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Loesses in Poland, Their Stratigraphy and Paleogeographical Interpretation *

Lessy w Polsce, ich stratygrafia oraz interpretacja paleogeograficzna

Лёссы в Польше, их стратиграфия и палеогеографическая интерпретация

ABSTRACT

The development of conceptions on the stratigraphy of loesses in Poland was discussed with particular consideration of a correlation with the glacial cycles. Against this background, the newest version of the stratigraphic scheme was presented. This version takes into consideration the latest paleomagnetic investigations and datings by the radiocarbon and thermoluminescence methods. This scheme was correlated with corresponding elaborations for loesses in West and East Europe. There are distinguished: a) residua of weathered oldest loesses (LN) from the periods previous to the Mazovian=Holsteinian→Mindel/Riss Interglacial; b) older loesses (LS) dated for 310/300—135/130 ka BP, from the periods of the Odranian and Wartanian glaciations=Saalian I and II→Riss I and II, which were correlated with ^{18}O stages of deep-sea deposits: 8—7—6; c) younger loesses (LM), dated for 100—15/12 ka BP, from period of the Vistulian→Würm glaciations, which was correlated with ^{18}O stages: 5—4—3—2. Paleogeographic analysis of these units of the first and also of second rank was carried out mainly on the basis of the results of lithologic and paleopedologic investigations of loesses and cryogenic structures occuring within them. An analysis of LM proves that their deposition with many breaks took place, i.e. as a result of extreme events mainly. Stages of the development of permafrost, and also the average deposition rate of LM and its changes in the glacial cycle were determined; indices of LM thickness and of the deposition rate were compared with those determined for other Eurasia regions.

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This paper deals with proper loesses, i.e. without loess-like deposits of various origin. Therefore, only those silt deposits were taken into consideration, in the formation of which eolian factor played a significant role. To avoid any doubts such deposits can be defined as typical (proper) loesses.

Typical loesses occur only in the southern part of Poland. They form abundant patches, at least several metres thick, groupped mainly in

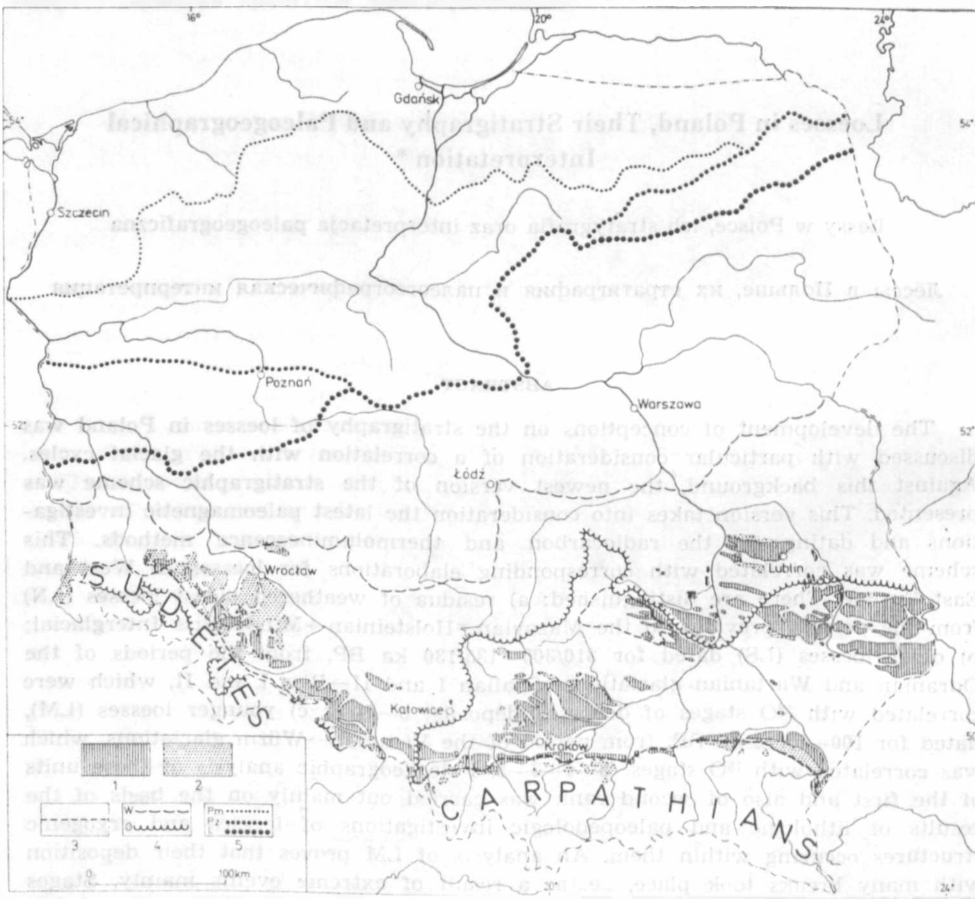


Fig. 1. Distribution of loesses in Poland (according to H. Maruszczak 1976, partly supplemented) and limits of the Saalian and Vistulian inland ice

1 — covers of proper loesses thicker than 2—3 m and characterized by a specific relief; 2 — covers of silty and clayey periglacial deposits with thin patches of eolian loesses which in some places are geomorphologically unrecognizable; 3 — boundaries of mountainous areas; 4 — limits of the maximum extent of inland ice of the Saalian glaciations: O — Odranian (Saalian I), W — Wartanian (Saalian II); 5 — limits of inland ice of the Vistulian glaciation: L — Leszno=Brandenburg stage (maximum), Pz — Poznań=Frankfurt stage, Pm — Pomeranian stage

three regions of the South-Polish Uplands: Lublin, Sandomierz and Kraków. Outside these uplands, the loesses are noted in the forelands of the Carpathian and Sudety Mts (Fig. 1).

The patches are composed of beds of different age, among which the younger loesses of the Vistulian predominate. The older loesses (Saalian) and the oldest ones (Elsterian) are usually covered by them, occupy smaller areas and are not so thick. Therefore, geological maps present mainly the distribution of the Vistulian loesses. Extents of these loesses are almost the same as of the primary ones formed as a result of accumulation; this is suggested by geological and geomorphological investigations. It makes then the basis for a paleographic interpretation of these extents, especially from the point of view of sedimentary environment of loessy silt during the last glaciation (H. M a r u s z c z a k 1969b, 1980a).

The distribution of typical loesses in southern Poland proves many regularities. They are connected mainly with a hypsometric level of 200—350 m, and their thickness decreases in the direction of the upper limit of this level. From the point of view of paleogeography more important is the fact that the thickness and largeness of loessy patches increase from west eastwards. The maximum total thickness of all loesses of different age is about 10 m in the west and increases to 40 m in the east. This differentiation is less distinct if only the Vistulian loesses are analyzed — their maximum thickness in the west reaches 9 m and 22 m in the east. Accordingly, the presence of loesses in the landscape is more distinct in the east than in the west. From this point of view the loesses of eastern Poland are very similar to the vast loessy regions of south-eastern Europe, whereas those in western Poland to the loessy regions of western Europe. With respect to these regularities, the most important for stratigraphical and paleogeographical investigations are the loess profiles which occur in south-eastern Poland (Fig. 2).

DEVELOPMENT OF STRATIGRAPHICAL CONCEPTIONS DURING THE LAST HUNDRED YEARS

Discussions on stratigraphy and paleogeography of Polish loesses were initiated a hundred years ago. After the idea of continental glaciations had been established, this subject was undertaken at first by W. N a ł k o w s k i (1887) and J. S i e m i r a d z k i (1888). They both considered loess as interglacial deposits; the former connected it with the last interglacial whereas the latter with the interglacial separating two glaciations in the Polish territory. Substantial data on loesses had not been collected

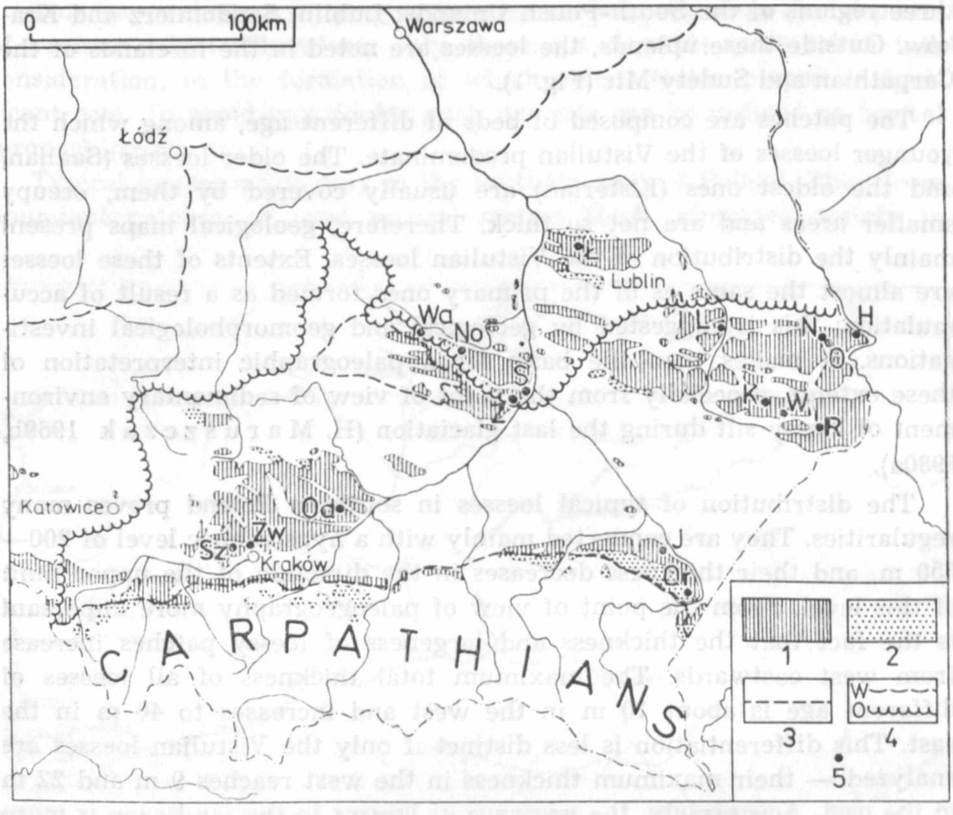


Fig. 2. Distribution of loess profiles in south Poland
1—4 explanation see Fig. 1; 5 — location of the main sections: H — Horodło, J — Jarosław, K — Komarów Górny, L — Latyczów, Ł — Łopatki, N — Nieledew, No — Nietulisko Małe, O — Obrowiec, Od — Odonów, S — Sandomierz, Sz — Szczyglice, W — Wożuczyn, Wa — Wąchock, Z — Złota, Zw — Kraków-Zwierzyniec

until starting the work on the Geological Atlas of Galicia 1 : 75 0000. Amongst the geologists engaged in this large collective work, most attention to loesses seems to have been paid by A. M. Łomnicki (1895, 1897, 1898). According to the opinions of this author, loesses could be divided into two beds of various ages. The older, distinctly stratified loesses with molluscs remains were connected with the middle stage of the diluvial period. The younger, typical eolian non-stratified loesses were considered as steppe-period deposits of the upper diluvial stage (A. M. Łomnicki 1898).

Several years later a paper of N. I. Krishtafovitch (1902) was published; it contained among other things a very profound study of the loesses in the Lublin Upland. He distinguished in that area also two loesses of different ages. The older were located in his scheme under the till of Glaciation II (named the Saxonian — the equivalent of the present Elsterian). The younger, considerably better preserved and typical loesses were expected to have been deposited during the interglacial after Glaciation II and during Glaciation III (Polandian — Mecklemburgian, i.e. the equivalent of the present Saalian).

In the mentioned as well as in many other papers of this early period, the stratigraphy of loesses was defined on the basis of an analysis of their relation to glacial, glacifluvial and fluvial deposits. S. Lencewicz (1916) was the first who pointed out that the inter-loessy paleosols can be used as a criterion to distinguish the beds of different ages. However, he did not use this criterion extensively due to the lack of real data. In spite of noticing the inter-loessy paleosols, S. Lencewicz did not put forward univocally a connection of the loess deposition with either interglacials or glaciations. A distinct connection of deposition of loesses was already noted in the papers of Lr. Sawicki (1922) and J. Samsonowicz (1924).

Not until the thirties, stratigraphy of loesses was significantly based on paleopedological criteria. They were fully and consistently applied by Lk. Sawicki (1932), the author of the first Polish study especially sacrificed to stratigraphy of loesses. Basing on investigations of paleosols and archeological facts, he distinguished in the Sandomierz area the older loesses (LR II) connected with the second advance of the Riss ice sheet, as well as lower and upper younger loesses (L I and L II), corresponding with two earlier advances of the Würm ice sheet (W_I and W_{II}).

In all later works a criterion of paleosols was accepted as the basic one in studies on stratigraphy of loesses. During the fifties this criterion was used to distinguish only the deposits that corresponded with the last glaciation or with several "partial" glaciations referred to the Würm period. Thus, only the eolian lower and upper loesses were distinguished (A. Jahn 1950, 1956), or older loesses and lower and upper younger loesses (W. Pożaryski 1953). Older loessy beds, not representing the typical subaerial loesses were still distinguished on the basis of analysis of their relation to glacial deposits.

During the sixties the studies on paleosols allowed to distinguish usually four loesses of different age: one from the last but one glaciation (Riss) and three from the last glaciation (Würm). In papers of that time a careful attention was paid to a typological variability of soils, corresponding to interglacials and interstadials (J. E. Mojski 1961, 1965b, J. Jersak 1965, 1969). Then the most important results on Poland's scale were those of J. E. Mojski for the Hrubieszów area. A particular attention was paid by him to the section at Nieledew, studied previously by many authors and known in foreign papers (J. E. Mojski 1965a, 1969). During the seventies two interglacial soils of various age were distinguished, and thus the loessy beds representing three glacial cycles of various age, respectively. Taking the interstadial soils into account, the number of stratigraphic units of the lower rank increased at that time to 5—6 (J. Jersak 1973) or 8—9 (H. Maruszczak 1976, 1980b).

The newest schemes distinguish the following stratigraphic units of loesses correlated with large glacial cycles (H. Maruszczak and J. Butrym 1984):

1. Oldest loesses LN (Elsterian). They are weathered silty-clayey deposits, the stratigraphy and origin of which cannot be univocally defined. Their top layers form the substrate of a well developed interglacial soil.

2. Older loesses LS (Saalian). They are already much better preserved, with layers of non-weathered loesses. Amidst them, there are 2—3 distinct soils of interstadial rank that divide the loesses into: lowest (LSn), lower (LSd), middle (LSs) and upper (LSg) ones. Inside the least transformed, carbonate upper older loesses there are beds of poorly developed interstadial soils and soil sediments. They allow us to divide LSg into 3—4 stratigraphic horizons. The top LSg layers form the substrate of a well developed interglacial soil, known from many exposures.

3. Younger loesses LM (Vistulian). The best preserved typical loesses, only slightly transformed by weathering processes. They comprise three interstadial soils that divide them into: lowest (LMn), lower (LMd), middle (LMs) and upper (LMg) loesses. Top layers of LMg form the substrate of the Holocene, recent soils.

CORRELATION OF LOESSES WITH GLACIAL CYCLES

In older papers the deposition of loesses was usually correlated with final phases of glaciations and with interglacials. It was Lk. Sawicki (1932) who stated on the basis of detailed analyses of numerous loess sections that the deposition of loesses was much longer. He supposed it to have generally occurred in three phases during every glacial cycle. The first and the third phases (ice sheet advance and retreat) are represented by a deposition of stratified deluvial and solifluction loesses. On the other hand the second phase, i.e. the maximum extent of an ice sheet, corresponded with the formation of typical eolian loesses.

More detailed considerations of the correlation of loesses with a glacial cycle are presented by A. Jahn (1950, 1956). He stated that a proper genetic approach to loess types and their separation from other periglacial deposits required studies on the cyclicity of deposition. According to this author, "a cycle of loess accumulation" occurred mainly during the maximum extent and retreat of the ice sheet (A. Jahn 1956, p. 448). At the same time he paid a particular attention to the second part of the loessy cycle when a role of the eolian factor decreased. In such a situation, a secondary solifluction and deluvial accumulation could develop on a larger scale, especially on cooler slopes. A strong emphasis put on the role of loess deposition during the retreat phases of a glaciation makes the idea of A. Jahn different from other earlier and later presented opinions known from the European literature.

A possible reference of the upper layers of younger loesses to the retreat phases of the Vistulian ice sheet was decidedly opposed by S. Z. Różycki (1961, 1972). Amidst the beds of younger loesses, he referred the lower ones (together with two paleosols) to steppe-tundra coolings that preceded the advance of the ice sheet into the territory of Poland. Only the upper bed of younger loesses was connected by him with the ice sheet advance, the maximum extent of which occurred during the Leszno Stage (about 20 ka BP). Thus, unlike A. Jahn, S. Z. Różycki underlined a particular role of accumulation during older phases of the glacial cycle. It was expressed in his stratigraphic subdivision of the last glaciation in Poland: he distinguished three older "loessy" stadials and only two younger as the "glacial" ones (S. Z. Różycki 1972).

Another approach to the cyclicity of loesses was presented lately by J. Jersak (1977). He took into account not only the processes of loess accumulation but also of their degradation and particularly, weathering and pedogenetic transformations. Therefore, this approach to cyclicity was similar to that presented earlier by J. Kukla (1969). Here we rather see "a cycle of development of a loessy cover" than the cycle of loess deposition. Such a cycle is divided by J. Jersak into two parts. During the first one (A), corresponding with the climax, i.e. pleniglacial phases, aggradation prevailed. The second one (B) that comprised the final phases of a glaciation with interglacials and the initial phases of the next glaciation, the degradation was the principal process. Therefore, this cycle is of the paleogeographic or even, paleopedologic type and does not correspond with stratigraphic cycles of glacial or periglacial deposition during the glaciations.

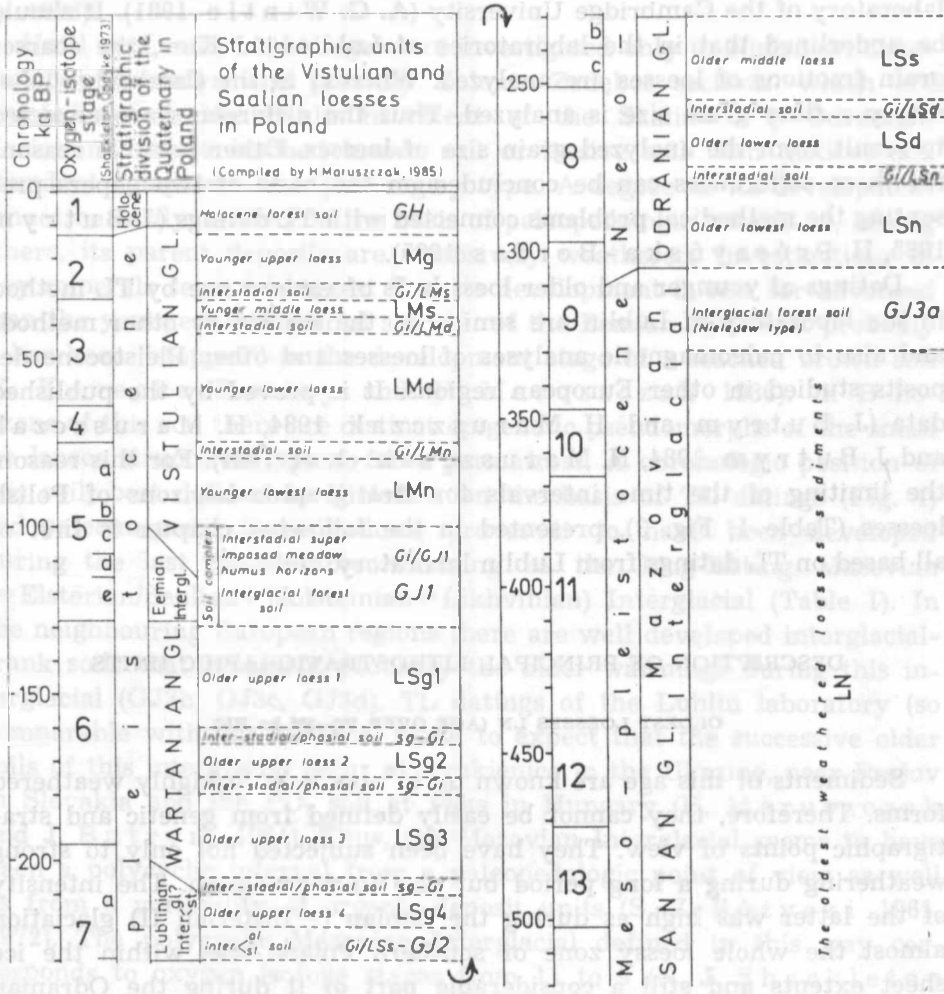
At the paleogeographic (paleopedologic) approach to the loessy cycle, a full evolution of events in Poland cannot be reconstructed by the last cycle. The older loesses are more poorly preserved and so, have not been sufficiently investigated; for this reason they cannot be univocally interpreted. Investigations have proved that they represented a single depositional cycle (H. M a r u s z c z a k 1980b, H. M a r u s z c z a k et al. 1984), but the results of the most recent TL datings indicate the two probable cycles to be recorded. None of them has enough data for a valid reconstruction. Both the older cycles are expected to have not been developed in full as the younger, i.e. the last cycle. Thus, the older loesses should be, at least for the time being, described from the point of view of sedimentologic cyclicity rather than in a paleogeographic way.

FOUNDATIONS OF LOESS CHRONOLOGY IN POLAND

The earliest attempts of loess datings were undertaken on the basis of geologic and geomorphologic criteria. A. J a h n (1956) connected the deposition of younger loesses with the Pleniglacial; during the Late Glacial, at the end of accumulation, only secondary loesses and loessy deluvia were formed. According to H. M a r u s z c z a k (1961) a complex analysis of the loessy relief suggested that the deposition of a primary eolian loess has still occurred during the Late Glacial, the Middle Dryas inclusive. In the Alleröd, i.e. about 12 ka BP, the loessy covers started already to be cut by erosion and denudation (dry erosive-denudation valleys). Similar conclusions were drawn from investigations of bones found in the upper beds of younger loesses. Datings of these remains made by the FCl/P/Coll method in the sixties and seventies by dr. Tadeusz Wysoczański-Minkowicz from the Laboratory of Quaternary Geology, Polish Academy of Sciences, proved their age of about 15—16 ka BP (H. M a r u s z c z a k 1976, 1980a). Thus, these results corresponded in general with radiocarbon datings of bone remains and charcoal pieces from the upper beds of younger loesses in the neighbouring countries (J. K u k l a 1969, M. P é c s i et al. 1977, A. A. V e l i c h k o and T. D. M o r o z o v a 1975).

In the seventies the radiocarbon datings of older beds were done, i.e. of middle and lower younger loesses (K. M a m a k o w a and A. Ś r o d o ń 1977, J. W o j t a n o w i c z and J. B u r a c z y ń s k i 1978, H. M a r u s z c z a k 1980a). As these datings were based on analyses of humus acids, various doubts arose. It was particularly found that age sequences are sometimes opposite to the location of samples in the studied sections. These facts proved that the humus of paleosols should have been "rejuvenated" after their formation, due to filtration of fresh humus acids during the Holocene (K. M a m a k o w a and A. Ś r o d o ń 1977). For this reason, studies of older beds of loesses were still based mainly on datings of bone remains by the FCl/P/Coll method and more recently, on results of paleomagnetic investigations done in the seventies (P. Tuchołka 1977). Particularly the reversed polarity (Blake event) in the lowest beds of the younger loesses enabled to date the beginning of their deposition for 110—100 ka BP. Similarly, symptoms of reverse polarity

Table 1. Stratigraphic subdivision of the loesses in Poland



(Chegan event) in lowest beds of older loesses enabled to define the beginning of their deposition for about 280 ka BP (H. Maruszczak 1980a, b).

In the seventies and eighties, datings of numerous loess samples were done by the thermoluminescence method (TL). The analyses needed for such datings are done by dr. Jerzy Butrym from the Department of Physical Geography, Maria Curie-Skłodowska University of Lublin. The results are compared with those from other laboratories. Therefore, the analyses of 20 samples collected together proved a significant concurrence with the results of the Institute of Geological Sciences, Ukrainian Academy of Sciences of Kiev (V. N. Shelkoplyas et al. 1985). On the other hand, they are much different from the results of the laboratory of the Cambridge University (A. G. Wintle 1981). It should be underlined that in the laboratories of Lublin and Kiev, the coarser grain fractions of loesses are analyzed. Whereas in the Cambridge laboratory a finer grain size is analyzed. Thus the differences are expected to result from the analyzed grain size of loesses. Other possible reasons for these differences can be concluded on the basis of two papers presenting the methodical problems connected with TL datings (J. Butrym 1985, H. Prószyńska-Bordas 1985).

Datings of younger and older loess beds of various age by TL method in the laboratory of Lublin are similar to the results by other methods and also to paleomagnetic analyses of loesses and other Pleistocene deposits studied in other European regions. It is proved by the published data (J. Butrym and H. Maruszczak 1984, H. Maruszczak and J. Butrym 1984, H. Maruszczak et al. 1984). For this reason, the limiting of the time intervals for stratigraphic horizons of Polish loesses (Table 1, Fig. 3), presented in the following chapter is first of all based on TL datings from Lublin laboratory.

DESCRIPTION OF PRINCIPAL LITHOSTRATIGRAPHIC UNITS

OLDEST LOESSES LN (AGE OVER 350—300 ka BP)

Sediments of this age are known up to now only in highly weathered forms. Therefore, they cannot be easily defined from genetic and stratigraphic points of view. They have been subjected not only to strong weathering during a long period but also to degradation. The intensity of the latter was high as during the Sanian (=Elsterian II) glaciation almost the whole loessy zone of southern Poland was within the ice sheet extents and still a considerable part of it during the Odranian (=Saalian I) glaciation (Fig. 1). In some older papers this unit was distinguished, at least partially, as "submorainic" or "intermorainic" loesses.

Interglacial soil formed on oldest loesses GJ3a/LN. The TL age of this soil is 330—310 ka BP. Much the same, 350—320 ka BP, was defined by the K/Ar method the age of the interloessy soil of the Ariendorf Interglacial from Kärlich section in Rhineland (K. Brunnacker et al. 1982). Hungarian travertines of the Holsteinian Interglacial were dated by the Th/U method for more than 300 ka BP (G. J. Hennig et al. 1983). Similarly, by the Th/U method, was defined the age of interglacial calcite speleothem in North America: in Rocky Mountains for approximately 350 and for 320—275 ka BP (R. S. Harmon et al. 1977), and in Minnesota for 290—270 ka BP (R. S. Lively 1983).

Until now, soils of this age were investigated only in Nieledew, Orzechowce, Wożuczyn and possibly Kolonia Zadębce sections, which are situated outside the maximum extent of the Saalian I (=Odranian) glaciation. It is a leached brown soil or lessivé soil with distinct and abundant symptoms of a pseudogley type. A degree of its development cannot be easily defined on the basis of paleopedologic criteria as, among others, its parent deposits are intensively weathered. Investigations of clay minerals seem to suggest that its development is less far advanced than the youngest interglacial soil, i.e. of the Eemian age. Most probably it has been "stopped" in the development stage of a leached brown soil (K. Konecka-Betley and H. Maruszczak 1986). In B horizons of this soil there are distinct epigenetic pseudomorphs of the small ice lenses structures typical for a permafrost. A chronologic position of this soil, best defined at Nieledew on the basis of TL datings (Fig. 4) and paleomagnetic investigations, proves it to have been developed during the last considerable warming of the long-lasting Mazovian (=Elsterian/Saalian=Holsteinian=Likhvinian) Interglacial (Table 1). In the neighbouring European regions there are well developed interglacial--rank soils that represent probably the older warmings during this interglacial (GJ3b, GJ3c, GJ3d). TL datings of the Lublin laboratory (so comparable with one another) allow to expect that the successive older soils of this interglacial occur at Krukienice in the Ukraine, near Prešov in Slovakia and the PD_2 soil at Paks in Hungary (H. Maruszczak and J. Butrym 1984). Thus, the Mazovian Interglacial seems to have been a polycyclic interval from a paleopedologic point of view as well as from a variability of organic deposit units (S. Z. Różycki 1961, 1972). The polycyclic Mazovian Interglacial defined in this way corresponds to oxygen isotope stages from 11 to 9 (N. J. Shackleton and N. D. Opdyke 1973).

OLDER LOESSES LS (310/300—135/130 ka BP)

They are much better preserved and considerably varying in their lithostratigraphy. As the interglacial-rank soil has been lately found within them, they can be considered to represent probably the two glacial

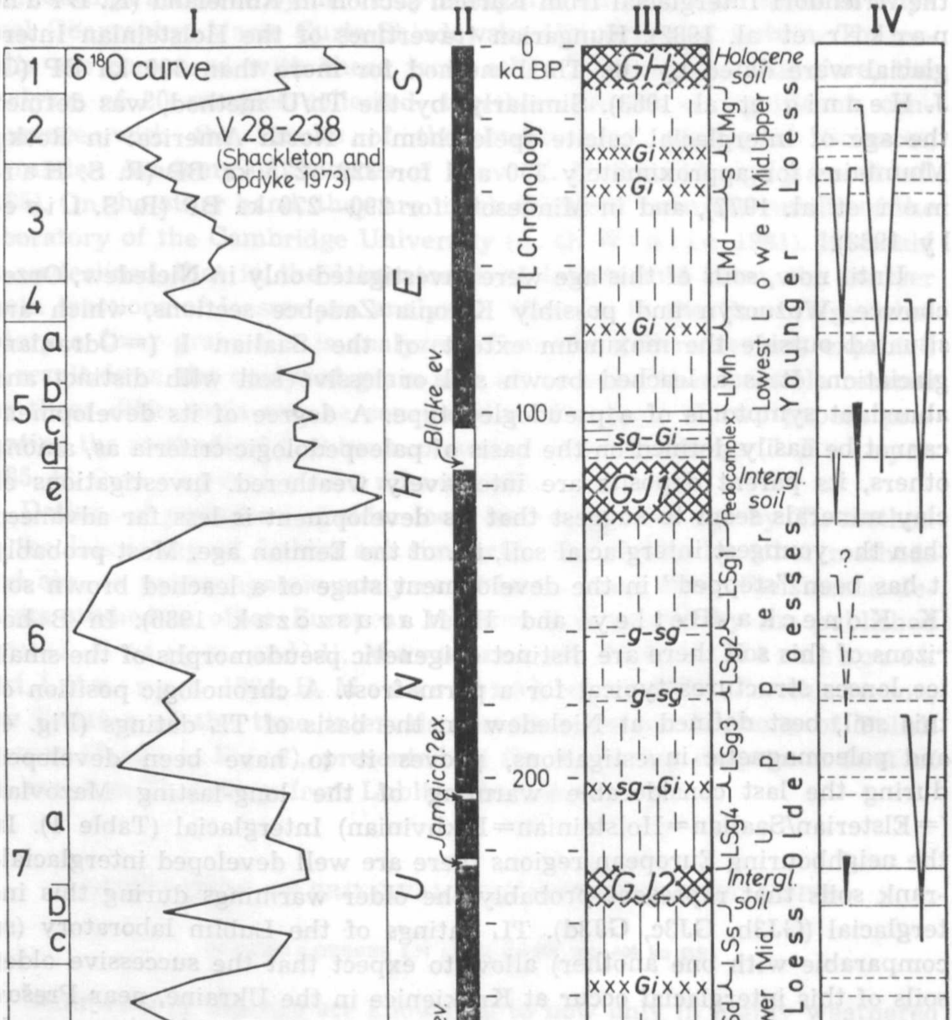


Fig. 3. Chronostratigraphic subdivision of the Polish loesses correlated with paleomagnetic events and oxygen isotope stages (after H. Maruszczak 1985, partly completed — graph IV)

cycles (Odranian=Saalian I and Wartanian=Saalian II) in southern Poland.

Lowest older loess LSn (310/300—280/270 ka BP). It is not very thick but is weathered and highly clayey with numerous gleyfication symptoms. It contains many secondary carbonates, particularly as very large concretions (Nieledew). These beds at Nieledew were found to contain a reverse magnetic polarity of the Chegan event (Fig. 3).

Weathering-soil bed sg-Gi/LSn (280—270 ka BP). It is composed of layers with symptoms of poor pedogenesis, locally passing into an initial gley soil of the type (Ag)-(Bg).

Lower older loess LSd (280/270—260/255 ka BP). It is usually weathered but less and with weaker gleyfication symptoms. There are secondary carbonates, mainly as rhizocoles and fine concretions.

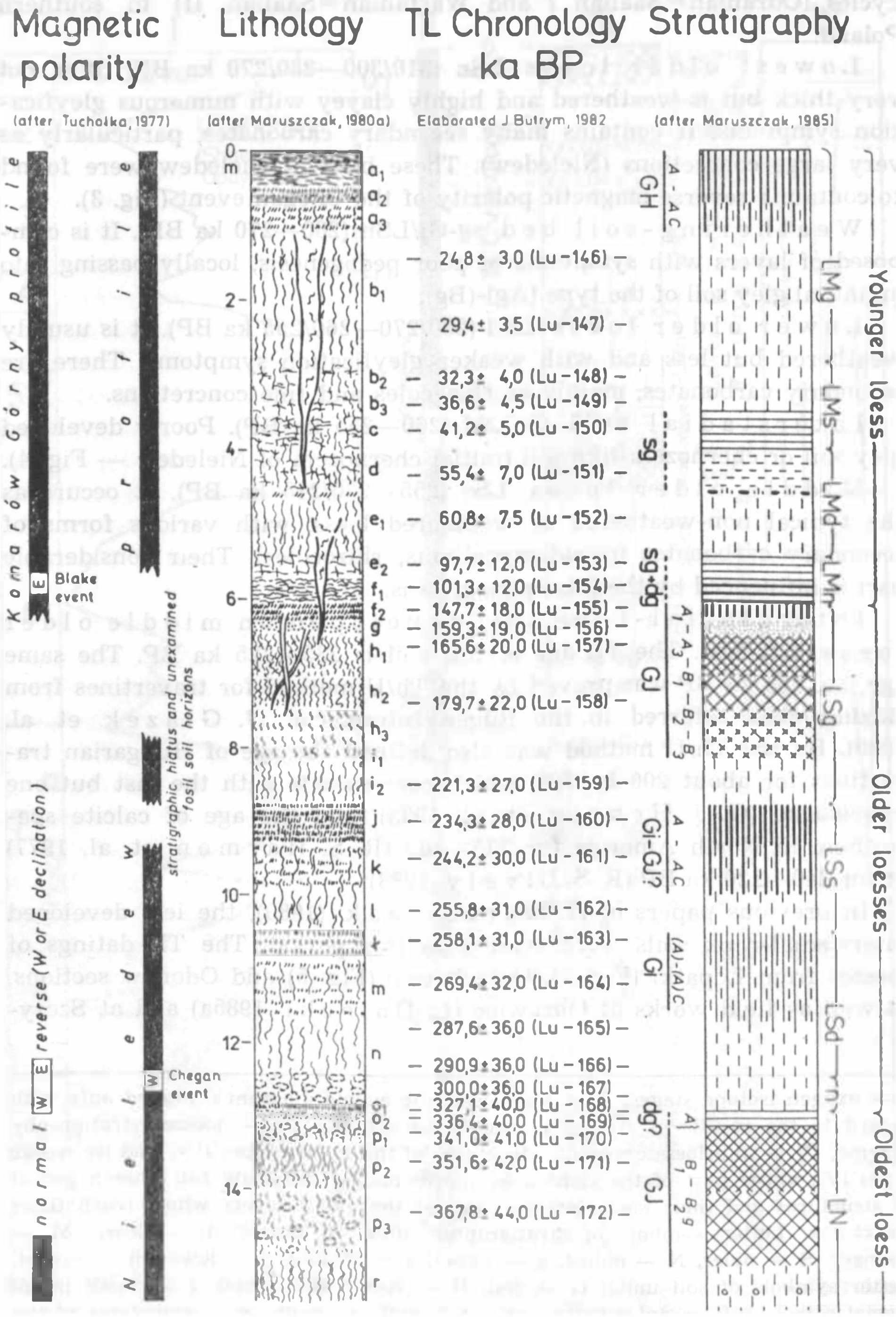
Interstadial soil Gi/LSd (260—255 ka BP). Poorly developed gley soil or chernozem-like soil (initial chernozem of Nieledew — Fig. 4).

Middle older loess LSs (255—230/225 ka BP). It occurs as the typical non-weathered or weathered loess, with various forms of secondary carbonates (pseudomyceliums, rhizocoles). Their considerable part is influenced by the later pedogenesis.

Interglacial-type soil developed on middle older loess GJ2/LSs. The TL age of this soil is 235—225 ka BP. The same age, i.e. 228 ka BP was proved by the Th/U method for travertines from Bilzingsleben referred to the Rügen Interglacial (J. Głazek et al. 1980). By the Th/U method was also defined the age of Hungarian travertines for about 200 ka BP, which corresponds with the last but one interglacial (G. J. Hennig et al. 1983), and the age of calcite speleothem in North America for 235—185 (R. S. Harmon et al. 1977) or for 240—220 ka BP (R. S. Lively 1983).

In previous papers of H. Maruszczak (1980), the less developed interstadial-rank soils were related to this period. The TL datings of loesses from Łopatki (Fig. 7), Orzechowce (Fig. 5) and Odonów sections, as well as field works at Obrowiec (L. Dolecki 1985a) and at Szczy-

I — oxygen isotope stages; II — paleomagnetic events diagram compiled only with regard to the results of studies of the Polish loesses; III — loesses stratigraphy scheme; IV — interloess cryogenic structures of the fissure types (! V) and ice wedge types (V): upper part of the signatures approximately designate full growth period of structures and their lower parts — age of the oldest layers which reach these structures. Letter symbols of stratigraphic units of loesses: L — loess, M — younger, S — older, N — oldest, g — upper, s — middle, d — lower, n — lowest. Letter symbols of soil units: G — soil, H — recent (Holocene), J — fossil interglacial soil, i — fossil interstadial soil, sg — soil sediments, g — symptoms of the development of pedogenesis


Magnetic polarity
Lithology
TL Chronology ka BP
Stratigraphy
(after Tucholka, 1977)
(after Maruszczak, 1980a)
Elaborated J. Butrym, 1982
(after Maruszczak, 1985)
Komarów Górny profile
Nieledew profile
Blake event
Chegan event
normal W E reverse (W or E declination)
stratigraphic hiatus and unexamined fossil soil horizons
24,8± 3,0 (Lu-146)
29,4± 3,5 (Lu-147)
32,3± 4,0 (Lu-148)
36,6± 4,5 (Lu-149)
41,2± 5,0 (Lu-150)
55,4± 7,0 (Lu-151)
60,8± 7,5 (Lu-152)
97,7± 12,0 (Lu-153)
101,3± 12,0 (Lu-154)
147,7± 18,0 (Lu-155)
159,3± 19,0 (Lu-156)
165,6± 20,0 (Lu-157)
179,7± 22,0 (Lu-158)
221,3± 27,0 (Lu-159)
234,3± 28,0 (Lu-160)
244,2± 30,0 (Lu-161)
255,8± 31,0 (Lu-162)
258,1± 31,0 (Lu-163)
269,4± 32,0 (Lu-164)
287,6± 36,0 (Lu-165)
290,9± 36,0 (Lu-166)
300,0± 36,0 (Lu-167)
327,1± 40,0 (Lu-168)
336,4± 40,0 (Lu-169)
341,0± 41,0 (Lu-170)
351,6± 42,0 (Lu-171)
367,8± 44,0 (Lu-172)
GH
sg
sg+dg
GJ
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Gi
dg?
GJ
LMg
LMs
LMd
LMr
LSg
LSs
LSd
LNr
LN
Younger loess
Older loesses
Oldest loess

glice (J. Rutkowski and Z. Śnieszko 1985) proved that besides such soils there also more developed ones. Among the latter there are three principal genetic horizons of forest soils, usually of a leached brown type. In their B horizons there also pseudomorphs of small ice lenses structures connected with permafrost. Investigations of larger exposures indicate that the more advanced forest soils formed a mosaic pattern with less developed bi-horizon soils. Among the latter degraded (leached) chernozem with specific, "breided" or "tongue-like" pseudomorphs of the contractional crack structures are distinguished (Fig. 4) *. It is not unlikely that the more advanced, i.e. three-horizon soils occur only on some relief elements, particularly on slopes with southern exposition. Thus, it seems that a typical environment of temperate forests has not been fully developed in southern Poland. Was it then the too short period or quite a cool one? Therefore, this interglacial was "incomplete" as if an embryonic one (cool interglacial?). Just this feature can be undoubtedly the explanation for numerous controversies and a discussion for dozens of years on the stratigraphic rank of the interval between the Saalian I and the Saalian II. In the stratigraphic horizon of the Saalian I/Saalian II, interstadials or interglacials have been therefore distinguished. More and more numerous papers have appeared lately in which this interval is considered for the interglacial: Lublin=Odranian/Wartanian (A. Środoń 1969, S. Z. Różycki 1980); Treenian=Drenthanian/Warthanian documented particularly on the basis of paleopedologic criteria (H. Stremme 1982); Odintsovian=Dnieprian/Moscovian (N. S. Čebotareva 1982). This embryonic interglacial corresponds to the oxygen isotope stage 7 (probably the substage 7a or 7c, with regard to the applied subdivision into three or five parts).

Earliest upper older loess LSg4 (225—200/195 ka BP). It forms a thin weathered clayey gleyed bed, locally in the lower part with secondary carbonates as small or big (e.g. Odonów) concretions. In the Orzechowce section these layers record a very short-lasting reverse polarity (Jamaica?) event or excursion.

* J. A. Liverovskiy (1974) named these recent soils as "tongue chernozems". After his data they occur especially in the forest-steppe zone of the western Siberia and the steppe zone of the Siberia-Kazakhstan borderland. The fissure--tongue structures themselves are connected with an intesive summer drying and strong winter freezing.

Fig. 4. Thermoluminescence chronology of the younger and older loesses of the section at Nieledew (after J. Butrym and H. Maruszczak 1983, H. Maruszczak et al. 1984; partly modified)

Explanation of the stratigraphic diagram — see Fig. 7

W e a t h e r i n g - s o i l b e d sg-Gi/LSg4 (200—195? ka BP). It indicates features of an initial gley or brown, poorly marked soil. In the Odonów section in the bottom layers of this bed an evidence of the reverse magnetic polarity (also Jamaica excursion?) was found.

E a r l y u p p e r o l d e r l o e s s LSg3 (195—180/175 ka BP). It is composed of non-weathered typical loess or weathered loess with secondary carbonates (pseudomyceliums, rhizocoles, small concretions). During its deposition ice wedge polygons developed, with horizontal size of several metres and wedges about 0.5 m wide. Pseudomorphs of these ice wedges prove that in this time a sporadic or discontinuous permafrost occurred.

Bed of initial pedogenesis g-sg/LSg3 (180—175? ka BP). It is composed of layers of carbonate loesses with quite distinct gleyfication symptoms.

M i d d l e u p p e r o l d e r l o e s s LSg2 (175—160? ka BP) and l a t e u p p e r o l d e r l o e s s (160—135/130 ka BP). They are carbonate typical loesses or weathered loesses subjected to later pedogenesis. Their upper layers are considerably degraded and with hiatuses in some sections. That is why no pseudomorphs of indubitable ice wedges have been found in these stratigraphic beds. In some sections they are probably separated by a gleyfication horizon.

I n t e r g l a c i a l s o i l d e v e l o p e d o n u p p e r o l d e r l o e s s GJ1/LSg. This soils was TL dated for 130/125—115/110 ka BP. These data differ from the time interval of the last interglacial, still accepted by many authors and defined for about 130—70 ka BP (S. Z. R ó ż y c k i 1972, I. P. G e r a s i m o v and A. A. V e l i c h k o et coll. 1982, R. J. F u l t o n 1984). However, the results of the investigations in Poland prove that the deposition of younger loesses began already about 100 ka BP, and well developed soils of the Eemian Interglacial were degraded and transformed in cool climate already from about 110 ka BP. So, these results are consistent with the latest results of the deep-sea sediment analyses, which indicate that climate deteriorated rapidly and drastically about 115 ka BP (W. D a n s g a a r d and J. C. D u p l e s s y 1981, C. P u j o l and J. C. D u p l e s s y 1983). The symptoms of rapid deterioration in this period were also found on the basis of palynological investigations of the known peat bogs in Grand Pile and Les Echets in France (G. W o i l l a r d 1979, J. P. B e a u l i e and M. R e i l 1984).

In this interglacial forest soils of larger thickness were formed, which were more developed than the Holocene soils. They were investigated in several sections, so it is possible to define their typological differentiation more exactly. The lessivé soils are the predominating, zonal type; besides them there are mainly brown and leached brown

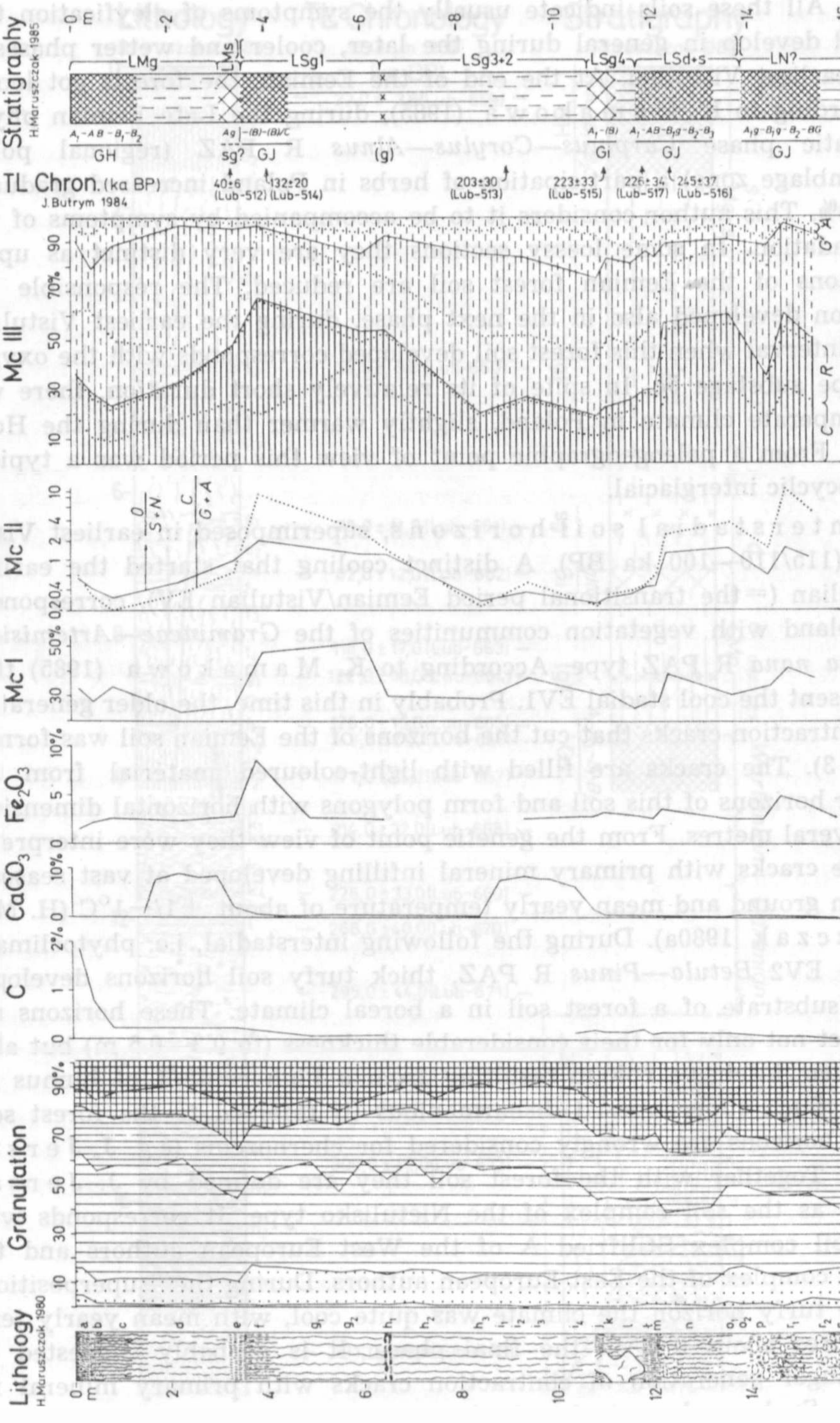

Fig. 5. The loess section at Orzechowce (explanation see Fig. 7)

soils. All these soils indicate usually the symptoms of gleyfication that could develop in general during the later, cooler and wetter phases of the earliest Vistulian. At the end of the Eemian, the forests got looser. According to K. M a m a k o w a (1985), during the Late Eemian phytoclimatic phase *Carpinus—Corylus—Alnus* R PAZ (regional pollen assemblage zone) a participation of herbs in Poland increased gradually to 30%. This author considers it to be accompanied by symptoms of soil degradation. In some loessy sections they are very distinct as upper horizons of the Eemian forest soil are reduced. The responsible soil erosion developed also in the next phase, during the earliest Vistulian. The interval when this forest soil developed corresponds with the oxygen isotope substage 5e. In spite of its relatively short duration, there was a temperate climate in Poland, slightly warmer than during the Holocene. From a paleogeographic point of view this period was a typical, monocyclic interglacial.

I n t e r s t a d i a l s o i l h o r i z o n s, superimposed in earliest Vistulian (115/110—100 ka BP). A distinct cooling that started the earliest Vistulian (= the transitional period Eemian/Vistulian EV), corresponded in Poland with vegetation communities of the *Gramineae—Artemisia—Betula nana* R PAZ type. According to K. M a m a k o w a (1985) they represent the cool stadial EV1. Probably in this time, the older generation of contraction cracks that cut the horizons of the Eemian soil was formed (Fig. 3). The cracks are filled with light-coloured material from the upper horizons of this soil and form polygons with horizontal dimensions of several metres. From the genetic point of view they were interpreted as the cracks with primary mineral infilling developed at vast seasonal frozen ground and mean yearly temperature of about $+1/-1$°C (H. M a r u s z c z a k 1980a). During the following interstadial, i.e. phytoclimatic phase EV2 *Betula—Pinus* R PAZ, thick turfy soil horizons developed on a substrate of a forest soil in a boreal climate. These horizons are distinct not only for their considerable thickness (to 0.3—0.5 m) but also, for their intensive colour resulting from a high content of humus (to 1.0%). Such superimposed disharmonious (if referred to the forest soil) turfy horizons are wrongly considered for chernozems (e.g. J. J e r s a k 1973). Together with the forest soil they are defined by J. J e r s a k (1973) as the soil complex of the Nietulisko type. It corresponds with the soil complex Stillfried A of the West European authors and the Mezin complex of the East European authors. During the "superposition" of the turfy horizon the climate was quite cool, with mean yearly temperatures about 0°C in the final phase. It is probably suggested by a younger generation of contraction cracks with primary mineral infilling. Such cracks cut also the horizons of the Eemian forest soil but

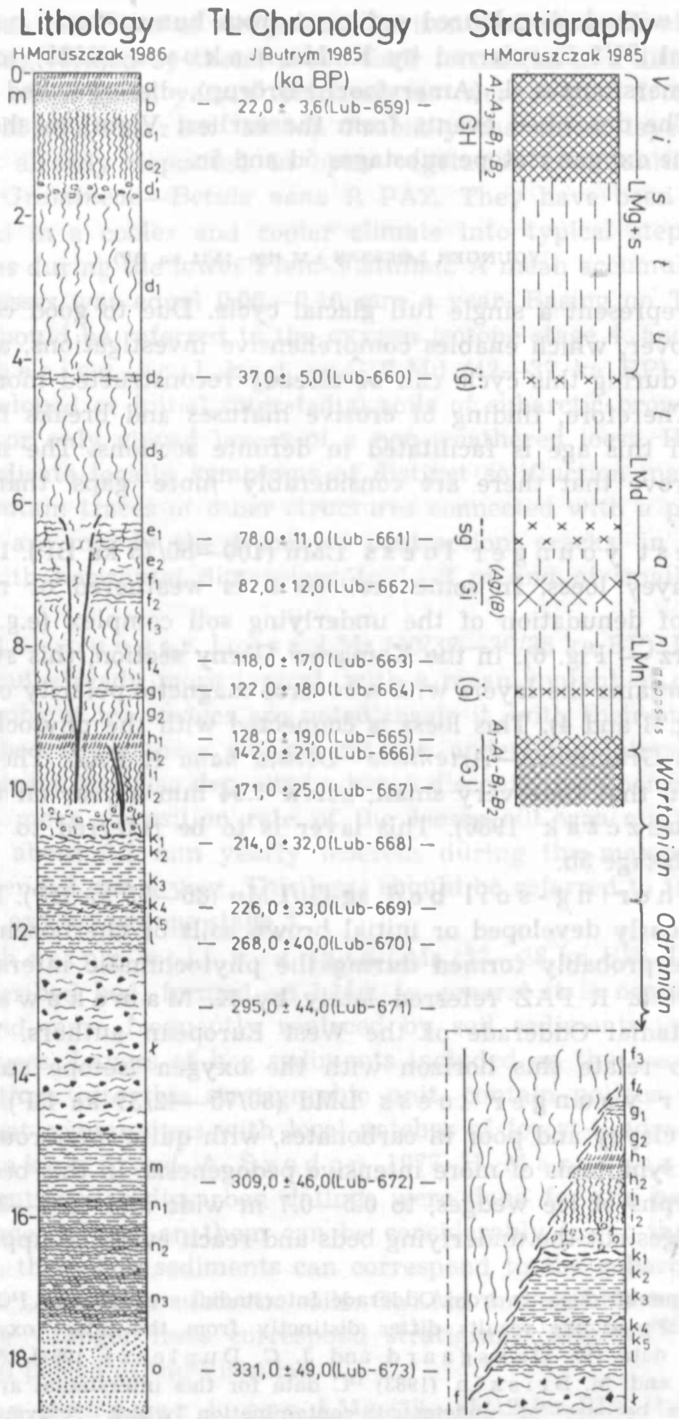

Fig. 6. Chronostratigraphy of the loesses and glacial deposits in the Sandomierz section (explanation of the stratigraphic diagram — see Fig. 7)

are filled with dark-coloured sediment from humus turfy horizons. The interstadial EV2 is referred by K. Mamakowa (1985) to the interstadial Amersfoort s. l. (Amersfoort+Brörup), distinguished in western Europe. The described events from the earliest Vistulian should be related to the oxygen isotope substages 5d and 5c.

YOUNGER LOESSES LM (100—15/12 ka BP)

They represent a single full glacial cycle. Due to good conservation of their cover, which enables comprehensive investigations, a succession of events during this cycle can be already reconstructed more precisely (Fig. 3). Therefore, finding of erosive hiatuses and breaks in loess deposition of this age is facilitated in definite sections. The most recent datings prove that there are considerably more gaps than expected previously.

Lowest younger loess LMn (100—80/75 ka BP). It is usually a thin clayey loess. In some sections it is weathered or replaced by products of denudation of the underlying soil complex (e.g. section at Sandomierz — Fig. 6). In the Komarów Górny section, this stratigraphic horizon contains the layers with a reverse magnetic polarity of the Blake event (Fig. 3 and 4). This loess is connected with the phytoclimatic cool stage EV3 *Gramineae—Artemisia—Betula nana* R PAZ. The deposition rate was in that time very small, below 0.04 mm a year on the average (H. Maruszczak 1986). This layer is to be referred to the oxygen isotope substage 5b.

Weathering-soil bed sg-Gi/LMn (80—75 ka BP). It is constituted of poorly developed or initial brown soils or chernozem-like soils. They were probably formed during the phytoclimatic interstadial EV4 *Pinus—Betula* R PAZ referred lately by K. Mamakowa (1985) to the interstadial Odderade of the West European authors. TL datings allowed to relate this horizon with the oxygen isotope substage 5a.*

Lower younger loess LMd (80/75—42/37 ka BP). This loess is usually clayey and poor in carbonates, with quite numerous interbeds indicating symptoms of more intensive pedogenesis. In this bed there are pseudomorphs of ice wedges, to 0.5—0.7 m wide and to 2—3 m height. These wedges cut the underlying beds and reach even the upper horizons

* Continental deposits from Odderade Interstadial are dated by ^{14}C method for 60—55 ka BP; so the results differ distinctly from the latest oxygen isotope substage 5a data (W. Dansgaard and J. C. Duplessy 1981). According to G. Kukla and M. Briskin (1983) ^{14}C data for this interstadial are too young by ca 15 ka because of undetected contamination which rejuvenate organic substance under examination.

of the Eemian soil. Sizes of wedges and horizontal dimensions of polygons (of 10—15 m), formed by them, prove their formation in a discontinuous permafrost when mean yearly temperatures were equal from −2 to −4°C (H. Maruszczak 1980a). Probably the oldest layers of this loess were already deposited in open vegetation communities of the stage EV5 *Gramineae—Betula nana* R PAZ. They have been gradually transformed in a cooler and cooler climate into typical steppe-tundra communities during the lower Pleni-Vistulian. A mean accumulation rate of these loesses was equal 0.06—0.10 mm a year. Basing on TL datings this loess should be referred to the oxygen isotope stage 4, and partly 3.

Weathering-soil bed sg-Gi/LMd (42—37 ka BP). They are poorly developed or initial interstadial soils of subarctic brown, gley or bog types, or only gleyed layers of a non-weathered loess. Horizons of this soil indicate locally symptoms of distinct solifluction mass-wasting but also contain traces of other structures connected with a permafrost. The latter are mainly the traces of contraction cracks in polygonal patterns with horizontal dimensions to 1—2 m and of small ice lense structures.

Middle younger loess LMs (40/37—30/28 ka BP). It is relatively thin but already more typical, with a mean content of carbonates. Pseudomorphs of ice wedges are noted inside it, with their sizes similar as in the bed LMd; these wedges cut the underlying interstadial soil. Thus, this loess was also deposited when a discontinuous permafrost was present. A mean deposition rate of the loessy silt was already higher and equal about 0.2 mm yearly whereas during the maximum phase reached even 0.3 mm a year. This loess should be referred to the younger part of the oxygen isotope stage 3.

Weathering-soil bed sg-Gi/LMs (32—28 ka BP). It is similar to the described bed, formed on LMd. In general it is not so well developed and more frequently replaced by soil sediments or layers of a gleyed loess. Layers of bog sediments included on the basis of radiocarbon datings into this stratigraphic unit, contain pollens typical for tundra plant communities with local patches of forest-tundra vegetation (K. Mamakowa and A. Środoń 1977, H. Maruszczak 1980a). As the mentioned radiocarbon datings were done for the humus acids, then the age defined on them can be considerably lower than the real one. Thus, these bog sediments can correspond to the subarctic soil developed on LMd. Both subarctic soils: Gi/LMd and Gi/LMs together with the middle younger loess correspond stratigraphically with the Interpleniglacial period of the Vistulian.

Upper younger loess LMg (28—15/12 ka BP). It is the most typical and homogeneous loess, with a lightest colour and a highest carbonate content. It usually constitutes slightly more than a half of the total thickness of younger loesses. Amidst its layers there are 1—3 poorly gleyed horizons that presumably indicate a more intensified pedogenesis. The bed of this loess is cut by pseudomorphs of large ice wedges of the following dimensions: a) width to 1.0 m, b) height to 4.0—5.0 m, c) horizontal dimensions of polygons to 20—25 m. In some sections the lower, fissure-derived parts of these wedges reach even the Eemian forest soil. Wedge sizes prove that the main deposition phase of this loess occurred when a continuous permafrost was present; thus, mean yearly temperatures reached presumably from −5 to −8°C (H. Maruszczak 1980a). According to severe climate and sharp continental features the deposition rate of a loessy silt was considerably higher than during the preceding periods: on the average it was equal 0.5 mm a year whereas during the phase of maximum intensity reached 0.8—1.0 mm a year. The upper younger loess was therefore deposited during the maximum extent of the Vistulian ice sheet, i.e. during the upper Pleni-Vistulian (Pleniglacial s.s.), correlated with the oxygen isotope stage 2.

Holocene soil developed on younger loess GH/LM (12/10—0 ka BP). From the typological point of view it is mainly the lessivé-type soil (zonal type) as well as forest brown or leached brown and forest gray soil. It is usually about 1.5 m thick, slightly less than the soil of the Eemian Interglacial age. This fact as well as poorer pedogenetic transformations of horizons B prove that during the Holocene the climate in the Polish territory was cooler than during the Eemian Interglacial.

SEDIMENTARY ENVIRONMENT AND TRENDS OF CHANGES IN A GLACIAL CYCLE BASED ON INVESTIGATIONS OF YOUNGER LOESSES

Loesses are commonly considered as sediments of the extraglacial zone, which comprise a relatively best preserved record of phenomena occurring in glacial cycles. However, if attempts of more detailed reconstructions of these phenomena are undertaken the loessy sections are found to enclose various stratigraphic hiatuses. Some of the latter are easily noticeable, especially if they are represented by erosion surface that cut the inter-loessy paleosols. Such hiatuses are most abundant in more intensively dissected loessy areas as it was indicated in numerous Polish papers (among others J. E. Mojski 1965, H. Maruszczak 1974). But they are indistinct if erosion surfaces cut the beds without the paleosols. In these cases a high homogeneity of loesses makes it difficult or even impossible to detect the hiatuses. Besides the hiatuses marked by erosion surfaces there are also those that correspond with longer breaks in sedimentation and they are more difficult to be found.

The latest results of chronostratigraphic investigations prove that even the best preserved and most widely distributed younger loesses enclose the hiatuses, indistinct in structural investigations. Such hiatuses are especially common in loesses of delluvial and eolian facies, and more rare in loesses of limnic-alluvial facies. Thermoluminescence datings

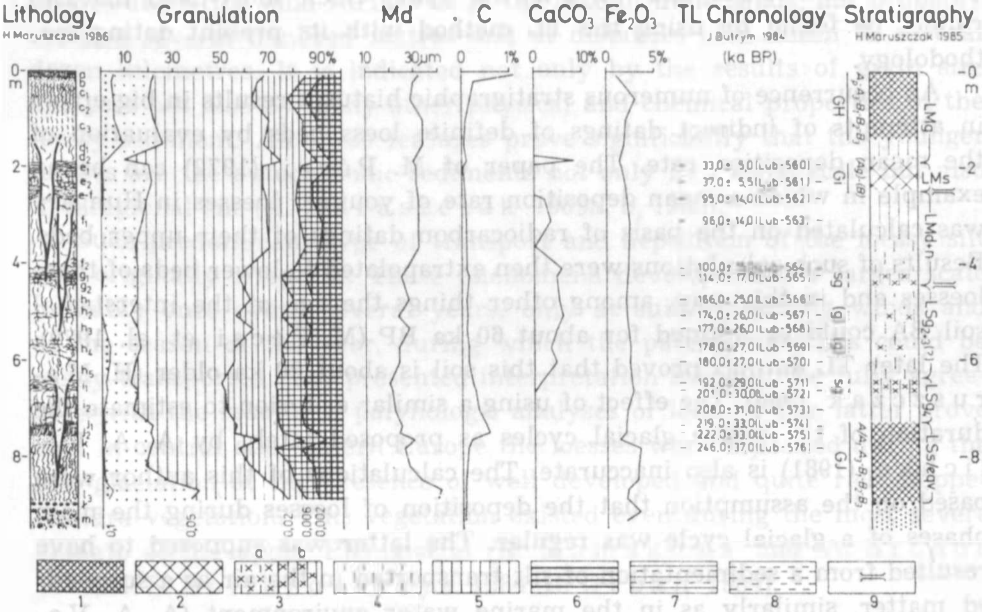

Fig. 7. The loess section at Łopatki

Legend of loess profile diagrams: Granulation — grain size distribution; Md — median grain size; C — humus content; $CaCO_3$ — carbonate content; Fe_2O_3 — iron oxides content; McI — opaque heavy minerals contents; McII — indices of the transparent heavy minerals composition; McIII — transparent heavy minerals composition. Letter symbols of transparent heavy minerals: C — zircon, R — rutile, G — garnet, A — amphiboles; O — most resistant minerals; S — medium resistant minerals; N — non-resistant minerals. Letter symbols of stratigraphic units of loesses: L — loess, M — younger, S — older, N — oldest, g — upper, s — middle, d — lower, n — lowest. Letter symbols of soil units: G — soil with well developed genetic horizons, H — recent (Holocene) soil, J — fossil interglacial soil, i — fossil interstadial soil, sg — soil sediments, dg — soil deluvia, (g) — symptoms of the development of pedogenesis. Graphic signatures: 1 — Holocene and interglacial soils; 2 — interstadial soils; 3 — soil sediments and poorly developed interstadial soils; 4 — non-weathered, carbonate loesses; 5 — weathered, carbonate-free loesses and deluvia of fossil soils; 6 — resistant heavy minerals; 7 — medium resistant heavy minerals; 8 — non-resistant heavy minerals; 9 — main hiatuses (gaps) among stratigraphic units of sections allow to find these hiatuses, indistinct from the morphologic-structural point of view, if they are chronologically shorter than several dozen thousands of years. This is supported by the results of studies of the sections at Łopatki (Fig. 7), Orzechowce (Fig. 5) and Nieledew (Fig. 4: a hiatus at the contact of the beds e_1 and e_2). The hiatuses noted in the Łopatki section are also univocally supported by the results of paleomagnetic analyses. The latter allow to record more numerous "short-lasting" hiatuses, being probably hardly several hundred years long (H. Maruszczak and M. Tkacz 1987). Such short-lived hiatuses cannot be found by using the TL method with its present dating methodology.

An occurrence of numerous stratigraphic hiatuses results in big errors in attempts of indirect datings of definite loess beds by evaluation of the mean deposition rate. The paper of M. Pécsi (1972) can be an example in which a mean deposition rate of younger loesses in Hungary was calculated on the basis of radiocarbon datings of their upper beds. Results of such calculations were then extrapolated to lower beds of these loesses and in this way, among other things the age of the interstadial soil BA could be defined for about 60 ka BP (M. Pécsi et al. 1979). The later TL datings proved that this soil is about 20 ka older (H. Maruszczak 1986). The effect of using a similar criterion to estimate the duration of the whole glacial cycles as proposed lately by A. A. Velichko (1981) is also inaccurate. The calculations of this author were based on the assumption that the deposition of loesses during the main phases of a glacial cycle was regular. The latter was supposed to have resulted from a sedimentation of silt transported in the air as a suspended matter, similarly as in the marine water environment (A. A. Velichko et al. 1987). Investigations of the Polish loesses do not support such an idea of sedimentation.

Just the pattern itself of distribution of loessy covers in Poland contradicts the suspension of uniform deposition of silt. The covers form patches, frequently well isolated and connected only with the areas of more diversified, moderate relief (Fig. 1). Close to these patches and amongst them there are vast flat zones without loesses and with no traces of their occurrence at any time in the past (H. Maruszczak 1969b, 1985).

The grain size composition of the Polish loesses also quite univocally proves that the predominant part of their sediment was not carried out in suspension. In this way only the silts below 0.005 mm in diameter are transported in the higher layers of the atmosphere and at larger distances. This is proved among other things by measurements of atmospheric silts deposited also at present in south-eastern Poland, once every several or several dozen years when large silt storms occur in the Ukraine (J. Wojtanowicz and A. Zinkiewicz 1966). On the other hand a mean loess grain is considerably larger, usually 0.025—0.035 mm. The volume of such a grain is 100—1000 times greater than that of the "suspended" eolian silts (H. Maruszczak 1969). A predominant part of the loessy sediment was then transported by lower atmospheric currents, i.e. in a similar environment as dune sands. In agreement with the grain size the transport has not occurred at several metres above the land surface as in the case of dune sands, but probably reached several hundred metres and at distances of a dozen to several dozen kilometres. It is indicated not only by the results of grain size analyses but also by many other physical and chemical properties of the loessy sediment. All these features prove significantly that the younger loesses are the autochthonic sediments not only in a zonal scale but also in a regional one (H. Maruszczak 1969a, b, 1985).

Such predominant type of transport and deposition of the loessy silt was originally irregular. These phenomena developed on a larger scale probably once every several years, only at suitably strong winds and in the season of the year, during which the parent materials could be easily transported. The presented interpretation seems to be fully agreeable with the results of palynologic analyses of loesses. The latter prove that in central and eastern Europe the loesses were deposited during the last glaciation at the presence of well developed and quite rich steppe--tundra vegetation. This vegetation existed even during the most severe climate of the upper Pleniglacial (K. Mamakowa and A. Środoń 1977, N. S. Bolikhovskaya 1984, B. Urban 1984).

The conclusion on the irregular deposition of loesses can be also drawn from the analysis of the loess structure. Even the most typical variants of the upper younger loesses indicate usually a fine lamination. The laminae are generally at least 1—2 mm thick and frequently considerably more. Therefore, these thicknesses are several times as large as the indices of the mean deposition rate, defined in Poland for about 0.5 mm a year for the younger upper loesses. To avoid misunderstandings one should underline that thicknesses of the laminae themselves cannot be treated as the direct indices of the type and intensity of eolian accumulation. They are most frequently the laminae that have been formed during washing of the fresh (non-consolidated) silt during more intensive spring floods or substantial summer rainfalls. Discontinuities and numerous erosive "micro-cuts" are the characteristic features of laminae. Such cuts represent short-lasting hiatuses in loessy sections, corresponding with the mosaic pattern of micro-patches with predominant erosion and deposition on slopes. A mosaic pattern is characteristic in the same time not only for valley slopes but also for flat watershed or terrace zones. Such flat areas covered with loess indicate in Poland a fine-wavy relief with numerous convex and concave mesoforms (H. Maruszczak 1985). Thus, the watershed zones cannot be assumed to have the loessy sections without greater stratigraphic hiatuses. In eastern Europe where such watershed zones are vaster, such geomorphologic

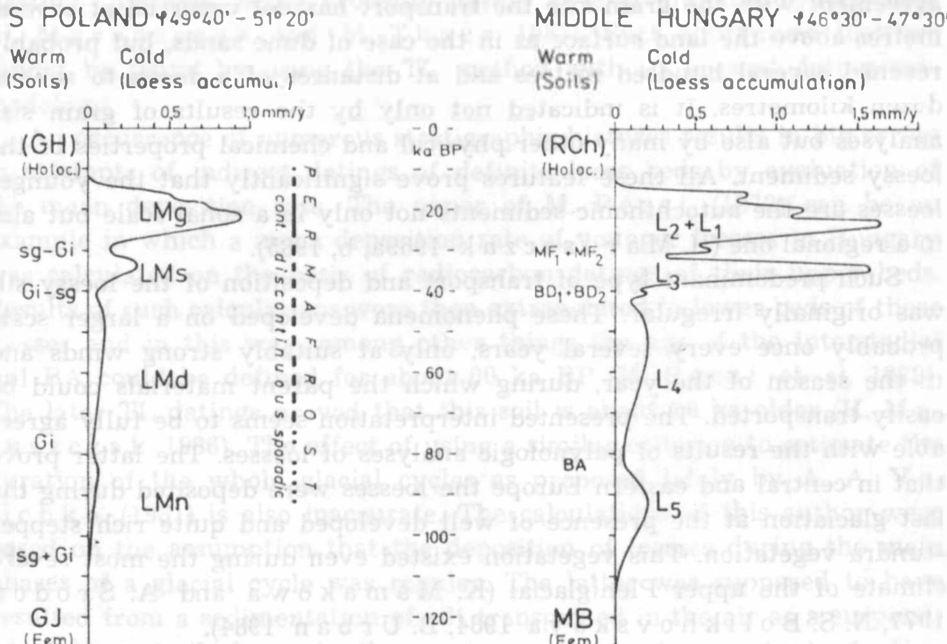

Fig. 8. Diagram of the intensity of accumulation of Vistulian loesses in southern Poland and central Hungary. While calculating the accumulation rate of loess silt in Poland the average thickness of the particular stratigraphical units were taken into account and in Hungary the thickness determined for the representative loess profile at Mende. Stratigraphy of Polish loesses after H. Maruszczak (1980) and Hungarian loesses after M. Pécsi (1982)

Letter symbols and stratigraphical index of loesses in Hungary: L_1 ... L_5 — young loess series; RCh — recent chernozem; MF — Mende Upper interstadial paleosol; BD — Basaharc Double interstadial paleosol; BA — Basaharc Base interstadial paleosol; MB — Mende Base soil complex (last interglacial)

locations may possess more complete loessy sections as it is accepted by A. A. Velichko et al. (1987).

Despite the conclusion on the irregularity and discontinuity of the loessy sedimentation, it seems reasonable to calculate its mean rate indices. But they should rather be used mainly for comparisons and paleogeographic reconstructions than for chronostratigraphic analyses.

What are then the paleogeographic conditions of loess deposition in Poland?

Mean indices of deposition rate of the whole younger loessy beds are equal about 0.1 mm a year for the time interval of 110/100—12 ka BP. They are typical for the areas in which a total thickness of these loesses is about 10 m. They are 2—3 times smaller for the areas of the lowest loess thicknesses. They can be also over twice as large in the case of loessy patches that are located at morphologic escarpment zones. In such zones the largest thicknesses of the younger loesses are noted near Hrubieszów where they are over 20 m (L. Dolecki 1985). Approximately usually 7—10 m mean thickness of loesses is typical for the central part of a vast zone with such sediments in eastern Europe. However, it considerably decreases southwards and is equal only about 2 m at the Black Sea (I. P. Gerasimov and A. A. Velichko et coll. 1982). A very similar thickness is also noted in the Loess Plateau in China as most frequently it reaches about 10 m if only the Chinese younger loesses, named the "Malan loess" are concerned (Zhang Zonghu 1984, Wen Quizhong and Zheng Honghua 1985). As their age is defined by the TL method for 120/110—10 ka BP (Li Huhou 1985), a mean deposition rate was not much different than that estimated for the Polish younger loesses. Thus, our loesses are similar to those in the most classical regions of Eurasia as regards their deposition rate.

The deposition rate of younger loesses varied considerably in time. Due to TL datings a more detailed analysis of the rhythm of this variation could be done (H. Maruszczak 1986). It proves that during the preliminary deposition phase, i.e. in the early Vistulian and the lower Pleniglacial, the mean rate was hardly equal 0.06—0.10 mm a year. During the Interpleniglacial it increased to about 0.2—0.3 mm a year and to 0.5 mm a year in the upper Pleniglacial. It distinctly decreased during the interstades as indicated by the presence of layers with pedogenetic transformations (Fig. 8). A very similar rhythm of sedimentation was reconstructed in a similar way also for the Hungarian loesses. The results of a suitable analysis were, however, accepted only from the loessy sections Mende and Paks, in which the younger loesses are uncommonly thick. This fact is being explained by the presence of an exceptionally rich source of loessy silt in the Danube alluvia, coming from a vast drainage basin. Therefore, in comparison of results (Fig. 8) for the Polish loesses based on analyses of average thickness and for the Hungarian loesses based on data from extremely thick sections, the emphasis should not be given the values of the indices of deposition intensity but the rhythm of changes.

Changes of the deposition rate of the loessy silt illustrate well the

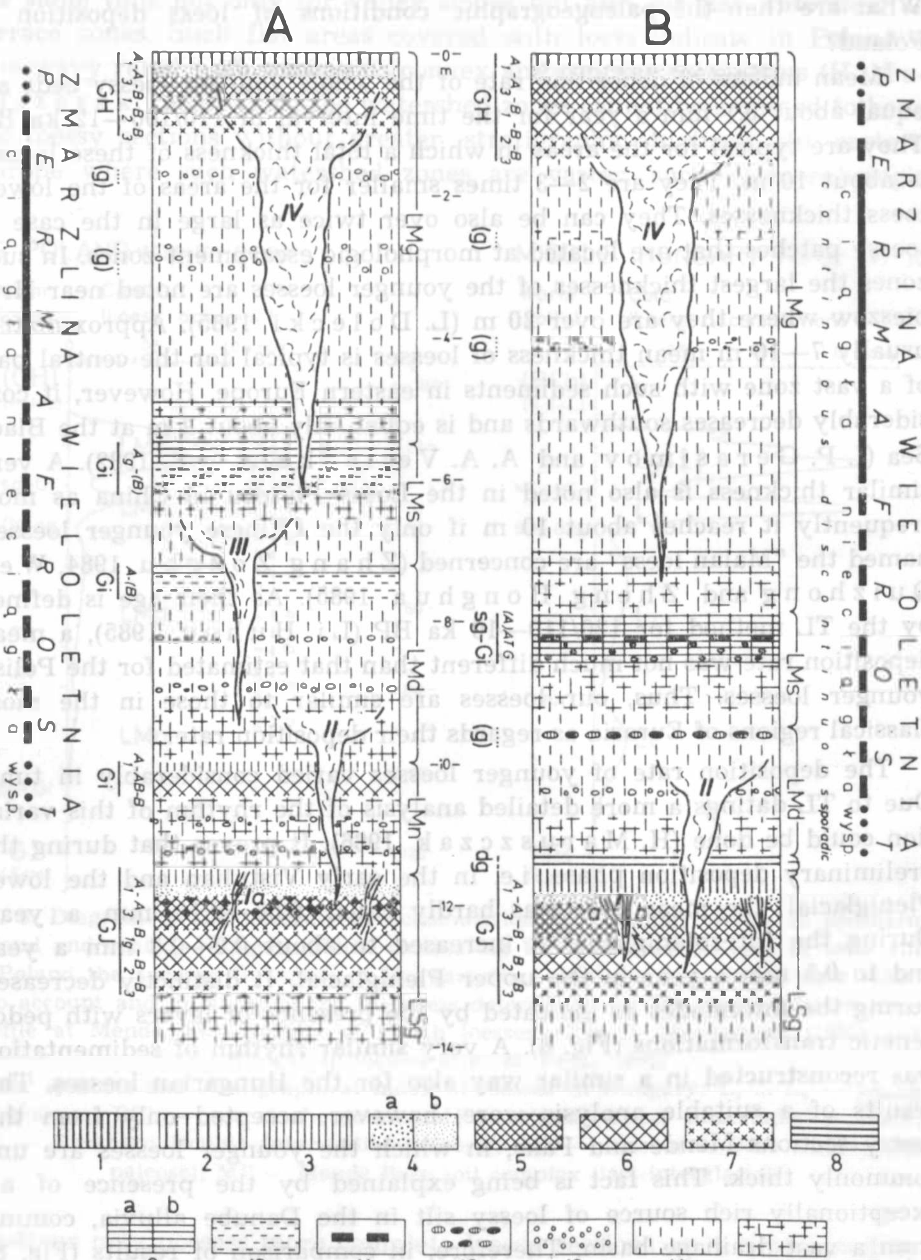

Fig. 9. Stratigraphic scheme of two main types of the Vistulian loess sections in Poland (according to H. Maruszczak 1980, partly modified). A — representative section for slopes with cool exposure; B — representative section for slopes with warm exposure

varying geographic conditions in a glacial cycle. During the upper Pleniglacial this rate was at least 5 times as large as during the lower one, which undoubtedly proves a specific character of the relatively short, culminant phase of a glacial cycle. A great similarity of the rhythm reconstructed for the Polish loesses of a periglacial zone with continuous permafrost and for the Hungarian ones, coming in fact from outside of this zone, proves that this rhythm depended on general factors, ruling the changes of the macroscale glacial cycle.

An analysis of the physico-chemical properties of younger loesses and first of all of the cryogenic structures and soils within them, allows to define some features of geographic conditions of the successive deposition phases. It indicates a general trend of grain size variation, showing a decreased content of the colloidal fraction, and of the chemical composition with a particular rise in the carbonate content. These observations prove a diminishing role of the chemical component of the weathering processes and an increasing dryness (continentalization) of the climate in the successive phases of the cycle. A decreasing content of the colloid fractions proves probably not only the decreasing role of chemical weathering. It seems to suggest the changes in the content of the far--distance grains (part of the finest grains of the loess body come from this transport). During the lower Pleniglacial the relative role of such grains was higher as conditions for incorporating and transport of grains of the loessy basic fraction were less favourable for the local sources. A more

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Graphic signatures: 1 — humus horizons of the chernozem type; 2 — other well pronounced humus horizons; 3 — poorly pronounced humus horizons; 4 — leached horizons: a) — well pronounced, b) — poorly pronounced; 5 — upper, more intensly coloured portion of brown-earth and illuvial horizons; 6 — middle, less intensly coloured portion of brown-earth and illuvial horizons; 7 — lower portion of illuvial horizons with irregular brownish and yellowish streaks; 8 — deluvia of chernozem type horizons; 9 — soil sediments with symptoms of initial humus horizons: a) well pronounced, b) poorly pronounced; 10 — soil sediments with browning evidence; 11 — mineral-peat lenses in swampy soil; 12 — spotty concentrations with increased humus or iron manganese compounds content; 13 — gleying symptoms; 14 — carbonate loess; 15 — carbonate-free loess (decalcified). Letter symbols of stratigraphic units of loesses: L — loess, M — younger, S — older, g — upper, s — middle, d — lower, n — the lowest. Letter symbols of soil units: G — soil with well developed genetical horizons, H — recent (Holocene) soil, J — fossil interglacial soil, i — fossil interstadial soil, sg — soil sediments, dg — soil deluvia, (g) — symptoms of the development of pedogenesis. Numerical symbols of pseudomorphs of cryogenic polygon structures: I — cracks with primary seasonal ground filling of the older (a) and younger (b) generations from the earliest Vistulian; II — wedges primarily with ice, and secondarily with mineral filling from the lower Pleni-Vistulian; III — also from the Interpleni--Vistulian; IV — also from the upper Pleni-Vistulian (Pleniglacial sensu stricto) distinctly marked predominance of the grain size of local origin in the upper Pleniglacial does not mean a limited intensity of the far-distance transport but only a drop in its relative participation.

More substantial conclusions of paleogeographic nature come from the analysis of cryogenic structures. They indicate that during the early Vistulian (110/100—75 ka BP) a strongly developed seasonal frozen ground occurred in cooler stages in southern Poland at mean yearly temperatures about 0°C. This seasonal frost is marked by pseudomorphs of small polygons with fissures with a primary mineral infilling (Figs 3, 9). On the other hand during the interstade warming the temperatures were several degrees higher and, therefore, a poorly developed seasonal frost did not leave any visible traces. During the lower Pleni-Vistulian (75—42 ka BP) sporadic and later discontinuous permafrost gradually developed, at mean yearly temperatures from —1/—2 to —4/—5°C. It is documented by pseudomorphs of small ice lense structures of ground ice and by fine wedges with a primary ice infilling (Fig. 9). During the Interpleni-Vistulian (42—28 ka BP) a discontinuous permafrost probably still existed. It is suggested by the fact that pseudomorphs of cryogenic structures, as in the lower Pleniglacial, occur in suitable loessy horizons. During the interstade warmings permafrost did not rather disappear either. It is indicated by the features of the tundra soils formed in that time, which usually show symptoms of gleization from the top and not only within the concave but also convex relief elements. Thus, it is to be expected that gleization was connected with the occurrence of an impermeable substrate, i.e. permafrost. During the upper Pleni-Vistulian (28—15/12 ka BP) discontinuous permafrost was gradually transformed into a continuous one at mean yearly temperatures from —5 to —8°C. It is documented by traces of large ice wedges that developed in the second part of this period. Melting of ice of these structures, marking a destruction of permafrost occurred locally still before the end of loess deposition. This phase is marked by gleization horizons that cover the pattern with polygons with large ice wedges, occasionally visible just under the Holocene soils. But in most sections the large wedges "enter" the layers that are transformed by the Holocene pedogenesis (Fig. 9). The diagenesis of these layers is so high that a more detailed reconstruction of the events in the interval 15—12 ka BP is impossible.

The rhythm of events reconstructed on the basis of the analyzed cryogenic structures in the younger loesses of Poland is similar to that reconstructed for eastern Europe (I. P. Gerasimov and A. A. Velichko et coll. 1982). These similarities are particularly distinct if referred to the upper Pleniglacial. Some differences in approach to the lower Pleniglacial can result from separate chronostratigraphic interpretation (H. Maruszczak, A. A. Velichko et al. 1982). The similarities in the development of the events in Poland and eastern Europe result undoubtedly from the action of general factors on a global scale. Some differences can result from changes of the permafrost in time as well as in space. The latter was not only arranged in zonal pattern from north to south but also in a provincial system from west to east. In Poland the latter changes can be noted not only by the analyses of cryogenic structures. They are also proved by results of analyses of the thickness, properties and facies of loesses in the Sudetic foreland near Wrocław and in south-eastern Poland near Hrubieszów (H. Maruszczak 1969a, 1985, J. Jersak 1985). Differences of climatic conditions reconstructed on this basis were in these far areas during the Pleniglacial close to those of the present days. In the Wrocław area the present climate indicates the predominance of maritime features and in the Hrubieszów area there is a distinct component of the continentalization. Therefore, even during the Pleniglacial the influence of the ice sheet did not predominated the global relations of the maritime and continental impacts in the mid latitudes of Europe.

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STRESZCZENIE

We wstępie omówiono rozwój poglądów na stratygrafię lessów. W najstarszych opracowaniach ustalano ją na podstawie analizy powiązań tych utworów z glinami zwałowymi kolejnych nasunięć lądolodów, później głównie na podstawie badań gleb kopalnych rangi interglacjalnej oraz interstadialnej. Zreferowano także nowsze koncepcje korelacji lessów z cyklami glacjalnymi.

Na tym tle przedstawiono aktualną wersję schematu stratygraficznego. Opracowano ją z uwzględnieniem nowszych wyników badań paleomagnetycznych i datowań metodą ^{14}C, a przede wszystkich licznych datowań metodą termoluminescencyjną (TL), wykonanych przez dr. Jerzego Butryma w laboratorium Zakładu Geografii Fizycznej UMCS. Opracowany w ten sposób schemat (Fig. 3 i Tab. 1) skorelowano z odpowiednimi opracowaniami dla lessów Europy zachodniej i wschodniej. Datowania TL umożliwiły także korelację ze stadiami izotopowymi tlenu (^{18}O) osadów głębokomorskich. W schemacie wyróżniono:

1. Lessy najstarsze (LN) z okresów poprzedzających interglacjał Mazovian= Holsteinian=Likhvinian. Nie można ich obecnie zróżnicować pod względem stra-

tygraficznym, gdyż zachowały się one szczątkowo i tylko w postaci zwietrzałej. Silna ich degradacja wiąże się z tym, że cała strefa występowania lessów w Polsce była w zasięgu lądolodu Sanu=Elstery II=Oki, a duża jej część także w zasięgu lądolodu następnego zlodowacenia. Na warstwach LN rozwinięta jest gleba leśna rangi interglacjalnej (GJ); w występujących nad nią warstwach lessów w Nieledwi stwierdzono oznaki odwrotnej polarności magnetycznej (zapewne Chegan event). Na tej podstawie oraz odpowiednio do wyników datowań glebę tę (GJ3a/LN) można wiązać z interwałem 330—310 ka BP.

2. Lessy starsze (LS) datowane na 310/300—135/130 ka BP, a więc reprezentujące cykle glacjalne Saalianu→Rissu. Są one znacznie lepiej zachowane, w tym także w postaciach niezwietrzałych. Można więc zróżnicować je pod względem stratygraficznym. Uwzględniając występowanie wśród nich gleb kopalnych podzielono je następująco:

a) Lessy starsze najniższe (LSn), 310/300—280/270 ka BP; rozwinięta jest na nich glejowa gleba interstadialna.

b) Lessy starsze dolne (LSd), 270—260/255 ka BP, z rozwiniętą na nich interstadialną glebą glejową lub typu inicjalnego czarnoziemu.

c) Lessy starsze środkowe (LSs), 255—230/225 ka BP. Rozwinięte są na nich gleby czarnoziemne wyługowane, którym dawniej przypisywałem rangę interstadialną. Datowania TL ostatnich lat wykazały jednak, że do tej jednostki stratygraficznej należy zaliczyć także leśne gleby brunatne wyługowane, które dawniej interpretowano jako młodsze i reprezentujące ostatni interglacjał.

Datowania TL świadczą, że tak wyodrębniona kolejna śródlessowa gleba rangi interglacjalnej (GJ2/LSs) powstała w interwale 235—225 ka BP, odpowiadającym 7a substadium ^{18}O. Z takim datowaniem zdaje się być zgodne stwierdzenie w warstwach lessów nadległych oznak odwrotnej polarności magnetycznej (Biwa II event lub Jamaica excursion?). Przypisywanie temu interwałowi rangi interglacjalnej jest jednak kontrowersyjne. W Polsce obecnie paleobotanicy raczej nie wiążą z nim sukcesji roślinnych typowych dla klimatu umiarkowanego. Tylko niektórzy wyodrębniają więc ten okres jako interglacjał Lublinian=Treenian=Odintsovian. Dzieli on dwa odrębne nasunięcia lądolodów Odry (=Saale I) i Warty (=Saale II). Przyjmując taki pogląd — jako uzasadniony z paleopedologicznego punktu widzenia — warstwy LSn, LSd i LSs traktuję łącznie jako odpowiadające cyklowi glacjalnemu Odranian=Drenthenian=Dnieprian. Wyniki datowań TL pozwalają skorelować je ze stadiami ^{18}O: 8 i 7 (jego częścią dolną).

d) Lessy starsze górne (LSg), 225—135/130 ka BP. Występują wśród nich tylko słabe oznaki pedogenezy, w postaci poziomów oglejenia, które tylko miejscami przechodzą w inicjalne gleby glejowe. Dzielą one te lessy na cztery jednostki stratygraficzne, oznaczone symbolami: LSg4, LSg3, LSg2 i LSg1. Podane są pierwsze, wstępne wyniki ich datowania metodą TL.

Warstwy LSg w obecnej wersji podziału prezentują więc cykl glacjalny Wartanian=Warthanian=Moscowian. Można je skorelować ze stadiami ^{18}O: 7 (część górna) i 6. W ich stropie występuje dobrze wykształcona interglacjalna gleba leśna (GJ1/LSg), przeważnie typu lessivé. Powstała ona w Eemianie, w interwale 130/125—115/110 ka BP odpowiadającym 5e substadium ^{18}O. Górne poziomy tej gleby lub produkty jej denudacji oraz słabej akumulacji lessowej są przekształcone w miąższy, nałożony poziom humusowy typu darniowego. Odpowiada on interstadiałowi Amersfoort (około 110—100 ka BP) z najwcześniejszego Vistulianu. W tych warstwach występują oznaki odwrotnej polarności (Blake event).

3. Lessy młodsze (LM), datowane na 100—15/12 ka BP, akumulowane podczas ostatniego cyklu glacjalnego, tzn. Vistulianu→Würmu. Są one najlepiej zachowane i zbadane w licznych profilach. Dzięki temu wcześniej ustalona ich stratygrafia nie uległa zmianom w rezultacie datowań metodą TL. Podzielono je następująco:

a) Lessy młodsze najniższe (LMn), 100—80/75 ka BP. Rozwinięte są na nich inicjalne gleby brunatnoziemne lub podobne do czarnoziemnych, odpowiadające wczesnoglacjalnemu interstadiałowi Odderade.

b) Lessy młodsze dolne (LMd), 75—42/37 ka BP, reprezentujące dolny pleniglacjał. Rozwinięte są na nich słabo wykształcone subarktyczne gleby brunatne, glejowe lub bagienne, paralelizowane z interstadiałem Hengelo.

c) Lessy młodsze środkowe (LMs), 37—30/28 ka BP, reprezentujące interpleniglacjał. Rozwinięte są na nich gleby podobne jak na LMd, sparalelizowane z interstadiałem Denekamp.

d) Lessy młodsze górne (LMg), 28—15/12 ka BP, odpowiadające górnemu pleniglacjałowi. Wykazują one wszystkie cechy reprezentatywne dla najbardziej typowego lessu. Górne ich warstwy są zmienione przez procesy glebotwórcze, które zaczęły się rozwijać od późnego glacjału. Na warstwach LMg rozwinięta jest współczesna gleba leśna (GH/LMg), przeważnie typu lessivé, reprezentująca okres holocenu.

Dzięki dobremu zachowaniu LM wyniki ich badań dają podstawę do rekonstrukcji zdarzeń w ostatnim cyklu glacjalnym. W najwcześniejszych etapach tego cyklu, tzn. we wczesnym Vistulianie, na obszarze Polski w najchłodniejszych okresach średnie roczne temperatury spadały do około 0°C. W warunkach silnie rozwiniętej zmarzliny sezonowej powstawały wówczas szczeliny mrozowe z pierwotnym wypełnieniem mineralnym, tworzące poligony o małych wymiarach. W dolnym pleni-Vistulianie rozwinęła się wieloletnia zmarzlina wyspowa i nieciągła. W takich warunkach, przy temperaturach średnich rocznych rzędu —2/—4°C, powstawały poligony kontrakcyjne średniej wielkości, z pierwotnym wypełnieniem szczelin typu klinów lodowych. Taka zmarzlina prawdopodobnie trwała z pewnymi fluktuacjami w interpleni-Vistulianie. W górnym zaś pleni-Vistulianie, przy średnich temperaturach rocznych rzędu —5/—8°C, rozwinęła się ciągła zmarzlina wieloletnia, z dużymi poligonami wielkich klinów lodowych.

Odpowiednio do warunków klimatycznych zmieniało się tempo akumulacji LM: od poniżej 0,06 mm/rok w najwcześniejszych fazach Vistulianu, do 1,00 mm/rok w niektórych fazach górnego pleni-Vistulianu. W ciągu całego ostatniego cyklu glacjalnego przeciętne tempo akumulacji wynosiło około 0,1 mm/rok i było podobne jak w klasycznych regionach lessowych Eurazji. Akumulacja następowała jednak nierytmicznie, prawdopodobnie z licznymi przerwami, głównie podczas krótkotrwałych ekstremalnych zdarzeń występujących raz na kilka lat.

РЕЗЮМЕ

В самом начале статьи рассматривается эволюция мнений касающихся стратиграфии лёссов. В самых древних работах она основывалась результатами изучения связей этих образований с моренами очередных надвигов ледникового покрова, позднее главным образом на основе исследований горизонтов ископаемых почв. Обсуждаются также новейшие попытки сопоставления лёссов с гляциальными циклами.

На этом фоне представляется новейшая версия стратиграфической схемы.

Она разработана на основе последних палеомагнитных исследований и радиоуглеродных датировок, а главным образом термолюминесцентных (ТЛ) датировок проведенных др. Ю. Бутримом в лаборатории Отделения физической географии Университета Марии Склодовской-Кюри в Люблине. Эту схему (Fig. 3, Table 1) сопоставлено с соответствующими работами применяемыми сейчас для лёссов западной и восточной Европы. Результаты многих ТЛ датировок использованы для сопоставления схемы с изотопно-кислородными (^{18}O) ярусами глубоководных океанических осадков. В схеме выделяются:

1) Лёссы самые древние (LN), из времен предшествующих Мазовецкому= =Гольштейнскому=Лихвинскому межледниковию. Их невозможно расслоить стратиграфически, так как сохранились в остаточном и только в выветрелом виде. Такое состояние характерно для зоны распространения лёссов в Польше. Она полностью находилась в пределах наступления ледника времени оледенения Сана=Эльстеры II=Оки, а частично в пределах очередного оледенения. Под воздействием этих ледников LN сильно деградировались. Их верхние слои в некоторых разрезах преобразованы в лесную почву межледникового ранга (GJ). Среди лёссовых слоев расположенных выше этой почвы в разрезе Неледев обнаружено признаки обратной намагниченности (вероятно Чеган эвент). На этой основе и соответственно ТЛ датировкам период образования вспомянутой почвы определяется в 330—310 тыс. лет тому назад.

2) Лёссы древние (LS) возрастом 310/300—135/130 тыс. лет т.н., отвечающие глациальным циклам оледенения Заале→Рисс. Они много лучше сохранены, даже встречаются в невыветрелом виде. Поэтому возможно их стратиграфически расслоить. На основании изучения ископаемых почв это расслоение представляется следующим образом:

а) Лёссы древние самые нижние (LSn), 310/300—280/270 тыс. лет тому назад; верхние их слои преобразованные в интерстадиальную глеевую почву.

б) Лёссы древние нижние (LSd), 270—260/255 тыс. лет тому назад, с интерстадиальной глеевой почвой или типа инициального чернозема.

в) Лёссы древние средние (LSs), 255—230/225 тыс. лет тому назад. На них образовались главным образом деградированные черноземные почвы, которые автор раньше рассматривал как интерстадиальные. Но последние результаты ТЛ датировок свидетельствуют о том, что в эту стратиграфическую единицу нужно включить тоже почвы бурые лесные выщелоченные, которые раньше рассматривались как младшие, отвечающие последнему межледниковию.

Новые ТЛ датировки свидетельствуют о том, что так определенная ископаемая почва межледникового ранга (GJ 2/LSs) образовалась в период 235—225 тыс. лет тому назад, отвечающий изотопно-кислородному подярусу 7а или 7с. Кажется, что это подтверждает обнаружение признаков обратной намагниченности (вероятно Бива II эвент, или событие Джамайка?) в тех слоях лёссов, которые выступают выше рассматриваемой почвы. Однако определение периода ее образования возбуждает сомнения. В Польше с этим периодом обычно не связывается палеофлор типичных для умеренного климата. Только некоторые палеоботаники выделяют этот период как Люблинское=Треене=Одинцовское межледниковие. Оно разделяет два отдельных надвига леденика оледенения Одры (=Заале I) и Варты (=Заале II). Принимая такое мнение как палеопедологически обоснованное, слои LSn, LSd и LSs рассматриваем совместно как отвечающие глациальному циклу оледенения Одры=Дренте=Днепра. На основании ТЛ датировок можно их сопоставлять с изотопно-кислородными ярусами 8 и 7 (нижняя его часть).

г) Лёссы древние верхние (LSg), 225—135/130 тыс. лет тому назад. Среди них обнаружено только признаки почвообразования, главным образом в виде горизонтов оглеения, которые местами имеют черты инициальных глеевых почв. Они расчленяют эти лёссы на четыре стратиграфические единицы обозначенные как: LSg 4, LSg 3, LSg 2 и LSg 1. Представлены первые вступительные результаты их датирования методом ТЛ.

Слои LSg в рассматриваемой схеме стратиграфического деления отвечают гляциальному циклу оледенения Варты=Москвы. Можно их сопоставлять с изотопно-кислородными ярусами 7 (верхняя часть) и 6. Самые верхние слои преобразованы в хорошо развитую лесную почву (GJ 1/LSg), главным образом псевдоподзолистого типа. Образовалась она в последнее, ээмское межледниковие, в период 130/125—115/110 тыс. лет тому назад, отвечающий изотопно-кислородному подярусу 5 е. Верхние горизонты этой почвы, или продукты их разрушения с примесями свежей лёссовой пыли преобразовались в мощные наложенные гумусовые горизонты (совсем нетипичные для лесных почв) дернового типа. Эти последние отвечают интерстадиалу амерсфоорт (около 110—100 тыс. лет тому назад) из начального времени последнего, значит вислинского оледенения. Среди слоев этого времени обнаружены признаки обратной намагниченности (Блаке эвент).

3. Лёссы молодые (LM), возрастом 100—15/12 тыс. лет, накопившиеся во время последнего оледенения Вислы→Вюрм. Они найлучшие сохранились и хорошо исследованы во многих разрезах. Благодаря тому раньше обоснованная схема их стратиграфического деления не изменилась на основании ТЛ датировок.

а) Лёссы молодые самые нижние (LMn), 100—80/75 тыс. лет тому назад. На этих слоях развиты почвы инициальные буроземные или черноземовидные, отвечающие раннеледниковому интерстадиалу оддераде.

б) Лёссы молодые нижние (LMd), 75—42/37 тыс. лет тому назад, отвечающие древним этапам полного оледенения. На верхних их слоях плохоразвитые бурые субарктические, глеевые и болотистые почвы сопоставляемые с интерстадиалом хенгело.

в) Лёссы молодые средние (LMs), 37—30/28 тыс. лет тому назад, отвечающие средним этамам полного оледенения. Верхние их слои преобразованные в почвы похожие как на LMd, сопоставляемые с интерстадиалом денекамп.

г) Лёссы молодые верхние (LMg), 28—15/12 тыс. лет тому назад, отвечающие младшим этапам полного оледенения. Они отличаются чертами найболее характерными для типичного лёсса. Верхние их слои измененные почвообразованием, которое началось развиваться в позднеледниковое время. Верхние слои LMg преобразованные в современные лесные почвы (GH/LMg), главным образом псевдоподзолистые, отвечающие голоценовому времени.

Благодаря хорошей сохраненности молодых лёссов результаты их исследований представляют хорошую основу для реконструкций явлений развивающихся во время гляциального цикла последнего оледенения. В самые ранние этапы этого цикла, значит в ранневислинское время, на территории Польши среднегодовые температуры в более прохладные интервалы снижалась до 0°C. Тогда в условиях широкого распространения сезонной мерзлоты развивались морозные трещины с первичным минеральным заполнителем, образующие полигональные сети мелких размеров. Древнейшие этапы полного оледенения характеризовались развитием постоянной мерзлоты островного и несплошного типа. При среднегодовых температурах от −2 до −4°C образовались средних размеров полигональные сети контракционных трещин с первичным заполнителем в виде ледяных клиньев небольшого размера. Мерзлота этого типа существовала тоже в средних этапах полного оледенения, наверно с колебаниями отвечающими похолоданиям и потеплениям. В младших этапах полного оледенения, при среднегодовых температурах от -5 до $-8°C$, развилась постоянная мерзлота сплошного типа с большими полигонами крупнейших ледяных клиньев.

Соответственно климатическим условиям изменялась скорость накопления молодых лёссов: от менее 0,06 мм/год в самые ранние этапы, до 1,00 мм/год в некоторых самых молодых этапах вислинского оледенения. Средняя для последнего гляциального цикла скорость накопления, определенная в 0,1 мм/год, была такая же как в классических районах распространения лёсса в Евразии. Пыль накапливалась однако очень неравномерно, с многими перерывами, главным образом в короткое время экстремальных явлений развивающихся раз на несколько лет.