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3. EVOLUTION OF VEGETATION, RELIEF AND GEOLOGY IN CENTRAL POLAND UNDER ANTHROPOPRESSURE

3.1. Introduction

Beginnings of the geomorphological research in the University of Łódź are closely related to the studies on the relief transformation under periglacial conditions in the last glaciation (Vistulian). The relief transformation in the Holocene has not been dealt with on a wider scale, and to the time of human activity has not been assigned a specific role. Nevertheless, Professor Jan Dylik in 1971 stated: "Forests which developed in the turn of Pleistocene and Holocene preserved landforms that originated under periglacial conditions of the last cold stage. Until deforestation and intensive farming and breeding developed in the place of forest, there was no remarkable transformation of former relief". Despite the passage of 40 years, nowadays this statement may be generally maintained. The present study is focused on the justification of the above statement and on the evidences of evolution of vegetation, relief and geological

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structure in Central Poland that occurred together with the development of human activity in the Neoholocene. It should be emphasised that these issues raise a keen interest in researchers of various specialties (Figure 3.1) and often lead to interdisciplinary studies.

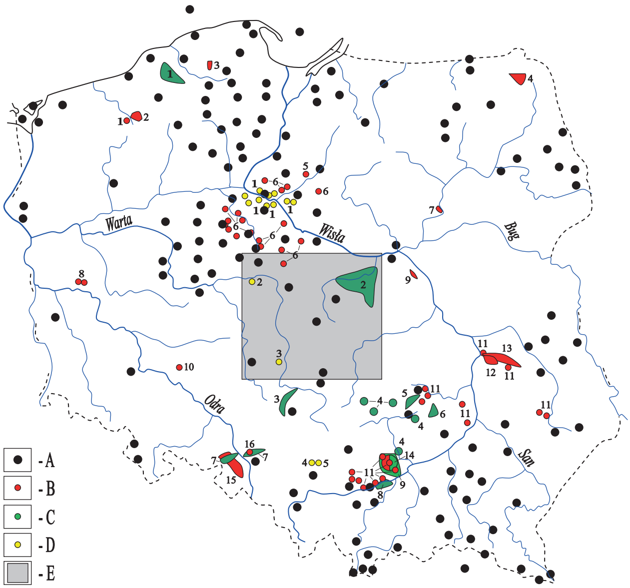

Figure 3.1. Location of studies on vegetation and on slope, aeolian and fluvial Neoholocene deposits in the Polish lowlands and uplands carried out during the last 20 years

A – palynological profiles (cf. Ralska-Jasiewiczowa et al. 2004), B – areas and sites of slope studies: 1 – Szpikowski (2002), 2 – Szpikowski (2010), 3 – Majewski (2006), 4 – Smolska (2005), 5 – Karasiewicz et al. (2012), 6 – Sinkiewicz (1998), 7 – Smolska and Wójcik (2007), 8 – Nowaczyk (1991), 9 – Szwarczewski et al. (2004), 10 – Traczyk (1996), 11 – Śnieszko (1995), 12 – Superson (2012), 13 – Zgłobicki (2002), 14 – Kruk et al. (1996), 15 – Klimek (2002, 2003), 16 – Klimek and Wójciki (2001), C – areas and sites of fluvial studies: 1 – Kaczmarzyk (2008), 2 – Kobojek (2009), 3 – Fajer (2009), 4 – Sołtysik (2002), 5 – Ludwikowska-Kędzia (2000), 6 – Ludwikowska-Kędzia et al. (2009), 7 – Wójcicki (2013), 8 – Dobrzańska et al. (2009), 9 – Michno (2004), D – areas and sites of eolian and fossil soils studies: 1 – Jankowski (2002), 2 – Nowaczyk (1994), 3 – Manikowska (2002), 4 – Szczypek (1994), 5 – Pełka-Gościniak (2000), E – study area (cf. Figure 3.2)

Source: based on above-mentioned authors

3.2. Study area

Field data for the purpose of this study was collected in the area shown in the section E of Figure 3.1. Figure 3.2 presents the relief and the hydrological network of the part of Central Poland, which is named "Łódź region" (Turkowska 2006). Recent studies place the whole study area within the Wartanian ice sheet extent (Rdzany 2009). The area consists of three prominent macroforms:

- in the north – the extensive Warsaw-Berlin ice-marginal streamway (pradolina), west-east trending depression, with monotonous relief. The landform is drained both westwards (the lower Ner River) and eastwards (the lower Bzura River). As it was a convenient area for the development of settlement, was inhabited by almost the entire prehistory and the historical period (Dylik 1971);
- in the west – the Warta River valley, north-south-oriented, with relatively more diversified relief, is the largest water artery in the region. In the Prehistory, and in the historical times it was part of the communication route between the north and the south, especially between Little Poland (Małopolska), Great Poland (Wielkopolska) and Kuyavia (Kujawy);
- in the southern and south-eastern part of the study area – the Łódź Hills. This macroform creates an elongated ridge, attaining up to 284 m a.s.l. From the north and the west it is separated by the mentioned river valleys, while in the south and the south-east by the Pilica River valley network. The Łódź Hills are characterised by diversified relief configuration. The area is dissected by a loosely-spaced network of rivers, represented only by small streams. Due to a poorer access to flowing waters, absence of lakes, poorer soils and location away from the main prehistoric routes, this area has shorter settlement traditions. Increased colonisation of the central parts of the Łódź Hills dates from the early Middle Ages, although some localities indicating the occupation from the Stone Age are present as well.

The above description of the study area points to the differences relevant to the issues raised in the present work. A climatic factor can be considered homogenous for the entire area, while among the main variables that differentiate the region are: relief configuration, lithology, river network and uneven settlement.

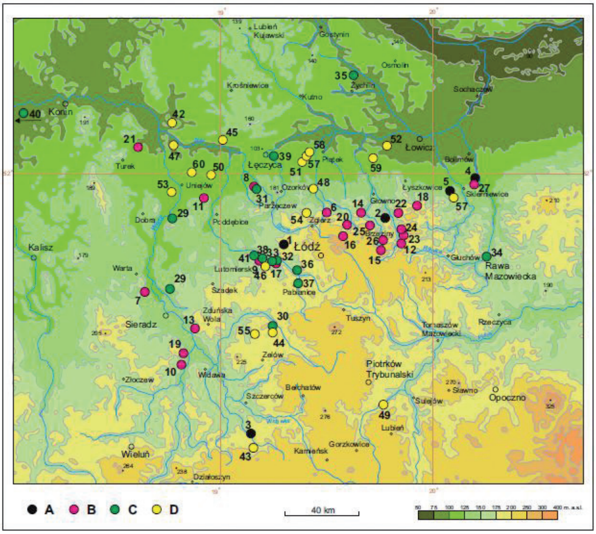

Figure 3.2. Location of sites in Central Poland in which were studied: vegetation cover (A); studied sites: 1 – Aleksandrów Łódzki, 2 – Żabieniec, 3 – Chabielice, 4 – Kopanicha, 5 – Polesie, slope deposits (B); studied sites: 6 – Dąbrówka Duża, 7 – Bartochów, 8 – Wierzbowa, 9 – Lutomiersk-Koziówki, 10 – Burzenin, 11 – Bronów, 12 – Rogów VII, 13 – Strońsko, 14 – Nowostawy, 15 – Brzeziny, 16 – Kalonka, 17 – Bechcice, 18 – Lipce Reymontowskie, 19 – Ligota, 20 – Borchówka, 21 – Józefów, 22 – Koziołki, 23 – Rogów IV, 24 – Rogów 4, 25 – Anielin-Lipka, 26 – Michałów, 27 – Kopanicha, fluvial deposits (C); studied sites: 28 – Nobela, 29 – Łęg Piekarski, 30 – Ldzań, 31 – Wierzbowa, 32 – Bechcice, 33 – Kolonia Bechcice, 34 – Rawa Mazowiecka, 35 – Białka, 36 – Lublinek, 37 – Szynkielew, 38 – Lutomiersk-Koziówki, 39 – Łęczyca, 40 – Ląd, 41 – Lutomiersk, and aeolian deposits (D); studied sites: 42 – Wojciechów, 43 – Grabek, 44 – Ldzań, 45 – Nagórki, 46 – Lutomiersk, 47 – Gaj, 48 – Warszyce, 49 – Kłudzice, 50 – Kraski, 51 – Karsznice I, 52 – Małe Mystkowice, 53 – Czarny Las, 54 – Leonów, 55 – Teodory, 56 – Polesie, 57 – Karsznice II, 58 – Karsznice IV, 59 – Stanisławów, 60 – Grabiszew

Source: own study

Currently, the majority of Central Poland is seen as an area of balance between aggradation and degradation and very weak intensity of morphogenetic processes (Bogacki and Starkel 1999). Only in the northern level of the Łódź Hills and the adjacent plateaux a tendency to degradation is observed. Among the dominant processes are: slope wash, aeolian processes and soil leaching; the slopes are characterized by a negative denudational balance while the river valleys bottoms by a positive balance.

3.3. Changes in vegetation in Central Poland under anthropopressure

The Central Poland area is located in the vegetation zone of deciduous trees that drop leaves in winter (Podbielkowski 1987), with increasing part of coniferous species toward the east. This vegetation pattern, which results from the natural plant succession, developed in the older part of the Holocene, underwent considerable anthropogenic changes, especially in the Neoholocene, until the current stage of strong synanthropisation. At present, forest areas constitute around 20% of the region, and wetlands around 3%. A scale of changes is illustrated by comparing the contemporary vegetation pattern with the maps of the potential natural plant communities (Matuszkiewicz et al. 1995) according to which the forests should be around 90% of the region area. Reconstructions of the previous vegetation cover and its changes in time are provided by palaeobotanical analyses carried out in biogenic deposits of lakes, peatlands and other wetlands. Pollen analysis is based on the composition of pollen spectrum and indicates the local presence of plants as well as their occurrence further of the site. Plant macrofossils provide information about the local vegetation assemblage. Biogenic deposits from the area of Central Poland were rarely studied (cf. Forysiak 2009), mainly because of the other problems of research carried out at Łódź (see: Introduction) and smaller number of localities with well-preserved fossil deposits, compared with other parts of Poland. This statement is illustrated in the map of distribution of palaeobotanical sites applied to analysis of history of vegetation in Poland (Figure 3.1, signature A; Ralska-Jasiewiczowa et al. 2004) based on the Late Glacial and Holocene isopollen maps (Ralska-Jasiewiczowa et al. 2004). In the area of our interest it was only 5 of such localities. Thanks to the work undertaken in the last decade, a number of sites studied by botanical methods has been doubled.

In the Boreal Period, multispecies mixed forest stands developed; pollen diagrams of this time are dominated by pine and birch (Wasylikowa 1964, Balwierz 1980, 2005, 2010, 2011) with gradually increasing amount of elm, oak and alder, while the largest increase was noted for hazel. The significant increase of these taxa in the Atlantic Period was mainly at the expense of the decrease of pine and birch. Apart from other tree species, the pollen records show a small contribution of herbaceous pollen which generally is about 2–3%. First anthropogenic transformations of vegetation, registered in pollen diagrams of the Łódź region, correspond with the activity of Mesolithic people of the Atlantic Period (Ralska-Jasiewiczowa et al. 2004, Pelisiak et al. 2006). Slight changes in the vegetation of that time are supported by the results of pollen analysis by K. Wasylikowa (1999a) and Z. Balwierz (2005, 2011, Balwierz et al. 2005). They consisted of a reduction of about 2% of the pollen of trees, growth of the Polypodiaceae and the appearance of individual pollen grains of ruderal plants. Also in the Early Neolithic, vegetation changes are more local in nature and limited in scale. It is noteworthy that in the pollen diagrams a decline of elm at the end of the Atlantic Period is common (cf. Wasylikowa 1999b, Ralska-Jasiewiczowa et al. 2004), most likely due to a substantial contribution of browse of this species taxon in animal feed. This decrease is also recorded in the palynological profiles from Central Poland (cf. Figure 3.2, sites Aleksandrów Łódzki – Balwierz 2005, 2011, Żabieniec – Balwierz 2010, Chabielice – Balwierz 2005, Kopanicha – Forysiak et al. 2011), despite the lack of unequivocal archaeological evidence proving the cattle breeding. More pronounced changes in the species composition are associated with the onset of the Subboreal Period. The biogenic sediments from the Rąbień peatbog (site Aleksandrów Łódzki) display the record of a significant increase in a total sum of herbaceous plants correlated with a significant decrease of pine and also elm and hazel (Balwierz 2005, 2011). Among the herbaceous plants appeared ribwort plantain – a plant confirming cattle grazing, and the first grains of cereal pollen. The presence of Polypodiaceae, especially *Pteridium*, may point to forest clearance by fire. These changes can be related to agricultural activity of the Linear Pottery Culture communities (Niesiołowska-Śreniowska and Płaza 2011). The pollen record relating to this period at the Żabieniec site shows much weaker changes; only a decline of elm and hazel pollen and a single grains of ribwort plantain have been registered (Balwierz 2010). However, around the peatbog any archaeological materials from the Neolithic have not been found yet (Kittel and Sygulski 2010). After regeneration of the forest cover in the middle Subboreal Period, manifested as an increase in oak as well as in hornbeam and beech (Ralska-Jasiewiczowa et al. 2004), a next phase of human interference took place. Reduction in pine, elm and hazel (Balwierz 2010, 2011) is accompanied by an increase in herbaceous plants associated with pastures such as sorrel and ribwort plantain and by distinctly higher amounts of cereal pollen. Despite the lack of archaeological evidence from the close vicinity of the palynological profiles from the Rąbień and Żabieniec sites, it can be assumed that these transformations are the result of agricultural activities of people of the Trzciniec Culture and Lusatian Culture in the Old and Middle Bronze Age (Kittel and Sygulski 2010, Niesiołowska-Śreniowska and Płaza 2011). Changes in vegetation, such as higher values of plants of pastures, plants of ruderal habitats and of cereal pollen, were recorded in the immediate vicinity of the major site of the Trzciniec Culture in the Łódź region in Polesie (Balwierz 2011). At the Bechcice site in the Ner valley, it has been reported very strong declines of trees (AP – 30–40%) and accompanying increase of charcoal in biogenic sediments, associated with the intensification of the people of the Lusatian Culture bronze metallurgy in the younger part of the Bronze Age (Kittel et al. 2011).

In the turn of the Subboreal and Subatlantic Periods, the amount of plants related to agricultural activity of people of the Lusatian and the Pomeranian Cultures increased, in opposition to falls in tree pollen as a result of deforestation and a rise of crops and plants of pastures and ruderal areas (Balwierz 1980, 2005, 2010, 2011, Forysiak et al. 2011). In periods of lower economic intensity woodland with the increasing amount of hornbeam, beech and fir was reestablished (Ralska-Jasiewiczowa et al. 2004). For transformation of the vegetation cover, very important phase of settlement was the Roman Period. Besides the changes in species composition, land clearance in Central Poland led to exposing of the surface to morphogenetic processes, discussed later in this work. The significant amount of cereal pollen, meadow plants and plants of pastures points to the development of farming and breeding. The forest composition was characterized by a reduction of oak, hazel, lime contribution (Balwierz 2005, 2011) and an increase of alder which easily encroached on moist habitats used as pastures. These changes took place primarily in the areas of valleys, human interference in the vegetation in the plateau areas was still limited (Balwierz 2010).

Subsequent few hundred years within the Migration Period and the beginning of the Early Middle Ages in lowland Poland was a period of less intense anthropopressure when the area was again covered with woodlands. Once again the contribution of oak increased, while beech and hornbeam reached maximum values (Ralska-Jasiewiczowa et al. 2004, Balwierz 2005, 2010). Regression in the cultivation of cereals and pastoral economy was manifested in decreasing amount of synanthropic plants (Makohonienko 2004).

The succeeding time period, from the end of the early Middle Ages until today, is characterised by increasing human pressure on the vegetation pattern. Deforestation was performed for farmlands and settlement processes. According to the needs, the wood of different species was exploited. In the Middle Ages, the modern forest management was conducted. In the region and across the country, reconstruction of the species composition of forests took place; contribution of pine, birch and alder on wet habitats increased at the expense of other deciduous trees (Ralska-Jasiewiczowa et al. 2004). The pollen spectra reflect the values of herbaceous plants of more than 50%, so they were as high as in cold phases of the Late Glacial, only that this value relates primarily to crops, meadow plants and of ruderal areas (Balwierz 2010). It should be emphasized that anthropogenic changes of vegetation in Central Poland progressed from large valleys towards plateaux (cf. Forysiak et al. 2011). Significant reconstruction of vegetation and ecological changes in the environment of Żabieniec peatbog occurred in the late Middle Ages and coincide with the colonisation and the development of the first located settlements (Lamentowicz et al. 2009).

The only areas with relatively naturally preserved habitats in Central Poland are wetlands and they were being subjected to human impact at the latest. Water management in river valleys was carried out in the Middle Ages, when the course of rivers was changed and water reservoirs were created (Kobojek 2009), which resulted in the conversions of riparian habitats. Transformations of peatbogs intensified since the 18th century, which was associated with their drying in order to establish grasslands and peat extraction. Abandonment of this type of activity in the 20th century results in a slow renaturisation of these habitats.

3.4. Changes in the relief and geology in Central Poland under anthropopressure

Now and in the past few thousand years, the area of Central Poland has been formed by four main morphogenetic processes: accretion of organic matter in peatbogs, slope processes, fluvial processes and aeolian processes. These processes in the lowland area of Central Poland were driven by different factors, besides required various climatic, morphological and geological conditions and proceeded with different intensity. Their course was an effect of both natural environmental changes and anthropopressure. Both factors often overlapped.

3.4.1. Slope processes, sediments and forms

Among slope processes that affect the Central Poland relief, slope wash in form of rillwash and sheetwash seems the most effective one. The most pronounced morphological imprint was left behind by rillwash which from the turn of the SA-1 and SA-2 of the Subatlantic Period was locally as intense that transformed to gully erosion (Twardy 1995, 2005, 2008). Less distinct morphological effects were generated by sheetwash, conditioned by deforestation, settlement and agricultural economy. Deposits mantled the foot of slopes with the covers of a small thickness of tens centimeters. These covers smoothed the footslope, which in combination with destruction of the slope upper part led to the transformations in slope profile into convex-concave one. The least effective were mass movements. From the territory of Central Poland only a few cases of mass movement correlative deposits have been reported (Twardy 2000, Twardy and Kittel 2002, Twardy et al. 2004a).

Processes operating on the slopes include also the tillage erosion (Zaslavskij 1978, Govers et al. 1994, Brown et al. 1981). Of all the slope processes it has the most significant relationship to human activity and occurred only during the agricultural land usage. Long-term land cultivation with use hand tools at first, then listers, plow and finally mechanized farming left a wide inventory of slope forms, like agricul-

Photo 3.1. Small, active holweg at Rogów, the Łódź Hills

Source: phot. by J. Twardy, 2006

tural terraces (Figure 3.3A, signatures 14, 15). The last one is so called wheel erosion, which took place in the prehistoric and historic times, is active currently, and has led to the formation of straight howlegs and often initiated slope dissection (Photo 3.1).

The slope deposits which were formed in Central Poland under anthropopressure are varied lithologically. Their textural diversity reaches up to 13 phi (from -6 to +7 phi). Similarly diverse is the structure of young slope deposits, with the frequent occurrence of massive structures. The division and brief characteristics of the Neoholocene slope deposits is given in Table 3.1.

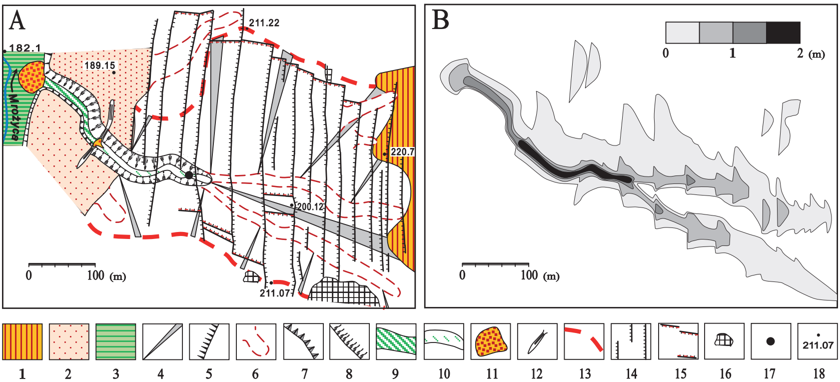

Figure 3.3. Brzeziny site, the Łódź Hills – an example of the relief modified by Neoholocene slope processes and long-term tillage. A – detailed geomorphological sketch of the right side of Mrożyca River valley with a dry valley, B – not generalized sketch of the thickness of deposits displaced by slope Neoholocene processes in the area showed in part A:

1 – undulated morainic plateau, 2 – high valley level, 3 – valley bottom, 4 – slopes, 5 – slope of the Holocene Mrożyca valley, 6 – dry valleys, 7 – natural slopes of the gully, 8 – slopes of the gully changed by anthropogenic denudation, 9 – accumulative, flat bottom of the gully, 10 – accumulative concave bottom of the gully, 11 – cone of the gully, 12 – holwegs, 13 – boundaries of the catchement of the studied dry valley, 14 – agricultural terraces resulted from accumulation, 15 – agricultural terraces resulted from degradation, 16 – gravel pits, 17 – Brzeziny II outcrop, 18 – height points (in m a.s.l.)

Source: J. Twardy (2008)

Table 3.1. Lithological features of Neoholocene slope deposits

Deposits	Facies	Textural features	Structural features	Chemical features
Delluvial sediments	delluvial sands	Mz 1–3 phi, δ_I 0.5–2, Sk_I increases towards finer grains	planar, ripple cross-stratification	C org 0.54% on average, low concentration of Fe_2O_3, strongly decalcified
	delluvial sandy silts	Mz 3–5 phi, δ_I 1.5–2.5, Sk_I decreases towards finer grains	subhorizontal stratification	C org 1.35% on average, concentration of Fe_2O_3 lower than in agricultural diamictons, strongly decalcified or free of $CaCO_3$
Prolluvial sediments		Mz above 1 phi, δ_I 1–6, Sk_I negative, increases towards finer grains	fill channels of single or multiple infill, trough stratification, erosional pavements with imbricated stones at the base	C org 0.0–0.5% (0.1% on average), $CaCO_3$ close to zero except for the series originating from cutting calcic horizon
Colluvial sediments		depends on source material	massive, uncompacted deposits	reflect properties of accumulation or eluvial and iluvial soil horizon
Agricultural diamictons		Mz 2–4 phi, δ_I 2–3, Sk_I positive	structureless, compacted deposits	C org 1.18% on average, highest concentration of Fe_2O_3, usually 1–1.75%, except for liming horizon

Source: J. Twardy (2008).

Delluvial sediments are correlative deposits of sheetwash and weak rillwash. The largest thickness attain in concave forms of the older relief, such as dry valleys. In such cases it is stratified deposit consisting of alternating light (mineral) layers of delluvial sands and dark (humic) layers of delluvial sandy silts (Photo 3.2). Delluvial sediments form also slope covers deposited in the lower slope sections and at the slope base, often entering river valley bottoms. The origin of the covers is connected with weak sheetwash, and with less intense slope processes, thus massive structures dominate.

Photo 3.2. Brzeziny site, the Łódź Hills – Neoholocene slope deposits.
A – fossil brown earth with fire horizon at the top, dated at 1590 BP,
B – stratified delluvia, C – coarse-grained prolluvia,
D – structureless tillage diamicton

Source: phot. by J. Twardy, 2006

Prolluvial sediments are correlative deposits of rillwash, particularly of gullying. They are coarse-grained, poorly sorted, minerogenic, and almost completely devoid of a clay fraction. Prolluvium frequently covers the previously deposited delluvial sediments or fills up the incisions (Photo 3.2). Their thickness in the lower sections of gullies exceeds 2 m (Figure 3.3B), locally reaches up to 3 m.

Agricultural diamictons is a sediment caused by the process of agricultural denudation. They are present on the slopes subjected to long-term cultivation. In Central Poland are marked by the predomination of a sand fraction, poor sorting and massive structure (Photo 3.2), which results from mixing of deposits during ploughing and other field work. The sediment is humic, dark in colour and $CaCO_3$ free; its bulk density up to 2 g·cm^{-3} is an effect of strong soil compaction during field work carried out by means of heavy agricultural equipment. Agricultural diamictons are characterised by the largest spread of the slope sediments, with the exception that occur only on sloping areas which were suitable for cultivation. Their largest thickness, up to 2.5 m, has been reported from the bottoms of gentle dry valleys. In such cases, the efficient and quick accumulation took place when the material was delivered from the opposite slopes of dry valleys ploughed with accordance to slope inclination.

Colluvial sediments are correlative deposits of mass movements. They are rare in Central Poland, mainly because morphometric conditions to landsliding are not fulfilled. In terms of texture and structure, a colluvial sediment is similar to agricultural diamictons, because during its formation only surficial layers and upper soil horizons are translocated. Repositioning by slow soil creep or shallow landslides took place without direct man interference, nevertheless in the previously deforested areas, that is why bulk density of colluvium is between 1.2–1.5 g·cm^{-3}.

The development of Neoholocene slope processes was introduced in Central Poland with the prehistoric settlements (Twardy 2011). This possibly dates back to the turn of the Middle and Late Neolithic (site Dąbrówka Duża – 4650 conv. BP, cf. Wieczorkowska 1997) or to the Late Neolithic (site Bartochów – 4100 conv. BP, cf. Forysiak and Twardy 2012). However, for the period of the Neolithic times, little evidence exists for slope evolution. The first phase (I) was detected for the Late Bronze Age (middle SB-2 phase). The initiation of the slope processes was connected with the Trzciniec Culture communities, as found at the multicultural Wierzbowa site (Kittel and Twardy 2003, Kittel et al. 2011), at the Polesie site (Twardy and Forysiak 2011) and at the Lutomiersk-Koziówki site (Kittel 2012a, b). In that period, sheetwash was dominant; delluvial sediments formed the slope covers up to 1 m thick. The phases II (3150–2940 conv. BP; sites Lutomiersk-Koziówki and Burzenin) and III (2730–2590 conv. BP; sites Bronów, Rogów VII, Strońsko) are similar in the nature of processes, nevertheless besides common delluvial sediments, agricultural diamictons and colluvium appeared in the structure of the slope covers and the accumulation fans. These phases may be linked to centuries activity of the Przeworsk Culture people in Central Poland. In the middle La Tène Period (decline of the Subatlantic SA-1 Period) the area of Central Poland were penetrated by people of the Pomeranian Culture and the slope development was reactivated for a short time (sites Nowostawy – 2250 conv. BP and Brzeziny – 2230 conv. BP). Delluvial sediments and agricultural diamictons were accumulated. After a short recovery of vegetation and stabilisation of slopes, there was the IV phase of their development in the period 1970 – 1590 conv. BP. It was the longest phase, and the development process was the most intense during the entire Prehistory (Twardy 2011). In addition to the delluvial sediments (sites: Kalonka, Brzeziny, Lutomiersk-Koziówki, Bechcice) accumulated were prolluvial sediments, which resulted from the initiation of gully erosion in Central Poland (site Lipce Reymontowskie – 1830 conv. BP). Agricultural diamictons (site Ligota) as well as colluvium (site Borchówka) were accumulated. Evolution of the slopes during the phase IV coincides with the activity of the expansive communities of the Przeworsk Culture, a probable rapid population growth, an increase of the settlement density and progress of technical developments, including ferrous metallurgy which in Central Poland was based on local iron ore and charcoal used in smelting. During this time various landscape systems were penetrated and exploited, while cultivation, breeding and metallurgy contributed to the devastation of the natural vegetation and its dynamic changes (Ralska-Jasiewiczowa and van Geel 1998).

Then the slopes became stabilized for about 300–400 years during the migration period and the beginning of the Middle Ages, which was due to significant depopulation of Central Poland and relatively low activity of the Slavic tribes. In the second millennium AD two successive phases (V and VI) and the contemporary phase (VII) covering the last 200 years have occurred (Twardy and Klimek 2008). Phases V–VII are detected from a number of localities with various categories of slope deposits recorded – delluvial sediments at sites Józefów, Koziołki, Rogów IV and Rogów 4, gullies at Anielin-Lipka, Brzeziny and Michałów, prolluvial sediments at Kopanicha and agricultural diamictons at Burzenin. In the last millennium, the spatial development of gullies (Twardy 1995, 2005) and, in particular in the phase VII, the intense tillage erosion (site Burzenin) are essential.

One should keep in mind that relief transformations in the individual phases might have been intensified by climatic changes. Particularly important are periodic short-term more humid periods, described as wetter phases (Starkel et al. 2013). It is emphasised that the greatest changes in a slope shape coincide with superimposition of phases of increased human pressure on the environment and unstable humid climate (Starkel 2005).

The relief of Central Poland was in this way intermingled with new, well-pronounced erosional forms – gullies. Currently they are inactive, while some of them, especially these smaller ones, became filled up with younger deposits (site Brzeziny – cf. Figure 3.3A, signatures 8–10 and site Nowostawy). The development of around 30–40% of the gullies was conditioned by the presence of older landforms – these are gullies that dissect periglacial depressions (dells) and dry valleys. These forms are the largest ones, with numerous side gullies, thus similar to loess gullies. The gullies reach up to 7–8 m in depth, 1–2 km in length and to 4–4.5 $km \cdot km^{-2}$ in density. Nevertheless, the presently observed forms are mostly smaller and occur predominantly on the slopes of river valleys and the edges of a higher terrace. They often have a V-shaped profile, straight course and lengths of 100–300 m. These smaller forms are defined by new routs of heavy runoff in the Neoholocene, conditioned possibly by prehistoric land-use, distribution of deforested areas and fields. At the same time, holwegs were formed. It is likely that some of the gullies were initiated as dirt tracts, which were routed along steep slopes or were directed to dry valleys. In the zones of former dirt tracts took place a vast destruction of vegetation and strong soil compaction by wheels, which weakened/stopped the infiltration of surface waters, caused fast runoff and dynamic erosion.

In contrast to gullying, tillage erosion smoothed the relief. Long-term, permanent ploughing on an inclined surface led to flattening of slopes, levelling of local small depressions and truncation of egdes. Where the ploughing was stopped, for example at the edges of fields, accumulation of the displaced material generated the specific microrelief (cf. Figure 3.3A, signatures 14, 15).

3.4.2. Fluvial processes and sediments and forms of river valley bottoms

Concentration of prehistoric and early medieval settlements in the river valleys in lowland areas and their location in river terraces or terrace residulas are commonly known from studies on environmental conditions of settlement. River valleys, and especially a proximity to valley bottoms, ensured easy access to water. These forms also marked the axes of communication routes. River terraces have been recognised as suitable cultivated areas in the Prehistory and in the Early Middle Ages (Bratkowski 1978). High productivity and biodiversity of river valleys guaranteed the relative ease in obtaining food, both vegetable and animal (Olaczek 2000). Extremely favourable conditions settlement have been indicated by: S. Kurnatowski (1968), T. Krzemiński and Z. Maksymiuk (1966), T. Krzemiński (1970, 1987), J. Kruk (1973, 1980), T. Bartkowski (1978), J. Goździk (1982), J. Pyrgała (1971, 1972), K. Godłowski (1983), Z. Kobyliński (1988), Z. Kurnatowska and S. Kurnatowski (1991), J. Kamiński

(1993), H. Dobrzańska and T. Kalicki (2003, 2009), A. Pelisiak (2003, 2004), A. Pelisiak and J. Kamiński (2004), Z. Balwierz et al. (2005), P. Kittel and J. Skowron (2009), P. Makarowicz (2010), J. Twardy and J. Forysiak (2011), P. Kittel et al. (2011), P. Kittel (2012a, b).

K. Turkowska (1988, 2006) claims that the periods of more intensive fluvial activity took place at the Boreal/Atlantic and Atlantic/Subboreal transitions and in the Subatlantic Period. J. Kamiński (1993) has placed the increase in fluvial processes in the Early Atlantic Period, the beginning of Subatlantic Period and the Middle Ages. Drying of the Moszczenica River valley bottom was, according to this author, characteristic of the Subboreal Period. J. Forysiak (2005) has registered the increase of groundwater level in the middle Warta River valley in the Middle and Early Atlantic Period and in the Subatlantic Period.

The earliest evidence of the Neoholocene intensification of fluvial activity in Central Poland, probably in response to anthropogenic factor, are alluvial fills in the palaeochannels of the Zwierzynka valley at Polesie (between 5160 and 3140 conv. BP – Twardy and Forysiak 2011) and the Warta valley (sites Nubela and Łęg Piekarski 3800 – 3200 conv. BP – Forysiak 2005). Overbank deposits dated at around 3500 conv. BP have been recognized from the Grabia River valley at the Ldzań site (Kamiński and Miklas 1998). From the Subboreal Period, between 4000 and 3000 conv. BP, the particularly active period of overbank deposition began. In the author's opinion these enhanced floods may have been partly initiated by anthropogenic transformation during the Bronze Age. It should be emphasised that the data quoted are based on small numbers of radiocarbon dated samples and there is no further analysis of the verification of the age of deposits.

At the Wierzbowa site (Gnida River valley), a profile of the overbank sandy deposits overlain by thick delluvial sediments and underlain by organic silts that form the fossil valley bottom (of Eo- and Mesoholocene age), was documented. Processes of the accumulation of the flood series and of the delluvia resting above date back to 1500 BC and were undoubtedly associated with intensive prehistoric settlement on the valley sides (Kittel et al. 2011, Kittel 2013, 2014).

In the Krasówka River valley (the Szczerców Basin), the accretion of overbank series started about 3020 conv. BP (Marosik 2002).

In the Subboreal Period, evidences of decreasing fluvial activity and drying of valley bottoms (Kamiński 1993, Kobojek 2000, Marosik 2002, Kobojek and Kobojek 2005) as well as the increase in flood tendency during the middle part of this period (Turkowska 1988, 1990; Kamiński 1993; Pelisiak and Kamiński 2004) exist in the river valleys of the Łódź region.

Records of the earliest direct impact of human societies on the river, which took place at the Bronze Age and the Iron Age transition, i.e. the beginning of Subatlantic Period, are available from the site Bechcice (middle Ner River valley). A case study was carried out there in the palaeochannel located at the foot of the Lusatian Culture settlement, which filling up began around 3000 conv. BP. The intensive use of the channel or palaeochannel are supported by the artefacts presence in the channel series. Pollen analyses of the palaeochannel infilling indicated significant forest clearances in the period between 3000 and 2650 conv. BP, which coincides with the time of activity of bronze metallurgy workshops at the archaeological site Bechcice (Kittel et al. 2008, 2011).

The results obtained from the AMS datings (770–430 BC) show that the beginning of Subatlantic Period was also the time of accumulation of organic silts that cover peats filling the palaeochannel at the Kolonia Bechcice site. The accumulation appeared in the early Iron Age under anthropopressure (Stachowicz-Rybka et al. 2011). The filling of the palaeochannels of the Rawka River (530–380 BC) and the Rylka River (620–400 BC) at Rawa Mazowiecka started from the beginning of Subatlantic Period (Kittel and Skowron 2007, 2009). Somewhat later, but prior to the Roman Period, the fluvial activity, dated at around 2300–2200 conv. BP, which caused covering of the cultural horizons with alluvium, was well-recognized at the Przysowa site (Twardy et al. 2004b).

Studies from Central Poland provided examples of the increased fluvial activity before 2000 conv. BP – e.g. the Ner River valley (Turkowska 1988, 1990), the Wolbórka River valley (Turkowska 1988) and the Moszczenica River valley (Kamiński 1993).

For the Roman Period, it exists in the Łódź region evidence of the quick accretion of overbank deposits, dated at 1930 conv. BP (charcoals buried by flood), 1900 and 1800 conv. BP (flood loam) from the Moszczenica valley (Kamiński 1993; Kamiński and Moszczyński 1996). The peat covers, recorded in the peripheral areas of the Ner River valley near the Lublinek site, are evidences of raising groundwater level that followed the Neoholocene aggradation of deposits dated at around 1780 conv. BP (Turkowska 1988). Before 1640 conv. BP, overbank series accumulated in the Krasówka valley in the Szczerców Basin (Marosik 2002).

A clear geological record of an anthropologically induced tendency to floods is stored in the profile from the Dobrzynka River valley at the Szynkielew site. The floods are supported by the set of radiocarbon dates for organic silts and peats underlying silty overbank series (between 1210 and 810 conv. BP). These processes should be combined with the settlement intensification in the turn of 11th and 12th centuries AD, in connection with the development of the so-called *Opole Chropskie*, which was substantiated by archaeological and historical data. Deforestation of the area also shows charcoals dating back to 1040 and 840 conv. BP, found in the slope cover interfingering with the overbank series (Kittel 2013).

The topmost series filling the palaeochannel of the Rawka River, close to Rawa Mazowiecka, with fragments of bricks have been deposited since the Late Middle Ages. The present-day valley bottom is built of the wide overbank cover of a thickness reaching to 1.5 m, containing many late-medieval and modern artefacts. Initially the river inundations led to the silt accumulation, with time coarser particles were deposited. These processes were probably responses to deforestation of the catchment in the historical period, probably after the 13th century AD, i.e. in the period of the urban city development. The overbank deposits covered Late Vistulian sediments which resulted in the widening of the modern floodplain (Kittel and Skowron 2007, 2009).

Sandy-silty deposits gradually altering into sandy deposits of the overbank cover in the vicinity of Kolonia Bechcice were accumulated in the modern times, most likely over the last 250–300 years (Stachowicz-Rybka et al. 2011). Coarse-grained sands accumulated during the intense overbank flow, which was an effect of draining of rettery basins system, were registered at the Lutomiersk-Koziówki site. This process took place between the half of the 17th century and the beginning of the 19th century AD (Kittel et al. 2012).

Accumulation of sand loams in the historical period are known in the following river valleys of the Łódź region: Luciąża (Goździk 1982, Wachecka-Kotkowska 2004), lower Moszczenica section (Kamiński 1993), Linda near Ozorków (Marosik 2003), Ner near Lutomiersk (Kittel et al. 2012, Kittel 2012a). Water-logging of the valley bottoms as a result of the development of settlement was found near Łęczyca (Krzemiński and Maksymiuk 1966; Krzemiński 1987) and Ląd (Bartkowski 1978). In the historical period, forest clearances associated with agricultural development and progress of colonisation remarkably affected the environments of river valleys (Olaczek 2000, Kobojek and Kobojek 2005). Deforestation leads to the increase of surface runoff, denudation and fluvial accumulation (Strzemski 1964, Dunin-Wąsowicz 1974, Wilgat 1999). Since the Middle Ages the direct method of anthropogenic interference in valley bottoms was the establishment of water mills, fullers (Kamiński 1993, Olaczek 2000) and retteries (Olaczek 2000). Recently, remains of modern rettey have been studied at the Lutomiersk site (Kittel et al. 2012). In the 18th century AD, the process of regulation of channels and melioration of valley bottoms began; in the Łódź region the first works were carried out in the valleys of the Warta River (Forysiak 2005, Forysiak et al. 2007) and Bzura (Olaczek 2000). In the 20th century AD, these processes as well as levelling of valley bottoms encompassed minor valleys of the region (Kobojek and Kobojek 2005).

Anthropopressure in the fluvial environment in the Łódź region is recorded mostly by the overbank deposits in the palaeochannels or expanded over the valley bottoms; much less likely to be connect with peat growth. Overbank series is represented by organic silts, sands and silts. The finer materials, which form covers of a small thickness (tens of centimeters), are a feature of the prehistoric processes, while from the historical period primarily sandy covers with silt alternations, of a thickness reaching 1.5 m, were inherited.

The earliest record of human impact in the fluvial environment dates at the Middle (possibly also Late) Bronze Age, thus in the end of the Subboreal Period. An increased amount of the anthropogenetic overbank series falls on the early Iron Age, thus in the beginning of the Subatlantic Period. Higher frequency of floods is well-documented in the Roman Period. The result of the intensification of anthropogenic changes in the geographical environment is the formation of extensive covers of overbank deposits in the historical times, from the Middle Ages onwards, with increasing intensity in the Modern Times. This rhythm is in accordance with a scheme of intensity of fluvial processes in the river valleys of Central Europe proposed by T. Kalicki (2006).

3.4.3. Aeolian processes, sediments and forms

In the Late Vistulian and the beginning of the Holocene, the territory of Central Poland was the scene of periodically intense wind activity. This produced a series of large inland dunes (Galon 1958), mostly parabolic, and transverse. Geomorphological research carried out in Łódź several decades ago allowed to establish stratigraphy of aeolian deposits and distinguish phases in the development of Late Glacial dunes (Dylikowa 1969) – the initial phase, the main phase, the transformation phase and the Holocene phase of destruction. Recently, J. Twardy (2008) proposed to replace the name “phase of destruction” into “anthropogenic phase” because the continuation of the development of dunes in moderate climate conditions and increasing anthropopressure, in fact, did not only consist of destruction.

The Holocene aeolian processes took place on the previously formed dunes, after settling them by man (Wasylikowa 1964, Cyrek 1996, Marosik 2011). Short-term interferences of small groups of Late Palaeolithic and Mesolithic people changed dunes to a limited extent; small amounts of material were after wind transportation deposited as thin sand series on the lee (eastern) dune sides. Neolithic evidences of dune activation can be assigned to two short phases. The first of these may be dated to the middle part of the Early Neolithic (site Wojciechów – 6050 conv. BP – cf. Krajewski 1977 and site Grabek – 5760 conv. BP – cf. Marosik 2002), the other to the Middle and Late Neolithic (site Ldzań – 4260 conv. BP – cf. Pelisiak and Kamiński 2004, site Nagórki – 4200 conv. BP – cf. Krajewski 1977 and Kittel et al. 2012 and site Lutomiersk – 4150 conv. BP – cf. Twardy 2008).

In the Bronze Age aeolian activity was much more intense, including the reactivation of migration of large Late Glacial dunes (site Gaj – 3770 conv. BP), the formation of small dunes on the dry bed of the Moszczenica River valley (sites Warszyce I and II – 3600 and 3500 conv. BP – cf. Kamiński 1984) and accumulation of pedolithes (site Kłudzice – 3620 conv. BP) and aeolian covers (site Nagórki – Kittel 2012c). For the second time in the Bronze Age there was a short mobilisation of dunes between 3050 and 2970 conv. BP (sites Kraski and Grabek). The wind activity, in addition to environmental changes caused by population of the Early Bronze Age, of the Trzciniec and Lusatian Culture, favoured the dry climate in the Subboral Period (phase SB-2).

In the Iron Age morphogenetic wind activity recorded in different ways in fossil soils, aeolian deposits and forms also reactivated twice. This took place during the Hallstatt Period, between 2540 and 2390 conv. BP (sites Karsznice I, Nagórki and Małe Mystkowice) and at the end of the Iron Age, in the Late Roman Period, around 1640 and 1490 conv. BP. While the first of these phases can be linked to the activity of the Lusatian Culture community, the second one corresponds to a period of activity of the Przeworsk Culture people. Recently, the confirmation of activation of aeolian processes by the Pomeranian Culture community has been obtained (site Czarny Las, 2090 conv. BP, cf. Forysiak and Twardy 2012).

Most of the mentioned-above sites is located in large concave landforms, such as the Warsaw-Berlin pradolina or the Szczerców

Basin, the earliest and most inhabited because of the sandy substratum, flat terrain and easy access to a dense network of flowing water. At the turn of the first and second millennium AD, after forest clearance, the old dunes of the Łódź Hills and the bordering plains were mobilized. This occurred around 1100 conv. BP (sites Leonów and Teodory), then continued around 1080 conv. BP (site Polesie), 1040 conv. BP (site Karsznice II), 1020 conv. BP (site Karsznice IV), 970 conv. BP (site Polesie), 920 conv. BP (site Stanisławów), 910 conv. BP (site Karsznice I), 780 conv. BP (site Nagórki). This lasted about 300 years phase, falling in the Early Middle Ages, should be attributed the economic activity of the population living in Central Poland. These facts point to the intensive use of dry ecosystems, including aeolian, which could be due to the strong moisture of the valley bottoms and the foot slopes. According to L. Starkel et al. (2013), in the periods 1000 – 825 and 750 – 675 calendar years BP wetter phases were noted. In warm climatic conditions of the Medieval Optimum, on the one hand, old dunes, activated already in the earlier Neoholocene cycles, were destructed (e.g. sites Karsznice I or Nagórki), on the second hand new aeolian covers (sites Karsznice II and Polesie) and new small dunes (site Leonów) were formed.

The last phase of wind reactivation corresponds to the modern times and may be related to unstable climatic conditions of the Little Ice Age. This phase coincides also with the activity of *Olęder* settlers, who were focused on development of wastelands, such as poor aeolian fields. For the phase two dates are available – 410 conv. BP (site Grabiszew) and 370 conv. BP (site Gaj – cf. Forysiak et al. 2007), pointing to the time of resumption the movement of the large Late Glacial dune.

Neoholocene aeolian deposits vary in structural and textural features. They are dominated by structureless sands mean with diameters of the grains of about 1.5 to 2.5 phi, therefore are generally similar to that of the source Late Glacial material. Young aeolian covers contain sands with horizontal lamination and pedolithes – stratified sandy and silty deposits with a humic admixture. Layers with humic and charcoal fragments make up the most commonly occurring admixture to the aeolian sand, and thus provide the base for relatively easy macroscopic differentiation between the Holocene and Late Glacial series. Humic material is of both autochthonous (colonisation by pioneer vegetation newly deposited aeolian layers) and allochthonous (winnowed from arable fields and dry pastures bordering the aeolian covers or dunes) origin. Less common are sands deposited as layers forming an angle of about 20–30°. They represent deposits of the lee slope and prove their movement by wind in the Neoholocene. This process was made possible after the dune clearance and deflation of soils covering old dunes. There were also Neoholocene aeolian deposits with distorted lamination, resembling small-scale involutions. Such deposits were always found in small initial aeolian hillocks that look like mounds of regular shape, 2–3 m high. These landforms are very characteristic element in the Neoholocene aeolian relief; they are vegetated and occur in groups up to several dozen over small aeolian fields. A distinctive feature of the Neoholocene aeolian relief are numerous small accumulation forms often showing the reversed slope asymmetry, which indicate a significant role of obstacles (e.g. clumps of vegetation) during the accumulation.

3.5. Conclusions

The review of the localities with biogenic, slope, fluvial and aeolian deposits in which the indirect impact of human activity on their origin is recorded, shows that evidence of changes of the vegetation pattern and evolution of the relief and geological structure are in Central Poland particularly numerous. The exact correlation of the sites is beyond the scope of this chapter, due to the strictly local nature of prehistoric anthropopressure and a variety of environmental conditions. Nevertheless it is possible to draw some general remarks.

1. More significant changes in the relief and geology of Central Poland that occurred under human pressure date back to the Neoholocene (the Early Subboreal Period and Subatlantic Period). More pronounced transformation of the slopes, river valley bottoms and

aeolian landforms occurred since the Middle Bronze Age, around 3500 years ago.

2. The punctuated changes, in both vegetation and abiotic components of the environment, were marked at the earliest in the large river valleys (e.g. Warta, Ner, Bzura rivers) and minor valleys within the Warsaw-Berlin pradolina. In higher lying parts of Central Poland, these changes on a similar scale emerged much later, only after ca. 2000–2500 years. It was connected with much worse conditions for the settlements in areas of more diversified relief configuration, with poorer soils and limited access to water.

3. The transformation of the vegetation, relief and geological structure took place gradually, along with the expansion of prehistoric settlement of the Trzciniec Culture , the Lusatian Culture and the Przeworsk Culture, whereas in the historical period – along with Early Medieval settlement. Less important for these changes were the impact of people of the Neolithic cultures, and short-stay of people of the Pomeranian Culture in the Central Poland area.

4. The studied transformations were driven by both natural factors, particularly climate, which has changed during the Holocene repeatedly (but on a relatively moderate scale), and by anthropogenic factors, the importance of which was growing rapidly in the expansion phases of prehistoric cultures. These influences are relatively easy to distinguish in the palynological profiles by a well-defined group of plants accompanying the settlement and economy, whereas their distinguishing in the relief and geology transformations is much more difficult. However, it should be stressed that the development of the slopes and aeolian geosystems, and superimposing increased fluvial activity, in many cases were synchronous. This synchronous response, noting at the same time in different sedimentary environments, rather indicates the dominance of anthropogenic factor, because the humid climate, favourable to stimulate fluvial and slope processes is less favourable for the simultaneous development of aeolian relief. Favourable natural conditions undoubtedly facilitated breaking the balance of the geosystem and the initiation of processes and their more efficient course under anthropogenic changes of the environment.

5. The trends of the Neoholocene relief transformations were very different. Both processes, leading to local increases of relief and diversified terrain morphology (e.g. gully erosion, so-called wheel erosion, formation of agricultural terraces, accumulation of series overlaying of Late Glacial dunes) and the processes of opposite trends (e.g. aggradation of valley bottoms, tillage erosion, dismantling of old dunes). Most Neoholocene morphogenetic processes resulted in the increased lithological differentiation, soil formation and increasing geodiversity of the environment.

6. A number of processes that affected the nature of the vegetation, relief and geology was a targeted, intentional and direct interference (e.g. land clearance in order to obtain arable fields, energy raw materials and building materials, construction of embankments in river valleys, exploitation of till, sand and other aggregates). However, most of the changes should be regarded as unintended and negative, so to speak, a side effect of centuries of settlement and economy. There may be mentioned here: planation of slopes used for agriculture, gully erosion, wheel erosion, the spread of poor aeolian areas or the increase in the frequency and scale of floods in the Central Poland rivers as a result of an accelerated water circulation on the vegetation-free slopes.

7. Obviously, the Holocene morphogenetic cycle occurred in the past (and is still occurring) under human impact, which proves the J. Dylik's thesis quoted in the Introduction. This cycle, superimposed on the periglacial morphogenesis, partially obliterates its effects and partially only modifies them. Taking into account the short duration of the Holocene cycle, it is characterised by a large dynamics of the processes being accelerated and intensified by man.

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