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Lithological and petrographic features of tills in the Koźmin region and their value for stratigraphical interpretation of glacial Lake Koźmin deposits, Central Poland

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In the middle section, the Warta River valley runs through the Adamów graben. The graben was characterized by subsidence since the end of the Paleogene and favoured accumulation during the Neogene and the Quaternary. The Quaternary deposits consist of several till horizons separated mainly by a series of fluvioglacial sand and a thick series of glaciolacustrine sediments. The research was concentrated on three upper levels of tills and selected series of sand available in Koźmin and Koźmin-Północ "Adamów" opencast mines. The lithological, petrographical features and long-axis azimuth of pebbles were analyzed. The results showed that the lower till could be dated to the Elsterian, middle till to the Wartanian, and the upper till is probably also Wartanian. Glaciolacustrine deposits which filled the erosional form and appeared in the middle till correlate with the end of the Wartanian.

Key words: till, indicator erratics, lithostratigraphy, stratigraphy, Saalian, middle Warta River valley

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INTRODUCTION

The study area is located in the Warta River valley, one of the main rivers of Central Poland. In the middle course, the Warta River valley flows northwards, through one of the grabens of the Konin elevation – an uplifted part of the Szczecin–Łódź–Miechów synclinorium. Grabens of the Konin elevation have been formed since the end of the Paleogene (Widera, 1998). The study area is situated within the Adamów graben. The tendency to subsidence in the graben favoured accumulation of thick Neogene and Quaternary deposits, including several levels of tills, fluvioglacial, fluvial series and thick glaciolacustrine deposits of the so-called Koźmin glacial lake. The area of research is located in the extraglacial zone of the Last Glaciation. Its maximum reach is delineated about 20 km towards the north (Fig. 1).

METHODS

Koźmin and the Koźmin-North excavations of the "Adamów" browncoal mine provide favourable conditions for research (Fig. 1). In the Koźmin excavation one level of till was investigated (Fig. 2), and three levels of tills were analyzed in the Koźmin-North excavation (Fig. 3).

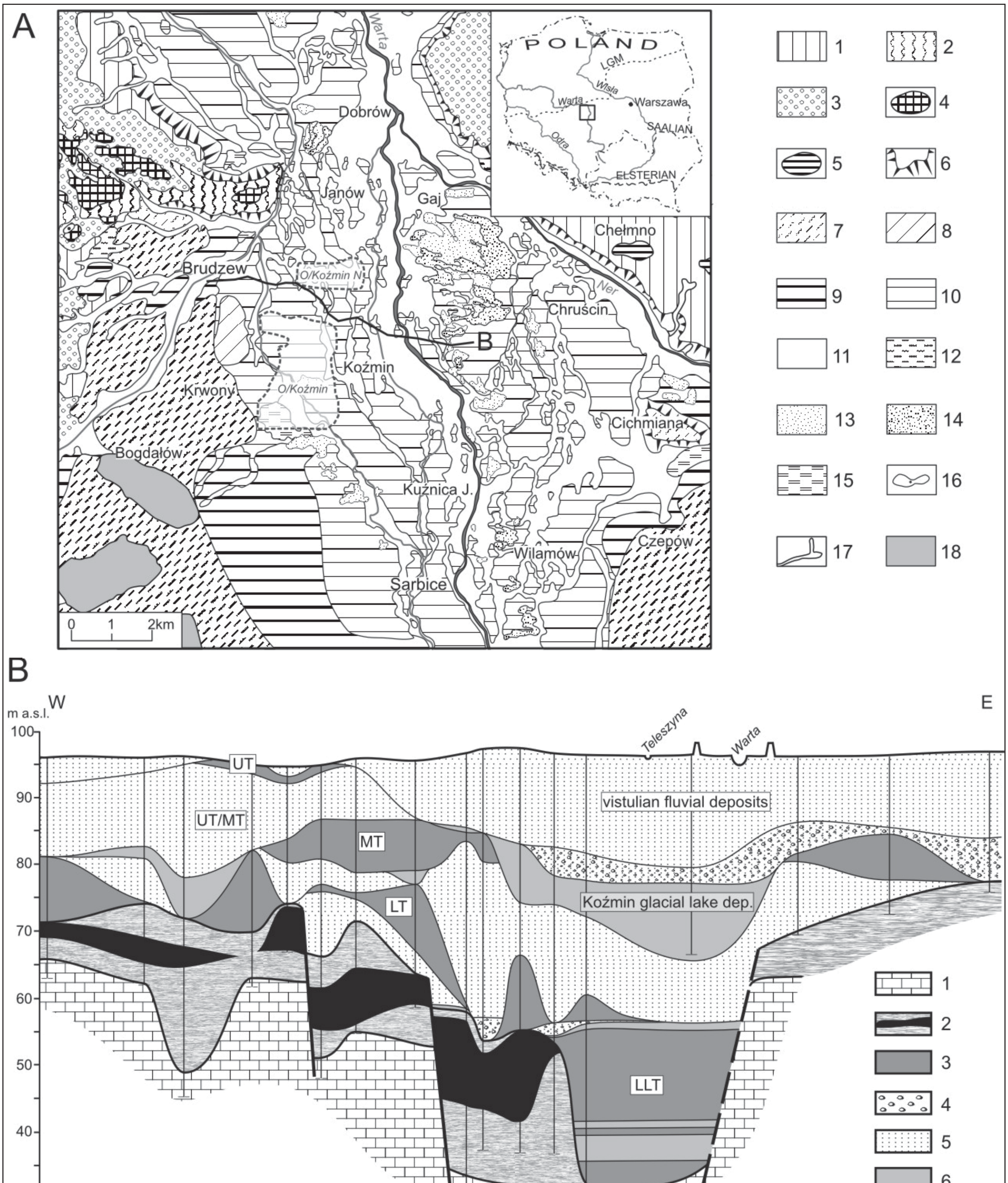

Fig. 1. *A* – geomorphological map (with location of Koźmin and Koźmin-North sites and cross-section – *B*):
1 – morainic plain, *2* – hummocky morainic plain, *3* – fluvioglacial plain, *4* – end-morainic hillocks, *5* – kames, *6* – slopes, *7* – lower terrace of marginal valley, *8* – erosional terrace, *9* – alluvial high terrace, *10* – alluvial low terrace, *11* – valley bottom, *12* – lacustrine plain, *13* – aeolian plain, *14* – dunes, *15* – peatlands, *16* – closed depressions, *17* – valleys of various origin, *18* – exploitation pits. *B* – geological cross-section: *1* – Cretaceous marl and limestone, *2* – Neogene silt and sand with brown coal; *3–6* – Quaternary: *3* – till, *4* – gravel, *5* – sand, *6* – silt

1 pav. *A* – geomorfologinis žemėlapis (*B* – Kožmino ir Šiaurės Kožmino vietovės):
1 – moreninė lyguma, *2* – kalvota moreninė lyguma, *3* – fliuvioglacialinė lyguma, *4* – kraštinės morenos kalvos, *5* – keimai, *6* – šlaitai, *7* – žemutinė terasa, *8* – erozinė terasa, *9* – viršutinė aliuvinė terasa, *10* – žemutinė aliuvinė terasa, *11* – slėnio dugnas, *12* – ežerinė lyguma, *13* – eolinė lyguma, *14* – kopos, *15* – pelkės, *16* – uždaros įdubos, *17* – įvairios kilmės slėniai, *18* – karjerai. *B* – geologinis pjūvis: *1* – kreidos mergelis ir klintis, *2* – neogeno aleuritas ir smėlis su anglies tarpsluoksniais; *3–6* – kvartero: *3* – morena, *4* – žvirgždas, *5* – smėlis, *6* – aleuritas

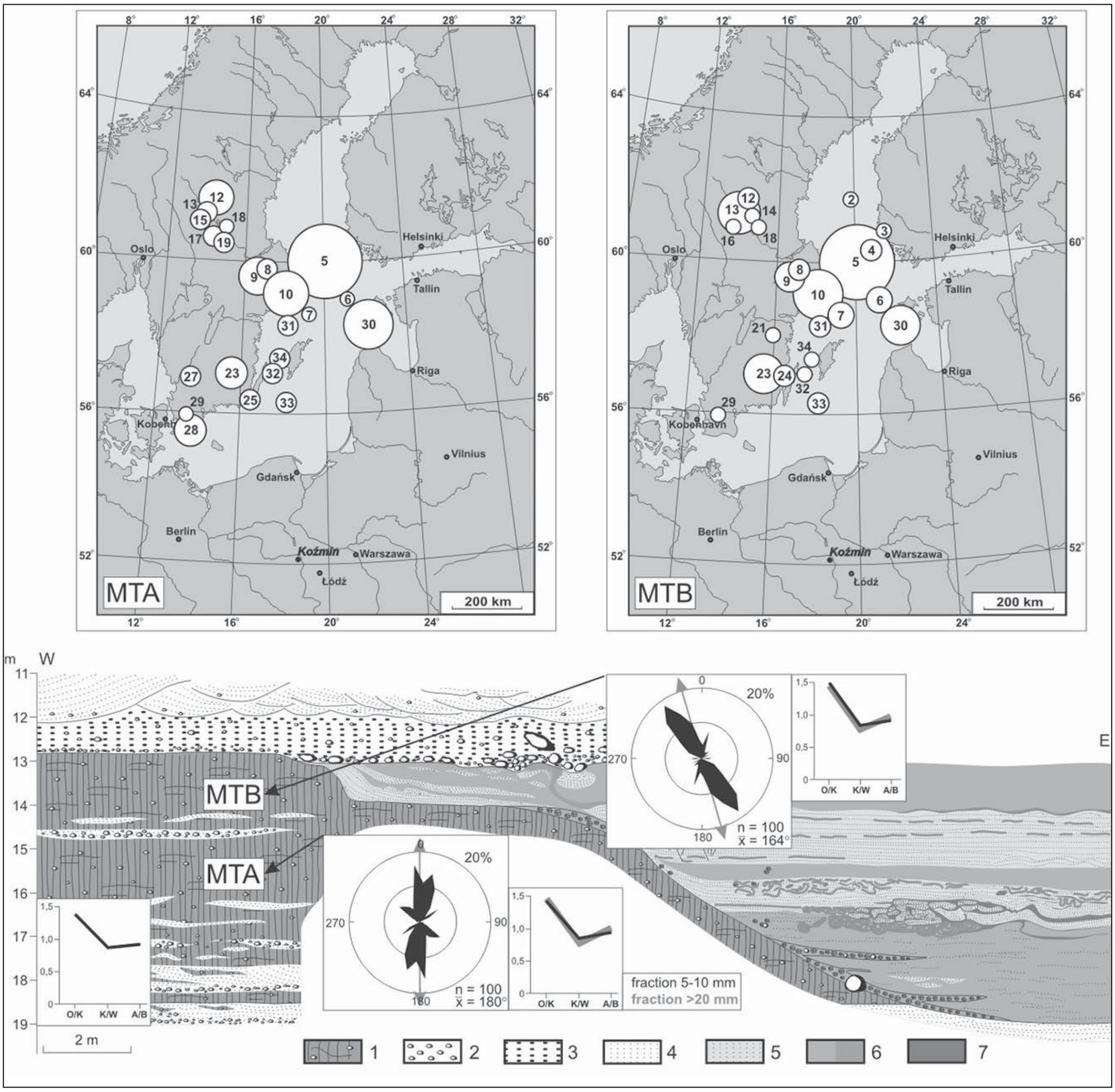

Fig. 2. Koźmin site. Middle till horizon (Wartanian), MTA – lower layer (98 specimens of indicator erratics), MTB – top layer (89 specimens of indicator erratics).

Upper figures show source areas of indicator erratic. The circle's area corresponds to the percentage of erratics from this area in an analysed stone sample. Sites: *1* – Rätan granite, *2* – Botten Sea Porphyries, *3* – Nystad Rapakivi and Nystad grey granodiorite, *4* – Åland and / or Nystad Pyterlite, *5* – Åland granite, Haga granite, Åland Rapakivi, Åland aplite granite, Åland granite porphyry, *6* – red Baltic quartz porphyry, *7* – brown Baltic quartz porphyry, *8* – Uppsala, Vänge and Arnö granites, *9* – Sala granite, *10* – Stockholm granite, *11* – Glöte porphyry, *12* – Grönklitt and grey Dalarna porphyries, Åsby diabase, *13* – Åsen, Bredvad and Kåtilla porphyries, Garberg granite, *14* – Blyberg porphyry, Klittberg ignimbrite and porphyry, Rännås, Blyberg, Orrlok and other Dalarna ignimbrites and porphyries, *15* – Dala sandstone, Digerberg sandstone and conglomerate, Öje diabase, *16* – Heden porphyry, *17* – Venjan porphyry, *18* – Järna granite, *19* – Siljan granite, Siljan Rapakivi, Mänsta porphyry, *20* – red and brown Graversfors granites, Östgöta granites, *21* – Kinda granite, *22* – Mariannelund granite, Emarp, Nymåla, Fagerhult and Lönneberga porphyries, *23* – red Småland granites, Vislanda granite, Småland porphyries, *24* – Vånevik granite, *25* – Kalmarsund and Tessini sandstones, *26* – Filipstad granite, *27* – garnet amphibolite, *28* – Kullaite, Scolithos and Hardeberga sandstones, *29* – Skåne basalt, *30* – dolomites, *31* – red Cambrian sandstones, *32* – red Ordovician limestones, *33* – Beyrichia limestone, *34* – Palaeoporella limestone.

The lower figure shows the azimuth of the long axis of gravels (*n* – sample dimension, *x* – resultant direction), petrographic coefficients for erratics: O / K – ratio of sedimentary rocks to crystalline rocks, K / W – ratio of crystalline rocks to limestones, A / B – ratio of easily weathered rocks to resistant rocks. Lithology: *1* – till, *2* – gravel, *3* – coarse sand, *4* – fine sand, *5* – sand with silt, *6* – silt, *7* – clay

2 pav. Kožmino vietovė. Vidurinis morenos sluoksnis (Vartos), MTA – apatinis sluoksnis, MTB – viršutinis sluoksnis.

Viršutiniuose paveikslėliuose pažymėtos gargždo grūdelių kilmės vietos; apskritimo spindulys atitinka riedulių procentą analizuotame bandinyje iš atitinkamos kilmės vietos; numeriai nurodo kilmės vietas ir uolienų tipą. Apatiniame paveikslėlyje nurodytas gargždo ilgųjų ašių azimutas (*n* – mėginio dydis, *x* – kryptis); gargždo grūdelių petrografiniai koeficientai: O / K – nuosėdinių uolienų santykis su kristalinėmis uolienomis, K / W – kristalinių uolienų santykis su klintimis, A / B – lengvai dūlančių uolienų santykis su atspariomis uolienomis. Litologiniai ženklai: *1* – morena, *2* – žvyras, *3* – stambus smėlis, *4* – smulkus smėlis, *5* – smėlis su aleuritu, *6* – aleuritas, *7* – molis

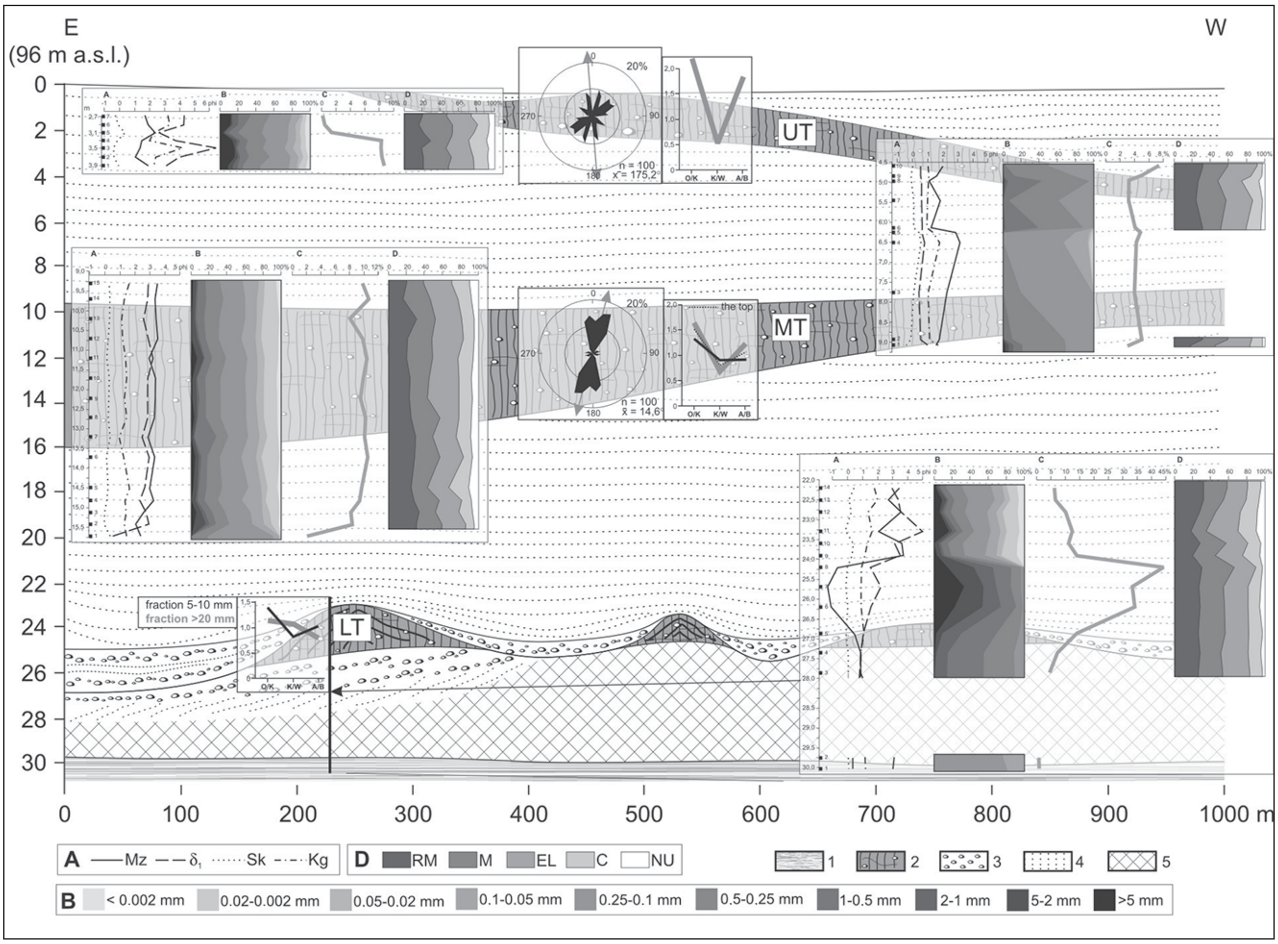

Fig. 3. Koźmin-North site. Scheme of till layers (UT, MT and LT) with results of investigations.
A – the grain-size coefficients: Mz – mean size, δ_1 – standard deviation, Sk – skewness, Kg – curtosis; *B* – the grain-size composition; *C* – calcium carbonate content; *D* – quartz grains abrasion by the Cailleux method (Cailleux, 1942; Manikowska, 1993): RM – round mat, M – intermediate, EL – shiny, C – crushed, NU – unabraded (fresh)

3 pav. Šiaurės Kožminio vietovė. Moreninių sluoksnių (viršutinio, vidurinio ir apatinio) schema.
A – grūdelių dydžio koeficientai: Mz – vidurkinis dydis, δ_1 – standartinis nuokrypis, Sk – asimetriškumas, Kg – išrūšiavimas; *B* – grūdelių dydis; *C* – kalcio karbonatų kiekis; *D* – kvarco grūdelių abrazija pagal Cailleux metodą (Cailleux, 1942; Manikowska, 1993): RM – matinis, M – vidutinis, EL – atsispindintis, NU – neabraduotas

The research was focused primarily on the characteristics of tills in all three levels and establishing their stratigraphic position. Also, it could be helpful in indirect determination of the stratigraphic position of glaciolacustrine deposits of the Koźmin glacial lake. No interglacial organic deposits, which would clearly confirm the stratigraphy of the Pleistocene, have been found in the study area.

The grain-size composition, quartz-grain abrasion by the Cailleux method (Cailleux, 1942; Manikowska, 1993) and calcium carbonate content in till and selected sand series were analyzed. The long-axis azimuth of gravels in non-deformed levels of tills was measured. Studies of erratics were conducted on the basis of the methodological assumptions by Lüttig (1958) with Smed (1993) and Czubla (2001) modification. The results are presented on circle maps, and theoretical stone centres were calculated. In addition, the petrographic coefficients O / K, K / W and A / B for erratics fraction of >20 mm were calculated, although the standard method is limited to the use of fractions 5–10 mm.

LITHOLOGICAL FEATURES OF THE DEPOSITS

In the Koźmin-North excavation, over the Neogene silt and clay, deposits represented by sand and gravels, the postsedimentary deformed Quaternary unit begins. Grain-size abrasion of the deposits shows a similar content of three types of grains – RM, EL and M (Fig. 3), indicating their glaciogenic origin. Till patches of LT (lower till) preserved above have a thickness of about 2 m. The till is involved in glaciotectonic deformations. The lower till is a very poorly sorted sediment, with a significant participation of skeletal fraction and the calcium carbonate content of 5 to 10%. In the base of the till, the content of crashed and unabraded grains (C and NU) is significant, and the percentage of RM type grains increases upwards.

A thick sandy series divides the LT and MT (middle till) till. The top of sand is fine-grained, well-sorted and contains about 2% of calcium carbonate (Fig. 3). The MT till occurs through the whole southern wall of the excavation. It is brown-grey in colour and about 3 to 6 m thick. The till base contains a large amount of sand. To the top, the percentage of gravel and clay fraction increases (Fig. 3). The content of calcium carbonate throughout the profile is relatively constant (approximately 10%), without decalcification at the top. The quartz-grain abrasion is similar to that observed in tills of the surrounding region (Klatkowa, 1993); only a significant percentage of cracked and unabraded grains draws attention (Fig. 3). The cube-like structure of the till is visible.

The next sandy series covers the middle till. The medium-grained sands are moderately well sorted and have a low calcium carbonate content (Fig. 3). Above it, a two-meter well-sorted fine sandy series with about 4% of calcium carbonate content lies. It is covered by another medium-grained sandy series. Quartz grain abrasion analysis showed a similar percentage of three types of grains (RM, M, EL) in the whole sandy level, which is typical of glacigenic deposits (Fig. 3).

Above, in the form of patches, lies diamicton (UT – upper till), brown in color, bipartite, with a thickness of approximately 1.5–2 m. The lower part of sediment has a massive structure and differs from the underlying tills (LT and MT) with a larger amount of sand and gravels. The content of calcium carbonate and quartz grains abrasion is similar to that found in tills described above. In the upper part of the sediment, streaks of sand and silt are visible. The deposit is extremely poorly sorted, and the content of clay fraction is smaller than in the lower part. The decalcification due to weathering is strongly marked (Grajoszek – personal information). The quartz grains abrasion is similar to that reported in the tills below, but a larger percentage of grains (up to 29%) are cracked and unabraded (Fig. 3).

In the western part of the study area, above the upper till, in some cases a thin sandy-silt series with organic matter of Vistulianin fluvial deposits occurs. In the eastern part, there is no upper till and underlying fluvioglacial sand (Fig. 1B), but there are Vistulian fluvial deposits up to several meters thick (Forysiak et al., 1999; Petera, 2002).

PETROGRAPHIC FEATURES OF THE GRAVEL FRACTION OF MORAINE TILLS

The samples for investigation of indicator erratics were taken in the middle and upper parts of the till horizon in the Koźmin exposure (MTA and MTB) as well as in all three horizons of tills in the Koźmin-North exposure (LT, MT and UT). The separate collection of two samples in the first exposure results from differences in the fabric of the highest part of the till layer and, first of all, separating it from the lower part with a weakly expressed gravel pavement (Fig. 2). Upon confirming the petrographic homogeneity of both parts of the till level, during later investigations in the Koźmin-North exposure only one sample of erratics from each moraine horizon was taken.

The oldest till (LT) is exposed in the Koźmin-North exposure only. An erratics assemblage taken from this till is char-

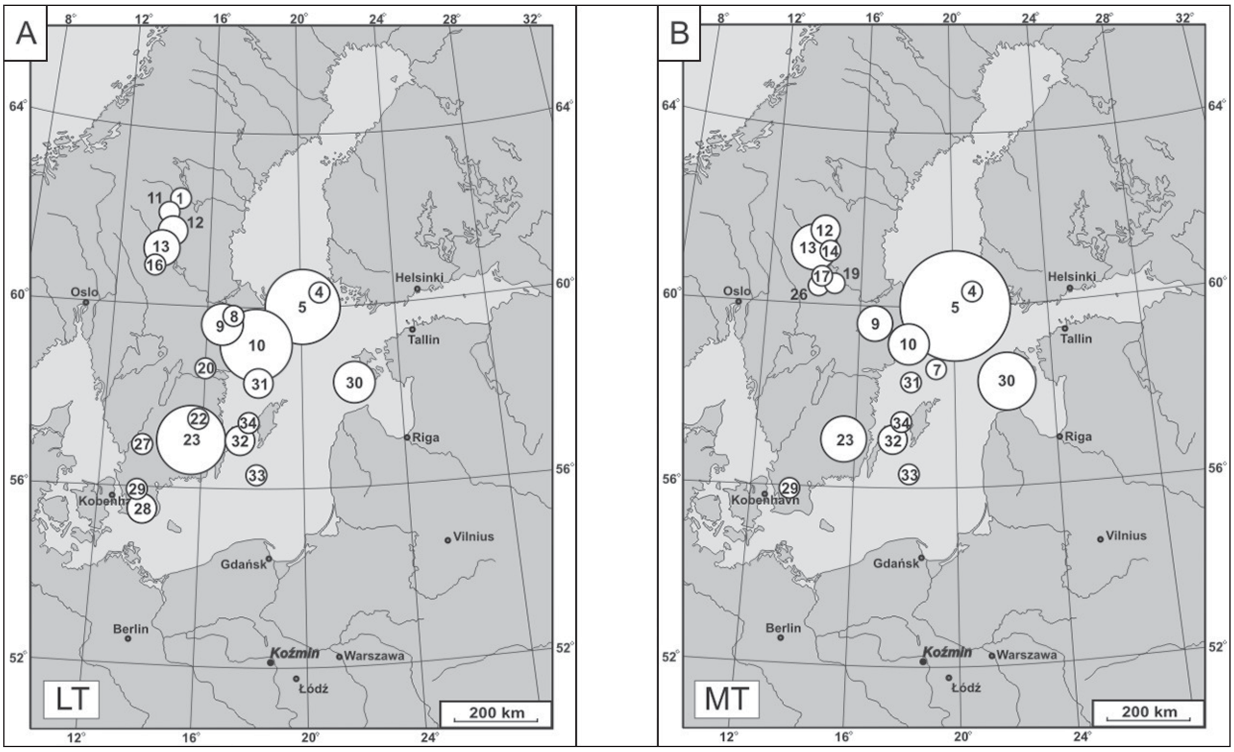

Fig. 4. Source areas of indicator erratics of Koźmin-North site:
A – in the lower till LT (66 specimens of indicator erratics in the sample); *B* – in the middle till MT (68 specimens of indicator erratics); for further explanations, see Fig. 2.

4 pav. Šiaurės Kožmino grūdelių, pagal kuriuos apskaičiuojami rodikliai, kilmės vietos:
A – apatinėje morenoje, *B* – vidurinėje morenoje. Kitus ženklus žr. 2 pav.

acterized by a high percentage of local rocks making up 19%. Limestones as well as mudstones and fine-grained sandstones including numerous fine glauconite grains are most common among local rocks.

The remaining 81% of erratic assemblages taken from the lower till are Fennoscandian rocks. Almost half of them (38%) fall on crystalline rocks, from which the absolute majority indicator erratics descend. On the circle map (Fig. 4a), a similar participation of rocks from Åland Islands, Småland as well as from Uppland and the neighbourhoods of Stockholm is visible. The comparatively small number of the easily recognizable erratics from the Dalarna region seems to suggest a more southern location of the source area of the glacier which deposited the analyzed till, or a comparatively small exposure of the volcanic bedrock during gathering of the ice mass. The high resistance to weathering, typical of most indicator erratics from Dalarna, excludes their secondary elimination during postdepositional processes. The theoretical stone centre calculated for LT till has the geographical co-ordinates of 16.94°E and 59.12°N. No long-axis azimuth measurements of pebbles were undertaken because of glacio-tectonic deformations of the till.

Middle till (MT) in both exposures lies in exactly the same stratigraphic position, but in the Koźmin exposure it is eroded and the erosional form is filled with glaciolacustrine deposits of the Koźmin glacial lake (Fig. 2). The content of local rocks in relation to the underlying till decreased more than by half; this is evident as the foot of the glacier was isolated from the bedrock with glacial and glaciofluvial sediments deposited by the previous glaciation. The percentage of Baltic-Fennoscandian rocks in MTA, MTB and MT samples ranges between 92 and 96%. Sedimentary rocks (about 56–57%) – mainly Palaeozoic limestones and dolomites – prevail. The content of dolomites in the middle till is considerably higher than in the lower one.

The high percentage of rocks from the region of Åland Islands as well as from the Baltic Sea bottom is documented in these samples (Figs. 2, 4b). Rocks from the Uppland, the neighbourhoods of Stockholm and the Dalarna region are present in small numbers, meanwhile Småland is represented by several red granites only, despite its extensive outcrops in SE Sweden. The theoretical stone centre of middle till from the Koźmin-North exposure (MT) is located in the locality with the geographical co-ordinates 17.96 °E, 59.80°N. The TSC calculations on the basis of the MTA and MTB samples gave very similar results: 17.24°E, 59.41°N and 17.81°E, 59.62°N. The results of the long-axis azimuth measurements of pebbles in the middle till in both exposures gave similar directions: N-S, NNW-SSE and NNE-SSW (Figs. 2, 3).

The upper till (UT) was studied in the Koźmin-North exposure only. The sample for erratics investigations was taken from the bottom part of the till having a massive structure. The percentage of local rocks appeared to be inconspicuous (<0.5%). Like in the middle till, sedimentary erratics among Northern rocks distinctly prevailed. Dolomite pebbles were particularly numerous, making up for almost 20% of assemblages. Among crystalline erratics, there are two typically eastern Åland granites. Indicator rocks from Småland as well as from the neighborhoods of Stockholm were present in a bigger number. The analysis of parent areas of the till and the delimitation of the theoretical stone centre were not undertaken because of the too small number of indicator and statistical erratics identified in the sample and a risk of wrong conclusions.

Investigations of fine gravel fraction (5–10 mm) were carried out in LT and MT only. The long-axis azimuth mea-

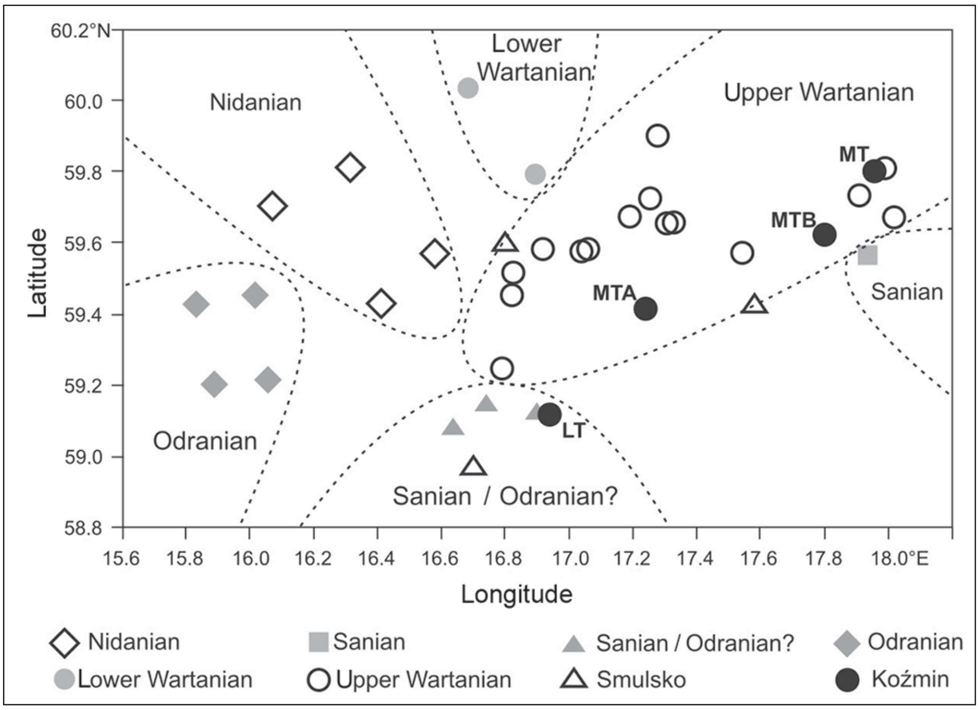

Fig. 5. Theoretical stone centres (TSC) calculated for Quaternary tills of Middle Poland

5 pav. Vidurio Lenkijos kvartero teoriniai akmenų centrai surements of the pebbles in UT diamicton showed a very large dispersion of values, which suggests its flowing nature (Fig. 3). In this case, collection of samples for investigations of fine gravel fraction was pointless.

The petrographic coefficients O / K, K / W and A / B, calculated for LT and MT tills, are almost identical. The O / K coefficient ranges from 1.319 to 1.520, the K / W from 0.767 to 0.911, meanwhile the A / B from 0.898 to 1.072.

Very different results were obtained in the fraction over 20 mm calculated for comparision. Only petrographic coefficients for MT from the Koźmin exposure are almost identical for both fractions (>20 mm and 5–10 mm). Rather great differences appear in the same till horizon in the Koźmin-North exposure. The greatest difference of the coefficients appears for two examined fractions in the oldest till.

DISCUSSION

The high participation of local rocks in the sample taken in lower till (LT) is typical of the oldest moraine horizons in the study area. The theoretical stone centre in LT is very similar to that determined for the lowest till in the eastern part of the neighbouring Smulsko exposure (16.70°E, 58.97°N) (Czubla, Forysiak, 2004). The analogous values of TSC were obtained also for tills in a controversial stratigraphic position (Sanian or Odranian) in the Bełchatów opencast mine situated about 100 km toward SE (Fig. 5). Both lower till beds (disturbed and undisturbed) in the Jóźwin exposure have TSCs situated a little further toward the north-west, which results in a larger participation of Dalarna rocks. This differentiation can indicate deposition by a separate ice stream or their belongings to another glaciation (stadial) (Czubla, 2001; 2006). The analysis of erratics composition allows to refer the LT to the South-Polish Glaciations (Elsterian).

The higher percentage of dolomites in all investigated samples collected in the middle till (MT, MTA and MTB) suggests a displacement of the source area eastwards where outcrops of dolomites create a bigger part of the bedrock. Proportions of the main crystalline erratics, identified in all three samples, confirm a conclusion about the eastern position of the alimentation area.

The position of the theoretical stone centre in the MT sample is almost perfectly compatible with tills from Bełchatów and Łaznowska Wola near Łódź. The Wartanian age of those tills is unquestionable. The TSCs obtained for MTA and MTB tills are approximately the same as those in other sites, e. g., Smulsko, Jóźwin, Bełchatów exposures, and are situated in a field typical of Wartanian tills in Middle Poland (Fig. 5) (Czubla, 2001; 2006). The values of pebble long-axis azimuths in the middle till are convergent with the directions measured in the Smulsko exposure situated several kilometers southwards from the study area (Klatkowa, 1993). The features of the MT, as well as the grain size composition, grain size abrasion and $CaCO_3$ content, are typical of the Wartanian tills of the region. In the neighbouring Konin area located to the north-east, and in the Smulsko site located to the south from the study area, two levels of Wartanian tills were recorded (Stankowski, Krzyszkowski, 1991; Klatkowa, 1993). In the Konin region, Wartanian tills are usually separated by a series of fluvioglacial deposits. Taking into account the geological conditions and features of till, it is possible to assume that the middle till corresponds to the lower level of the Wartanian till.

The high number of dolomites in the sample taken from diamicton (UT) indicates the eastern position of its source area. The presumption mentioned above, however, contradicts the proportions of crystalline erratics among which only two typically eastern Åland granites were identified.

The UT diamicton has numerous features of flow till: a fluvial structure in places with stratification as a result of sorting during flowing, a great variability in grain-size distribution and a large dispersion of long-axis azimuth (Dreimanis, 1989; Ruszczyńska-Szenajch, 1998). The petrographic analysis shows that the material of distant derivation dominates as the percentage of local rocks is only about 0.5%, indicating that the supraglacial or englacial material was a source of flow till (Dreimanis, 1989). Nevertheless, a secondary deposition of the diamicton cannot be excluded.

The petrographic coefficients O / K, K / W and A / B, calculated for lower and middle tills, are nearly the same as obtained by Klatkowa in Wartanian tills in the Smulsko exposure (1994) as well as by Zabielski in tills of the Jóźwin exposure also recognized as Wartanian (2004). The petrographic coefficients in the oldest till lie in the same range, despite the fact that this till represents a distinct stratigraphic horizon.

The results of the till investigations are very important for establishing, the stratigraphic position of the Koźmin glacial lake deposits. The first information about the Koźmin glacial lake and its stratigraphic position was given by Czarnik (1972). According to this author, the glacial lake developed during the Wartanian glacial transgression. A different interpretation was proposed by Trzmiel (1996) who located the accumulation of fine deposits in the Early Vistulian (Toruń Glaciation) as a glacial lake or a lake existing under periglacial conditions. Glacial lake deposits are covered by a gravel series of unrecognized origin and well-documented Vistulian alluvia. Our research does not confirm any of these opinions, but it suggests that the Koźmin glacial lake was formed at the end of the Wartanian.

CONCLUSIONS

From the three tills tested, the lower two may be of stratigraphic significance. The lower level was associated with Elsterian glaciations, mainly on the basis of petrographic analyzes. In the light of the research, both the petrographic and long-axis azimuth measurements of the Wartanian age of middle till raise no doubt. The till (UT) was formed during the Wartanian, but it has no stratigraphic significance as its position might be secondary.

The glaciolacustrine deposits of the Koźmin glacial lake might have been deposited at the end of the Wartanian as they are younger than the Wartanian till (MT) and older than the overlying Vistulian fluvial deposits.

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KOŽMINO RAJONO MORENŲ LITOLOGINIAI BEI PETROGRAFINIAI BRUOŽAI IR JŲ SVARBA STRATIGRAFINEI KOŽMINO EŽERO VIDURIO LENKIJOJE NUOGULŲ INTERPRETACIJAI

Santrauka

Tyrimų vieta – vidurinėje Vartos upės slėnio dalyje, plačios viršsalpinės terasos kairėje pusėje (1 pav., *A*). Šioje vietoje Vartos upės slėnis kerta Adamovo gabeną, užpildytą neogeno ir kvartero nuogulomis. Kvartero storymę sudaro keli moreniniai horizontai, ledyno tirpsmo vandenų suklostyti smėlingi dariniai bei ledyninio ežero nuogulos (1 pav., *B*). Buvo tirti trys viršutiniai moreniniai horizontai ir smėlio sluoksniai iš Kožmino ir Šiaurės Kožmino atodangų, esančių atviroje rusvos anglies kasykloje „Adamov". Autoriai išanalizavo litologinius nuogulų ypatumus, kurie yra būdingi ledyninės kilmės morenoms: diferencijuotos frakcijos, blogas išrūšiuotumas, skirtingai apzulintų grūdelių ir kalcio karbonato (iki 10 %) subalansuotas kiekis (3 pav.). Be to, buvo ištirta žvirgždo frakcijos petrografinė sudėtis. Apskaičiuoti smulkios frakcijos (5–10 mm) petrografiniai koeficientai ir teorinės riedulių centrų padėtys (4 ir 5 pav.) leido palyginti tirtuosius moreninius horizontus su Vidurio Lenkijos moliu. Nustatyta, kad žvirgždo grūdelių ilgosios ašies orientacija yra tokia pati, kaip ir pastarojo rajono morenų (Vartos ledyno stadialo dariniai). Tyrimo rezultatai leido apatinį sluoksnį (LT) priskirti Pietų Lenkijos apledėjimui, o vidurinį (MT) – Vartos stadialui (ekvivalentiškas Maskvos apledėjimui). Viršutinis horizontas (UT), matyt, yra alochtoninės kilmės. Ledyninio ežero nuosėdos, užpildančios erozinį paviršių, MT sluoksnyje yra padengtos storesniu nei 10 cm Vyslos (ekvivalentiškas Valdajaus apledėjimui) aliuvinių nuogulų sluoksniu. Nuosėdos galėjo susikaupti Vartos stadialo pabaigoje.

Raktažodžiai: morena, litostratigrafija, stratigrafija, Vartos upės slėnis