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ROCK MAGNETIC STUDY OF KYIV POLISSIA SANDS AND SANDY SOILS

(Представлено членом редакційної колегії д-ром геол. наук К.М. Бондар)

Background. Late Pleistocene and Holocene deposits in Ukraine have traditionally been studied in detail using magnetic methods; however, sands and sandy soils have not been sufficiently studied. The purpose of this article is to provide rock magnetic characteristics of sands and sandy soils in the Kyiv Polissia region, northern Ukraine.

Methods. Field work involving sampling from mini-pits and standard laboratory rock magnetic studies (Evans, & Heller, 2003; Maxbauer, Feinberg, & Fox, 2016) have been conducted.

Results. The average magnetic susceptibility values of the Demydiv and Oзера sections fluctuate within insignificant limits ($1\text{--}10 \cdot 10^{-8} \text{ m}^3/\text{kg}$), with higher values observed in soil horizons compared to sands. High values of frequency-dependent magnetic susceptibility of humus horizons of sandy soils (11–13 %) indicate the presence of superparamagnetic magnetite grains formed as a result of pedogenic processes. The S parameter also indicates the dominance of magnetite. The thermomagnetic susceptibility curves are characterized by a Curie point of 675°C and a typical hematite "tail." The SIRM and χ_{ARM} values for the pilot samples indicate their dependence rather on the concentration of ferrimagnetic material: increased values are observed in the upper parts of the sections (humus horizons of soils), decreased values – in sands. This behavior of magnetic properties is explained by local geomorphological conditions, weaker influence of pedogenic processes, and significant impact of physical and chemical weathering processes.

Conclusions. Sand deposits of the Polissia Lowland were formed under conditions of a "transitional" model of magnetic record, which is also characteristic of loess-soil deposits of the Volyn Upland. The sensitivity of rock magnetic and mineralogical properties to local climatic conditions, namely the degree of moisture and waterlogging, has been established, which in the case of the "transitional" model correlates inversely with the content of superparamagnetic grains. For the Kyiv region, the classical pedogenic model of magnetic properties (increase in magnetite content with the degree of pedogenesis) is observed only for loess-soil sections of the Dnieper Upland.

Keywords: magnetic susceptibility, Adrenosol, Abruptic Retisol, magnetic minerals, paleoclimate.

Background

Quaternary deposits in Ukraine are mainly represented by loess-soil sequences covering about 70 % of its area, which have been traditionally comprehensively studied by paleogeographic methods (Bogutskyi, 1986; Bonchkovskyi, 2025; Gerasimenko, 2006, 2022; Gozhyk, Gerasimenko, & Bortnyk, 2019; Matviishyna et al., 2010; Matviishyna, & Doroshkevych, 2019; Sirenko, & Turlo, 1986; Sirenko, 2019; Veklich, 1982). The loess-soil sequences have also been studied in detail using paleomagnetic and rock magnetic methods since the 1960s (see references in Bakhmutov, Hlavatskyi, & Poliachenko, 2023). Previous studies focused on determination of the stratigraphic boundary of the last Matuyama–Brunhes polarity reversal (773 ka), and only in the last two decades the studies appeared devoted to the use of rock magnetic parameters (primarily magnetic susceptibility) as paleoclimatic proxies (see review in Hlavatskyi et al., 2021a), as well as anthropogenic pollution indicators (Bondar et al., 2024; Jeleńska et al., 2008; Menshov et al., 2020, 2023). Dozens of sections in the Dnieper Lowland, Dnieper Upland, Black Sea Lowland, and Volyn-Podillia Upland have been investigated so far. However, another widespread Quaternary deposits in Ukraine – sands of different origin – remain insufficiently studied.

In the world literature devoted to environmental magnetism, a few studies have been conducted on sands (Faust et al., 2020; Hamza et al., 2025; Lyons, Oldfield, & Williams, 2010). More studies are devoted to the Holocene climatic evolution based on multi-proxy investigations of sandy and loessic soils (Ahn, Lim, & Kim, 2021; Ahn, Park, & Lim, 2024; Anwar et al., 2018; Buynevich et al., 2023;

Chen et al., 2024; Jordanova, & Jordanova, 2021; Song et al., 2024). In Ukraine, magnetic sands from the Northern Black Sea region have been magnetically analyzed (Kurnikov, & Orlyuk, 2011). In northern Ukraine, anisotropy of magnetic susceptibility was investigated at the Pleistocene sequence at Cherepyn (Nawrocki et al., 2019). However, we have not found any magnetic data on sandy soils or sands within the Kyiv Polissia region.

The purpose of this article is to present the magnetic characteristics of sands and sandy soils deposited within the Irpin River valley in northern Kyiv region and to compare them with other Late Pleistocene deposits.

Research objects. A total of three sites, two sites near the village of Demydiv in the Vyshhorod district, and one site at the Oзера cottage cooperative near the village of Rakivka in the Bucha district of the Kyiv region were studied. The study area is located 35 km north of Kyiv, within the Irpin River valley (Fig. 1), slightly northwards from the border between the Dnieper Upland and the Polissia Lowland. The relief of the study area is flat. Coniferous forests and, to a lesser extent, mixed forests are widespread. The study area is characterized by sandy soils with low fertility, formed on glacial and alluvium deposits. The region in general is characterized by Abruptic Retisols according to the WRB classification (WRB, 2022). The climate is temperate continental with warm and humid summers and mild winters. The average annual temperature is $+6.5^{\circ}\text{C}$... $+7.5^{\circ}\text{C}$. Annual precipitation is 550...650 mm (Menshov et al., 2024). The territory was temporarily occupied by Russian troops from February 25 to April 1, 2022.

The *Demydiv S-1* section (50°43'09.8"N, 30°18'49.9"E) was a temporary mini-excavation on the territory of the Demydiv magnetic station (Center for Collective Use of Magnetometric Equipment of the National Academy of Sciences of Ukraine).

The section is 2.2 m thick. It consists (from top to bottom) of sandy soil (Adrenosol according to the WRB classification, WRB, 2022), sand, loamy Gleysol with ochre stripes, and a lower sandy layer with wide iron pinnes (Fig. 2).

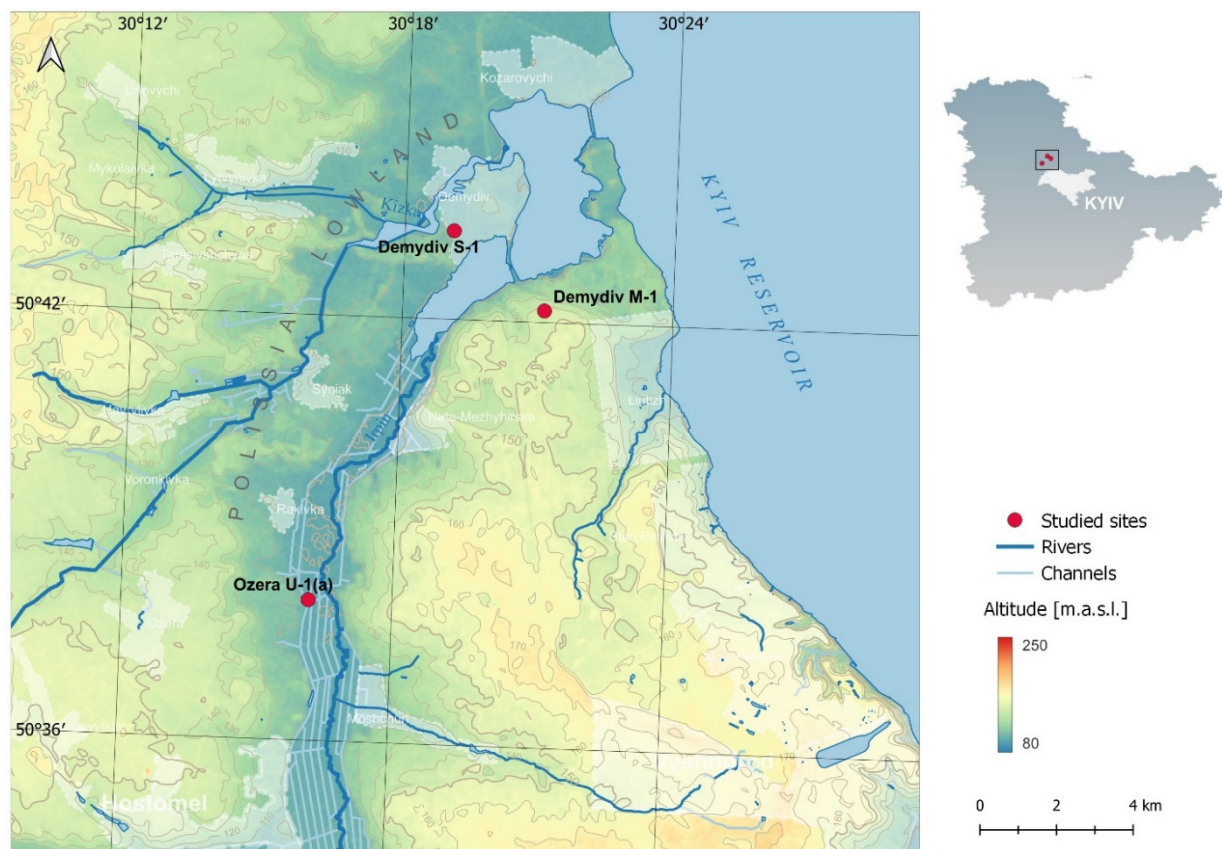


Fig. 1. Location of research objects on the relief map of the northern part of the Kyiv region.
The map was created based on Shuttle Radar Topography Mission (SRTM) 1 Arc-Second Global elevation data (Earth Resources Observation and Science (EROS) Center, 2017)

The following objects were processed together with planar sections (profiles and grids) as a part of the PAN.BFB.S.BWZ.394.022.2023 project, implemented in the framework of the Polish Academy of Sciences program to support Ukrainian research teams in cooperation with the US National Academy of Sciences to study potential heavy metal contamination of soils due to military operations (project leader – Ksenia Bondar). Preliminary results of geochemical and magnetic research on surface profiles in this area have been published in (Bondar et al., 2023, 2025; Hlavatskyi et al., 2024; Menshov et al., 2024).

The *Demydiv M-1* outcrop (50°42'10.6"N, 30°21'14.7"E) is a crater with a diameter of 20 m formed by the impact of a Russian X-type missile. At a depth of up to 3 m, the following layers were exposed (from the top to bottom): thin sandy soil (Adrenosol), sand horizon, and hard hydromorphic soil (clayey or loamy Gleysol; Fig. 2).

The *Ozera U-1* and *Ozera U-1a* duplicate sections (50°37'56.9"N, 30°16'07.2"E) were taken from a single mini-excavation with a depth of up to 0.9 m. The sequence is represented by Albic Abrupt Retisol, a sandy horizon, no signs of loamy Gleysol were observed (Fig. 2).

Methods

Fieldwork was conducted in 2022 (*Demydiv S-1* section) and in 2023 (other sites). Samples were collected from mini-excavations, and samples from the *Demydiv M-1* section were collected from outcrop in the crater resulting from a

rocket explosion. Samples weighing 10–25 g were collected every 5 cm (and every 2 cm at the *Ozera U-1a* section). The samples were sieved through 1 mm mesh screens and placed in non-magnetic zip-lock bags.

Magnetic susceptibility was measured at two frequencies (low frequency – χ_{lf} or χ at 976 Hz; and high frequency χ_{hf} at 15616 Hz) on a MFK-1FB Kappabridge at the Center for Collective Use of Magnetometric Equipment of the National Academy of Sciences of Ukraine (*Demydiv* village, Kyiv region). The magnetic susceptibility was measured for a total of 87 samples, including 44 samples from the *Demydiv S-1* section, 12 samples from the *Demydiv M-1*, 18 samples from the *Ozera U-1*, and 13 samples from the *Ozera U-1a*. Typically for sand horizons, frequency-dependent magnetic susceptibility (χ_{fd}) was not calculated due to abnormally low χ_{hf} values and, accordingly, exceeding the maximum error in measurements.

Then, the material from the pilot sample collection was moved to special plastic cubes with a 2 cm edge for further magnetic mineralogical studies in the paleomagnetic laboratory of the Institute of Geophysics of the Polish Academy of Sciences (Warsaw). Anhysteretic remanent magnetization (ARM) was measured using a LDA5/PAM1 AF Demagnetizer (AGICO, Czech Republic) with a maximum alternating (AC) field of 100 mT and a constant (DC) field of 100 μ T, and subsequent measurements on a cryogenic SQUID magnetometer (2G Enterprises, USA).

Saturation isothermal remanent magnetization (SIRM or M_{rs}) was obtained in a 1 T magnetic field using a MMPM10 Pulsemagnetizer (Magnetic Measurements, UK). Then, anhysteretic magnetic susceptibility, χ_{ARM} , was calculated.

The S ratio was calculated as the difference between SIRM in a 1 T magnetic field and the reverse induced saturation magnetization at -300 mT (Evans, & Heller, 2003; Maxbauer, Feinberg, & Fox, 2016).

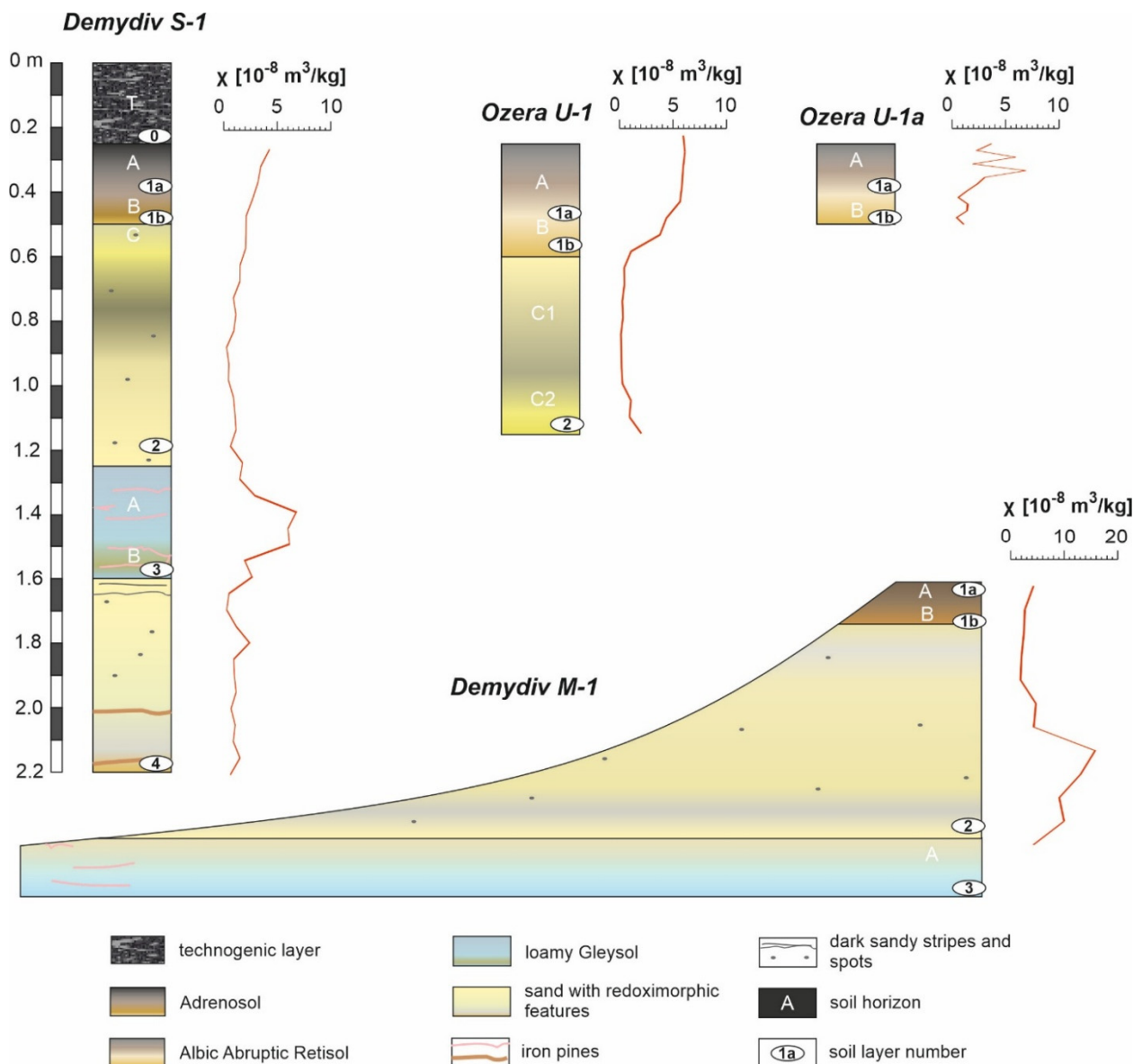


Fig. 2. Lithostratigraphy and magnetic susceptibility of the studied sections of the Kyiv Polissia region

Results

Magnetic susceptibility values vary within a narrow range from 0.1 to 6 m³/kg in all sections except Demydiv M-1 (Fig. 2). In general, χ tends to decrease in sandy horizons, while it has the highest value in upper soils. Only in the middle part of the Demydiv M1 section, the χ values are slightly increased (up to

16 m³/kg; Fig. 2), which may be caused by anthropogenic activity. Frequency-dependent magnetic susceptibility as an indicator of pedogenic processes proved to be informative only for the upper sandy soils at the Demydiv S1 and Ozera U-1/1a sites (11.5–13.4 %). The average values of χ and χ_{fd} are given in the Table.

Table

Average values of selected magnetic parameters of the studied sections

Section	n	χ_{lf} , 10^{-8} m³/kg	χ_{fd} , %	SIRM, 10^{-5} Am²/kg	χ_{ARM} , 10^{-8} m³/kg	S
Technogenic layer at Demydiv S-1 (0-20 cm depth)	5	718	2.8			
Demydiv S-1 (20-65 cm depth)	8	2.4	13.4	74.8	26.8	0.99
Demydiv S-1 (below 65 m depth)	30	1.6	≈0			
Demydiv M-1 (upper part)	6	3.0	4.7	123.6	32.1	1.0
Demydiv M-1 (lower part)	5	10.9	2.4	28.4	8.3	1.0
Ozera U-1/1a (upper 20 cm)	5	5.5	11.5	52.9	36.1	0.93
Ozera U-1/1a (below 20 cm depth)	14	1.09	≈0			

The SIRM and χ_{ARM} values for the pilot samples indicate rather their direct dependence on the concentration of ferrimagnetic material: increased values are observed in the upper parts of the sections (soils), decreased values in sands (Table). This is explained by

local geomorphological conditions, the weak influence of pedogenic processes and, accordingly, a small proportion of organic matter in the soils, as well as the significant influence of gleying processes due to the proximity to the Irpin River and high groundwater circulation.

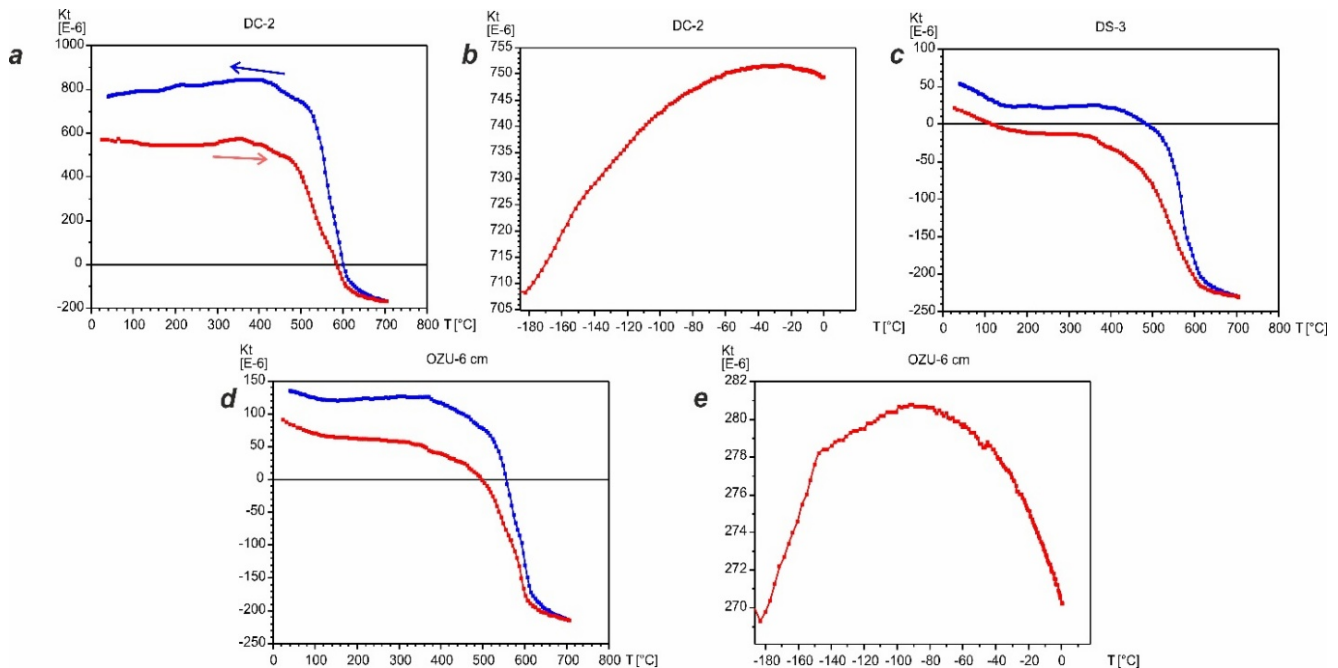


Fig. 3 Thermomagnetic heating and cooling curves (a, c, d) and heating curves at low temperature (b, e) for samples from the Demydiv M-1 (a, b), Demydiv S-1 (c), and Ozera U-1a (d, e) sections

The identification of magnetic minerals in soils is performed using thermomagnetic analysis (the dependence of magnetic susceptibility on the applied temperature) (Fig. 3).

Samples from all locations demonstrate typical pedogenic "behavior" expressed by a hematite "tail" on the heating curves at a temperature of 600–700 °C (Curie point of hematite is 675°C) (Fig. 3). It is noteworthy that the samples are characterized by a high rise of both curves from 0 to 500 °C with a sharp drop to 580–600 °C, with the cooling curve (blue) lying above the heating curve (red) (Fig. 3). This can be explained by the presence of oxidized titanomagnetite and its further oxidation during cooling (McElhinny, & McFadden, 2000).

Changes in magnetic susceptibility values in the low temperature range from -190 to 0 °C (low-temperature analysis) were minimal (up to 3.5–5 %), which is characteristic of fine-grained iron oxides (Eyre, & Shaw, 1994). It should be noted that according to the S parameter (from 0.93 to 1.0; Table), the dominant magnetic mineral in humus horizons is magnetite with a slight admixture of hematite.

Discussion and conclusions

The studied sands and sandy soils of the Kyiv Polissia region are characterized by very low magnetic susceptibility values (within the range of 0.1–16 m³/kg). The same values are characteristic of soil horizons and pedosediments of the Volyn-Podillia Upland (Bonchkovskiy et al., 2023; Bonchkovskiy, & Hlavatskiy, 2025; Hlavatskiy et al., 2021b). Moreover, in the case of soils of some Volyn sections, it was proved that the influence of imported sand during soil sedimentation was decisive in reducing the values of concentration-sensitive magnetic parameters. In contrast, the majority of loess of Volyn and the soils of the forest-

steppe and steppe zones of Ukraine usually have values of $\chi > 25$ m³/kg. Compared to other loess-soil deposits, similar to Kyiv Polissia sands values are characteristic only of loess horizons in southern Ukraine and partly in the Dnieper Lowland (8–12 m³/kg; Hlavatskiy, & Bakhmutov, 2020).

Nevertheless, based on the frequency-dependent magnetic susceptibility factor (11–13 %) in the upper humus horizon (A) of sandy soils, the presence of superparamagnetic magnetite grains has been proven, which is an indicator of intense pedogenic processes. As for the lower hydromorphic soil, which is widespread in the area, the magnetite grains were probably destroyed as a result of waterlogging; thus, the magnetic properties of hematite are more pronounced here. We have repeatedly observed a similar pattern of decrease in the concentration of ferrimagnetic minerals due to physical and chemical weathering processes in subaerial sections (Bonchkovskiy, & Hlavatskiy, 2025; Hlavatskiy et al., 2023). A conceptual diagram of the dependence of climatic conditions on soil formation, sand sedimentation, and magnetic properties is shown in Fig. 4.

Therefore, the magnetic properties of sands and sandy soils of the Kyiv Polissia region were formed in accordance with a typical "transitional" model of magnetic record (Bonchkovskiy, & Hlavatskiy, 2025), which is characterized by low magnetic susceptibility values combined with high χ_{td} and the predominant influence of chemical and physical weathering processes rather than pedogenesis. In the Kyiv region, we propose to draw the boundary between the "transitional" and "pedogenic" models of magnetic record between the Dnipro Upland and the Polissia Lowland.

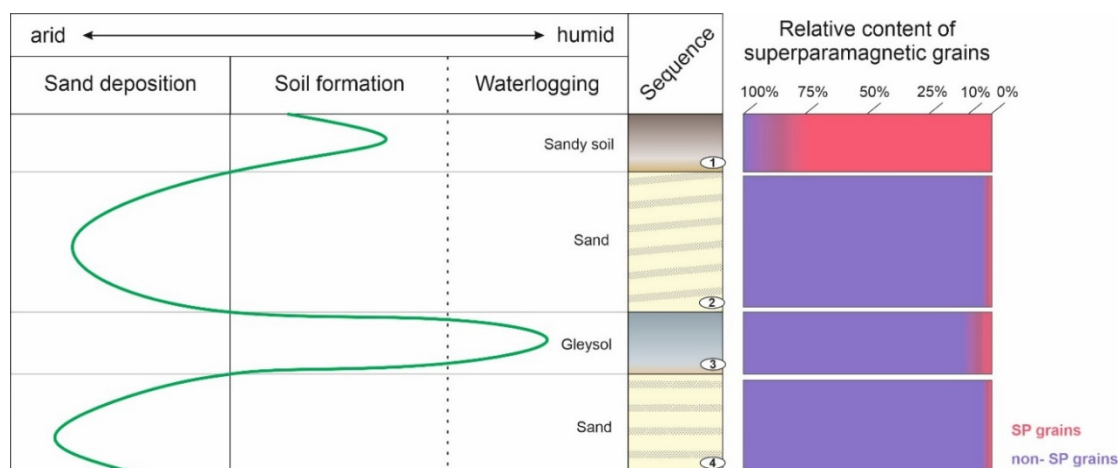


Рис. 4. Conceptual model of moisture dependent and magnetic granulometry transformation processes of sand sequence in the Irpin river valley. The concentration of superparamagnetic (SP) grains is estimated according to the Table 2.6 in Dearing (1999)

Authors' contribution: Dmytro Hlavatskyi – writing, investigation, formal analysis, conceptualization, field work, data curation, supervision; Viktor Yakukhno – validation, methodology.

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ПЕТРОМАГНІТНІ ДОСЛІДЖЕННЯ ПІСКІВ І ПІЩАНИХ ҐРУНТІВ КИЇВСЬКОГО ПОЛІССЯ

Вступ. Пізньоплейстоценові і голоценові відклади на території України традиційно детально досліджені магнітними методами, однак піски і піщані ґрунти вивчені недостатньо. Метою статті є надання петромагнітної характеристики пісків і піщаних ґрунтів півночі України – Київського Полісся.

Методи. Проводились польові роботи з відбором зразків із міні-шурфів, стандартні лабораторні петромагнітні дослідження (Evans, & Heller, 2003; Maxbauer, Feinberg, & Fox, 2016).

Результати. Середні значення магнітної сприйнятливості розрізів Демидів і Озера коливаються в незначних межах ($1 - 10 \cdot 10^8 \text{ t}^3/\text{kg}$), підвищені значення спостерігаються у ґрунтових горизонтах порівняно з пісками. Високі значення частотно-залежної магнітної сприйнятливості гумусових горизонтів піщаних ґрунтів (11–13 %) вказують на наявність суперпарамагнітних зерен магнетиту, утворених унаслідок педогенних процесів. Параметр S теж вказує на домінацію магнетиту, однак для кривих залежності магнітної сприйнятливості від температури характерна точка Кюрі 675 °C і типовий гематитовий "хвіст". Величини SIRM та χ_{IRM} для пілонтних зразків вказують на їх залежність від концентрації феримагнітного матеріалу: підвищені значення спостерігаються у верхніх частинах розрізів (гумусових горизонтах ґрунтів), понижені – у пісках. Така поведінка петромагнітних властивостей пояснюється місцевими геоморфологічними умовами, слабшим впливом педогенних процесів і суттєвою дією процесів фізичного та хімічного вивітрювання.

Висновки. Піщані відклади Поліської низовини формувались в умовах "перехідної" моделі запису магнітних властивостей, яка притаманна також лесово-ґрунтовим відкладам Волинської височини. Встановлено чутливість магнітно-мінералогічних властивостей порід до місцевих кліматичних умов, а саме ступеня зволоження і підтоплення, які у випадку "перехідної" моделі зворотно корелюють із вмістом суперпарамагнітних зерен. Для Київського регіону класична педогенна модель магнітних властивостей (ріст вмісту магнетиту із ступенем педогенезу) спостерігається лише для лесово-ґрунтових розрізів Придніпровської височини.

Ключові слова: магнітна сприйнятливість, піщаний ґрунт, дерново-підзолистий ґрунт, магнітні мінерали, палеоклімат.

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