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LATE PLEISTOCENE VEGETATIONAL AND SOIL EVOLUTION AT THE KIEV LOESS PLAIN AS RECORDED IN THE STARI BEZRADYCHY SECTION, UKRAINE

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Abstract

Pollen and paleopedological studies have been carried out in parallel for the Stari Bezradychy sequence of the Upper Pleistocene age. The paleoenvironmental information derived from both sets of data is in general well correlated. The section presents a rather complete sequence of the last interglacial-glacial cycle. It includes eight units of the Ukrainian Stratigraphical Framework of the Pleistocene. Interglacial climatic optimum is registered by pollen succession of the Mikulino (Eemian) type in the climax forest paleosols of Pryluky-Kaydaky pedocomplex at the base of the sequence, above the Dnieper Glacial deposits. The coldest and most continental environment is recorded in the youngest loess. The soils of Upper Pryluky, Vytachiv and Dofinivka units are correlated with the Early Glacial and four Pleniglacial interstadials. Multiple environmental variations during the Upper Pleistocene recorded in the Stari Bezradychy sequence are important for study of global climatic changes and interregional correlation. Tentative correlation with marine isotopic stages is proposed.

Key words: Pleistocene, paleosol, loess, pollen, Ukraine.

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INTRODUCTION

The paper presents the results of palynological and paleopedological study of the Stari Bezradychy section, one of the most complete sequence of the Upper Pleistocene deposits at the Kyiv loess plain (Fig. 1). The loess series of the Kyiv plain is rather thick (up to 30 m), well stratigraphically subdivided, and has been intensively studied (Veklitch *et al.* 1984, Khristoforova *et al.* 1982, Gerasimenko 1984, 1988, Barshchevsky *et al.* 1989, Matoshko 1999). The regional stratigraphical schemes of the area have been compiled by Veklitch *et al.* (1984). The important stratigraphical marker within the loess series of the Kyiv plain is a till of the Dnieper Glaciation which is correlated with Saalian Glaciation of the Western Europe (Gozhik 1995). Above the Dnieper unit, eight main stratigraphic units are distinguished in accordance with the Stratigraphical Framework of the Pleistocene of Ukraine (Veklitch ed. 1993): the Kaydaky soil unit (kd), the Tyasmyn loess unit (ts), the Pryluky soil unit (pl), the Uday loess unit (ud), the Vytachiv soil unit (vt), the Bug loess unit (bg), the Dofinivka soil unit (df) and the Prychernomorsk (pc) loess unit. The aim of this study is to detect the soil and vegetational successions within the main stratigraphical units. These successions are evidences of short-range paleoenvironmental and climatic oscillations during the Late Pleistocene.

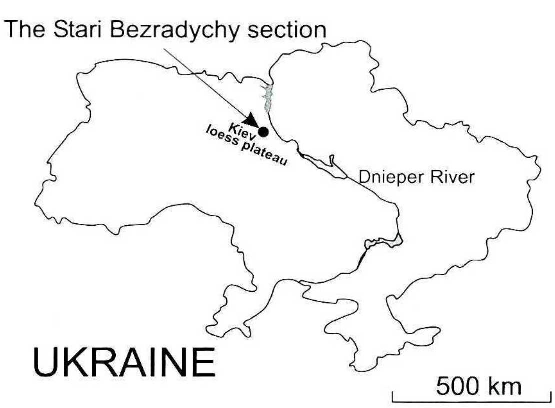

Fig. 1. Location map of the section studied.

The Stari Bezradychy section (50° 11'N, 30° 33'E) is located in the ravine of the right bank of the Tikhan' river at the northern vicinity of the Stari Bezradychy village, 20 km south from Kyiv. The section is not far from the northern boundary of the loess belt of Ukraine. This makes it important for correlation with pollen records from the lacustrine-paludal deposits of the northern regions of Ukraine.

METHODS

Palynological and paleopedological methods were applied in order to obtain paleoenvironmental information. The methodology of paleopedological study has been developed for Ukrainian loess series by Veklitch and Sirenko (Veklitch *et al.* 1979). It has been shown that a complete soil complex consists of soils of the initial, optimal and final phases of pedogenesis. These are marked respectively by indices a, b and c, for instance kd $_b$. Soils of climatic optima, usually two ($_{b1}$, $_{b2}$), are most expressive and reflect well the past environment. Soils of the initial and final phases provide evidence of cooler climate, at the transition to a cold stage.

The first stage in the identification of paleosol genesis is a morphological study of the soil profile and its genetic horizons. The thickness, colour, structure, consistency and the type of soil boundaries indicate the pedogenetic processes as well as pedogenic accumulations (carbonates, iron and manganese hydroxides, silica powder, *etc.*). In the next stage, the visual interpretation is compared with the laboratory tests of carbonate, salt and humus contents; of bulk chemical analyses, in particular Fe_2O_3, A_2O_3 contents, ratio SiO_2/R_2O_3 (Al_2O_3+Fe_2O_3); of grain-size analysis (especially < 0.001 mm content). To reveal the primary paleosol genetic type, factors of fossilization are examined (*e.g.* gleying, carbonate impregnation). The loess units are also subjected to physical-chemical study to recognize their paleoenvironmental characteristics.

Palynological study of loess sections requires, first of all, sufficient amount of pollen grains to be extracted at each sampled level. Extraction involved treatment with 10% HCl, 10% KOH, cold treatment with HF, disintegration in a solution of pyrophosphate ($Na_4P_2O_7$) and separation in heavy liquid (KdI_2 and KI) with specific gravity 2.2 g/cm^3. The transfer functions of vegetation and palynospectra based on surface samples (Grichuk, Zaklinskaya 1948, Dinesman 1977, Arap 1976) are used in the interpretation of pollen diagrams. The combination of palynological and paleopedological approaches allows to consider the relationship between pollen spectra formation and pedogenesis, and between sedimentation and pedogenesis, and improves reliability of paleoenvironmental reconstructions.

In the pollen diagram of the Stari Bezradychy section, the number of pollen grain counted for the total sum is between 100 and 400. Some non-arboreal taxa are included in groups: xerophytes (*Artemisia, Ephedra*, and Chenopodiaceae), hydrophytes (water plants: Typhaceae, Sparganiaceae, Alismataceae, Potamogetonaceae) and Herbetum mixtum (all herbs, with exception of Gramineae, Cyperaceae, xerophytes and hydrophytes). Herbetum mixtum includes mainly mesophytic herbs.

RESULTS

The Stari Bezradychy loess-soil sequence (Fig. 2) lies on sediments of the Dnieper unit (dn): glacio-fluvial sandy loams overlying a till. The lower part of Section 1 (Fig. 3) is mainly represented by fossil soils: Kaydaky (kd), Pryluky (pl) and Vytachiv (vt) soil units, interspersed with thin loess units and subunits, whereas the upper part is formed by the thick Bug (bg) loess unit with several embryonic soils within. The uppermost Dofinivka (df) and Prychernomorsk (pc) units can be observed in the superposition to the Bug loess in the Section 2, located somewhat lower on the slope of Tikhan' valley than the Section 1. The lithological column and analytical data are shown in Fig. 3, pollen results in Fig. 4, whereas a comparison of the main indices in Fig. 5. Upwards

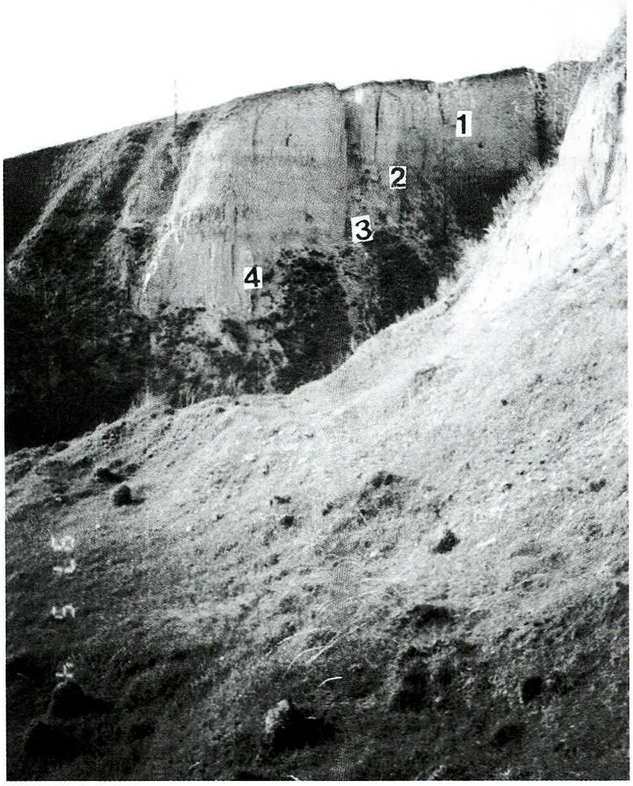

Fig. 2. General view of the Stari Bezradychy sequence. 1 – Bug loess unit, 2 – Vytachiv soil unit, 3 – Pryluky-Kaydaky soil unit, 4 – Dnieper unit. The stratigraphic subdivision is by the Stratigraphic Framework of the Pleistocene of Ukraine (Veklitch *et al.* 1993).

the bottom, the Stari Bezradychy sequence includes following layers.

The Kaydaky-Pryluky soil complex

The Kaydaky-Pryluky soil complex (kd-pl) is represented by a chernozem overlying a well developed forest soil with preserved detailed differentiation of its profile. These climax soils are underlain and overlaid by immature soil formations. In the most complete loess sections of Ukraine (Veklitch *et al.* 1967), the Kaydaky-Pryluky interval is more complicated and includes two soil complexes separated by a thin loess layer (Tyasmyn unit). The phases of climatic optima of both Kaydaky and Pryluky pedocomplexes are represented by lower forest soils and upper humic ones. Such a detailed stratigraphy can be observed only in paleodepressions, with highest sedimentation rates. In the most other sequences, the Tyasmyn loess and the upper Kaydaky humic soil are deeply reworked by the illuvial pedogenic processes of the early Pryluky phase. Nevertheless sometimes the corresponding sediments can be recognised by pollen analyses of the Pryluky soil substrata, as shown below.

At the base of Kaydaky-Pryluky pedocomplex, an initial

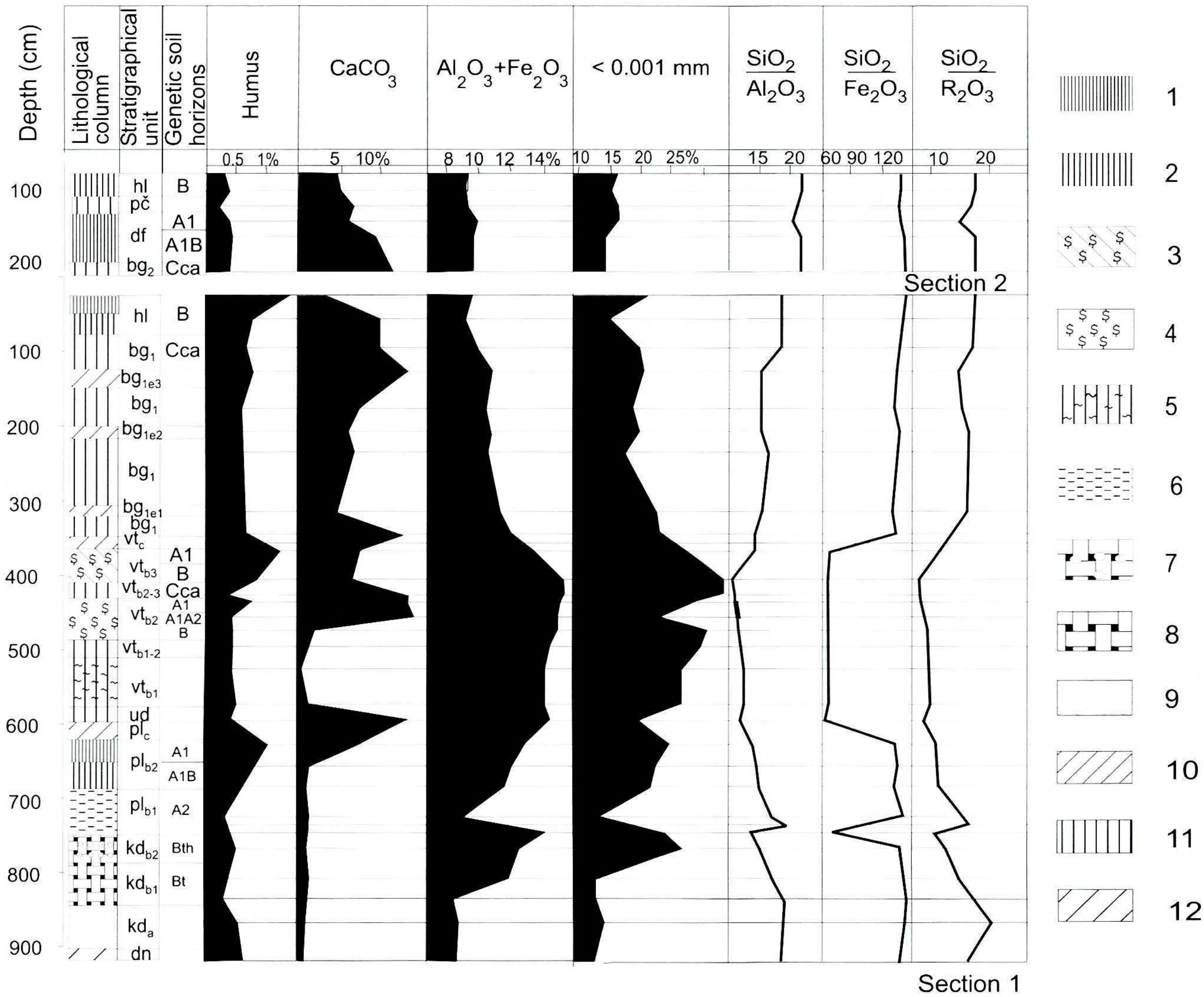

Fig. 3. Lithology of the Stari Bezradychy sequence. The stratigraphic subdivision is by the Stratigraphic Framework of the Pleistocene of Ukraine (Veklitch *et al.* 1993). *1* – Al horizon of chernozem, *2* – AlB horizon of chernozem, *3* – leached rendzina, *4* – boreal brown forest soils, *5* – boreal brown gley soil, *6* – A2 horizon of gray forest soil, *7* – Bth horizon of gray forest soil ("humus illuvium"), *8* – Bt horizon, *9* – ferruginous gley soil, *10* – embryonic soil, *11* – loess, *12* – sandy loam.

gley ferruginous soil (kd_a) occurs. Bluish and rusty mottled in color, it is characterized by an enrichment in iron-aluminum sesquioxides (R_2O_3) and clay content as compared to the glacio-fluvial loams of the Dnieper unit. The spore-pollen composition of the deposits is very different from the rest of sequence and dominated by *Picea* and Polypodiaceae. The other mesophytes Cyperaceae are also rather abundant, whereas pollen of broad-leaved trees is absent.

Above the initial soil, the well developed Bt horizon of forest soil (kd_{b1}) is formed. A strong prismatic structure with brown colloidal coatings of illuviation on prism facets and a hard consistency are its characteristic features. R_2O_3 content increases sharply in its upper part. Pollen spectra are the richest in arboreal pollen (AP) within the whole sequence. At the lower part of the Bt horizon, *Pinus* dominates definitely, though some pollen of broad-leaved trees (*Quercus* and *Ulmus*) already appears. At the upper part of the Bt horizon, the share of *Quercus* and *Ulmus* increases, as well as of grasses.

The Bt horizon is overlaid by the Bth horizon (Bt horizon with illuviated humus) of much darker brown colour: both in organic-mineral coatings and in bulk of soil substrata inside prisms. The structure is as strong, and the consistency as hard, as in Bt horizon. The Bth horizon is the richest in R_2O_3 and clay within the whole Kaydaky-Pryluky interval, molecular ratios SiO_2/R_2O_3, SiO_2/Al_2O_3, SiO_2/Fe_2O_3 are minimum. The content of humus is somewhat increased at the lower part of the horizon. The pollen spectrum of the lower, humus-enriched part of the Bth horizon is very different from that of its upper part. A share of AP drops drastically at the lower part of Bth, whereas a share of non-arboreal pollen (NAP) increases, at the expense of Gramineae and Herbetum mixtum. The pollen ratio is typical for steppe ecotones – less than 20% of AP (Grichuk *et al.* 1948). *Quercus* and *Ulmus* pollen occur only in a low number. The upper part of the Bth horizon by its pollen composition can be combined in one pollen complex with the overlying layer of A2 horizon (see below) and shows the existence of forest ecotones. As illuvial processes are developed under forest vegetation, it is suggested that the substrata of the upper part of the Bth horizon have been formed synchronously with pedogenesis, whereas

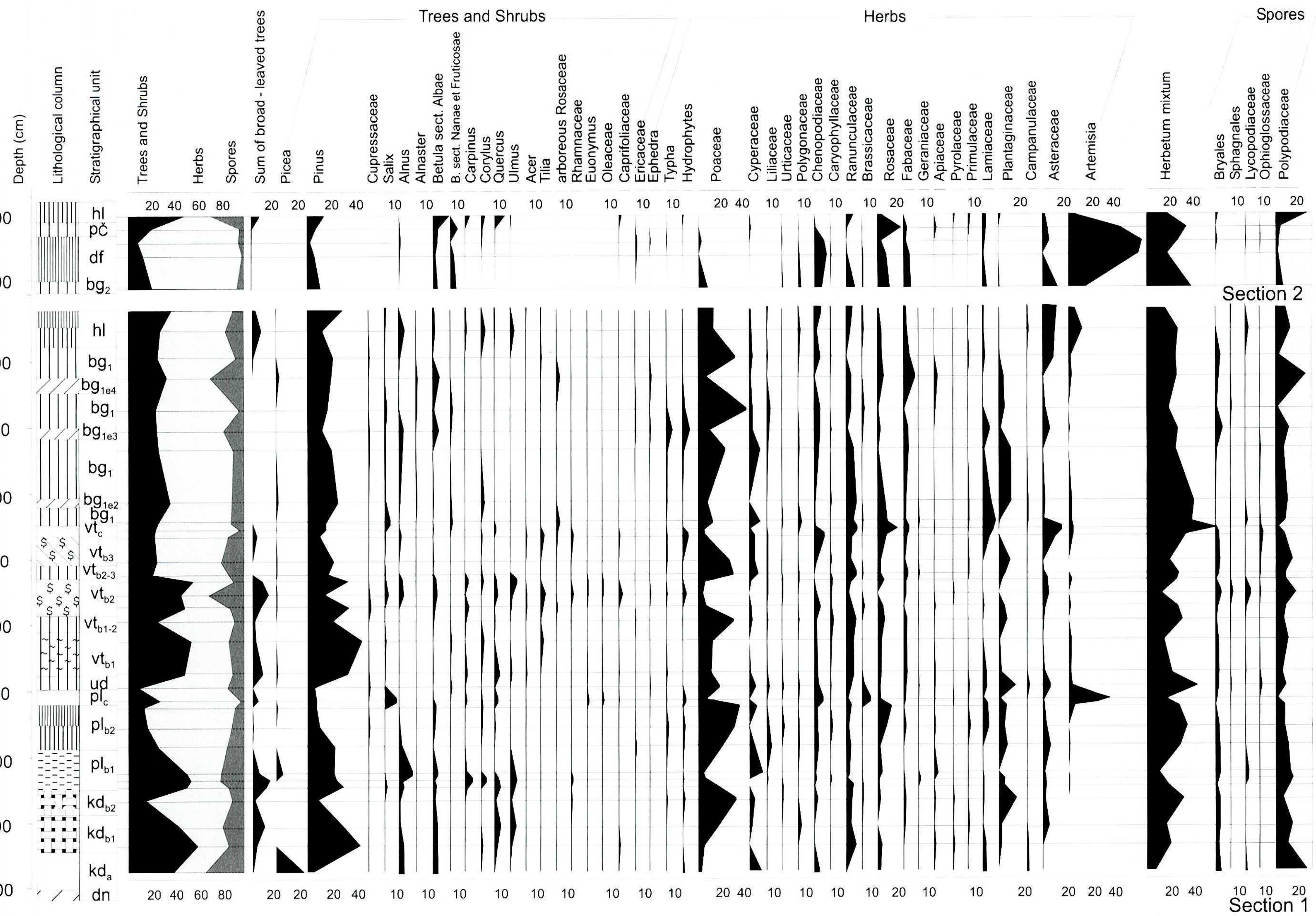

Fig. 4. Pollen diagram of the Stari Bezradychy sequence. Signs for the lithological column as in Fig. 2.

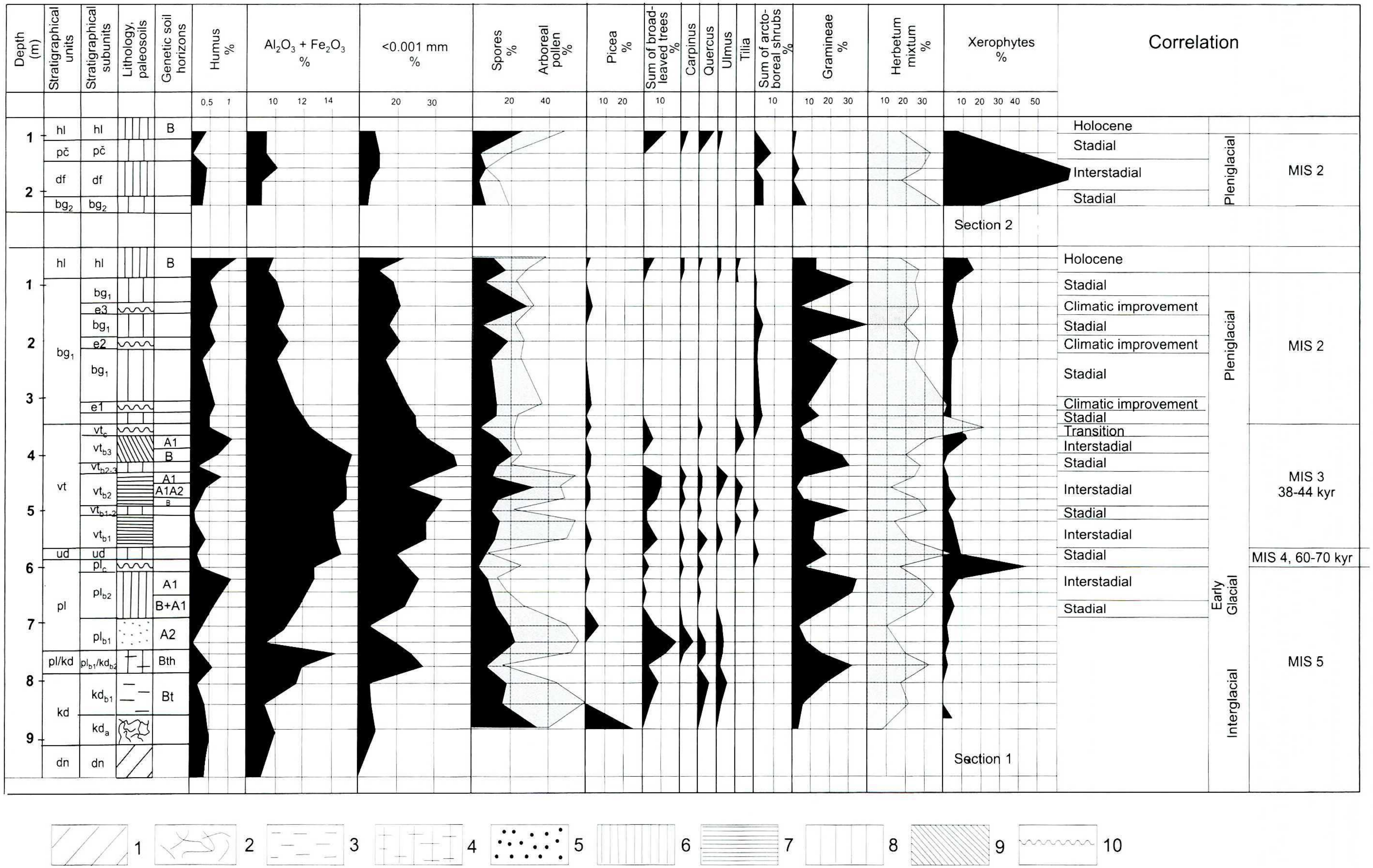

Fig. 5. Main indices of Upper Pleistocene deposits of the Stari Bezradychy sequence. The stratigraphic subdivision is by the Stratigraphic Framework of the Pleistocene of Ukraine (Veklitch *et al.* 1993). *1* – glacio-fluvial sandy loam, *2* – ferruginous gley soil, *3* – Bt horizon of gray forest soil, *4* – Bth horizon of gray forest soil ("humus illuvium"), *5* – A2 horizon of gray forest soil, *6* – A1 horizon of chernozem, *7* – boreal brown forest soil, *8* – leached rendzina, *9* – loess, *10* – embryonic soil.

the substrata of its lower part has been deposited before the illuviation and later transformed by it in a postgenetic way. The deposits with a steppe type of pollen spectra likely correspond to the steppe phase (kd_{b2}) recorded by chernozem soils in the complete sections of the Kaydaky-Pryluky interval. The following phase of the illuviation is determined in other stratigraphically complete sections as the early Pryluky – pl_{b1} (Veklitch *et al.* 1967). In the Stari Bezradychy sequence, the pl_{b1} soil contains A2 and Bth horizons.

The A2 horizon is very thick (0.4 m), whitish, with a platy structure and loose consistence. It contains silica powdering and abundant concretions of iron-manganese hydroxides. The last ones give evidence of pseudogleying development, which enhanced an intensity of eluvial processes. The A2 horizon, and in particular its middle part, is strongly impoverished in humus, R_2O_3 and especially in clay particles leached down the soil profile. Impoverishment in R_2O_3 is also reflected in their molecular ratios with SiO_2. The pollen spectra are characterized by high AP and spore values. The spectrum of the lower sample forms a single pollen complex with that derived from the upper part of the Bth horizon. Its indicative feature is the highest share of broad-leaved species within the whole sequence, as well as an appearance and then the highest share of *Carpinus* pollen. In the middle part of the A2 horizon, a value of broad-leaved tree pollen decreases (*Carpinus* is present, but *Quercus* disappears), whereas *Picea* and especially *Alnus* occur in significant amount. The increase of *Alnus* corresponds well with the evidence of pseudogley processes.

The humic soil pl_{b2} is dark gray, almost black in its A1 horizon and gradually gets lighter down the profile. A granular structure of the A1 horizon and abundant worm and mole routs show an intensive biogenic activity during soil formation, whereas punctuation by iron-manganese hydroxides in the lower layers give evidence of gleying processes. The soil is leached of carbonates, rich in humus in the A1 horizon, its profile is not differentiated by R_2O_3 content. These are features of a leached meadow variety of chernozem. Pollen spectra show a drop of AP, and are of a steppe type in the A1 horizon. The disappearance of broad-leaved tree pollen is a characteristic of the pollen complex. Only single *Quercus* and *Corylus* pollen has been found. NAP is dominated by Gramineae and Herbetum mixtum.

The brownish embryonic soil pl_c is at the top of Kaydaky-Pryluky pedocomplex. The pollen data allow us to suggest a spread of eroded soils and disturbed substrata during its formation. *Artemisia* and Chenopodiaceae dominate in NAP, whereas *Salix* in AP. Few pollen of broad-leaved trees are likely redeposited. The pollen spectrum is very different from the rest of diagram and indicates a sharp change of environmental conditions.

The Uday unit

The Uday unit (ud) is a thin (0.2 m) loess layer, poor in humus, almost white due to abundant carbonates (Cca of the above soil). It differs from the other loess units by a higher content of clay particles and especially of R_2O_3 that is probably also caused by the later pedogenetic processes. A tongue-like pattern of the lower boundary was formed by primary ground wedges (up to 0.4 m long) filled with the loess material. A share of arboreal pollen is very low, and their floristic composition is very poor. The appearance of arcto-boreal plants (*Betula* sect. Nanae et Fruticosae) is a characteristic feature. NAP is dominated by Herbetum mixtum, mainly Plantaginaceae and Asteraceae, that show a presence of unstable substrata.

The Vytachiv soil unit

Vytachiv soil unit (vt) is presented by three main soils separated by thin loess layers and an embryonic soil at the top. The lower boundary of all soils is disturbed by abundant thin ground veins. The characteristic feature of Vytachiv soil unit is the highest of the whole sequence content of Al_2O_3, Fe_2O_3 and clay particles. The lower soil (vt_{b1}) has rather thick, but not differentiated brown-colored profile, with abundant punctuation and small concretions of iron-manganese hydroxides. The soil is poor in humus and leached of carbonates. According to the analytical data, illuviation of clay and R_2O_3 did not take place. The characteristic of pollen complex is a highest share of *Pinus* of the whole sequence and a predominance of AP. *Picea* and broad-leaved trees (*Quercus*, *Ulmus*, *Carpinus* and *Tilia*) occur in a small amount, though *Quercus* forms a small peak at the lower part of the soil.

The vt_{b1-2} subunit is a loess-like loam leached of carbonates and strongly gleyed. Nevertheless, the R_2O_3 content is lower than in the underlying and overlying deposits. Arboreal pollen drops sharply, whereas Gramineae and Herbetum mixtum share dominance in NAP. Single pollen grains both of *Quercus* and of *Betula* sect. Nanae et Fruticosae occur.

The profile of vt_{b2} soil, more bright brown-colored than the lower soil, consists of the following horizons: A1, somewhat enriched in humus, A1A2, impoverished in clay, and B, the most compacted and enriched in clay particles. This indicates clay leaching downwards. Carbonate accumulations at the upper part of the soil seem secondary, as they disappear downwards. The pollen complex is characterized by a rather high share of AP and of broad-leaved trees (*Ulmus*, *Carpinus*, *Quercus* and *Tilia*), though still less than for the forest soils of the Kaydaky-Pryluky interval. Pollen of *Alnus*, arboreal *Betula* and various shrubs is more abundant than in the lower soil, whereas a share of *Pinus* is much lower. The not-arboreal parts of the spectra are dominated by Herbetum mixtum and spores.

The loess vt_{b2-3} is very poor in humus and very rich in carbonates (Cca of the overlying soil). R_2O_3 and clay content is high, probably also as a result of the later pedogenesis impact. Pollen spectra from the loess layer and the lower part of the above soil are the same that confirms a postgenetic reworking of the sediments by soil processes. The pollen complex is characterized by a sharp predominance of NAP: mainly Gramineae and Herbetum mixtum. The AP composition is very poor: *Pinus* dominates absolutely, and single pollen grains of *Picea*, *Salix* and *Betula* sect. Albae occur. Thin fissures filled with the loess material dissect boundaries of the underlying soil.

The vt_{b3} soil is a rendzina of darkish gray color and with much higher humus content than in the below Vytachiv soils, especially in its A1 horizon. The worm and mole routes give evidence of biological activity during its formation, whereas enrichment of its lower part with clay and R_2O_3 suggests initial development of lessivage processes. This is also reflected in the minimum SiO_2/R_2O_3 ratio at B horizon. Carbonates primarily were also leached in the subsoil. Their content in Cca is the maximum of the whole sequence. The pollen spectrum from the upper part of the soil forms a common pollen complex with that from the vt_c embryonic soil. The complex is dominated by herbaceous pollen, and in particular by Herbetum mixtum which share is the highest for the whole sequence. Asteraceae, Lamiaceae and Rosaceae are most abundant among herbs, whereas a share of Gramineae is very low. AP composition is richer than in the below complex and characterized by presence of broad-leaved species: *Quercus* and *Tilia*, of which the last one is more abundant. The brownish vt_c embryonic soil differs from the underlying one by lower humus content and a more silty texture.

The Bug unit

The Bug unit loesses (bg) are carbonate silty loams with lower clay and R_2O_3 contents than in the Uday and intra-Vytachiv loess layers. Only the lowermost part of the Bug unit is somewhat enriched in clay and R_2O_3. Cca horizons of the Holocene and Bug embryonic soils have higher carbonate contents. Thin fissures filled in with the loess material dissect the boundary of the Vytachiv soil. Four embryonic soils occurring within the unit are thin (0.2 m), brownish, partly leached and slightly enriched in humus, clay and R_2O_3 as compared to the loesses. Pollen spectra of loesses and embryonic soils are also somewhat different. NAP dominated AP through the whole Bug unit, though a share of arboreal pollen is higher in embryonic soils, in particular in the lower one. Embryonic soils are richer in spores, especially the upper one. The whole Bug unit is characterized by a noticeable share of pollen of arcto-boreal plants (*Betula* sect. Nanae et Fruticosae and *Alnaster*), but in embryonic soils it is lower. On the contrary, arboreal *Betula* and *Picea* occur only in embryonic soils and even single *Corylus* in the lower one. Loess layers are distinguished by peaks of Gramineae pollen, the highest one at the middle part of the Bug unit. NAP of embryonic soil is presented mainly by Herbetum mixtum, though the lowermost loess layer is also rich in Herbetum mixtum. The uppermost Bug loess layer (Section 2) is very poor in clay and R_2O_3. The share of Gramineae drops here at the expense of *Artemisia* increase.

The Dofinivka unit

The Dofinivka unit (df) is a weakly developed chernozem with low humus, clay and R_2O_3 contents that are only slightly higher than in the loess subsoil. Molecular ratios SiO_2/R_2O_3 are more similar to those of loess units than of soil units (Fig. 3). Carbonates are not leached from soil profile. Nevertheless, the soil is rather dark gray and with abundant worm and mole routes. The pollen complex is characterized by the highest NAP content of the whole sequence. Strong predominance of *Artemisia* and presence of *Betula* sect. Nanae et Fruticosae are indicative. Broad-leaved species are absent, and shares of *Pinus*, Gramineae and spores are the lowest of the whole sequence.

The Prychernomorsk loess

The Prychernomorsk loess (pc) is thin (0.3 m) and very poor in humus, clay and R_2O_3. Its pollen complex is similar to that of the Dofinivka soil by predominance of *Artemisia*, single spores and Gramineae. A slightly higher AP share is due to increase of *Betula* sect. Nanae et Fruticosae. Predominance of *Betula* (sect. Nanae et Fruticosae + sect. Albae) over *Pinus* is characteristic only for Dofinivka and Prychernomorsk units. A peak of Rosaceae is observed – representatives of this family are described as plants, which keep and fix substrata in the cold steppes of Chukotka (Polozova 1983).

PALEOENVIRONMENTAL EVOLUTION

The above data show multiple changes of paleoenvironment since the Dnieper stage. At the kd_a phase of the Kaydaky-Pryluky interval, *Picea* forests alternated with wet meadows. Initial soil argillization and intensive gleying processes took place. Climate was cool and humid. During the kd_{b1} phase, pine forests were replaced by broad-leaved elm-oak forests with abundant ferns and Herbetum mixtum in a herb cover. Soil argillization developed together with illuvial processes and lead to climax gray forest soil formation. The soil and pollen spectra correspond to wetter climatic conditions than the present one of the locality, though equally warm. At the kd_{b2} phase, Herbetum mixtum-Gramineae steppes dominated, and humus accumulation took place. Chernozem formation is shown for the other sections (Veklitch *et al.* 1967). The climate became much drier than in the previous phase and somewhat drier than the present one.

At the pl_{b1} phase, broad-leaved forests reached maximal spread, with a high share of *Carpinus* in ecotones, but later on the role of boreal elements *Picea* and *Alnus* increased. The light-gray forest soils of the pl_{b1} phase were characterized by more intensive development of eluvial-illuvial processes, strengthened also by pseudogleying, than in the kd_{b1} phase. This, together with *Carpinus* growth, gives evidence of a wetter climate of the pl_{b1} phase. The climate, firstly rather mild (*Carpinus* peak), got cooler and probably excessively humid (*Picea-Alnus* peak). At the pl_{b2} phase, Herbetum mixtum-Gramineae steppe on chernozems dominated almost absolutely, whereas broad-leaved trees occurred only sporadically. A boreal element *Picea* appeared at the end of the phase. It gives evidence that the climate was drier and colder than the present one and that of the kd_{b2} steppe phase. At the phase pl_c, vegetation of disturbed substrata (*Artemisia* and *Salix*) spread on immature soils formed under an intensive sediment influx. This phase was a final one of soil formation stage, transitional to the next sedimentation stage.

The pollen succession of the forest soils of the Kaydaky-Pryluky pedocomplex (*Picea-Pinus-Quercus*+ *Ulmus-Carpinus-Picea*) shows a pattern of the Mikulino interglacial. The Mikulino interglacial is generally considered to be the East-European equivalent of the Eemian (Grichuk 1972b), and is characterized by two climatic optima: M4 (*Quercus-Ulmus* forests) and M6 (*Carpinus* forest) separated by cooling M5 (Bolikhovskaya 1995, Yelovicheva 1989). In the

Stari Bezradychy sequence, two optima of broad-leaved forest vegetation (kd_{b1} and pl_{b1}) are separated by a steppe phase (kd_{b2}) that shows increased aridity. The cool phase M5 might correspond to the thin loess layer of Tyasmyn interval which separates the Kaydaky and Pryluky units in the most complete sections (Veklitch ed. 1993), and which is obviously re-worked by later pedogenetic processes in the Stari Bezradychy sequence. The upper chernozem of the Pryluky stage is an equivalent of humic soils of the Krutitsa interstadial proposed by Velichko (1975) and correlated with Amersfoort (Grichuk 1972a, Bolikhovskaya 1995) or Brørup–Amersfoort (Velichko 1988). In the Stari Bezradychy sequence, its pollen assemblage has much lower share of broad-leaved tree pollen that in the underlying interglacial deposits or in the Holocene. The TL-ages from the overlying Uday loess range from 60 to 70 kyrs (Shelkoplyas *et al.* 1986). This allows to suggest the correlation of the Pryluky-Kaydaky pedocomplex with marine isotope stage (MIS) 5 which corresponds to the Eemian and Early Glacial interstadials of Western Europe (Kukla 1977, Behre 1989).

The Uday stage, an equivalent of MIS 4, or the first half of Pleniglacial (see above), was characterized by loess accumulation, development of primary ground wedges, appearance of arcto-boreal elements of vegetation and almost complete deforestation of the Kyiv loess plain. The ecotones were dominated by Herbetum mixtum, which include a great number of plants of disturbed substrata. The insignificant value of xerophytes show that the summer precipitation was not very low, and the ground wedges formation was caused rather by cold snowless winters than by dry summers. Small thickness of the Uday loess, as well as peculiarities of its physicochemical composition, give evidence that the rates of silt sedimentation were lower than at the later stages of loess formation.

During the Vytachiv stage, the environmental changes were as follows. At the vt_{b1} phase, the pine forest dominated, though broad-leaved trees and *Picea* also occur. Argillization, carbonate leaching and gleying were the main pedogenic processes recorded in the soils. Bioenergetic resources of soil formation were likely insignificant, as neither the soil profile differentiation nor the soil structure were well formed. It indicates a rather temperate interstadial climate. At the vt_{b1-2} phase, meadow steppes dominated, though deforestation was not as strong as during the Uday stage. Few broad-leaved trees still occurred, but arcto-boreal elements also appeared. This fact as well as reduction of arboreal vegetation and depletion of pedogenic processes, indicate environmental conditions of a stadial. The phase vt_{b2} was the last one with prevalence of arboreal ecotones. Pine shared dominance with other boreal trees (*Alnus*, *Betula*, *Salix*) and with various broad-leaved species and shrubs. The soils vt_{b2} resemble boreal brown forest soils with initial development of illuvial processes. Clay migration has been previously shown for the Vytachiv unit by soil micromorphology (Matviishina 1982). The phase had optimum climatic conditions for the Vytachiv stage, though they still did not reach interglacial ones and rather characterized a 'warm' interstadial. At the phase vt_{b2-3}, steppe Herbetum mixtum-Gramineae ecotones dominated, broad-leaved species disappeared completely, loess accumulation took place and the substrata were dissected by a network of thin fissures. This indicates a continental cold climate, likely of a stadial. At the vt_{b3} and vt_c phases, the vegetation was more mesophytic – meadow steppes and meadows dominated, a few arboreal ecotones included some broad-leaved trees – *Tilia* and *Quercus*. At the phase vt_{b3}, leached rendzina soils were spread, whereas at the vt_c phase, increase of silt accretion slowed down soil processes and immature soils were formed. Abundance of Asteraceae indicates development of erosion and spread of disturbed substrata. The vt_{b3} phase was characterized by interstadial conditions, where the vt_c phase demonstrates transition to the next cold stage.

The Vytachiv soil unit reflects three interstadials separated by two stadials, with the warmest climate in the second interstadial. At the Kyiv Dnieper area, the unit is dated to 38–44 kyr BP (Shelkoplyas *et al.* 1986). This enables its tentative correlation with MIS 3 which corresponds to the Pleniglacial interstadials of Western Europe (Behre 1989). In the plains of North-Western Europe, climatic conditions of these interstadials were shown as cool, though in the loess uplands of the Dniester basin, relatively warm climate in corresponding intervals have been reported (Bolikhovskya 1995). Probably, the dissected relief of loess plains provided refugia for broad-leaved trees.

The overlying loess with embedded embryonic and Dofinivka paleosols correspond to MIS 2, or the second half of the Pleniglacial characterized by the most intensive loess accumulation. In the first half of the Bug stage, Herbetum mixtum-Gramineae steppes dominated, though at the very beginning of the stage, Herbetum mixtum still prevailed. Nevertheless, just at this wetter phase, a dense network of fissures dissecting the substrata was formed which indicates cold snowless winters. Since this phase, arcto-boreal elements (shrub *Betula* and *Alnaster*) became rather abundant and showed stadial climatic conditions. Three phases of climatic improvement recorded by embryonic soils were characterized by more mesophytic Gramineae-Herbetum mixtum ecotones, by appearance of *Picea*, *Alnus*, arboreal *Betula* and development of initial carbonate leaching and gleying. During the first half of the Bug stage, eroded substrata were occupied by more mesophytic plants of Plantaginaceae, whereas during the second half, by Asteraceae. The increase of climatic aridity at the late Bug substage is shown also by intensive spread of *Artemisia*.

In the Dofinivka interval, weakly developed carbonate chernozems were formed under specific steppe ecotones including both *Artemisia* and Herbetum mixtum. Such a combination is shown for the present Eastern Siberian steppes (Tomskaya 1979, Polozova 1983). In few arboreal ecotones, birches dominated over pine and included some shrub forms that, together with presence of Ericaceae is also typical for the Eastern Siberia. This indicates a cool continental climate, more arid but less cold than a stadial one. Stadial conditions existed at the Prychernomorsk interval, when steppe ecotones were similar to those of Dofinivka stage, but arcto-boreal plants were the most abundant. An increase of *Artemisia* ('cryoxeric phase of a glacial stage') is shown for many sequences of Russian plain (Grichuk 1972a, Bolikhovskaya 1995). The Dofinivka soil unit might be possibly correlated with weak humic soils of Western-Central Europe dated around 20 kyr BP and characterized by cold environment (Pecsi 1993).

CONCLUSION

The Stari Bezradychy section reflects a rather complex sequence of environmental changes during the last interglacial-glacial cycle. The pollen assemblages and pedogenic signs studied in the section generally agree in their paleoenvironmental inferences. The discrepancies between paleosol and pollen results are only observed for deposits reworked by pedogenic processes in a postgenetic way, for instance, by clay illuviation which makes soils to 'grow' downwards. The transformed substrata can still preserve their original pollen composition.

Eight units of the Ukrainian Stratigraphical Framework of the Pleistocene (Veklitch ed. 1993) are present in the Stari Bezradychy section: the Prychernomorsk, Bug and Uday loess units, the Dnieper till unit and the Dofinivka, Vytachiv, Pryluky and Kaydaky soil units. The last two units form a single pedocomplex, the only one in the section, which includes climax interglacial soils. The pollen succession from the forest soils of the Pryluky-Kaydaky pedocomplex at the base of the sequence shows a pattern of Mikulino (Eemian) interglacial. This, together with TL ages of the overlying Uday loesses (around 70 kyr BP), allows us to suggest a correlation of the Pryluky-Kaydaky interval with marine isotopic stage 5. The chernozem at the top of pedocomplex might be formed during the Early Glacial interstadials.

In the Stari Bezradychy sequence, the Vytachiv unit correlated by its TL ages with MIS 3 is presented by three interstadial soils separated by deposits of two stadials. The climatic optimum of the Vytachiv interval corresponds to the middle soil (vt_{b2}), whereas the lower forest gley soil was formed in more cool and wet climate, and the upper rendzina soil in more arid climate. The stadial deposits by their indices of chemical weathering and pollen composition represent environments comparable to those of the main loess units – the Uday and Lower Bug ones.

The upper loess units (Prychernomorsk and Bug) are tentatively correlated with MIS 2 and characterized by the highest rates of dust accumulation. The Lower Bug deposits indicate less severe climate, especially during three phases of embryonic pedogenesis, whereas the Upper Bug and Prychernomorsk units recorded the coldest and most continental environment. The Dofinivka interstadial soil was formed under cool and arid climatic conditions. The Stari Bezradychy sequence presents multiple environmental variations during the Upper Pleistocene and is important for study of global climatic changes and interregional correlation.

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