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Significance of the Ukrainian loess-palaeosol sequences for Pleistocene climate reconstructions: rock magnetic, palaeosol and pollen proxies[1]

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Variations of rock magnetic parameters in loess-palaeosol sequences, related to climatic and environmental conditions during their formation, are a powerful tool for palaeoclimate reconstruction. Combined enviromagnetic study of loess deposits in Ukraine and its assessment for the palaeoreconstruction purposes are carried out in the framework of the National Research Foundation of Ukraine project 2020.02/0406 'Magnetic proxies of palaeoclimatic changes in the loess-palaeosol sequences of Ukraine'. Environmental/climatic reconstructions of the past are fulfilled using a significant number of palaeoindicators: morphology and lithological properties of palaeosols and loesses, their pollen assemblages and a wide range of magnetic characteristics. In this paper, we present a multi-proxy approach to palaeoenvironmental reconstructions, and introduce preliminary results obtained from magnetic susceptibility of loess-palaeosol sequences in the northern (at Vyazivok), central (Stari Kaydaky) and southern (Roksolany) parts of the Ukrainian loess belt. The amplitudes of palaeoclimate change established using magnetic proxies are well correlated with the lithological, palaeopedological and palynological patterns of the sites, and with the global oxygen-isotope scale (MIS). Ongoing studies of the Stari Kaydaky section confirm the correlation of the Upper Zavadivka (S3) soil unit and Lower Zavadivka (S4) soil unit with MIS 9 and MIS 11, respectively (this was proved earlier at the Vyazivok and Roksolany sites). The underlying Lubny (S5) pedocomplex likely corresponds to MIS 13, and the Martonosha (S6) pedocomplex to MIS 15. Palaeomagnetic investigations at Stari Kaydaky have not so far reached the Lower Shyrokyne unit, in which the Matuyama—Brunhes boundary has been detected at Roksolany and Vyazivok. The Upper Shyrokyne (S7S1) palaeosol unit has normal polarity and is preliminarily correlated with MIS 17.

Key words: loess-palaeosol sequence, rock magnetism, magnetic susceptibility, palaeopedology, palynology, palaeoclimate, stratigraphic correlation.

Introduction. A key to the solution of the urgent problem of the world community — global climate change — is a knowledge about the global and regional patterns of climate fluctuations in the past. The history of the past enables the understanding of the present, and it provides a possibility for predictions of the future. Alongside with the well-known natural 'archives' of palaeoenvironmental events, recorded in ice cores, marine and lake sediments, the Quaternary climatic cycles are also presented in loess-palaeosol

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sequences which are another valuable archive of palaeoenvironmental information.

Despite of significant amount of data obtained by Quaternary geology and palaeogeography, the forecasts of future climate change differ significantly. Therefore, nowadays a great attention is paid to implementation of new research methods within a multidisciplinary approach, to the search of new complete sections within the terrestrial archives, and to analysis of the factors that have caused palaeoenvironmetal changes [Vandenberghe, Nugteren, 2001; Buggle et al., 2013; Sümegi et al., 2015, 2019; Marković et al., 2018; Zeeden et al., 2018; Chmielowska, Woronko, 2019; Molnár et al., 2021; Scheidt et al., 2021; Wacha et al., 2021].

The new advances in rock magnetic methodologies and analytical techniques expand our ability to obtain important information on palaeoenvironmental change, including reconstruction of past geomagnetic field variations and environmental parameters, and understanding the processes of loess-palaeosol magnetic properties formation. Palaeoclimatic studies of the key loess-palaeosol sequences in the Chinese Loess Plateau (CLP), Central Asia, Danube Basin and East European Plain [Heller, Liu, 1984; Kukla et al., 1988; Forster et al., 1994; Jordanova, Petersen, 1999; Evans, Heller, 2001, 2003; Rousseau et al., 2001; Buggle et al., 2009; Fitzsimmons et al., 2012; Marković et al., 2015; Necula et al., 2015; Bakhmutov et al., 2017; Chen et al., 2018; Song et al., 2018; Sümegi et al., 2018; Költringer et al., 2020; Bradák et al., 2021; Laag et al., 2021 and many others] have shown that rock magnetic palaeoenvironmental proxies, primarily magnetic susceptibility (MS), display strong similarities and can be correlated with the marine oxygen-isotope stages (MIS) [Shackleton et al., 1990; Lisiecki, Raymo, 2005].

The similarity in variations in the MS records and other palaeoclimate proxies (ratio of oxygen isotopes, organic carbon, biogenic silica) in the same age rocks confirms the possibility of palaeoclimatic reconstruction using magnetic properties of marine and lake sediments, but also of subaerial deposits [Evans, Heller, 2001, 2003]. Palaeosol types and pollen assemblages in these sediments are other important proxies for this purpose. Thus, rock magnetic (magnetic properties of rocks) and palaeomagnetic (magnetostratigraphy) methods, especially combined with lithological-palaeopedological and pollen studies, is a powerful tool for the reconstruction of palaeoenvironmental changes, as well as in applied sciences: engineering geology, economics, archaeology, modern environmental and forecasting tasks [Evans, Heller, 2001, 2003; Maher, 2011; Menshov, 2019; Jordanova, Jordanova, 2021; Zeeden, Hambach, 2021 and others].

In this paper, we present methods and directions for our investigation and new results on magnetic susceptibility from loess-palaeosol deposits in the northern, central and southern parts of Ukraine, carried out in the framework of National Research Foundation of Ukraine' project 2020.02/0406 'Magnetic proxies of palaeoclimatic changes in the loess-palaeosol sequences of Ukraine'. At present, the three most complete loess-palaeosol sequences of the Dnieper River basin (Stari Kaydaky and Vyazivok) and the Black Sea Lowland (Roksolany) are compared by magnetic, palaeosol and pollen proxies and correlated with the marine isotope record.

The Ukrainian loess belt: short overview of the previous studies. Loess-soil deposits, covering over 70 % of the territory of Ukraine, are prominent in their stratigraphic completeness. They form the Ukrainian loess belt located in the central part of the Eastern Europe (Fig. 1). Their pedostratigraphy and palaeoenvironmetal proxies (palaeosols and pollen) have been studied by Ukrainian scientists since the 1920s [Krokos, 1926; Veklitch et al., 1967, 1979, 1984, 1993; Veklitch, 1968, 1982; Sirenko, Turlo, 1986; Gozhik et al., 1995, 2000, 2001, 2007; Gozhik, Gerasimenko, 2011; Gozhik, 2012; Bogucki, 1986; Boguckyj, Łanczont, 2002; Boguckyj et al., 2009; Bogucki et al., 2013, 2014; Matviishina et al., 2001; Matviishyna et al., 2010; Matviishyna, Doroshkevych, 2019; Gerasimenko, 2001, 2004, 2006, 2020; Gerasimenko, Matvijishyna, 2007; Sirenko, 2017a,b, 2019a,b; Doroshkevych, 2018; Karmazinenko, 2019; Veklych, 2019; Bonchkovskyi, 2019, 2020a,b and many others]. The significant input has been also made by researchers from other European countries [Velichko, 1997; Bolikhovskaya, Molodkov, 2006; Rousseau et al., 2001, 2011; Haesaerts et al., 2003, 2016, 2019; Lindner et al., 2006; Łanczont, Boguckyj, 2007; Łanczont, Madeyska, 2015; Łanczont et al., 2019; Buggle et al., 2008, 2009; Bokhorst et al., 2009; Veres et al., 2018; Tecsa et al., 2020].

The Stratigraphic framework of the Quaternary deposits of Ukraine [Veklitch et al., 1993], modified in recent two decades [Gozhik et al., 2001; Gerasimenko, 2004, 2006; Matviishyna et al., 2010] and the Stratigraphic Code [Gozhik, 2012] are the main tool for stratigraphical division of the Quaternary deposits in Ukraine. The multidisciplinary palaeogeographical approach was used as the base to substantiate the framework which includes the following methods of palaeoenvironmental studies: lithology, palaeopedology (including micromorphology), clay mineralogy, palaeogeomorphology, mammal fauna, mollusc fauna, pollen, cryolithology, luminescence and radiocarbon dating, palaeomagnetism, and, finally, palaeoclimatology and palaeolandscapes. It should be mentioned that many luminescence and radiocarbon dating results remain contradictory.

The study of the magnetic properties of these rocks began in the 1970s [Tretyak, Volok, 1976; Tretyak, 1980, 1983; Tretyak et al., 1987, 1989; Tretyak, Vigilyanskaya, 1994] and have been continued during the last 20 years [Vigilyanskaya, Tretyak, 2001, 2002; Bakhmutov et al., 2005, 2017; Bakhmutov, Hlavatskyi, 2014; Bakhmutov, Glavatskiy, 2016; Hlavatskyi et al., 2016a,b; Hlavatskyi, 2019; Hlavatskyi, Bakhmutov, 2019, 2020; Nawrocki et al., 1999, 2002, 2016; Gendler

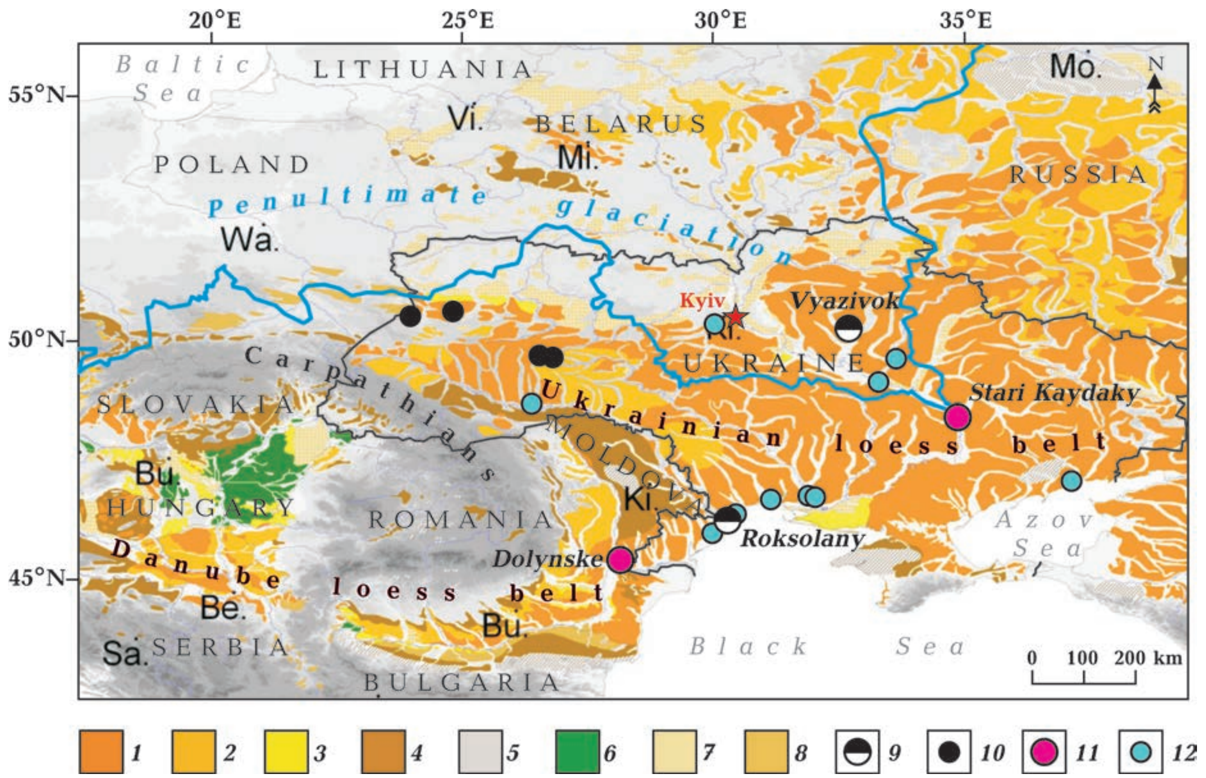

Fig. 1. Map of loess deposits in Central—Eastern Europe [Haase et al., 2007]. Loess distribution (facies): *1* — loess, >5 m; *2* — loess, <2 m; *3* — sandy loess; *4* — loess derivates; *5* — loess and loess derivates in fragmentary distribution; *6* — alluvial loess; *7* — aeolian sand; *8* — loess thickness not differentiated. *Selected Ukrainian loess sections*: *9* — in which the MBB was detected by co-authors of the present study [Bakhmutov, Hlavatskyi, 2014; Hlavatskyi et al., 2016b; Bakhmutov et al., 2017; Hlavatskyi, Bakhmutov, 2019, 2020]; *10* — other loess sections, studied palaeomagnetically by [Hlavatskyi et al., 2016a, 2021b; Bakhmutov et al., 2017]; *11* — loess sections currently under investigation; *12* — promising research sites, declared within the framework of the Project. The extent of the penultimate glaciation according to [Ehlers et al., 2011].

et al., 2006; Boguckyi et al., 2009; Bogucki et al., 2013; Menshov, 2015; Bondar, Ridush, 2015; Bondar et al., 2019]. The results of early research, due to the lack of accurate magnetometers and some methodological issues, in many cases led to misinterpretations. An illustrative example is the contradiction in the definition of the Matuyama—Brunhes boundary (MBB) in the Roksolany section by different scientific teams (discussed in [Hlavatskyi, Bakhmutov, 2020]).

Due to the absence of reliable magnetic (and geochronological) markers for chronostratigraphic subdivision of loess-palaeosol sections in Ukraine, the problems of regional (and global) correlation appear. A lack of reliable geochronometric markers in the reference sections of different regions of Ukraine makes serious difficulties in the synthesis of the palaeoclimatic information. The publications on palaeoclimate and palaeoenvironmental changes in Eurasia demonstrate insufficient study of Eastern Europe, and, in particular, its central part — Ukraine. A lack of reliable geochronometric data from this region, where many stratigraphically complete Quaternary sequences are located, limits the reliability of spatial palaeoclimatic reconstructions and climate change models. Thus, an amplification of chronostratigraphy of the loess-palaeosol sequence in Ukraine and its correlation with global framework, based on updated magnetostratigraphic data, is one of the urgent problems in the present-day study of regional palaeoenvironmental change.

Studied sites. The *Vyazivok* section is located on the western bank of the Sula River, a tributary of the Dnieper (49°57′ N; 32°57′ E), in the Vyazivok village of the Lubny region (see Fig. 1). It is the most stratigraphically complete section in the Dnieper Lowland [Veklitch et al., 1967; Veklitch, 1968, 1982; Matviishina et al., 2001; Rousseau et al., 2001]. This section is 59 m thick and includes well developed pedocomplexes which alternate with thick loess units. The new results of rock magnetic studies and the stratigraphic positioning of the MBB were presented recently in [Hlavatskyi et al., 2016b; Hlavatskyi, Bakhmutov, 2020]. The MBB has been detected at the depth of 56.2 m within the Lower Shyrokyne palaeosol ‘sh_1’ (according to stratigraphic subdivision of [Veklitch, 1982; Matviishina et al., 2001]).

The *Stari Kaydaky* section (48°22′ N, 35°07′ E) is located in the Stari Kaydaky village, near the Dnipro City airport, on the right bank of the Dnieper River (see Fig. 1). In this site, regarded as the main reference section of the Pleistocene in Ukraine, all stratigraphical units of the Ukrainian Quaternary framework have been studied [Veklitch, Sirenko, 1972] in several sections (the integrated thickness of the sequence is 59 m). The pedostratigraphical and palaeoenvironmental study of the upper 18.5 m of one of the sections, including the correlation of the MS curve with those from the Mircea Voda (Romania) and Batajnica/Stari Slankamen (Serbia) sites, and with the marine isotope record, was provided by [Buggle et al., 2008, 2009]. According to this correlation, the first palaeosol (SK-L1S1) corresponds to MIS 3, the second double palaeosol (SK-S1S1 and SK-S1S2) to MIS 5, the third palaeosol (SK-S2) to MIS 7, the fourth (SK-S3) to MIS 9. The fifth palaeosol (SK-S4) was regarded as a truncated pedocomplex being correlated with MIS 11. The lowermost studied double palaeosol (SK-S5) has been equated to MIS 13—15. Two erosional events represented by the truncated soils have been documented within Upper Middle Pleistocene deposits.

In this study, for palaeomagnetic and rock magnetic analysis, the samples were taken in the depth interval of 17.5—28.2 m, with particular attention to lowermost layers, in which the MBB was expected. Thus, we have adopted MS curve of the upper part of the section [Buggle et al., 2009] and have added the new results from the lower units. We continue to follow stratigraphic nomenclature proposed by [Buggle et al., 2008, 2009] (also using the Ukrainian stratigraphical framework), but different interpretation has been suggested for the lowermost beds of the Buggle et al. excavation (see chapter ‘Results’).

The *Roksolany* section is located on the coast of the Dniester estuary west of the Roksolany village (46°11′ N; 30°26′ E; Fig. 1). This section is one of the most representative exposures of the Pleistocene loess series in the Black Sea Lowland (approximately 55 m thick). The stratigraphy of the Roksolany section and the position of the MBB was a matter of debate for a long time (for a comprehensive overview, see [Hlavatskyi, Bakhmutov, 2020]). Our initial palaeomagnetic studies of the Roksolany profile (Bakhmutov, Hlavatskyi, 2014; Bakhmutov et al., 2017; Hlavatskyi, Bakhmutov, 2019) revealed that the MBB is located at a depth of 46.6 m between two soils, which were stratified by [Gozhik et al., 1995, 2000, 2007; Bogucki et al., 2013; Łanczont, Madeyska, 2015; Nawrocki et al., 2018] as the Lubny (MIS 13—15) and Martonosha (MIS 17—19) units. A narrow zone of reversed polarity was also established at 42.0—42.5 m depth in the uppermost part of the Zavadivka soil. In our recent study [Hlavatskyi, Bakhmutov, 2020], we have proposed a new chronostratigraphic model following the Chinese loess designation system, supported by magnetic susceptibility variations, magnetostratigraphic markers, compiled existing radiocarbon and optically luminescence dates, local and regional sedimentological and palaeosol proxies. The Lubny soil, in the lower part of which the Matuyama—Brunhes reversal was detected, has been reinterpreted as the correlative of the Shyrokyne (R-S7) unit. The reversed polarity zone above, in the interpretation of [Hlavatskyi, Bakhmutov, 2020], represents Stage 17 excursion (at 670 ka), indicating the end of the Martonosha (R-S6, MIS 17) stage. For establishing the chronostratigraphy for the Roksolany section, the stratigraphy of the key locality of the loess-palaeosol sequence at Vyazivok was used as a corner stone.

Sampling strategy and rock magnetic methods. Field works include detailed lithological and pedostratigraphic description of outcrops, in particular, of facial changes of rocks. The representative collections of samples have been taken from the above mentioned three sections by following strategy: 1) with a sampling density of about every 2—10 cm — 150 specimens from the Stari Kaydaky section below the 17.5 m depth (taken as a pilot collection); 2) with a sampling density of about every 2—15 cm — from the Vyazivok section (from 6 continuous exposures) — 750 specimens; 3) with a sampling density of about every 2—15 cm — more than 800 specimens from the Roksolany section (whole section represented by 9 overlapping exposures). For palaeomagnetic measurements, standard oriented cylinders (2.2 cm in length and 2.5 cm in diameter) and cubes (2.0 cm side) were cut while for rock magnetic experiments non-oriented specimens (each weighing about 10—15 g) were taking more densely. In addition, for each section the sampling has been made 1) for palaeopedological study (50 g) — from each lithological type of rocks and genetic horizons of palaeosols; 2) for pollen study (200 g) — with interval of every 10 cm and 10 cm in depth from the excavation wall.

The enviromagnetic parameters commonly accepted in rock magnetic investigations of the loess-soil deposits [Evans, Heller, 2003; Matasova, Kazansky, 2004], and used in our study, are given in Table 1. The analysis of these parameters allows to determine: mineralogical and granulometric changes in rocks associated with different sources of aeolian material, chemical and biogenic processes; concentration, size and domain state of magnetic grains in rocks, origin of the magnetization of rocks (terrigenous, chemogenic, biogenic magnetic minerals); type of recording of magnetic susceptibility in different provinces of pedosedimentogenesis; directions of palaeowinds; identification of magnetic minerals and carriers of normal remanent magnetization (NRM). The latter is a necessary component of palaeomagnetic studies; the directions of the NRM components allow specifying magnetostratigraphic markers and performing independent correlation and dating of the loess-palaeosol sequences.

Measurements of magnetic parameters, their ratios and plots are performed according to commonly accepted methods represented by [Butler, 1992; Evans, Heller, 2003].

In this study, specimens were thermally demagnetized using a MMTD 80 furnace up to 270—300 °C. Specimens from the SK-S6S3 and SK-S7S1 soil units at Stari Kaydaky have been thermally demagnetized up to 500 °C. The residual field in the furnace was less 10 nT. After each heating step, bulk susceptibility (κ) at room temperature was measured to monitor possible mineralogical changes. Duplicate specimens were subjected to alternating field (AF) demagnetization

T a b l e 1. Common rock magnetic parameters and their bivariate ratios

Symbol	Magnetic quantities	Description
Group 1. Represents the concentration of magnetic minerals (concentration-sensitive or concentration-dependent)		
κ	10^{-6} SI	Volume magnetic susceptibility (dimensionless): subject to a small amount of superparamagnetic (SP) particles
χ	m^3/kg	Mass-specific magnetic susceptibility
χ_{ferri}	m^3/kg	Ferrimagnetic susceptibility
M_s or M_s	Am^2/kg	Saturation magnetization (mass normalized)
M_{rs} or J_{rs}	Am^2/kg	Saturation remanent magnetization (SIRM)
M_i or J_i	Am^2/kg	Isothermal remanent magnetization (IRM)
M_{ri} or J_{ri}	Am^2/kg	Anhysteretic remanent magnetization (ARM): subject to a small amount of single domain particles
M_n or J_n	mA/m	Natural remanent magnetization (NRM): subject to the constant composition of the magnetic fraction
Group 2. Composition of the magnetic fraction (relative content in the magnetic fraction)		
Q-ratio	—	Koenigsberger ratio
S-ratio	—	Relative amounts of high coercivity («hard», like magnetite/maghemite) to low coercivity («soft», like goethite/hematite) remanence
H_s	mT	Saturation field or field, in which 90 % of the saturation magnetization is acquired
B_c or H_c	mT	Coercive force
B_{cr} or H_{cr}	mT	Remanence coercivity
Curie temperatures T_c (by χ (T), M_s (T)); unblocking temperatures T_{ub}, (by SIRM (T), NRM (T)); median destructive AF field MDF (by AF demagnetization of remanent magnetization NRM, SIRM, ARM), residual magnetization after maximum demagnetization M/M_{max}; hard isothermal remanent magnetization HIRM		
Group 3. Particle size of magnetic minerals and the associated domain state of ferromagnetic (structurally sensitive)		
FD%-ratio		Frequency-dependent factor; FD% = $100\times(\chi_{lf}-\chi_{hf})/\chi_{lf}$
M_{ri} or J_{ri}	Am^2/kg	Anhysteretic remanent magnetization (ARM): subject to a small amount of single domain particles
Ratios χ/SIRM, χ/ARM, SIRM/ARM (proportional to the grain size); bivariate plots of hysteresis parameters M_{rs}/M_s, B_{cr}/B_c		
Group 4. Anisotropy of magnetic susceptibility (AMS; quantitative parameters)		
L	—	Degree of magnetic lineation
F	—	Degree of magnetic foliation
P	—	Degree of anisotropy
T	—	Shape parameter of AMS ellipsoid
Directions of maximum (K_1), intermediate (K_2), and minimum (K_3) axis of AMS ellipsoid		
Group 5. Represents the contribution of paramagnetic minerals to magnetic properties (by minor concentrations of ferromagnetic, such a contribution can be significant)		
M_{max} or J_{max}	mA/m	Maximum of magnetization (by 1.5 T)
M_{par} or J_{par}	mA/m	Magnetization of paramagnetic minerals (M_{max}–M_s)
χ_{par}	m^3/kg	Paramagnetic susceptibility
χ_{sp}	m^3/kg	Superparamagnetic susceptibility

with steps 5—20 mT up to 60—100 mT using a LDA-3A demagnetizer. Remanent magnetization of specimens was measured by JR-6 spinner magnetometer. Measurements of mass-specific magnetic susceptibility (χ) were carried out using by MFK1-FB Kappabridge. The equipment is placed in a non-magnetic room MMLFC, which eliminates the effect of remagnetization of samples by viscosity. The data (multicomponent analysis of NRM and separation of characteristic (ChRM) components) were proceeded by Remasoft 3.0 software [Chadima, Hrouda, 2006].

Palaeopedological descriptions and interpretations in the new excavations at Vyazivok and Stari Kaydaky followed the methodology by [Veklitch et al., 1979; Gerasimenko, 2020]. Individual palaeosols were described within pedocomplexes, and if the welded soils occurred in a studied section, additional excavations were entertained in order to trace a palaeopedocatena and to reveal the well-developed pedocomplex of the corresponding soil unit. To define soil types of palaeosols, the following features of them have been studied: genetic soil horizons, color, thickness, grain-size characteristics, soil structure, forms of carbonate calcium, iron and manganese (if available), biological elements of a profile, types of soil boundaries, palaeocryogenic forms. The primary and secondary (diagenetic) features were distinguished.

Pollen samples were taken each 5—10 cm from the Upper Pleistocene deposits at Vyazivok and from each soil genetic horizon from the Upper and Middle Pleistocene deposits at Stari Kaydaky. The sample processing has followed the technique [Malyasova, Spiridonova, 1989] which includes boiling of a 100 g sample in 10 % solution of HCl in order to remove carbonates, in 25 % solution of sodium pyrophosphate in order to remove clay fraction. Then the secondary carbonates have been removed by boiling in 10 % solution of HCl again, and organic matter was dissolved in 10 % solution of KOH. All steps were separated by decanting of a sample in distilled water to the neutral reaction of a solution. The next step was a separation in heavy liquid (CdI_2 and KI) of specific gravity 2.2. If a sample included many sand grains, in addition to the described technique, cold treatment with 10 % solution of HF has been applied for at least 18 hours.

Results and interpretation. The results from the Vyazivok and Roksolany sections were published (or partly published) earlier [Matviishina et al., 2001; Rousseau et al., 2001; Gerasimenko, Matvijishyna, 2007; Haesaerts et al., 2016; Hlavatskyi, Bakhmutov, 2020]. Here, we provide the results of the new pedostratigraphical and rock magnetic studies of the lower part of the excavation at Stari Kaydaky which upper part was described in [Buggle et al., 2008, 2009].

Litho- and pedostratigraphy. In order to make connection between the upper and lower sequences at the Stari Kaydaky site, the short description of the Upper Pleistocene and the Upper Middle Pleistocene pedocomplexes are given, as well as their correlation with the Middle Danube loess nomenclature [Buggle et al., 2008, 2009].

The uppermost palaeosol is related to Vytachiv unit ('vt') and correlated with SK-L1S1 (MIS 3). In the southern wall of the excavation it is a welded soil but in its western wall, Vytachiv pedocomplex consists of two thin Calcaric Cambisols, light-brown, enriched in coarse silt, non-compacted, without well-developed structure, with pure white farinaceous-carbonate horizon in the subsoils. These soils are separated by a thin loess bed ('vt_2') and underlain by a thin Uday loess ('ud'/SK-L1L2, MIS 4).

Below, there is a thick pedocomplex consisting of three palaeosols. From the top to bottom, they are two Chernozems and a thick Luvisol. The Chernozems are dark-grey, enriched in fine silt, slightly compacted, crumbly, primarily leached from carbonates, and they are separated by a thin loess-like bed. The similar bed separates the lower Chernozem from the Luvisol. The latter has a very distinct differentiation of the soil profile into grey A horizon, pure white loose E horizon, and bright-brown Bt horizon, strongly compacted clayey silt, with blocky-prismatic structure, and a sharp boundary with the underlying thick loess. This pedocomplex has all typical features of the Pryluky—Kaydaky palaeosol succession ('pl—kd') which is correlated with MIS 5 [Rousseau et al., 2001; Gerasimenko, 2001; Haesaerts et al., 2016]. At this excavation, the Pryluky Chernozem has been correlated with SK-S1S1 (MIS 5a—c) and Kaydaky Luvisol with SK-S1S2 (MIS 5e) [Buggle et al., 2008, 2009]. The underlying typical loess, composed by coarse silt — the Dnipro loess ('dn'/SK-L2, MIS 6) — reaches 5 m in thickness in the southern wall.

The Potyagaylivka pedocomplex ('pt') is partly eroded from the top. The two upper soils are truncated, and only the lower soil is represented by a Cambisol, with well differentiated soil profile (dark-grey A horizon and bright-brown B horizon, both clayey silty, crumbly-prismatic, with distinct biological boundaries). This pedocomplex is correlated with MIS 7, the individual soils with SK-S2S1, SK-S2S2 and SK-S2S3, respectively [Buggle et al., 2008, 2009]. The underlying thin pale-brown loess-like bed (SK-L3, MIS 8) separates SK-S2 from the SK-S3 pedocomplex. Cryogenic fissures, connected with a cold climate of MIS 8, strongly disturbed the Upper Zavadivka pedocomplex ('zv_3').

The Upper Zavadivka soil succession (SK-S3) consists of the well developed pedocomplex from Chernozem 'zv_{3b2}' (SK-S3S1) and Greyzemic Luvisol 'zv_{3b1}' (SK-S3S2), and from a thin Luvic Cambisol 'zv_{3a}' (SK-S3S3), separated from the pedocomplex by a thin loess bed. All palaeosols are compacted (particularly Bth and Bt horizons of Greyzemic Luvisol) and composed by clayey silt. The Chernozem is dark-grey, with multiple krotovinas and frost fissures from above, both filled with loess; the transition downward is gradual. The Bth and Bt horizons of Greyzemic Luvisol are dark-brown and brown, respectively, with strong blocky-prismatic structure, with glossy clay cutans on the ped surfaces; transition downward is gradual. The Luvic Cambisol 'zv_{3a}' might be truncated, as its upper boundary is rather sharp. Then only the reddish-brown Bw horizon of this soil is present in the section. This subunit has been formerly considered as the truncated Lower Zavadivka ('zv_1'/SK-S4, MIS 11) [Buggle et al., 2008, 2009]. It is underlain by a thin loess, related to the 'zv_2' unit (SK-L4, MIS 10). In palaeodepressions, the 'zv_{3b2}' Chernozem is overlain by a thin bed of dark-brown pedosediments 'zv_{3c}', with many carbonate rootlets and sharp erosional boundaries.

Below in the section, there is a thick soil unit of a complex structure (now preliminarily regarded as Lower Zavadivka, SK-S4). It includes (from the top to bottom): a weakly developed Haplic Phaeozem 'zv_{1c}' (SK-S4S1), underlain by a thin loess-like bed, two thick Colluvic Luvisols ('zv_{1b2}'/SK-S4S2 and 'zv_{1b1}'/SK-S4S3), separated by a thin non-soil bed, filled with white carbonates, and underlain by a thin loess-like bed, and a very thin Cambisol 'zv_{1a}' (SK-S4S4). The Haplic Phaeozem has a dark-grey A horizon, pale AB horizon, and light-brown B horizon. The soil contains much less clay particles than the overlying and underlying soils. It has less compacted material (with crumbly structure) and gradual boundaries; primarily it was leached from carbonates. The two Colluvic Luvisols have reddish-brown colour, particularly bright in the lower soil. They are enriched in clay fractions but do not have a distinct structure (probably because of some input of colluvial silt material). The upper soil was primarily leached from carbonates — many soft carbonate nodules, representing the Ck horizon of the 'zv_{1b2}' soil, occur in the material of the soil 'zv_{1b1}' and in the underlying loess-like loam. The Phaeozem 'zv_{1c}' and the very top of the 'zv_{1b2}' soil were formerly regarded as the Lubny unit (SK-S5, MIS 13—15) [Buggle et al., 2008, 2009]. Luvisols are typical for Lower Zavadivka in the northern part of Ukraine, whereas Chromic Luvisols are characteristic of this unit in the southern part of Ukraine.

Below the loess-like bed (SK-L5, Tyligul unit?), underlying the described pedocomplex, there is a soil unit (SK-S5), consisting of two pedocomplexes, with completely different types of palaeosols than in SK-S4. Its upper pedocomplex includes a Chernozem (SK-S5S1), dark brownish-grey, clayey, compacted, crumbly-prismatic, leached from carbonates, with several krotovinas, filled with loess, and with gradual boundaries. The lower soil is a Luvisol (SK-S5S2) with such genetic horizons: A/E — brown, contain less clay particles than the overlying Chernozem; E — whitish, sandy silt, enriched in SiO_2, slightly gleyed, with a sharp lower boundary; Bt — bright-brown, sandy clayey, blocky-prismatic, with the gradual lower boundary. The soil succession in the lower pedocomplex (Fig. 2) is similar. The upper soil is clayey Chernozem (SK-S5S3), brownish-grey, compacted, blocky. The lower soil is a Luvisol (SK-S5S4) with such genetic horizons: A — dark-brown, clayey silt, with an admixture of SiO_2 and a sharp lower boundary; E — whitish sandy silt, greatly enriched in SiO_2; E-Bt — light-brown, with whitish spots of SiO_2 and small silicified nodules of $CaCO_3$ (Ck horizon of the overlying soil); Bt — brown, clayey, compacted, prismatic, the lower boundary is sharp. Clayey Chernozems and Luvisols occur both in Lubny ('lb') and Upper Shyrokyne ('sh_3') units, but the lower pedocomplex is not enough clayey for the Shyrokyne unit, and Luvisols with such differentiated genetic profile and with abundance of SiO_2 are also not typical (even in palaeodepressions) for the Upper Shyrokyne pedocomplex.

On the contrary, the upper palaeosol (SK-S6S1) of the underlying soil unit (SK-S6; Fig. 2) is most enriched in clay fraction, has bright reddish-brown colour and prismatic structure, with glossy coatings on ped surfaces. The middle soil (SK-S6S2) of this pedocomplex preserves its A horizon — dark-grey, clayey, with punctuation of manganese hydroxides and secondary carbonates, with the distinct transition to the Btw horizon. The latter is dark-brown, clayey, prismatic, glossy, with manganese and secondary carbonate punctuations. The Bt horizon of the soil is lighter, bright-brown, prismatic, with manganese punctuation, the transition downward is distinct. A very thin bed of loess-like clay separate the SK-S6S2 soil from the lowermost soil of this pedocomplex. The latter (SK-S6S3) includes A horizon (dark-brown, with manganese punctuation) and Btw horizon (light-brown, prismatic, with abundant manganese punctuation); the lower boundary is sharp. The two upper soils of the SK-S6 pedocomplex are very similar to the Mediterranean red-brown soils, which are described as Chromic Cambisols in the mountainous areas of the Mediterranean, but in the accumulative plains, they must be much thicker than common Cambisols. The lowermost soil is a Chromic Luvisol with E(gl) and Bt horizons. Its development indicates a greater atmospheric and underground moisture during its formation as compared with the overlying palaeosol. The soil types and soil succession of the pedocomplex has a typical feature of the Martonosha ('mr') unit.

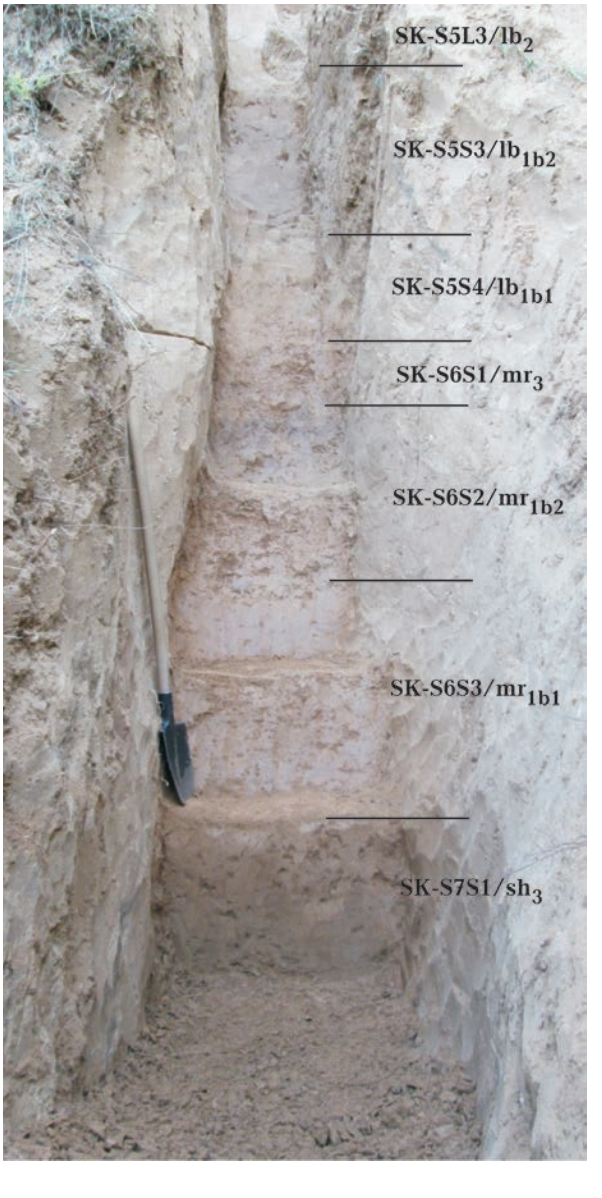

Fig. 2. Field photograph of the lowermost units of the exposure studied at the Stari Kaydaky site.

The lowermost soil in the section (preliminarily designated as SK-S7S1; Fig. 2) is a Vertisol, which A horizon is exposed — dark-brown, very clayey, the most compacted, has great prismatic peds with slick sides features. Vertisols are most typical for the Shyrokyne unit in Ukraine.

Pollen. The pollen data from the Stari Kaydaky site will be completely presented in the next paper but here we can mention that the Vytachiv soil was formed under boreal steppe environments, whereas the Pryluky Chernozems under south-boreal steppe (few broad-leaved trees grew in gullies), and the humus horizon of the Kaydaky soil under the subboreal forest-steppe. The lessivage processes in the Kaydaky times developed under the broad-leaved woodlands. Pollen succession from the larger part of the Luvisol resembles that of the Last Interglacial, with first appearance of elm and oak, then lime and hazel, and, finally, hornbeam. The lower Potyagaylivka soil was formed under forest-steppe of subboreal climate, which was less humid than at Kaydaky times. The Upper Zavadivka Chernozem is a product of steppe vegetation of subboreal climate (broad-leaved trees in gullies), whereas both Luvisols of this unit developed under broad-leaved woodlands. The Greyzemic Phaeozem of the Lower Zavadivka unit was formed under subboreal mesophytic steppe (few broad-leaved trees in gullies), and the upper Colluvic Luvisol under a sparse broad-leaved woodland (the warmth-loving walnut occurred at this time).

Magnetic susceptibility. The variations in the low-frequency magnetic susceptibility (χ_{lf}) values for the composite section are shown in Fig. 3. The changes are highly consistent with the alternation between loess and palaeosol units, with enhanced values in palaeosols, and generally reduced values in loess units. The χ_{lf} values in loess range from 7 to 15×10^{-8} m^3/kg. SK-S2, SK-S3 and SK-S4 palaeosols are significantly magnetically enhanced (up to 70×10^{-8} m^3/kg) relative to other soils, due to strong pedogenesis. Two samples from well-developed rubified SK-S4 pedocomplex have higher values: 85 and 96×10^{-8} m^3/kg. Measurements of other rock magnetic parameters are currently in progress.

The good correspondence of the MS curve with changes in the marine $\delta^{18}O$ signal (see Fig. 3), provides a strong evidence for correlating the Pryluky—Kaydaky (SK-S1) pedocomplex at Stari Kaydaky to MIS 5 [Buggle et al., 2008, 2009], as well as that in the Vyazivok section [Rousseau et al., 2001; Hlavatskyi, Bakhmutov, 2020]. The correlation between MS curve of lower palaeosol units and the marine isotope record is rather speculative (see Fig. 3).

The background magnetic susceptibility in the Stari Kaydaky section is similar to that of the Roksolany and Vyazivok sections (5—10)$\times10^{-8}$ m^3/kg (Fig. 4), but is much lower compared to that in the Danube (2—5 times) and Chinese (4—10 times) sequences. This difference indicates a contribution from different dust sources in Ukrainian, Danube and Chinese loess archives.

Magnetostratigraphy. For now, 90 specimens were palaeomagnetically investigated: 48 specimens in the depth interval of 21.5 to 28.2 m were subjected to thermal demagnetization (up to 300—500 °C); and 42 specimens in the depth interval of 17.5 to 25.1 m were subjected to stepwise AF demagnetization (up to 60—80 mT). Secondary viscous magnetization parallel to the present-day field, or acquired during storage, was removed by heating samples to 240—270 °C. The ChRM components for most samples separated between 240 °C and 500 °C (Fig. 5, *a*), and retain a relatively stable direction up to 500 °C. These stable high temperature components decay with increasing temperature toward the origin along nearly the same trajectory as the medium temperature components (e.g., Fig. 5, *a*). All samples between 270 and 500 °C, including those from the lowermost part of the SK-S7S1 soil subunit ('sh_3'), show entirely a normal polarity.

In most specimens after stepwise AF demagnetization, a high-coercitivity component was totally removed only by 60—80 mT field (Fig. 5, *b*), indicating that hematite is the main ChRM carrier in these samples. The ChRM components also demonstrate the stable trajectory towards the origin, indicating the normal polarity of all specimens collected from the SK-S6S2 to SK-S4 unit. However, additional AF demagnetization investigation of the lowermost part of the profile (in 25.1—28.2 m depth range) is required, and it will be presented in further submissions.

Thus, our palaeomagnetic data indicates that the entire studied part of the section formed during the Brunhes chron, i.e. younger than 780 ka.

Discussion. Fig. 4 presents the correlation of the master Ukrainian loess-palaeosol sequences based on the geochronology of the

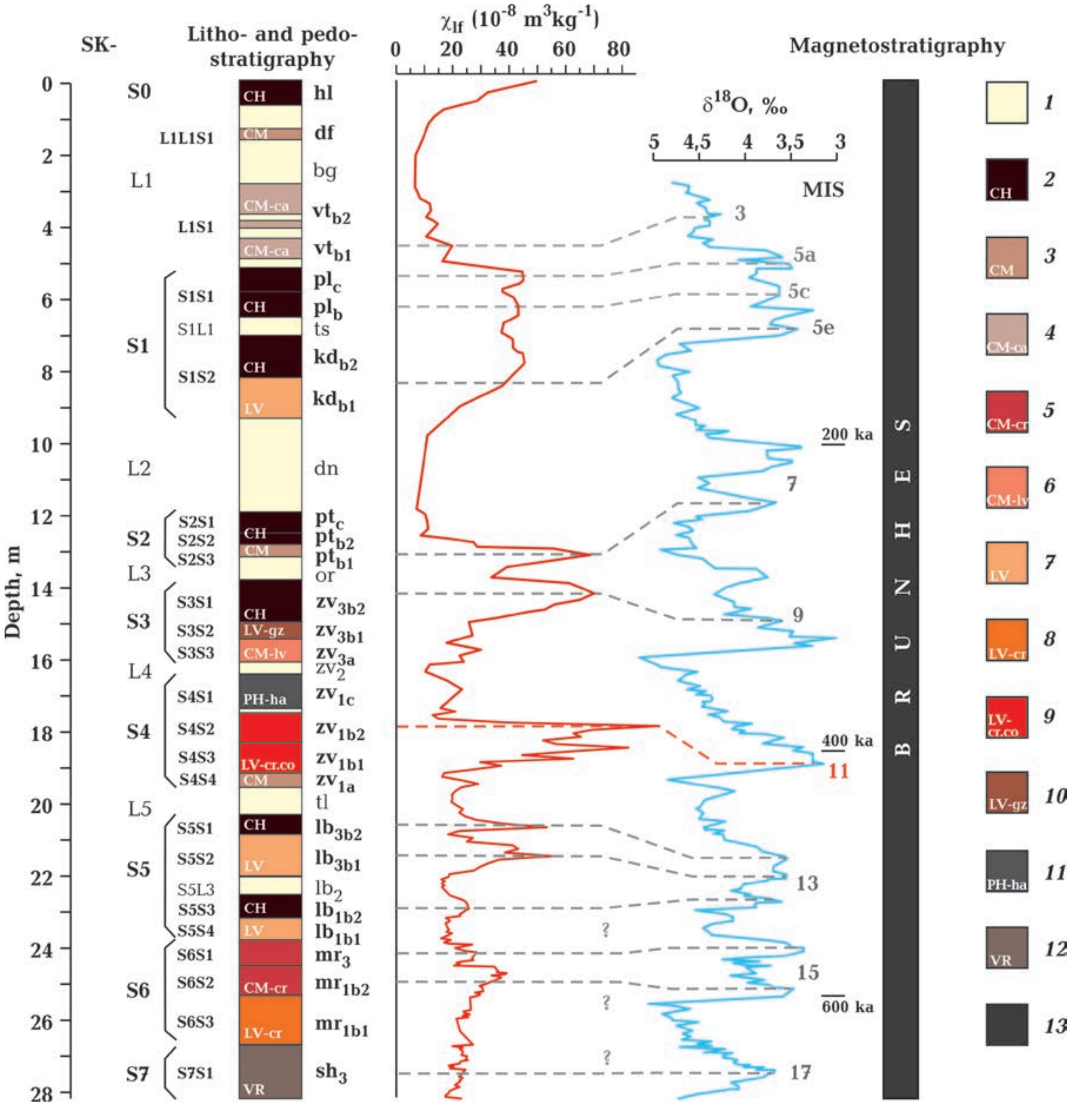

Fig. 3. Revised litho- and pedostratigraphy, magnetic susceptibility (χ_{lf}) curve (in the depth interval of 0—17 m adopted from [Buggle et al., 2009]), preliminary correlation with the benthic δ^{18}O record from ODP site 677 [Shackleton et al., 1990] with reference to marine isotope stages (MIS) [Railsback et al., 2015], and magnetostratigraphic chart of the Stari Kaydaky section. To the left of lithological column the stratigraphic nomenclature modified from [Buggle et al., 2008, 2009] is shown, to the right stratigraphic subdivision following the labelling system of [Veklitch et al., 1993; Gerasimenko, 2004] is proposed by this study. Lithology: *1* — loess. *Soil types*: *2* — Chernozem (CH); *3* — Cambisol (CM); *4* — Calcaric Cambisol (CM-ca); *5* — Chromic Cambisol (CM-cr); *6* — Luvic Cambisol (CM-lv); *7* — Luvisol (LV); *8* — Chromic Luvisol (LV-cr); *9* — Chromic Colluvic Luvisol (LV-cr.co); *10* — Greyzemic Luvisol (LV-gz); *11* — Haplic Phaeozem (PH-ha); *12* — Vertisol (VR). *Geomagnetic polarity*: *13* — normal.

Roksolany and Vyazivok sites discussed in [Hlavatskyi, Bakhmutov, 2020], and supported by new data from the Stari Kaydaky section introduced in this study. At Stari Kaydaky, the correlation of SK-S1, SK-S2 and SK-S3 palaeosols with MIS 5, MIS 7 and MIS 9, respectively, presented in [Buggle et al., 2008, 2009], is accepted in our paper. The SK-S4 palaeosol at Stari Kaydaky like its equivalents at Stari Slankamen and Batajnica sites, and in the composite profile for Vojvodina [Marković et al., 2015], was assigned to MIS 11 [Buggle et al., 2008, 2009]. According to the new Eurasian stratigraphic scheme adopted in [Sümegi et

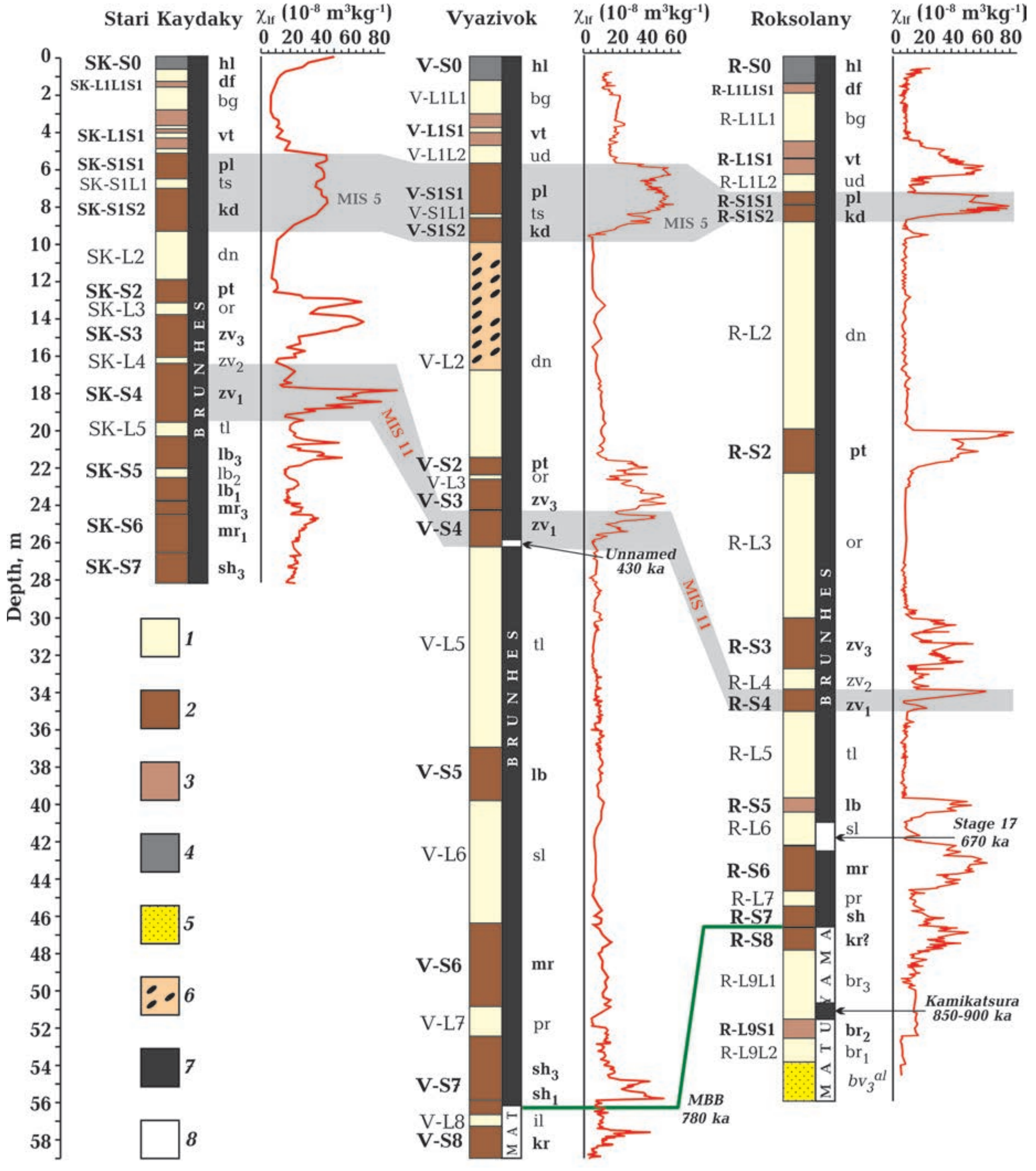

Fig. 4. Correlation chart of the sequences studied resulting from palaeomagnetic and magnetic susceptibility records. Simplified lithology: *1* — loess and loess-like loam; *2* — palaeosol; *3* — embryonic soil; *4* — recent soil; *5* — sand; *6* — glacial till. *Geomagnetic polarity*: *7* — normal; *8* — reversed. Names of detected geomagnetic excursions are typed by bold italic font.

al., 2018], both S3 and S4 of the Serbian sites (except Mošorin), Bulgarian and some Romanian sites (e.g., Zimnicea) have been merged into a single pedocomplex representing MIS 9. Based on our record for MIS 9 from Roksolany and Vyazivok, and the similar palaeosol succession patterns at Stari Kaydaky, the former SK-S4 soil unit is now preliminarily related to the lower part of SK-S3. Remarkably, the lower member of this newly designated S3 pedocomplex (formerly marked as S4) has a lower magnetic susceptibility as compared to the upper one. This feature is valid for all Serbian, Romanian and Bulgarian sites [Sümegi et al., 2018]. On the contrary, the lower pedomember of the S3 pedocomplex at Roksolany and Vyazivok represented by two soils of climatic optima ('zv_{3b1}' and 'zv_{3b2}'), is characterized by the specific double peaks (see Fig. 4), which most likely correspond to marine isotope substages 9c—e.

The well-developed Colluvic Luvisols, previously regarded as the SK-S5 unit and correlated with MIS 13—15 [Buggle et al., 2008, 2009], are preliminarily compared now with SK-S4 unit. The latter corresponds to one of the warmest and longest interglacials of the past 800 ka, the MIS 11 [Shackleton et al., 1990; Lisiecki, Raymo, 2005; Head, Gibbard, 2015; Sümegi et al., 2018 and references therein]. In Chinese loess-palaeosol sequences a strong MIS 13 interglacial is hallmarked by a well-developed S5S1 pedocomplex [Lu et al., 2018] because of an enhanced East-Asian Summer Monsoon bringing more precipitation [An et al., 1987; Clemens et al., 2008; Guo et al., 2009]. In Europe, in contrast to Eastern Asia, the higher degree of pedogenesis development and, particularly, rubification is recorded in MIS 11 pedocomplexes [Sümegi et al., 2018; Bradák et al., 2019]. Besides, the regional diversity in the intensity of the S5S1 soil formation exists also in China. For instance, as opposite to the central and eastern

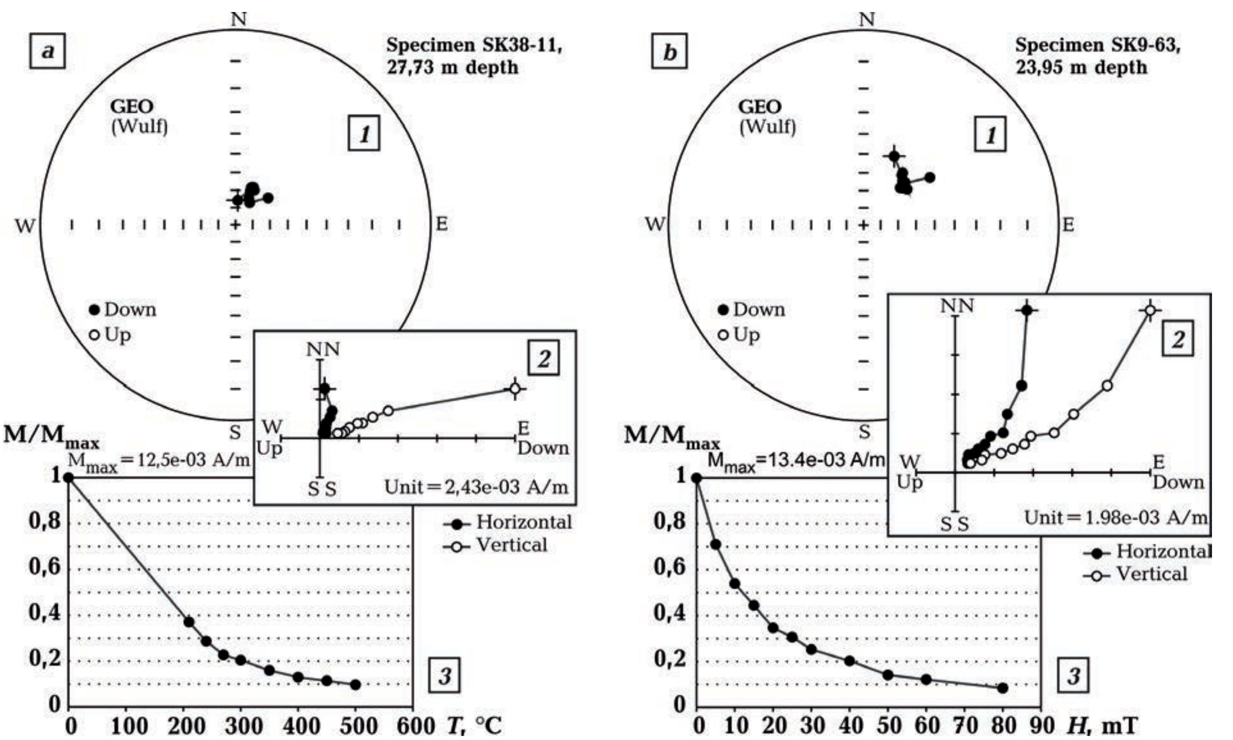

Fig. 5. Examples of stepwise thermal (*a*) and alternating field (*b*) demagnetization of palaeosol specimens in the Stari Kaydaky section: from the SK-S7S1 (sh_3) subunit (*a*); from the SK-S6S1 (mr_3) subunit (*b*): *1* — stereographic projections of demagnetization directions (full and open circles represent projections in the lower and upper hemispheres, respectively); *2* — orthogonal demagnetization paths (Zijderveld diagrams) on horizontal and vertical planes; *3* — NRM intensity decay curves of demagnetization (M/M_{max}).

CLP, the S5S1 palaeosol is weakly developed in the western CLP whereas the S4 palaeosol (formed during MIS 11) is the best developed soil in the Quaternary loess-palaeosol sequences [Lu et al., 2018].

Consequently, the SK-S5 pedocomplex at Stari Kaydaky, formed in a more temperate climate, according to the palaeopedological features, might be correlated with MIS 13. In contrast to MIS 11, MIS 13 is regarded as the coolest interglacial of the past 800 ka in different types of long palaeoenvironmental records from all over the world. MIS 13 is characterized by the lower greenhouse gas (CO_2, CH_4) concentrations, the cooler Antarctic temperatures and high benthic $\delta^{18}O$ values [Lisiecki and Raymo, 2005; Lu et al., 2018; Sümegi, 2018 and references therein] which are related to the higher global ice-volume and/or the colder deep ocean temperatures.

These correlations and patterns are in very good correspondence with the palaeoclimate reconstructions obtained from the central Ukrainian loess-palaeosol records in the previous studies. The warmest climate during the Middle Pleistocene (i.e. the Early Middle Pleistocene in the global frameworks) existed during the Early Zavadivka times [Veklich, 1968, 1982; Sirenko, Turlo, 1986; Matviishyna et al., 2010; Gozhik, Gerasimenko, 2011; Sirenko, 2019a], associated with MIS 11 [Gerasimenko, Matvijishyna, 2007], whereas the very cold Tyligul time, reflected in the first glacier appearance in Ukraine, corresponds to MIS 12. According to the above references, the Lower Zavadivka (S4) unit is represented by strongly rubified Luvisol already at the latitude of Stari Kaydaky. The climate of the Lubny warm stage, which is represented by 3—4 soils (Chernozems, Greyzems, Luvisols, and/or Gleysols), is commonly characterized as less warm than that of the Early Zavadivka, and this unit is correlated by the majority of Ukrainian loess researchers with MIS 13—15. Palaeopedological characteristics of SK-S5 at Stari Kaydaky matches well with those of the Lubny pedocomplex elsewhere in the northern and central Ukraine [Sirenko, Turlo, 1986; Gozhik, Gerasimenko, 2011; Sirenko, 2017a,b]. The Tyligul cold stage in-between is correlated with the very extensive glaciation of MIS 12, associated with the advance of large ice sheets in the temperate belt [Lisiecki, Raymo, 2005; Head, Gibbard, 2015].

The next lower soil unit at Vyazivok and Roksolany — Martonosha (S6) — based on the position of the MBB in the underlying Shyrokyne unit, and general assumption about presence of a single MIS 13—15 pedocomplex in Europe, and in Ukraine in particular, has been preliminarily correlated with MIS 17 [Hlavatskyi, Bakhmutov, 2020]. However, MIS 17 was a relatively cold interglacial as it was recorded by global reference curves [Shackleton et al., 1990; Lisiecki, Raymo, 2005; Varga, 2015]. From a pedostratigraphic point of view, the Martonosha soils at Vyazivok, Roksolany, and at Stari Kaydaky as well, are well-developed, rubified forest soils, transitional to subtropical ones, representing a more intense, warmer interglacial period, in contrast to preceding Late Shyrokyne stage and succeeding Lubny stage. Furthermore, the cold event corresponding to MIS 14 is reflected in Lake Baikal, Antarctic, and stacked $\delta^{18}O$ LR04 palaeoclimatic records. The absolute values of $\delta^{18}O$ for MIS 14 are commensurate with similar quantities for MIS 8, MIS 34, and MIS 36 treated as glaciations in the LR04-stack [Lisiecki, Raymo, 2005]. Therefore, the correlation of the Martonosha unit with relatively warm MIS 15, and the Upper Shyrokyne unit with colder MIS 17 seems reasonable, but reliable age control is required for more conclusive results.

The position of the MBB in the Ukrainian loess-palaeosol sequences was established, with a high level of confidence, within the Lower Shyrokyne ('sh_{1b1}') subunit, for instance, at Roksolany and Vyazivok [Hlavatskyi, Bakhmutov, 2020]. At Stari Kaydaky, the MBB has not been detected yet as the base of the present profile is located within the upper 'sh_3' subunit, which has normal polarity elsewhere in the Ukrainian loess sequences [Tretyak, Vigilyanskaya, 1994; Hlavatskyi, 2019; Hlavatskyi et al., 2021b]. In the Brunhes chron, no reversed polarity episodes were identified at Stari Kaydaky as well.

Conclusions. The palaeoclimatic reconstructions obtained from rock magnetic studies of the three reference sections in the northern, central and southern parts of Ukraine (the Vyazivok, Stari Kaydaky and Roksolany sites) are in a good correspondence regarding the correlation of the units of the Ukrainian stratigraphical framework with the Central European loess-palaeosol nomenclature and with the marine oxygen-isotope stages. Furthermore, the palaeoclimatic signals from the rock magnetic studies of the Vyazivok and Stari Kaydaky sections correspond well to those obtained from the same sites with palaeopedological and palynological methodologies. This leads to high expectation in using multidisciplanary approach (rock magnetism, palaeopedology and palynology), supported by palaeomagnetic studies, for elaboration of reliable reconstructions of the Pleistocene environmental changes detected from the other loess-palaeosol sequences in Ukraine. The new multidisciplinary studies of the Stari Kaydaky section preliminarily confirm the correlation of the Upper Zavadivka (SK-S3) unit with MIS 9, the Lower Zavadivka (SK-S4) unit with MIS 11, the Lubny (SK-S5) and Martonosha (SK-S6) units with MIS 13 and MIS 15, respectively, and the Upper Shyrokyne (SK-S7S1) unit with MIS 17. The excavated profile studied at Stari Kaydaky has not reached so far the Lower Shyrokyne unit with the expected Matuyama—Brunhes boundary, found at this stratigraphical level at the two other sections.

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Значимость лессово-почвенной формации Украины для реконструкций изменений климата в плейстоцене: петромагнитные, палеопедологические и палинологические индикаторы

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Вариации петромагнитных характеристик в лессово-почвенных породах, обусловленные изменением климатических и ландшафтных условий их формирования, являются мощным инструментом применения этих параметров как индикаторов при палеоклиматических реконструкциях. Определение закономерностей изменения магнитных параметров, установленных в лессово-почвенных отложениях Украины, в зависимости от динамики палеоклиматов и древней природной среды, и, как следующий шаг, оценка их информативности и значимости для палеореконструкций выполняются в рамках проекта Национального фонда исследований Украины 2020.02/0406 «Магнитные индикаторы палеоклиматических изменений в отложениях лессово-почвенной формации Украины». Палеоэкологические реконструкции выполняются с использованием значительного количества палеоиндикаторов: педостратиграфии, литологии, морфологии ископаемых почв, палинологии и широкого спектра петромагнитных характеристик. В этой статье представлен мультидисциплинарный подход к реконструкциям древней природной среды, осуществляемый в проекте, а также предварительные результаты корреляции педостратиграфических (частично палинологических) данных с показателями магнитной восприимчивости лессово-почвенных пород в северной, центральной и южной частях Украинской лессовой провинции. Выполнено сравнение петромагнитных параметров трех наиболее полных лессово-почвенных разрезов в бассейне Днепра и на Причерноморской низменности (Старые Кайдаки, Вязовок и Роксоланы). Амплитуды палеоклиматических изменений, установленные по магнитным индикаторам, хорошо сопоставляются с результатами литолого-палеопедологических и палинологических исследований этих разрезов, и с глобальной морской кислородно-изотопной шкалой (MIS). Петромагнитные, педостратиграфические и палинологические исследования разреза Старые Кайдаки позволяют предварительно предположить корреляцию верхнезавадовского (zv_3) и нижнезавадовского (zv_1) климатолитов с MIS 9 и MIS 11, соответственно, как это было ранее показано для разрезов Вязовок и Роксоланы. Нижезалегающий лубенский педокомплекс (lb), вероятно, может соответствовать MIS 13, а мартоношский педокомплекс (mr) — MIS 15. В ходе палеомагнитных исследований разреза Старые Кайдаки еще не была опробована нижняя часть разреза, в частности, нижнеширокинский субклиматолит (sh_1), в котором в Роксоланах и Вязовке была определена граница Матуяма—Брюнес. Верхнеширокинский почвенный горизонт (sh_3) характеризуется прямой полярностью и предварительно сопоставляется с MIS 17. В рамках проекта будут проводиться дальнейшие исследования разреза Старые Кайдаки и других лессово-почвенных профилей.

Ключевые слова: лессово-почвенная формация, петромагнетизм, магнитная восприимчивость, палеопедология, палинология, палеоклимат, стратиграфическая корреляция.

Важливість лесово-ґрунтової формації України для реконструкцій змін клімату в плейстоцені: петромагнітні, палеопедологічні і палінологічні індикатори

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Варіації петромагнітних параметрів у лесово-ґрунтовій формації, зумовлені кліматичними й ландшафтними умовами формування порід, є потужним інструментом застосування їх як індикаторів при палеокліматичних реконструкціях. Визначення закономірностей змін магнітних параметрів у лесово-ґрунтових відкладах України залежно від динаміки палеокліматів і давнього природного середовища і, таким чином, оцінювання їхньої інформативності для палеореконструкцій виконується у рамках проєкту Національного фонду досліджень України 2020.02/0406 «Магнітні індикатори палеокліматичних змін у відкладах лесово-ґрунтової формації України». У проєкті палеоекологічні реконструкції здійснюють із використанням значної кількості палеоіндикаторів: морфологічних та літологічних властивостей викопних ґрунтів і лесів, їхніх паліноспектрів і широкого набору магнітних параметрів. У цій статті представлено мультидисциплінарний підхід до реконструкції давньої природи, пропонований проєктом, і наведено попередні результати зіставлення педостратиграфічних, частково палінологічних, даних із показниками магнітної сприйнятливості відкладів у розрізах лесово-ґрунтової формації у північних, центральних і південних районах України. Виконано порівняння за петромагнітними параметрами трьох найбільш повних лесово-ґрунтових розрізів у басейні Дніпра та на Причорноморській низовині (Старі Кайдаки, В'язівок і Роксолани). Амплітуди палеокліматичних змін, встановлені за магнітними індикаторами, добре зіставляються із результатами літолого-палеопедологічних і палінологічних досліджень цих же розрізів та із глобальною морською киснево-ізотопною шкалою (MIS). Петромагнітні, педостратиграфічні й палінологічні дослідження розрізу Старі Кайдаки дають змогу попередньо корелювати верхньозавадівський (zv_3) і нижньозавадівський (zv_1) кліматоліти із MIS 9 та MIS 11 відповідно, як було раніше запропоновано для розрізів В'язівок і Роксолани. Припускається, що сформований до завадівського лубенський педокомплекс (lb) може відповідати MIS 13, а мартоноський педокомплекс (mr) — MIS 15. Опробування на палеомагнітні дослідження ще не досягло найнижчої частини розрізу Старі Кайдаки, зокрема, нижньоширокинського субкліматоліту (sh_1), у якому було встановлено межу Матуяма—Брюнес у Роксоланах і В'язівку. Верхньоширокинський ґрунтовий горизонт (sh_3) характеризується прямою полярністю і попередньо зіставляється із MIS 17. У рамках проєкту проводитимуться подальші дослідження розрізу Старі Кайдаки та інших лесово-ґрунтових відслонень.

Ключові слова: лесово-ґрунтова формація, петромагнетизм, магнітна сприйнятливість, палеопедологія, палінологія, палеоклімат, стратиграфічна кореляція.