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2. GLACIAL-INTERGLACIAL CYCLES IN CENTRAL POLAND AS REFLECTED IN THE ŁÓDŹ UNIVERSITY GEOMORPHOLOGICAL SCIENTIFIC ACHIEVEMENTS

2.1. Introduction

Two last glacial-interglacial cycles, the late Saalian-Eemian and the Vistulian-Holocene, were of crucial importance in relief evolution of Central Poland. Aspects of morphogenesis and processes forming the area during the ice-sheet presence and under periglacial conditions as well as in the warm intervals were considered in geomorphological studies by scientists from the Łódź University for decades. The chapter is a review of current problems of the subject, except for the Holocene epoch presented in a separate work of this issue.

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Central Poland is in the chapter understood as the area between maximum extents of the late Saalian (Warta Stadial of the Odranian Glaciation) and the Vistulian Glaciation ice-sheets, while from the west and east is limited by river valleys, respectively the Warta and Pilica with Rawka (Figure 2.1). Also the area within the Płock ice-lobe, the characteristic element in the margin of the last Scandinavian ice-sheet contour, is taken into account in our considerations.

Figure 2.1. Palynologically documented Eemian Interglacial sites against the ice-sheet limits of the main glacial events in Poland

Source: M. Bruj and M. Roman (2007), supplemented

In recent years research carried out in the Łódź University were generally focused on glacial, periglacial and fluvial environments, especially of both older and younger cold periods (Turkowska 1988, 2006, Kamiński 1993, Klatkowa 1996, 1997, Manikowska 1996, Kobojek 2000, Petera 2002, Roman 2003, 2010, Wachecka-Kotkowska 2004, Forysiak 2005, Goździk 2007, Dzieduszyńska 2011, Majecka 2012).

Studies on periglacial shaping of the old morainic area of the Saalian belt in Central Poland for nearly 100 000 years of the Vistulian were initiated by Professor Jan Dylik and his collaborators about 1950s. Great contributions of researchers from the Łódź University to the understanding of fossil periglacial realm caused that their achievements have become known as the so called Łódź school of periglacial geomorphology (e.g. Dylik 1953, 1963, 1967, 1968, 1972, Klatkowa 1965, Goździk 1973, Turkowska 1975, Wieczorkowska 1975).

2.2. Warta Stadial (Late Saalian) of the Odranian Glaciation

The last glacial advance in Central Poland, known as the Warta Stadial, took place during the Middle Pleistocene, estimated at 130–160 ka BP. The maximum extent of the glacier within this period was approximately 140–145 ka. Wartanian ice-sheet occupied this whole area.

The Warta Stadial as a separate stratigraphic unit of the Pleistocene was distinguished in the 1920s on the basis of geomorphological criteria. Palaeogeography of the Wartanian episode in Central Poland has been discussed in the 1950s and 1960s, however glacial environment was treated marginally. Since the 1970s, the Warta Stadial has been more and more frequently named the Wartanian Glaciation (Klatkowa 1972, Klajnert 1978, Marks et al. 2006, Rdzany 2009) in spite of a lack of convincing evidence for its stratigraphic individuality. Problems of the Warta cold stage were widely discussed during the INQUA-SEQS Symposium held in 1994 in Łódź (Klatkowa 1995). L. Lindner (2005) came back to the Wartanian as the subordinate to the Odranian, but included both to one oxygen isotope stage (MIS 6), without separating any interglacial-rank interval. In the last opinion by L. Marks (2011) the Warta cold stage, named Wartanian, belongs to the Middle Polish Complex and more specifically to the last stage of the Odranian Glaciation (late Saalian).

As is clear from latest morpho- and chronostratigraphical investigations we can no longer accept the limit of the Warta Stadial in the vicinity of Łódź as has been outlined by M.D. Baraniecka et al. (1969), H. Klatkowa (1972) and S.Z. Różycki (1972). More possibly, the extent runs along the lower Luciąża and Pilica rivers to Tomaszów Mazowiecki and Inowłódz (Marks et al. 2006, Rdzany 2009). Petrographical studies and OSL (optically stimulated luminescence) datings (Czubla 2001, Wachecka-Kotkowska 2012, 2013, Wachecka-Kotkowska et al. 2013) show that the Wartanian ice-sheet covered the Piotrków Plateau and reached northern slopes of the Radomsko Hills and the Przedbórz Upland (Figure 2.2).

K. Turkowska (2006) confirms that the Wartanian ice-sheet in Central Poland was composed of three lobes: Widawka lobe, Bzura lobe and Rawka, Pilica, Luciąża lobe (Figure 2.2). Last investigations reveal inflow of ice-masses in a few stages from the N and NNW (Widawka lobe) and NE and E (Rawka, Pilica, Luciąża lobe) (Wachecka-Kotkowska et al. 2012, Wachecka-Kotkowska 2013). The Widawka and Rawka, Pilica, Luciąża lobes met, forming an interlobal zone. During the transgression, the old valleys (e.g. Widawka, Rawka, Pilica and Luciąża valleys) facilitated the spread of ice-masses (Krzemiński 1997, Turkowska 2006, Rdzany 2009, Wachecka-Kotkowska 2013). When the ice-sheet decayed these longitudinal forms were used as marginal valleys (e.g. Wachecka-Kotkowska 2004).

K. Turkowska (2006) described also four phases of glacial relief development, i.e. ice-sheet transgression (I), ice lobes convergence/divergence and glacier decay under conditions of uplifted elevation (II), deglaciation (III) and advanced deglaciation, especially intensive in depressions and glacial valleys (IV). However, Z. Rdzany (2009) claims that during deglaciation ice-streams incidentally activated and described these incidents as Dobrzynka, Ner and Bzura subphases. In the light of recent investigations at least two retreat stages occurred on the lines of the Radomsko Hills and the Dobryszyce Hillocks (Wachecka-Kotkowska et al. 2013) and possibly along the Kutno moraines (Klatkowa 1972).

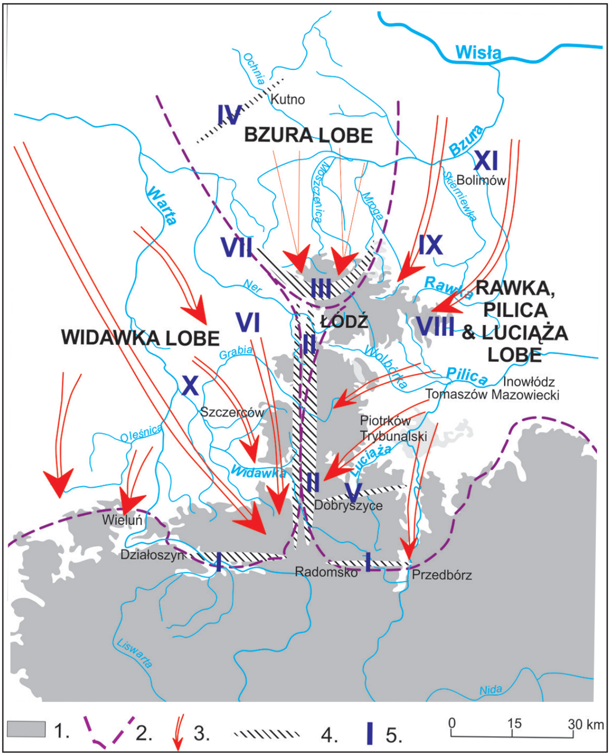

Figure 2.2. Wartanian ice-sheet lobes in the Łódź region, Central Poland and the main groups of the glacial forms

1 – area above 200 m a.s.l., 2 – extent of lobes, 3 – direction of the ice-masses inflow, 4 – chains of the marginal forms, 5 – number of a group of glacial forms (explanations in the text)

Source: based on K. Turkowska (2006)

Marginal zones of the Warta Stadial were found to predominate in the Central Poland landscape (Klatkowa 1993, 1995). H. Klatkowa (1972) distinguished two types of glacial forms – the structural and accumulative ones. The structural relief characterises the transgression phase and mixed deglaciation (Wachecka-Kotkowska 2013). The accumulative relief has resulted from the areal deglaciation (Klatkowa 1972, Krzemiński 1974, Klajnert 1978, Rdzany 1997, 2009, Jaksa 2006).

In its retreat, the Wartanian ice-sheet left terminal moraines. A number of groups of glacial forms was found on the uplifted substratum. In the south (zone I, Figure 2.2) on the transversal elevation of the substratum, morainic hillocks accumulated within the Przedbórz Upland (Radomsko Hills – Turkowska 2006, Wachecka-Kotkowska 2012, 2013) and the Wieluń Upland (Działoszyn Hills – Krzemiński 1974, 1997). In central part of the area the glacial forms were superimposed on the longitudinal elevation of the substratum by the ice-masses coming from the W and NW and also from NE and NEE (Turkowska 2006, Wachecka-Kotkowska et al. 2012, 2013). Large kames or dead ice moraines formed between Łódź and Radomsko (Krzemiński 1997, Turkowska 2006, Rdzany 2009, Wachecka-Kotkowska et al. 2012, 2013) (zone II). To the north from Łódź (i.e. in external part of the Bzura lobe – Figure 2.2) the Smardzew, Stryków, Katarzynów and Wola Mąkolska levels with glaciotectonic deformations were formed and described by H. Klatkowa (1972) as the edge zone of the Łódź Plateau (zone III). Chains of the glacial forms create the Kutno moraine ridge (zone IV) and the Dobryszyce Hillocks (zone V) (Wachecka-Kotkowska et al. 2013).

In some parts of Central Poland, other crevasse forms were found in the watersheds (Figure 2.2), e.g. Grabia and Ner (zone VI), Ner and Bzura (zone VII), Pilica and Rawka (zone VIII) and Rawka and Skierniewka (zone IX) (Turkowska 2006, Rdzany 2009). Characteristic is also an accumulation of crevasse forms in the glaciodepressions, e.g. in the Szczerców Basin (zone X) (Baraniecka et al.

1969), the Upper Rawka valley (Rdzany 1997, 2009) and in the vicinity of Bolimów, in the southern edge of the Warsaw-Berlin Pradolina (zone XI) (Klajnert 1978).

In the Uniejów Basin, a large ice-glacial lake developed, from which, apart from geological studies, investigations of biotic environment are provided (Pawłowski et al. 2013).

2.3. Eemian Interglacial

Numerous sites of lacustrine and peat deposits of the Eemian Interglacial have been documented in Central Poland (cf. Klatkowa 1990, Bruj and Roman 2007, Kołaczek et al. 2012) – Figure 2.1. They are an evidence of a so called "Eemian lakeland", resulting from the decay of the Warta Stadial ice-sheet (Klatkowa 1990, 1997). Part of those palaeolakes existed also during the Vistulian. A particularly long record of changes in the environmental conditions is provided from the Zgierz-Rudunki site (Jastrzębska-Mamełka 1985) and, mostly, the Kubłowo (Roman and Balwierz 2010) – Figure 2.3. Whether the Eemian deposits in sites located in the glaciomarginal zone have been till-covered, provides sufficient reliable evidence to establish the limit of the Last Glacial Maximum in Central Poland (Baraniecka 1989, Roman 2010, Roman and Balwierz 2010).

Eemian Interglacial, particularly marked in erosion in the river valleys, determined postglacial river pattern in the region (Turkowska 1975, 1988, 2006, Kamiński 1993, Kobojek 2000, Wachecka-Kotkowka 2004, Forysiak 2005).

In most sites was recognised the entire interglacial vegetation succession recorded as 7 local pollen assemblages which are concurrent with regional pollen assemblage zones of the Eemian Interglacial (MIS 5e) as defined for Poland by K. Mamakowa (1988, 1989) and also with stratigraphy established for western Europe (Behre and Lade 1986, Behre 1989, Menke and Tynni 1984).

The Kubłowo profile, mentioned above, is situated slightly to the south from the limit of the Last Glacial Maximum (LGM) and comprises one of the longest upper Pleistocene interglacial-glacial successions in Poland (Roman and Balwierz 2010). The pollen sequence from Kubłowo recorded continuous evolution of vegetation for the whole Eemian Interglacial (MIS 5e), Early Vistulian (MIS 5 d-a), Lower Plenivistulian (MIS 4) and part of the Middle Plenivistulian (MIS 3). In the Early Vistulian two warm (Brörup and Odderade) and two cool (Herning and Rederstall) periods were distinguished. Three next climatic oscillations have been noted in the Plenivistulian, corresponding to the Schalkholtz and Ebersdorf Stadials and the Oerel Interstadial. Fito-climatic relations determined as against vegetation development of that profile, show that in the northern part of Central Poland (i.e. Płock Basin area), there was no ice-sheet either in the Early (MIS 5d–a) or the Lower Plenivistulian (MIS 4) (Roman 2010). The lack of till or till residua overlying on the Eemian-Vistulian deposits at Kubłowo indicates the area as being beyond the reach of the last Scandinavian ice-sheet.

For the last two decades, the number of palynologicaly documented Eemian fossil lake sites significantly increased. Their distribution has been the basis for delimitation of the Eemian lakeland and, indirectly, the ice-sheet extent of the pre-Eemian Glaciation (Bruj and Roman 2007). The map at Figure 2.1 presents 263 selected sites of the Eemian Interglacial against the background of marginal zones of the Scandinavian Glaciations in Poland. The appearance of lacustrine deposits sites from Eemian Interglacial in morainic uplands between the Wartanian and Odranian ice-sheet limits along with an absence of older interglacial sediments (before the Wartanian Glaciation, i.e. of the Lublinian Interglacial age) at sites of the Eemian – is supportive argument for accepting both the Warta and Odra advances as stadials within one glaciation (Bruj and Roman 2007). The glaciation would have embraced a chronostratigraphic position of the Wartanian (Lindner 2005) as correlated with the 6^{th} oxygen isotope stage, i.e. ca 210–130 ka.

2.4. Vistulian Glaciation

2.4.1. Area outside the ice-sheet extent

Over the years, the Vistulian palaeogeography in the non-glaciated area has been well recognised in various sedimentological environments: fluvial, valley slope and aeolian. The most valuable information about the Vistulian climate provides pollen record from the organic series filling closed depressions, though so far no full Vistulian palynological profile has been found in Central Poland. In recent years the survey has been extended by analysis of cladocerans, chironomids, testae amoebae that significantly complement pollen studies. New data are provided by a more frequently used geochemical analysis. Also, interaction between different environments in cool though inhomogeneous climatic conditions of the Vistulian are well recognised.

Environment in the Early Vistulian (MIS 5d–a) has been recognised primarily based upon studies of the organic infillings of closed depressions (Figure 2.3). In most cases it was a time in which the accumulation in basins of the Eemian lakeland finished. Research carried out for selected localities show a series of changes in the environment in the Early Vistulian, with the clearly pronounced interstadials of Amersfoort and Brörup (separately or together) and Odderade (Dylik 1968, Klatkowa 1997, Klatkowa and Załoba 1991, Balwierz and Roman 2002, Roman and Balwierz 2010, Kołaczek et al. 2012, Majecka 2012). For Central Poland, a key pollen profile for this period is that of the Zgierz-Rudunki site (Jastrzębska-Mamełka 1985); its geological position was compiled by H. Klatkowa (1989).

Slope processes that started during the Early Vistulian stadials were not intense enough to stop sedimentation in closed depressions (Wieczorkowska 1975, Klatkowa 1997). In river valleys weak tendencies to aggradation occurred (Turkowska 1988, Petera 2002, Forysiak 2005). At the time of the Early Vistulian, first symptoms of insular or discontinuous permafrost appeared (Klatkowa 1996) – Figure 2.3.

The Lower Plenivistulian (the older part of the Middle Weichselian; MIS 4) is still poorly recognised in Central Poland. Significant cooling of this time is correlated with the Świecie ice-sheet advance (Lindner 1992, Mojski 2005). Its geological evidence are glaciolacustrine deposits reported from the northern part of the region (Roman 2003) and from the Kubłowo pollen profile (Roman and Balwierz 2010).

At that time there was continuous permafrost with a trend to aggrade (Klatkowa 1996), which is supported by the presence of ice wedge casts (Klatkowa 1996, Balwierz and Goździk 1999, Petera 2002). During the Lower Plenivistulian the first phase of intensive erosion took place in the river valleys (Turkowska 1988, Kamiński 1993, Goździk and Zieliński 1999, Kobojek 2000), although in the Warta River valley some aggradational stretches existed (Krzemiński 1965), while within the Uniejów basin the depositional environment is interpreted as a sand-bed braided river (Petera 2002) – Figure 2.3.

Precursory investigations of dry valleys by H. Klatkowa (1965) were the starting point for further studies allowing to date their formation at the turn of the Lower and Middle Plenivistulian, as well as their relationship with the functioning of closed depressions and incorporation of these into the valley open systems (e.g. Klatkowa 1997, Majecka 2012).

The Middle Plenivistulian (the early part of the Middle Weichselian; MIS 3) was a period in which intensive slope processes occurred (Dylik 1972, Wieczorkowska 1975; Goździk and Zieliński 1999). At the beginning of the second half of the 20th century these processes were regarded as the most important in periglacial shaping of the landscape. The river valleys experienced strong aggradation (Figure 2.3). The delivery of the material was due to not only longitudinal transport, but also from the valley slopes and the effect of these processes was the deposition of rhythmically bedded silt and sand (e.g. Klatkowa 1965, Krzemiński 1965, Turkowska 1975, 1988, 1999, Manikowska 1996, Goździk and Zieliński 1999). In the bottoms of some valleys there were shallow extensive pools (Turkowska 1988), in other cases, such as in some parts of the Warta

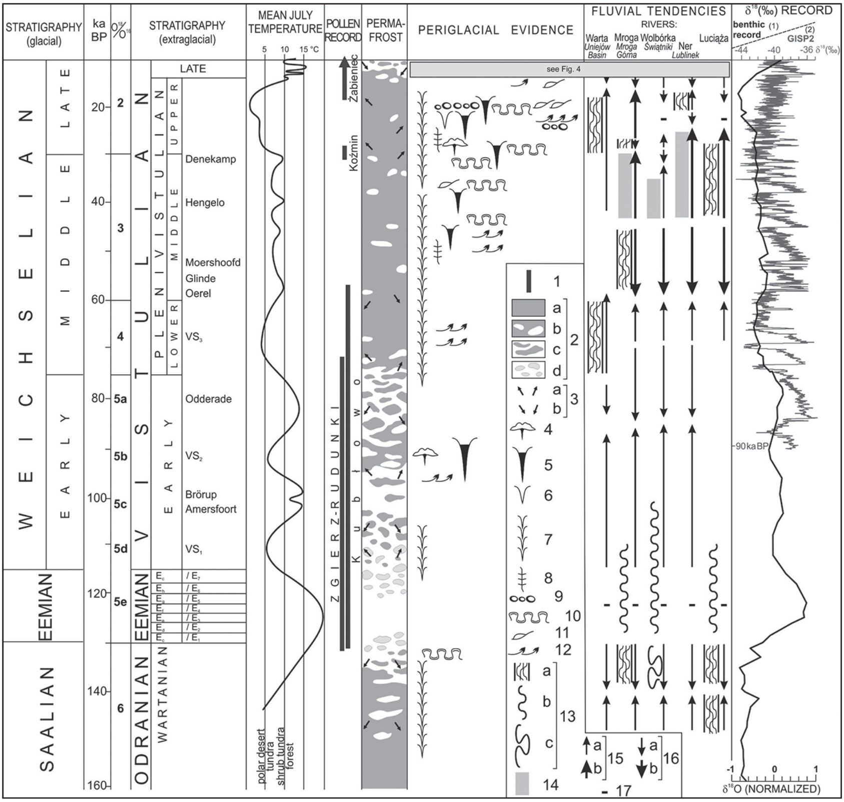

Figure 2.3. Features of natural environment in Central Poland during the Warta Stadial – Eemian Interglacial – Vistulian cycle

1 – extent of pollen diagrams; 2 – permafrost: a – continuous, b – discontinuous, c – sporadic, d – seasonal; 3 – tendencies to: a – aggradation, b – degradation; 4 – hydrolaccolith; 5 – epigenetic ice-wedge pseudomorphs; 6 – sand wedges; 7 – syngenetic ice-wedge pseudomorphs; 8 – frost fissures; 9 – gravelly-stony pavements; 10 – involutions; 11 – solifluction structures; 12 – intense aeolian activity; 13 – river pattern: a – braided, b – small meanders, c – big meanders; 14 – backwaters; 15 – tendency to aggradation: a – medium, b – intensive; 16 – tendency to erosion: a – medium, b – intensive; 17 – dynamic balance

Source: M. Jastrzębska-Mamełka (1985), D.G. Martinson et al. (1987), K. Turkowska (1988, 2006), H. Klatkowa (1996), M. Stuiver and P.M. Grootes (2000), J. Petera (2002), L. Wachecka-Kotkowska (2004), J. Forysiak (2005), Z. Balwierz (2010), M. Roman and Z. Balwierz (2010) valley bottom peatbogs were formed, after which the horizons of organic deposits remained (Forysiak et al. 1999, Petera 2002, Forysiak 2005). Results of pollen analysis reveal only interstadial features of these deposits, that is why their assignment to any of Middle Plenivistulian interstadials is difficult (Forysiak et al. 1999, Balwierz 1995). In such cases ^{14}C dating is helpful, because a significant portion of Middle Plenivistulian organic deposits is within the range of the method (e.g. Krzyszkowski 1990, Manikowska 1995, Petera 2002).

The geological record in many localities of Central Poland contains evidence for the formation of ice wedge casts, indicative of permafrost conditions (Figure 2.3). The apogee of the development of such structures is associated with the period of the Upper Plenivistulian (the Late Weichselian; MIS 2), when sand wedges also developed (e.g. Dylik 1963, Goździk 1973, Klatkowa 1996, Petera-Zganiacz 2011). Very cold conditions of an arctic desert promoted aeolian processes, reflected, among others, in an increased amount of wind-abraded grains in a river alluvium (Goździk 1996, 2007, Manikowska 1995, Petera 2002, Wachecka-Kotkowska 2004, Forysiak 2005) or the formation of the autochtonic stone pavement with ventifacts on the plains (e.g. Dylik 1967, Klatkowa 1965, Goździk 1973). Intensive slope processes contributed to the development of the allochtonic stone pavements on the slopes and in the dry valleys (Klatkowa 1965, Dylik 1967, Wieczorkowska 1975). Despite very severe climatic conditions, vegetation cover could have been present under favourable circumstances, as evidenced by the organic inserts within Upper Plenivistulian depositional series (e.g. Turkowska 1988, 1990, Petera and Forysiak 2003). Studies focused on the river valley evolution have shown strong aggradation, which occurred in a braided-river environment (Turkowska 1988, Petera 2002, Wachecka-Kotkowska 2004, Forysiak 2005). The sandy or sandy-gravelly deposits covered the sandy-silty series, thus forming the top of the Plenivistulian terrace.

Transformation of the environment in the close of the last glacial cycle (Late Vistulian, Weichselian Lateglacial, termination of MIS 2) took place under conditions of a progressive warming. On the other hand, it was a period characterised by rapid and relatively short, alternating coolings and warmings. The Greenland ice core isotopic record (e.g. Björck et al. 1998) shows an increase in mean temperature between 14 700 and 12 650 years ago (Greenland Interstadial 1) followed by the ca. 1100 years of severe cooling (Greenland Stadial 1) up to the end of the Pleistocene at 11 700 years ago (Figure 2.4). The diverse conditions as seen from terrestrial records is greater, especially in the part relating to GI–1.

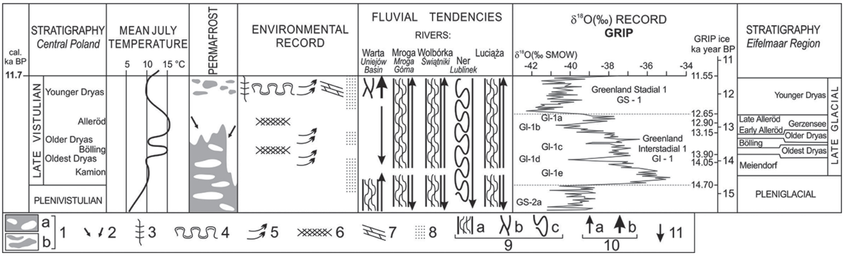

Figure 2.4. Features of natural environment in Central Poland during the Late Vistulian

1 – permafrost: a – discontinuous, c – sporadic; 2 – tendencies to degradation; 3 – frost fissures; 4 – involutions; 5 – intense aeolian activity; 6 – soil horizons; 7 – over-snow deposits; 8 – thinly laminated sands; 9 – river pattern: a – braided, b – anabranching, c – big meanders; 10 – tendency to aggradation: a – medium, b – intensive; 11 – tendency to medium erosion

Source: A. Dylikowa (1967), K. Turkowska (1988, 2006), H. Klatkowa (1984, 1996), B. Manikowska (1995), S. Björck et al. (1998), T. Litt et al. (2001), J. Petera (2002), L. Wachecka-Kotkowska (2004), D. Dzieduszyńska (2011)

In the stratigraphical division based on records from Central Poland, the Late Vistulian encompasses three warm units – Kamion Phase, Bölling, Alleröd – and three cool units – Oldest Dryas, Older Dryas and the longest and coldest, Younger Dryas (GS–1 in the Greenland stratigraphy after Björck et al. 1998). The initial Kamion Phase was detected in Central Poland and introduced to the Vistulian stratigraphy by B. Manikowska (1995) – Figure 2.4. This unit coincides with the GI–1e warmer episode in the Greenland ice core record (Björck et al. 1998) and the Meiendorf in annually laminated lake sediments from the German profile (Litt et al. 2001).

Studies on the Vistulian periglacial environment, which were leading research carried out in the Łódź periglacial school, referred to the Late Vistulian time in a limited extent (Dylik 1967). The complexity of morphogenetic processes under sudden climate changes is a subject of interest since the mid-1990s of the last century (see Turkowska 1995, 2006).

Climatic conditions of the Late Vistulian (Figure 2.4) are reconstructed from the palaeoecological data and geologic record. In Central Poland, are known only two palynological profiles covering the entire period, Witów (Wasylikowa 1964, 1999) and Żabieniec (Balwierz 2010). The former is a profile of more than a local importance, moreover, it was possible to correlate its part in the section of the Younger Dryas cooling with the best known, high-resolution Polish record in Lake Gościąż (Ralska-Jasiewiczowa et al. 1998). Within the last decade, a number of palaecological data which are important source of information on the environmental conditions, increased. From two sites, Żabieniec and Koźmin Las, chironomid-based quantitative inferences of mean summer temperatures are provided (Płóciennik et al. 2011, Dzieduszyńska et al. 2014). This contribution is the first one based on this index for the Late Vistulian time available in Poland.

In the mentioned site Koźmin Las, located in the Warta River valley, a multiproxy study is currently being conducted which has provided a high resolution record of the variability of the Late Vistulian environment. The discovery of well preserved riparian forest remains rooted in the organic-rich sediment sequence (Photo 2.1) has allowed to investigate a series of local terrestrial events interrupted by flood episodes in response to the Younger Dryas cooling (Dzieduszyńska and Petera-Zganiacz 2012, Dzieduszyńska et al. 2011, 2014). The study is a significant contribution to the knowledge of the last cold cycle termination in the extraglacial area in the Polish Lowlands.

Photo 2.1. Remains of the Alleröd / Younger Dryas riparian forest in Koźmin Las site. The view of the three exploitation levels in the test pit

Source: phot. by J. Petera-Zganiacz, 2011

The Late Vistulian morphogenetic processes took place under conditions of permafrost disappearance (Figure 2.4). In Central Poland, similar to the north-western European territory, final permafrost retreat occurred in the Alleröd. Its reactivation in the Younger Dryas cold spell still remains in doubt. Studies provide some basis for the conclusion that ice wedges might have been present (Manikowska 1995, Goździk 1996, Klatkowa 1996). Seasonal or at least local permafrost conditions are suggested from the study in the Warta River valley where indirect permafrost indicators including flat-bottomed involutions of a Younger Dryas age have been found (Petera 2002, Dzieduszyńska and Petera-Zganiacz 2012).

The Late Vistulian left legible changes in the geology and landscape. In river valleys this time period in Central Poland is considered as dominated by tendency to erosion with the reversal of the trend in the Younger Dryas, triggered by renewed cold-climate conditions (e.g. Turkowska 1995, 1999, 2006, Dzieduszyńska 2011).

Positive erosional balance in the river valleys of the region led to their deep incision, which resulted in the morphological emergence of the Plenivistulian terrace (Turkowska 1988, Kamiński 1993, Kobojek 2000, Wachecka-Kotkowska 2004, Forysiak 2005). This erosion was responsible for transformation in the river network, such as the changes of a river course (e.g. Wieczorkowska 1992, Wachecka-Kotkowska 2004, Forysiak 2005) or the elongation of the valley axes due to headward cutting (Klatkowa 1965, 1984, 1989). The channel pattern and tendency shows diversity (Figure 2.4), depending largely on local conditions (cf. Turkowska and Dzieduszyńska 2011). The cooling of the Younger Dryas caused an increase in bedload and a tendency to intensified braiding (Mroga River – Turkowska 1975, 1988) or multichanneling (middle Warta River – Turkowska et al., 2004; Bzura River – Kobojek 2009) or no change has been registered (e.g. Ner River – Turkowska 1990). In Warta River valley, the multichannel style has been defined as an anabranching river type 2 for the first time in Poland (Petera 2002). In the valleys of Mroga and Warta rivers aggradation resulted in the formation of the terrace step.

The leading hillslope process in Central Poland during the Late Vistulian was slopewash. The sedimentary archives point to the formation of the series of thinly laminated deposits (Figure 2.4) that are the uppermost periglacial unit of the dry valleys of the region. In the Younger Dryas the material transported along a slope was accumulated on the snow, while a snow decay caused discontinuous disturbances of the series (so-called over-snow deposits – Figure 2.4) (Klatkowa 1965, 1984, Dzieduszyńska 2011). The most vulnerable for slopes processes were east- and north-facing slopes (Turkowska 1999, 2006).

The Late Vistulian evolution of the aeolian sedimentary system is one of the best recognized in Central Poland (e.g. Dylikowa 1967, Krajewski 1977, Manikowska 1995, Goździk 2007). The sands were derived from broad aggradational plains of Plenivistulian braided rivers, gradually drained as a result of a positive balance of erosion. A. Dylikowa (1967) identified three phases of the formation of inland dunes (Figure 2.4): the initial phase completed with the accumulation of aeolian patches (Oldest Dryas), the main phase of the formation of parabolic dunes (Older Dryas) and the dune transformation phase (Younger Dryas). From dune morphology and internal structure, predominate west wind direction and wind speeds were calculated (Krajewski 1977). Deposition of sand in the form of aeolian hillocks was interrupted with the initial soil-forming processes (e.g. Manikowska 1999).

2.4.2. Glaciated area

The northern part of Central Poland has been embraced by the Płock lobe which constituted a distinct element in the last Scandinavian ice sheet margin contour (Figure 2.1). It is being referred to the glacier that invaded the territory of Poland flowing southward along the depression of the Vistula palaeovalley, reached the Płock Basin and the surrounding morainic plateaux, and, finally delineated the Last Glacial Maximum (LGM) in Central Poland. The number, extent and age of glacial events in the Płock lobe advances during the last glacial period have been largely debated (e.g. Skompski 1969, Baraniecka 1989, Marks 1988, 2010, Roman 2003, 2010, Wysota et al. 2009). As shown in recent geological investigations having been carried out in the Płock lobe area any possible ice-sheet advance at earlier Vistulian cool periods (MIS 5d, b; MIS 4) has been disclaimed. Prevalent fito-climatic conditions of that time determined as against vegetation development recorded at the Kubłowo profile (Roman and Balwierz 2010) also support the opinion. Only a singular glacial event occurred in the Upper Plenivistulian (Late Weichselian, MIS 2). Age of the ice-sheet advance is given by OSL datings of the sand from beneath and above the till, and is believed to fall between 22.9 and 18.7 ka BP (Roman 2010) – Figure 2.5.

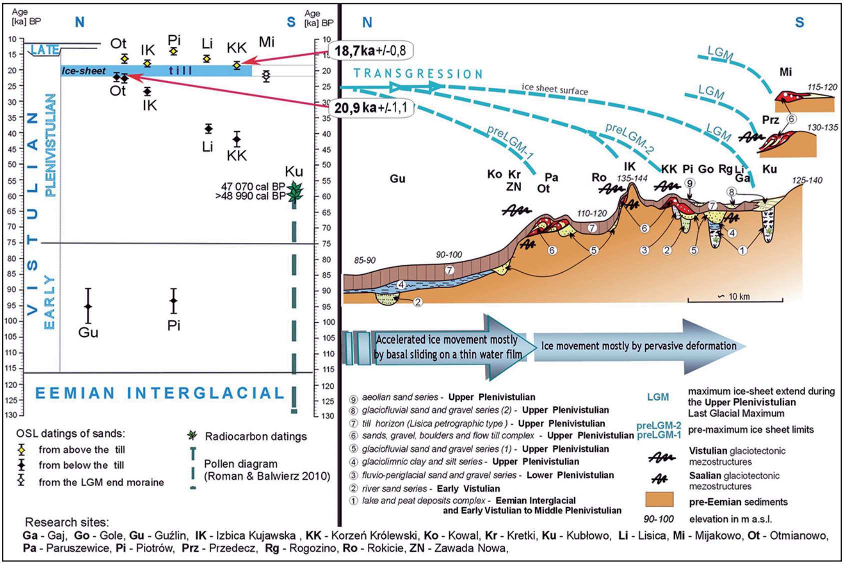

Figure 2.5. Lithostratigraphy and time-distance model of the Płock lobe

Source: based on M. Roman (2010), modified

Another argument, supporting one only advance of the last ice-sheet onto the Płock lobe area is kinetostratigraphy (Roman 2010). Documented in a number of exposures glaciotectonic mezostructures and also small-scale shear deformings, were studied in disturbed sediment sequences. From this, the direction of ice movement which caused the deformations can be deduced and used as a stratigraphic indicator (cf. Berthelsen 1978). Two kinetostratigraphic units were distinguished i.e. the older, the Odranian (Saalian) Glaciation and younger, the Vistulian manifesting itself by a progressive sequence. Such sequence combined from proglacial and subglacial structural domains is a record of a singular deformative transgression cycle. Important for palaeogeography and assessment of the Płock lobe dynamics is, that the progressive sequence pertains as well the glaciomarginal zones allocated in the LGM hinterland. Proved was, that the transverse ranges in the LGM hinterland are overridden end moraines. Ranges determined as preLGM-1 and preLGM-2 were being formed during short standstills of transgression along transverse terrain obstacles (Figure 2.5). The results obtained allow to abrogate earlier findings, mainly based on morphostratigraphic criteria, treating of an oscillative–recessive nature of the LGM hinterland zones examined (e.g. Galon and Roszkówna 1967, Niewiarowski 1983, Pasierbski 1984, Mojski 2005).

Dynamics of the Płock lobe was influenced by local conditions – topography, subglacial hydrology and ice base thermics (Roman 2010). Derived from geological evidence, the ice-sheet featured a warm base system. Dominant in the mechanism of the ice movement, prior to the subglacial channel drainage build-up and stabilizing the ice front at the LGM line, was a basal sliding on a thin water film, resulting in an apparent acceleration of ice speed and a pervasive subglacial deformation (Figure 2.5). It has been proved that the ice travel geometry in the Płock lobe was of a fan-like character (Roman 2007), typical for a distal part of a land-based ice stream. Elaborated parameters for the dynamics and geometry of the ice-masses inflow admit to accept as valid that the Płock lobe evolved at the end of the fast moving ice stream and was intensively fed from its hinterland. That distinctive element of the LGM margin contour has featured the main ice flow artery in the distal part of the Vistula palaeo-ice stream (Roman 2010).

2.5. Conclusions

Results of a few decades of investigations on relief evolution of Central Poland in successive morphogenetic cycles were summed up in the monograph by K. Turkowska (2006) and visualised in the Geomorphological map of the Łódź region at a scale of 1:226 000 published in 2012. Recently, the aforementioned problems were widely discussed during the conference "Czynniki różnicowania rzeźby Niżu Polskiego" (Differentiation factors of the Polish Lowland relief) held in Uniejów in June 2012. Some current studies were presented in the anniversary issue of *Acta Geographica Lodziensia* (no. 100), which is a platform for the exchange of scientific ideas and opinions for 60 years.

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