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# Stratigraphy of Loesses and of Fossil Soils within the Russian Plain and Their Correlation with the Rhythms of Oceanic Bottom Deposits

Stratygrafia lessów i gleb kopalnych na Równinie Rosyjskiej oraz ich korelacja z rytmami sedymentacji na dnie oceanu

Стратиграфия лёссов и ископаемых почв Русской равнины и их корреляция с ритмикой донных осадков океана

ABSTRACT

As a result of many year studies of loess-soil formations of the Russian Plain by a group of co-workers from the Department of Paleogeography, Institute of Geography of the USSR Academy of Sciences, the regions of the Dnieper, Sredne-russkaya Vozvyshennost, the Azov and Volyno-Podolia were successively investigated by a single method involving cryolithological, lithological, paleopedological, spore-pollen, microtheriological approaches as well as those of absolute and relative dating and conjugated-stratigraphic one. As a result of these efforts a scheme of chronostratigraphic classification of loess-soil deposits of the Russian Plain was compiled. Since the end of Eopleistocene not less than 7 warm (interglacial) cycles and nine cold (periglacial) ones are distinguished according to the data on loess-soil formation of the Russian Plain. Development of ice sheets is quite reliably stated for five cold cycles. At the same time problems of correlation of continental subaerial deposits with marine ones remain insufficently studied both by paleoclimatic and sedimentologic data.

Many problems of chronostratigraphy and paleogeography of the Quaternary period are associated with the loess-soil formation of periglacial areas. As compared to other continental formations of the

Quaternary system, the loess-soil has an insignificant number of interruptions and consequently contains in itself quite a complete information on the sequence of natural events for the last 1.0 Ma or 1.5 Ma, including evidence of the alteration of glacial and interglacial epochs, data on the history of permafrost, on the evolution of the soil cover and vegetation, etc. And here quite important is the depth and validity of the chrono-stratigraphic division of the loess-soil strata.

For the last three decades the Paleogeographical Department of the Institute of Geography of the USSR Academy of Sciences has carried out a systematic study of the loess-soil deposits of the Russian Plain, including field works in the basin of the Dnieper river, in the Sredne-russkaya Vozvyshennost', on the Oka-Don Plain, in the Azov Region, and in Volyno-Podolia (Fig. 1). Abundant field and laboratory material

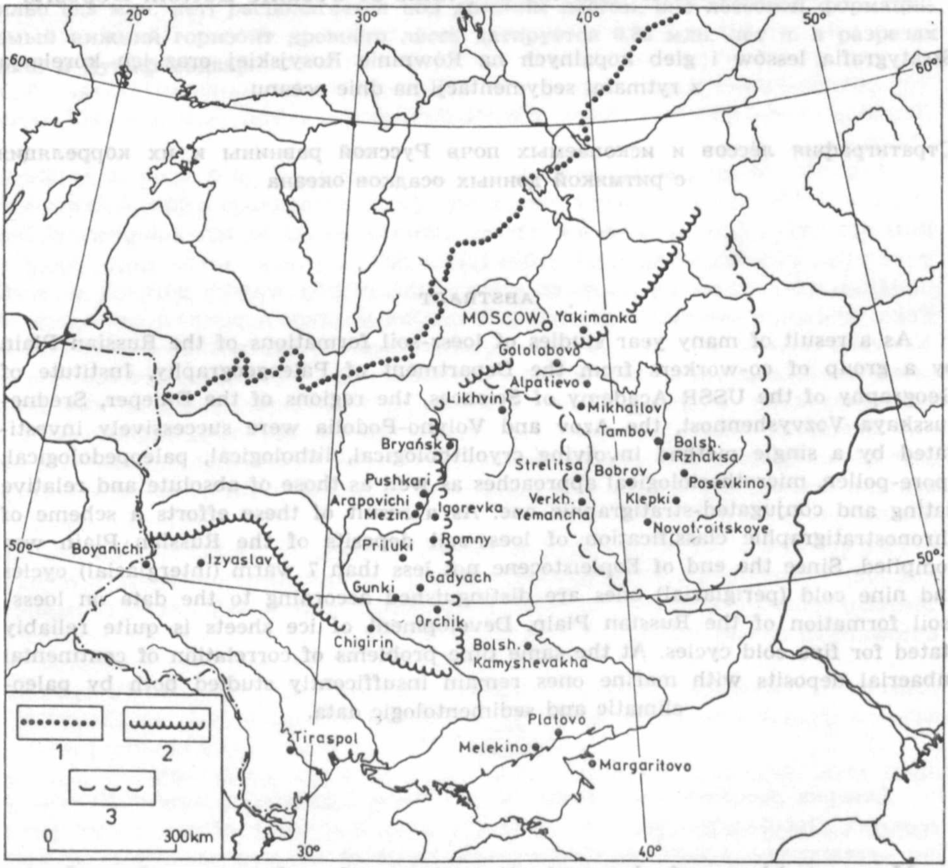


Fig. 1. Situation of the loess-soil sections of the Russian Plain
1 — boundary of the Valdai ice sheet; 2 — boundary of the Dnieper ice sheet; 3 — boundary of the Don ice sheet

has been accumulated and analyzed with the help of a specially elaborated technique and a complex of methods: geomorphological, lithological and geochemical, paleopedological, paleontological (spore-and-pollen, microtheriological, malacological), paleogeomorphological, paleocryological, mehods of relative and absolute datings, and facies-stratigraphic correlations. Such a comprehensive study of the loess-soil strata allows to make a reliable chronostratigraphic division of the deposits in the above regions and a spatial correlation of loess and soil horizons (Fig. 2).

By the degree of reliability, the existing scheme may be divided into three parts: 1) Late Pleistocene — here the scheme is of the greatest chronological validity; 2) Middle and Low Pleistocene — in recent years this part has been much specified and its chronological argumentativeness has considerably improved; 3) Eopleistocene — the chronostratigraphic subdivision of the loess strata in this stage is most retarded and cannot so far be presented in the form of a substantiated scheme.

Below a short account is given of the results that have so far been accumulated on the subdivision of the Pleistocene loess-soil formation in the Russian Plain. First of all, it should be noted that the structural features and, correspondingly, the geological age of loesses and fossil soils in great measure depend on the geographical situation of the studied region, which, in its turn, is conditioned by the following: 1) an uneven preservation of the loess-soil deposits in the region of repeated glaciations (and correspondingly incomplete information on them), as compared with the periglacial zone of the Russian Plain and 2) specificities of the accumulation and preservation of the loess deposits. The most complicated structure of the Late Pleistocene deposits is characteristic of the zone of the maximal accumulation of loesses, i.e. of the middle part of the Russian Plain within the Dnieper Lowland. To the south and to the east (the Oka-Don Plain, the Azov region, the middle and the south Dnieper regions) the thickness of the Late Pleistocene deposits considerably diminishes and their structure is much simpler. Here Middle and Low Pleistocene deposits come close to the present-day surface, which should be taken into account in geological mapping.

In the broadest terms, the following three latitudinal areas may be distinguished in the loess region of the Russian Plain. In the northernmost of them most common are Late Pleistocene series. In the middle area — the Late Pleistocene series are less prominent, while Middle and Low Pleistocene ones are represented more completely. In the southern area there is the predominance of Middle-, Low- and Eopleistocene series, while the Late Pleistocene ones are usually reduced.

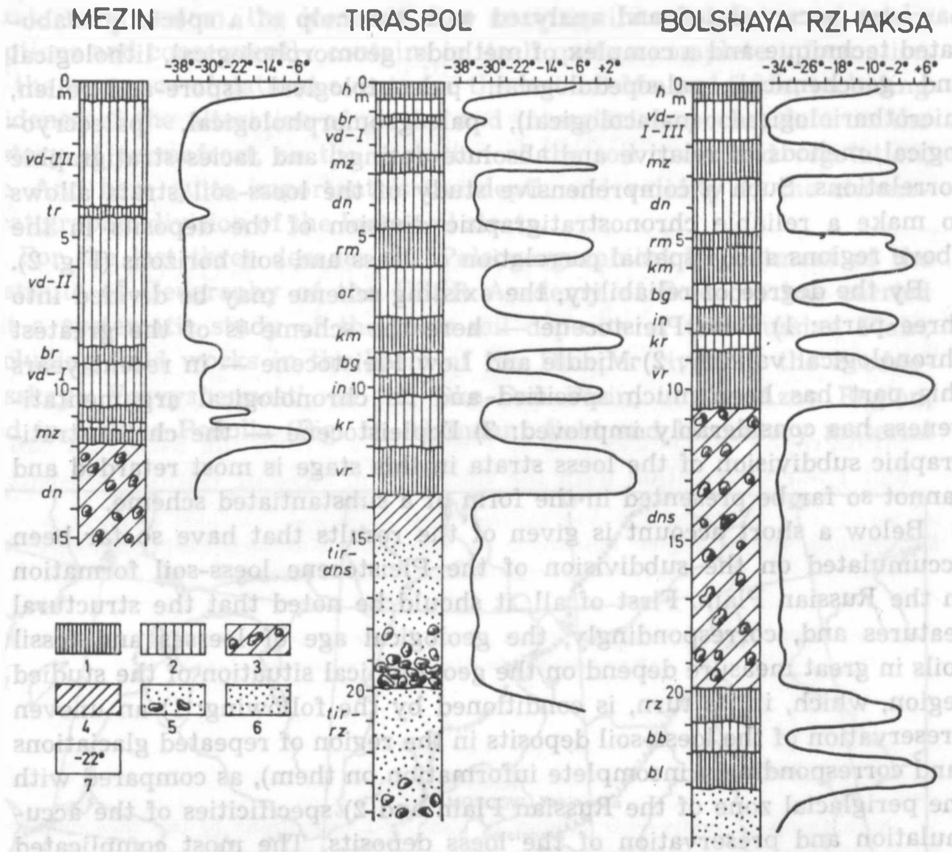


Fig. 2. Relationship of the thickness of loesses and fossil soils with the paleotemperatures in the selected sections

1 — soils; 2 — loesses; 3 — morainic loams; 4 — aquatic loams; 5 — sands with boulders; 6 — alluvial sands; 7 — mean January temperatures. Letter symbols of stratigraphic horizons: h — Holocene, vd — Valdai, tr — Trubchevsk, br — Bryansk, mz — Mezin, dn — Dnieper, rm — Romny, or — Orchik, km — Kamenka, bg — Borisoglebsk, in — Inzhavino, kr — Korostylevo, vr — Vorona, tir — Tiraspol, dns — Don, bl — Balashov, bb — Bobrov, rz — Rzhaksa

## THE LATE PLEISTOCENE LOESS-SOIL SERIES

The Late Pleistocene loess-soil series is most completely represented in the northern half of the Dnieper Lowland, in Volyno-Podolia, in some parts of the Srednerusskaya Vozvyshennost', and in the north of the Oka-Don Plain.

The bedding of the Late Pleistocene loess series is built by a thick polygenetic soil complex — the Mezin complex, which is most stratigraphically valid among other fossil soil complexes. There are two phases in its formation: one during the Mikulino Interglacial and the other during the Krutitsy Interstadial, which has probably corresponded to the interstadials of Brörup and Amersfoort of the beginning of the Valdai glacial epoch. These two phases are divided by a period of temperature fall during which loess material (inter-Mezin Sevsk loess) of a small depth (0.5 to 1.0 m) has accumulated. Soils of the Mikulino Interglacial are well preserved and are quite distinct in the loess sections thanks to their characteristic diagnostic features. By the set of genetic types of soils the Mikulino Interglacial was close to Holocene. In the greater part of the Russian Plain the Mikulino soils are represented by forest soils with an eluvial-illuvial type of profile differentiation, which within the ancient forest-steppe have been replaced by a complex combination of soils of chernozemic and meadow-chernozemic formation and soils in padings with a profile differentiated according to an eluvial-gley type. Only in the southernmost sections there are soils of a chernozemic sequence (T. D. M o r o z o v a 1981). The age of the Mikulino soil formation is determined by spore-and-pollen data, in particular, in the sections of Mezin and Yakimanka, where in depressions soils are facially replaced by peat beds, and by the location of soils above the Dnieper moraine. The following species, "representative" for the Mikulino Interglacial, have been discovered in the section near Mezin village: *Carpinus betulus* L., *Quercus pubescens* W i l l d., *Quercus petraea* L i e b l, *Tilia platyphyllos* S c o p., *Osmunda cinnamomea* L. (A. A. V e l i c h k o et al. 1963). The chronological commonness of the soils has been established by clear genetic interrelations among soils in sections and by morphotypes of cryogenic formations (the Smolensk cryogenic horizon — a system of small wedge-like structures).

During the second (Krutitsy) phase of soil complex formation there has been a strong predominance of a chernozem-like and soddy genesis. Their structure is quite monotonous in the large area, beginning with Volyno-Podolia in the west and up to the Oka-Don Plain in the east. The chronological commonness of the soils is corroborated by the genetic conjugation of soils, by their location above the soils of the Mikulino Interglacial and by radiocarbon datings exceeding the limits of the method, which does not contradict the correspondence of the age of the Krutitsy Interstadial to that of the Amersfoort-Brörup interstadials in the West European schemes (between 65 and 54 ka ago). The age of the soils is also corroborated by the presence of uniform cryogenic deformations (phase "a" of the Smolensk cryogenic horizon). They are represented by non-structural deformations in the form of a series of crumplings and tongues with signs of squeezing out (involution and cryoturbation). The following forest-steppe fauna of small mammals has been discovered in krotovinas (the Gadyach section): *Lagomorpha: Ochotona pusilla; Rodentia: Citellus* sp., *Cricettulus migratorius, Lagurus aff. lagurus, Microtus (Stenocranius) gregalis, M. agrestis* (A. K. Markova 1982).

The Mezin soil complex is covered by a horizon of the Valdai loess I (Khotylevo) with a sustained depth of about 2 m. This loess serves as a bedrock for the soils of the Bryansk time. The Bryansk interval is considered by the authors to be a rise in temperature of an interstadial kind. Its age limits between 24 and 32 ka BP have been determined by the radiocarbon method (Table 1). At that time soils of predominantly cryogenic-gley genesis have formed. Chronologically the unity of the

Table 1. The absolute age of the Bryanski fossil soil and of its analogues

| Section | Horizon | Material for dating | Number and index | Age BP according to $^{14}C$ |
|---|---|---|---|---|
| Sungir' | Bryansk soil | Charcoal | | 25,500 ± 200 |
| Bryansk | Bryansk soil | IK sum | Mo-337 | 24,920 ± 1800 |
| Arapovichi | Bryansk soil | IK sum | IGAN-46 | 24,000 ± 300 |
| Mezin | Bryansk soil | IK sum | Mo-342 | 24,200 ± 1680 |
| Mezin | Bryansk soil | IK sum | IGAN-88 | 24,300 ± 370 |
| Mezin | Bryansk soil | IK sum | IGAN-89 | 24,210 ± 270 |
| Fatianovka | Bryansk soil | IK sum | IGAN-197 | 22,300 ± 250 |
| Zheleznogorsk | Bryansk soil | IK II fr. | IGAN-338 | 26,390 ± 900 |
| Mezhirich | Bryansk soil | GK II fr. | IGAN-337 | 25,150 ± 740 |
| Novokhopersk | Bryansk soil | IK sum | IGAN-87 | 22,840 ± 220 |
| Krasnoselka | Dubnovka soil | IK sum | IGAN-170 | 29,400 ± 1000 |
| Basov Kut | Dubnovka soil | IK sum | IGAN-74 | 28,400 ± 850 |
| Dolní Věstonice | PK I | IK sum | GrN-2092 | 28,300 ± 300 |
| Dolní Věstonice | PK I | Charcoal | GrN-2598 | 29,000 ± 200 |
| Mende | Mende | Charcoal | Mo-422 | 29,800 ± 600 |
| Mende | Mende | Charcoal | USA-3130 | 27,200 ± 1100 |
| Loza III, No 2 | Glain soil | Loam | Bln-360 | 25,246 ± 1000 |
| Stillfried | Stillfried B | Coal | GrN-2533 | 28,120 ± 200 |
| Sittard | soil | unknown | GrN-2371 | 27,990 ± 670 |
| Zelzate | "Kesselt" | unknown | GrN-4783 | 28,270 ± 270 |

soils is established by the structure of profiles which are genetically interlinked within a vast territory with clear diagnostic indices and by the character of cryogenic deformations of the Vladimir cryogenic horizon characterized by smal structural wedge-shaped deformations of the type of patches-medallions in the central regions of the Russian Plain and non-structural deformations in the western ones (A. A. Velichko and T. D. Morozova 1972b, T. D. Morozova 1981).

According to Z. P. Gubonina (A. A. Velichko et al. 1980) and E. E. Gurtovaya (1981), the basis of the spore-and-pollen spectres from the horizon of the Bryansk fossil soils, in the section of the centre of Arapovichi, Mezin and in the south-west of the Russian Plain (Izyaslav and Boyanichi) is comprised by the pollen of those species which belong to yernik communities with *Betula nana, Betula humilis*, and *Alnaster fructicosus* (the modern area of the latter does not go beyond the southern boundary of permafrost). There is also some amount of the pollen of *Botrychium boreale, Selaginella selaginoides, Lycopodium alpinum, Lycopodium selago*, whose present-day areas are mainly found within the European Arctic region.

In the Bryank soils near the village of Arapovichi a tundra-steppe fauna of rodents has been discovered, including *Rodentia: Marmota* sp., *Citellus* sp., *Lagurus aff. lagurus, Dicrostonyx guliemi-henseli, Microtus gregalis* (A. K. Markova 1972).

The Bryansk fossil soil is covered by a horizon of the Valdai loess II (Desna), which is the thickest among the Late Pleistocene loess horizons (3 or 4 m). It has the most typical loess properties as it has not been subjected either to recent or to ancient soil formation. The horizon of the Valdai loess II (Desna) is separated from the horizon loess III (Altynovo) by the Trubchevsk fossil soil (the level of gleyification) — a thin soil formation of a cryogenic genesis, which has probably corresponded to the time of a certain warming of climate during the long Valdai glacial epoch. Judging by the datings from the Eliseevichi site, the radiocarbon age of this level is close to 17 ka. As compared to loess II, the loess III is somewhat sandy.

The concluding stages of the Valdai glacial epoch are noted for a new cryogenic period during which the Yaroslavl' cryogenic horizon has formed.

Loess III has served as a bedrock for the Holocene soils, including the best expressed Timonovka middle Holocene soil. The radiocarbon age of the humus substances in the system of Holocene soil formation is 8 or 9 ka BP.

THE MIDDLE AND THE LOW PLEISTOCENE

The horizon of the Dnieper loess is the most recent and most important stratigraphic horizon of the complex Middle and Low Pleistocene series. Its geological age may quite accurately be determined thanks to the facies relationships with the Dnieper glacial deposits. The facies replacement of the Dnieper loess by the Dnieper moraine may be observed in a number of sections of the Dnieper basin (Pushkari, Arapovichi, Mezin, Priluki) and of the Oka (Gololobovo and Alpatievo). The age of the Dnieper loess, as well as the age of the moraine of the Dnieper tongue, is indirectly indicated by the bedding of the Mezin soil complex above it, while just beneath it in the southern half of the Russian Plain there is the Romny soil. In the fluvio-glacial deposits lying in the base of the Dnieper loess, in the Alpatievo section of the Oka river, V. P. Udartsev (1980) collected fauna reflecting cold conditions (A. K. Markova 1982), which in its species and evolution level is comparable with the lemming fauna in the Kipievo I section belonging to the glacial epoch of Middle Pleistocene (A. K. Agadzhanyan and K. I. Isaychev 1976).

The Dnieper glacial epoch was characterized by intensive processes of loess accumulation. To the south of the boundary of the Dnieper glacier, loesses of this age are found practically in all the sections up to the coastal regions. In the north of west Ukraine, of Srednerusskaya Vozvyshennost' and of the Oka-Don Plain, the Dnieper loesses reach maximal depth from between 6 and 7 m, to between 10 and 12 m. To the south and the south-east the thickness of the loess gradually diminishes to 3 or 4 m, and sometimes to between 1.5 and 2 m.

Inside the Dnieper loess one may distinguish one (two?) weakly developed levels of soil formation of an interstadial character (in particular the Kursk soil), as well as two levels of cryogenesis with structural deformation of a pseudomorphosis type along secondary vein ice, which are particularly prominant in the basin of the Oka river in the sections of Mikhailov and Alpatievo (A. A. Velichko et al. 1984).

Directly under the Dnieper glacier deposits there is the Romny fossil soil, which is predominantly common in the loess deposits of the central and south Russian Plain. In the zone of the Dnieper glacier extent the soils of this age are changed by the processes of diagenesis, they are gleyed and often partially destroyed. In the extraglacial area the soils are preserved much better (A. A. Velichko and T. D. Morozova 1972a, T. D. Morozova 1971, V. P. Udartsev and S. A. Sycheva 1981). T. D. Morozova referred these soils to brown-like ones. They are distinguished by a brown-chestnut color of a strongly clayed soil profile and by a carbonate illuvial horizon (T. D. Morozova 1971, A. A. Velichko et al. 1984). It is characteristic that the soils of this horizon in the sections are close to the older soil complex — the Kamenka one (in the former sense — Senzharsky; A. A. Velichko and T. D. Morozova 1972a). The Kamenka fossil soil is one of the most expressive ones marking the Middle Pleistocene loess-soil series of horizons. These are thick humified soils which, in the early development stages, have been characterized by the processes of lessivage. The latter have brought about the formation of textural differentiated profiles, irregularly preserved and lying beneath the humus-accumulative horizons that have formed in the following phases of pedogenesis. In the south regions of the Russian Plain the processes of lessivage are not expressive. Here quite common were soils with illuvial carbonate horizons.

In the krotovinas of the Kamenka soil, in the sections of Priluki and Rasskazovo, the Khazar fauna of rodents has been discovered (A. K. Markova 1982). All the bone remains are of the genera which exist at present as well, although there are features showing that they are archaic *. The fauna of Priluki includes only steppe species (A. K. Markova 1982).

Beneath the Kamenka horizon, in the middle part of the Russian Plain, there is a horizon of loess (Borisoglebsk) and above it a layer of burozem-like soils, which in the southern sections are replaced by reddish soils sometimes divided into two levels similar in structure. This soil stratum forms the Vorona soil complex (A. A. Velichko et al. 1984).

The soils of the Vorona complex are found in the basin of the Dniestr, Dnieper, Severnyi Donets and Don rivers. Their specific features are as follows: a brownish colour (in the more southern sections — reddish -brown), a clayey texture, the presence of a horizon with abundance of big stone-like carbonate concretions, an intensive colouration of the fine-dispersed mass by iron hydroxides, and in the northern sections — the presence of the features of gleying and of the mobility of clay mass (lessivage). In relief depressions there are dark hydromorphic soils. In the basin of the Don river the Vorona soils complex lies on the horizon of the Don moraine.

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* Meadow mice of *Lagurus genus* include several specimens of a "Transiens" structure. *Lagurus transiens* is most characteristic of the developed Tiraspol faunas, but remains of the "Transiens" outlook are also found in the Singil faunas, where they prevail over the teeth typical of *L. lagurus*. In Priluki the remains of voles with a structure characteristic of *L. lagurus* predominante, contrary to those from the Singil sites.

In a number of sections of the Oka-Don Plain (Perevoz, Posevkino) and of the Severnyi Donets basin (V. Kamyshevakha), from the krotovinas of the lower part of the Vorona soil complex lying directly on the Don moraine A. K. Markova (1982) extracted and determined late Tiraspol heat-requiring faunas of small mammals, characterized by the presence of remains of the last representatives of *Mimomys-M. intermedius genus* — the voles of *Lagurus transiens* species and by several species of the *Microtus genus*. All these faunas consist of predominantly steppe species; cold-enduring species have not been discovered, while forest ones have been met with in quite insignificant numbers. Thus, one may assume that at least the initial phases of the formation of the soil complex above the Don moraine have coincided with the time of the late Tiraspol fauna.

Thus, the above series of soils and loesses occuring between the Dnieper and Don moraines is in a chronological "fork", where the findings of the Khazar fauna from the krotovinas of the Kamenka soil in the sections of Priluki and Rasskazovo are the most recent reference point and those of the late Tiraspol fauna from the bottom layers of the Vorona complex — the most ancient one. The findings of the Singil fauna are the third — middle reference point. Unfortunately, the findings of the Singil fauna are not directly connected with the soil horizons. In the sections of Gun'ki, Chigirin, and V. Yemancha they have been discovered in the alluvium beneath the Kamenka fossil soil. The latter is developed on a loess-like material corresponding to the upper layers of the Borisoglebsk loess, which turns into alluvium proper — equivalent of the Borisoglebsk horizon. The lower part of the alluvium stratum is of a different character. In the Gun'ki section there is an interglacial turf peat of a Likhvin (Holstein) age (Z. P. Gubonina 1980).

The Singil fauna is known to have existed in the period of the Likhvin Interglacial, which is proved by simultaneous findings of bone remains and spore-and-pollen complexes of a Likhvin type in the sections of Gun'ki and Likhvin (Z. P. Gubonina 1980). Contrary to the more ancient Tiraspol faunas, the Singil ones do not contain any remains of the ancient molar teeth voles of the *Mimomys genus* and the ancient genus of *Prolagurus*. The Singil faunas are distinguished by the flourishing of *Microtus genus*, meadow mice are represented by the *Lagurus genus* (the species of *Lagurus transiens* and *L. lagurus*). In these faunas the first specimens of the ancient water voles *Arvicola mosbachensia* appear. In the Khazar faunas they are replaced by a more progressive *A. chosaricus*. Thus, the Singil faunas differ quite distinctly from the older Tiraspol and the younger Khazar ones (A. K. Markova 1982).

Proceeding from the geological data, one may assume that the Likhvin

Interglacial may most probably correspond to the upper of the reddish-brown coloured soils of the Vorona complex. The more ancient phase of the Vorona complex lying on the Don moraine, in whose krotovinas there are remains of small mammals of the late Tiraspol age, is parallel to the Muchkap Interglacial. At the same time, because soils in the section are located close to each other, one may raise the question about existence of one interglacial with a complex nature and with several phases of intensification of soil formation, corresponding to the interval which embraces the Muchkap and the Likhvin time with possible fall of temperature inside it.

Thus, judging by the structure of loesses and fossil soils, within the interval between the Don and the Dnieper glaciations one may distinguish not less than three independent warm epochs of an interglacial type divided by cold epochs of loess accumulation.

As noted above, the age of the moraine of the Don glacial tongue is determined as being Early Pleistocene according to the fauna of small mammals. In the extraglacial zone a horizon of loess corresponds to the Don moraine. The greatest thickness of the Don loess (up to 10 m) is found in the section of the east Azov regions. Here, inside the loess two weak brown levels of soil formation are distinguished, which are probably of an interstadial character.

Beneath the Don moraine, still within the Pleistocene stratum, the Novaya Pokrovka loess-soil series is distinguished. In the sections this series is underlain by the Trostnyansk loess and by red-coloured Eopleistocene clays. Data from the sections of the Oka-Don Plain (V. P. Udartsev) and of the Azov regions show that in the Novaya Pokrovka loess-soil series two fossil soils may be distinguished — Rzhaksa and Balashov, as well as the Bobrov loess. The Trostnyansk loess belonging already to Eopleistocene directly lies on red-coloured soils. Unlike the above, the cover deposits of this time interval are much less studied. The fossil soils — Rzhaksa and Balashov ones — within the Oka-Don Plain have quite a similar structure of profiles.

The Rzhaksa soils have a clear humus-accumulative horizon, which in the more southern sections acquire a brown colour, while in the lower part of the profile there appear an illuvial-carbonate horizon. So far no zonal changes in the properties of the Balashov soils have been established.

The Bobrov and Trostnyansk horizons of loesses have not been preserved in the sections in a pure form. They are not thick — between 1.5 and 2 m and, as a rule, they have been subjected to soil processes. The age interval of this loess-soil series is quite reliably determined by the fauna of small mammals and by the paleomagnetic boundary of Brunhes--Matuyama.

A krotovina horizon of the Balashov soils from the Novotroitskoye section has yielded a rodent fauna, which in the species composition is somewhat older than the Eopleistocene faunas of Karai-Dubina and Petropavlovka (R. A. Krasnenkov and A. K. Agadzhanyan 1975). In these faunas the *Microtus genus* appears for the first time (species *M. ex gr. eoconomys*). In the Novotroitskoye site remains of *M. oeconomys* have not been discovered, which may be due to this site being older than the Karai-Dubina and the Petropavlovsk ones. In accordance with paleomagnetic data, the Balashov fossil soil containing the fauna belongs to the Matuyama epoch.

In the sections of the Azov region this Early Pleistocene series is underlain by liman-marine deposits containg fauna of the Nogai complex. The Rzhaksa fossil soil, as well as a number of sites with the Tiraspol fauna of rodents (the sections of Novokhopersk, Klepki, Uryv IV, Platovo I—II) are found in the zone of a normal Brunhes polarity. Proceeding from the above, we may circumscribe the transitional Brunhes-Matuyama zone by the Bobrov loess dividing the Balashov and Rzhaksa fossil soils (A. A. Velichko et al. 1984).

Thus, in accordance with the data on the structure of the loess-soil formation of the Russian Plain, since the end of Eopleistocene not less than 7 warm (interglacial) and 9 cold (periglacial) cycles are distinguished within the Pleistocene stratum. The development of ice sheets during five cold cycles has been quite definitely proved.

As shown by the above, the scheme of periodization of the Pleistocene loess-soil series of the Russian Plain, elaborated at the Institute of Geography of the USSR Academy of Sciences, in its present form is based on a complex of reliable methods providing for a geochronological verification within certain ranges. At the same time, the methods have been applied with account of their workable ability. Of the polarity changes the scheme has so far used only the boundary of the Brunhes--Matuyama epochs, while data on the episodes inside the Brunhes zone (Chegan, Blake, Lashamp or Geteborg) have not been used. The work to this end is undertaken, but for the present there are no reliable results for the series of similar sections. Thermoluminescence dating results have not been included into the scheme either, although research in this field is also carried out. Even from the most verified isotope--carbon method only dates not older than 30—40 ka BP are used and only those which have been directly received from the studied horizons of fossil soils. The major geochronological information within the Middle and Low Pleistocene is provided by the microtheriological method, which is very detailed and whose degree of verification is high and, in fact, is of a global character. In the suggested scheme almost every soil horizon has a microtheriological characteristic. Moreover, the faunistic remains have been extracted directly from these horizons and, correspondingly, they are of special significance for dating.

Thanks to the use of a complex of methods, the presented scheme may be utilized for correlating geochronological schemes of loess-soil series in different regions.

## PROBLEMS OF GLOBAL CORRELATIONS

The results of many studies have illustrated a high efficiency of chronostratigraphic constructions based on loess-soil series for the purposes of interregional and intercontinental correlations of natural events of the whole Quaternary system (La stratigraphie des loess... 1969, Paleogeografiya Evropy... 1982). However, such correlations could embrace only continents.

Chronostratigraphic studies of the Quaternary period by data on the deep-water deposits of the ocean have expanded much later than the studies of loesses and soils, which is due to great technical and methodological difficulties. Nevertheless, the rapid progress in the development of this branch of geology has allowed to obtain important results about the specificity of thermal changes in the Quaternary time within the ocean, about the cyclic character of these changes, and about the structure of the whole sequence of temperature fluctuations.

The type of high-frequency fluctuations detected in the bottom deposits has shown their principal similarity with those registered on the land while studying loess-soil series. The comparability of the curves plotted for the ocean bottom deposits with those for the loess layers is also due to some similarity in the processes of sedimentations: in both the cases the accumulation of strata goes on mainly with the predominance of a vertical deposition of suspended matter (from the water medium in the ocean and from the air on land) of predominantly fine — silt and clay fractions, although, naturally, in both the media a significant role has been played by the lateral components of sedimentation as well (due to water and air flows, drifting and redeposition in the relief wrinkles, etc.).

At the same time, the materials on chronostratigraphy of loess-soil series and of oceanic bottom sediments accumulated so far are so diverse that one should sooner speak about prospects of correlation than about undertaking a detailed correlation, which in the present stage seems to be hardly valid.

The difficulties lie in the level of scientific knowledge of both the objects. Let us examine data on deep-water deposits (N. I. Shackleton and N. D. Opdyke 1976, and others). The oxygen-isotope curves obtained by the materials of deep-water drilling have two chronological reference points. One of them refers to the last, Late Pleistocene cycle (stages 1 to 5) — stage 5 has been dated by a non-equilibrium uranium within the range between 130 and 110 ka BP in the terraces of Barbados and in other sections. The second reference point is the boundary of the normal and reverse polarity of Brunhes-Matuyama established in the columns themselves. According to the most accepted data, its age is 730 ka BP* in this chronological "fork" there is a series of the levels of isotope $O^{18}$ content changes (peaks). These peaks do not contain specific chronostratigraphic criteria and their age is determined on the basis of the calculations of sedimentation rates. Estimations are made proceeding from the depth of layers belonging to a certain epoch of polarity. Conditionality of such estimations for the chronostratigraphic purposes is obvious. The more so as the volumes of key wells, which are used for the construction of the general oxygen-isotope curve, differ much.

For instance, in the column V 28—238 the boundary of Brunhes--Matuyama is at the depth of 1,200 cm, while in the column V-28-239 at 730 (740) cm. There is almost a twofold difference in the rates of sedimentation of the boreholes — correspondingly 0.02 mm/year (0.017 mm/year) and 0.01 mm/year. And although the authors believe that in chronological constructions one should rely more on the data from the borehole V 28—238, one cannot but pay attention to the fact that both the boreholes are located next to each other. It suggests an idea that the conditions of bottom sedimentation even in one place are very changeable, which is an additional proof of the conditionality of such chronological estimations.

One must note that for chronological calculations general velocity of sedimentation (1 cm for 1 ka) was assumed with no account of differences in accumulation intensity in glacial and interglacial epochs. Meanwhile by the results of studies of bottom sediments of Late Pleistocene proper velocity and volume of sedimentation during glaciation epoch is known to sharply increase if compared to interglacial. With the account of mentioned differences the nature of peaks and their intercorrelation on oxygen-isotope curve will change. Finally, we can not but pay attention to the fact that even without such correction the character of peak alternation in both wells located side by side is remarkably different

* In the given article we do not consider older time intervals, as the probability of correlation with the loess horizons at these levels greatly decreases due to the absence of mature loess strata.

(even after they were adjusted to ones and the same stages), which warns against chronological absolutization of the distinguished peaks.

As for loess-soil series we may note that researches of their chronostratigraphy are in a more favourable position. Here again the mentioned chronological "fork" may be used. Besides a successive series of dates obtained by radiocarbon method may be used at the range of the second half of Late Pleistocene. This allows to make differentiated estimates of velocities of loess accumulation at different intervals of the glacial epoch, in addition to age determination for some horizons. The calculations performed (A. A. Velichko 1973) showed the maximum velocities to be at the interval of 25—16 ka ago when they were close to 0.3—0.4 mm/year. As for the epoch of accumulation of the early Valdai (early Vistulian) Khotylevo horizon of loess, the velocity in it comprised 0.04 or 0.05 mm/yr., i.e. it became less almost by an order.

The data on loess horizon accumulation velocities obtained for Late Pleistocene were used for calculations of continuous accumulation of Middle and Lower Pleitocene loess horizons of different age within the limits of Brunhes epoch. A choice had to be made between two obtained velocities of sedimentation. High velocity data (0.3—0.4 mm/year) led to deliberately lower values of the duration of cold epochs. Their total value for the whole Brunhes epoch would have been equal to 50 ka, i.e. shorter than the duration of even one Late Pleistocene glacial epoch. Therefore another lower velocity of sedimentation was assumed which was equal to 0.05 mm/year. It is natural that the estimates of continuation of cold epochs obtained in this case also should be considered as conditional since loess accumulation velocity had to change not only within one glacial epoch (and it is yet unclear whether this accumulation took place during the whole epoch), but it had to change from one epoch to another. Nevertheless the order of the obtained values is rather realistic. However it would be more correct to speak about duration of loess accumulation epochs than about that of cold epochs, since these notions concerning the duration may be not quite identical.

The values of loess accumulation epoch duration are also proportional to thicknesses of loess horizons. Let us dwell upon compiling a system series of loess horizon thicknesses. The first part of the article showed the thicknesses of loess horizons of different age to vary regularly in meridional direction. In the northern zone the maximal thickness is typical for Late Pleistocene loesses, in the middle zone — for those of Middle Pleistocene, in the southern — for Lower Pleistocene ones. The mentioned differences are regular, they correlate with the position of boundaries of ice sheets of different age whose dimensions reduce on the whole from Early to Late Pleistocene. On the basis of such dependence thicknesses of horizons of different age were selected in the zones of their maximal accumulation, i.e. in that part of periglacial area of a respective glaciation where loess accumulation process was manifested most of all. Being so we assumed the mean values of thickness of a given horizon occurring in certain geomorphological conditions, within the limits of watershed plateaus where these levels have minimal inclination to river valleys.

To implement the mentioned proceedure plain areas of Eastern Europe are referred to the number of regions with two advantages: 1) loesses are widely distributed here, 2) they occur on solidified surfaces where the effect of local removal conditions — redeposition — is reduced. From this point of view loesses of Central Europe, which were used earlier for chronostratigraphic correlations with deep-sea sediments, are very difficult for analysis — we must introduce here additional corrections for the processes of local redistribution of loesses under conditions of rough hill-hollow relief when loesses themselves have discontinuous island-like and on the whole not wide distribution with large variability of thicknesses.

On the basis of the above-said prerequisites calculations were made of the duration of loess accumulation in cold epochs of different age (Fig. 3). It became clear that even at low sedimentation velocities the total duration of these epochs within the last 700 ka did not exceed 400 ka which correlates with the conclusions made before (A. A. Velichko 1973) to the effect that duration of warm (interglacial) epochs was also great (on the total even within the limits of Pleistocene it reached 40%). At these periods, processes of primary sedimentation significantly reduced and soil formation took place, the soils being later on buried under younger loess horizons. Sharp irregularity stated in sedimentation velocities in cold and warm epochs is almost beyond any account, whether quantitative or factual, since criteria of concrete estimates of duration of these or other soil formation processes do not exist so far. Estimation of duration of warm epochs is based on only very general considerations (thickness of soil profiles, the type of pedogenesis). Moreover the known values of warming referring to Late Pleistocene were subtracted from the sum of time of warm epochs.

As was already mentioned we may have no doubt that such irregularity is "concealed" in oxygen-isotope curves of oceanic sediments as well, while the averaged velocity of their sedimentation equal to 0.01 mm/year does not reflect a change of sedimentation velocities from cold to warm epochs. By the way, we can obtain the same value of velocities of 0.01 mm/year if we divide the sum of thicknesses of all loess horizons by the time of epoch. As follows from the above-said

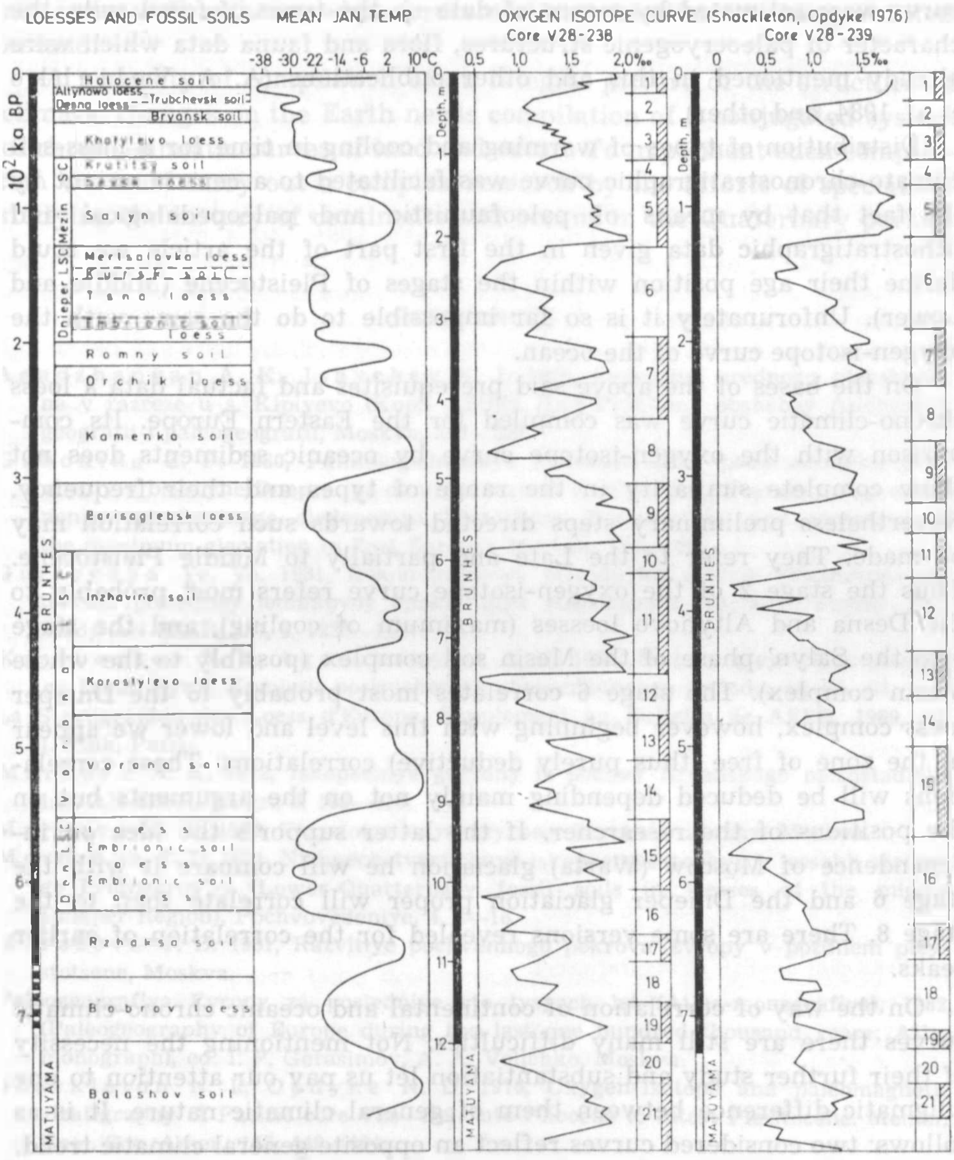


Fig. 3. Correlation of warm and cold cycles of Pleistocene according the data on continental loess-soil formations and oceanic sediments

however loess accumulation velocities in fact were different. Such a discrepancy is an indirect confirmation of the conclusion that the oxygen-isotope curve after being corrected for velocities may look essentially different.

Temperature variations on a loess-soil climato-chronostratigraphic curve were estimated by means of data on the types of fossil soils, the character of paleocryogenic structures, flora and fauna data which were already mentioned in this and other publications (A. A. Velichko et al. 1984, and other).

Distribution of types of warming and cooling in time for a loess-soil climato-chronostratigraphic curve was facilitated to a certain extent by the fact that by means of paleofaunistic and paleopedological and lithostratigraphic data given in the first part of the article we could define their age position within the stages of Pleistocene (Middle and Lower). Unforunately it is so far impossible to do the same with the oxygen-isotope curve of the ocean.

On the bases of the above said prerequisites and factual data a loess chrono-climatic curve was compiled for the Eastern Europe. Its comparison with the oxygen-isotope curve by oceanic sediments does not show complete similarity in the range of types and their frequency. Nevertheless preliminary steps directed towards such correlation may be made. They refer to the Late and partially to Middle Pleistocene. Thus the stage 2 of the oxygen-isotope curve refers most probably to the Desna and Altynovo loesses (maximum of cooling), and the stage 5 to the Salyn' phase of the Mesin soil complex (possibly to the whole Mesin complex). The stage 6 correlates most probably to the Dnieper loess complex, however beginning with this level and lower we appear in the zone of free (thus purely deductive) correlations. These correlations will be deduced depending mainly not on the arguments but on the positions of the researcher. If the latter supports the idea on independence of Moscow (Warta) glaciation he will compare it with the stage 6 and the Dnieper glaciation proper will correlate then to the stage 8. There are some versions revealed for the correlation of earlier peaks.

On the way of correlation of continental and oceanic chrono-climatic curves there are still many difficulties. Not mentioning the necessity of their further study and substantiation let us pay our attention to one enigmatic difference between them of general climatic nature. It is as follows: two considered curves reflect an opposite general climatic trend. Investigation of fossil soils of different age, cryogenic phenomena, pollen spectra and so on indicate a general trend to cooling from the beginning of Pleistocene towards its end. The subsequent interglacial warm peaks are mostly colder than the preceding ones the same refers to cold peaks of loess accumulation to a certain extent.

A reverse trend is revealed by an oxygen-isotope curve — it is directed just as individual successive cold and warmth peaks towards warming from the beginning of Pleistocene towards its end which does not agree well with the whole process of natural climatic changes stated on land.

A necessity of compilation of an integral picture of the structure of climatic changes on the Earth needs compilation of a conjugated system of chrono-climatic curves of land and ocean. To implement such compilation we must carry out a complex research by the efforts of specialists studying the history of continents and oceans in the Quaternary period.

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## STRESZCZENIE

Schemat chronostratygraficznego podziału (Fig. 3) lessowo-glebowej formacji Równiny Rosyjskiej był opracowany na podstawie wieloletnich badań w rejonach Dniepru, Wyżyny Środkoworosyjskiej, Wołynia, Podola i Niziny Nadazowskiej, prowadzonych według stałych zasad i przy zastosowaniu metod: paleopedologicznych, litologicznych, palinologicznych, datowania bezwzględnego i względnego oraz kompleksowej analizy stratygraficznej.

Według tych badań dolną granicę młodoplejstoceńskiej serii lessowo-glebowej wyznacza okres rozwoju gleby w interglacjale mikulińskim (optimum — 125 ka BP). Gleby z tego okresu mają wyraźne cechy diagnostyczne pedogenezy środowiska leśnego i stepowego strefy subborealnej; jest to sałyńska faza (Salyn soil) poligenicznego kompleksu mezińskiego. Warstwy lessów wałdajskich (vistuliańskich) zawierają trzy gleby kopalne rangi interstadialnej: kruticką (Krutitsy soil), briańską (Bryansk soil), trubczewską (Trubchevsk soil) oraz cztery poziomy lessów: sewski (Sevsk loess), chotylewski (Khotylevo loess), deśniński (Desna loess) i ałtynowski (Altynovo loess). Gleba interstadiału krutickiego, reprezentująca młodszą fazę mezińskiego kompleksu (64—55 ka BP), oddzielona jest od gleby mikulińskiej lessem „wewnątrzmezińskim", czyli sewskim. Poziom lessu I (chotylewskiego) o miąższości około 2 m powstał w interwale 60—33 ka BP. Gleba briańska ma wyraźne cechy diagnostyczne pedogenezy typu zmarzlinowo-glejowego i zawiera szczątki małych ssaków lemingowego zespołu faunistycznego; jej wiek radiowęglowy określono na 32—24 ka BP. Pewne złagodzenie klimatu w okresie długotrwałego zlodowacenia wałdajskiego rejestruje zmarzlinowo-glejowa gleba trubczewska (17—16 ka BP) oraz jarosławski poziom kriogenezy (15—14 ka BP). W końcowych etapach zlodowacenia (16—13 ka BP) powstał less III (ałtynowski).

Środkowo- i staroplejstoceńska seria lessowo-glebowa obejmuje co najmniej trzy gleby kopalne. Oznaki i natężenie pedogenezy świadczą, że są to gleby inne niż młodoplejstoceńskie związane z warunkami umiarkowanego klimatu okresu interglacjalnego czy peryglacjalnego okresów interstadialnych. Tak więc występujące pod lessem dnieprzańskim gleby interglacjału romieńskiego zalicza się do grupy buropodobnych, z interglacjału kamieńskiego — do poligenicznych czarnoziemnopodobnych z teksturalnym poziomem iluwialnym, a z interglacjału worońskiego — do brunatnoziemnopodobnych i czerwonobrunatnych oraz wiążących się z nimi ciemno zabarwionych gleb zagłębień bezodpływowych. Wśród utworów morenowych dnieprzańskiego zlodowacenia oraz odpowiadających im lessów występują szczątki fauny należącej do zespołu chazarskiego. Romieńska gleba (Romny soil), występująca bezpośrednio pod dnieprzańskimi osadami glacjalnymi, jest podobna do starszej od niej gleby kamieńskiej (Kamenka soil). W kretowinach gleby kamieńskiej stwierdzono szczątki małych ssaków zespołu chazarskiego, ale bez form arktycznych charakteryzujących okres zlodowacenia dnieprzańskiego. Pod glebą kamieńską występuje less borisoglebski (Borisoglebsk loess), oddzielający ją od worońskiego kompleksu glebowego. Górna gleba (Inzhavino soil) z tego kompleksu zawiera szczątki małych ssaków singilskiego zespołu faunistycznego. Natomiast gleba dolna (Vorona soil), występująca na morenach zlodowacenia dońskiego, jest dobrze datowana przez szczątki małych ssaków młodotiraspolskiego zespołu faunistycznego. Wiek moreny lądolodu dońskiego określa fauna małych ssaków zespołu tiraspolskiego. Poniżej moreny dońskiej występuje nowopokrowska seria lessowo-glebowa. Wydzielono w niej w sposób pewny dwie gleby kopalne: rżaksińską (Rzhaksa soil) i bałaszowską (Balashov soil). W dolnej części nowopokrowskiej serii (gleba bałaszowska w sensie genetycznym zaliczana do grupy buropodobnych i czerwonoziemnych) występują szczątki mikroteriofauny zespołu pietropawłowskiego. Bałaszowska gleba, w której stwierdzono tę faunę, należy już według danych paleomagnetycznych do epoki Matuyamy. Pod nowopokrowską serią lessowo-glebową występuje trośniański less i czerwono zabarwione gliny eoplejstoceńskie.

Tak więc na podstawie badań lessowo-glebowej formacji plejstoceńskiej na Równinie Rosyjskiej można wyróżnić — poczynając od końca eoplejstocenu — co najmniej siedem okresów ciepłych (interglacjalnych) i dziewięć chłodnych (peryglacjalnych). Stwierdzono także dostatecznie pewnie, że w okresie pięciu cykli chłodnych rozwijało się zlodowacenie kontynentalne.

Porównanie chronostratygraficznych wykresów ilustrujących rytmy zmian warunków akumulacji osadów kontynentalnych (lessowo-glebowej formacji) i oceanicznych (krzywa izotopów tlenu) świadczy, że różniły się one istotnie (Fig. 3). Jeśli bowiem krzywa klimatyczna zestawiona na podstawie badań osadów kontynentalnych wskazuje na ogólną tendencję do ochłodzenia postępującego od początku plejstocenu, to krzywa izotopów tlenu w osadach oceanicznych wskazuje na tendencję do ocieplania.

## РЕЗЮМЕ

Хроностратиграфическая схема расчленения лёссово-почвенной формации Русской равнины была разработана в результате многолетнего последовательного изучения районов Днепра, Средне-Русской возвышенности, Волыно-Подолии

и Приазовья по единой методике с применением комплекса методов: палеопедологического, литологического, споровопыльцевого, методов абсолютного и относительного датирования, сопряженно-стратиграфического.

Согласно этим исследованиям нижний возрастной предел позднеплейстоценовой лёссово-почвенной серии ограничен эпохой почвообразования микулинского межледниковья (оптимум — 125 тыс. лет назад). Почвы этого времени имеют яркие диагностические признаки лесного и степного почвообразования умеренного суббореального пояса; это салынская фаза мезинского полигенетического комплеска. Валдайская лёссовая толща включает три горизонта ископаемых почв интерстадиального характера — крутицкий, брянский, трубчевский — и четыре горизонта лёссов — севский, хотылевский, деснинский, алтыновский. Почва крутицкого интерстадиала (верхняя фаза мезинского комплекса, 64—55 тыс. лет назад) отделена от микулинской почвы внутримезинским (севским) лёссом. Горизонт лёсса I (хотылевского) мощностью около 2 м сформировался в интервале 60—33 тыс. лет назад. Брянская почва имеет четкие диагностические признаки мерзлотно-глеевого педогенеза, содержит леммингову фауну мелких млекопитающих; ее радиоуглеродный возраст 32—24 тыс. лет. Самый мощный (3—4 м) среди позднеплейстоценовых лёссовых горизонтов, горизонт лёсса II (деснинский) сформировался около 23—17 тыс. лет назад. Некоторое смягчение климата во время продолжительной валдайской эпохи фиксируется мерзлотно-глеевой трубчевской почвой (17—16 тыс. лет назад) и ярославским криогенным горизонтом (15—14 тыс. лет назад). В заключительные этапы валдайского оледенения (16—13 тыс. лет назад) сформировался горизонт лёсса III (алтыновский).

Средне- и раннеплейстоценовая лёссово-почвенная серия включает не менее трех горизонтов ископаемых почв. Направление и интенсивность педогенеза свидетельствуют о значительном отличии его от умеренного межледникового и мерзлотноглеевого интерстадиального, свойственного позднему плейстоцену. Так, почвы роменского межледниковья, залегающие под денепровским лёссом, отнесены к группе коричневоподобных, каменского — к группе полигенетических черноземовидных почв с текстурным иллювиальным горизонтом, воронского — к группе буроземоподобных и красно-бурых, сочетающихся с темноцветными почвами западин.

В горизонте днепровской морены и соответствующем ей лёссе содержатся остатки млекопитающих хазарского фаунистического комплекса. Роменская почва, залегающая непосредственно под днепровскими ледниковыми отложениями, сближена с более древней — каменской. Из кротовин каменской почвы получена фауна мелких млекопитающих хазарского фаунистического комплекса, но без арктических форм, характерных для днепровского времени. Под каменской почвой залегает горизонт борисоглебского лёсса, отделяющий ее от более древнего воронского почвенного комплекса. Верхняя из почв этого комплекса содержит остатки мелких млекопитающих сингильского фаунистического комплекса. Нижняя почва, залегающая на донской морене, хорошо датируется позднетираспольской фауной мелких млекопитающих. Возраст морены донского языка датируется ранним плейстоценом по фауне мелких млекопитающих тираспольского комплекса. Ниже донской морены еще в объеме плейстоцена выделяется новопокровская лёссово-почвенная серия.

В новопокровской лёссово-почвенной серии уверенно выделяются две ископаемые почвы — ржаксинская и балашовская. Низы новопокровской серии (балашовская почва, генетически относимая к группе коричневоподобных и красноцветных) содержат микротериофауну петропавловского фаунистического комплеска. Балашовская ископаемая почва, из которой получена фауна, по палеомагнитным данным уже относится к палеомагнитной эпохе матуяма. Новопокровска лёссово-почвенная серия в разрезах подстилается тросиянским лёссом и краснецветными эоплейстоценовыми глинами.

Таким образом, с конца эоплейстоцена по данным изучения лёссово-почвенной формации Русской равнины в объеме плейстоцена выделяется не менее 7 теплых (межледниковых) эпох и девяти холодных (перигляциальных). Для пяти холодных циклов достаточно надежно установлено развитие покровных оледенений.

Сравнение континентальной и океанической хроностратиграфических кривых свидетельствует о существенном различии между ними. Если климатическая кривая, основанная на данных изучения континентальных отложений, указывает на общий тренд к похолоданию от начала плейстоцена к его концу, то изотопно-кислородная кривая отражает направленность в сторону потепления от начала плейстоцена к его концу.