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The loess section in Wąchock as the key site of Vistulian loesses and palaeosols in the Holy Cross Mountains (Poland)

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The Wąchock section (N part of the Holy Cross Mountains) is bipartite, with a sub-loess lower part and a loess upper part. The sub-loess part lying on Lower Triassic sandstones includes fluvial, glacial and ice-dammed lake deposits, TL-dated at 352 ky BP to 157 ±23 ky BP. They represent the Mazovian (MIS 11) (Zbójnian?, MIS 9?) Interglacial and the Odranian Glaciation (MIS 6). The upper part comprises loesses intercalated with palaeosols, which reach a total thickness of 9 m and have TL ages at 148 ±23 ky BP to 15.8 ±8 ky BP. This part of the succession begins with horizon B of a brown soil from the Eemian Interglacial (MIS 5e) with an interstadial black soil from the oldest Vistulian (MIS 5c). Four younger loess horizons from the middle and younger Vistulian occur above; loesses with arctic and tundra palaeosols correspond to younger isotope stages (MIS 5b–MIS 2). The loess and palaeosol horizons distinguished in Wąchock were correlated with loess sections in Poland (Zwierzyniec and Polanów Samborzecki) and western Ukraine (Kolodiiv 3), showing large similarities of both loesses and palaeosols. Due to this, the Wąchock site is proposed as a one of key sections for Vistulian loess sequences not only in the Holy Cross Mts. region but also in Central Europe. Palaeomagnetic studies of the Wąchock loesses have registered palaeomagnetic inclinations with values lower than the average values expected in this locality (63°).

Key words: East-Central Europe, loess stratigraphy, soil complexes, TL-dating, palaeomagnetism.

INTRODUCTION

Among terrestrial deposits, loess is of great importance for palaeogeographical studies, being a carrier of rich palaeoclimatic and palaeoenvironmental data, which often cover the whole Pleistocene. The basic record of palaeoenvironmental changes is reflected in loess-palaeosoil sequences noted in exposures (Kemp, 2001; Jary, 2007). Dust accumulation took place in a cold and dry climate (glacial, stadial), whereas soils developed under warm and humid climatic conditions (interglacial, interstadial; Jahn, 1950). Based on multi-proxy studies of loess-palaeosoil sequences, detailed stratigraphic schemes were proposed and successfully correlated with the deep-sea core data (e.g., Kukla, 1977; Maruszczak, 1991, 2001; Jary, 2007; Łanczont and Bogutsky, 2007). Loess profiles also store data on the intensity of accumulation processes (Fedorowicz and Łanczont, 2007), conditions of soil development (Łanczont and Bogutsky, 2007; Łącka et al., 2007; Nawrocki et al., 2007), wind direction and source of the material (Chlebowski and Lindner, 1975, 1992; Racinowski, 2007; Bradák et al. 2018), as well as on the development of permafrost processes (Jersak, 1975; Chlebowski and Lindner, 1989; Jary, 2009) and others. Due to its location in the northern zone of loess occurrence in Europe and the long history of research, the Wąchock site is an important point in the discussion on aeolian deposition in the region, especially after considering the novel data presented in this study. Especially important is the fact that studied loess developed on glacial deposits of a penultimate glacial cycle and appears to contain the full record of climatic changes of the Upper Pleistocene.

The main aim of the study is the reconstruction of the patterns of climate change in the last interglacial-glacial cycle based on detailed investigation of loess and palaeosols. It also focuses on the verification of previous results and their correlation with loess profiles of southern Poland and western Ukraine. We show that the Wąchock profile is unique due to the abundance of recorded palaeoenvironmental changes and thus may offer a correlation benchmark and a source of better knowledge of central Poland palaeogeography in the extraglacial area of the last glaciation.

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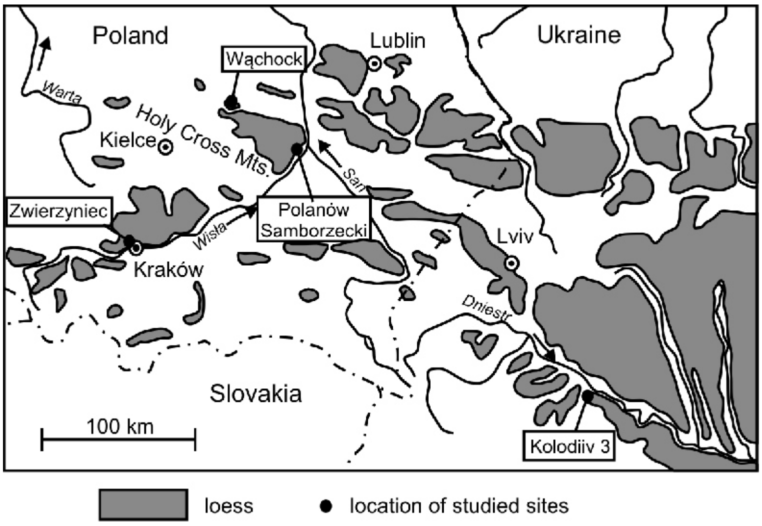

Fig. 1. Sketch-map with location of the studied Wąchock loess section; locations of loess sections in Zwierzyniec, Polanów Samborzecki and Kolodiiv 3, with which it was correlated, are also marked

The loess succession in Wąchock was analysed for the first time by Karaszewski (1954), who found a tooth of a mammoth (*Elephas primigenius*) in the wall of the ravine in loess lying above palaeosol from the last interglacial. A detailed study of Pleistocene sediments occurring there was performed in the late 1970s (Karaszewski et al., 1977; Lindner and Prószyński, 1979) and the obtained results, including TL-dating, were correlated with the archaeological site at Zwierzyniec (Lindner and Madeyska, 1980). Later, the section was exposed once again (Boguszewski, 2000), and samples for subsequent TL-dating (Kusiak, 1999) and palaeomagnetic analyses (Piotrowska, 2007) were collected. Preliminary results of these analyses were presented during the XXVI Conference Pleistocene Stratigraphy in Poland (Dzierżek et al., 2019b).

GEOLOGICAL SETTING

The analysed loess section in Wąchock (northern part of the Holy Cross Mountains) is located in a small loess island, 6 km long and 3 km wide (Fig. 1). This loess belongs to the northern margin of the European loess belt spreading from Ukraine, through southern Poland, to Western Europe. The most complete section was measured in the western part of the ravine. The ravine represents a very young landform. According to historical data, towards the end of the 19th century the stream in the ravine was narrow enough to be crossed by pupils of the nearby junior high school. At present, the ravine walls are 20–30 m apart and their height exceeds 15 m in places (Fig. 2).

MATERIAL AND METHODS

The research objectives were achieved through detailed lithological and stratigraphical characteristics of exposed sediments in the Wąchock profile with regard to archival data, unpublished results of TL dating, and new palaeomagnetic results. The study includes the older, sub-loess part of the section, represented by glacial deposits of the second last glaciation (Lindner, 1978, 1980, 1984), and a younger, loess part of the section comprising a Vistulian loess-palaeosol succession. The upper part of the section was subject to grain-size and carbonate content analyses. The presence of humus and the obtained results were analysed taking into account previous studies (see Karaszewski et al., 1977).

A different methodology was applied for detailed analysis of the mid-loess palaeosols from the oldest (interglacial) forest soil to younger (tundra-type) soils, representing interstadials of the Vistulian Glaciation. These soils are characterized by contemporary climatic conditions and correspond well to the existing vegetation conditions (Granoszewski, 2003). The loess-palaeosol part of the succession was also subject to palaeomagnetic analysis. The analysed loess section was correlated with loess sites of that age from Poland and western Ukraine (Lindner and Madeyska, 1980; Jary, 2007; Łanczont and Boguckyj, 2007). The loess-soil stratigraphy is according to Maruszczak (2001). Based on the analysis of heavy mineral composition (Chlebowski and Lindner, 1992), the source areas for the material of the Upper Younger Loess (LMg) and the direction of loess-forming winds were established. The results were correlated with regional palaeoclimatic data for the Late Pleistocene (Marks et al., 2019).

RESULTS

LITHOLOGY

The oldest strata are Lower Triassic sandstones (Studencki, 1993), overlain by fluvial gravel and sands with a thickness of 0.5 m, with clasts of local and Scandinavian material (Fig. 3). The distribution of these deposits and their relation to the overlying varved-clays, 0.5 m thick, and glacial till, up to 3.5 m thick, indicate that they were deposited during an interval directly preceding the advance of the Scandinavian ice sheet of the second-last glaciation (Odra – Lindner, 1980, presently Odranian – Marks et al., 2016; Lindner and Dzierżek, 2019). The glacial till is brown-cherry red in colour and has a relatively uniform structure. In the southern (higher) part of the ravine, where Triassic sandstones occur at relatively shallow depths, the till contains smudges and interbeds of lower Roetian cherry-red clays and thin sand smudges. The interbedding and

Fig. 2. Western side of the loess ravine in Wąchock. Loesses of the Vistulian Glaciation occur in the upper part of the ravine wall, and the glacial till from the Odranian Glaciation occurs in the lower part of the ravine wall

smudges, as well as the distribution of boulders and rock fragments, emphasize the layered structure of the till. This structure seems to be the primary property of the glacial till derived from the activity of the ice sheet intensely eroding the rock substrate. The grain-size composition of the uppermost part of this till is characterized by an almost 50% contribution of the sand fraction at a relatively high content (20%) of the clay fraction (Fig. 3).

The clay fraction contributes up to 30% in the overlying silt at a distinct decrease of the sand content. The sand content in the overlying layer reaches 90%. Accumulation of silt and sand with blocks of local (Triassic sandstones) and Scandinavian material – derived from the washing out of glacial till preserved in the higher part of the ravine – was probably related to the retreat of the Scandinavian ice sheet of the Odranian Glaciation (Lindner, 1978, 1980; Lindner et al., 2016), which earlier covered the entire area (cf. Dzierżek et al., 2019a). The uppermost part of the mentioned sand layer (with a thickness up to 0.5 m) is characterized by a higher content of the fine fraction and resembles a sandy cover (of aeolian origin?).

These deposits are overlain by a typical, >9 m thick, loess succession (Figs. 2–4). From the base (at a depth of 9.2–9.6 m) it begins with a 40 cm sandy layer affected by soil processes, probably representing horizon B of podzolic soil. The overlying distinct humus horizon represents probably chernozemic soil whose topmost part shows traces of solifluction. The thin loess layer separates both these soil horizons (cf. Lindner and Madeyska, 1980). The overlying yellow-brown calcareous loess (Lowest Younger Loess – LMn) attains a thickness of 1.5 m and contains traces of two poorly developed horizons of tundra glayed soil at a depth of 7.8–8.7 m. In the topmost part of this loess, at a depth of 6.7–7.0 m, occurs a well-developed tundra soil covered with 1.4 m of yellow calcareous loess (Lower Younger Loess – LMd). This loess is covered with a subsequent, well-developed, probably bipartite tundra soil, at a depth of 5.4–5.7 m.

At a depth of 4.4–5.4 m, there is the non-calcareous yellow Middle Younger Loess (LMs), on which an upper soil complex is developed. It comprises three overlapping soil horizons, emphasized by iron precipitations. They are preserved at a depth of 3.6–4.4 m and reach a total thickness up to 0.8 m. All these horizons are incised by a 1 m long ice wedge, filled with the calcareous yellow Upper Younger Loess (LMg). The youngest loess layer is almost 2.5 m thick. No breaks in aeolian accumulation of this material were noted in this loess; in turn, its upper part is characterized by increased content of garnets, zircons, amphiboles and epidotes, which are observed also in its lower part (see Karaszewski et al., 1977). This fact, coupled with the upsection-increasing sand content and the occurrence of sand smudges, points to the close vicinity and simultaneous blowing out of glacial sediments and waste-mantle of Triassic sandstones, and aeolian incorporation of this material into the Wąchock loess mass.

PALAEOSOLS

Palaeosol horizons characterizing the upper, loess part of the Wąchock section are represented by two main soil complexes, occurring in the lower (depth 8.7–9.6 m) and upper (depth 3.6–4.4 m) parts of the section, and four initial gley horizons occurring within the loess separating the two main complexes (Fig. 4).

The lower soil complex (Fig. 5A) is referred to in Poland as the “Nietulsko I soil complex” (Jersak, 1965, 1973) and marked as Gi + GJ1 (Maruszczak, 1991, 2001; Jary, 2007). The (illuvial) horizon B within this complex is the lowermost, leached part of a

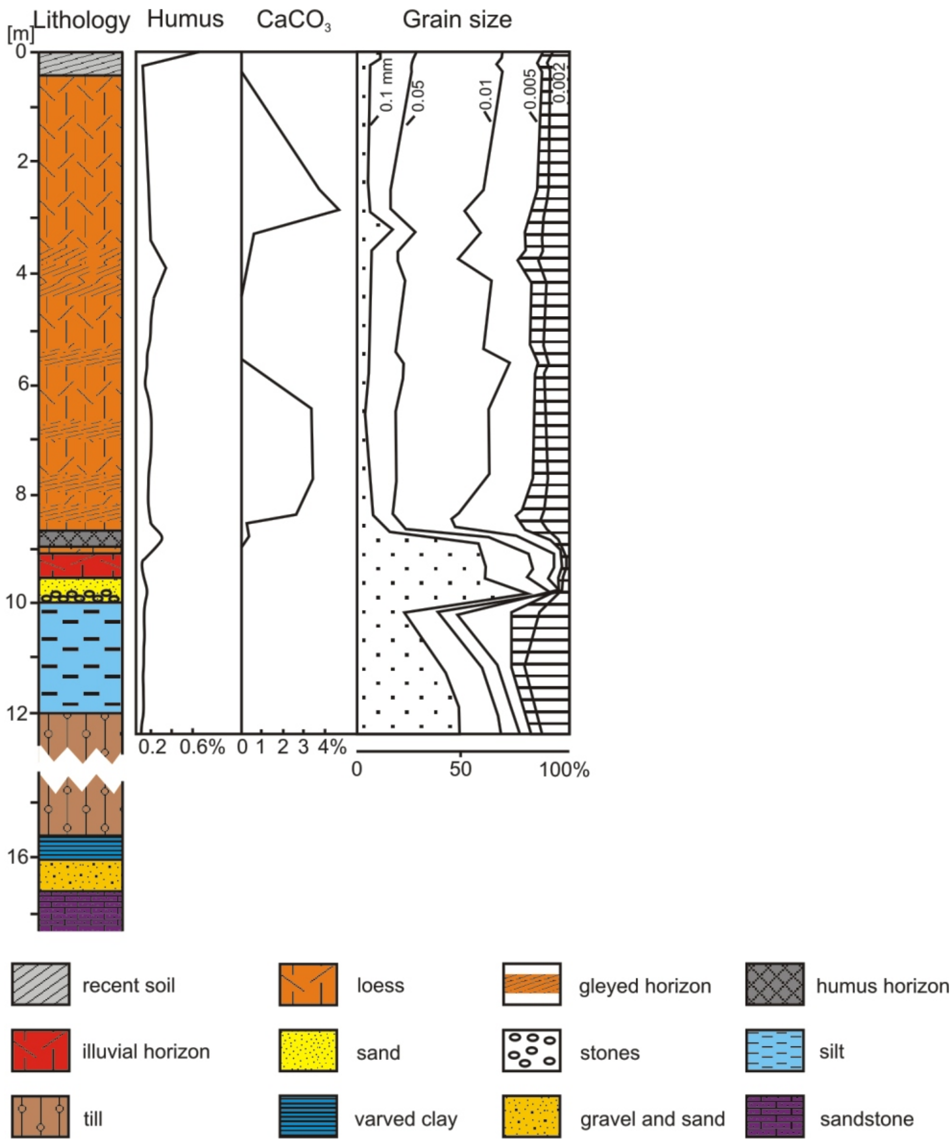

Fig. 3. Lithological column of the Wąchock section

forest (podzolic) soil commonly linked with the Eemian Interglacial (GJ1). Soil development at that time was favoured by a warm climate with considerable oceanic influence (Marks et al., 2019) and dominance of forests with *Quercus* and *Corylus* in the interglacial optimum (Środoń and Gołąbowa, 1956; Jastrzębska-Mamełka, 1985). An important part of this complex is chernozemic, overlapping the earlier deposited loess, whose accumulation was the consequence of trends of climate aridification and cooling from the end of the Eemian Interglacial (Kalińska-Nartiša et al., 2016; Marks et al., 2019). This chernozemic soil is correlated (Jersak, 1973; Maruszczak, 1991; Jary, 2007) with the Brörup Interstadial (Gi/GJ1), which in the pollen sections of central Poland is recorded as the first warm forest stadium of the Vistulian (Mamakowa, 1989). A successive climate change in the Early Vistulian (Weichselian) resulted in the accumulation of a sequence of mineral and organic deposits with a record of deforestation and expansion of tundra vegetation in numerous sections of central Poland (Jastrzębska-Mamełka, 1985; Granoszewski, 2003; Kalińska-Nartiša et al., 2016; Marks et al., 2019). The above-preserved Lowest Younger Loess (LMn) contains two poorly developed horizons of gley tundra soils in the lower part (Fig. 4). The development of these loesses could characterize short breaks in accumulation at the boundary between tundra and arctic climates. The well-developed tundra soil in the topmost part of the Lowest Younger Loess (Fig. 5B) can indicate the climatic conditions as typical for the older interstadial (Gi/LMn = Odderade).

The subsequent gley horizon, preserved in the topmost part of the Lower Younger Loess (LMd), is characterized by a greater thickness and a bipartite structure (Fig. 5C). The development of this soil profile can be related to the Oerel (lower horizon) and Glinde (upper horizon) Interstadials, when subarctic climate prevailed in the area of Poland (Granoszewski, 2003; Marks et al., 2019).

The upper soil horizon (Figs. 4 and 5D) is preserved above the Middle Younger Loess (LMs); in central Poland it is referred to as the "Komorniki soil" (Jersak, 1965, 1973). In the Wąchock section, it is developed as three accumulation-gley horizons, poorly expressed by illuvial horizons. The complex is characterized by a relatively high organic carbon content and a higher content of colloidal parts compared to the over- and underlying loesses. Strong decalcification below this horizon is surprising.

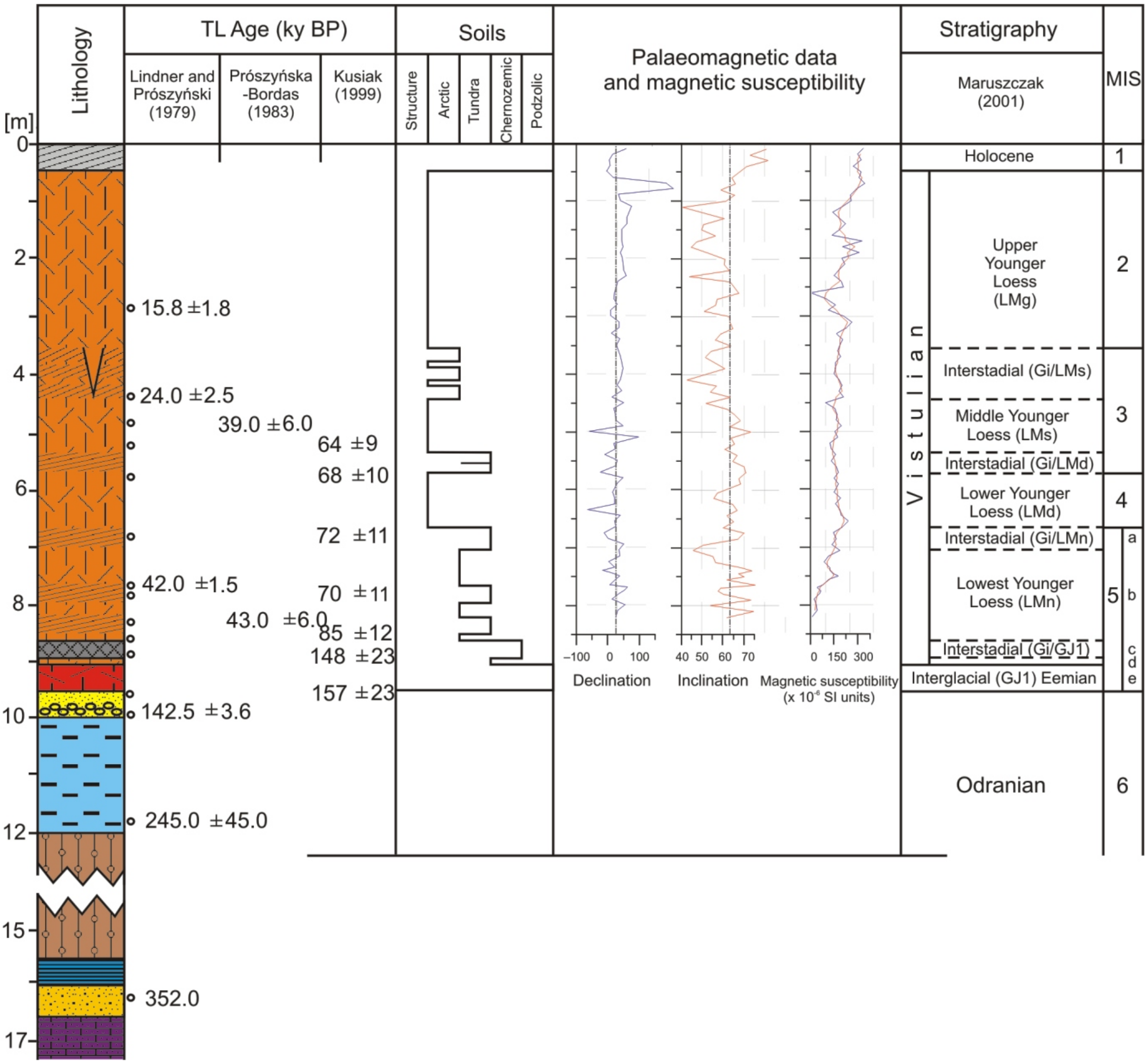

Fig. 4. Wąchock loess section and its age determination

Palaeomagnetic data and magnetic susceptibility after Piotrowska (2007); explanations as on Figure 3

It may be linked with short but overlapping gley processes (Fig. 5D). According to earlier suggestions (Karaszewski et al., 1977), the upper soil complex represents the main megainterstadial of the Vistulian (Gi/LMs), encompassing three interstadials: Moershoofd, Hengelo and Denekamp. Pollen analysis of the lake-peatland sediments from this part of the Vistulian indicates that a steppe-tundra with local presence of bush tundra covered the area of central Poland at that time (Granoszewski, 2003; Dzierżek, 2009; Dzierżek and Szymanek, 2013; Marks et al., 2019). Incision of the soil by an ice wedge is related to intensification of processes within the permafrost in an interval preceding the development of the last ice sheet during MIS 2 (e.g., Dzierżek and Stańczuk, 2006; Dzierżek, 2009; Marks et al., 2016, 2019; Ewertowski et al., 2017).

TL DATING

The analysed section was subject to TL age determinations during three stages (Fig. 4). The first stage included TL dating of the entire section, performed by M. Prószyński (Lindner and Prószyński, 1979) in the laboratory of the Faculty of Geography and Regional Studies of the University of Warsaw. The oldest age of 352.0 ky BP was obtained for gravelly-sandy deposits covering the Triassic sandstones. A younger age of 245 ±45 ky BP was noted for the basal part of silts covering the glacial till. The next age of 142 ±36 ky BP was established for the overlying sands preserved above the silts. The oldest age, 42.0 ±1.5 ky BP, was measured from the loesses in the lower part of the section, and two younger ages, 24.0 ±2.5 ky BP and 15.8 ±1.8 ky

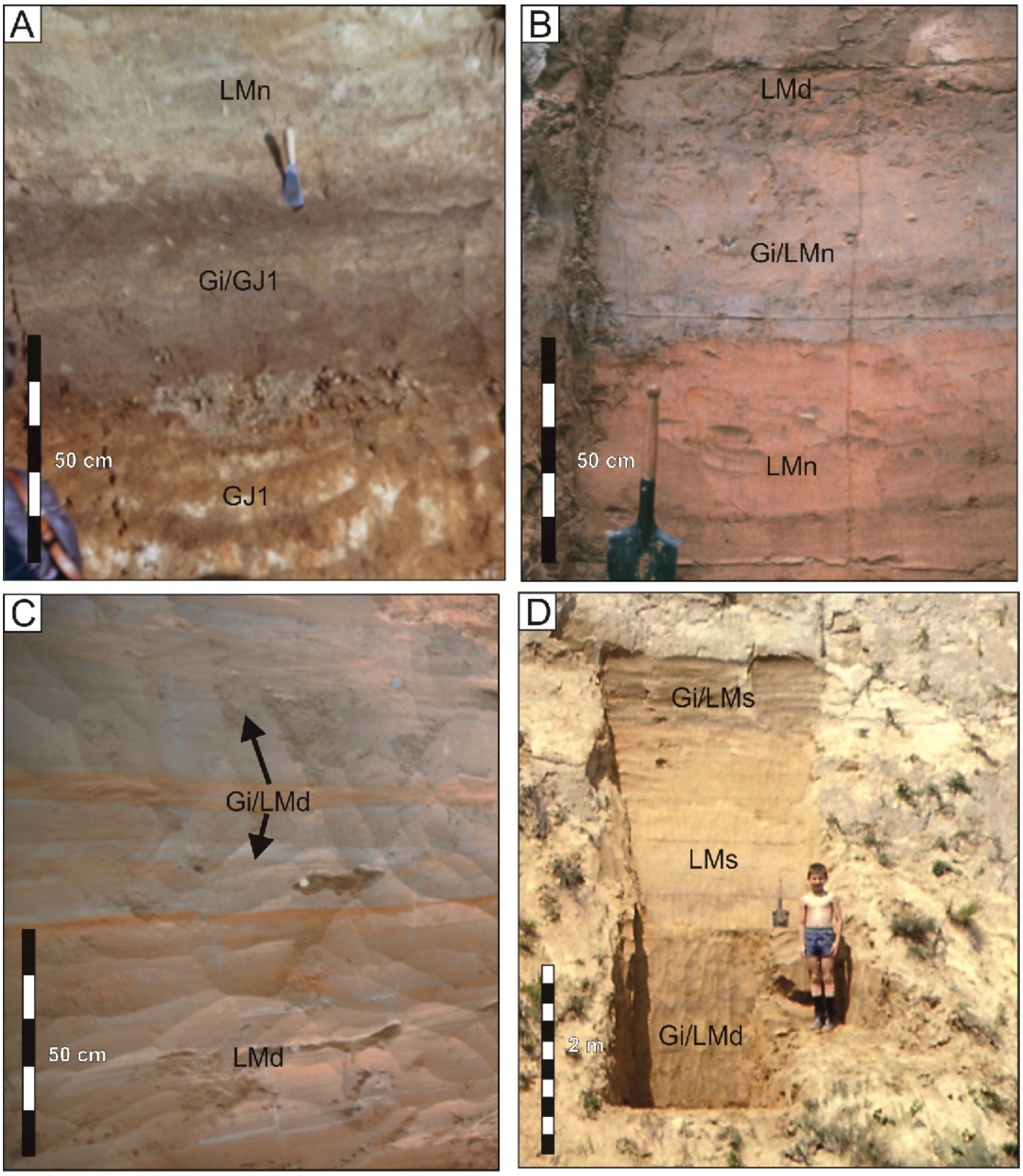

Fig. 5. Fragments of the Wąchock loess section

A – GJ1 – horizon B of soil from the Eemian Interglacial, Gi/GJ1 – chernozemic soil from the Brörup Interstadial, LMn – Lowest Younger Loess; **B** – LMn – Lowest Younger Loess, Gi/LMn – older interstadial tundra soil, LMd – Lower Younger Loess; **C** – LMd – Lower Younger Loess; Gi/LMd – bipartite, younger interstadial tundra soil; **D** – Gi/LMd – younger interstadial tundra soil, LMs – Middle Younger Loess, Gi/LMs – youngest, tripartite arctic interstadial soil

BP, were attributed to the loesses below and above the upper complex of megainterstadial soils incised by the frost wedge (Figs. 3 and 4).

The second stage of TL dating was focused only on loesses from the studied section and was performed in the same laboratory as the stage 1 analyses (Prószyńska-Bordas, 1983). Two dates were obtained, of which the older of 43.0 ±6.0 ky BP and the younger of 39.0 ±6.0 ky BP corresponded to the lower and middle part of the section, respectively (Fig. 3).

The third stage of TL dating was performed by Kusiak (1999) in the laboratory of the Department of Physical Geography and Palaeogeography of Maria Curie-Skłodowska University in Lublin (Table 1).

The obtained results most fully document the TL ages of the analysed loesses and intervening palaeosols. These results

Table 1

Results of TL dating for the Wąchock leoss section (after Kusiak, 1999)

Depth [m]	Lab. No Lub-	Annual dose Dr [Gy/ka]	Geological dose ED [Gy]	Age [ky]
5.3	3644	3.284	211 ±29	64 ±9
5.7	3645	3.356	230 ±30	68 ±10
6.9	3646	3.138	226 ±34	72 ±11
7.9	3647	3.526	246 ±37	70 ±11
8.6	3648	3.078	263 ±34	85 ±12
8.9	3649	1.597	236 ±35	148 ±23
9.5	3650	1.602	252 ±35	157 ±23

largely confirm the stratigraphic interpretation of the sediments performed on the basis of their lithological analysis and the genetic-climatic characteristics of the palaeosols (Fig. 4).

The oldest age of 157 ±23 ky BP confirms the age for the sands earlier established as older from the Eemian Interglacial. The younger age of 148 ±23 ky BP also confirms the age of the upper part of the “Nietulisko I soil complex” (Gi/GJ1), and the three upper dates of 85 ±12 ky BP, 70 ±11 ky BP, and 72 ±11 ky BP confirm the age of the Lowest Younger Loess (LMn) and the younger interstadial (Odderde, Gi/LMn). Two subsequently younger ages of 68 ±10 ky BP and 64 ±9 ky BP, obtained for the Lower Younger Loess (LMd) and Middle Younger Loess (LMs), respectively, indicate that the palaeosol located between them represents the Oerel + Glinde Interstadials (Gi/LMd).

PALAEOMAGNETIC ANALYSIS

Analysis of the remnant geomagnetic field was made during a M.Sc. study (Piotrowska, 2007) for 85 loess samples collected from the first 8 m of the section (Fig. 4). The samples were demagnetized in an alternating magnetic field with an amplitude of up to 100 mT. The chart of characteristic palaeomagnetic declinations and inclinations along the analysed section indicates that all samples record a magnetic field with a normal polarity. Therefore, the section does not contain samples from at least two excursions of the geomagnetic field, which took place in this part of the Pleistocene at 33 ky BP and 41 ky BP (e.g., Singer, 2014). In the upper part of the section, inclinations obtained for most samples attain lower values compared to the average inclination expected in the study locality (63°). This fact may point to sedimentation of this part of the succession on a slope. This conclusion seems to be confirmed by the distribution of the axis of magnetic anisotropy measured in the upper part of the Wąchock section (Fig. 6). The evident dip of the axis of minimal susceptibility and the axes of maximal susceptibility randomly distributed on the large circle may be linked with sedimentation on a slope, oriented probably to the south (see Nawrocki et al., 2006; Bradák et al., 2018).

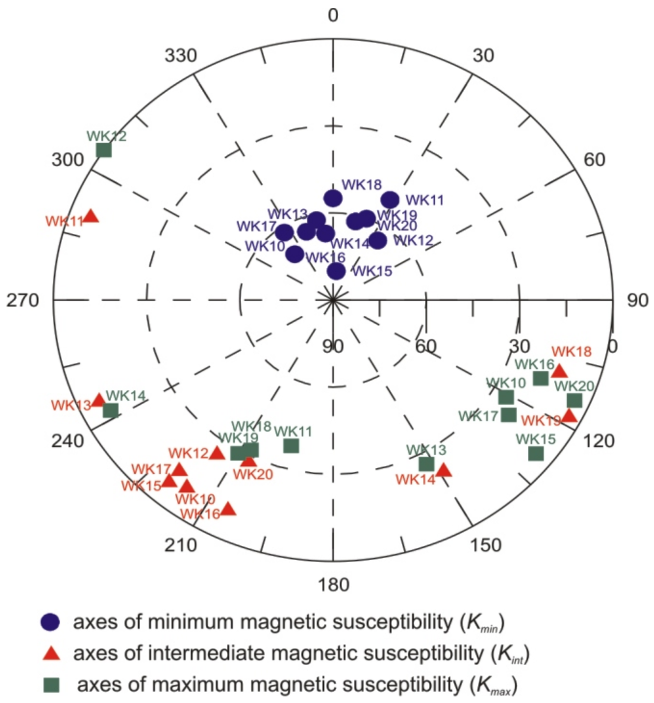

Fig. 6. Spherical projection of the axis of magnetic susceptibility of palaeomagnetic samples from the Wąchock loess section (after Piotrowska, 2007)

Magnetic susceptibility values for loesses and interstadial palaeosols are similar. Lack of increased susceptibility in zones of interstadial soils, and even a decrease of its value, e.g., in the interglacial horizon from a depth of ~8 m is probably the effect of gley processes. Worth noting is that the highest values of magnetic susceptibility (up to ~350 10^{-6} units SI) occur in the youngest loess layers and the youngest palaeosol (Fig. 4). Such high susceptibility of loess may point to relatively high accumulation of magnetite, which may be the effect of short transport.

DISCUSSION

CORRELATION WITH SELECTED LOESS SECTIONS

ZWIERZYNIEC

The attempt to correlate the loesses and palaeosols from the Wąchock section with loesses and palaeosols in the archaeological site at Zwierzyniec (Figs. 1 and 7) was undertaken many years ago owing to the very similar successions of the loesses and the typology of sub-loess and mid-loess palaeosols (Lindner and Madeyska, 1980). The Zwierzyniec (Kraków–Zwierzyniec) section has been well known for many tens of years, being studied, e.g., by Sawicki (1952) and Chmielewski et al. (1977). Several Palaeolithic culture horizons were used to date the succession (Fig. 7).

Intervals of loess-palaeosol successions representing the Eemian Interglacial and the Brörup Interstadial were distinguished both in Wąchock and Zwierzyniec. In the latter site they were TL-dated by W. Stańska-Prószyńska (Lindner and Madeyska, 1980) as younger than 318.3–306.86 ky BP and older than 75.9–72.95 ky BP. Assemblages of the Levallois-Mousterian culture also occur here in both the interval representing the Eemian Interglacial and above. In the upper part of the section, determined by the cited author as older than 71.7–67.6 ky BP, and in Wąchock determined as the Lower Middle Loess (LMd), occur (probably redeposited) artefacts of the Micoquo-Prondnikian culture. Artefacts of the Aurignacian culture were recorded higher up, at the base of the “Komorniki-type” palaeosol (Gi/LMs), and two assemblages were noted within this palaeosol: Jerzmanowice and Upper Palaeolithic, covered by the Upper Younger Loess (LMg) dated at 31.57–27.28 ky BP (Lindner and Madeyska, 1980; Łanczont et al., 2015).

POLANÓW SAMBORZECKI NEAR SANDOMIERZ

The section is located on the southeastern margin of the Opatów-Sandomierz loess upland (Fig. 1). According to Jary (2007), the section comprises 13 m of loess separated by palaeosols (Fig. 7). It is characterized by several horizons of periglacial deformation. The section was TL-dated by S. Fedorowicz, J. Kusiak (Kusiak and Łanczont, 2000) and OSL-dated by A. Bluszcz (Jary, 2007). From the base it begins with the illuvial horizon B (eroded) of forest soil from the Eemian Interglacial (GJ1) and an overlapping humus horizon (chernozemic soil) of the lowermost Vistulian interstadial soil (Gi). A horizon of the Lower Younger Loess (LMd) occurs above, TL-dated at 89.0 ±9.3 ky (Jary, 2007). The loess is characterized by the presence of four poorly developed gley horizons (sg) and is covered by a bipartite interstadial soil (Gi/LMd).

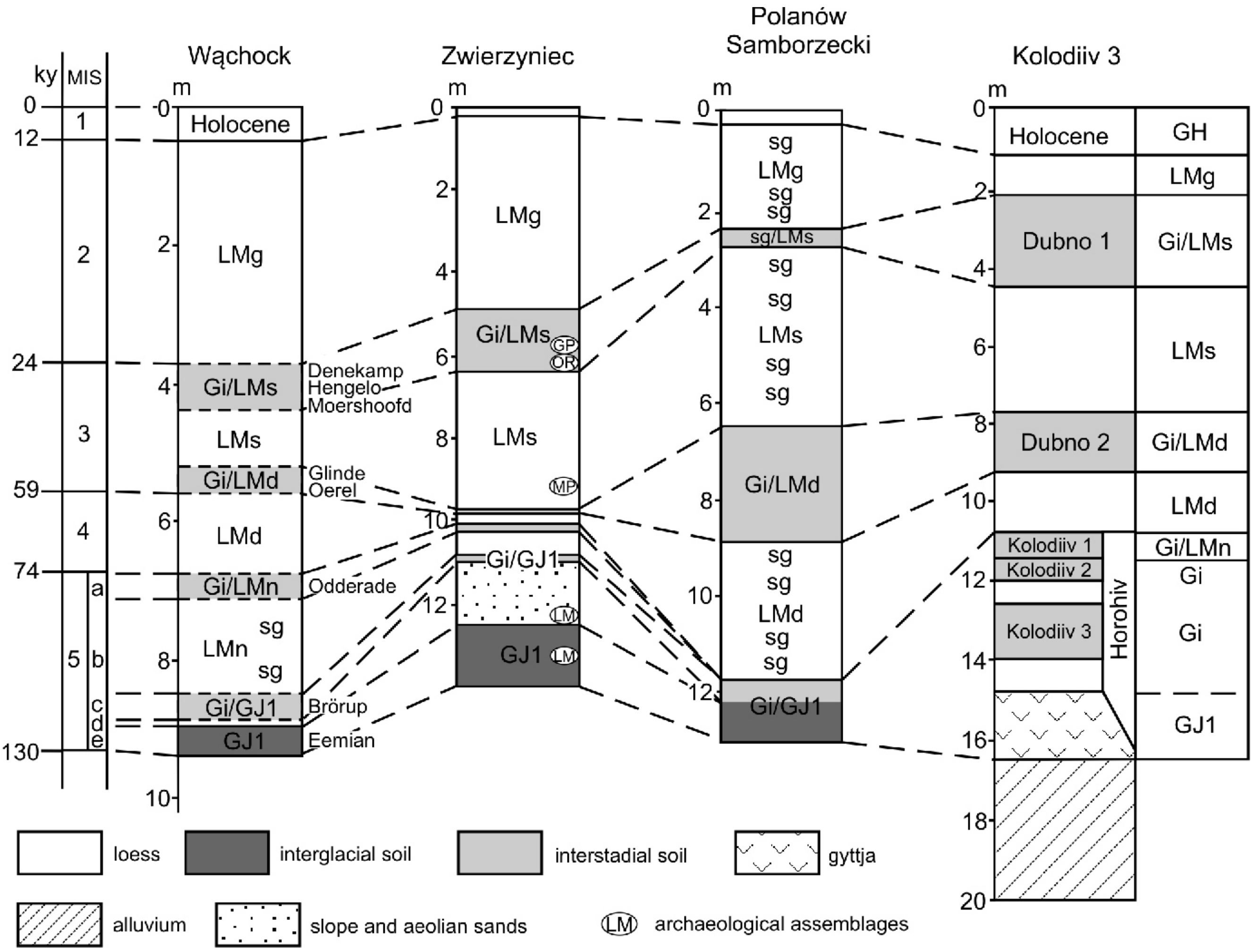

Fig. 7. Correlation of loesses and palaeosols from Wąchock, Zwierzyniec (Lindner and Madeyska, 1980), Polanów Samborzecki (Jary, 2007) and Kolodiiv (Łanczont and Bogutsky, 2007) sections

Letter symbols for loess and palaeosols after Maruszczak (2001); letter symbols for archaeological assembages after Chmielewski et al. (1977): LM – Levalluois-Mousterian; MP – Micoquo-Prondnikian; OR – Aurignacian; GP – Jerzmanowice and Upper Palaeolithic

The two-part soil resembles to some degree the Gi/LMd bipartite soil attributed to the Glinde Interstadial, preserved in the Wąchock section (Fig. 7).

Above, there is the Middle Younger Loess (LMs) with four gley horizons (sg), TL-dated at 37.8 ±4.2 ky BP to 24.4 ±3.0 ky BP, and with OSL ages in the range of 28.6 ±2.1 ky BP to 19.3 ±1.2 ky BP (Jary, 2007). Like in the Wąchock section, a very distinct gley horizon from the youngest interstadial (sg/LMs) is preserved in the topmost part of this loess; it is also affected by periglacial deformation. The youngest part of the section in Polanów Samborzecki is a 2.5 m thick horizon of the Upper Younger Loess (LMg) with several gley smudges (spots), not recorded in the Wąchock section.

KOLODIIV 3 (WESTERN UKRAINE)

The Kolodiiv 3 loess section, like other sections of this site, has numerous references (e.g., Łanczont and Bogucky, 2007; Frankowski et al., 2007; Nawrocki et al., 2007). It is located on the right bank of the Sivka River valley, the tributary of the Dniester River. The succession begins with almost 4 m of fluvial deposits. Above, there is 2 m of lake gyttja from the Eemian (Horohiv) Interglacial, covered by a loess-soil series with a thickness of 14 m (Fig. 7). The lake deposits were TL-dated at 164 ±30 ky BP to 146 ±22 ky BP, and the oldest loess sediments – at 164 ±26 ky BP (Kusiak, 2007). The loesses are separated by three palaeosol horizons, partly displaced downslope. The uppermost soil, younger than 95 ±15 ky BP, is referred to as the Kolodiiv 1 soil and located within the Odderade Interstadial, whereas two older soils (Kolodiiv 2 and 3) are considered equivalents of the Amersfoort and Brörup interstadials (Łanczont and Bogucky, 2007). Following Maruszczak (1991), the overlying loess is referred to the Lower Younger Loess (LMd). A two-part subarctic palaeosol is found above, like the analogous soils (Gi/LMd) in the Wąchock and Polanów Samborzecki sections. In the Kolodiiv 3 section, it is determined as soil (soils) of the Dubno 2 horizon, and the loess horizon above – as the equivalent of the Middle Younger Loess (LMs) in the cited sections from Poland.

Subsequent (1–5) tundra palaeosol horizons are developed in the topmost part of this loess (LMs) in the Kolodiiv 3 section; their evidently overestimated TL age was determined at 115 ±28 ky BP to 76 ±12 ky BP (Kusiak, 2007). They are determined as the Dubno 1 palaeosols and correspond to the youngest mid-loess interstadials of the last glaciation: Moershoofd, Hengelo and Denekamp (Łanczont and Bogucky, 2007) – as in the case of soils of the "Komorniki-type" complex in Wąchock. The assemblage of these soils in the Kolodiiv 3 section is covered by the Upper Younger Loess (LMg) with two initial tundra soils probably being the equivalents of gley horizons (sg) in the Polanów Samborzecki section (Fig. 7).

CONDITIONS OF LOESS ACCUMULATION AT WĄCHOCK

As it may be concluded from the above description, deposits representing the loess part of the Wąchock section, along with the correlative strata from sections in Małopolska and Ukraine, correspond largely to the climate changes in the Late Pleistocene of Poland and Central Europe (Granoszewski, 2003; Marks et al., 2019). However, the regional individuality of loess accumulation in Wąchock is quite clear. Numerous smudges and interbeddings of sandy material preserved in the Upper Younger Loess (LMg), like in many loesses of that age in the western part of the Holy Cross Mountains (Lindner, 1972a), point to rhythmic blowing out of the waste-mantle of local sandstones (Buntsandstein and Liassic) during loess sedimentation. High intensity of the contemporary aeolian processes in the western and northern part of the area is confirmed also by the distribution of corrosion-deflation sandstone outliers in the area (Lindner, 1972b). The outliers bear traces of the activity of westerly winds (Chlebowski and Lindner, 1992), whereas the collected cartographic data indicate that the main cycle of aeolian modification took place during the terminal loess-forming interval.

Studies of heavy mineral composition in the younger loesses building the loess islands in this part of the Holy Cross Mountains, including the Upper Younger Loess (LMg) in the Wąchock section (Chlebowski and Lindner, 1992), have indicated that the composition of transparent heavy minerals is dominated by muscovite, biotite, amphiboles, as well as chlorite and garnets. Weathering-resistant minerals, such as zircon, rutile, tourmaline, staurolite and dystene, occur in very small quantities. The composition of these minerals, particularly the quantitative proportions, are clearly related to the basement composed of rocks of glacial origin (sands and glacial tills), containing fragments of magmatic rocks or their waste-mantle (Chlebowski and Lindner, 1975).

Based on the presence of these minerals and the geomorphological setting of the loess islands (Lindner, 1967, 1971), it may rather be assumed that the transportation distance of the loess-forming material was short, as indicated by the direct mineral link of loesses with the local source areas. This points that the main transportation of aeolian loess material took place from the west with local deviations from the north-west (cf. Marks et al., 2019). As a rule, the winds were typical for the lower parts of the atmosphere (Chlebowski and Lindner, 1989). Palaeomagnetic studies of samples collected from the Wąchock section seem to confirm the hypothesis that the upper part of the analysed loesses could have accumulated on a slope, locally facing to the south (Nawrocki et al., 2006).

CONCLUSIONS

Compilation of archival material and new reports, including results of TL-analysis and palaeomagnetic studies of loesses and palaeosols in the Wąchock section, as well as comparison with other loess sections, allows drawing the following conclusions.

1. The entire Wąchock section, including loesses and palaeosols within them, as well as deposits from the Odranian Glaciation (MIS 6, according to Marks et al., 2016) were TL-dated in three stages, of which the first stage fully documents the age of deposits from this glaciation and the preserved forest soil from the Eemian Interglacial (MIS 5e), and the youngest age indicates the position of younger loesses and tundra soils from the Vistulian Glaciation (MIS 5b-2).

2. Palaeosols and loesses in the Wąchock section represent a particularly complete succession of climate changes characterizing the Vistulian Glaciation, which gives a possibility of relating them to changes recorded in the sequences of lake deposits in Poland.

3. Both the analysed loesses and the intervening palaeosols were depicted with symbols suggested by Maruszczak (1991, 2001) and commonly used by scientists studying loesses in Poland and western Ukraine, which allowed correlation of the analysed sequence with type sections (Zwierzyniec, Polanów Samborzecki, Kolodiiv 3) in these areas.

4. Analysis of the remnant magnetic field has indicated that the studied succession records only normal polarity, whereas the dip of maximal polarity and dispersed axes of this susceptibility on the large circle may register sedimentation of the upper part of the loesses on a slope facing to the south.

5. The attempt to determine the accumulation conditions of the Upper Younger Loess (LMg) in the analysed section, based on analysis of its geomorphological position and composition of heavy minerals, point to a local source of loess material and a westerly and northwesterly direction of the contemporary loess-forming winds.

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