Contributions to Geophysics and Geodesy Vol. 39/1, 2009 (83–94)

Magnetic susceptibility record of loess/paleosol sequence: Case study from south-west Slovakia

Ondrej ĎURŽA[1], Pavel DLAPA[2]

[1] Department of Geochemistry, Faculty of Natural Sciences, Comenius University
Mlynská dolina, 842 15 Bratislava, Slovak Republic; e-mail: durza@fns.uniba.sk

[2] Department of Soil Science, Faculty of Natural Sciences,Comenius University
Mlynská dolina, 842 15 Bratislava, Slovak Republic; e-mail: dlapa@fns.uniba.sk

Abstract: The paper proposes a new method to distinguish between paleosols and glacial loess deposits. The aim of our study is to test whether magnetic susceptibility measurements can be used as proxies for determining the boundary between the loess and paleosol. The measurements show excellent correlation with occurrence of the horizons influenced with pedogenesis. These values are generally explained in terms of the greater concentrations of ultrafine ferrimagnetic minerals in the recent soils and paleosols. The observed relationship between the susceptibility and lithology follows the behavior observed on the Chinese Loess Plateau, which is the complete opposite of the pattern reported from Alaskan and Siberian loess deposits.

Key words: magnetic susceptibility, soil forming processes, loess-paleosol sequence, SW Slovakia

1. Introduction

Magnetic measurement techniques are widely used in present environmental studies *(Chaparro et al., 2004; Desenfant et al., 2004)*. Special attention is paid to determining the connections between different soil forming regimes (e.g. pedoenvironments) and types, properties and occurrence of Fe-oxides along the soil depths *(Maier and Scholger, 2004; Petrovský et al., 2004)*.

This question is particularly significant in applying the magnetic properties of soils to the detection of anthropogenic pollution *(Bityukova et al., 2000; Garcia-Sanchez and Alvarwez-Ayuso, 2003)*, as well as to paleoclimatic reconstructions based on susceptibility variations along loess/paleosol sequences *(Verosub et al., 1993; Matasova et al., 2001; Liu et al., 2004).*

"Soil memory" defined as an assemblage of persistent pedogenic solid-phase properties, storing the information about paleoenvironments *(Targulian and Sokolova, 1996)* plays an important role in understanding the geosystem history since 3000 million years ago, i.e. Precambrian. For the Quaternary, loess-paleosol sequences represent one of the most detailed terrestrial records of global and regional climate changes, in particular - glacial/interglacial cycles. For these sequences rock-magnetic properties, intensively studied over last decades, have proven to be a sensitive paleoclimate indicator. Paleoclimatic interpretation of the magnetic susceptibility values of the paleosols and sediments was based on the fact that soil formation is typically linked to enhanced concentration of fine and ultrafine magnetite/maghemite grains *(Heller and Evans, 1995)*, caused, probably by weathering, pedogenetic processes and bacteriological magnetite synthesis *(Maher and Thomson, 1992).* Magnetic measurements of the thick loess deposits in the Chinese loess plateau, first carried out by Heller and Liu (1982, 1984 in *Schellenberger et al., 2003*) and followed by series of detailed studies *(Verosub et al., 1993; Spasov et al., 2003; Maher et al., 2003; Liu et al., 2004)* as well as in loess sequences of Tadschikistan *(Forster and Heller, 1997)*, Siberia *(Matasova et al., 2001)*, United States of America *(Geiss et al., 2004)*, Argentina *(Schellenberger et al., 2003)*, Bulgaria *(Jordanova and Petersen, 1999)*, Hungary *(Sartori et al., 1999)*, Czech Republic *(Šroubek et al., 1998)*, Poland and Ukraine *(Nawrocki et al., 1999).*

Magnetic properties of the Late Pleistocene loess-paleosol sequences in Slovakia can be regarded as one of the missing links to our understanding of the last glacial development of Europe. The purpose of this study is to measure and discuss magnetic susceptibility determined in Senec brickyard loess/paleosol sequence loess and fossil soil horizons (south-west Slovakia).

1.1. Soil magnetometry and loess-paleosol sequences

The magnetic properties of paleosol developed in Quaternary sequences of loess have been used for: stratigraphic definition; correlation with other terrestrial and deep-sea sequences and paleoclimatic (paleorainfall) reconstruction *(Tang et al., 2003).*

The major existing problem for deciphering and using the detailed climate record in loess/paleosol sequence is understanding the physical and chemical processes by which climate has controlled magnetic susceptibility. Most workers now conclude that pedogenic processes are responsible for most of the variations in magnetic susceptibility in loess/paleosol sequences. Studies published at the last century-end *(Banerjee and Jackson, 1996; Sartori et al., 1999)* showed that the enhancement of magnetic susceptibility in paleosols is associated with ferrimagnetic minerals produced during pedogenesis. Many such pedogenic grains are extremely fine-grained magnetic particles and called superparamagnetic (SP). The magnetization of superparamagnetic particles can align very quickly with an external magnetic field, giving them a high magnetic susceptibility. Mineral magnetic properties of loess/paleosol sequences are very sensitive indicators of climatic change *(Šroubek et al., 1998)*. Hence the paleosols, the concentrations of SP-sized grains, and the past extent of the summer monsoons are all linked.

The positive correlation between magnetic susceptibility and pedogenic degree or weathering intensity, observed in the loess-paleosol sequences from China and central Europe, has been widely used by Quaternary scientists for paleoclimatic studies. The in-situ pedogenic enhancement of ferromagnetic contents is normally believed to be the main reason for the increase of susceptibility in soil units. However, this pattern of high magnetic susceptibility in paleosols, and lower values in loess, is not replicated in some loess deposits. Alaskan and Siberian loess deposits display a completely opposite susceptibility behaviour: high values in loess and low values in paleosols. This inverse relationship has been explained by the idea that magnetic susceptibility is reflecting the magnitude of an aeolian ferromagnetic component of consistent mineralogy, the grain size of which is related to average wind velocity *(Liu et al., 2001)*.

Present knowledge indicates that there is a high percentage conversion of iron oxide to the ferromagnetic form and a concomitant high magnetic susceptibility in well-drained soils developed in regions with a climate that includes a pronounced hot dry period. It is, therefore, possible that magnetic susceptibility measurements could be used to identify those paleosols, for example, which were formed in warmer dryer climatic conditions than exist at the present time. In interpreting the magnetic susceptibility of soils it must, however, always be remembered that high percentage conversions can also be produced by burning associated either with the clearance of land for agriculture or with human habitation *(Tite and Linington, 1975).*

The true reason of varying magnetic susceptibility values is still not sufficiently cleared. Two theories exist to explain this pattern:

- Decrease of magnetic susceptibility values in loess sequences occurred as a result of dilution of ultra-fine magnetic particles constant supply originating from low susceptibility material. Maximal dilution should occur in this case during glacial periods, i.e. supply of low magnetic susceptibility material was dominant *(Evans and Walton, 1999; Jordanova and Petersen, 1999; Liu et al., 2004).*
- The most commonly accepted pedogenetical alternative states that the increase of magnetic susceptibility in paleosols is affecting by pedogenesis in situ during more humid and rather warm periods. Organic matter presence, good draining regime as well as the change of humid and arid conditions are supposed to support the bacterial detrital iron oxides reduction and ultra fine magnetite chemical precipitation during these periods *(Verosub et al., 1993; Matasova et al., 2001; Spassov et al., 2003).*

2. Materials and methods

The study area is located in the Senec brickyard (SW of Slovakia) (Fig. 1). Loess-paleosol profile is situated on the northern wall of the former brickyard which is more than 6 m high. Magnetic susceptibility measurement was performed in the field directly in the brickyard wall with 0.1 m interval. Soil samples were taken at 0.5 m interval for laboratory analyses. The samples were air-dried and passed through a 2 mm sieve before analysis.

The determinations of soil pH, total organic carbon content, and particle size distribution were made following standard methods *(Fiala, 1999).* Soil pH values were determined using a soil/solution ratio 1:2.5. Soil organic matter (SOM) content was determined by oxidation with $K_2Cr_2O_7-H_2SO_4$ and titration of non-reduced dichromate. Determination of calcium carbonate was based on carbonate decomposition by reaction with HCl which released CO_2. Carbon dioxide was then determined volumetrically.

There is a wide variety of methods available for the measurement of

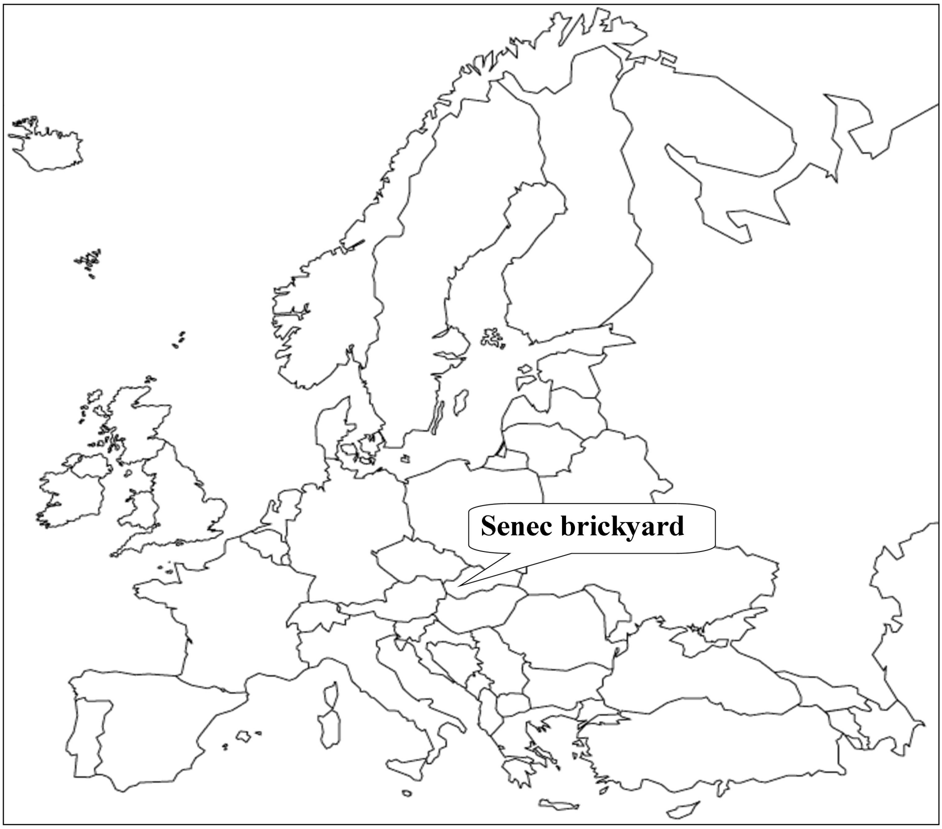

Fig. 1. The location of the loess profile.

magnetic susceptibility of which only a few are appropriate to soil studies. Microkappa KT-5 was applied for the field measurement of magnetic susceptibility (κ). All soil susceptibility values quoted in this article were measured in weak alternating fields at frequencies around 10 kHz.

The fundamental part of the instrument is an LC oscillator of 10 kHz. The frequency of the oscillator is measured with the coil at some distance from the soil (so called "free space" measurement) and then with the coil applied to the soil surface. From the frequency difference the apparent susceptibility is computed by the microcomputer and displayed in 10^{-3} SI units.

3. Results and discussion

3.1. Loess-paleosol sequence

In Czech Republic and Slovakia, the Pleistocene paleosols are normally pedocomplexes *(Smolíková, 1990)*. Pedocomplexes have been recently redefined by the Paleopedology commission of INQUA as comprising two or more soils (pedomembers), which are separated over large areas by thin, almost unmodified deposits or by a layer of calcareous nodules and are overlain or underlain by greater thickness of unmodified deposits or by unconformities *(Catt, 1998)*.

More than 6 m deep profile of loess-paleosol sequence is exposed for research on the northern wall of an abandoned brickyard at Senec. Well developed pedocomplex at the base of the profile (depth of 5.3–6.7 m) represents the Mindel/Ris (M/R) interglacial *(Šajgalík and Modlitba, 1983)* and corresponds to pedocomplex PKV according to *Smolíková (1990)*. *Bronger (2003)* correlates the pedocomplex PKV with the F5a paleosol at Mende near Budapest. This paleosol is correlated with δ^{18} O-substage 9c *(Bronger, 2003)* and dated to about 330 ka. M/R pedocomplex consists of two rubified paleosols with illuvial horizons developed under Mediterranean climate. Climate characterized by alternating of warm dry and warm moist periods is evidenced with Cochlodina fauna *(Šajgalík and Modlitba, 1983)*.

Superposed Riss sediments were not preserved as well as Early Würm (W) loess. There is a sharp boundary between rubified pedocomplex and overlying Würm2 (W_2) sediments. Würm sedimentation was interrupted during Würm2/Würm3 ($W_{2/3}$) interstadial. $W_{2/3}$ interstadial is represented by paleosol of brownearth type at depth of 3.9-4.3 cm, which is of initial character with frequent finds of carbon and is usually without or with a negligible content of conchylia *(Vaškovská, 1984)*. Interstadial corresponds to pedocomplex PKI according to *Smolíková (1990)* and to Stillfried B in Austria. *Zhu et al. (2001)* correlated the pedocomplex PKI with L1SS1 on the Chinese Loess Plateauand and dated between 24 and 57 ka. Pedocomplex L1SS1 is equivalent of δ^{18} O-stage 3.

Würm3 (W_3) stadial as the youngest Würm stadial is of the largest extension. It is represented by loess with thickness more than 3 m. The W_3 stadial loess is found below the recent soil (0.8–3.9 m). Its accumulation is interrupted by weak pedogenesis at depth 2.9–3.2 m, which indicates the subinterstadial and shows aggregation in thin sections *(Vaškovská, 1984)*. The loess of the upper subhorizon has high aleurite content (0.05–0.005 mm)–72%, of it coarse dust (0.05–0.01 mm) is 54%. The content of clayey particles (< 0.002 mm) is 15%. The loess has Md = 0.026, So = 1.9–2.1 and a high content of carbonates ($CaCO_3$ = 33–28%) and low humus content (0.18–0.25%). In the chemical composition of loess SiO_2 (50%), CaO (14%), and R_2O_3 (13%) dominate. Among clay minerals, montmorillonite and less illite were found *(Vaškovská, 1984)*.

In the upper part of the profile, the recent calcaric Haplic Chernozem is developed with mollic A horizon.

3.2. Magnetic susceptibility

The measured results in loess-paleosol complex of Senec brickyard demonstrate the indicative importance of magnetic susceptibility measurements (κ). The measured data of magnetic susceptibility (Table 1) plotted in Fig. 2 show a strong increase of magnetic susceptibility in soils compared to loess deposits. The highest values were recorded in recent Chernozem as well as in rubified pedocomplex. Lower values of magnetic susceptibility were measured in paleosol of brownearth type, which is in initial stage of development. The specific magnetic susceptibility values at loess-paleosol sequence positively correlate with the intensity of pedogenesis. Relative maximum tends to correspond mainly with paleosol horizons and relative minimum with loess layers. There is an absolute maximum of 0.96×10^{-3} SI u. in paleosol horizon at a depth of 6.2 m. In contrast, the loess layer is characterized by the lowest measured susceptibility of 0.17×10^{-3} SI u.

All studies of magnetic properties in Senec brickyard sediments so far revealed a pattern of high magnetic susceptibility in paleosol horizons and lower values in loess. Analogous relationships were found in the Chinese Loess Plateau *(Sun and Liu, 2000)* and Europe (Bulgaria - *Jordanova and Petersen, 1999*; Hungary - *Sartori et al., 1999*; Czech Republic - *Šroubek et al., 1998)*. Some authors, however, evidenced that the correlation of susceptibility data with paleoclimate is more complex. *Nawrocki et al. (1999)* investigated five loess-paleosol sections located in the Black Sea region, the western Ukraine and Poland where they observed distinct magnetic depletion or dilution in gley soils and leached horizons of podzols and brown

Table 1. Measured values of the magnetic susceptibility of Senec brickyard loess/paleosol sequence

depth (m)	pH/KCl	Cox (%)	$CaCO_3$ (%)	κ (10^{-3} SI u.)	depth (m)	pH/KCl	Cox (%)	$CaCO_3$ (%)	κ (10^{-3} SI u.)
0.1	7.20	0.9	6.4	0.96	3.9				0.28
1.2				0.18	4.0				0.26
1.3				0.21	4.1	7.83	0.2	12.0	0.27
1.4				0.21	4.2				0.28
1.5				0.23	4.3				0.29
1.6	7.81	0.2	24.8	0.22	4.4				0.25
1.7				0.23	4.5				0.22
1.8				0.25	4.6	7.86	0.2	17.0	0.23
1.9				0.24	4.7				0.26
2.0				0.24	4.8				0.23
2.1	7.85	0.1	23.0	0.21	4.9				0.23
2.2				0.22	5.0				0.26
2.3				0.22	5.1	7.83	0.2	14.8	0.24
2.4				0.25	5.2				0.26
2.5				0.23	5.3				0.61
2.6	7.77	0.2	19.0	0.23	5.4				0.78
2.7				0.23	5.5				0.77
2.8				0.22	5.6	7.57	0.2	4.0	0.70
2.9				0.21	5.7				0.62
3.0				0.23	5.8				0.62
3.1	7.89	0.2	21.8	0.22	5.9				0.69
3.2				0.17	6.0				0.93
3.3				0.20	6.1	7.44	0.2	3.2	0.94
3.4				0.22	6.2				0.96
3.5				0.21	6.3				0.77
3.6	7.90	0.2	23.4	0.23	6.4				0.74
3.7				0.24	6.5				0.55
3.8				0.22	6.6				0.53
					6.7	7.41	0.1	1.0	0.47

- loess (white)
- paleosol (grey)

pH/KCl - soil pH measured at soil:solution ratio of 1:2.5
Cox - organic carbon content
κ - magnetic susceptibility

type soils. Also the results of *Zhu et al. (2001)* indicated that the relationship between magnetic susceptibility and paleoprecipitation can be far from certain on the Chinese Loess Plateau. They explained lower magnetic susceptibility as a result of pedogenic hydromorphic processes affecting the iron minerals responsible for the susceptibility signal.

Regardless of the existing controversies in paleoclimatic interpretations at some loess sections there is a global significance of the magnetic suscepti-

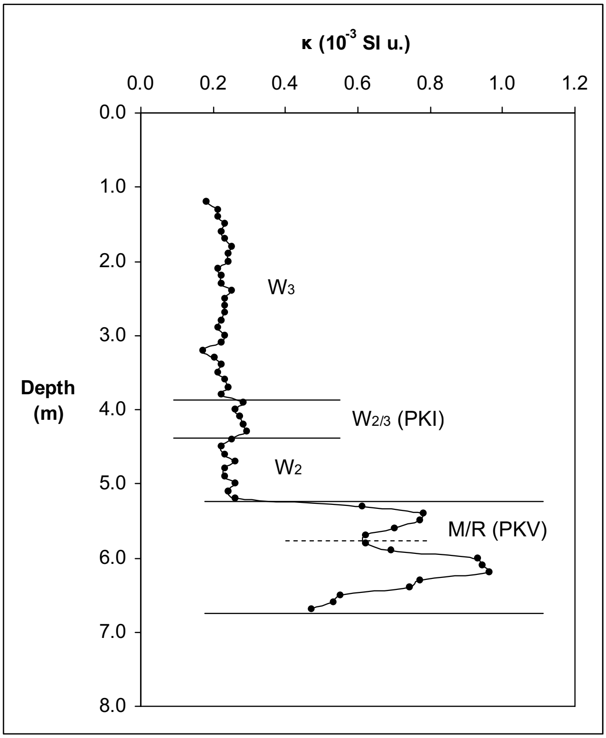

Fig. 2. Distribution of magnetic susceptibility values toward the depth.

bility in most of loess-paleosol sequences because of good similarity with the oxygen isotope fluctuation in deep sea sediments. The investigated loess-paleosol sequence in Senec brickyard does not consist of paleosols affected by hydromorphic processes or leached horizons and obtained results clearly demonstrate the increase of magnetic susceptibility with intensity of pedogenesis. Magnetic susceptibility measurement must be considered as an important diagnostic tool especially for paleosol horizons affected by progressive decomposition of soil organic matter with increasing age, making difficult to identify paleosol horizon as in the case of initial brownearth representing $W_{2/3}$ interstadial. Measurements in rubified pedocomplex from M/R interglacial are also of considerable importance, clearly indicating the strong pedogenesis and the sharp boundary between two paleosols where a thin layer of unmodified deposits is absent.

4. Conclusion

Variations in magnetic properties, such as the susceptibility, in loess/paleosol sequences have been widely recognised as a proxy indicator of Quaternary climatic evolution. However, the link between magnetic susceptibility and climate is not consistent, the magnetic susceptibility of paleosols is enhanced relative to the intervening loess due to the formation of ultrafine ferrimagnetic material during pedogenesis.

A strong contrast between the soil and loess susceptibility is present. The magnetic susceptibility signal follows the known behavior of Chinese Loess Plateau. Relative susceptibility minima tend to be associated with loess layers, whereas relative maxima correspond to paleosol. The underlying causes and mechanisms are still the subject of active debate.

Magnetic susceptibility measurements show excellent correlation with occurrence of the horizons influenced with pedogenesis. The elevated values of the magnetic susceptibility were observed in the recent A horizon of calcaric Haplic Chernozem and in paleosols. Magnetic susceptibility values are generally explained in terms of greater concentrations of ultrafine ferrimagnetic minerals, notably magnetite and maghemite, in the recent soils and paleosols. Two theories exist to explain this pattern. The first explained the vertical variations in terms of the dilution of a constant atmospheric influx of ultrafine magnetic particles by dust of small susceptibility blown from the loess source areas. The second, the most commonly accepted pedogenic alternative to the dilution mechanism, involves the in situ inorganic or biogenic formation of ultrafine ferrimagnetic minerals.

Acknowledgments. The authors are grateful to the Scientific Grant Agency of Ministry of Slovak Republic and Slovak Academy of Sciences for their financial support (grant VEGA 1/0476/09 and VEGA 1/0238/08).

References

Banerjee S. K., Jackson M., 1996: Wind-Borne Dust Holds Clues to Early Climate. Earth in Space, **8**, 8, 12–14.

Bityukova L., Shogenova A., Birke M., 2000: Urban geochemistry: A study of element distributions in the soils of Tallinn (Estonia). Environmental Geochemistry and Health, **22**, 173–193.

Bronger A., 2003: Correlation of loess-paleosol sequences in East and Central Asia with SE Central Europe: towards a continental Quaternary pedostratigraphy and paleoclimatic history. Quaternary International, **106-107**, 11–31.

Catt J. A., 1998: Report of Working Group on definitions used in paleopedology. Quaternary International, **51-52**, 84 p.

Chaparro M. A. E., Bidegain J. C., Sinito A. M., Jurado S. S., Gogorza C. S. G., 2004: Magnetic studies applied to different environments (soil and stream sediments) from a relatively polluted area in Buenos Aires Province, Argentina. Environmental Geology, **45**, 654–664.

Desenfant F., Petrovský E., Rochette P., 2004: Magnetic signature of industrial pollution of stream sediments and correlation with heavy metals: Case study from South France. Water, Air and Soil Polution, **152**, 297–312.

Evans T., Walton D., 1999: Environmental magnetism: two climatic models. CENT99, Session PPO1 – Poster Session V.

Fiala K. (ed.), 1999: Standard Methods of Soil Analyses. Soil Fertility Research Institute: Bratislava, 142 p. (in Slovak).

Forster T., Heller F., 1997: The process of magnetic enhancement in loess sediments from Tajikistan, China and Hungary. Geophys. Res. Lett, **24**, 17–20.

Garcia-Sanchez A., Alvarez-Ayuso E., 2003: Arsenic in soils and waters and its relation to geology and mining activities (Salamanca Province, Spain). Journal of Geochemical Exploration, **80**, 1, 69–79.

Geiss C. E., Zanner C. W., Banerjee S. K., Joanna M., 2004: Signature of magnetic enhacement in a loessic soil in Nebraska, United States of America. Earth and Planetary Science Letters, **228**, 3-4, 355–367.

Heller F., Evans M. E., 1995: Loess magnetism. Review of Geophysics, **33**, 211–240.

Jordanova D., Petersen N., 1999: Paleoclimatic record from a loess-soil profile in northeastern Bulgaria-I. Geophysical Journal International, **138**, 2, 520–532.

Liu Q. S., Banerjee S. K., Jackson M. J., Chen F., Pan, Y., Zhu R., 2004: Determining the climatic boundary between the Chinese loess and paleosol: evidence from aelian coarse-grained magnetite. Geophysical Journal International, **156**, 2, 267–274.

Liu X. M., Hesse P., Begét J., Rolph T., 2001: Pedogenic destruction of ferrimagnetics in Alaskan Loess deposits. Australian Journal of Soil Research, **39**, 1, 99–115.

Maher B. A., Alekseev A., Alekseeva T., 2003: Magnetic mineralogy of soils across the Russian STAPPE: Climatic dependence of pedogenic magnetite formation. Paleography, Paleoclimatology, Paleoecology, **201**, 3-4, 321–341.

Maher B. A., Thomson R., 1992: Paleoclimatic significance of the mineral magnetic record of the Chinese loess and paleosols. Quaternary Research, **37**, 155–170.

Maier G., Scholger R., 2004: Demonstration of connection between pollutant dispersal and atmospheric boundary layers by use of magnetic susceptibility mapping, St. Jacob (Austria). Physics and Chemistry of the Earth, **29**, 13-14, 997–1009.

Matasova G., Petrovský E., Jordanova N., Zikina V., Kapička A., 2001: Magnetic study of Late Pleistocene loess/paleosol sections from Siberia: paleoenvironmental implications. Geophys. J. Int., **147**, 367–380.

Nawrocki J., Bakhmutov V., Bogucki A., Dolecki L., 1999: The Paleo- and Petromagnetic record in the Polish and Ukrainian Loess-Paleosol Sequences. Phys. Chem. Earth, **24**, 9, 773–777.

Petrovský E., Hulka Z., Kapička A., 2004: A new tool for in situ measurement of the vertical distribution of magnetic susceptibility in soils as basis for mapping deposited dust. Environmental Technology, **25**, 9, 1021–1029.

Sartori M., Heller F., Forster T., Borkovec M., Hammann, Vincent E., 1999: Magnetic properties of loess grain size fractions from the section at Paks (Hungary). Physics of the Earth and Planetary Interiors, **116**, 53–64.

Schellenberger A., Heller F., Veit H., 2003: Magnetostatigraphy and magnetic susceptibility of the Las Carreras loess-paleosol sequence in Valley de Tafi. Quaternary International, **106**, 159–167.

Smolíková L. 1990: Problems of paleopedology. In: Němeček J., Smolíková L., Kutílek M., (Eds.): Pedology and paleopedology. Academia Praha, 381–479 (in Czech).

Spassov S., Heller F., Evans M. E., Yue L. P., von Dobeneck T., 2003: A lock-in model for the complex Matuzama-Brunhes boundary record of the loess/paleosol sequence at Lingtai (Central Chinese Loess Plateau). Geophys. J. Int. **155**, 350–366.

Šajgalík J., Modlitba I., 1983: Loess in Podunajská nížina lowland and its properties. Veda, Bratislava, 242 p. (in Slovak).

Šroubek P., Diehl J., Kadlec J., Valoch K., Heller F., 1998: Environmental/climatic study on clastic sediments deposited in Kulna cave, Czech Republic during the last glacial and interglacial. Geologica Carpathica, **49**, 3, 233–234.

Sun J., Liu T., 2000: Multiple origins and interpretations of the magnetic susceptibility signal in Chinese wind-blown sediments. Earth and Planetary Science Letters, **180**, 287–296.

Tang Y., Jia J., Xie X., 2003: Records of magnetic properties in Quaternary loess and its paleomagnetic significance: a brief review. Quaternary International, **108**, 33–50.

Targulian V. O., Sokolova T. A., 1996: Soil as a biotic/abiotic natural system: A reactor, memory and regulator of Biospheric Interactions. Eurasian Soil Science, **29**, 1, 30–38.

Tite M. S., Linington R. E., 1975: Effect of climate on magnetic susceptibility of soils. Nature, **256**, 565–566.

Vaškovská E. 1984: New stratigraphic subdivision and typology of soils of the Late Pleistocene in loess series of the Danube lowland in Czechoslovakia. In: Lithology and Stratigraphy of Loess and Paleosols, XI-th Congress of INQUA, Budapest 1984, 8 p.

Verosub K. L., Fine P., Singer M. J., TenPas J., 1993: Pedogenesis and paleoclimate: Interpretation of the magnetic susceptibility record of Chinese loess-paleosol sequences. Geology, **21**, 1011–1014.

Zhu R. X., Shi C. D., Suchy V., Zeman A., Guo B., Pan Y., 2001: Magnetic properties and paleoclimatic implications of loess-paleosol sequences of Czech Republic. Science in China (Series D), **44**, 5, 385–394.