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ODRANIAN GLACIOLACUSTRINE SEDIMENTATION IN THE KLESZCZÓW GRABEN, CENTRAL POLAND

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Abstract: The Lower Saalian (Odranian) glaciolacustrine sequence exposed in the Bełchatów outcrop is a narrow (2-4 km), 10-40 m thick deposit bordered by faults of the Kleszczów Graben. The proglacial deposition was controlled by the tectonic evolution of the graben. Varved clays were deposited in deep basins; silty-sandy deposits were formed on the deltaic slopes, near the trough margins. Additionally, gravity-flow sediments, including subaqueous diamictons, were generated on the active fault scarps within the basin. They are interbedded with both deep and shallow water deposits. The diamictons consist of a mixture of older glaciofluvial and glaciolacustrine deposits and reworked tills. A model of proglacial lake sedimentation in the tectonically active basin is proposed.

Abstrakt: W odkrywce Bełchatów położonej na obszarze rowu Kleszczowa znaleziono osady zastoiskowe ze zlodowacenia Odranian. Mają one grubość około 10 - 40 m i zasięg ograniczony uskokami ramowymi rowu. Depozycja osadów zastoiskowych była silnie uzależniona od tektonicznej ewolucji rowu. Iły warwowe były deponowane w mikrobasenach rowu ulegających szybszej subsydencji niż sąsiednie obszary. Na tych ostatnich znaleziono tylko osady płytkowodne (deltowe). Dodatkowo, w basenach o wzmożonej subsydencji obserwuje się liczne warstwy osadów stokowych: glin, piasków masywnych i redeponowanych iłów warwowych. Osady te powstawały najprawdopodobniej na skarpach uskokowych formowanych w głębokich partiach zbiornika. W artykule przedstawiono model sedymentacji zastoiskowej dla strefy aktywnej tektonicznie.

Key words: Glaciolacustrine sedimentation, Saalian, Kleszczów Graben, central Poland

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INTRODUCTION

Central Poland is located in the tectonically unstable area of the Central Polish Anticlinorium, a part of the Young Palaeozoic-Mesozoic Platform (Pożaryski, 1977). Deep and narrow tectonic grabens are features characteristic of this region. During the Middle Pleistocene, they were infilled with glacial and proglacial sediments. An excellent example of the tectonically influenced proglacial sedimentation is found in the Kleszczów Graben (Czerwonka & Krzyszkowski, 1992; Krzyszkowski 1993). The graben is a more than 200 m deep trough which was active from late Palaeogene up to Middle Pleistocene (Krzyszkowski, 1994) (Fig. 1).

In Poland, glacial lakes were often formed during the advances of ice-sheets. This is due to topography that is inclined gently to the north. The lakes usually originated between the advancing glaciers in the north and the uplands to the south (Różycki, 1967) (Fig. 2). The Odranian (Lower Saalian) proglacial basins in central Poland had varying sizes, but usually were shallow, ice-contact lakes or river-lakes. The deep-water facies, i.e. varved clays, have been rarely observed (Baraniecka & Sarnacka, 1971; Karaszewski, 1952; Jurkiewiczowa, 1961; Czarnik, 1966; Ruszczyńska-Szenajch 1966). These lakes were supplied both by glacial streams and periglacial rivers flowing from the south.

The Bełchatów outcrop (Fig. 3) that is located in the Kleszczów Graben exhibits several thick glaciolacustrine series formed from the Elsterian up to the Wartanian (Krzyszkowski & Czerwonka, 1992; Krzyszkowski 1993, 1994). This paper describes a 10 - 40 m thick glaciolacustrine sequence of the Odranian (Lower Saalian, Drenthe) age, which forms a part of the glacial Ławki Formation (Krzyszkowski, 1991, 1994). The paper presents data which show the effect of differential subsidence upon glacial lake sedimentation. These descriptions are important because they document the vertical and lateral lithofacies variation in glacial environment formed in a tectonically active zone.

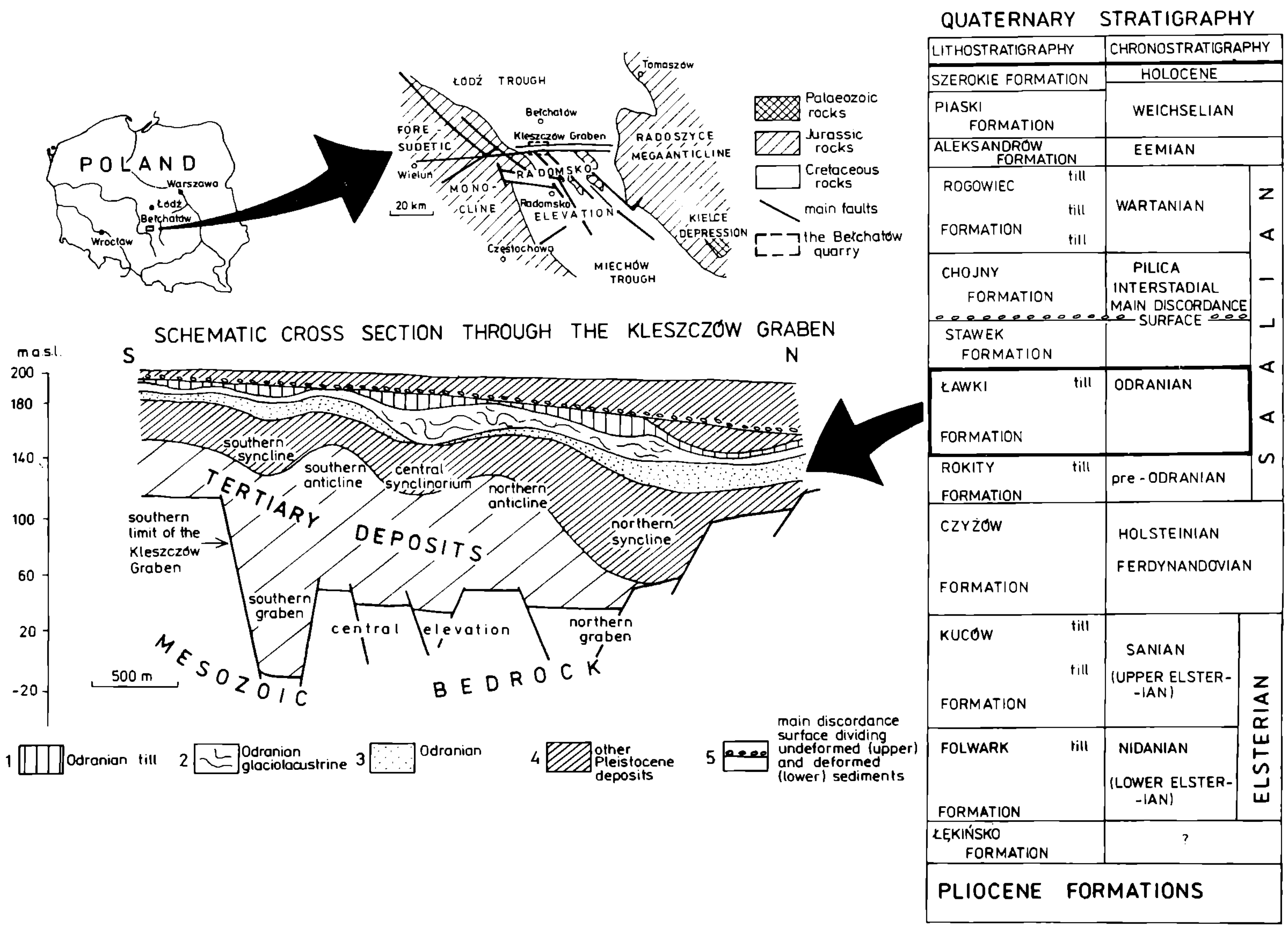


Fig. 1. Location of the Kleszczów Graben and the Bełchatów outcrop in central Poland; schematic cross-section through the Kleszczów Graben (down), and stratigraphy of the Quaternary deposits in the Bełchatów outcrop (right)

Lokalizacja rowu Kleszczowa i odkrywki Bełchatów w Polsce środkowej; z prawej stratygrafia osadów czwartorzędowych w rowie Kleszczowa; na dole schematyczny przekrój przez rów Kleszczowa: *1* – gliny zlodowacenia Odranian; *2* – osady zastoiskowe zlodowacenia Odranian; *3* – osady glacifluwialne zlodowacenia Odranian; *4* – inne osady plejstoceńskie; *5* – główna niezgodność kątowa rozdzielająca osady zdeformowane (dolne) od niezdeformowanych (górne)

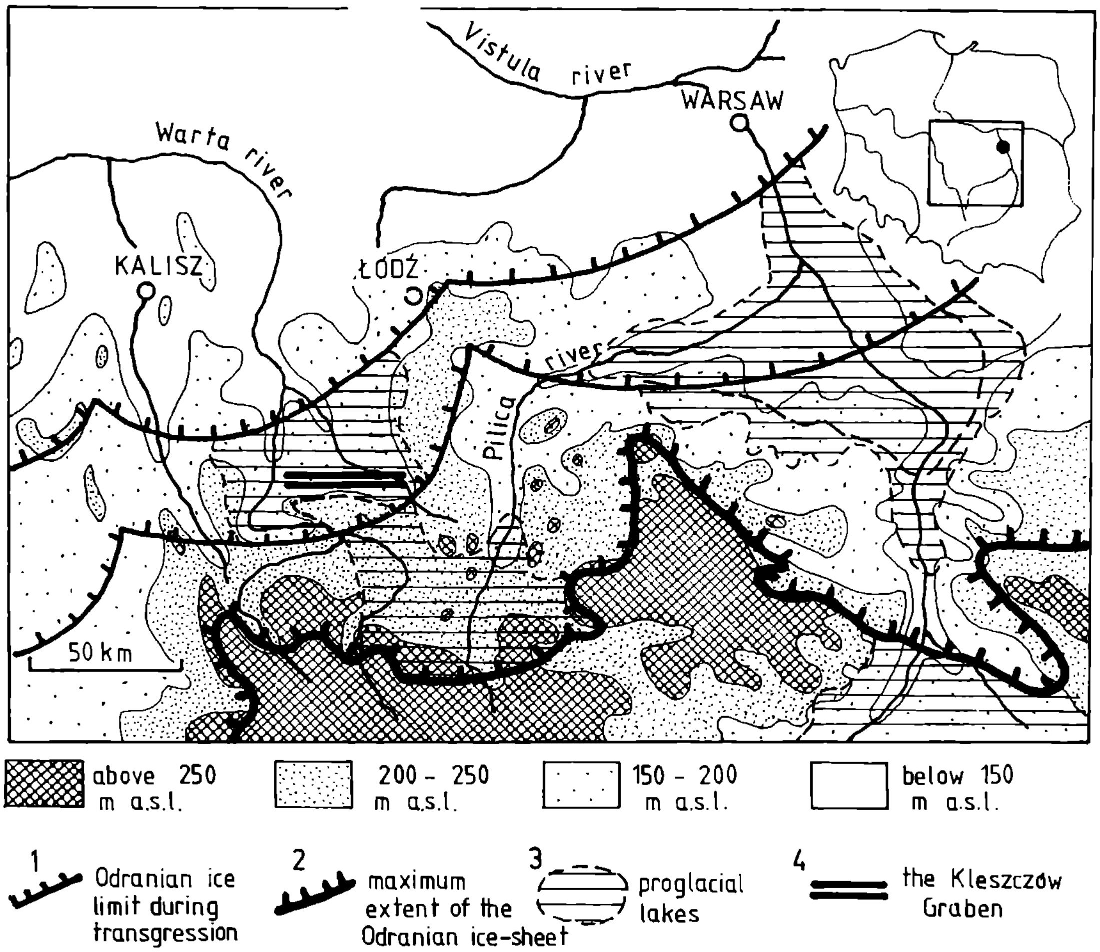


Fig. 2. Large ice-dammed lakes in central Poland formed during advance of the Odranian (Lower Saalian) ice sheet

Wielkie jeziora zastoiskowe w Polsce środkowej formowane w czasie zlodowacenia Odranian: *1* – lądolód zlodowacenia Odranian w czasie transgresji; 2 – lądolód zlodowacenia Odranian w czasie swojego maksymalnego zasięgu; *3* – jeziora zastoiskowe; *4* – rów Kleszczowa

STRATIGRAPHY

The Ławki Formation is a part of the Saalian Complex and was deposited during the Odranian stage (Fig. 1). Its detailed stratigraphic position has been discussed in a separate paper (Krzyszkowski, 1991). The formation contains six lithological units, which represent a glacial transgressive sequence. These are, from bottom to top:

Lower glaciofluvial pebbly sands. This unit comprises 5 - 20 m thick cross-bedded pebbly sands, coarse and medium sands. Trough cross-bedding prevails. Some gravelly beds and thin layers of rippled sands and/or sandy silts and clayey silts have also been observed. The sediments were most probably deposited in the middle part of a proglacial fan (Boothroyd & Ashley, 1975; Boothroyd & Nummedal, 1978).

Lower glaciofluvial sands. This unit comprises 10-15 m thick, mostly horizontally and planar cross-bedded, medium and fine sands. Fine sands with small-scale cross-bedding occur mostly in the upper part. These sediments were most probably deposited in the distal part of the proglacial fan. The unit was deposited in a rapidly aggrading fluvial environment and is succeeded by glaciodeltaic-glaciolacustrine successions.

Main glaciolacustrine deposits. This sedimentary unit will be discussed in detail in the present paper. It is a both laterally and vertically variable succession with a thickness varying from 10 to 40 m. Generally three sub-units can be recognized: lower fine sands with climbing ripples and parallel bedded silts and sandy silts. In the middle there are laminated and massive silts, varved silts and occasionally fine sands; and the uppermost part consists of varved clays with only a minor portion of sandy deposits. Varved clays and laminated silts may interfinger laterally with gravity flow deposits (diamictons, gravels, sands).

Upper glaciolacustrine deposits. This unit overlies varved clays of the middle glaciolacustrine unit and contains 5 - 10 m of mostly massive and laminated silts, rippled fine sands and occasionally rhythmites

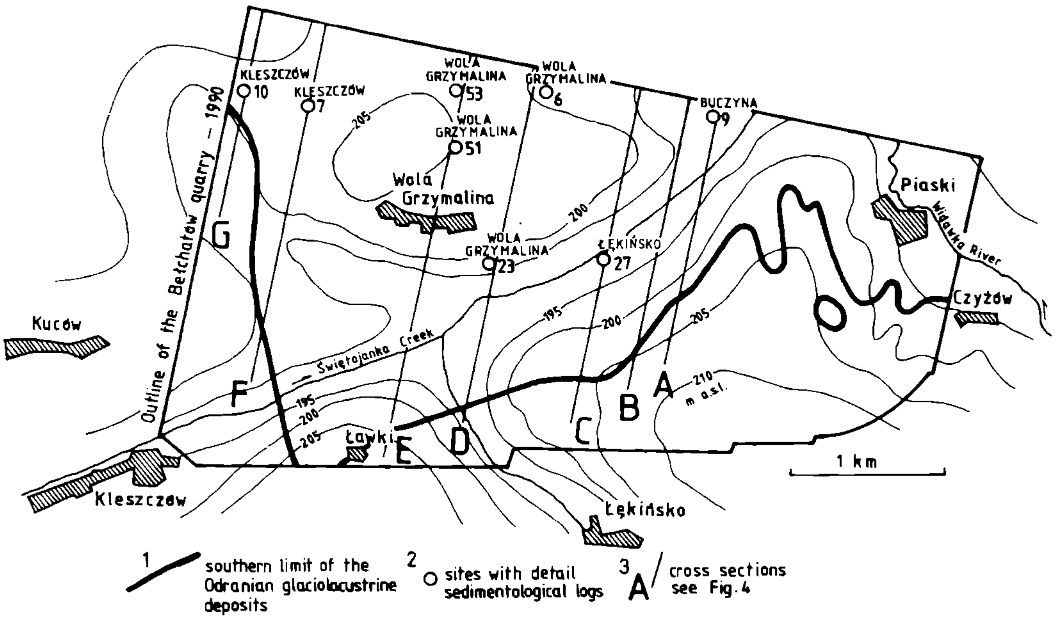


Fig. 3. The Bełchatów outcrop: location of the cross sections (Fig. 4) and sites with the Odranian glaciolacustrine deposits (Ławki Formation)

Odkrywka Bełchatów: lokalizacja przekrojów z fig. 4 oraz badanych stanowisk z osadami zastoiskowymi ze zlodowacenia Odranian (Formacja Ławki)

but no varved clays.

Upper glaciofluvial sands and gravels. This unit is 5 - 10 m thick and consists of trough and planar cross-bedded, medium and coarse sands and a few gravels. The upper glaciofluvial deposits were most probably deposited in the middle or upper part of a proglacial fan. The fan likely formed on the margin of advancing ice-sheet because the sandy deposits are covered by a till.

Ławki till. This is a glacial, muddy diamicton with a large portion of clasts ranging from a few milimetres up to 1 - 2 m. Additionally, some layers and lenses of sorted deposits can be observed. The thickness of the till varies from 2 - 4 m to 15 - 25 m. The till was deposited subglacially, representing most probably the lodgement and in part melt-out facies (Czerwonka & Krzyszkowski, 1990, 1992).

The sediments of the Ławki Formation are tectonically deformed (Krzyszkowski, 1989, 1991). They form anticlinal and synclinal zones with average wavelenght 300 - 600 m and occur above the uplifted or subsided micro-blocks of the Mesozoic basement (Figs. 1 & 4). The uppermost units of the Ławki Formation occur often only in the cores of synclines; they usually do not appear in the anticlinal zones (Fig. 4).

CHARACTERISTICS OF GLACIOLACUSTRINE SEDIMENTS

Lithofacies of the glaciolacustrine sequences of the Bełchatów outcrop, including the Ławki Formation, are described and discussed in detail in the separate paper (Krzyszkowski, 1993). Three groups of sediments have been found within the glaciolacustrine sequence under discussion. These are rhythmites and other fine grained facies, which have been described and interpreted elsewhere in the literature (Ashley, 1975, 1989; Ashley *et al.*, 1985; Sturm, 1979; Krzyszkowski, 1993). These are associated with deposits which also occur in non-glacial environments, and interpreted as sandy facies formed by flowing water in river or deltaic distributory channels (facies St, Sp, Sh, Sr) and by sandy or gravelly gravity flow facies and diamictons (facies Dmm, Dmb, Dcc, Gm, Gg, Sm).

Some facies are important indicating specific nature of the lake basin. Varved clays are composite and have usually very thick summer layer, in extremal cases up to 1 m thick. The summer layer may contain only silt or multiple layers of clayey silt, silt, sand and even gravels and diamictons. This suggests, that composite varved clays formed not only by annual alternation of dispersal processes but also by numerous slumps (Krzyszkowski, 1993). The common occurrence of gravity flow facies confirms this interpretation. Two types of gravity flow facies can be found. One is formed by continuous mixing of former deltaic/lacustrine deposits on the delta slope. It contains gravels (facies Gm, Gg) and sands (facies Sm) from the upper part, massive matrix-supported diamictons formed by mixing of sands and silts (facies Dmm) from the middle part and the Dcc facies from the lower part of the delta. The latter facies is a mixture of silt and clay balls, suggesting re-deposition of only

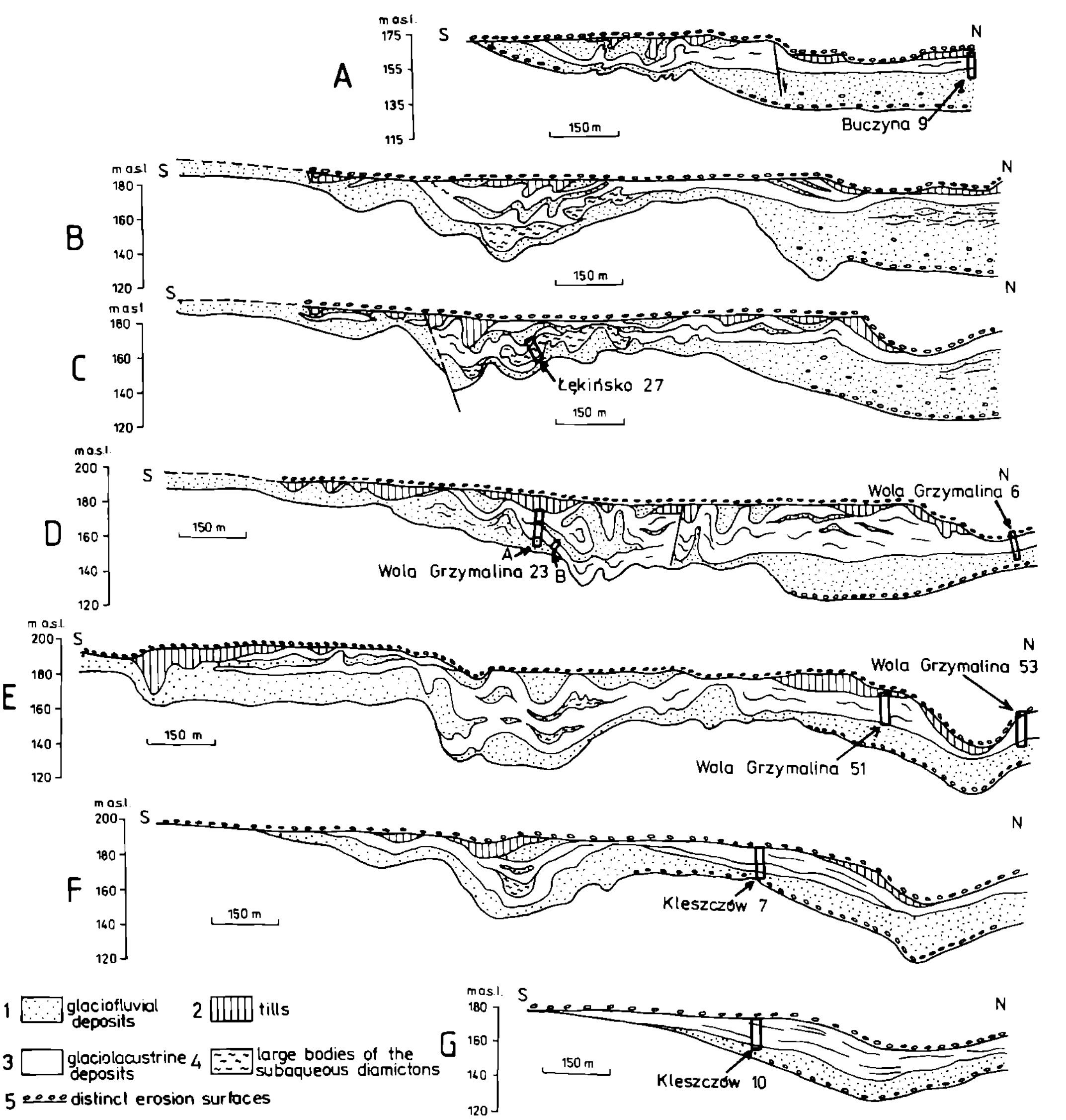


Fig. 4. Geological cross-sections through the Odranian sequences (Ławki Formation) in the Bełchatów outcrop. Location of sections on Fig. 3

Przekroje geologiczne osadów zlodowacenia Odranian (Formacja Ławki) w odkrywce Bełchatów. Lokalizacja na fig. 3. *1* – osady glaciofluwialne; *2* – gliny lowowcowe; *3* – osady zastoiskowe; *4* – grube pokłady glin subakwalnych; *5* – wyraźne powierzchnie erozyjne

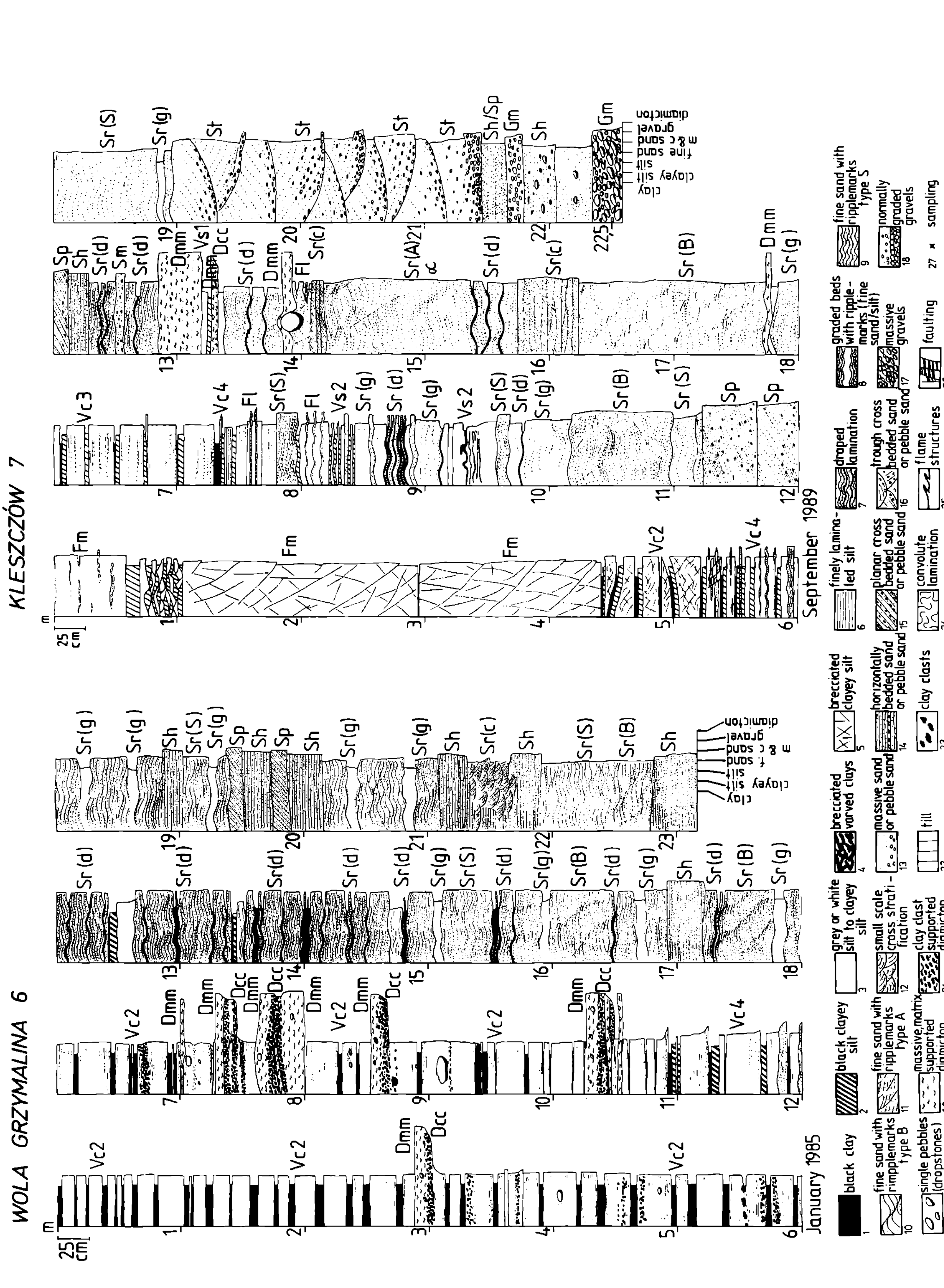
varved clays. The second type of gravity flow deposits contains re-deposited tills (facies Dmb and a part of facies Dmm). Possible sources are older tills exposed on banks of the lake and/or ice-rafted debris. The latter is very possible source as the most of diamicton layers have similar petrographic composition as the Ławki till from the same formation (Czerwonka & Krzyszkowski, 1992). Moreover, many dropstones were found both in sandy deltaic as in the fine-grained lacustrine deposits.

The vertical successions of glaciolacustrine deposits have been studied in detail in seven logs (Figs 5, 6). The lateral successions have been studied in sections when they were exposed in the outcrop (Fig. 4). Eleven facies associations have been distinguished, though all sediments can be subdivided into two groups. The first one contains diamictons and the other one does not.

Six facies associations have been found, succeeding one after another. These are, from bottom to the top (Fig. 7):

Association A. This association comprises cross-bedded and horizontally bedded sands (St,Sp,Sh), which are interbedded with fine sands with small-scale cross-bedding (Src) or with climbing ripples(SrA-S). Horizontal bedding predominates.

Association B. This association comprises mostly fine sands with climbing ripples (SrA-S). Draped lamination (Srd) and graded ripples (Srg) are also common. Laminated silts and massive silts (Fl, Fm)



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January 1985
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black clay
black clayey silt
grey or white silt to clayey silt
brecciated varved clays
brecciated clayey silt
finely laminated silt
draped lamination
graded beds with ripple-marks (fine sand/silt)
fine sand with ripplemarks type S
fine sand with ripplemarks type B
fine sand with ripplemarks type A
small scale cross stratification
massive sand or pebble sand
horizontally bedded sand or pebble sand
planar cross bedded sand or pebble sand
trough cross bedded sand or pebble sand
massive gravels
normally graded gravels
single pebbles (dropstones)
massive, matrix supported diamicton
clay clast supported diamicton
till
clay clasts
convolute lamination
flame structures
faulting
sampling
clay
clayey silt
silt
f. sand
m & c sand
gravel
diamicton

are less frequent.

Association C. This association comprises varved silts (Vs), laminated silts (Fl) and massive silts (Fm) which are interbedded with rippled fine sands (SrB-S) or with sands with draped lamination (Srd).

Association D. This association comprises varved silts (Vs) and varved clays of type Vc4, and only thin layers of rippled sands (Sr, type B or draped lamination).

Association E. This association comprises different types of composite and simple varved clays, except Vc2 facies. In the Ławki Formation, they are characterized by relatively thick varves (over 20 cm, up to 1 m in sporadic cases).

Association F. This association comprises simple varved clays of the Vc2 type, with average thickness of individual varves between 5 and 15 cm, not exceeding 20 cm.

This group of glaciolacustrine deposits shows a typical proximal-distal glacial lake depositional history with underflows as a main depositional agent, accompanied by overlow-interflows, which stimulate winter deposition from suspension (clay layers). In vertical profile, the sequence shows an evolution of the lake basin from the upper delta (association A) to mid- and lower delta conditions (associations B, C & D) and then to the deep lake with high proportion of surge currents (association E) and to the distal lake (association F).

The second group of glaciolacustrine profiles contain gravity flow deposits which are superimposed on the other lake sediments, forming five facies associations with limited lateral extent (lobate structures) (Fig. 7). These are:

Association P. This association is composed of rippled fine sands (Sr), laminated and massive silts (Fl, Fm), varved silts (Vs) and only occasionally varved clays of type Vc4 which are interbedded with massive sands (Sm), and massive, matrix-supported diamictons (Dmm).

Association Q. This association comprises varved silts and varved clays (Vc3, Vc4) that are interbedded with massive sands (Sm), normally graded gravels or massive gravels (Gg, Gm) and diamictons (Dmm, Dmb). Gravity flow sediments may form, together with rhythmites, cyclic or semi-cyclic couplets.

Association R. This association have the same sediments as association Q, but it lacks diamictons.

Association S. This association is composed of composite varved clays of Vc3 and Vc2 type, which are interbedded with large bodies of diamictons (Dmb) and thin layers of massive, matrix-supported diamictons (Dmm) and clay clast-supported diamictons (Dcc).

Association T. This association comprises varved clays (Vc3, Vc2) and single beds of clay clast-supported diamictons (Dcc) and matrix-supported diamictons (Dmm). Individual diamicton layers may be formed of two facies: Dcc at the base and Dmm at the top, with gradational contact between both deposits.

In glaciolacustrine environments, the diamicton facies usually occur near the glacier margins (ice-contact deltas, subaqueous outwash). However, the characteristic feature of the glaciolacustrine sediments of the Ławki Formation is, that diamictons occur in the deltaic and in the deep water facies, both located far from the glacier margin.

DEPOSITIONAL ENVIRONMENT

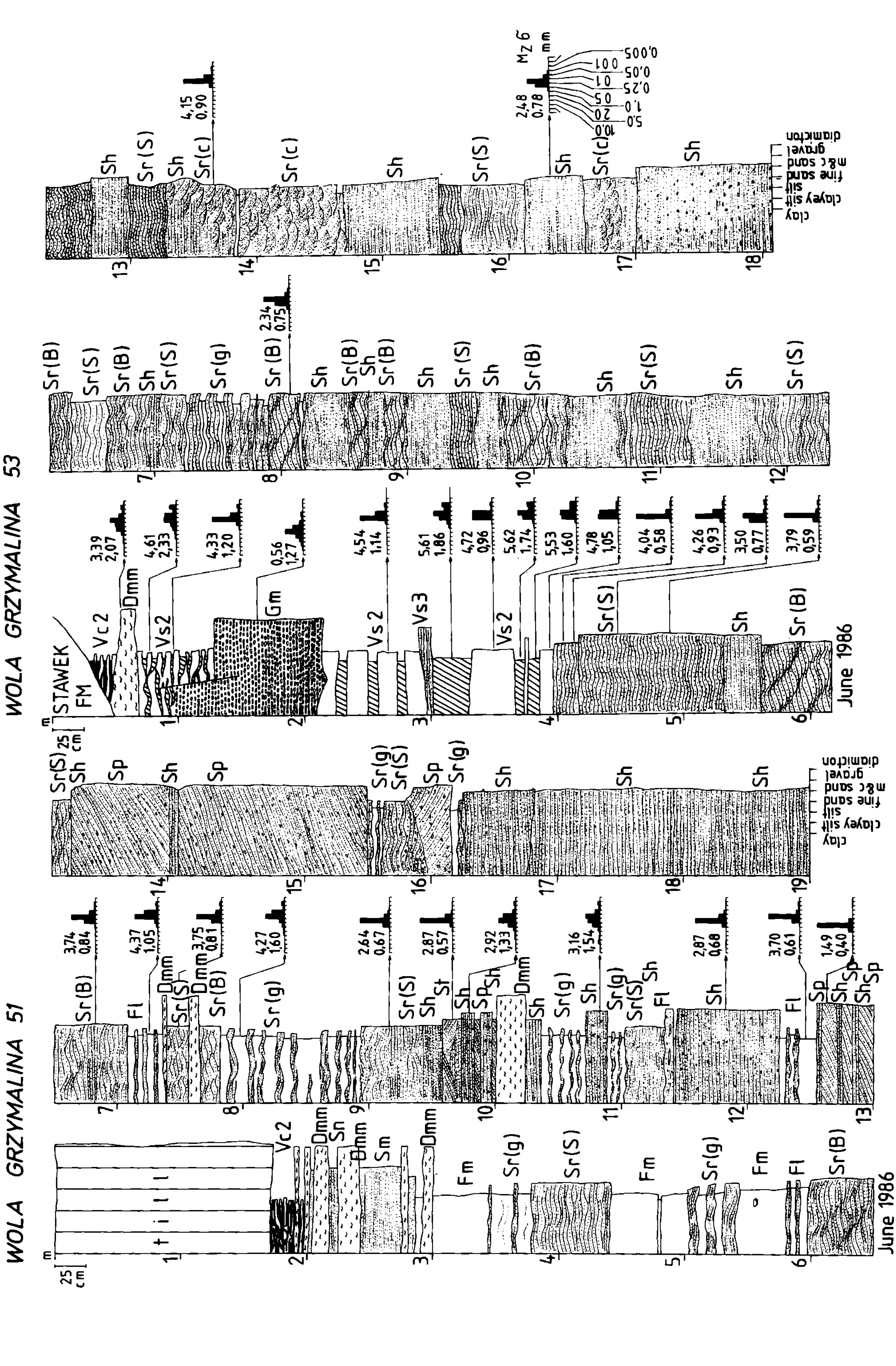
Distribution of deposits

A large area (about 30 km^2) of the lake basin, including both the Bełchatów outcrop and its western foreland, has been analysed (Fig. 10). The latter was investigated using subsurface data from boreholes (Krzyszkowski & Czerwonka 1992). The facies and facies associations have been described in borings using the same model as that applied for the sections in the open-pit.

Figure 8B shows a general distribution of the glaciolacustrine deposits of the Ławki Formation in the Kleszczów Graben. The most characteristic feature is that a large part of the trough is free of Odranian lake deposits. The sediments occur in a relatively narrow zones which represent, most probably, the sedimentary basins during deposition of the glaciolacustrine sequence. The map (Fig. 8B) shows four types of deposits: bottom facies (associations E & F), bottom

Fig. 5. Sedimentological logs from the glaciolacustrine deposits of the Ławki Formation – selected sections with varved clays. Location on Figs. 3 & 4. Lithofacies code and its detailed description in Krzyszkowski (1993)

Profile sedymentologiczne osadów zastoiskowych z Formacji Ławki – wybrane profile z iłami warwowymi. Lakalizacja na fig. 3 i 4. Kod litofacjalny i szczegółowy opis facji w Krzyszkowski (1993). *1* – czarne iły; *2* – czarne mułki ilaste; *3* – szare lub białe mułki ilaste; *4* – zbrekcjowane iły warwowe; *5* – zbrekcjowane mułki ilaste; *6* – drobno laminowane mułki; *7* – laminacja falista w piaskach z oblekającymi warstewkami mułków; *8* – warstwowania riplemarkowe w osadach kohezyjnych (mułkach); *9* – drobne piaski z laminacją falistą; *10* – drobne piaski z riplemarkami typu B; *11* – drobne piaski z riplemarkami typu A; *12* – warstwowania przekątne w małej skali; *13* – masywne piaski lub piaski ze żwirami; *14* – piaski lub piaski ze żwirami warstwowane horyzontalnie; *15* – piaski lub piaski ze żwirami warstwowane przekątnie w zestawach planarnych; *16* – piaski lub piaski ze żwirami warstwowane przekątnie w zestawach rynnowych; *17* – masywne żwiry; *18* – żwiry z warstwowaniem frakcjonalnym normalnym; *19* – pojedyncze głaziki (dropstony); *20* – gliny masywne z wypełnieniem mułkowo-ilastym; *21* – gliny z przewagą szkieletu ziarnowego; *22* – gliny lodowcowe; *23* – klasty ilaste; *24* – warstwowania konwolucyjne; *25* – struktury płomieniowe; *26* – uskoki; *27* – opróbowanie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WOLA GRZYMALINA 53
STAWEK FM
June 1986
June 1986

Fig. 6. Sedimentological logs from the glaciolacustrine deposits of the Ławki Formation – sections with varved clays of reduced thickness; mainly with deltaic sequences. Explanation in Fig. 5, location on Figs. 3 & 4.

Profile sedymentologiczne osadów zastoiskowych Formacji Ławki – profile z cienkimi seriami iłów warwowych zawierające głównie osady strefy deltowej. Objaśnienia na fig. 5. Lokalizacja na fig. 3 i 4

facies with gravity flow sediments (associations R, S & T), deltaic/shallow water facies (associations A, B, C & D) and deltaic facies with gravity flow sediments (associations P, Q & R). The bottom facies occur in northern, and partially in central zone of the trough (Fig. 8B). The latter zones have also the most complete and thick lake sequences (Fig. 7). The facies associations of gravity-flow sediments form lobate structures at the margins of the basin leaving only a part of the central lake (0.5 - 1.0 km wide) with no gravity flow sediment (Figs 7, 8A & 8B). Re-deposited tills (Dmb facies) and large erratics occur only in the southern margin of the lake; other types of diamictons occur both in the northern and southern slopes of the basin.

The upper glaciolacustrine unit of the Ławki Formation, which overlies the above succession has the same extent as association F (bottom facies), i.e. the northern and partially central parts of the trough.

The glaciolacustrine sequence under discussion is characterized by highly variable thicknesses. There are alternating belts of thick deposits (up to 40 m) with relatively thin sequences (Fig. 8C, compare also with figure 4). Deep lake deposits have been found in the central synclinorium (Fig. 1). However, zones with extremely thick succession have limited lateral extent (Fig. 8C). Thickness of the lake sediments was partly reduced by erosion, particularly in the anticlinal zones. The thickness of the bottom deposits and especially the 10 m isopach delineates the deepest parts of the lake basin. These sub-basins occupy small, isolated areas in the northern and central part of the trough (Fig. 8C).

Tectonic framework

A complex fault system is present in the Mesozoic bedrock of the Kleszczów Graben (Gotowała, 1982; Krzyszkowski, 1989) and it continues upwards into the Neogene and Pleistocene sediments. In Pleistocene sequences, the presence of these faults are usually marked as shear zones or flexure zones. The latter are characterized by distinct increase of sediment thickness in the downthrown blocks and great number of gravity faults of the second order. The shear zones are narrow (10 - 50 m) and are characterized by strong deformation of sediments, often indicating mixing of lithologically variable sequences, and the occurrence of almost vertically oriented sand bodies. Stratigraphic sequences on both sides of the shear zones are usually quite different, e.g. with gla-

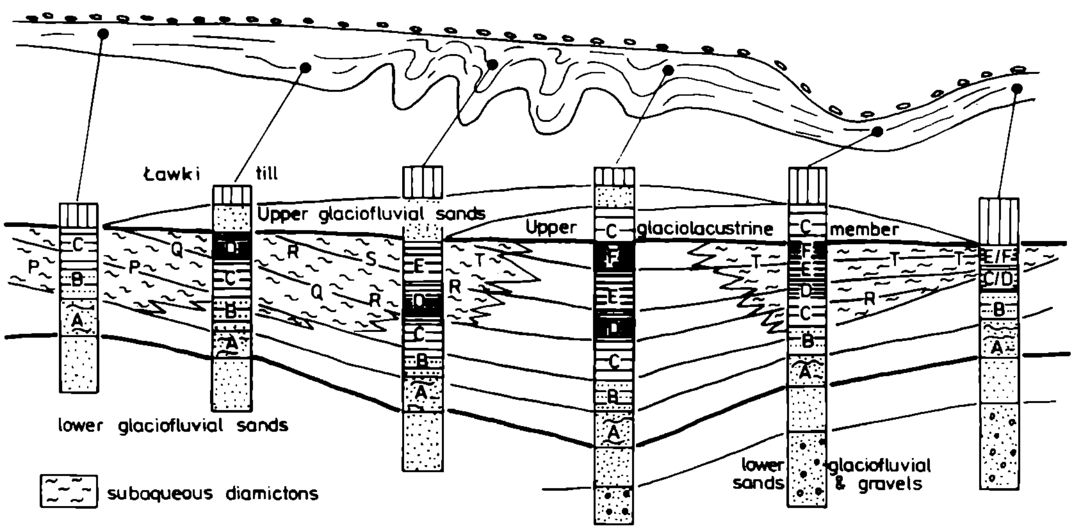

Fig. 7. General sediment succession in the Odranian proglacial lake of the Kleszczów Graben. A-F & P-T – facies associations described in detail in the text. The glaciolacustrine succession is 20 - 40 m thick and it is exposed in ca 3 - 4 km long sections; the central part of the succession is strongly deformed

Zgeneralizowana sukcesja osadów proglacjalnych ze zlodowacenia Odranian z rowu Kleszczowa. A-F i P-T – asocjacje facjalne opisane dokładnie w tekście. Seria zastoiskowa ma miąższość 20 - 40 m i jest odsłonięta na przestrzeni 3 - 4 km ściany kopalni; środkowa część jest silnie zaburzona

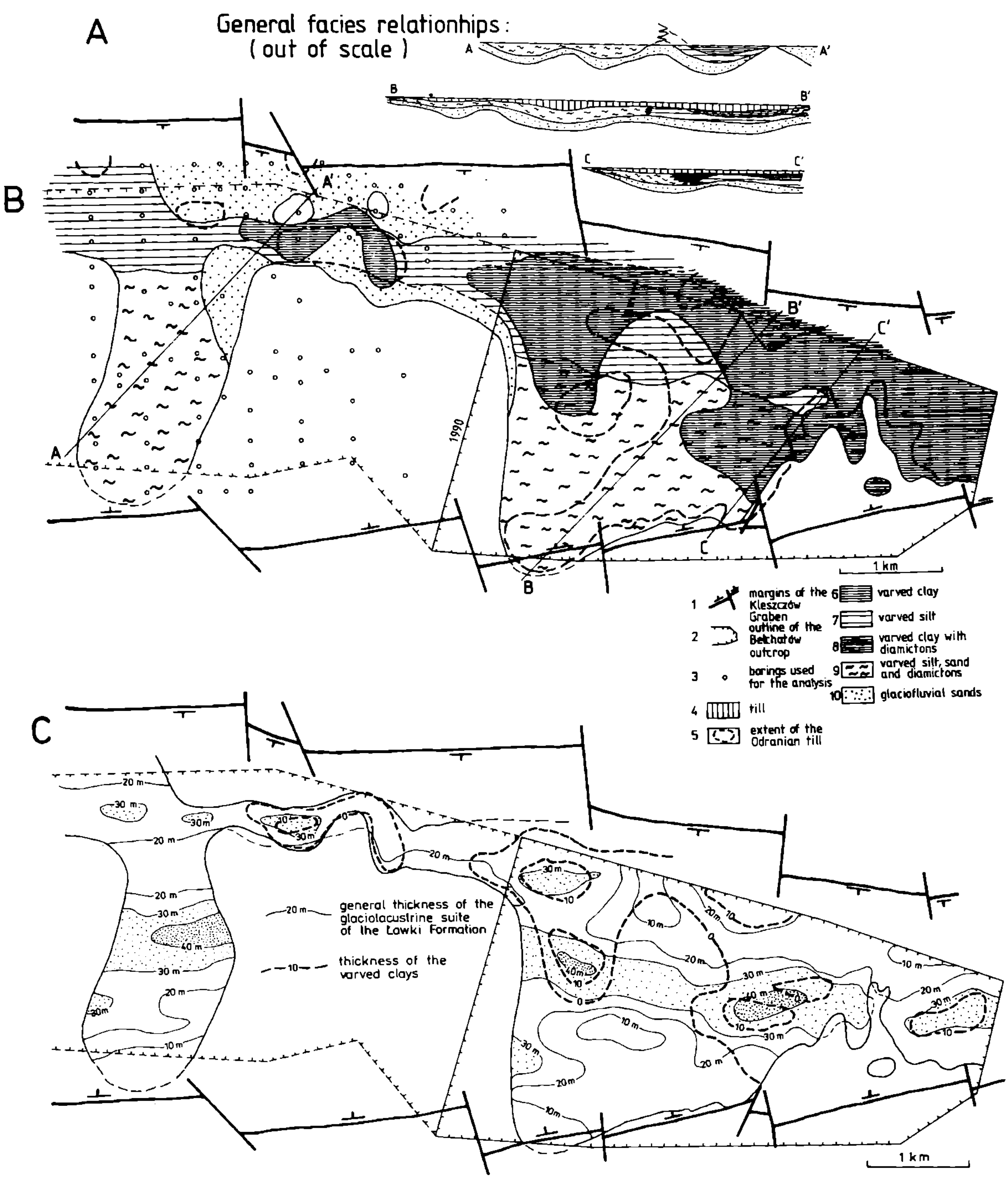

Fig. 8. Facies relationships within the Odranian glaciolacustrine sequences (Ławki Formation) in the Kleszczów Graben: generalized cross sections (A), distribution (B), and thickness (C).

Stosunki facjalne w obrębie sekwencji zastoiskowych zlodowacenia Odranian w rowie Kleszczowa: zgeneralizowane przekroje (A), występowanie osadów zastoiskowych (B) i ich miąższość (C). *1* – granice rowu Kleszczowa; *2* – granice odkrywki Bełchatów; *3* – otwory wiertnicze wykorzystane do analizy; *4* – gliny lodowcowe; *5* – zasięg glin ze zlodowacenia Odranian w odkrywce; *6* – iły warwowe; *7* – mułki zastoiskowe; *8* – iły warwowe w glinami subakwalnymi; *9* – mułki i piaski zastoiskowe z glinami subakwalnymi; *10* – piaski glacifluwialne

cial deposits from different glaciations. The latter is checked by gravel petrography of tills (Krzyszkowski 1994). The Pleistocene fault zones are continuous throughout the graben, and their position can be correlated with fault zones in the basement.

The general fault pattern is dominated by two major W-E trending faults roughly following the trough margins (Fig. 9). Minor W-E trending faults probably belong to this regime, too. The second-order fault pattern comprises NNE-SSW, NE-SW, N-S and NW-SE trending faults which are mostly oblique-normal-slip faults. Intersection of faults of different orien-

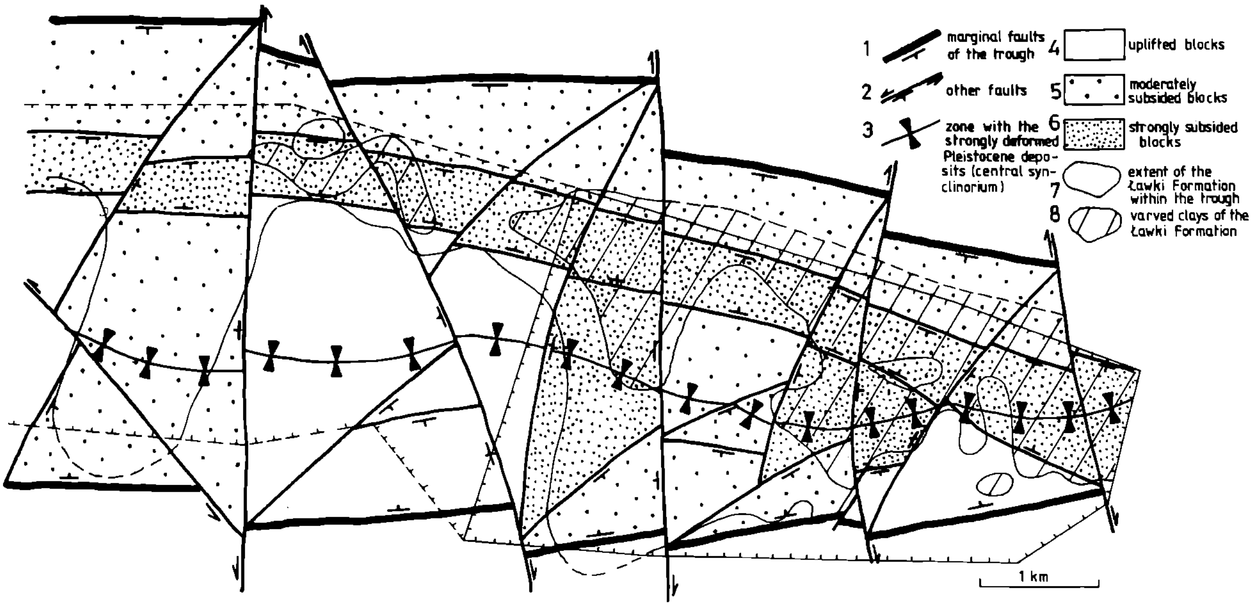

Fig. 9. Fault pattern in the Kleszczów Graben and position of sub-basins with different subsidence during deposition of the Ławki Formation (Odranian). The extent of varved clays shows approximately zones with strong subsidence

Uskoki w rowie Kleszczowa oraz pozycja basenów ze zróżnicowaną subsydencją w czasie depozycji Formacji Ławki (zlodowacenie Odranian). Zasięg iłów warwowych pokazuje strefy ze zwiększoną subsydencją. *1* – uskoki ramowe rowu; *2* – inne uskoki; *3* – strefa dużych zaburzeń osadów plejstoceńskich (środkowe synklinorium); *4* – bloki podnoszone; *5* – bloki umiarkowanie obniżane; *6* – bloki silnie obniżane; *7* – zasięg Formacji Ławki w rowie Kleszczowa; *8* – zasięg iłów warwowych z Formacji Ławki

tation caused a complex pattern of tectonic blocks in the bedrock.

Faults in Cainozoic deposits were rejuvenated during all tectonic phases in the graben, although each time different zones were being down-faulted or uplifted (Krzyszkowski 1989, 1993, 1994). Figure 9 shows the general extent of the subsiding areas during sedimentation of the glaciolacustrine deposits of the Ławki Formation. They are characterized by a thick and probably continuous record of lacustrine sediments deposited in a deep water. These deep lake basin deposits have a high preservation potential, whereas sediments are thin or absent in the uplifted areas.

MODEL OF GLACIOLACUSTRINE SEDIMENTATION IN TECTONICALLY ACTIVE GRABEN

During deposition of the Ławki Formation the Kleszczów Graben was located in the distal part of a large, ice-contact lake (Fig. 2). The deep basin analysed above was only a minor part, limited to the tectonic graben, of larger lake basin. The latter was a relatively shallow lake as the lake deposits found in the geological record are strongly sandy and similar to the facies associations A, B & C of the Bełchatów outcrop. The Kleszczów Graben in the distal part of the large lake basin formed a local, strongly subsiding basin. The sediments were transported from banks into the central part of the trough forming delta-like slopes (Fig. 10A). Simultaneously, glacial debris was transported by ice-bergs to the distal part of the lake. It was melted-out and deposited as subaqueous tilloids in the deltaic sequences. In addition, gravity flow sediments created on the delta slope, may have been induced by earthquakes in the tectonically active area.

The next, main stage of the trough basin development began with an increase of subsidence rate (Fig. 12B). Several subbasins were formed, and increased subsidence was not compensated by sediment influx. This led to the creation of deep lake sub-basins. Varved clays were deposited at the bottom of deep sub-basins and deltaic/shallow water facies on their margins. The gravity-flow sediments were formed particularly on the steep fault scarps bordering the sub-basins. Diamictons formed due to mixing of older deposits were created on such scarps (facies Dcc, Dmm). The subaqueous tilloids (Dmb facies), in turn, were moved down into the deeper part of the lake as mass flows from the upslope position, where they had been deposited before.

In the final stage of sedimentation, the tectonic activity in the trough diminished. This was, most probably, caused by an advancing ice-sheet. A thick ice mass within a short distance and/or above the graben

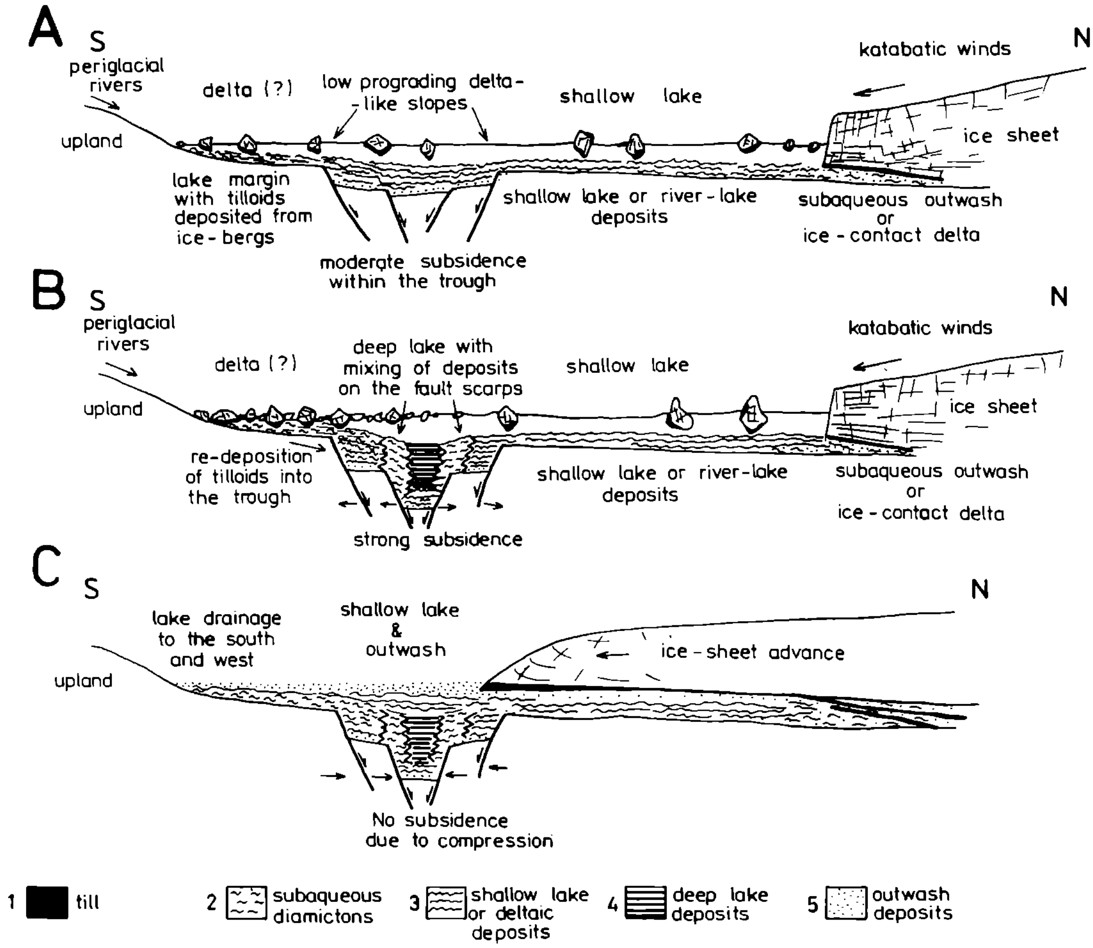

Fig. 10. A model of glaciolacustrine sedimentation in an active trough zone, based on data from the Odranian succession (Ławki Formation) in the Kleszczów Graben. **A** – initial stage: shallow, lake deposition, **B** – main stage: rapid subsidence in the trough, **C** – final stage: an advance of the ice-sheet, shallow lake and outwash deposition

Model sedymentacji zastoiskowej w aktywnym rowie tektonicznym, interpretacja na podstawie danych z Formacj Ławki (zlodowacenie Odranian) z rowu Kleszczowa. **A.** faza początkowa: depozycja w płytkim zbiorniku, **B.** faza główna: szybka subsydencja w rowie tektonicznym, **C.** faza końcowa: awans lądolodu, depozycja w płytkim jeziorze lub na stożkach sandrowych. *1* – glina lodowcowa; *2* – gliny subakwalne; *3* – osady płytkiego jeziora lub delty; *4* – osady głębokiego jeziora; *5* – osady glacifluwialne stożków sandrowych

caused local compression conditions (Fig. 10C). A shallow lake formed again, represented by the upper glaciolacustrine unit, which occupied the same areas as the bottom facies of the middle glaciolacustrine unit. No transitional facies associations have been found between them (Fig. 9) suggesting a rather rapid change of the sedimentary environment. The upper, shallow lake deposit was superceded by glaciofluvial deposits on the margin and till deposited below the ice sheet.

Deposition of the glaciolacustrine sequence of the Ławki Formation was influenced by tectonic movements in the lake basin. This is visible from the occurrence of some specific gravity flow facies formed on fault scarps by mixing of varved clays (Dcc facies) and from differentiated sediment distribution and thickness in the small subbasins with differing tectonic history. Similar lake basins are probably common in central Poland, because there are many tectonic grabens (Baraniecka, 1971, 1975; Pożaryski, 1977). The model presented for the Odranian deposits in the Kleszczów Graben (Ławki Formation) may be attributed also to other tectonically active zones in the glaciated areas of Poland.

CONCLUSIONS

1. The Kleszczów Graben contains glaciolacustrine suites with many specific features that have been formed due to the occurrence in a tectonically active zone. Among them, the Ławki Formation of the older Saalian stage is very well exposed.

2. The tectonically influenced glaciolacustrine deposits can be distinguished from other sequences by their large thickness; "mosaic" distribution of deep

water and deltaic/shallow water lithofacies in the basin, the occurrence of gravity-flow lithofacies at least in a part of deep water deposits and the narrow, thick geometry of deposits. Moreover, they should be juxtaposed to thin proglacial suites with "normal" facies.

3. Despite scarce descriptions of the glaciolacustrine deposits formed in tectonically active zones can rarely be found in the literature, it seems that they may commonly appear, at least in central Poland, where many tectonic grabens have been reactivated during the Quaternary.

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Streszczenie

Lodowcowo-jeziorna sedymentacja ze zlodowacenia Odranian w Rowie Kleszczowa (Polska centralna)

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W odkrywce Bełchatów w Polsce środkowej, leżącej na obszarze rowu Kleszczowa, znaleziono osady zastoiskowe ze zlodowacenia Odranian, które wykazują cechy wskazujące na aktywność tektoniczną tej strefy w czasie plejstocenu (Fig. 1, 2). Seria zastoiskowa ma 10 - 40 m miąższości i jej występowanie jest ograniczone uskokami ramowymi rowu. Szczegółowa analiza sedymentologiczna kilkunastu profili osadów (Fig. 3 - 6) oraz dystrubucja poszczególnych litofacji i ich miąższości (Fig. 7, 8) w obrębie rowu wykazały specyficzne cechy badanych osadów. Można wydzielić dwa typy sukcecji osadów zastoiskowych. Pierwszy typ obejmuje obejmuje klasyczną sekwencję transgresywną, rozpoczynającą się osadami górnego członu delty, poprzez osady środkowego członu łagodnie nachylonej delty do osadów dennych. Te ostatnie obejmują iły warwowe "proksymalne" z grubymi warstwami letnimi i iły warwowe "dystalne" z cienkim warstwami letnimi i zawierające tylko materiał ilasto-mułkowy. Inny typ sekwencji zastoiskowych

zawiera osady stokowe: gliny różnych typów, piaski masywne, oraz redeponowane klasty iłów warwowych. Osady stokowe występują zarówno w strefach deltowych (przy krawędziach zbiornika) jak i w strefach dystalnych (Fig. 7, 8). Ta ostatnia pozycja, niespotykana w normalnych warunkach w jeziorach zastoiskowych, sugeruje istnienie skarp uskokowych w strefie dystalnej jeziora. Występowanie iłów warwowych z warstwami osadów stokowych jest ograniczone tylko do pewnych stref w rowie Kleszczowa. W tych samych strefach obserwuje się także wzrost miąższości zarówno iłów warowych jak i całej serii zastoiskowej (Fig. 8). Omówione strefy zinterpretowano jako obszary o wzmożonej subsydencji w czasie depozycji zastoiskowej i oddzielone od innych stref, bardziej płytkowodnych, przez aktywne skarpy uskokowe (Fig. 9). Przedstawiono model sedymentacji zastoiskowej w aktywnym rowie tektonicznym. Sedymentacja przebiegała w trzech etapach (Fig. 10). W pierwszym etapie formuje się płytkie jezioro zastoiskowe z sedymentacją na łagodnie nachylonych deltach. W drugim etapie wzmożona tensja na obszarze rowu tektonicznego prowadzi do powstania głębokiego zbiornika. Obszar zajmowany przez jezioro proglacjalne dzieli się na dwie, wyraźnie oddzielone od siebie strefy: płytkowodną z sedymentacją "normalną" oraz głębokowodną, z silnym wpływem tektoniki podłoża. W ostatnim etapie, w wyniku awansu lądolodu, obszar rowu ulega kompresji i zbiornik jeziorny zanika.