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LITHOLOGY OF GLACIAL SEDIMENTS OF SANIAN-2 (ELSTERIAN-2) STAGE IN TENCZYNEK BASIN, KRAKÓW REGION, SOUTHERN POLAND

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Abstract: The paper deals with the lithology of Quaternary sediments that fill the Tenczynek Basin, Kraków Upland. The basin was eroded within Carboniferous strata before or during the Elsterian. The basin fill can be subdivided into three complexes, the middle one of which records a nearly complete glacial cycle, represented by glacier advance and standstill during the Elsterian-2 (Sanian-2) glacial stage. Sediments of the lower complex were deposited before or during that stage. Following this deposition, a terminoglacial lake was formed and became gradually filled with glaciolacustrine clays and silts that bear a few intercalations of diamictons, some of them shed by slumps. These sediments compose the middle, strongly disturbed complex which, in turn, is unconformably overlain by periglacial sands of the upper complex, deposited during a time-span comprised between the Sanian and Weichselian. The petrographic composition of gravels and cobbles, determined for a wide spectrum of grain-size classes, is highly variable due to differentiated exaration and the changeable supply of extraglacial material.

Abstrakt: Artykuł omawia litologię osadów czwartorzędowych wypełniających Kotlinę Tenczynka na zachód od Krakowa. Kotlina została wyerodowana w skałach karbonu przed lub w trakcie zlodowacenia Sanu-2. Piaski i żwiry dolnego kompleksu osadowego powstały przed zlodowaceniem i w wyniku zatamowania odpływu przez lądolód. Następnie doszło do utworzenia jeziora terminoglacjalnego i sedymentacji osadów glacilimnicznych, z wkładkami diamiktytów o bardzo zmiennym uziarnieniu. Osady te, budujące kompleks środkowy, są silnie zaburzone i przykryte niezgodnie przez peryglacjalne piaski pokrywowe kompleksu górnego, osadzone po zlodowaceniu Sanu. Skład petrograficzny żwirów i głazików w osadach glacjalnych, analizowany dla różnych przedziałów frakcyjnych, jest bardzo zmienny z uwagi na zróżnicowanie lokalnej egzaracji i zmiany w dostawie materiału ekstraglacjalnego.

Key words: lithology, petrography, Sanian-2 (Elsterian-2) glacial stage, Quaternary, Tenczynek Basin, Southern Poland.

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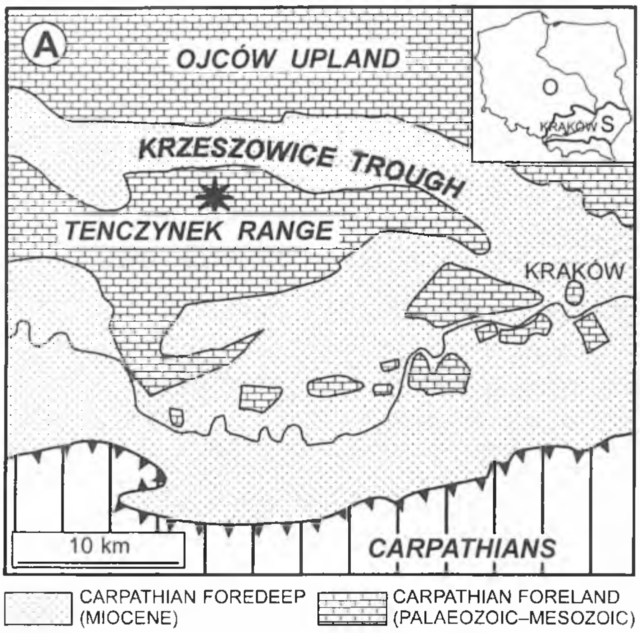
INTRODUCTION

The paper deals with glacial sediments of Sanian-2 (Elsterian-2) age that crop out in the Tenczynek Basin, Kraków Upland, some 25 km west of Kraków (Figs. 1, 2). These sediments are composed of highly variable series of silts, clays and diamictons, rarely sands and gravels. They are underlain mostly by Carboniferous rocks and overlain by periglacial sands. The Tenczynek Basin provides a rare opportunity in Southern Poland to study a nearly complete sedimentary record of the advance and standstill of the Sanian-2 icesheet, the most extensive from among Pleistocene icesheets in Poland and the only one which encroached upon this area. This glacial stage is usually correlated with the Elsterian-2 stage of the West European stratigraphic scheme (*cf.* Lindner, 1991; Lindner *et al.*, 1998).

Sediments of the Sanian-2 stage in Southern Poland are preserved only locally due to strong denudation during the subsequent glacial-interglacial stages. Therefore, the Tenczynek Basin, with a nearly 50 m-thick Quaternary infill,



has been chosen as a study area. The only one extensive exposure of glacial sediments and overlying periglacial sands in this area is situated on top of an active quarry of Permian diabases at Niedźwiedzia Góra (*cf.* Figs. 1–4) where Quaternary deposits, a dozen or so metres thick, are accessible in a 250-m-long, southern exploitation wall. It is the most extensive exposure of glacial sediments in Southern Poland which has not yet been described, except preliminary contributions by Rutkowski *et al.* (1993, 1994). From the nearby area, SE of Brodła in the Rybna Depression, tills overlain by aeolian sands have been reported by Dżułyński (1956).

MATERIAL AND METHODS

During field studies individual exposures have been logged (*cf.* Figs. 4–10) and detailed geological mapping of the Tenczynek Basin margins near Liguniowa Góra, Tenczynek, and east of Niedźwiedzia Góra has been made (*cf.* Figs. 2, 3), supplementing the existing 1:50,000 geological

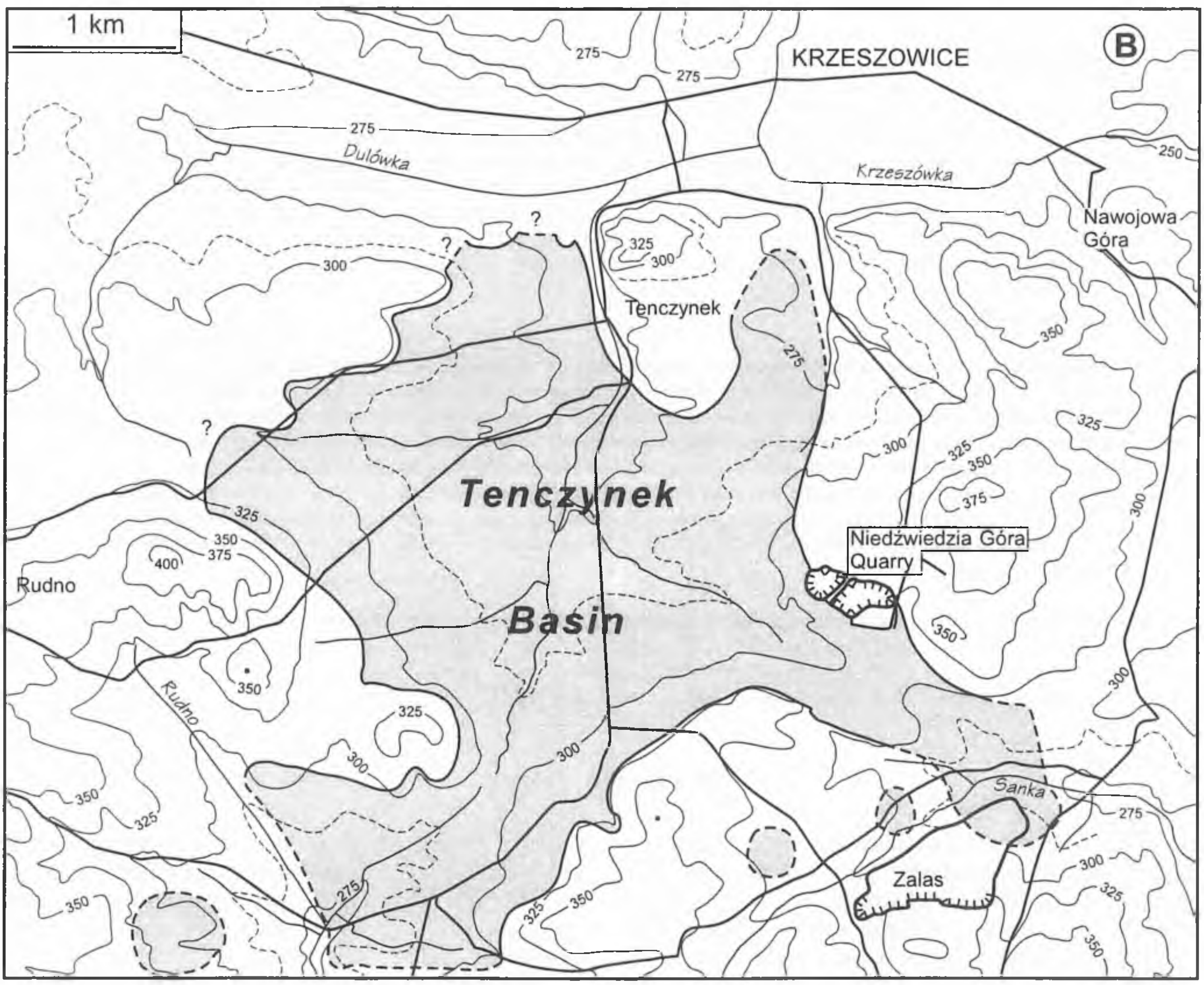


Fig. 1. Tenczynek Basin versus topography of Krzeszowice region, west of Kraków, southern part of the Kraków Upland: **A** – geological sketch, insert cartoon shows the maximum extent of Odranian (Drenthe; O) and Sanian (Elsterian; S) glaciations; location of Niedźwiedzia Góra quarry shown by asterisk; **B** – topographic sketch (hatchure denotes glaciolacustrine sediments)

maps of that area (Płonczyński & Łopusiński, 1992).

Geological setting of glacial sediments has been described on the basis of an analysis of well-log data pertainig to coal and diabase prospection. More than 100 logs of wells and excavation pits have been used, half of them drilled after the World War II, up to the 1960s. The number of wells changes from 1–2 per sq. km in the NE part of the Basin, through 5–6 per sq. km in the remaining part, to 35 per sq. km in the quarry itself. These wells served as a basis for construction of a detailed map of the sub-Quaternary topography (*cf.* Fig. 2) and geological cross-sections (*cf.* Fig. 3).

Seismic refraction and reflection profiles have been shot by Ślusarczyk (1997) to determine the boundary between Quaternary and underlying sediments. Seven profiles have been analysed by the use of 24-channel Terraloc Mk6, the results being computed on the base of Seiatrix3 or Sextette systems. A comparison between geological cross sections and geophysical profiles makes the unequivocal determination of geological boundaries impossible. These difficulties result from great variability in grain-size of Quaternary sediments, very limited knowledge on the velocity of propagation of elastic waves within these deposits, and from too small differences in velocity ranges between Carboniferous and Quaternary strata.

Laboratory studies consisted of grain-size analyses of silts, clays, diamictions and sand-gravelly sediments (*cf.* Fig. 11), performed on sieves for gravel and sand fractions. In the course of the analysis samples were successively reduced in size by the quartering method. For silt-clayey fractions, smaller than 0.1 mm, the grain-size has been determined using the Sartorius sedimentation weight. The results obtained by different techniques have then been combined to show the full spectrum of grain-size distribution of diamictons (*cf.* Fig. 11), and not only that of smaller fractions, as it is customary in the Polish literature. From selected samples of silts, clays and diamictons, the fraction <0.002 mm has been separated and analysed by X-ray diffractometry in respect to its qualitative mineral composition. X-ray diagrams for clay fraction (<0.002 mm) separated from 4 samples have been obtained by the X-ray diffractometer DRON 3.0. Qualitative analysis consisted in the study of diffractograms registered for samples oriented due to sedimentation from suspension of <0.002 mm fraction, air-dried and saturated with ethylene glycol.

Particular attention has been paid to gravels and cobbles (*cf.* Fig. 12), separated from diamictons and other sediments. Their petrographic composition has been determined for several fractions larger than 2 mm, using phi scale. The results are presented in per cent of the number of clasts, taking each grain-size class as 100%. From each class 300 clasts have been analysed, except those of the largest diameters (Rutkowski, 1977, 1995). Due to insignificant amount of gravel-size clasts within some diamicton samples, the following separation technique has been applied. Clasts larger than 32 mm in diameter have been picked up in the field, whereas the remaining material has been brought to the laboratory, then air-dried and sieved to separate 4–32 mm clasts. The smaller-size material has been wet-sieved. Taking into account the small proportion of coarse-grained material, large, several hundred kilogram each, samples had to be collected. For instance, to obtain a sufficient number of <32 mm clasts from sample 3P, ca. 250 kg of diamicton must have been sieved. For fractions <2 mm, the amount of $CaCO_3$ has been determined by the volumetric method (*cf.* Figs. 8–9).

Thermoluminescence dating was performed by one of us (A. Bluszcz) at the Gliwice Technical University on 4 samples of silts and sands, collected from the eastern part of the Niedźwiedzia Góra exposure (*cf.* Figs. 7, 9). Each time quartz grains of 90–150 μm fraction have been analysed.

GEOLOGICAL SETTING OF TENCZYNEK BASIN AND ITS SURROUNDINGS

The Tenczynek Basin represents a depression situated south of Krzeszowice (Figs. 1, 2), within the Tenczynek Range horst (Dżułyński, 1953; Gilewska, 1972). The basin is filled with Quaternary sediments and its top occurs at 310–290 m a.s.l. in the south and the west, sloping to some 270–290 m a.s.l. in the north. The Tenczynek Basin is drained mainly to the north by tributaries of the Rudawa River, flowing through and east of Tenczynek, subordinately towards the Sanka River in the SE part and the Rudno River valley in the SW part.

The topography and geological setting of the Tenczynek Basin and its surroundings are shown in Figs. 1 and 2, and described in detail by Dżułyński (1953), Doktorowicz-Hrebnicki (1954), and Płonczyński and Łopusiński (1992).

The well-log data show that the base of the basin is relatively flat, being placed at 230–240 m a.s.l., and sloping to some 220 m a.s.l. in the SE part only (Figs. 2, 3). Judging from the pre-Quaternary topography (Fig. 2), the basin was initially drained south-eastwards, toward the present Sanka River valley and, possibly, also south-westwards, to the valley of Rudno.

The central part of the basin reveals a minor uplift (256.7 m a.s.l.), accompanied by a small depression (224.5 m a.s.l.). The lack of wells within zones of other possible outflows and inflows from and to the basin (*cf.* Fig. 2) does not enable us to comment on Dżułyński's *et al.* (1966) reconstruction of the Pliocene valley pattern in the area.

QUATERNARY SEDIMENTS OF TENCZYNEK BASIN

The description of Quaternary sediments of the Tenczynek Basin consists of two parts. The first one includes an analysis of well logs which are the only source of information pertaining to the basin substratum. The second part summarizes characteristics of the exposed surficial deposits.

The Quaternary basin fill can be subdivided into three complexes (Figs. 3–5). The lower complex is composed of gravels and sands bearing infrequent intercalations of diamictons. These sediments are either of fluvial (pre-Elsterian) or glaciofluvial (Elsterian) origin. The middle, glaciolacustrine and glacial Sanian (Elsterian) complex comprises clays, silts and diamictons, whereas the upper complex is

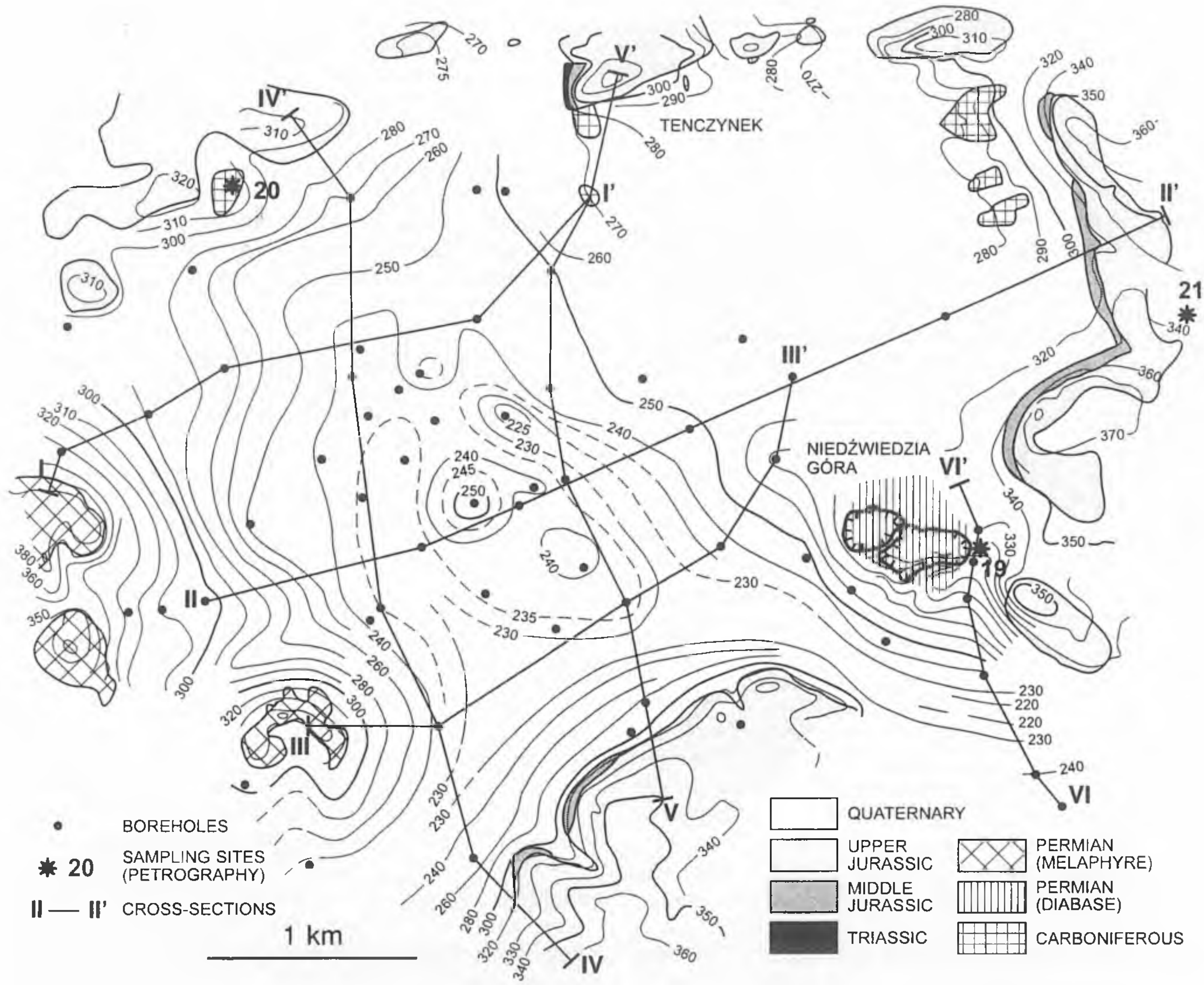


Fig. 2. Topography of the base of Quaternary sediments in the Tenczynek Basin

composed of periglacial, mostly fluvial, sands with some intercalations of gravels and angular debris.

LOWER COMPLEX

The lower complex, up to 19 m thick (Fig. 3), makes up the lowermost part of the Tenczynek Basin fill. Its top rarely exceeds 245–250 m a.s.l. It is composed chiefly of sands, rarely gravels, bearing subordinate thin layers of diamictons and clays. According to well-log data, these gravels comprise exclusively local material, dominated by quartz, limestones, flints, diabases and infrequent melaphyres. The only one surficial exposure of this complex occurs in the eastern part of Niedźwiedzia Góra quarry (Fig. 4, site 12). In a narrow, steep-sided furrow cut into Permian diabases (Fig. 2) there crop out silts overlain by strongly silty and rusty sands and sands with gravels. The topmost part of the series is capped by varved clays, belonging to the middle complex.

Petrographic composition of gravels of this complex (*cf.* Fig. 12, sample 14) is represented in the outcrop by exclusively local material. These are Oxfordian and – rarely – Callovian limestones, Callovian sandstones and quartz granules, being accompanied by strongly weathered clasts of diabases.

From the genetic point of view, the lower complex may represent fluvial and/or glaciofluvial sediments that could have been deposited between the late Pliocene and Elsterian ages.

MIDDLE COMPLEX

The middle complex is composed of clays, silts, and diamictons, with rare intercalations of sands and gravels. The interpretation of wells drilled in the study area during the last century is relatively difficult, since the well-log charts are far from detail. It is for this reason why glaciolacustrine and glacial sediments drilled by boreholes are treated here together; another group is represented by sands and gravels that form interlayers within the former unit.

The thickness of sediments ranges from a few to *ca.* 50 m, averaging at 40 m. Their top is situated at 310–320 m a.s.l. in marginal parts of the basin and 290 m a.s.l. in its

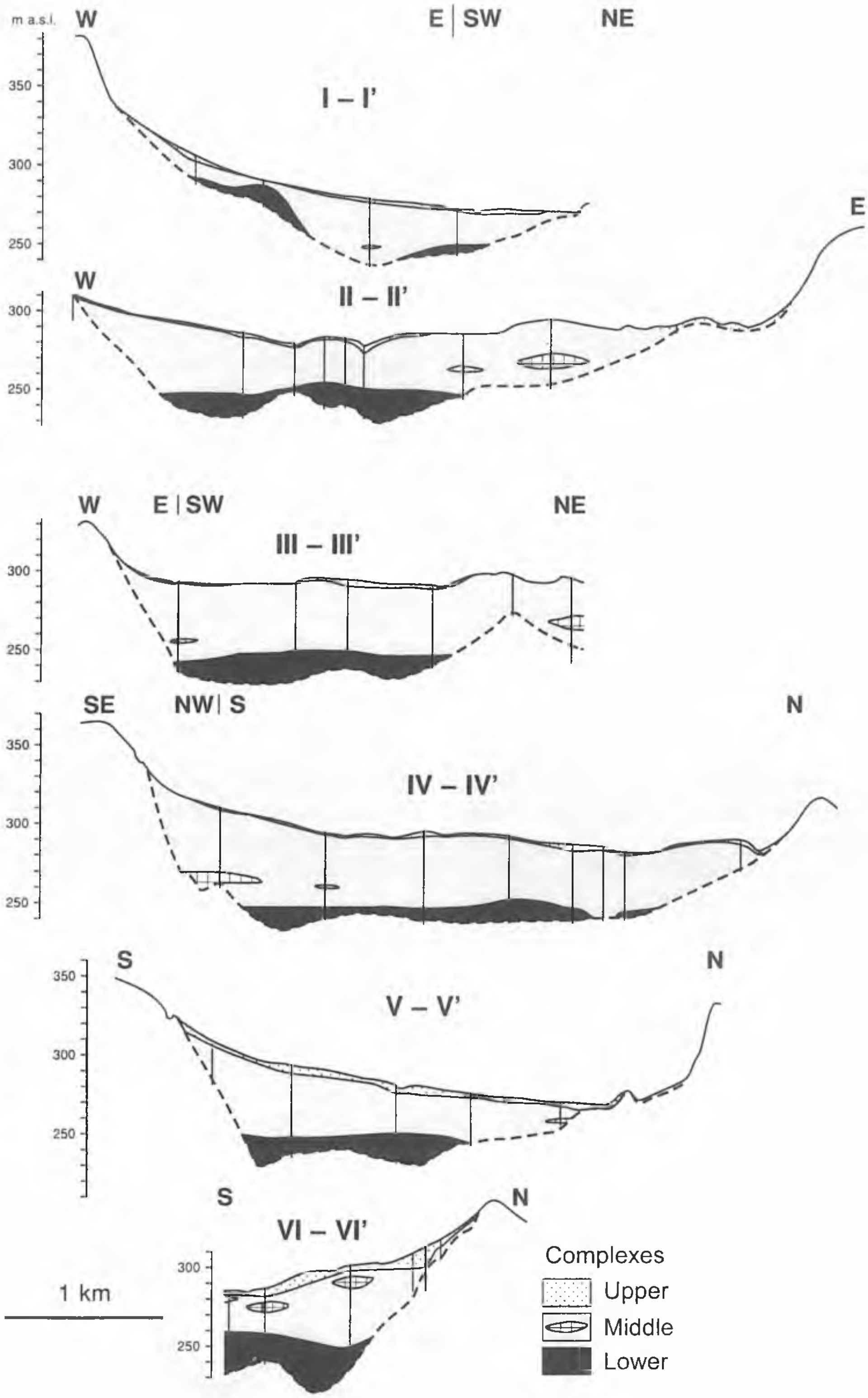


Fig. 3. Geological cross-sections through Quaternary infill of the Tenczynek Basin. Dense hatchure in the middle complex unit denotes lenses of sand and gravel

central, partly eroded part (Figs. 3, 5).

Outcrops within the excavation pit at Niedźwiedzia Góra enable us to identify the following sedimentary units within the middle complex: varved clays, silts, diamictons, as well as sands and gravels, the lithology of which will be presented below. The most extensive are silts (Fig. 5); diamictons have smaller extent. Varved clays occur at the base of the complex, whereas sands and gravels occur sporadically throughout the complex.

Varved clays

Varved clays play a minor role within the middle com-

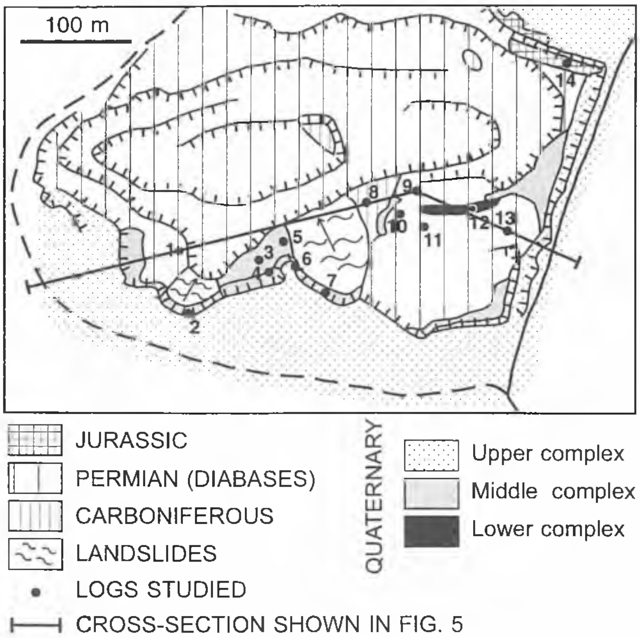


Fig. 4. Location of analysed logs of Quaternary sediments in the Niedźwiedzia Góra pit

plex, occurring in the eastern and western parts of the excavation pit, at its bottom (Figs. 6, 7). Their thickness ranges from 20 cm to 50 cm. The varved clays are composed of alternating light and dark laminae, each pair being a few millimetres thick. Light-grey laminae comprise silts with some admixture (*ca.* 10%; *cf.* Fig. 11, sample 1b) of clay, whereas dark-grey laminae, 2 mm thick, include up to 62% of clay. The $CaCO_3$ content is 5.0–9.8% and 3.0–6.5%, respectively.

X-ray studies performed for fractions <0.002 mm, separated from dark laminae, indicate predominance of finely dispersive smectite with a subordinate amount of illite and kaolinite. Quartz and traces of calcite occur as well.

Silts

The major part of glaciolacustrine sediments at Niedźwiedzia Góra is composed of dark-grey silts, occurring principally in the central part of the excavation pit (Fig. 5). These are usually bluish and bluish-grey, massive, more rarely laminated silts that contain infrequent dropstones and rare lenses of gravels (up to 10–15% of gravel fraction; *cf.* Figs. 10, 11, sample 15). The grain-size composition of glaciolacustrine silts (*cf.* Fig. 11, sample 6) is dominated by silts with a dozen or so per cent of sand, and a comparable amount of clay. The mean grain diameter Mz is 5.64–7.09 phi, i.e. 0.01–0.02 mm.

The $CaCO_3$ content within unweathered silts ranges from 7.0% to 13.4% (Figs. 7, 8). The topmost part of weathered silts is greenish to yellow-grey and completely decalcified. The silts contain sometimes thin intercalations of clays, whose grain-size composition (sample 5: 78% of clay) does not differ much from that of dark laminae of varved clays (Fig. 11). X-ray studies show predominance of smectite, accompanied by a dozen or so per cent of illite. Kaolinite, quartz, as well as calcite and goethite admixtures have also been found.

Palynological determinations revealed a very poor assemblage of pollen, composed of some redeposited Tertiary taxa within varved clays and infrequent pollen of Quaternary conifers within silts, pointing to a cold climate. Micropalaeontological determinations, in turn, showed very poor redeposited microfauna, composed mostly of Cretaceous and Miocene foraminifers, Inoceramus prisms and sponge spicules.

Diamictons

Diamictons are the second important component of gla-

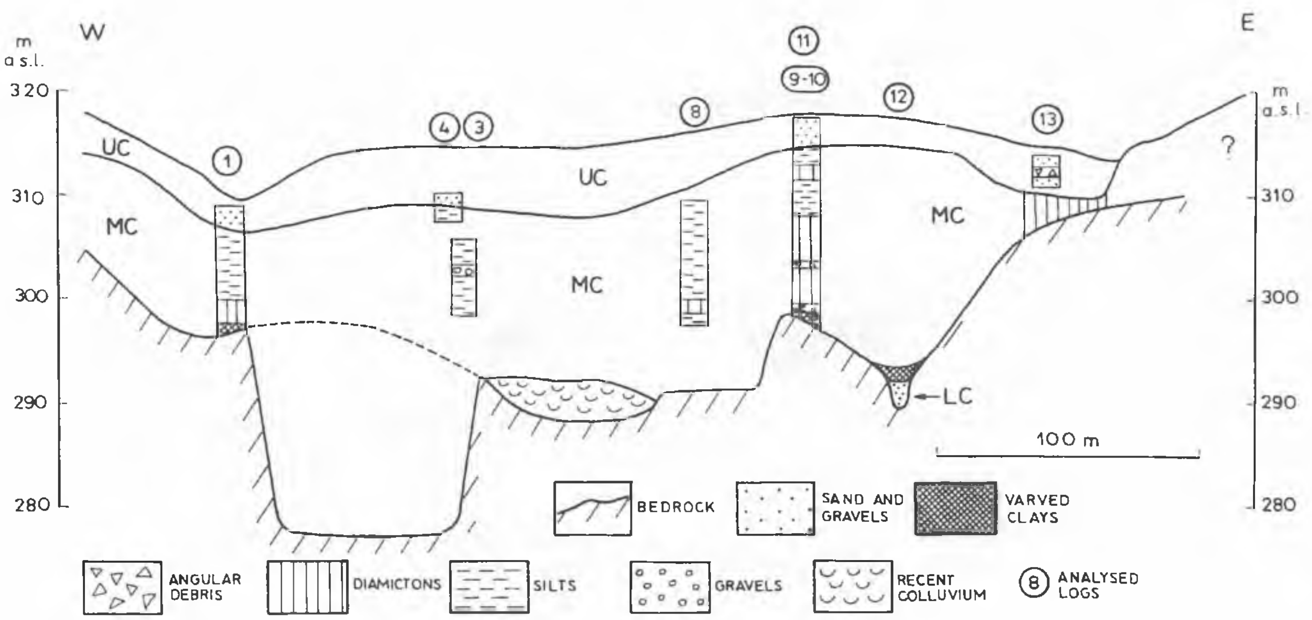


Fig. 5. Section along the southern exploitation wall of the Niedźwiedzia Góra quarry. Quaternary complexes: LC – lower, MC – middle, UC – upper

cial sediments exposed at Niedźwiedzia Góra. They cluster mainly in the eastern part of the exposure (Figs. 4, 5, 7, 8) where their thickness attains 7 m; they also occur in the central and western parts (Figs. 4–6), although showing a much smaller thickness.

These are mostly massive and matrix-supported sediments, sometimes with evidence of resedimentation; clast-supported or indistinctly stratified diamictons occur subordinately (*cf.* Figs. 6–8, and lithofacies description given in the subsequent paragraph).

Grain-size analyses (Fig. 11) indicate that the main component of diamictons are silts with admixtures of sands, gravels and clays in variable proportions. The diamictons contain 40–60% of grains <0.1 mm, including from a few to 28% of clays (<0.002 mm), 5–20% of sands, a few to 20% of gravels, and 0–9% of clasts larger than 64 mm. The largest clasts are a few tens of centimetres in diameter and can be found only sporadically at the foot of the excavation wall. Their percentage within the diamictons is insignificant. The mean grain diameter Mz is 1.32–6.16 phi (0.27–0.01 mm), exceptionally attaining 0.44 phi (0.74 mm). Extrapolating the grain-size cumulative curve by 2 phi within small fractions, one can obtain the sorting index ρ_1 of 3.40–6.07 phi, pointing to very poor and extremely poor sorting measures.

Mineralogical studies performed on clays separated from diamictons (samples 3 and 8) show a composition similar to that observed within clay intercalations within silts. The $CaCO_3$ content within fractions <2 mm changes from 7.5% to 15.8% (*cf.* Figs. 7, 8, 10).

Special attention has been paid to the petrographic composition of clasts within the diamictons (*cf.* Fig. 12, samples 2, 3, 7, 9, 18). They represent: local material, derived from the underlying substratum and nearby hills, material derived from the South and Central Poland, as well as rocks of Scandinavian and the Baltic Sea bottom provenance. The local material is composed principally of white or white-greyish Oxfordian limestones, whose clasts are usually angular, pointing to a very short transport. Some of Jurassic limestones, however, could have been transported from more distant areas situated in the Kraków Upland. This type of material occurs throughout all grain-size classes, from <1mm to 256 mm, its proportion changing depending on grain-size class and sample, from *ca.* 1% to >95%. The highest amount of Jurassic limestones has been encountered within diamictons exposed in the eastern part of the pit (*cf.* Fig. 12, samples 3, 7, 9). Another local component is represented by coarse-grained sandstones with gravels, derived from the Middle Jurassic rocks that crop out in the northern part of the quarry, as well as by yellowish-brown, limonitised sandy limestones bearing abundant faunistic remains (Callovian). Jurassic limestones are accompanied by cherts and flints. These rocks are relatively rare within nearby limestone exposures, but ubiquitous in regoliths of Tertiary (Palaeogene and Pliocene) age (Rutkowski, 1987). Such regoliths occur in the study area east of Niedźwiedzia Góra (*cf.* Fig. 12, sample 21; see also Fig. 2).

Cherts are usually dark-brown and grey, sometimes yellow. More rarely, nearly black flints of irregular shape, covered by white weathering coatings, can be found. Cherts are usually angular, rarely well rounded. Their content changes from 0 to ca. 10%. Strongly silicified rocks of uncertain provenance, either Polish Carboniferous or Scandinavian Palaeozoic, can also be encountered. The diamictons contain at places white, light and porous siliceous marls (opokas) of Upper Cretaceous (Senonian) age.

Another important local component are Permian diabases. Their clasts within the diamictons immediately overlying varved clays (Fig. 9; see also Fig. 12, sample 2) are usually angular, strongly weathered and grey to brown-yellowish. Their content within grain-size class up to 128 mm attains even 100%. Diabase clasts have also been found in the diamictons exposed in the western part of the pit (*cf.* Fig. 12, sample 18).

Table 1

Lithofacies codes used in log description
(based on Miall, 1977 and Eyles *et al.*, 1983)

Code	Description
Diamictons	
Dmm	matrix-supported, masive
Dmm(r)	matrix-supported, massive, with evidence of resedimentation
Dms	matrix-supported, stratified diamict; stratification more than 10% of unit thickness
Dmg	matrix-supported, graded, exhibits variable vertical grading in either matrix or clast content
Dmg(s)	matrix-supported, graded, sheared
Dcm	clast-supported, masive
Dcm(r)	clast-supported, massive, with evidence of resedimentation
Dcs	clast-supported, stratified
Dcs(r)	clast-supported, stratified, with evidence of resedimentation
Gravels	
Gp	stratified gravel
Sands	
Sm	massive
Sr	rippled
St	trough cross stratification
Sh	horizontal lamination
Se	erosional scours with intraclasts, crude cross bedding
Sd	soft-sediment deformation
Silts	
Fm	massive
Fl	laminated
Fd	with dropstones
Fr	rootlet traces, seat earth

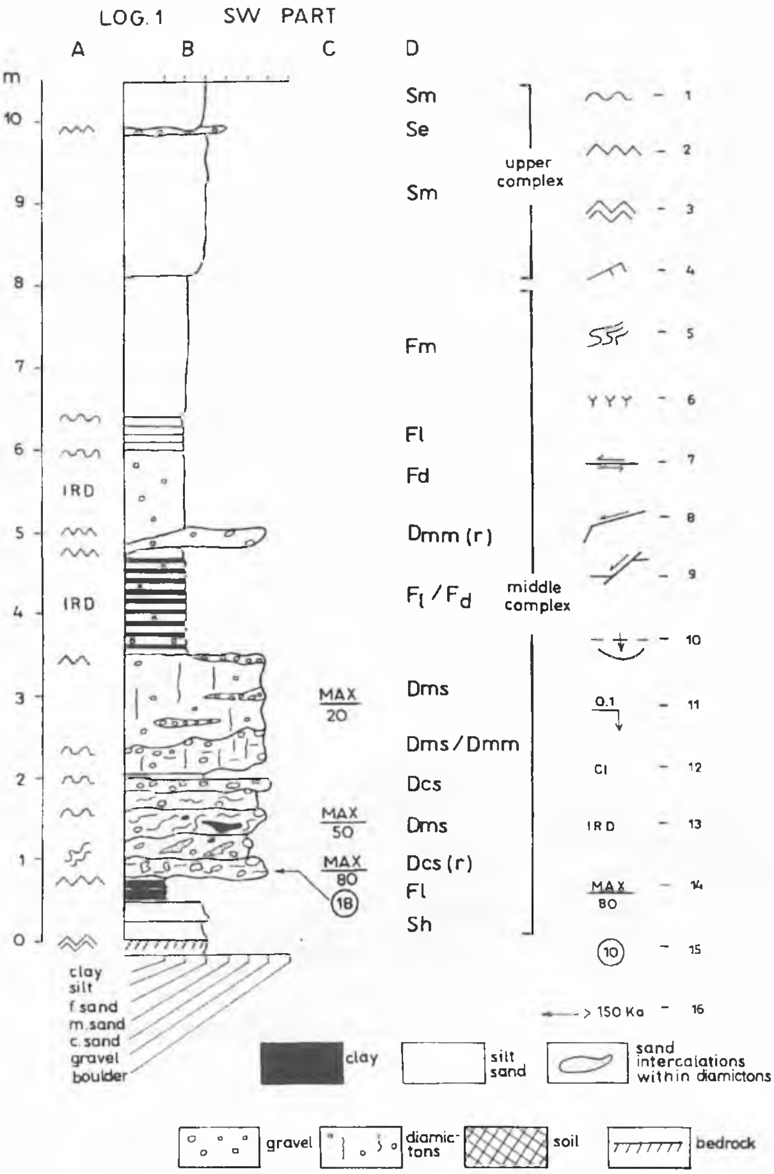


Fig. 6. Sedimentological log of Quaternary sediments exposed in the south-western part of the quarry (log 1): **A** – processes and structures, **B** – lithological log, **C** – sampling sites, maximum clast fraction, palaeotransport directions, **D** – lithofacies codes; symbols: *1* – depositional contact, *2* – erosional contact, *3* – distinct hiatus, *4* – ripplemarks, *5* – gravity flow, *6* – rootlets, *7* – shear plane, *8* – slip plane, *9* – fault plane, *10* – local depression, *11* – deformational horizon with vertical extent of 0.1 m, *12* – increase of $CaCO_3$ content, *13* – ice-rafted debris, *14* – maximum clast diameter in millimetres, *15* – sampling points, *16* – TL age determinations. For location see Figs. 4 and 5

Quartz grains could have been derived either from Scandinavia, Northern Poland or local rocks. In the last case, their source are Callovian sandstones (Fig. 4, site 14; *cf.* Fig. 12, sample 19), containing 70–85% of quartz, or regoliths of Upper Carboniferous sandstones exposed west of Tenczynek (Fig. 12, sample 20), and comprising 71–96% of quartz.

The Scandinavian material is represented first of all by crystalline rocks. These are pink and grey granitoids, rarely pink porphyres and gneisses. Pink Jotnian quartzites occur sporadically. The proportion of Scandinavian rocks in individual samples changes from 0 to >35%. These rocks occur in some samples only, being most frequent within diamictons exposed in the western part of the pit (*cf.* Fig. 12, sample 18), as well as in glaciofluvial gravels (sample 15). Crystalline rocks of Scandinavian provenance are present in all grain-size classes. The largest erratic blocks, usually granitoids, are infrequent and attain a few tens of centimetres in diameter.

An important component of the sediments in question are also grey or blue-grey, sometimes marly limestones that bear abundant remains of brachiopods, bivalves, crinoids and, rarely, trilobites, derived from Ordovician and Silurian strata of the south-eastern Scandinavia. Their occurrence is restricted to glacial diamictons wherein their content attains some 25%.

Glacial diamictons contain as well hard, compact limestones of unknown age. They could represent either more compact varieties of Jurassic limestones or Lower Carboniferous limestones that crop out near Czatkowice.

In exceptional cases, the diamictons contain fragmented shells of oysters, several milimetres thick, pitted sometimes by Cliona-produced burrows, 1 mm in diameter. These shells have been derived from marine Miocene strata. There also occur fragments of white calcirudites and medium- to coarse-grained calcareous sandstones of similar provenance. In addition, dark-grey, nearly black, hard and compact chunks of lignite derived from freshwater Miocene sediments, have also been found.

From the petrographic point of view, the diamictons occurring at Niedźwiedzia Góra can be subdivided into two groups. The first crops out in the eastern part of the exposure, where the diamictons contain mainly Jurassic limestones (Fig. 12, samples 3, 7, 9), and whose petrographic composition does not change from one grain-size class to another. The other components, like crystalline rocks and limestones of Scandinavian provenance, as well as sandstones, quartzites and cherts make up 30%, exceptionally to 40% of all clasts. Jurassic limestones are abundant both in gravelly and more clayey varieties of diamictons.

The second group, occurring in the western part of the exposure (Fig. 12, sample 18), comprises mostly Scandinavian material (crystalline rocks and Lower Palaeozoic limestones), with a minor admixture, up to few percent, of Jurassic limestones. There also occur clasts of diabases, whose ratio increases from a few per cent within small-size grains to a dozen or so per cent in coarse-grained sediment. Quartz shows the opposite tendency.

Another character display two samples of diamictons collected in the eastern part of the pit. The material immedi-

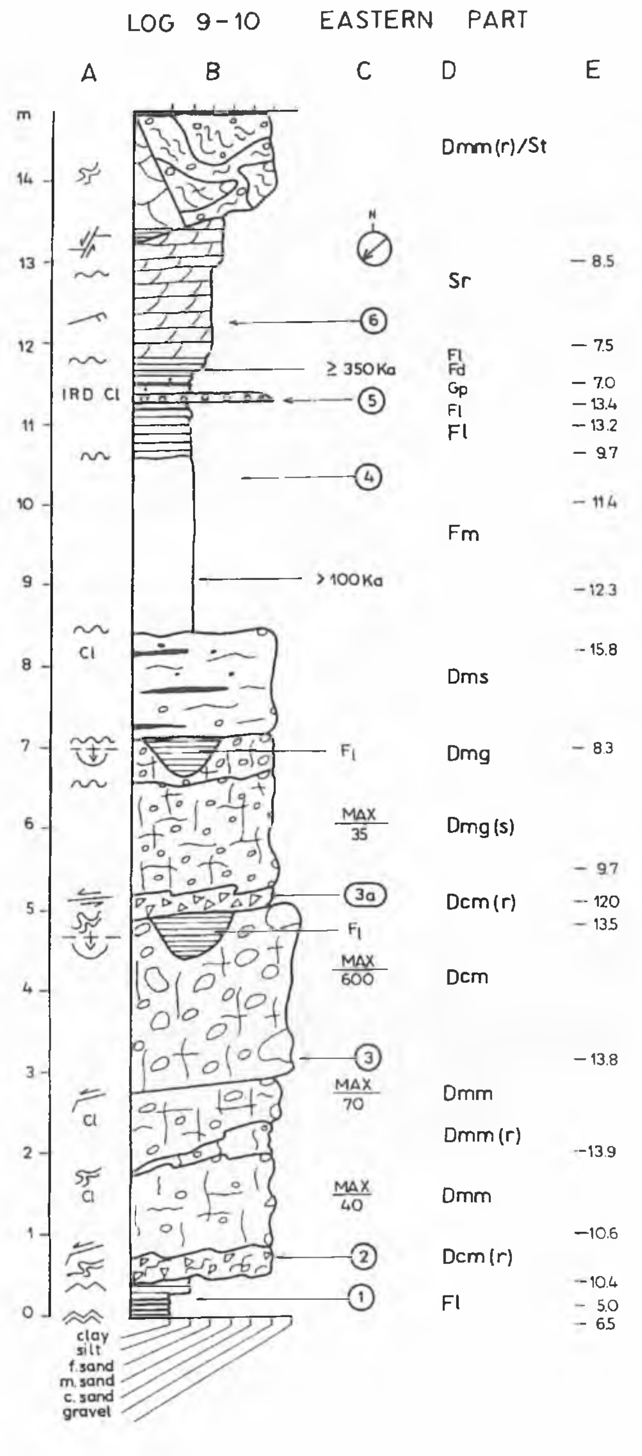


Fig. 7. Sedimentological log of Quaternary middle complex sediments exposed in the eastern part of the quarry (log 9–10); E – $CaCO_3$ content in per cent. For location see Figs. 4 and 5; other explanations in Fig. 6 and Table 1

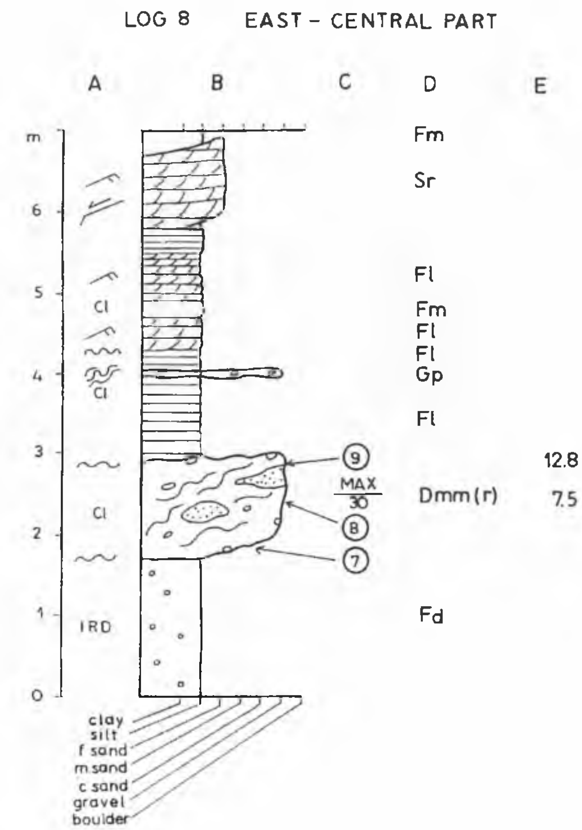


Fig. 8. Sedimentological log of Quaternary middle complex sediments exposed in the east-central part of the quarry (log 8). For explanations see Figs. 6, 7 and Table 1; location in Figs. 4 and 5

ately overlying varved clays (Figs. 7, 12, sample 2) contains nearly exclusively diabases, with a negligible admixture (0.6%) of cherts and crystalline rocks of Scandinavian provenance. A sample collected from the higher part of the section contains only angular fragments of Jurassic limestones. These sediments can be interpreted as representing debris flows shed from diabase or limestone weathering mantles.

The inventory of heavy minerals (Table 2), fraction <0.5 mm, is dominated by zircon. The ratio of poorly resistant (amphiboles, pyroxenes, andalusite, sillimanite) minerals, most probably glacially-derived, is clearly higher in sample 18 than in sample 3, which conforms with the higher content of crystalline rocks in the former sample (Fig. 12, samples 18, 3).

Gravels

The middle complex of glacial sediments in the Tenczynek Basin contains infrequent intercalations of sands and gravels. Their thickness, judging from well-log description, ranges from 2–3 m to even 10 m (Fig. 3). An irregular intercalation of gravels, a dozen cm thick, has been found within glaciolacustrine silts (Fig. 10, sample 15) in the central part of the pit.

These gravels (Figs. 11, 12, sample 15) represent a poorly sorted mixture of sand, gravel and silt. Cobbles occur sporadically. Petrographic composition of small-size clasts (Fig. 12) is dominated by quartz and Scandinavian-derived crystalline rocks, whose proportion diminishes with the diminishing grain size. Another tendency display cherts, whose ratio in the coarsests fractions exceeds 50%. Such a feature is typical for Quaternary gravels of the Kraków region (Rutkowski & Sokołowski, 1983; Rutkowski, 1995).

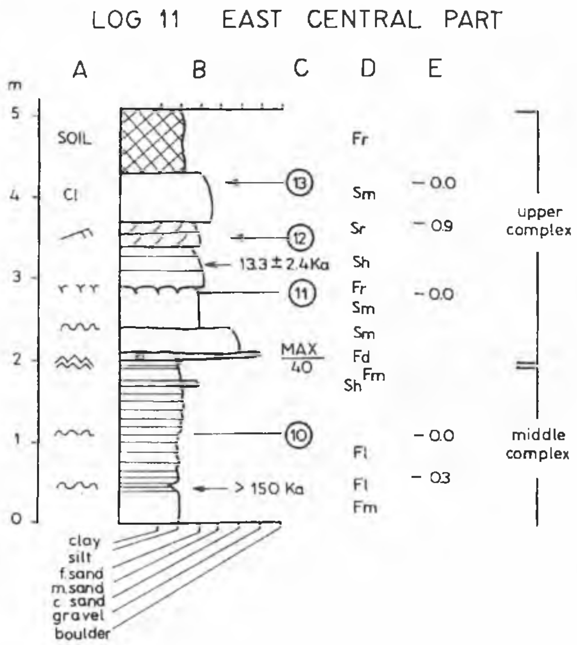


Fig. 9. Sedimentological log of Quaternary sediments exposed in the east-central part of the quarry (log 11 situated above log 9–10). For explanations see Figs. 6, 7 and Table 1; location in Figs. 4 and 5

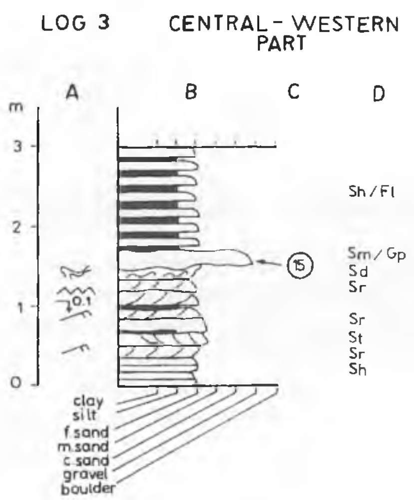


Fig. 10. Sedimentological log of Quaternary middle complex sediments exposed in the central-western part of the quarry (log 3). For explanatons see Fig. 6 and Table 1; location in Figs. 4 and 5

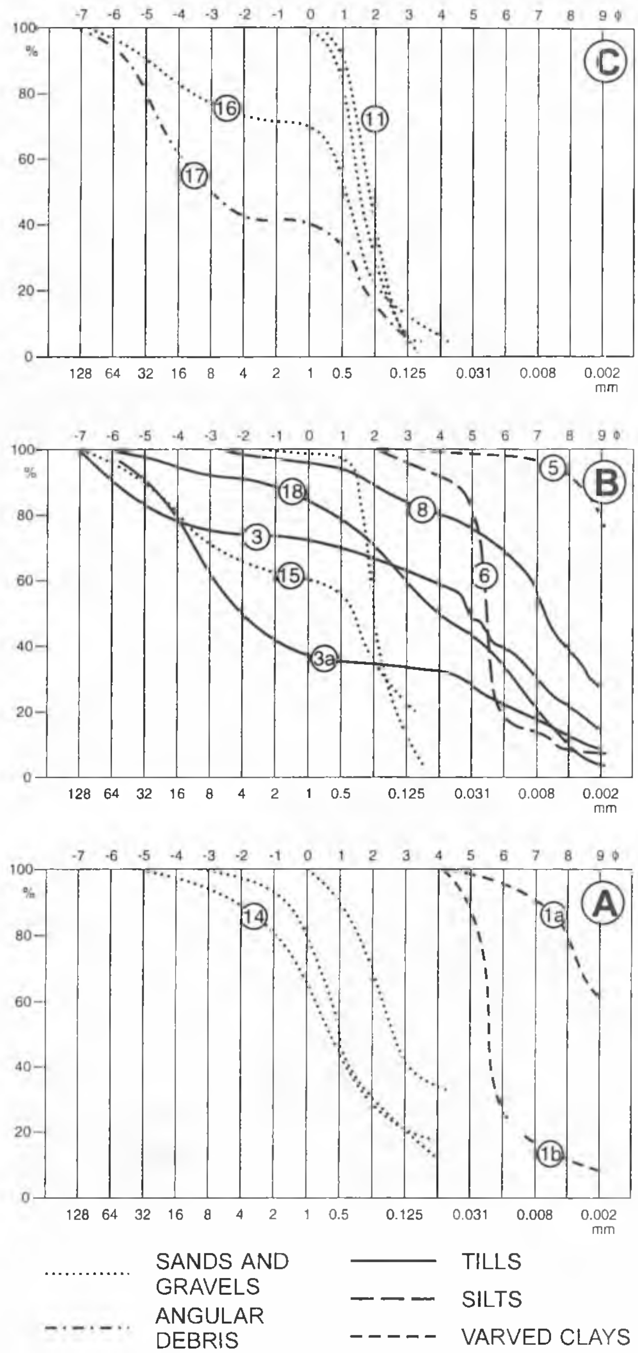


Fig. 11. Grain-size composition of main types of Quaternary sediments in the Niedźwiedzia Góra pit: A – lower complex and varved clays from the base of the middle complex, B – middle complex, C – upper complex

One should take notice of the complete lack of carbonate clasts which have probably been dissolved by ground waters. Similar regularity has been observed throughout glacial sediments of the Kraków, Miechów and Witów areas (Rutkowski, 1995).

The assemblage of heavy minerals differs from that of diamictons by higher content of zircon and a smaller amount of poorly-resistant minerals (Table 2, sample 15).

The gravels in question are of glaciofluvial origin. However, the relatively high ratio of cherts indicates that transporting water must have been enriched in extraglacial material. This is also confirmed by the character of heavy mineral assemblages. The lack of carbonates can be associated with postdepositional decalcification.

Discussion

Comparing the petrographic composition of diamictons (fraction 16–32 mm) of Tenczynek Basin with clayey tills from Bibice near Kraków (*cf.* Rutkowski, 1993) one can conclude that the latter comprise 16.4% of Scandinavian

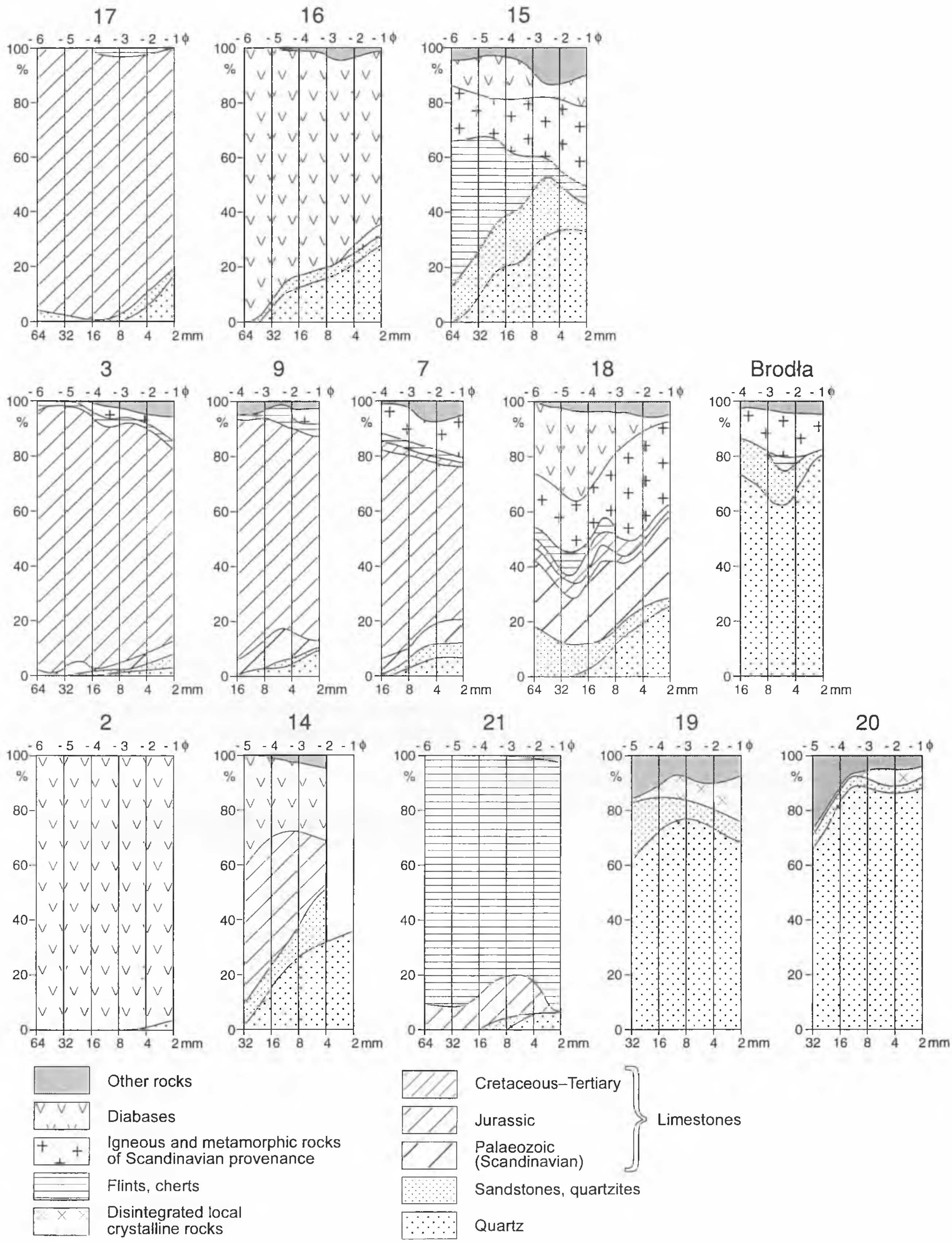


Fig. 12. Petrographic composition of gravel-size fraction. Quaternary sediments (*cf.* Figs. 2 and 6–10) – upper complex: 17 – debris flow, 16 – gravels; middle complex: 15 – glaciofluvial gravels, 3 – diamictons from the eastern part (log 9–10), 9 and 7 – diamictons from the east-central part (log 8), 18 – diamicton from the western part (log 1), Brodła – diamictons of Elsterian age, 2 – debris flow deposits from the base of log 9–10; lower complex: 14 – gravels. Pre-Quaternary strata (*cf.* Fig. 2): 21 – Tertiary (close to Niedźwiedzia Góra), 19 – Callovian (Niedźwiedzia Góra), 20 – Upper Carboniferous regoliths (west of Tenczynek)

Table 2

Heavy mineral composition (%) of Quaternary sediments expoased at the Niedźwiedzia Góra pit (det. by M. Krysowska-Iwaszkiewicz); fraction <0.5 mm

sediment	diamictons		glaciovluvial gravels	coversands	
sample #	**3**	**18**	**15**	**11**	**13**
garnet	36.0	53.5	11.0	25.0	42.0
zircon	26.5	10.5	40.0	38.5	17.5
tourmaline	4.0	3.5	5.5	6.0	5.5
rutile	5.0	2.0	12.0	8.5	1.5
staurolite	2.0	1.5	8.0	4.0	6.5
kyanite	3.5	1.5	1.5	–	1.5
epidote	4.5	4.5	3.5	6.5	11.5
zoisite	0.5	1.0	–	1.0	0.5
titanite	4.5	–	2.5	–	–
topase	1.0	2.0	3.5	2.5	1.0
monazite	1.0	2.0	1.5	2.0	1.5
amphibole	6.5	14.5	6.0	3.5	7.0
pyroxene	4.0	2.5	3.5	1.5	2.5
andalusite	1.0	1.0	1.0	0.5	1.0
syllimanite	–	–	–	0.5	0.5

crystalline rocks, 20.7% of cherts and 35.3% of unweathered Jurassic, Scandinavian and Miocene limestons. Such a picture resembles that encountered at Niedźwiedzia Góra. As compared to glaciofluvial gravels from north-eastern Poland, the described gravels include considerably more local material at the expense of the Scandinavian one.

The difference between clasts separated from diamictons and those of glaciofluvial gravels consists in postdepositional dissolution of carbonates in the latter. Analogous processes have commonly been observed within glaciofluvial sediments in Kraków (Prokocim, Library of Collegium Medicum) that comprise 30.4% of crystalline rocks and 11.7% od cherts, but not carbonates. At another site west of Kraków (Bogucianka near Tyniec), glacial and glaciofluvial sediments contain 26.4% of crystalline rocks, 19.2% of cherts, and only 2.6% of Jurassic limestones derived from the bedrock.

UPPER COMPLEX

The upper complex is composed predominantly of sands which unconformably overlie the eroded top of sediments of the middle complex. The thickness of this discontinuous cover in the Tenczynek Basin does not exceed 10 m (Fig. 3, section VI–VI'). Moreover, the sands build a vast cover overlying older sediments upon slopes and interfluves of nearby hills, rising up to 400 m a.s.l. In few cases, the sand cover is overtopped by small dunes, particularly west of Tenczynek.

In the excavation pit at Niedźwiedzia Góra the sands are usually yellow-greyish, rarely rusty, and medium to fine-grained (Fig. 11, samples 11, 13). They are either rippled, massive or showing horizontal lamination. Infrequent erosional scours are to be encountered as well. The mean grain diameter Mz is 1.69–1.88 phi (0.27–0.31 mm). The sands are moderately sorted (σ_1 0.64–0.69). Coarse-grained sand grains reveal surfaces indicative of aeolian reworking. The sands are mostly devoid of carbonates or contain a minor admixture of $CaCO_3$.

The variable proportion of resistant and nonresistant heavy minerals (Table 2) indicates that these sands have been derived both from glacial sediments and pre-Quaternary bedrock.

The base of the sand cover (Figs. 5, 6, 9) contains at places a marked admixture of gravels. The mean grain diameter Mz is is here 0.27 phi (0.83 mm), the sorting is very poor (σ_1 *ca.* 3.2 phi), and gravels are usually composed of diabase clasts (Figs. 5, 12, sample 16). Some of these clasts are unweathered or show traces of aeolian reworking.

In the eastern part of the pit (Figs. 4, 5, log 13, Fig. 12, sample 17) an interlayer of angular debris, 0.5 m thick, has been found within the sands. It comprises 52.7% of gravel and 5.9% of cobble-size fraction. The mean grain diameter Mz is 2.07 phi (0.24 mm), the sorting is very poor (σ_1 3.23 phi), and the largest clasts attain a dozen centimetres in diameter (Fig. 11). The latter are mainly angular fragmens of Oxfordian limestones with subordinate admixture of sandy and organogenic Callovian limestones (Fig. 12, sample 17). The whole intercalation appears to represent a solifluction tongue.

DIAMICTON LITHOFACIES OF THE MIDDLE COMPLEX: DESCRIPTION

The middle complex comprises the major part of sediments exposed at the Niedźwiedzia Góra pit (Fig. 5) and, therefore, provides some clues to sedimetological interpretation of glacigenic sediments of the Elsterian stage. The poor state of exposure does not allow us to draw a detail picture of spatial distribution of individual diamicton lithofacies; the following description is based on a few logs which were accessible to observation (Figs. 4–10, Table 1).

Matrix-supported, massive diamictons [Dmm]

These deposits occur in logs 9–10 and 1 (Figs. 6, 7), being represented by 0.4 to 1.1 m thick bodies of brown and brown-grey diamictons with infrequent, chaotically dispersed clasts 0.5–1 cm to 7 cm in diameter, averaging at 2–4 cm. No striation or polishing has been found. The $CaCO_3$ content increases from the bottom upwards.

Matrix-supported, massive diamictons with evidence of resedimentation [Dmm(r)]

They build lenticular bodies, 10–45 cm thick, observed at logs 9–10, 8 and 1 (Figs. 7, 8, 6) and composed of dark-brown, calcareous, clayey diamictons, resting within massive, brown-grey and calcareous sediments with small clasts of limestones (log 9–10). At the top of log 9–10 (Fig. 7) these deposits are represented by wedges of clayey diamictons, underlain by a 20–30 cm thick layer of lacustrine rhythmites, embedded within very fine-grained and silty sands. The whole unit is here strongly disturbed and cut on the SW by a normal fault, separating the diamictons from lacustrine silts. The diamictons of log 8 (Fig. 8) bear rare clasts, 0.5–3 cm in diameter, and isolated lenses of light-grey silts and ellipsoidal lumps of very fine-grained and silty sands, 6 15 cm in size. They are underlain by massive silts with ice-rafted debris and overlain by laminated silts. It is the only one interlayer of diamictons observed in this log. In log 1 (Fig. 6), 20 cm-thick lenses of massive diamictons with lumps of sands embedded within silt-clayey matrix, and bearing infrequent clasts 2–5 mm to 1 cm in diameter, have been found.

Matrix-supported, stratified diamictons [Dms]

The topmost part of diamicton series in log 9–10 (Fig. 7) is represented by 1.3 m thick brown-grey, strongly calcareous, diamictons with irregular intercalations of silts and showing faint lamination. Clasts are small and infrequent, usually 2–4 mm to 2 cm in diameter, and chaotically orientated. In the topmost part, isolated clasts of Jurassic limestones, 5–7 cm across, occur. In log 1 (Fig. 6), this lithofacies occurs twice. The lower layer is 0.8 m thick and composed of grey diamictons with isolated clasts 0.5–1 cm to 3–5 cm in diameter, including lenticular bodies of finely laminated silts, 5–8 cm long. The upper part of this layer bears more lenses of cross-laminated, white-grey silts, alternating with silty clays and steel-grey clays. Lenticular silt bodies, 2–4 cm thick and 5–6 cm long, resemble flow structures. The topmost part, 20 cm thick, shows discontinuous wavy lamination. The second, upper layer of Dms in log 1 (Fig. 6) is 1.5 m thick and composed of grey diamictons with chaotically orientated clasts, 0.5–2 cm in diameter, and bearing thin, irregular lenses enriched in clasts 2–3 mm to 1.5 cm in diameter.

Matrix-supported, graded diamictons [Dmg]

These are 0.5 m thick bodies of grey-brown, calcareous diamictons occurring in log 9–10 (Fig. 7). They contain clasts 2–3 mm to 1–2.5 cm in diameter, their size decreasing from the bottom upwards. The top is truncated by a melt-out depression, 1 m in diameter and 0.5–0.6 m deep, filled with grey-bluish silts.

Matrix-supported, graded and sheared diamictons [Dmg(s)]

In log 9–10 (Fig. 7) they are represented by a 1.4 m thick layer of grey-brown, calcareous diamictons with clasts 0.5–1 cm to 6–7 cm in diameter, averaging at 2–3 cm. The diamictons are massive, show platy fissility, and are cut at places by subvertical joints. Apart from dominant Jurassic limestones, cherts 3–3.5 cm in diameter and infrequent quartz granules, 1 cm across, are to be found. The contact with underlying Dcm(r) is sheared, the upper boundary of sedimentary character.

Clast-supported, massive diamictons [Dcm]

In log 9–10 (Fig. 7) these are 2.1 m thick light-grey and brown-grey, massive diamictons with numerous clasts, 20–27 cm to 60 cm in diameter, dominated by Jurassic limestones. The base is of tectonic character; the whole unit is tilted to S20°W. Thin interlayers of light-grey diamictons occur as well. The $CaCO_3$ content is variable, from moderate to significant. The top is truncated by a depression, 4.5–5 m long and 0.6 m deep, probably of melt-out origin, filled with a 5 cm thick layer of laminated clays overlain by bluish massive silts.

Clast-supported, massive diamictons with evidence of resedimentation [Dcm(r)]

In log 9–10 (Fig. 7), these deposits immediately overlie the basal varved clays and form an intercalation within the middle part of the diamicton series. The lower layer is represented by yellow-brown and rusty, sandy, carbonate-free loams, bearing abundant angular debris of diabases, 0.5–7.0 cm in diameter, averaging at 1.2–2.5 cm. No traces of Scandinavian material has been found. The layer dips 200/20 and resembles a debris-flow deposit shed from the nearby slope. The upper layer in this log, also of the debris-flow type, is represented by grey loams with abundant angular debris of Jurassic limestones, 2–3 cm in diameter.

Clast-supported, stratified diamictons [Dcs]

In log 1 (Fig. 6) these deposits, 20 cm thick, rest within Dms sediments. These are sandy diamictons with numerous clasts 2–5 mm to 2–3 cm in diameter.

Clast-supported, stratified diamictons with evidence of resedimentation [Dcs(r)]

In log 1 (Fig. 6) they immediately overlie the basal varved clays. These are 20 cm thick, rusty-brown, sandy silts bearing angular clasts of diabases, 0.5–8 cm in diameter, as well as erratic clasts, 5 cm across. The base is erosional, the contact with overlying deposits being of sedimentary character.

Discussion

The thickest series of diamictons has been found in the eastern and east-central part of the Niedźwiedzia Góra pit. The central and western parts bear no or only isolated, thin, lense-like bodies of diamictons (Fig. 5). These bodies either overlie the basal varved clays (logs 1 and 9–10; Figs. 6, 7) or form irregular intercalations within massive or – rarely – laminated silts with dropstones. Poor state of the exposure does not allow for reconstruction of the diamicton architecture; it appers, however, that individual layers are discontinuous and certainly do not resemble lodgement tills. The predominantly matrix-supported diamictons, either showing traces of resedimentation or crude stratification, underlined by thin interlayers of silts or sands, probably represent flow tills or – at least in case of some of the layers in log 9–10 (Fig. 7) – melt-out tills (*cf.* criteria listed in Bennett & Glasser, 1996). The clast-supported diamicton varieties, found both in log 9–10 (Fig. 7) and 1 (Fig. 6) represent debris flow deposits, probably shed from nearby slopes built up from Permian diabases or Jurassic limestones.

AGE OF THE MIDDLE COMPLEX

Thermoluminescence age determinations, performed on silts sampled in the eastern and east-central parts of the middle complex exposed at the Niedźwiedzia Góra pit (Figs. 7, 9) are, from the bottom upwards: >100 ka (GdTL-342), ≥350 ka (GdTL-344), and >150 ka (GdTL-343). These ages and their inversion indicate that the material studied is beyond the lower datable limit.

INTERPRETATION

The facies inventory described in the preceding paragraphs suggests that the exposed part of the middle complex at Niedźwiedzia Góra was deposited in a terminoglacial lake (*sensu* Brodzikowski, 1993), close to the icesheet margin. The most complete sequence of sediments is represented by logs 9–10, 8 and 11 (Figs. 5, 7–9) that appear to reflect a part of the cycle of glacial advance and standstill.

The onset of the terminoglacial lake formation is marked by a relatively thin cover of varved clays, upon which debris flows from the surrounding slopes were shed. Higher up the section thin layers of melt-out and/or flow tills appear, being replaced by glaciolacustrine silts with occasional cross-laminated silt intercalations, marking episodes of sporadic flow. Infrequent dropstones shed from small icebergs occur as well. The topmost part of the eastern log (Fig. 7) is marked by lacustrine rhythmites, disturbed by wedges of flow tills. The deformation pattern of the deposits includes compaction-induced fissility, minor faults, subvertical fractures, diapiric and flow structures (Figs. 13–18), which may indicate ice disintegration, associated with areal deglaciation (*cf.* Eyles *et al.*, 1983; Kozarski, 1987; Brodzikowski & Van Loon, 1991; Brodzikowski, 1993; Bennett & Glasser, 1996).

In the western section of the Niedźwiedzia Góra exposure (log 1, Fig. 6) the lithofacies transition within the middle complex reflects the nearly complete record of a glacial cycle: starting from outwash sands overlain by varved clays, through a reduced sequence of melt-out and flow tills, to glaciolacustrine silts with infrequent dropstones, bearing as well isolated wedges of flow tills. The top part of the sequence is dissected again by erosional scours filled by fine-grained, cross-bedded and then massive sands. The upper parts of logs 9–10 and 1 (Figs. 6, 7), dominated by facies Fl and Fm, appear to resemble the Slims type facies assemblage of outwash rivers, distinguished by Miall (1978, 1996).

The lacustrine sediments in logs 8 and 11 (Figs. 5, 8, 9) are cut by an erosional surface, upon which much more younger sands were deposited. These sands are either massive or show low-angle cross lamination, rarely horizontal lamination, and bear traces of erosional scours and ice-wedge casts, alongside with debris flows with local material (log 13, Fig. 5) that represent solifluction tongues. All these properties point to activity of flowing waters under periglacial conditions, aided by aeolian remodelling of the topmost part of the sediments. From the stratigraphic point of view, the sands of the upper complex could have been deposited in a time-span ranging from the decline of Elsterian stage up to the Holocene. A TL date of 13.2 ± 2.4 ka (GdTL-341) from the eastern part of the pit (Fig. 4, site 11; Fig. 9) points, however, to a Late Weichselian age.

DEFORMATIONS IN QUATERNARY SEDIMENTS

Quaternary sediments that compose the middle complex at Niedźwiedzia Góra are strongly disturbed by faults, fractures, folds, tilting and overturning of beds (Figs. 6, 7; *cf.* also Figs. 13–18). These disturbances can be either of synsedimentary or glaciotectonic character (Figs. 14–18).

Minor synsedimentary deformations include those related to dropstones shed from the melting icebergs. These structures, few centimetres deep, have been observed within glaciolacustrine silts and silty clays in the eastern part of the pit. The other examples are represented by ellipsoidal lumps of diamictons slumped into lacustrine silts (Fig. 6).

The second group comprises deformations probably formed due to dynamic and/or static pressure of ice. Such structures are ubiquitous throughout the excavation pit (Figs. 13–18), their frequency and intensity increasing from the bottom towards the top of the middle horizon. In the eastern part (Fig. 7) the bedding is nearly horizontal, although individual layers of diamictons display minor displacements along subhorizontal surfaces. The upper part of the log in question is cut by a steeply dipping normal fault that separates very fine-grained and silty sands and clayey diamictons (Fig. 7). In the central part of the southern excavation wall (Fig. 4, site 3) silts and diamictons lie subhorizontally. Immediately east of this site (site 9–10), however, the diamictons are cut by a subvertical fault, across which strongly clayey diamictons occur. A moderate, several degrees tilting of silty beds is also observed in the central part of the pit, close to the gravel intercalation (Fig. 7). Further west of this site, in turn, the beds dip a few tens of degrees towards the SW in a limb of an overturned fold. Subhorizontal folds, sometimes of the sheath fold type within glaciolacustrine silts (Fig. 17), frequently observed in the south-western part of the exposure, represent at places a transition from folding to tectonic lamination (*cf.* Bennett & Glasser, 1996).

We conclude that most of the above structures are the effects of penecontemporaneous deformations, whereas static pressure exerted by ice produced diamicton wedges or diapirs (Figs. 13, 14, 18), similar to those described by Brodzikowski (1985) from the Kleszczów Graben. Some of the deformation structures could have also been related to dynamic pressure of the icesheet front (Figs. 15, 16).

FINAL REMARKS

The Tenczynek Basin is the only locality of glacial diamictons and glaciolacustrine sediments near Kraków that due to its location in an open diabase quarry is easily accessible to Quaternary geologists.

The basin represents a depression formed in the poorly

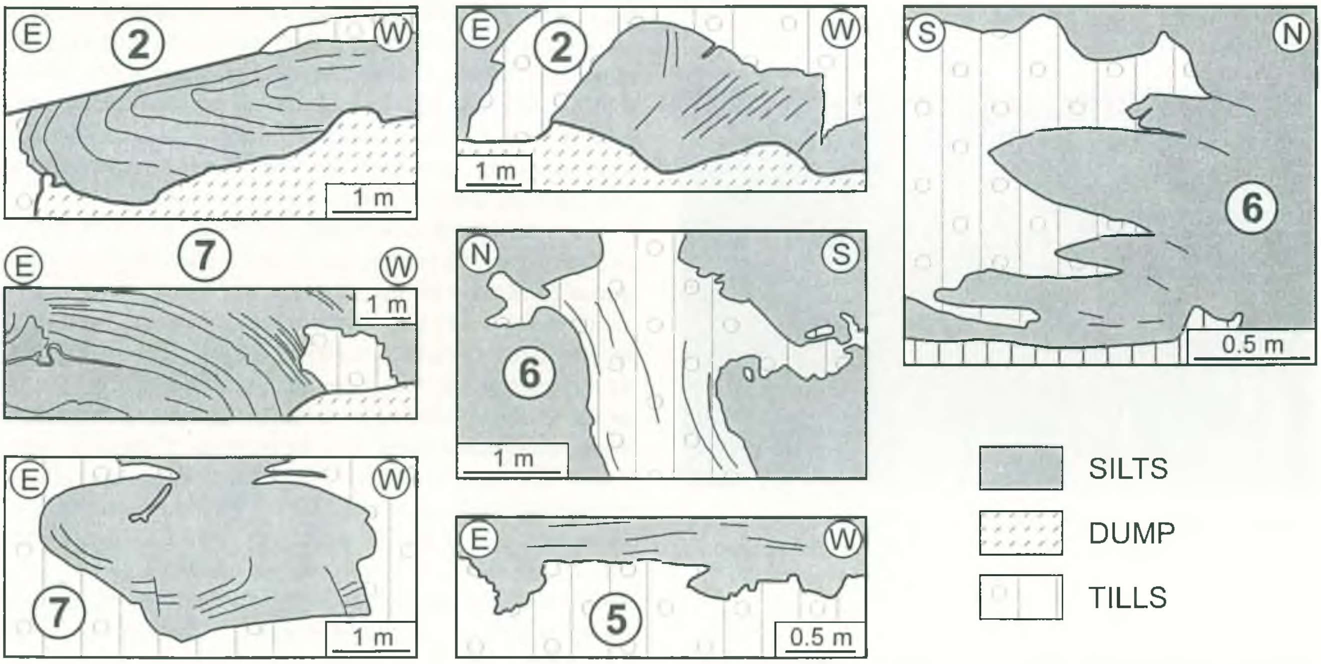


Fig. 13. Drawings of deformations visible within the middle complex at Niedźwiedzia Góra pit. Circled numbers refer to logs shown in Figs. 4 and 5

resistant Carboniferous coal measures. Its origin is not fully understood, since the basin margins have been drilled by infrequent wells and, therefore, their possible association with Pliocene valleys, passing through the Krzeszowice Graben, as well as the Sanka and Rudno stream valleys (*cf.* Dżułyński *et al.*, 1966), remains unclear. The basin could have been eroded either due to fluvial activity before or during the Sanian (Elsterian-2) icesheet advance, or due to glacial scour-

Fig. 14. Diapiric fold deforming clayey diamictons, squeezed into glaciolacustrine silts. Central part of the Niedźwiedzia Góra pit, close to log 6

Fig. 15. Inclined fault-propagation fold deforming glaciolacustrine silts in the central part of the Niedźwiedzia Góra pit, close to log 7. Exposure *ca.* 7 m tall

Fig. 16. Hinge zone of an upright open fold, cut by small-scale normal faults and joints. Central part of the Niedźwiedzia Góra pit

Fig. 17. Hinge zone of an overturned fold deforming glaciolacustrine silts in the south-western part of the Niedźwiedzia Góra pit

Fig. 18. Conjugated shears within laminated glaciolacustrine silts in the central part of the Niedźwiedzia Góra pit

ing. It appears, however, that the basin is clearly of erosional character and that it existed long before the Elsterian advance. Some gravels of the lower complex are of Pliocene or early Quaternary age. The advancing icesheet blocked the outflow from the basin at an elevation of 240–250 m a.s.l. Melting waters could have deposited sands and gravels that now build the topmost part of the lower complex.

A younger episode of blocking the outflow, at *ca.* 300 m a.s.l. or higher, turned the basin into a terminoglacial lake, gradually filled with varved clays and laminated silts that compose the lower part of the middle complex. Infrequent delivery of coarse-clastic material was provided by the melting icebergs. In the next stage, the basin became covered by the advancing Elsterian-2 icesheet which, at the incipient phase, encroached upon outliers built up of Jurassic limestones. The melting of such a lobe led to deposition of diamictons rich in Jurassic material, which are exposed now in the eastern part of the Niedźwiedzia Góra pit. Higher-situated ice layers were sliding over stagnating basal ice, their contact with the bedrock being negligible. The diamictons left by these layers, presently exposed in the western part of the pit, contain a minor admixture of Permian diabases and Jurassic limestones, but are enriched in far-travelled material. Similar regularities have been described by Lamparski (1970) from the northern slopes of the Holy Cross Mts. of Central Poland.

Both in- and extraglacial waters played a minor role during the deposition of glacial deposits of the middle complex, leaving infrequent layers of sands and gravels. These waters carried a large proportion of local material, dominated by Jurassic cherts.

Diamictons and glaciolacustrine sediments have undergone significant syn- and postdepositional deformation, due to either lateral and vertical pressure exerted by the advancing icesheet or during another (?), short-term icesheet advance. Similar features have been reported from Brzozowica near Będzin, where varved clays and sands of Elsterian (Lewandowski, 1987) or Middle-Polish Glacial age (Gilewska, 1963) were strongly deformed during a subsequent oscillation of the same icesheet.

The extensive sand cover in the Tenczynek Basin appears to be of mostly fluvial origin and contains at places wedges of debris flows that represent solifluction tongues. Aeolian remodelling made its appearance in the final stage of sand deposition.

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REFERENCES

Bennett, M. R. & Glasser, N. F., 1996. *Glacial Geology. Ice Sheets and Landforms*. Wiley & Sons, Chichester, 364 pp.

Brodzikowski, K., 1985. Glacial deformation environment in the subsiding zone with special reference to the Kleszczów tectonic graben. *Quatern. Stud. Poland*, 6: 5–22.

Brodzikowski, K., 1993. Glacilacustrine sedimentation. Part I. Depositional processes and lithofacies characteristics. (In Polish, English summary). *Acta Geogr. Lodziensia*, 62: 1–162.

Brodzikowski, K. & Van Loon, A. J., 1991. *Glacigenic Sediments*. Elsevier, Amsterdam, 674 pp.

Doktorowicz-Hrebnicki, S., 1954. *Mapa geologiczna Górnośląskiego Zagłębia Węglowego 1: 50 000, arkusz Krzeszowice*. Państw. Inst. Geol., Warszawa.

Dżułyński, S., 1953. Tectonics of the southern part of the Cracow Upland. (In Polish, English summary). *Acta Geol. Polon.*, 3: 1–340.

Dżułyński, S., 1956. Przewodnik wycieczki na południowy brzeg Wyżyny Krakowskiej XXVII Zjazdu Polskiego Towarzystwa Geologicznego. (In Polish only). *Rocz. Pol. Tow. Geol.*, 24: 435–448.

Dżułyński, S., Henkiel, A., Klimek, K. & Pokorny, J., 1966. The development of valleys in the southern part of the Cracow Upland. (In Polish, English summary). *Rocz. Pol. Tow. Geol.*, 36: 329–343.

Eyles, N., Eyles, C. H. & Miall, A. D., 1983. Lithofacies types and vertical profile models: an alternative approach to the description and environmental interpretation of glacial diamict and diamictite sequences. *Sedimentology*, 30: 393–410.

Gilewska, S., 1963. Relief of the Mid-Triassic escarpment in the vicinity of Będzin. (In Polish, English summary). *Prace Geogr. IG PAN*, 44: 1–135.

Gilewska, S., 1972. Wyżyny Śląsko-Małopolskie. (In Polish only). In: Klimaszewski, M. (ed.), *Geomorfologia Polski*, T. 1, PWN, Warszawa, pp. 232–339.

Kozarski, S., 1987. Depositional models and ice-front dynamics in NW Poland: a methodological approach. *Geogr. Polon.*, 53: 43–51.

Lamparski, Z., 1970. The dynamics of ice movement of the marginal part of the ice sheet during the advance of the Middle Polish glaciation onto the north-eastern slopes of the Holy Cross Mts. (In Polish, English summary). *Acta Geol. Polon.*, 20: 587–602.

Lewandowski, J., 1987. Odra Glaciation in the Silesian Upland. (In Polish, English summary). *Biul. Geol. Uniw. Warsz.*, 31: 247–312.

Lindner, L., 1991. Main units of subdivision of Pleistocene of Poland. (In Polish, English summary). In: Kostrzewski, A. (ed.), *Geneza, litologia i stratygrafia utworów czwartorzędowych*. Wydawnictwo UAM, Ser. Geografia, 50, Poznań, pp. 519–530.

Lindner, L., Wojtanowicz, J. & Bogutsky, A. B., 1998. Main stratigraphical units of the Pleistocene in southeastern Poland and the northwestern Ukraine, and their correlation in Western and mid-eastern Europe. *Geol. Quart.*, 42: 73–86.

Miall, A. D., 1977. A review of the braided-river depositional environment. *Earth Science Reviews*, 13: 1–62.

Miall, A. D., 1978. Lithofacies types and vertical profile models in braided river deposits: a summary. In: Miall, A. D. (ed.), *Fluvial Sedimentology. Can. Soc. Petrol. Geol. Memoir*, 5: 597–604.

Miall, A. D., 1996. *The Geology of Fluvial Deposits. Sedimentary Facies, Basin Analysis, and Petroleum Geology*. Springer, Berlin-Heidelberg, 582 pp.

Płonczyński, J. & Łopusiński, S., 1992. *Szczegółowa mapa geologiczna Polski 1: 50 000, arkusz Krzeszowice*. Państw. Inst. Geol., Warszawa.

Rutkowski, J., 1977. On petrographic variability of Holocene gravels in the Polish Carpathians. *Studia Geomorph. Carpatho-Balcan.*, 11: 53–65.

Rutkowski, J., 1987. O niektórych trzecio- i staroczwartorzędowych żwirach rejonu Krakowa. (In Polish only). In: Rutkowski, J. (ed.), *Trzecio- i staroczwartorzędowe żwiry Kotliny Sandomierskiej*. Mater. Konf. Kom. Bad. Czwart. PAN, Kraków, pp. 24–26.

Rutkowski, J., 1993. *Objaśnienia do szczegółowej mapy geologicznej Polski 1: 50 000, arkusz Kraków*. (in Polish only). Państw. Inst. Geol., Warszawa, 46 pp.

Rutkowski, J., 1994. Warunki tektoniczne występowania wapieni jurajskich na południe od Krzeszowic. (In Polish only). *Spraw. Pos. Kom. Nauk. PAN Oddz. Krak.*, 32 (1-2): 239–241.

Rutkowski, J., 1995. Badania petrograficzne żwirów. (In Polish only). In: Mycielska-Dowgiałło, E. & Rutkowski, J. (eds.), *Badania osadów czwartorzędowych. Wybrane metody i interpretacja wyników*. Wydz. Geogr. i Stud. Reg. UW, Warszawa, pp. 133–150.

Rutkowski, J. & Sokołowski, T., 1983. Preliminary petrographic study of Quaternary fluvial gravels of the Cracow region (southern Poland). (In Polish, English summary). *Studia Geomorph. Carpatho-Balcan.*, 16: 99–107.

Rutkowski, J., Zuchiewicz, W., Helios-Rybicka, E. & Bluszcz, A., 1994. Nowe dane o utworach glacilimnicznych w Niedźwiedziej Górze koło Krzeszowic. (In Polish only). *Spraw. Pos. Kom. Nauk. PAN Oddz. Krak.*, 37 (1): 221–222.

Rutkowski, J., Zuchiewicz, W. & Hoffmann, M., 1993. Uwagi o utworach zlodowacenia Sanu w Niedźwiedziej Górze koło Krzeszowic. (In Polish only). *Spraw. Pos. Kom. Nauk. PAN Oddz. Krak.*, 35 (1-2): 293–295.

Ślusarczyk, R., 1997. *Wyniki badań sejsmicznych w rejonie Tenczynka (unpublished)*. (In Polish only). Zakład Geofizyki, Wydz. Geol. Geofiz. i Ochrony Środ. AGH, Kraków: 1–5.

Streszczenie

LITOLOGIA OSADÓW GLACJALNYCH Z PIĘTRA SANU-2 W KOTLINIE TENCZYNKA NA ZACHÓD OD KRAKOWA

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Artykuł omawia osady lodowcowe zlodowacenia Sanu-2, wypełniające Kotlinę Tenczynka (Fig. 1–3) i odsłaniające się w południowej części kamieniołomu permskich diabazów w Niedźwiedziej Górze (Fig. 4), około 25 km na zachód od Krakowa. Są one wykształcone jako zmienna seria mułków, glin zwałowych oraz iłów, rzadziej piasków i żwirów (Fig. 3, 5). Jest to najlepsze odsłonięcie tego typu osadów w południowej Polsce.

Kotlina Tenczynka (Gilewska, 1972) jest inwersyjnym zagłębieniem morfologicznym o wys. 310–270 m n.p.m., położonym w obrębie zrębowego Pasma Tenczyńskiego (Fig. 1). Morfologię i budowę geologiczną otaczających ją wzgórz ilustruje Fig. 2. Kotlina została wyerodowana w mało odpornych skałach karbonu produktywnego przed lub w czasie transgresji lądolodu Sanu-2.

Zróżnicowanie litologiczne osadów czwartorzędowych

Osady czwartorzędowe Kotliny Tenczynka dzielą się na trzy kompleksy (Fig. 3–5). *Dolny* reprezentują piaski, rzadziej żwiry, niekiedy z przeławiceniami glin lub iłów, o miąższości do ok. 19 metrów. Ich strop nie przekracza na ogół 245–250 m n.p.m. Z opisów wierceń wynika, że żwiry zawierają materiał miejscowy i krystaliczny, w tym pochodzenia skandynawskiego. W odsłonięciu w Niedźwiedziej Górze (Fig. 4, 5, 12; próba 14) żwiry zawierają jedynie materiał miejscowy.

Kompleks środkowy budują mułki, diamiktyty oraz iły, z wkładkami piasków i żwirów. Leży on na osadach kompleksu dolnego lub karbonu, permu i jury (Fig. 2–4). Miąższość osadów kompleksu środkowego wynosi od kilku do 50 m. Ich erozyjny strop znajduje się na wys. 310–320 m n.p.m. na obrzeżeniu Kotliny, a w części środkowej nie przekracza 290 m n.p.m.

W odsłonięciu iły warwowe (Fig. 5–7) mają miąższość 20–50 cm. Laminy jasne są zbudowane z pyłów z niewielką domieszką frakcji ilastej (Fig. 11); laminy ciemne zawierają ok. 60% iłu. Badania rentgenograficzne frakcji <0.002 mm, wyseparowanej z laminy ciemnej wykazały, że ich głównym składnikiem jest smektyt, z podrzędnym udziałem pakietów illitowych. Stwierdzono także obecność kaolinitu i muskowitu. Zbliżony skład ma frakcja ilasta zawarta w przeławiceniach ilastych w obrębie mułków i w diamiktytach.

Mułki barwy ciemnoszarej, laminowane, rzadziej masywne, słabo wapniste (7.5–13.4% $CaCO_3$), stanowią większą część osadów glacilimnicznych w Niedźwiedziej Górze (Fig. 5). W składzie ziarnowym (Fig. 11) przeważa frakcja pyłowa z domieszką piasku i iłu. Niekiedy obserwuje się zrzutki (*dropstones*), związane z opadaniem klastów wytapianych z kier lodowych, przeławicenia z domieszką frakcji żwirowej oraz cienkie wkładki iłów (próba 5).

Diamiktyty występują głównie we wschodniej części wyrobiska w Niedźwiedziej Górze (Fig. 5). Ich skład ziarnowy jest bardzo zróżnicowany (Fig. 11). Zawartość $CaCO_3$ we frakcji <2mm wynosi zazwyczaj 11.4–15.8%. Wśród klastów zawartych w diamiktytach występuje materiał miejscowy, pochodzący z bezpośredniego podłoża i okolicznych wzgórz, materiał z Polski środkowej oraz skandynawski. Materiał miejscowy to głównie wapienie oksfordu (do >95%), piaskowce i wapienie piaszczyste z fauną keloweju oraz diabazy. Z wapieni oksfordu lub ich trzeciorzędowych zwietrzelin (paleogen i/lub pliocen; por. Rutkowski, 1987) pochodzą krzemienie (do 10%; Fig. 12). W glinach występują także twarde i zwięzłe wapienie, pochodzące ze skał dolnego karbonu rejonu Czatkowic, względnie jury. Kwarc może pochodzić ze Skandynawii, z Polski środkowej oraz z materiału lokalnego (żwiry środkowej jury i zwietrzeliny karbonu). Materiał skandynawski (0–35%) to głównie skały krystaliczne, rzadziej różowe kwarcyty oraz szare lub niebieskawoszare wapienie (do 25%), często z bogatą fauną brachiopodów, małżów, krynoidów, sporadycznie trylobitów (sylur i ordowik).

Diamiktyty ze wschodniej części łomu zawierają głównie wapienie jurajskie (Fig. 12; próby 3, 9). Pozostałe składniki występują w ilości do 40%. Skład petrograficzny frakcji żwirowej nie wykazuje związku z uziarnieniem diamiktytów. Diamiktyty z zachodniej części wyrobiska (Fig. 12, próba 18) zawierają materiał skandynawski z kilkuprocentową domieszkę wapieni jurajskich. Na uwagę zasługuje obecność diabazów.

Występują tu także diamiktyty zawierające ostrokrawędziste okruchy wapieni jurajskich lub diabazów (Fig. 5, 12; próby 2, 3), reprezentujące spływy soliflukcyjne.

Piaski i żwiry w kompleksie środkowym osiągają miąższość 10 m (Fig. 3). Żwiry drobnokalibrowe (Fig. 5, 11, 12; próba 15) zawierają głównie kwarc i krystaliczne skały skandynawskie. We frakcjach grubych wzrasta ilość krzemieni (do >50%), co jest cechą typową dla żwirów rejonu krakowskiego (Rutkowski & Sokołowski, 1983; Rutkowski, 1995). Brak tutaj skał węglanowych, które uległy rozpuszczeniu dzięki działalności wód gruntowych, co obserwowano także w rejonie Krakowa, Miechowa i Witowa (Rutkowski, 1995). Omawiane żwiry są pochodzenia wodnolodowcowego. Znaczna zawartość krzemieni i zespół minerałów ciężkich wskazują na dużą domieszkę materiału ekstraglacjalnego.

Kompleks górny budują piaski, o miąższości do 10 m (Fig. 3, 5), leżące niezgodnie na ściętej erozyjnie powierzchni osadów kompleksu środkowego lub starszym podłożu. Piaski są przeważnie średnio i drobnoziarniste (Fig. 11), umiarkowanie wysortowane, na ogół bezwapniste. Grubsze ziarna są w znacznym stopniu zmatowiałe wskutek eolizacji. Zróżnicowana zawartość odpornych i nieodpornych minerałów ciężkich (Tab. 2) może sugerować, że pochodzą one zarówno z osadów lodowcowych, jak i ze starszego podłoża. W spągu piaski zawierają niekiedy domieszkę żwiru (Fig. 4, 5, 6, 12; próba 16), utworzonego głównie z diabazów, czasem ze śladami obróbki eolicznej. We wschodniej części wyrobiska w piaskach występuje wkładka rumoszu soliflukcyjnego (Fig. 5, 12, profil 13; próba 17), złożonego z ostrokrawędzistych okruchów wapieni.

Zróżnicowanie litofacjalne kompleksów środkowego i górnego

Litofacje wyróżnione w osadach kompleksu środkowego (por. Fig. 6–10; Tab. 1) wskazują na depozycję w zbiorniku terminoglacjalnym. Sekwencja osadów w profilach 9–10 (Fig. 7) i 1 (Fig. 6) rejestruje zapis części cyklu, obejmującego transgresję i postój lądolodu. W początkowym etapie w dnie kotliny były osadzane piaski glacifluwialne. Następnie powstało jezioro terminoglacjalne, w którym nastąpiła depozycja cienkiej warstwy iłów warwowych, na które wkroczyły spływy rumoszu z otaczających wzgórz, transportujące głównie rumosz diabazów lub skał jurajskich. Wyżej w profilu pojawiają się cienkie pokłady glin zwałowych, w większości wytopnieniowych oraz spływowych, zastąpione następnie przez mułki glacilimniczne. W górnej partii profili wschodniej części wyrobiska (Fig. 5, 7, 9) występują rytmity jeziorne przechodzące w stropie w mułki z laminacją riplemarkową, zaburzone ponownie przez płaty glin spływowych. Stan odsłonięć nie pozwala na bliższe określenie relacji przestrzennych między poszczególnymi typami osadów; w szczególności dotyczy to charakteru deformacji (Fig. 13–18) obserwowanych w części stropowej kompleksu środkowego, przypuszczalnie genezy glacitektonicznej.

Uwagi końcowe

Żwiry i piaski dna kotliny (kompleksu dolnego) reprezentują okres od pliocenu po piętro Sanu-2, którego lądolód zabarykadował odpływ na wys. 240–250 m n.p.m. Po zabarykadowaniu odpływu na wys. 300 m n.p.m. lub wyżej, w Kotlinie utworzyło się jezioro, w którym były osadzane iły warwowe oraz mułki kompleksu środkowego. Na powierzchni jeziora pływały kry lodowe, będące źródłem materiału gruboklastycznego w osadach drobnoziarnistych.

W kolejnym etapie cały obszar został przykryty lądolodem. Początkowo przesuwał się on po podłożu zbudowanym z wapieni jurajskich, pobierając z nich materiał. Po stopieniu lodu pozostały diamiktyty bogate w materiał jurajski, odsłaniające się we wschodniej części wyrobiska (Fig. 12; próba 3). Kolejne warstwy lądolodu przesuwały się już po lodzie stagnującym i mogły mieć bardziej ograniczony kontakt z podłożem (diamiktyty z zachodniej części wyrobiska; Fig. 12; próba 18). Zbliżone prawidłowości obserwował Lamparski (1970) na północnym obrzeżeniu Gór Świętokrzyskich.

Osady kompleksu środkowego zostały zaburzone przez synsedymentacyjne ruchy masowe oraz – przypuszczalnie – w wyniku nacisku lądolodu. Stan odsłonięcia uniemożliwia jednoznaczną interpretację tych deformacji (Fig. 13–18).

Piaski kompleksu górnego mogą reprezentować okres od schyłku zlodowacenia Sanu po holocen. Mogły być one w tym czasie przerabiane przez procesy peryglacjalne oraz wiatr. Data 13,3 ± 2,4 ka (GdTL-341; Fig. 5, 9) sugeruje jednak, iż badane osady powstały u schyłku vistulianu.