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Loess–soil sequences as a source of climatic proxies: an example from SW Poland

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Loess in SW Poland occurs in several isolated patches which differ in sediment thickness, stratigraphy and physical properties. The most representative loess sequences provide a record of climate changes for the Last Glacial cycle (Eemian–Weichselian). A representative loess section in SW Poland can be subdivided into four units: two polygenetic fossil soil sets and two, usually calcareous, loess units. On the top of the younger loess unit, recent soil has formed. Differences in the physical properties of these units result from the climatic conditions during sedimentation, which influenced the intensity of pedogenic processes and the rate of loess accumulation. Combined climatic proxies obtained from palaeosols, lithological composition and periglacial structures enable reconstruction of Late Pleistocene climate conditions as well as of proper correlations between continental, marine and ice-core events.

Key words: loess–palaeosol sequence, lithostratigraphic units, proxy data, climate change, Late Pleistocene, SW Poland

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INTRODUCTION

Loess is a unique terrestrial deposit characterized by almost continuous deposition during Pleistocene cold intervals. In some representative, properly selected sections, the differentiation of certain features (e. g., grain size, carbonate content, magnetic susceptibility, geochemical characteristics, periglacial phenomena) can be used as a proxy record of climate changes (Porter, An, 1995; Vandenberghe et al., 1997, 1998; Lu et al., 1999; Vandenberghe, Nugteren, 2001; Muhs, Bettis III, 2003; Jary, 2007, 2009). However, a correct interpretation of palaeoclimate proxy data is rather difficult and needs adaptation of comparable methods following the rules of geological stratigraphy and correlation.

The European loess is a product of the cold Pleistocene climate. The rate of loess deposition decreased significantly during warmer intervals of the Pleistocene. Primary lithological loess features can thus change due to the development of soils, often superimposed one onto another. The rate of loess deposition in Europe varied, even within cold phases, due to migration of latitudinal climatic zones and the labile balance with respect to the degree of continentality (which was related to the alternating expansion and decay of the ice sheet). Unstable climatic conditions, particularly in the northern part of the European loess belt, influenced periglacial phenomena within the loess depositional environments: they indicate periods of great environmental changes such as extreme cooling, permafrost development and, finally, permafrost decay (Jary, 2007; 2009).

The Polish loess is situated in the central part of the European loess belt, along its northern margin. Because of its intermediate geographic position (between the west and east parts of the belt), Polish loess forms a bridge for loess studies in eastern and western Europe. For instance, loess in the eastern part of Poland is relatively thick (max. 40 m) and is similar to the Ukrainian loess, both from the stratigraphical and lithological points of view, whereas loess patches in SW Poland are thinner (3–5 m, max. 15 m) and do not differ fundamentally from the western European loess. The development of loess covers in Poland reflects present and past regional climatic conditions: continental in the east and more oceanic in the west (Cegła, 1972; Jersak, 1973; Jary, 1996; 2007; Jary et al., 2002; 2004).

STUDY AREA

Loess in SW Poland is distributed in several isolated patches (Fig. 1) which differ in sediment thickness, stratigraphy and

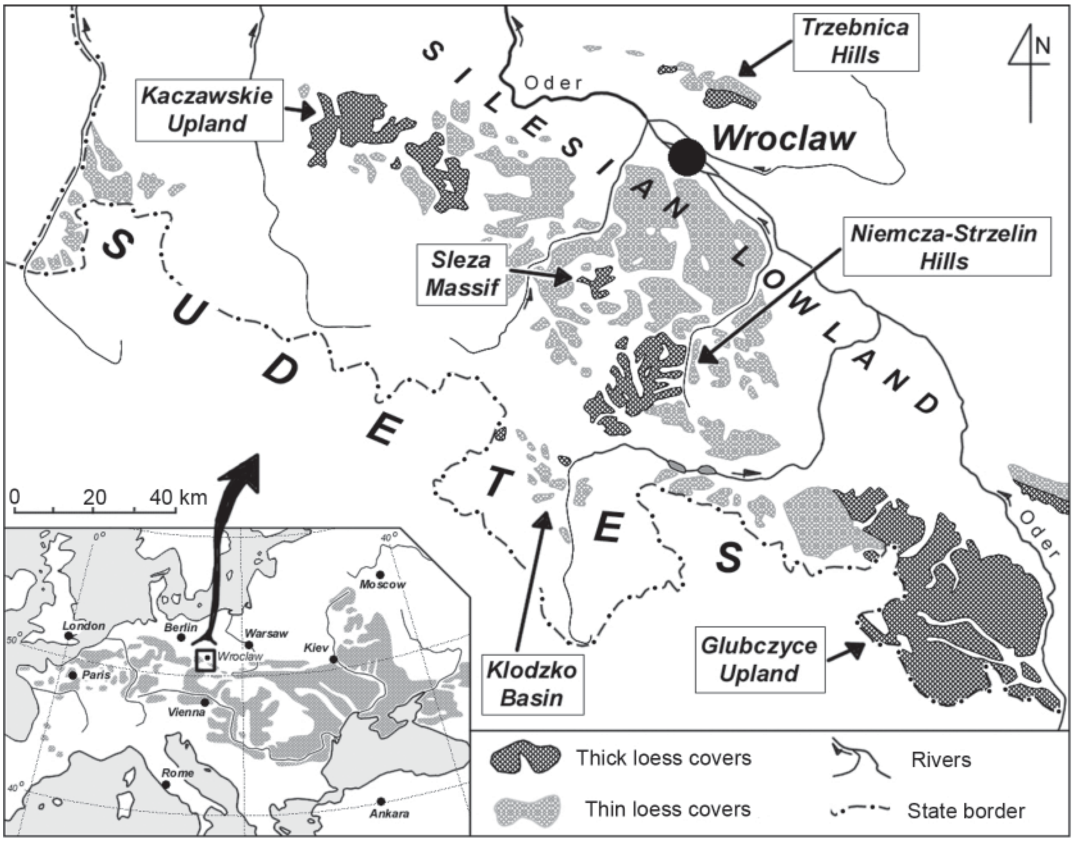

Fig. 1. Location of the study area and loess distribution in SW Poland

1 pav. Tyrimų vietos ir liosų paplitimas pietvakarių Lenkijoje

physical properties. On the basis of features mentioned above, these loess patches of SW Poland can be subdivided into two groups (Jary et al., 2002):

(1) loess covers thicker than 2–3 m, which show a clear vertical zonation and are characterized by a specific erosional relief;

(2) thin (0.3–2 m), loamy (sandy and / or clayey) loess and loess-derived discontinuous patches, which stratigraphically are usually not internally differentiated.

Thick loess covers occur mainly in the foreground of the Sudetes Mountains. They are, however, also found far away from these mountains (e. g., in the Trzebnica Hills) and within intramountain depressions (e. g., in the Kłodzko Basin). Thin loess and loess-derived patches occur in the surroundings of thick loess covers and within the Silesian Lowland.

STRATIGRAPHIC FRAMEWORK

Loess in SW Poland dates mainly from the last glacial. In addition, some older loess, deposited at the end of penultimate glaciation, is present in the study area. It remains unclear whether the paucity of older loess results from its original absence in the area or, alternatively, from its subsequent erosion. The most representative loess sequences provide a record of climate changes for the last glacial cycle (Eemian–Weichselian).

Well-developed Late Pleistocene loess sequences in SW Poland can be divided into four units (Fig. 2): two polygenetic fossil soils (fossil soil sets) and two, usually calcareous, loess units. On the top of younger loess unit, recent soil has developed.

Each of these units can be easily distinguished within vertical sections on the basis of their macroscopic features. These units also form major litho-pedostratigraphic units in the loess sequences. The units are as follows (from bottom to top):

- polygenetic pedocomplex (fossil soil set) with a well developed Bt horizon,
- lower loess unit (LMd – lower younger loess),
- tundra-gley type fossil soil (soil complex),
- upper loess unit (middle younger loess (LMs) and upper younger loess (LMg)).

Differences in the physical properties of these units are a result of climatic conditions during sedimentation, which influenced the intensity of pedogenic processes and the rate of loess accumulation. A special feature of loess sequences in SW Poland is the occurrence of well preserved relicts of periglacial horizons (Jahn, 1975). These horizons are well distinguishable within almost all loess sections in the study area and provide a record of climate changes; hence, they may constitute stratigraphic markers within the last glacial sequences (Jary, 2003; 2007; 2009).

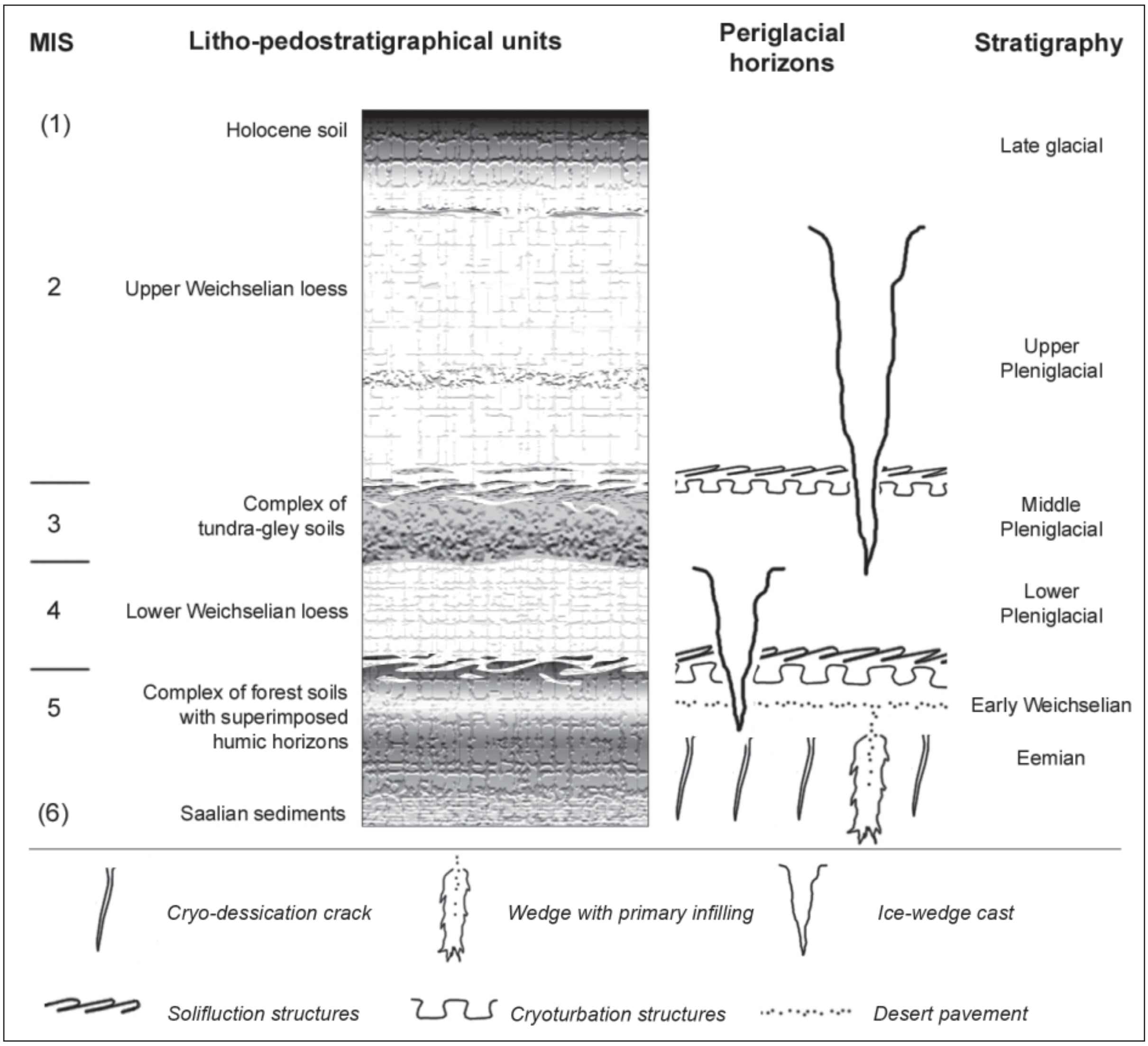

Fig. 2. The main litho-pedostratigraphical units with periglacial horizons and structures within the Late Pleistocene loess succession in SW Poland and their relation to marine isotopic stages (MIS) and general chronostratigraphical units

2 pav. Svarbiausi vėlyvojo pleistoceno litopedostratigrafiniai sluoksniai su periglacialiniais horizontais ir lioso–dirvožemio sekomis PV Lenkijoje bei jų ryšys su jūrinėmis izotopinėmis stadijomis (MIS) ir bendraisiais chronostratigrafiniais sluoksniais

Analysis of the available results of absolute dating (TL and ^{14}C) within loess sequences in SW Poland generally shows an agreement with the stratigraphic interpretation (Kida, 1984; Jary, Kida, 1996; Jary, 1996; 2007), but these data do not provide a reliable basis for the construction of a chronological scheme.

MAIN LATE PLEISTOCENE LITHOSTRATIGRAPHIC UNITS OF LOESS SUCCESSIONS OF SW POLAND AND THEIR PALAEOCLIMATIC INTERPRETATION

Pedocomplex with well developed Bt horizon correlated with Eemian and Early Weichselian

In the lower part of the investigated sequences, a polygenetic pedocomplex (fossil soil set) was formed. The composition of this soil complex of SW Poland markedly differs from that of the corresponding soil in Central and Eastern Poland (Jersak, 1973; 1991; Jersak et al., 1992; Maruszczak, 1991; 2001). The essential morphological and genetic differentiation of this pedocomplex is a consequence of local climatic conditions and the heterogeneity of source material for soil substrate. The Eemian–Early Weichselian soil complex could be formed during 2–3 stages of forest-type pedogenesis. The final, steppe soil forming, phase has been noted only in a few sites within loess sequences in SW Poland. Stages of soil formation were interrupted by intervals of a sudden increase of climate continentality. During these cold periods, two generations of periglacial structures were formed. The inventory of the periglacial structures is differentiated (e. g., wedges with primary infilling, seasonal frost wedges, cryo-desiccation cracks, desert pavements). They evidence periods of climate deterioration during pedocomplex development. Forest soils were developed during the Eemian Interglacial (MIS 5e) and probably throughout Brörup and Odderade Interstadials (MISS 5c, 5a). Cold periods, which interrupted three stages of the pedogenesis, are correlated with the Herning (MISS 5d) and Rederstall (MISS 5b) Stadials. Locally, in the end of the last stage of pedogenesis, a period of steppe condition occurred, when welded accumulation (chernozem-like) horizons were formed.

Lower loess unit (LMd – lower younger loess) correlated with Lower Pleniweichselian

There were two main stages of loess sedimentation during the Last Glacial period in loess areas of SW Poland. They are represented by two calcareous loess units. The lower loess unit (LMd – lower younger loess) was probably deposited during the Lower Pleniweichselian (MIS 4). The thickness of LMd usually does not exceed 1 m and is very differentiated within particular loess sequences. However, in most localities this loess unit was completely transformed by succeeding processes of pedogenesis and now represents the substrate of the overlying fossil soil complex. The most spectacular grain-size changes within the described unit as well as in the whole Late Pleistocene loess-soil sequence occur in the lower part of LMd (directly above the Eemian–Early Glacial soil complex). This part of the LMd unit frequently shows cryogenic deformation, an evidence of redeposition by solifluction and other slope processes, which imply that it was formed contemporaneously with the most important climate-induced environmental changes of the Last Glacial period on the study area. Most probably, this period can be correlated with a rapid shift on the normalized ^{18}O curve (the onsets of MIS 4 (Martinson et al., 1987)).

The ice wedge casts within LMd, which indirectly indicate a former permafrost, were found only in one loess section (Zaprężyn – Trzebnica Hills), suggesting that, during the Lower Pleniweichselian, discontinuous permafrost was developed only in the northern margin of the study area (Jary, 2007, 2009).

Tundra-gley type fossil soil complex correlated with Middle Pleniweichselian

Tundra-gley type fossil soil complex (Gi / LMd soil acc. Maruszczak, 1991; 2001; komorniki soil acc. Jersak, 1973; Dubno soil acc. Bogutsky, 1986; 1987; Bryansk soil acc. Velichko, 1990; Velichko et al., 1997) is the most important fossil soil (soil complex) within the Weichselian loess succession. It separates two main stages of loess accumulation during the Last Glacial. Morphological and genetic differentiation and varied preservation of this fossil soil complex is the major feature of this unit. Sometimes the stratigraphic correlation between particular sections is difficult. It is the only carbonate-free soil in the Last Glacial interfluve loess sequences. The substrate of this soil is characterized by a high index of chemical weathering, indicating a considerable role of transformation by soil processes. However, the morphology and the presence of periglacial features suggest a tundra-gley type of pedogenesis. ^{14}C dating of macro-remnants or humus substances is usually much younger in comparison with TL and OSL dating (Jary, 2007). The chronostratigraphic position of Gi / LMd (= Komorniki, Dubno, Bryansk) soil is usually correlated with the final phases of MIS 3 (Hengelo and Denekamp interstadials), contrary to some Polish authors (e. g., Maruszczak, 1991; 2001) who correlate this soil with the onset of MIS 3 (Oerel and Glinde interstadials). Author suggests that the chronostratigraphic position of the Gi / LMd (= Komorniki, Dubno, Bryansk) soil complex should be correlated with the whole MIS 3. Climatic changes during MIS 3 in the investigated loess areas were probably not rapid and / or significant enough to evoke effective processes of loess accumulation.

The upper loess unit (middle younger loess (LMs) and upper younger loess (LMg)) correlated with the upper Pleniweichselian

The upper loess unit occurs above the Gi / LMd (= Komorniki, Dubno, Bryansk) soil and consists of middle younger loess (LMs) and upper younger loess (LMg). This calcareous loess was deposited during the Upper Pleniweichselian (MIS 2). The thickness of the upper loess unit is considerable and in some sections exceeds 6 m (Kida, 1984; Jary, 1996; 2007). There are several weak tundra-gley horizons within Upper Pleniweichselian loess sequences, which indicate short climate variations in the time of loess accumulation. One of them is the sg / LMs horizon (Maruszczak, 1991) which developed in the upper part of middle younger loess (LMs) and separates middle younger loess (LMs) from upper younger loess (LMg). It may be correlated with the Rivne (Bogutsky, 1986; 1987) and the Trubchevsk (Velichko, 1990; Velichko et al. 1997) horizons. Nevertheless, its recognition and correlation are rather ambiguous because there are a few other initial tundra-gley horizons within the Upper Pleniweichselian loess. A special feature of the sg / LMs horizon, which is noted in most of the sections, is a distinct, abrupt increase of the magnetic susceptibility (MS) value. It can be related to climate change of the loess sedimentary environment. The rapid increase of MS may be also linked with the magnetic properties of deposited aeolian silt, which suggests changes of loess source areas (Maher, 1998; Maher, Thompson, 1991; 1992; 1995; 1999; Maher et al., 1999).

The lower part of the upper loess unit (lower part of LMs directly above the Middle Pleniweichselian soil complex) shows cryogenic deformation and an evidence of redeposition by solifluction and other slope processes. This period can be correlated with a rapid shift on normalized ^{18}O curve (the onsets of MIS 2). In the upper loess unit of SW Poland, ice-wedge casts (2–3 m deep) are recognized in a few sites on the Głubczyce Upland. However, in Trzebnica Hills, which are situated in the northern margin of SW Poland, the depth of these structures is 3–4 m. Ice-wedge casts in the SW Poland loess area were probably developed within both continuous (northern part – Trzebnica Hills) and discontinuous permafrost (southern part – Głubczyce Upland; Jary 2007; 2009).

Grain-size usually demonstrates a systematic increase of coarse silt fraction percentage towards the top of loess-soil sequences. It can be interpreted as an evidence of the growing rate of loess accumulation, which can be associated with the availability of and the decreasing distance to loess alimentation areas (Jary et al., 2004). In the loess of SW Poland, the mean grain-size diameter decreases from north (Trzebnica Hills) to south (Glubczyce Upland). This phenomenon is probably connected with variations of the latitudinal climate zones, indirectly showing the position of major primary source areas for loess particles.

CONCLUSIONS

Loess sedimentation in SW Poland is mostly related to the Last Glacial period (Weichselian). A detailed analysis of the lithological and structural features of Late Pleistocene loess-soil sequences in SW Poland revealed the presence of four lithostratigraphical units within the thick, interfluvial loess sequences. These units are a result of climatic conditions during sedimentation, which influenced the intensity of pedogenic processes and the rate of loess accumulation.

The most representative loess-soil sequences in SW Poland provide a good record of climatic events during the Last Glacial. Combined climatic proxies obtained from palaeosols, lithology and periglacial structures enable reconstruction of palaeogeographic conditions. However, a reliable reconstruction of climate changes on a regional scale is possible only in thick, subaerial, interfluve loess sequences not disturbed by slope processes induced by the local palaeotopographic situation.

The current state of investigations brings many uncertainties concerning the origin and palaeoenvironmental interpretation of various proxy data recorded in loess successions. Further investigations of these proxies recorded in Last Glacial loess sequences in SW Poland and other loess areas, performed by comparable methods, will be of crucial importance for palaeogeographic reconstructions of the Late Pleistocene. It may be an important step in evaluating a precise correlation among continental, marine and ice-core events.

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LIOSŲ–DIRVOŽEMIŲ SEKOS KAIP INFORMACIJOS ŠALTINIS APIE KLIMATO POKYČIUS PIETVAKARIŲ LENKIJOJE

Santrauka

Pietvakarių Lenkijoje keliuose izoliuotuose plotuose randami liosai skiriasi savo storiu, stratigrafine priklausomybe ir fizinėmis ypatybėmis. Pilniausios liosų–dirvožemių sekos gerai atspindi paskutinio apledėjimo ciklo (Emio–Veichselio) klimato pokyčius. Tokius pilnus liosų pjūvius pietvakarių Lenkijoje dažniausiai sudaro keturios dalys: du fosiliniai poligenetinio dirvožemio sluoksniai ir du dažniausiai karbonatiniai lioso sluoksniai. Šių sluoksnių fizinių savybių skirtumus lėmė klimato sąlygos sedimentacijos metu, kurios buvo svarbios liosų akumuliacijai, storiui ir pedogeniniams (dirvodariniams) procesams. Klimato raida, užfiksuota paleodirvožemiuose, nuogulų litologijoje ir periglacialinėse struktūrose, leidžia rekonstruoti vėlyvojo pleistoceno klimato pokyčius ir juos koreliuoti tarp žemyninės, jūrinės ir ledyninės aplinkos nuogulų pjūvių. Tačiau patikima klimato pokyčių rekonstrukcija galima tik esant pakankamai storiems ir gerai išlikusiems pjūviams, kurių nepaveikė šlaitiniai procesai tam palankiose paleotopografinėse aplinkose. Tolesni liosų–dirvožemių sekų tyrimai pietvakarių Lenkijoje ir kituose liosų paplitimo rajonuose bus reikšmingi rekonstruojant vėlyvojo pleistoceno paleogeografines sąlygas.

Raktažodžiai: liosų–dirvožemių sekos, vėlyvasis pleistocenas, litostratigrafiniai sluoksniai, klimato pokyčiai