Late Pleistocene Environments of the Central Ukraine

Article *in* Quaternary Research · November 2001

DOI: 10.1006/qres.2001.2270

Denis-Didier Rousseau
Université de Montpellier

Natalia Gerasimenko
National Taras Shevchenko University of Kyiv

George Kukla
Columbia University

Quaternary Research **56**, 349–356 (2001)
doi:10.1006/qres.2001.2270, available online at http://www.idealibrary.com on IDEAL®

Late Pleistocene Environments of the Central Ukraine

Denis-Didier Rousseau

Paléoenvironnements et Palynologie, Institut des Sciences de l'Evolution (UMR CNRS 5554), Université Montpellier II, case 61, place E. Bataillon, 34095 Montpellier Cedex 05, France and Lamont-Doherty Earth Observatory of Columbia University, Palisades, New York 10964

E-mail: denis@dstu.univ-montp2.fr

Natalia Gerasimenko and Zhanna Matviischina

Paleogeography, Institute of Geography of the National Academy of Sciences of Ukraine, Volodymyrska, 44, 01034, Kyiv, Ukraine

and

George Kukla

Lamont-Doherty Earth Observatory of Columbia University, Palisades, New York 10964

Received September 22, 1999; published online October 5, 2001

The Vyazivok loess sequence from the Dnieper Plain, Ukraine, documents regional environmental changes during the late Pleistocene and Holocene. Pedological and palynological analyses and low-field magnetic susceptibility document changes from dense temperate forest during the last interglacial maximum to open, harsh, loess–steppe during the latest Pleistocene. The Vyazivok section overlies hillwash derived from a lower Pleistocene terrace and consists of two stratified soil complexes (Kaydaky and Pryluky; marine isotope stage [MIS] 5 equivalent) separated by a layer of eolian dust (Tyasmyn silt). The lower soils in both complexes formed within forest. These soils are overlain by the Uday (MIS4) and Bug (MIS2) loess units, which are separated by boreal soils of the Vytachiv (MIS3) complex. The coldest conditions within the record occurred in the youngest loess. Holocene soils cap the Bug loess. The Vyazivok section shows remarkable similarities with other classical loess sequences in western Europe, the Czech Republic, and Austria. The Kaydaky, Pryluky, and Vytachiv deposits, correlate with the PKIII, PKII, and PKI soil complexes, respectively, of the Czech Republic. The Tyasmyn and Prylyky silt layers correspond to marker horizons from central Europe.

Key Words: **loess; Ukraine; pedology; pollen; magnetic susceptibility; last climatic cycle; upper Pleistocene.**

INTRODUCTION

The rich loess records (Krokos, 1932; Veklitch, 1968, 1979, 1982, 1993; Velichko, 1973; Matviishina, 1982; Shelkoplyas *et al.*, 1986; Sirenko and Turlo, 1986; Gerasimenko, 1988a) from the Dnieper Plain, Ukraine, located in the central part of the Eurasian loess belt, provide key information for the comparison of European loess stratigraphies. The Vyazivok section (Ukrainian spelling, 49°198′N, 32°58.8′E) overlies a lower Pleistocene terrace found near the town of Lubny along the Sula River (Fig. 1). It is one of the most important late Quaternary sites found in previously glaciated areas of Ukraine (Veklitch, 1968; Veklitch *et al.*, 1984). The regional Pleistocene stratigraphy has been defined through multidisciplinary studies, including research in pedostratigraphy, pedology, mineralogy, palynology, and malacology (Veklitch, 1993). Building on previous work, we analyzed high-resolution changes in the low-field magnetic susceptibility, pedology, lithology, and pollen content of these late Pleistocene deposits to compare the Vyazivok stratigraphy with better known loess sequences of western and central Europe.

MATERIAL AND METHODS

After a careful cleaning of the section, we measured the low-field magnetic susceptibility (Fig. 2), using a portable MF2 Bartington susceptibility meter. Measurements were first taken in 1995 (Kukla) and again in 1998 (Rousseau). Both times we averaged 10 independent readings located along the bedding. Measurements were vertically displaced by 10 cm, although readings were closer near the soil boundaries. Both sets of measurements were nearly identical ($r = 0.916$), so only the most recent ones are presented.

We took new samples for pedological and palynological analyses from the base of the sequence (the Kaydaky-Pryluky soils) to refine earlier results of Veklitch *et al.* (1967, 1984). Pollen samples were prepared using 10% HCl, cold 40% HF, and 20% KOH. Disaggregation in a $Na_4P_2O_7$ solution and separation with KdI_2 and KI (specific gravity of 2.2) followed. Two hundred pollen grains were counted in most of the samples. Although shells had been described in the previous work (Veklitch *et al.*, 1967, 1984), none were recovered in the sieved materials (~10 kg taken every 10 cm). A series of undisturbed

0033-5894/01 $35.00

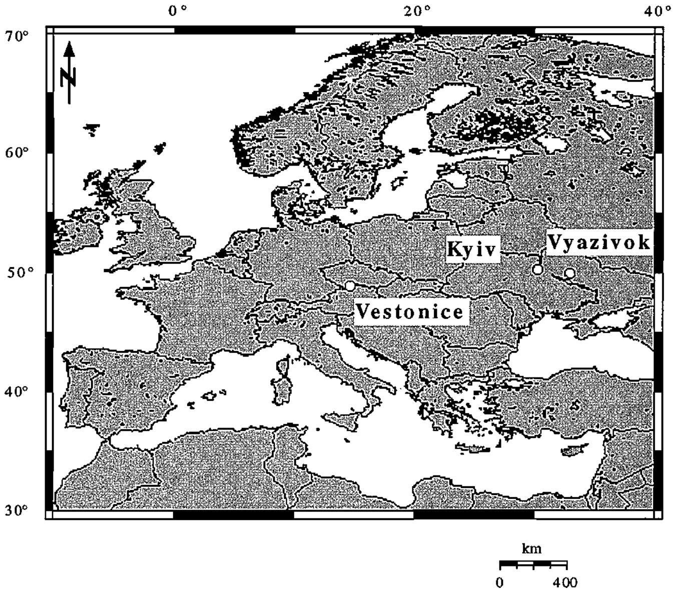

FIG. 1. Map showing the localities discussed in the text.

blocks were removed from the soil and loam horizons, and micromorphological slides, were prepared following Kubiena (1956). A standard slide was checked using the interference colors of quartz minerals.

RESULTS

Pedostratigraphy

Following the same criteria as Veklitch *et al.* (1967, 1984), who previously defined the main stratigraphic units, we identified, characterized, and named several new subunits (Fig. 2; Table 1). We did not find either the Prychornomorsky loess or the Dofinivka soil (Veklitch, 1993). The Vyazivok soil–loess sequence rests on a sandy loam that contains redeposited erratic gravel. These deposits fill a gully that was cut by glacial outwash into a till plain formed by the Dnieper glacier. This ice advance correlates with the European Saale glaciation (Veklitch, 1968; Veklitch *et al.*, 1984) and is believed to correspond to marine isotope stage (MIS) 6. The Vyazivok sequence includes the following units (Fig. 2).

The Kaydaky soil complex (kd; 9.8 to 8.7 m depth) is a gray forest soil (luvisol). The first subunit (kd_{b1}; 1.6 m thick) consists of a reddish-brown Btf, a dark brown Bth, and a transitional Al-Bt horizon. A thin, light-colored silt band (ts) with carbonate nodules and impregnation separates kd_{b1} from the Pryluky complex. Although not present in the studied sequence, Kaydaky deposits seen elsewhere at Vyazivok also include a whitish A2 horizon in the forest soil (kd_{b1}) and a meadow-chernozem soil or mollisol (kd_{b2}).

The Pryluky soil complex (pl; 8.7 to 6.1 m depth) is represented by three subunits. The lower one (pl_a) is a weakly developed meadow soil (mollisol, 0.4 m thick). Pl_b is a 0.7-m-thick brown forest soil (luvisol) with a compact prismatic structure (B horizon) overlain by a humic chernozem. The uppermost layer (pl_c; 1.4 m thick) includes a brown compact B-horizon with a prismatic structure and a thin humus-rich A1 horizon. The Pryluky silt ($Pl_{b\text{—}c}$) which separates pl_b from pl_c, is a newly described horizon. It is a ca. 10-cm-thick, light-colored, fine silt band impregnated with carbonate that shows no signs of pedogenes.

The Uday loess unit (ud; 6.1 to 5.0 m depth) is a light yellowish-brown, clayey silt with occasional manganese hydroxides and carbonate impregnations. An embryonic, slightly darker soil has been identified midway through the unit.

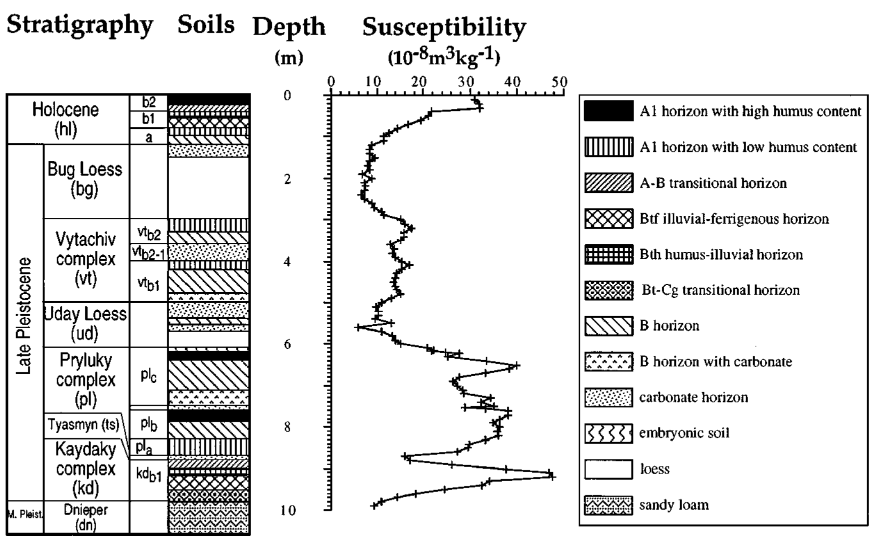

FIG. 2. Late Pleistocene and Holocene stratigraphy, soil sequence, and low-field magnetic susceptibility from the Vyazivok loess sequence. Soil complexes include materials from the initial, optimal, and final phases of pedogenesis. These soils are differentiated by indices with the basal horizon indicated by "a," the next by "b," etc. "B" soils are usually strongly expressed and correspond to the relative climatic optimum. Soils of initial and final phases "a" and "c" show signs of development under cooler climates.

TABLE 1
Quaternary Deposits for the Loess Region of the Dnieper Glaciation (Modified from Veklitch, 1993)

Stratigraphy[1]	Index	Average Thickness (m)	Lithology
H			
Holocene	h1		Gray forest soils, chernozems, meadow, swamp soils
L. P.			
Prychernomorsky loess	pr	0.3–2.0	Loess, loess-like loam, sandy loam, sand, cryoturbation features
Dofinivka soil complex	df	0.3–1.5	Weakly developed, chernozem-like, turf or brown soils
Bug loess	bg	1.0–15.0	Loess, loess-like loam, sandy loam with embryonic soils, cryoturbation features
Vytachiv soil complex	vt	0.4–2.5	Boreal brown and dark-brown soils, occasionally with thin layers of silty loess
Uday loess	ud	0.5–3.0	Loess and loess-like loam, cryoturbation features
Pryluky soil complex	pl	0.5–2.5	Boreal brown soils (p_{lc}), leached chernozems (p_{b2}), brown and gray forest soils (p_{b1})
Tyasmyn loess	ts	0.2–1.0	Loess, loess-like loam, cryoturbation features
M. I.			
Kaydaky soil complex	kd	0.5–2.5	Boreal brown soils (kdc), leached chernozens (kd_{b2}), gray and ligh-gray forest soils (kd_{b1}), hydromorphous soils (kd_a)
M. P.			
Dnieper loess and till	dn	2.0–30.0	Till, glaciofluvial sand and loam, loess with embryonic soils, cryoturbation feature

Note. [1] H = Holocene, L. P. = Late Pleistocene, M. I. = Mikulino Interglaciation, M. P. = Middle Pleistocene.

The Vytachiv soil complex (vt; 5.0 to 3.0 m depth) is composed of two weakly developed, partly decalcified soils (cambisols), vt_{b1} and vt_{b2}. Both soils include A1 and B horizons and are separated by a well-defined light-colored loess-like silty loam (vt_{b2-l}) that is 0.4 m thick.

The Bug loess (bg; 3.0 to 1.2 m depth) is a homogenous, light yellowish-brown silt with carbonate rootcasts of Poaceae. Its upper part also contains abundant carbonate concretions.

The Holocene soil complex (h1) spans the upper 1.2 m of the section. It is a gray forest soil (alfisol, luvisol) with a brown Bt horizon capped by a dark-gray humic A1 horizon.

Low-Field Magnetic Susceptibility

Variations in low-field magnetic susceptibility (MS) relate to the soil stratigraphy (Fig. 2). The basal Dnieper unit shows MS of $\sim 10 \times 10^{-8}\,m^3\,kg^{-1}$. Readings in the Bt horizon of the Kaydaky complex increase to $48 \times 10^{-8}\,m^3\,kg^{-1}$ in kd_{b1}, the highest values in the sequence. A sharp decrease occurs in the Tyasmyn silt (ts) with MS less than $16 \times 10^{-8}\,m^3\,kg^{-1}$.

The thin, humic B horizon (pl_a) of the Pryluky complex records MS between 16 and $28 \times 10^{-8}\,m^3\,kg^{-1}$. These readings are greater than those from the silt layers but less than from the B and Bt horizons higher in the sequence. Pryluky subunit pl_b, with values of $\sim 36 \times 10^{-8}\,m^3\,kg^{-1}$ does not differ significantly from subunit kb_{b1}. Pryluky subunit pl_{b-c} displays a sharp drop to $\sim 28 \times 10^{-8}\,m^3\,kg^{-1}$. The MS increases slightly above the pl_{b-c} silt, but decreases to $\sim 26 \times 10^{-8}\,m^3\,kg^{-1}$ in the lowest B horizon. Values then increase to $\sim 40 \times 10^{-8}\,m^3\,kg^{-1}$ in the upper B horizon. MS decreases to $\sim 21 \times 10^{-8}\,m^3\,kg^{-1}$ at the top of the Pryluky complex.

MS of the Uday loess is low, especially in the upper unit (minimum of $\sim 6 \times 10^{-8}\,m^3\,kg^{-1}$ in the carbonate horizon). The Vytachiv complex (range of 18 to $10 \times 10^{-8}\,m^3\,kg^{-1}$) shows lower values than in the two older soil complexes. Bug (bg) loess yields the lowest values ($\sim 6 \times 10^{-8}\,m^3\,kg^{-1}$). The Holocene soil shows an increasing trend from $\sim 11 \times 10^{-8}\,m^3\,kg^{-1}$ at the base to $\sim 32 \times 10^{-8}\,m^3\,kg^{-1}$ in the uppermost layer. The latter value approximates the MS of the Kaydaky and Pryluky soil complexes.

Pedology

The micromorphology of kd_{b1} of the Kaydaky complex indicates the horizon is poor in clay and humus, has a laminated structure within the eluvial A2 horizon, and contains numerous cutans of optically oriented clays in the illuvial B horizon. Small particles of rough, clayey humus are visible in the cutans. The kd_{b1} paleosols are comparable to the “parabraunerdes” of western Europe.

Small clayey accumulations and thin cutans of optically oriented clays and mottled gleys in the B horizon characterize the pl_{b1} soil. As in kd_{b1}, indications of leaching are well developed. The pl_{b2} soil is a humic chernozem horizon with compact microaggregates (2–3 orders) and partly coagulated plasma. The pl_c soil has gray-brownish, clay-humus plasma, loose microtexture with compact microaggregates (2–4 orders) and strongly developed pores. Accumulation of clay and humic matter and signs of leaching were observed. Thin carbonate accumulations around pores, carbonate microconcretions, and microcrystalline calcite in the plasma characterize the BC_k horizon of pl_c.

The Uday loess has been partly alterred by pedogenic processes of the overlying Vytachiv complex. The structure is relatively loose in the middle part of the loess. Dispersed forms of microcrystalline calcite in the plasma share dominance with the mineral skeleton.

The micromorphology of the Vytachiv paleosols is unlike any of the modern soils in Ukraine. The upper part of vt_{b1} consists of blocks and coagulated dark-brown microaggregates that are occasionally compacted. Grains of efflorescent feldspar indicate corrosion and *in situ* weathering. Ooidic organic-clay nodules, which have a concentric structure, microcrystalline calcite, and lublinite in the carbonate horizon, indicate fluctuations in seasonal moisture supply. This soil is somewhat similar to weakly developed, brown forest soils found today in Ukraine.

Compact blocks and clots of humus characterize the upper Vytachiv soil (vt_{b2}). In the lower and middle parts of the profile, the clay–carbonate matter is concentrated in ooidic nodules. The plasma is not uniform in color and is saturated with microcrystalline calcite.

The micromorphology of the Bug unit is typical of loess. The mass is loose, with numerous grains of silt ($d = 0.02$ to 0.07 mm) that are surrounded by carbonate–clay films. The pore network is well developed, the plasma is coagulated, and microcrystalline calcite concentrations are abundant. Concentric microortsteins and manganese hydroxide segregation were observed above the boundary with the Vytachiv paleosol.

Holocene soils have been artificially disturbed by agriculture. They show several interlayers of light-colored silt indicative of intermittent sediment accretion.

Palynology

Pollen analyses were done for the Kaydaky, Pryluky, and lower Uday units (Fig. 3). The Tyasmyn silt was palynologically sterile. The pollen data from the Vytachiv, Bug, and Holocene units are from Veklitch *et al.* (1967). Subunit kd_{b1} is dominated by arboreal pollen (AP). The AP percentages in the lower part of the subunit consist of *Pinus*, *Alnus*, *Betula*, *Picea*, and *Salix*. *Quercus*, *Ulmus*, and *Corylus* pollen appear in the upper part of the Btf horizon, and *Pinus* pollen remains abundant. Percentages of broad leaf taxa increase upward through the Bth horizon. Total AP and individual broad leaf taxa decrease in the Al-Bt horizon. In contrast, *Alnus* pollen becomes prominent, and few *Picea* grains occur.

NAP dominates the pl_a assemblage, with an abundance of Poaceae, Plantaginaceae, and Compositae pollen. *Pinus*, *Alnus*, *Quercus*, and *Tilia* pollen comprise most of the AP. High AP percentages (59–63%) and a great diversity of tree types (9–10 taxa including *Tilia*, *Quercus*, and *Carpinus*) occur in the B horizon of pl_b. However, these numbers are less than those recorded in kd_{b1}. The Al horizon of pl_b also is dominated by NAP with AP consisting primarily of *Pinus*. Contrary to the ts silt, pollen is relatively abundant in unit $pl_{b–c}$. Asteraceae, Cichoriaceae, and Poaceae pollen are prominent. AP is low and includes only *Pinus* pollen. AP percentages increase in the middle portion of pl_c, corresponding to a peak in *Pinus* pollen. Broadleaf taxa are rare. *Betula* pollen, although occurring in moderate percentages, becomes a more significant component of the assemblage. NAP prevails at the base and the top of pl_c. The highest and lowest percentages of *Artemisia* and spores, respectively, characterize the base of the soil. At the top of the subunit, mesophytic herbs dominate, especially Asteraceae, Cichoriaceae, and Plantaginaceae *Artemisia* and Poaceae pollen display moderate values.

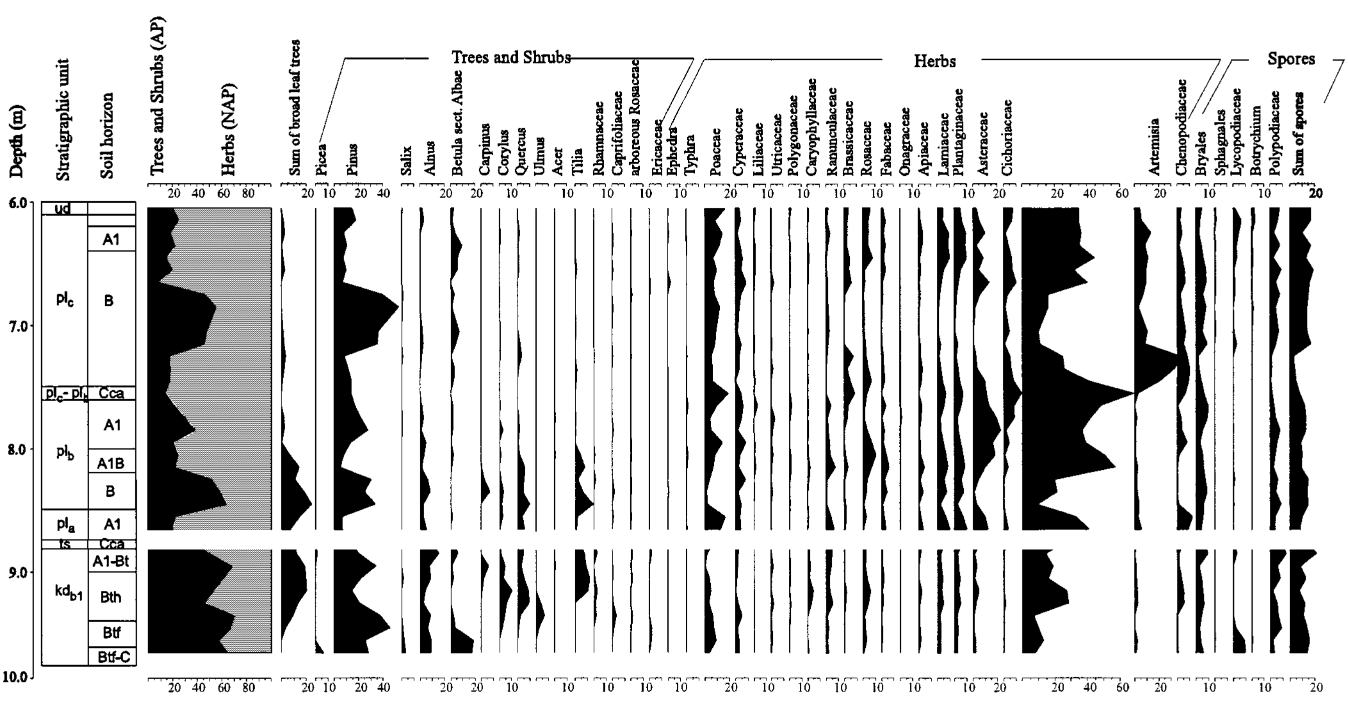

FIG. 3. Pollen diagram of the Kaydaky and Pryluky units of the Vyazivok section. All herbaceous pollen taxa with the exception of *Ephedra*, Typhaceae, Poaceae, Cyperaceae, *Artemisia*, and Chenopodiaceae are summed in the mesophytic herbs curve. Pollen and spores were taken as a total sum (100%), and 200 grains per level were typically counted. See Figure 2 for key to stratigraphic units and soils.

The Uday loess has been studied by both Veklitch *et al.* (1967; upper unit, data not shown) and ourselves (lower unit, Fig. 3). Percentages of xeric herbs (e.g., Chenopodiaceae, *Artemisia*) and Poaceae pollen peak in the upper part of the deposit although the pollen counts are low. The lowermost (6.0–6.1 m) layer of the loess contains sufficient numbers of pollen and spores for interpretation and shows a higher percentage of AP and spores than the upper Uday loess. *Pinus* with lesser amounts of *Alnus* and *Betula* pollen represent the arboreal elements.

In the lower soil of the Vytachiv complex, AP dominates and shows an increasing trend from the bottom to the top of the soil (Veklitch *et al.*, 1967). *Pinus*, *Picea*, *Corylus*, *Salix*, and *Alnus* pollen dominate in the B horizon, and *Quercus* and *Ulmus* pollen characterize the A horizon. Pollen of Poaceae, mesophytic herbs (e.g., Fabaceae, Rosaceae, Cyperaceae), Chenopodiaceae, and *Artemisia* are present. A decrease in AP characterizes vt_{b2-1}. The second soil 'vt_{b2}' includes moderate pollen frequencies of broadleaf trees (e.g., *Quercus*, *Ulmus*, and *Tilia*), but the AP percentages are lower than in the basal unit.

The Bug loess is extremely poor in pollen. Only a few grains of Chenopodiaceae, *Artemisia*, and Poaceae were observed. In contrast, *Pinus*, *Quercus*, *Ulmus*, *Carpinus*, and *Corylus* dominate the Holocene pollen assemblage of the B horizon (Veklitch *et al.*, 1967). The pollen spectrum from the base of the unit shows small number of AP, limited principally to *Pinus* and *Quercus*.

CHRONOLOGY

The chronology of the Vyazivok sequence has been defined by previous studies. Amino-acid ratios of mollusk shells found within Dnieper deposits indicate they are of MIS6 age (Oches *et al.*, 2000). Radiocarbon dates from the top of the Bug loess range from 10,000 to 14,000 ^{14}C yr B.P. (Veklitch, 1993). These dates, however, may be too young, because data from other European loess sequences show that loess sedimentation typically stopped at ∼15, 000 ^{14}C yr B.P. (cf. Rousseau *et al.*, 1998b; Antoine *et al.*, 1999, 2001). Thermoluminescence ages from the Uday loess range from 60,000 to 70,000 yr (Shelkoplyas *et al.*, 1986).

TABLE 2
Select Ages from Dolni Vestonice

Age Key[a]	Age (^{14}C yr B.P.)	Method	References
D1	29,000 ± 200	^{14}C charcoal	Klima *et al.* (1962)
	28,300 ± 300	^{14}C soil	Klima *et al.* (1962)
D2	> 34, 000	^{14}C loess	Klima *et al.* (1962)
D3	> 51, 800	^{14}C soil	Klima *et al.* (1962)
	51,100 ± 1400	TL and IRSL	Musson and Wintle (1994)
D4	60,800 ± 8000	TL and IRSL	Frechen *et al.* (1999)
	81,300 ± 7100	TL and IRSL	Frechen *et al.* (1999)
D5	69,800 ± 8000	TL and IRSL	Zöller *et al.* (1994)
	63,700 ± 1500	TL and IRSL	Musson and Wintle (1994)
D6	75,300 ± 11, 600	TL and IRSL	Frechen *et al.* (1999)
	61,900 ± 5400	TL and IRSL	Frechen *et al.* (1999)
D7	> 50,000	^{14}C soil	Klima *et al.* (1962)
	74,200 ± 3300	TL and IRSL	Musson and Wintle (1994)
D8	84,900 ± 600	TL and IRSL	Musson and Wintle (1994)
D9	116,600 ± 11,300	TL and IRSL	Frechen *et al.* (1999)
	132,900 ± 11,500	TL and IRSL	Frechen *et al.* (1999)

[a] See Fig. 5.

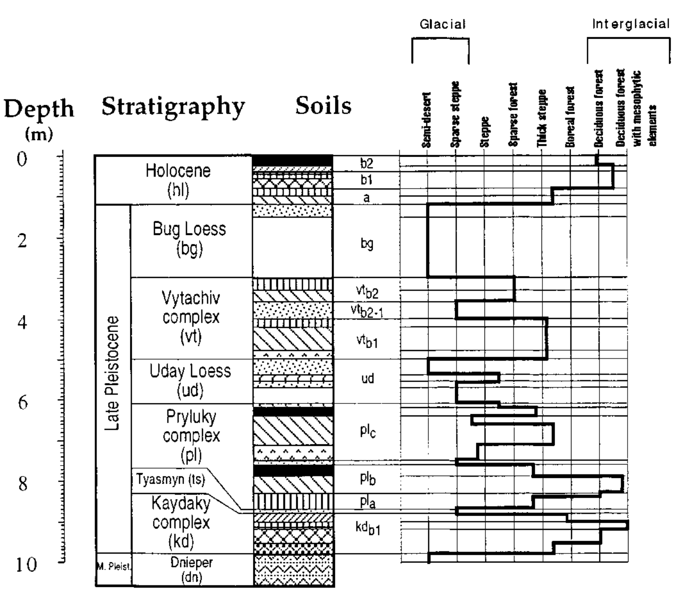

FIG. 4. Correlation of the late Pleistocene Vyazivok sequence, the Vestonice (Czech Republic) loess section, and marine isotope stages. Ages (D1–D9) are given in Table 2. The open arrows indicate the location of the marker horizons identified by Kukla (Kukla and Cilek, 1996).

A major change in sedimentology occurs at the Pryluky-Uday boundary, with soils prevailing beneath this boundary and major loess deposits occurring above it. This shift is contemporaneous with the MIS5/MIS4 transition, approximately 70,000 to 75,000 yr ago (Kukla and Briskin, 1983; Martinson *et al.*, 1987). A similar boundary has been documented in the loess sequences of western (Antoine *et al.*, 2000, 2001) and central Europe (Rousseau and Kukla, 2000; Rousseau *et al.*, 1998a). Thus, we infer that the Pryluky-Kaydaky soil complexes formed during MIS5, whereas the Uday, Vytachiv, and Bug units correspond to MIS4, MIS3, and MIS2, respectively (Fig. 4).

INTERPRETATIONS

Paleoenvironments of the Vyazivok Region

The data from the Vyazivok section indicate the following late Pleistocene environmental changes (Fig. 4). The earliest record of interglacial vegetation documents the presence of *Pinus-Betula* forest, with a minor component of *Picea*. *Pinus* forest, which included the occasional broadleaf tree, was established next. A succession of deciduous forests, including *Ulmus-Quercus*, *Quercus-Corylus*, *Tilia-Quercus*, and *Quercus-Carpinus* then occupied the landscape. *Pinus*–*Picea*–broadleaf communities occurred in the area by late Kaydaky times. This vegetational history is similar to that of the Mikulino interglaciation, the eastern European equivalent of the Eemian (Grichuk,

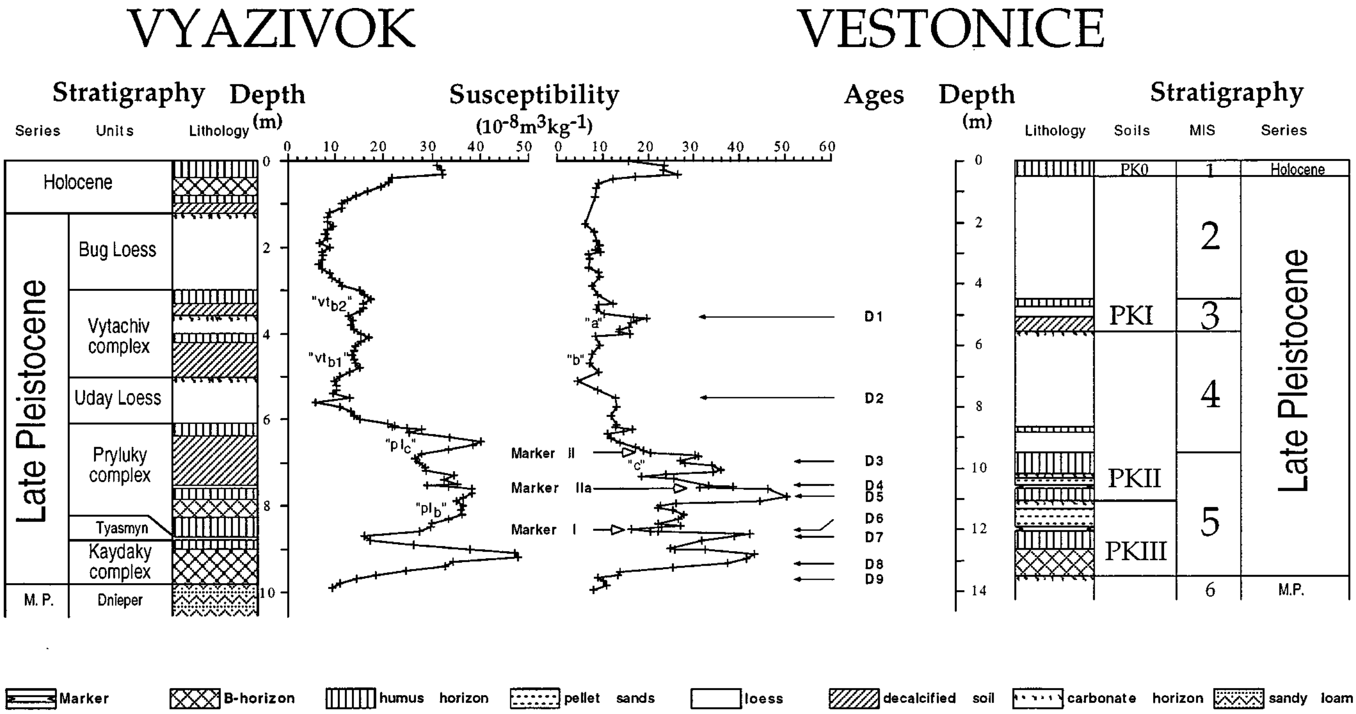

FIG. 5. Stratigraphy, soils, and paleoenvironments of the Vyazivok section. Environmental reconstructions are based on soil and pollen analyses. See Fig. 2 for key to stratigraphic units and soils. See Table 2 for Dages.

1972). Comparable forest successions were described for portions of the Kaydaky-Pryluky complexes (correlative to the Mezin complex in the Russian stratigraphy) in other sites of the middle Dnieper region (Gerasimenko, 1988b; Bolikhovskaya, 1995). The presence of *Carpinus* pollen (upper levels only) and the morphology of the kd_{b1} soil indicate higher precipitation and a moister climate than the modern.

The Vyazivok Tyasmyn layer, with its low magnetic susceptibility and lack of pollen, is similar to Czech marker horizons believed to be deposited by continental dust storms. Pollen data of Tyasmyn deposits from other sections in the middle Dnieper region indicate cold, sparse steppe (Sirenko and Turlo, 1986).

Steppe was present during the initial stages of the Pryluky complex but was replaced by a deciduous forest, as indicated by the high pollen percentages of broadleaf taxa. A temperate climate predominated during the formation of the B horizon in pl_b. A decrease in the percentages of deciduous taxa at the Al horizon possibly indicates a cooling and return to steppic vegetation. The general decrease in AP suggests increased aridity, an interpretation supported by the pedological data. The dry episode is particularly marked in the pl_c–pl_b transition, which consists of silt deposited in an open grassland. Dry climate continued during pl_c times as suggested by increased percentages of Poaceae-*Artemisia* pollen. A spread of *Pinus* boreal fores is associated with the middle part of the B horizon, whereas a strong reduction in forest is recorded in the upper part of this horizon. The Al horizon was formed in steppe with small groves of *Betula*. The decrease of humus accumulation at the top of pl_c implies a decline in the herbaceous component of the vegetation. The pollen data suggest a slight increase in *Pinus* populations at this time.

Sparse steppe occurred at the beginning of the Uday loess and probably during the formation of the embryonic soil. The data imply that the climate was wetter than during the second half of the Uday unit, when a cold semidesert was present.

The most significant climatic change in the Vyazivok section is recorded in the Vytachiv complex. Open *Pinus* forest, which included a few broadleaf trees, established during vt_{b1} times. The boreal forest was replaced by sparse steppe as indicated by the loess-like loam of vt_{b2-1}. The presence of a more productive forest–steppe mosaic is indicated by the upper soil of the vt_{b2} complex. Broadleaf trees perhaps increased on the landscape, but *Pinus* likely remained the most common tree.

A dramatic environmental change occurred with the deposition of the Bug loess. Compared with the Uday loess, data from this younger loess unit indicate a harsher, more continental climate and the coldest conditions within the section. The Bug reconstructions agree with other interpretations of the last glacial maximum Frenzel, 1964; Lozek, 1969; Rousseau, 1987, 1991; Rousseau *et al.*, 1998b; Antoine *et al.*, 1999). The Holocene soil indicates a return to a temperate climate, with a shift from sparse herb-dominated vegetation to boreal forest and finally to a deciduous forest with *Quercus*, *Ulmus*, *Carpinus*, and *Corylus*.

Comparison with Other European Records

Paleoenvironmental data from the Vyazivok site are similar to those of other late Pleistocene deposits preserved elsewhere in Europe (Antoine *et al.*, 1999; Rousseau *et al.*, 1998b; Kukla and Cilek, 1996).

The MS and radiometric dates particularly indicate that the stratigraphy and chronology of the Vyazivok section closely resembles the classical sequence from Vestonice (Unter Wisternitz) in the Czech Republic and from Stillfried in Austria (Fig. 1). Czech pedocomplexes PKIII and PKII (Klima *et al.*, 1962; Frenzel, 1964; Kukla, 1975, 1977; Musson and Wintle, 1994) clearly correspond to the Kaydaky and Pryluky soil complexes (Fig. 5). PKIII has a forest B horizon capped by a silt interval, a succession similar to that of the Kaydaky and Tyasmyn units at Vyazivok. PKIII at Vestonice and Stillfried is characterized by temperate snail fauna and the last pre-Holocene presence of deciduous or mixed forests (Frenzel, 1964; Lozek, 1964, 1969; Smolikova, 1982; Urban, 1984). The Bt horizon of the kd_{bl} soil contains a similar vegetation succession and one that is characteristic of the last interglaciation in western and central Europe. The Pryluky pedocomplex shows two soil subunits separated by a silt (pl_{c-b}), a pattern similar to that encompassed in PKII and the intervening "marker IIa" (Kukla and Cilek, 1996). The main difference between the soil complexes of the three regions is the occurrence of a B horizon in the Ukrainian sequence, which suggests a relatively moist climate in eastern Europe at this time. Dust storm layers, called *markers* in the Czech Republic (Kukla, 1961; Klima *et al.*, 1962) and western European systems (Rousseau *et al.*, 1998b), appear to correspond to the two silt layers within the Kaydaky and Pryluky complexes.

The remarkable similarity of the Vyazivok and the Vestonice sections brings into question the absolute dating of the upper part of the late Pleistocene stratigraphic scheme developed for Ukraine (Table 1). There is little doubt that both sequences are essentially continuous and have a last interglacial soil at the base. At both sites, weakly developed soil complexes separate the two major loess units. The Vytachiv pedocomplex should date to ~60,000 yr ago, according to the Ukrainian stratigraphy and TL dates. The overlying loess is thought to be ~58,000 yr and ~70,000 yr old. The pedocomplex PKI, with its weakly developed arctic brownearth, contains hearths from Gravettian settlements (Klima *et al.*, 1962; Kukla, 1975, 1977). This charcoal has been dated between 27,660 and 29,000 yr ^{14}C B.P. Thus, the PKI soil in Vestonice is ~29,000 yr old and is overlain by a younger loess. Obviously, the TL dates in the Ukrainian stratigraphic scheme are too old, especially when considering other TL ages from the Vytachiv soils, which range from 30,000 to 45,000 yr B.P. (Shelkoplyas *et al.*, 1986).

ACKNOWLEDGMENTS

This work has been supported by CNRS, National Academy of Sciences of Ukraine, and the U.S. National Research Council of the Academy of Sciences. Thanks to Sergei Ganaga, Victor Serben, and Andrei Kasyanenko for their assistance in the field. Thanks also to William McCoy and an anonymous reviewer for useful comments that improved the manuscript and to Joyce Gavin and Patricia Anderson for editorial help. This is Institut des Sciences de l'Evolution de Montpellier contribution ISEM 2000-113 and the Lamont-Doherty Earth Observatory of Columbia University contribution 6129.

REFERENCES

Antoine, P., Rousseau, D. D., Lautridou, J. P., and Hatté, C. (1999). Last interglacial-glacial climatic cycle in loess-paleosol successions of north-western France. *Boreas* **28,** 551–563.

Antoine, P., Rousseau, D. D., Zöller, L., Lang, A., Munaut, A. V., Hatté, C., and Fontugne, M. (2001). High-resolution record of the last interglacial-glacial cycle in the loess palaeosol sequences of Nussloch (Rhine Valley-Germany). *Quaternary International* **76/77,** 211–229.

Bolikhovskaya, N. S. (1995). "Evolutsia lessovo-pochvennoy formatsii Severnoy Evrazii (Evolution of loess-soil formation of Northern Eurasia)." Moscow Univ. Press, Moscow.

Frechen, M., Zander, A., Cilek, V., and Lozek, V. (1999). Loess chronology of the last interglacial/glacial cycle in Bohemia and Moravia, Czech Republic. *Quaternary Science Reviews* **18,** 1467–1493.

Frenzel, B. (1964). Zur Pollenanalyse von Lössen. *Eiszeitalter und Gegenwart* **15,** 5–39.

Gerasimenko, N. (1988a). "Paleolandshafty pravoberezhya Kievskogo Pridneprovya v Pleistotsene (Paleoenvironment of the Kyiv Dnieper Region in the Pleistocene)." VINITI, Moscow.

Gerasimenko, N. (1988b). "Dynamika roslynnogo pokryvu Kyivs'koi lessovoi rivnyny u piznomy pleistotseni (Vegetation dynamics of the Kyiv Loess Plain in the Late Pleistocene." *Ukrainsky botanichny zhurnal* **45,** 43–48. [In Russian]

Grichuk, V. P. (1972). "Osnovnye etapy razvitia rastitel'nosti yugo-zapada Russkoy ravniny v pozdnem Pleistotsene (Main Stages of Vegetational History of the South-west of the Russian Plain during the Late Pleistocene)." *In* "Palinologia Pleistotsena" (V. P. Grichuk, Ed.), pp. 9–53. Nauka, Moscow. [In Russian]

Klima, B., Kukla, J., Lozek, V., and DeVries, H. (1962). Stratigraphie des Pleistozäns und Alter des palaeolithischen Rastplatzes in der Ziegelei von Dolni Vestonice (Unter-Wisternitz). *Anthropozoikum* **11,** 93–145.

Kubiena, W. L. (1956). Zur Micromorphologie, Systematik und Entwicklung der rezenten und fossilen Lossboden. *Eiszeitalter und Gegenwart* **7,** 102–112.

Kukla, J. (1961). Lithologische Leithorizonte der tschechoslowakischen Lössprofile. *Vestnik Ustredniho Ustava Geologickeho* **XXXVI,** 369–372.

Kukla, G. (1975). Loess stratigraphy of Central Europe. *In* "After the Australopithecines" (K. W. Butzer and G. L. Isaac, Eds.), pp. 99–188. Mouton, The Hague.

Kukla, G. (1977). Pleistocene land-sea correlations. 1. Europe. *Earth-Science Review* **13,** 307–374.

Kukla, G., and Briskin, M. (1983). The age of the 4/5 isotopic stage boundary on land and in the oceans. *Palaeogeography Palaeoclimatology, Palaeoecology* **42,** 35–45.

Kukla, G., and Cilek, V. (1996). Plio-Pleistocene megacycle: Record of climate and tectonics. *Palaeogeography, Palaeoclimatology, Palaeoecology* **120,** 171–194.

Krokos, V. I. (1932). Instruktsia do vyvchennya chetvertynnyh pokladiv Ukrainy (Directions on studies of Quaternary deposits in Ukraine). *Chetvertynny Period* **3,** 17–55. [In Russian]

Lozek, V. (1964). Mittel- und JungPleistozäne Löss-serien in der Tschechoslowakei und ihre Bedeutung für die Löss-stratigraphie Mitteleuropas. *VI INQUA Congress Warsaw 1961* **4,** 525–549.

Lozek, V. (1969). Le loess et les formations assimilées: Corrélation entre l'Europe centrale et la France par la faune de mollusques. In "Études sur le Quaternaire dans le monde," pp. 597–606. VIII Congrès INQUA, Paris. [In French]

Martinson, D. G., Pisias, N. G., Hays, J. D., Imbrie, J., Moore, T. C., and Shackleton, N. J. (1987). Age dating and the orbital theory of the ice ages: Development of a high-resolution 0 to 300,000 year chronostratigraphy. *Quaternary Research* **27,** 1–29.

Matviishina, Z. (1982). "Micromorphologia pleistocenovych pochv Ukrainy" (Micromorphology of the Pleistocene Soils of Ukraine). Naukova dumka, Kiev. [In Russian]

Musson, F. M., and Wintle, A. G. (1994). Luminescence dating of the loess profile at Dolni Vestonice, Czech Republic. *Quaternary Science Reviews* **13,** 411–416.

Oches, E. A., McCoy, W. D., and Gneisser, D. N. (2000). Aminostratigraphic correlation of loess/paleosol sequences across Europe. *In* "Perspectives in Amino Acid and Protein Geochemistry" (G. Goodfriend, M. Collins, M. Fogel, S. Macko, and J. F. Wehmiller, Eds.), pp. 331–348. Oxford Univ. Press, New York.

Rousseau, D. D. (1987). Paleoclimatology of the Achenheim series (middle and upper Pleistocene, Alsace, France). A malacological analysis. *Palaeogeography, Palaeoclimatology, Palaeoecology* **59,** 293–314.

Rousseau, D. D. (1991). Climatic transfer function from Quaternary molluscs in European loess deposits. *Quaternary Research* **36,** 195–209.

Rousseau, D. D., and Kukla, G. (2000). Abrupt paleomonsoon decline at the S1/L1 boundary in China? *Global and Planetary Change* **26,** 189–198.

Rousseau, D. D., Kukla, G., Zöller, L., and Hradilova, J. (1998a). Early Weichselian dust storm layer at Achenheim in Alsace, France. *Boreas* **27,** 200–207.

Rousseau, D. D., Zöller, L., and Valet, J. P. (1998b). Climatic variations in the Upper Pleistocene loess sequence at Achenheim (Alsace, France). Analysis of the magnetic susceptibility and thermoluminescence chronology. *Quaternary Research* **49,** 255–263.

Shelkoplyas, V. N., Gozhik, P. F., Khristoforova, T. F., Matsuy, V. M., Chugunny, Y. G., Palatnaya, N. N., Shevchenko, A. I., Morozov, G. V., and Lysenko, O. B. (1986). "Antropogenovye otlozhenia Ukrainy" (Quaternary Deposits of Ukraine). Naukova dumka, Kiev. [In Russian]

Sirenko, N. A., and Turlo, S. I. (1986). "Razvitie pochv i rastitel'nosti Ukrainy v pliotsene i pleistocene." (Evolution of Soils and Vegetation in Ukraine during the Pliocene and Pleistocene). Naukova dumka, Kiev. [In Russian]

Smolikova, L. (1982). Fossilni pudy ve sprasovych seriich (Fossil soils in loess series). Kvarter Brnenske kotliny. Stranska skala IV. *Studia Geographica* **80.**

Urban, B. (1984). Palynology of central European loess-soil sequences. *In* "Lithology and Stratigraphy of Loess and Paleosols" (M. Pecsi, Ed.), pp. 229–248. Hungarian Academy of Sciences, Budapest.

Veklitch, M. F. (1968). "Stratigrafia lessovoy formatsii Ukrainy i sosednih stran" (Stratigraphy of Loess Series of Ukraine and Adjacent Areas). Naukova dumka, Kiev. [In Russian]

Veklitch, M. F. (1979). Pleistocene loesses and fossil soils of the Ukraine. *Acta Geologica Academiae Scientiarum Hungaricae* **22,** 35–62.

Veklitch, M. F. (1982). "Paleoetapnost' i stratotipy pochvennyh formatsiy Ukrainy" (Paleogeographical Stages and Stratotypes of Soil Formations of Ukraine). Naukova dumka, Kiev. [In Russian]

Veklitch, M. F., Ed. (1993). "Stratigraficheskaya shema chetvertichnyh otlozheniy Ukrainy" (Stratigraphical Scheme of Quaternary Deposits of Ukraine). State Committee for Geology of Ukraine, Kiev. [In Russian]

Veklitch, M. F., Artyushenko, A. T., Sirenko, N. A., Dubnyak, V. A., Mel'nichuk, I. V., and Parishkura, S. I. (1967). "Opornye geologicheskie razrezy antropogena Ukrainy" (Key Sections of the Anthropogene of Ukraine). Naukova dumka, Kiev. [In Russian]

Veklitch, M. F., Sirenko, N. A., Volkov, N. G., Shovkoplyas, I. G., Dubnyak, V. A., Korniets, N. L., Lavrushin, Y. A., Matviishina, Z. N., Mel'nichuk, I. V., Nagirhy, V. N., Peredery, V. I., Solovitsky, V. N., Turlo, S. I., Chugunny, Y. G., Barshchevsky, N. E., Vozgrin, B. D., Gerasimenko, N. P., Gladkikh, M. I., and Kolomiets, G. D. (1984). Quaternary geology of the Dnieper area. *International Geological Congress*, **XXVII Session,** 64–81.

Velichko, A. A. (1973). "Prirodny protses v pleistotsene" (Nature Evolution Processes during the Pleistocene). Moscow, Nauka. [In Russian]

Zöller, L., Oches, E. A., and McCoy, W. (1994). Towards a revised chronostratigraphy of loess in Austria with respect to key sections in the Czech Republic and in Hungary. *Quaternary Geochronology* **13,** 465–472.