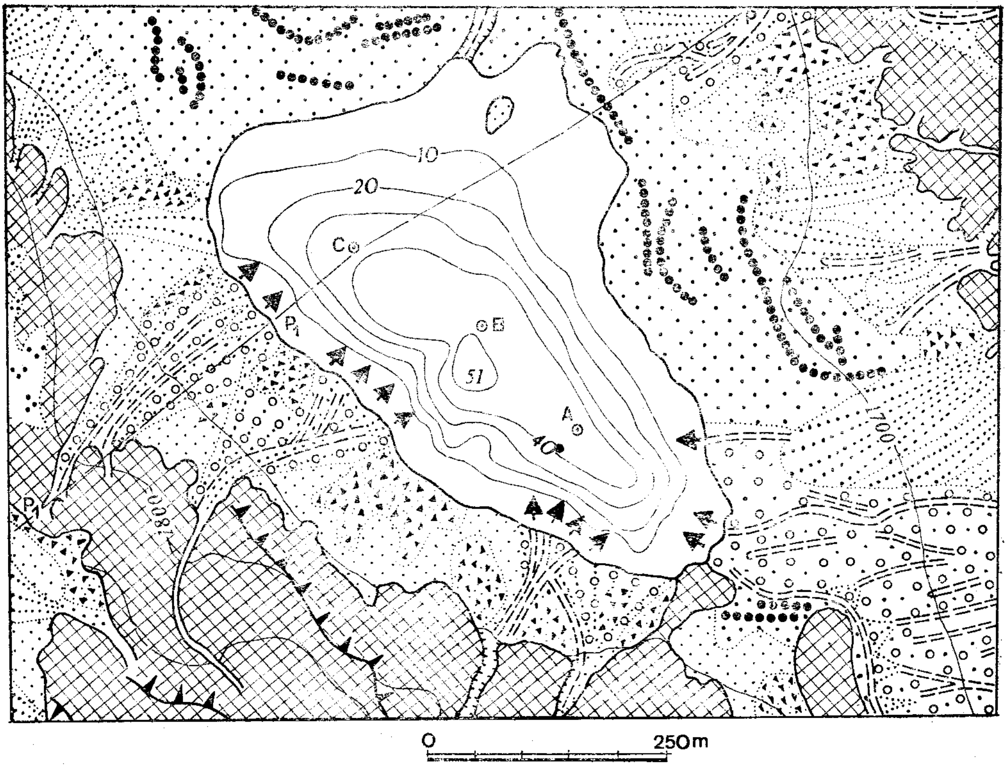

Fig. 2. Detail geomorphological map of Czarny Staw Gąsienicowy. Explanations on Fig. 3

Ryc. 2. Szczegółowa mapa geomorfologiczna otoczenia Czarnego Stawu Gąsienicowego. Objaśnienia na Ryc. 3

Smaller lake — Zielony Staw — is located 1671 m above sea level. Its maximum depth is 15.1 m. This lake is less affected by geomorphic slope processes at present. Lichenometrical studies has shown that important debris flow tracks were triggered on the slopes during the Little Ice Age (Kotarba 1989). Nowadays, there is no substantial sediment supply to the lake from slopes (Fig. 3).

Both lakes are located above timberline in the dwarf pine zone. The landform system is characterized by glacial valley bottoms, locally overdeepened, mantled by glacial, glacifluvial and colluvial deposits and filled with lake water (Fig. 1). The mean monthly temperature of the coolest month — January is —8.5° C while the temperature of the warmest month — July is 8.2° C (Hess 1965). Elevational position of the lakes correspond with annual isotherm of 0° C.

Cores were taken from positions where the lakes are in connection to the surrounding slopes. The sampling positions are located far away from the inlets of streams. This means that periods or events of debris

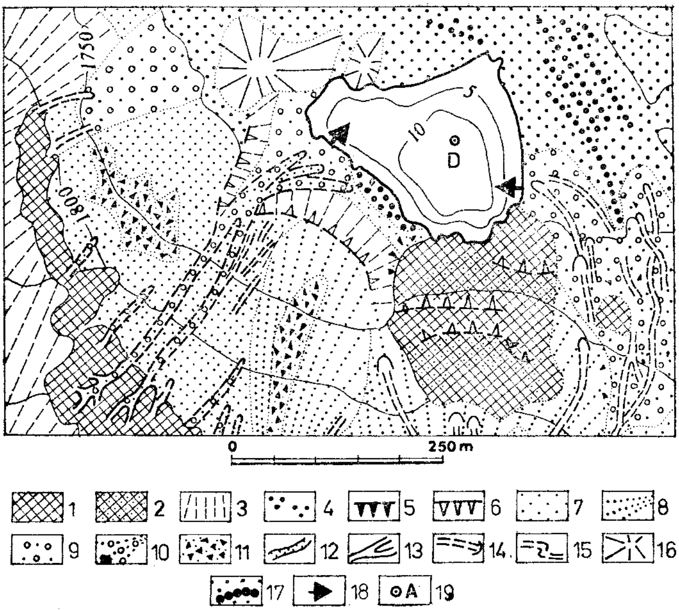

Fig. 3. Detail geomorphological map of Zielony Staw Gąsienicowy. 1 — rockwall or rocky slope, 2 — debris-mantled slope, 3 — Richter-denudational slope stabilized by vegetation, 4 — block slope, 5 — convex break on rockwall or rocky slope, 6 — convex rounded break, 7 — gravity sorted talus slope, 8 — gravity sorted talus cone, 9 — alluvial talus slope, 10 — alluvial talus cone, 11 — rock slide/rock-fall slope, 12 — rocky gorge, 13 — chute cut in solid rock, 14 — debris flow gullies and levees and tongues, 15 — permanent stream, 16 — roche mutonée, 17 — moraine cover with distinct ridge, 18 — sediment supply to lake, 19 — location of sediment core

Ryc. 3. Szczegółowa mapa geomorfologiczna otoczenia Zielonego Stawu Gąsienicowego. 1 — ściany i stoki skalne, 2 — stoki gruzowe, 3 — stoki Richterowskie utrwalone roślinnością, 4 — stoki okryte blokami, 5 — załomy wypukłe na ścianach lub stokach skalnych, 6 — załomy wypukłe zaokrąglone, 7 — stoki gruzowe grawitacyjne, 8 — stożki gruzowe grawitacyjne, 9 — stoki gruzowe modelowane przez spływy, 10 — stożki gruzowe modelowane przez spływy, 11 — stoki grawitacyjne obrywowe, 12 — gardziel skalna, 13 — żleb skalny, 14 — rynny spływów gruzowych, wały i jęzory, 15 — stały odpływ, 16 — wygłady lodowcowe, 17 — pokrywy morenowe z wyraźnymi wałami, 18 — miejsca dostawy osadów do jeziora, 19 — lokalizacje pobranych rdzeni

flow activity should be visible within the lake sediments as turbidity current layers of sandy or silty material, depending on the distance from the slopes and magnitude of the debris flows.

In a previous work by Jonasson (1988), similar sedimentological conditions were found in a Norwegian lake on the Andoya island in northern Norway. The similarities between this lake and the two investigated lakes in the Polish Tatra Mountains are more than one;

— there are no present-day glaciers bringing sediments to the lakes,

— the uppermost layer contains gyttja with distinctive layers of minerogenic material,

— active debris flow slopes are in close connection to the lakes,

— the lakes are all situated close to the water divide and have small drainage areas.

METHODS

The sediment cores were collected by using a gravity corer developed at the Institute of Physical Geography of Uppsala University (Axelsson 1979; Axelsson and Håkansson 1972, 1978). The equipment consists of rectangular, exchangable coring tubes, which are screwed into a corer head, fitted with a valve system. Lead weights, 5—20 kg, are added to a movable brass frame mounted on the coring tube. In this study 10 kg lead weights were used that caused sediment penetration down to about 30—40 cm depth. The total diameter of the equipments is less than 17 cm, which makes it easy to take samples from lake ice by using a standard 20 cm ice-driller (Axelsson and Håkansson 1972).

The valve system allows the water to flow through the corer while the coring tube penetrates the sediment. This technique will diminuish the disturbances, caused by sampling, of the water rich uppermost sediment. As the corer is lifted after sampling, the valve system will immediately close and create a vacuum which prevents the sediment core from sliding out of the coring tube. After sampling, the sediment core is brought to the laboratory in an upright position in order to avoid disturbance of the sediment structures.

The rectangular coring tubes, 34 mm×64 mm, are made of 4 mm acrylic glass and are specially designed for X-ray radiography scanning of the cores. The dimension of the coring tubes are found to be a good compromise between the need for a relatively large cross section to wall thickness ratio in order to avoid deformation and compaction of the sediment during coring and the desire for a relatively thin coring tube for core scanning by X-radiography (Axelsson and Håkansson 1978).

X-ray radiography of the sediment cores is utilized to reveal the vertical bulk density variation and the structures of the sediment layers. It is a fast, non-destructive scanning and recording technique. The information about sedimentary structures provided by X-ray radiographs is obtained before the sediment core is taken out from the coring tube. The technique is, therefore, especially valuable when studying the uppermost, often very soft part of a deposits (Axelsson 1983; Axelsson and Händel 1972).

The absorption of the X-rays is dependent upon the wavelength of the radiation, the density and thickness of the sediment and the atomic number of the absorbing material. Different material within the sediment core will cause variable darkening of the X-ray film. Structure variations less than 1 mm will be visible on the X-ray film. Thin layers containing material of high density will be easily detected. These kind of structures are generally not revealed by other method of analysis. All sediment cores were investigated twice, therefore, curves demonstrated on Figs. 5—8 are double drawn.

Layers recognized within sediment cores on the X-ray films were investigated in term of loss of ignition (450° C) and grain-size composition. Wet sieve analysis was used for determination grain size of particles 0.125 mm and 0.063 mm. Percentage of grains coarser than 0.125 mm: fine sand and medium sand, as well as silt and clay content was calculated. Silt and clay content was determined by using a Sedigraph Particle Size Analyzer. Sedimentation rates of particles in suspension were automatically presented as a cumulative mass percent distribution.

SEDIMENT CORES FROM CZARNY STAW GĄSIENICOWY

Core A, 44 cm thick was located at the depth of 46.16 m and at a distance of 200 m from a small inlet — mountain stream draining the uppermost part of the valley which has an area of about 2 km^2. Core B, 32 cm thick taken from the depth 47.75 m was located 350 m from the inlet, while core C, 33 cm thick was taken from the depth of 38.72 m and 550 m from the inlet and 150 m from the rocky threshold limiting the lake from the north. Bulk density of the sediments is similar for the cores: A — 1.15 g/cm^3, B — 1.23 g/cm^3 and C — 1.15 g/cm^3. In core A, 12 layers were distinguished (A $_{1-12}$) (Fig. 5), respectively in the next cores 15 layers (B $_{1-15}$) and 13 (C $_{1-13}$) (Fig. 6 and 7).

As indicated by the environmental characteristics of the lake there are no sedimentological differentiation in terms of a proximal — distal system. This shows that the small stream has a very limited influence on the sedimentation. This stream has formed only small alluvial cone, 5 m long, built up by gravels and very coarse sand. The basin morphology is rather simple; a longitudinal trough is flanked by steep (30°) lateral slopes (Fig. 4). Bathymetry does not reveal any delta type features. Analysis of the bathymetry of the lake and inspection of the cores revealed transversal sediment supply to the lake from alpine cliffs, rocky slopes and talus slopes, especially from the Kościelec Mt. 2155 m. The sediment supply from the opposite slope is limited by moraine ridges (Fig. 2). Se-

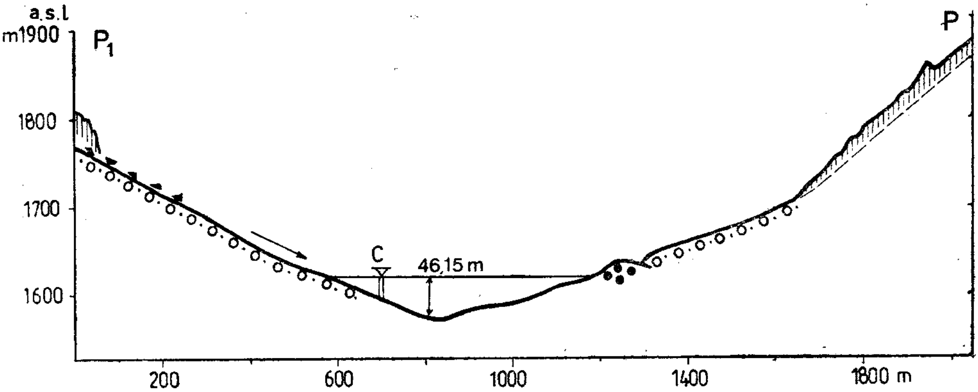

Fig. 4. Cross profile of Czarny Staw Gąsienicowy showing sampling site C
Ryc. 4. Przekrój przez Czarny Staw Gąsienicowy z lokalizacją rdzenia C

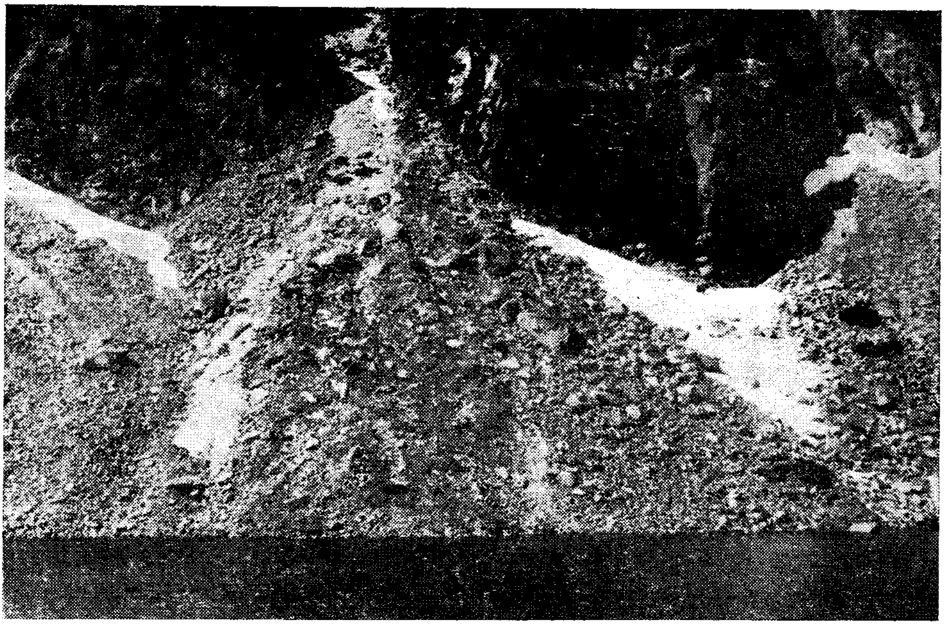

Photo 1. Talus cone below Kościelec Mt. affected by debris flows, supplying Czarny Staw Gąsienicowy with sediments (photo by M. Kot 9 VI 1986)

Fot. 1. Stoki gruzowe poniżej Kościelca, modelowane przez spływy gruzowe dostarczające osadów do Czarnego Stawu Gąsienicowego

diment supply to the lake basin is closely related to debris flow activity (see Fig. 2 and Photo 1). This is well visible in the core C, located at front of the talus cone just below the Karb Pass (1852 m a.s.l.) within the crystalline bedrock strongly shattered and enriched with mylonites. Core C was taken 125 m from the shore formed by talus cone and in-

Photo 2. Talus cone near Zielony Staw Gąsienicowy. Debris flow trucks were generated during the Little Ice Age (photo by M. Kot)

Fot. 2. Stoki gruzowe blisko Zielonego Stawu Gąsienicowego. Rynny spływów gruzowych powstałe w czasie Małej Epoki Lodowej

tensively modelled by slope processes. Core B represents sedimentological conditions typical for the central, deepest point of the trough. Core A represents similar conditions, but in this part of the lake, the sedimentation was disturbed by falling stones or local mass movements (layers 18—22 cm below the bottom). The event recorded in the sediment structure destroyed the upper layers in the core A. Non-laminated unstructural sandy silt material (0—14 cm) filled small "hollow" within the sediment. The lower portion of the filled hollow contain only 20——25% of silt and 75—80% sand (up to 40% sand, of the diameter coarser than 0.125 mm). This suggests gravitational sorting of the material.

CORE B

This core taken from central part of the lake, 150 m from the shoreline is characterized by alternating sandy silt and silty sand layers. The sandy layers are 0.8—2.5 cm thick and contain 75—85% of sandy fraction; where 35—63% is coarser than 0.125 mm (Fig. 6). Within these sandy layers the amount of organic matter is very small; 3.5—6%, while within sandy silt layers organic matter is higher, up to 13—16%.

Within core B one can distinguish the upper section 0—10.5 cm thick built of fine sand (20—30%) and containing 11.5—13% of organic matter. Below this section two layers of alternating sandy and silty layers are evident. Layers of fine or medium sand are well recognized on the densitometric curve. Distinct layers of up to 3 cm thick contain 60—65% of silt and clay and 13—16% of organic matter. Within more organic layers quartz grains are visible (B_3, B_6, B_8). Within the layers where fine and medium sand dominate one can distinguish horizontal structures, underlined by dark discontinuous interlayers containing higher amounts of organic matter. Some inorganic layers are rich in silt (B_{13}, B_4). Within the lower section of the core B, 9.5—32 cm one can easily recognize five sandy "events" (B_5, B_7, B_9, B_{12}, B_{15}) and one silty "event" (B_{13}) (Fig. 6). Mineral layers 1—4 cm thick containing thin organic laminae should be interpreted as layers recording periods characterized by frequent extreme events on the slopes surrounding the lake, while the layers rich in organic matter (B_6, B_8, B_{12}, B_{14}) seem to be compatible with quiet periods, without extreme events. Within core B there are no distinguish varve-like pairs.

CORE C

Within core C, numerous distinct layers can be observed on the X-ray film (Fig. 7). There are sandy layers C_9, C_{12a}, C_{12b} and silty layer C_{11} containing less than 5% of organic matter and different but low bulk density layers C_3, C_5, C_7, C_{10} and C_{13} with organic matter 7—11% containing coarser particles.

The organic matter content of the upper most 8 cm is 11—16%. This section contains 75—88% of silt and clay. Such high content of very fine particles is interpreted as a rather quiet sedimentological environment.

Various sedimentological conditions recorded in the core are represented by turbidity current deposits. This suggestion is additionally confirmed by large amounts of small, mainly 1—2 mm particles, sometimes up to 2 cm in diameter. These particles are interpreted as drop stones. Such layers as C_1, C_3, C_5, C_7, C_{10}, C_{13} contain angular debris related to more active debris slopes, could be interpreted as ungraded, chaotic structures. Fresh mica particles confirm our conclusion that the main source area for the deposition in this part of the lake is the lithologically weak zone of the Karb Pass, and the alluvial talus cone below.

CORE A

The lower undisturbed section of the core (29—44 cm) is similar to core B in terms of sandy and silty material content. The X-ray radiograph show existence of sandy layers up to 1 cm thick, with low content of organic matter (4%). Within silty sand layers, organic matter content is higher (13—20%).

In the middle section (18—29 cm) there is a disturbance, that has destroyed some layers. The vertical features are filled with sand.

The upper, structureless section contains 50—60% of silty and clayey material. Organic contant is 15—24%. When comparing grain-size distribution in the upper structureless section and lower filling of the "hollow", it is easy to observe that gravitation sorting has taken place. In the lower part of the filling 80% is sandy fraction, while the upper part only contains 47%. Core A presents the result of one big "event" which destroyed some layers.

A comparison of the sediments in core B and C shows the differences in the sedimentological environments of the deepest portion of the trough (48 m) and in the trough at a depth of 33 m in the zone of lake shallowing at the front of alluvial talus cone below the Karb Pass. These differences could also be connected with different kind of material supplied to the lake. The talus cone in the centre of the western shoreline supply another fraction than the more weathered, but frequently active alluvial talus, below the Karb Pass.

In both cores we have distinguished an upper section indicating a quiet, younger sedimentation, and a lower one, recording extreme "catastrophic" events or periods on surrounding slopes.

It is an interesting finding, that during periods of quiet sedimentation, characterized by high content of organic matter, one generally observes deposition of coarser material in the central part of the lake (in core B — 35—45% of the material was coarser than 0.063 mm) in comparison with quiet sedimentation below the Karb Pass (22—32% of the material coarser than 0.063 mm). This regularity is also visible in the uppermost section of the cores. An explanation of this phenomena is as follows; the central part of the lake is supplied with sediments from debris flow generated on talus slope located below Kościelec Mt., built of coarser material, while the alluvial talus cone below the Karb Pass contain finer debris conditioned by local lithology. It is also interesting, that in core C (125 m from the shore line), where we observe generally finer material in comparison with core B (150 m from shore line), numerous layers of angular particles, up to 1—2 cm, are to be seen in ungraded layers. This could be explained by the influence of smaller distance from the shore line in the case of core C or more active zones with frequent turbidity currents.

SEDIMENT CORE FROM ZIELONY STAW GĄSIENICOWY

The core was taken from the central, deepest (13.7 m) part of the lake basin. In the core (D), 37.5 cm thick, 11 layers were distinguished (D_{1-11}). Silt and clay particles dominate (80—95%). Fine sand content is up to 23%, while medium sand content is less than 3% (Fig. 8). Bulk density is 1.14 g/cm^3. When comparing grain size composition and organic matter content in the core, one can distinguish three sections related to the different supply condition to the lake. The upper section (0—9 cm) contains up to 3% of sand and relatively high amounts of organic matter (16—18%). The middle section (9—23 cm) contains up to 20% of fine sand and only 7—10% of organic matter. In the lower section fine sand content is 18—22%, and mineral matter content reach 20%. Densitometric analyse of X-ray films shows in the middle section 8 mineral layers seperated by dark organic layers. In the lower section between 23 and 37.5 cm, it is possible to distinguish only 2 more mineral layers, containing up to 15% of organic matter. Sandy layers are 0.5—1 cm thick and free of coarse sand. This fact suggests that during periods of sandy layer deposition the same source of sediment supply to the lake existed and the amount of material supplied to the lake was changed in time only.

Aeolian material deposited at present close to the lake and investigated by Izmaiłow (1984) was compared with grain-size composition of lacustrine sediments. This comparison shows that aeolian material is not an important component of sedimentation in the lake. According to Izmaiłow's measurements, sand and gravel was deposited by aeolian processes. Silt material is probably transported for a longer distance.

It should be an accepted view point, that sediment supply to the lake shows the effect of high-energy, slope processes, especially debris flows and slope wash. Sediments represent lake deposition in the central, deepest point, which is separated from the basin platform at the depth of 5—7.5 m from the western side, and 10—12.5 m from the eastern side. Mineral layers contain horizontal or sub-horizontal, very thin lamina, well visible on radiographic images. Thickness of mineral layers is different according to the rate of sedimentological processes. Content of medium and fine sand in mineral layers is similar as in more organic layers of the lower core section. This fact can be explained by bottom dynamics; the central deepest point of the lake was reached only by finest material, both during periods of quiet sedimentation and during periods of extreme events on the surrounding slopes. Very distinct mineral layers (silty, clayey deposits) are interpretated as underflow turbidity currents, reaching the central portion of the lake in suspension. There is no visible coarse-grained rapidly accumulated material. Probably, graded depositional features typical for discontinuous influx of turbidity currents are to be recognized on the flat basin platform. This was confirmed by the analysis of a sediment core taken from the lake in 1989.

The sediment core taken from Zielony Staw Gąsienicowy was dated in Radiocarbon Laboratory in Gliwice, Poland. The age of the lowermost layer, 34—37 cm below the actual lake bottom is 1760 ± 150 years BP (Gd—4407). It means that mean rate of deposition is of the order of 0.2 mm per year. The same rate was established by Wicik (1984) for Zielony Staw Gąsienicowy and for Przedni Staw in the valley of Five Polish Lakes, for the whole Holocene, i.e. from the Youngest Dryas up to the present. This value is at about 10 times greater than the value of present-day aeolian deposition calculated by Izmaiłow (1984) for the nearest surrounding of Zielony Staw (13—45 g/m^2 or 0.01—0.04 mm per year). These values suggest that the aeolian supply of mineral matter to the lake is not important in terms of a total sediment supply to the lake. The main source of minerogenic sediment supply to the lake is connected with debris flow activity, melt water transport and dirty avalanches. Even if snow avalanches never reach the centre of the lake, one can observe redistribution of dirty avalanche material over the whole lake on ice pieces drifting on the water during spring, and supplying lake basin with drop stones (layers D_{10} and D_5). Sediment sypply to the lake by fluvial transport by mountain streams is of less importance (Fig. 3).

The middle section of the sediment core is correlated with intensive debris flow activity on the surrounding slopes during the final stage of the Little Ice Age. These slopes were very much changed by debris flow tracks (distinct troughs, levees and tongues) dated by lichenometry for the first half of the nineteenth century. These debris flow features were much bigger than present day features in terms of size, volume and extent (Kotarba 1989). In this context, calculated rate of sedimentation in central part of the lake (0.2 mm per year) have more statistical than real physical sense. Turbidity currents connected with the Little Ice Age produced sediment layers much faster than the above value suggest.

CONCLUSIONS

In the paper we have concentrated our description on the youngest, up to 45 cm thick, upper Holocene deposits from two lakes situated above timberline in the Polish Tatra Mountains. This high-mountain environment, free of glaciers, have no sedimentological evidence to distinguish between the proximal and distal parts of sedimentation, in terms of classical terminology of lake environments. Present-day permanent streams entering the lakes are free of suspended matter. Sediment supply to the lakes is controlled by active debris slopes which are in connection with the lakes. A significant component of the sedimentary record in the high alpine lakes is related to episodical extreme events on slopes, first of all, debris flow activity. Aeolian supply is of secondary importance.

Czarny Staw Gąsienicowy and Zielony Staw Gąsienicowy are supplied with sediments mainly by melt water and debris flows generated on talus slopes. Both sediment supply and sediment dynamics in the two investigated lakes are different. Czarny Staw Gąsienicowy is supplied with sediments directly from talus cones. The rate of sediment yield in the past and at present is greater than in Zielony Staw Gąsienicowy, where surrounding slopes are partly isolated from the lake by a moraine ridge. Also, the shape of the lake basin in Zielony Staw, makes favourable conditions for sediment diversity. The central, deeper part of the lake is supplied with silty material only, while coarser material is trapped on the platform. The steep, underwater slope (30°) below Kościelec Mt. in Czarny Staw makes it possible to displace different materials into the trough. Typical varve-like sediments are not found in the cores.

Grain size changes in the cores are interpreted as sedimentation variations during quiet periods, separated by periods with extreme events. Sediment deposited during quiet periods are rich in organic matter (13—20%), while sandy layers, sandy-silty and silty layers only contain 1—5% of organic matter. In some sections of the sediment cores, turbidity currents are documented. In the case of active supply from the cone built of finer material, the chaotic ungraded sediments with coarse particles on the distance of about 125 m from the shoreline were observed (core C). This concerns also the layers with relative high organic content up to 16%. In the case of supply from a talus cone built of coarse material, the turbidity currents can transport mainly fine sand and silt material at a distance of about 150 m (core B). The peaks on densitometric curve are interpreted as periods with numerous extreme events. Some peaks are relatively broad or consist of several smaller culminations.

All sediment cores are characterized by an upper section 8—10 cm thick, representing the quiet, youngest sedimentation period and a lower section characterized by differentiated sedimentation caused by relatively higher intensity processes. In Zielony Staw, 8 such layers (core D) were found, in Czarny Staw, 7 layers (core B), and respectively 10 layers in the core C. In Zielony Staw, the third lowest section was found, where the quiet sedimentation period was marked. In this section only two distinct sandy events were observed.

Radiocarbon dating in the lowermost position of core D makes it possible to conclude that these two events mentioned above happened before 1760 years BP. Lichenometric studies on talus slope above Zielony Staw (Kotarba 1989) make it possible to correlate the middle section of core D with the Little Ice Age. Therefore, we can conclude that sediments located 10 cm below the bottom of Czarny Staw are also related to the Little Ice Age. At that time substantial debris flow activity was recorded on the slopes.

The mean rate of deposition in Zielony Staw (0.2 mm per year) gives only a general idea about sedimentation rate. Real values were changing in time, and even one big event on a slope was able to produce a 2 cm thick layer (sedimentological unit) in the lake.

First results of research in these dimictic and oligotrophic lakes in the Tatra Mountains lead to the conclusion that the most significant component of sedimentation is debris flow activity on slopes.

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STRESZCZENIE

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Badania młodych osadów jeziornych w Tatrach Wysokich

Celem artykułu jest przedstawienie zróżnicowania sedymentacji młodych osadów jeziornych w świetle analizy materiału z 4 płytkich rdzeni, do 45 cm długości. Rdzenie pochodzą z dwóch poglacjalnych jezior położonych ponad górną granicą lasu (Ryc. 1). Misa Zielonego Stawu Gąsienicowego posiada centralną głębię do 15 m i rozległą platformę o głębokości 8—10 m (Ryc. 2). Rdzeń pobrano z misy centralnej. Misę Czarnego Stawu Gąsienicowego stanowi podłużna, głęboka do 50 m, rynna glacjalna (Ryc. 3), w której profilu podłużnym pobrano 3 rdzenie. Oba jeziora zasilane są głównie wskutek procesów stokowych, w szczególności przez spływy gruzowe na stożkach i spłukiwanie w czasie roztopów. Zarówno warunki dostawy, jak i osadzania się w obu jeziorach są różne. Czarny Staw zasilany jest bezpośrednio ze stożków i wielkość tego zasilania w przeszłości i współcześnie jest zdecydowanie większa niż dostawa do Zielonego Stawu ze stoków bardziej oddalonych i częściowo odciętych wałem morenowym. Konfiguracja misy jeziornej Zielonego Stawu powoduje, że centralną głębszą część osiągają tylko utwory pylaste, a grubsze zatrzymują się przypuszczalnie na platformie. Stromy stok podwodny (30°) Kościelca w Czarnym Stawie ułatwia transport i przenoszenie materiału w strefę dna rynny.

Charakterystyczny jest brak typowych warw, a zmienność granulometryczna osadów odzwierciedla okresy spokojniejsze od okresów ze zdarzeniami katastrofal-

nymi. W osadach składanych w okresach „spokoju" większy udział mają części organiczne (13—20%), podczas gdy warstwy piaszczyste i piaszczysto-pylaste i pylaste mały (1—5%). Przypuszczalnie większość zdarzeń odnotowana w osadach jest związana z głębokimi spływami gęstościowymi osadów (turbidity current underflow). Warstwy mineralne są rezultatem albo pojedynczego zdarzenia i wtedy występuje grawitacyjne rozwarstwienie osadu, albo okresu z większą częstotliwością spływów gruzowych na stokach, co zdają się potwierdzać subhoryzontalne smugi organiczne, rozdzielające osady mineralne. Datowany C14 spąg rdzenia D z Zielonego Stawu na 1760±180 (Gd-4407) pozwala obliczyć średnie tempo sedymentacji za ten okres na 0,2 mm/rok. Jest to wartość średnia, a wiadomo, że pojedyncze zdarzenia mogły osadzać warstwy do miąższości 2 i więcej centymetrów.

We wszystkich rdzeniach (Ryc. 4—7) można wyróżnić 2—3 człony. Górny o miąższości 8—10 cm reprezentuje spokojną, najmłodszą sedymentację. Niżej leżący człon rejestruje zróżnicowaną sedymentację, świadczącą o większej intensywności procesów na stokach i w jeziorze. W tym członie występuje 7—10 warstw bardziej mineralnych (maksyma na krzywej densytometrycznej). Tylko w Zielonym Stawie można wyróżnić trzeci człon wcześniejszej spokojnej sedymentacji. Przypuszczać należy, że osady poniżej 10 cm można odnieść do Małej Epoki Lodowej, która zaznaczyła się wzmożoną aluwiacją na stokach, udokumentowaną dzięki badaniom lichenometrycznym na stożkach gruzowych (Kotarba 1989).

РЕЗЮМЕ

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ИССЛЕДОВАНИЯ МЕЛКИХ ОЗЕРНЫХ ОТЛОЖЕНИЙ В ВЫСОКИХ ТАТРАХ

Цель настоящей статьи — представить дифференциацию в седиментации молодых озерных отложений в свете анализа материала из 4 мелких кернов до 45 см мощности. Керны взяты из двух постгляциальных озер, расположенных выше верхней границы леса (Рис. 1). Чаша Зеленого Гонсеницового Пруда достигает в своей центральной части глубину до 15 м, а обширная платформа — 8—10 м (Рис. 2). Керн был взятый из центральной чаши. Чаша Черного Гонсеницового Пруда — это продолговатый, глубокий на 50 м гляциальный желоб (Рис. 3), из продольного профиля которого были взяты 3 керны. Оба озера питаются, как правило, в результате склоновых процессов, в частности — грязекаменных потоков на конусах и смыва во время таяния снегов. И условия доставки и условия осаждения в обоих озерах различны. Черный Пруд питается непосредственно с конусов; размеры этого питания — как в прошлом, так и в настоящее время, намного больше питания Зеленого Пруда со склонов, более отдаленных и частично отделенных моренным валом. Конфигурация озерной чаши Зеленого Пруда приводит к тому, что центральной, более глубокой части достигают только пылеобразные образования, более же крупные задерживаются, по-видимому, на платформе. Крутой подводный склон (30°) Косьцельца в Черном пруду облечает транспортировку и перенос материала в зону дна желоба.

Характерно отсутствие типичных ленточных глин, а гранулометрическое разнообразие наносов отражает более спокойные и отличающиеся катастрофическими событиями периоды. В наносах, откладывавшихся в „спокойные" периоды, больше доля органических частей (13—20%), в то время как песчаные и песчано-пылевые составляют всего 1—5%. Вероятно, большинство событий, отмеченных в отложениях, связано с глубокими густотными стоками наносов (turbidity current underflow). Минеральные слои — это результат либо единичного события, что сопровождается гравитационным расслоением отложения, либо же — чаще — периода более многочисленных грязекаменных потоков со склонов, что подтверждается, по-видимому, субгоризонтальными органическими полосками, разделяющими друг от друга минеральные наносы. Датированная по методу С-14 подошва керна Д из Зеленого Пруда 1760±180 (Гд-4407) дает возможность высчитать средние темпы седиментации в данный период — 0,2 мм/год. Это средняя величина, но ведь известно, что в ходе отдельных событий могли откладываться слои мощностью 2 и более сантиметров

Во всех кернах (Рис. 4—7) можно выделить 2—3 составных члена. Верхний, мощностью 8—10 см, представляет спокойную самую младшую седиментацию. Расположенный ниже член отмечает собой дифференцированную седиментацию, свидетельствующую о большей интенсивности склоновых процессов и в озере. В данном члене имеется 7—10 слоев более минеральных (максимумы на денситометрической кривой). Только в Зеленом Пруду можно выделить третий член — снова более спокойной седиментации. Следует предполагать, что отложения ниже 10 см можно отнести к Малой ледниковой эпохе, отмеченной усиленной аллювиацией на склонах, что было документировано лихонометрическими исследованиями на щебневых конусах (Котарба 1989).

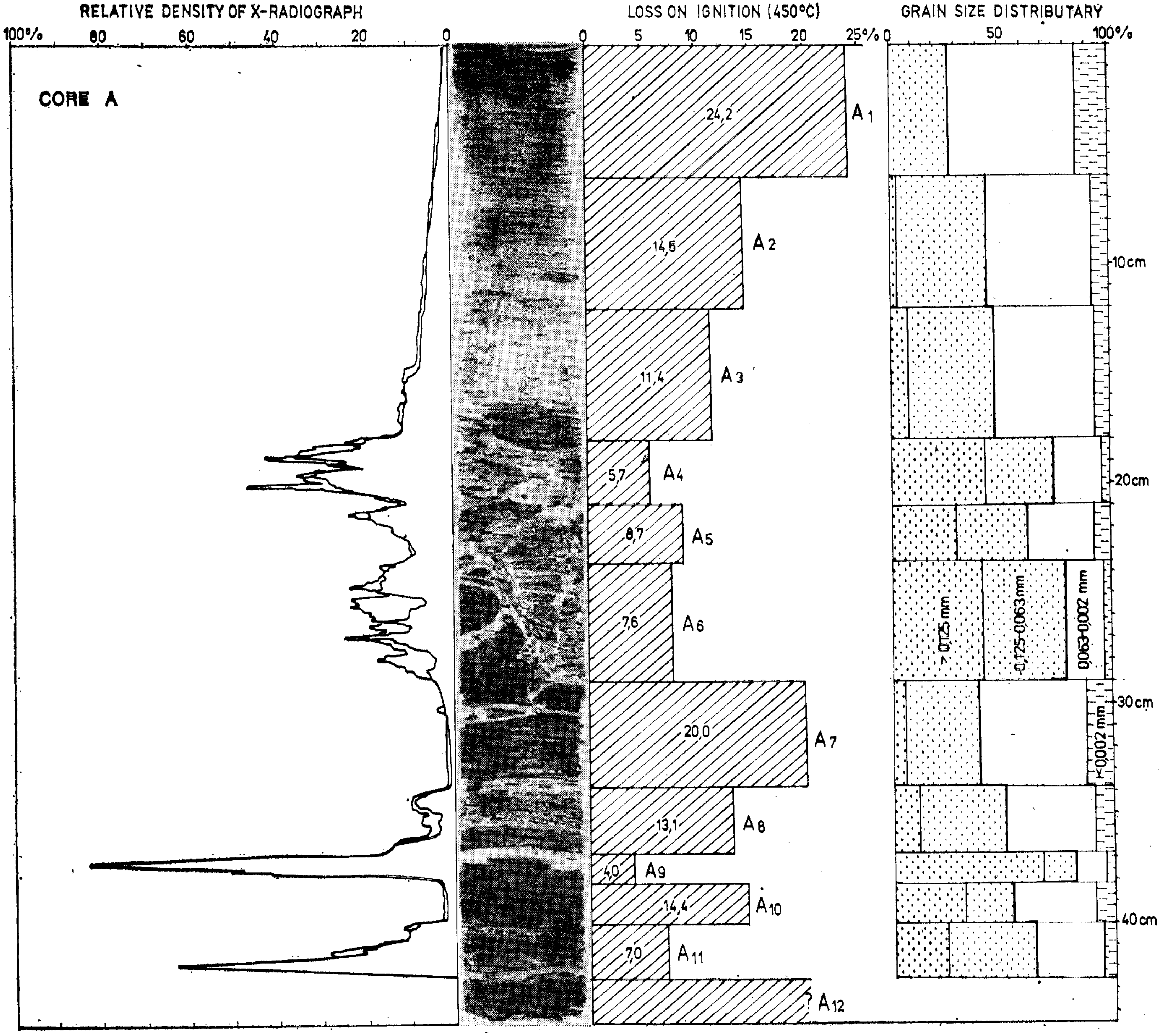

Fig. 5. Sediment core A, Czarny Staw Gąsienicowy. Densitometric curve, loss on ignition and grain-size composition. Sedimentological structures drawn according to X-ray film

Ryc. 5. Rdzeń z wiercenia A, Czarny Staw Gąsienicowy. Krzywa densytometryczna, straty wyprażenia, skład mechaniczny. Struktury sedymentacyjne rysowane według klisz z prześwietleń promieniami X

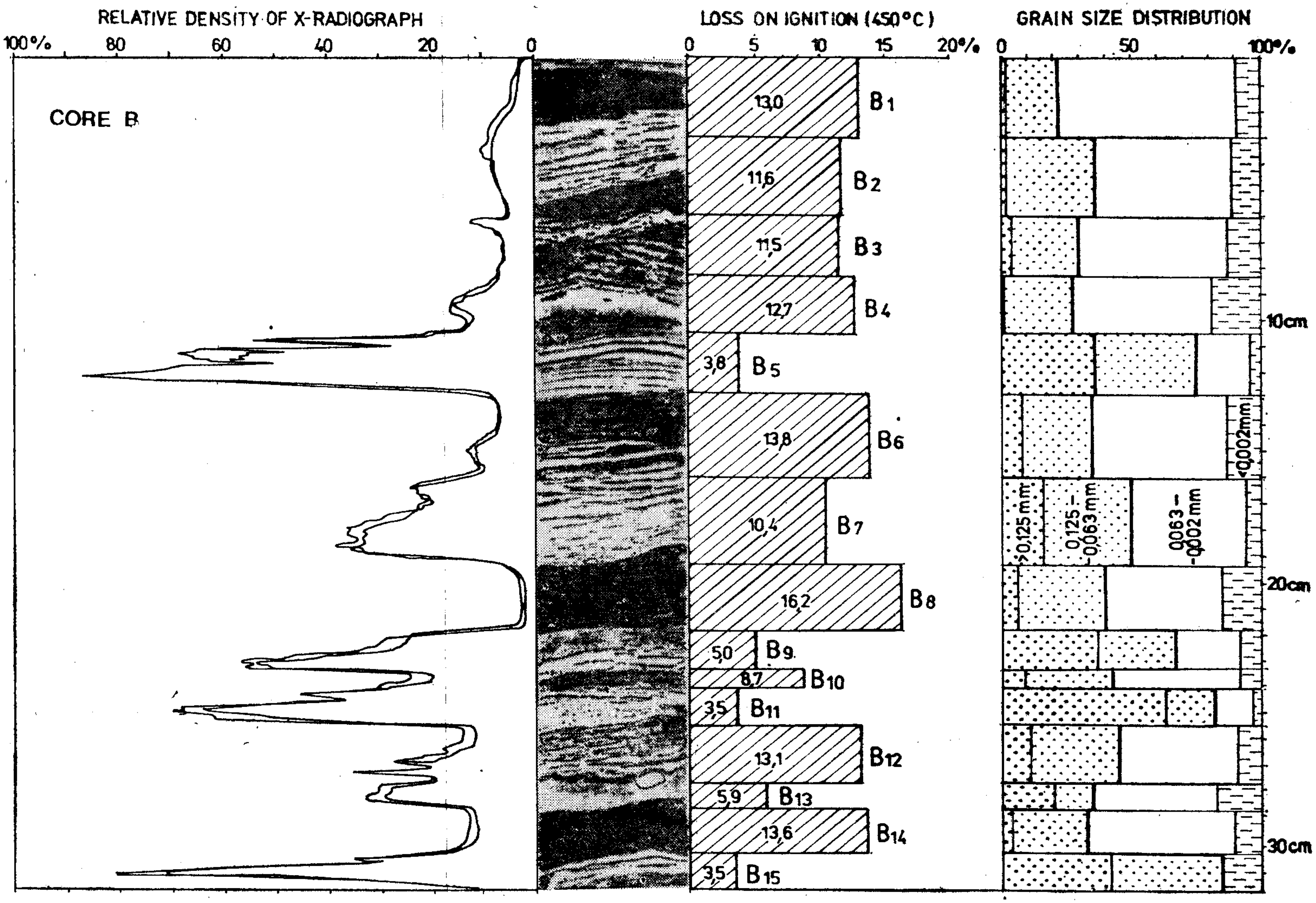

Fig. 6. Sediment core B, Czarny Staw Gąsienicowy

Ryc. 6. Rdzeń z wiercenia B, Czarny Staw Gąsienicowy

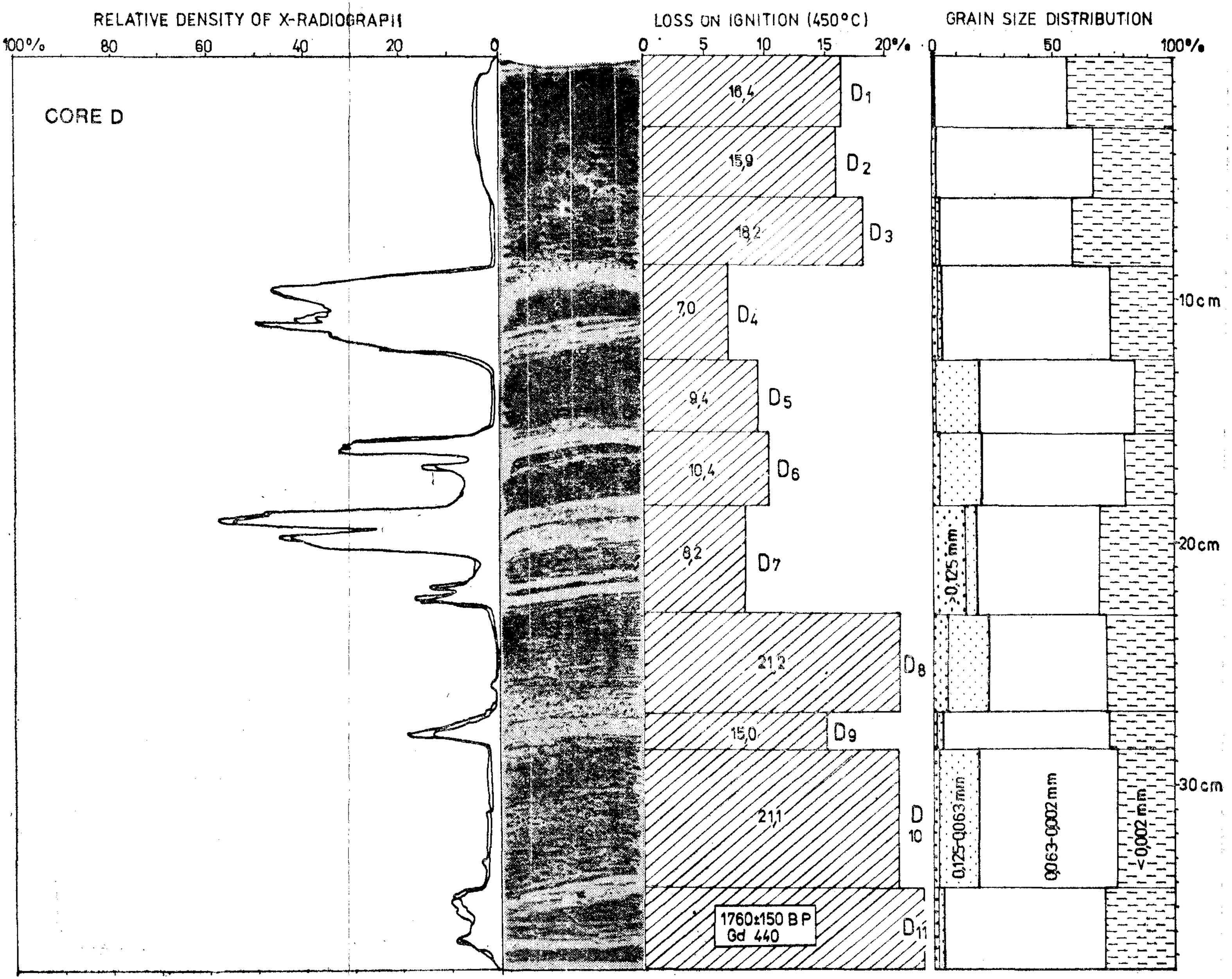

Fig. 8. Sediment core D, Zielony Staw Gąsienicowy

Ryc. 8. Rdzeń z wiercenia D, Zielony Staw Gąsienicowy

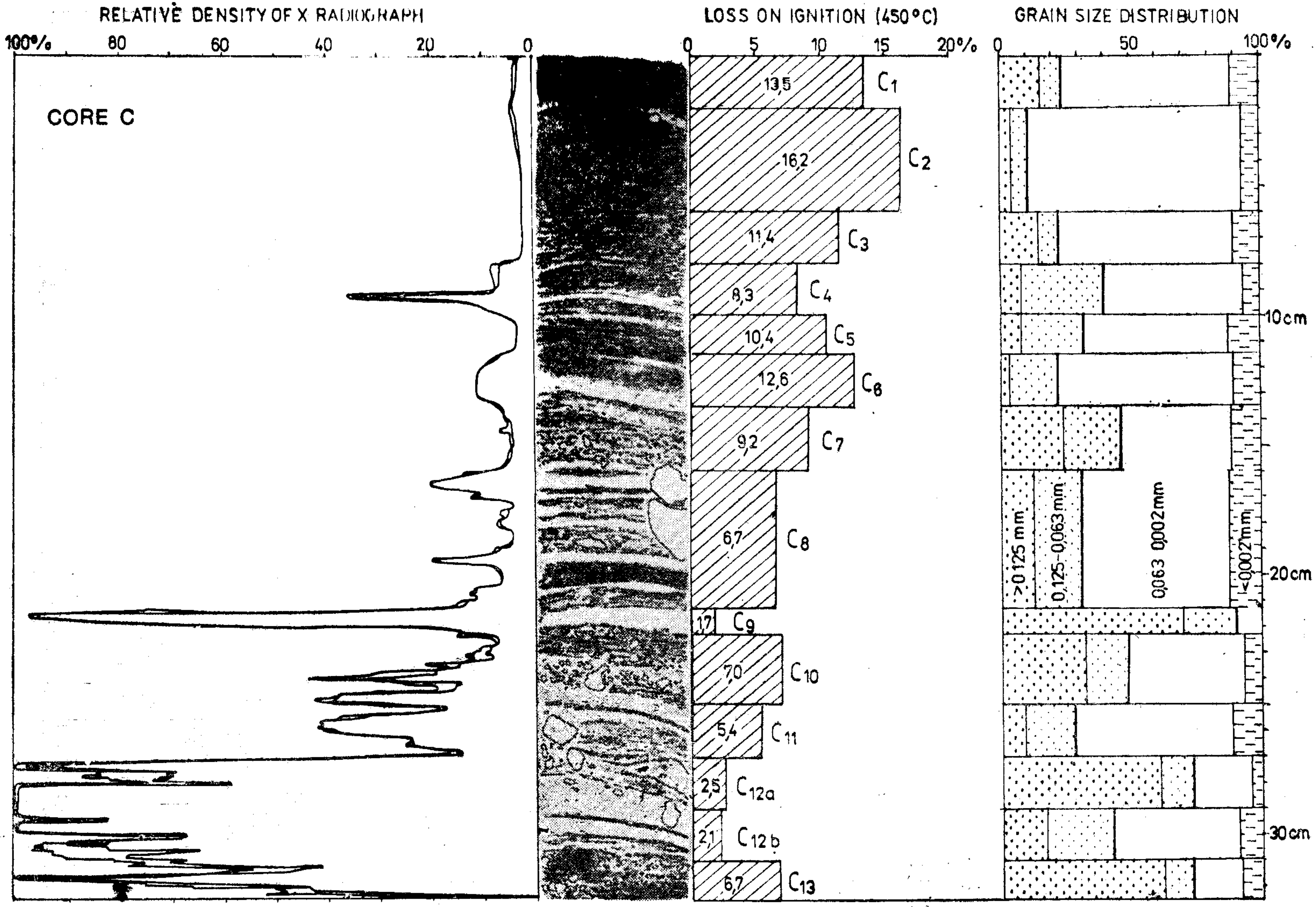

Fig. 7. Sediment core C, Czarny Staw Gąsienicowy

Ryc. 7. Rdzeń z wiercenia C, Czarny Staw Gąsienicowy