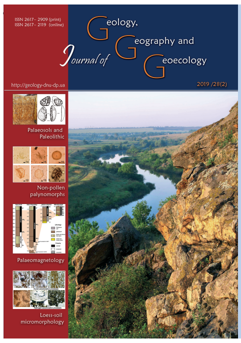

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The Late Pleistocene soils as indicators of the impact of environmental changes on development of pedogenic processes (the study case from the Kryva Luka site, Donetsk area)

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Abstract. The aim of this paper is to reveal connections between Upper Pleistocene soil types and the vegetation, which existed during their formation. Palaeovegetation was reconstructed on the basis of pollen analysis, whereas morphological description of palaeosols and the data from their laboratory study (grain-size and bulk chemical analyses, contents of Corg., $CaCO_3$ and dry salts) were used to reconstruct palaeopedological processes. The Kryva Luka sedimentary sequence was accumulated in a deep palaeogully (the incision of which occurred in early Kaydaky times), where, as a result of high sedimentation rates, well-developed Upper Pleistocene pedocomplexes formed, on one hand, and very good preservation of pollen was thus guaranteed. Several phases of soil development occurred in Kaydaky, Pryluky and Vytachiv times (the Ukrainian Quaternary framework), all represented in the section by individual palaeosols, separated by loess-like beds, or by erosional surfaces. The data collected demonstrates a cyclic pattern of short-period palaeoenvironmental changes during the Late Pleistocene. The last interglacial is related by paleopedological and pollen data to the Kaydaky unit. The pre-temperate stage of the interglacial is revealed in the gully deposits of subunit 'kd_{1a}'. The early-temperate stage corresponds to the Luvisol of subunit 'kd_{1b}', which was formed under broad-leaved woods dominated by oak. The late-temperate stage is recorded in the Greyzemic Phaeozem of the soil 'kd_{3b1}' (by the appearance of hornbeam) and the Mollisol 'kd_{3b2}'. The post-temperate stage of the interglacial and the transition to the early glacial occurred during formation of the uppermost bed of the latter and the incipient soil 'kd_{3c}'. (pedosediments were also accumulated at this time). Both vegetational composition and the soil types reflect a warmer and wetter climate for the temperate part of the last interglacial, as compared to that existing in modern times. The soils of different phases of Pryluky and Vytachiv times were formed during interstadials, with cooler climates than at present. As recorded both in soil types and pollen assemblages, the climates during the early interstadials of Pryluky and Vytachiv times were wetter than now (particularly during the 'pl_{1b1}' phase), but during their late interstadials, the climate was drier than the modern one (particularly during the phase 'pl_{3b2}'). On the basis of TL-dating obtained in sections in western Donetsk area and Central Ukraine, Pryluky times correspond to interstadials and stadials of the early glacial, whereas Vytachiv unit may be related to the middle pleniglacial. Types of cryostructures, connected with loess-like deposits of the stadials, indicate that the studied area in those times was under a severe continental climate, with deep seasonal freezing of the grounds. Nevertheless, the absence of ice pseudomorphs and of pollen of arcto-alpine plants indicates that permafrost was not present. Changes in palaeopedogenic processes (as well as in types of sedimentation) mainly paralleled changes observed in the palaeovegetation. The extent of wooded areas, the role of broad-leaved trees in the forest composition, and the spread of xeric herbal associations had particularly notable effects on the development of pedogenic processes.

Key words: palaeopedology, pollen analysis, short-period palaeoenvironmental changes

Пізньоплейстоценові ґрунти як індикатори впливу змін природного середовища на розвиток процесів педогенезу (на прикладі розрізу с. Крива Лука, Донецька обл.)

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Анотація. У статті наведено реконструкцію динаміки пізньоплейстоценових змін таких компонентів давнього природного середовища як палеорослинність, палеоґрунти і палеокріогенез (які є індикаторами палеоклімату) та показано взаємозв'язки між ними. Дослідження виконано із застосуванням паліногічного і палеопедологічного (зокрема, аналітичних методів) вивчення розрізу верхньоплейстоценових відкладів Крива Лука. У цьому розрізі, розташованому на акумулятивних схилах палеобалки, закладеної на початку кайдацького часу, завдяки значній інтенсивності седиментації, повно представлені фази ґрунтоутворення впродовж кайдацького, прилуцького і витачівського етапів. Показано, що зміна типів педогенезу (а також і седиментогенезу) відбувалася за умов змін рослинності, при цьому особливе значення мала участь у її складі деревних порід (особливо широколистих) і трав'янистих ксерофітів. Останній інтергляціал виявлено в утвореннях кайдацького кліматоліту: його початкову стадію у балкових відкладах ‘kd_{1a}’, кліматичні оптимуми у ґрунтовій світі ‘kd_{1b1} – kd_{3b2}’, заключну стадію – у ґрунті (чи у педоседиментах) ‘kd_{3c}’. Тип і склад рослинності та типи викопних ґрунтів відображають вологіший і тепліший клімат оптимумів кайдацького етапу у порівнянні із сучасним. Ґрунти прилуцького і витачівського часів формувалися за інтерстадіальних умов, прохолодніших від сучасних. Впродовж фази ’pl_{1b1}’ клімат був вологішим від теперішнього, а у час ’pl_{3b2} ’ – суттєво посушливішим. Відсутність у розрізі пилку кріофітів та наявні форми кріоструктур свідчать, що територія розташування розрізу впродовж стадіалів, виявлених у його відкладах, знаходилася не у зоні багаторічної мерзлоти, але у зоні глибокого сезонного промерзання ґрунтів за умов суворого континентального клімату.

Ключові слова: палеопедологія, спорово-пилковий аналіз, короткоперіодичні зміни природного середовища

Introduction. Fossil soils, intercalated with loesses in the Upper Pleistocene deposits of Ukraine, are a valuable source of information about past pedogenic processes, which changed (in time and laterally) depending on trends in palaeoenvironmental development. To establish the connection between the climatic and vegetational dynamics of the past and changes in the genetic types and properties of the corresponding palaeosols is an important task in the elaboration of a prognosis for possible future changes of the modern soil cover. This goal is especially actual in the modern time of climatic and environmental instability. The older Pleistocene soils, or soils in the northern-western Ukraine which existed under much more humid climate than at present, may have no genetic correlatives in the modern soil cover of Ukraine. Nevertheless, it is possible to determine the modern analogues of Upper Pleistocene northern steppe-belt soils belt in the southern steppe or the forest-steppe belts of Ukraine. The aim of this paper is to reveal the connection between the changes in palaeosol properties and the reconstructed environments where they were formed. The realization of this aim is founded on the study case of the Upper Pleistocene loess-palaeosol section at Kryva Luka, which includes most of the Upper Pleistocene soil units, enriched in pollen. The latter, together with palaeosols themselves, is the main tool for palaeoenvironmental reconstruction.

In the Donetsk area, Upper Pleistocene soils have previously been studied by M. Veklitch *et al*. (1973), N. Sirenko (1972) and Zh. Matviishina (1982). Fossil pollen was first revealed by A. Artyushenko *et al*. (1973). Palaeoenvironmental reconstructions of the area of Ukraine (including the Donetsk region) have been promoted using palaeosol and pollen studies by N. Sirenko and S. Turlo (1986). All results described were obtained for relatively long-lasting time periods (the interglacial and interstadials), whereas the short-period dynamics of pedogenic processes and vegetational changes were first obtained in the Western Donetsk area by N. Gerasimenko and G. Pedanyuk (1991), N. Gerasimenko (2010, 2011). The additional study was fulfilled by the authors in 2013. The Quaternary framework of Ukraine (Veklitch, 1993) is used for the site stratigraphy. The short-term periodization of the Upper Pleistocene in the Western Donets area, applied in this paper, was outlined by N. Gerasimenko (2010).

Material and methodology. The section at Kryva Luka is located in the right slope of a ravine, which deeply dissects the right bank of the Siverskyi Donets River (48°52′10″ N, 37°54′46″ E, 138 m a. s. l.) to the east of Kryva Luka village, in the northern part of the Donetsk region (Fig.1). The right bank of the river consists here of Cretaceous rock, which were cut during the Upper Pleistocene by a series of deep ravines.

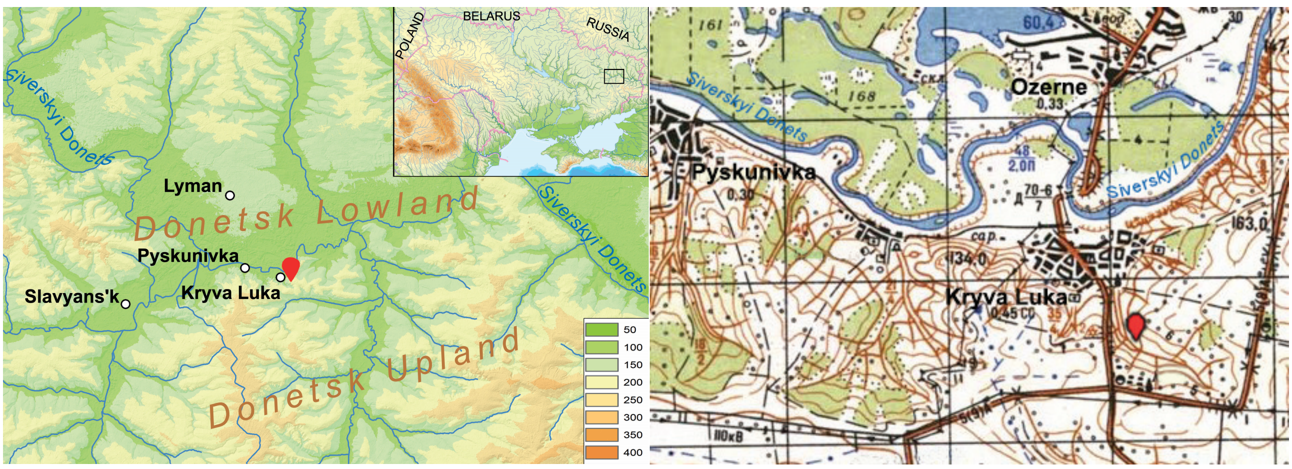

Fig.1. Location of the studied site.

The inclination of the Upper Pleistocene deposits, exposed in the ravine sides, confirms that the palaeoslopes were inherited by Holocene erosional processes. Judging from the stratigraphy of the infilling deposits in the palaeoravines, incisions occurred at the beginning of Vytachiv times (the terrestrial equivalent of MIS 3), and, more commonly, at the beginning of Kaydaky times − the first interglacial after the Dnieper (Saalian) glaciation. The studied section is exposed in the part of the palaeoravine created during Kaydaky times, and later completely filled with younger sediments and palaeosols. At present, the right bank of the Siverskyi Donets is gently sloping in the direction of the river valley. In general, the studied area is located within the NW part of the Donets Upland whose relief is represented by accumulative-denudational hilly plain, deeply dissected by valleys (Vakhrushev *et al*., 2010).

The modern soils are Mollisols, which are not leached of their carbonates (Calcic Chernozems). The modern vegetation of the slopes and plateau is that of mesophytic steppe, comprising diverse forbs and grasses. The dense trees (mainly *Acer, Fraxinus* and *Salix*) cover the bottom of the lower part of the gully, whereas bushes (*Elaeagnus angistifolia*, *Rosa canina, Pyrus* sp.) are scattered on its slopes. The eroded exposed parts of slopes are inhabited by Chenopodiaceae, *Artemisia* and Asteraceae. The high floodplain of the Siverskyi Donets is covered by broad-leaved forest made up of oak, elm and ash, and the distant sandy terraces are occupied by pine woods.

52 samples were collected from the main section (with an interval 10-20 cm) in such a way that each soil genetic horizon was sampled, though the pedosediments and gully alluvium were sampled at a significantly larger interval. Grain-size, bulk chemical and pollen analyses had been carried out for each sample. Contents of C_{org}, CO_2 of carbonates (re-calculated to $CaCO_3$ content) and dry salts were determined. Despite all components of the bulk chemical composition having been obtained, only the contents of R_2O_3 ($Al_2O_3 + Fe_2O_3$) are shown in the summary in Fig. 2, as well as their molecular ratio with SiO_2. According to Veklitch *et al*. (1979), these indices, as well as the clay fraction (< 0, 001 mm) are crucial for the estimating the intensity of clay weathering in soils, whereas their re-distribution in a soil profile allows judgments on the development of translocation processes. The sum of silicate CaO and MgO is provided in order to demonstrate the accumulation of bases in the deposits. The $CaCO_3$ re-distribution indicates the primary and secondary carbonate horizons in the upper part of the section, whereas its lower part does not include any carbonate. The content of dry salts, represented mainly by $CaSO_4$ and $NaHCO_3$, provide evidence that the majority of the soils and other deposits were not solonized. All chemical analyses were carried out according to standard methodologies, whereas grain-size analysis was done by the Kachinsky 'pipette' method. With the exception of the main section, several additional excavations have been dug up and down the course of the ravine.

As the studied section is located in a kind of a 'sediment trap' in the gully, the accumulation rates of deposits were rather high and pollen-bearing beds were buried quickly, which prevented these microfossils being oxidated. At least 300-400 well-preserved pollen grains were counted in each sample. Re-deposited Neogene palynomorphs occur only at one level (Neogene deposits are exposed at the top of the gully). Sample processing for pollen analysis completely corresponds to the method described in Gerasimenko *et al*., 2019 in this volume. The two surface pollen samples, taken from the top bed of the Mollisols near the gully, differ from the pollen spectra that would be expected from the vegetational zone of mesophytic steppe, in that they have very high percentages of Chenopodiaceae pollen (30-40%). The common percentages of these in grassland is <30% (according to V. Grichuk, 1989). This anomaly can be clearly explained by over-representation of Chenopodiaceae pollen, produced by the ruderal plants from this family (different species of *Chenopodium*), observed at present on the eroded slopes of the ravine. This fact should be taken into account when interpreting spectra of the fossil taxa from the section. Arboreal pollen (10-15%), present in the surface samples, include *Pinus sylvestris* (dominates), *Betula, Quercus, Acer* and arboreal Rosaceae. The sum of pollen of broad-leaved trees in the steppe associations is ≤ 5%, which also should be taken to consideration when interpreting fossil spectra. The percentages of *Pinus sylvestris* pollen (9-12%) are unusually low for an open landscape, which means that this long-distance wind-blown pollen is 'swamped' by the abundant pollen coming from the local steppe vegetation, which there produces dense ground cover. Pollen grains were identified with the aid of pollen atlases (Kupriyanova, Alyeshina, 1972, 1978; Reille, 1995) and the reference pollen collection of the Geography Faculty of the Taras Shevchenko National University of Kyiv. The reconstructions of past vegetation are based on the methodological principles elaborated by V. Grichuk (1989), N. Bolikhovskaya (1995) and L. Bezys'ko *et al*. (2010). In the pollen diagram (Fig. 3), those abbreviations are used: AP – arboreal pol-

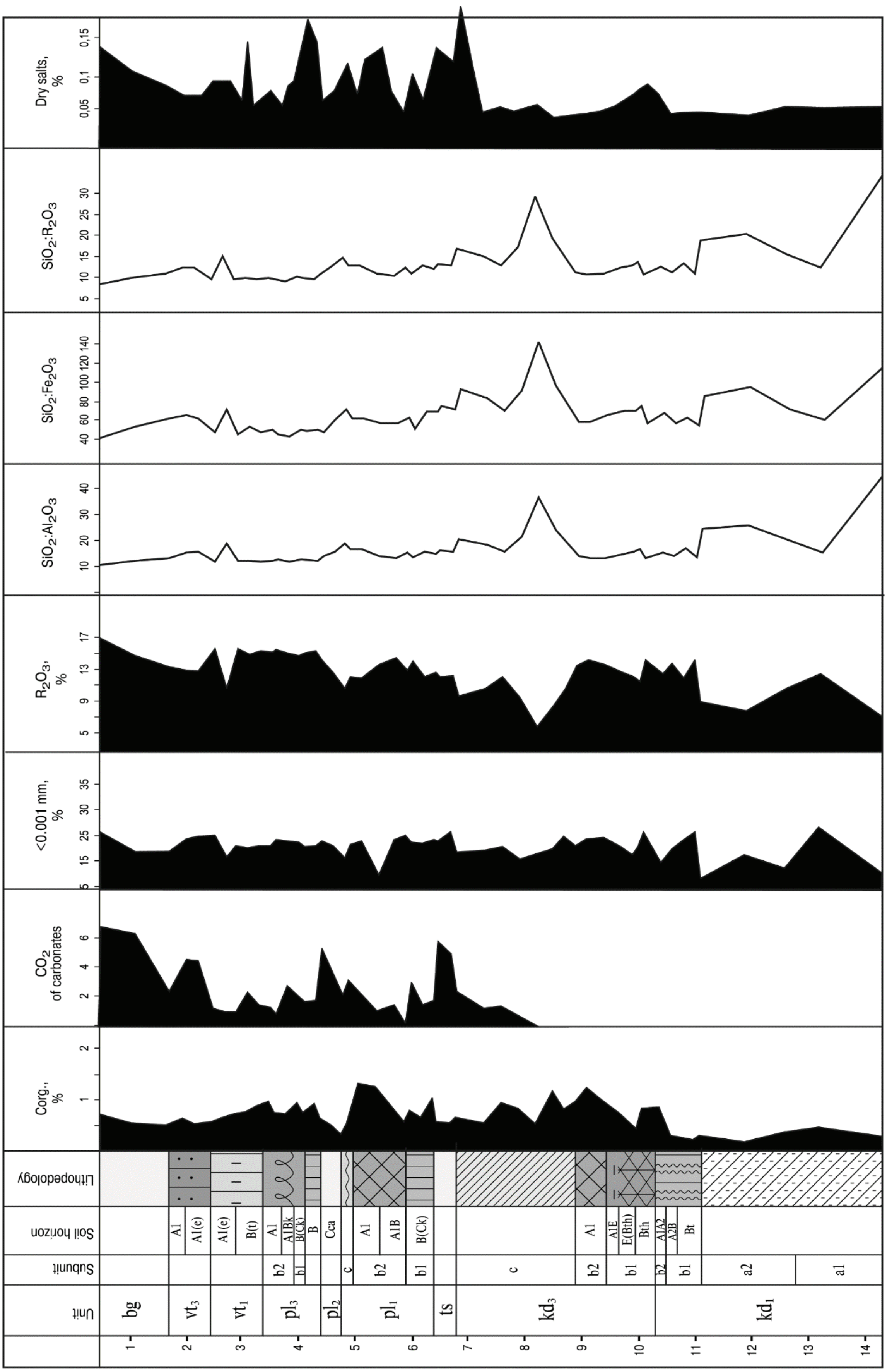

Fig. 2. Main chemical and grain-size characteristics of the deposits of the Kryva Luka site.

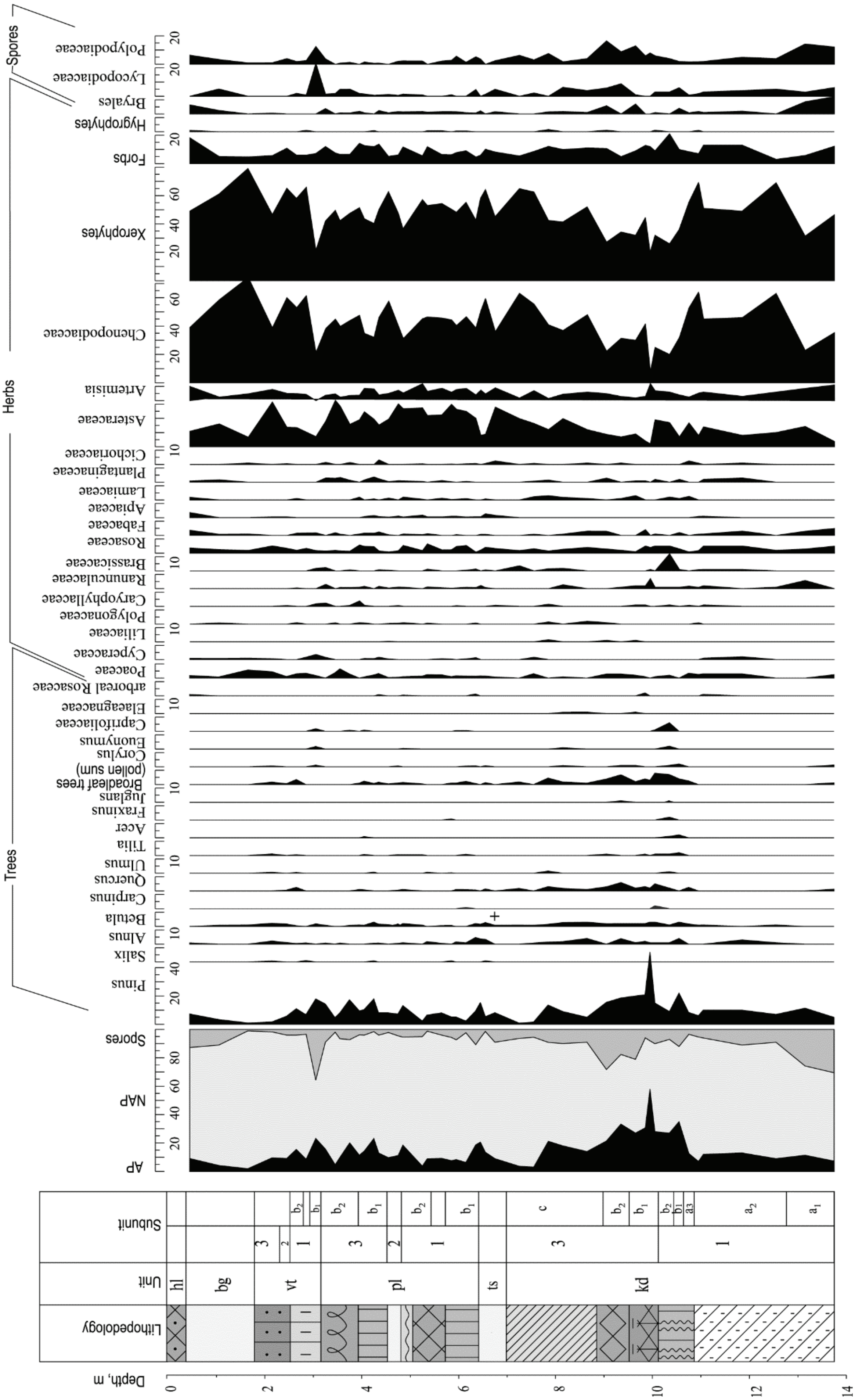

Fig. 3. Pollen diagram of the deposits of the Kryva Luka site. '+' – presence of pollen of *Betula* sect. Nanae et Fruticosae.

len, NAP − non-arboreal pollen. Asteraceae pollen is not included in the sum of forbs because of its over-representation, controlled by the local development of erosional processes and, thus, the disturbed soil cover.

Results. The section includes from the top to bottom those units. ***The Holocene*** (0.0-0.3 m) is represented by the A1C horizon of the truncated Mollisol (a grey loam, with granular-crumbly structure, and $CaCO_3$, penetrating along the root casts).

The Bug (bg)unit (0.3-1.8 m) is a loess, densely penetrated with thin carbonate veins and including humiferous warm routes in its upper part – C(A1)k horizon of the Mollisol. Thin fissures filled in with the loess dissect the underlying Vytachiv soil. The C_{org} content is low (0.5-0.7%) and that of $CaCO_3$ is very high (14-15%). The significant content of R_2O_3 is controlled by the impact of the Holocene pedogenic processes, and it decreases downwards, as well as the content of clay particles (from 26 to 18%). The sum of CaO and MgO is high (6.1%), whereas the content of dry salts, represented mainly by calcium sulfates and hydrocarbonates, is medium (from 0.14 to 0.09% downwards).

Pollen assemblages from the Bug unit is dominated by NAP (81-97%), with Chenopodiaceae pollen being most abundant (53-77%). Pollen of Asteraceae and *Artemisia* is well noticeable (up to 11-19% of each), whereas Poaceae and forbs occur less frequently (up to 4-6% of each). The increase in pollen of forbs in the uppermost bed is connected with the transition to the Holocene soil at this level. The AP (2-8%) is dominated by *Pinus sylvestris* though few grains of *Betula pendula*, *Alnus glutinosa* and arboreal Rosaceae occur. The TL-date from the lower part of the unit is 26±3 ka BP (Gerasimenko, Pedanyuk, 1991).

The Vytachiv (vt) unit (1.8-3.20 m) consists of two palaeosols. The upper one (1.80-2.50 m) – $\boldsymbol{vt_3}$ – is a Calcaric Cambisol, with darker A1 and brownish A1B horizons. The soil structure is not well-developed, whereas carbonates are seen through the whole soil profile. In its upper part, they are secondary forms but in the primary A1Bk horizon, the bright spots of farinaceous carbonates are abundant. The C_{org} content is slightly higher in A1 horizon (0.65%) than in A1B, and the distribution of carbonates and dry salts is opposite. The contents of R_2O_3 and clay fraction is higher than in Bug loess, and the sum of CaO and MgO is much lower (1.8%). The lower soil (2.50-3.20 m) – $\boldsymbol{vt_1}$ – is also a Calcaric Cambisol but with the features of lessivage processes (the content of clay particles and, especially, R_2O_3 is smaller in the middle part of the soil profile (A1E horizon) than in its lower part (Bt horizon). The A1 and A1E horizons have the low content of secondary carbonates, where in the lower part of the Bt horizon, there is a small increase (5%) in $CaCO_3$ (probably connected with several phases in this soil development). The development of lessavage processes is also confirmed by prismatic structure of the bright-brown compacted Bt horizon. There is a network of thin fissures, filled in with loess-like material, which opens from the surface of this soil. This indicates some phase of aridification and wind-blown dust accumulation that occurred between the two main pedogenic phases of the Vytachiv time. There is the erosional level at the base of the 'vt_1'soil – a thin layer of gravel grains and crumbles of the Cretaceous rocks.

Pollen assemblages of the two Vytachiv soils are somewhat different. The 'vt_3' soil has a typical steppe pollen spectra (AP 8-10%, NAP 88-89%, spores 2-4%), whereas the 'vt_1' soil includes both steppe and forest-steppe spectra (the AP up to 24%). The AP from the 'vt_3'soil includes a few (but diverse) pollen of *Alnus glutinosa, Betula pubecens, Salix, Pinus sylvestris, Tilia cordata, Ulmus* sp., *Corylus avellana* and *Rhamnus cathartica.* The NAP is dominated by Chenopodiaceae and Asteraceae but their percentages are lower than in Bug loess. Pollen of *Artemisia*, Poaceae and Roasceae is noteworthy, whereas the other forbs are rare. The AP from the 'vt_1'soil differs in different horizons of soils. The pollen assemblage from the A1E horizon is the richest in palynomorphs of broad-leaved trees (mainly *Quercus*), whereas the pollen spectra from the Bt horizon are either of a steppe type (without pollen of broad-leaved taxa), or of a forest-steppe type (with pollen of *Corylus avellana, Euonymus* and *Sambucus*. Here the percentages of Polypodiaceae and Lycopodiaceae (*Lycopodium annotinum, Diphazium complanatum*) spores strongly increased at the expense of the drop in pollen sum of xerophytes.

The Pryluky (pl) unit is represented by a well-developed thick pedocomplex (3.20-6.40 m), consisting from two palaeosols ('pl_3'and 'pl_1') separated by a thin loess subunit 'pl_2'. The upper ***'pl_{3b2}' soil*** (3.20-4.0 m) includes A1 and A1Bk horizons, both grey but significantly lighter in colour than the modern Mollisols, crumbly and non-compacted, with abundant carbonate pseudomycelium in A1Bk horizon. The upper boundary of the soil is dissected by the wedges (some of them 1.4 m in depth), filled in with loess. The lower boundary is disturbed by shallow ground wedges (0.2 m in depth), filled in with the soil material. Taking in account the degeneration of humus matter in palaeosols, this soil is enriched in organic carbon (0.9-1%).

It has a high position of carbonate horizon, the relatively high sum of CaO and MgO (up to 3.6%). The content of dry salts (0.16%) increased at the level below the humiferous profile. In the pollen assemblage of this soil, AP constitutes only 5-18%, whereas NAP is 82-94%. The AP is dominated by *Pinus sylvestris*. A very few pollen of *Betula pubescens, Alnus glutinosa, Rhamnus cathartica* and *Sambucus* sp. occur. In the NAP, Chenopodiaceae is less abundant than in the Vytachiv soils at the expense of the increase in pollen of Poaceae and forbs.

Below the 'pl_{3b2}' soil (4.0-4.40 m), the remnants of the preceding soil formation is revealed – the B(t) horizon of the ***'pl_{3b1}' soil***, brown-coloured, compacted, prismatic (but without glance films on ped surfaces). The carbonate pseudomycelium (obviously secondary) is less frequent, but in the Ck horizon of this soil, the content of $CaCO_3$ reaches 12%. Dry salts is washed down from the overlying soil. The content of R_2O_3 and clay fraction in the soils of the 'pl_3' subunit is similar to that in the Vytachiv unit, but without their re-distribution in the soil profiles. The pollen spectra from the 'pl_{3b1}' soil are both of steppe (the lower and upper beds) and forest-steppe (the middle beds) types. Besides the AP, represented in the 'pl_{3b2}', pollen of broad-leaved taxa (*Quercus, Ulmus, Acer* and *Tilia cordata*), *Sambucus* and arboreal Rosaceae occur. The NAP is similar to those of the 'pl_{3b2}' soil, and the content of spores are miserable on both soils.

The thin loess-like ***subunit 'pl_2'*** (4.4-4.7 m) is the Ck horizon and the level of accumulation of dry salts, washed down from the overlying soils. It has the low content of C_{org} in its lower part, whereas in the upper part, root casts and warm routs include some humus material. The content of R_2O_3 and clay fraction is much smaller than in all overlying soils and similar to that in the Bug loess. The pollen assemblage of this subunit is dominated by NAP, and namely by Chenopodiaceae and Asteraceae, whereas the pollen percentages of grasses and forbs are very low. No pollen of broad-leaved pollen is found.

The 'pl_1' subunit consists of two palaeosols. The upper one ***'pl_{1b2}'*** (4.7-5.85 m) is a well-developed Mollisol, dark-grey in its A1 horison and brownish-grey in A1B horizon. The material of A1 horizon is granular-crumbly, loose, enriched in C_{org} (1.4%) and, in its upper part, includes soft nodules of $CaCO_3$ (the secondary carbonate horizon). The own carbonate horizon of this soil, represented by the pseudomycelium and small infrequent nodules of $CaCO_3$, is located in the lower part of A1B horizon and in the Ck horizon below the humiferous part of the soil profile. The A1B horizon has prismatic structure. It is more compacted and more enriched in R_2O_3 and clay fraction than A1 horizon. The lower boundary of the soil is uneven – with short 'tongues' of humiferous material (0.2 m in depth) and very thin veins, inclined oppositely to the general downhill sloping of the soils. The pollen assemblage of the soil is of a steppe type (AP 5-12%), with the high percentages of Chenopodiaceae and Asteraceae in the NAP but still a diverse composition of pollen of forbs. The AP includes a very few pollen grains of *Quercus, Tilia cordata, Corylus avellana, Euonymus* sp. and arboreal Rosaceae.

Below the described Mollisol, the B horizon of Cambisol ***'pl_{1b1}'*** (5.85-6.4 m) is located which differs by its bright brown colour and prismatic structure (without glance films on peds surfaces) of the compacted material. It includes less of C_{org} than the Mollisol, the contents of R_2O_3 and clay particles are the same as in the A1B horizon of the 'pl_{1b2}' soil. The B horizon is overlapped by the Ck horizon of the overlying soil but the spots of the primary material, leached from carbonates, are traced. The content of dry salts is much lower than in the overlying deposits. Pollen spectra of this horizon are of steppe and forest-steppe types (in the forest-steppe spectrum from the bottom of the horizon, pollen of *Pinus sylvestris, Alnus glutinosa* and *Betula pubescens* is more abundant than in the steppe spectra). A very few pollen of broad-leaved taxa are presented in all spectra and include *Quercus, Fraxinus, Tilia cordata, Corylus avellana, Sambucus*, and arboreal Rosaceae. The presence of a few grains of *Carpinus betulus* is a special feature. The NAP composition is similar to that in the overlying deposits, but the small peak in Polypodiaceae spores is observed.

The Tyasmyn unit (6.4-6.8 m) is a light-yellow loess (in places up to 0.7 m thick), loose, porous, filled in with carbonates in root casts, with multiple krotovinas. The thin ground wedges in a raw opened from its lower boundary and dissect the underlying deposits. The C_{org} content is low (0.3-0.5 %) and $CaCO_3$ content is high (5-8%). The loess does not differ from the overlying soils in the contents of R_2O_3 and clay fraction, obviously because of the impact of the following pedogenic processes on this thin layer, but the sum of CaO and MgO is higher than in the soils (4%). The pollen assemblage is dominated by NAP (85-88%) of the same composition as in the overlying deposits. The AP (10-14%) consists of *Pinus sylvestris* (dominates), a few *Betula pendula* and *B*. sect. Nanae et Fruticoase, *Alnus glutinosa*, and, at one level, a few grains of broad-leaved taxa (*Quercus* sp. and *Corylus avellana*).

The Kaydaky unit (6.8-14.2 m) includes well-developed pedocomplexes, pedosediments and gully alluvium. The upper part of the unit is represented by pedosediments of subunit ***'kd$_{3c}$'*** (6.8-8.9 m) – the alternation of brownish-grey and dark-grey sandy loams, which includes thin (< 5 cm; rarely up to 10 cm) sand layers. The deposits are thinly bedded and gently inclined downslope. In their upper part, the pedosediments are penetrated by carbonate pseudomycelium ($CaCO_3$ from 7% to 1% downwards), and, at the level around 7 m, the peak in dry salts content (mainly calcium sulfates) occurs. Below this level, the content of dry salts in the Kaydaky unit is very low. The content of C_{org} increased downwards (up to 1.2%) in parallel with the predominance of dark-grey re-deposited soil material. The contents of R_2O_3 and clay fraction is lower than in the overlying and underlying soil deposits because of a strong increase in sand fraction in the pedosediments.

There is no point in establishment of pollen assemblages in pedosediments as they include re-deposited pollen. Nevertheless, two palynologically different parts of these pedosediments are traced. The upper brownish-coloured beds (6.8-7.8 m) has the very low AP (4-9%), represented mainly by *Pinus sylvestris* (a few grains of *Alnus, Betula* and *Quercus*). The percentages of Chenopodiaceae pollen here are the same as in the overlying deposits. The lower darker-coloured beds (7.8-8.9 m) are richer in AP (up to 21%) which includes *Alnus, Betula, Quercus, Ulmus, Corylus, Euonymus* and Elaeagnaceae. The percentages of Chenopodiaceae in the NAP are less than in the overlying deposits.

In the excavation, located higher up in the course of the ravine, the pedosediments above the Kaydaky pedocomplex are absent, and the latter is overlain by the incipient soil 'kd$_{3c}$' (0.3 m thick). It is light-brown in colour, not-compacted, and dissected by the wedges filled in with the Tyasmyn loess (up to 0.2 m in width in their upper part and 0.7 m in depth). The C_{org} content in the soil is low (0.6%), as well as that of dry salts, whereas the content of $CaCO_3$ is high (7%). The pollen assemblage of the incipient soil is dominated by NAP (75%), in which the percentages of Chenopodiaceae, Asteraceae and the sum of other forbs are approximately equal. *Pinus sylvestris* dominates the AP, but pollen of *Alnus glutinosa, Betula pubescens, B. pendula, Quercus* sp., *Tilia cordata* and *Euonymus* sp. occur.

In the main excavation, the Mollisol '***kd$_{3b2}$***' (8.9-9.4 m) is partly truncated by the overlying pedosediments but still has very high contents of C_{org} (1.2-1.3%) and R_2O_3 (12-14% %). It is leached from carbonates and dry salts. The soil material is dark-grey silty loam, loose, with granular-crumbly structure, and the gradual transition downward. Higher up in the course of palaeogully, this soil is 0.8 m thick, with A1 and A1B horisons. The A1 horizon is penetrated by the secondary carbonate pseudomycelium which disappears downward, but in the lowermost part of the A1B horizon, the own carbonate horizon of the soil is located (large spots of loose carbonates). The pollen assemblage of the truncated leached Mollisol is of a forest-steppe type (AP 23-33%, NAP 50-52%, spores 17-25%). The AP is dominated by *Pinus sylvestris* but differs from all overlying deposits by the higher percentages of pollen of broad-leaved trees, particularly of *Quercus robur*. A few grains of *Tilia cordata, Corylus avellana, Cornus mas* and *Juglans regia* are present. The other AP includes *Alnus glutinosa, Betula pubescens,* and one pollen grain of *Picea* occurs in the uppermost soil bed. In the NAP, the percentages of Chenopodiaceae pollen decrease (20-35%) as compared to the overlying soils. The maximum of Polypodiaceae spores (up to 15-20%) is observed.

The soil '***kd$_{3b1}$***' (9.4-10.2 m) is a Luvic Greyzemic Phaeozem, completely leached of carbonates. The A1E horizon (9.4-9.5 m) is a grey loose silty loam, with SiO_2 powder. The E(Bth) horizon (9.5-9.8 m) is whitish from SiO_2, with the lenses completely filled in with it. Prismatic structures occur rarely. The Bth (9.8-10.2 m) horizon is dark-brown, compacted, with perfectly developed blocky-prismatic structure, with glance colloidal films on the ped surfaces. The dark colour of these films indicate translocation of organic matter, together with clay particles and R_2O_3. The visual signs of eluviation-illuviation in the soil is confirmed by the analytical data. The content of clay fraction in the Bth horizon is 12% larger than in the E horizon, and the content of R_2O_3 follows the same pattern. The content of C_{org} is equally high (0.9%) in A1E and Bth horizons that testifies its translocation. The sum of CaO and MgO is very low (1.5-2%).

Pollen spectra from this soil are of a forest-steppe type, and one bed of the Bth horizon has pollen spectrum of a forest type (AP 63%, NAP 30% and spores 7%). *Pinus sylvestris* dominates the AP, particularly in the forest spectrum. Pollen of small-leaved and broad-leaved trees is well noticeable. The broad-leaved taxa include pollen of *Quercus robur, Carpinus betulus, Tilia cordata* and *Corylus avellana*. Pollen percentages of Chenopodiaceae remain not significant, whereas Polypodiaceae spores are noteworthy.

The '***kd$_{1b}$***' soil (10.2-11.1 m) is a Luvisol, which is characterized by a stronger clay translocation than the Phaeozem but without organic matter illuviation. The A1E horizon is a very thin (10.2-10.3 m) and transformed by translocation processes from the overlying Greyzemic Phaeosem, but the SiO_2 powder from the primary pedogenic processes is present. The Btf horizon (10.3-11.1 m) is bright-ochre-brown, with a kind of marble-like colouration, prismatic, compacted, with orange-brown glossy films of the ped surfaces, with punctuations of Fe-Mn hydroxides, and with a very small content of C_{org}. The redistribution of clay fraction and R_2O_3 is well-expressed, and their contents are rather high, despite this soil was formed on sandy deposits.

The pollen assemblage of the soil includes 23-35% of AP, 53-66% of NAP and 6-12% of spores. Only the lowermost bed of Bth horizon has a steppe type spectrum (AP 13%, NAP 84%, spores 3%). This fact can be a result of transformation of the upper bed of the underlying subunit by translocation processes. The AP, besides pollen of *Pinus sylvestris* and small-leaved trees, includes pollen of broad-leaved taxa – *Quercus robur, Tilia cordata, Ulmus, Acer, Fraxinus, Corylus avellana*, and one pollen grain of *Juglans regia.* Pollen of bushes also includes *Euonymus, Viburnum* and *Sambucus*. In the upper part of the soil, pollen of Chenopodiaceae practically disappears, and pollen of forbs reaches its maximum.

The ***'kd$_{1a}$'*** subunit (11.0-14.2 m) is represented by the palaeogully alluvium – bedded sandy silts and sands, which sloping the same direction as the modern gully thalweg does (but with much larger inclination). The thickness of the beds varies from 3 to 20 cm. The sands are yellowish-brown, mainly small-grained, though, in places, coarse (particularly at the base of the subunit). The loams are greyish-brown, sandy, with manganese punctuations. The lower boundary is sharp, erosional, cut into Cretaceous rocks. The brown loamy beds can be slightly enriched in R_2O_3 (up to 12%). The subunit includes two pollen assemblages, both with pollen spectra of a steppe type. The upper one 'kd$_{1a2}$' (11.0-12.4 m) has very high percentages of Chenopodiaceae pollen (up to 77%), whereas the AP includes only *Pinus sylvestris* and a few *Alnus glutinosa, Betula pubescens* and arboreal Roasaceae. The lower assemblage 'kd$_{1a1}$' (12.4-13.8m) is characterized by the high percentages of spores (up to 29%), the occurrence of a few pollen of broad-leaved trees (*Quercus* and *Corylus*) and the smaller percentages of Chenopodiaceae pollen than the overlying subunit.

Interpretation. At the beginning of ***Kaydaky times***, strong erosion caused an incision in the Cretaceous chalk, and intense accumulation of the gully alluvium started. Judging from the inclination of bedded sands and silts, as compared to that of the modern thalweg, the palaeogully slope was sharper than at present. Pollen data indicates that the incision started at a time when the first broad-leaved taxa (oak and hazelnut) appeared in the vegetation, Polypodiaceae ferns spread, as well as plants of Chenopodiaceae, though they were less abundant than later. This phase can be compared with the time span '***kd$_{1a}$***' in other areas, a period at the transition from the penultimate glaciation to the last interglacial (Gerasimenko, 2006). The upper part of the gully alluvium, less enriched in R_2O_3 and clay, was formed in a treeless area (only a few alder near the river and Rosaceae bushes in the gully). Ferns almost disappeared, and Chenopodiaceae plants became most abundant. All of these indicate a much more arid and cooler climate than during the preceding phase. The same climatic dynamics are revealed in Central Ukraine during the second phase of the pre-temperate stage of the last interglacial – '***kd$_{a2}$***' (Gerasimenko, 2006). A parallel can be traced between these phases and the Allerød interstadial and the Young Dryas stadial, which preceded the beginning of the modern Holocene interglacial. It has been proved (Sidorchuk *et al*., 2008) that the incision of Holocene rivers and gullies also started during the transition from the last glaciation to the modern interglacial. The last phase of the pre-temperate stage of the interglacial – '***kd$_{a3}$***'– is indicated by the pollen found in the lowermost bed of Btf horizon of the 'kd$_{1b1}$' Luvisol. At that time a few oaks re-appeared and Chenopodiaceae became much less abundant, which indicates some increase in warmth and humidity.

The temperate stage of the interglacial had started by the time the erosional processes in the gully stopped, and soils developed under the woodland, whose spread obviously was larger than at present. Alder and *Betula pubescens* framed the river course; and pine appeared on the sandy and chalky rocks. Diverse broad-leaved trees (oak, elm, lime-tree, maple, and, later on, ash-tree and walnut), as well as mesophilic bushes (such as hazelnut, spindle-tree, viburnum and elder) grew in the gully. The minimum of Chenopodiaceae and the maximum of forbs indicate that the upper parts of slopes and the plateau were covered by mesophytic steppe. During this time translocation processes developed in the Luvisols. The climate was warmer and much more humid than at present. This phase, '***kd$_{1b1}$***', is related to the first (early temperate) climatic optimum of the interglacial. During the next phase, '***kd$_{1b2}$***', some humus accumulation started, forming the A1E horizon of the Luvisols, and there was a decrease in the diversity of broad-leaved trees (oak dominated). This phase might reflect some cooling (indicated by the disappearance of walnut).

The next phase in the development of the vegetation is revealed in the lowermost bed of the Bth horizon of the Greyzemic Phaeozem. It was marked by the maximum spread of pine in the area, probably controlled by the enlargement of chalk exposures in the slope of the River Donets. The presence of eroded slopes is also evidenced by the increase in Chenopodiaceae pollen and the appearance of *Elaeagnus angustifolia*. The relatively high content of coarse silt ('loess fraction') at this level (33%, as against 16-19% below) indicates the strengthening in the region of aeolian processes. The new silt input allowed the Phaeozem to develop without transforming the underlying Luvisol with its translocation processes. During this time, the areas with broad-leaved woods became smaller, and they consisted only of oak and lime. All of this indicates the increase in the continentality of the climate during the short '$\boldsymbol{kd_2}$' time period.

During the formation of the Greyzemic Phaeozem (the phase'$\boldsymbol{kd_{3b1}}$'), erosional processes lessened, and the gully was occupied by broad-leaved taxa − oak (dominant), hornbeam, hazelnut and walnut. Chenopodiaceae became much less abundant, and ferns and club-mosses spread. It was the second (late temperate) optimum of the interglacial, with a warmer and wetter climate than nowadays. At present, hornbeam does not grow in Eastern Ukraine. The '$\boldsymbol{kd_{3b2}}$' Mollisol has a strong humus accumulation, which could not have formed under a forest canopy. Thus, the gully slope studied was covered by herbs and grasses. Broad-leaved trees (oak and lime) and ferns grew at the gully bottom. The change in pedogenic processes and the disappearance of highly mesophilic arboreal taxa indicate that the interglacial climate became drier, but it was still more humid than at present, as modern Mollisols are not leached.

The end of the interglacial (the post-temperate stage) is not well recorded in the studied sequence because of the affect of erosional processes, followed by accumulation of pedosediments '$\boldsymbol{kd_{3c}}$'. Nevertheless, changes in lithology and pollen enable one to trace the trend in environmental development. The lower pedosediments is similar to the material of the 'kd_{3b2}' Mollisol in both the content of $C_{org.}$ and the absence of $CaCO_3$, but it differs significantly in its impoverishment in clay and, particularly, in R_2O_3. The latter features were controlled by erosional processes, which are clearly indicated by the increase in the sand fraction, as well as the sharp increase in ruderal plants, particularly Chenopodiaceae. The upper pedosediments were not formed as a result of the redeposition of 'kd_b' soils, as they have a high content of carbonates and, in their uppermost beds, even of dry salts. The pollen data demonstrate that these deposits were accumulated in treeless landscapes (only a few oak occurred in the gully). Chenopodiaceae or Asteraceae dominated the steppe associations. A study of the chemistry and pollen of the poorly developed 'kd_{3c}' soil, located higher up in the course of the palaeogully, give evidence that these pedosediments were formed through re-deposition of the material of the 'kd_{3c}' soils. Thus, in the studied area, the very end of the interglacial and the transition to the early glacial was very arid and rather cool.

During ***Tyasmyn times***, soil formation ceased at the site despite the fact that at first the vegetation's composition was similar to that during the 'kd_{3c}' phase, with a few oak and hazelnut persisting in the gully. Erosional processes weakened, as it evidenced by the decrease in sand (8-28%) as compared with the upper 'kd_{3c}' pedosediments (47-50%), and an increase in the input of coarse silt. The intense accumulation of carbonates indicates an arid climate (though some of them were a result of $CaCO_3$ leaching from the overlying soil). The area became treeless (only some pines on chalky rocks and a few alder near the water). Chenopodiaceae and Asteraceae dominated steppe vegetation, whereas the role and diversity of forbs significantly diminished. Later on, the arid climate became cold: a few shrub birches grew, and broad-leaved taxa completely disappeared. The fissures in raw, dissecting the underlying deposits, indicate deep seasonal freezing of the ground, under a severe continental climate.

Several drastic environmental changes characterized ***Pryluky times***. A first phase, '$\boldsymbol{pl_{1b1}}$', was marked by formation of a Cambisol. Clay weathering and leaching of carbonates, typical for this soil, indicate a relatively warm climate, which provided moisture in the gully. Arboreal vegetation grew here, whereas steppe occupied the plateau. Forbs became more abundant and diverse than during Tyasmyn times, though Chenopodiaceae still dominated in the eroded parts of the slope. The few trees in the gully included oak, lime, ash, and hornbeam, with ferns growing under them. The existence of mesophilic trees and the spread of mesophytic herbs and ferns indicate a semi-humid climate, which was wetter than at present.

A Mollisol formed during the next phase '$\boldsymbol{pl_{1b2}}$'. As compared to the Cambisol, it differs by its enrichment in humus, the relatively high position of its carbonate horizon, and the lower content of clay and R_2O_3 in its A1 horizon. The prismatic structure in its Bk horizon may indicate that it was formed in the material of the preceding Cambisol. The plateau around the gully was completely treeless. Low percentages of pine pollen do not allow one to surmise the growth of pine trees in the vicinity of the site, as a long-distance pollen transport much be inferred. A very few oak, lime and hazelnut grew near the bottom of the gully, but not in the studied site. The more extensive spread of xeric herbs and less abundant broad-leaved species that are found now indicate that the climate of that time was somewhat cooler and drier than today.

The formation of a loess-like bed during the phase '***pl***$_2$' reflects further aridification. Humus accumulation stopped, and the content of coarse silt increased, the opposite trend to that of clay particles. Only alder and *Betula pubescens* grew near the water, and a few Rosaceae bushes on slopes. Xerophytization of steppe coenoses is reflected in the spread of Chenopodiaceae and lesser numbers of forbs. The humus 'tongues' along the lower boundary of the underlying soil, as well as thin fissures in raw, dissecting the soil's upper boundary, indicate a continental climate with dry summers and very cold winters. The next phase, '***pl***$_{3b1}$', is represented only by the remnants of a Cambisol, its B horizon, overprinted by the Ck horizon of the overlying soil; and its own carbonates are deeply leached from the soil profile. In general, the content of carbonates is lower and that of R_2O_3 higher than above and below in the section, which indicates some clay weathering. The change in the vegetation, as compared with the preceding phase, is rather distinct. The spread of forbs and a lessening of Chenopodiaceae indicate that mesophytic steppe occupied the plateau. A few broad-leaved trees (oak, elm, maple, and lime) appeared in the gully, and pine grew on chalk rocks. The semi-humid steppe climate was similar, but somewhat drier, than that of phase '***pl***$_{1b1}$'.

The palaeosol developed during the phase '***pl***$_{3b2}$' is less enriched in humus than the '***pl***$_{1b2}$' Mollisol, and it has a larger content of $CaCO_3$ and the higher position of carbonate horizon. Calcium sulphates and potassium hydrocarbonates were deposited during its formation, but, later on, they were washed downward. The rather high content of R_2O_3 is inherited from the underlying soil. The '***pl***$_{3b2}$' soil was formed in a treeless steppe, dominated by Chenopodiaceae on the eroded slopes, and with more grasses on the plateau than during the preceding phases, when forbs were more important. Pine grew sporadically on chalk. It is suggested that the '***pl***$_{3b2}$' soil is a kind of Kashtanozem, with weak, deep solonization. Such soils form in an arid climate.

The deposits of ***Uday times*** are truncated, as evidenced by the erosional level at the base of the Vytachiv unit. In the lower reaches of the gully, the light-brown coloured Vytachiv alluvium is exposed, overlain by the thick Bug loess. In the studied section, the Uday loess survives only in deep ground wedges that dissect the Pryluky soils. Smaller humus 'tongues', filled with 'pl$_{3b2}$' Kastanozem at the lower boundary of this soil, demonstrate the first phase of frost wedging that occurred at the beginning of the Uday times. Later the soil was affected by stronger wedging under a continental climate, with very severe winters.

At the beginning of ***Vytachiv times***, lessivage processes developed in the Cambisol (with the re-distribution of R_2O_3 and clay within the soil profile). In this time, mesophytic steppe covered the plateau. Pine spread on the chalk, and groves of small-leaved trees grew in the gully, with a rich ground cover formed from club-mosses and ferns. The appearance later of oak, a few hazelnut and spindle-tree indicates that the climate became warmer (the south-boreal). At the same time, the sharp decrease in mesophytic herbs and, particularly, the disappearance of spore plants and the extensive spread of herbal xerophytes on the steppe show that the warming was followed by aridification. Trees retreated in the lower part of the gully, whereas in the studied locality, calcium carbonate accumulated and transformed the leached soil in the Calcaric Cambisol '***vt***$_1$'. Thin fissures, opening from the top of this soil and infilled with loess, indicate a further increase in climatic continentality, obviously during the '***vt***$_2$' phase, represented in the other section by a thin loess bed (Gerasimenko, Pedanyuk, 1991; Gerasimenko, 2010). During the '***vt***$_3$' phase, a typical Calcaric Cambisol was formed under the steppe. The role of xeric herbs and grasses was larger and that of forbs smaller than during '***vt***$_1$' soil formation. The climate was arid, but not cold. Pine disappeared from the slopes, but in the wet gully, buckthorn and a few broad-leaved species (elm, lime and hazelnut) grew. Both phases of Vytachiv soil formation were relatively warm.

During ***Bug times***, pedogenic processes ceased, and coarse silt ('loess fraction') accumulated much more than in the underlying soils. The enrichment in $CaCO_3$ and impoverishment in R_2O_3 indicate an arid and cold climate. The area was treeless (only a few alder and *Betula pubescens* grew near the river). Xeric herbs in the steppe vegetation reached their maximum. Nevertheless, the phase, represented in the studied section (dated to 26±3 ka BP), was not the coldest of Bug times. The absence of cryoturbations and of pollen of arcto-boreal plant species does not allow the interpretation of a periglacial climate.

Conclusion. Studies of lithology and palynology applied to deposits at Kryva Luka have demonstrated multiple short-period environmental and climatic changes during the Late Pleistocene. The palaeogully's sediment trap was also a pollen trap, and this pollen allows reconstruction of short-lasting phases in vegetational development. Usually it is not an easy task to interpret palynological assemblages from steppe coenoses. On the other hand, the position of the section in a palaeogully, where intense erosion occurred on its slopes, caused an over-representation of pollen from ruderal plants (particularly Chenopodiaceae) that had has to be taken into account when interpretating the palynology.

The interglacial climate, which was warmer and wetter than now, existed only during Kaydaky times, when Luvisol and Greyzemic Phaeozem developed on the slopes of the gully. The modern southern limit of disconnected patches of Greyzemic Phaeozems extends to more than 200 km north from Kryva Luka. In the climatic optima during Kaydaky times, the area was located in the forest-steppe realm, with the highest Late Pleistocene incidence of broad-leaved species. Mesophilic hornbeam occurred in woodland. The southern limit of its distribution is now located about 450 km north from the studied locality. Thermophilic walnut grew sporadically, and its occurrence in the vegetation of Kaydaky times has been recorded elsewhere in Ukraine (Sirenko, Turlo, 1986; Bolikhovskaya, 1995; Gerasimenko, 2010). Pollen assemblages from the site, located in the modern steppe belt of eastern Ukraine, differ from the typical last interglacial succession in western and northern Europe, in having large percentages of herbal pollen. Nevertheless, considering the succession within the AP in the lower and middle part of the Kaydaky unit – *Pinus+Betula+Alnus* – *Pinus+Quercus* − *Quercus+Ulmus+Tilia+Corylus* – *Quercus+Carpinus+Tilia* – *Pinus+Alnus+Betula +Picea* − *Pinus+Alnus+Betula*, one can see the similarity with the last interglacial succession. Thus, we correlate Kaydaky times with the last interglacial, as has been suggested previously (Rousseau *et al*., 2001; Gerasimenko, 2006; Matviishina *et al*., 2010; Haesaerts *et al*., 2016), though a contrary opinion has been also suggested in Ukraine − on a correlation of early Pryluky time with the MIS 5e (Gozhik *et al*., 2000; Boguckyj *et al*., 2002; Lindner *et al*., 2006).

According to the data obtained from the Kryva Luka site, forest soils and forest vegetation never spread in the area as extensively as they did during Kaydaky times. During later phases of soil formation ('pl_{1b1}', 'pl_{1b2}', 'pl_{3b1}', 'vt_1' and 'vt_3') broad-leaved species rarely grew in wooded gullies, though they did not occur during the driest pedogenic phase ('pl_{3b2}'), when Kastanozems formed. Hornbeam grew sporadically in the gullies during 'pl_{1b1}', when Cambisols formed on their slopes. All the above-mentioned phases of soil formation are related to interstadials, with that of the 'pl_{1b1}' phase having had the mildest climate. TL-dates of 75.0±4 ka BP and 57.5±3 ka BP were obtained from the Uday loess unit and the lowermost soil of the Vytachiv unit, respectively, and 90±5 ka BP from the Tyasmyn unit in other sites in the western Donetsk area (Gerasimenko, Pedanyuk, 1991; Gerasimenko, 2011). Thus, the Pryluky interstadials are compared with those of MIS 5, whereas the interstadials of Vytachiv times are correlated with MIS 3.

Stadials, represented by loess beds, are those from Tyasmyn, middle Pryluky and Bug times. Pollen of broad-leaved species is absent in these deposits. It is also absent in the other two levels – between subunits 'vt_3' and 'vt_1', and within subunit 'pl_{1b}'. The same have been revealed in the other east Ukrainian sites (Gerasimenko, Pedanyuk, 1991; Gerasimenko, 2006, 2010) that enables the suggestion on the existence of stadials at the corresponding times − 'vt_2', and between 'pl_{1b1}' and 'pl_{1b2}' phases. Cryoturbation and desiccation fissures were formed during the aforementioned phases, indicating a cold continental climate. Nevertheless, cryoturbation types and their sizes, and the absence of pollen of arcto-alpine species (with the exception of one level within the Tyasmyn unit), do not allow the reconstruction of permafrost in the studied area. The absence of pollen of cryophytes in the other sections of the Donetsk area (Artyushenko *et al*., 1973; Gerasimenko, 2011) enables the suggestion to be made that during these stadials, ground wedges developed in deeply frozen soils under a very severe winter climate.

The comparison of palynologically based vegetation reconstruction with the lithopedosequence at Kryva Luka, characterized by an intense sediment accumulation and pedogenic processes, demonstrates the very good correspondence in the palaeoclimatic interpretations derived from the palaeosol types and the reconstructed vegetation. The direct correlation between characteristics of the palaesols and the composition of the coeval vegetation, which is one of the most important factors affecting soil formation, proves the importance of palaeosols as reliable palaeoenvironmental and palaeoclimatic indicators.

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