Geological Quarterly, 2007, **51** (2): 161–166

Palaeomagnetic studies of the loess-palaeosol sequence from the Kolodiiv section (East Carpathian Foreland, Ukraine)

Jerzy NAWROCKI, Andrij BOGUCKYJ and Maria ŁANCZONT

Nawrocki J., Boguckyj A. and Łanczont M. (2007) — Palaeomagnetic studies of the loess-palaeosol sequence from the Kolodiiv section (East Carpathian Foreland, Ukraine). Geol. Quart., **51** (2): 161–166. Warszawa.

The Upper Pleistocene loess-palaeosol sequence from the Kolodiiv section (East Carpathian Foreland) has been palaeomagnetically studied. Almost all samples displayed moderate to high positive palaeomagnetic inclinations and declinations enclosed between 320° and 40°. However, one sample from the fossil soil of the last interglacial pedocomplex (at 16.6 m profile depth) was reverse magnetized and therefore can be correlated with the Blake Palaeomagnetic Event. Consequently that palaeosol can be related to (Oxygen Isotope Stage) OIS 5e1. Another sample from the Dubno 1 interstadial palaeosol demonstrated southern declination and significant lowering of inclination (up to 40°). This might be a record of the Laschamp Palaeomagnetic Event or of any Late Pleistocene palaeomagnetic excursion. The magnetic susceptibility and anhysteretic remanent magnetization data reflect the presence of several soils forming during the warm conditions of OIS 5 and the complex nature of the Eemian warming. Two palaeosols that developed between *ca.*115 ka and 120 ka indicate at least two climatic optima during the Eemian. High values of magnetic susceptibility (up to 300×10^{-6} SI units) noted in the middle of the section that contains slump deposits (9.5 m to 11m of depth) suggest that this material was derived from older soils of interglacial type.

Jerzy Nawrocki, Palaeomagnetic Laboratory, Polish Geological Institute, Rakowiecka 4, PL-00-975 Warszawa, Poland, e-mail:Jerzy.Nawrocki@pgi.gov.pl; Andrij Boguckyj, Department of Geography, Lvov University, Dorošenka 41, 790000 Lvov, Ukraine; Maria Łanczont, Department of Physical Geography and Palaeogeography, Maria Curie-Skłodowska University, al. Kraśnicka 2 CD, PL-20-718 Lublin, Poland, e-mail: lanczont@biotop.umcs.lublin.pl *(received: March 3, 2006; accepted: January 17, 2007*).

Key words: Western Ukraine, Kolodiiv, loess, Upper Pleistocene, palaeomagnetism.

INTRODUCTION

The concentration of magnetic minerals in sediments, expressed by magnetic susceptibility or other petromagnetic parameters, can reflect the climatic conditions in which they were deposited. The magnetic susceptibility patterns of loess-palaeosol sequences have been stratigraphically correlated with patterns of deep-sea sequences. On the Chinese loess plateau, magnetic susceptibility has been used for quantitative palaeorainfall reconstruction (Maher and Thompson, 1995). Preliminary petro- and palaeomagnetic studies of the Polish and Western Ukrainian loess-palaeosol sequences (Nawrocki *et al*., 1996; 1999) showed that the correlation of susceptibility data with palaeoclimate is more complex than for the Chinese sections. The major causes of the complexities are the relatively thin loess units and the diverse geochemical processes that affected loess surfaces during interglacials.

Within the Brunhes Chron several short inversions of geomagnetic field termed palaeomagnetic events have been detected (e.g. Tarling, 1983; Nowaczyk and Fredrichs, 1999). These horizons may serve as important chronostratigraphic tools. Up till now our studies of Western Ukrainian loesses has not revealed any well-documented record of palaeomagnetic inversion (event) apart from one detected in the Bojanice section (Nawrocki *et al*., 1999).

This study describes petro- and palaeomagnetic results from the Ukrainian Kolodiiv section, a relative thick loess-palaeosol sequence deposited during the last interglacial-glacial period.

GEOLOGICAL SETTING

The Kolodiiv 2 profile is situated in the central part of the East Carpathian Foreland (Fig. 1), on the NE margin of the Vojnylivsk Upland. The loess-soil sequence is underlain by fluvial deposits, which cover the Pleistocene terrace II of the Sivka River, a tributary of the Dniester River. The profile described

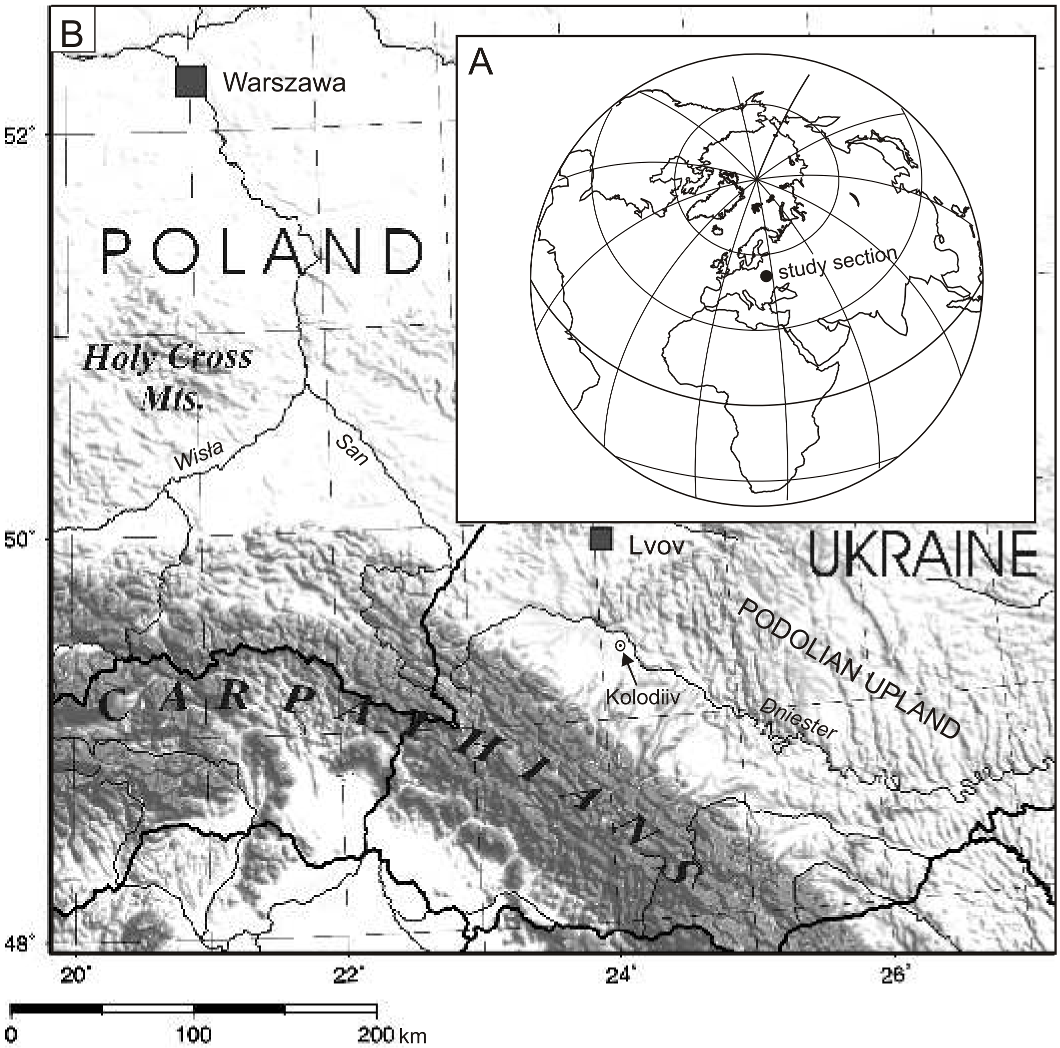


Fig. 1. Location maps (A — general World) and shadow relief (B) indicating the loess section studied at Kolodiiv

here belongs to a set of profiles, exposed along the almost 1 km long section of the high (>20 m) edge of the Sivka River terrace, which have been investigated in detail. These investigations have provide, important data concerning the conditions of accumulation and the stratigraphy of the Peri-Carpathian loess from the Last Glacial (Łanczont and Boguckyj, 2002). The Kolodiiv 2 profile contains a complete sequence of stratigraphically diverse deposits. Therefore, it has been selected for palaeomagnetic investigations and was sampled in 1999.

The Early Vistulian-Eemian (Oxygen Isotope Stage — OIS 5) set of palaeosols occurs at a depth of 13.5–19.1 m. It consists of three interstadial palaeosols, and a unique succession of two forest soils representing the Eemian Interglacial (OIS 5e). These interglacial soils are locally replaced horizontally by gyttja and peat, which formed in different parts of a fossil meander cut-off. An Eemian age for these organogenic deposits was supported by the results of pollen analysis (Demedyuk and Khrystoforova, 1975; Kalinovych, 2002).

The Kolodiiv 2 profile contains the following lithological horizons:

0–0.4 m. Humus layer, younger part of the Holocene soil.

0.4–1.8 m. Eet and Bt layers, older part of the Holocene soil.

1.8–2.3 m. Krasyliv layer, silty. Distinct lower boundary.

2.3–4.1 m. Sandy loess, weak, initial, gleyed Rivne (?) horizon with distinct lower boundary.

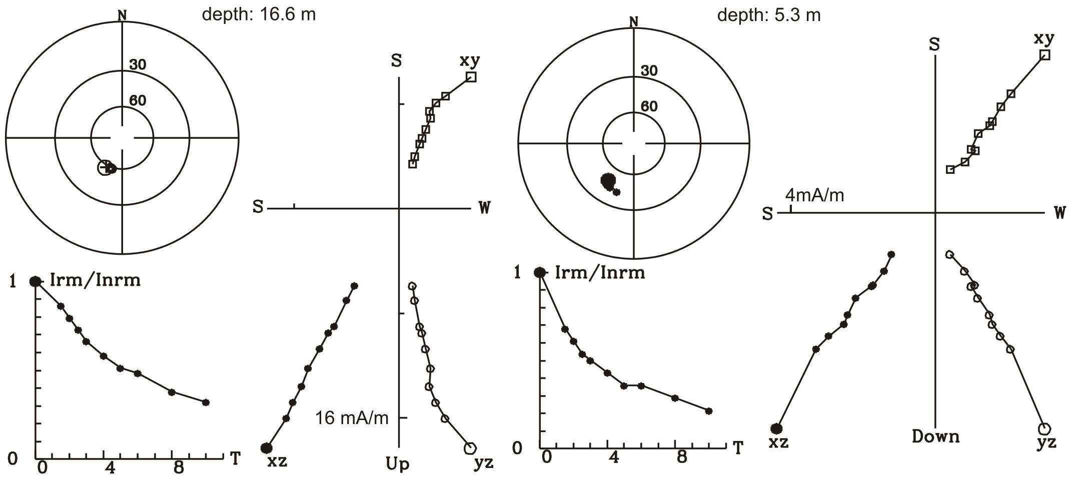
4.1–5.1 m. Sandy silt, gleyed, stratified, deformed by solifluction. Distinct lower boundary.

5.1–7.9 m. Set of 4 interstadial palaeosols representing the Dubno 1 palaeosol (i.e. the Dubno younger soil). Three upper palaeosols of subarctic brown gleyed type, the lowest of tundra gley type. Lower boundary sharp with undulose hardpan up to 1 cm thick.

7.9–10.9 m. Sandy-silty and loamy, stratified deposit, with distinct solifluction structures in the lower part, strongly gleyed. Boundary distinctly marked by a change in colour.

10.9–12.8 m. Set of 2 interstadial palaeosols of subarctic brown gleyed type, representing the Dubno 2 palaeosol (i.e. the Dubno older soil), separated by a series of fine- and medium-grained, stratified sands deformed by solifluction, which occur at a depth of 11.5– 12.0 m. The lower boundary is sharp, sinuous, of erosional origin.

12.8–13.5 m. Yellow-grey, silty sands with thin interlayers of pale grey, medium-grained sands.



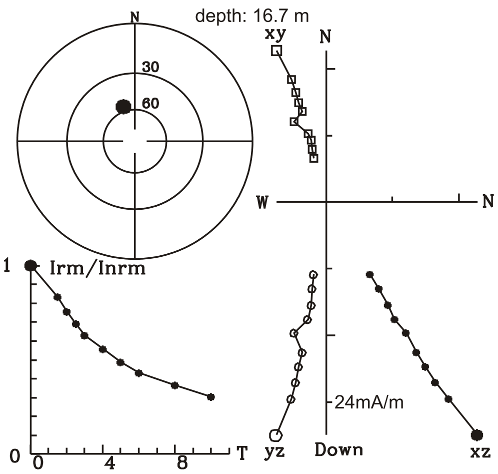


Fig. 2. Demagnetization characteristics (stereographic projections of directional tracks, intensity decay curves and orthogonal plots) of loess-palaeosol samples from the Kolodiiv section with reverse (16.6 m depth) and deviated (5.3 m depth) palaeomagnetic directions. The third sample (16.7 m depth) displays a typical Late Pleistocene normal polarity palaeomagnetic direction

Circles in the orthogonal plots represent vertical projections, squares represent horizontal projections. Irm — intensity of remanent magnetization, Inrm — initial intensity of natural remanent magnetization

13.5–14.1 m. Early Vistulian palaeosol Kolodiiv 1, truncated, represented by a sandy-loamy-silty B layer.

14.1–15.0 m. Early Vistulian palaeosol Kolodiiv 2, developed on sandy-loamy-silty material. Lower boundary distinct.

15.0–16.1 m. Interstadial humus layer of the Kolodiiv 3 palaeosol, stratified, sandy-loamy-silty, strongly deformed by deluvial processes.

16.1–17.0 m. Younger Eemian forest soil, loamy and loamy-silty, composed of Eet layer (0.2 m) and Bt layer (0.7 m). The bottom part of the Bt horizon is probably developed on material of the A horizon of the underlying interglacial soil.

17.0–19.1 m. Older Eemian forest soil, loamy and loamy-silty, composed of an Eet layer of variable thickness (0.6–1 m), and a Bt horizon also of variable thickness (1.1–1.5 m). Distinct lower boundary.

19.1–20.0 m. Beige-grey, stratified sands.

METHODS OF INVESTIGATION

193 oriented samples were taken from 19 m of loess-palaeosol deposits exposed in the Kolodiiv 2 section. One inch in diameter and 22 mm long samples were taken from fresh exposure walls by the means of a cylindrical steel sampler. Samples were collected at 10 cm and partly at 5 cm interval. The natural remanent magnetisation (NRM) was measured using *JR-5* spinner magnetometers. All samples were subjected to stepwise alternating field (AF) demagnetisation in fields of up to 100 mT. The AF demagnetisation and the ARM (anhisteretic remanent magnetization) acquisition experiment was conducted using Molspin devices. The magnetic susceptibility was measured by the means of a *KLY-2* bridge. Analyses of magnetic minerals were not performed for this particular section. Results of petromagnetic analyses of several other loess sections from Western Ukraine indicated the presence of magnetite and hematite in the loess layers, and additionally maghemite in the palaeosol horizons (Nawrocki *et al*., 1999, 2002).

RESULTS OF DEMAGNETIZATION

Stepwise AF demagnetisations displayed simple NRM behaviour with univectorial remanence after 20 mT of demagnetising field (Fig. 2). Distinct directional changes, probably associated with secular variations, were observed in all parts of the section studied (Fig. 3). One sample from the penultimate interglacial palaeosol shows a reversed palaeomagnetic direction. Another sample taken from the Dubno 1set of palaeosols (at 5.3 m depth) demonstrated a southern declination and a significant lowering of inclination (up to 40°). In some places changes of declination and inclination seem to have been very rapid. These shifts are most probably connected with stratigraphic gaps marked in Figure 3.

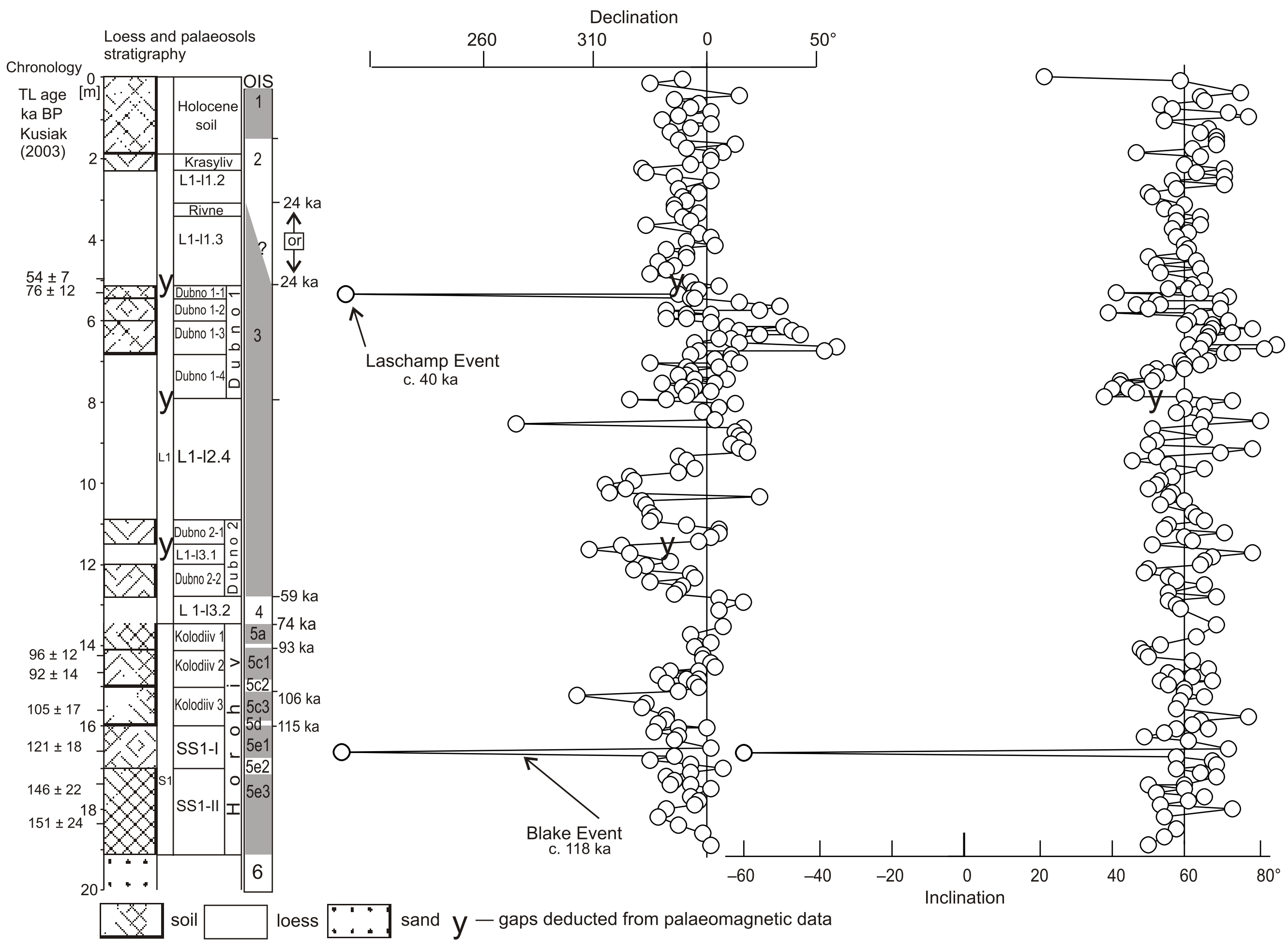


Fig. 3. Inclination and declination changes as a function of depth at the Kolodiiv section

Data are presented after stepwise demagnetization in fields of 0–100mT and calculation of palaeodirections as fitted lines (Kirschvink, 1980); near the stratigraphical column the subdivision of the section studied into the time equivalents of Oxygen Isotope Stages (OIS) is proposed

MAGNETIC SUSCEPTIBILITY AND ARM CHANGES

The ARM and magnetic susceptibility curves prepared for the entire sample set from Kolodiiv are very similar. The only differences can be observed in the lower parts of interglacial soils (OIS 1 and 5e3; see Fig. 4) where the ARM signal is not as distinctly elevated as are the magnetic susceptibility values. This is most probably connected with the notable contribution of paramagnetic and superparamagnetic fractions in this part of the section. This phenomenon has been observed earlier in some other loess sections from Western Ukraine (Nawrocki *et al.*, 1999). The ARM and magnetic susceptibility increase sharply in the Holocene soil and in the three soils developed during OIS 5 and have been correlated with substages 5c1, 5e1 and 5e3 (Fig. 4). It should be stressed, however, that unexpected high values of ARM and magnetic susceptibility occur also in the loess and slumped sediments from the middle part of the section. There are no elevated values in the samples from interstadial deposits correlate that with the Dubno 1 and Dubno 2 set of palaeosols.

DISCUSSION

The low-coercivity component of magnetization, common to the loess and soil deposits, does not provide any clustered palaeodirection. After removal of this soft component, loess and soil samples display the presence of a stable component that is not totally removed even in a field of 100 mT. This may indicate hematite as an important carrier of characteristic magnetization. In most samples the mean declination and inclination values (357° and 64°) of the stable component is the same as expected for normal polarity directions recorded during the Brunhes Chron. A reversed direction recorded in one sample from the Horohiv soil (Fig. 3) can be correlated with the Blake Palaeomagnetic Event. This event have been documented in several places worldwide. It is located in the 5d or 5e1 Oxygen Isotope Substages (see Parès *et al.*, 2004). In the section studied the reversed sample was taken from an interglacial palaeosol and therefore we correlate it with OIS 5e1. Consequently the oldest palaeosol from Kolodiiv is correlated with OIS 5e3.

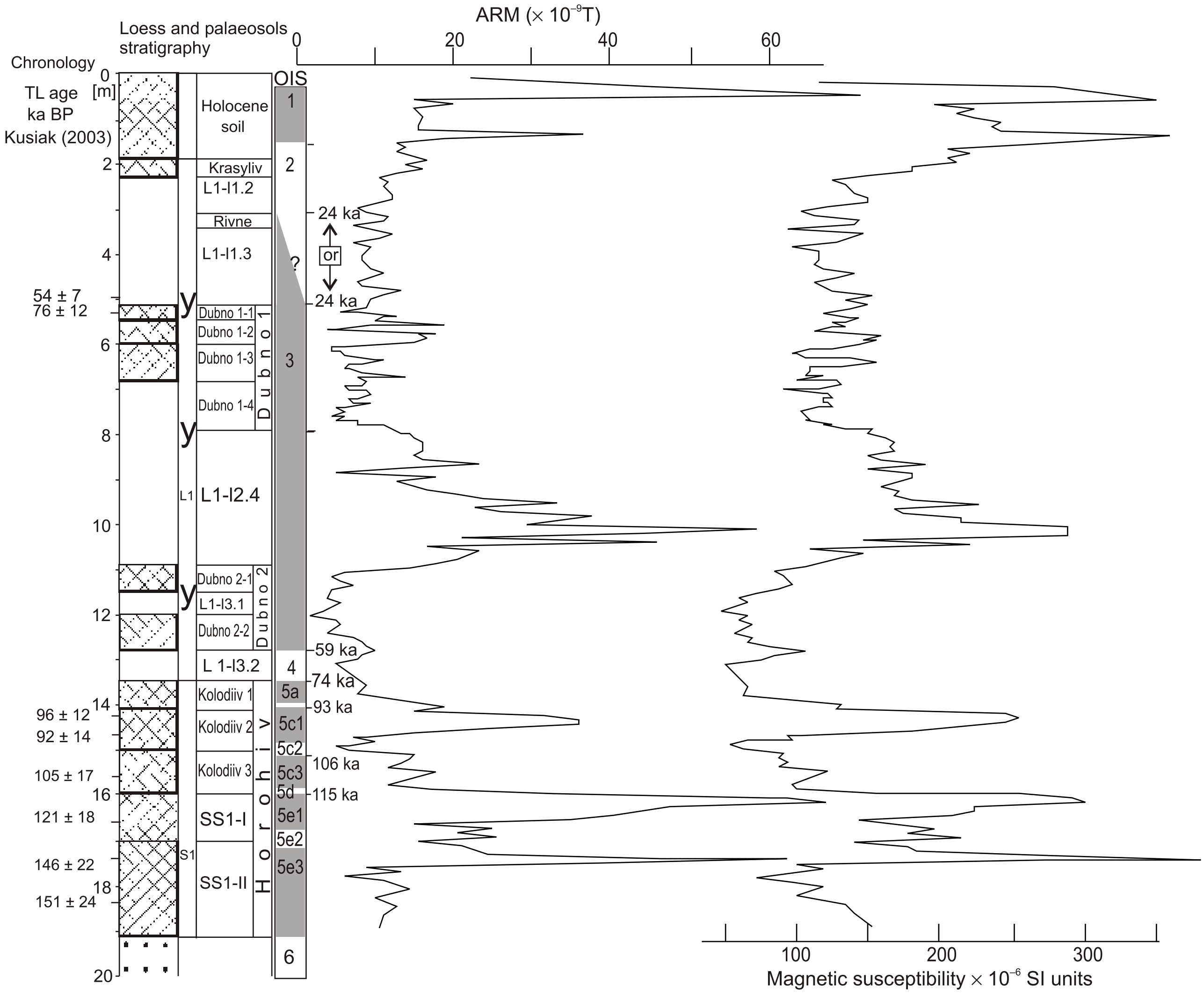


Fig. 4. Anhysteretic remnant magnetization (ARM) and low-field magnetic susceptibility changes as a function of depth at the Kolodiiv section

Explanations as in Figure 3

The abnormal palaeodirection with a southern declination noted in the Dubno 1 interstadial palaeosol may be correlated with the Laschamp Palaeomagnetic Event. Many studies of rocks containing a record of this event indicate that its age is about 40 ka (see e.g., Guillou *et al*., 2004). Hence the palaeosol Dubno 1-1 may have developed around 40 ka. However if we assume the presence of the Laschamp Event, the correlation of sediments that cover the Dubno 1 set of palaeosols is equivocal. They correspond to OIS 2 or partly also to OIS 3 (Fig. 3). That first solution implies a large (*ca*. 15 ka) gap between the Dubno 1 and the overlying loess or a different correlation of the abnormal palaeomagnetic direction (i.e. not with the Laschamp). The second possibility suggests loess sedimentation during the younger part of OIS 3, as observed in some sections in western Europe (see e.g., Frechen *et al*., 2001). We prefer the solution in which the abnormal palaeomagnetic record is not related to the Laschamp Event, and in which the Dubno 1 soil developed during the younger part of OIS 3. Six soils are enclosed in the Dubno1 and Dubno 2 sets of soils and this is generally in agreement with the number of climatic optima noted throughout OIS 3. The occurrence of a thick loess layer within OIS 3 deposits is a common feature in many loess-palaeosol sections (Heslop *et al*., 2000; Evans *et al*., 2003).

The magnetic susceptibility and anhysteretic remanent magnetization graphs have several maxima associated with higher contents of magnetic minerals. In loess sections this phenomenon occurs in places where interglacial soils were developed (Heller and Liu, 1984; Heller and Evans, 1995). Data from the Kolodiiv section imply the presence of several soils forming during the interglacial conditions of OIS 5 and show the complex nature of the Eemian warming. Two palaeosols, developed between *ca*.115 ka and 120 ka, indicate at least two climatic optima during the Eemian. However, high values of petromagnetic parameters (magnetic susceptibility up to 300×10^{-6} SI units) can be also observed in the middle part of the section containing loess and slumped deposits (9.5 m to 11m depth). This suggests that these sediments were derived from older soils of interglacial type, most probably from the Horohiv, soil unit where values of magnetic susceptibility and ARM are similar.

CONCLUSIONS

1. The Upper Pleistocene loess-palaeosol sequence from the Kolodiiv section shows mainly moderate to high positive palaeomagnetic inclinations and declinations enclosed between 320° and 40°, recorded during the normal polarity of the Brunhes Chron.

2. One sample from the fossil soil of the last interglacial soil succession (at 16.6 m depth) is reverse magnetized and therefore likely correlates with the Blake Palaeomagnetic Event. Consequently that palaeosol should be referred to OIS 5e1.

3. Another single sample from the Dubno 1 interstadial soil succession yielded a southern declination and a significant lowering of inclination (up to 40°). This might record traces of the Laschamp Palaeomagnetic Event or of any Late Pleistocene palaeomagnetic excursion.

4. The magnetic susceptibility and anhysteretic remanent magnetization data reflect the presence of several soils forming during the warm conditions of OIS 5 and show the complex nature of the Eemian warming. Two palaeosols, developed between *ca.*115 ka and 120 ka, indicate at least two climatic optima during the Eemian.

5. High values of magnetic susceptibility noted in the middle part of the section suggest that this material was derived from older soils of interglacial type.

Acknowledgements. We wish to thank Dr R. Dmytruk and Dr A. Jacyšyn for their help in the fieldwork, express our gratitude to Z. Jary and J. E. Mojski for revision of the manuscript.

REFERENCES

DEMEDYUK N. S. and KHRYSTOFOROVA T. F. (1975) — On the first finding of buried peat of the Mikulino period in the Forecarpathian area. Dopovidi AN URSR, seria B, **8**: 678–682.

EVANS M. E., RUTTER N. W., CATTO N., CHLACHULA J. and NYVLT D. (2003) — Magnetoclimatology: Teleconnection between the Siberian loess record and North Atlantic Heinrich events. Geology, **31** (6): 537–540.

FRECHEN M., VAN VLIET-LANOE B. and VAN DEN HAUTE P. (2001) — The Upper Pleistocene loess record at Harmignies/Belgium — high resolution terrestrial archive of climate forcing. Palaeogeogr., Palaeoclimat., Palaeoecol., **173**: 175–195.

GUILLOU H., SINGER B. S., LAJ C., KISSEL C., SCAILLET S. and JICHA B. R. (2004) — On the age of the Laschamp geomagnetic excursion. Earth Planet. Sc. Lett., **227**: 331–343.

HELLER F. and LIU T. S. (1984) — Magnetism of Chinese loess deposits. Geophys. J. R. astr. Soc., **77**: 125–141.

HELLER F. and EVANS M. E. (1995) — Loess magnetism. Rev. Geoph., **33**: 211–240.

HESLOP D., LANGEREIS C. G. and DEKKERS M. J. (2000) — A new astronomical timescale for the loess deposits of Northern China. Earth Planet. Sc. Lett., **184**: 125–139.

KALINOVYCH N. (2002) — Plant cover in the Carpathians foreland (Ukraine) during the last Interglacial epoch (in Polish with English summary). In: Starsza i środkowa epoka kamienna w Karpatach (ed. J. Gancarski): 9–15. Muzeum Podkarpackie. Krosno.

KIRSCHVINK J. L. (1980) — The least square line and plane and the analysis of paleomagnetic data. Geoph. J. R. Astron. Soc., **62**: 699–718.

ŁANCZONT M. and BOGUCKYJ A. (2002) — The examined loess sites in the Halyč Prydnistrov`ja region (in Polish with English summary). Stud. Geol. Pol., **119**: 33–181.

MAHER B. and THOMPSON R. (1999) — Palaeomonsoons I: the magnetic record of palaeoclimate in the terrestrial loess and palaeosol sequences. In: Ouaternary climates, environments and magnetism (eds. B. Maher and R. Thompson): 81–125. Cambridge Univ. Press.

NAWROCKI J., WÓJCIK A. and BOGUCKI A. (1996) — The magnetic susceptibility record in the Polish and western Ukrainian loess-palaeosol sequences conditioned by paleoclimate. Boreas, **25**: 161–169.

NAWROCKI J., BAKHMUTOV V. BOGUCKI A. and DOLECKI L. (1999) — The paleo- and petromagnetic record in the Polish and Ukrainian loess-paleosol sequences. Phys. Chem. Earth (A) **24**: 773–777.

NAWROCKI J., BOGUCKI A., ŁANCZONT M. and NOWACZYK N. R. (2002) — The Matuyama-Brunhes boundary and the nature of magnetic remanence acquisition in the loess-paleosol sequences from the western part of the East European Loess province. Palaeogeogr., Palaeoclimat., Palaeoecol., **188** (1–2): 39–50.

NOWACZYK N. R. and FREDERICHS T. W. (1999) — Geomagnetic events and relative palaeointensity variations during the past 300 ka as recorded in Kolbeinsey Ridge sediments, Iceland Sea: indication for a strongly variable geomagnetic field. Int. J. Earth Sc., **88**: 116–131.

PARÈS J. M., VAN DER VOO R. and YAN M. (2004) — After the dust settles: Why is the Blake Event imperfectly recorded in Chinese loess ? In: Timescales of the Paleomagnetic Field. Geoph. Monograph Ser., **145**: 191–2004. American Geophysical Union.

TARLING D. H. (1983) — Palaeomagnetism. Chapman and Hall. London.