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## FIELD SURVAY AND MATERIALS

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# LIDAR, BARROWS AND AEOLIAN HILLOCKS. BETWEEN THEORY AND PRACTICE

**ABSTRACT**

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The article discusses the results of research that was done on an aeolian hillock in the Załęcze Wielkie, Wieluń district. It was discovered in 2011 and initially considered to be the remains of a barrow which was suggested by the results of laser scanning (LiDAR). Archaeological and geological research, however, univocally state the natural origin of the hillock. The authors emphasize the ambiguity of the data obtained from the laser scanning. Research extending beyond LiDAR itself must be a necessary element to acknowledge the anthropomorphic origin of various forms of hillocks.

Keywords: LiDAR, barrow, aeolian hillock, Załęcze Wielkie
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Until recently, wooded areas, only occasionally received interest from archaeologists, who are involved in large-scale excavations. This is obviously connected with the developed vegetation cover which is almost impenetrable for archaeological perception. This limitation is the reason that nearly 30% of our country is proverbial *terra incognita*. Its attractiveness is even greater because in many cases an exclusion from the regular agricul-

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tural economy may be conductive to the preservation of features of visible terrain form such as for instance barrows. In recent years there has been a systematic breaking of the "forest barrier" thanks to modern technology such, as the use of laser scanning (Light Detection and Ranging, LiDAR; cf.: Deveraux et al. 2005; White 2013). The opportunity to avail of the national data, the use of the ISOK (Information System of the State Protection) programme and its low costs, make LiDAR a favourable tool being used more and more by archaeologists. Therefore, it is not surprising that the media, especially the electronic media (e.g. archeowiesci.pl) are regularly providing information about spectacular discoveries of special types of features, i.e. hillocks of regular (round or oval) plan. In such reports they are defined as "barrows". The aim of the present article is to attempt to draw attention to the fact that as in the case of classic aerophotography the relation between the identification of the feature and its functional interpretation is quite complicated and must go beyond the use of laser scanning itself (cf. Rączkowski 2002). Further on in the discussion we would like to draw attention to two levels, i.e. practical and theoretical, of the issue under consideration. In the case of the first part, we will use an example of a hillock identified and verified in Załęcze Wielkie.

The aforementioned village is located in southern Łódź voivodeship within the Warta river arc of Załęcze. What is characteristic of this area landscape is a change of the Warta river valley route — from a western to eastern direction. According to Krzemiński (1965) the Warta river bow of Załęcze is part of the Warta river gap of Wieluń where the valley crosses the formations of Jurassic substratum and leaves the area of the Wieluń Upland coming, in a distance of *ca* 10 km to the north of Załęcze Wielkie into the area of the Złoczew Basin. In the bow zone the valley has distinct morphogenesis levels connected with fluvial and glaciofluvial processes which shaped the main forms of the area after the Warta Glaciation (Saalian) (Krzemiński 1965, Klatkowa 1972, Krzemiński *et al.* 1993). In the zone of the bow of Załęcze Krzemiński (1965) is an area of middle terrace, situated immediately below the Holocene valley floor, and high terrace. Krzemiński connected their formation with the Vistulian glaciation (Weichselian). The located areas above were built of fluvioglacial sands and were defined as a sander terrace formed at the decline of the Warta glaciation. In the scheme of development of river valleys in the Lodz region (Turkowska 1988, 2006; Forysiak 2005) the sander terrace (of Saalian) is defined as the highest (Fig. 1), the high terrace formed in the Plenivistulian is located lower, whereas another one, which occurred in the Late Vistulian, is a low terrace (according to Krzemiński — middle terrace). The authors of the Detailed Geological Map of Poland (in scale 1:50.000) accepted similar norms for distinguishing floodplain terraces (Haisig, Wilanowski 1997).

What is also important for the present considerations is the data referring to the cultural landscape features of the Załęcze area, and more broadly — the Wieluń district (cf. Abramek 1986). There is no need to outline the complete history of the discussed region's settlement, it is however, worth drawing attention to the most essential element for the present reasoning, that is the occurrence of necropoles consisting of barrows. At present,


**Fig. 1**. Geomorphological sketch of a fragment of the Warta river valley in the arc of Załęcze (according to Krzemiński 1965, slightly modified). Key: 1 — morainic plateau, 2 — the highest (sander) terrace, 3 — high terrace, 4 — low (middle) terrace, 5 — the valley floor, 6 — slopes, 7 — denudation valleys, 8 — dingle, 9 — riverbeds, 10 — location of the investigated aeolian hillock

six sites of the discussed type are known from the Wieluń district. The most famous include cemeteries of the Trzciniec culture in Strugi (Wójcikowa, Makiewicz 1969) and Okalew (Abramek 1971), "princes' graves" of the Przeworsk culture from Przywóz (Błaszczyk 1975), and features connected with the early Middle Ages from the site of Krzętle (Wiklak 1972). It is worth noting that the cemeteries at Przywóz and Strugi are located in the vicinity of Załęcze Wielkie (accordingly: *ca* 5 km and 8 km). Therefore, there is no exaggeration in saying that the hitherto state of research and knowledge on the durability of a round hillock idea should lead to the discovery of other barrows. Relevant explorations have been carried out, among others, by Waldemar Golec from the Museum of Wieluń Land.

Hillocks from Załęcze Wielkie are located within the low floodplain terrace, about 250 m to the east of the contemporary Warta riverbed. The surface of this fragment of terrace is situated about 172.0–174.0 m above sea level and is diversified by palaeochannel depressions, elongated and weakly elevated elements of an old valley floor. In addition the low terrace is formed of loose sand with gravel admixture (Haisig, Wilanowski 1997). T. Krzemiński (1965) in his study of lithology of this valley, distinguished a level surface series of sand with gravel, and below lay a series of silty sand.

In the first stage the features were inspected and the results of laser scanning were conducted within the earlier mentioned ISOK programme. In both cases the results were extremely encouraging and highlighted several objects, at least, with a characteristic high regularity of form (Fig. 2). At this stage two preliminary hypotheses were formulated. According to the first, the features under consideration are formed by the remains of a barrow cemetery, possibly connected with the Trzciniec culture or the early Middle Ages. According to the alternative hypothesis they belonged to aeolian hillocks. It is worth commenting further on the latter subject.

Aeolian hillocks belong to the smallest forms formed as a result of an aeolian accumulation. They are forms commonly found on areas where the relief was formed in the Holocene under strong human impact (Twardy 2008). They diversify the landscape of the Late Vistulian and Holocene aeolian covers, as well as dunes of different ages. According to the classification presented by Migoń (2005) aeolian hillocks correspond to phytogenic aeolian hillocks, which belong to a group of so-called “strained” dunes, that are conditioned by vegetation dunes.

The discussed forms mostly do not reach large sizes, of a few or several metres. Their height closes between 1 and 2 m; the smallest are merely several dozen centimetres. In central Poland objects higher than 2–3 m are rarities. Therefore, in the aeolian hillocks, in most cases, several cubic meter of aeolian deposits are accumulated. Forms of the discussed structures quite often resemble a loaf of bread (Twardy 2008); they are most often built on a plan of a weakly elongated ellipsis, and the ratio of long to short axis oscillates around 2 (Fig. 3). Shapes of the hillocks may also be very irregular — such forms were named “sand drifts” by Dylikowa (1958). They also include structures built on the plan of a circle. In addition, the diversity of the orientation of the aeolian hillock axes may be a function of air flow stability. In the case of constant air flow the elongation becomes more intense, and the ratio of the hillock axis length increases and reaches about 4 (cf. Fig. 3, part B) to transform the hillock into a longitudinal dune with an axis length ratio of *ca* 8–9. On the other hand, more circular shapes of hillocks can be interpreted as a derivate of the strong differentiation of air flow. The slope gradient of the discussed forms reaches from a few to several degrees. Hitherto, there have been no slopes of aeolian hillocks with gradients similar to leeward slopes of dunes, that is oscillating around 30 degrees, registered which proves a lack of their mobility. In other words, in contrast to dunes they are not independent migrating forms. What influences the formation of most eaolian hillocks is

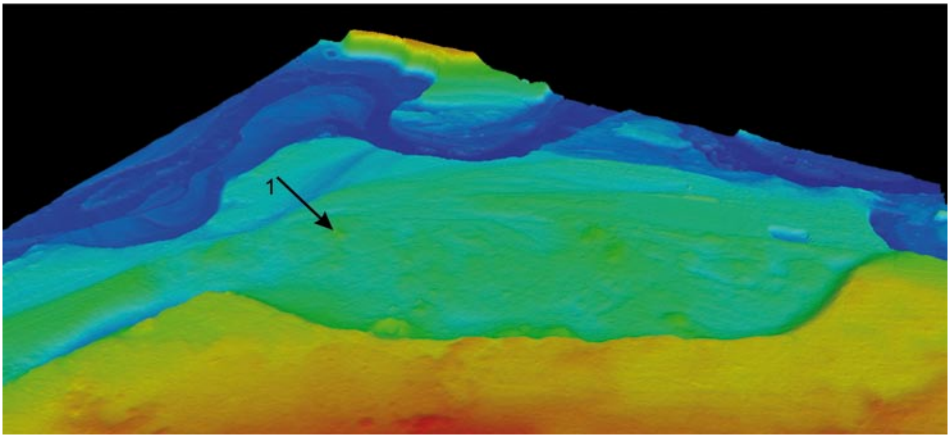


**Fig. 2**. Załęcze Wielkie. A model of the site area made on the grounds of laser scanning. The arrow indicates feature no. 1

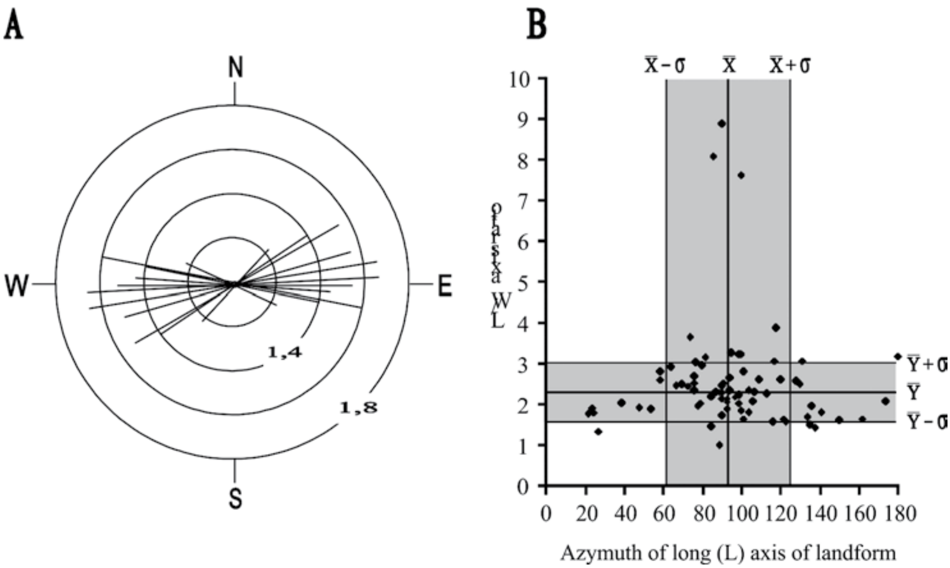


**Fig. 3**. Relations between aeolian hillocks shapes and the directions of dune-forming winds at the sites of Karsznice (A) and Małe Mystkowice (B) after: Twardy 2008. Explanations to part A: circles show the ratio of the long axis to short axis length of the aeolian hillocks


**Fig. 4**. Exposure in the aeolian hillock in Załęcze Wielkie and the results of lithological research. Key: A — an outcrop with location of the samples (P1-P6); B — granulometric indicators: $M_z$ _average diameter, $\delta_I$ _standard deflection, $Sk_I$ — skewness, $K_g$ — kurtosis; C — quartz grains processing: RM — round, mat grains, M — transitional, EL — shiny, C — broken and unprocessed, D — content of organic carbon (%)

a sharp decrease in the speed of wind which has been transporting inorganic and organic deposits in zones of various obstacles, mainly vegetation barriers. Their role might be played even by clumps of grass giving rise to initially small sandy “nebkha hillocks” (Szczypek 1994 a; 1994b). P. Migoń (2005) in this context lists European marram grass (*Ammophilia arenaria*), grey hair-grass (*Corynephorus canescens*), and sea sandwort (*Honckeria peploides*). Among other psammophilous plants attention is paid (Szczypek 1994b; Pełka-Gościniak 2000) to long-leaved violet willow (*Salix acutifolia*) thickets, and tamarix bushes (Mycielska-Dowgiałło 2001). It is evident that young trees, especially these with low-slung treetops such as birch, pine or juniper may have acted as obstacles to the wind (Kobendza, Kobendza 1958).

Environmental conditions are conductive to the formation of aeolian hillocks. What is important is the low relief, there are no obstacles in free wind activity and lithological features. The substratum on which aeolian hillocks are formed must be sandy; what is especially important is the percentage of very fine sands and fine sands forming sand dunes. In central Poland the mentioned conditions correspond to: vast, monotonous Vistulian fluvial terraces, Wartian (Saalian) glaciofluvial plains (built of coarse sands), as well as Vistulian aeolian covers and dunes. Whereas, what is a difficulty for the development of aeolian hillocks is clay, gravelly and stony as well as a loamy substratum and a high relief with distinct convex and concave landforms, situated transversely to the predominant air flow.

The chronology of the aeolian hillocks’ formation is poorly recognized. Hitherto, the most effort has been put into investigating the age of more typical and considerable dune forms. However, both were probably formed in the Late Vistulian and in the Holocene under strong human impact (Twardy 2008). They are always formed nowadays in areas with good anemological conditions (e.g. in a zone of the sea coast), and wherever sandy substratum is exposed (Wojtanowicz 1999).

Returning to Załęcze Wielkie, it should be emphasized that terrain works were conducted in November 2013. They were connected with a sondage trench cutting object 1 (Fig. 2). a clearly visible form on the site, it is 4 m in diameter and *ca* 0.8 m high. The trench itself was a form of a segment covering 1/8 of the object area. It should also be added that no cultural content that indicates its connection with human activity has been found.

The outcrop shows a small sandy aeolian hillock and its substratum (Fig. 4). The rock bed is formed of a sandy series. A sample collected from this part of the profile contains fine sands with quite good sediment sorting ($\delta_I$ = 0.71), with a minimum content of organic carbon, without calcium carbonate (Fig. 4, B, D). Another sample evidences sand with silt of very weak sorting ($\delta_I$ = 1.50) what results from a larger share of silty fraction. This series was deposited in a fluvial environment, the results of quartz abrasion show that it might have formed in the Vistulian. There is a discontinuous humic horizon of buried soil above, which is built of fine sand with a silt admixture and increased share of carbon (C org. = 1.19%). Above the buried soil there are formations of aeolian hillocks. This series is of a massive structure, without a visible sediment structure but the collected samples indicate the diversified grain size composition (Fig. 4). Directly above the soil level, are well sorted fine sands with an inconsiderable share of organic carbon. Above the fine sands, very weakly sorted sands with silts with a higher share of organic admixtures were registered. Such textural features suggest that material drifted from an exposed area of the low terrace to the hillock, and the aeolian transport could have been short because the source material was not transformed.

Aeolian deposits from which the hillock in Załęcze Wielkie is built are generally similar to features of the Holocene aeolian sediments recognized on other sites. They are characteristic of the smallest mean size parameters ($M_z$) corresponding to fractions of very fine sand which evidences the relatively low wind speeds which led to aeolian accumulation. As for the Vistulian dunes, the average wind speed reached 6–6.5 $m \cdot s^{-1}$, and gusting up to 5–7 $m \cdot s^{-1}$ , at present it is estimated at 2.5–3 $m \cdot s^{-1,}$ gusting up to 5–7 $m \cdot s^{-1}$ (Krajewski 1977). Another feature of the discussed aeolian accumulation is the higher than usual organic carbon admixture in the form of humus particles frequently reaching over 1%. This demonstrates the blowing out of the loose and dried up accumulative (humus) horizon of soil. In comparison with other investigated cases where the concentration of organic carbon reaches 1.65–2.3%, the horizon of buried soil beneath the aeolian hillock was exceptionally poor (C org. = 1.19%, sample P4). Only in the case of sample P3 was the material collected from beneath the soil, there was a drop in organic carbon content to 0.4%. What is untypical of aeolian sediments is the very poor sorting of deposits reaching as high as 1.42 phi (cf. fig. 4B). It may be connected with features of the source material, which are similarly poorly sorted ($\delta_I$ = 1.50 in sample P5). This evidences a short aeolian transport and a lack of essential transformation of textual features of deflated deposits. The very clear positive skewness of the deposit ($Sk_I$ do = +0.45) indicates the occurrence of important, 10–20% silty admixture to the sand fraction. The accumulation of a large amount of silt and humus confirms the relatively low wind speed, otherwise silt and humus would be dispersed further and to a lesser degree they would take part in the appearance of the investigated form.

The age of the aeolian hillock in Załęcze Wielkie is testified by a result of $^{14}C$ dating which is 10 ±50 BC (MKL-2111). It was obtained from a trunk of undetermined species of tree which grew on the buried soil near the hillock (cf. Fig. 4). It was probably an obstacle for wind and initiated aeolian accumulation, the effect of which is the investigated form. The result of dating formally locates the beginning of the hillock formation to 1940 AD, it should however be remembered that indications younger than 200 BP should be taken with caution. These kind of results are connected with the beginnings of the so-called industrial era that brought i.a. important disturbances in the carbon cycle in the environment. In this situation, it should be cautiously assumed that the aeolian hillock in Załęcze Wielkie occurred at the end of the 19th century or in the first half of the 20th century. In Poland at that time processes of overpopulation of the country took place, and in connection to this clearings spread, and also the weakest sandy soils were cultivated. It is most likely that, in the period under consideration the forest covering the low terrace of the Warta river, in the area of Załęcze Wielkie, was grubbed out, and the sandy substratum susceptible to winds was exposed. After a short period of agricultural use of the area, microrelief of the terrace was inconsiderably transformed as a result of wind activity. This situation is documented in an image on an archival map *Karte des Westlichen Russlands*, sheet C37 Wieluń (scale 1: 100 000) published in 1897. The extent of the forest cover included, at that time, only the northern part of the bend of the Warta river. In the southern part of the Warta river bow a term thicket/wasteland was used which can indicate both freshly cleared areas, and areas becoming overgrown with bushes, i.e. excluded from cultivation a short time earlier. A suggestion about the relatively short-time episode of deforestation is confirmed in other cartographic materials. Both the older (e.g. *The Topographical Map of the Polish Kingdom* in scale 1: 126 000), and younger than 1897 (e.g. a tactical map by the Military Institute of Geography in scale 1:100 000, sheet P 44 S 27 Wieluń) afforestation documents of the aeolian hillock area.

There is, of course, a lot of evidence for the occurrence of processes similar to that described above, which dated to the Middle Ages and modern times. The evidence was collected i.a. in Karsznice, Stanisławów, Leonów, Bród (Twardy 2008), on a multicultural site in Polesie (Twardy 2008; Twardy, Forysiak 2011), and on sites of Teodory and Grabiszew (Wiśniewska, Twardy, *in press*). A review of literature results show that at the beginning and middle of the 20th century in central Poland active aeolian processes were observed as well as the dynamic development of various landforms which were connected with them (Lencewicz, Małkowski 1953). For example, at the beginning of the 20th century a dune in Aleksandrów Łódzki was still developing (Kossman 1930), whereas in the 1950s dunes of the Kampinos Forest were active (Kobendza, Kobendza 1958). Thus, processes that determined the appearance of the aeolian hillock in Załęcze Wielkie should be connected with the youngest, covering the latest 200 years, the VIIth phase of relief transformation (Twardy 2008; 2012; Twardy, Klimek 2008).

It is worth summarizing this part of the argument. Firstly, the aeolian hillock in Załęcze Wielkie, despite its regular, round shape, is a geomorphological natural landform formed as a result of aeolian accumulation in a zone of vegetal barriers. Secondly, morphological criteria are insufficient to decide on a connection of such features with barrow cemeteries. It is necessary to study the forms of geological structures, combined with grain size composition, laboratory analyses and the analyses of the absolute age of the geological formations ($^{14}C$ and dendrochronological analyses). Thirdly, to preliminarily distinguish barrows from similar natural forms, for instance aeolian hillocks, it is important to analyse the substratum lithology. The natural genesis of convex forms is most probable in the case of sandy substratum occurring with fluvial terraces, Late Vistulian aeolian covers and dunes as well as fluvioglacial and sander plains. As far as clay substratum (moraine plains) is concerned, the autonomous formation of hillocks is less probable.

As it was stated above, the results of laser scanning themselves are not sufficient criteria to ascribe a function of barrows to regular, convex landforms. However, it seems that a possibility of wrong identification of barrows does not result only from their similarity to certain forms of aeolian hillocks. It is also a derivate of “archaeological” conceptualisation of directions and forms of cultural landscape transformations. Its present-day condition can be described for instance with the use of a model of palimpsest (Bailey 2007; Rzepecki 2014) emphasizing the significance of long-lasting and overlapping interactions between human activity and natural factors. Most often a vector of these interactions is unfavourable for maintaining the oldest cultural content, and in optics of our science they occur burdened by serious deformations to which they were subjected at successive stages of functioning (cf. e.g. Urbańczyk 1986; Coveney, Highfield 1990, 144–145). An awareness of the constant decomposition of sources that may result in their complete destruction is described with the use of the arrow of time (Ascher 1968; Coveney, Highfield 1990, 144–145). Let us remember the conception of origins from the use of the second law of thermodynamics which says that irreversible processes result in the increase in entropy. This model seemingly adequately describes the transformations of archaeological sources; pottery sherds do not display tendencies to spontaneous reconstruct vessels, and, what is more, with time the degree of its defragmentation (entropy) is increasing. At the same time, the information they contain is subjected to dissipation.

However, the above characterized approach is quite one-dimensional. As a matter of fact, it explicitly assumes that the only factor arranging the chaos is a human, and human intervention is a necessary factor for the occurrence of any regular forms of features differing from the background (for instance geomophological background). Even observations disturbing this picture can be rationalised through a reference to the influence of the arrow of time — processes of unavoidable degradation of archaeological sources. However, in actual fact, natural factors are also able to “organize” matter and therefore imitate human activity (e.g. Schiffer 1983). The example of the hillock from Załęcze leaves no doubt in this respect.

There occurs another problem. If in conditions of deforestation, wind activity sometimes results in the occurrence of aeolian hillocks several metres long and 2–3 m high, a question will be justified how these processes were conceptualized in the past. After all, it can be thought that such a “spontaneous” occurrence of barrow — sacred mountain imitation could have aroused interest and inspire observers of these events. Moreover, strictly source-based problems arise; in how many cases were barrows actually anthropogenically transformed forms of eaolian hillocks. And furthermore, how many barrows without burials that were interpreted as cenotaphs were in fact only aeolian landforms. Answers to these questions would go beyond the convention of the present text, but they, however, have to be still present in the course of estimations of both contemporary discoveries and these known from literature. Archaeologists entering the forest areas using, among others, LiDAR will still bring such dilemmas.

## References

Abramek B. 1971. Cmentarzysko kurhanowe kultury trzcinieckiej w Okalewie, pow. Wieluń. Sprawozdanie za lata 1966–1968. *Sprawozdania Archeologiczne* 23, 67–77.

Abramek B. 1986. Pradziejowe osadnictwo na terenie Załęczańskiego Parku Krajobrazowego. *Acta Universitatis Lodziensis, Folia Sozologica* 2, 69–89.

Ascher R. 1968. Time's arrow and the archaeology of a contemporary community. In K. C. Chang (ed.), *Settlement archaeology*. Palo Alto: National Press Books.

Bailey G. 2007. Time Perspectives, Palimpsests and the Archaeology of Time. *Journal of Anthropological Archaeology* 26, 198–223.

Błaszczyk Z. 1975. Rozwój społeczno-gospodarczy Polski środkowej w okresie rzymskim. *Prace i Materiały Muzeum Archeologicznego i Etnograficznego w Łodzi. Seria Archeologiczna* 22, 255–269.

Coveney P. and Highfield R. 1990. *Strzałka czasu*. Poznań: Zysk i S-ka.

Devereux B. J., Amable G., Crow P. and Cliff A. 2005. The potential of airborne lidar for detection of archaeological features under woodland canopies. *Antiquity* 79, 648–660.

Dylikowa A. 1958. Próba wyróżnienia faz rozwoju wydm w okolicach Łodzi. *Acta Geographica Lodziensia* 8, 233–268.

Forysiak J. 2005. Rozwój doliny Warty między Burzeninem i Dobrowem po zlodowaceniu Warty. *Acta Geographica Lodziensia* 90, 1–116.

Forysiak J. and Twardy J., 2012. Development of human-inducted geomorphological processes in the vicinity of peatlands of Central Poland. In J. Forysiak, L. Kucharski and M. Ziułkiewicz (eds.), *Peatland in semi-natural landscape — their transformation and possibility of protection*. Poznań: Bogucki Wydawnictwo Naukowe, 85–99.

Haisig J. and Wilanowski S. 1997. *Szczegółowa Mapa Geologiczna Polski w skali 1:50 000, arkusz Rudniki*. PIG Warszawa.

Klatkowa H. 1972. Paleogeografia Wyżyny Łódzkiej i obszarów sąsiednich podczas zlodowacenia warciańskiego. *Acta Geographica Lodziensia* 28, 1–220.

Kobendza J., Kobendza R. 1958. Rozwiewanie wydm Puszczy Kampinoskiej. In R. Galon (ed.), *Wydmy śródlądowe Polski* 1. Warszawa: Państwowe Wydawnictwo Naukowe, 95–170.

Kossman O. 1930. *O wydmie aleksandrowskiej*. Łódź: Wydawnictwo Towarzystwa Przyrodniczego im. St. Staszica w Łodzi.

Krajewski K. 1977. Późnoplejstoceńskie i holoceńskie procesy wydmotwórcze w pradolinie warszawsko-berlińskiej w widłach Warty i Neru. *Acta Geographica Lodziensia* 39, 1–87.

Krzemiński T. 1965. Przełom doliny Warty przez Wyżynę Wieluńską. *Acta Geographica Lodziensia* 21, 1–95.

Krzemiński T., Świerczewska A. and Uchman J. 1993. Udział skał lokalnych w utworach wodnolodowcowych środkowej Polski. *Acta Geographica Lodziensia* 65, 185–204.

Migoń P. 2005. *Geomorfologia*. Warszawa: Wydawnictwo Naukowe PWN.

Lencewicz S. and Małkowski S. 1953. *Wydmy śródlądowe Polski*. Warszawa: Wydawnictwa Geologiczne.

Mycielska-Dowgiałło E. 2001. Wpływ warunków klimatycznych na cechy strukturalne i teksturalne osadów mineralnych. In A. Karczewski and Z. Zwoliński (eds.), *Funkcjonowanie geosystemów w zróżnicowanych warunkach morfoklimatycznych — monitoring, ochrona, edukacja*. Poznań: Bogucki Wydawnictwo Naukowe, 377–394.

Pełka-Gościniak J. 2000. Development of aeolian relief in areas transformed by human impact (a case study of Bukowno neighbourhood — eastern part of Silesian Upland). In R. Dulias and J. Pełka-Gościniak (eds.), *Aeolian processes in different landscape zones*. Sosnowiec: Uniwersytet Śląski SGP, 129–142.

Rzepecki S. 2014 Palimpsest, time perspectivism and megaliths. *Sprawozdania Archeologiczne* 66, 273–291.

Schiffer M. B. 1983. Toward the Identification of Formation Processes. *American Antiquity* 48, 675–706.

Schiffer M. B. 1987. *Formation Processes of the Archeological Record*. Albuquerque: University of New Mexico Press.

Szczypek T. 1994a. Inicjalne kopczyki piaszczyste typu "nebkha". In B. Nowaczyk and T. Szczypek (eds.), *Vistuliańsko-holoceńskie zjawiska i procesy eoliczne (wybrane zagadnienia)*. Poznań: Wydawnictwo SGP, 89–98.

Szczypek T. 1994b. Pasowość rzeźby deflacyjno-akumulacyjnej (na przykładzie piaskowni w Bukownie na Wyżynie Śląskiej*)*. In B. Nowaczyk and T. Szczypek (eds.), *Vistuliańsko-holoceńskie zjawiska i procesy eoliczne (wybrane zagadnienia)*. Poznań: Wydawnictwo SGP, 77–88.

Turkowska K. 1988. Rozwój dolin rzecznych na Wyżynie Łódzkiej w późnym czwartorzędzie. *Acta Geographica Lodziensia* 57, 1–157.

Turkowska K. 2006. *Geomorfologia Regionu Łódzkiego*. Łódź: Wydawnictwo Uniwersytetu Łódzkiego.

Twardy J. 2008. *Transformacja rzeźby centralnej części Polski Środkowej w warunkach antropopresji*. Łódź: Wydawnictwo Uniwersytetu Łódzkiego.

Twardy J. 2012. Influence of man and climate changes on relief and geological structure transformation in central Poland since the Neolithic. *Geographia Polonica* 84 (*special issue* 1), 163–178.

Twardy J. and Forysiak J. 2011. Charakterystyka środowiska geograficznego okolic stanowiska archeologicznego Polesie 1 oraz neoholoceńskie zmiany jego budowy geologicznej i rzeźby. In J. Górski, P. Makarowicz and A. Wawrusiewicz, *Osady i cmentarzyska społeczności trzcinieckiego kręgu kulturowego w Polesiu, stanowisko 1, woj. Łódzkie* 1 (= *Spatium Archaeologicum* 2). Łódź: Instytut Archeologii Uniwersytetu Łódzkiego, Fundacja Uniwersytetu Łódzkiego, 227–250.

Twardy J. and Klimek K. 2008. Współczesna ewolucja strefy staroglacjalnej Niżu Polskiego. In L. Starkel, A. Kostrzewski, A. Kotarba and K. Krzemień (eds.), *Współczesne przemiany rzeźby Polski*. Kraków: IGiGP UJ, 229–270.

Urbańczyk P. 1986. Formowanie się układów stratyfikacyjnych jako proces źródłoznawczy. In W. Hensel, G. Donato and S. Tabaczyński (eds.), *Teoria i praktyka badań archeologicznych*. Wrocław: Ossolineum, 184–245.

White D.A. 2013 *LIDAR, Point Cloud, and Their Archaeological Applications*. In D. C. Comer and M. J. Harrower (eds.), *Harrower Mapping Archaeological Landscapes from Space*. New York: Springer, 175–186.

Wiklak H. 1972. Cmentarzysko kurhanowe w Krzętlach, pow. wieluńskim. *Prace i Materiały Muzeum Archeologicznego i Etnograficznego w Łodzi. Seria Archeologiczna* 19, 249–263.

Wojtanowicz J. 1999. Procesy eoliczne. In L. Starkel (ed.), *Geografia Polski. Środowisko przyrodnicze*. Warszawa: Państwowe Wydawnictwo Naukowe, 410–413.

Wójcikowa E. and Makiewicz T. 1969. Sprawozdanie z badań kurhanów kultury trzcinieckiej w Strugach, pow. Wieluń. *Sprawozdania Archeologiczne* 20, 77–81.