GEOGRAPHIA POLONICA
2011, 84, Special Issue Part 1,
163–178

INFLUENCE OF MAN AND CLIMATE CHANGES ON RELIEF AND GEOLOGICAL STRUCTURE TRANSFORMATION IN CENTRAL POLAND SINCE THE NEOLITHIC

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Abstract: This paper presents the results of a study of relief transformation in central Poland (Fig. 1), which took place in the Neoholocene in the context of growing human impact and climate fluctuations. Standard methods used in Quaternary geology and geomorphology were employed to examine Neoholocene aeolian, slope and fluvial deposits. Seven major stages and a few short-term episodes (Fig. 2), during which the process of relief transformation accelerated, have been distinguished. These stages are characterized by their varying length (from 160 to 480 years) while their duration became gradually longer at the expense of those periods, during which the relief transformation was slow. Major geomorphological processes in each stage and their consequences for relief transformation are briefly discussed. The results obtained are linked to the development of prehistoric cultures in central Poland and to the periods of unstable climate.

Key words: human impact, aeolian deposits, slope deposits, fluvial deposits, Neoholocene, central Poland

INTRODUCTION

The analyses of geological sediments provide one of the sources of information about the evolution of the environment (Mannion, 2001). They enable one to reconstruct geomorphological processes and to describe landform evolution of the relief. It should be stressed out that the geological sediments reflect long-term human intervention in the environment (Starkel, 1988), linked to permanent settlement, extensive deforestation, agricultural development and prehistoric metallurgy. Forest clearance (followed by the introduction of ploughing) is believed to have had the biggest impact on environmental changes (Lang et al., 2000). It is estimated that along with the development of settlement, the acceleration of natural geomorphological processes increased by two orders of magnitude (Obrębska-Starkel and Starkel, 1991). Furthermore, geological sediments reflect climate fluctuactions and sometimes even one-off meteorological events of unusual intensity. It is especially difficult to distinguish accurately between natural and anthropogenic factors (Starkel, 2006) and their influence upon the changes in slope, aeolian and fluvial systems. The difficulty is compounded if geomorphological investigations are carried out in the lowlands with a dull relief and monotonous geological structure.

Human impact upon relief transformation has been studied in central Poland (Fig. 1) for over 25 years. So far, studies have focused on the transformation of river valley

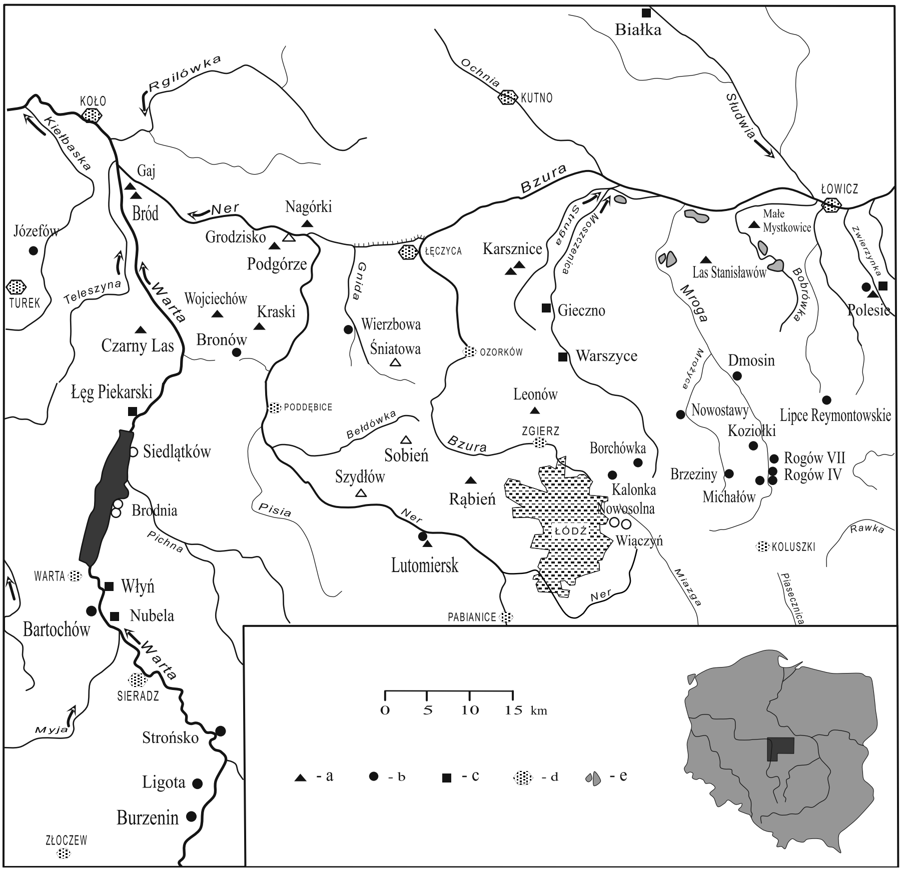

Figure 1. Study area against the background of the hydrological network in Central Poland

a – sites with aeolian sediments, b – sites with slope sediments, c – sites with fluvial sediments, e – major cities, f – lakes, ponds. Black symbols show sites examined by means of the ^{14}C method

bottoms, slopes, dunes and aeolian covers. The analysis of results of these independently conducted studies suggests that there was some coincidence between the periods of increased intensity of fluvial, slope, and aeolian processes. The present study attempts to provide a correlation of data obtained after analyzing the Neoholocene fluvial, slope and aeolian sediments. The results were compared with the development of prehistoric cultures and the influence of climate. A number of phases in the acceleration of relief transformation in central Poland has been distinguished, along with a few minor and short-term episodes. In the latter part of this study, these materials are presented chronologically.

STUDY AREAS

Field material for this study was collected in the area shown in Fig. 1. It shows part of central Poland frequently referred to as "the Łódź region". Only an area situated south and south-east of Łódź has been the least investigated and it has not been possible to find evidence for important relief transformation due to human impact. It is now universally recognized that the entire area under investigation was formed during the Wartanian Glaciation (Rdzany, 2009). This area consists of three large landforms:

- The Warsaw – Berlin ice marginal valley, trending E-W and marked by a monotonous relief. It is now being drained both to the West (through the lower part of the Ner River) and to the East (through the lower Bzura River). The valley has always provided a convenient and important link between the Odra and Vistula river basins, i.e., between Great Poland (Wielkopolska region) and Masovia. As a result, it was populated throughout almost the entire prehistory and the historic period (Dylik, 1971);
- The Warta River valley, situated roughly N-S in western Poland and the largest waterway in the region. It is characterized by a relatively varied relief. It was a prehistoric route between Silesia and Kuyavia. The strategies of using the Warta valley by prehistoric communities and the consequences of its long-term settlement for the landform evolution were described in several articles (Andrzejewska, 2004; Janiak, 2004; Rzepecki, 2004; Twardy, 2004; Twardy et al., 2004a; Urbaniak, 2004; Zawilski, 2004).
- The Łódź Plateau, situated in the south and south-east of the area under investigation. They are shaped as a latitudinal embankment rising up to 284 meters above sea level and flanked in the north and west by the above-mentioned valleys, and by the Pilica River valley in the south and south-east. The Łódź Plateau lies in the Odra/Vistula watershed as well as the Bzura/Pilica watershed. The watersheds are marked by varied landform and a loose hydrological network with only small rivers. Given the poor access to flowing waters, the absence of lakes, poor soils, and their location away from the major prehistoric communication routes, this area has a considerably shorter tradition of settlement. A more intensive settlement of the central part dates back to the Mediaeval and Modern Times.

The above brief description of the investigated area carries important implications for the topic of this paper. The climate factor is practically same for the entire area. However, the major variables include varied relief, differences in the density of the hydrological network, and inconsistent settlement patterns by prehistoric communities. Fig. 2 shows the results of radiocarbon analyses carried out in the three above-mentioned areas (symbols d–f) and the results obtained by other researchers from the Szczerców Basin, the Piotrków Plane, and the Kutno Plane (Fig. 2, symbol f).

RESEARCH METHODS AND MATERIALS USED

The sites shown in Fig. 1 were investigated by means of standard methods used in Quaternary geology and geomorphology. Lithological features of the Neoholocene slope, aeolian, and fluvial deposits have been analysed. This enabled one to link the results with specific sedimentary environments and geomorphological processes. Thanks to the lithological analysis, it was possible to determine the dynamics of geomorphological processes and to trace the landform evolution of the relief.

The grain size composition of the sediments was examined by means of sieve analysis, which was complemented by the pipette analysis in order to include the finest fractions. Selected sampled sediments were analysed by means of grain size abrasion (0.8–1.0 mm). There were also several chemical determinations of the sediment features, for example, the concentration of organic matter, $CaCO_3$, Fe_2O_3, P_2O_3 and pH indication. The determination of chemical features were complementary to the grain size analysis and they made it possible to distinguish individual categories of sediments despite the similarity of their texture and their massive structure or structureless form. The organic samples, such as charcoal from fire horizons, peats or organic silts, were dated by means of the ^{14}C method using the standard gas gauge from the ^{14C} Labora-

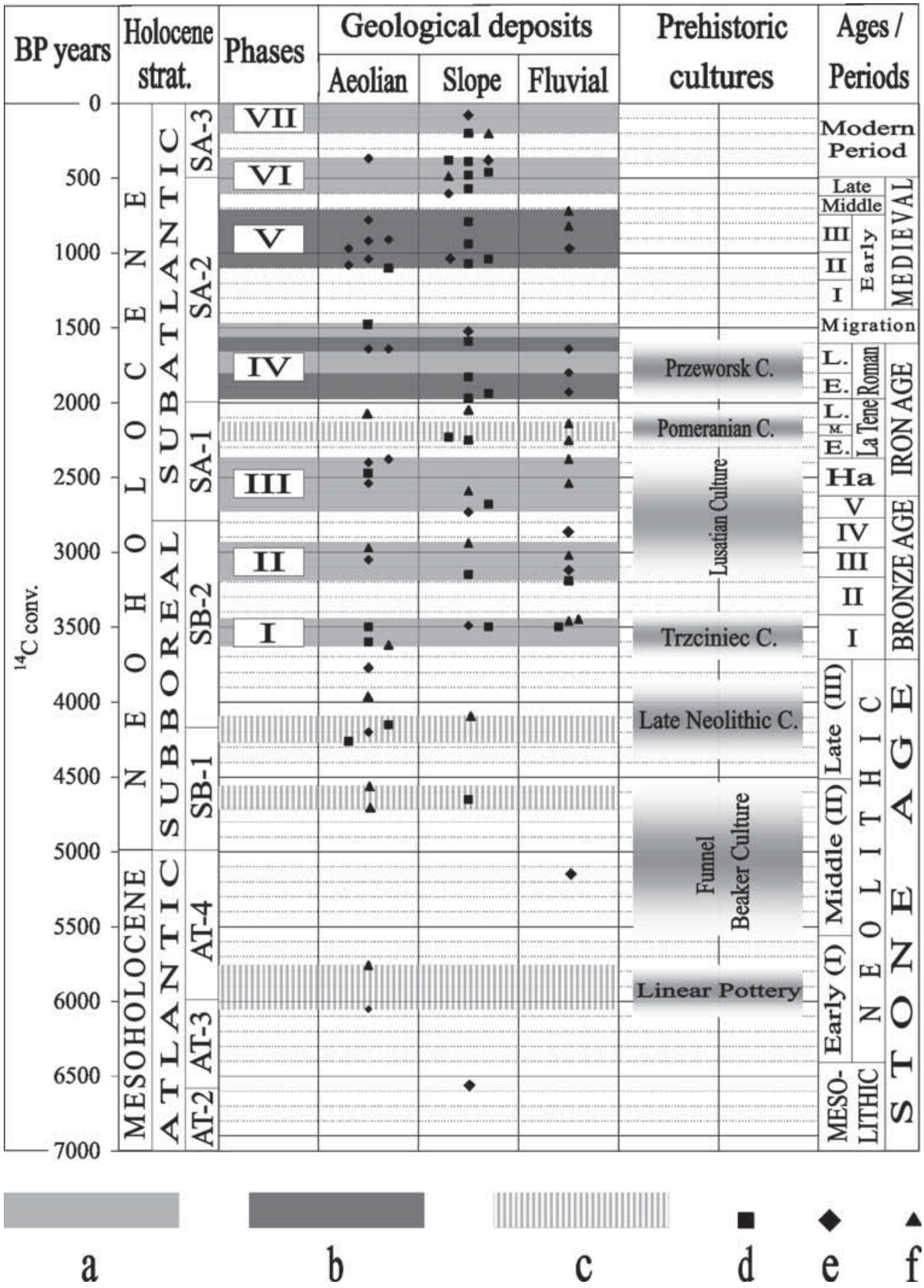

Figure 2. The phases of relief transformation in Central Poland

a – phases with numbers, b – major phases, c – short-term episodes, d – the Łódź Plateau sites, e – sites in the Warsaw – Berlin ice marginal valley, f – sites in the Warta valley and the Szczerców Basin, the Piotrków Plain, and the Kutno Plain tory at the Archaeological and Ethnographic Museum in Łódź. Importantly, most of the results cited in this study were obtained in this laboratory.

Extensive studies of archaeological literature of central Poland were also conducted. Especially noteworthy were those publications, which include maps of prehistoric settlement patterns (Jażdżewski, ed. 1975) examined by means of excavation methods. In addition, the present study relied on the results of archaeological surface examinations summarized by Papińska (2002) for the Łódź area and it also used selected sheets of Poland's Archeological Map.

THE PHASES OF RELIEF TRANSFORMATION IN CENTRAL POLAND

Essential evolution of central Poland's landforms started in the Neoholocene (Fig. 2) during phase I located at the beginning of the Bronze Age. This phase was preceded by three older, short-term and less important episodes (Fig. 2, symbol c) which can be located in the Neolithic. This phase shows a delay in starting these changes in comparison with loess plateaus, Kuyavia and Pałuki. Śnieszko (1995) locates IV subphase of the mechanical denudation in the late Neolithic. The mechanical denudation was found in 10 out of 16 examined sites. It corresponds to Neolithic phases of increased soil erosion in the plateaus of southern Poland, which were recently distinguished by Starkel (2005). Sinkiewicz's (1998) study suggests that there is just as persistent evidence of increased anthropogenic denudation in Kuyavia and Pałuki at that time. Both loess plateaus and Kuyavia were the cradle of Neolithic farming. Poor soils in central Poland were not attractive for Neolithic farmers. Similarly, a poor reflection of soil erosion processes in the Neolithic was found in the Suwałki Lake District (Smolska, 2005; Prudziszki site 2 dated at 5,405 ± 80 years BP) and in NW Poland (Borówka, 1992). Thus, the dynamics of anthropogenic denudation in Poland in the Neolithic varied considerably and the location of areas more strongly modelled was closely related to the location and intensity of the Neolithic settlement.

In central Poland, the Neolithic was found primarily in changes of aeolian systems. A local and short-term rejuvenation

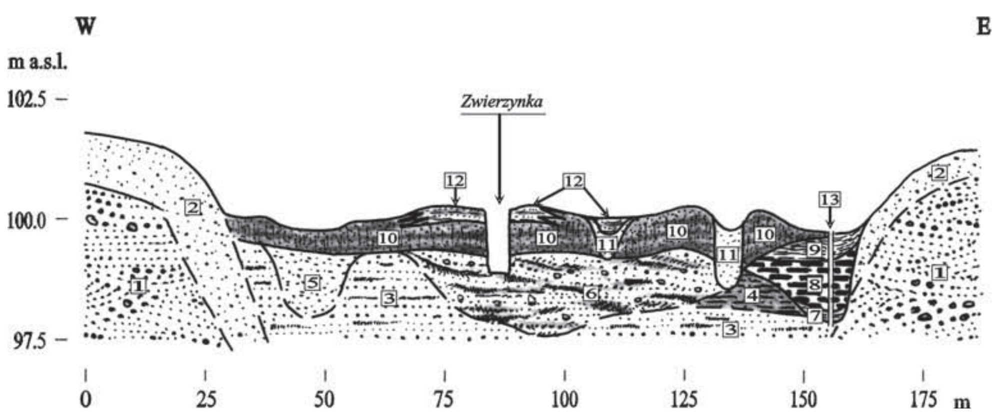

Figure 3. Geological cross-section of the Zwierzynka valley in Polesie

Wartanian Glaciation: 1 – glaciofluvial sands and gravels; the last glaciation (Vistulian): 2 – fine and medium sands; Late Glacial: 3 – fine and medium sands, loamy in some places, 4 – organic and mineral muds, 5 – channel medium sands; the Holocene: 6 – vari-grained sands with organic interlayers, 7 – organic muds and clays, 8 – peat, 9 – organic muds, 10 – overbank deposits, 11 – channel fine and medium sands with plant debris, 12 – muds with sands, 13 – section location (Fig. 4) occurred as well as Late Glacial dunes were activated. Thin aeolian covers were buried on fossil soils in dunes. This could be linked to the activities of the representatives of the Early Neolithic Linear Pottery Culture and then to the Middle Neolithic Funnel Beaker Culture (dating from its earliest Lubońska phase, see Wiklak, 1975) and, finally, to the Late Neolithic cultures (Globular Amphorae Culture and Corded Ware Culture). Transformations of dunes are commonly known in Poland (Nowaczyk, 1986, 2002; Rotnicki, 1999). The tabulation prepared by Nowaczyk (1995) indicates that the amplest evidence of morphogenetic wind activity comes from the broadly defined area of central Poland. The results obtained by the author of the present study closely correlate with those of Jankowski (2002) who investigated fossil soils in the Toruń Basin dunes.

Rivers in central Poland at the turn of the Atlantic and the Subboreal were characterized by meandering channel pattern (the so-called small meanders) and by the stability of their beds (Turkowska, 1988). A detailed investigation of a small peat-bog in the Zwierzynka valley at the Polesie site shows that the process of flooding the peat-bog started right before 5,160 ± 60 years BP. This process was reflected in the sudden reduction in the organic matter content (Fig. 4, part C) and a fall in the rate, at which peats were formed (Fig. 4, part D) as well as a pH reduction (Fig. 4, part E). The date provided above could be associated with the beginning of accumulating overbank deposits in small river valleys in the Łódź region.

13 Neolithic sites, at which sediments were dated using the ^{14}C method, are characteristically located. Most of them (10 out of 13) lie in two large negative landforms (the Warta River valley and the Warsaw-Berlin ice marginal valley). Relief transformation in the Łódź Plateau dates from as late as the Bronze Age.

Phase I (3,620–3,460 years BP) started by depositing layered aeolian sands with humus in fossil soil at fire horizons (Kłudzice site in the Piotrków Plain; see Wachecka-Kotkowska, 2004) and it ended with the accumulation of alluvial sands with organic silts and organic debris filling the palaeochannel in Łęg Piekarski in the Warta River valley

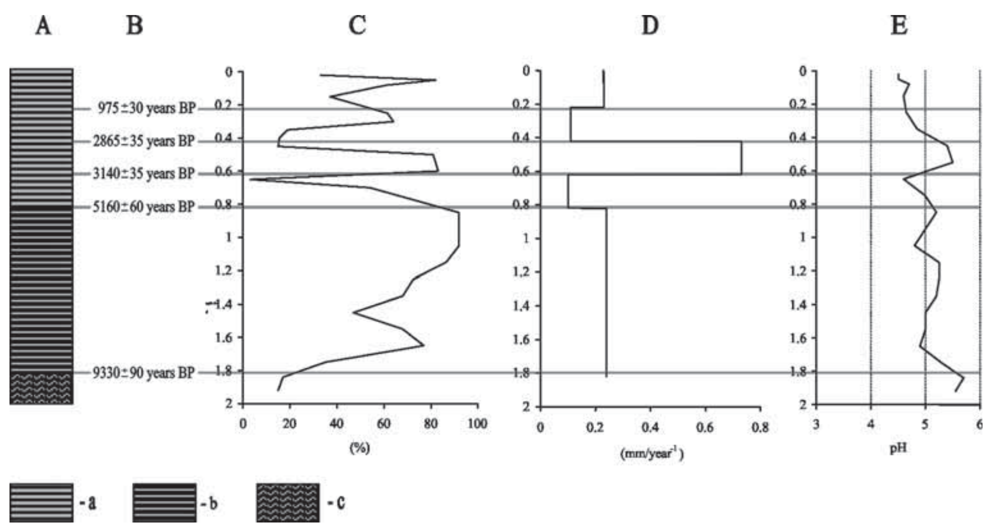

Figure 4. The results of analyses of a section with organic deposits of Zwierzynka River valley bottom (location in Fig. 3)

A – lithological log, B – results of ^{14}C datings (years BP), C – content of organic matter, D – rate of peat sedentation and mineral material growth, E – pH reaction; a – clays with peat, b – sedge peat, c – organic clays with peat

(Forysiak, 2005). Phase I was short-lived (160 years) but, while it lasted, both aeolian and slope processes became activated as well as the alluvial processed increased (Fig. 2). This phase falls on the middle part of SB – II and it could be located in the Bronze I Period. The activation of the above-mentioned processed should be linked to human intervention in central Poland during the Trzciniec Culture or even the Late Neolithic Cultures. Phase I started with the exploration of aeolian systems. During this exploration, the areas of prehistoric industrial exploration moved already to the slopes of river valleys. Three small dunes were formed at that time (3,600 ± 140 and 3,500 ± 140 years BP; see Kamiński, 1984) on the dried bottom of the Moszczenica valley, at Warszyce site, and then slope covers began to form at Wierzbowa site (3,490 ± 50 years; see Kittel and Twardy, 2003), which occupied the lower parts of slopes of small river valleys. Accumulation of overbank deposits and aggradation of valley floors began. As a result of the aggradation, the anabranching channel pattern became activated in the Warta River valley, which has remained on its floor from as early as the Younger Dryas (Forysiak, 2005). In the Zwierzynka valley, phase I corresponds to the deepest pessimum (the depth of 0.65 m) in the diagram showing the organic material content in the peat-bog, which has been linked to the activities of the Trzciniec Culture population (Twardy and Forysiak, in print).

Phases II and III could be correlated with the activities of the Lusatian Culture community, which was much better developed in central Poland (Kaszewski, 1975). Phase II (3,190–2,940 years BP) corresponds to the activities of a population belonging to the early stage of the Lusatian Culture (the so-called Konstantynów Phase). The longer phase III (2,730–2,380 years BP) corresponds to the fully developed Lusatian Culture and its decline. There is a two-hundred-year hiatus occurring in the Bronze IV Period, during which the intensity of aeolian, slope and fluvial processes decreased. This is confirmed by partial regeneration of the peat-bog in the Zwierzynka valley, which is reflected in the increased organic matter content at a depth of 0.5 m (Fig. 4C), the abrupt rise in growth of peats (Fig. 4D) and pH (Fig. 4E). Unlike in Phase I and in the Neolithic, the exploitation of aeolian systems is moved to the end period of Phases II and III. This could have resulted from accelerated water circulation in catchments caused by anthropogenic changes in natural environment and then, in consequence, the search for drier systems. The structure of slope covers formed in Phases II and III became more complicated. The covers consisted of stratified sandy and sand-silty deluvial sediments, i.e., sediments related to slope-wash (3,150 ± 50 years BP at Lutomiersk site; 2,940 ± 50 years BP at Burzenin site; and 2,680 ± 110 years BP at Rogów VII site; see Twardy, 2008). Apart from the above, poorly sorted colluvial sediments formed due to a shallow landslide (2,590 ± 50 years BP at Strońsko site; cf. Twardy and Kittel, 2002) were deposited. There were also deposited tillage diamictons (2,730 ± 50 years BP at Bronów site; cf. Forysiak and Twardy, 2002). These sediments are synchronous with the ploughing in the Neoholocene slope deposits documented and described by Sinkiewicz (1995) in the vicinity of Biskupin. Apart from slopes in the fluvial valleys, dry denudational valleys appearing in them were also active. Their development reflects the shift of prehistoric settlement from fluvial valleys to plains. This is illustrated by parts II and III of Fig. 5. During the period corresponding to the Lusatian Culture, the floors of fluvial valleys in the Łódź region showed the tendency to aggradation (Turkowska, 1988; Forysiak, 2005).

Characteristically, the duration of Phase II (250 years) and Phase III (350 years) was longer than that of Phase I (160 years). At the same time, the interval between them (210 years) was shorter than that between Phases I and II (270 years). This trend increased in the subsequent part of the prehistory.

Between Phases III and IV, there was the awakening of slope and fluvial processes which occurred in the Middle La Tene Period

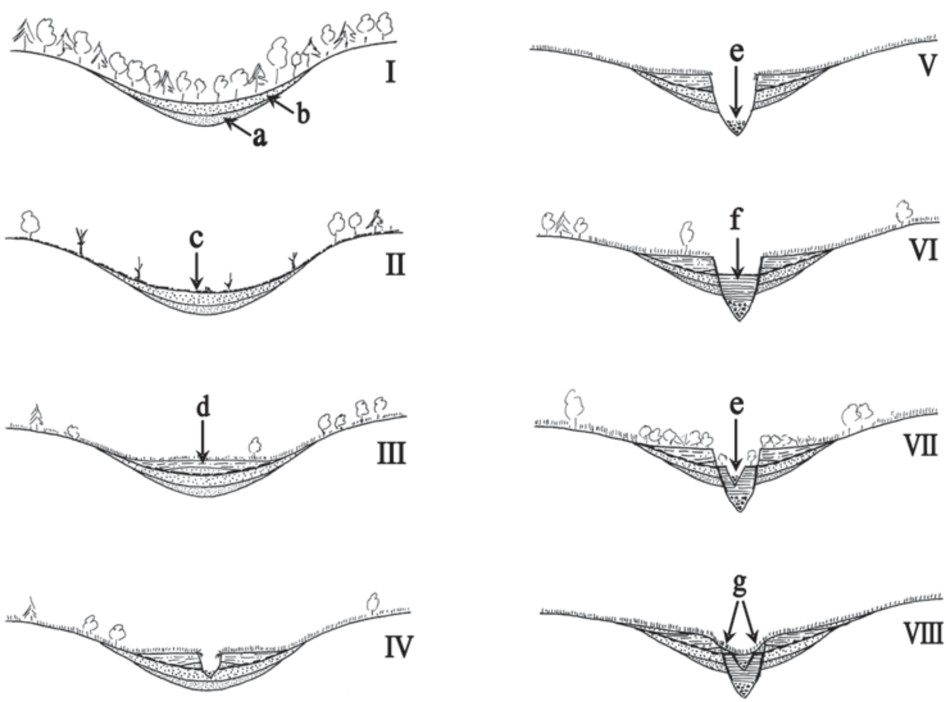

Figure 5. The phases of gully development in the Łódź Plateau

Main sediment series; last glaciation (Vistulian); a – sandy-silty deposits of dry denudational valley infill; Late Glacial: b – fine-laminated sands of dry denudational valley infill; Neoholocene: c – fire horizon, d – deluvial sands and clays, e – stony pavement, f – sands and gravels of gully fills, g – tillage diamictons

of the Iron Age. The anthropogenic denudation may have been spurred by the activities of the East-Pomeranian Culture or the Bell Graves Culture. Importantly, the development of the above-mentioned cultures in central Poland was a short-lived and local phenomenon (Jadczykowa, 1975). The episode in question is characterized by traces of ploughing preserved in tillage diamictons and deluvial sediments. This issue was presented by Twardy (2009). The short hiatus between this episode and Phase IV occurs in the Late La Tene Period, for which there is some scant evidence for the renewed wind activity (at Czarny Las site) and the development of agrotechnical denudation at Ligota site (2,050 ± 50 years; see Twardy, 2008, 2009).

Between the end of the Neolithic and the beginning of the present, there were changes in the location of sites where evidence for Neoholocene relief changes under the human impact was collected. By around 1/3 increased the proportion of sites located in the Łódź Plateau, which were less colonized in the Mesolithic and the Neolithic.

Phase IV was the most distinctive phase in relief transformation among those phases that corresponded to prehistory (1,970–1,490 years BP). The settlement of the Przeworsk Culture, common at that time in central Poland, was extremely dynamic (Kaszewska, 1975; Godłowski, 1985), while the human pressure on the environment was the strongest of all the above-mentioned phases. This was due to both population growth, but also to the qualitative transformation of the living standards among the Przeworsk Culture (increased range of farming land, more advanced farming, the development of prehistoric iron metallurgy based on wood as the power resource, and the flourishing of other types of manufacturing). The settlement of this culture gained access to the high-relief Łódź Plateau area, which led to the acceleration of anthropogenic denudation including the commencement of gully erosion. This trend is documented by dating sediments covered by accumulative fan of the gully in Lipce Reymontowskie (1,830 ± 60 years BP; see Twardy, 2005) and illustrated by part IV of Fig. 5. The slope covers included more coarse deposits, i.e., proluvial sediments, which represent deposits related to gullying (Fig. 6). It can be assumed that there was a periodic linking between slope and channel systems (Twardy et al., 2004b), that is, the sediments activated on slopes were carried to river channels. It was documented that there were floods, which led to the inundation of human settlement from the Roman Period (Kamiński and Moszczyński, 1996), avulsion (Kaminski, 1998), and overbank sediments aggradation. The beginning of a very efficient overbank deposits (flood deposits) accumulation in small fluvial valleys in the Łódź Plateau took place between 1,930 ± 100 years BP (at Wola Branicka site in the Moszczenica valley; see Kamiński and Moszczyński, 1996) and 1,800 ± 80 years BP (Gieczno site in the same valley; see Kamiński, 1993).

The 480-year-long Phase IV was varied in terms of relief transformation dynamics (Fig. 2, symbols a and b). This may have been caused by the changing prevalence of anthropogenic and climate factors. At the beginning of this phase (the Early Roman Period), collectively, the anthropogenic factors (rapid increase in population density in central Poland from 1.5–1.8 person per one square kilometer in 50 AD to 3.3–4.1 per-

Figure 6. Brzeziny I excavation. The buried soil (a)at the base (^{14}C dated at 1590 ± 50 years BP), above the Neoholocene deluvial deposits (b), coarse proluvial (c) deposits of buried gully fill, and structureless tillage diamicton (d) at the top.

Source: Photo by J. Twardy 1997

sons per one square kilometer in 200 AD; see Kurnatowski, 1992) and the climatic ones (heavy rainstorms in the Roman Period; cf. Starkel, 2001, 2002) may have played a significant role. Later, as the impact of the Przeworsk Culture on the environment subsided, the climatic factors (increase in precipitation at the beginning of the Migration Period; cf. Ralska-Jasiewiczowa and Starkel, 1988) gained more importance.

Phase IV ended with the Migration Period when the area of central Poland decreased in population (Łaszczewska, 1975). This was a time of forests and soil regeneration and aeolian and slope processes died down.

The last thousand years is marked by a continuous acceleration of aeolian relief transformation and changes in slopes and river valley bottoms (phases V–VII). Phase V (1,100–720 years BP) corresponds to the activities of the Slavic tribes in the pre-'Piast' dynasty period, which were subsequently organized as the early Polish state. The relief transformation was affected by both the warm and humid climate favourable for farming as well as by the growing human impact. Worth stressing is another bout of heavy rainfalls in the second half of the 11th century AD (Starkel, 2002). The high human factor was determined by a sudden population growth and advances in farming. In the age of mediaeval industrial breakthrough in farming, it became possible to cultivate heavy soils (ploughing aided by a horse using an iron plough), the acreage extended to plains, and the skill of well building enabled human settlement to move away from fluvial valleys. Soil erosion followed, turning into gully erosion and even leading to the formation of soilless areas. These were then modelled by the wind, which led to the creation of young initial dunes (1,100 ± 50 years BP at Leonów site; cf. Twardy, 2008). New aeolian covers were also formed (Fig. 7), which contained a large humus admixture. Similar, synchronous forms of wind activity were also found

Figure 7. Karsznice II excavation. Subatlantic aeolian cover with fossil soil at the bottom, ^{14}C dated at 1,040 ± 50 years BP.

Source: Photo by J. Twardy, 2002

in the Toruń Basin at Rudak site (Jankowski, 2002). The gully erosion was intensive. There was both the deepening of initial gullies, the development of which started in Phase IV (Fig. 5, part V), and the emergence of new forms (940 ± 100 years at Michałów site; cf. Twardy, 1995). The development of river valley bottoms was modified by milling based on energy obtained from the water wheel. This led to the accumulation of fluvial sediments in mill ponds (Kamiński, 1993; Kobojek, 2009). The bottom of a small Zwierzynka valley stabilized, which was confirmed by the renewed peat growth at a depth of 0.22 m, dated by ^{14}C at 975 ± 30 years BP (Fig. 4). A short-term (about 100 years) slowdown in the relief transformation, dated at the Middle Mediaeval Ages, was caused by a relative climate stability, a slightly less frequent flooding in the Odra (Dubicki et al., 1999) and Vistula river basins (Starkel, 2001) and the stability of settlement.

Phase VI (600–370 years BP) falls on the heyday of Poland's feudal state and the Little Ice Age. During this phase, there was a further development of the gullies, that is, the lengthening of major forms, the growth of side branches, and accumulation of proluvial sediments on gullies' floors. Completely new, smaller erosional dissections and cart road cuts (holwegs) emerged. Wide and flat accumulation floors of the biggest gullies were cut again (Fig. 5, part VII). It can be assumed that the development of gully erosion was reflected in fluvial processes and river valley bottoms aggradation, although there is no direct evidence for this in the Łódź region. Alluvial sediments from this phase may have been accumulated in the basin of old mill ponds. They may also have been part of overbank sediments. The aeolian processes were activated locally on a larger scale by the "Olęder" settlement (Forysiak et al., 2007), which cultivated intensively less fertile areas, including aeolian covers. The stability after Phase VI, which lasted about 150 years (17th through 18th century), was most probably caused by anthropogenic reasons (i.e., the Swedish invasion, the economic slump during the partitions of Poland, etc.)

Phase VII (the present) has been conventionally defined as related to the last 200 years. Rather than being a result of low intensity of transformation in relief, the absence of sediment dating from this phase (Fig. 2) is connected with limitations of the 14C method in the case of geological sediments younger than 200 years BP. Phase VII corresponds to the industry development in Łódź. It is marked by intensive deforestation in central Poland, which peaked before the World War II. There is evidence of the primacy of tillage erosion over slope-wash. The evidence comes from both very young geological sections (younger than 200 years BP) and from field experiments. Extensive agrotechnical denudation contributed to relief transformation. Small negative landforms were filled with tillage diamictons, while larger positive landforms became truncated. This also applied to certain parts of old gullies, which underwent rehabilitation. Their sections were profoundly changed due to many centuries of ploughing (Fig. 5, part VIII). The aeolian processes were initiated by inappropriate land management. The fluvial processes were seriously affected by a gradual removal of the so-called 'small retention', which lasted continuously throughout the 20th century (Kobojek, 2009). Raising embankments for big rivers, such as the Warta River, involved interfering with the hydrological systems and rerouting waters into a wide, shallow and meandering (or straight) channel. This led to the destruction of a unique anabranching channel pattern of this river (Forysiak, 2005) and the narrowing of a zone actively modelled by fluvial processes down to only a few hundred metres (see Twardy and Klimek, 2008 for a more detailed discussion).

CONCLUSIONS

The Neoholocene relief transformation in central Poland took place during seven phases, 160 to 480 years long, and during four less remarkable and short-term episodes. It consisted in **comprehensive** changes recorded **at the same time** in aeolian, slope and fluvial sediments. This indicates that the anthropogenic factor played a significant role in those changes. Fig. 2 suggests that the Neoholocene phases of accelerated relief transformation became increasingly longer, while the intervals in between got shorter. Over the last 5,000 years, the periods during which relief transformation accelerated took in total 51% of the time, while during the last millennium they lasted as much as 77% of the time. In author's opinion, the sequence of phases and episodes does not reflect any climatic trend. Instead, it is a fairly accurate reflection of a population growth and density in central Poland and the succession of prehistoric cultures. The periods of exceptionally intensive relief transformation correlate with phases of dynamic population growth and population density in the Roman Period of the Iron Age (Phase IV) and in the early mediaeval times (Phase V). In addition, they coincided with the progress of civilization in the broad sense of this word (e.g., the development of farming and various forms of manufacturing, which consumed an increasing amount of energy resources). This led to the "pulsating" nature of the relief transformation process, mimicking the rhythm of social and economic changes rather than climate changes. However, one should bear in mind that the Neoholocene climatic "crises" may have enhanced the relief transformation (Starkel, 2005) and thus may have made the records in geological sediments clearer and more easily found.

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Paper first received: April 2011
In final form: August 2011