Geological Quarterly, 2003, **47** (3): 261–268

Stratigraphy and sedimentology of the Bug loess (Pleistocene: Upper Vistulian) between Kiev and Odessa (Ukraine)

Roman CHLEBOWSKI, Petro GOZHIK, Leszek LINDNER, Maria ŁANCZONT and Józef WOJTANOWICZ

Chlebowski R., Gozhik P., Lindner L., Łanczont M. and Wojtanowicz J. (2003) — Stratigraphy and sedimentology of the Bug loess (Pleistocene: Upper Vistulian) between Kiev and Odessa (Ukraine). Geol. Quart., **47** (3): 261–268. Warszawa.

Documented type sections (Vyazivok, Stayky, Uman, Troitskoye, Altestovo, Roxolany and Lebedivka) provide a basis for Pleistocene stratigraphy between Kiev and Odessa, and have been used to characterise the heavy mineral composition and part of the light fraction of the Bug loess in this area. These sections document an almost complete succession of climatic change during the last 780 ka, worked out mostly using loesses and palaeosols though also in the case of the first two sections, of glacial deposits. The heavy mineral composition of the Bug loess in these sections documents five mineral groups on the basis of their resistance to weathering and susceptibility to deflation and aeolian transport. Radar charts with particular mineral groups indicate mineralogical and genetic trends in the loesses. Moreover, in some sections the light fraction of the loess investigated contains derived microfossils (mainly foraminifers) of Cretaceous age, indicating source areas for the loess-forming material, and constraining the palaeowind directions. The data obtained allow distinction of three accumulation zones of the Bug loess in this area, reflecting loesses derived from different source areas and transported by winds from different directions. In northern sections (zone A), the Bug loess was accumulated by winds blowing from the west and north-west. More to the south (zone C), the same loess was accumulated by winds from the east and south-east. Loess preserved in zone B, between these areas, could be accumulated by winds from either of these directions.

Roman Chlebowski, Institute of Geochemistry, Mineralogy and Petrology, University of Warsaw, Żwirki i Wigury 93, PL-02-089 Warszawa, Poland; Petro Gozhik, Institute of Geological Sciences, National Academy of Sciences of Ukraine, Gonchara 55B, 01 601 Kiev, Ukraine; Leszek Lindner, Institute of Geology, University of Warsaw, Żwirki i Wigury 93, PL-02-089 Warszawa, Poland; Maria Łanczont, Institute of Earth Sciences, Maria Curie-Skłodowska University, Akademicka 19, PL-20-033 Lublin, Poland; Józef Wojtanowicz, Institute of Earth Sciences, Maria Curie-Skłodowska University, Akademicka 19, PL-20-033 Lublin, Poland (received: December 13, 2002; accepted: April 17, 2003).

Key words: Ukraine, Kiev–Odessa area, alimentation areas, heavy minerals, last glaciation, loess.

INTRODUCTION

This paper describes the heavy mineral composition of the Bug loess that accumulated during the Upper Vistulian (Valdaynian, Weichselian) between Kiev in the north and Odessa in the south. This loess forms an almost continuous cover over the entire area and is exposed in the uppermost part of the sections. Seven sections have been selected for this study (Figs. 1 and 2). Two of these (Vyazivok, Stayky), considered type sections (Veklich *et al*., 1984; Putievoditel..., 1999) for the Pleistocene in the middle Dnieper basin, have been described previously (Chlebowski *et al*., 2000, 2001). Three sections (Uman, Troitskoye, Altestovo) are located within the Dnieper/Dniester interfluve. The remainding two sections (Roxolany, Lebedivka) can be considered as type sections (Gozhik *et al*., 2000) for the northwestern border of the Black Sea. The Bug loess preserved here, unlike the other sections (Fig. 2) is covered here by several thin beds of loess and palaeosol representing the Late Glacial part of the Vistulian (Valdaynian) Glaciation.

This paper was supported Grant no. 6PO4E02918 (Polish Committee for Scientific Research), which focused on investigations of the heavy mineral composition and geomorphological-geological setting of the upper younger loess (LMg) in southeastern Poland and the corresponding Bug loess in western Ukraine (Chlebowski *et al*., 2000, 2001, 2002). These investigations will eventually help in determining the source area for the loess-forming material in these areas, and the course of loess accumulation linked with the changing palaeogeography of central-eastern Europe *ca*. 25–12 000 years BP.

The mineral composition in the Bug loess links with studies of material from Poland (Chlebowski and Lindner, 1975, 1976, 1989, 1992), and Ukraine (Chlebowski *et al*., 2000, 2001, 2002; Gozhik *et al*., 2001). The analyses show the heavy min-

Fig. 1. Location of the study area between Kiev and Odessa

1 — sections with Pleistocene deposits subjected to analyses; 2 — loesses (after Krasnov *et al.*, 1971); 3 — range of the Scandinavian ice sheet during the Dnieperian (Drenthian) Glaciation (after Krasnov *et al.*, 1971)

eral composition in the 0.06–0.01 mm fraction, typical of loesses, and give additional data on the composition of the light fraction and derived microfossils preserved in the loess (Paruch-Kulczycka *et al.*, 2002).

Five mineral groups can be distinguished, based on resistance to weathering factors and susceptibility to aeolian transport (Table 1) within transparent heavy minerals represented by several dozens of components (Chlebowski *et al.*, 2002): I — minerals most resistant to weathering; II — minerals mode rately resistant to weathering; III — minerals susceptible to weathering, and especially to crushing; IV — minerals least resistant to weathering (both physical and chemical); V — platy minerals, most susceptible to aeolian transport. Each of the groups distinguished includes about a dozen (group I) to several components (groups II, III and V). Group IV is characterised by a single component (glauconite). Chlebowski *et al.* (2002) discus these groups and their component mineral in detail.

An additionally group, VI, was distinguished to encompass non-transparent minerals, the analysis of which necessitates specific investigation methods. Results of these investigations will soon be published.

OUTLINE OF PLEISTOCENE STRATIGRAPHY IN THE AREA STUDIED

Pleistocene deposits between Kiev and Odessa (Fig. 2), contain several correlation horizons (see i.e. Veklich, 1968, 1979; Veklich *et al.*, 1984; Gozhik *et al.*, 2000, 2001). The oldest of these is the Kryzhaniv (kr) horizon represented in the Vyazivok section (Fig. 2) by clayey sands documenting fluvial-soil deposition during a warm period, correlated with the Western European Waalian and the Celestynovian in Poland (Bogutsky *et al.*, 2001). It is overlain by silty deposits (Fig. 2) of the Ilyichivsk horizon (il) linked with lacustrine accumulation taking place during the Menapian climatic cooling episode corresponding to the Narevian Glaciation in Poland (Bogutsky *et al.*, 2001; Lindner *et al.*, 2002). In Vyazivok the latter deposits are overlain by palaeosols of the Shyrokino horizon (sh), preserved also in the Stayky section and correlated with the Bavelian *sensu lato* and Cromerian I climatic cooling, as well as with the Augustovian (Podlasian) Interglacial with several climatic optima (Ber, 2001; Lindner *et al.*, 2002).

In the Vyazivok and Stayky sections, above the palaeosols there occurs loess of the Pryozovsk horizon (pr), and, in the Roxolany section (Fig. 2), silty-loess deposits. Most probably the accumulation of these deposits took place during the climatic cooling correlated with the Western European Glacial A (Cromerian I/II) and the Nidanian Glaciation in Poland (Lindner *et al.*, 2002). Palaeosol of the Martonosha horizon (mr), which occurs higher in all three sections, indicates a distinct climatic warming with typical forest pollen (Putievoditel..., 1999; Matviishina., 2001). This palaeosol likely correlates with the Western European Cromerian II and with the Małopolanian Interglacial in Poland (Lindner *et al.*, 2002). In the Vyazivok and Roxolany sections (Fig. 2) the boundary between the Matuyama/Brunhes palaeomagnetic epochs (780 ka) is preserved in the upper part of this layer.

In Vyazivok the palaeosol is covered by loess of the Sula horizon (sl), considered the equivalent of the Sanian 1 Glaciation in Poland (Lindner *et al.*, 2002). Younger than this is the palaeosol of the Lubny horizon (lb), which is bipartite in the Roxolany section (Fig. 2). Its development took place during an interval corresponding to two climatic warmings (Cromerian III and IV) in Western European sections and the bi-optimum Ferdynandovian Interglacial in Poland (Lindner *et al.*, 2002).

In Vyazivok, Stayky and Roxolany (Fig. 2) this palaeosol is covered by loess of the Tiligul horizon (tl), correlated with the Elsterian II = Sanian 2 Glaciation (Lindner *et al.*, 2002). The Zavadivka palaeosol (zv) of forest origin, bipartite and in some cases tripartite, is developed on this loess. Episodes of reversed and unstable magnetic polarity are preserved within this palaeosol. The lower horizon of the soil (zv_1) probably encompasses the interstadial warming (Mrongovian in Poland, *cf.* Lindner and Marks, 1999; Lisicki and Winter, 1999) in the terminal part of the previous glaciation, and the middle horizon (zv_2) is correlated with the Holstein = Mazovian Interglacial (Gozhik *et al.*, 2000; Lindner *et al.*, 2002). In turn, the upper horizon of the soil (zv_3) should correspond to the Reinsdörfian = Dömitzian = Zbójnian Interglacial (Fig. 2). The soil is developed on the locally preserved loess of the Orel horizon (or) linked with the Fuhneinian climatic cooling (zv_2/zv_3), correlated with the Liviecian Glaciation (Gozhik *et al.*, 2000; Lindner *et al.*, 2002).

The Zavadivka palaeosols are covered by deposits of the Dnieperian horizon (dn), preserved in three sections (Vyazivok, Stayky, Roxolany). In the first two sections the deposits include silts and tills of the Scandinavian ice sheet, and

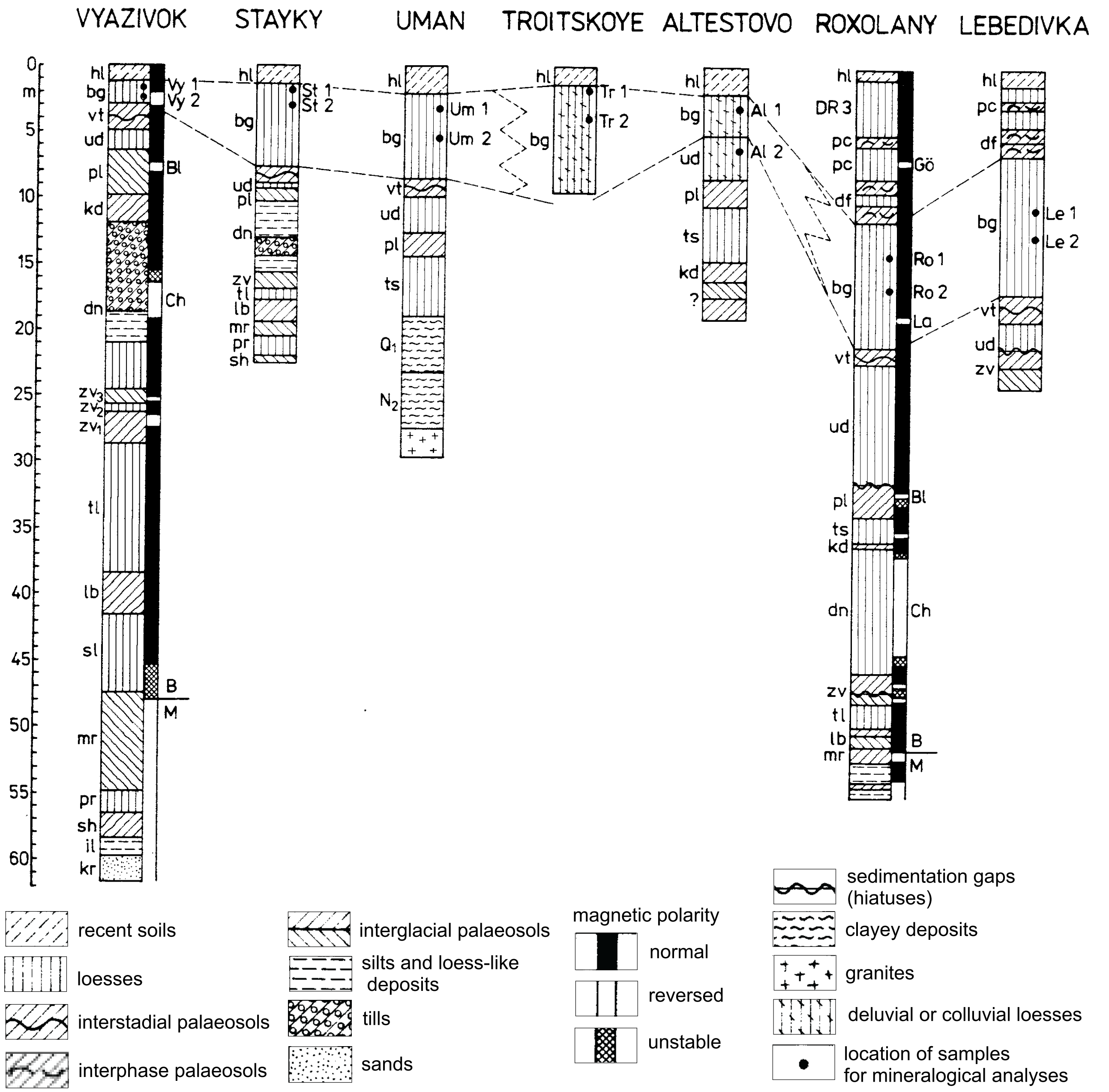


Fig. 2. Selected sections with Pleistocene deposits, after Veklich *et al*. (1984), Putievoditel... (1999), Gozhik *et al*. (2000), Matviichina *et al*. (2001) and authors

Symbols of stratigraphic intervals: N_2 — younger Neogene; Q_1 — older Quaternary; kr — Kryzhaniv (Waalian?); il — Ilyichivsk (Menapian?); sh — Shyrokino (Bavelian *sensu lato* + Cromerian I); pr — Pryozovsk (Glacial A); mr — Martonosha (Cromerian II); sl — Sula (Glacial B); lb — Lubny (Cromerian III and IV); tl — Tiligul (Elsterian); zv_1 — Zavadivka 1 (Mrongovian?); zv_2 — Zavadivka 2 (Holsteinian); zv_3 — Zavadivka 3 (Reinsdörfian); dn — Dnieperian (Drenthian); kd — Kaydaky (Schöningenian); ts — Tyasmyn (Wartanian); pl — Pryluky (Eemian); vl — Valdaynian (Vistulian): ud — Uday, vt — Vytachiv, bg — Bug, df — Dofinov, pc — Prychernomorsk, DR3 — Younger Dryas; hl — Holocene; **palaeomagnetic epoch event**: M — Matuyama, B — Brunhes, CH — Chegan, Bl — Blake, La — Laschamp, Gö — Göteborg

loesses present also in the Roxolany section (Fig. 2). A reversed polarization episode (Chegan), dated at *ca.* 290 ka, is preserved both in the Vyazivok and Roxolany sections. Deposits of the Dnieperian horizon correlate with the Drenthian Glaciation in Western Europe and with the Odranian = Krznanian Glaciation in Poland (Lindner and Marks, 1999). The palaeosol from the Kaydaky horizon (kd) = Schöningenian = Lubavian = Lublinian (Lindner *et al*., 2002) is developed above in the Vyazivok and Roxolany sections. It is covered by loess of the Tyasmyn horizon (ts) = Wartanian, particularly well developed in Roxolany and possibly also in the Uman and Altestovo sections (Fig. 2). In Roxolany the episode of reversed polarity within the Bruhnes epoch is also preserved.

In these sections, as well as at Vyazivok and Stayky, the directly overlying horizon is Pryluky (pl), comprising a succession of forest fossil soil and black earth. It encompasses the Eemian

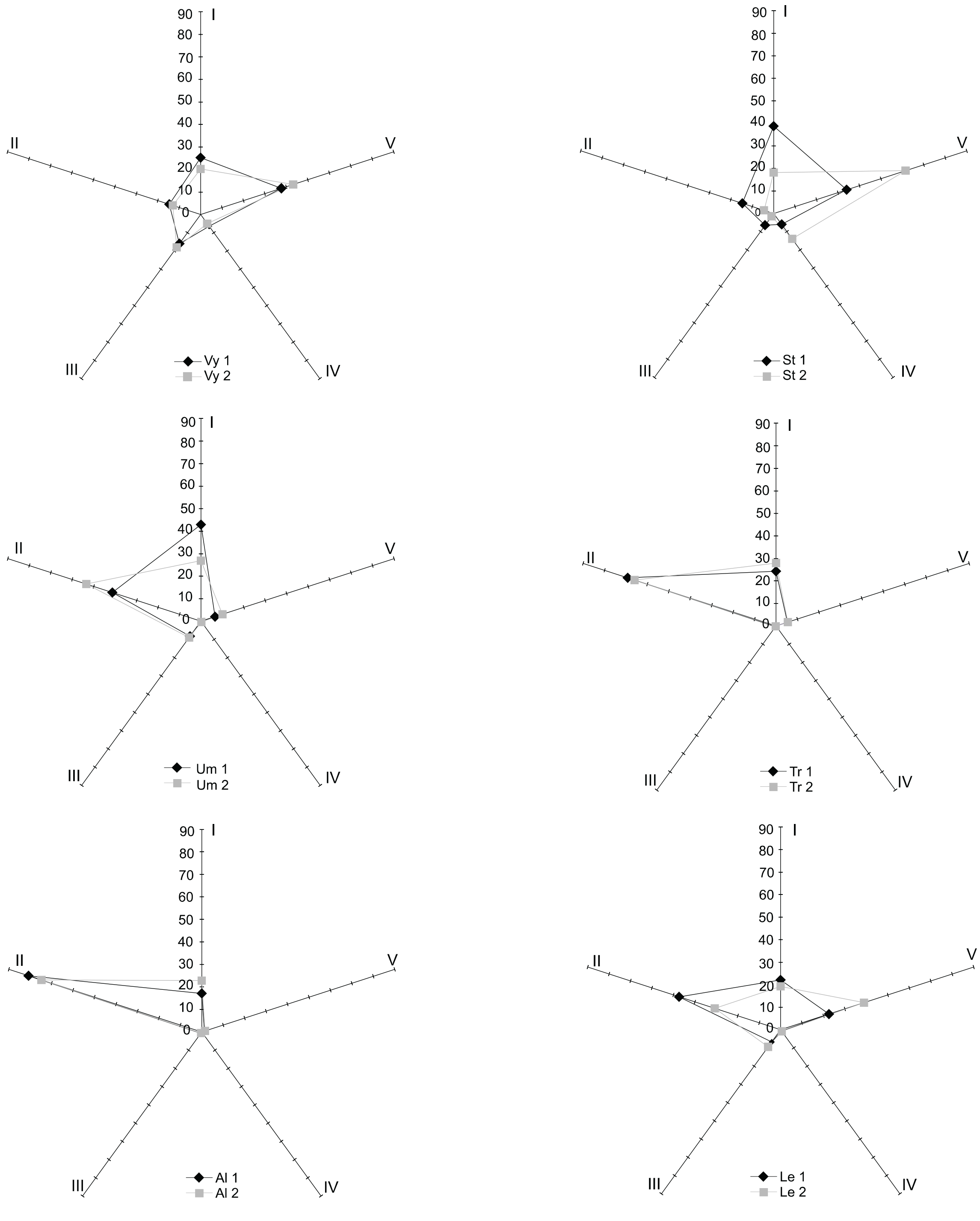
Table 1

Composition of the transparent heavy minerals fraction in percent and the content of carbonates and microfossil remnants (foraminifers) in Bug loess (Late Vistulian) beetwen Kiev and Odessa (Ukraine)

Profiles / Minerals	Vyazivok		Stayky		Uman		Troitskoye		Altestovo		Lebedivka		Roxolany		Mineral groups
	Vy 1	Vy 2	St 1	St 2	Um 1	Um 2	Tr 1	Tr 2	Al 1	Al 2	Le 1	Le 2	Ro 1	Ro 2	
Anatase	0.1	0.1	0.1	0.0	0.3	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	I
Andalusite	0.0	0.0	0.0	0.0	0.5	0.0	0.2	0.0	0.2	0.0	0.0	0.2	0.0	0.0	
Zirkon	9.0	9.5	10.0	7.5	14.1	10.2	9.8	12.1	2.1	6.7	8.5	7.6	5.6	5.9	
Kyanite	6.0	3.5	7.0	3.0	4.4	2.5	0.9	0.6	0.5	1.6	1.7	1.1	0.9	1.4	
Monazite	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	
Rutile	7.0	5.5	16.0	5.0	16.9	12.1	11.5	11.1	9.8	11.5	8.7	6.6	7.7	9.9	
Staurolite	1.5	1.0	2.0	0.1	5.1	0.6	1.3	2.9	2.3	2.3	1.0	0.7	0.2	1.2	
Topaz	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
Tourmaline	1.5	0.5	3.5	2.5	1.3	1.5	0.6	1.0	1.6	0.7	2.2	3.0	1.7	2.4	
Sphene	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.2	0.2	0.0	0.0	0.0	0.0	0.2	
Apatite	0.0	0.0	0.1	0.0	1.0	0.4	0.0	0.0	0.0	0.0	0.7	0.0	0.6	0.5	II
Epidotes	1.5	0.5	1.0	0.5	4.6	1.9	1.1	1.2	0.9	1.4	3.7	2.1	1.1	1.4	
Garnets	13.0	12.5	13.5	4.0	35.7	51.1	67.8	64.6	79.9	73.3	42.9	28.6	36.4	64.3	
Sillimanite	0.1	0.0	0.0	0.0	0.0	0.0	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	
Amphiboles	14.0	16.5	4.5	1.5	7.7	8.5	0.4	0.2	0.7	0.4	6.0	9.2	1.5	0.5	III
Pyroxenes	2.0	1.5	2.0	0.1	0.5	0.4	0.0	0.0	0.0	0.2	0.7	0.2	0.4	0.0	
Glauconite	6.5	5.0	6.0	14.0	0.0	0.4	0.0	0.0	0.0	0.0	0.7	0.9	2.8	1.2	IV
Biotite	4.5	8.0	13.0	23.0	1.0	3.0	0.6	0.8	0.0	0.2	2.5	5.7	9.6	2.4	V
Chlorite	0.1	0.1	1.0	1.5	0.5	0.6	0.0	0.4	0.7	0.2	12.4	22.0	11.6	2.6	
Muscovite	33.0	35.0	20.0	37.0	5.1	6.4	4.7	4.3	0.5	1.1	7.6	11.2	19.7	5.4	
Others	0.1	0.7	0.2	0.3	1.0	0.4	0.9	0.4	0.2	0.4	0.7	0.9	0.2	0.7	
Carbonates	++	+++	+	+	+++	++	+	+	+	+	+	+	++	++	
Foraminifers	+	+	+	+	–	++	–	–	–	–	–	+	+	++	

Interglacial and the first stadial and first interstadial climatic unit of the Valdaynian = Vistulian Glaciation. Within this succession, both at Vyazivok and Roxolany, the reversed magnetic polarity episode (Blake), dated at *ca.* 110 ka, is preserved.

In all these sections this succession, and in the Lebedivka section the older soil succession (Zavadivka), is covered by loesses and palaeosols from the mid and late part of the Valdaynian = Vistulian Glaciation. In stratigraphic order the lithological column begins with the Uday loess (ud) with a palaeosol of the Vytachiv horizon (vt) developed on it. The soil is covered by the Bug loess (bg), which is the youngest Pleistocene horizon in loess sections of the middle Dnieper basin (Vyazivok, Stayky) and in the Dnieper/Dniester interfluve (Uman, Troitskoye, Altestovo). This horizon correlates with the upper younger loess in Poland and determined at 25–15/12 ka (Maruszczak, 1991). In two sections lying within the north-western margin of the Black Sea, westwards of Odessa (Roxolany, Lebedivka), the Bug loess (bg) is covered by a several metres thick succession of the youngest loesses and palaeosols. These loesses (Prychernomorsk — pc) and palaeosols preserved in them (Dofinov — df) represent the climatic conditions of the Late Glacial part of the Valdaynian = Vistulian Glaciation. At Roxolany, the Laschamp palaeomagnetic episode (25 ka) is preserved within the Bug loess, and the Göteborg



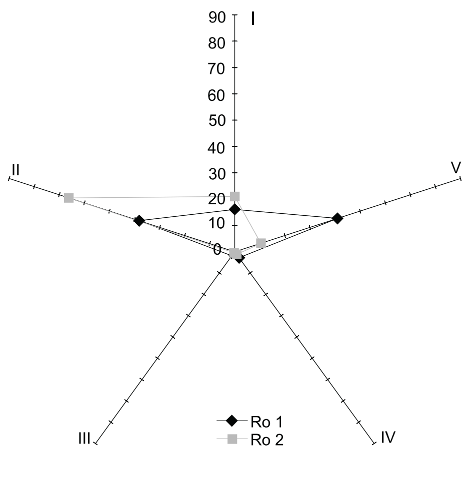


Fig. 3. Charts showing the contents of transparent heavy mineral groups (groups I–V) (see Table 1) in individual loess sections

a — Vyazivok, b — Stayky, c — Uman, d — Troitskoye, e — Altestovo, f — Lebedivka, g — Roxolany

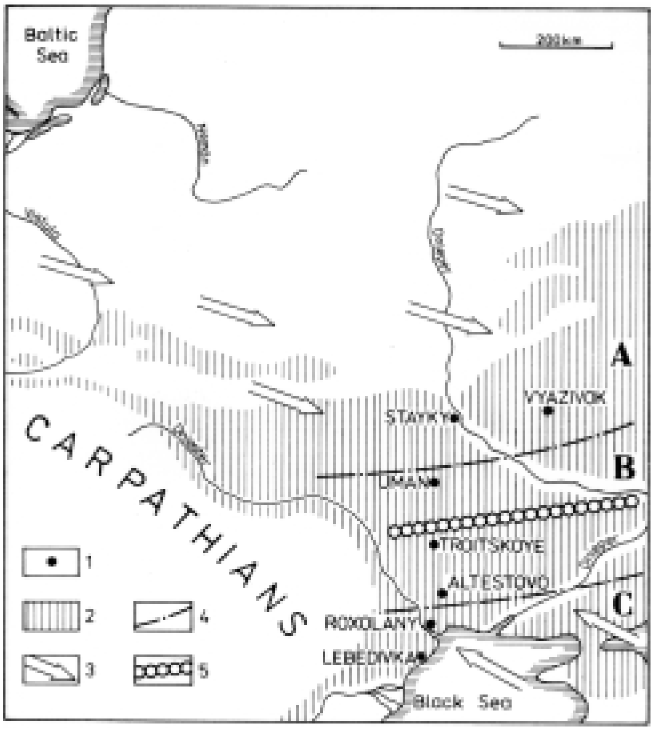


Fig. 4. Conditions of the accumulation of the Bug loess north-east of the Carpathian Mts.

1 — loess sections analysed; 2 — loesses; 3 — main directions of the loess-forming winds; 4 — possible boundaries of mineralogically different loess zones (A–C, explanations in text); 5 — "Voyeykov axis" — line separating the Atlantic wind and West-Asiatic systems (after Różycki, 1991)

palaeomagnetic episode (11 ka) is preserved within the Prychernomorsk loess.

In this study, the Bug loess (bg) was sampled for mineralogical analyses in all 7 sections. The location of samples is marked on the right hand side of the individual lithological columns (Fig. 2). In the Troitskoye and Altestovo sections this loess represents a slope facies with a clay content and signs of weathering (decalcification) in deluvial or colluvial conditions. In the case of the Altestovo section the lower sample is from the Uday loess (ud). In other sections the Bug loess analysed represents typical aeolian sediment accumulated on a plateau.

MINERAL COMPOSITION OF THE BUG LOESS

Results of heavy and light mineral analyses of this loess are given in Table 1. Based on this data and on the transparent heavy mineral groups distinguished (I–V), 5-axial radar charts were constructed with the help of computer software (Fig. 3) for all loess samples analysed (two for each loess section characterised).

Based on the content of transparent heavy minerals (groups I–V) certain patterns can be observed in the study area (over an area extending over 500 km from N to S):

1. The mineral composition of the Bug loess in sections located in the northernmost part of the area analysed (Stayky and Vyazivok) is almost identical, but differs significantly from the mineral composition in all other sections. In this area platy minerals representing group V are most common (with muscovite and biotite prevalent), characterising the so-called "aeolian vector" (Chlebowski *et al.*, 2002). Second most common are group I minerals (mainly rutile and zircon). The remaining groups occur generally in much smaller quantities, although minerals poorly resistant to weathering occur in both sections. Amphiboles (group III) are particularly common at Vyazivok, and at Stayky there are large quantities of glauconite representing group IV. In the Bug loess in both sections carbonates (in larger amounts at Vyazivok) and single shells of well-preserved microfossils (foraminifers) were also noted.

2. The mineral composition of the Bug loess in Uman is different than that in sections to the south (Troitskoye and Altestovo, with a prevalence of minerals of group II) and north (Stayky and Vyazivok where minerals from group V and I are prevalent). The loess is dominated by minerals of group II, particularly garnets, and group I, mainly rutile and zircon. This loess contains a large admixture of carbonates, and numerous derived microfossils (foraminifers).

3. The mineral composition of the Bug loess at Altestovo and Troitskoye, located to the south, is almost identical to those discussed above and differs significantly from the mineral composition of the loess from the southern part of the study area (Lebedivka and Roxolany). It is dominated by minerals of group II (mainly garnets), with minimal quantities of minerals of groups II, IV and V, whereas the content of minerals of group I (mainly rutile and zircon) is as in previous sections. The loess contains small quantities of carbonates, whereas microfossils (foraminifers) were not observed.

4. The Lebedivka and Roxolany loess sections located in the southernmost part of the study area (Black Sea region) are characterised by a more or less uniform mineral composition dominated by minerals of group II (garnets) and V (platy minerals, particularly muscovite and chlorite), with lesser amounts of minerals of group I (rutile and zircon). Glauconite, which represents group IV, occurs also in considerable quantities. Large amounts of carbonates were noted in both sections, as well as derived marine microfossils preserved as crushed as well as well-preserved foraminifers. The mineral composition of loess in both sections differs significantly from the remaining sections.

DISCUSSION

The mineralogical analyses of the Bug loess in 7 sections within the study area between Kiev and the Black Sea allow the distinction of three regional accumulation zones of loess (A–C on Fig. 4). Zone A is located in the northern part of the study area, with loess preserved in the Stayky and Vyazivok sections. Zone B, located in the central part of the study area, includes loesses from Uman, Troitskoye and Altestovo, and zone C is represented by loess from Lebedivka and Roxolany.

In the case of zone A (Stayky and Vyazivok), loess containing a considerable content of minerals poorly resistant to weathering (group III — amphiboles and pyroxenes), as well as platy minerals most susceptible to aeolian transport (group V

— mainly biotite and muscovite) indicates that the source area of the loess-forming material included the glacial and fluvioglacial deposits of the Middle and Late Pleistocene glaciations. In turn, the considerable content of glauconite (group IV), a mineral least resistant to weathering (both physical and chemical) is evidence of an additional source of loess material, probably local Quaternary basement rocks. Short transport of local material and its direct link with residual basement rocks is suggested by the presence of derived crushed and well-preserved microfossils (mainly foraminifers). They are derived from the residua of local Tertiary clastic deposits and Cretaceous carbonates (Marakhovska *et al*., 2000) containing glauconite and foraminifers. Considering the position of these sections in relation to the extent of the Scandinavian ice sheet and to exposures of Cretaceous and marine Tertiary rocks, the accumulation of the Bug loess in the northern part of the study area took place in the presence of winds from the west (Fig. 4).

The Bug loess in the sections from the second zone (B — Uman, Troitskoye, Altestovo) is characterised by a decrease in poorly resistant minerals (group III — amphiboles and pyroxenes), in those least resistant to weathering (group IV — glauconite) and in platy minerals susceptible to aeolian transport (group V — biotite, chlorite, muscovite). In turn, the content of resistant minerals (group I — zircon and rutile) increases. In particular, the lower content of amphiboles and pyroxenes, differentiates this loess from its age equivalents in the northern sections in the middle Dnieper basin (Chlebowski *et al*., 2000) and in sections in the Volhynian Upland (Chlebowski *et al*., 2002). The differences may possibly be linked with the slope character of this loess (particularly at Troitskoye and Altestovo), and also with a smaller admixture of material from residual glacial and fluvioglacial deposits and local basement rocks. The lack, or only minimal content of, glauconite and foraminifers is notable. Data thus indicate a peripheral alimentation zone of loess silt transported by winds from the west. Some similarities in mineral composition to loesses lying to the south (zone C) may also indicate another, possibly southern and/or southeastern source of loess-forming material (Fig. 4).

The third zone (C) of the Bug loess (Lebedivka, Roxolany) lies in the southernmost part of the study area, around the northwestern margin of the Black Sea. The Bug loess is characterised here by a prevalence of minerals from two groups (II and V). As regards easily wind-transported minerals (group V — biotite, chlorite and muscovite) there is an increase in the chlorite and muscovite content, and garnets prevail among minerals from group II. Furthermore, a high content of group I minerals (mainly zircon and rutile) was observed, and, in the case of the Lebedivka section, of group III minerals (mainly amphiboles). At Roxolany there is a high content of glauconite representing group IV. In both sections, varying amounts of derived wind-transported foraminifers were also noted. Thus, here the source of loess-forming material must have been different from those of the other zones. The source could include the residua of local rocks exposed in the northern and eastern margin of the Black Sea, notably those forming mountains on the Crimean Peninsula (Marakhovska *et al*., 2000), as well as those occurring around the Caspian Sea. The material was transported by winds from the south or south-east (Fig. 4).

FINAL REMARKS

The loess sections described, in some cases dating from before the Bruhnes/Matuyama palaeomagnetic boundary (780 ka), document an almost complete record of Mid to Late Quaternary climatic change in central and southern Ukraine. The Bug loess, which represents the youngest stadial of the Last Glaciation (Vistulian = Valdaynian), has particularly good documentation in terms of geological, palaeopedological, palaeontological and palaeomagnetic data.

The heavy mineral composition of this loess, the character of recent and Pleistocene dust storms (i.e. Wojtanowicz, 1972; Różycki, 1986) and their relation to the transport patterns (i.e. Różycki, 1968, 1976, 1991; Maruszczak, 1967; Jersak, 1976; Chlebowski and Lindner, 1989, 1999; Lindner and Chlebowski, 2001) suggest that accumulation of the Bug loess took place under influence of variable, and periodically even reversing winds in the lower and upper parts of the atmosphere. Considering the extents of the European and Asian loess provinces (Różycki, 1991) and the location of the "Voyeykov axis" — a line separating the present-day limits of Atlantic cyclones and West-Asiatic dust storms — it may be stated that:

1. The Bug loess in sections within zone A (Stayky, Vyazivok) accumulated from winds blowing from the west and north-west.

2. The same loess in sections within zone C (Lebedivka, Roxolany) was deposited by winds from the east and south-east.

3. The Bug loess preserved in sections within zone B (Uman, Troitskoye, Altestovo) may have accumulated, at different times, from winds of both of the two zones above. Atmospheric fronts, meeting on a wide area along the "Voyeykov axis", likely enhanced rainfall and therefore led to redeposition of loess on slopes into a deluvial or colluvial deposits. These, deposits became enriched in resistant (group II, particularly garnets) and very resistant (group I — mainly zircon and rutile) minerals. At the same time poorly resistant (group III — amphiboles and pyroxenes) and very poorly resistant minerals (group IV — glauconite) were strongly degraded and were locally removed from the deposit. Similarly, a low or vestigial content of platy minerals in these loesses indicates the importance of deluvial or colluvial rather to aeolian processes in their accumulation.

Acknowledgements. The manuscript benefited from reviews by Prof. H. Maruszczak and Dr N. Gerasimienko. We also thank mgr E. Bartocha for assistance in editing the manuscript.

REFERENCES

BER A. (2001) — Pleistocene of northeastern Poland in connection to neighboring areas. In: The Ukraine Quaternary Explored: the Middle and Upper Pleistocene of the Middle Dnieper Area and its Importance for the East-West European Correlation. INQUA–SEQS, Kyiv: 10

BOGUTSKY A., GOZHIK P., LINDNER L., ŁANCZONT M. and WOJTANOWICZ J. (2001) — Tentative correlation of the main stratigraphic units of the Pleistocene in Poland and Ukraine. In: The Ukraine Quaternary Explored: the Middle and Upper Pleistocene of the Middle Dnieper Area and its Importance for East-West European Correlation. INQUA–SEQS, Kyiv: 13–14.

CHLEBOWSKI R., GOŻYK P. F. and LINDNER L. (2000) — Preliminary comparative characteristic of upper younger loesses in the Małopolska Upland (Poland) and the central basin of the Dnieper (Ukraine) on the basis of mineralogical studies (in Polish with English summary). Biul. Państw. Inst. Geol., **393**: 95–113.

CHLEBOWSKI R. and LINDNER L. (1975) — Relation between heavy mineral composition and source material of main “loess islands” in NW part of Małopolska Upland (in Polish with English summary). Acta Geol. Pol., **25** (1): 163–178.

CHLEBOWSKI R. and LINDNER L. (1976) — Attempt to apply the heavy minerals analysis to the loess research problems exemplified by younger loesses of the western part of the Góry Świetokrzyskie area (in Polish with English summary). Biul. Inst. Geol., **297**: 293–305.

CHLEBOWSKI R. and LINDNER L. (1989) — Weathering processes of the Pleistocene periglacial environment and origin of loess. In: Weathering; its Products and Deposits (eds. K. S. Balasubramanian *et al.*). Processes. Theophrastus Publ. S.A., **1**: 439–456.

CHLEBOWSKI R. and LINDNER L. (1992) — Sources of sediments and sedimentary environment of younger loesses on the Małopolska Upland (in Polish with English summary). Biul. Geol. Uniw. Warsz., **32**: 15–48.

CHLEBOWSKI R. and LINDNER L. (1999) — Periglacial weathering processes and younger loess accumulation conditions in the Małopolska Upland (in Polish with English summary). Acta Geogr. Lodz., 76: 25–40.

CHLEBOWSKI R., LINDNER L., BARCZUK A., BOGUCKI A., GOZHIK P., ŁANCZONT M. and WOJTANOWICZ J. (2002) — Warunki akumulacji lessów młodszych górnych Wyżyny Lubelskiej (Polska) i Wyżyny Wołyńskiej (Ukraina) na podstawie badań geologicznych i mineralogicznych. In: II Świętokrzyskie spotkania geologiczno-geomorfologiczne n.t. Peryglacjał plejstoceński w osadach i rzeźbie obszaru Polski (ed. R. Sołtysik): 18–20. Kielce–Jodłowy Dwór.

CHLEBOWSKI R., LINDNER L. and GOZHIK P. F. (2001) — Genetic interpretation of mineral composition of bugsky loess for Middle Near-Dnieper (in Ukrainian with English summary). Geol. J., **4**: 15–18.

GOZHIK P. F., CHLEBOWSKI R. and LINDNER L. (2001) — New graphic interpretation of the mineral composition of the Bug loess (Late Vistulian) from the Middle Dnieper Drainage Basin (Ukraine). In: The Ukraine Quaternary Explored: the Middle and Upper Pleistocene of the Middle Dnieper Area and its Importance for East-West European Correlation. INQUA–SEQS, Kyiv: 30–31.

GOZHIK P. F., SHOLKOPLYAS V. M., KOMAR M. C., MATVIISHINA Z. M. and PEREDERY V. I. (2000) — Putivnik X Polsko-Ukrainsky Seminar: Korelatsya lessiv i lodovikovykh vikladiv Polszi i Ukraini. Kyiv.

JERSAK J. (1976) — Origin of loess of the South Polish Uplands (in Polish with English summary). Biul. Inst. Geol., **297**: 103–120.

KRASNOV I. I., DUPHORN K. and VOGES A. (eds.) (1971) — Internationale Quartär — Karte von Europe, Blatt 7, 1:250 000. Moskva, Hannover.

LINDNER L., BOGUCKI A., GOŻYK P., MARCINIAK B., MARKS L., ŁANCZONT M. and WOJTANOWICZ J. (2002) — Main climatic cycles in the Pleistocene stratigraphy of Poland and Ukraine (in Polish with English summary). Prz. Geol., **50** (9): 787–792.

LINDNER L. and CHLEBOWSKI R. (2001) — Forst weathering and niveo-eolic processes on the basis of selected regions of Spitsbergen In: The Operation of Glaciosystems in Different Morphoclimatic Condition. Monitoring, protection, education (eds. A. Karczewski and Z. Zwoliński): 281–295. Poznań.

LINDNER L. and MARKS L. (1999) — New approach to stratigraphy of palaeolake and and glacial sediments of the younger Middle Pleistocene in mid-eastern Poland. Geol. Quart., **43** (1): 1–7.

LISICKI S. and WINTER H. (1999) — Mrongovian and Brokian, new stratigraphic units of the Middle Pleistocene in northeastern Poland. Geol. Quart., **43** (1): 9–18.

MARAKHOVSKA I. I., DEMEKHIN L. O., METALIDI G. M., SYDOROVA D. A. and SOLOVYTSKY V. M. (2000) — Geological map Pre-cenozoic formations of Ukraine, scale 1:1000 000 (ed. D. S. Hursky). State Geol. Serv. Ukraine, Kiev

MARUSZCZAK H. (1967) — Wind directions during the accumulation of the younger loess in the East–Central Europe (in Polish with English summary). Rocz. Pol. Tow. Geol., **37** (1): 177–188.

MARUSZCZAK H. (1991) — Stratigraphic differentiation of Polish Loesses (in Polish with English summary). In: Main Sections of Loesses in Poland (ed. H. Maruszczak). Publ. UMCS, Lublin, A.13–A.35.

MATVIISHINA Z. (2001) — The Middle and Late Pleistocene paleosols of Ukraine. In: The Ukraine Quaternary Explored: the Middle and Upper Pleistocene of the Middle Dnieper Area and its Importance for East–West European Correlation. INQUA–SEQS, Kyiv: 59–59.

PARUCH-KULCZYCKA J., CHLEBOWSKI R. and LINDNER L. (2002) — Szczątki mikroskamieniałości morskich w lessach ostatniego zlodowacenia oraz ich znaczenie dla rekonstrukcji procesów lessotwórczych w środkowo-wschodniej Europie. Mat. XVIII Konf. Naukowej Paleontologów Pol. Tow. Geol. “Morfogeneza i implikacje środowiskowe”: 25–27, Poznań 26–28.09.2002.

PUTIEVODITIEL IX POLSKO-UKRAINSKOVO POLEVOVO SEMINARA (1999) — Stratigraphya y korrelatsya lessov i lednikowykh otlozhenyi Polszi y Ukrainy (in Russian): 1–32, Kiev.

RÓŻYCKI S. Z. (1968) — The directions of winds carrying loess dust as shown by analysis of accumulative loess forms in Bulgaria. VIIth INQUA Congr. Boulder and Denver (Colorado), **12**: 233–245.

RÓŻYCKI S. Z. (1976) — Conditions of the formation of loess (in Polish with English summary). Biul. Inst. Geol., **297**: 77–92.

RÓŻYCKI S. Z. (1986) — Loess type dust deposits in the World; their distribution and origin (in Polish with English summary). Studia Geol. Pol., **85**.

RÓŻYCKI S. Z. (1991) — Loess and loess-like deposits. Evolution of views on the genesis of loess, classical loess provinces, loess of the warm zone. Ossolineum.

VEKLICH M. F. (1968) — Stratigraphya lessovoy formatsy Ukrainy y sosiednikh stran (in Russian). Naukova Dumka, Kiev.

VEKLICH M. F. (1979) — Pleistocene loesses and fossil soils of the Ukraine. Acta Geol. Sc. Hungariae, **22** (1–4): 35–62.

VEKLICH M. F. *et al.* (1984) — Excursion 025 — Quaternary geology of the Dnieper area. In: Guidebook International Geological Congress, Session, **25**: 64–81, Kiev.

WOJTANOWICZ J. (1972) — Dust storms and their geomorphological significance (in Polish with English summary). Czas. Geograf., **43** (3): 265–294.