A DETAILED MIDDLE AND LATE PLEISTOCENE CYCLOSTRATIGRAPHIC RECORD USING ROCK MAGNETISM AND PALAEOSOL PROXIES IN THE MIDDLE DNIEPER BASIN LOESS DOMAIN

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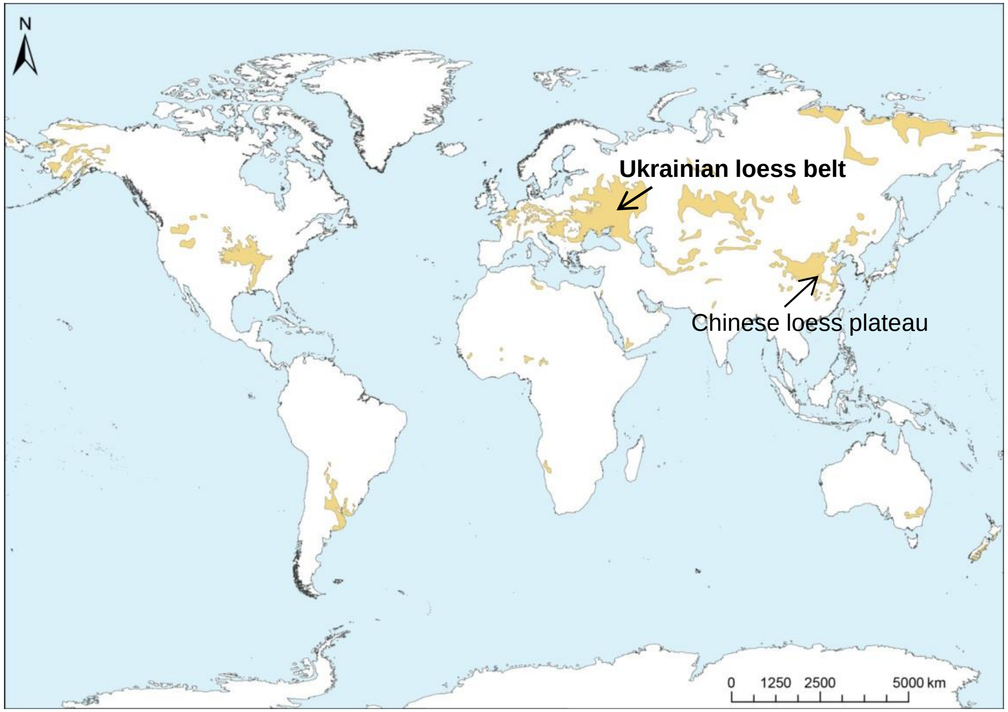
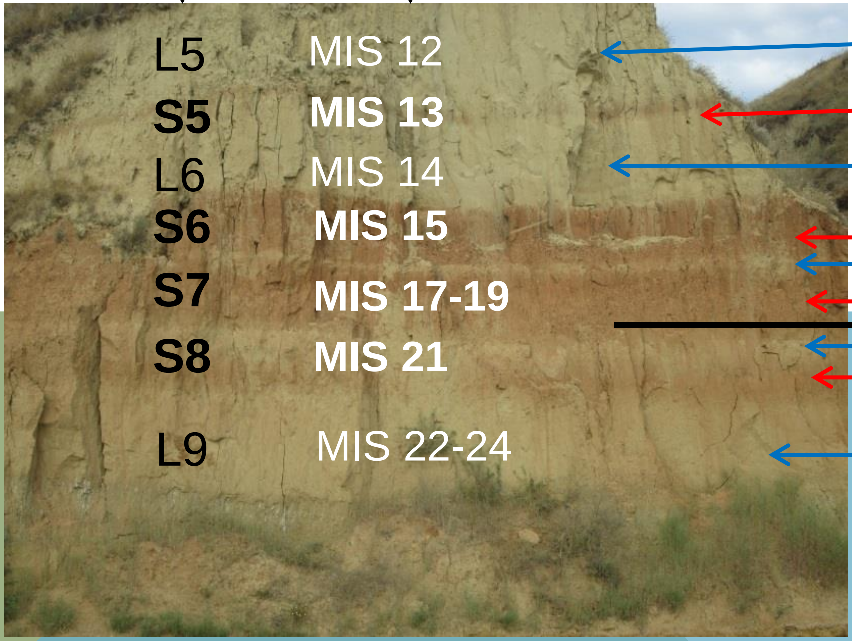
LOESS/SOIL SEQUENCES

Loess occupies an area of 479 000 km^2 in Ukraine being the largest loess belt in Europe. Loess-palaeosol sequences in Ukraine have been investigated by multi-proxy approach in ~70 main profiles and at more than 200 additional sites for the last hundred years. Since the 1970s, magnetostratigraphic studies have been carried out on 60 key profiles.



Loess/**soil** nomenclature

Marine isotope stage equivalent



loess - glacial - cooler climate - even MIS

soil - interglacial - warmer climate - odd MIS

loess

Matuyama/Brunhes boundary (780 ka or 773 ka)

soil

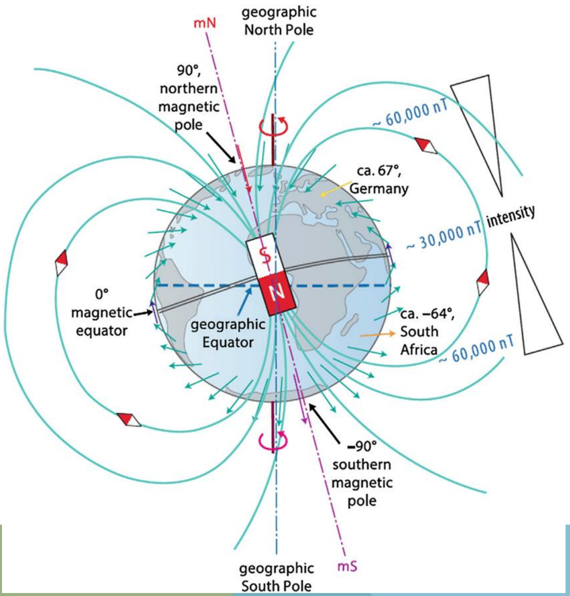
loess

▲ Map of world loess distribution.

◄ Alternation of loess/soil deposits (Roksolany section, Ukraine.

ENVIROMAGNETIC PARAMETERS

Rock magnetic parameters are related to climatic and environmental conditions during formation of loess deposits; they are a powerful tool for application to palaeoclimate reconstruction

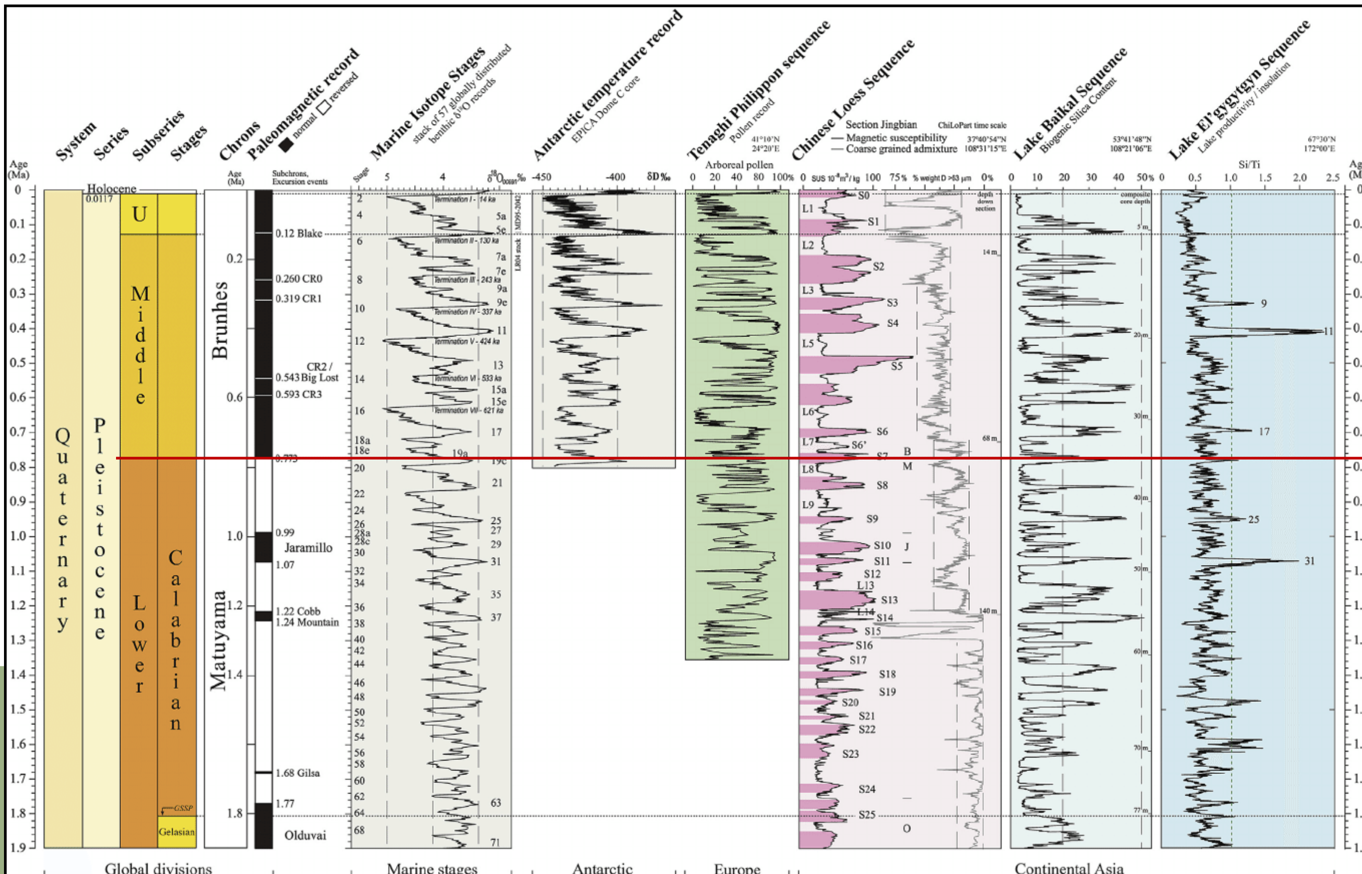


Hlavatskyi, D. V.; Gerasimenko, N. P.; Bakhmutov, V. G.; Bonchkovskyi, O. S.; Poliachenko, I. B.; Shpyra, V. V.; Mychak, S. V.; Kravchuk, I. V.; Cherkes, S. I. Significance of the Ukrainian Loess-Palaeosol Sequences for Pleistocene Climate Reconstructions: Rock Magnetic, Palaeosol and Pollen Proxies. *Geofizicheskiy Zhurnal* **2021**, *43*, 3–26. https://doi.org/10.24028/gzh.v43i3.236378.

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 J_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

MAGNETOSTRATIGRAPHY

Magnetostratigraphic studies provide the key absolute time control for the loess-palaeosol deposits. The Matuyama–Brunhes boundary (MBB), the last change in the Earth's magnetic field, dated at ~780 ka, is one of the most frequently used time markers in the Quaternary stratigraphy. The determination of the MBB allows correlating even remote loess-palaeosol sequences regardless of their lithostratigraphic subdivision



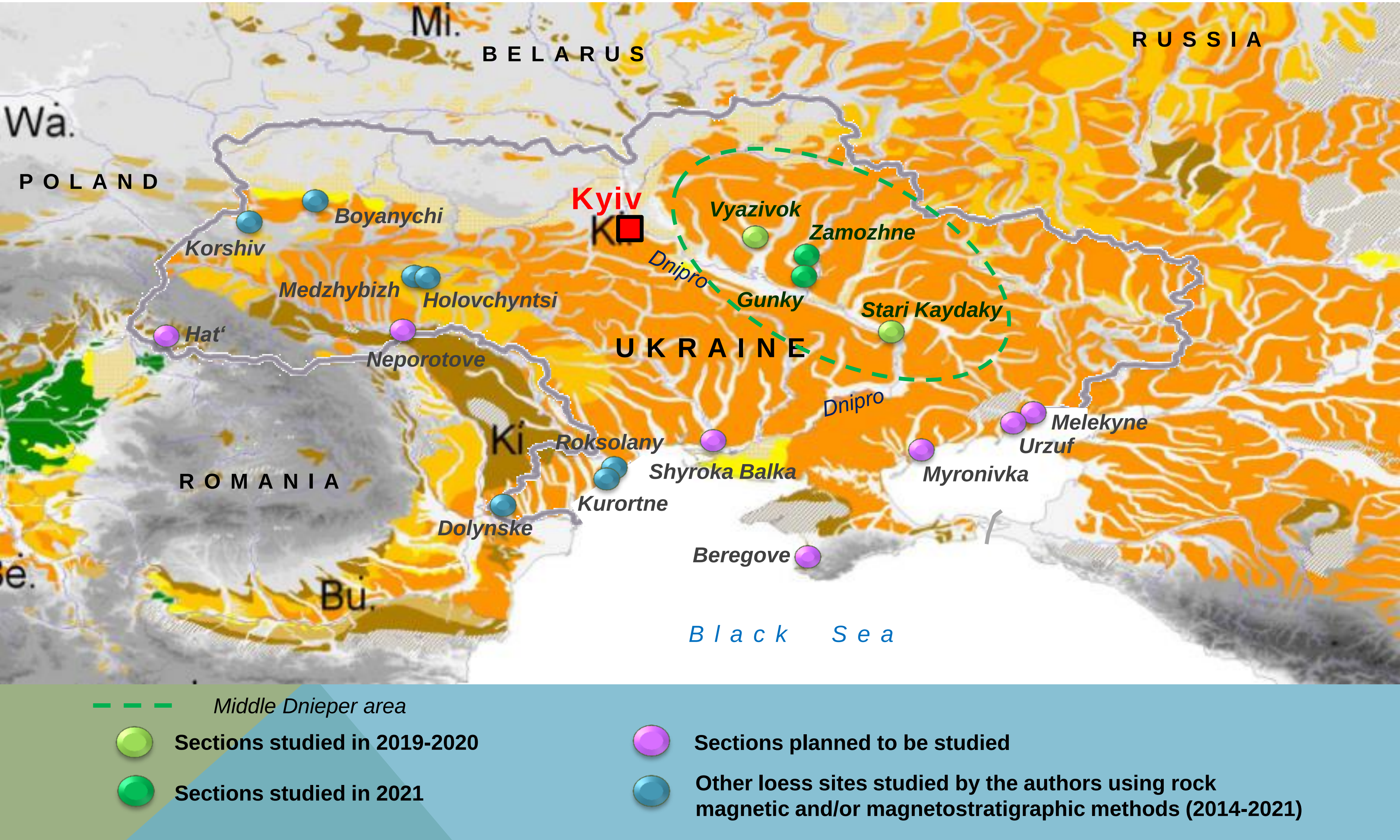
BRUNHES CHRON

MBB
780 ka
(or 773 ka)

MATUYAMA CHRON

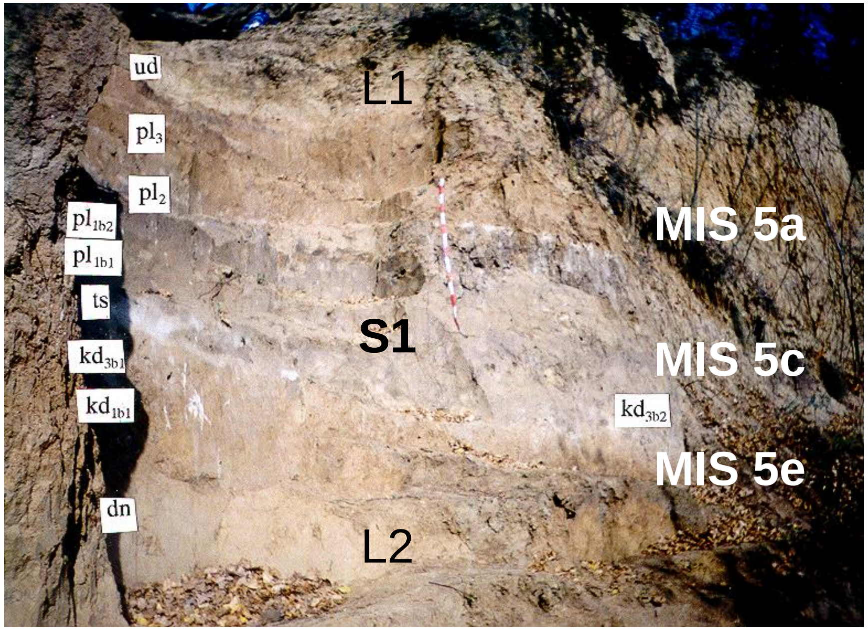
Head, M. J.; Gibbard, P. L. Early–Middle Pleistocene Transitions: Linking Terrestrial and Marine Realms. *Quaternary International* **2015**, *389*, 7–46. https://doi.org/10.1016/j.quaint.2015.09.042.

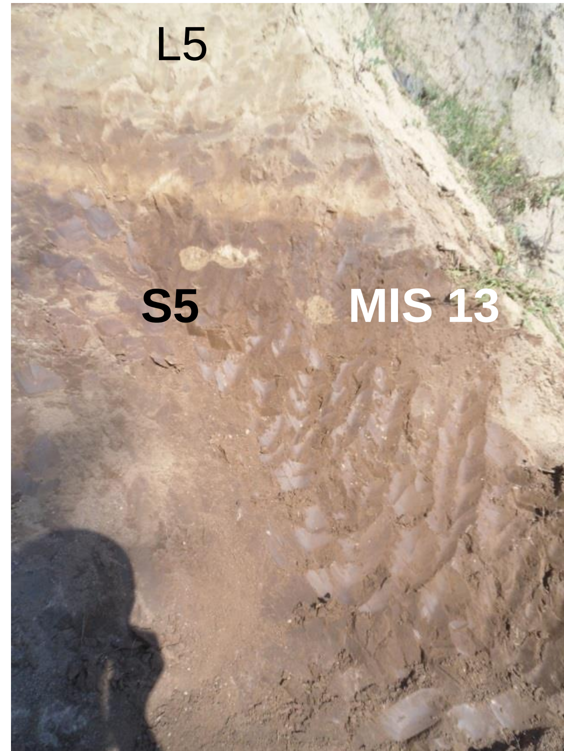
STUDIED SITES

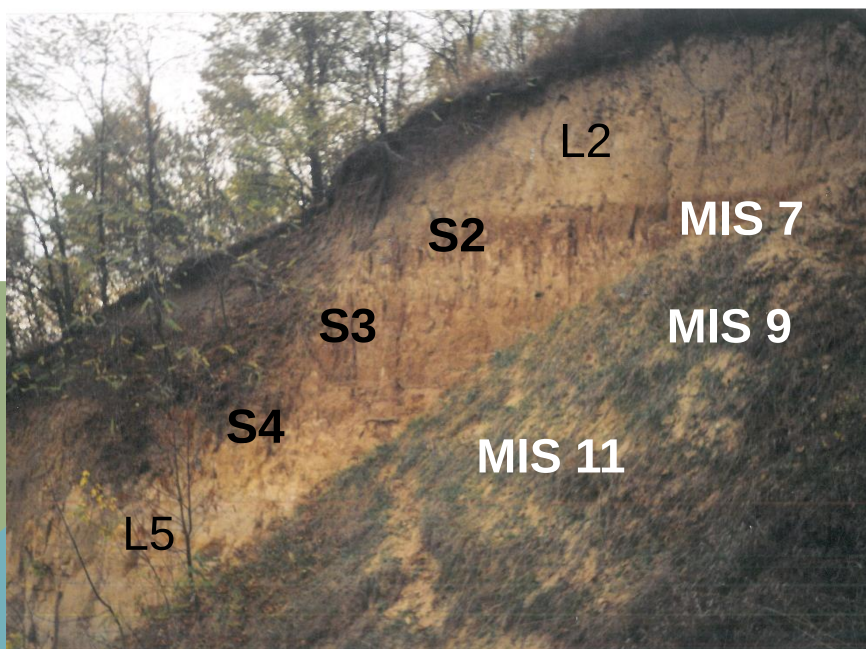


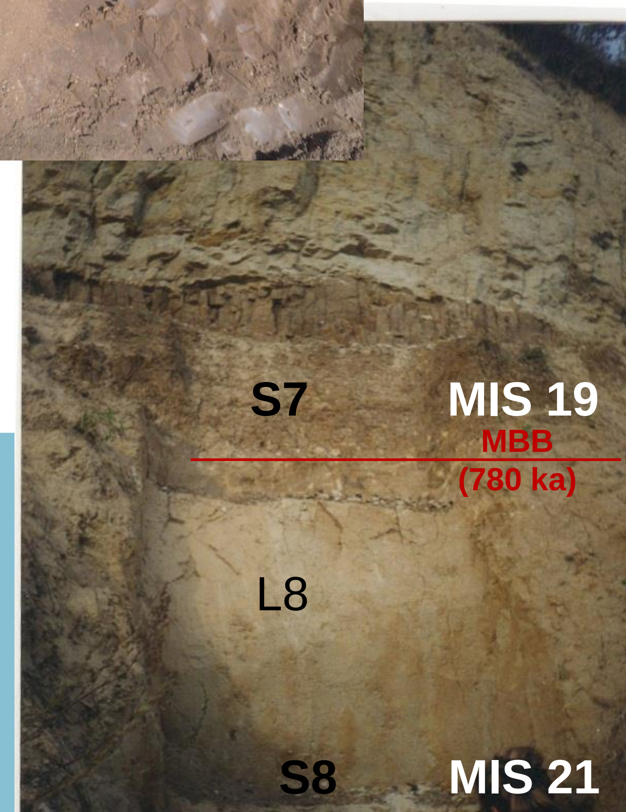
Map of loess deposits in Central—Eastern Europe (Haase et al., 2007); and location of studied loess sites

VYAZIVOK

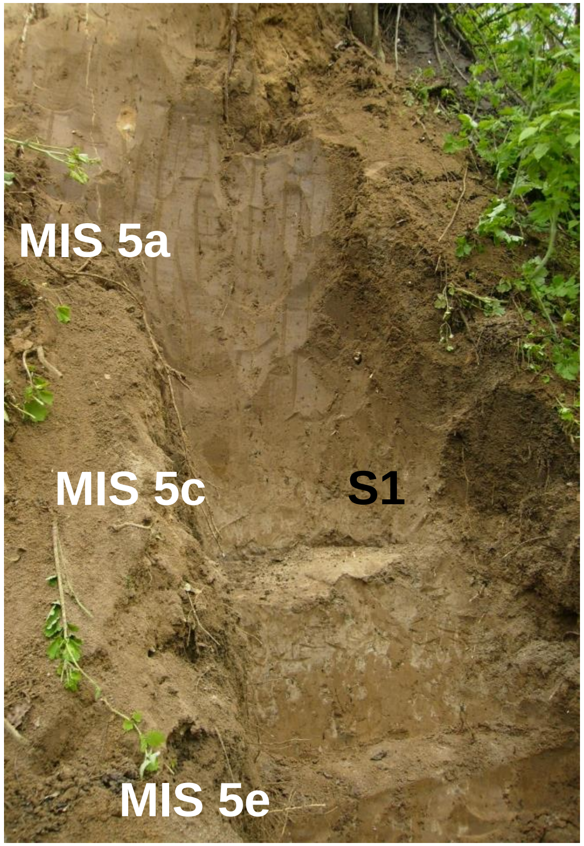

ud
pl_3
pl_2
pl_{1b2}
pl_{1b1}
ts
kd_{3b1}
kd_{1b1}
kd_{3b2}
dn
L1
MIS 5a
S1
MIS 5c
MIS 5e
L2

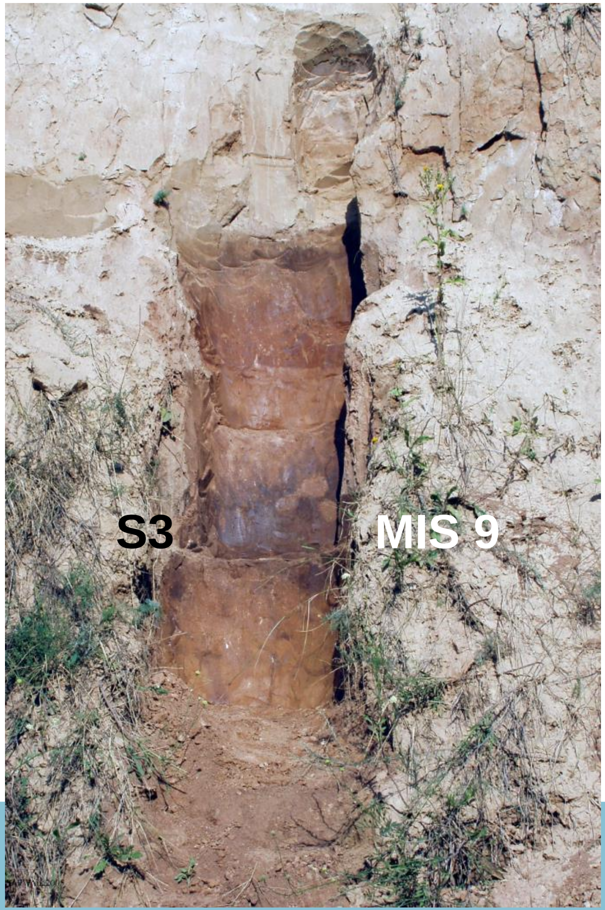

L5
S5
MIS 13

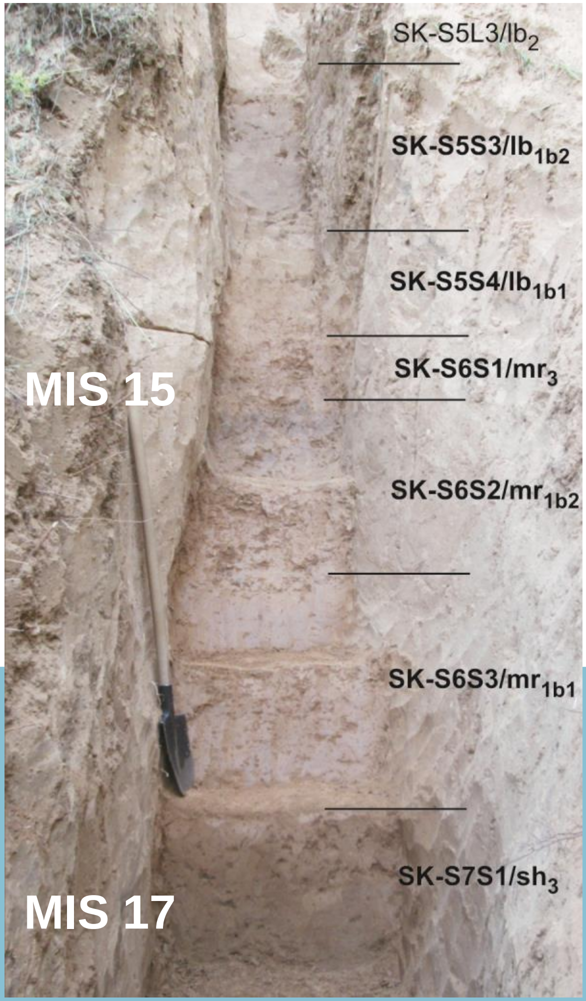

L2
S2
MIS 7
S3
MIS 9
S4
MIS 11
L5


S7
MIS 19
MBB
(780 ka)
L8
S8
MIS 21

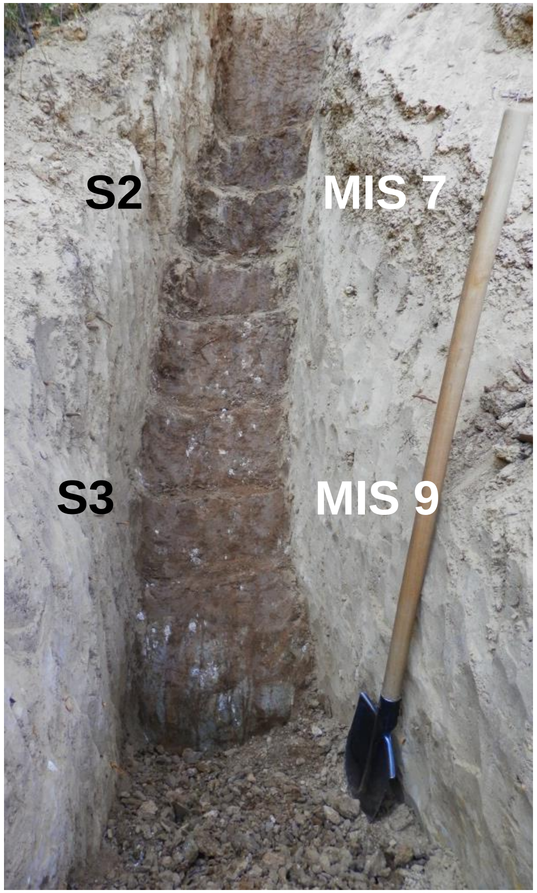
STARI KAYDAKY

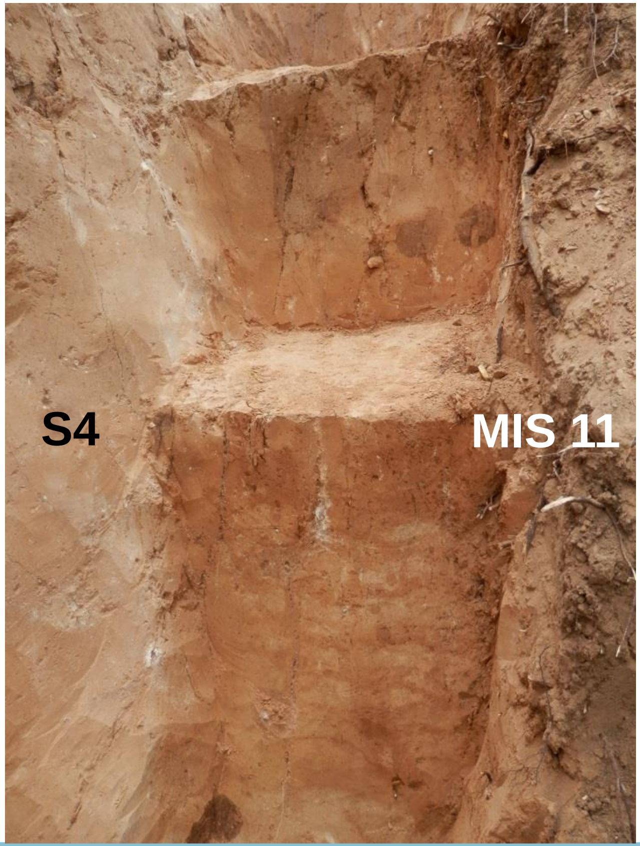




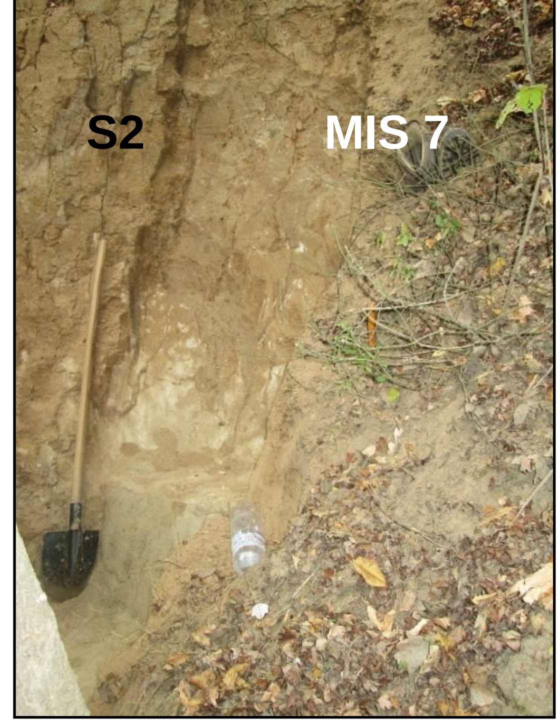


ZAMOZHNE



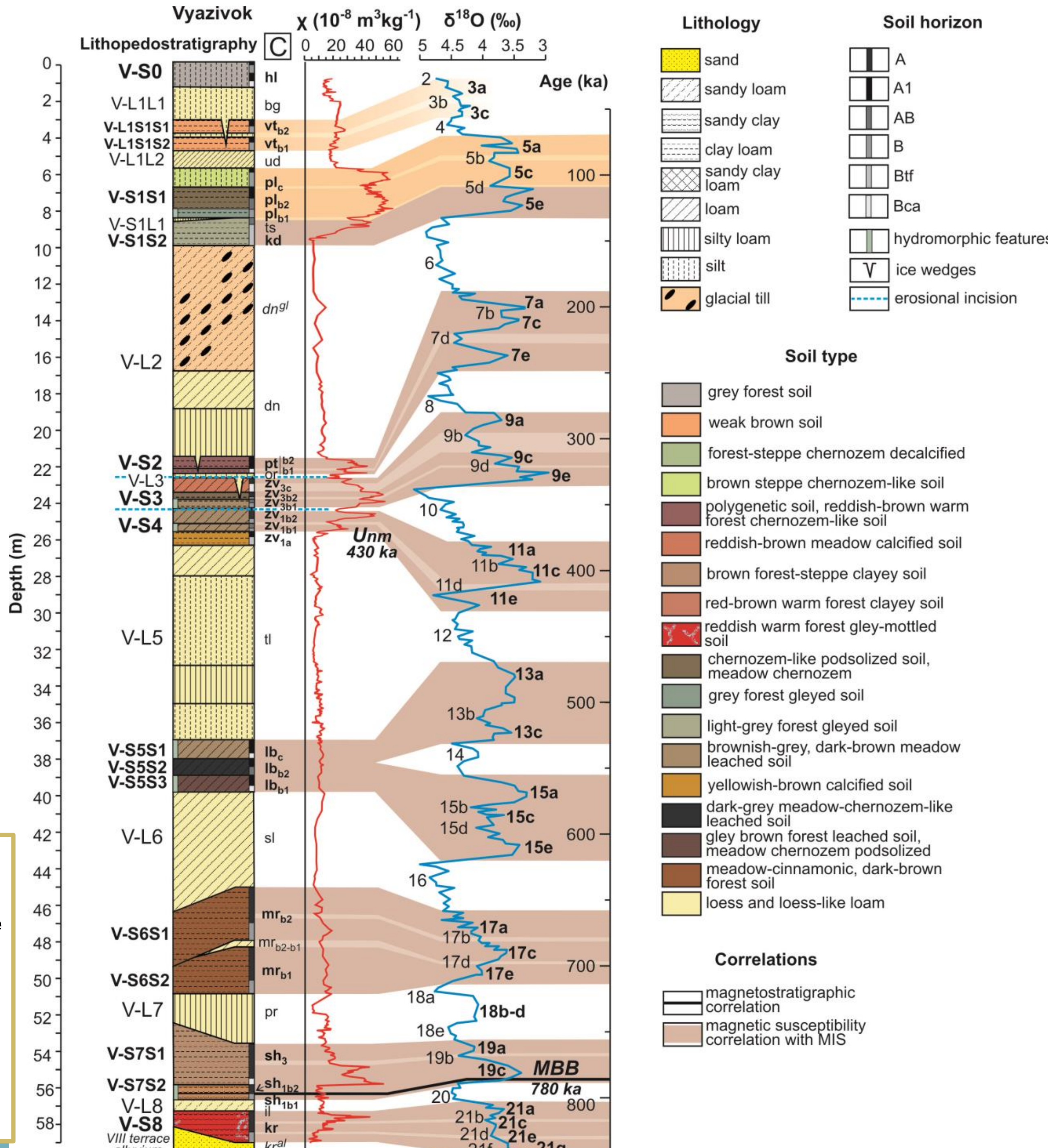


GUNKY



VYAZIVOK

- The most stratigraphically complete section in the Dnieper Lowland (Veklitch et al., 1967; Veklitch, 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 M/B boundary has been detected within the Shyrokyne/S7 soil unit (Vigillyanskaya, 2001; Hlavatskyi et al., 2016; Hlavatskyi and Bakhmutov, 2020).

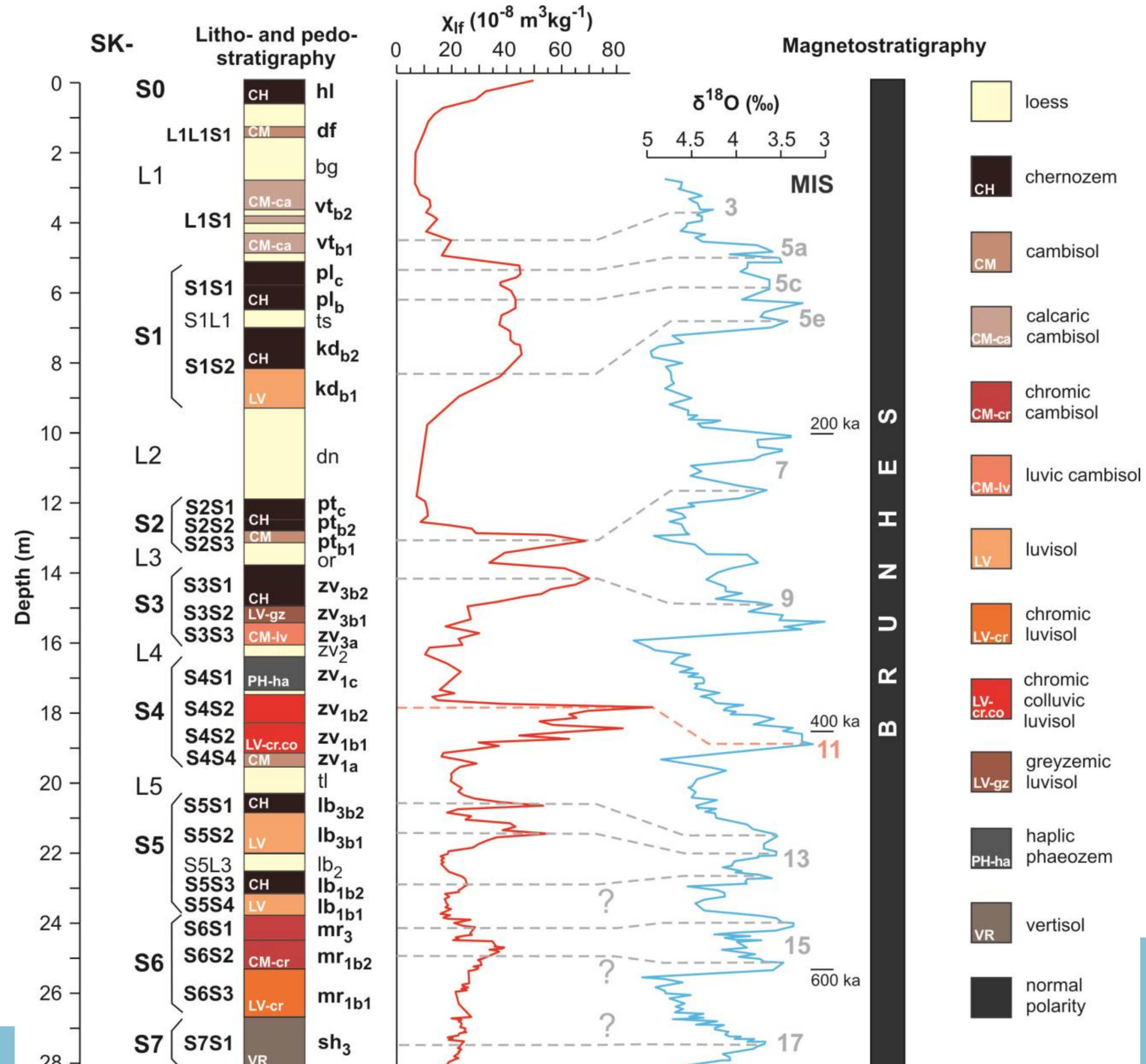


Revised lithostratigraphic subdivision and correlation of magnetic susceptibility (χ) of the Vyazivok loess-palaeosol sequence with marine oxygen isotope record (Hlavatskyi and Bakhmutov, 2020)

Summarized lithological and pedological characteristic of Vyazivok section (Matviishyna et al., 2001; Rousseau et al., 2001) are modified

STARI KAYDAKY

- 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).
- Our section is 28.2 m thick and includes S7S1 to L1S1 palaeosols.
- The entire studied part of the section formed during the Brunhes chron, i.e. younger than 780 ka.
- The former SK-S4 soil unit (Buggle et al., 2008, 2009) is now preliminary related to the lower part of SK-S3, representing MIS 9. SK-S5 is presumably marked as SK-S4 (MIS 11).
- The M/B reversal has not been detected yet at Stari Kaydaky.

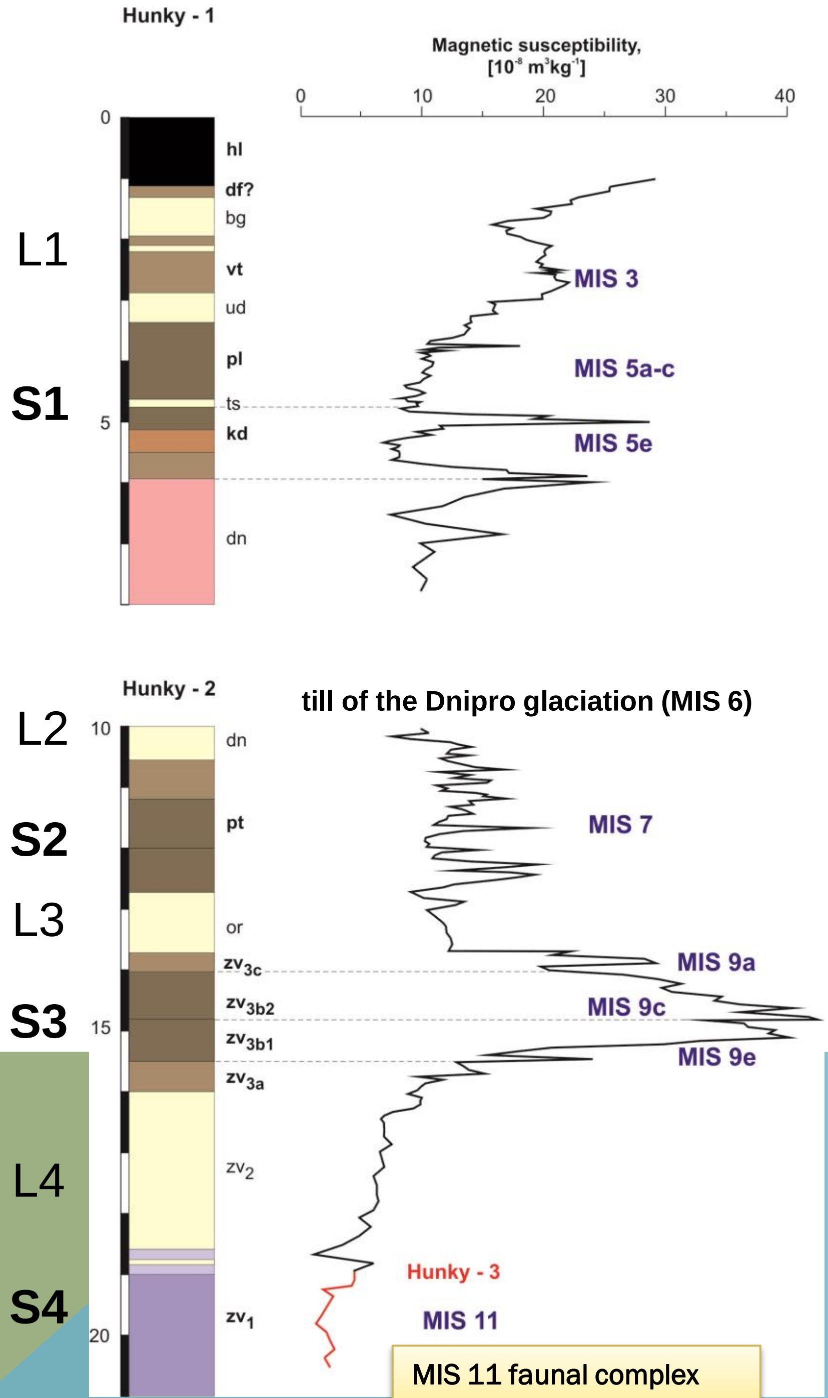


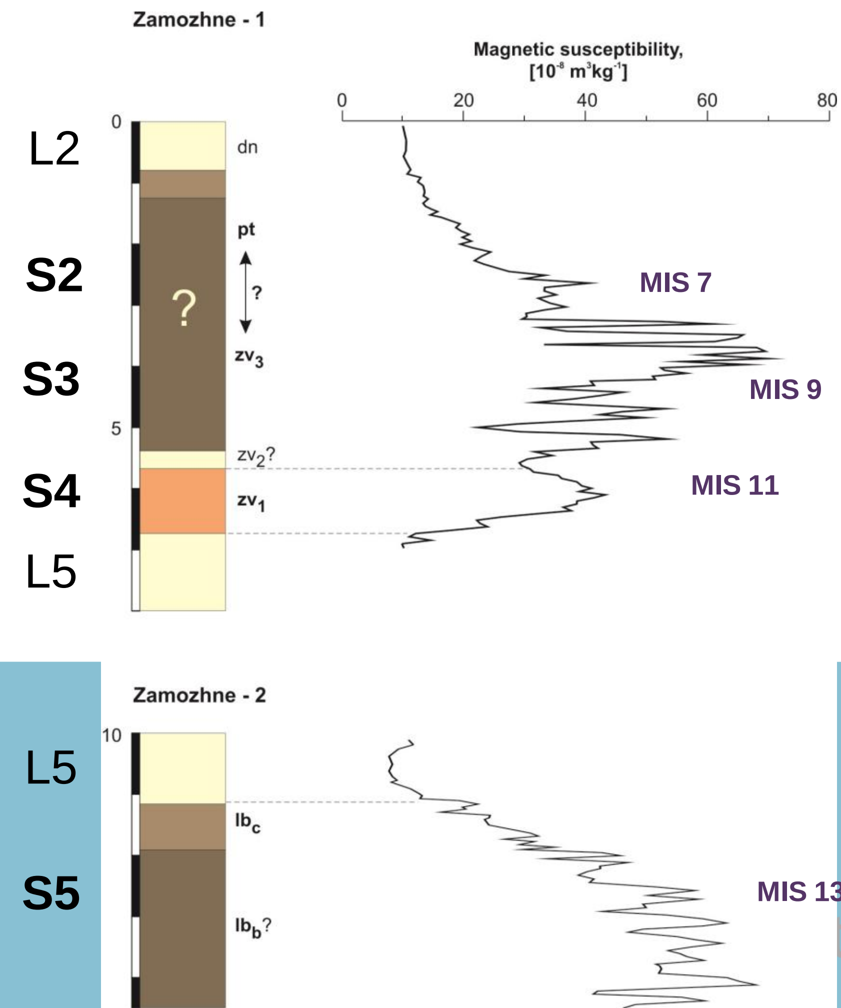
Revised litho- and pedostratigraphy, magnetic susceptibility (χ_{lf}) curve (in the depth interval of 0—17 m adopted from (Buggle et al., 2009), preliminary correlation with the marine benthic $\delta^{18}O$ record from ODP site 677 (Shackleton et al., 1990) , and magnetostratigraphic chart of the Stari 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, 1982; Gerasimenko, 2004)

GUNKY & ZAMOZHNE

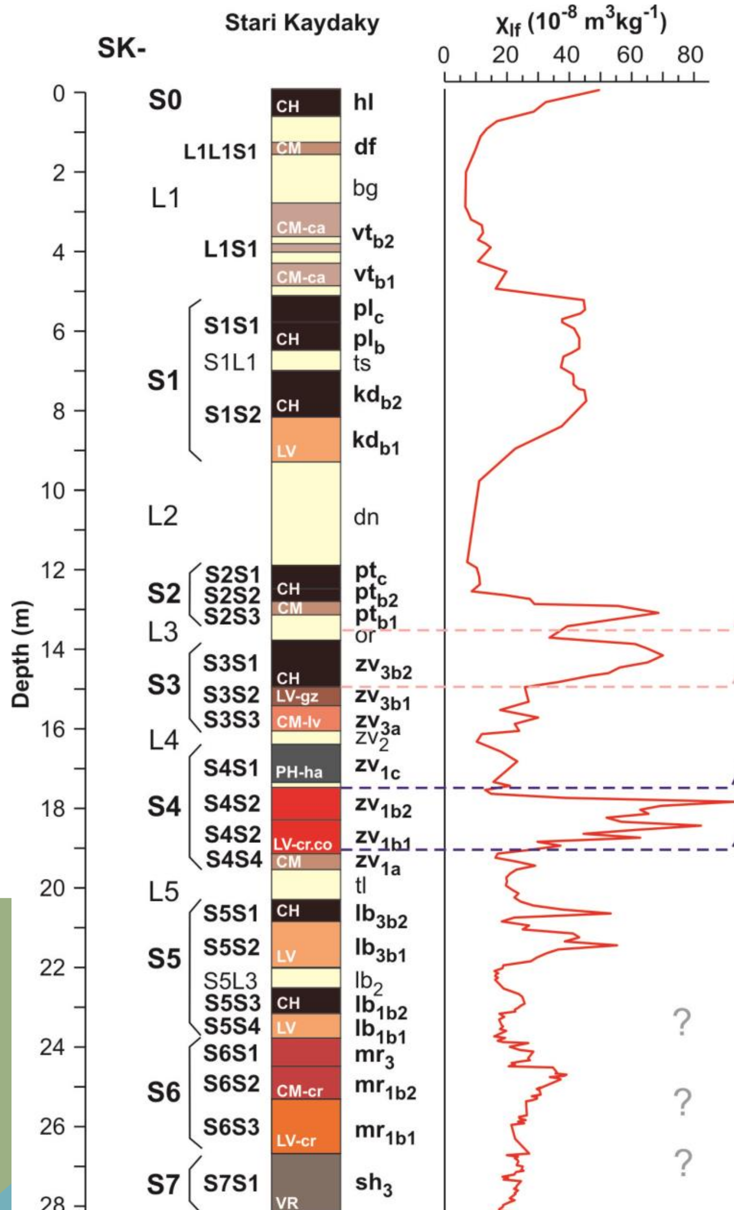
- Gunky – famous loess profile containing alluvial sediments with MIS 11 faunal complex (Markova, 2007).
- Zamozhne – additional loess profile with the automorphous MIS 11 palaeosol.

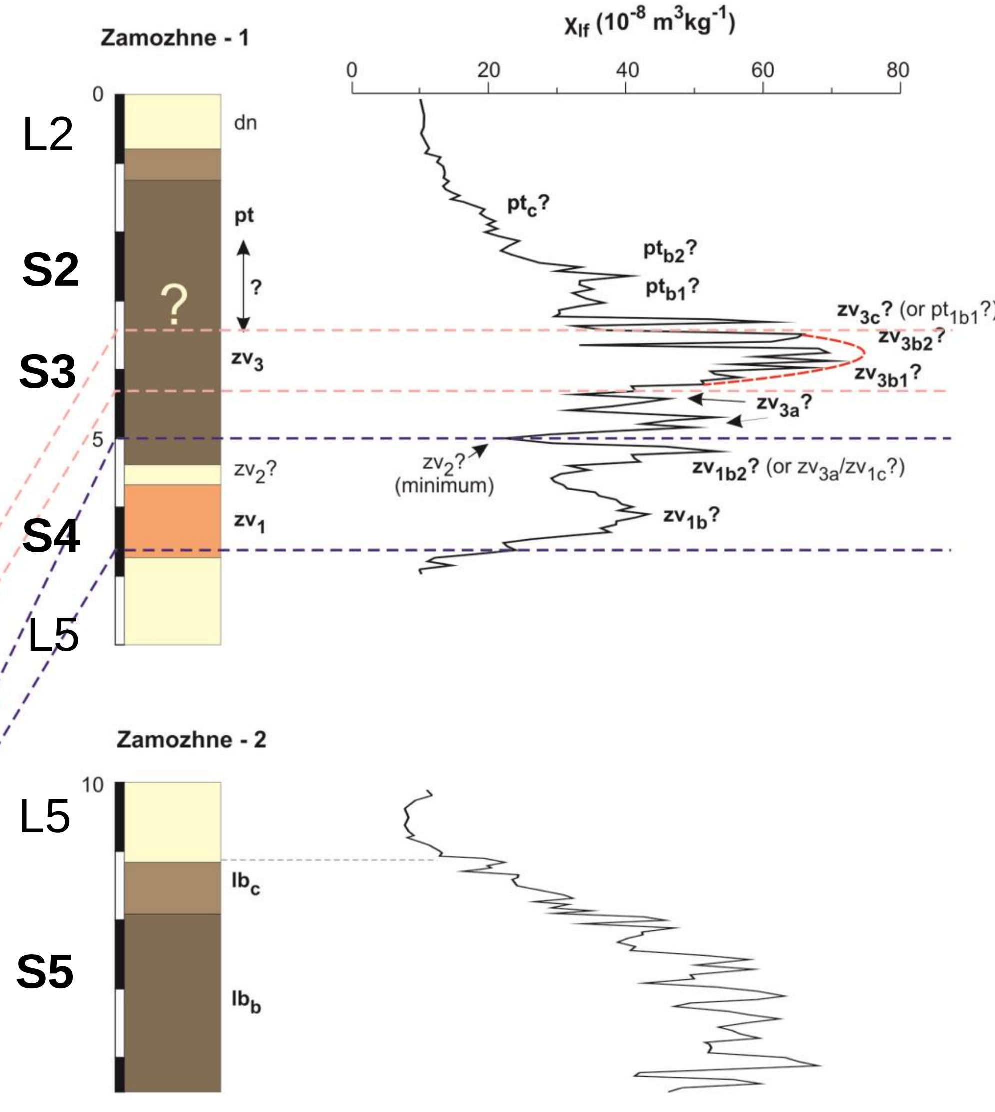




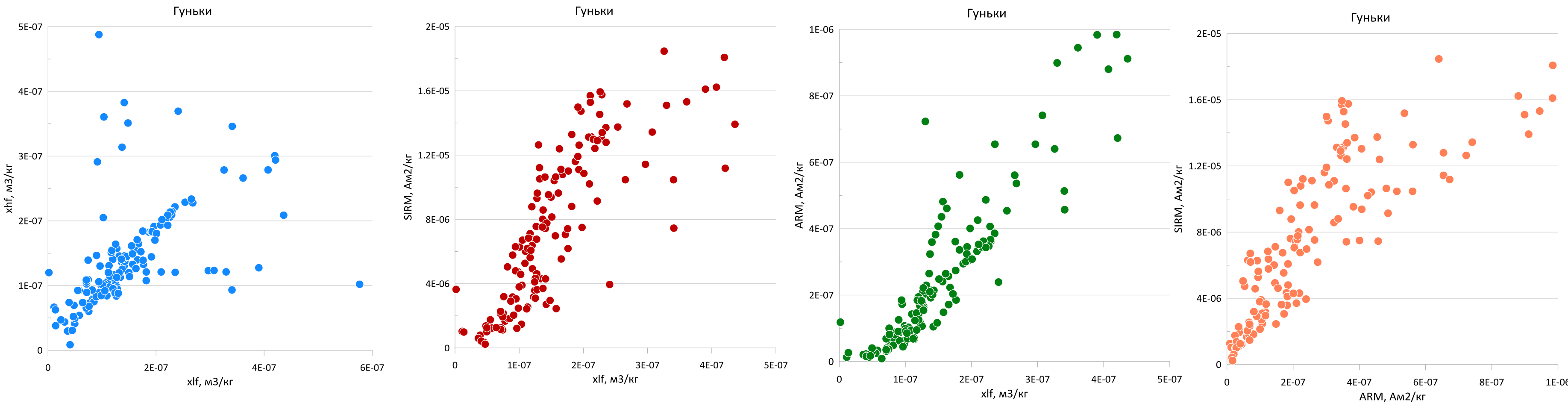
STARI KAYDAKY & ZAMOZHNE

- Similar local magnetic susceptibility patterns confirm the proposed cyclostratigraphy.





GUNKY



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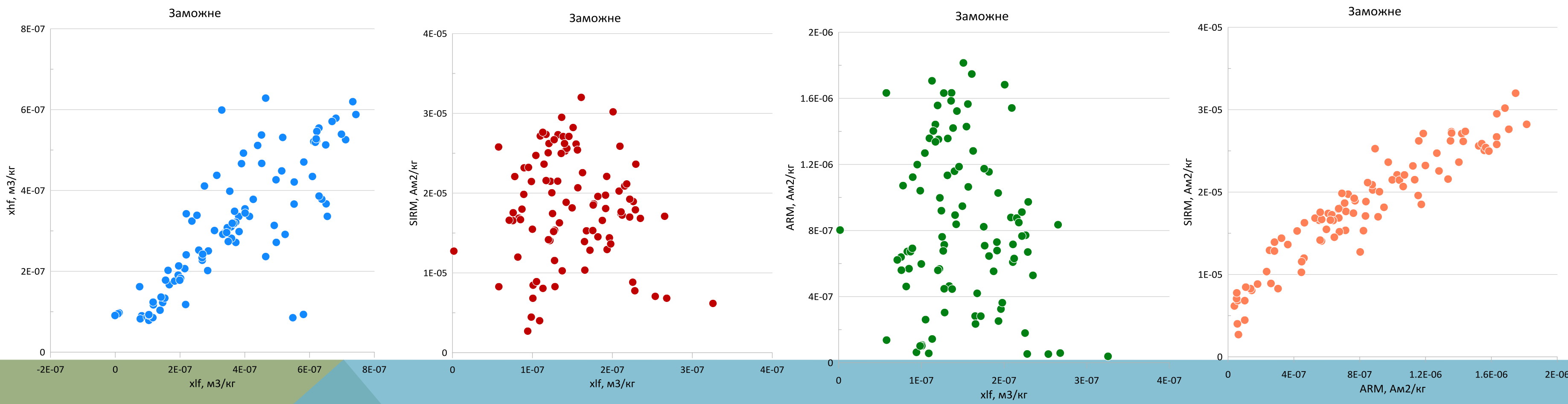
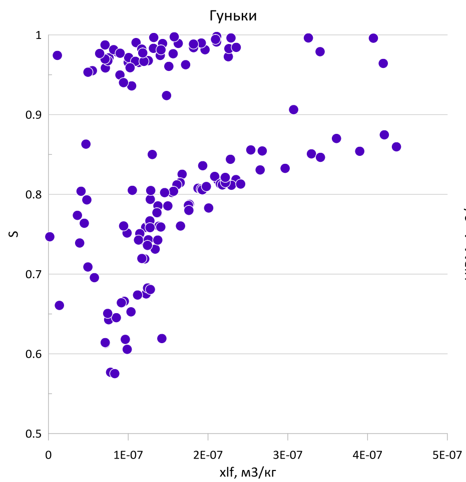
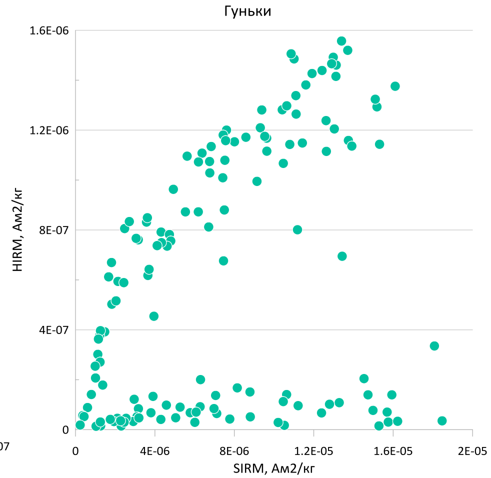


Ratio of concentrate-dependent magnetic parameters (χ_{hf}/χ_{lf}; SIRM/χ_{lf})

Ratio of composition-dependent magnetic parameters (ARM/χ_{lf}; SIRM/ARM)

GUNKY





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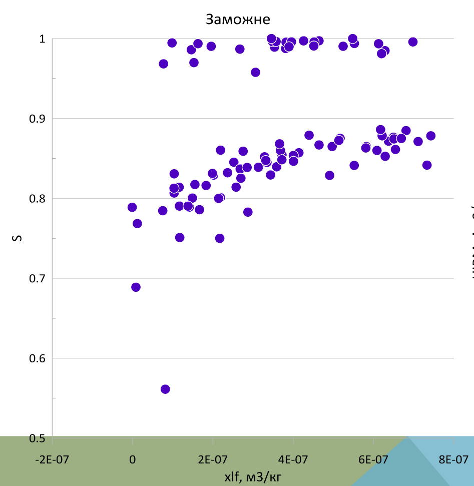
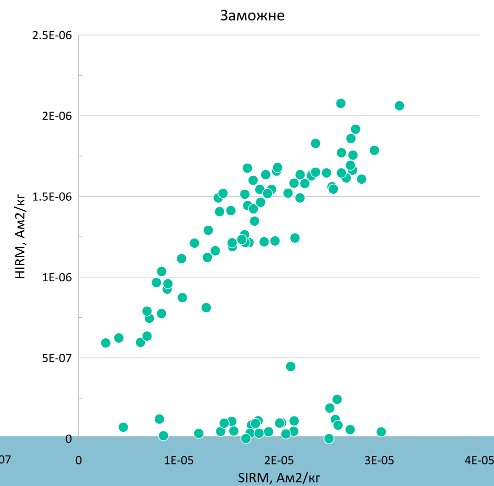
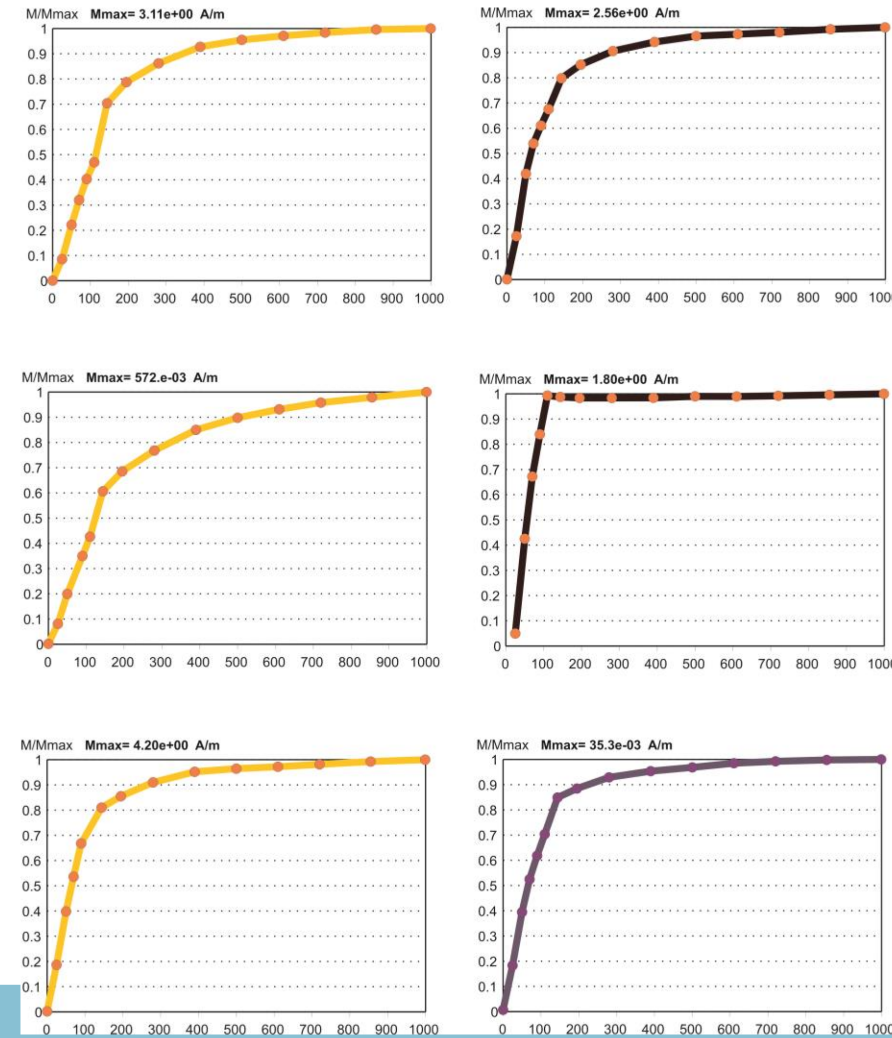




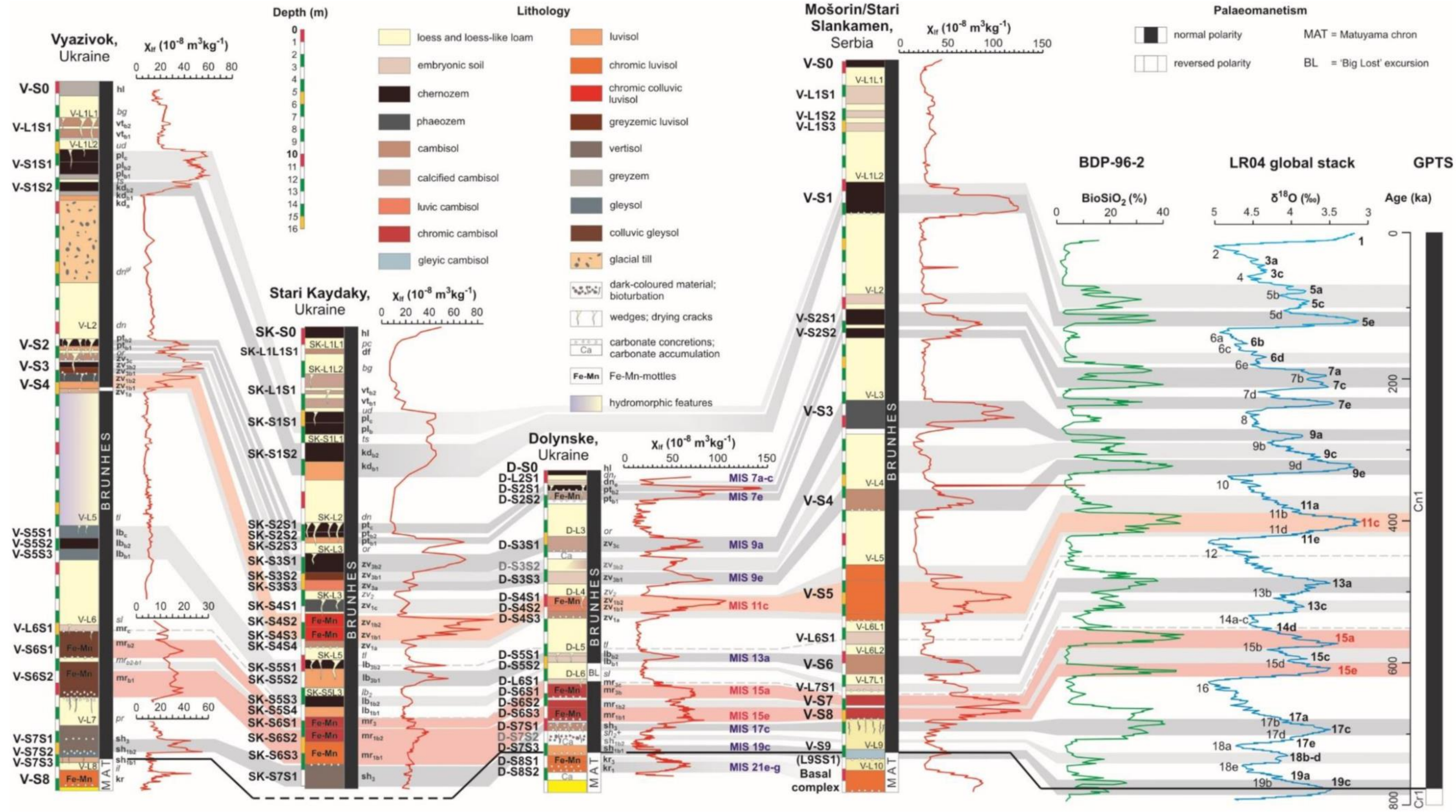


Ratio of magnetic-mineralogical parameters (S/χ_{lf}; HIRM/SIRM)

IRM acquisition curves of selected specimens from the Gunky and Zamozhne sections

- Loess
- Palaeosol
- Hydromorphic soil

REGIONAL CORRELATION



Correlation chart of the sequences studied at Vyazivok, Stari Kaydaky and Dolynske, Serbian reference sequence of Mošorin/Stari Slankamen, adapted with permission from Marković et al. (2015), palaeoclimatic record of biogenic silica (%) from Lake Baikal, adapted from Williams et al. (1997), marine oxygen isotope stack LR04 and Geomagnetic Polarity Time Scale. Magnetic susceptibility curve of the upper 17 m of the Stari Kaydaky section adapted from Buggle et al. (2009).

CONCLUSIONS

A combined pedostratigraphic and rock magnetic study of four loess-palaeosol sequences in the Middle Dnieper area, Ukraine (at Gunky, Zamozhne, Vyazivok and Stari Kaydaky) have been performed in order to determine the suitability of these sites for rock magnetic cyclostratigraphy and the establishment of magnetostratigraphic markers. Two geomagnetic events – the Matuyama/Brunhes boundary (at 780 ka) and Unnamed excursion (at 430 ka) – have been detected at the long Vyazivok loess-paleosol record (Hlavatskyi et al., 2016; Hlavatskyi and Bakhmutov, 2020). The till of the Dnipro glaciation (MIS 6) and the corresponding thick loess (U-L2), present in all sections, and faunal remains at the Gunky section, typical for MIS 11 (Markova, 2004), serve as reliable age benchmarks for developing a comprehensive cyclostratigraphic model. The studied sections are most similar by their rock magnetic and palaepedological characteristics to the Hungarian loess-palaeosol sequences (Udvari-U2 and Paks), which are also located in the temperate climatic zone. These sections can be related to the «Chinese» type of formation of magnetic properties, with very low magnetic susceptibility values in loesses and higher values in palaeosols. However, the magnetic susceptibility pattern in palaeosols of northern Ukraine is distorted by the later cryoturbation and gleying processes of the subsequent cold phases. In contrast to the Chinese, Danube and southern Ukrainian loess sequences, these sites are characterized by much lower concentration of ferrimagnetic material, especially in the Lubny (U-S5, correlative of MIS 13) and Potyagaylivka (U-S2/MIS 7) palaeosols. The highest magnetic enhancement is characteristic for the Lower Zavadivka (U-S4/MIS 11), Upper Zavadivka (U-S3/MIS 9) and, in part, the Pryluky-Kaydaky (U-S1/MIS 5) pedocomplexes. Rock magnetic investigations show predominance of pseudo-single domain magnetite in palaeosols and higher proportion of hematite in loesses. It is suggested that wet conditions in northern Ukraine, which periodically appeared due to its closeness to the ancient ice fronts, facilitated the oxidation of ferrimagnetic grains and the formation of high coercive minerals.

Acknowledgements

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FOR FURTHER DETAILS, SEE:

Hlavatskyi, D. V.; Bakhmutov, V. G. Magnetostratigraphy and Magnetic Susceptibility of the Best Developed Pleistocene Loess-Palaeosol Sequences of Ukraine: Implications for Correlation and Proposed Chronostratigraphic Models. *Geol. Q.* **2020**, *64* (3), 723–753. https://doi.org/10.7306/gq.1544.

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THANK YOU!