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THE EVOLUTION OF LOESS COVERS IN POLAND BETWEEN 20 AND 8 KA BP

Abstract

An evolution of loess covers in the period 20–8 ka BP took place in three phases. They are as follows: a phase of loess accumulation (the younger loess IIb – 21–14 ka BP), a phase of streambed erosion in river valleys and gully erosion in ephemerally flooded valleys (14–10 ka BP), and a phase of intensive chemical weathering and soil development (10–8 ka BP).

Lithological variability of loess types cause necessity of distinguishing dry, intermediate and temperate-humid loess formations. In all of them a cryogenic horizon with ice-wedge pseudomorphoses was created short time before the end of aeolian accumulation.

The main river valleys attained, as a result of erosion, the level of present-day flood terrace, before 13 ka BP. The gully erosion have been developed in tributary valleys since at least 12,5 ka BP, and from 10 ka BP a chemical sedimentation has dominated (peat, gyttja, locally travertine). From that time simultaneous forming of brown, lessive and chernozem soils has been started while mechanical denudation has been stopped.

In the loess-coverd areas of Poland (Fig. 1) between 20 and 8 ka BP IIb loesses of the Middle Vistula Substage,[1] slope wash deposits and Eoholocene deposits of various geneses and lithologies were accumulated. The initiation of the younger IIb loess accumulation is evident by the youngest radiocarbon dating available for the Komorniki horizon which immediately underlies the loess. The latter is generally correlated with the Stillfried B., Hengelo-Denekamp, Dubno, Briańsk and PK1 horizons. In the loess profiles of Poland this horizon consists of tundra brown soil with overlying pseudogley or hydromorphous soil and also deposits which have formed in thermokarst depressions. This horizon coincidents with the boundary between the middle and the main Palaeolithic times. It contains artefacts, mammal bones, charcoal and peat relicts.

The sedimentary nature of the several Palaeolithic sites near Kraków (Piekary, Zwierzyniec and Spadzista) have been described by Kozłowski, Sobczyk (1987) and Chmielewski (Chmielewski *et al.*, 1977; Fig. 1). The peat deposits which underlie the IIb loess have been extensively investigated in the Jarosław profile (Maruszczak 1985). Hydromorphous deposits which correspond to the Komorniki horizon have been described in sev-

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[1] The stratigraphic division of the Vistulian suggested by Jersak, Sendobry and Śnieszko (1992) for the loess-covered areas of Poland is that used in this paper.

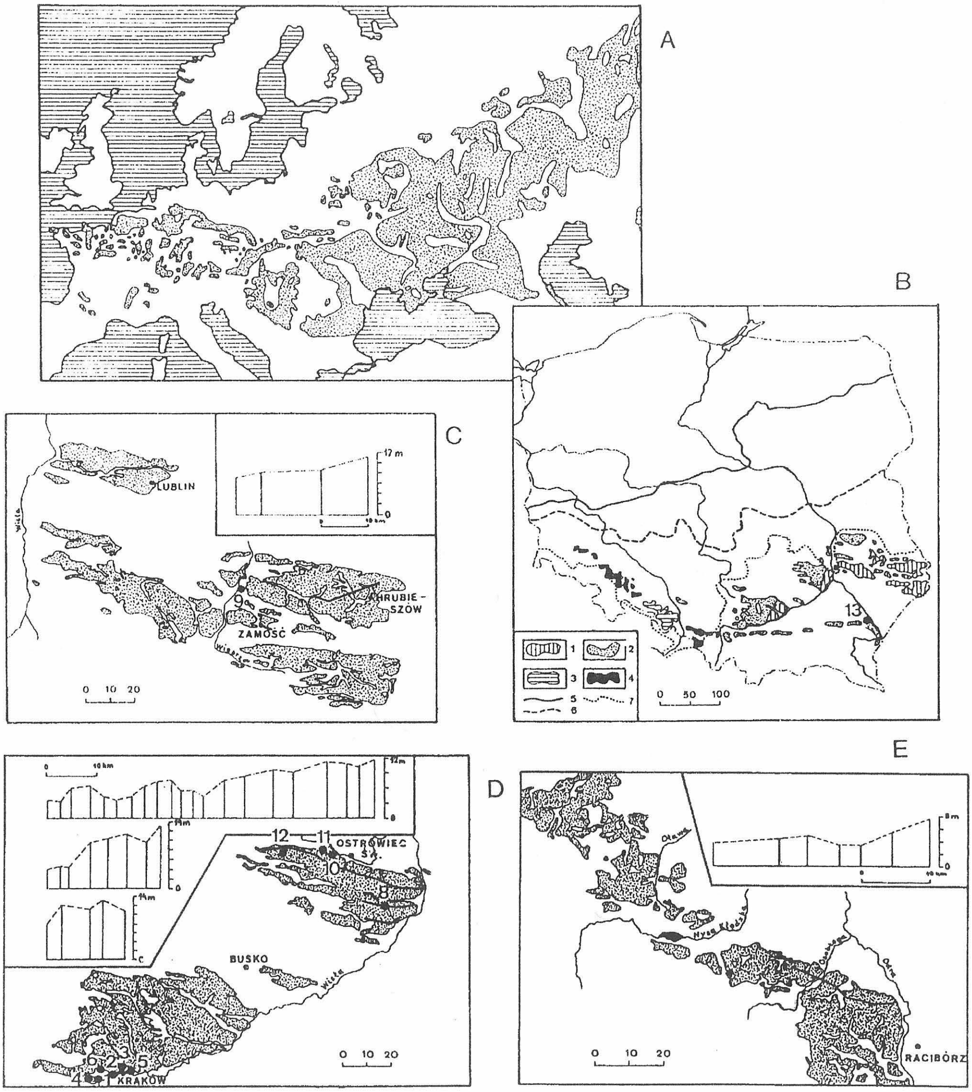


Fig. 1. Distribution of loess in Europa with special reference to Poland

A – distribution of loess in Europe; B – distribution of loess in Poland; C – loess cover in the Lublin Upland; D – loess cover in the Małopolska Upland; E – loess cover in west Poland; 1. loess of dry formation; 2. loess of intermediate formation; 3. loess of temperate humid formation; 4. loess of humid formation; 5. maximum extent of the Vistula Stage ice-sheet; 6. maximum extent of the Odra Stage ice-sheet. Numbers 1–12 – sites cited in the text: 1. Piekary; 2. Zwierzyniec; 3. Spadzista; 4. Ściejowice; 5. Kraków Nowa Huta; 6. Kryspinów; 7. Brzeźnica; 8. Rożki; 9. Tarzymiechy; 10. Nietulisko Małe; 11. Kunów-Ciołek; 12. Sieradowice

eral profiles of terrace deposits, e.g. at Ściejowice, Kraków – Nowa Huta, Brzeźnica and Kryspinów (MAMAKOWA, RUTKOWSKI, 1989a, 1989b; MAMAKOWA, ŚRODOŃ, 1977; MAMAKOWA, STARKEL, 1974).

The ^{14}C datings established for the Komorniki horizon were obtained from bone material, charcoal and humus. The ^{14}C datings of the bones from the Komorniki horizon at Spadzista (17,4–21 ka BP) correlate with ^{14}C datings from charcoal present in that horizon (23–24,4 ka BP) (KOZŁOWSKI, SOBCZYK, 1987). The datings for the humus fraction of the hydromorphous soil at Jarosław range between 21,6 and 27,3 ka BP MARUSZCZAK 1985).

The TL datings for the Komorniki horizon are of the order of 50 ka BP (MARUSZCZAK, 1991) but the Authors regard this method to be so error-strewn that no further consideration is given to the results here.

Thus, to summarise, on the ^{14}C datings of material from the horizons which underlie the IIb loesses it may reasonably be concluded that the loess accumulation began not earlier than 20 ka BP.

Palynologic and palaeopedologic studies of the Komorniki horizon both suggest the presence of tundra (sites: Rożki, Ściejowice, Kraków – Nowa Huta, Brzeźnica) or park tundra (site Jarosław) conditions in the loess-covered areas at that time. KUBIAK considered that the bone remains from Spadzista (*Canis Lupus, Alopex lagopus, Equus caballus, Rangifer tarandus, Mummuthus primigenius*) indicate a tundra or steppe-tundra environment (KOZŁOWSKI, SOBCZYK, 1987). The occurence of charcoal in this horizon (54% of the charcoal consists of larch at Piekary) also suggest that park tundra conditions prevailed here.

It seems likely that all the plant formations mentioned above were present in the loess-covered areas in Poland. At the base of the loess terrace at Tarzymiechy (Lublin Upland) fossil remains of *Dryas octopetala, Betula nana* and *Salix herbacea* have provided radiodates of 18,4–19,3 ka BP. Such a flora suggests that tundra conditions were fully established at that time (ŚRODOŃ, 1954).

In valleys, an erosion surface is present beneath the IIb loess, and the Komorniki horizon appears to be absent. Clarely, this surface represent what is, elsewhere, the upper part of the Komorniki horizon. Studies at Piekary and Spadzista suggest that the erosion phase might have occured even later, when it was associated with the Lascaux warm period. We do not yet have sufficient data to enable us to date the younger erosion surface.

Loess deposits are present in the Polish Uplands exist in three regions: Lublin, Sandomierz and Kraków regions. They are also preserved in the Carpathian and Sudety foreland areas (MARUSZCZAK, 1991). JERSAK (1973) distinguished the following loess covers: Nałęczów, Horodło, West Roztocze and Sokal in the Lublin Upland, Opatów–Sandomierz and Miechów in the Małopolska Upland and Racibórz in West Poland.

The altitudinal range of Polish loess deposits is from 170 to 450 a.s.l. Most lie below the 350 m countour line; the IIb younger loesses are the dominant sediments at lower altitudes.

Loess has been classified into four types by JERSAK (1973); the classification is based on their lithological characteristics and the presence or absence of frost structures and fossil soils. Four types are recognised: dry loess, intermediate loess, temperate-humid loess and humid loess formations (Fig. 1B). He further classified them as topofacies: interfluve loess, slope loess and valley loess deposits.

In order to investigate the thickness of the IIb loesses several boreholes have been sunk into the horizontal segments of interfluve loess. Generally, the loess deposits of Western Poland are much thinner than those of comparable age in the east. Also in any loess cover, the western part is always thinner than the eastern (Fig. 1, C, D, E).

The thiskness of the loess in the eastern part of the Opatów/Sandomierz cover near Wisła valley varies beetween 12,5 and 14 m. The eastern part of the Horodło cover (Lublin Upland) is comparably thick, whereas in the Racibórz basin in the Odra valley of Western Poland the loess is never more than 8 m thick.

Boreholes show that in the Opatów/Sandomierz loess outcrop there is a steady reduction in the thickness of the IIb loess from east (12,5 m) to west (3,4 m) over the distance of 40 km.

JERSAK (1973) demonstrated similar change in the properties of the loess, which was most evident in terms of changes in the mean grain size and $CaCO_3$ content. There is systematic decrease in the values of both westwards across Poland; the changes are also quite evident across any single outcrop of loess. This research has been extended by DWUCET (1993, 1994) who investigated the mineral content and particle size distribution of waterproof aggregates, quantitative distribution of carbonate forms and weathered state of samples from 18 profiles from every known loess region in Poland.

As well as monomineral grains, polymineral and polydispersial elements occur in loesses; these are connected by structural bonds, the intensity of which may be evaluated by investigating the aggregatization degree using various coefficients. In this paper the Vogeler coefficient has been applied:

$$V = \frac{100\,(\mathrm{fi} - \mathrm{fai})}{\mathrm{fi}}$$

where fi – percentage content of clay in the grain size distribution;
fai – percentage content of clay in the aggregate distribution.

The bigger the value of V, the more solid the structure of the loess and the higher the degree of aggregatization.

V coefficient of mean value of loesses younger than 20 ka BP ranges from 60,2% in the dry loess formation, to 54,5% in the intermediate loesses and to 36,6% in the temperate-humid loesses (Fig. 2). *V* values are also different in respect of the depth of the sample at any particular locality. In dry and intermediate loesses, *V* values tend to be lower near to the base of the loess and in any gley horizons which may be present in the profiles. This contrasts to the temperate-humid loess formation, where lower *V* values are revealed in samples taken from the upper levels.

Within the loess as a whole, there is a positive correlation between V values and the $CaCO_3$ content and a negative correlation between V values and Fe_2O_3 content.

The percentage of the carbonates is lowest close to the base of the IIb loesses and it increases systematically upwards. With respect to individual covers of loess, the eastern parts tend to be comparatively rich in carbonates whereas, in the western parts, less carbonate is present (Fig. 2). It may even be absent from the western parts.

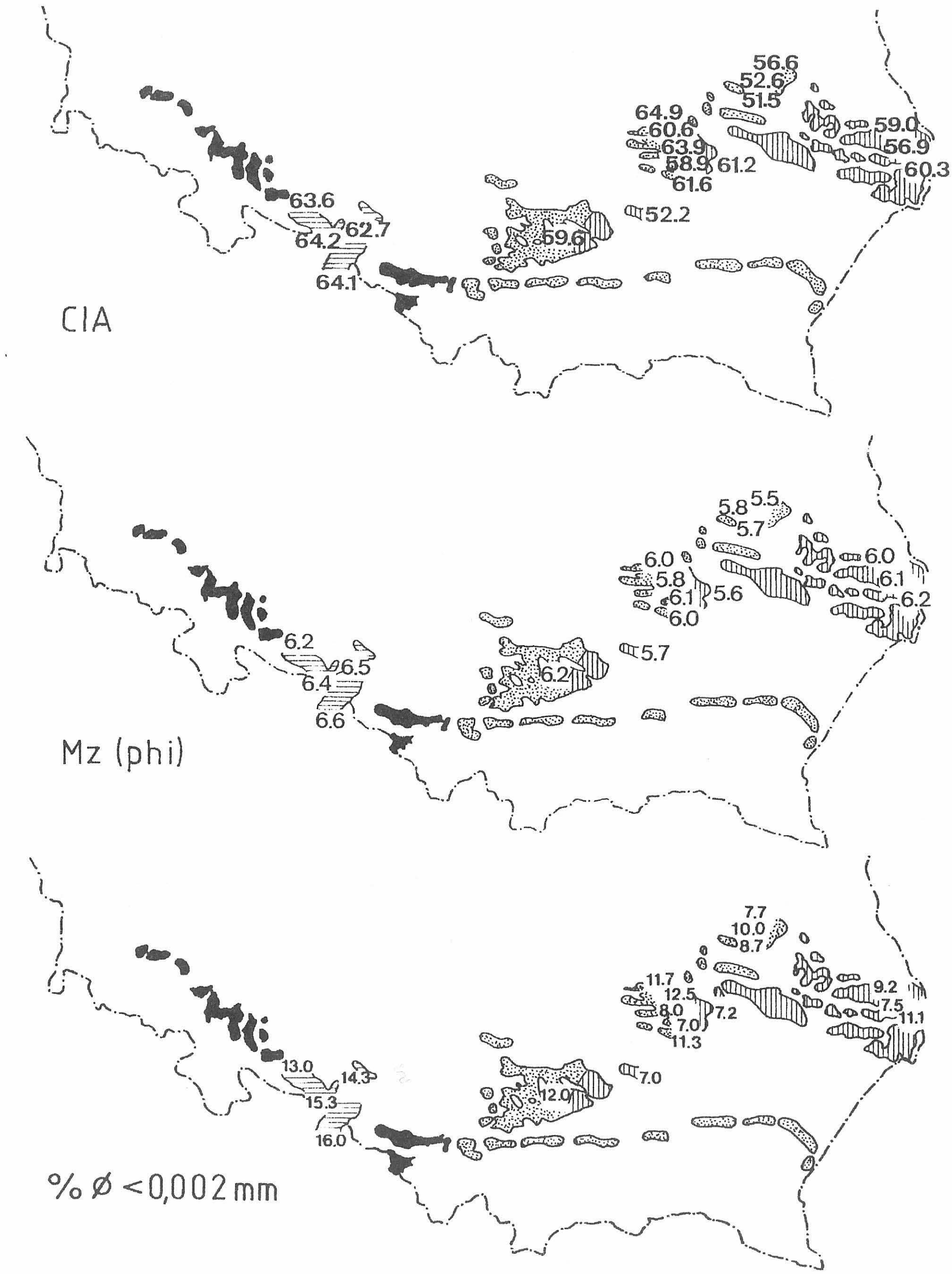
Carbonates are present both as crystals and pellets and also as secondary forms such as micritic aureoles, spherules and microconcretions (DWUCET, ŁAPOT, 1993). Quantitative analyses revealed that primary forms are dominant, representing from 76 to 91% of the total carbonate content (Fig. 3).

Microaggregatization and carbonate content in the loesses are both authigenic features which are similar to these from the dust-source areas. JERSAK (1973) considered that the floors of river valleys with braided channels became the source areas for the upland loesses in Poland. Also, the zone of glaciofluvial accumulation in the front of the Vistulian icesheet might well have been another source area. Gerlach (GERLACH *et al.*, 1992) demonstrated the relationship between the mineral content of loess and that of Carpathian flysh. MYCIELSKA (1994) suggested that the loesses may have been transported as windblown dust from remote areas such as the deserts of Asia. It is, of course, possible that all these areas became sources of dust for the Polish loess covers, the dust accumulating on tundra vegetation during or shortly after deglaciation of the area (JERSAK, *et al.*, 1992).

In order to represent the spatial changes in the physico-chemical characteristics of loess, DWUCET (1994) introduced Ls as a coefficient:

$$Ls = \frac{CIA}{V + CaCO_3}$$

where $$CIA = \frac{Al_2O_3}{Al_2O_3 + CaO + K_2O + Na_2O} \times 100$$


56.6
52.6
51.5
64.9
60.6
63.9
58.9
61.2
61.6
59.0
56.9
60.3
63.6
62.7
64.2
64.1
59.6
52.2
CIA
5.8
5.5
5.7
6.0
5.8
6.1
5.6
6.0
6.0
6.1
6.2
6.2
6.5
6.4
6.6
6.2
5.7
Mz (phi)
7.7
10.0
8.7
11.7
12.5
8.0
7.2
7.0
11.3
9.2
7.5
11.1
13.0
14.3
15.3
16.0
12.0
7.0
% ø <0,002 mm

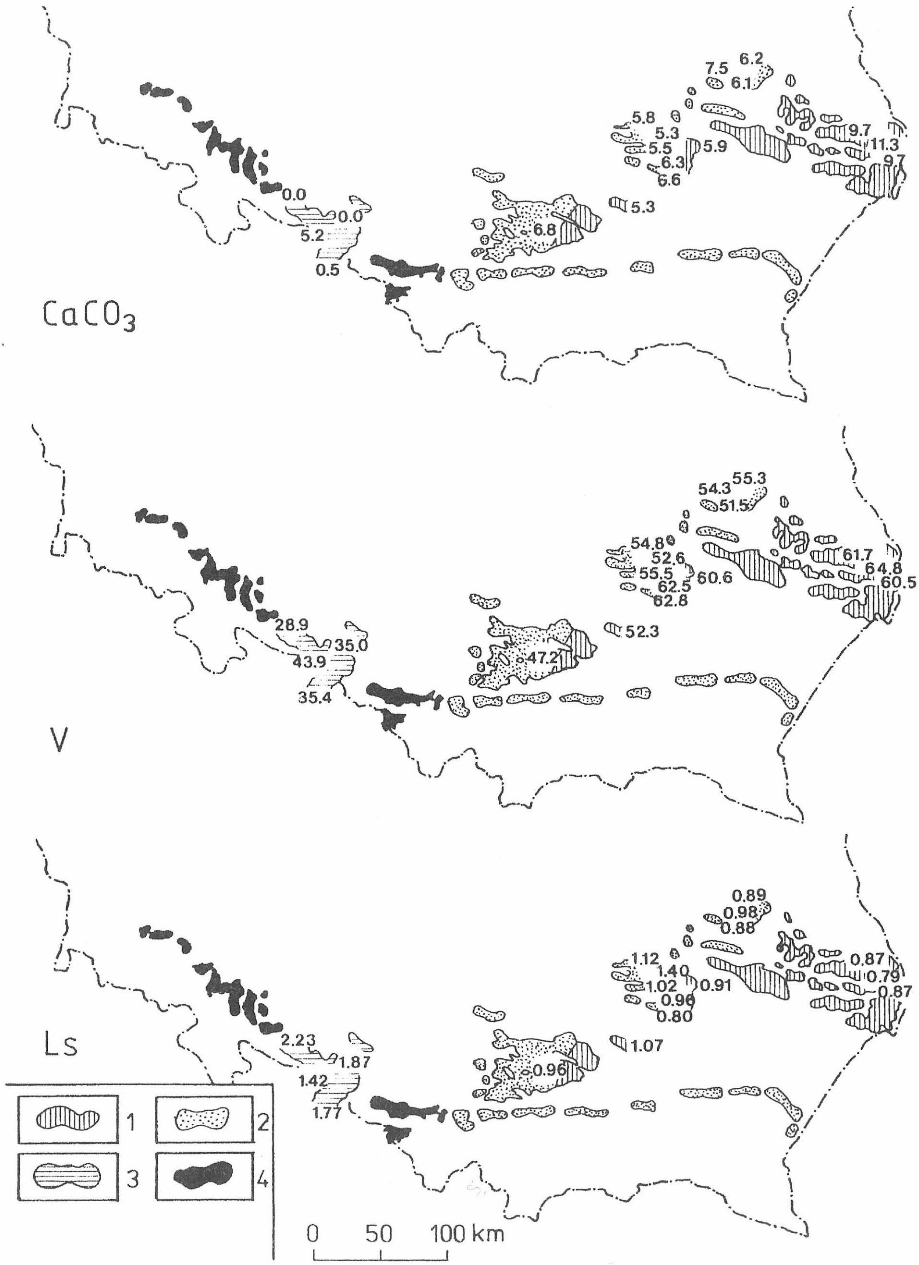


Fig. 2. Spatial distribution of the selected characteristics of loess (Mz, Ø < 0,002mm, $CaCO_3$, V, CIA, Ls)

1. loess of dry formation; 2. loess of intermediate formation; 3. loess of temperate humid formation; 4. loess of humid formation

this was introduced in order to valuate the degree of chemical transformation of loess,

V – Vogeler coefficient,

$CaCO_3$ – carbon carbonate content.

Bacause correlation of CIA, $CaCO_3$ and V with other characteristics of loess has been demonstrated, it may reasonably be assumed that Ls represents the physico-chemical state of the loess. The mean values of the Ls coefficient rarely exceed 1,0 for dry and intermediate loess formations, whereas for temperate-humid formation the Ls may exceed 2,0 in extreme cases (Fig. 2). The Ls coefficient is a function of the humidity of the surface where the loessic dust accumulated and of the rate of that dust accumulation. Its distribution in a vertical profile is different for loesses of dry and intermediate formations (here the Ls values decrease towards the surface) and loess of temperate humid-formation (Ls values increase towards the surface).

In the loess profiles of dry and intermediate formations there are sections where the Ls decreases which would appear to indicate a reduction in the rate of dust accumulation. During accumulation of IIb loesses in the temperate humid formations the accumulation rate was initially greater than that in the final phase. In contrast, in areas of dry and temperate formations the rate of accumulation increased in time.

Occasionally, and only in the thicker profiles, there were short interruptions to IIb loess sedimentation and, during these intervals, humus-rich and gley horizons developed. It is very difficult to date these. At Spadzista (Fig. 3) the age of a humus horizon has been established by radiocarbon dating of animal bones which both underlie and overlie the palaeosoil. These demonstrate that the horizon was developed between 17,4 and 15,4 ka BP. On this basis the palaeosoil may be well correlated with the Lascoux horizon. At Piekary (Fig. 3), at a level comparable with that at Spadzista, three humus horizons have been developed.

Molluscs are the commonest fossils present in the IIb loesses. The assemblages have been described mainly by ALEXANDROWICZ (1991). The sequence begins with a very varied fauna where as well as such typical loess Molusca as *Succinea oblonga elongata, Pupilla loessica, Pupilla muscorum* and *Vallonia Tenuilabris*, there are also species which are commonly regarded as having much more refired ecological requirements (e.g. *Arianta arbustorum, Vallonia costata, Euconulus fulvus*) and sometimes also in the valley facies *Lymnea truncatula*. Towards the surface of the loess cover the fauna becomes more restricted and *Pupilla loessica* becomes the dominant species along with *Succinea elongata*. In the uppermost levels, *Succinea elongata* becomes the dominant species, with *Pupilla loesica* in a minority. Deposits of valley topofacies of IIb loess also contain aqueous forms such as *Gyraulus laevis, Gyraulus rossmaessleri, Lymnea truncatula, Pisidium obtusale lapponicum, Pisidium stewarti.*

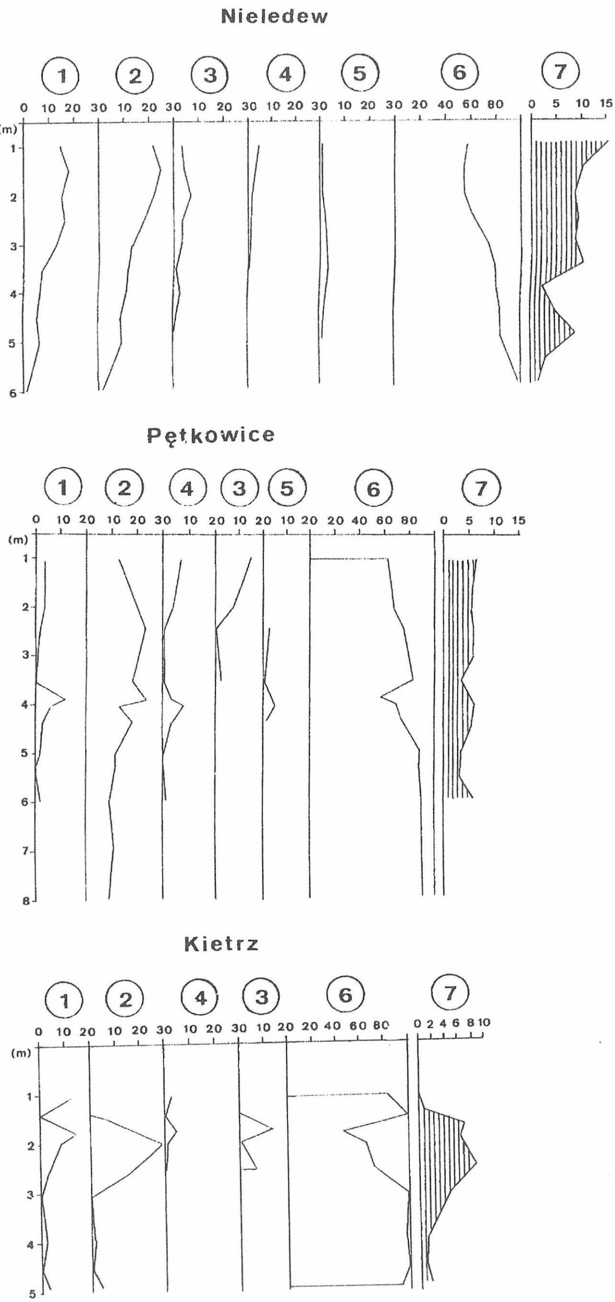


Fig. 3. Quantitative distribution of carbonate forms content in the IIb younger loess

1. crystals; 2. peloids; 3. micritic envelopes; 4. microconcretions; 5. spherulites; 6. another components; 7. total content of $CaCO_3$

Analysis of the molluscan fauna present in slope loesses shows the essencial influence of slope exposition on the malacological composition of loess deposits (FAJER, SARNO, 1994). The studies carried out on IIb loess in the Holy Cross Mountains show that molluscs present in deposits resting on NE-facing slopes are not very varied. *Pupilla loessica* and *Vallonia tenuilabris* are dominant and are accompanied by *Pupilla muscorum* and *Succinea oblonga elongata.* In contrast, loesses present on the slopes which face south contain a loessic fauna which is appreciably richer in those species which prefer dry, warm and sunny sites (e.g. *Chondrula tridens, Cochlicopa lubricella, Truncatellina cylindrica).*

As confirmed by datings of dust in the Zawalona and Maszycka caves and datings of the valves of molluscs present close to the upper surface of the loess covers (14,8 ka) (ALEXANDROWICZ, 1989), the accumulation of loess in Poland ended 14 ka BP. Coincident with the end of loess accumulation the climate deteriorated as a result of which very deep ice wedges were formed. These have been correlated with the large wedges at Jarosław (VELIČKO, 1992). The ice wedges are commonly present in flat or very slightly inclined slopes in loesses of dry formation. They do not occur in slope steeper than 5–7° of inclination. In some places the ice wedges start from the surface of the loess; elsewhere they are present several meters below this. The maximum height of ice fissures is 7 m (mean: 3–5 m). In every fissure the upper part is much widened and U-shaped, whereas the lower is narrow and wedge-like. The upper part is 1–2 m high and 1–2 m wide. The lower part is 20–40 cm wide and it tapers with depth. The diameter of ice-wedge of the order of 10 to 20 m. Debris torn from the walls is preserved in the wedge fill, indicating that, initially, the wedge was filled with ice. The wedges are smaller in the intermediate loesses, being 1–3 m high, and their upper widened parts being 0,5–1 m wide. In the temperate-humid loesses, wedges occur only rarely; here, they are 1–2 m high and are not notably widened in the upper half.

In the deposits of valley facies which correlate with IIb loesses at Tarzymiechy (Fig. 3) two generations of ice-wedge structures are observed; both are younger than 18,4 ka BP.

It is difficult to establish when loess accumulation in Poland terminated. It is assumed that it took place before the Bølling epizode. Two metods have been applied to this problem. The first involved ^{14}C and TL datings of the uppermost levels of the loess covers. Using ^{14}C dating on molluscs valves present near to the upper surface of the IIb loess ALEXANDROWICZ (1989) determined it to be 14,8 ka BP. Further, datings of aeolian dust from the Zawalona and Maszycka caves show that the dust was still being transported in the atmosphere between 15 and 14 ka. Dating of a humus horizon present just below the upper surface of the loess suggest that the rate of accumulation was reduced after this time, but it was still alive at ca. 13,4 ka BP. Dating from the Spadzista bone material suggest, however that the termination of loessic accumulation may have been earlier.

The other method used to establish when loess accumulation terminated is the dating of fluvial incision both in valleys and slopes. According to KALICKI (1991), the oldest erosion surface which is not covered with IIb loesses in the Wisła valley naer Kraków is at least 13,5 ka old. JERSAK (1985) has described a fossil gully present in Kamienna valley (Fig. 3 – Nietulisko Małe). Radiocarbon dating from the early-formed soils developed on the fossil slopes of this gully gave an age of 12,5 ka BP. Above the filling of this fossil gully there is no traces of any loess, which would suggest, therefore, that the accumulation of loess ceased in Kamienna valley before the Bølling episode. The fill deposits contain a malacofauna which camprises typical loessic species together with mesophyllic types. The assemblage consists of *Vallonia tenuilabris, Pupilla loesica, Euconulus fulvus, Cochlicopa lubrica, Punctum pygmaeum, Perpolita radiatula, Vallonia costata, Vertigo genesi* and *Lymnea truncatula* (ALEXANDROWICZ, 1983a). These data suggest that the end of loess accumulation may have been metachronic and took place in different places between 12,5 and 14,0 ka.

As soon as the accumulation of dust ceased, the process of loess degradation begun immediately. Soils development on the flat surfaces of interfluve areas, mechanical degradation of slopes took place, while bottom erosion in river valleys and gully erosion in dry valleys was extensive (ŚNIESZKO, 1994).

A complicated mosaic of soils of different ages is present on the surface of loess covers. The oldest are represented by degradated chernozems and much-differenciated pseudo-podzolic soils.

The degradated charnozems show the following structures: A_0–A_1–A_1B–C, A_0–A_1–(B)C–C, A_0–A_1–A_1A_3–(B)B–C, A_0–A_1–A_1A_3–(B)C–Cg. The thickness of the A horizon ranges from 1 to 0,6 m, which is quite typical for chernozems, whereas the content of humus is smaller. The content of organic carbon in the upper levels is from 2,2 to 1,4%, and in the lower parts of A_1 it is less than 1%. All the chernozems are leached. These features of chernozem soils indicate the relict character of the profile. Attempts to date the initiation of this soil development produced values which varied according to the sample location in the catena (ŚNIESZKO, 1995) (Fig. 6). However, the humins and humic acids of the floor of A horizon have been dated. In the interfluve areas they ranged from 4,8 to 6,0 ka BP; in the fossil soils present in the interslope deposits it was 8,3 ka BP and in the slope foot soils in the range from 4,0 to 8,0 ka BP. The oldest determinations were obtaibed from the humus present in the fossil soils in the floors of dry valleys. These soils are covered with later deposits to a depth of 5,0 m or more. The ages determined vary between 8,6 and 10,1 ka BP. The zoopedoturbation processes (intensive in the interfluve

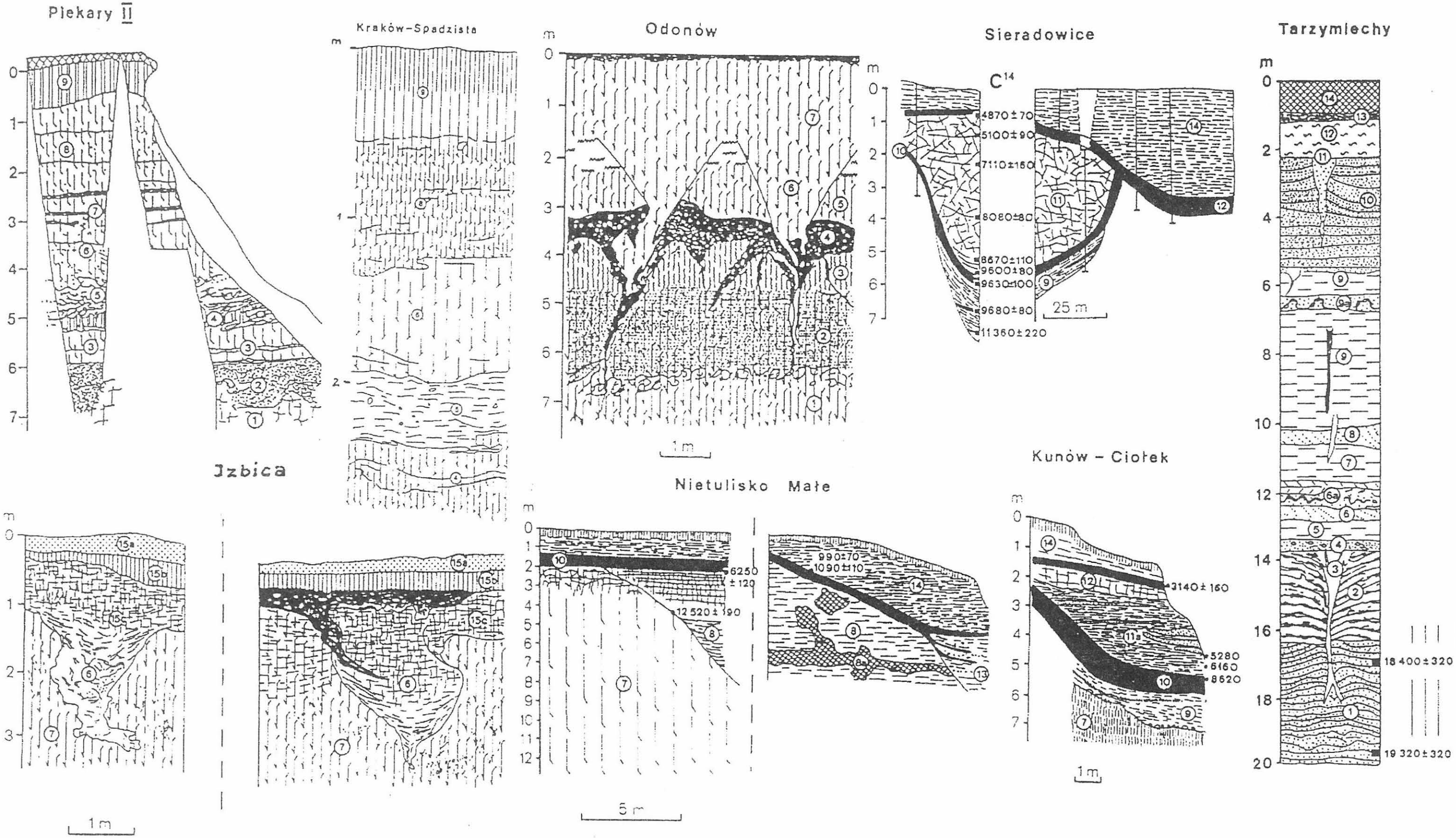

Piekary II
Kraków-Spadzista
Odonów
Sieradowice
Tarzymiechy
C14
4870±70
5100±90
7110±160
8080±80
8670±110
9600±80
9630±100
9680±80
11360±220
25 m
1 m
Izbica
Nietulisko Małe
Kunów - Ciołek
6250 ±120
12520±190
990±70
1090±110
3140±160
5280
6160
8620
18400±320
19320±320
5 m
1 m
1 m

Fig. 4. Selected profiles of sites documenting the evolution of loess areas in Poland between 20 and 8 ka

Piekary site: 1. Jurrasic limestone; 2. sands and gravels; 3. silty and sandy loess; 4. loamy loess of aggregated structure, orange in colour (illuvial clay horizon); 5. a sequence of silts and loess with solifluction structures; 6. light-yellow carbonate loess; 7. initial grassy soils; 8. light-yellow carbonate loess; 9. yellowish-brown loess (illuvial clay horizon). Kraków–Spadzista site (after Pawlikowski); 4. yellowish sandy silt and yellow loess with traces of charcoal; 5. a sequence of silts and loess with displaying solifluction structures; 6. yellow-brown loess, massive, contains interrupted lamina of organic matter; 8. yellowish-brown loess, eolian, with fine lamination; 9. yellowish-brown loess (illuvial clay horizons). Tarzymiechy site (after Jersak, Sendobry, Śnieszko, 1992): 1. grey-green silt and sand with horizontal lamination; 2. fine sand and silt with horizontal graded lamination; 3. epigenetic pseudomorphosis after ice wedge; 4. brown silt with lenses of rust-coloured crudely laminated sands; 5–9. fine sands and silts with lamination; 10. laminated sands; 11. epigenetic pseudomorphosis after ice wedge of younger generation; 12–14. Holocene soil complex. Odonów site (after Jersak, Sendobry, Śnieszko, 1992): 1. Wartanian loess; 2. loamy loess of aggregate structure, orange in colour, illuvial Bt horizon; 3. silty loess, ash-coloured with „pelletic" structure; A3Bt – Eemian warm stage; 4. loess rich in humus, dark-grey with brown shade, with numerous „crotovines"; 5. loess with loam content, somewhat lighter in the lower part; 6. frost fissure cast; 7. light-yellow loess (the younger loess IIb). Izbica site: 6. frost fissure cast; 7. light-yellow loess (younger loess IIb); Holocene soil complex: 15a, b. humus accumulation horizon; 15c. illuvial clay horizon. Nietulisko Małe site (after Jersak, 1985): 7. massive loess with faint stripes; 8. laminated loessic material of brown and blue-grey colouration; 8a. laminated material with the laminae of humus – the fillings of fossil suffosion channels; 10. brown-black loamy loess – Early Holocene; 13. dark-grey stratified loessic material with humus and charcoal pieces, stratified. Irregular pebbles of local rocks, very poorly segregated are visible; 14. loessic material rhytmically interlayered. Sieradowice site (after Śnieszko, 1994); 9. laminated silts with wood fragments; 10. structureless black-grey loessy mud with carbonate and wood fragments; 11. calcareous tufa and travertine chips with thin peat layers; 12. dark-grey soil horizon; 14. loessic silts. Kunów–Ciołek site (after Jersak, 1973): 7. loess of valley facies, laminated with intercalations of silty sands; 9. light-grey laminated silts; 10. boggy soils, black humus horizons with numerous charcoals and rusty spots; 11a. clayey silt, grey-brown, striated and stratified with layers and lenses of gravels; 12. dark-grey decalcified soil horizon; 14. laminated silt with lenses of stratified sands and scarce pebble area though limited by the high level of underground water in the floors of dry valleys) appear to be one of the reasons for the differences in the datings. Also, the fossilization of the soil must have been an important factor. The earlier it was covered by younger deposits, the older the apparent age as determined from the humus (Śnieszko, 1995). The datings indicate that the chernozem process started at the beginning of Holocene and was probably continued until the beginning of AT. The relict chernozems occur only in parts of the loess covers (Fig. 6). The greater part of the loess surface is covered by pseudo-podzolic and pseudo-podzolic/brown soils (A_0–A_1–A_3–Bt–C and A_0–A_1A_2–A_1B–A_3–Bt–C). Bearing in mind the distribution of the soils it may be assumed that, at the beginning of Holocene, the steep-meadow vegetation occured only in isolated patches and that it was gradually overwhelmed by the forest vegetation. After the loess accumulation and up to the time when the loess covers were dominated by forest-meadow vegetation, the slopes and floors of dry valleys were subjected to mechanical denudation. The slopes were formed mainly by sheet flow whereas the floors of dry valleys by linear flow. There is also some evidence of suffosion at that time (the Nietulisko site). The processes of mechanical denudation finally ceased at the beginning of the Holocene. They were replaced by pedogenesis and chemical denudation. Investigations at Kunów–Ciołek (Fig. 4) and Sieradowice (Holy Cross Mountains) has yielded valuable data concerning the relative effects of mechanical and chemical denudation after the end of loess accumulation. At Kunów, malacofaunal studies show that the lower levels in the silt which underline the chernozems contain a fauna which is similar to that of loess. At higher levels, the forest-meadow species (*Perforatella bidentata*) and forest-steppe species (*Vallonia costata*) come to dominate and there is also an increase of hydromorphous species. The warm-climate species *Accicula polita, Orcula dolioum* and *Discus rotundatus* occur in the deposits on which the A_1 chernozem horizon developed. Forest-meadow and forest species are in majority (Piechocki, 1977). The chernozem represents a long break in the deposition in the valley floors (between 10 and 5 ka).

At Sieradowice (Fig. 4 – the spring area of the Psarka valley) in silts which overlie the erosion surface, as well as the meadow and mesophillic species represented by *Punctum pygmaeum, Euconulus Fulvus, Perpolita radiatula, Carychium minimum*, and *Vallonia costata*, there are forms characteristic of a cold climate (*Pupilla loesica, Succinea oblonga elongata, Vertigo genesi, Vertigo geyeri*). In the upper levels of the silts snails typical of loessic sedimentation died out and the warm-climate forms (*Vitrea crystallina, Perforatella bidentata, Discus ruderatus*) took their place (Alexandrowicz, 1983b). Hydromorphic soil developed in these silts. Travertines began to form at Sieradowice about 9 or 8 ka BP but rate of travertine accretion was clearly not regular. Below the travertine wall, it was 1 cm/100 years

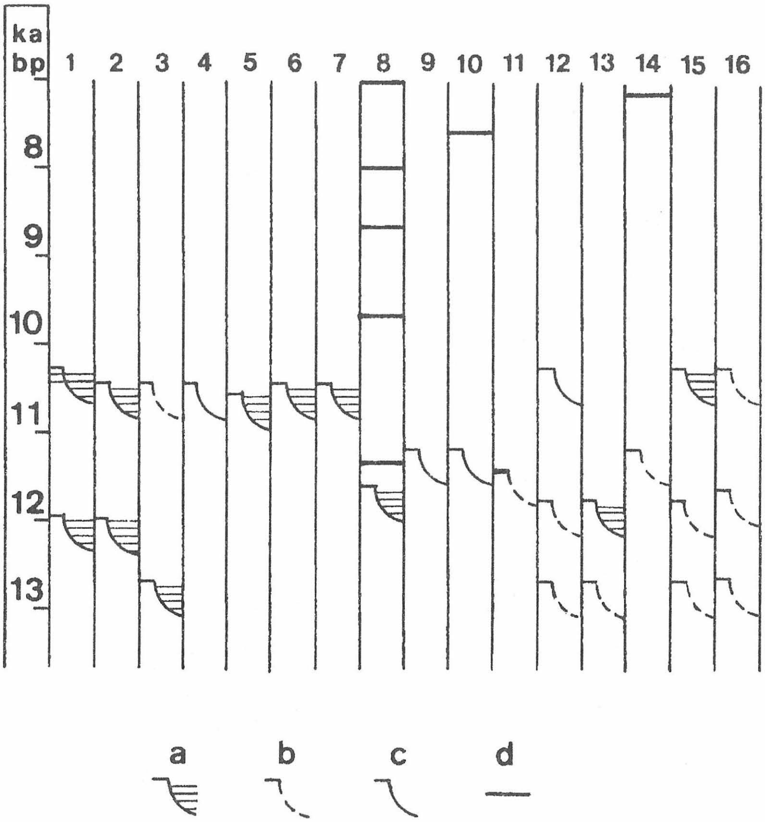


Fig. 5. Datings of erosional surfaces in valley of Polish Uplands (after Śnieszko, 1995)
a. ^{14}C dated sediments; b. erosional surfaces; c. ^{14}C dated erosional surfaces; d. ^{14}C dated cessations in sedimentations. 1–16. studied sites

between 9,6 and 8,7 ka BP and 2,53 cm/100 years between 8,7 and 8,1 ka BP. The rate of sedimentation then decreased to 1,51 cm/100 years between 8,1 and 7,1 ka BP and to 0,44 between 7,1 and 5,1 ka BP (Śnieszko, 1994).

The Kunów–Ciołek and Sieradowice sites described above were included in studies of the loesses of 16 Polish valleys by Śnieszko (1995). These suggest that the processes of streambed and linear erosion ceased at the beginning of Holocene (Fig. 5) when they were replaced by peat accretion in small river valleys and soil forming processes in the interfluve areas, slopes and dry valleys. At the beginning of Holocene, chemical denudation ceased almost completely. Since then the stabilization process of forms which developed at the end of Vistula Stage has started.

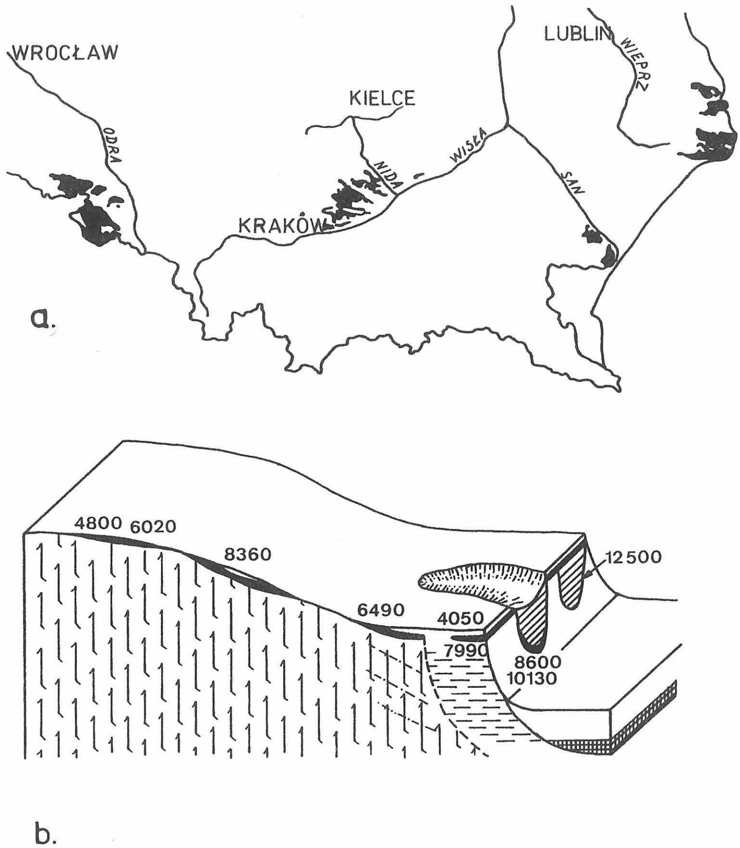


Fig. 6. The distribution and age of relict chernozems in Poland

A – the distribution of chernozems on loess covers; B – the relative radiocarbon age of chernozems according to their location in the catena

The interval from 20 to 8 ka BP as defined by the IGCP programme comprises a complete cycle of relief evolution in the loess-covered areas of Poland. It started with loess accumulation (20 – 30 ka) which was followed by mechanical denudation (13 – 10 ka) and, in turn, by chemical denudation (from 10 ka).

Translated by Iwona Morawiecka

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