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Main climatic changes in the Quaternary of Poland, Belarus and Ukraine

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26 units are described and correlated, representing the main climatic episodes during the Quaternary in Poland, Belarus and Ukraine. They comprise 13 cool and 13 warm intervals. The four oldest ones are Różcian (Olkhovskian, Siver), Ponurzycian (Grushevskian, Beregovo), Otwockian (Vselubskian, Berezan) and Celestynovian (Yelenynskian, Kryzhaniv); these correspond to Praetiglian, Tiglian, Eburonian and Menapian, respectively of the Early Pleistocene in the Netherlands. In Poland this part of the Quaternary is named the Pre-Glacial or the Pre-Pleistocene. The Mid and Late Quaternary (the glacial epoch in Europe) comprises 11 glaciations or global coolings, namely the Narevian in Poland (Zhlobynskian, Ilyichivsk), the younger pre-Augustovian (Rogachevian 1/2, Shirokino 1/2), Augustovian 1/2 (Rogachevian 2/3, Shirokino 2/3), Nidanian (Narevian in Belarus, Pryazovsk), Sanian 1 (Servetskian, Sula), Ferdynandovian 1/2 (Belovezhian 1/2, Lubny 1/2), Sanian 2 (Berezinian, Tiligul), Liviecian (Orel), Krznanian (Dnieper 1), Odranian+Wartanian (Dnieperian+Sozhian, Dnieper 2 = Tyasmyn), Vistulian (Poozerian, Valday); and 10 interglacials or global warmings: early pre-Augustovian (Rogachevian 1, Shirokino 1), Augustovian 1 (Rogachevian 2, Shirokino 2), Augustovian 2 (Rogachevian 3, Shirokino 3), Małopolanian (Korchevian, Martonosha), Ferdynandovian 1 (Belovezhian 1, Lubny 1), Ferdynandovian 2 (Belovezhian 2, Lubny 2), Mazovian (Alexandrian, Zavadivka), Zbójnian (Smolenskian, Potagaylivka), Lubavian (Shklovian, Kaydaky), Eemian (Muravian, Pryluky) and Holocene. All these units are correlated with oxygen isotope stages identified in deep-sea sediments, shown relative to the palaeomagnetic epochs and correlated with main cool and warm stratigraphic units of Western Europe. Particular attention was placed on correlation of glacial and lake deposits, loesses and palaeosols.

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INTRODUCTION

Detailed studies of Pleistocene climatic events identified within the extent of the Scandinavian glaciations and in the area with extensive loesses of Mid-Eastern Europe have suggested that the greatest number of the Pleistocene global coolings and warmings (of glacial or interglacial rank) have been recorded in Poland (Różycki, 1978, 1980; Lindner, 1984), Belarus (Voznyachuk, 1981, 1985; Goretsky, 1986) and Ukraine (Veklich, 1979; Gozhik, 1981; Shelkoplyas *et al*., 1985). New data supported this opinion and enabled identification of glaciations and interglacials as the main units of the climatostratigraphic subdivision of the Quaternary in Europe (Lindner, 1988, 1991).

A lack of glacial sediments in the Early Quaternary of Mid-Eastern Europe made the Różycki (1980) name it the Pre-Glacial or the Pre-Pleistocene. In Poland it comprises Różcian, Otwockian, Ponurzycian and Celestynovian; the first and third ones are cool whereas the second and the fourth are warm (Baraniecka, 1991). According to the authors, the Polish Pre-Pleistocene corresponds in Belarus with two cold (Olkhovskian and Vselubskian) and two warm (Grushevskian and Yelenynskian) horizons, distinguished by Velichkevich *et al*. (2001). In Ukraine these horizons correspond presumably to two coolings (Siver and Berezan) and two warmings (Beregovo and Kryzhaniv) of Veklich (1979).

In the Dutch scheme (De Jong and Maarleveld, 1983; Zagwijn, 1989, and others) the Lower Quaternary of Western Europe comprises two cold (Praetiglian and Eburonian) and two warm stages (Tiglian and Waalian). In Germany (*cf.*

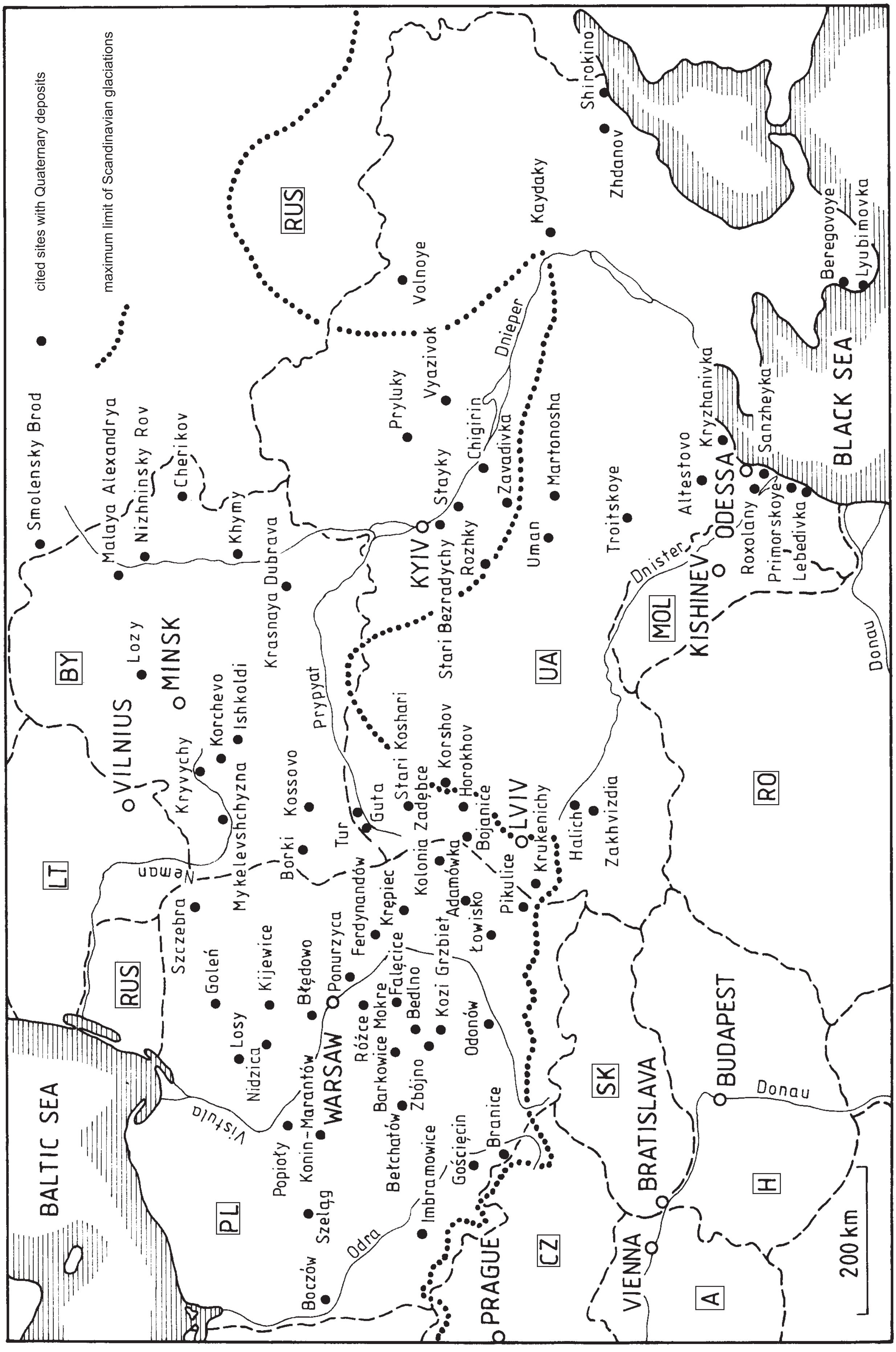

Fig. 1. Location sketch

Eissmann, 1994) they are the Mulde and Wyrha coolings, and the Wyrha/Mulde and Pleisse/Wyrha warmings, respectively.

Most researchers in Poland accept (Lindner, 1987; Baraniecka, 1990; Lindner and Marks, 1999; Lisicki and Winter, 1999; Ber, 2000; Marks, 2000, and others) that within the Mid and Late Quaternary there were 10 glaciations or coolings (Narevian, Augustovian 1/2, Nidanian, Sanian 1, Ferdynandovian 1/2, Sanian 2, Liviecian, Krznanian, Odranian+Wartanian, Vistulian) separated by 9 interglacials or warmings (Augustovian 1, Augustovian 2, Małopolanian, Ferdynandovian 1, Ferdynandovian 2, Mazovian, Zbójnian, Lubavian, Eemian). In Belarus, 9 glaciations or coolings (Narevian, Servetskian, Belovezhian 1/2, Berezinian, cooling 4, cooling 5, Dnieperian, Sozhian, Poozerian) and 8 interglacials or warmings (Korchevian, Belovezhian 1, Belovezhian 2, Ishkoldian, Alexandrian, Smolenskian, Shklovian, Muravian) have been distinguished lately (*cf.* Yelovicheva, 1996, 1997, 2001). In Ukraine (Veklich and Sirenko, 1976; Veklich, 1979; Gozhik, 1981; Veklich *et al.*, 1984; Gozhik *et al.*, 1995, 2000; Shelkoplyas and Khristoforova, 1987, 1996, and others) 8 main loesses (Ilyichivsk, Pryazovsk, Sula, Tiligul, Orel, Dnieper, Tyasmyn, Valday) represent the Mid and Late Quaternary. They are separated by 7 palaeosols (Shirokino, Martonosha, Lubny, Zavadivka, Potagaylivka, Kaydaky, Pryluky), among which 4 are complex units, composed of 2–3 overlapping interglacial soils.

Several warm and cool units numbered by the authors within several megainterglacials (Augustovian = Rogachevian = Shirokino, Ferdynandovian = Belovezhian = Lubny) are identified tentatively only until new names, derived from the names of key sections, are proposed.

This paper presents a concise description of climatostratigraphic units distinguished in Poland, Belarus and Ukraine; the result is a new approach to a number and correlation of the main Quaternary climatic changes in Mid-Eastern Europe. This scheme could be constructed on the basis of previous stratigraphic correlations (Lindner *et al.*, 1998, 2001; Lindner and Marciniak, 1998; Lindner and Yelovicheva, 1998, 2001; Lindner and Astapova, 2000; Velichko and Shick, 2001; Marciniak and Khursevich, 2002), studies of numerous sections (Fig. 1) with glacial deposits and corresponding loesses, as well as with interglacial organic deposits and palaeosols in this part of Europe (Figs. 2–4; Lindner and Astapova, 2000).

The attempt at correlation of identified climatostratigraphic units should be considered as the authors proposal for classifying of the climatic changes in the Quaternary of Mid-Eastern Europe. It was based mainly by reference to bio- and lithostratigraphic sequences of analysed deposits (tills and lake sediments, loesses and palaeosols). In the case of lake sediments the floristic successions were compared, and additionally plant relics and diatom biochronological indices typical for individual interglacials were noted.

Distinguished cool and warm stratigraphic units were correlated with oxygen isotope stages (OIS) in deep-sea sediments (*cf.* Funnell, 1995; Gibbard *et al.*, 1998) and with the palaeomagnetic record (*cf.* Paepe *et al.*, 1996).

Some limited research problems have been outlined in our previous papers. They dealt with glacial-interglacial and loess-palaeosol cycles in the Pleistocene of Poland and Ukraine (Lindner *et al.*, 2002*a*, *b*), with global climatic changes (Kukla and Cilek, 1996) and with a proposal for the climatostratigraphic subdivision of the Pleistocene in Mid-Eastern Europe (Yelovicheva *et al.*, 2003).

MAIN COOL AND WARM INTERVALS OF THE EARLY QUATERNARY

RÓŻCIAN = OLKHOVSKIAN = SIVER (104–95 OIS)

In Poland sandy-clayey sediments represent this cooling. They are 8.9 m thick and occur at a depth of 87.7–78.8 m on Reuverian sands and silts at Różce (Fig. 1; Baraniecka, 1991). Palynological analysis of deposits at Stuchlik (Baraniecka, 1991) documented woodless boreal steppe of Praetiglian age (Fig. 5).

This interval corresponds in Belarus, e.g. at Lozy (Fig. 1), to the lower part of the Dvorets horizon, named the Olkhovskian subhorizon (Fig. 5; *cf.* Velichkevich *et al.*, 2001). In Belarus this cooling is correlated both with the Praetiglian as well as with the Różce horizon, but it was referred to the Pliocene by Velichkevich *et al.* (2001).

In central and southern Ukraine this cooling is represented by the Siver horizon (Fig. 5) comprising weathered clays and fluvial silts e.g. at Beregovoye, referred by Veklich (1965, 1982) to the Pliocene. These sediments contain pollen of herbs, mostly grasses, and record reversed palaeomagnetic polarity (Veklich, 1982), thus indicating them to be younger than the Gauss palaeomagnetic epoch (Fig. 5). The age of their deposition was estimated at 2640–2430 ka by Veklich (1979).

PONURZYCIAN = GRUSHEVSKIAN = BEREGOVO (94–65 OIS)

In Poland this interval is represented by sands and silts, e.g. at Ponurzyca (Fig. 1) and Różce (Baraniecka, 1991). According to Stuchlik (Baraniecka, 1991) this interval had a warm temperate and temperate interglacial-like climate, and it has been correlated with the Tiglian (Fig. 5).

In Belarus, e.g. at Kossovo (Fig. 1), this stratigraphic interval is occupied by the Grushevskian subhorizon i.e. the upper part of the Dvorets horizon, considered by Velichkevich *et al.* (2001) as of latest Pliocene age.

In Ukraine this warming is represented by the Beregovo horizon (Fig. 5), known, for example, from Beregovoye. It contains widespread subaeral facies of red palaeosols (Veklich, 1965, 1982). Spore and pollen diagrams document early occupation by forest-steppe vegetation. These palaeosols occur above the Gauss-Matuyama boundary (Fig. 5), and developed at 2430–1900 ka (Veklich, 1979).

OTWOCKIAN = VSELUBSKIAN = BEREZAN (64–58 OIS)

In Poland silty-sandy deposits of this age were found in boreholes in the vicinity of Warsaw: at Różce (Fig. 1) they are 1.2 m thick and occur at depths of 66.2–65.0 m. According to Stuchlik (Baraniecka, 1991) this interval was represented by a

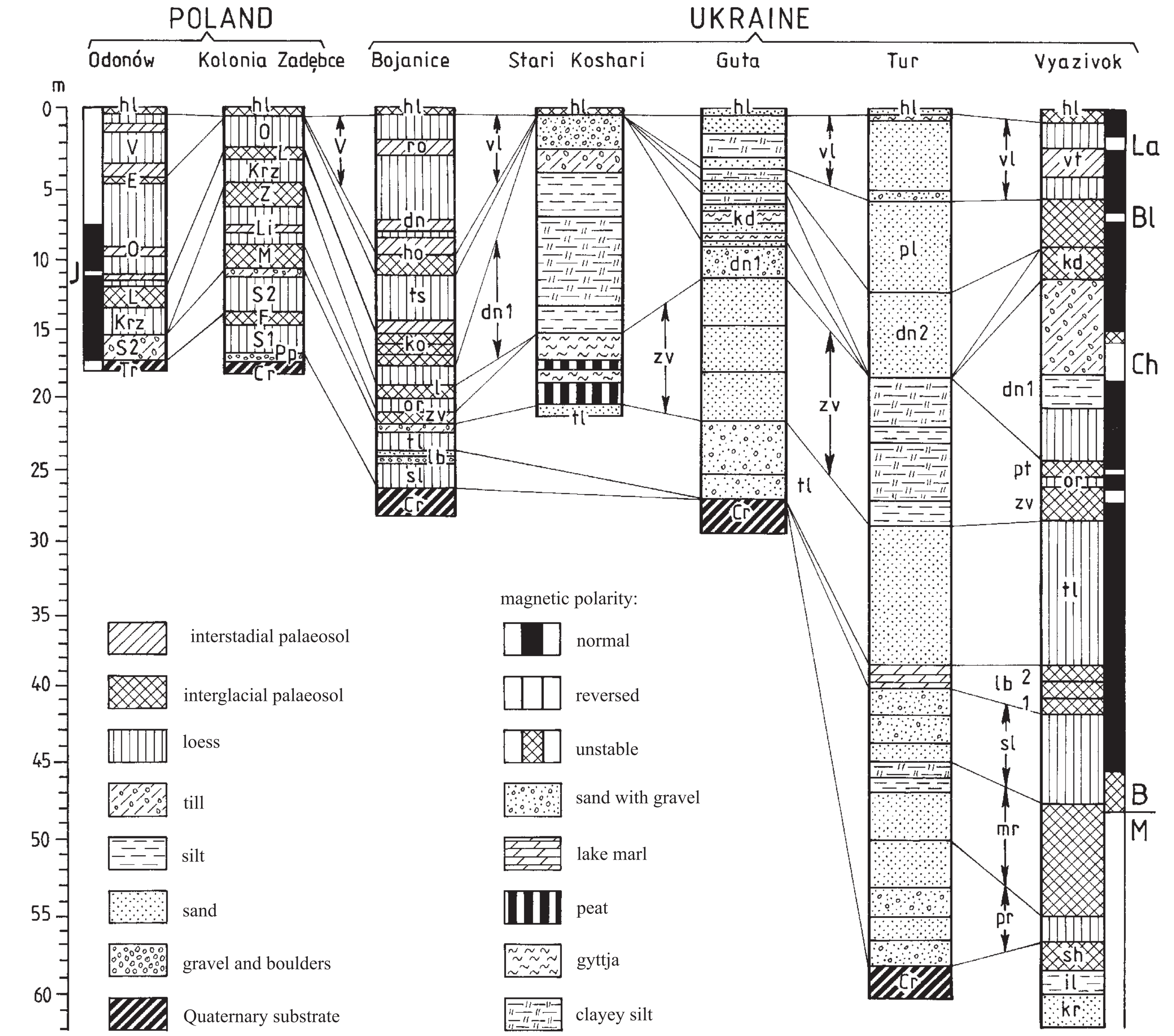

Fig. 2. Sites with Quaternary deposits: Odonów (Jersak, 1977; Nawrocki and Siennicka-Chmielewska, 1996), Kolonia Zadębce (Dolecki, 1995), Bojanice (Bogutsky *et al.*, 1980; Lindner *et al.*, 1998), Stari Koshari (Karaszewski and Rühle, 1976), Guta and Tur (Yelovicheva, 2003), Vyazivok (Veklich *et al.*, 1984)

Palaeomagnetic epochs: B — Brunhes, M — Matuyama; palaeomagnetic episodes: La — Laschamp, Bl — Blake, J — Jamaica, Ch — Chegan; Cr — Cretaceous, Tr — Tertiary, kr — Kryzhaniv = Pp — Pre-Pleistocene, il — Ilyichivsk, sh — Shirokino, pr — Pryazovsk, mr — Martonosha, S1 — Sanian 1 = sl — Sula, F — Ferdynandovian = lb — Lubny, S2 — Sanian 2 = tl — Tiligul, M — Mazovian = zv — Zavadivka, Li — Liviecian = or — Orel, Z — Zbójnian = l — Luck = pt — Potagaylivka, Krz — Krznanian = dn1 — Dnieper 1, L — Lubavian = ko — Korshov = kd — Kaydaky, O — Odranian+Wartanian = dn2 — Dnieper 2 = ts — Tyasmyn, E — Eemian = ho — Horokhov = pl — Pryluky, V — Vistulian = vl — Valday including: vt — Vytachiv, dn — Dubno, ro — Rovne, hl — Holocene

woodless steppe of cool temperate and temperate climate, and corresponds to the Eburonian (Fig. 5).

In Belarus sediments of the Vselubskian horizon (Fig. 5) are known from drainage basins of the Dnieper (Lozy) and Neman (Kryvychy) rivers. They are composed of clays and silts with rare fragments of crystalline rocks and were deposited in a cool climate. They contain remains of *Betula*, *Pinus*, *Artemisia* and Poaceae, also *Selaginella selaginoides*, *Potamogeton filiformis*, *P. vaginatus* and *Carex paucifloroides* (Velichkevich *et al.*, 2001). This Belarusian horizon is referred to the Otwockian in Poland and to the Eburonian in the Netherlands, and Velichkevich *et al.* (2001) postulated that it starts the Quaternary at 1.7 mln years ago.

In Ukraine this cooling is also considered as the very beginning of the Quaternary (palaeomagnetic episode Olduvai) and is represented by the Berezan horizon (Fig. 5), particularly well developed at the Black Sea seaside (e.g. Crimea, Lyubimovka and Kryzhanivka). It is composed of clays and silts of the Upper Kuyalnyk (Veklich, 1965, 1968, 1982) that represents steppe of a cool temperate climate. These sediments indicate normal and, in the upper part, reverse magnetic polarity typical of the upper part of the Olduvai episode (Tretjak and Volok,

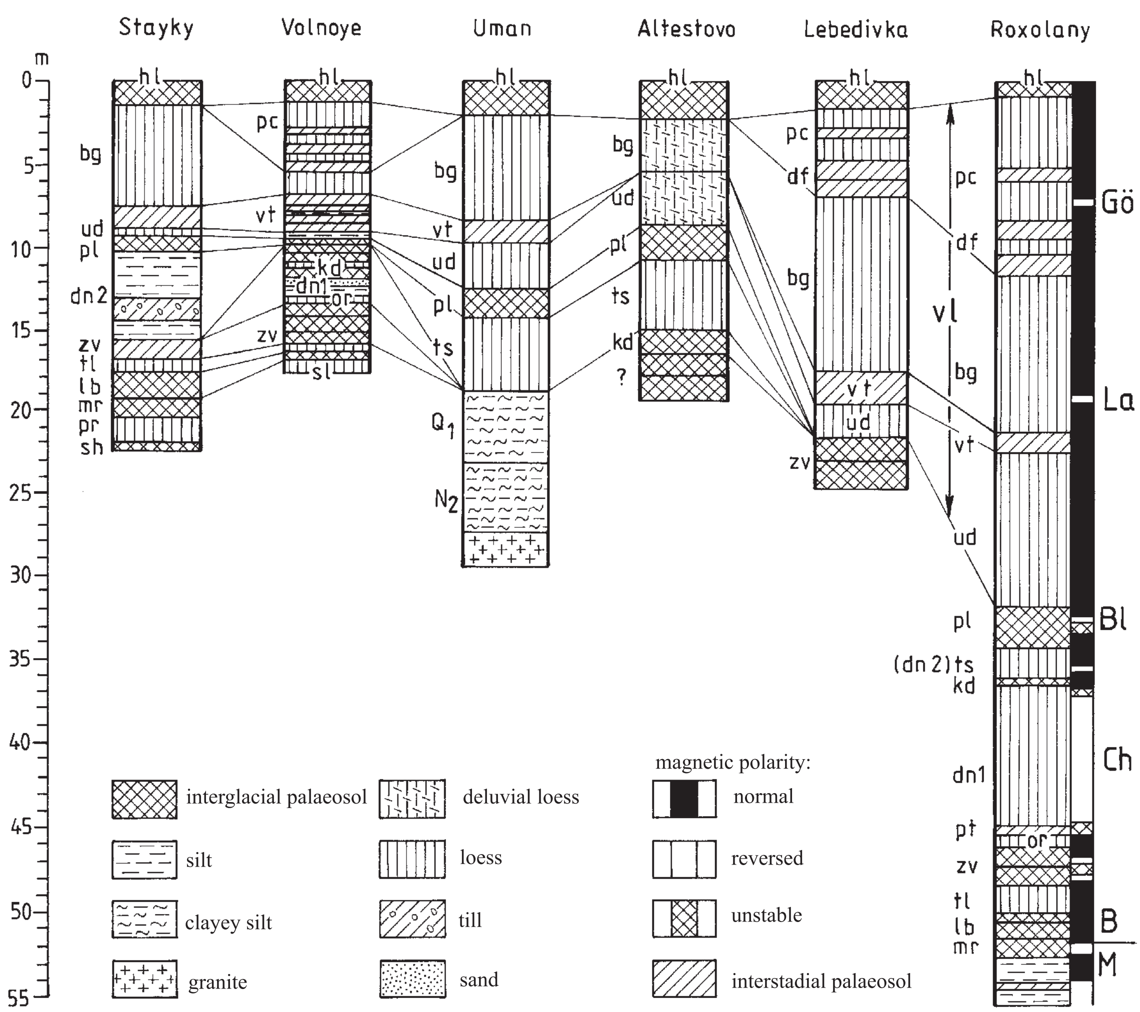

Fig. 3. Sites with Quaternary deposits: Stayky (Putievoditiel, 1999), Volnoye (Yelovicheva, 2003), Uman and Altestovo (Chlebowski *et al*., 2003), Lebedivka and Roxolany (Gozhik *et al*., 2000)

Palaeomagnetic episodes: Gö — Göteborg; N_2 — Lower Neogene, Q_1 — Early Quaternary, sh — Shirokino, pr — Pryazovsk, mr — Martonosha, lb — Lubny, tl — Tiligul, zv — Zavadivka, or — Orel, pt — Potagaylivka, dn1 — Dnieper 1, kd — Kaydaky, dn2 — Dnieper 2 = ts — Tyasmyn, pl — Pryluky, vl — Valday including: ud — Uday, vt — Vytachiv, bg — Bug, df — Dofinov, pc — Prichernomorye, hl — Holocene; other explanations as on Figure 2

1976; Tretjak *et al*., 1987). The age of this cooling is estimated at 1900–1670 ka and it has also been referred to the very beginning of the Quaternary (Veklich, 1979; Gozhik *et al*., 2000).

CELESTYNOVIAN = YELENYNSKIAN = KRYZHANIV (57–37 OIS)

In Poland sands and silts of this age are known from boreholes in the vicinity of Warsaw. At Różce they are 15.8 m thick and occur at depths of 65.0–49.2 m (Baraniecka, 1991). According to palynological analyses made by Stuchlik (Baraniecka, 1991), they were deposited in lakes, surrounded by forest of warm temperate interglacial-type climate, and correspond to the Waalian (Fig. 5).

In Belarus clays and silts of the Yelenynskian horizon (Fig. 5) were noted at Mykelevshchyzna (Fig. 1). Silty-peaty intercalations (Goretsky, 1973; Yakubovskaya, 1978) contain remains of thermophilous plants (including *Salvinia natans*, *Azolla interglacialis*, *Aracites johnstrupii*), correlated with the Celestynovian of Poland and the Waalian of the Netherlands (Velichkevich *et al*., 2001).

In southern Ukraine this warming corresponds to the Kryzhaniv horizon (Veklich, 1965, 1968, 1982, 1990), known from numerous sections (e.g. Kryzhanivka and Zhdanov). It is composed of two red-brown clayey palaeosols, in total up to 3.5 m thick, and also with sands in the Vyazivok section (Fig. 2). Palaeosols are separated locally by a thin layer of clay. The soils indicate reversed magnetic polarity, typical of the Matuyama Epoch (Tretjak *et al*., 1987). They have developed in forest-steppe at 1670–1400 ka (Veklich, 1979).

MID AND LATE QUATERNARY GLACIATIONS AND INTERGLACIALS

NAREVIAN GLACIATION IN POLAND = ZHLOBYNSKIAN = ILYICHIVSK (36–34 OIS)

In Poland the Scandinavian ice sheet reached the northern foreland of the Lublin and Małopolska Uplands, occupied Kujawy and northeastern Wielkopolska (Lindner and Marks, 1995). Its till (Lindner and Astapova, 2000) was dated at 890 ka in the Narew drainage basin (Bałuk, 1991). In Poland this glaciation is presumably older than the oldest i.e. Narew Glaciation in Belarus (Voznyachuk, 1985).

In Belarus (Khymy) this interval is occupied by the Zhlobynskian horizon (Fig. 5), typical of marked tundra-steppe cooling (Velichkevich *et al*., 2001).

In southern Ukraine clayey sediments of the Ilyichivsk horizon (Figs. 2 and 5) are underlain by palaeosols and sands of the Kryzhaniv horizon (Veklich, 1965, 1968, 1982). They are 0.7–4 m thick and were deposited in a temperate steppe environment (Veklich, 1982). They show reversed magnetic polarity, typical of the Matuyama Epoch (Tretjak and Volok, 1976; Tretjak *et al*., 1987). The age of their deposition is estimated at 1400–1290 ka (Veklich, 1979).

This glaciation corresponds to the Menapian of the Netherlands (Fig. 5).

OLDER PRE-AUGUSTOVIAN WARMING (INTERGLACIAL?) = ROGACHEVIAN 1 = SHIROKINO 1 (33–31 OIS)

In Poland no organic deposits and palaeosols have been identified over this interval. Presumably this setting is occupied by deposits of the oldest fluvial cycle of the Podlasian Interglacial in the buried valley near Wyszków on the Bug River (Straszewska, 1968).

In Belarus at Khymy (Fig. 1) this stratigraphic setting is presumably occupied by the lowermost silts, peat and gyttjas of the Rogachevian horizon (Fig. 5), with interglacial forest vegetation (Velichkevich and Rylova, 1988; Velichkevich *et al*., 2001). In this paper the oldest part of this horizon is named the Rogachevian 1 and presumably represents the Podlasian Interglacial in Poland.

In southern Ukraine this interglacial is represented at sections including those at Zhdanov, Shirokino, Primorskoye and Vyazivok (Fig. 1) by the lowermost palaeosol of the Shirokino horizon (Fig. 2; Veklich, 1982). It records reversed magnetic polarity (Matuyama), and normal polarity typical of the Jaramillo episode (Tretjak *et al*., 1987). The age of the Shirokino horizon is estimated at 1290–1000 ka (Veklich, 1979).

This warming corresponds presumably to the Bavelian *s.s.* of the Netherlands (Fig. 5).

YOUNGER PRE-AUGUSTOVIAN COOLING = ROGACHEVIAN 1/2 = SHIROKINO 1/2 (30–28 OIS)

In Poland this cooling is connected with episodes successive fluvial deposition within a buried valley of the Podlasian Interglacial near Wyszków on the Bug River (Straszewska, 1968). In Belarus it can be represented by the lower part of the Rogachevian horizon, named Rogachevian 1/2 by the authors (Fig. 5).

In Central and Southern Ukraine this cooling is represented by the Shirokino 1/2 horizon, with thin loess or erosional remnants of the older palaeosol (Veklich, 1965, 1968, 1982). It is also preserved in many other sections e.g. Zhdanov, Zavadivka and Sanzheyka. During deposition temperate climate prevailed and forest developed along river valleys. The palaeomagnetic record locates this loess in the upper part of the Matuyama Epoch (Fig. 5).

This cooling corresponds to the Linge cooling in Western Europe (Fig. 5).

AUGUSTOVIAN 1 INTERGLACIAL = ROGACHEVIAN 2 = SHIROKINO 2 (27–25 OIS)

In Poland this interglacial was recorded at Kijewice (Fig. 1), with considerable amounts of reworked Tertiary pollen (Bałuk, 1991). Recently this stratigraphic setting was occupied (*cf.* Ber, 2000) by organic deposits of the Augustovian at Szczebra (Fig. 1). They represent the first optimum (warming) of the Augustovian *sensu lato*, with boreal forest dominated by pine, birch and spruce, and small amounts of alder and thermophilous deciduous trees. The climatic rank was determined by *Azolla filiculoides* (Janczyk-Kopikowa, 1996).

In Belarus this interglacial is probably represented by the middle part of the Rogachevian complex, named the Rogachevian 2 (Fig. 5). It comprises a varied content of tree pollen (15–70%), with predominance of *Pinus* and *Betula*, and participation of *Quercus* (to 4%), *Tilia* (9%), *Ulmus* and *Carpinus* (to 0.5%), and occasionally *Alnus* (to 10%). There are also remains of *Azolla* and *Salvinia* (Velichkevich *et al*., 2001).

In Ukraine this interglacial corresponds presumably to the middle palaeosol of the Shirokino complex, defined as the Shirokino 2 (Fig. 5). This palaeosol is well preserved, at localities including Martonosha, Zavadivka, Rozhky, Primorskoye and Kaydaky (Fig. 1). It is particularly distinct at Sanzheyka (Gozhik *et al*., 2000; Chlebowski *et al*., 2003) and constitutes the middle part of the soil complex at Vyazivok (Fig. 2) and Roxolany (Fig. 3). Thermophilous plants with Tertiary relics prevail in the spore-pollen spectrum.

This palaeosol corresponds to the Leerdam warming of Western Europe (Fig. 5).

AUGUSTOVIAN 1/2 COOLING = ROGACHEVIAN 2/3 = SHIROKINO 2/3 (24 OIS)

In Poland this cooling follows the Augustovian 1 Interglacial and at Szczebra (Fig. 1) is represented by herbs (Janczyk-Kopikowa, 1996). Cyperaceae, *Artemisia* and abundant Gramineae reach their maximum. There are *Armeria* and other photophillous plants of open areas, accompanied by *Ephedra*. Lack of full forest cover is also indicated by *Selaginella selaginoides* and *Selaginella helvetica*. The climate was subarctic.

In Belarus this cooling seems to be represented by the upper part of the Rogachevian complex (Rogachevian 2/3), dominated by *Pinus* and *Artemisia* pollen (Velichkevich *et*

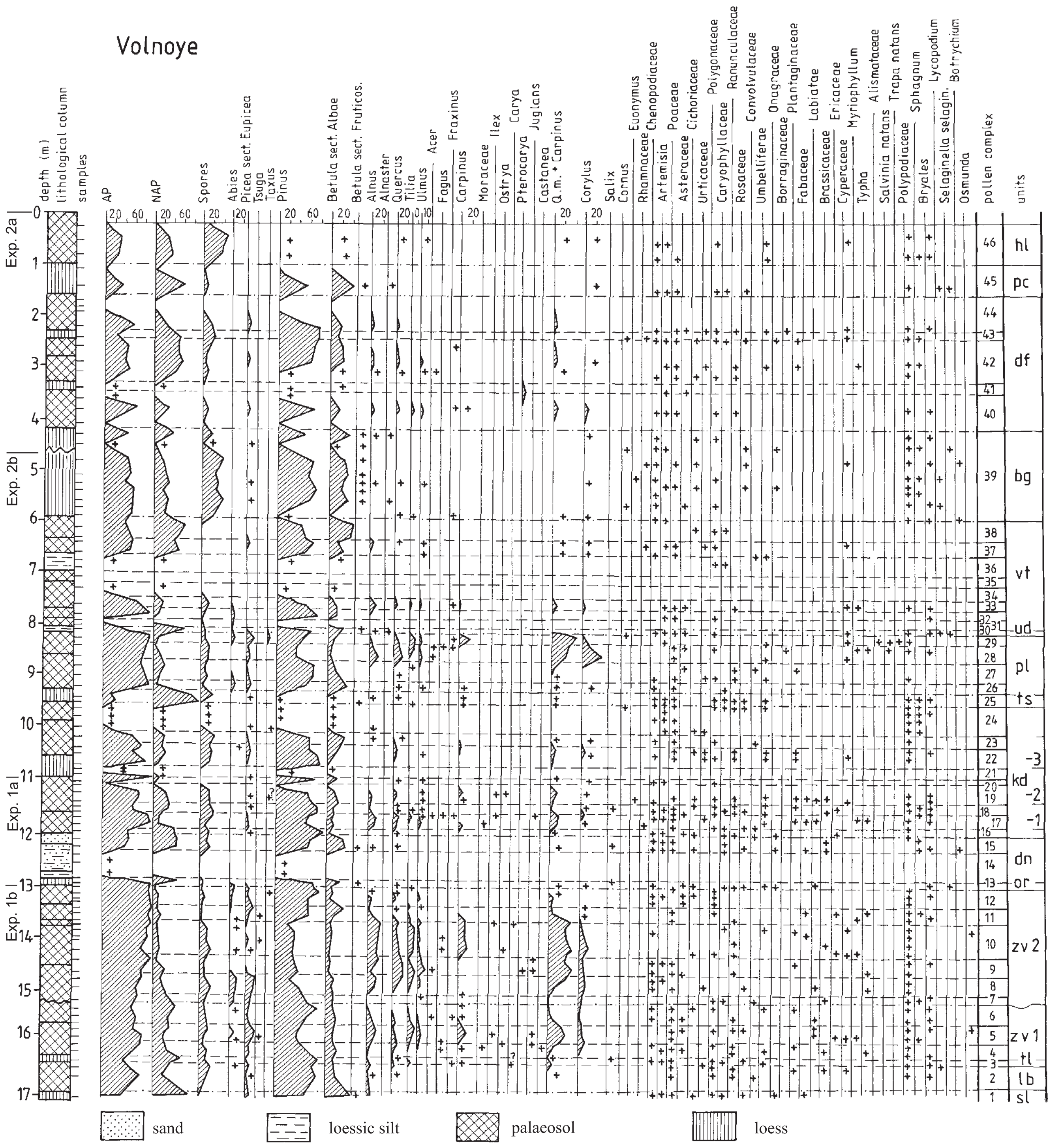

Fig. 4. Palynological diagram of the Volnoye section, exposures 1ab–2ab (Yelovicheva, 2003)

Units: sl — Sula, lb — Lubny, tl — Tiligul, zv — Zavadivka, or — Orel, dn — Dnieper 1, kd — Kaydaky, ts — Tyasmyn (Dnieper 2), pl — Pryluky, ud — Uday, vt — Vytachiv, bg — Bug, df — Dofinov, pc — Prichernomorye, hl — Holocene

al., 2001). In Ukraine this interval was presumably dominated by soil-forming processes in the upper part of the Shirokino soil complex, defined as the Shirokino 2/3 (Fig. 5). In the Netherlands the Dorst interval probably corresponds to this cooling (Fig. 5).

AUGUSTOVIAN 2 INTERGLACIAL = ROGACHEVIAN 3 = SHIROKINO 3 (23–21 OIS)

In Poland this interglacial is documented by the second optimum of the Augustovian at Szczebra (Fig. 1). Palynologic examination shows that this interglacial was dominated by deciduous forest with alder, oak, elm and hornbeam. There was also significant participation of *Juglans*, *Carya*, *Celtis*, *Tsuga* and *Eucommia* as well as *Azolla filiculoides* and *Salvinia* (Janczyk-Kopikowa, 1996).

In Belarus this interval is representated by the uppermost part of the Rogachevian horizon (Velichkevich *et al*., 2001). It contains a rich flora, including abundant macrofossils, among others of *Selaginella reticulata*, *Azolla interglacialis*, *Carex paucifloroides* and *Potamogeton perforatus*. In this paper it is named the Rogachevian 3 (Fig. 5).

In Ukraine this interglacial is presumably represented by the upper palaeosol of the Shirokino complex (Veklich, 1965, 1968, 1982; Sirenko, 1974; Matviishina, 1982). The soil is well developed, at sections including Martonosha, Zavadivka, Rozhky and Sanzheyka (Fig. 1) and in this paper it is named the Shirokino 3 (Fig. 5).

In Western Europe this interval is occupied by the Waardenburg = Cromerian I warming (Fig. 5).

NIDANIAN GLACIATION = NAREVIAN IN BELARUS = PRYAZOVSK (20 OIS)

In Poland an ice sheet covered Wielkopolska and considerable part of Lower Silesia, reached the Holy Cross Mts. and the Lublin Upland, and advanced as an immense lobe into the Upper Odra Basin (Lindner and Marks, 1995). Its till is particularly well preserved in northeastern Poland (Lindner and Astapova, 2000). Clays with remains of glaciofluvial Scandinavian material were examined at the Kozi Grzbiet cave site (Lindner, 1982) in the extraglacial zone (Fig. 1). The oldest subtill loess in Poland records this interval in Małopolska and the Lublin Uplands (Lindner and Wojtanowicz, 1997).

In Belarus this setting is represented by the Narevian Glaciation (Voznyachuk, 1985). The ice sheet passed over the latitude of Brest, reached Pińsk, Bragin and Klimovichy (Matveyev, 1995). In Ukraine deposition of loess of the Pryazovsk horizon occurred. The loess is 0.5–2 m thick and occurs in many sections. It corresponds to the Glacial A cooling of Western Europe (Fig. 5).

MAŁOPOLANIAN INTERGLACIAL = KORCHEVIAN = MARTONOSHA (19–17 OIS)

In Poland this interglacial is represented by cave clays at Kozi Grzbiet (Fig. 1). They contain heavy minerals from reworked older glacial sediments and also Late Cromerian remains of snails, amphibians, reptiles and mammals (e.g. Głazek *et al*., 1977). Fluvial deposits with plant detritus occur at Barkowice Mokre and in the Vistula Gap across the South Poland Uplands (Pożaryski *et al*., 1994, 1995). In the Sandomierz Basin this interglacial is documented by organic deposits at Łowisko (Stuchlik and Wójcik, 2001).

At Korchevo in Belarus (Fig. 1) organic deposits of the Korchevian Interglacial (Lindner and Astapova, 2000; Lindner *et al*., 2001) were examined (Voznyachuk *et al*., 1978; Yelovicheva, 2001). The initial part of this interglacial was dominated by widespread coniferous forest with *Betula*, followed gradually by mixed and deciduous forest with *Quercus*, *Ulmus*, *Tilia* and *Carpinus*, and the some *Celtis*, *Vitis*, *Taxus* and *Pilularia*. Termination of the interglacial was connected with a return of coniferous trees and a spread of herbs.

In Central, Southern and Western Ukraine this interglacial is expressed by palaeosols of the Martonosha complex (Veklich, 1965, 1968, 1982; Sirenko, 1974; Matviishina, 1982; Madeyska, 2002), preserved at site including Martonosha, Zavadivka, Rozhky, Primorskoye, Kaydaky, Roxolany and Zakhvizdia (Fig. 1). The spore-pollen spectrum of these soils contains thermophilous plants. The lower part of these palaesols includes the Matuyama/Brunhes palaeomagnetic boundary, dated at about 780 ka. At Tur in Volhynian Polesye (Fig. 2) there are fluvial sands and silts with individual pollen of *Pinus*, *Betula* and *Quercus* that indicate a temperate climate (Yelovicheva, 2003).

In Western Europe this interval is represented by the Westerhoven = Cromerian II warming (Fig. 5).

SANIAN 1 GLACIATION = SERVETSKIAN = SULA (16 OIS)

In Poland the ice sheet passed over the South Poland Uplands and advanced onto the northern Sandomierz Basin, entered the Upper Odra Basin and reached the Sudetes (Lindner and Marks, 1995). Recent studies in the Sandomierz and Oświęcim Basins indicate that the ice sheet reached its southernmost limit in the Carpathians (Lindner, 2001). This glaciation is also represented by subtill loess preserved in the Sandomierz Basin (Łanczont *et al*., 2000) as well as in Małopolska and in the Lublin Uplands (Lindner and Wojtanowicz, 1997).

In Belarus this glaciation is represented by the Servetskian Glaciation (=Yaseldinian) i.e. the most extensive among the "middle" glaciations, when the ice sheet reached the Minsk area (Voznyachuk, 1985).

In northwestern Ukraine (Lindner *et al*., 1998) this glaciation is represented by the lower of the two subtill loesses at Bojanice (Fig. 2). In Central and Southern Ukraine (Krokos, 1927, 1934; Veklich, 1965, 1968) this glaciation is expressed by loess of the Sula horizon, 1.5–4 m thick (Figs. 1 and 3). This loess records normal magnetic polarity (Tretjak *et al*., 1967; Veklich, 1982). For the first time the climate was typical of a periglacial zone. At Volnoye (Fig. 3) this loess is dominated by pollen of *Pinus* (50%) and *Betula* (48%) that indicate a cool climate (Yelovicheva, 2003).

In Western Europe this cooling is defined as the Glacial B or Elster 1 (Fig. 5).

FERDYNANDOVIAN 1 INTERGLACIAL = BELOVEZHIAN 1 = LUBNY 1 (15 OIS)

In Poland this interglacial is documented by the lower climatic optimum, identified sites including at Ferdynandów (Fig. 1). Palynological studies show a dominance of thermophilous, deciduous trees and a lack or occasional occurrence of *Carpinus* (Janczyk-Kopikowa *et al*., 1981). The geologically best-constrained interglacial deposits are at Falęcice (Fig. 1) where they are overlain by three glacial units and underlain by a till. Diatoms indicate (Marciniak and Lindner, 2003) that the second most complete lake succession of this interglacial occurs at Popioły

Ma	palaeomagnetism	stratigraphy		WESTERN EUROPE	MID-EASTERN EUROPE: POLAND	MID-EASTERN EUROPE: BELARUS	MID-EASTERN EUROPE: UKRAINE	OIS (cool / warm)	CYCLES	MEGACYCLES
0.0	BRUNHES	QUATERNARY		HOLOCENE	HOLOCENE	HOLOCENE	HOLOCENE	1	A	MC 1
				WEICHSEL	VISTULIAN	POOZERIAN	VALDAY	2–4		
				EEMIAN	EEMIAN	MURAVIAN	PRYLUKY	5	B	
0.2			SAALIAN	DRENTHE+WARTHE	ODRANIAN+WARTANIAN	DNIEPERIAN + SOZHIAN	DNIEPER 2 (TYASMYN)	6		
				SCHÖNINGEN	LUBAVIAN	SHKLOVIAN	KAYDAKY	7	C	MC 2
				?	KRZNANIAN	?	DNIEPER 1	8		
				REINSDORF	ZBÓJNIAN	SMOLENSKIAN	POTAGAYLIVKA	9	D	
				FUHNE	LIVIECIAN	COOLING	OREL	10		
0.4				HOLSTEINIAN	MAZOVIAN	ALEXANDRIAN	ZAVADIVKA	11	E	
				ELSTER 2	SANIAN 2	BEREZINIAN	TILIGUL	12		
			CROMERIAN	IV	FERDYNANDOVIAN 2	BELOVEZHIAN 2	LUBNY 2	13	F	
				GLACIAL C	FERDYNANDOVIAN 1/2	BELOVEZHIAN 1/2	LUBNY 1/2	14		
				III	FERDYNANDOVIAN 1	BELOVEZHIAN 1	LUBNY 1	15	G	MC 3
0.6				GLACIAL B (ELSTER 1)	SANIAN 1	SERVETSKIAN	SULA	16		
				II	MAŁOPOLANIAN	KORCHEVIAN	MARTONOSHA	17 18 19	H	
0.8	MATUYAMA			GLACIAL A	NIDANIAN	NAREVIAN	PRYAZOVSK	20	I	MC 4
			BAVELIAN	I	AUGUSTOVIAN 2	ROGACHEVIAN 3	SHIROKINO 3	23–21	J	
				DORST	AUGUSTOVIAN 1/2	2/3	SHIROKINO 2/3	24		
				LEERDAM	AUGUSTOVIAN 1	2	SHIROKINO 2	27–25	K	MC 5
				LINGE	younger pre-AUGUSTOVIAN	1/2	SHIROKINO 1/2	30–28		
				BAVELIAN *s.s.*	older pre-AUGUSTOVIAN	1	SHIROKINO 1	33–31	L	
1.2				MENAPIAN	NAREVIAN	ZHLOBYNSKIAN	ILYICHIVSK	36–34		
				WAALIAN	CELESTYNOVIAN	YELENYNSKIAN	KRYZHANIV	57–37		MC 10
				EBURONIAN	OTWOCKIAN	VSELUBSKIAN	BEREZAN	64–58		
				TIGLIAN	PONURZYCIAN	GRUSHEVSKIAN	BEREGOVO	94–65		
2.6				PRAETIGLIAN	RÓŻCIAN	OLKHOVSKIAN	SIVER	104–95		
	TERTIARY									

Fig. 5. Main stratigraphic units of the Quaternary in Western Europe based on Eissmann (1994), Urban (1995), Zagwijn (1996) and Gibbard *et al.* (1998), and in Eastern Europe after the present authors; oxygen isotope stages (OIS) after Paepe *et al.* (1996)

(Fig. 1), although it is neither underlain nor overlain by glacial deposits. At Popioły there is considerable similarity of the five local diatom assemblage zones (LDAZ PD-1 to PD-5) with the corresponding 5 phases of diatom development at Ferdynandów (Khursevich *et al*., 1990). Similar dominant species (within the genera *Stephanodiscus* and *Cyclotella*) were also noted in 4 diatom zones near Bełchatów (Marciniak, 1991*a*) and at Podlodów (Marciniak, 1991*b*).

Palaeosols of this interglacial occur both in Małopolska and in the Lublin Uplands (Lindner and Wojtanowicz, 1997). They have developed on loess at Kolonia Zadębce. River valleys were formed in Central and northeastern Poland (Lindner and Astapova, 2000).

In Belarus deposits of the Belovezhian 1 Interglacial are known at site including Borki (Fig. 1). As in Poland, there is a simultaneous occurrence of pollen of *Quercus* and *Ulmus* and slightly later, of *Tilia* and *Corylus*, with an insignificant content of *Carpinus* (Bogomolova *et al*., 1985). This interglacial also typically including exotics such as *Taxus*, *Vitis* and *Zelkova* (Yelovicheva, 1996, 2001).

The diatom succession in a key section of this interglacial at Krasnaya Dubrava (Fig. 1) indicates 5 phases of lake development (Makhnach *et al*., 1982; Khursevich and Loginova, 1986). This succession have been compared with the one at Ferdynandów (Khursevich *et al*., 1990). Synchronicity of the diatom successions analysed from the Belovezhian and Ferdynandovian interglacials is supported by the abundant occurrence of extinct taxa (e.g. *Cyclotella reczickiae* et var. *diversa*, *Stephanodiscus rotula*, *S. niagarae* var. *insuetus*, *S. styliferum*, *S. peculiaris*, *S.* cf. *determinatus*, *S. raripunctatus*). These are more and more widely used as biochronologic indices, not only for the Belovezhian Interglacial in Belarus but also for the Ferdynandovian 1 Interglacial in Poland.

In Bojanice section, northwestern Ukraine (Fig. 2) gravel-sandy fluvial(?) deposits of this, as well as of the younger interglacials (horizons Lubny 1 and 2), separate loesses of the Sanian 1 and Sanian 2 Glaciations (Lindner *et al*., 1998). Palaeosols of this interglacial (Madeyska, 2002) at Zakhvizdia (Fig. 1) form the lower part of the soil Solotvyn (=Lubny) complex.

In southern Ukraine this interglacial is presumably documented by the lower and middle palaeosol of the Lubny horizon (Krokos, 1934; Veklich, 1965, 1982, 1990; Sirenko, 1974, Matviishina, 1982), determined as Lubny 1. This palaeosol is well developed (1.5–2 m thick) in many sections, among others Martonosha, Rozhky, Primorskoye, Vyazivok (Fig. 1) and indicates normal magnetic polarity (Brunhes; Fig. 2). At Volnoye (Fig. 4) it contains 47–72% tree pollen with predominant *Pinus* but also up to 9% of broad-leaved trees (*Quercus*, *Tilia*, *Fraxinus*, *Carpinus*, *Carya*, *Corylus*) and numerous grasses, indicating extensive occurrence of a steppe-forest community (Yelovicheva, 2003). At Tur, Volhynian Polesye (Fig. 2), this interglacial is represented by lake marl with pollen of *Pinus*, *Betula*, *Picea* (8%), *Carpinus* (4%) and *Artemisia* (Yelovicheva, 2003).

In Western Europe this interglacial is presumably represented by the Rosmalen = Cromerian III warming (Fig. 5). Zagwijn (1996) correlated the lower optimum of the Ferdynandovian with the Comerian II (Westerhoven).

FERDYNANDOVIAN 1/2 COOLING = BELOVEZHIAN 1/2 = LUBNY 1/2 (14 OIS)

In Poland this cooling has not been considered as a significant stratigraphic event. Only recently it has been found to separate the climatic optima of the Ferdynandovian (Pidek, 2000). It was found earlier to record tundra-steppe vegetation with rare *Betula*, occasionally even comprising two cold oscillations, the second one of which indicated a considerably higher participation of herbs (Janczyk-Kopikowa *et al*., 1981).

In Belarus this cooling is represented by the Belovezhian 1/2, determined also as the Nizhninian (Velichkevich *et al*., 2001). It is dominated by *Betula*, abundant herbs and *Selaginella selaginoides* that indicate a severe subarctic climate, interrupted by an insignificant warming.

In Ukraine this cooling should correspond to poor soil-forming processes between the lower and the upper palaeosols of the Lubny complex (Veklich, 1979; Gozhik *et al*., 2000; Figs. 2 and 3). In this paper this cooling is named the Lubny 1/2 and is correlated with the Glacial C of Western Europe (Fig. 5).

FERDYNANDOVIAN 2 INTERGLACIAL = BELOVEZHIAN 2 = LUBNY 2 (13 OIS)

In Poland this represents the second warming of the Ferdynandovian Interglacial *sensu lato* (Janczyk-Kopikowa *et al*., 1981; Pidek, 2000), described in detail at sites including Ferdynandów (Fig. 1). The pollen succession starts with *Betula* and *Pinus*. The climatic optimum is firstly dominated by *Pinus*, *Quercus* and *Ulmus*, then by *Carpinus*, *Quercus* and *Alnus*. The post-optimum part of the interglacial starts with dominant *Pinus* and then contains *Pinus* and *Betula* (Pidek, 2000).

In Belarus this warming, defined as the Mogilevian horizon (Velichkevich *et al*., 2001), is expressed by a similar floristic succession during the climatic optimum, with a maximum of broad-leaved trees (52%), including *Carpinus* (to 36%).

In Southern and Eastern Ukraine this warming is indicated by the upper mid-loess palaeosols of the Lubny complex. It is named the Lubny 2 in this paper. It is well preserved at many sites, Vyazivok (Fig. 2) and Volnoye (Fig. 3) included. In the latter, the palaeosol contains pollen of *Pinus*, *Quercus*, *Tilia*, *Carpinus* and *Carya* (Yelovicheva, 2003). In western Ukraine there are fluvial gravels and sands in the lower part of the Bojanice section and the upper part of the lake marl at Tur (Fig. 2). At Zakhvizdia (Fig. 1) there is the upper part of the Solotvyn = Lubny soil copmlex (Madeyska, 2002).

In Western Europe this interval is represented by the Noordbergum = Cromerian IV warming (Fig. 5).

SANIAN 2 GLACIATION = BEREZINIAN = TILIGUL (12 OIS)

The ice sheet occupied almost the whole territory of Poland, reaching the Carpathians (Lindner, 2001) and the Sudetes, and entering the Upper Odra Basin (Lindner and Marks, 1995). The time immediately before the ice sheet advance is represented in the Carpathians Foreland by loess with typical loessic molluscs. At Pikulice, on the northern edge of the Carpathians, ice sheet decay was connected with deposition of sands and gravels with erratic material and with overlying loess-like sands and silts (Maruszczak *et al*. 1992; Łanczont, 1997*a*, *b*).

In Belarus there were 1–2 ice sheet advances during the Berezinian Glaciation (Lindner and Astapova, 2000). The ice sheet occupied almost the whole territory of Belarus, leaving only the southern part of the present Prypyat Basin ice-free (Matveyev, 1995).

In Volhynia, northwestern Ukraine, a till of this glaciation was TL dated at Bojanice at 472 (530?) ka, and subtill loesses at about 496 ka (Lindner *et al*., 1998). A complete record of the glaciation occurs at the ice sheet limit at Krukenichy, on the interfluves of the San and Dniester rivers (Fig. 1). It comprises transgressive glaciofluvial deposits, ablation till, recessional sands and gravels and silty loess-like deposits (Bogucki *et al*., 2000*a*, *b*). Loesses connected with this glaciation were noted also at Korshov (Lindner *et al*., 1998).

In Central and Southern Ukraine this glaciation corresponds to extensive deposition of loess of the Tiligul horizon (Krokos, 1927, 1934; Veklich, 1965, 1968, 1992). This loess is 1–4 m thick, represents normal magnetic polarity (Brunhes) and occurs particularly in the Dniester central drainage basin and close to the Black Sea, at sites including Rozhky, Chigirin, Roxolany, Volnoye, Sanzheyka and Vyazivok (Figs. 2 and 3). At Volnoye (Fig. 4) this loess is dominated by *Pinus* (86%), with small contents of *Picea* (2%) and rare *Quercus* (0.5%), suggesting a cool climate in Eastern Ukraine (Yelovicheva, 2003). In Western Europe the second ice sheet advance (Elster 2) occurred (Fig. 5).

In the upper part of the Sanian 2 Glaciation deposits in Poland there are lake, bog and fluvial deposits of the Mrongovian Interstadial, overlain by a till of the Brokian Stadial, both recognised at Goleń (Fig. 1). In Belarus this interstadial can be represented by lake deposits at Ishkoldi (Yelovicheva, 1992), followed presumably by minor ice sheet advance of the Vileyskye Glaciation (Voznyachuk, 1985) or by a cooling (Yelovicheva, 1997). In Ukraine this interstadial is probably represented by the oldest palaeosol within the Zavadivka complex (Gozhik *et al*., 2000) and by initial development of the Sokal palaeosol at Bojanice (Fig. 2).

MAZOVIAN INTERGLACIAL = ALEXANDRIAN = ZAVADIVKA 2 (11 OIS)

In Poland this interglacial is well known, from lake sediments at Gościęcin, Boczów, Barkowice Mokre and Krępiec and other localities (Fig. 1). Pollen spectrum shows (Janczyk-Kopikowa, 1981) that the pre-optimum was represented at first by pine-birch forest, which was then supplemented with more thermophilous trees such as *Ulmus*, *Quercus* and *Tilia*, accompanied by *Corylus*, *Carpinus* and *Taxus*. The climatic optimum was primarily dominated by *Taxus*, then by *Carpinus* and *Abies*, with *Vitis* and *Azolla*. In the post-optimum part there was comeback of pine-birch forest with dominant *Pinus*. Diatom analysis of these deposits at Krępiec shows a dominance of nannoplankton diatoms in the lower part, followed by a rising content of littoral and rheophyllic taxon; the upper part is dominated by diatoms that indicated shallowing and overgrowing of the lake (Marciniak, 1980). Deposits in the lower part were TL dated at 400 ka and the overlying sands at 350 ka (Harasimiuk *et al*., 1988). Similar interglacial lake sediments have been noted, for example in the vicinity of Biała Podlaska (Krupiński, 1988; Marciniak, 1998; Lindner and Astapova, 2000).

In Belarus sediments of the Alexandrian Interglacial are known also from many lake sections, such as Malaya Alexandria (Fig. 1) and in the vicinity of Grodno (Lindner and Astapova, 2000). The floristic succession of this interglacial is almost the same as that of the Mazovian Interglacial in Poland. The climatic optimum is dominated by *Carpinus* and *Abies*, with *Vitis*, *Celtis*, *Zelkova*, *Juglans*, *Pterocarya*, *Buxus*, *Hedera*, *Osmuda* and *Taxus* (Yelovicheva, 1992, 1996, 2001).

At Adamówka and Krępiec in Poland (Fig. 1), and Matveev Rov and Gvoznitsa in Belarus there are the same diatom species in both Mazovian and Alexandrian interglacial deposits (Marciniak and Khursevich, 2002). The age of lake sediments is shown not only by palynology but also by the extinct diatoms *Cyclotella* (*C. comta* var. *lichvinensis* (Jousé) Loginova, *C. comta* var. *pliocaenica* Krasske, *C. temperiana* (Loginova) Loginova and *C. michiganiana* var. *parvula* Loginova (*C. parvula* Loginova), typical of this interglacial in Poland and Belarus.

Based on qualitative and quantitative analysis of diatoms at these sites, local diatom assemblage zones (LDAZ) were distinguished and correlated with phytophases or pollen zones. Diatom zones represent three (Adamówka and Matveev Rov) or four (Krępiec and Gvoznitsa) main phases of the Mazovian (Alexandrian) Interglacial. Diatom analysis enabled distinction of three types of diatom succession. The first type: 1. *Cyclotella-Fragilaria*, 2. *Cyclotella-Stephanodiscus*, 3. *Fragilaria-Cyclotella* was noted at Adamówka and Matveev Rov, the second: 1. *Stephanodiscus-Synedra-Fragilaria crotonensis-Cyclotella*, 2. *Stephanodiscus-Cyclotella-Aulacoseira*, 3. *Cyclotella-Stephanodiscus-Synedra-Asterionella Formosa*, 4. Periphyton *s.l.-Aulacoseira-Fragilaria* spp.) is typical of Krępiec and the third: 1. *Cyclotella*, 2. *Cyclotella-Aulacoseira-Stephanodiscus*, 3. *Aulacoseira-Cyclotella-Stephanodiscus*, 4. *Aulacoseira* was found at Gvoznitsa. These diatom successions show the typological and genetic variety of interglacial lakes and enable biostratigraphic correlation of lake sediments of the Mazovian and Alexandrian Interglacials (Marciniak and Khursevich, 2002).

Similar lake sediments in northwestern Ukraine occur at Krukenichy (Bogutsky *et al*., 1980) and Stari Koshari (Karaszewski and Rühle, 1976). They correspond to the middle part of lake and fluvial sediments of the Zavadivka horizon at Tur and Guta in Volhynian Polesye (Fig. 2) and to palaeosols in loess at Bojanice, Korshov and Krukenichy (Fig. 1). The Sokal palaeosol at Bojanice (Fig. 2) is developed on a till of the Sanian 2 Glaciation (Lindner *et al*., 1998).

In Central, Southern and Eastern Ukraine this interglacial is indicated by middle (younger) brown mid-loess palaeosols of the Zavadivka complex (Krokos, 1934; Veklich, 1965, 1968, 1982; Sirenko, 1974; Matviishina, 1982), known from Zavadivka, Vyazivok, Roxolany, Chigrin, Kaydaky and Primorskoye and other sites (Fig. 1). They developed when forest and steppe-forest with representatives of Tertiary exotics occupied the area. The palaeosols record normal magnetic polarity (Brunhes) with episodes of reverse polarity in the middle. At Volnoye (Figs. 3 and 4) the pollen spectrum is dominated by forest with *Picea*, *Abies*, *Alnus*, and the participation of *Tsuga*, *Taxus*, *Ilex*, *Ostrya*, *Carya*, *Pterocarya* and *Juglans* (Yelovicheva, 2003).

In Western Europe this interval is represented by the Holsteinian Interglacial (Fig. 5).

LIVIECIAN GLACIATION = COOLING IN BELARUS = OREL (10 OIS)

In Poland the ice sheet reached Mazovia and southern Podlasie, presumably also the northern foreland of the South Polish Uplands (Lindner and Marks, 1995). Loess of a periglacial zone is known from Kolonia Zadębce (Fig. 2) in the Lublin Upland (Dolecki, 1995). Loess-like deposits were noted in the Middle San River (Łanczont, 1997*a*, *b*; 2000).

In Belarus there is a cooling, named the Glacial 5 (Yelovicheva, 1997). In northwestern Ukraine loesses are known from Bojanice and other localities (Lindner *et al*., 1998) and in the vicinity of Krukenichy (Bogucki *et al*., 2000*a*, *b*). In Central and Southern Ukraine a thin (0.3–1 m) loess (Veklich, 1965, 1968) records normal magnetic polarity (Brunhes) and is known from many sections with Zavadivka palaeosols (Figs. 2 and 3).

In Western Europe this interval is represented by the Fuhne cooling (Fig. 5).

ZBÓJNIAN INTERGLACIAL = SMOLENSKIAN = POTAGAYLIVKA (9 OIS)

In Poland this interglacial is represented at sites including Zbójno and Konin-Marantów (Fig. 1). The palynology of these deposits indicates (Lindner and Brykczyńska, 1980) that the initial part of the Zbójnian Interglacial was dominated by pine forest with *Betula*, *Quercus* and *Corylus*. The climatic optimum with a drop in pine was accompanied by the rapid development of *Tilia* (to 48%), and its subsequent decrease (to 20%) but accompanied by a rise in *Alnus*, *Carpinus*, *Picea* and *Corylus*, and the presence of *Quercus*. The post-optimum part of this interglacial was at first dominated by coniferous trees and then by a continuous rise of *Pinus*. Deposits of this interglacial are overlain by a till, the age of which was estimated at 256–239 ka (Lindner and Marciniak, 1998). In loesses of the Lublin Upland this interglacial is represented by a palaeosol or a soil complex, noted at Kolonia Zadębce (Dolecki, 1995; Maruszczak, 1996).

In the border zone of Belarus and Russia there are lake sediments at Smolensky Brod (Fig. 1), typical of the Smolenskian Interglacial (Fig. 5). According to Yelovicheva (1992, 1996, 2001), the beginning of this interglacial is represented by birch-pine forest, gradually replaced by thermophilous forest with *Ulmus*, *Quercus*, *Tilia* and *Carpinus*, accompanied by *Picea orientalis*, *Zelkova* and *Osmunda claytoniana*. The decline of the interglacial is represented by abundant *Abies* and *Pinus*, then by renewed development of birch-pine forest and grasses.

In loesses at Bojanice and Korshov, northwestern Ukraine (Figs. 1 and 2), there is the Luck palaeosol (Bogutsky *et al*., 1980). It occurs also at Krukenichy, on the interfluves of the San and Dniester rivers, where it is buried under a thin loess-like deposit (Bogucki *et al*., 2000*a*, *b*). In the eastern Carpathian Foreland (Bogutsky *et al*., 2000) a Luck-type soil occurs also at Halich (Fig. 1).

In Central and Southern Ukraine there is a red-brown forest-steppe palaeosol of the Potagaylivka horizon (Veklich, 1965, 1968, 1982; Sirenko, 1974; Matviishina, 1982). This soil is relatively thin (0.5–1.2 m) and in many cases directly underlain by older soils (Zavadivka: Figs. 2 and 3). In some cases this soil is also superposed by a chernozem. This soil has developed in subtropical conditions and it records normal magnetic polarity (Brunhes).

In Western Europe it is represented by the Reinsdorf Interglacial (Fig. 5).

KRZNANIAN GLACIATION = DNIEPER 1 (8 OIS)

Recently collected data (*cf*. Lindner and Marks, 1999) suggest the possible statut of the "Krzna Stadial" of Rühle (1970) as separate glaciation. An ice sheet occupied northeastern Poland but presumably reached the northern foreland of the Lublin and Małopolska Uplands, and probably also the Silesian Upland and the Sudetes Foreland. A till in this area has been considered previously as evidence of the pre-maximum stadial of the Odranian Glaciation (Lindner, 1992).

In Belarus this glaciation may be represented by glacial and extraglacial sediments, deposited before the maximum of the Dnieperian Glaciation (Dnieperian+Sozhian).

In northwestern Ukraine the loess of this glaciation was noted at localities including Bojanice (Fig. 2) and Korshov (Lindner *et al*., 1998). At Halich (Fig. 1) there is a bipartite loess (Bogutsky *et al*., 2000). In the Volhynian Polesye there are silts, overlain by a till at Stari Koszari (Fig. 2), and also fluvioperiglacial deposits at Guta (Fig. 2), indicating a cool environment (Yelovicheva, 2003). In Central Ukraine this glaciation is named the Dnieper 1 (Lindner *et al*., 2004), and is represented by subtill and supratill loesses, separated at Vyazivok by a till (Fig. 2) and also by glaciofluvial and glaciolacustrine sediments (Krokos, 1927, 1934; Veklich, 1965, 1968, 1982, 1990; Gozhik *et al*., 1995). Outside of the ice sheet limit at Roxolany (Fig. 3), both loesses occur superposed, and total 4–10 m thick. Palaeomagnetic examination records normal polarity (Brunhes) with a distinct Chegan reverse episode (Gozhik *et al*., 1976; Veklich, 1982; Tretjak *et al*., 1987).

In Western Europe this interval is represented by a cooling between the Reinsdorf and Schöningen interglacials (Fig. 5).

LUBAVIAN INTERGLACIAL = SHKLOVIAN = KAYDAKY (7 OIS)

In Poland this interglacial is represented by lake deposits at Losy near Lubawa (Fig. 1; Krupiński and Marks, 1986). Palynological examination shows that the interglacial starts with birch forest with *Pinus* and *Larix*, then accompanied by trees of needing a warmer climate (*Picea*, *Quercus*, *Ulmus*) and *Typha latifolia*. The middle part of the interglacial is represented firstly by mixed and then by oak-birch forest with *Tilia*, then with *Corylus*, accompanied by *Ulmus*, *Alnus* and *Tilia*. At Losy there are no deposits that represent the termination of the interglacial. In the Lower Vistula valley region in Northern Poland this interglacial may be recorded by marine sediments of the so-called "Sztum sea" (Makowska, 1986; Lindner and Marks 1999). In the loess area of Southern Poland, for instance at Odonów (Figs. 1 and 2), this interglacial is represented by a mid-loess palaeosol complex, determined as a "Tomaszów"-type soil (Jersak, 1973), composed of a forest soil and superposed by a forest-steppe soil (Maruszczak, 1991). In the Lublin Upland the Lubavian (there: Lublinian) Interglacial is represented by organic sediments (Buraczyński *et al*., 1982), and, in the northern Polish Carpathians, by a palaeosol (Łanczont, 1995).

In Belarus there are deposits of the Shklovian Interglacial (Fig. 5), known for instance from Nizhninsky Rov (Lysaya Gora; Fig. 1). These deposits possibly indicate 3 warmings during this interglacial in Belarus (Yelovicheva, 1992, 2001). The first of these was indicated by predominant forest with *Quercus*, *Ulmus* and *Tilia*, the second one starts with prevailing *Quercus* and *Ulmus*, subsequently accompanied by *Carpinus*, and the third one by *Tilia*, *Quercus* and *Ulmus*. Deposits of this interglacial also contain *Ostrya*, *Ilex*, *Picea sect. Omorica*, *Pinus sect. Strobus*, *Pinus sect. Cembrae*, *Azolla filiculoides*, *Ulmus poropingua*, Eriocaulaceae, *Woodsia* cf. *manschuriensis*, *Quercus pubescens* and *Tilia tomentosa* as exotics.

In Volhynia, northwestern Ukraine, this interglacial is represented by the "Korshov" mid-loess soil complex at Bojanice (Fig. 2) and Korshov. It is composed of 2–3 forest palaeosols, with superposed chernozems (Bogutsky *et al*., 1980). At Halich, eastern Carpathian Foreland, the soil complex is composed of two forest soils (Bogutsky *et al*., 2000). At Guta, Volhynian Polesye (Fig. 2), this interglacial is represented by fluvial sandy silts and sands with humus, with a pollen spectrum predominated by trees (over 90%), mainly Pinus, with 2–3% of broad-leaved trees and with exotics (Yelovicheva, 2003).

In Central and Eastern Ukraine, particularly near Dniepropietrovsk (Kaydaky) there is a mid-loess tripartite palaeosol of the Kaydaky horizon (Figs. 2 and 3); in Southern Ukraine it is bipartite only (Fig. 2). The lowest part is a brown forest-steppe soil, the middle part is a transformed chernozem and the uppermost part is a typical steppe chernozem (Sirenko, 1974; Matviishina, 1982; Veklich, 1982). The soils are 1.2–3.5 m thick and record normal magnetic polarity (Brunhes). At Volnoye (Fig. 4) a soil complex of this interglacial contains only 45% of tree pollen and 40% of herbs. Trees are predominated by *Pinus* (91%), with a small participation of *Betula* (4%), *Alnus* (1%), *Quercus* (0.5%) and *Picea* (0.5%). Among exotics there are *Tilia platyphyllos*, *Ilex*, *Juglans* and Moraceae? (Yelovicheva, 2003).

In Western Europe this setting is represented by the Schöningen Interglacial (Fig. 5).

ODRANIAN+WARTANIAN GLACIATION = DNIEPERIAN+SOZHIAN = DNIEPER 2 = TYASMYN (6 OIS)

During the maximum stadial (Odranian) the ice sheet reached the northern slopes of the South Polish Uplands (with a lobe in the Lower San drainage basin), the Silesian Upland and the Sudetes, occupying most of the Upper Odra drainage basin (Lindner and Marks, 1995). During the post-maximum stadial (Wartanian), previously treated as separate glaciation (Lindner, 1992), the ice sheet occupied southern Wielkopolska, Łódź Upland, Mazovia and southern Podlasie (Marks *et al*., 1995; Lindner and Marks, 1999). In extraglacial Southern and Central Poland the upper older loess was deposited (Jersak, 1973; Maruszczak, 1976).

In Belarus the older (maximum) stadial of this glaciation is named the Dnieperian. The ice sheet reached the Prypyat drainage basin (Marks and Pavlovskaya, 2001*a*, *b*) and entered Ukraine. During the younger stadial (Sozhian) the ice sheet deposited a till and end moraines in the vicinity of Bereza, Storabin and Klimovichy (Matveyev, 1995).

In northwestern Ukraine this glaciation corresponds to Dnieper 2 (Lindner *et al*., 2004) and is represented by loess, among others at Bojanice (Fig. 2), Korshov and Halich (Bogutsky *et al*., 1980, 2000). In Central, Southern and Eastern Ukraine the loess is 0.5–2 m thick (e.g. at Sanzheyka), records normal magnetic polarity (Brunhes) and is named the horizon Tyasmyn (Veklich, 1965, 1968, 1972, 1982; Gozhik *et al*., 1976, 1995).

In Western Europe this glaciation is represented by the Drenthe and Warthe ice sheet advances (Fig. 5).

EEMIAN INTERGLACIAL = MURAVIAN = PRYLUKY (5E OIS)

In Poland this interglacial has been noted in numerous sections of lake sediments, for instance at Szeląg, Nidzica, Imbramowice and Bedlno (Fig. 1). Palynological studies indicate that the initial part of the Eemian Interglacial is represented by pine-birch forest with rare trees of warmer climatic requirements (*Quercus*, *Ulmus*, *Tilia*, *Carpinus*, *Corylus*, *Alnus*). Deciduous trees with *Quercus*, *Corylus* and *Tilia*, and the first traces of *Picea* represent the middle part with the climatic optimum. The third, post-optimum part of the interglacial is represented again by pine-birch forest with *Picea* and *Larix* (Środoń and Gołąbowa, 1956).

The most complete biostratigraphic examination of pollen and diatoms has been made at Imbramowice (Fig. 1; Kaczmarska, 1976; Mamakowa, 1989). The diatoms indicate a shallow lake with very rich, mainly littoral taxa and only a few euplanktonic species, particularly during the climatic optimum (Kaczmarska, 1976). Based on changes in diatom composition in lake sediments at Zbytki, a shallow lake with a predominance of *Fragilaria* was reconstructed; it was occasionally dry, particularly during the climatic optimum when halophilous and brackish diatoms appeared (Marciniak, 1994).

Numerous planktonic diatoms with predominant *Cyclotella*, accompanied by *Stephanodiscus*, were recovered from Nidzica (Fig. 1). They indicate a deep, oligo-mesotrophic lake during most of the interglacial. At this site there are thick (about 26 m) lake sediments, with a considerable content (to 80%) of calcium carbonate (Marciniak and Kowalski, 1978).

In Poland this interglacial is also represented by marine incursion (the Tychnowy Sea) in the Lower Vistula valley (Makowska, 1986, 1991). Mid-loess soil complexes of "Nietulisko I"-type are known from Southern and Central Poland, for instance from Branice and Odonów (Figs. 1 and 2; Jersak, 1973). In most loess sections they represent not only interglacial forest soils but also the Early Vistulian chernozems (Maruszczak, 1976).

In Belarus, deposits of the Muravian Interglacial (Fig. 5) are known from numerous sites, for instance from Cherikov (Fig. 1). Palynological examination enabled distinction of two climatic optima (Yelovicheva, 1992, 2001). The older one was represented by forest with *Quercus*, *Carpinus*, *Ulmus*, *Tilia* and *Corylus*, and the younger one by forest with *Tilia*, *Quercus*, *Carpinus* and *Ulmus*, accompanied by *Ephedra*, *Osmunda cinnamonea*, *Picea obovata*, *Larix* and *Cornus* (Yelovicheva, 1996).

Diatom analyses at numerous sites of the Muravian Interglacial in Belarus prove (Velichkevich *et al*., 2001) that, by comparison with Poland, they represent mostly palaeolakes with abundant planktonic diatoms, primarily of the genus *Cyclotella*. The latter is particularly common in the lower part of the interglacial succession whereas the upper part is dominated by increased participation of the genera *Aulacoseira* and *Stephanodiscus*. Very shallow and small lakes, typical of the sites in western Belarus, are less common. In most sites of the Muravian Interglacial in Belarus and the Eemian Interglacial in Poland there are abundant diatoms, typical both of Late Glacial–Holocene and of modern lakes. Diatoms typical of the Middle Pleistocene are absent.

In northwestern Ukraine this interglacial is represented by the lower part of the soil complex of "Horokhov"-type (Bogutsky and Morozova, 1981). It is preserved at the top of the upper older loess, for instance at Bojanice (Fig. 2), Korshov, Horokhov and Halich (Bogutsky *et al*., 1980, 2000; Lindner *et al*., 1998; Nawrocki *et al*., 1999). In Central, Eastern and Southern Ukraine this interglacial is also represented by a mid-loess complex, named the Pryluky horizon (Veklich, 1982, 1990; Gozhik *et al*., 1995). Its lower part is an illuvial horizon of a brown soil and the upper part is represented by a chernozem, developed presumably at the beginning of the following glaciation. At Roxolany in Southern Ukraine (Fig. 1) this soil complex comprises the Blake palaeomagnetic episode (Fig. 3) of reversed magnetic polarity (110 ka) within the Brunhes (Gozhik *et al*., 1976; Tretjak and Volok, 1976). At

Volnoye in Eastern Ukraine (Figs. 1 and 4) palaeosols contain abundant tree pollen (74–81%) with predominant *Pinus* and abundant *Betula* (Yelovicheva, 2003). Among broad-leaved trees there were *Quercus* (0.5–4.0%), *Ulmus* (2%) and *Tilia* (0.5%), also *Corylus* (0.5–1.0%).

In Western Europe this interglacial is represented by the Eemian (Fig. 5).

VISTULIAN GLACIATION = POOZERIAN = VALDAY (5D–2 OIS)

In Poland the ice sheet during the Świecie Stadial (60–50 ka) and the Leszno–Pomeranian Stadial (about 20 ka) occupied central Wielkopolska, Kujawy, Dobrzyń and the Mazury Lakeland (Lindner and Marks, 1995). The younger loesses connected with this glaciation (Jersak, 1973; Maruszczak, 1976) were deposited mainly in Central and Southern Poland, for instance at Baranice and Odonów (Fig. 2).

In Belarus, the ice sheet of the Poozerian (Fig. 3) occupied only the area to the north of Grodno and Minsk, with its limit along the Ostrovets–Dokshitsy–Orsha line (Matveyev, 1995).

In northwestern Ukraine this glaciation is represented by several loesses, well preserved at many key sites including Bojanice (Fig. 2), Korshov and Galich. Most loesses are separated from one another by initial tundra soils, many deformed by congelifluction and frost wedges (Bogutsky *et al*., 1980). In Central, Southern and Eastern Ukraine there are thick loesses separated by interstadial palaeosols. All these are connected with the Valday horizon (Krokos, 1927, 1934; Veklich, 1965, 1968, 1972). Recent studies at Vyazivok (Roussean *et al*., 2000) proved that there were several Early Valday interstadial palaeosols, including the earlier identified horizons of the Bug loess (2 OIS), 4–8 m thick, and of the Uday loess (4 OIS), 1–2.5 m thick. These loesses are separated by the Vytachiv palaeosol (3 OIS), 1.2–2 m thick (Fig. 2). The palaeosoil was radiocarbon dated at over 45 ka. The Bug loess was radiocarbon dated at 25–10 ka (Gozhik *et al*., 1976, 1995; Shelkoplyas *et al*., 1986). In the lower part of the Bug loess there is the Laschamp episode (Fig. 2), expressed by reversed magnetic polarity within the Brunhes Epoch (Gozhik *et al*., 1976). At Volnoye (Figs. 1 and 4) soils of the Vytachiv complex contain up to 34% of tree pollen and *Selaginella selaginoides* as an index of boreal-arctic climate. The Bug loess shows a drop in tree pollen (Yelovicheva, 2003).

In Western Europe this glaciation is named the Weichselian (Fig. 5).

HOLOCENE (1 OIS)

Palaeogeographic conditions during the Holocene in Poland, Belarus and Ukraine can be considered as examples of interglacial warming. In Poland and Belarus this interval is reconstructed firstly by examination of lake sediments (e.g. at Błędowo: Fig. 1) and rivers. In Ukraine a principal role was played by examination of fluvial sediments and soils. Human activity played significant role over the whole area, expressed firstly by transformation of forest, and then by grazing and farming.

FINAL REMARKS

The description given of the main climatic changes, followed by correlation of the main stratigraphic units of the Quaternary in Poland, Belarus and Ukraine, is a pioneering study. It shows 26 climatic fluctuations, comprising global coolings and warmings (Fig. 5).

The four oldest ones (Różcian = Olkhovskian = Siver, Ponurzycian = Grushevskian = Beregovo, Otwockian = Vselubskian = Berezan, Celestynovian = Yelnynskian = Kryzhaniv) may be reliably correlated with the Early Quaternary succession of Western Europe.

Mid and Late Quaternary consists of 11 glaciations or coolings of the first rank. They are represented both by glacial deposits and loesses in the extraglacial zone or by hiatuses in mid-loess palaeosol complexes. These units are separated from one another by 10 interglacials or global warmings and terminate with the Holocene. All these are indicated by buried lake deposits with specific floristic successions, and/or by mid-loess palaeosols or their complexes. Both as regards glacial units and in coolings, as well as interglacials and warmings, their characteristics is presented for Poland, Belarus and Ukraine, and correlation with corresponding units in Western Europe is suggested (Fig. 5).

Glacial deposits and landforms, preserved in Poland, Belarus and northwestern Ukraine, provide the best correlation of glacial units. They represent the two youngest glaciations: Vistulian (Poozerian, Valday) and Odranian+Wartanian (Dnieperian+Sozhian, Dnieper 2 = Tyasmyn), and also the older and well-determined Sanian 2 Glaciation (Berezinian). In Western Europe these glaciations are the Weichsel, Drenthe+Warthe and Elster 1, respectively. The other glaciations, sediments of which usually do not occur at the land surface, and other global coolings, were distinguished mainly on the basis of the geological setting of older and younger interglacial lake deposits or by reference to the superposed palaeosols. In this case the best correlation was given by the pollen successions of the interglacials: Eemian (Muravian), Mazovian (Alexandrian), Ferdynandovian 2 (Byelovezhian 2) and Ferdynandovian 1 (Byelovezhian 1), as well as by pollen analysis of the corresponding palaeosols: Pryluky, Zavadivka, Lubny 2 and Lubny 1 (Fig. 5).

Remaining units of the Mid and the Late Quaternary climatic changes in this area, particularly expressed by loesses and palaeosols, formed the basis for determination of their age succession, integrated palaeomagnetic data. This succession is expressed in this part of the Quaternary by distinct cycles equal to 110–90 ka (Lindner *et al*., 2002*a*, *b*) and is fully consistent with the rhythm of climatic changes, recorded in sediments of Lake Baikal (*cf.* Williams *et al*., 1997), in northern Eurasia (Bolikhovskaya and Molodkov, 2002) and in deep-sea sediments as oxygen isotope stages (OIS in Fig. 5).

The material presented suggests that in Poland two new stratigraphic units (warm and cool) may be located between the Narevian Glaciation and the Augustovian 1 warming. There are also indications of global coolings (glaciations?) of the Augustovian 1/2 and Ferdynandovian 1/2. In Belarus, the occurrence of sediments indicating a global cooling between the

Smolenskian and Shklovian Interglacials seems also possible. In both areas the younger glacial units, composed of two stadials i.e. the older — Odranian (Dnieperian) and the younger — Wartanian (Sozhian) correspond to the Drenthe and Warthe stadials of Western Europe. In Ukraine the Shirokino, Lubny and Zavadivka soil complexes, comprising 2–3 interglacial soils each, can represent several warmings of the first rank. These warmings correspond not only with interglacial units in Poland and Belarus, but also with warmings within the Bavelian and Cromerian, and with the Holstein and Reinsdorf Interglacials in Western Europe.

These data show that Poland and Belarus with the most complete succession of glacial sediments, and Ukraine, with the fullest loess-palaesol succession, constitute the model for reconstruction of Quaternary climatic patterns in Europe.

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