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In memoriam MÁRTON PÉCSI

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Paleoenvironments and climatostratigraphy of the loess–paleosol formation of Northern Eurasia

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Abstract

This paper is a summary of some chapters of the author's book – N.S. Bolikhovskaya: The Evolution of Loess-Paleosol Formation of Northern Eurasia. Moscow. Moscow State University Publishing House. 1995. 270 pp. Illustrated. (Reviewers: Prof. A.A.Velichko and Prof. V.N. Konischev), – which discusses problems of paleogeography, chronostratigraphy and genesis of loess and fossil soils.

The results of a multi-member chronostratigraphic subdivision of the loess-paleosol formation (LPF) of the Russian Plain are presented. A correlation of basic paleogeographical events of the loess areas in the Pleistocene are assessed. Landscape and climatic conditions of the epochs of the loess-paleosol formations in the East European, West European and Central Asian loess provinces are characterised. It was defined that the Matuyama-Brunhes paleomagnetic inversion is confined to the base of the Gremyach'e = Cromer II = Westerhoven interglacial sediments. Brunhes normal polarity epoch contains 8 interglacials: Gremyach'e = Westerhoven, Semiluki = Rosmalen, Muchkap = Voigtstedt = Noordbergum, Likhvin *s.str.* = Holstein, Chekalin = Kamenka = Domnitz, Cherepet' = Romny. Mikulino = Eem, Holocene and dividing them 7 glacials: Devitsa = Glacial B, Don = Glacial C. Oka = Elster, Kaluga = Borisoglebsk, Zhizdra = Orchik, Dnieper = Saale, Valdai = Weichsel. For the first time detailed reconstructions of phytocoenotic and climatic successions of the main stages. i.e. 8 interglacials and 7 glacials (including 9 interstadials and 10 stadials during Valdai = Weichsel) of the loess-paleosol formation and another sediments of the Russian Plain, various glacial-periglacial and extraglacial regions have been identified.

Introduction

When considering results of more than 160 years of investigations into loesses and interbedded fossil soils, it should be admitted that many problems related to their origin, stratigraphy, and correlation are still debated, as are environmental and climatic conditions of loess formation. The most controversial items are the genesis of loess, as well as its specific property of collapsibility, age and correlation of paleosols and loess horizons. and paleoenvironments having existed during loess formation.

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The principal method applied to these studies was the palynological approach. It permits to characterise paleoenvironments of all the stages, including loess formation, and not only those of soil formation. In this way, a whole sequence of changes in flora, vegetation, and climate can be traced within each stage of the evolution of the loess-paleosol formation (LPF).

The first attempts at palynological studies of loess and fossil soils of Northern Eurasia were made in the 1930s by V.N. Sukachev, Z.K. Dolgaya (1937), and V.P. Grichuk (1940). Later on, the studies were stopped and resumed only in the 1950s by E.T. Lomayeva. Since the 1960s a number of specialists have been engaged continuously in research on the spore and pollen of LPF (V.P. Grichuk, B. Frenzel, S.I. Parishkura-Turlo, A.T. Artyushenko, G.A. Pashkevich, N.S. Bolikhovskaya, Z.P. Gubonina, R.E. Giterman, M.M. Pakhomov, E.E. Gurtovaya, L.G. Bezus'ko, B. Urban, N.P. Gerasimenko, E.M. Malaeva, and many others). Detailed palynological studies have been conducted on loess-paleosol series of different age, on the layer-by-layer basis, (see Bolikhovskaya 1975, 1981, 1982, 1984, and others; Pashkevich 1977, Pakhomov 1983). The results including other published palynological data on LPF (summarised by the author) revealed a prevailing misconcept that loesses and loess-like deposits were formed under conditions of glacial climate exclusively, while fossil soils were products of interglacial and interstadial environments. To substantiate the conclusion, it was necessary to carry out a detailed paleobotanical analysis of the most representative sequences in loess regions, which were studied using an integrated approach.

Problems of paleogeography of the loess-paleosol formation

An overview of extensive literature on the loess genesis in Northern Eurasia shows that the cornerstone in loess formation theory is an assumption that loess originates as a result of transformation of the initial (aleuritic = loessial) fine-grained material by hypergenic processes under subaerial conditions; the material itself may be deposited by different agents (wind, slope wash, perennial streams, glacial floods, etc.). The most complicated problem of cardinal importance seems to reconstruct the climatic and environmental conditions under which the fine material was transformed into loess by hypergenic processes: it is equally important to date the loess-paleosol formation. Since the late 1960s, the author conducted palynological research on main constituents of the LPF, that is loess and fossil soils, as well as on the Late Cenozoic sediments of other genesis (glacial, alluvial, lacustrine, etc.) exposed in key sections of different loess regions; the sediments are generally in paragenetic association with loess.

The history of the LPF studies illustrates well a diversity of opinions regarding climatic and environmental conditions of the loess and paleosol formation. There is an extensive literature on the LPF of the Russian Plain. A.I. Nabokikh (1915) stated that loess could have been formed both under glacial climate (cold and dry, or cold and moderately humid) and during drier intervals of interglacials. Similar views have been advocated by I.P. Gerasimov (1939). V.D. Laskarev (1919) and G.F. Mirchink (1928) placed loess into interglacial intervals. A conclusion by D.N. Sobolev (1924) that loess (synchronous to morainic horizon) was formed in the periglacial zone at the time of the glacial maximum has been accepted and elaborated by a majority of researchers; V.I. Krokos, A.I. Moskvitin and their followers associate loess horizons with glacial epochs and attribute soils to warm intervals. The sensor character of many loess properties has brought many experts (K.I. Lukashev 1961; N.I. Kriger 1965; K.K. Markov *et al.* 1965) to a conclusion that loess and paleosol are mutually exclusive notions, because soil formation leads to degradation of properties of the underlying loess. This conclusion which is justified from lithological and geochemical viewpoints has also served as a basis for opposing loess and fossil soil horizons while solving problems of genesis, paleogeography and chronostratigraphy of the loess.

An analysis of the currently dominating schemes of the LPF chronostratigraphy and correlation on the East European platform (Velichko *et al.* 1984; Veklich *et al.* 1984) as well as a consideration of some regional schemes (Bogutsky 1975; Gozhik *et al.* 1984; Krasnenkov *et al.* 1984; Zarrina and Krasnov 1985; Shelkoplyas *et al.* 1986), together with paleogeographical data they are based on, have elucidated the most essential points of disagreement. They are the number of stratigraphically significant horizons of loess and paleosols, and reconstructions of types of the Middle and Late Pleistocene pedogenesis. Different as their views on the LPF stratigraphy and paleogeography may be, the authors of the mentioned stratigraphical schemes however are unanimous in the crucial point, that is in position of LPF horizons relative to climatic rhythms of different order. They consider the loesses as having formed under glacial climate, and the fossil soils related to interglacial and interstadial warming. The question is not so simple, however, when viewed from the palynological standpoint.

Regional aspects of the palynoindication of the loess-paleosol formation

The development of LPF within the *East European loess province* has been closely related to the ice sheet dynamics. An overwhelming majority of the LPF sections (not only those in Northern Eurasia, but all over the world) studied by the pollen method is located in the south-western sector of this province. Many of the sections have been characterised only by fragmentary pollen spectra which does not allow an unambiguous interpretation; therefore, they have been hardly mentioned in discussions of the LPF paleogeography, stratigraphy and correlation. When studied in detail, taking advantage of new data, the sections provided a new insight into the main issues related to the palynoindication of the LPF.

A.T. Artyushenko, S.I. Parishkura-Turlo, S.I. Medyanik, and other specialists (see publications of 1970 to 1992; Sirenko and Turlo 1986) noted some general features typical of the glacial epochs. Of them it should be mentioned the lack of pollen and spores of Arctic-Alpine and Arctic-Boreal plants in horizons dated to the glacial time, such as Priazovye, Tiligul, Tyasmin and others correlated with them in Ukraine and Moldova; high percentage of broad-leaved species pollen in some instances; rather rare localities with microtherms included in the Sula and Dnieper loessial palynofloras, while thermophilous and cryophilous elements are often found together and they show similar degree of preservation. Based on the above evidence the following vegetation units could be reconstructed during the glacial epochs: 1) periglacial forest steppes and steppes, locally with intrazonal broad-leaved forests; 2) steppes similar to the recent steppe communities in the south of the Russian Plain; 3) steppes and forest steppes, locally with pine-birch forests along rivers and in ravines. The latter included little admixture of broad-leaved species and cryophytes (*Betula nana, B. fruticosa, Alnaster fruticosus*) in the shrub level. A detailed analysis of such materials together with palynologic evidence of fully developed soils formed during glacial stages (see G.A. Pashkevich. N.S. Bolikhovskaya and others) suggest that some of loess horizons in Ukraine and Moldova belong to interglacials. It seems necessary to distinguish stenoperiglacial and extraglacial types of vegetation within the vast periglacial zone which existed during glacial stages of the LPF development in the Russian Plain.

Reconstructions of vegetation, climate, paleopedogenesis, compared with data on paleomagnetism and other materials, along with the analysis of geographical groups of genera in interglacial dendrofloras have led to the conclusion that the Shirokino stage in the LPF development on the Ukrainian territory (marked by the dominance of forest steppes in coastal regions of the Black and Azov seas and in the Donets Lowland) corresponded to the time of formation of the loess-paleosol series attributed to the complex Ilyinka *s.l.* interval recognised in the central regions of the Russian Plain. The Martonosha warm stage is correlated with the Muchkap interglacial of the central and southern regions of European Russia. This correlation is based on a number of indicators, such as on a wide distribution of mixed forests dominated by thermophilous and hydrophilous species almost all over the territory of Ukraine, predominance of *Taxodium, Podocarpus, Juglans, Pterocarya, Carya, Liquidambar,* etc. in the Neogene relict dendroflora (see A.T. Artyushenko. S.I. Turlo-Parishkura, and others), increased hydromorphism of the prevailing brown, lessivated and other forest soils of the Martonosha stage (see M.F. Veklich, N.A. Sirenko, J.N. Matviishina). From this interval onward, there had been a progressive increase in climatic continentality which reached its maximum at the Late Valdai time of the loess formation. The Lubny stage of the LPF development in Ukraine is correlated with the Likhvin *s.str.* interglacial. It is with less confidence that the early Zavadovka stages of pedogenesis can be attributed to the Chekalin (= Kamenka) interglacial, and soils of the late Zavadovka stages to the Cherepet' (= Romny) interglacial. There is no formation indicative of glacial climate between the Priluki and Kaidaki soils; on this ground, the period of their formation may be considered as a single interglacial rhythm with successional changes and the flora typical of the Mikulino thermochron.

The LPF of the *West European loess province* reflects a landscape evolution influenced by both ice sheets and mountain glaciers. Chronostratigraphy and reconstructions of environments of loess-paleosol formation in this region are primarily based on lithological, paleopedological, paleofaunistic, paleomagnetic data, radiocarbon and thermoluminescent dating (Pécsi 1966, 1993; Fink 1969; Haase *et al.* 1969, Smolíkova 1969; Maruszczak 1970; Somme 1977; Morozova 1981; Lautridou *et al.* 1982; Vaškovska 1985; Maruszczak 1986; Minkov *et al.* 1986; Lebret and Lautridou 1991; Sajgalik 1991 and many others), while paleobotanic evidence is much sparser. A major contribution to understanding of the LPF paleogeography and stratigraphy has been made by M. Pécsi; his monograph (1993) summarizes analytical data and reconstructions of environmental and climatic conditions of the loess and paleosol formation in Eurasia as a whole, with a special reference to Hungary.

It was B. Frenzel (1964) who laid methodical foundations for palynological studies of the loess-paleosol series in Western Europe. He developed a special technique for pollen and spores extraction from loess deposits and was the first to obtain 8 complete palynospectra for the Oberfellabrunne and Stillfried sections in the Vienna basin. The data thus obtained suggest that the Eemian interglacial forest steppes were characteristic not only of the time of the Fellabrunne pedocomplex formation but (in our opinion) also of the underlying loess. The expansion of periglacial steppes and forest steppes marked the Early Wurmian stage of initial pedogenesis. In the extraglacial (similar to interglacial) forest steppes that interval corresponds to the time when the Stillfried B pedocomplex (its studied part) and the basal part of the overlying loess were formed.

Of considerable importance for the palynology of West European LPF are the works by B. Urban (1984). She analysed horizons in a number of sections, such as Stillfried, Dolní Vestonice, Paks and Mende. The Paks section has also been studied by G.A. Pashkevich (1979) and by the author. Palynological studies on two additional sections: Lopatki in Poland and Vetovo in Bulgaria (Bolikhovskaya, 1995c) are under way. J. Heim published results of palynological studies of the Achenheim I pedocomplex from the section of the same name in Alsace (Heim *et al.* 1982; Somme *et al.* 1986). Besides, loess and paleosol horizons were characterised partially when cultural layers of Mousterian and Late Paleolithic sites were studied palynologically in Germany, Belgium, France and elsewhere (Leroi-Gourhan 1977; Renault-Miskovsky and Leroi-Gourhan 1981). As evidenced by the above facts, a majority of palynological materials from the West European LPF sections refer to the Late Pleistocene.

It should be noted that many researchers of the LPF in Western Europe (as well as those who studied other regions of Northern Eurasia) ascribe all the Wurmian fossil soils and pedosediments to interstadials. Many palynologists share this opinion, even though their own material do not agree with this unfortunately dominant "paleogeographic axiom". As an example palynospectra of the Dolní Vestonice section (on the right bank of the Morava River 50 km south of Brno) can be referred to.

As it is presented in a paper by B. Urban, the composition of the spectra suggests a few changes in the climatic-stratigraphic interpretation of paleobotanic data on a number of horizons. For example, grass communities were dominant at the time when the first post-Eemian loess was formed. The PC III chernozem soil developed under conditions of interstadial forest steppes (Amersfoort – N.B.) where steppe communities (*Artemisia, Ephedra, Helianthemum, Compositae* etc.) and patches of bare ground alternated with forest stands of *Pinus sylvestris* with admixture of *P. cembra* and, less frequently, with broad-leaved species. Both the overlying loess and degraded chernozem are attributed to the succeeding stadial, as both of them feature similar palynospectra indicative of dominating steppes and much more arid climate between the first and second stages of Wurm. The loess interlayer within PC III accumulated, in our opinion, under more humid climate of interstadial forest steppes with dominating open coniferous forests of *Pinus sylvestris* and *P. cembra* with some thermophilous species (Brörup – N.B.). A soil diagnosed as pararendzina by L. Smolíkova suggests a considerable cooling manifested in a complete absence of broad-leaved species and by an overwhelming dominance of open woodland with pine. The beginning of the subsequent loess accumulation is marked by pollen spectra indicative of forest steppes of interstadial type and more arid climate compared to the previous interstadial. One can see, therefore, that the Wurmian fossil soils of Dolní Vestonice were formed not only during interstadials, but also during the glacial stages, while the loess formation proceeded during both stadials and interstadials. Data on LPF in Austria and Czech Republic, when compared with results of pollen analysis of the corresponding sediments on the Russian Plain, show a distinct similarity between features of the Late Pleistocene LPF evolution of the Lower Morava valley and those of the LPF development in the Middle Dniester basin (located at the same latitude). Both regions reveal similar trend in the change of climate, phytocoenoses and floras.

That loess may have been formed not only under glacial and interstadial climates, but also in interglacials, has been clearly demonstrated by the reconstructions of some Early Pleistocene stages of the LPF development on the Lower Danube Plain (the Vetovo section in northern Bulgaria). It has been proved that loess 5 (that is the uppermost loess in the Ilyinka subaerial series developed in forest steppe environments) was formed at the optimum phases of the Semiluki (Cromer III) interglacial. At that time, flat interfluves and upper slopes on the right bank of the Danube were predominantly covered with herb and grass communities, with sporadic eroded ecotopes. Limited patches of forests were dominated by broad-leaved species (*Tillia tomentosa, T. platyphyllos, Quercus robur, Q. petraea* and others), stands of *Alnus glutinosa* and those of spruce, pine and birch occurred locally. Lithogenesis of the lower half of loess 4 corresponds to moderately warm and humid climate of the Muchkap (Cromer IV) interglacial; the area under study was then occupied by forests of beech, hornbeam, hazel and oak showing a considerable diversity in species composition. Among the most typical taxa of the Muchkap palynoflora in northern Bulgaria, there are *Tsuga canadensis, T. sp., Pterocarya sp., Juglans cinerea, J. re-*

gia, J. sp., Fagus sylvatica, R. orientalis, Carpinus betulus, N. orientalis, Quercus petraea, Q. robur. Tilia platyphyllos, Corylus colurna and others.

Therefore, the palynological materials obtained from the loess-paleosol sections of Western Europe reveal a marked similarity in the LPF development of some regions of the western and eastern loess provinces of Europe during the Eem = Mikulino and Würm = Weichsel = Valdai, as well as at earlier stages (Bolikhovskaya and Bolikhovsky, 1996).

Palynological studies of key sections in the *Central Asian loess province* are yet few in number. However they have provided important evidence which may be used in the hot discussion about environmental and climatic conditions about the formation of the loess and fossil soils in this region. Materials obtained by R.E. Giterman (Lazarenko *et al.* 1977), M.M. Pakhomov (1983). N.S. Bolikhovskaya (1980, 1983) and other researchers made it apparent that the loesses were formed there under rather various conditions. Loess formation extended over dry and warm interglacial steppes, locally with arid open woodlands; cold and dry periglacial steppes, extraglacial deserts and the like; cold extraglacial forest steppes, with more humid climatic conditions than the present-day ones. All the data point to the fact that loess formation proceeded during thermoxerotic phases of interglacials, as well as during cryoxerotic and cryohygrotic stages of glacial epochs. Fossil soils developed under warm and wet climate (mixed coniferous/broad-leaved forests), warm and dry climate (dry steppes), cool and relatively humid climate (pine and birch forests with admixture of broad-leaved species) characteristic of interglacials and during cryohygrotic stages of glacial epochs. No pollen spectra belonging to interglacial deserts have been found in the fossil soils.

Detailed reconstruction of phytocoenotic and climatic conditions during stages of loess-paleosol formation in the Russian Plain

The Russian Plain is considered a key stratoregion for the periodisation and correlation of the LPF in Northern Eurasia. Data obtained by detailed palynostratigraphic studies of the most comprehensive sections found in the region are in reasonable agreement with the loess and paleosol stratigraphy developed by A.A. Velichko and his co-workers (1984), and with the scheme of the subdivision of Quaternary deposits worked out for the central regions by a team led by S.M. Shik and R.V. Krasnenkov (1985). Both schemes are taken here as a basis for the LPF chronostratigraphy.

On the basis of palynological data it has been established that the period of the LPF development on the Russian Plain comprises 17 paleogeographic stages (9 interglacials and 8 glacial epochs between them) which reflect global Pleistocene climatic rhythms of the highest level *(Fig. 1)* (Bolikhovskaya 1995c). No representative paleobotanic characteristics are available which could ascertain position of

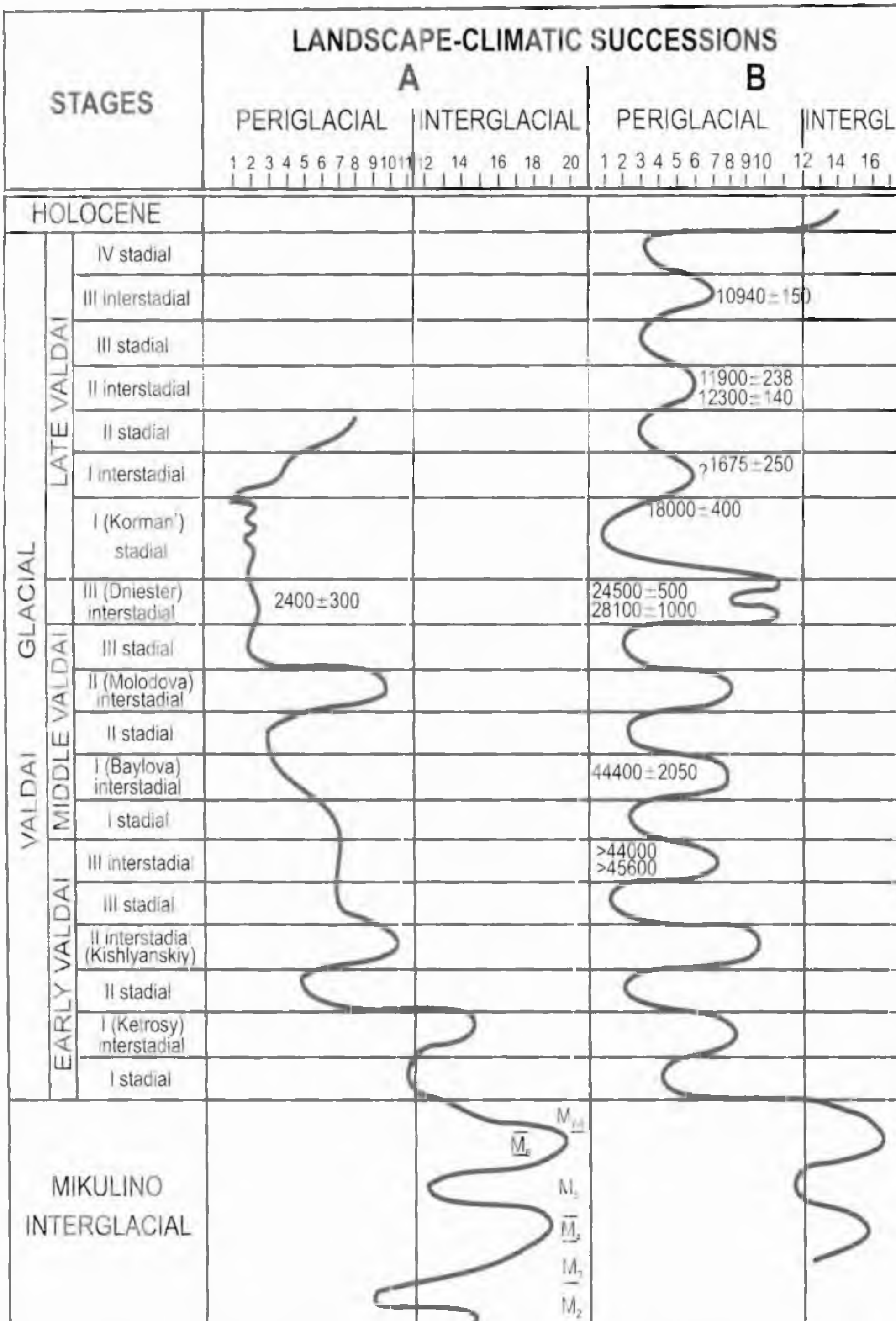
INTERREGIONAL STRATIGRAPHIC SCALE (1986)			MAGNETOST.	STAGES
PLEISTOCENE	UPPER	HOLOCENE HORIZON	BRUNHES	HOLOCENE INTERGLACIAL
		VALDAI HORIZON		VALDAI GLACIAL
		MIKULINO HORIZON		MIKULINO INTERGLACIAL
	MIDDLE	CENTRAL RUSSIAN SUPERHORIZON		DNIEPER GLACIAL
		LIKHVIN SUPERHORIZON (COMPLEX)		CHEREPET' (ROMNY) INTERGLACIAL
				ZHIZDRA (ORCHIK) GLACIAL
				CHEKALIN (KAMENKA) INTERGLACIAL
				KALUGA (BORISOGLEBSK) GLACIAL
				LIKHVIN S.STR. INTERGLACIAL
	LOWER	OKA HORIZON		OKA GLACIAL
		BELOVEZHSK (MUCHKAP) HORIZON		MUCHKAP INTERGLACIAL
		DON HORIZON		DON GLACIAL
		IL'INKA SUPERHORIZON		SEMILUKI (EARLY IL'INKA) INTERGLACIAL
				DEVITSA (MIDDLE IL'INKA) GLACIAL
				GREMYACH'E (LATE IL'INKA) INTERGLACIAL
		POKROVKA HORIZON	MATUYAMA	POKROVKA GLACIAL
		PETROPAVLOVKA HORIZON		PETROPAVLOVKA INTERGLACIAL

Fig. 1. Interglacial and glacial stages through the evolution of the loess-paleosol formation (LPF) in the Russian Plain

boundaries of interglacial and glacial climatic rhythms neither in the stratotypes of the Borisoglebsk, Kamenka, Orchik, and Romny horizons, nor in those of the LPF members attributed to the Ilyinka *s.l.* horizon. This being so, the author named the stages after the sections, which provided most comprehensive information (including palynological characteristics) on the corresponding stratigraphic units, so that boundaries between the latter could be located with reasonable accuracy.

The *Dniester-Prut extraglacial loess region* includes loess areas in the extreme south-west of the non-glaciated territory of the Russian Plain, that is in valleys of the Lower and Middle Dniester and Prut, and on the adjoining watersheds. The most detailed subdivision of the LPF has been performed, and climatic and environmental conditions of loess and soil formation have been reconstructed with the highest possible degree of accuracy for the Middle Dniester drainage basin. The thickest and most complete series of loess and paleosols are exposed along the scarp of the second terrace of the Dniester; fluvial deposits of about 10 m thickness are overlain by a 25 m thick mantle of loess-like eolian and deluvial deposits including 8 paleosols. Some well-known Paleolithic sites are associated with sediments of this terrace. Sections of Molodovo, Korman', Ketrosy, Kishlyansky Yar were studied by L.K. Ivanova, A.P. Chernysh, A.K. Agadjanian, N.S. Bolikhovskaya, S.V. Gubin, N.V. Rengarten and others. The results of the studies, supplemented by detailed palynological data (Pashkevich 1977; Bolikhovskaya 1981, 1986, etc.) provided information on the development of LPF, vegetation, climates and other features of paleolandscapes in the Middle Dniester stratoregion during the Mikulino interglacial and 19 stages within the Valdai epoch (9 interstadial and 10 stadial intervals, see *Fig. 2B*). It has been confirmed that material of loess horizons dated to the Late Pleistocene was accumulated both during the stadials (in tundra steppes, periglacial steppes, and forest steppes) and interstadials (in extraglacial steppes and forest steppes with patches of birch-pine forests with an admixture of hornbeam, elm etc.) of the Valdai glacial epoch, as well as during the Mikulino endothermal cooling. At the base of the section two brown forest soils are found separated with a loess layer; they developed during the thermoxerotic and thermohygrotic phases of the Mikulino interglacial. The optimum of the thermoxerotic phase was marked by zonal occurrence of forest steppes with a prevalence of oak in forests with hornbeam, elm, and ash patches; whereas the peak of the thermohygrotic phase featured hornbeam forests with an admixture of hazel, oak etc.

The Valdai paleosols formed during interstadials under extraglacial forest steppe and steppe conditions and during the Late Valdai cryohygrotic phase (the Korman' cryomorphic soil). The latter was characterised by development of tundra-forest steppes with widespread Arctic-Alpine species (*Arctous alpina, Arctostaphyllos uva-ursi, Rubus chamaemorus, Diphazium alpinum,* etc.), by dominance of steppe coenoses, bush formations of *Juniperus, Betula fruticosa, B. nana, Alnaster fruticosus,* communities typical of eroded ecotopes and wetland environment, and patches of birch-pine open woodland.


LANDSCAPE-CLIMATIC SUCCESSIONS
A
B
STAGES
PERIGLACIAL
INTERGLACIAL
PERIGLACIAL
INTERGL.
HOLOCENE
VALDAI GLACIAL
LATE VALDAI
MIDDLE VALDAI
EARLY VALDAI
IV stadial
III interstadial
III stadial
II interstadial
II stadial
I interstadial
I (Korman') stadial
III (Dniester) interstadial
III stadial
II (Molodova) interstadial
II stadial
I (Baylova) interstadial
I stadial
III interstadial
III stadial
II interstadial (Kishlyanskiy)
II stadial
I (Ketrosy) interstadial
I stadial
MIKULINO INTERGLACIAL
2400±300
10940±150
11900±238
12300±140
?1675±250
18000±400
24500±500
28100±1000
44400±2050
>44000
>45600

The *Volhyno-Podolian glacial-periglacial loess region* includes loess-till and loess regions of the Volhynian Upland, north-western Podolian Upland, and the denudational-accumulational plain of the Lesser Polessye between the two uplands. The most representative loess-paleosol series are found on interfluvial plateaus and upper slopes. Their stratigraphic division is based on schemes developed by A.B. Bogutsky (1975), M.F. Veklich *et al.* (1984), A.A. Velichko *et al.* (1992). A number of sections on the Volhynian Upland, in the area of Lesser Polessye and in the north of the Podolian Upland have been studied palynologically (Bezus'ko 1981, 1989; Gurtovaya 1981; Artyushenko *et al.* 1982; and others). Even though reliable data are rather few, they give an insight into special features of interglacial and interstadial floras and phytocoenoses of the region. They also allow to calculate climatic parameters for most of the established stages of the LPF development and to date the Kaidaki, Dnieper, and Priluki horizons and the Dubny soil more precisely (Bolikhovskaya 1995c). It has been found that the pollen spectra from the Priluki and Kaidaki soils together with the underlying loess-like loam, which are attributed by R.Ya. Arap to the Dnieper glacial epoch, are of interglacial type (with *Juglans, Carpinus, Quercus, Tilia, Acer, Morus, Ulmus, Corylus, Cornus, Rhamnus, Berberis* etc.). They were probably formed within a single interglacial rhythm i.e. during the Mikulino interglacial. The Vitachev soil corresponds to the expansion of extraglacial steppes, while at the time of the early Valdai loess formation periglacial steppes were widespread, with bush formations of microtherms *(Betula fruticosa, Alnaster fruticosus,* etc.). Pollen spectra described by E.E. Gurtovaya and L.G. Bezus'ko from the Dubny (= Bryansk) soil suggest, in our opinion, that this well developed soil ho-

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Fig. 2. Detailed climatostratigraphy of the Upper Pleistocene loess-paleosol formation. Landscape-climatic successions in the Desna-Dnieper glacial-periglacial (A) and Dniester-Prut extraglacial (B) loess regions during the Late Pleistocene. – *Landscape-climatic successions:* A: 1 = cryoarid tundra; 2 = tundra; 3 = forest tundra with birch open woodland; 4 = forest tundra with coniferous open woodland; 5 = forest steppe with birch open woodland; 6 = forest steppe with coniferous open woodland; 7 = steppe; 8 = dry steppe; 9 = extraglacial steppe; 10 = extraglacial forest steppe; 11 = pine-birch open woodland; 12 = pine forests; 13 = Siberian cedar pine-spruce and birch forests; 14 = birch forests with broad-leaved arboreal species; 15 = pine-birch forests with broad-leaved arboreal species; 16 = birch-pine forests with broad-leaved arboreal species; 17 = spruce-pine forests with broad-leaved arboreal species; 18 = mixed coniferous–broad-leaved forests; = hornbeam-oak forests; 20 = oak-hornbeam forests. B: 1 = tundra-forest steppe; 2 = forest steppe; 3 = steppe; 4 = pine open woodland; 5 = pine forests; 6 = extraglacial steppe; 7 = extraglacial dry steppe; 8–11 = extraglacial forest steppe: 8 = with spots of pine forests with oak, hornbeam, elm and linden; 9 = with spots of spruce-pine forests with oak, hornbeam, elm and linden; 10 = with spots of coniferous–broad-leaved forests with predominance of oak; 11 = with spots of broad-leaved forests with oak as edificator; 12 = pine forests with rare cryophytes; 13–17 = forest steppe: 13 = with pine forests with broad-leaved arboreal species; 14= with pine–broad-leaved forests; 15 = with Siberian cedar–broad-leaved forests; 16 = with oak forests; 17 = with hornbeam forests rizon interbedding in the Valdai loess series may be of different age in various parts of the Volhynia-Podolian region. In Volhynia (the Boyanichi section) it developed during one of the Middle Valdai cold phases, while in Lesser Polessye (Podbereztsy and other sections) it spans the warmest Middle Valdai interstadial as well as the preceding and subsequent coolings. The Dubny soil in the Izyaslav section (northern Podolian Upland) was dated to the end of the warmest Middle Valdai interstadial and the subsequent stadial cooling. Material of Late Valdai loess was accumulated in this region in periglacial environments characteristic of the cryoxerotic stage of the last ice age.

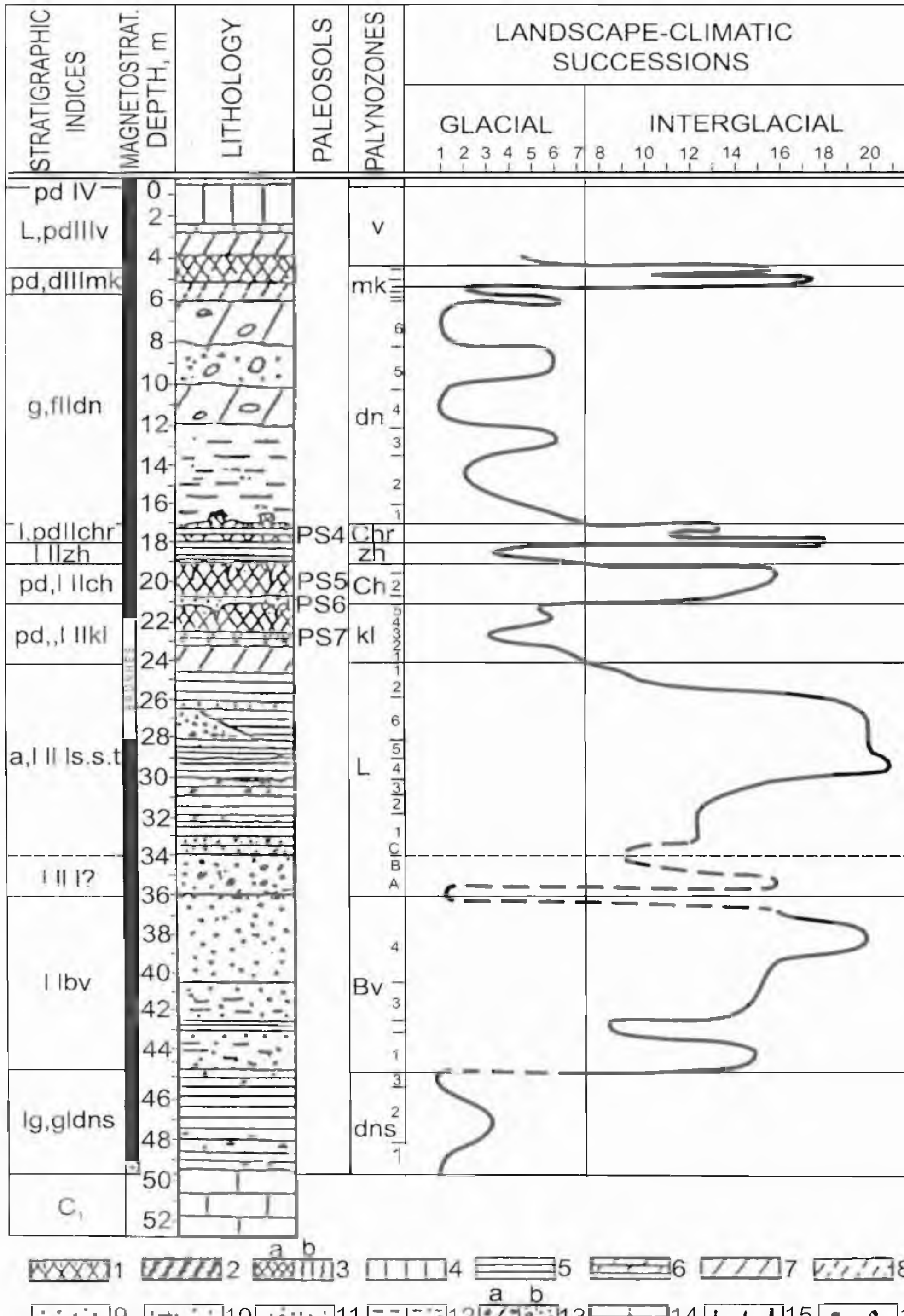
The *Desna-Dnieper glacial-periglacial loess region* is located north-east of the Dnieper Lowland, within the limits of the Dnieper ice sheet; it includes regions of the Upper Dnieper and Desna LPF. A most complex structure and considerable thickness are the characteristic features of the loess-paleosol series along the left bank of the Desna River. The author has performed a detailed analysis on the Arapovichi section which is one of most representative in the region and is located on the interfluvial plateau south-west of Novgorod-Seversky.

The section has been studied by A.A. Velichko, V.P. Grichuk, A.K. Markova, T.D. Morozova thoroughly, and by many others (see publications of 1957 to 1985), and it is one of the key sections for the stratigraphic scheme of LPF developed by the above named researchers.

Character and sequence of the palynozones identified in the section, regularities in the phytocoenotic successions, total composition of the palynoflora and individual significant species (Bolikhovskaya, 1991, 1993) testify that not only the Salyn' fossil soil belongs to the Mikulino interglacial, but also the whole series of formations overlying the till and the lower third of the Krutitsa soil (salt affected chernozem, according to T.D. Morozova 1981) *(Fig. 2A)*. Most typical of the Mikulino palynoflora in the Desna loess region are *Picea s. Omorica, P. s. Strobus, P. s. Cembra, Carpinus betulus, Fagus sylvatica, Quercus robur, Q. petraea, Q. pubescens, Tilia platyphyllos, T. tomentosa, T. cordata, Ulmus glabra, U. laevis, Celtis sp., Corylus colurna, Corylus avellana, Humulus lupulus, Lonicera,* etc. An Early Valdai interstadial has been identified within the Krutitsa soil. Another similar warming was revealed in the lower part of the Khotylevo loess horizon. Judging from palynological data, the Bryansk soil is a composite paleogeographic formation: its parent material and the genetic horizons themselves developed throughout three Middle Valdai interstadials and intermediate phases of cooling and at the beginning of the first (Ostashkov) Late Valdai stadial. The data argue against the previous belief about this soil being formed during only one interstadial. An interstadial (dated at about 16.500–15.000 yr. BP in the European sections) and three earlier warm intervals of interphase level are recorded in the sequence of the Desna and Altynovo loesses. The loess horizons in this region were accumulated in the environments of periglacial tundra and forest tundra during glacial stages, as well as in periglacial steppes and forest steppes corresponding to interphase and interstadial intervals of the Valdai epoch. The loess-like sandy loam underlying the Salyn' soil could be associated with the thermoxerotic maximum (hornbeam and oak forest phase) of the Mikulino interglacial. The fossil soils were formed under forests during both stages within the Mikulino interglacial rhythm, as well as under interstadial pine-birch forests (with oak, lime and elm) and in periglacial forest steppes. Soils also developed during interphase intervals in periglacial forest tundra, locally with open woodland composed of coniferous species and birch, and during the cryohygrotic stage of the Valdai glacial epoch when periglacial bush tundra dominated (*Fig. 2A*).

The *Northern Central Russian glacial-periglacial loess region* occupies the north of the Central Russian Upland within the limits of the most extensive Middle Pleistocene (Dnieper = Saale) glaciation. The composition and structure of the Quaternary sediments are represented most fully in the Likhvin section near Chekalin; the majority of paleogeographic events of the Pleistocene are recorded within the sequence. A 50 m thick sequence of loess, paleosols, tills and glacio-lacustrine, alluvial, lacustrine and bog sediments is exposed in a 2 km long scarp extending along the Oka River or in the nearby pits and boreholes. The literature on the section is quite voluminous. Most numerous are papers dealing with sediments of an oxbow lake (25 to 34 m from the top of the section) unanimously accepted as the stratotype for the Likhvin interglacial on the Russian Plain.

A comprehensive layer-by-layer characteristic of the whole sequence obtained by the author permitted its detailed subdivision and made possible the reconstruction of the diversified environmental and climatic events in the Upper Oka basin. The sequence spans the period from the Don glaciation to the Holocene (*Fig. 3*), that is six glacial epochs (Don, Oka, Kaluga, Zhizdra, Dnieper, Valdai) and six interglacials (Muchkap, Likhvin, Chekalin, Cherepet', Mikulino, and the Holocene); they are presented either as complete climatic rhythms of glacial and interglacial rank, or by considerable portions of climatic-phytocoenotic phases i.e. constituents of the rhythm (Bolikhovskaya 1995 b,c). Environments under severe climates of the periglacial tundra dominated by cryophytes (*Betula nana, B. fruticosa, Alnaster fruticosus, Dryas octopetala, Selaginella selaginoides* etc.) were characteristic of the Dnieper (= Saale) and Oka (= Elster) glaciations, with the ice sheet extending into the Upper Oka valley; they were also typical of the time when the Don glacio-lacustrine sediments accumulated. Lacustrine sediments of the Muchkap interglacial yielded palynospectra representing diversity of the interglacial flora. They include taxa characteristic of the Muchkap flora (*Tsuga canadensis, Picea s. Omorica, P. s. Eupicea, Abies sp., Pinus s. Cembra, P. s. Strobus, Larix sp., cf. Rhus sp., Carpinus betulus, C. orientalis, Fagus sylvatica, Quercus robur, Q. pubescens, Tilia platyphyllos, T. cordata, Ilex aquifolium, Ulmus laevis, U. glabra, U. campestris, Osmunda cinnamomea, O. claytoniana* etc.) along with species – indicators of this interglacial at the centre of the Russian Plain (*Cedrus sp., Tilia amurensis, Osmunda regalis, Woodsia manchuriensis, W. fragilis*). The Muchkap climatic optimum was marked by the prevalence of spruce and elm-oak-hornbeam forests. At the optimum of the Likhvin *s.str.* interglacial first oak-hornbeam forests dominated, later they had become replaced by spruce-fir and hornbeam-


STRATIGRAPHIC INDICES
MAGNETOSTRAT.
DEPTH, m
LITHOLOGY
PALEOSOLS
PALYNOZONES
LANDSCAPE-CLIMATIC SUCCESSIONS
GLACIAL
INTERGLACIAL
pd IV
L,pdIIIv
pd,dIIImk
g,fIIdn
l,pdIIchr
l IIzh
pd,l IIch
pd,,l IIkl
a,l II ls.s.t
l II l?
l Ibv
lg,gIdns
PS4
PS5
PS6
PS7
v
mk
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beech-oak forests. Typical of the Likhvin flora are representatives of the European, Mediterranean, East Asian and North American floras, such as *Larix sp., Abies alba, Picea s. Omorica, P. excelsa, Pinus s. Cembra, P. s. Strobus, P. sylvestris, Betula s. Costatae, B. pendula, B. pubescens, Juglans regla, Carpinus betulus, Fagus sylvatica, Quercus petraea, Q. robur, Q. pubescens, Zelkova sp., Celtis sp., Ulmus propinqua, U. laevis, U. campestris, Fraxinus sp., Tilia platyphyllos, T. tomentosa, T. cordata, Acer sp., Corylus colurna, C. avellana, Alnus glutinosa, A. incana, Ligustrina amurensis, Rhododendron sp., Vitis sp., Myrica sp., Osmunda cinnamomea, Salvinia natans* and others, including species-indicators *Tsuga canadensis, Taxus baccata, Pterocarya fraxinifolia, Juglans cinerea, Castanea sativa, Ilex aquifolium, Fagus orientalis, Quercus castaneifolia, Buxus sp., Osmunda claytoniana.* During the Kaluga cool interval, in periglacial environments of forest tundra, lacustrine and fluvial sediments formed, as well as the overlying PS7 soil and parent material of the PS6 soil did, showing post-cryogenic structure. The Chekalin interglacial (its peak of heat and moisture supply was marked by the dominance of spruce-broad-leaved forests) has been recorded in the pedocomplex including paraburozem PS5 and podzolic PS6 soils. Characteristic floristic elements of this thermochron are *Picea s. Omorica, P excelsa, Pinus s.g. Cembra, P. sibirica, P. sylvestris, Betula pendula, B. pubescens, Carpinus betulus, Quercus robur, Tilia cordata, T. platyphyllos, T. tomentosa, Acer sp., Ulmus laevis, U. glabra, U. campestris,* etc. The flora of periglacial forest-tundra of the Zhizdra cooling recovered from the lake and bog deposits includes less diversified cryophytes compared to the Kaluga flora; the latter is represented *by Larix sp., Pinus sylvestris, Betula pubescens, B. pendula, B. fruticosa, B. nana, Alnaster fruticosus, Dryas octopetala, Selaginella sibirica, Lycopodium appressum, L. pungens, Artemisia s.g. Seriphidium, Thalictrum sp.,* and others. Bog gleyed soil PS4 developed during the Cherepet' interglacial; its optimum phases are marked by hornbeam-oak and

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Fig. 3. Stratigraphic subdivision of the Likhvin key section. Phytocoenotic and climatic successions on the territory of the Upper Oka loess region in the Pleistocene (according to palynological data). *Lithology:* 1 = recent soil; 2 = Eopleistocene fossil soils and pedosediments (see *Fig. 4*); 3 = Pleistocene paleosols: a) horizon A; b) horizon B; 4 = loess and loess-like deposits; 5 = clay; 6 = foliated marl; 7 = loam; 8 = loamy sand; 9 = sand; 10 = sand with loamy interlayers; 11 = sand with gravel and pebble; 12 = fluvioglacial deposits; 13 = till; a) clayey; b) sandy; 14 = limestone; 15 = inclusions of carbonate concretions; 16 = mollusc shells. – Landscape-climatic successions: 1 = ice cover; 2 = periglacial tundra; 3 = periglacial forest tundra; 4 = periglacial steppe; 5 = periglacial forest steppe; 6 = pine-birch open woodland; 7 = larch-pine-birch open woodland; 8 = spruce forest; 9 = birch forests with broad-leaved arboreal species; 10 = pine-birch forests with broad-leaved arboreal species; 11 = birch-pine forests with broad-leaved arboreal species; 12 = pine-spruce forests with broad-leaved arboreal species; 13 = birch-broad-leaved forests; 14 = pine-cembra pine-broad-leaved forests; 15 = pine-spruce-broad-leaved forests; 16 = spruce-broad-leaved forests; 17 = spruce-fir-broad-leaved forests; 18 = broad-leaved (*Quercetum mixtum*) forests; 19 = broad-leaved shady (with *Carpinus betulus* domination) forests; 20 = spruce-broad-leaved forests with subtropical taxa; 21 = broad-leaved forests with subtropical taxa

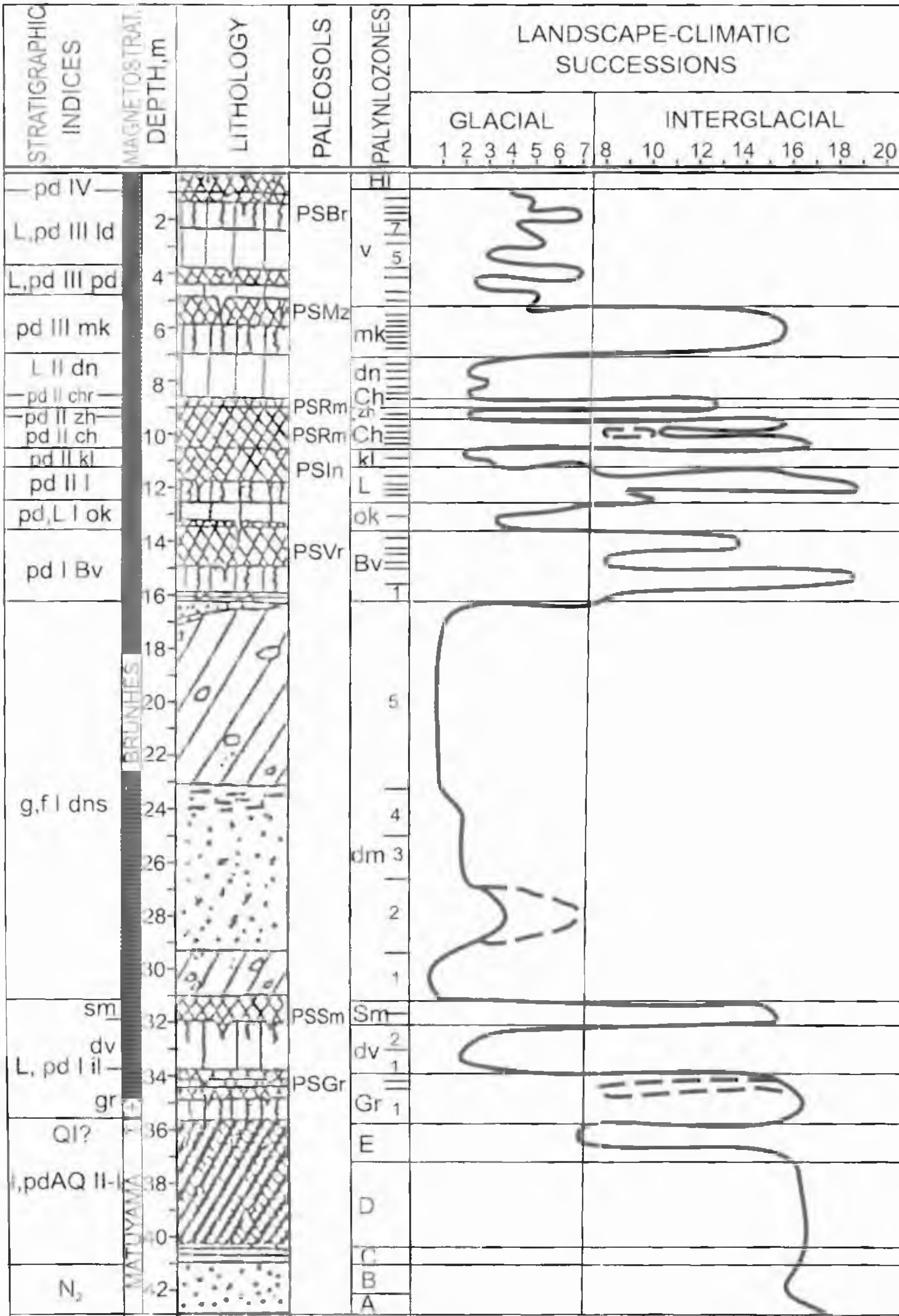
coniferous/broad-leaved forests with *Dinus s. Cembra, Pinus sylvestris, Betula pendula, B. pubescens, Carpinus betulus, C. cf. orientalis, Ostrya sp. Quercus robur, Q. cf. pubescens, Tilia cordata, T. tomentosa, Ulmus laevis, U. campestris* etc. among characteristic taxa.

During the Dnieper *s.l.* stage the following series were deposited: a) Early Dnieper glacio-fluvial silts with lemming fauna: *Dicrostonyx cf. simplicior, Lemmus sibiricus etc.* (Agadjanian 1973), and palynospectra mostly of tundra steppe type (Bolikhovskaya 1975); b) three layers of till attributed to the Dnieper and Moscow stadials and to the Dnieper-Moscow interstadial; the landscapes of the latter were dominated by open woodlands of pine, *Alnaster* and dwarf birch; c) the Late Moscow loess-like sandy loam. An Early Dnieper interstadial has been identified in the upper part of silts underlying the till; periglacial open woodlands with pine prevailed at that time. Late Moscow interstadial warming (established in ferruginous sands above the tills) is represented by a phase of periglacial birch open woodlands with *Betula fruticosa* in the shrub layer and a cover of herbs and dwarf shrubs (with *Arctous alpina, Cannabis sp., Artemisia s.g. Seriphidium, Thalictrum cf. alpinum* and others). The Mikulino interglacial (when a lessivated soil of PS2 complex formed) was marked by a dominance of forests, such as pine-birch ones at the beginning and at the end of the thermochron; elm-hornbeam-oak and birch forests at the thermoxerotic maximum; oak-elm-linden-hornbeam and spruce-pine-birch forests at the thermohygrotic maximum. The first Early Valdai cold phase established at the top of A2 horizon of forest soil was characterised by the dominance of birch forests, with *Betula fruticosa* and *B. nana* in the shrub layer.

The first Early Valdai interstadial is manifested in the sod horizon of PS2 complex by a palynozone indicative of periglacial forest steppes with steppe herb and grass communities and those of chenopods and wormwood; meadow coenoses; pine-spruce-birch forests with an admixture of oak and linden. The onset of the succeeding loess formation was marked by a sharp increase in continentality of the climate involving the expansion of tundra steppes: the periglacial flora of the latter is characterised by the presence of pollen and spores of *Pinus sylvestris, Betula pendula, B. pubescens, B. fruticosa, B. nana, Alnaster fruticosus, Cannabis sp., Ephedra strobilacea, Selaginella sibirica,* and others. Final stages of the loess formation took place during the second Early Valdai interstadial, when dominating forests were composed of *Pinus sylvestris, P. sibirica, Picea excelsa.* The overlying fossil soil PS1 (correlated unanimously by paleopedologists with the Bryansk soil), as well as the uppermost loess horizon, formed in periglacial environments dominated by birch open woodlands with *Juniperus sp., Betula fruticosa, Alnaster fruticosus* in shrub layer.

As it is evident from the foregoing, fossil soils of the Northern Central Russian glacial-periglacial loess region developed during interglacials (PS6, PS5, PS4, PS3, and PS2 forest soil) and an interstadial (sod soil of PS2 complex); some of the soils (PS7 and PS1) formed under stenoperiglacial conditions corresponding to glacial stages of glacial epochs. Loess horizons in this region formed under glacial climate only.

The *Oka-Don glacial-periglacial loess region* occupies the lowland of the same denomination and the eastern part of the Central Russian Upland within the limits of the Don ice lobe. Detailed reconstructions of landscapes and climates of the region during all the main stages of the LPF development have been worked out by the author using data obtained by studies of the Strelitsa key section located on the right bank of the Don River, 20 km from Voronezh. An almost complete sequence of the LPF is seen there in a number of quarries at the upper slope of the Devitsa River valley. Investigations carried out for many years provided detailed palynological data for the whole sequence of subaerial, lacustrine and fluvioglacial formations underlying and overlying the till deposited during Don glaciation (Bolikhovskaya 1975, 1995 b,c). Floristic, phytocoenotic and climatic successions reconstructed for all the stages of the LPF formation in the discussed region have been compared with results of lithological, paleopedological, paleofaunistic, paleomagnetic and other analyses of the exposed deposits (Krasnenkov *et al.* 1970; Agadjanian 1971; Bolikhovskaya 1984 and others; Udartsev 1980; Velichko *et al.* 1985; Zarrina and Krasnov 1985). It has turned out that in most cases there is a discrepancy between the boundaries of glacial and interglacial rhythms on the one hand, and loess and fossil soil boundaries, on the other hand *(Fig. 4)*. The submorainic loess-paleosol series superimposing the Eopleistocene red beds formed in the course of the Ilyinka interval, which comprises two interglacial rhythms and the intermediate cooling. During the early Ilyinka (Gremyach'e) interglacial steppes and forest steppes prevailed and the lower soil of this series developed at that time; during the Devitsa cooling, under conditions of periglacial tundra and forest tundra, the middle horizon of loess (separating two soils), the parent sediment of the B soil horizon, and the base of A horizon of the upper soils were formed. The overwhelming part of the thick humus horizon of the upper soil (its top has been eroded) corresponds to the Semiluki (late Ilyinka) interglacial. Palynological data on the post-Don loess-paleosol members testify that subhorizons $A1^{1}$ of the Vorona PC, Inzhavino, Kamenka, and Krutitsa soils correspond to cryohygrotic stages or substages of cold epochs. There is only one (Vorona) soil in the second Pre-Dnieper PC; it developed throughout the Muchkap interglacial (with coniferous/broad-leaved forests dominant at its optimum) and during the first half of the Oka glaciation. Material of the Korostylevo loess was accumulated, horizon $A1^{i}$ of the Vorona soil was formed and penetrated by ice wedges under conditions of the Oka periglacial environment. The upper Pre-Dnieper PC of the sequence, including the Inzhavino, Kamenka and Romny fossil soils, was formed in the course of three interglacial and two glacial climatic rhythms. Most part of the Inzhavino soil developed under forests of the Likhvin *s.str.* interglacial (pine-birch forests→birch forests with some *Carpinus betulus* and *Carpinus orientalis*→birch-cembra pine-spruce-pine forests with oak and elm→pine-fir-cembra pine-spruce forests with hemlock, hazel, hornbeam and beech→fir-spruce and beech-hornbeam-elm-oak forests→forest steppes with patches of broad-leaved forests→coniferous/broad-leaved and birch forests). The Likhvin flora includes taxa as *Tsuga canadensis, Abies sp., Picea s. Omorica, P. s.*


STRATIGRAPHIC INDICES
MAGNETOSTRAT.
DEPTH, m
LITHOLOGY
PALEOSOLS
PALYNLOZONES
LANDSCAPE-CLIMATIC SUCCESSIONS
GLACIAL
INTERGLACIAL
pd IV
L,pd III ld
L,pd III pd
pd III mk
L II dn
pd II chr
pd II zh
pd II ch
pd II kl
pd II l
pd,L I ok
pd I Bv
g,f I dns
sm
dv
L, pd I il
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QI?
l,pdAQ II-k
N2
BRUNHES
MATUYAMA
PSBr
PSMz
PSRm
PSRm
PSIn
PSVr
PSSm
PSGr
Hl
V
mk
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Ch
zh
Ch
kl
L
ok
Bv
dm
Sm
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D
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A

Eupicea, Pinus s. Cembra, P. s. Strobus, P. sylvestris, Larix sp., Betula s. Costatae, B. pendula, B. pubescens, Juglans regia, Carpinus betulus, C. orientalis, Quercus robur, Q. petraea, Q, pubescens, Ulmus laevis, U. carpinifolia, Humulus lupulus, Euonymus sp. In terms of taxa diversity and participation of Neogene relicts, it is on a par with that of the preceding Muchkap thermochron (the latter includes *Abies sp., Picea s. Omorica, P. s. Eupicea, Pinus s. Cembra, P. s. Strobus, P. sylvestris, Betula s. Costatae, B. pendula, B. pubescens, Zelkova sp., Carpinus caucasica, C. betulus, C. orientalis, Ostrya sp., Corylus colurna, Acer sp., Quercus petraea, Q. robur, Q. pubescens, Tilia platyphyllos, T tomentosa, T cordata, Lonicera sp., Rhamnus* sp., *Osmunda cinnamomea* and others). The Kaluga (= Borisoglebsk) cooling was characterised by dominance of periglacial tundras and forest-tundras. The successions of the Kamenka interglacial soil formation is reconstructed as follows: forest steppes, locally with linden-hornbeam-oak and birch-pine forests→herb and grass steppes→pine-birch, oak-hornbeam and alder forests→pine-birch forests of the endothermal interval→forest steppes. At the Zhizdra (Orchik) cooling, the periglacial steppes of the first phase were replaced by periglacial tundras. The optimum stage of the Romny pedogenesis featured hornbeam-oak forests with *Carpinus orientalis* and *Ostrya sp.*, alder forests and coniferous-birch stands. The Dnieper loess formed in cryoarid environments of periglacial tundras. Most part of the Mezin PC was associated with the Mikulino interglacial forest steppes, which were considerably reduced in area in the Upper Don drainage basin at the phase of dominance of hornbeam-oak and birch-pine forests. The first Early Valdai cooling and the subsequent interstadial can be correlated with the upper subhorizon $A1^1$ of the Krutitsa soil. 5 interstadials and 6 alternating cooling of stadial level are recorded along the interfluvial LPF profiles dated to the Early and Middle Valdai. The Late Valdai horizons are found in the cover sediments of the first and second terraces of Don. On the northern Central Russian Upland the materials obtained so far do not permit identification of interglacial loess formations. The loess horizons of the Oka-Don lowland are generations of glacial climate.

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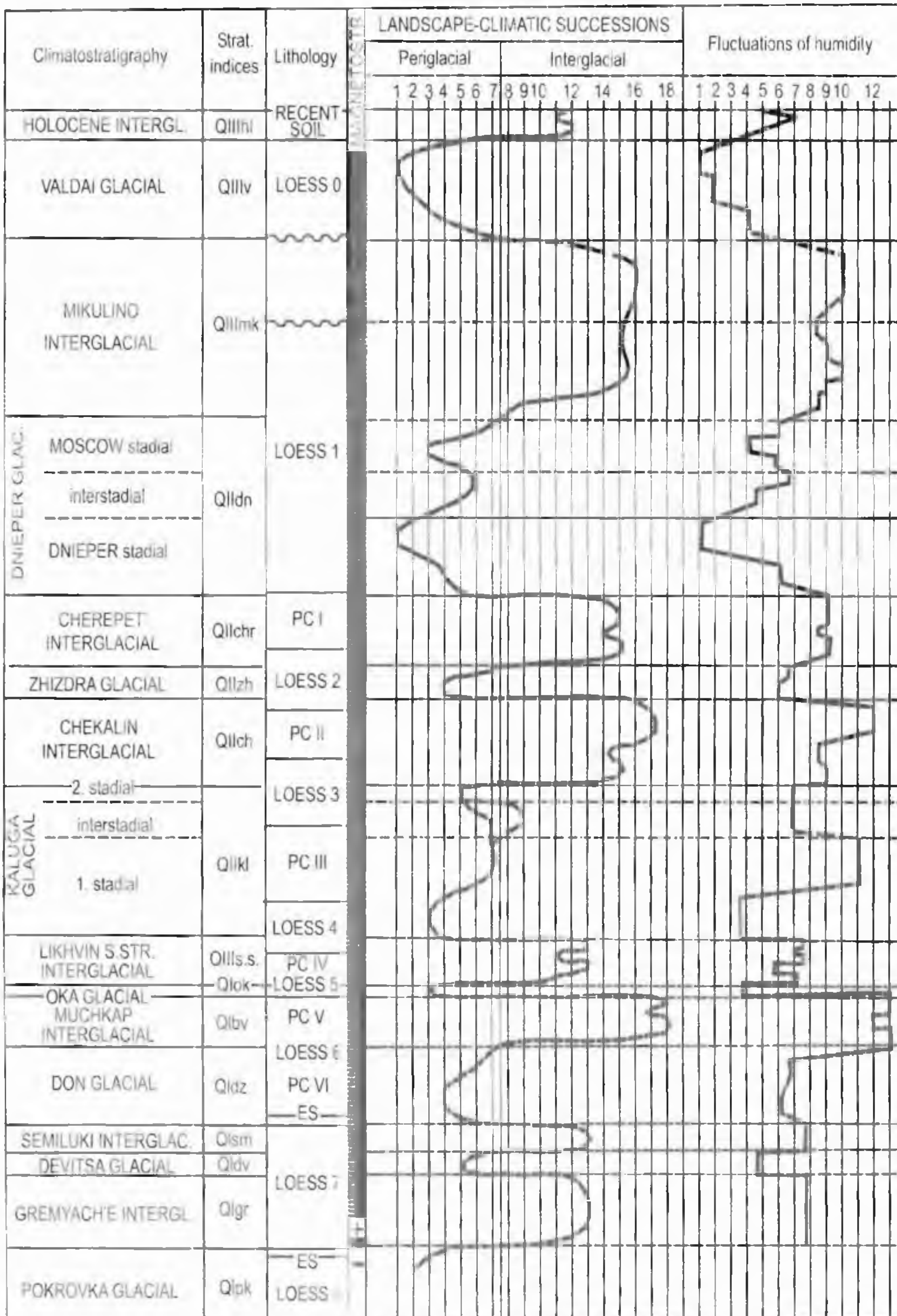
Fig. 4. Stratigraphic subdivision of the Strelitsa key section. Phytocoenotic and climatic successions on the territory of the Upper Don loess region through the Pleistocene (according to palynological data; for symbols of lithological column see *Fig. 3*). – Landscape-climatic successions: 1 = ice cover; 2 = periglacial tundra; 3 = periglacial forest tundra; 4 = periglacial steppe; 5 = periglacial forest steppe; 6 = pine-birch open woodland; 7 = extraglacial steppe; 8 = pine-birch forests; 9 = birch forests with broad-leaved arboreal species; 10 = pine-birch forests with broad-leaved arboreal species; 11 = birch-pine forests with broad-leaved arboreal species; 12 = spruce-pine-birch forests with broad-leaved arboreal species; 13 = pine-birch-broad-leaved forests; 14 = spruce-pine-birch-broad-leaved forests; 15 = broad-leaved forests; 16 = forest steppe; 17 = steppe; 18 = coniferous forests with rare subtropical taxa; 19 = mixed coniferous-broad-leaved forests with rare subtropical taxa; 20= broad-leaved forests with subtropical taxa


Climatostratigraphy
Strat. indices
Lithology
MAGNETOSTR.
LANDSCAPE-CLIMATIC SUCCESSIONS
Periglacial
Interglacial
1 2 3 4 5 6 7 8 9 10 12 14 16 18
Fluctuations of humidity
1 2 3 4 5 6 7 8 9 10 12
HOLOCENE INTERGL.
QIIIhl
RECENT SOIL
VALDAI GLACIAL
QIIIv
LOESS 0
MIKULINO INTERGLACIAL
QIIImk
DNIEPER GLAC.
MOSCOW stadial
interstadial
DNIEPER stadial
QIIdn
LOESS 1
CHEREPET INTERGLACIAL
QIIchr
PC I
ZHIZDRA GLACIAL
QIIzh
LOESS 2
CHEKALIN INTERGLACIAL
QIIch
PC II
KALUGA GLACIAL
2. stadial
interstadial
1. stadial
QIIkl
LOESS 3
PC III
LOESS 4
LIKHVIN S.STR. INTERGLACIAL
QIIls.s.
PC IV
OKA GLACIAL
QIok
LOESS 5
MUCHKAP INTERGLACIAL
QIbv
PC V
LOESS 6
DON GLACIAL
QIdz
PC VI
ES
SEMILUKI INTERGLAC.
QIsm
DEVITSA GLACIAL
QIdv
GREMYACH'E INTERGL.
QIgr
LOESS 7
POKROVKA GLACIAL
QIpk
ES
LOESS 8

The *extraglacial loess region of the East Caucasian piedmonts* is one of the most remote areas from the glaciated territories of the Russian Plain. The loess-paleosol series represent maximum thickness (70–100 m) on the European subcontinent. Previous attempts at stratigraphic subdivision of the LPF in the Caucasian piedmont and its correlation with horizons of glacial and periglacial zones of the Russian Plain were based on lithological and geochemical analyses, as well as on paleomagnetic and thermoluminescent data (Balaev and Tsarev 1964; Shelkoplyas *et al.* 1987; Fainer and Lizogubova 1987; and others). The author participated in the study of the most representative LPF sections in the extraglacial zone as a member of a group of specialists under the guidance of A.A. Velichko. A 140 meter sequence of Eopleistocene and Pleistocene deposits was studied, exposed in natural scarps and penetrated by boreholes on the interfluve and on the Kuma valley slopes and terraces near Otkaznoye village (Morozov 1989; Udartsev *et al.* 1989; Virina *et al.* 1990; Bolikhovskaya 1995a,b,c; and others). Using data obtained from studies of paleomagnetism, paleosols, small mammals, as well as palynological characteristics, the author produced reconstructions of climates and environments for all 15 climatochrons of the Brunhes epoch of normal polarity *(Fig. 5)*.

For the most part of the period of more that 700 thousand years duration (from the Gremyach'e interglacial to the present days) the western part of the Terek-Kuma lowland was occupied by forest steppe interglacial landscapes or by periglacial and extraglacial forest steppes. For the first time in the Pleistocene history, steppes became dominant here during one of the phases of the thermoxerotic interval of the Likhvin interglacial. Vegetation of dry steppes and semideserts prevailed in the Middle Kuma basin at some warm Eopleistocene intervals; during the Pleistocene it as-

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Fig. 5. Phytocoenotic and climatic successions of the Middle Kuma basin during the Pleistocene (according to palynological data). – Landscape-climatic successions: 1 = periglacial semi-desert and dry steppe; 2 = periglacial steppe; 3 = periglacial forest steppe; 4 = birch and coniferous-birch open woodland; 5 = extraglacial forest steppe; 6 = extraglacial birch open woodland; 7 = extraglacial spruce and cembra pine-spruce forests; 8 = birch open woodland with broad-leaved arboreal species; 9 = birch forests with broad-leaved arboreal species; 10 = coniferous-birch and birch-coniferous forests with broad-leaved arboreal species; 11 = forest steppe; 12 = steppe; 13 = piedmont forest steppe; 14 = shrub hornbeam groves; 15 = elm-oak, oak, hornbeam-oak forests; 16 = hornbeam forests; 17 = oligo- and polydominant broad-leaved forests; 18 = polydominant broad-leaved forests with subtropical taxa. – Fluctuations of humidity curve: 1 = periglacial semi-desert and dry steppe (annual precipitation <250 mm); 2 = interglacial desert and semi-desert (250 mm and less); 3 = periglacial steppe (280–300 mm); 4 = periglacial forest steppe (300–450 mm); 5 = interglacial steppe (300–450 mm); 6 = periglacial open woodland (400–500 mm); 7 = interglacial forest steppe (400–650 mm); 8 = interglacial open woodland (600–700 mm); 9 = interglacial oak forest (550–700 mm); 10 = interglacial hornbeam forests (700–800 mm); 11 = extraglacial spruce and cembra pine-spruce forests (up to 800 mm); 12 = oligo- and polydominant broad-leaved forests under interglacial temperate climate (up to 1500 mm); 13 = polydominant broad-leaved forests under interglacial subtropical climate (>1500 mm)

sumed greater importance first at the cryoxerotic substage of the Dnieper ice age, and later at the same stage of the Valdai glaciation; the vegetation at those stages bore evidence of periglacial phytocoenoses. Dominance of forest landscapes in the region has been established with certainty for five intervals. At the Muchkap interglacial broad-leaved polydominant and oligodominant forests prevailed with a considerable share of subtropical species. Broad-leaved forests, mesophytic or xerophytic to a different degree, occupied the Middle Kuma basin during the Chekalin, Cherepet', and Mikulino interglacials. Forests of spruce and Siberian cedar pine dominated the territory at individual phases of the cryohygrotic stage of the Kaluga glaciation. The five "forest" periods mentioned above are assumed to correspond to the maximum levels of the Caspian Sea during the Pleistocene.

Automorphic fossil soils of the eastern part of the Caucasus piedmont were formed during interglacials, interstadials and cryohygrotic stages of ice ages, while loess horizons developed during glacial epochs, as well as at thermoxerotic stages and endothermic coolings of interglacials. Taphonomic and ecological-coenotic characteristics of the studied palynofloras confirmed conclusion of many researchers about primarily eolian origin of the terrigenous loess material on the Terek-Kuma Lowland.

Conclusions

1. The LPF development on the Russian Plain comprises 17 paleogeographic stages (9 interglacials and 8 glacial epochs between them). Climatic rhythms reconstructed on the basis of palynological studies of the most representative sections within glacial-periglacial and extraglacial zones were compared with paleomagnetic data from the same sections obtained by M.A. Pevzner, S.S. Faustov, A.N. Tretyak and others. It appeared that the Brunhes epoch of normal polarity spanned 8 interglacial and 7 intervening glacial climatic rhythms. The Matuyama/Brunhes reversal is located at the base of the Gremyach'e (= Westerhoven) interglacial (see *Figs 4, 5)*.

2. Smaller climate-stratigraphic units are identified within climatic rhythms of the glacial and interglacial levels: those are endothermal coolings, thermoxerotic and thermohygrotic stages and substages of interglacial climatic rhythms; stadials, interstadials, interphasials, cryohygrotic and cryoxerotic stages and substages of glacial climatic rhythms. *Endothermals* have been identified in a majority of interglacials. The Gremyach'e, Muchkap, Likhvin *s.str.*, Chekalin and Cherepet' interglacials featured one endothermal each, separating thermoxerotic and thermohygrotic stages of the interglacial in concern *(Figs 3–5)*; in loess-paleosol formation of the Mikulino interglacial two endothermals were recorded, one between the stages of this rhythm, and another one in the first half of the interglacial *(Figs 2–5)*. The most complicated pattern of climatic rhythms has been reconstructed for four glacial stages of the LPF development: the Valdai stage features 10 stadial intervals, 9 interstadials and several interphasials; the Dnieper glacial rhythm is divided by a prolonged (Odintsovo?)

interstadial into two (Dnieper and Moscow) stages, with Early Dnieper and Late Moscow interstadials within them *(Fig. 3)*; deposits of the Don and Kaluga glacial stages have been found to contain one interstadial each *(Figs 3* and *4)*.

3. The cold stages of longest duration in the LPF formation, marked by the expansion of ice sheets, were undoubtedly the Don glacial epoch, both stages (Dnieper and Moscow ones) of the Dnieper glaciation, and the Valdai glaciation. It is strongly suggested by the composition of periglacial and glacial palynofloras and reconstructed phytocoenoses, as well as by thickness of periglacial and glacial deposits, the presence of prolonged interstadials and distinct regular alternation of stages and substages within climatic rhythms.

The reconstructions indicate a wide expansion of periglacial tundras and forest tundras in the central regions of the Russian Plain, and dominance of periglacial steppes and forest steppes (less frequently – tundra-forest steppes) in the south; they also suggest a considerable complexity of succession processes in the evolution of phytocoenoses. Ice sheets probably covered the north of the Russian Plain during all the cold stages, and occasionally penetrated the central regions of the plain. Several cold stages in the LPF development – Pokrovka, Devitsa, Kaluga and Zhizdra – which cannot be reliably correlated with till horizons on the Russian Plain resembled closely the Don, Dnieper and Valdai glaciations in the scale of climatic changes and regarding transformation of ecosystems.

4. The results of detailed studies of an almost continuous succession series of the Pleistocene interglacial and periglacial floras made necessary to revise the conclusion drawn by V.P. Grichuk (1989) who considered impossible a paleogeographic situation when on the whole territory of extra-tropical Eurasia an interglacial characterised by a flora poor in exotic elements preceded another interglacial with richer flora. A comparison has been made between series of palynofloras recovered from most complete, almost continuous Pleistocene sequences in the glacial-periglacial and extraglacial loess regions. It appeared that even though the process of depletion of exotic elements in interglacial floras had been undoubtedly in progress throughout the Cenozoic, it was interrupted occasionally during the Early and Middle Pleistocene by the appearance of floras marked by more diverse composition (at levels of species and genera) and richer in Neogene relicts as compared with preceding interglacials. A thorough analysis of the LPF sections in the extreme south-east of the East European loess province (in the middle reaches of the Kuma river) revealed that older interglacial floras – Gremyach'e (= Early Ilyinka) and Semiluki (= Late Ilyinka) – include less Neogene relicts and less taxa altogether than the younger Muchkap warm flora: in the Gremyach'e flora there are less than 50 taxa, amoug them *Nedrus sp., Picea s. Omorica, Betula s. Costatae, Fagus orientalis, Quercus robur, Q. petraea, Q. castaneifolia, Q. ilex, Carpinus caucasica, C. betulus, C. orientalis, Ostrya cf. carpinifolia, Corylus colurna, Tilia platyphyllos, T. tomentosa, T. cordata, Morus sp.* and others, while the Muchkap flora contains 90 taxa, including *Tsuga canadensis, Cedrus, Pinus s. Cembra, Pterocarya pterocarpa, Carya, Juglans cinerea,*

J. regia, Liquidambar, Castanea, Celtis, Ilex aquifolium, Fagus orientalis, F. sylvatica, Carpinus caucasica, C. betulus, C. orientalis, Hedera, Kalonymus, Staphylea, Daphne, Rhododendron, Osmunda regalis, O. claytoniana, O. cinnamomea and many others. By contrast, within the present-day forest zone (the Upper Oka region) the younger Likhvin (= Holstein) flora is by far richer than the Muchkap (= Belovezhsk) one in practically every index. The analysis of quantitative and qualitative changes of palynofloras within the East European loess province strongly suggests a progressive depletion of Neogene relicts in the Pleistocene interglacial floras along with reduction of the taxa number since the Likhvin *s.str.* interglacial in the loess regions within the limits of the modern forest zone, while in the present-day steppe and forest steppe these processes began in the Muchkap interglacial.

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REFERENCES

Agadzhanyan, A.K. 1973. Kopytnye lemmingi pleistotsena. Noveyshaya tektonika, noveyshie otlozheniya i chelovek. Moscow, MGU Press, pp. 320–352.

Artyushenko, A.T.–Arap, R.Ya. and Bezus'ko, L.G. 1982. Istoriya rastitel'nosti zapadnykh oblastey Ukrainy v chetvertichnom periode. Kiev, Naukova Dumka, 135 p.

Balaev, L.G.–Tsarev, P.V. 1964. Lyossovye porody Tsentral'nogo i Vostochnogo Predkavkaz'ya. Moscow, Nauka, 248 p.

Bezus'ko, L.G. 1989. Palinologicheskie dannye k stratigrafii pozdnego pleistotsena zapadnykh oblastey Ukrainy. Saratov, SGU Press, pp. 103–108.

Bogutsky, A.B. 1975. Chetvertynni vidklady. Priroda Volynskoy oblasti. Kiev, Vishcha shkola, pp. 34–67.

Bolikhovskaya, N.S. 1975. Paleogeografiya pleistotsena tsentral'nykh i yuzhnykh rayonov Russkoy ravniny (po palinologicheskim dannym). Avtoreferat kandidatskoy dissertatsii. Moscow, 23 p.

Bolikhovskaya, N.S. 1984. Paleogeography of loess accumulation in the light of palynological data /Lithology and Stratigraphy of Loess and Paleosols. Budapest, pp. 185–194.

Bolikhovskaya, N.S. 1986. Paleogeography and Stratigraphy of Valdai (Wurm) Loesses of the South-Western Part of the East European Plain by Palynological Data. Problems of the stratigraphy and paleogeography of loesses. Lublin, pp. 111–124.

Bolikhovskaya, N.S. 1991. Paleogeography, Stratigraphy and Genesis of the Loess-Paleosol Formation of Northern Eurasia (palynological data). GeoJournal. Dordrech/Boston/London: Kluwer Academic Publishers, *24*. 2, pp. 181–184

Bolikhovskaya, N.S. 1995a. Periglyatsial'nye i mezhlednikovye landshafty pleistotsena Vostochno-Predkavkazskoy lyossovoy oblasti. Moscow, VINITI Press (52–A95), 125 p.

Bolikhovskaya, N.S. 1995b. Periodizatsiya paleogeograficheskikh sobytiy pleistotsena Vostochno-Evropeyskikh lyossovykh oblastey po palinologicheskim dannym. Palinologiya v Rossii, Moscow, pp. 93–123.

Bolikhovskaya, N.S. 1995c. Evolyutsiya lyossovo-pochvennoy formatsii Severnoy Evrazii. Moscow, MGU Press, 270 p.

Bolikhovskaya, N.S. Bolikhovskiy, V.R 1996. Zonal'no-geograficheskie aspekty lyossoobrazovaniya v Evrope. Moscow, VINITI Press (203–A96), 99 p.

Fayner, Yu.B.–Lizogubova, R.N. 1987. Raschlenenie otlozheniy lyossovoy formatsii stepnogo Stavropol'ya i yeyo korrelyatsia s obrazovaniyami periglyatsial'noy zony Evrazii. Inzhenerno-geologicheskie osobennosti tsiklichnosti lyossov. Moscow, Nauka, pp. 103–109.

Fink, J. 1969. Löss – Periglazial – Paläolithikum. Loess–periglaciaire–paleolithique sur le territoire de l'Europe moyenne et orientale. Moscow, pp. 33–60.

Frenzel B. 1964. Zur Pollenanalyse von Lössen. Untersuchungen der Lössprofile von Oberfellabrunn und Stillfried (Niederösterreich). Eiszeitalter und Gegenwart. *15*, pp. 5–39.

Gerasimov, LP. 1939. Problema genezisa i vozrasta lyossovykh otlozheniy v paleogeograficheskom osveshchenii. Izv. geograficheskogo obshchestva. *71*. 4, pp. 497–502.

Grichuk, V.P. 1940. O pyl'tsevoy flore chetvertichnykh otlozheniy (lyossov i drugikh porod) yuga evropeyskoy chasti SSSR. Izv. AN SSSR. Seriya geogr. i geofiz., *4*. pp. 599–616.

Grichuk, V.P. 1989. Istoriya flory i rastitel'nosti Russkoy ravniny v pleistotsene. Moscow, Nauka, 181 p.

Gurtovaya, E.E. 1985. Usloviya formirovaniya dubnovskogo gorizonta na severnoy okraine Podol'skoy vozvyshennosti. Palinologiya chetvertichnogo perioda. Moscow, Nauka, pp. 147–158.

Haase, G.–Lieberoth, I.–Ruske, R. 1969. Diffusion et stratigraphie des loess. Loess-periglaciaire-paleolithique sur le territoire de I'Europe moyenne et orientale. Moscow, pp. 80–100.

Heim, J.–Lautridou, J.-P.–Maucorps, J.–Puissegur, J-J.–Somme, J.–Thevenin, A. 1982. Achenheim: une sequence-type des loess du Pleistocene moyen et supérieur. Bull. Ass. Fr. Et. Quat. *2–3*. pp. 147–159.

Ivanova. L.K. 1981. O stratigraficheskom raschlenenii pozdnego pleistotsena (po materialam Srednego Pridnestrov'ya). Biul. Inst. Geol. *321*, pp. 99–116.

Krasnenkov, R.V.–Holmovoy, G.V.–Glushkov, B.V. 1984. Opornye razrezy nizhnego pleistotsena verkhnego Dona. Voronezh, VGU Press, 212 p.

Kriger, N.I. 1965. Lyoss, ego svoystva i svyaz' s geograficheskoy sredoy. Moscow, Nauka, 296 p.

Lautridou, J.-P.–Paepe, R. and Somme, J. 1982. The Quaternary of Normandy. Livret-quide excursion Q.R.A. BuIL Centre Geomorph. Caen, *26*, 92 p.

Lazarenko, A.A.–Pakhomov, M.M.–Pen'kov, A.V. 1977. O vozmozhnosti klimatostratigraficheskogo raschleneniya lyossovoy formatsii Sredney Azii. Pozdniy kainozoy Severnoy Evrazii. Moscow, GIN Press, pp. 70–133.

Lebret, P. and Lautridou, J.-P. 1991. The loess of West Europe. GeoJournal, *24*. 2, pp. 151–156.

Leroi-Gourhan, A. 1977. Les climats, les plantes et les Hommes (Quaternaire supérieur d'Europe occidentale). Studia Geologica Polonica, Warszawa *52*, pp. 249–261.

Lukashev, K.V. 1961. Problema lyossov v svete sovremennykh predstavleniy. Minsk, AN BSSR Press, 219 p. Markov, K.K., Lazukov, G.I., Nikolaev, V.A. 1965. Chetvertichnyy period. Moscow, Nedra, *2*, 435 p.

Maruszczak, H. 1986. Loesses in Poland, Their Stratigraphy and Paleogeographical Interpretation. Ann. UMCS. Sectio B. Lublin. XLI. *2*. 15–54.

Minkov, M.–Donchev. P. and Evlogiev. J. 1986. Loess Stratigraphy of North-East Bulgaria. Ann. UMCS. Sectio B. Lublin, XLI *3*. pp. 55–65.

Morozova, T.D. 1981. Razvitie pochvennogo pokrova Evropy v pozdnem pleistotsene. Moscow, Nauka, 282 p.

Pakhomov, M.M. 1983. Novye dannye k paleogeografii lyossovo-pochvennoy serii Sredney Azii. Dokl. AN SSSR, 271. 4, pp. 967–972.

Pashkevich, G.A. 1979. Some results of the palynological investigation of the Paks loess profile. Acta Geol. Acad. Hung. 22. 1–4, pp. 461–465.