PERGAMON

Quaternary International 76/77 (2001) 129–139

Vistulian loess deposits in western Poland and their palaeoenvironmental implications

Katarzyna Issmer*

Department of Geomorphology, Quaternary Research Institute, Adam Mickiewicz University, H. Wieniawskiego 17/19, 61-713 Poznań, Poland

Abstract

The loess deposits of western Poland are a periglacial facies, having been deposited in the Plenivistulian. So far, western Poland is the only part of the country in which Vistulian loess deposits, occurring as small patches on different glacial and glaciofluvial landfoms, have been found. The diagnostic features of these sediments provide a tool for the sub-division of the main lithofacies. Loess deposits occur in two main lithofacies: massive loess (Lm) and laminated loess (Ll). There are three sub-lithofacies within the laminated loess: cryptolaminated (sl), laminated loess sensu stricto (ll) and banded loess (sm). Loess lithofacies are associated with a varied topography and are distributed in the end moraines, till plains and outwash plains. There is a significant correlation with the periglacial zone and aeolian processes active during the Vistulian in western Poland. © 2001 Elsevier Science Ltd and INQUA. All rights reserved.

1. Introduction

Successive studies have shown (Dammer, 1941; Schoenhals, 1944; Siebertz, 1988; Kolstrup, 1991) the presence of loess deposits outside the northern limit of continuous loess in Europe. The main aim of the present study is to discuss the occurrence and nature of loess deposits in western Poland. Investigations have been undertaken in two main areas, namely Western Pomerania (Myślibórz Upland) and in the Dalków Hills. Until recently, Western Pomerania is the only area of Poland in which Late Vistulian loess deposits, occurring in small patches on different glacial and glaciofluvial landfoms, have been found. An unusual deposit for this young glacial landscape was found during geological mapping (Berendt et al., 1908). German geologists found it among the glaciofluvial deposits and called it *"Toniger Sand"*, or *"Mergelsand"*, but did not discuss its origin. Dammer (1941) was the first to propose an aeolian origin, and to give the material a new name, *"Flottsande"*. Systematic studies and investigations in Western Pomerania have shown that loess deposits are present outside the northern limit of the contiguous loess deposits of Poland (Cegła and Kozarski, 1976; Issmer et al., 1990; Kozarski and Nowaczyk, 1991, 1992; Issmer, 1995, 1998; Biernacka and Issmer, 1996).

In contrast, the Vistulian loess deposits on the Dalków Hills still remain to be researched in detail. They were first described by Rokicki (1952), who considered them to be the product of wash processes, with accumulation in water. He termed them clayey sands. Kowalkowski (1966) linked the origin of the silt deposits of the Dalków Hills with aeolian processes during the periglacial climatic conditions of the Leszno phase of the Last glaciation (20 ka BP).

2. Locations of the study sites

Within Western Pomerania, loess profiles are found at three sites in the Myślibórz Upland, named Klępicz, Stare Objezierze, and Żelichów. These sites are contiguous with the marginal zone of the Pomeranian phase (16.2 ka BP, Kozarski, 1995) of the Last glaciation (*Vistulian*), formed by the lobe of Odra (Fig. 1). The Klępicz and Stare Objezierze sites are located within the moraine upland (Fig. 2), north of the marginal forms delimiting the maximal limits of the Pomeranian phase: they formed as end moraines and consist of boulder pavement (Kozarski, 1965, 1995). South of the end moraines of the Pomeranian phase there are extensive areas

---

* Fax: + 48-61-853-02-34.

E-mail address: issmer@man.poznan.pl (K. Issmer).

1040-6182/01/$20.00 © 2001 Elsevier Science Ltd and INQUA. All rights reserved.
PII: S1040-6182(00)00097-5

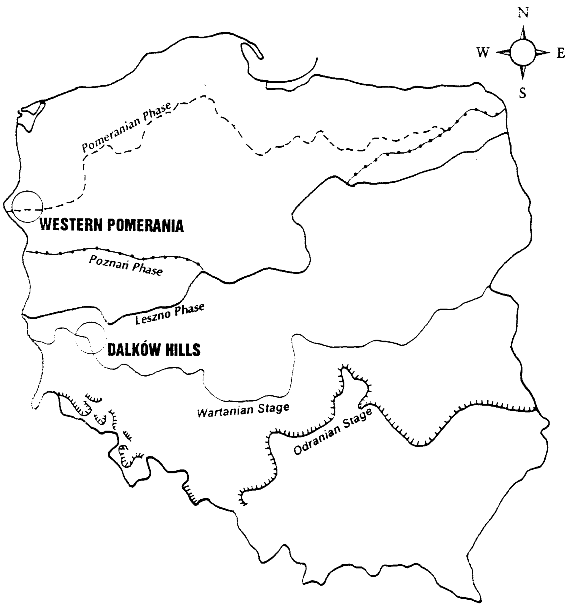

Fig. 1. Location of the main study areas.

of outwash fans. The sites in Żelichów are located directly on the end moraines of the Pomeranian phase.

The Dalków Hills form the north-western range of the Trzebnicki Ridge. The Trzebnicki Ridge is a product of glaciotectonics during the Wartanian stage (Rotnicki, 1960, 1966; Krygowski, 1972; Dyjor, 1991). It has been proposed that the glaciotectonic dislocation of the Trzebnicki Ridge was a result of subglacial dislocation (Brodzikowski, 1986; Szczepankiewicz, 1989), making the age of the Ridge no later than the Odranian stage of the Middle Polish glaciation (*Saalian*). The hills are formed by the higher parts of the end moraine (Krygowski, 1953), 80–100 m above sea level (asl) in the north and up to 180–200 m asl in the south (Figs. 1 and 3). The Cisów 1, 2 and 3 study sites are located south of Kożuchów, in small erosional valleys within the northern slope of the Dalków Hills. The loess of the Dalków Hills occurs as a mantle on the hillslopes consisting of glacial and glaciofluvial deposits (Issmer, 1999).

3. Lithological and sedimentological features

Laboratory studies of loess deposits were undertaken with respect to grain size distribution, calcium carbonate content, physical features such as bulk density, volumetric density, porosity, actual moisture content and capillary capacity. Detailed sedimentological investigations were also carried out. The sedimentary structures in the loess are mainly of periglacial type such as frost cracks and fissures.

Micromorphological features were also studied. These diagnostic features have been used as a basis for the recognition of the main lithofacies (Issmer, 1998). There are two principal lithofacies, namely massive loess (Lm) and laminated loess (Ll). Three sub-lithofacies were found within the laminated loess: cryptolaminated (sl), laminated loess sensu stricto (ll) and banded loess (sm).

3.1. Loess deposits of Western Pomerania

The loess of Western Pomerania shows several lithofacies variations. All show a link with periglacial environments, and the aeolian and slope processes that occur in such environments. The two lithofacies and three sub-lithofacies described above were found. The main loess profiles in Western Pomerania show the following lithology:

Klępicz 4 (55.0 m a.s.l.):

0.0–0.3 m	Humic horizon of the surface soil
0.3–0.9	Massive loess lithofacies — yellow–brown homogeneous, non-calcareous silt
0.9–2.0	Laminated loess sensu stricto sub-lithofacies — yellow–brown laminated, calcareous silt; at 1.0 m first level of syngenetic cracks; at 1.4 m second level of syngenetic cracks; at a depth of 1.0 m — decalcification level
2.0–2.5	Banded loess sub-lithofacies — yellow–brown banded, calcareous silt; in the bottom layer single inserts of fine sand
> 2.5	Glaciofluvial sands and gravels, cross-bedding

Stare Objezierze 1 (65.0 m a.s.l.):

0.0–0.3 m	Humic horizon of the surface soil
0.3–1.55	Argillaceous loess — brown-yellowish heterogeneous, calcareous silt; at 1.35–1.40 m level calcium carbonate accumulation
1.55–1.85	Cryptolaminated loess sub-lithofacies — yellow–brown, cryptolaminated calcareous silt; at 1.55 m discrete frost cracks with clay-carbonate filling
1.85–2.57	Laminated loess sub-lithofacies — yellow–brown, laminated calcareous silt
2.57–3.8	Banded loess sub-lithofacies — yellow–brown, banded calcareous silt; in the bottom layer single lenses of fine sand
> 3.8	Glaciofluvial gravels, cross-bedding

Żelichów 1 (72.7 m a.s.l):

0.0–0.3 m	Humic horizon of the surface soil
0.3–0.8	Massive loess lithofacies with ferruginous horizon — yellow–brown homogeneous non-calcareous silt with concentric ferruginous nodules
0.8–1.2	Massive loess lithofacies — yellow–brown homogeneous calcareous silt; in the bottom layer sigle lenses of fine and coarse sand
> 1.2	Boulder pavement; in the top layer horizon of weathered pebbles

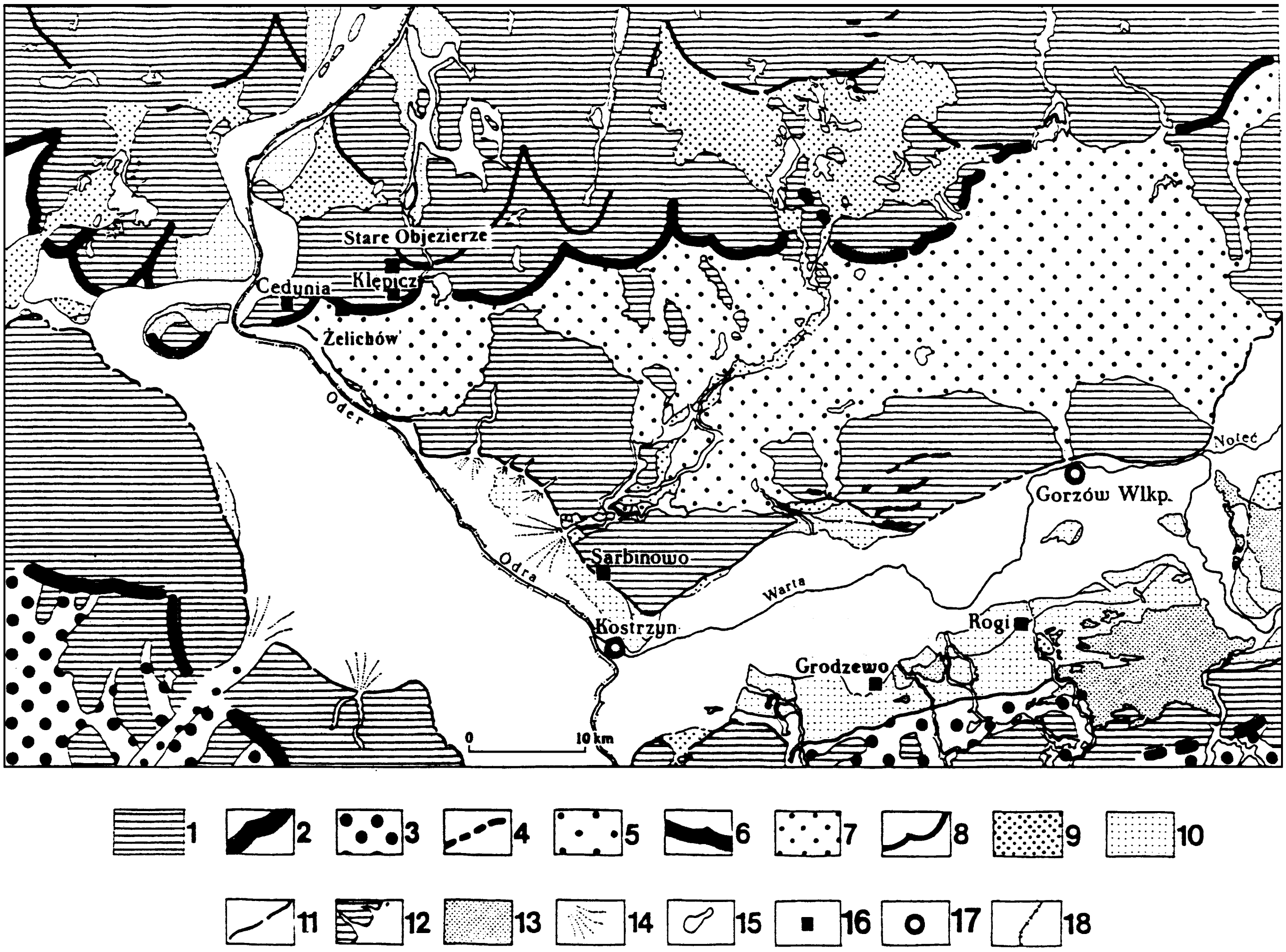

Fig. 2. Geomorphology of the Lower Warta and Lower Odra Region (Kozarski, 1965). 1. Till plains, 2. Poznań phase end moraines, 3. Poznań phase outwash plains, 4. recessional end moraines, 5. Pomeranian phase outwash plains, 6. Pomeranian phase end moraines, 7. Chojna subphase outwash plains, 8. Chojna subphase end moraines, 9. pradolina terraces, 10. Late Vistulian river terraces, 11. pradolina scarp, 12. flood plains, 13. dune fields, 14. alluvial fans, 15. lakes, 16. sites, 17. major towns, 18. state boundary.

The massive loess lithofacies (Lm) is characterized by a homogeneous grain size, a low (3.63–8.20%) content of calcium carbonate and an absence of visible sedimentary structures. The thickness of this lithofacies is from 0.6 to 1.5 m. It is covered by the 0.20–0.45 m thick humic horizon of the surface soil, except for the Stare Objezierze 2 exposure where deposits of massive loess are covered by a flow till (Fig. 4). The massive loess lithofacies directly overlies glacial (Żelichów) or glaciofluvial deposits (Klępicz 1, Stare Objezierze 2), as well as deposits of laminated loess (Klępicz 2, 4). The boundary between laminated loess and glaciofluvial deposits is discontinuous.

In the massive loess lithofacies the maximum average sand fraction (1–0.1 mm) content is 6.1–21.9%, the coarse silt fraction (100–50 μm) is 13.1–27.1%, the fine silt fraction (50–20 μm) 30.8–42.1%, the clay (< 20 μm) 20.2–36.8%, and the colloidal clay (< 2 μm) 9.7–12.3% (Table 1). The grain size distribution varies, depending upon available material transported by the wind, and later diagenetic changes and processes related to the development of the soil profile.

The massive loess has no visible structure, in the general sense, but does include periglacial structures of different type e.g. frost cracks, ice-wedges, and cryoturbations (Jersak, 1973). In the sites in question loess deposits examined macroscopically show no structures, a result confirmed by micromorphological investigation. The exception is the lowermost parts of the Żelichów, Stare Objezierze 2 and Klępicz 1 exposures. Here, small sandy interbeds (1–5 cm) are found. Optical thin sections show a compact uniform mass which has clearly been subjected to haploidization (Biernacka and Issmer, 1996). This process, in which the primary structure is completely obscured by the effects of soil processes, leads to the homogenization of deposits (Johnson and Watson-Stenger, 1987). This is evidenced by the presence of *striotubule* (= traces of earthworms; Brewer, 1976;

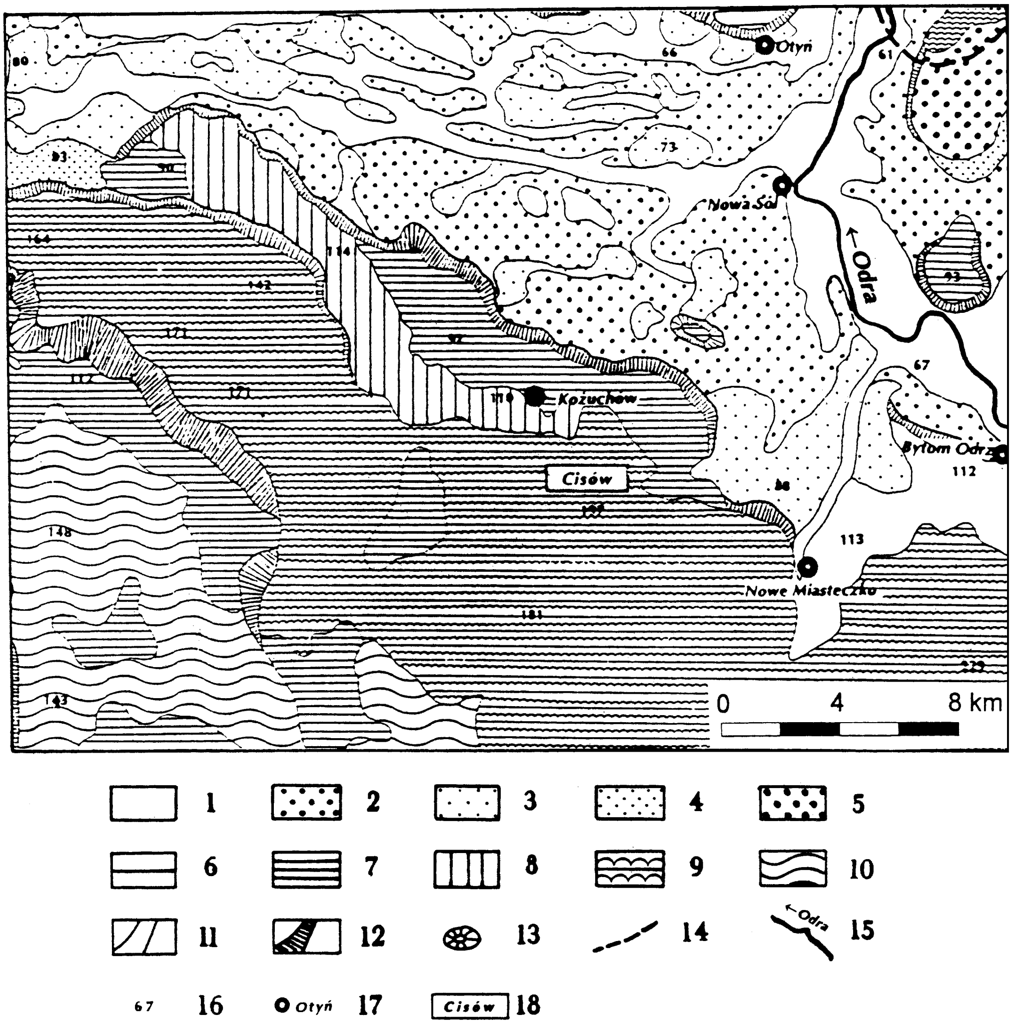

Fig. 3. A fragment of the geomorphological map (Szprotawa sheet) and legend from Krygowski (1953). 1. Flood and bottom terrace, bottoms of basins and tunnel valleys, 2. middle terrace, 3. high lower terrace, 4. high higher terrace, 5. outwash plains, 6. flat till plains, 7. undulated till plains, 8. hillocky till plains of accumulation origin, 9. a hill zone of end moraine with a higher relief, 10. strongly hillocky till plains of older glaciation, 11. tunnel valleys with a flat bottom, 12. scarps, edge lines, and valley slopes, 13. residual hills, 14. southern border of the Last Glaciation, 15. rivers, 16. altitude points, 17. towns, 18. study sites.

Brewer and Sleeman, 1988; Fig. 5) and *cutan* (= illuviated clay minerals; Brewer, 1976; Brewer and Sleeman, 1988; Fig. 6) microstructures and considerable decalcification of the upper part of the massive lithofacies.

The laminated loess lithofacies (Ll) is characterized by clear laminations, visible macroscopically as a change of colour between individual laminae and as a variation in the particle size. Yellow laminae are thicker and contain more coarse silt and calcium carbonate than brown (thinner) laminae (Issmer et al., 1990). Laminae reach a thickness of 1–5 cm. Deposits of laminated loess contain, on average, from 10.45 to 13.63% calcium carbonate. This lithofacies contains three sub-lithofacies: cryptolaminated loess (sl), laminated loess sensu stricto (ll) and banded loess (sm).

The thickness of the laminated loess lithofacies ranges from 0.30 to 1.25 m. In Western Pomerania, it is covered either by a 0.20-m-thick humic horizon of the surface soil or by other lithofacies variants of loess, and rests directly on fluvioglacial deposits originating from the Pomeranian phase, in the form of sands and gravels (Fig. 4). In addition to the laminae, this lithofacies also contains syngenetic cracks making up hexagonal polygons (Fig. 7), as well as small (1–2 cm) faults, and single undulations such as inserts or lenses consisting of material different from the main body of the lithofacies. These structures have many features in common with those of periglacial origin (Dylik, 1963; Jahn, 1970; Goździk, 1973; Washburn, 1979). Within the series was also found a group of periglacial microstuctures e.g. silt droplets, microcracks with clastic infillings, and *quasidish*

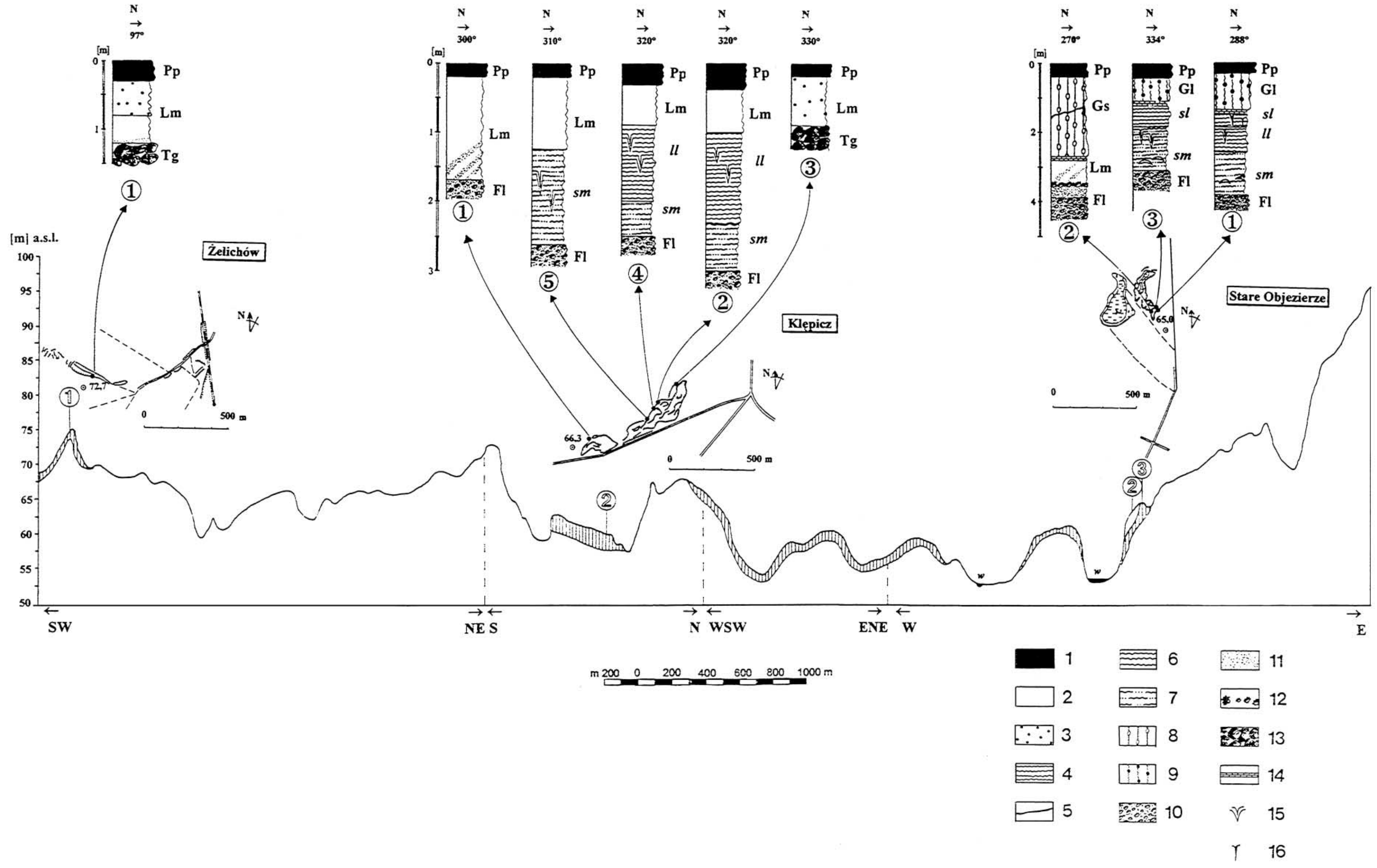

Fig. 4. Morphological profile through moraine upland and end moraines with marked places of loess deposits and individual lithological profiles for the Żelichów, Klępicz and Stare Objezierze sites (Western Pomerania). Legend for lithological profiles Żelichów, Klępicz and Stare Objezierze: 1. humic horizon of the surface soil (Pp), 2. massive loess (Lm), 3. ferriferous horizons, 4. cryptolaminated loess (sl), 5. clay material accumulation horizons, 6. laminated loess sensu stricto (ll), 7. banded loess (sm), 8. flow till (Gs), 9. argillaceous loess (Gl), 10. cross-bedding sands, gravels and fluvioglacial stones (Fl), 11. structureless fluvioglacial sands (Fl), 12. the horizons of the so-called weathered pebbles, 13. boulder pavement (Tg), 14. the horizons of calcium carbonate accumulation, 15. syngenetic cracks, 16. cracks with clay-carbonate filling.

Table 1
Grain size distribution of massive loess lithofacies[a]

	Gravel (> 1 mm)	Sand (1–0.1 mm)	Silt (100–20 µm)		Clay (< 20 µm)	
			Coarse silt (100–50 µm)	Fine silt (50–20 µm)	< 20 µm	< 2 µm
Klępicz						
Max	—	10.0	28.6	47.9	46.1	20.3
Min	—	1.6	14.3	36.2	25.3	5.3
$\bar{x}$	—	6.1	19.7	42.1	32.1	12.1
σ	—	2.7	3.7	3.1	5.4	4.1
Stare Objezierze						
Max	5.3	15.0	18.4	49.6	39.5	11.7
Min	0.0	6.0	4.9	29.1	34.5	7.9
$\bar{x}$	1.8	9.2	13.1	39.1	36.8	9.7
σ	2.5	4.1	5.9	8.4	2.1	1.6
Żelichów						
Max	0.5	31.4	36.5	37.2	27.8	18.3
Min	0.0	16.1	19.1	24.2	11.8	7.9
$\bar{x}$	0.2	21.9	27.1	30.8	20.2	12.3
σ	0.2	6.1	5.5	4.7	5.7	3.7
Cisów						
Max	0.5	29.7	23.8	51.4	47.3	28.2
Min	0.0	2.9	9.9	23.8	20.0	2.2
$\bar{x}$	0.0	12.3	17.1	38.8	31.8	13.6
σ	0.1	9.2	3.2	8.1	6.4	6.2

[a] max — maximum (%), min — minimum (%), $\bar{x}$ — arithmetic mean (%), σ — standard deviation. Grain size classification after Polish Pedological Society (Mocek et al., 1997).

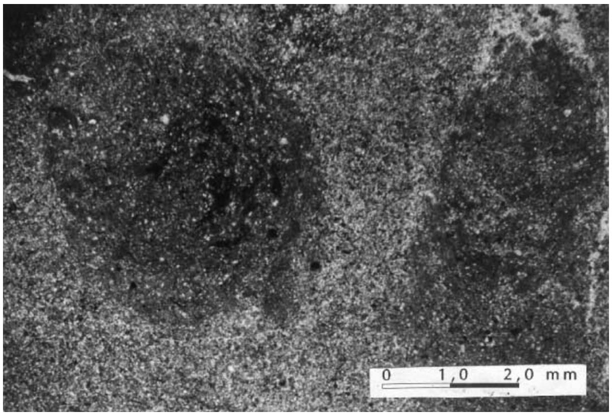

Fig. 5. Traces of earthworms (*striotubule*). Klępicz 4, depth 1.7 m; plane-polarized light.

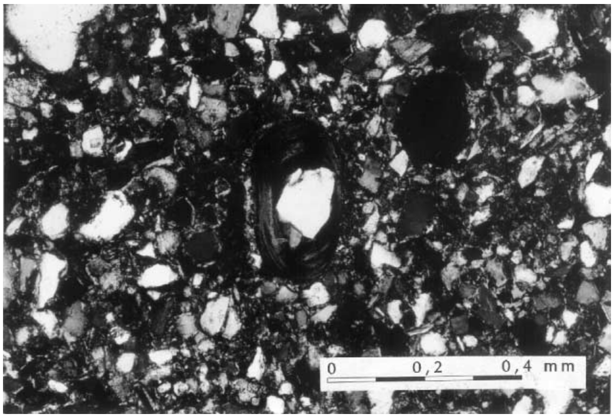

Fig. 6. Illuviated clay minerals (*cutan*). Klępicz 4, depth 0.9 m; crossed polars.

(= "water-escape") structures indicative of the former presence of a periglacial climate (Coutard and Mücher, 1985; Mücher, 1986; van der Meer, 1987; Hujizer, 1993; Biernacka and Issmer, 1996).

The grain size distribution of the laminated loess lithofacies varies with each sublithofacies, but fine silt is dominant in all cases. The cryptolaminated loess sub-lithofacies contains, on average, 6.9% sand, 25.1% coarse silt, 40.9% fine silt and 27.0% clay, of which 9.0% is colloidal clay. The banded loess lithofacies contains from 17.1 to 45.9% sand, 24.2 to 24.7% coarse silt, 16.8 to 25.8% fine silt and 13.1 to 31.9% clay, of which 7.3 to 14.1% is colloidal clay (Table 2). The change of grain size visible in the banded loess sub-lithofacies is caused by the presence of single sandy inserts with lenticular bedding.

3.2. Loess deposits of the Dalków Hills

The loess deposits of the Dalków Hills occur in two lithofacies directly linked to a former periglacial environment

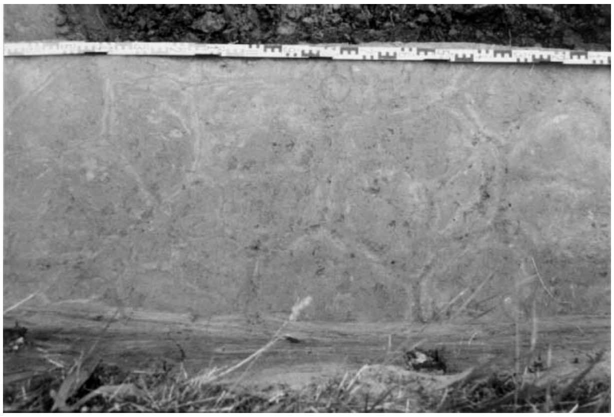

Fig. 7. Hexagonal polygons of syngenetic cracks. Klępicz 4, depth 1.41 m.

and associated aeolian processes. Massive loess lithofacies and the cryptolaminated variant of the laminated loess lithofacies have been recognised (Issmer, 1999). The lithology of the loess profiles is as follows:

Cisów 1 (165.0 m a.s.l):

0.0–0.1 m	Humic horizon of the surface soil
0.1–1.4	Massive loess lithofacies — brown homogeneous non-calcareous silt; at 0.7 and 1.1 m levels frost fissures were identified
1.4–3.0	Cryptolaminated loess sublithofacies — dark yellow–brown cryptolaminated non-calcareous silt
> 3.0	Medium sized and coarse sands with single pebbles; single inserts of light grey muds

Cisów 2 (162.5 m a.s.l.):

0.0–0.1 m	Humic horizon of the surface soil
0.1–0.6	Massive loess lithofacies — brown homogeneous non-calcareous silt
0.6–0.7	Structureless glaciofluvial sand
> 0.7	Brown till, many pebbles in the top layer

Cisów 3 (175.0 m a.s.l.):

0.0–0.45 m	Humic horizon of the surface soil
0.45–2.1	Massive loess lithofacies — brown homogeneous non-calcareous silt; in the bottom layer single inserts of fine sand
2.1–2.25	Dark grey very clayey till
> 2.25	Structureless glaciofluvial sands and gravels

The massive loess lithofacies (Lm) features massive non-carbonate loess deposits in the upper layer. The thickness of this lithofacies is from 0.50 to 1.65 m (Fig. 8). At the Cisów 1 site, at a depth of 0.7 and 1.1 m, frost fissures were found that, in the horizontal plane, form unclear hexagonal polygons. At this site the massive loess lithofacies passes directly into the laminated loess lithofacies in the form of the cryptolaminated loess sub-lithofacies. The massive loess lithofacies contains 38.8% fine silt, 17.1% coarse silt, 31.8% clay, and 13.6% colloidal clay (Table 1).

The cryptolaminated loess lithofacies (sl) is described from only one study site (Cisów 1). Here, this lithofacies is 1.65 m thick. Individual laminae are 1–2 cm thick, from dark yellow to brown. The contact between cryptolaminated loess deposits and the underlying deposits is very clear. At this study site, fine silt averages 42% with 33.2% clay; the percentage of colloidal clay being around 11.2% (Table 2).

At all investigated sites in the Dalków Hills (Cisów 1, 2 and 3) more sandy material is noticeable in the lower parts of the loess series, i.e. when it comes in contact with glaciofluvial deposits (Fig. 8). The ice-sheet left glacial deposits in the form of tills, sands and glaciofluvial gravels and was responsible for glaciotectonic thrusting of the patchy Pliocene clays (Mojski, Kawecka, 1976).

All study sites have very low calcium carbonate contents; the average percentage in the profiles being only 2.87 (Cisów 2) to 4.58% (Cisów 1). Such low values, even at considerable depth (2.9 m — Cisów 1), is attributable to decalcification of deposits within the periglacial erosional valleys. Vreeken and Mücher (1981) investigated areas of the Netherlands and found that, within dry periglacial valleys where dewatering led to increased permeability, the decalcification processes are greater in the loess compared to areas composed of other materials.

4. Palaeoenvironmental implications

It is notable that no fossil soil horizons or other biostratigraphic data have yet been found in the loess deposits of western Poland. An attempt to date the Pomeranian loess at the Klępicz site using the thermoluminescence (TL) method did not produce satisfactory results, because the standard error reached 165% (Bluszcz et al., 1992). It is considered that TL dating may distinguish statistically two phases of Pomeranian loess accumulation in the time range 20–7 ka BP. However, as biostratigraphic data are lacking and the TL method has so far proved unreliable, reliance is placed here on lithofacial analysis for the establishment of a lithostratigraphic sequence in the loess.

It has been shown that, for Western Pomerania, the loess consists of two main lithofacies that rest upon glaciofluvial and glacial deposits of the Pomeranian phase of the Last glaciation (16.2 ka BP). The banded loess (sm) sub-facies of the laminated loess rests directly on the underlying materials. This sub-lithofacies is thicker in the north-eastern part of the loess patch (Stare Objezierze) and thinnest in the south-western part (Klępicz) (Fig. 4). The periglacial structures found within this sub-facies indicate that, in the first accumulation phase of the Pomeranian loess, permafrost had existed

Table 2
Grain size distribution of laminated loess sublithofacies[a]

	Gravel (> 1 mm)	Sand (1–0.1 mm)	Silt (100–20 µm)		Clay (< 20 µm)	
			Coarse silt (100–50 µm)	Fine silt (50–20 µm)	< 20 µm	< 2 µm
Cryptolaminated loess sublithofacies (sl)						
Stare Objezierze						
Max	0.5	23.6	44.3	48.1	34.1	11.9
Min	0.0	2.5	18.0	25.0	14.7	7.3
$\bar{x}$	0.1	6.9	25.1	40.9	27.0	9.0
σ	0.1	5.0	7.5	6.5	5.7	1.3
Cisów						
Max	—	5.1	26.3	44.2	39.1	14.5
Min	—	3.7	16.7	40.2	27.4	7.7
$\bar{x}$	—	4.4	20.4	42.0	33.2	11.2
σ	—	0.6	3.3	1.3	4.4	2.4
Laminated sensu stricto loess sublithofacies (ll)						
Klępicz						
Max	—	49.8	38.1	53.3	85.1	27.0
Min	—	1.0	3.0	9.2	15.4	8.2
$\bar{x}$	—	6.6	19.4	36.6	37.4	14.9
σ	—	10.9	9.8	12.1	15.3	4.7
Stare Objezierze						
Max	1.0	13.6	32.5	48.3	33.3	12.5
Min	0.0	3.3	13.1	36.1	20.1	5.4
$\bar{x}$	0.2	8.1	21.4	42.8	27.4	8.2
σ	0.2	2.6	4.3	2.7	3.4	1.6
Banded loess sublithofacies (sm)						
Klępicz						
Max	—	62.3	37.2	45.2	78.0	33.1
Min	—	1.7	6.4	6.1	12.1	6.6
$\bar{x}$	—	17.7	24.7	25.8	31.9	14.1
σ	—	15.2	10.3	8.8	18.3	6.1
Stare Objezierze						
Max	—	87.6	47.0	52.0	30.7	13.9
Min	—	6.1	10.5	1.9	0.0	0.0
$\bar{x}$	—	45.9	24.2	16.8	13.1	7.3
σ	—	20.0	6.7	11.3	6.3	2.6

[a] max — maximum (%), min — minimum (%), $\bar{x}$ — arithmetic mean (%), σ — standard deviation. Grain size classification after Polish Pedological Society (Mocek et al., 1997).

for many years. The presence of permafrost is confirmed by lithofacial analysis of this series, and similar facies have been described from Spitsbergen (Bryant, 1982), Greenland, and Alaska (Hamilton et al., 1987; Dijkmans and Koster, 1988; Koster, 1995).

Under favourable aerodynamic conditions, accumulation of banded loess could be synchronous with accumulation of massive loess (site Żelichów). The relationship between these structureless loesses and the periglacial zone is emphasized by the presence of pebbles at the base of this series on which traces of thermal contraction can be found.

Generally, the massive facies of the Pomeranian loess occur in subaereal positions. However, in the Stare Objezierze 2 exposure they are covered by a flow till (Gs) nearly 3 m thick. Thus, these loess deposits are regarded as a 'fossil' type. The stratigraphic position of the thinner series of massive loess in the Stare Objezierze 2 exposure has stratigraphic significance for the Pomeranian loess deposits (Issmer, 1995).

The thickness of the laminated loess sub-lithofacies sensu stricto (ll) increases towards the south-west within the loess patch (Fig. 4). Structures such as syngenetic cracks and a group of periglacial microstuctures,

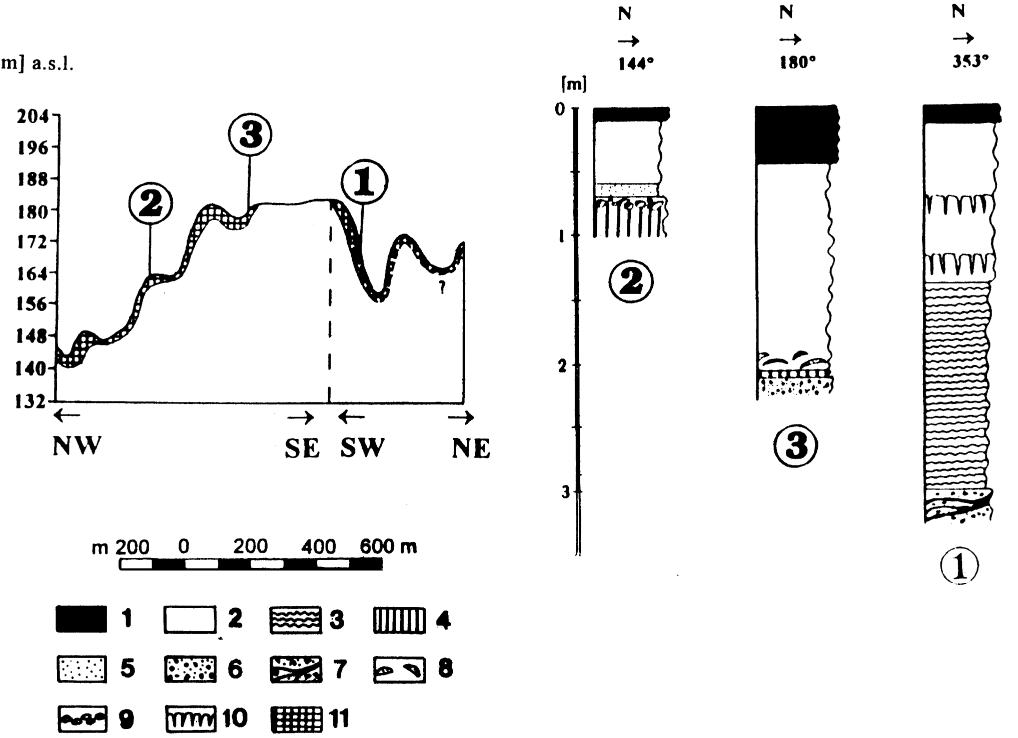

Fig. 8. Morphological profile through the end moraine with loess deposits and lithological profiles for the Cisów study sites (Dalków Hills). Legend to Cisów lithological profiles: 1. humic horizon of the surface soil, 2. massive loess, 3. cryptolaminated loess, 4. till, 5. structureless glaciofluvial sands, 6. structureless glaciofluvial sands and gravels, 7. muds and clayey inserts within glaciofluvial deposits, 8. sandy inserts, 9. stone levels, 10. fissures levels, 11. loess deposits.

indicating the presence of former periglacial conditions, also occur within this series. Thus, accumulation of massive loess on favourable surfaces continued during the accumulation of the laminated loess.

In the distinctive lithostratigraphic situation found in Western Pomerania, it can be said that loess deposition was able to commence after the ice-sheet had receded from the area. It follows that accumulation of the Pomeranian loess generally occurred in the Late Vistulian. Intensification of the supply of silty material and accumulation or redeposition of loess during the cooler periods probably occurred in the presence of continuous or non-continuous permafrost, as indicated by the presence of many periglacial structures in these deposits. On the other hand, accumulation and redeposition of loess also occurred during warmer periods, although to a slightly more limited extent. This conclusion is based on the occurrence of aeolian cover sands and dune fields over extensive areas of Western Pomerania (Stankowski, 1963; Kozarski and Nowaczyk, 1992). Therefore, the loess deposits of Western Pomerania discussed here, with an origin attributable to the the same aeolian factor, could have developed in the same period, i.e. the in Late Vistulian. On the other hand, the development of the soil profile and post-depositional diagenetic changes would have contributed to the obliteration of the primary structures in these deposits.

In the Dalków Hills, only two loess lithofacies (described as massive loess lithofacies and cryptolaminated sublithofacies) have been found (Fig. 8). The loess lithofacies at Cisów (Dalków Hills), found within the range of influence of periglacial processes and phenomena occurring during the Vistulian, accumulated on the end moraines of the Wartanian stage at 160–175 m asl. On litho- and morphostratigraphic grounds, the origin of the loess series at Cisów should be related to the Leszno phase of the Last glaciation (20 ka BP) (Issmer, 1999). The relationship between the Vistulian loess and the glacial deposits and forms is not only morphological but also genetic.

In general, loess deposits described from western Poland constitute periglacial loess and were deposited in the Vistulian. In Western Pomerania, loess rests on the Pomeranian end moraine (16.2 ka BP, Kozarski, 1995) and, in the Dalków Hills they cover the Wartanian stage end moraine, but they acumulated during the Leszno phase of the Last glaciation (20 ka BP).

Goossens (1988) is of the opinion that silty deposits with an average grain diameter of 30 μm mainly accumulate in front of orographic obstacles or directly on the obstacles, depending on the dominant wind direction. The orographic obstacle itself strengthens the turbulence of the moving air but does not weaken the accumulation process. The loess deposits in western Poland, occurring in the upper parts of the end moraines of the Last glaciation (Western Pomerania) and the Middle Polish glaciation (Dalków Hills) are consistent with the views of Goossens (1988) that loess deposits can accumulate in areas of increased turbulence, that is on the highest parts of an orographic feature.

5. Conclusions

(1) The lithological variability of loess deposits in western Poland, manifested in the lithofacial variability, indicates both the lithological differentiation of the areas of alimentation and different climatic conditions between 20 and 16.2 ka BP.

(2) These loess lithofacies were clearly connected to the former periglacial zone and the associated aeolian processes that prevailed during the Vistulian in western Poland. It is clear that the beginning of the accumulation of the loess deposits of the Dalków Hills and Western Pomerania occurred in the Plenivistulian. The genesis of the subaereal loess series was fundamentally linked to the presence of a periglacial zone. Consequently, these deposits should be termed Vistulian periglacial loess deposits (Maruszczak, 1990).

(3) Lithostratigraphic investigations lead to the conclusion that the loess lithofacies in western Poland are associated with a varied topography and are distributed on end moraines, till plains and outwash plains.

(4) Apart from the lithological and climatic factors, the morphological factor should also be considered as it conditions the origin of loess mantles in certain places. Non-continuous loess covers in the uper parts of end moraines (the Pomeranian phase end moraine and the Wartanian stage end moraine, Figs. 4 and 8) point to the fact that it was mainly aeolian transport in all its variations that was responsible for the delivery of silty materials to these sites.

References

Berendt, G., Finckh, L., Korn, J., Schroder, H., 1908. Erläuterungen zur Geologischen Karte von Preußen und benachbarten Bundesstandten. Lieferung 81, Blatt Zehden, Gradabteilung 45, 12, Berlin, 87 pp.

Biernacka, J., Issmer, K., 1996. Analiza mikrostrukturalna osadów lessowych w Klępiczu Pomorze Zachodnie (Summary: Micromorphological analysis of loess deposits from Klępicz, Western Pomerania). Przegląd Geologiczny 44 (1), 43–48.

Bluszcz, A., Kozarski, S., Nowaczyk, B., 1992. Termoluminescencyjne datowanie vistuliańskich pokryw lessowych Pomorza Zachodniego (Summary: Thermoluminescence dating of Vistulian loessy cover in Western Pomerania). Zeszyty Naukowe Politechniki Śląskiej, Geochronometria 10, 225–251.

Brewer, R., 1976. Fabric and Mineral Analysis of Soils. Krieger, Huntington, 482 pp.

Brewer, R., Sleeman, J.R., 1988. Soil Structure and Fabric. CSIRO Australia, Division of Soils, Adelaide, 173 pp.

Brodzikowski, K., 1986. Środowiskowe podstawy analizy i interpretacji glacitektonizmu Eurpy Środkowej (Summary: Environmental principles of analysis and interpretation of glacitectonism in Central Europe). Acta Univesitatis Wratislaviensis, 934, Studia Geograficzne 43, 331.

Bryant, I.D., 1982. Loess deposits in Lower Adventdalen, Spistbergen. Polar Research 2, 2–103.

Cegła, J., Kozarski, S., 1976. Osady lessopodobne na morenach czołowych stadium pomorskiego fazy zasięgu maksymalnego lobu Odry. Sprawozdania PTPN 91, 38–40.

Coutard, J.P., Mücher, H., 1985. Deformation of laminated silt loam due to repeated freezing and thawing cycles. Earth Surface Processes and Landforms 10, 309–319.

Dammer, B., 1941. Öber Flottsande in der Östlichen Mark Brandenburg. Jb. Reichss Bodenforsch. Bd 61, 186–197.

Dyjor, S., 1991. Wpływ ewolucji paleogeograficznej na rozwój zlodowaceń w Polsce zachodniej (Summary: Influence of the palaeogeographical evolution on the development of glaciations in western Poland). In: Kostrzewski, A. (Ed.), Geneza, litologia i stratygrafia utworów czwatorzędowych, UAM Seria Geografia, Vol. 50, pp. 419–433.

Dylik, J., 1963. Nowe problemy wiecznej zmarzliny plejstoceńskiej. Acta Geographica Lodziensia 17, 98.

Goossens, D., 1988. The effect of surface curvature on the deposition of loess: a phisical model. Catena 15 (2), 179–194.

Goździk, J., 1973. Geneza i pozycja stratygraficzna struktur peryglacjalnych w środkowej Polsce (Summary: Origin and stratigraphical position of periglacial structures in Middle Poland). Acta Geographica Lodziensia 31, 119.

Hamilton, T., Galloway, J.P., Koster, E., 1987. Late Wisconsin Activity and Related Alluviation. Central Kobuk River Valley, Geological Studies in Alaska, US Geological Survey, pp. 39–43.

Hujizer, A.S., 1993. Cryogenic microfabrics and macrostructures: Interrelations, processes, and paleoenvironmental significance. Vrije Univesitet, 245 pp.

Issmer, K., 1995. Analiza litofacjalna i litostratygrafia osadów lessowych w strefie kontaktu z osadami glacjalnymi fazy pomorskiej ostatniego zlodowacenia w Starym Objezierzu, Pomorze Zachodnie (Summary: Lithofacies analysis and loess sequences in the contact zone with glacial deposits of the Last glaciation Pomeranian phase at Stare Objezierze, Western Pomerania). Badania Fizjograficzne nad Polską Zachodnią. 46, A, Geografia fizyczna, 63–84.

Issmer, K., 1998. Analiza litofacjalna osadów lessowych północnozachodniej Polski (Summary: Lithofacial analysis of loess deposits in the north western Poland) In: Pękala, K. (Ed.), Główne kierunki badań geomorfologicznych w Polsce stan aktualny i perspektywy. IV Zjazad Geomorfologów Polskich, June, 3–6 Lublin, pp. 293–305.

Issmer, K., 1999. Vistulian loess deposits of the Dalków Hills. Geological Quarterly 43 (1), 113–120.

Issmer, K., Kozarski, S., Nowaczyk, B., 1990. Late Vistulian loess on Pomeranian landform and deposits. In: Kozarski, S., Nowaczyk, B. (Eds.), International Symposium: Late Vistulian and Holocen aeolian phenomena in Central and Northern Europe, 14–18 May, 1990, Poland. Guide-Book of Excursions.

Jahn, A., 1970. Zagadnienia strefy peryglacjalnej. PWN, Warszwa, 202 pp.

Jersak, J., 1973. Litologia i stratygrafia lessu wyżyn południowej Polski (Summary: Lithology and stratigraphy of the loess on the Southern Polish Uplands). Acta Geographica Lodziensia 32, 142.

Johnson, D.L., Watson-Stegner, D., 1987. Evolution model of pedogenesis. Soil Science 143 (5), 349–366.

Kolstrup, E., 1991. Danish Weichselian and Holocene aeolian deposits. Zeitschrift für Geomorphologie, Supplementband 90, 89–97.

Koster, E., 1995. Progress in cold-climate aeolian research. Questiones Geographicae (Special Issue 4) Adam Mickiewicz University Press, Poznań, pp. 155–163.

Koster, E., Dijkmans, J.W.A., 1988. Niveo-aeolian deposits and denivation forms, with special references to the Great Kobuk sand dunes, Northwestern Alaska. Earth Surface Processes and Landforms 13, 153–170.

Kowalkowski, A., 1966. Główne kierunki rozwoju gleb w warunkach środowiska morfogenetycznego Wzgórz Dalkowskich (Summary: Main trends in development of soils in conditions of Dalkowo Hills morphogenetic environment). Roczniki Gleboznawcze 16 (2), 357–411.

Kozarski, S., 1965. Zagadnienie drogi odpływu wód pradolinnych z zachodniej części Pradoliny Noteci — Warty (Summary: The problem of outflow way of pradolina waters from the west part of the Noteć-Warta Pradolina). PTPN, Prace Komisji Geograficzno-Geologicznej 5 (1), 154.

Kozarski, S., 1995. Deglacjacja północno-zachodniej Polski: warunki środowiska i transformacja geosystemu (~ 20 ka → 10 ka BP) (Summary: Deglaciation of northwestern Poland: environmental conditions and geosystem transformation ~ 20 ka → 10 ka BP). Dokumentacja Geograficzna 1 (PAN IGiPZ) 82.

Kozarski, S., Nowaczyk, B., 1991. Lithofacies variation and chronostratigraphy of Late Vistulian and Holocene aeolian phenomena in northwestern Poland. Zeitschrift für Geomorphologie, Supplementband 90, 107–122.

Kozarski, S., Nowaczyk, B., 1992. Późnovistuliańskie i holoceńskie zjawiska eoliczne w regionie dolnej Odry i dolnej Warty (Summary: Lithofacies variation and chronostratigraphy of Late Vistulian and Holocene aeolian phenomena in northwestern Poland). In: Szczypek, T. (Ed.), Wybrane zagadnienia geomorfologii eolicznej. UŚ Wyd. Nauk o Ziemi, pp. 37–114.

Krygowski, B., 1953. Mapa Geomorfologiczna, Nizina Wielkopolska, skala 1:100,000, współpraca Bartkowski, A. Kowalska, E. Staszewski, A. Karczewski, S. Kozarski, L. Krygowska, L. Pilarczyk, K. Rotnicki, M. Żurawski, S. Żynda.

Krygowski, B., 1972. Nizina Wielkopolska. In: Galon, R. (Ed.), Geomorfologia Polski Vol. 2. PWN, Warszawa, pp. 186–223.

Maruszczak, H., 1990. Zróżnicowanie strefowe lessów na półkuli wschodniej, Przegląd Geograficzny (Summary: Zonal differentiation of loesses on the Eastern hemisphere) 62 (1–2), 51–72.

Mocek, A., Drzymała, S., Maszner, P., 1997. Geneza, analiza i klasyfikacja gleb. Akademia Rolnicza, Poznań, 416 pp.

Mojski, J.E., Kawecka, A., 1976. Podstawowa mapa 1 : 50 000 do Mapy Geologicznej Polski 1 : 200,000, A. Mapa utworów powierzchniowych, arkusz Zielona Góra.

Mücher, H., 1986. Aspects of loess and loess-drived Slope deposits: an experimental and micromorphological approach. Nederlandse Geografische Studies 23. Koninklijk Nederlands Aardijkskundig Genootschap. Fysisch Geografisch en Bodemkundig Laboratorium Universiteit van Amsterdam, 267 pp.

Rokicki, J., 1952. Less i utwory pyłowe Wzgórz Trzebnickich. Biuletyn Państwowego Instytutu Geologicznego 65, 479–512.

Rotnicki, K., 1960. Uwagi o genezie Wzgórz Ostrzeszowskich w świetle nowych danych geologicznych i geofizycznych (Summary: Considerations on the genesis of the Ostrzeszów Hills (Southern Great-Poland Lowland, Warta Stadium) in the light of new geological and geophysical data). Zeszyty Naukowe UAM, Geografia 3, 105–124.

Rotnicki, K., 1966. Rzeźba Wzgórz Ostrzeszowskich jako rezultat rozwoju stoku podczas Würmu (Summary: The relief of the Ostrzeszów Hills as results of slope development during the Würm). PTPN, Wydz. Mat.-Przyr., Prace Komisji Geograficzno-Geologicznej, 5, 2, Poznań, 260 pp.

Schoenhals, E., 1944. Jungglazialer Loess auf Ruegen. Ber. Reichsamt. Bodenforsch. 1/4, 45–49.

Siebertz, H., 1988. Die Beziehumg der äolischen Decksedimente in Nordwestdeutschland zur nördlichen Lößgrenze, Eiszeitalter u. Gegenwart 38, 106–114.

Stankowski, W., 1963. Rzeźba eoliczna Polski północno-zachodniej na podstawie wybranych obszarów (Summary: Eolian relief of northwest Poland on the ground of chosen regions). PTPN Prace Komisji Geograficzno-Geologicznej 4 (1), 146.

Szczepankiewicz, S., 1989. Ziemie południowo-zachodniej Polski, morfogeneza i dzieje czwartorzędowe (Summary: The lands of southern Poland — morphogenesis and Quaternary history). Acta Univesitatis Wratislaviensis, 1029, Studia Geograficzne 47, 136.

van der Meer, J.J.M., 1987. Micromorphology of glacial sediments as a tool in distinguishing genetic varieties of till. Geological Survey of Finland Special Paper 3, pp. 77–89.

Vreeken, W.J., Mücher, H.J., 1981. (Re)deposition of loess in Southern Limbourg, The Netherlands. 1. Field evidence for conditions of deposition of the Lower Silt Loam Complex. Earth Surface Processes and Landforms 6 (3–4), 337–354.

Washburn, A.L., 1979. In: Geocryology. A Survey of Periglacial Processes and Environments. E. Arnold Publishers, London, 406 pp.