DE GRUYTER Open Geosciences 2020; 12: 753–763

Research Article

Magdalena Anna Drążczyk*

Structure of end moraines and dynamics of the recession phase of the Warta Stadial ice sheet, Kłodawa Upland, Central Poland

https://doi.org/10.1515/geo-2020-0045
received January 31, 2020; accepted May 15, 2020

Abstract: The occurrence of end moraines reflects the dynamics of an ice sheet, and their inner structure is determined by processes taking place in marginal zones. In the southern part of the Kłodawa Upland of Central Poland, such moraines were formed, but opinions conflict as to their origin, including the influence of local transgression of the ice sheet, as well as its areal and frontal recession. The primary aim of this article is to analyse the inner structure of forms to define the dynamic state of the Warta Stadial ice sheet of the Odra Glaciation (Saalian). The conducted research includes fieldwork at four key sites, where lithofacial analysis was performed, as well as a geomorphological and geological mapping that included two cross-sections in greater detail. In exposures, the work focused on deformed structures of sediments. Description of key sites was extended by the creation and the analysis of general geological cross-sections. Considering the results of the research, the Kutno end moraines should not be classified as push moraines – they were revealed to be accumulative in character.

Keywords: end moraines, marginal zone, lithofacial analysis, Pleistocene

1 Introduction

End moraines are formed in ice sheet marginal zones, and their types (i.e. push or accumulation moraines) are integrally related to the predominant processes that took part in shaping them. Push moraines are characterised by a relative altitude of up to 100 m, more steep distal slopes, and glacial erosive hollows on the forefield, whereas accumulation moraines have lower relative altitudes and are built of coarse morainic material [1,2]. However, forms developed in different dynamic states of ice sheets may occur even in relatively small areas. One example is the Liwiec ice lobe of north-east Poland, where all three states – frontal and areal recession, as well as advance – marked their occurrence in the topography [3].

To the west of Kutno in central Poland (Figure 1a), there are end moraines whose classification into one type has caused several problems. To date, research on the origin of these forms known as "the Kutno moraines" has been conducted on different levels and resulted in conflicting opinions. By contrast, one indisputable fact about these forms is their age, dated firmly to the Warta Stadial (MIS 6) recession [4–7], although the end moraines' proximity to the last glacial maximum (LGM) could have resulted in them being determined as having formed during the Vistulian Glaciation. Research conducted by Roman [8] specifically stated the LGM limit in the Płock lobe, 25 km north of the analysed landforms (Figure 1a).

Lencewicz [4] initially characterised the Kutno end moraines and, based mainly on their lack of deformation structures, qualified them as accumulation moraines, where each belt determines consecutive lines at which an ice sheet's front stagnated during its recession. Many years later, research on the origin of the Kutno moraines was carried out by Domosławska-Baraniecka [6]. On the basis of the analysis of deformation structures, she distinguished 13 stages of sedimentation. In the study by Domosławska-Baraniecka [6], the formation of the Kutno moraines was strongly related to abrupt ice re-advance during the ice sheet recession phase. She uses the term "Kutno transgression" [9,10]. However, Domosławska-Baraniecka [6] pointed out that the melting was related to the formation of the moraines.

The last publication on the origin of the moraine ridges near Kutno belongs to Jewtuchowicz [7]. He negated the thesis by Domosławska-Baraniecka [6]

* **Corresponding author: Magdalena Anna Drążczyk,** Department of Geomorphology and Palaeogeography, University of Łódź, Faculty of Geographical Science, Łódź, Poland,
e-mail: magdalena.drazczyk@unilodz.eu

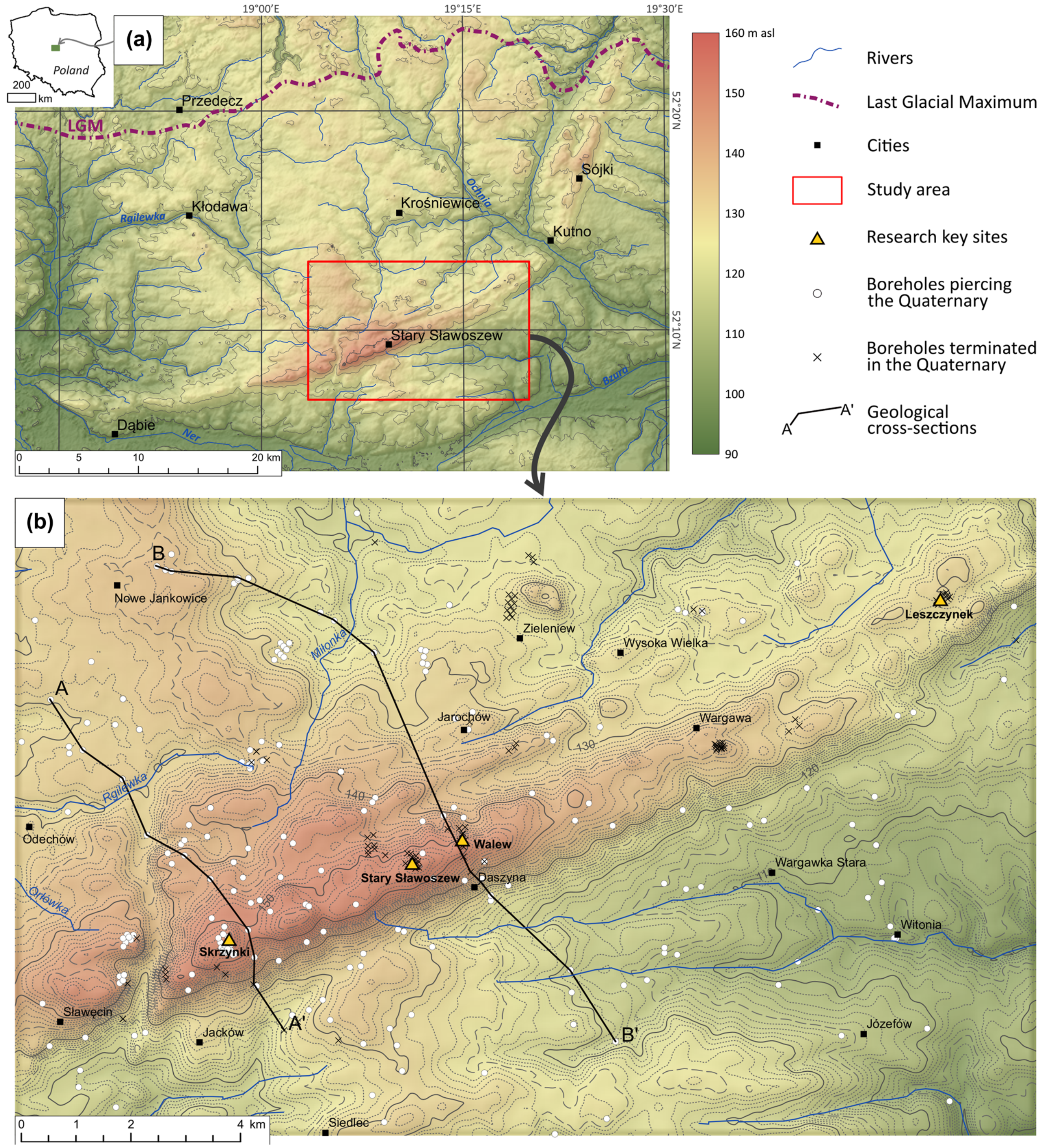

Figure 1: (a) Topographic features and setting of study area against the limit of the last Scandinavian ice sheet (line of LGM based on Roman [8]) and (b) documentation map.

about the moraines having been pushed by local transgression. He supposed that all deformed structures visible in outcrops were developed during the melting of dead ice blocks.

There are three models concerning the origin of the Kutno moraines in the literature. Two relate to accumulation processes during frontal or areal ice sheet recession (Lencewicz [4] and Jewtuchowicz [7], respectively) and one to local re-advance of the ice sheet (Domosławska-Baraniecka [6]). In some older articles that mention these forms, they are described as push moraines [11] although younger publications usually considered their nature to be accumulative [12–14]. In the south east of the study area, the recession of the Warta Stadial ice sheet is determined to be only areal [15].

The main aim of this article is to define the dynamic state of the Warta Stadial ice sheet during its recession phase near Stary Sławoszew and its influence on the development of landforms in this region. Furthermore, opinions and views presented in the source literature are also discussed.

2 Geological and geomorphological setting

The Kutno end moraines are located in the Kłodawa Upland, and more specifically, they determine the southern boundary of this mesoregion [16]. The forms extend in an arch for approximately 45 km (SW–NE) from Dąbie by the Ner River to Sójki, north-east of Kutno (Figure 1a). The elongated moraine ridges comprise three belts, with the southernmost being the highest (Figure 2). The study focuses on the central part of the end moraines (from Sławęcin to Leszczynek), where the relative altitude is up to 25 m (156 m above sea level [a.s.l.]; Figure 1b).

The relief of the research area is poorly varied. Glacial landforms predominate and morainic plateaux are the most frequent to both the north and south of the moraine belts (Figure 2). Outwash plains are commonly formed in the forefield of the ice sheet [2], and thus, the rare occurrence of such forms is important for area characteristics and was noted and analysed by other researchers [4,6,7]. This is mostly related to denudation during periglacial conditions of the Vistulian glaciation and insufficient outflow of glacier waters [6,7]. The Kutno moraines feature asymmetrical slopes, where the distal slope is steep (inclination exceeds 6°, with an average of 3–4°), and the proximal slope transitions gently into the morainic plateau (Figure 2).

In reference to the geological regional subdivision of Poland, at the sub-Cenozoic palaeosurface, the study area is located on the Kujavian Swell, close to the Łódź Trough [21]. The occurrence of the Kłodawa salt dome to the west of the research area is perceived as an important factor affecting the present-day relief. Poborski [22] associates the change of the course of the Rgilewka River with the salt dome, while Jewtuchowicz [7] and Molewski [23] determine the highest part of the Kutno moraines (near Skrzynki) as a result of uplift movements along the Kujavian Swell axis. Palaeogene and Neogene deposits create a continuous sheet, except in the zone directly above the salt dome [24].

The oldest Quaternary sediments that build the investigated area are claimed to be derived from South Polish Glaciations (Cromerian–Elsterian) [10,19,20]. Tills of the Odra Glaciation (Saalian) and its Warta Stadial are usually separated by layers of sands and varved clay [10].

3 Methods

The research methods comprise field and deskwork, as well as studies on archival cartographic and geological materials that include, in particular, studies on 348 archive boreholes.

Geological and geomorphological mappings were carried out, and a detailed geological mapping was conducted along two geological cross-sections (Figure 1b). Lines of cross-sections were directed perpendicularly to the end moraine ridge. Public data were used, such as a digital elevation model and data on the distribution and description of boreholes.

Field studies were conducted at four key sites on the southern belt of end moraines at Leszczynek, Walew, Stary Sławoszew and Skrzynki, and at each site, a lithofacial analysis was performed. The lithofacial code by Zieliński and Pisarska-Jamroży [25] was used to describe the texture and the structure of the sediments in the exposures (Table 1). Sediments were classified into 14 units of different lithologies and depositional conditions.

The descriptions of the Leszczynek and the Skrzynki sites were expanded by performing and analysing general geological cross-sections.

Maps and sections were prepared in GIS software using the following programs: ArcMap (v10.6.1), Strater (v5) [26] and Surfer (v10) [27], and with graphics software, that is, Inkscape (v0.9.24).

4 Results

4.1 Key sites

The Leszczynek site is located in the north-east of the research area, where the Kutno moraines are slightly visible in the relief (Figure 1b). The relative altitude of end moraines reaches 12 m. The exposure has a height of about 4 m. Sediments were classified into three units: Le1, Le2 and Le3. Unit Le1 is built of horizontally

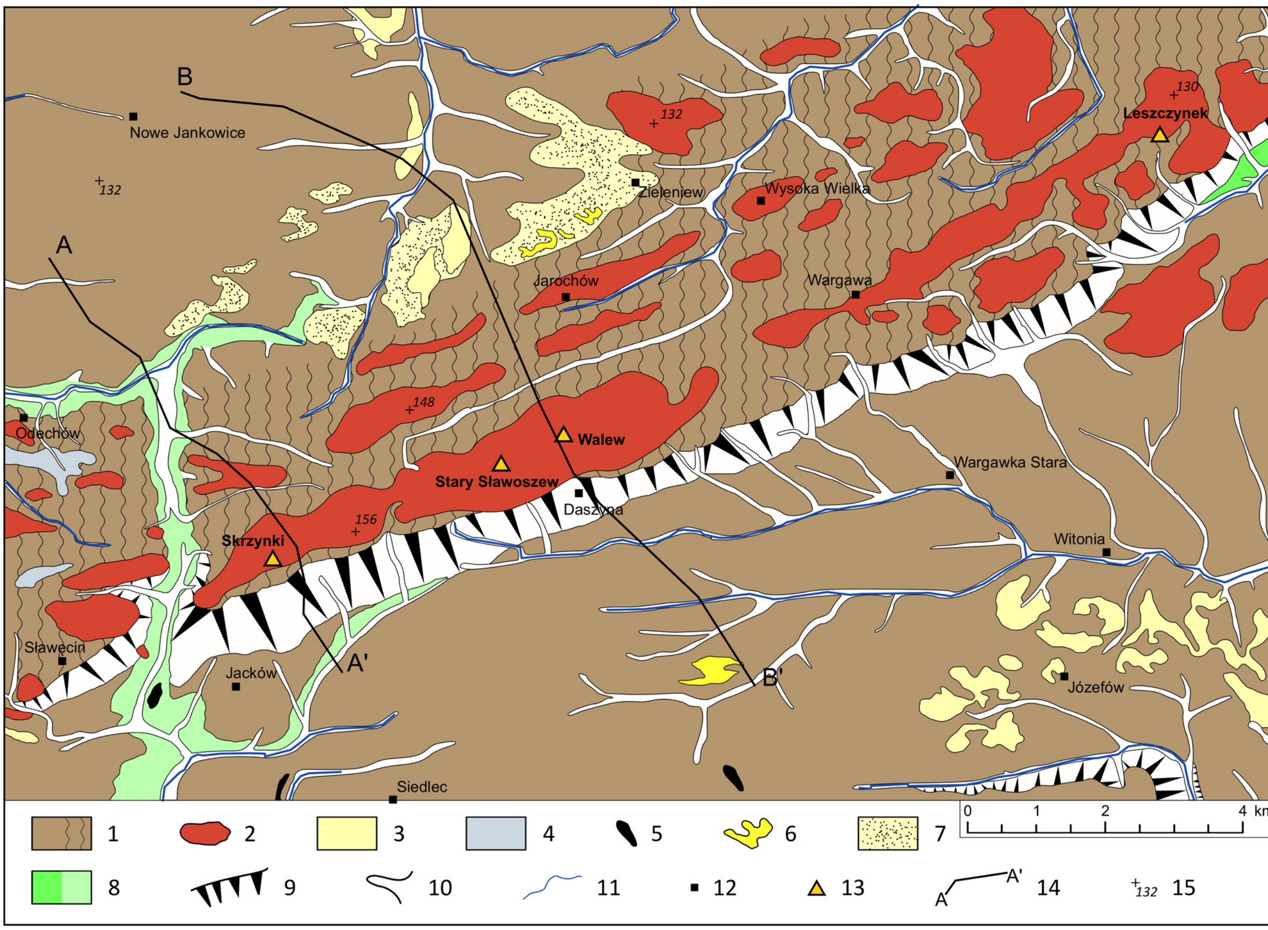

Figure 2: Geomorphological sketch (based on topographic maps and after Domosławska-Baraniecka [9,10], Domosławska [17,18], Szałamacha [12,13] and Jeziorski [19,20]). 1 – flat and undulating morainic plateau; 2 – end moraines; 3 – outwash plain; 4 – ice-dammed lake plain; 5 – eskers; 6 – dunes; 7 – plain of aeolian coversands; 8 – flood and meadow terraces; 9 – slopes; 10 – river valleys; 11 – rivers; 12 – towns; 13 – key research sites; 14 – geological cross–sections and 15 – elevation (in m a.s.l.).

laminated silty sands (STh) with some gravel interbeddings in the lower part, whereas unit Le2 includes massive boulderly gravels (GBm). The thickness of this layer is up to 60 cm. The contact between units Le1 and Le2 is erosive, and small normal faults occur beneath it (Figure 3b). Unit Le3 is composed of horizontally laminated silty sands (STh) at the base and sands (Sh) with admixture of maximum 10 cm gravels at the top.

Table 1: Lithofacial code used in the work

Lithofacial code	Lithofacial type, texture and structure
D	Diamicton
Dm	Massive diamicton
B/BG	Boulder/gravelly boulder
Bm	Massive boulder
G/GB/GS	Gravel/boulderly gravel/sandy gravel
Gm	Massive gravel
Gh	Horizontally stratified gravel
S/SG/ST	Sand/gravelly sand/silty sand
Sh	Horizontally laminated sand
Sd	Deformed sand
T	Silt
Th	Horizontally laminated silt
M	Mud
Mh	Horizontally laminated mud

Lithofacies distinguished within units Le1 and Le3 are typical of sheet-flow deposits [28], and according to Krzyszkowski and Zieliński [29], similar sediments may build fans at ice sheet margins. Unit Le2 characterises a sedimentation environment of higher transport force. Not only does the average grain size of the analysed units but also the occurrence of small normal faults developed in the underlayer (unit Le1) and the erosive contact between units Le2 and Le1 indicate this characteristic. Unit Le2 was probably deposited during true mass flow rather than hyperconcentrated flow because there is no gradual contact between units Le2 and Le3 [29]. True mass flow deposits represent the most proximal terminoglacial environment [30].

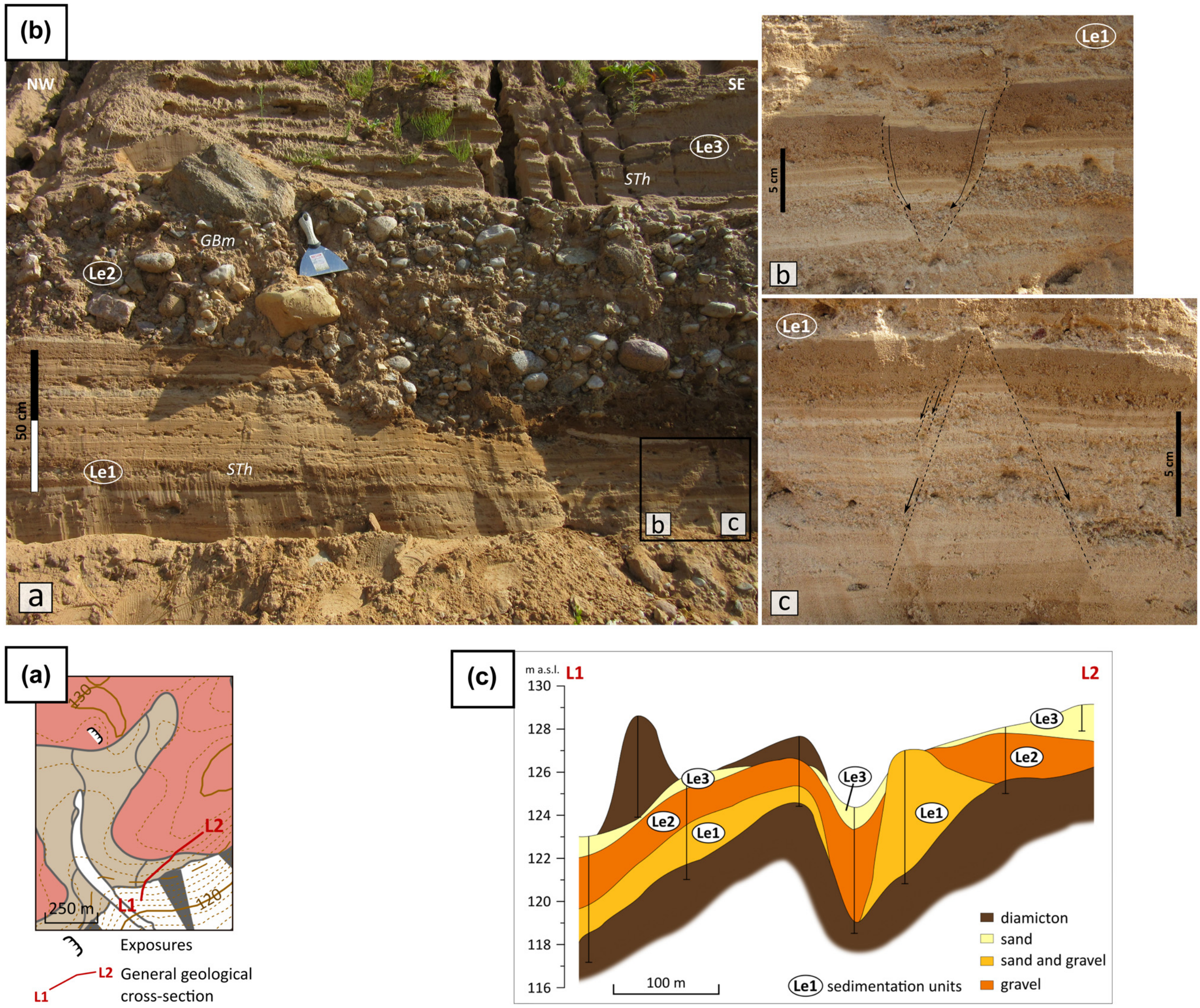

Figure 3: The Leszczynek site. (a) Topographic and geomorphological situation of the site (cf. Figure 2); (b) details of a – erosive contact between units Le1 and Le2; b and c – small normal faults and (c) general geological cross-section L1–L2. Lithofacial code symbols are presented in Table 1.

About 0.7 km south of the exposure, there runs the line of the general geological cross-section L1–L2. It partly cuts the southern slope of the Kutno moraines (Figure 3a). The main units distinguished in the exposure have their equivalents in the section (Figure 3c). An additional layer of diamicton was identified above unit Le3. The strata dip southwards and that is relevant to the outflow of glacier waters.

The Walew site is located in the central part of the southern moraine belt, where the relative altitude of the Kutno end moraines reaches 20 m. The dip of the beds gradually descends from 35° in a southward direction (Figure 4b-a). The sediments were classified into four units (Wa1, Wa2, Wa3 and Wa4).

Unit Wa1 was observed to lie shallowly under the surface in the northern part of the exposure and at a depth of 10 m in the southern part. This unit is built of horizontally stratified deposits that differ in the grain size, starting with the layer of boulderly gravels (GBh) and then alternating layers of gravels (Gh) and sands (Sh). Unit Wa2 occurs locally and is composed of rhythmically laminated clay (Mh) whose thickness reaches 20 cm. Next, horizontally laminated sands (Sh) of 7 m thick were deposited, and this layer was classified to unit Wa3. In the northern part of the exposure, where the inclination of sediments is higher, there was a system of small normal faults (Figure 4b-b). These deformed structures could have developed because of the melting of a dead ice block. Unit Wa4 is composed of massive diamicton

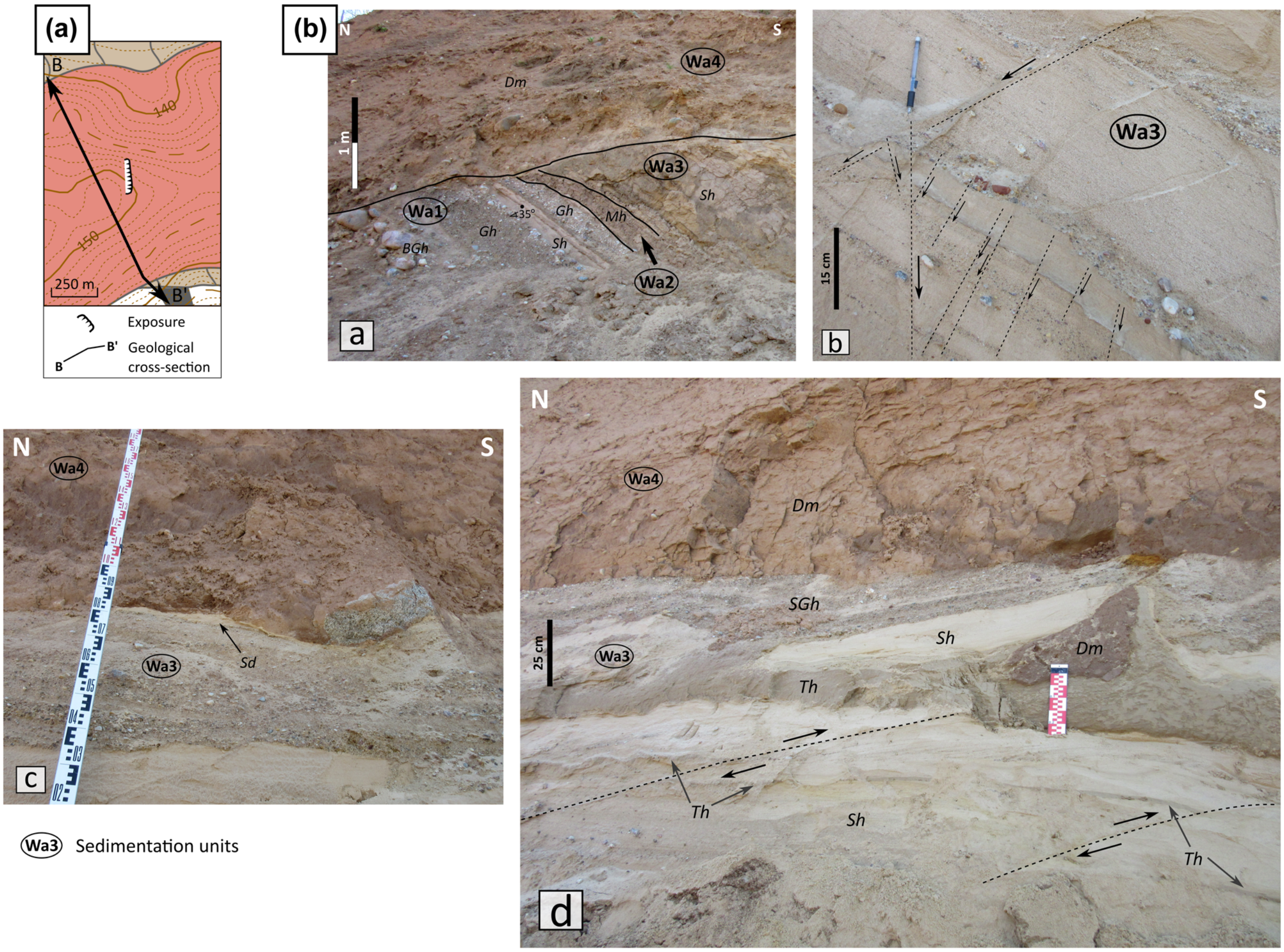

Figure 4: The Walew site. (a) Topographic and geomorphological situation of the site (cf. Figure 2) and (b) details of a – dip of the strata in the north part of the exposure; b – system of normal faults; c – dragged boulder with deformed sands behind and d – zone of major deformations including reverse faults and subsided part of the diamicton. Lithofacial code symbols are presented in Table 1.

(Dm) of 4–5 m thick. The diamicton forms a consistent sheet, and the contact zone of units Wa3 and Wa4 is erosive (Figure 4b-d). Two dragged boulders with deformed sand laminae behind them occurred in the analysed site (Figure 4b-c). There were a few reverse faults, including the one that caused part of the diamicton to disconnect and subside into sediments below (Figure 4b-d).

The differentiated sediments within unit Wa1 indicate changes in outflow force, probably in the marginal zone of the ice sheet. The sequence of units Wa1 and Wa3 is similar to a type-B end-moraine fan, defined by Krzyszkowski and Zieliński [29] – first, the fan was formed by mass flows and then mainly by sheet flows, which gradually decreased the average grain size of deposits. Unit Wa2 indicates the occurrence of a small basin within the end moraine fan. The layer of diamicton (unit Wa4) probably originated from the ice-front gravity flow and can be classified as the flow till. The character of the flow till is perceived to be loose and incoherent, especially in places with co-occurring water-sorted sediments [31,32]. Those features suit the diamicton found in the exposure. Its deposition must have happened suddenly with high water content, because it eroded the layers underneath and part of the flow till disconnected and subsided into unit Wa3.

The Stary Sławoszew site is located to the south west of the Walew site at a distance of less than 1 km (Figure 1b). The exposure is situated on a ridge and the northern slope of the southern moraine belt (Figures 2 and 5a). Here, the relative altitude of the Kutno end moraine reaches 25 m. Four units were distinguished (St1, St2, St3 and St4).

Horizontally stratified sands (Sh) observed in two parts of the exposure were classified into unit St1. They have a dip directed northward (Figure 5b-a), and coarser sediments were identified underneath (mainly sandy gravels and gravels). In the northern part of the exposure, the overlying unit St2 is built of massive gravelly boulders and gravels (BGm, Gh; Figure 5b-b).

To the south, the amount of alternating layers of horizontally stratified boulderly gravels and gravels (GBh, Gh) with sand interbeddings are most common (Figure 5b-c). They build unit St3.

Deposition of massive diamicton (Dm, unit St4) caused several normal faults in the western part of the exposure, where it lies directly over unit St1 (Figure 5b-d).

Unit St1 indicates low energy conditions of meltwater flow, while the deposition of unit St2 may be related to the mass flow. The content of silt and clay fraction within unit St2 is relatively minor and features cohesionless debris flows [28]. The alternation of gravelly and gravelly sandy layers within unit St3 is repeated gradually. This feature indicates the hyperconcentrated flow origin [28]. The unclear contacts may also be related to the process of amalgamation. Unit St3 occurs to the south of unit St2 and is built of finer

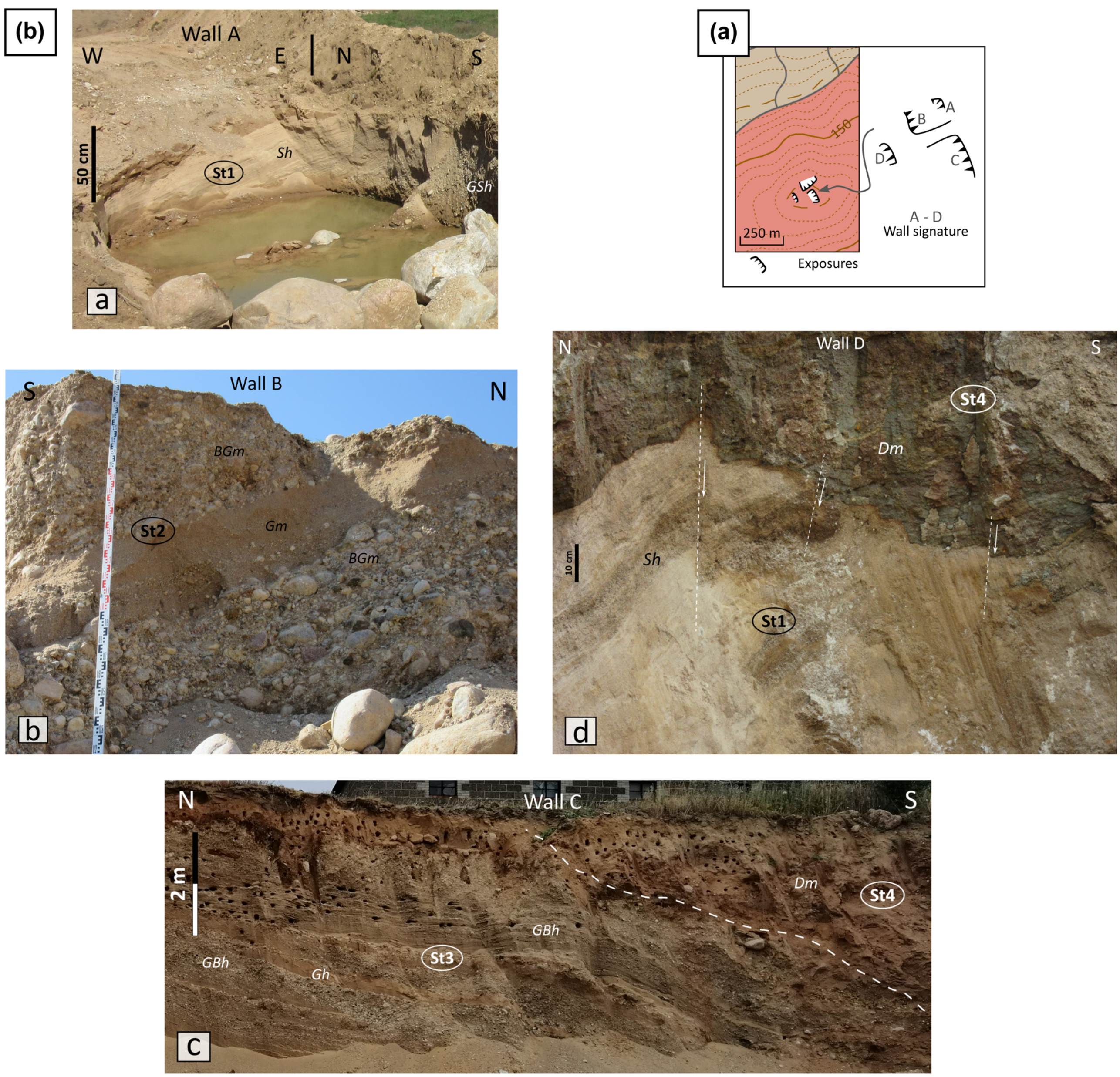

Figure 5: The Stary Sławoszew site. (a) Topographic and geomorphological situation of the site (cf. Figure 2); (b) details of: a – northern dip of the unit St1; b – massive and unsorted material of unit St2; c – alternating layers of gravels and boulderly gravels within unit St3 and d – zone of normal faults. Lithofacial code symbols are presented in Table 1.

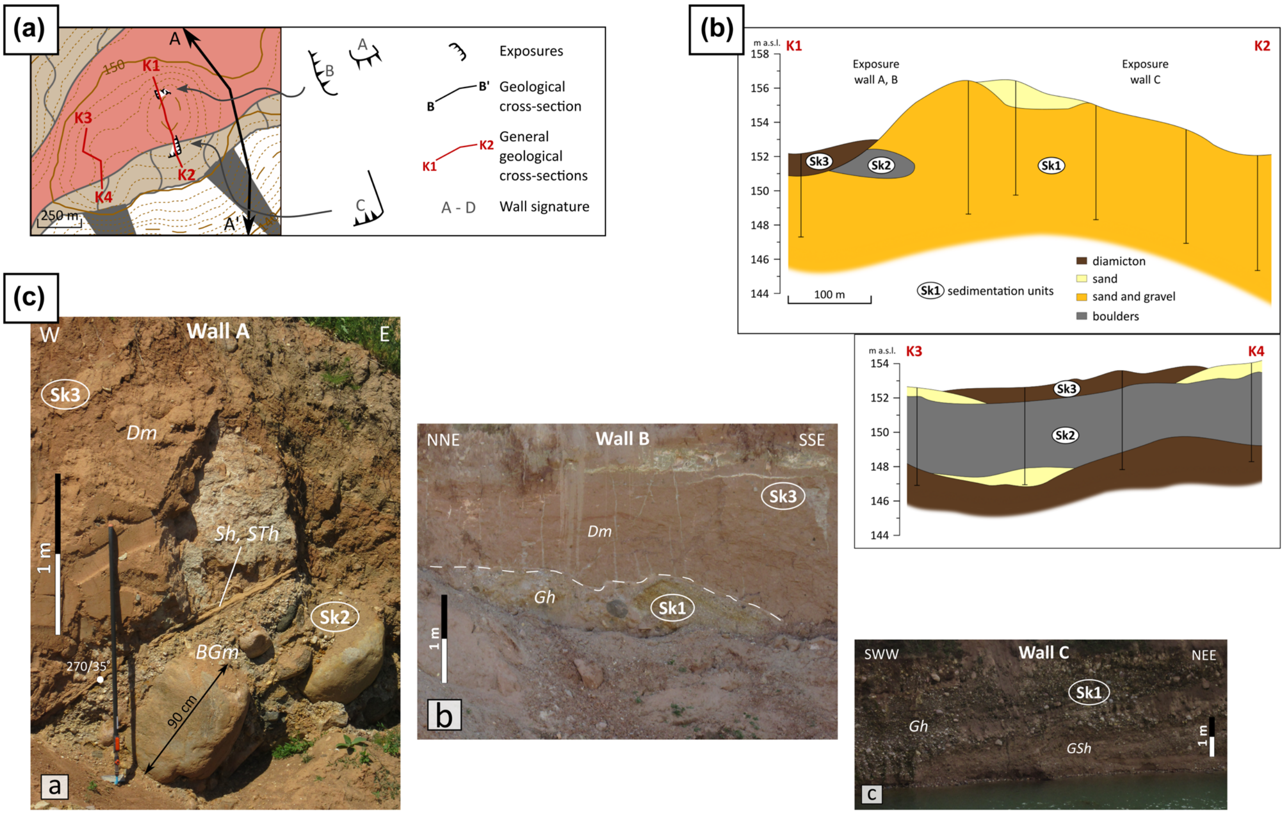

Figure 6: The Skrzynki site. (a) topographic and geomorphological situation of the site (cf. Figure 2); (b) generalised sections; (c) details of a – contact zone of units Sk2 and Sk3; b – erosive boundary between horizontally stratified gravels Sk1 with massive diamicton Sk3 and c – variety of unit Sk1 sediments in the southern part of the exposure. Lithofacial code symbols are presented in Table 1.

materials. This sequence is in consonance with the thesis of type-B end moraine fans forming first by mass flows and then by water-lain deposits [29].

The Skrzynki site is situated on the highest part of the Kutno moraines (155 m a.s.l.), where the relative altitude of the analysed forms reaches 25 m (Figure 6a). Three sedimentation units were distinguished (Sk1, Sk2 and Sk3). Unit Sk1 is composed of alternating layers of horizontally stratified gravels and sandy interbeddings (Figure 6c-b and c-c). The overlying unit Sk2 is composed of unsorted, massive gravelly boulders (BGm) of up to 90 cm in diameter (Figure 6c-a). The contact zone of units Sk2 and Sk3 is marked by the occurrence of horizontally stratified sands and silty sands (Sh, SFh) of thickness not exceeding 5 cm, and their dip azimuth and dip equals 270/35°. Above, a thick layer (about 3–4 m) of massive diamicton (Dm) was deposited (unit Sk3).

Unit Sk1 is similar to unit St3 (the Stary Sławoszew site) and probably formed under similar conditions, that is, hyperconcentrated flows. Unit Sk2 probably formed from mass flow, where even 1 m boulders were transported.

Two generalised sections were created (Figure 6b). Section K1–K2 crosses two parts of the exposure and presents mainly gravelly sands (unit Sk1). In the north-western part of the section, an overlying layer of till was detected, which corresponds to unit Sk3 found in exposures. Section K3–K4 is placed 0.5 km west of the exposure. An extremely thick layer (about 4 m) of boulders was detected, above which there is a layer of diamicton.

4.2 Geological cross-sections

The geological cross-section A–A′ is located in the south-west part of the research area (Figure 1b). The Cenozoic substratum is mainly of Middle Jurassic rocks, comprising limestones, mudstones, sandstones and shales (Figure 7). The altitude of the Mesozoic surface reaches 70 m a.s.l. Palaeogene and Neogene deposits were drilled in the majority of boreholes (of both cross-sections), and their thickness comes to 40 m. They consist mainly of sands, clay and silts, as well as layers of lignite. Within the Quaternary sediments, three layers of till were distinguished and

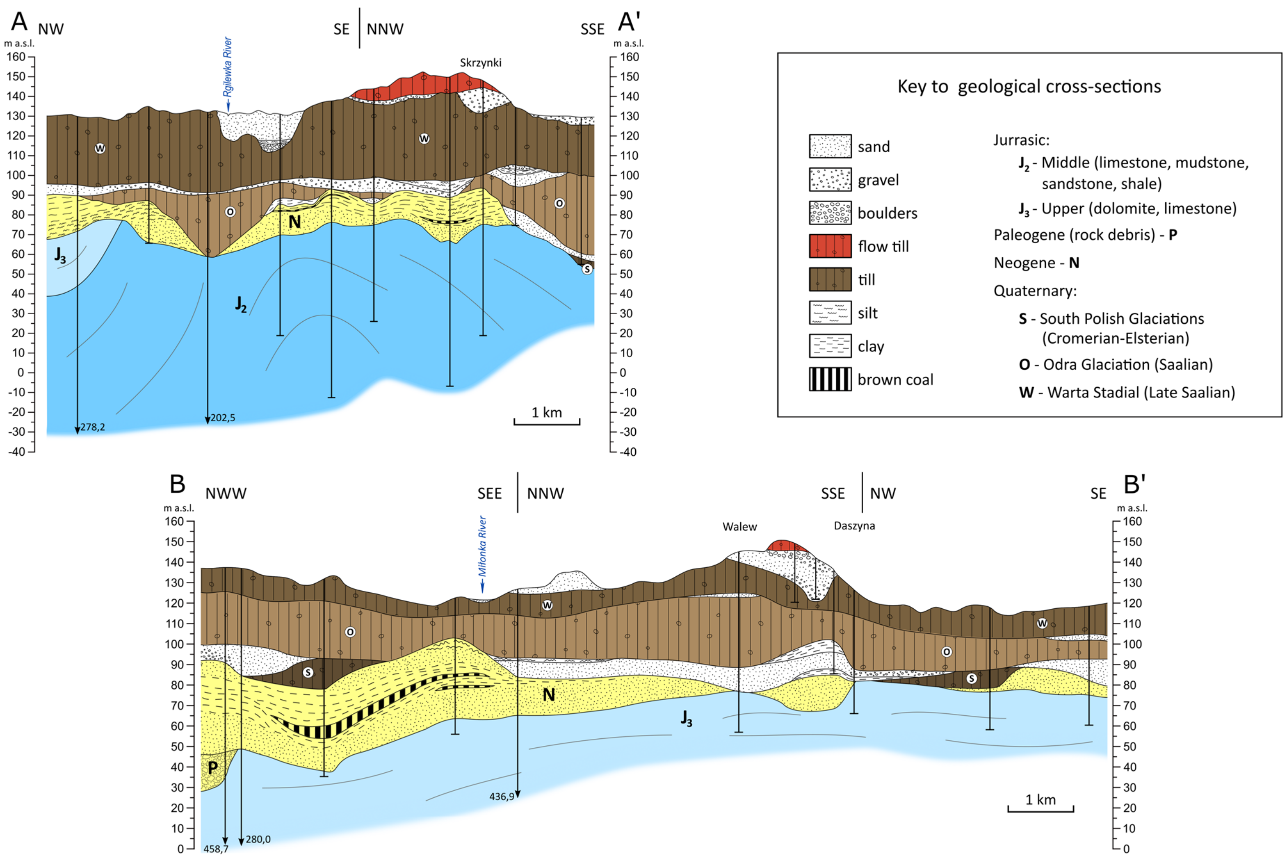

Figure 7: Geological cross-sections A–A′ and B–B′.

correlated with the South Poland glaciations (S; Cromerian–Elsterian), the Odra glaciation (O; Saalian) and the Warta Stadial (W; Late Saalian). In the zone of the Kutno moraines, an additional layer of till was recognised although the results of this study suggest that it is a flow till. Its thickness does not exceed 5 m. There was a rather thick layer (5 m) of gravels beneath it, on the southern slope of the end moraines, close to the Skrzynki site.

The geological cross-section B–B′ characterises the central part of the study area, 100 m west of the Walew site. The Cenozoic substratum is built of Upper Jurassic dolomites and limestones. The Upper Jurassic surface lies at 40–70 m a.s.l. Three layers of till were also distinguished within the Quaternary. The deposited material in the Kutno moraines area is composed of boulders, gravels and sands and it dips southward. The overlying layer of flow till is thin (max 4 m) and was drilled in only one borehole.

5 Discussion

On the basis of the analysed key sites on the southern belt of the Kutno moraines, some similarities in sediment successions were found. One is the occurrence of materials deposited in extreme mass flows. Such sediments were recognised in three key sites (the Leszczynek, Stary Sławoszew and Skrzynki sites) and were classified into units: Le2, St2 and Sk2. The size of the biggest boulders found within those units reaches 0.9 m. These layers were most probably deposited during true mass flows. Dylikowa [11] mentioned that the boulderly material observed in Daszyna was deposited during the gravity flow. Pisarska-Jamroży [33] discussed the occurrence of types of mass flow in the glaciomarginal zone. According to Pisarska-Jamroży, cohesive flows are characterised by poorly sorted material, massive structure, deformed bottom, a several-metres-thick laminar flow and also the common occurrence of megaclasts. By contrast, the features of grain flows are as follows: sharp, erosional contacts with underlying deposits; a lack of megaclasts and deformations; inverse grading; and massive structure [33]. So, more specifically, unit Sk2 can be classified into cohesive flow deposits, whereas units Le2 and Sk2 have more common features with grain flow deposits or they originated from density-modified grain flow. True mass flows are typical of a proximal terminoglacial environment [30].

Another deposition mechanism was identified for units St3 and Sk1, and it was determined as the hyperconcentrated flow. Both units are composed of alternating layers of coarser material gradually passing into finer. This feature and the unclear contacts between those layers indicate their mentioned origin. Hyperconcentrated flows represent a more distal terminoglacial environment, for example, distal marginal moraines [30]. The occurrence of these units was observed to the south of the units originating from mass flows.

Sediments originating from sheet flows were identified in exposures of the Leszczynek and Walew sites (units Le1, Le3 and Wa3). According to Krzyszkowski and Zieliński [29], similar sediments build the top parts of the type-B ice-contact fans (where the bottom parts are built by mass flow deposits).

Most of the deformation structures observed in the key sites were normal faults derived from the loosening of material (ice-contact structures). Such processes could have happened due to the melting of dead ice blocks. Jewtuchowicz [7] claimed that all deformed structures found in the Kutno moraines formed due to this process. However, one place with reverse faults was found (the Walew site). It was probably derived from shearing as a consequence of flow till deposition.

Most of the identified sedimentation units are related to a terminoglacial environment. Mass flows usually form the most proximal part of this environment, when the distal is formed by hyperconcentrated flows and sheet flows [30]. These sedimentation mechanisms may lead to the formation of end-moraine fans – especially of type B according to Krzyszkowski and Zieliński [29].

The conducted research does not confirm the thesis of Domosławska-Baraniecka [6] concerning the influence of a local transgression of the Warta Stadial ice sheet on the formation of the Kutno moraines. Based on the results, the ice-front of the Warta Stadial ice sheet stopped at the line of the end moraines, where meltwaters started to accumulate material. According to Lencewicz [4], each belt of the analysed moraines determines consecutive lines where the ice-front stopped. Research focused on the southern-most moraine belt, so Lencewicz's [4] thesis was confirmed only partially. The influence of dead ice blocks melting to form end moraines is rather minor although Jewtuchowicz [7] claims it to be crucial. The deformed sediments that might indicate this process were identified only in the Walew site.

The analysed deformed structures and sedimentation units are mainly associated with a terminoglacial environment where mass flows occurred and end-moraine fans were formed. In conclusion, the character of the southern belt of the Kutno moraines should be determined as accumulative.

References

[1] Klimaszewski M. Geomorfologia. Warszawa: Państwowe Wydawnictwo Naukowe; 2005 (in Polish).

[2] Migoń P. Geomorfologia. Warszawa: Państwowe Wydawnictwo Naukowe; 2009 (in Polish).

[3] Godlewska A. Z jaką dynamiką lodu należy wiązać formy szczelinowe? – przegląd badań [What sort of ice dynamics are crevasse fillings connected with? – research overview]. Annales Universitatis Mariae Curie-Sklodowska. 2015;70(2):27–43 (in Polish with English summary).

[4] Lencewicz S. Dyluwium i morfologia środkowego Powiśla. Prace Polskiego Instytutu Geologicznego. 1927;2(2):1–129 (in Polish).

[5] Domosławska-Baraniecka MD. Z zagadnień czwartorzędu okolic Łęczycy i Kłodawy. Przegląd Geologiczny. 1959;81:552–4 (in Polish).

[6] Domosławska-Baraniecka MD. Przebieg sedymentacji i kształtowania kutnowskich moren czołowych w okolicy Sławęcina. In: Różycki S, editor. Prace o plejstocenie Polski Środkowej. Warszawa: Polska Akademia Nauk; 1961. p. 59–77 (in Polish).

[7] Jewtuchowicz S. Geneza pradoliny warszawsko-berlińskiej między Nerem i Moszczenicą [Origin of the Warsaw-Berlin pradolina between the rivers Ner and Moszczenica]. Prace Geograficzne Instytutu Geografii Polskiej Akademii Nauk. 1967;62:1–91 (in Polish with English summary).

[8] Roman M. Rekonstrukcja lobu płockiego w czasie ostatniego zlodowacenia [Reconstruction of the Płock lobe during The Last Glaciation]. Acta Geograph Lodziensia. 2010;96:1–171 (in Polish with English summary).

[9] Domosławska-Baraniecka MD. Objaśnienia do Szczegółowej Mapy Geologicznej Polski w skali 1:50 000. Arkusz Krośniewice (516). Warszawa: Instytut Geologiczny; 1968. p. 1–34 (in Polish).

[10] Domosławska-Baraniecka MD. Objaśnienia do Szczegółowej Mapy Geologicznej Polski w skali 1:50000. Arkusz Łęczyca (552). Warszawa: Instytut Geologiczny; 1968. p. 1–80 (in Polish).

[11] Dylikowa A. Daszyna. In: Dylik J, editor. Guide-book of Excursion: From the Baltic to the Tatras, part II, vol. II Middle Poland. Poland: International Association on Quaternary Research VIth Congress; 1961. p. 9–11.

[12] Szałamacha G. Szczegółowa Mapa Geologiczna Polski (1:50000). Kutno (517). Warszawa: Instytut Geologiczny; 1991.

[13] Szałamacha G. Objaśnienia do Szczegółowej Mapy Geologicznej Polski w skali 1:50000. Arkusz Kutno (517). Warszawa: Państwowy Instytut Geologiczny; 1996. p. 1–32 (in Polish).

[14] Molewski P, Weckwerth P, Wysota W. Cyfrowa mapa geomorfologiczna (1:100000). Wysoczyzna Kłodawsko-Kutnowska. Warszawa: Główny Urząd Geodezji i Kartografii; 2013.

[15] Rdzany Z. Osady deglacjacyjne zlodowcenia warty we wschodniej części regionu łódzkiego [Sediments of the Warta ice-sheet deglaciation in the eastern part of the Łódź region]. Przegląd Geologiczny. 2006;54(4):343–51 (in Polish with English summary).
[16] Solon J, Borzyszkowski J, Bidłasik M, Richling A, Badora K, Balon J, et al. Physico-geographical mesoregions of Poland – verification and adjustment of boundaries on the basis of contemporary spatial data. Geograph Polonica. 2018;91(2):143–70.
[17] Domosławska MD. Szczegółowa Mapa Geologiczna Polski (1:50000). Krośniewice (516). Warszawa: Instytut Geologiczny; 1956.
[18] Domosławska MD. Szczegółowa Mapa Geologiczna Polski (1:50000). Łęczyca (552). Warszawa: Instytut Geologiczny; 1956.
[19] Jeziorski J. Szczegółowa Mapa Geologiczna Polski (1:50000). Piątek (553). Warszawa: Instytut Geologiczny; 2002.
[20] Jeziorski J. Objaśnienia do Szczegółowej Mapy Geologicznej Polski w skali 1:50 000 Arkusz Piątek (553). Warszawa: Państwowy Instytut Geologiczny, Państwowy Instytut Badawczy; 2013. p. 1–51 (in Polish).
[21] Narkiewicz M, Dadlez R. Geologiczna regionalizacja Polski – zasady ogólne i schemat podziału w planie podkenozoicznym i podpermskim [Geological regional subdivision of Poland: general guidelines and proposed schemes of sub-Cenozoic and sub-Permian units]. Przegląd Geologiczny. 2008;56(5):391–7 (in Polish with English abstract).
[22] Poborski J. Cechsztyńska struktura solna Izbica-Łęczyca. Przegląd Geologiczny. 1957;1:31–2 (in Polish).
[23] Molewski P. Paleogeograficzne uwarunkowania odpływu wód z zastoiska warszawskiego doliną Bachorzy i pradoliną warszawsko-berlińską w czasie stadiału głównego zlodowacenia Wisły [Paleogeographical conditions of the outflow from the Warsaw ice-dammed lake through the Bachorza valley and the Warsaw-Berlin pradolina]. Landf Anal. 2014;25:105–14 (in Polish with English abstract).
[24] Baraniecka MD, Skompski S. Mapa Geologiczna Polski (1:200 000)B – mapa bez utworów czwartorzędowych. Płock. Warszawa: Instytut Geologiczny; 1979.
[25] Zieliński T, Pisarska-Jamroży M. Jakie cechy litologiczne osadów warto kodować, a jakie nie? [Which features of deposits should be included in a code and which not?]. Przegląd Geologiczny. 2012;60(7):387–97 (in Polish with English abstract).
[26] Strater 5 – User's Guide. Golden Software LCC, 2016.
[27] Surfer 17 – User's Guide. Golden Software LCC, 2019.
[28] Zieliński T. Sedymentologia – Osady rzek i jezior. Poznań: Wydawnictwo Naukowe Uniwersytetu im. Adama Mickiewicza; 2015 (in Polish).
[29] Krzyszkowski D, Zieliński T. The Pleistocene end moraine fans: controls on their sedimentation and location. Sediment Geol. 2002;149:73–92.
[30] Zieliński T, van Loon AJ. Characteristics and Genesis of moraine-derived flowtill varieties. Sediment Geol. 1996;101:119–43.
[31] Marcussen IB. Distinguishing between lodgement till and flow till in Weichselian deposits. Boreas. 1975;4:113–23.
[32] Marcusen IB. Studies on flow till in Denmark. Boreas. 1973;2:213–31.
[33] Pisarska-Jamroży M. Środowisko depozycyjne osadów spływowych jako wskaźnik zmian warunków hydrologicznych strefy marginalnej lądolodu (plejstocen Pomorza Zachodniego) [Environment of mass-flow deposition as indicator of hydrological regime changes in ice-sheet margin (Pleistocene of Western Pomerania)]. In: Więcław M, editor. Środowisko przyrodnicze w badaniach geografii fizycznej, Vol. 9, Bydgoszcz: Promotio Geographica Bydgostiensia; 2012. p. 63–79 (in Polish with English abstract).