Acta Geologica Polonica, Vol. 52 (2002), No. 4, pp. 459-469

Correlation of main climatic glacial-interglacial and loess-palaeosol cycles in the Pleistocene of Poland and Ukraine

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ABSTRACT:

Lindner, L., Bogutsky, A., Gozhik, P., Marciniak, B., Marks, L., Łanczont, M. & Wojtanowicz, J. 2002. Correlation of main climatic glacial-interglacial and loess-palaeosol cycles in the Pleistocene of Poland and Ukraine. *Acta Geologica Polonica*, **52** (4), 459-469. Warszawa.

An integrated analysis of climatic rhythms in the territory between the Baltic Sea and the Black Sea is presented. There is precise agreement between the Pleistocene climatic changes in Poland and Ukraine, expressed on the one hand by continental glaciations and loess deposition, and on the other hand by interglacial lake deposition and the development of soil-forming processes. These changes are expressed by eleven (from A to K) climatic cycles. Each of them comprised a glaciation and a following interglacial. The number and duration of these cycles seem to support their possible correlation with 110-90 kyrs astronomic cycles. In the older cycles (from F to K) there were presumably more glaciations and separating interglacials than accepted at present. Grouping either of two or three climatic cycles into megacycles is presumably due to the varied duration of the former, either because of shorter interglacials (e.g. Eemian) or glaciations (e.g. Liviecian). The recognition of climatic megacycles could result from grouping some Pleistocene glaciations into megaglaciations in order to establish close correlation to the classic scheme of the Alpine glaciations.

Key words: Poland, Ukraine, Pleistocene, Megacycles, Glaciations, Interglacials, Loess, Palaeosols.

INTRODUCTION

Glacial and interglacial units (glaciations and interglacials) are the main stratigraphic subdivisions in the Pleistocene of Poland and Ukraine. In the areas occupied by the Scandinavian glaciations the glacial units are not distinguished on the basis of the number, thickness and extent of tills or accompanying glaciofluvial sediments that were deposited during ice sheet advances. The primary role is played by the intervening non-glacial sediments, particularly buried biogenic deposits (mainly the lake deposits) because of their faunal and floral content. They document best the climatic conditions during deposition and therefore indicate their interglacial, interstadial or interphasal rank.

Interglacial climatic conditions refer to the climate during periods when the climate during the optimum determined by means of biostratigraphic methods was at least as warm as the Holocene optimum in the same area. Such successive warmings during the Pleistocene (from about 1200000 to 10250 years ago) were separated from one another by coolings. Most of the latter are expressed in Poland by glaciofluvial deposits that indicate successive glaciations (among others LINDNER 1988a, b, 1991a, BARANIECKA 1990, LINDNER & MARKS 1993a).

Similarly in the extraglacial area, including a considerable part of Ukraine, some of the main stratigraphic units of the Pleistocene are not defined by the number, thickness and extent of loess covers but by the presence and features of the palaeosols that separate the individual loess beds. In this area, interglacial conditions are indicated by buried brown soils, developed by plants of deciduous and mixed forest (among others VEKLICH 1979, MATVIISHINA 1982, BOGUTSKY & MOROZOVA 1981, GOZHIK & *al*. 1995).

These remarks result in the seemingly paradoxical conclusion that both in the area of the Pleistocene glaciations and of loess deposition, the number of main coolings (glaciations) is determined by the number of warmings (interglacials) expressed by biogenic sediments or palaeosols, but not by till beds or loess covers. Thus, the extremes of climatic conditions can be defined by the existence of a glacial-interglacial (or loess-palaeosol) climatic-stratigraphic cycle. An important role in the classification of the Pleistocene is played by the floral and faunal content of the biogenic sediments.

In most biogenic sediments the individual interglacials are typical for the so-called floral successions or faunal zones, occasionally assemblages (JAŃCZYK-KOPIKOWA 1987, MADEYSKA 1987). In the case of palaeopedologic research, interglacials correspond to palaeosol complexes (KONECKA-BETLEY 1987). Such information does not enable determination of the mutual age relation between individual sites of biogenic sediments or palaeosol beds. It is particularly true in cases where they do not superpose one another, providing no information about mutual correlation of biogenic sediments and palaeosols. In some cases, the age relation of the sediments and soils, and of the underlying or overlying glacial or loess deposits, can be determined from their geological (lithological and spatial) setting. In other cases, different methods of the so-called absolute dating of sediments can be applied.

During the last twenty years, the methodology discussed above has enabled a number of previously distinguished interstadials to be raised to interglacial rank. It allowed the distinction of eight or nine main glacial units (glaciations) in the Pleistocene of Poland and Ukraine, separated by seven or eight interglacials (LINDNER 1988a, b, 1991a; BARANIECKA 1990; BOGUTSKY & *al*. 2001a, b). These units express continued global climatic changes, initiated in the Neogene and reaching their peak during the Pleistocene (LINDNER 1992). In Poland and Ukraine their chronologic setting was determined by research methods and correlated with the oxygen isotope stages ($^{18}O/^{16}O$) in deep-sea sediments. This ratio determines changes in oxygen isotope content in foraminifer shells and corresponds to changes of sea water, connected mainly with the development or collapse of the Pleistocene ice sheets.

GENERAL PRINCIPLES

The presented examples of global and, at the same time, cyclic climatic changes, express the phenomena that are also a driving force for glaciations. The most important of these are astronomic phenomena, the cyclic occurrence of which has been accepted since the times of Milankovitch (DYLIK 1974, KOZARSKI 1988). These are expressed by:

1 – rotation of the Galaxy every 275 million years (first order cycle), presumably responsible for initiation of the ice ages,

2 – eccentricity cycle (second order cycle) with periodicity 110-90 kyrs, caused by eccentric variation of the Earth's orbit and which creates the glacial-interglacial or loess-palaeosol cycle,

3 – axial obliquity (third order cycle) with periodicity about 40 kyrs, caused by variation of the Earth's axis against the ecliptic,

4 – precession cycle (fourth order cycle) with periodicity 29-13 kyrs, caused by precession of the equinox.

These phenomena are mainly responsible for the development and decline of the Pleistocene glaciations. They are also influenced by drift of continents, topographic changes of the Earth surface, varied composition of the atmosphere, interstellar matter or variation in solar radiation. As mentioned before, the rhythms of these phenomena are expressed in a cyclic way and are determined either for a glacial, loess, glacial-interglacial, or loess-palaeosol cycle. In the case of the second order cycles they are occasionally combined into megacycles, each about 400 kyrs long (STANKOWSKI 1996).

Eleven (A–K) glacial cycles in the Pleistocene were distinguished on the basis of the classic loess sections with palaeosols from Austria and the Czech Republic (KUKLA 1961, 1977, 1978). They were correlated with glaciations in the Alps as well as with glaciations and interglacials noted in the 1960s and 1970s in the European Lowland, connected with the oxygen isotope stages in deep-sea sediments. These cycles were numbered, starting from the oldest one and each comprised an interglacial and a following glaciation.

At the same time, BRUNNACKER (1978) pointed out cyclic deposition in loesses at Kärlich on the Rhine. He distinguished 9 main units (*Abschnitte*) of the Pleistocene, each composed of a cooling (glaciation) and a following warming (interglacial), and correlated them with the oxygen isotope stages in deep-sea sediments. Later on, cyclic succession of glacial and interglacial units within the limit of the Scandinavian glaciations documented in Germany was emphasized by WIEGANK (1982) and MENNING & WIEGANK (1982), and correlated with the oxygen isotope stages.

Subsequently, the first proposal of glacial-interglacial cycles was presented for the Pleistocene of Poland (LINDNER & MARKS 1993b) with reference to the remarks on the Pleistocene climatic background for the cyclic development of soils (DZIĘCIOŁOWSKI & TOBOLSKI 1982), relief of the Lublin Upland (Wojtanowicz 1984), cyclic loess deposition in Poland (MARUSZCZAK 1980, MARUSZCZAK & BUTRYM 1984, 1987; MARUSZCZAK & *al.* 1992) and contemporary glacial-interglacial phenomena (LINDNER 1984). This proposal was based on a number of sites with palaeontological evidence for interglacial sediments and separating glacial deposits (LINDNER 1988a, b, 1991a, b; BARANIECKA 1990; BAŁUK 1991; LINDNER & MARKS 1993a), interglacial palaeosols and separating loess covers (MARUSZCZAK 1980, 1987, 1991a, b; MARUSZCZAK & BUTRYM 1984; MARUSZCZAK & *al.* 1992). Such information was supplied with chronologic correlation of the mentioned deposits, loess covers and palaeosols in central-eastern (LINDNER 1991b) and central-western Europe (LINDNER & MARKS 1994). Both the Quaternary and the Pleistocene were accepted to begin with coolings (glaciations) but not with warmings (interglacials), therefore every cycle should start with glacial cooling and terminate with interglacial warming, as presented earlier by BRUNNACKER (1978). The state of Pleistocene climatostratigraphic research at that time permitted numbering of the cycles starting with the youngest and best known (A), comprising the Vistulian Glaciation and the Holocene, and terminating with the oldest cycle and least known (H), composed of the Narevian Glaciation and the Podlasian Interglacial.

This subdivision could be followed by the previously distinguished glacial and interglacial units in the territory of Poland and their more complete correlation with similar units in the neighbouring areas of Europe (LINDNER & *al.* 1998, LINDNER & MARCINIAK 1998). Correlation with loess horizons and palaeosol complexes in particular exposures of the Pleistocene in Ukraine (cf. BOGUTSKY & *al.* 1980, 1997; GOZHIK & *al.* 2001a, b), could be the basis for the new approach presented here to correlate the glacial-interglacial and loess-palaeosol cycles in the Pleistocene of our countries.

CLIMATIC MEGACYCLES AND CYCLES

The mentioned climatic units discussed in this paper have been distinguished on the basis of 38 key sections of Pleistocene sediments in Poland and Ukraine (Text-fig. 1), including 5 main loess exposures at Odonów, Kolonia Zadębce, Bojanice, Vyazivok and Sanzheika (Text-fig. 2). These units were defined firstly as the cycles, designated from the youngest to the oldest as A to K (cf. LINDNER & MARKS 1993) and then grouped in megacycles from MC1 to MC5 (Text-fig. 3), following the proposal of KUKLA & CILEK (1996).

Megacycle MC1 (oxygen isotope stages 1-6)

This megacycle comprises the last two glacial-interglacial and loess-palaeosol cycles (A and B). **Cycle A** starts with the Vistulian Glaciation (Weichselian = Valday) and ends with the Holocene as the recent interglacial. In Poland the Vistulian Glaciation is documented by glacial sediments in the north, e.g. the Szwajcaria site near Suwałki, and by younger loesses in numerous sections, including Wąchock and Odonów (Text-figs 1-2). In Ukraine, there are no glacial sediments of this glaciation but on the other hand there are common thick loesses, exposed for example at Bojanice, Vyazivok and Sanzheika (Text-figs 1-2). A younger part of this cycle is documented, particularly in Poland, by dozens of the Holocene lake sites e.g. at Błędowo near Warsaw (Tex-fig. 1). In Ukraine, the Holocene is expressed primarily by very well developed palaeosols, mainly by chernozems 2 m thick that cover most patches of loess.

Cycle B starts with the Wartanian Glaciation, documented in Poland by glacial sediments occurring as far south as central Poland, e.g. at Losy and Szwajcaria (Text-fig. 1), and by older upper loesses, e.g. at Odonów and Kolonia Zadębce (Text-figs 1-2). In the lower part of these loesses at Odonów the reversed Jamaica palaeomagnetic episode has been identified above the oldest interstadial zone (NAWROCKI & SIENNICKA-CHMIELEWSKA 1996), dated at about 180 kyrs (Text-fig. 2). In Ukraine, the loesses of this cycle occur in sections including Vitachiv, Korshov, Galich, Bojanice and Sanzheika (Text-figs 1-2), where they are classified as the loesses of the Tyasmin bed. This cycle is terminated at the top by the Eemian Interglacial with its biogenic deposits, known in Poland from Błonie, Bedlno and Szwajcaria sections (Text-fig. 1). In loess sections this interglacial is expressed by a lower part of the soil complex of the type ”Nietulisko I”, preserved for example in the Odonów section (Text-figs 1-2). In Ukraine, it corresponds to the lower part of the Horokhov intra-loessic soil complex, preserved for example at Bojanice (Text-figs 1-2) and the lower part of the intraloessic Pryluky soil complex, occurring at sections including Vyazivok and Sanzheika (Text-figs 1-2).

Within megacycle MC1 there are palaeomagnetic two events characterised by reverse magnetic polarisation (Blake – 110 kyrs, Laschamp – 25 kyrs) within the Brunhes Epoch, which are clearly seen, for example in the Vyazivok section (Text-fig. 2). In the scheme of KUKLA & CILEK (1996) the megacycle should be correlated with oxygen isotope stages 1-6 in deep-sea sediments. In western Europe, it comprises, as in Poland, an interval from the Wartanian Glaciation (Warthe) to the Holocene.

Megacycle MC2 (oxygen isotope stages 7-12)

This megacycle comprises the three oldest glacial-interglacial and loess-palaeosol cycles (C, D, E). **Cycle C** begins with the Odranian (Dnieper) Glaciation and terminates with the Lubavian Interglacial (Lublinian, Kaydaky). In Poland, the Odranian ice sheet occupied the western and central part of the country. It is documented both by glacial deposits, e.g. in the Barkowice Mokre, Zbójno, Wąchock and Ferdynandów sections (Text-fig. 1), as well as by older lower loesses, preserved for example, at Odonów and Kolonia Zadębce (Text-figs 1-2). In Ukraine, there are also glacial deposits of this i.e. Dnieper Glaciation, with the Chegan palaeomagnetic episode in the Vyazivok section (Text-figs 1-2), dated to 250-260 kyrs. In this section as well as in many others e.g. at Bojanice and Sanzheika (Text-fig. 2), a loess is correlated with the Dnieper Glaciation. This cycle terminates with the Lubavian Interglacial (Lublinian), documented in Poland by biogenic deposits in the Losy section (Text-fig. 1) and by palaeosols of the "Tomaszów" complex, known from numerous loess sections, e.g. Odonów and Kolonia Zadębce (Text-figs 1-2). In Ukraine, this interglacial is well represented by the intra-loessic palaeosols of the Korshov (Kaydaky) complex, well developed in many sections, including those at Bojanice, Vyazivok and Sanzheika (Text-figs 1-2).

Cycle D represents the Liviecian Glaciation, the corresponding cooling Zavadivka 2/3 and younger, Zbójnian Interglacial (Zavadivka 3). In Poland, glacial sediments of this cycle are preserved mainly in the northeastern part of the country, e.g. from the Szczebra section (Text-fig. 1). Loess of the same age is classified in Poland as the highest oldest loess and occurs in many sections, including Kolonia Zadębce (Text-figs 1-2). In Ukraine, there are no glacial sediments of this glaciation but loess of this age was noted for example at Bojanice and Vyazivok, where it was designated as the Orel loess (Text-fig. 2). The

Fig. 1. Location sketch of main sections of Pleistocene sediments in Poland and Ukraine; dotted is the maximum limit of Scandinavian glaciations

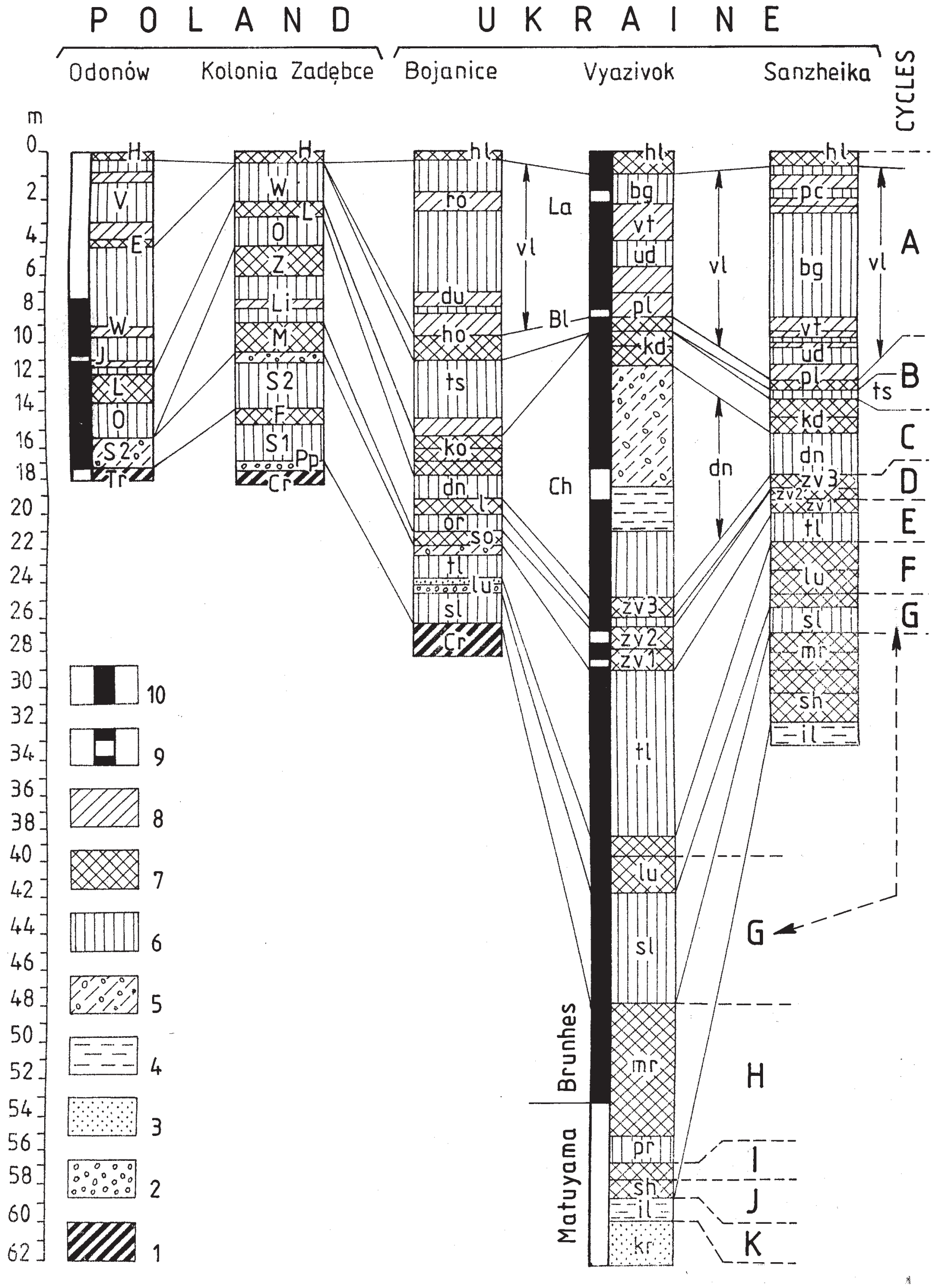

Fig. 2. Geologic sections of main loess exposures in Poland: Odonów after JERSAK (1977) and NAWROCKI & SIENNICKA-CHMIELEWSKA (1996), Kolonia Zadębce after DOLECKI (1995), and in Ukraine: Bojanice after BOGUTSKY & *al.* (1980) and LINDNER & *al.* (1998), Vyazivok after VEKLICH & *al.* (1984) and Sanzheika after GOZHIK & *al.* (2000).

Lithology: 1 – Quaternary substrate, 2 – gravel, 3 – sand, 4 – silt and clay, 5 – till, 6 – loess, 7 – interglacial palaeosol, 8 – interstadial or interphasal palaeosol, 9 – reverse magnetic polarisation, 10 – normal magnetic polarisation; **Palaeomagnetic episodes**: Ch – Chegan, J – Jamaica, Bl – Blake, La – Laschamp; **Stratigraphy**: Cr – Cretaceous, Tr – Tertiary, kr – Krizhanov = Pp – Pre-pleistocene, il – Ilyichivsk (=Narevian), sh – Shirokino (=Podlasian), pr – Pryazovsk (=Nidanian), mr – Martonosha (=Malopolanian), sl – Sula = S1 – Sanian 1, lu – Lubny = F – Ferdynandovian, tl – Tiligul = S2 – Sanian 2, zv1+2 – Zavadivka 1+2 = so – Sokal = M – Mazovian, or – Orel = Li – Liviecian, l – Luck = zv3 – Zavadivka 3 = Z – Zbójnian, dn – Dnieper = O – Odranian, kd – Kaydaky = ko – Korshov = L – Lubavian = Lublinian, ts – Tyasmyn = W – Wartanian, pl – Pryluky = ho – Horokhov = E – Eemian, vl (V) – Valday (Vistulian) including: ud – Uday, vt – Vitachiv, bg – Bug, pc – Prichernomorye, hl (H) – Holocene

Zbójnian Interglacial is known in Poland from several sections of biogenic deposits, of which the most important is the section Zbójno (Text-fig. 1). On the other hand this interglacial is represented by palaeosols, preserved for example at Kolonia Zadębce (Text-figs 1-2). In Ukraine, the Liviecian Glaciation is represented by the cooling Zavadivka 2/3, which favoured deposition of thin loess, known from numerous sections e.g. Bojanice and Vyazivok (Text-figs 1-2). This loess is designated as the Orel horizon. At its top there is a palaeosol termed at Zavadivka, Primorskoye, Vyazivok and Sanzheika (Text-figs 1-2) the Zavadivka 3 horizon, and in western Ukraine, e.g. at Bojanice, the Luck soil (Text-fig. 2).

Cycle E, the oldest within the Megacycle MC2 starts with the Sanian 2 Glaciation (Okanian) and the corresponding Tiligul loess, and terminates with the Mazovian Interglacial (Likhvin) and the corresponding Zavadivka 1+2 soil complex.

In Poland, the Sanian 2 Glaciation is documented by glacial sediments as far south as the Carpathians and preserved in numerous sites, including Pikulice, Kijewice, Ferdynandów, Odonów and Kolonia Zadębce (Text-figs 1-2). This glaciation is also indicated by deposition of subtill loesses, e.g. at Kolonia Zadębce (Text-fig. 2). In Ukraine, glacial sediments of this cycle are preserved both to the northwest of Lvov, e.g. at Krukenichy (Text-fig. 1) and Bojanice (Text-fig. 2), and in many sites in northern Ukraine. The loess of this glaciation, defined as the Tiligul horizon, is preserved both at Vyazivok and Sanzheika (Text-figs 1-2), and equates with the subtill loess at Bojanice (Text-figs 1-2). In Poland, the Mazovian Interglacial, terminating this cycle, is documented by many sites with biogenic deposits, including the sections at Barkowice Mokre and Krępiec (Text-fig. 1), and sites with palaeosols e.g. Kolonia Zadębce (Text-figs 1-2). In Ukraine, biogenic deposits of this interglacial (Likhvin) are preserved, for example, at Krukenichy (Text-figs 1-2). The corresponding intra-loessic palaeosol in the Bojanice section (Text-figs 1-2) is termed the Sokal soil, and in many sections of central and southern Ukraine, including sections at Chigrin, Kaydaky, Zavadivka, Primorskoye, Sanzheika and Vyazivok (Text-figs 1-2), the Zavadivka 1+2 soil complex.

The individual glaciations and interglacials as well as loesses and interglacial palaeosols of the three glacial-interglacial and loess-palaeosol cycles (C-E) that comprise megacycle MC2, correlate well from a climatologic point of view with analogous stratigraphic units of this part of the Pleistocene in western Europe (Text-fig. 3). According to KUKLA & CILEK (1996), megacycle MC2

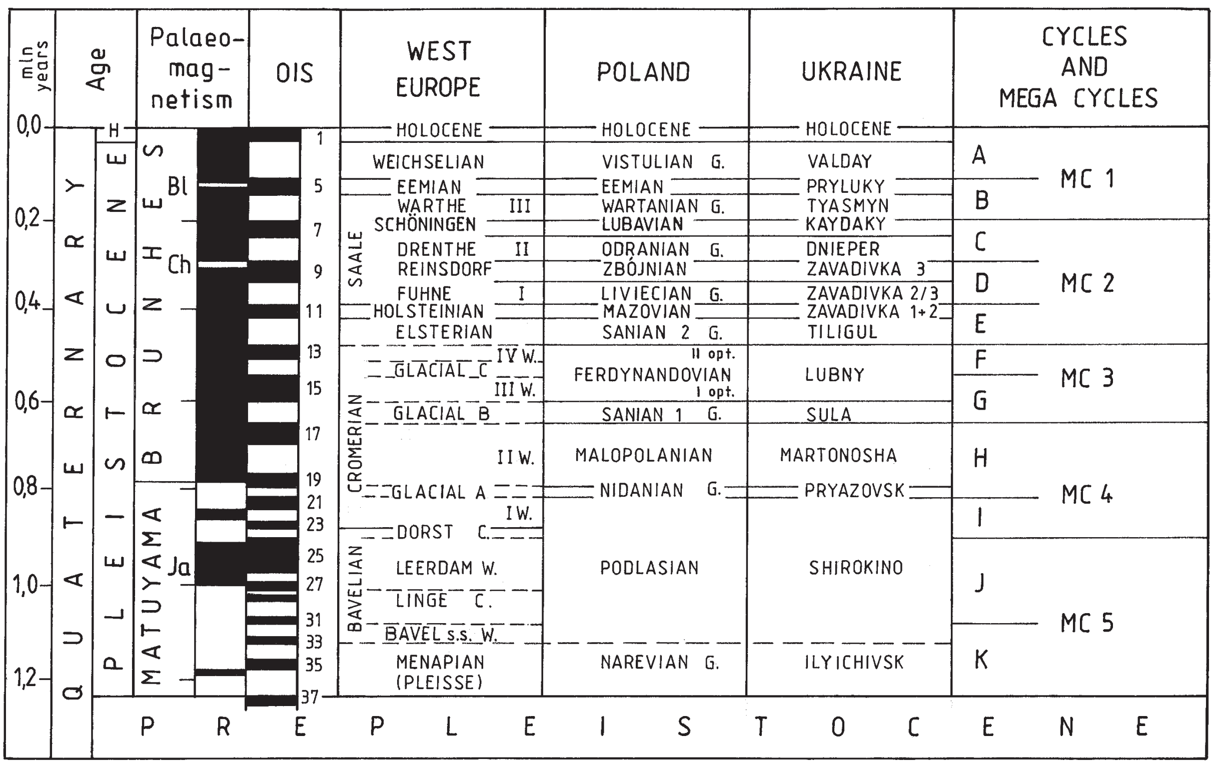

Fig. 3. Main units of the stratigraphic subdivision of the Pleistocene in western Europe after EISSMANN (1994), URBAN (1995), ZAGWIJN (1996), GIBBARD & *al.* (1998); in Poland after LINDNER (1992), LINDNER & MARKS (1994) and in Ukraine after GOZHIK & *al.* (2000); W - warming, C - cooling, G - glaciation Palaeomagnetism and oxygen isotope stages (OIS) after PAEPE & *al.* (1996); palaeomagnetic episodes: Ja – Jaramillo, Ch – Chegan, Bl – Blake

comprises oxygen isotope stages 7-12 recorded in deep-sea sediments. Within the interglacial soil at the end of cycle E of this megacycle there are also, recorded in Ukraine (Vyazivok section), two episodes with reverse magnetic polarisation, determined at 360-380 kyrs.

Megacycle MC3 (oxygen isotope stages 13-16)

This megacycle comprises two successive older Pleistocene glacial-interglacial and loess-palaeosol cycles (F, G). **Cycle F** starts presumably with a cooling (glaciation?) that separates the lower and the upper climatic optimum of the Ferdynandovian Interglacial as well as the interval between the uppermost and older palaeosols of the Lubny horizon. In Belarus this cooling (glaciation) is named (RYLOVA & SAVCHENKO 2001) the Nizhninian horizon. This cycle terminates in the upper climatic optimum of the Ferdynandovian Interglacial and the period of development of the uppermost palaeosol of the Lubny horizon. In Belarus this intertval is named the Mogilevian Interglacial (cf. RYLOVA & SAVCHENKO 2001).

At sites in Poland a cooling (glaciation?) in the lower part of cycle F is known for example from the Ferdynandów section (Text-fig. 1) and has been considered recently to represent a separate glaciation (PIDEK 2000). In sections from Ukraine, no loess connected with this cooling has been unequivocally distinguished. This loess could have had a small thickness and therefore, was either completely subjected to younger soil-forming processes or the cooling was indicated by a hiatus only, preceding development of the uppermost palaeosol of the Lubny horizon, for example at Martonosha, Rozhky, Primorskoye (Text-fig. 1), Vyazivok and Sanzheika (Text-figs 1-2). As mentioned before, this climatic cycle in Poland terminates at the top with the deposition of biogenic sediments that record the upper climatic optimum of the Ferdynandovian Interglacial. In Ukraine, this climatic optimum is indicated by the uppermost palaeosol of the Lubny horizon, preserved at sections such as Vyazivok and Sanzheika (Text-figs 1-2).

Cycle G starts with the Sanian 1 Glaciation (Donian) and terminates with the lower optimum of the Ferdynandovian Interglacial and with the presumably corresponding development of the lower two palaeosols of the Lubny horizon. In Belarus the lower optimum of this interglacial is indicated as a separate, Belovezhian Interglacial (RYLOVA & SAVCHENKO 2001). In Poland, the Sanian 1 Glaciation is expressed by glacial sediments that reach the foreland of the Carpathians and are known from numerous sections e.g. Łowisko (Text-fig. 1). The subtill loess connected with this glaciation is known from many sections in the Holy Cross Mountains region and also from Kolonia Zadębce (Text-figs 1-2). In Ukraine, traces of ice sheet advance during this glaciation are to be found only to the north of Kiev, as farther to the south, deposition of the loess of the Sula horizon occurred. This loess, which is preserved in many sections, contains occasionally a short episode of reverse magnetic polarisation. This episode is particularly well developed in the Bojanice, Vyazivok and Sanzheika sections (Text-figs 1-2).

The coolings and glaciations as well as interglacial warmings of this cycle can be tentatively correlated with coolings and warmings (III-IV) in the upper part of the Dutch Cromerian Complex and the German Thuringian Complex. They all occur within the megacycle MC3, corresponding to the oxygen isotope stages 13-16 (cf. KUKLA & CILEK 1996).

Megacycle MC4 (oxygen isotope stages 17-24)

This megacycle is composed of two older glacial-interglacial and loess-palaeosol cycles (H, I). **Cycle H** comprises the Nidanian Glaciation (= Pryazovsk cooling) and the younger warming of the Malopolanian Interglacial (Martonosha horizon). In Poland, the Nidanian Glaciation is expressed by glacial sediments in the Holy Cross Mts, is indicated in speleothems at Kozi Grzbiet, and also in the Kijewice and Szczerba sections in NE Poland (Text-fig. 1). The oldest subtill loesses, known mainly from deep valleys of the Holy Cross Mts region, were deposited during this glaciation. In Ukraine, probably an extraglacial area at that time, the loess of the Priazovye horizon was deposited. This loess is preserved in numerous sections, including Zhdanov, Zavadivka and Vyazivok (Text-fig. 1), and it is unequivocally correlated in the last section with the upper part of the Matuyama epoch with reverse palaeomagnetic polarisation (Text-fig. 2). A younger warming of this cycle, correlated in Poland with the Malopolanian Interglacial, is indicated primarily by the cave palaeofaunal site at Kozi Grzbiet in the Holy Cross Mts (Text-fig. 1). In the lower part of the sediments of this site there is the Brunhes/Matuyama palaeomagnetic boundary, at present determined at 780 kyrs. The same age is to be ascribed to the biogenic sediments at the Łowisko site (Text-fig. 1) in the northern foreland of the Carpathians (cf. STUCHLIK & WÓJCIK 1996). In Ukraine, this warming corresponds to the Martonosha complex of 2-3 palaeosols in the Vyazivok section (Text-figs 1-2) which contains the above-mentioned Brunhes/Matuyama palaeomagnetic boundary.

Cycle I is not so well documented as the previous ones. It seems to correspond to climatic changes in the younger part of the episode that enables development of the Shirokino soil complex. In Poland, this cycle starts with a cooling that separates older and younger warmings within the oldest biogenic sediments at the Szczebra site (Text-fig. 1). In Ukraine, this cooling could correspond to the interval between deposition of the older and the younger palaeosol of the Shirokino horizon, in sections including Shirokino, Zhdanov, Primorskoye and Vyazivok (Text-figs 1-2). A younger part of this cycle corresponds presumably to biogenic deposition, recording the upper climatic optimum of the floral succession of the Augustovian, i.e. the warming known in Poland from the Szczebra section (Text-fig. 1). In the Ukrainian sections, this interval corresponds to the younger palaeosol of the Shirokino horizon, which is recognised, for example, in the Sanzheika and Vyazivok sections (Text-figs 1-2).

Taking into consideration these facts, as well as the rhythm of climatic changes in western Europe at the boundary of the Bavelian and Cromerian, cycle H seems to correlate with the so-called Glacial A and the warming Cromerian II, and cycle I with the cooling (glaciation?) Dorst and the warming Cromerian I in the Dutch scheme (cf. ZAGWIJN 1996). All of these climatostratigraphic units should be located within megacycle MC4, which is located by KUKLA & CILEK (1996) within oxygen isotope stages 17-24 in deep-sea sediments (Text-fig. 3).

Megacycle MC5 (oxygen isotope stages 25-36)

The authors propose to take this megacycle for a new climatostratigraphic unit after the four units of this kind (MC1-MC4) distinguished by KUKLA & CILEK (1996). As before, megacycle MC5 is presumably composed of two glacial-interglacial and loess-palaeosol cycles (J, K).

Cycle J is considerably less well developed. In Poland, it is represented by thick periglacial solifluction sediments, preserved downslope in most Pleistocene sections of the Holy Cross Mountains region. There are also thick valley infillings of the Early Pleistocene, noted both in the South Polish Uplands and in the lower parts of the drainage basins of the rivers Bug and Narew. In Ukraine this cycle presumably begins with the soil-forming processes, accentuated by a hiatus in the Shirokino soil horizon, e.g. in the Vyazivok and Sanzheika sections (Text-figs 1-2). A warming that terminates this cycle resulted in Poland presumably in the deposition of biogenic sediments of the older climatic optimum, represented in the floral succession of the Augustovian Interglacial at Szczebra (Text-fig. 1). In Ukraine, this period presumably corresponded to the deposition of an older soil of the Shirokino horizon, preserved, for example, in the Sanzheika and Vyazivok sections (Text-figs 1-2).

Cycle K comprises the Narevian Glaciation (Ilyichivsk) and the following warming in the lower part of the Podlasian Interglacial, when a palaeosol of the Shirokino horizon developed. The Narevian Glaciation is indicated generally by glacial sediments preserved mainly in northeastern Poland, where this oldest Pleistocene glacial series is noted in rare sections, e.g. at Kijewice and Szczebra (Text-fig. 1). In Ukraine, this interval is presumably represented by clays of the Ilyichivsk horizon, known for example from the Kryzhanivka, Vyazivok and Sanzheika sections (Text-figs 1-2). A younger part of this cycle is presumably documented in Poland by the oldest warming of the Podlasian Interglacial, studied in the Kijewice section (Text-fig. 1) as the so-called Kijewice Interglacial (cf. BAŁUK 1991). In Ukraine, this stratigraphic setting is represented by one of two palaeosols from the Shirokino horizon, well preserved, for example, in the Zhdanov, Shirokino, Primorskoye, Sanzheika and Vyazivok sections (Text-figs 1-2).

Based on these data, the coolings (glaciations) and warmings can be correlated. They represent two climatic cycles (J, K), in western Europe (Text-fig. 3) with well documented cooling of the Menapian (Pleisse) and the following: the Bavel warming *sensu stricto* with the Linge cooling and the Leerdam warming within the Dutch Bavelian (cf. ZAGWIJN 1996). Such a chronologic interpretation of these cycles creates the basis to determine megacycle MC5 as the oldest climatostratigraphic unit of this rank in the Pleistocene. The latter is accepted by the authors as that part of the Quaternary, during which the Scandinavian ice sheets advanced to mid-eastern Europe for the first time. Therefore, megacycle MC5 seems to be located within oxygen isotope stages 25-36 in deep-sea sediments.

FINAL REMARKS

The principles to distinguish and correlate stratigraphic units of the Pleistocene glacial-interglacial and loess-palaeosol cycles in Poland and Ukraine represent a first attempt of an integrated analysis of rhythmical climatic changes in the territory between the Baltic Sea and the Black Sea. The collected and presented data supported extensively by the authors' fieldwork during the last twenty years seem to show precise agreement between the Pleistocene climatic changes in the area under consideration. These climatic changes drove, on the one hand, the development of the continental glaciations and the deposition of loess, and on the other hand, the formation of interglacial lake deposition and the development of soil-forming processes.

All of the collected data indicate that these changes were rhythmic and expressed by eleven (from A to K) climatic cycles. Each of them, from the oldest (K) to the youngest (A), comprised a glaciation and a following interglacial. Analysis of the number and duration of these cycles seem to support their possible correlation with astronomic cycles, lasting 110-90 kyrs. The correlation was mainly possible because the glacial and interglacial units, previously distinguished in Poland and documented repeatedly in many different sections, could be identified in loess sections in Ukraine as the corresponding and superposed loesses, separated by palaeosols. The analysis shows that, in the case of the older cycles (from F to K), the new data available support the opinion regarding a larger number of glaciations and separating interglacials than accepted at present. In the first case it will deal with the already initiated suggestion to distinguish a separate cooling (glaciation?) within the Ferdynandovian Interglacial. Furthermore, it results in a more complete documentation of coolings (glaciations?) and warmings (interglacials) within the Malopolanian and Podlasian Interglacials.

It is noteworthy that the grouping of 2-3 Pleistocene climatic cycles into individual megacycles, as already suggested by KUKLA & CILEK (1996), presumably relates to the fact that the duration of individual cycles or their parts could be slightly different due to incorporation both of shorter interglacials (e.g. Eemian) or shorter glaciations (e.g. Liviecian). However, the identification of climatic megacycles could be connected with the trend to group some Pleistocene glaciations into megaglaciations (cf. LINDNER 1991b) and create the possibility (cf. KUKLA & CILEK 1996) of closer correlation with the classic scheme of the Alpine glaciations.

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Manuscript submitted: 10th January 2002
Revised version accepted: 15th September 2002