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The role of the paraglacial environment in the transformation of glacial wartanian relief in Poland

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Abstract. The article comprises a justification for the need to distinguish the record of the paraglacial environments in the belt of relief formed as a result of the Warta Glaciation in Poland. The zone covers the foreland of the Weichselian Glaciation, occupying a strip of land from several to more than 200 kilometres in width.

Simplified, two periods are marked in the history of views on relief genesis of the area. The first, which covers the first half of the 20th century, was dominated by the idea of glacial genesis of the area. The latter period is characterised by the discussion between advocates of the periglacial character of relief of the Wartanian zone and those who defended the thesis of the good preservation of glacial relief of the area.

Taking the paraglacial environment into account in analysing relief transformations introduces a new quality and may result in a more complete and precise evaluation of post-Wartanian morphogenesis. It is also consistent with tendencies in worldwide literature and results from the principle of uniformitarianism.

Key words
paraglacial environment,
Wartanian belt,
old glacial landscape,
Central Poland

Introduction

The aim of the article is to justify the need for distinguishing the paraglacial environment in areas of the Warta Glaciation in Poland and to determine its role in the morphogenesis of the area, with respect to changes in morphology as well as temporal relations between the operation of paraglacial processes and periods of activity of other environments.

The basis for the study is a review of literature on the subject, taking into consideration the research results of the author and other authors whose materials may concern the paraglacial environment.

The analysed area is the belt of Wartanian relief, widening eastwards, whose width is from several to over 200 kilometres in Poland (Figs 1 and 2). In the south, this zone of lowland relief is adjacent to the metachronous line of extent of the Weichselian Glaciation (LGM, Leszno Phase and Poznań Phase of the Main Stadial of the Weichselian) (Marks 2011; Wysota, Molewski 2011). In the light of views dominating for more than half a century, the morphologic landscape of the area w as shaped as a result of the Warta Glaciation (Late Saalian, Wartanian). In the literature it is still the subject of discussion whether the rank of this glacial period in the climatostratigraphic sense is a glaciation, a stadial or merely a phase. However, there are no doubts that it was a separate advance of the ice-sheet, divided into several lobes from the side of the contemporary Baltic Sea, along several hundred kilometres. It is recorded in Central Europe between the vicinity of Hamburg and Central Belarus, with

a complex inventory of landforms and various facies of glacigenic sediments (Klatkowa 1972; Rdzany 2009). This article will use the term "Warta Glaciation" to denote a glaciation *sensu stricto*, i.e. advance of the ice-sheet over the area of the Polish Lowland and deglaciation of this area, without taking a stand on the climatostratigraphic rank of this part of MIS 6.

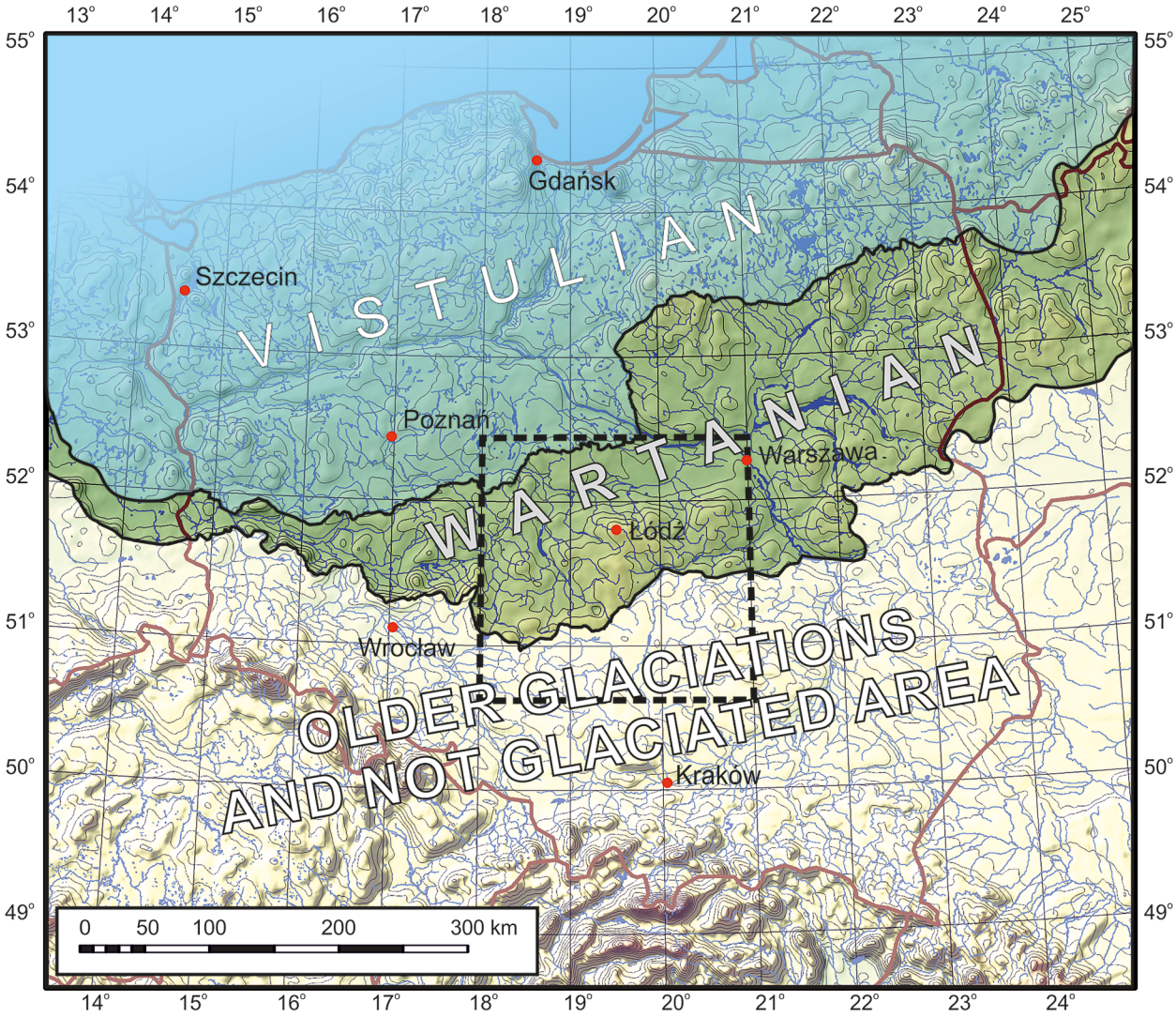

Fig. 1. Wartanian zone in Poland (based on Digital Elevation Model SRTM-3). The rectangle shows the location of Central Poland on Fig. 2

The concept of distinguishing the paraglacial environment is not a proposal to distinguish processes unknown so far, but an idea to describe non-glacial processes which resulted from glaciation and deglaciation. At the same time, they are such processes that cannot be included in the periglacial environment according to its contemporary definitions (e.g. Brown, Kupsch 1995; French 2007; Knight, Harrison 2009).

On the Need to Distinguish the Paraglacial Environment

Until 2014, no traces of paraglacial environment were distinguished in the Warta Glaciation area, as was also the case for the Weichselian Glaciation area and the remaining lowland areas (Rdzany 2014a, b).

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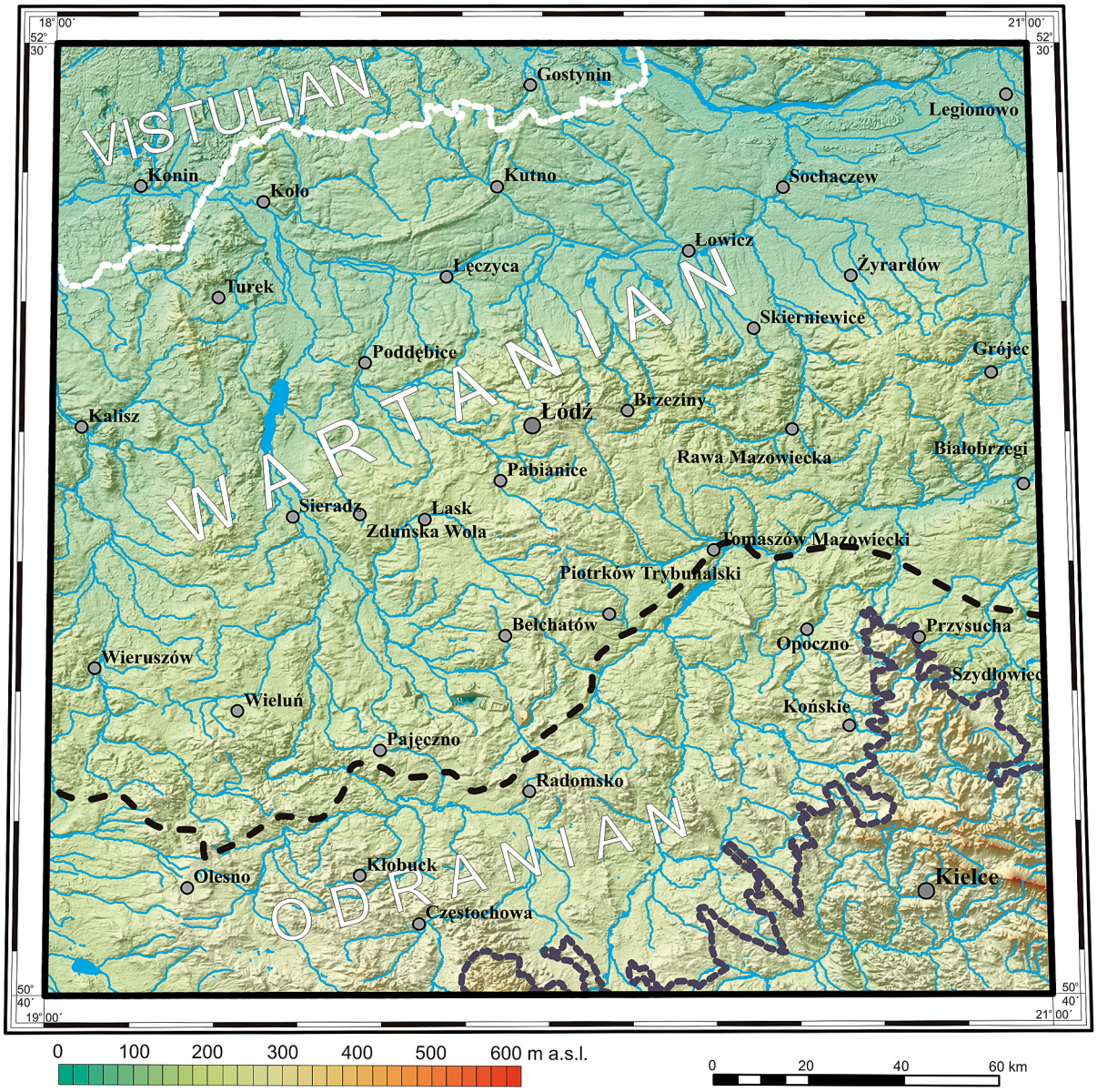

Fig. 2. Wartanian zone in Central Poland (based on Digital Elevation Model SRTM-3)

Recently, individual cases of records of paraglacial processes were indicated by Traczyk and Kasprzak (2014) in the example of colluvial covers of the Ślęża massif in the Sudetes Foreland, in the maximum extent zone of the Odranian Glaciation (Saalian max). Traces of mass movements during the adjustment of rock slopes to the new conditions of paraglacial environment in the foreland of the retreating ice-sheet were documented there. Formerly, these colluvia were believed to be manifestations of periglacial processes.

The need to distinguish the paraglacial environment is also noticed in recent research into the relief of mountainous glaciations in the Tatra Mountains (Kotarba 2013).

The first instances of paraglacial processes reported in worldwide literature have a fairly long history – about fifty years – and they come from the period of Pleistocene glaciations in the territory of Scotland (Godard 1965, cf. Jarman 2007). However, the paraglacial concept was more formally articulated for the first time by Ryder (1971) and Church and Ryder (1972) for describing non-glacial processes which are consequent to glacial conditions and operate during a glacial period and sometimes after it finishes. The authors presented two examples

of a fluvial environment: one came from Baffin Island, where rapid fluvial accumulation in the postglacial valley continues today, and the other from the area of British Columbia, where records of efficient denudation and sedimentation during the paraglacial period contrast sharply with the current energy level of the environment.

Church and Ryder (1972) defined paraglacial processes as non-glacial, conditioned by glaciation. Areas of their occurrence include both the surroundings of the ice-sheet and the deglaciated area, and the duration of paraglacial processes may extend beyond the period of deglaciation and occurrence of glacier ice. Some areas, e.g. drift-mantled hillslopes, may stabilise within several hundred years, while others, such as large fluvial systems, may transform glacigenic sediments even more than 10,000 years after deglaciation. A review of research conducted in the following years allows the conclusion to be drawn that the term "paraglacial environment" was widely understood as rapid adaptation of glacial areas to non-glacial conditions (e.g. Benn, Evans 1998).

As follows from the description of the progress of research on the paraglacial environment by Ballantyne (2002), more studies appeared in the second half of the 1980s. The studies revealed several trends:

- Firstly, research on the diversity of the environment in the geomorphologic context intensified. In particular, attention was paid to slope processes, developing on drift-mantled hillslopes, freshly uncovered as an effect of deglaciation. Dynamics of littoral processes and areas of river mouths was also studied.
- Secondly, studies on the paraglacial system which developed during the last 200 years as a result of retreating glaciers after the maximum of the Little Ice Age developed in order to look for analogies to rapid environment changes at the turn of the Pleistocene and Holocene.
- Thirdly, the concept of "paraglacial environment" was used for studies on the diversity of contemporary deglaciation environments in mountainous areas, from the Antarctic to moderate climate coasts.
- Fourthly, more attention was paid to the palaeogeographic significance of paraglacial facies in studies of the sequence of events in stratigraphy.

On the basis of analysis of the state of research at the end of the 20th century, Ballantyne (2002) proposed to define the "paraglacial environment" as "*nonglacial earth-surface processes, sediment accumulations, landforms, landsystems and landscapes that are directly conditioned by glaciation and deglaciation*". It is a broad definition. The term "paraglacial" is becoming a descriptor, or identifier, of processes, sedimentation facies, landforms, sets of landforms as well as landsystems. This research is the domain of paraglacial geomorphology. According to Ballantyne (2002), the leading characteristic of a paraglacial system is instability. The duration of the related processes lasts from 10^1 to 10^4 years. Areas uncovered by the retreating ice-sheet are very vulnerable to rapid changes. Other researchers stress not only the short duration of paraglacial processes but also their high sensitivity to advancing warming. So state, among others, Knight and Harrison (2009), who also believe that knowledge of both the contemporary periglacial and paraglacial environment and that of the turn of the last glaciation and the Holocene is considerable, whereas we know very little about older glaciations. This results from poor preservation of structures due to pedogenic processes and growth of flora, which is a limitation in the application of the principle of uniformitarianism.

Attempts at systematisation of paraglacial relief were made. Such a proposal was presented by Ballantyne (2002), who distinguished and described 6 paraglacial landscape systems: rock slopes, drift-mantled slopes, glacier foreland, alluvial, lacustrine and coastal landsystems.

Polish researchers started to deal with the paraglacial environment – using the above mentioned terminology – relatively late, in works concerning contemporary Arctic and Antarctic areas (e.g. Zwoliński 2005, 2007; Rachlewicz 2010; Strzelecki 2011).

One may expect that distinctions of geomorphologic landscapes in the glacial relief area of the Wartanian period in Poland will be slightly different from the contemporary deglaciated areas under study, and the difficulty of reconstruction will be greater. Certainly, greath difficulties are bound to occur in the application of the principle of uniformitarianism owing to the long stage of post-paraglacial morphogenesis (since the War-

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ta Glaciation). As was stressed earlier, the fact that no traces of paraglacial environment in lowland Poland, all the more in the so-called old glacial zone, have been described yet leaves a specific gap. Due to this, there is a need to fill the gap, as is already being done in terminology used for describing contemporary processes of the cold zone. This involves using such terms as "paraglacial environment", "paraglacial processes", "paraglacial relief", "paraglacial landforms and structures" or "paraglacial geomorphology".

Introducing terms related to the paraglacial environment is very important, which can also be seen when looking at the history of changing scopes of other terms, in particular the term "periglacial environment".

Paraglacial Environment Versus Periglacial Environment

Despite over one hundred years of studies into relief genesis of the central part of the Polish Lowland, the degree of recognition of the main stages of relief evolution, and in particular the significance of individual morphogenetic environments is still unsatisfactory. Until the second half of the 20th century, hardly anyone doubted that the relief of the area was glacial, and the main postglacial landforms were believed to be "glacial uplands", currently referred to as moraine plateaus, eskers, terminal moraines and "diluvial gravel pits" (Lencewicz 1927).

Although the concept of "periglacial environment" had been known since the second decade of the 20th century (Łoziński 1909, 1912), for a long time it was not associated with the area of the Polish Lowland. Łoziński distinguished the "periglacial facies" as a kind of eluvium – the effect of frost action on sandstones in Gorgany, the Świętokrzyskie Mountains or other mountain ranges in Central Europe. It must be noted that the term was used with reference to the fossil environment. According to Łoziński the "periglacial zone" is a belt around the ice-sheet cap, with a set of phenomena conditioned by frost action.

It was only Dylik (1952, 1953) who presented a thesis that the relief of central Poland is polygenetic, and the original glacial relief lost its features as a result of the quite diverse activity of the periglacial environment (Fig. 3). According to these views, the glacial relief of central Poland was thoroughly transformed by periglacial processes during the last cold stage of the Pleistocene and became largely denudational. The analysed zone of Wartanian relief was defined by him as a periglacial area on formations of glacial accumulation. Dylik's concept of periglacial morphogenesis initiated the period of views on the high significance of processes of the cold climate, which were supposed to dominate the initial glacial relief, and what was left of it included mainly areas of periglacial pediments with periglacial tors.

Dylik (1964) considerably expanded the range of terms concerning periglacial phenomena. He described the periglacial environment as a set of frost and snow-ice morphological processes. He did not restrict their occurrence to the vicinity of the ice-sheet. This view became popular, also in worldwide literature, but was not commonly accepted, as even in 1978 Klimaszewski was in favour of the traditional definition of the periglacial zone, related with the ice-sheet in terms of area.

On the other hand, the periglacial environment as defined by Jahn (1970) was based on characteristics of climate. The periglacial zone – in his opinion – was the area of dry and frosty climate, with its extent border close to the isothermal line of annual temperature of approximately -1°C. According to Brown and Kupsch (1995), French (2007) and Knight and Harrison (2009), the present use of the term "periglacial" refers to frost action processes in the area which was not occupied by the ice-sheet. Besides processes related to permafrost, the role of seasonal, marine, lacustrine and fluvial ice as well as snow is taken into account. The current discussion on the scope of the term "periglacial environment" comes down to accepting the convention whether it concerns only the area of permafrost or also the area of deep seasonal freezing. In the former case, it currently corresponds to 20% of the area of land, in the latter 35% (Knight, Harrison 2009).

Irrespective of differences as to the detailed definition of the periglacial zone, since the 1950s, Dylik's concept of periglacial denudation has had numerous advocates – not only in the Łódź geomorphological centre. Most facts were documented in the central part of the Wartanian zone, which includes the Łódź Region. Considerable transformation of

slopes of large hills in the range of the Ostrzeszów Hills in southern Greater Poland was also reported (Rotnicki 1967). The view that the Wartanian zone is a periglacial area based on the formations of glacial accumulation has been quite firmly established and gained many supporters among authors of larger syntheses, including regional studies (Jahn 1970; Kondracki 1978).

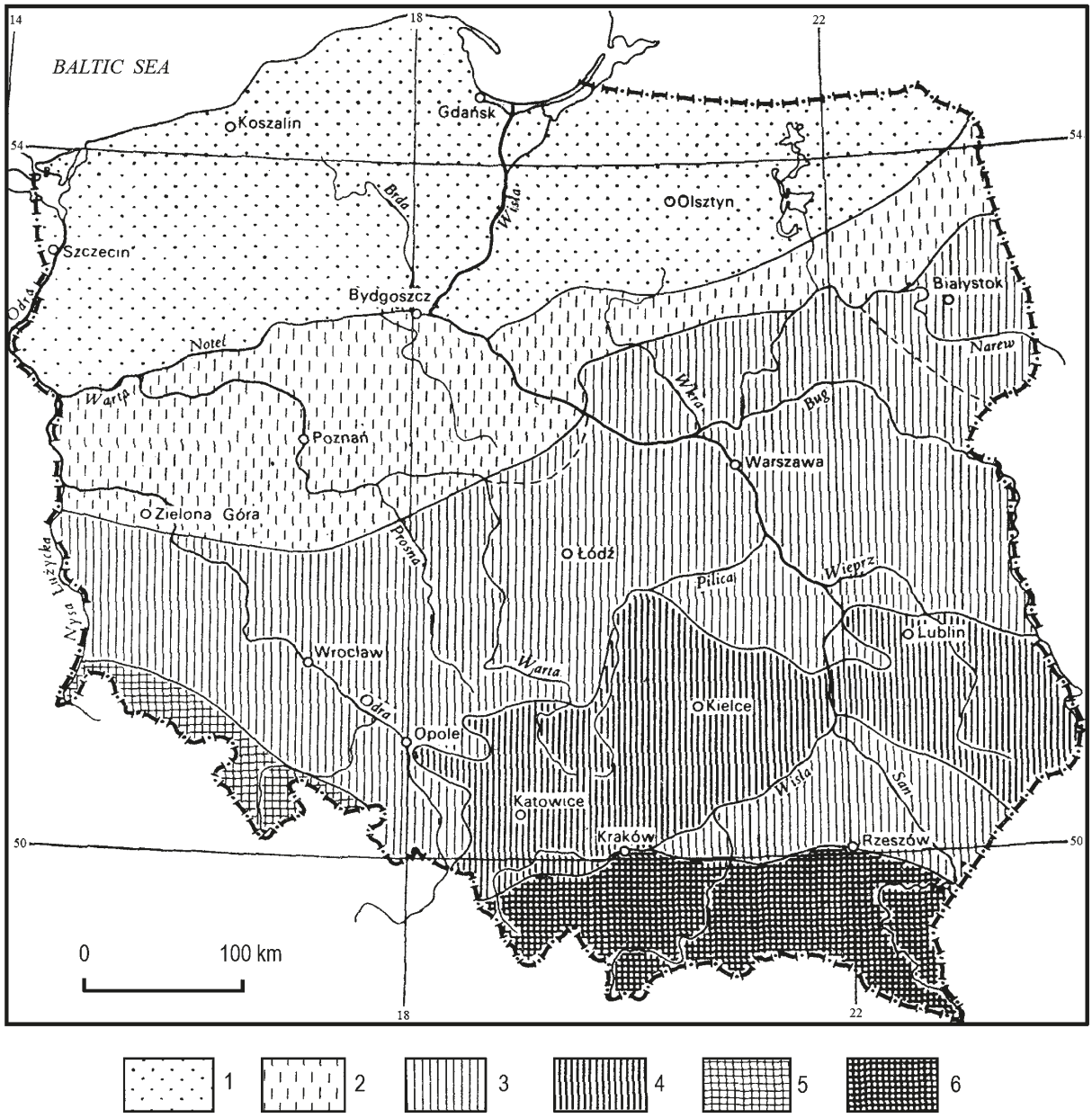

Fig. 3. Periglacial zone of the last glaciation according to Dylik (1956) (based on Jahn 1970): 1 – area of glacial morphogenesis with traces of periglacial environment, 2 – periglacially transformed glacial area, 3 – periglacial area on formations of glacial accumulation, 4 – area of periglacial morphogenesis with relief of pre-Pleistocene denudation, 5 – area of periglacial modelling upon old fold structures, 6 – area of periglacial modelling upon young fold structures

However, as early as the mid-1960s, a geomorphological monograph of the Domaniewice Hills was published, which documented good preservation of vast kame ridges around Łowicz (Klajnert 1966). Although it was a doctoral dissertation written under the supervision of Jan Dylik, it was clear that in many details it did not confirm the significance of periglacial transformations in the analysed

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set of large kames. Several years later, the thesis that vast fragments of glacial landscape had survived until the present time, particularly within the range of kame fields, was established in subsequent studies (Klatkowa 1972; Krzemiński 1974; Klajnert 1978, 1984). However, the discussion on the efficiency of periglacial morphogenesis continued and even in recent years the views on its significance in the origination of landforms and even landsystems in the Łódź region have been supported. Its significance is indicated with reference to sections of river valleys as well as some convex landforms of tor-like character in plateaus near Łódź (Turkowska 2006).

Distinguishing the paraglacial environment raises the question about the necessity of revising the interpretation of many structures, so far considered to be glacial, proglacial, periglacial or related to a moderate climate. A review of literature concerning, for example, the record of periglacial processes such as involution may provide arguments for a different interpretation of these structures – directed towards the paraglacial environment. In some cases, it can be found that, for example, these disturbances are not related to the boundary surface of the active layer. Verification of the already documented sites – usually non-existent outcrops – is difficult and may not be necessary. However, it is worth paying attention to more interpretation possibilities in future research.

A more accurate description of the transformation process of glacial relief into old glacial relief requires a more precise range of terms related to glacial, proglacial, periglacial and paraglacial relief. Criteria to distinguish between periglacial, proglacial and paraglacial environments were proposed by Slaymaker (2011). In his opinion, "periglacial" is a function of processes, "proglacial" is a function of location, and "paraglacial" is the degree or way of the environment returning to its "normal" state, i.e. as before the glaciation – a specific "relaxation of the environment".

Stratigraphic Position of Paraglacial Formations and Structures in the Wartanian Zone

During research in the Wartanian relief zone, which was aimed at identifying sediments and structures of the paraglacial environment, the author found, among other things, a number of partial landforms, as well as examples of sediments and structures in outcrops, which can be attributed to the paraglacial environment. Some of them result from reinterpreting formerly collected materials, both by the author and other researchers.

Characteristic manifestations of paraglacial processes include structures of gravitational slope deformations, formed soon after direct impact of glacial processes on sediments and glacial forms had ceased (mainly slumps, flows, settlement and creep). The thickness of deformed sediments reaches several, sometimes more than 10 metres. Such examples may be found on slopes of kames and glaciofluvial marginal ridges (Fig. 4a, b), as well as along edges of kettle holes. They were described in several studies (including Klajnert 1978; Klatkowa 1997; Rdzany 1997, 2014a; Majecka et al. 2014, Frydrych 2014), though the processes were, in all cases, qualified as glacial environment. Due to the lack of or only a slight impact of glaciogenic processes on their course, they should be treated as paraglacial processes.

Examples of structures related to slope processes which are known to the author resemble structures after such processes in young slopes of glaciofluvial landforms in contemporary glacial areas. The example shown in Fig. 4c presents a dynamically changing slope profile of a glaciofluvial landform in the marginal zone of the Skeiðarárjökull in Iceland. The slope as shown in the photograph was 9 years old – since its forming as a result of a jökulhlaup in autumn 1996. You can see here examples of rotary slides and other slope processes, which transform the slope and decrease its inclination. A characteristic relief feature of contemporary paraglacial slopes is the occurrence of antiscarps (Fig. 4c). Such examples are difficult to find in highly transformed slopes of the Wartanian age in Poland.

One may suppose that the pace of changes in fresh slopes of forms originating during the retreat of the Warta ice-sheet in the latitudinal belt of Central Poland was similar. The pace and course of these phenomena may have depended on the melting progress of buried glacial ice, as well as on the plant succession related to the advance of warming.

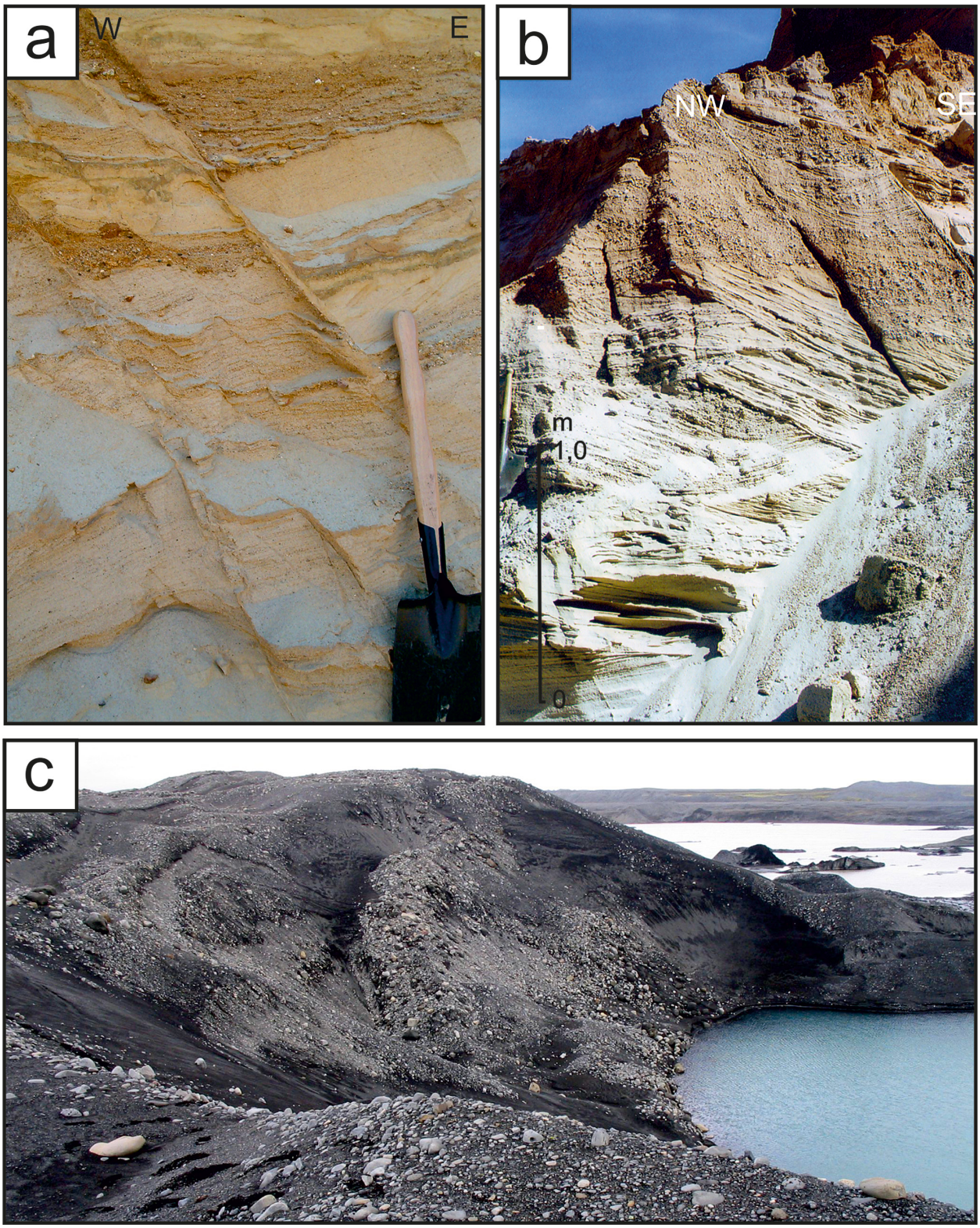

Fig. 4. Examples of deformations in the slope portions of glaciofluvial forms: a – sandy-silty sediments in the slope of a kame, Wola Zaradzyńska near Pabianice (N 51.6482, E 19.4342), b – sandy-gravelly sediments of the slope portion of a kame, Rosocha (N 51.6482, E 19.4342), c – sandy-gravelly sediments in the slope part of the marginal ridge in the foreland of the Skeiðarárjökull glacier, Iceland (N 63.9933, W 17.1824)

It must be noted that there occur transformations of slope zones as a result of periglacial processes, in which the main part was played by the activity of ground ice and gravity processes. Manifestations of deformation, for example, in the form of involutions or fissure structures of thermal contraction, as well as records of polar solifluction transformed the sediments more than the slope profile, and their range usually does not exceed 1 metre, and very rarely more than 2 metres. It must also be noted that only a few periglacial structures can be connected in terms of age with the final stage of the Warta glaciation – they originated mainly in the Weichselian Glaciation (cf. Petera-Zganiacz 2011).

In addition, the following were found: sediments of sandy alluvial fans, varved sediments and other signs of glaciolimnic sedimentation in small reservoirs, sandy sediments from surface wash, and load casts structures, resembling involutions.

One may suppose that some degree of chemical denudation occurred in the described area, but an attempt at documenting it would be very difficult to evaluate due to overlapping of such processes in the post-Wartanian period. Application of the principle of uniformitarianism is particularly difficult in this case.

Paraglacial processes, as follows from the research conducted so far, caused changes of local character in the relief. They may be described as point-like changes, sometimes mosaic, less frequently encompassing, for example, a larger form. They were intense, but usually fairly short-term. They occurred after direct impact of the ice-sheet or its meltwater had ceased. It took place at the end of MIS 6. Their record in sediments does not reveal features characteristic of the periglacial environment, especially if we take into account the current definitions of this environment. Paraglacial processes were responsible for relatively fast remodelling of the fresh glacial relief, released from underneath the Warta ice-sheet, and the proglacial relief (e.g. sandars).

The shaped glacial and proglacial relief, modified in MIS 6, was at the stage of young glacial relief at the turn of the Wartanian/Eemian and during the Eemian Interglacial (Fig. 5). The answer to the question whether it resembled contemporary young glacial relief, shaped under conditions of interglacial morphogenesis in the Holocene is not simple for several reasons. Among other things, in the area of the Wartanian Glaciation, slightly different relations were documented between relief from both glaciation and deglaciation compared with that within the range of the Weichselian, and between different types of deglaciation. In the analysed area, the stronger influence of deep bedrock was also evident. Besides, young glacial relief of the Eemian was not subject to anthropopressure, which is very characteristic in the Holocene.

Periglacial transformations at the end of the Warta stage were present, but their record is very limited. If there was aggradation of long-term permafrost, which could be indicated by rare pseudomorphoses from syngenetic ice wedges, it was only of insular character. Only in several locations, for example, near Bełchatów, was aeolian reworking of glaciofluvial and fluvial sands noticeable (Goździk 2007). In the author's opinion, periglacial transformations of Wartanian relief at the end of the Warta stage were less intense than effects of paraglacial processes.

Young glacial relief, formed at the turn of the Wartanian and Eemian, modified in the paraglacial and periglacial environments, was transformed with varying dynamics in subsequent stages of the Pleistocene (from MIS 5e to MIS 1) under conditions of changing climate – from extremely arctic to moderate.

Relief transformations in the Eemian Interglacial (MIS 5e) are roughly linear and point-like: they are mostly restricted to vertical erosion in river valleys and in plateaus are to partial filling of kettle holes with lacustrine sediments and peats (Klatkowa 1997; Kołaczek et al. 2012; Majecka 2012; Majecka et al. 2014).

Records of the periglacial environment in the Weichselian (MIS 5d-2) are nearly universal, but at the same time, spatially limited to shallow, near surface changes in structural and textural characteristics of sediments. As regards relief, moderate evolution of valley bottoms of that time can be seen, as well as origination of sets of aeolian relief in valleys and plateaus, where a local increase in landscape diversity occurred.

Relief changes in the Holocene have been and still are intense. Their course is to a large extent an expression of anthropopressure (cf. Twardy 2008).

Currently, a number of relief types can be distinguished with different relations of morphogenetic

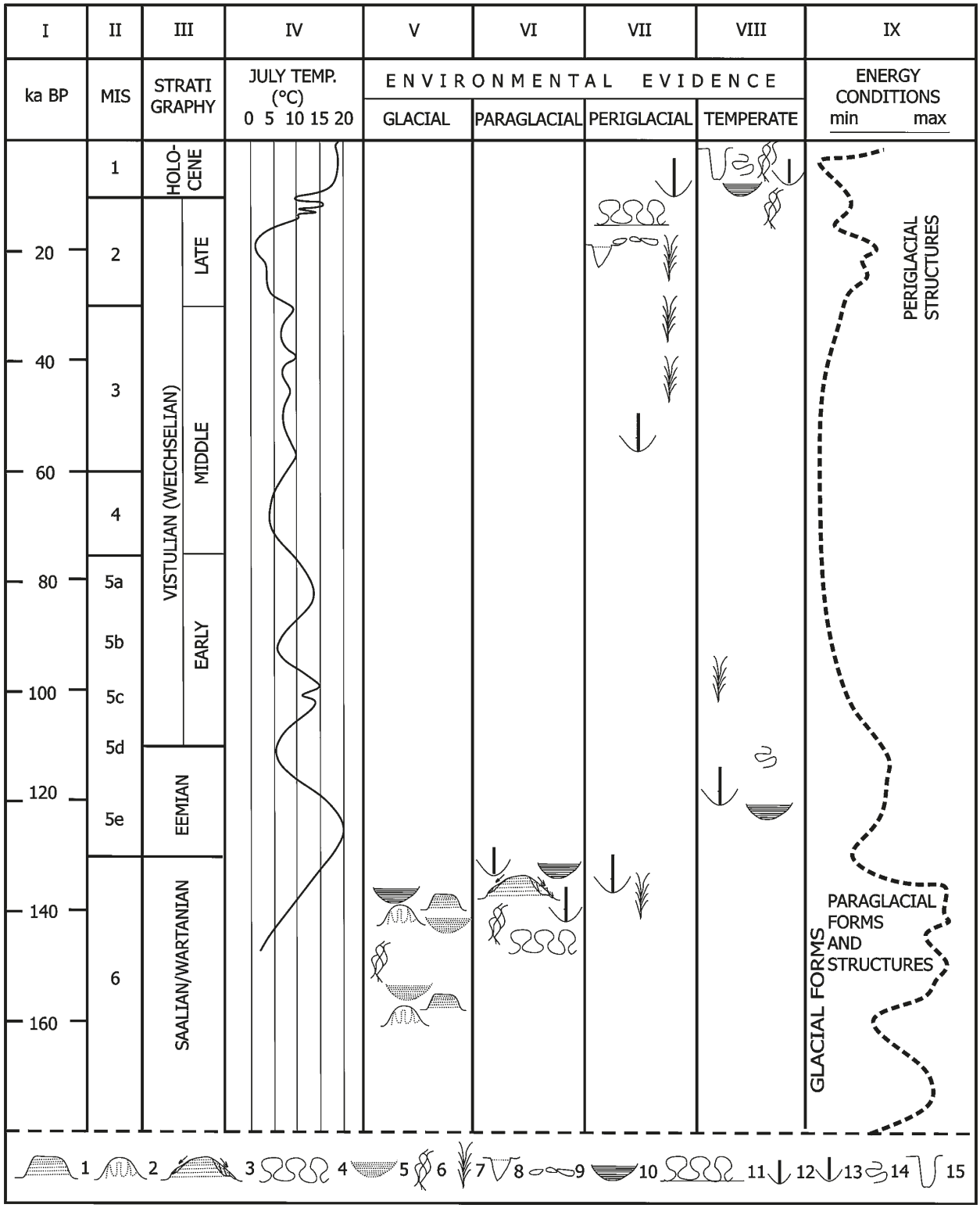

Fig. 5. Environmental evidence of the evolution of the Wartanian landscape. Transition from glacial landscape to a polygenetic old glacial landscape of the Holocene. Findings of the author on the basis of different sources (mainly after: Martinson at al. 1987; Mojski 2005; Rdzany 2009; Petera-Zganiacz 2011; Roman at al. 2014): 1 – kames, eskers and other glaciofluvial forms, 2 – marginal ridges and hills with glaciotectonic deformations, 3 – paraglacial slides, debris flow and other movements of sediments by gravity, 4 – deformations of inverse density gradient in paraglacial environment, 5 – glaciolacustrine sediments, 6 – braided river sediments, 7 – syngenetic ice-wedge pseudomorphs, 8 – sand wedges, 9 – gravelly-stony pavements, 10 – limnic sediments, 11 – involutions in periglacial environment, 12 – tendency to erosion in river valleys, 13 – tendency to aggradation in river valleys, 14 – meandering rivers, 15 – gullies and other anthropogenic forms and sediments

environments – from well preserved glacial landscapes (they include in particular sets of kames and areas of moraine plateaus with low diversity) to areas with locally strong denudational and erosional transformation.

Conclusions

- Distinguishing the paraglacial environment in analysis of relief transformation introduces a new quality and may make evaluation of post-Wartanian morphogenesis more complete and more accurate. It may help in making the theory which explains the role of individual morphogenetic environments in transformation of the relief of the Wartanian belt in Poland more precise. In the future, it may become the basis for preparing a more accurate model of such transformations.
- Adopting the terminology of paraglacial geomorphology is consistent with tendencies in worldwide literature, as well as resulting from the principle of uniformitarianism. The terminology is already used in works by Polish authors who conduct research in the Antarctic and Arctic areas and some areas of mountainous glaciation.
- Taking into consideration the current definitions of the periglacial environment, such a distinction is also necessary. Otherwise, a considerable conceptual gap appears.
- The role of the paraglacial environment in the analysis of transformations of the Wartanian belt is important from the stratigraphic point of view. These processes occurred for a short time (perhaps for less than $1/10^{th}$ of the time of postglacial relief transformation), but they resulted in significant changes in the morphology of slopes of glacial landforms, river valleys, in the range of kettle holes and other locations. It cannot be ruled out that paraglacial processes are responsible for smoothing the slopes of glacial landforms to a larger degree than periglacial processes.
- There is a need to conduct comparative research with other glaciation zones of the Polish Lowland and the upland belt.

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References

BALLANTYNE C.K., 2002, Paraglacial geomorphology. Quaternary Science Reviews, 21: 1935–2017.

BENN D.I., EVANS D.J.A., 1998, Glaciers and Glaciation. Arnold, London.

BROWN R.J.E., KUPSCH W.O., 1995, Permafrost terminology (in English, French, German, Polish and Russian). [in:] Dylikowa A., (ed.), Biuletyn Peryglacjalny, 32.

CHURCH M., RYDER J.M., 1972, Paraglacial sedimentation: consideration of fluvial processes conditioned by glaciations. Geological Society of America Bulletin, 83: 3059–3072.

DYLIK J., 1952, The concept of the periglacial cycle in Middle Poland. Bulletin de la Société des Sciences et des Lettres de Łódź, 3, 5.

DYLIK J., 1953, O peryglacjalnym charakterze rzeźby środkowej Polski. Acta Geographica Universitatis Lodziensis, 4.

DYLIK J., 1956, Coup d'oeil sur la Pologne périglaciaire. Biuletyn Peryglacjalny, 4: 195–238.

DYLIK J., 1964, Eléments essentiels de la notion de "periglaciaire". Biuletyn Peryglacjalny, 14: 111–132.

FRENCH H.M., 2007, The periglacial environment. 3rd ed., John Wiley & Sons, Ltd., Chichester.

FRYDRYCH M., 2014, Rekonstrukcja zdarzeń zapisanych w osadach odsłonięcia klifu w Siedlątkowie nad zbiornikiem Jeziorsko. Master thesis, Department of Physical Geography, Łódź Univ.

GODARD A., 1965, Recherches en géomorphologie en Écosse du Nord-Ouest. Thèse d'État, Université de Paris Sorbonne, Les Belles Lettres.

GOŹDZIK J., 2007, The Vistulian Aeolian succession in central Poland. Sedimentary Geology, 193: 211–220.

JAHN A., 1970, Zagadnienia strefy peryglacjalnej. PWN, Warszawa.

JARMAN D., 2007, Alain Godard on the NW Highlands of Scotland: present relevance for long-term landscape evolution studiem. Géomorphologie: relief, processus, environnement, 2: 177–203.

KLAJNERT Z., 1966, Geneza Wzgórz Domaniewickich i uwagi o sposobie zaniku lodowca środkowopolskiego. Acta Geographica Lodziensia, 23.

KLAJNERT Z., 1978, Zanik lodowca warciańskiego na Wysoczyźnie Skierniewickiej i jej północnym przedpolu. Acta Geographica Lodziensia, 38.

KLAJNERT Z., 1984, Analysis of kames for palaeogeographical reconstructions. Boreas, 13: 95–109.

KLATKOWA H., 1972, Paleogeografia Wyżyny Łódzkiej i obszarów sąsiednich podczas zlodowacenia Warciańskiego. Acta Geographica Lodziensia, 28.

KLATKOWA H., 1997, Zagłębienia bezodpływowe w Polsce środkowej i przydatność analizy ich wypełnień do interpretacji paleogeograficznych. Acta Universitatis Lodziensis, Folia Geographica Physica, 1: 23–45.

KLIMASZEWSKI M., 1978, Geomorfologia. PWN, Warszawa.

KNIGHT J., HARRISON S. (eds.), 2009, Periglacial and Paraglacial Processes and Environments. Geological Society, London, Special Publications, 320.

KOŁACZEK P., KARPIŃSKA-KOŁACZEK M., PETERA-ZGANIACZ J., 2012, Vegetation patterns under climate changes in the Eemian and Early Weichselian in central Europe inferred from a palynological sequence from Ustków (Central Poland). Quarternary International, 268: 9–20.

KONDRACKI J., 1978, Geografia fizyczna Polski, PWN, Warszawa.

KOTARBA A., 2013, Rzeźba systemu dolinnego Suchej Wody i Pańszczycy. Prace Geograficzne, 239: 15–33.

KRZEMIŃSKI T., 1974, Geneza młodoplejstoceńskiej rzeźby glacjalnej w dorzeczu środkowej Warty. Acta Geographica Lodziensia, 33.

LENCEWICZ S., 1927. Dyluwium i morfologia środkowego Powiśla. Prace Państwowego Instytutu Geologicznego, 2, 2.

ŁOZIŃSKI W., 1909, Über die mechanische Verwitterung der Sandsteine im gemässigten Klima. Bulletin International de l'Academie des Sciences de Cracovie.

ŁOZIŃSKI W., 1912, Die periglaziale Fazies der mechanischen Verwitterung. Comptes Rendus, XI Congrès Internationale Géologie, Stockholm 1910: 1039–1053.

MAJECKA A., 2012, Postwarciańskie przekształcenia rzeźby obszarów wododziałowych na Wysoczyźnie Łódzkiej (na przykładzie międzyrzecza Mrogi i Mrożycy). PhD thesis, Department of Quaternary Research, University of Lodz.

MAJECKA A., RDZANY Z., SZMIDT, 2014, Morfologia i ewolucja glacigenicznych zagłębień bezodpływowych w regionie łódzkim. Poster, X Zjazd SGP „Krajobrazy młodoglacjalne, ich morfogeneza, teraźniejszość, przyszłość", Toruń: 69–70.

MARKS L., 2011, Quaternary Glaciations in Poland. [in:] Ehlers J., Gibbard P.L., Hughes P.D. (eds.), Quaternary Glaciations – Extent and Chronology, a closer look, Developments in Quaternary Science, 15: 299–303.

MARTINSON D.G., PISIAS N.G., HAYS J.D., IMBRIE J., MOORE T.C., SHACKLETON N.J., 1987, Age dating and the orbital theory of the ice ages: development of a high-resolution 0 to 300 000-year chronostratigraphy. Quaternary Research, 27: 1–29.

MOJSKI J.E., 2005, Ziemie polskie w czwartorzędzie. Zarys morfogenezy. PIG, Warszawa.

PETERA-ZGANIACZ J., 2011, Changes in the development of frost wedges in the middle Warta valley deposits (Central Poland). Geologija, 53: 15–20.

RACHLEWICZ G., 2010, Paraglacial modifications of glacial sediments over millennial to decadal timescales in the high Arctic (Billefjorden, central Spitsbergen, Svalbard). Quaestiones Geographicae, 29: 59–67.

RDZANY Z., 1997, Kształtowanie rzeźby terenu między górną Rawką a Pilicą w czasie zaniku lądolodu warciańskiego. Acta Geographica Lodziensia, 73.

RDZANY Z., 2009, Rekonstrukcja przebiegu zlodowacenia warty w regionie łódzkim. Wyd. Uniw. Łódzkiego, Łódź.

RDZANY Z., 2014A, Zanik młodoglacjalnej rzeźby warciańskiej – przekształcenia peryglacjalne czy paraglacjalne? Streszczenie referatu, X Zjazd SGP „Krajobrazy młodoglacjalne, ich morfogeneza, teraźniejszość, przyszłość", Toruń: 91–92.

RDZANY Z., 2014B, Stages of evolution of the glacial landsystem in Central Poland after Warta Glaciation (Late Saalian). Geomorphology and Environmental Challenges. Geomorfológia a environmentálne výzvy. 8 vedecká konferencja Asociácie slovenských geomorfólov pri SAV, Snina 6.-8.10.2014, Book of Abstracts, Bratislava, 40.

ROMAN M., DZIEDUSZYŃSKA D., PETERA-ZGANIACZ J., 2014, Łódź region and its northern vicinity under Vistulian Glaciation conditions. Quaestiones Geographicae, 33: 155–163.

ROTNICKI K., 1967, Geneza Wzgórz Ostrzeszowskich. Badania Fizjograficzne nad Polską Zachodnią, 19: 93–154.

RYDER, J.M., 1971, Some aspects of the morphometry of paraglacial alluvial fans in south-central British Columbia. Canadian Journal of Earth Sciences, 8: 1252–1264.

SLAYMAKER O., 2011, Criteria to distinguish between periglacial, proglacial and paraglacial environments. Quaestiones Geographicae, 30: 85–94.

STRZELECKI M.C., 2011, Cold shores in warming times – current state and future challenges in Arctic coastal evolution studies. Quaestiones Geographicae, 30: 103–115.

TRACZYK A., KASPRZAK M., 2014, Plejstoceńska rzeźba stoków Ślęży (Przedgórze Sudeckie) – reinterpretacja na podstawie danych LiDAR oraz pomiarów elektrooporowych (ERT). Streszczenie referatu, X Zjazd SGP „Krajobrazy młodoglacjalne, ich morfogeneza, teraźniejszość, przyszłość", Toruń: 111–112.

TURKOWSKA K., 2006, Geomorfologia regionu łódzkiego. Wyd. Uniw. Łódzkiego, Łódź.

TWARDY J., 2008, Transformacja rzeźby centralnej części Polski Środkowej w warunkach antropopresji. Wyd. Uniw. Łódzkiego, Łódź.

WYSOTA W., MOLEWSKI P., 2011, Chronologia i zasięgi nasunięć lądolodu na obszarze lobu Wisły podczas stadiału głównego ostatniego zlodowacenia. Przegląd Geologiczny, 59: 214–225.

ZWOLIŃSKI, ZB., 2005, Geosukcesja w geomorfologii para glacjalnej. [in:] Jóźwiak M., Kozłowski R., (eds.), Funkcjonowanie obszarów polarnych oraz jego współczesne i reliktowe cechy w krajobrazach, AŚ, Kielce: 165–169.

ZWOLIŃSKI Z., 2007, Mobilność materii mineralnej na obszarach paraglacjalnych, Wyspa Króla Jerzego, Antarktyka Zachodnia [Mobility of mineral matter on paraglacial areas, King George Island, Western Antarctica]. Wyd. Nauk. UAM, Seria Geografia, 74.

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