Studia Quaternaria, vol. 19: 3–17.

PALAEOCLIMATE AND PEDOSEDIMENTARY RECONSTRUCTION OF A MIDDLE TO LATE PLEISTOCENE LOESS-PALAEOSOL SEQUENCE, PRYMORSKE, SW UKRAINE

Mark Stephens[1], Dariusz Krzyszkowski[2], Andriy Ivchenko[3], Marek Majewski[4]

[1] *Centre for Quaternary Research, Department of Geography, Royal Holloway, University of London, Egham, Surrey, TW20 0EX, UK, email: m.stephens@rhul.ac.uk*
[2] *7/8, Krucza, 53-408, Wroclaw, Poland*
[3] *Institute of Geography, National Academy of Sciences of Ukraine, 44, Volodymyrska, 01034, Kiev, Ukraine, email: ivchenko@geogr.freenet.kiev.ua*
[4] *Department of Quaternary Geomorphology and Geology, Institute of Geography, Pedagogical University of Słupsk, 27, Partyzantów, 76-200, Słupsk, Poland, email: majom@go2.pl*

Abstract

A new investigation and palaeoenvironmental reconstruction of the loess-palaeosol sequence at Prymorske, SW Ukraine is presented using soil structures, grain size, mineral magnetics, organic carbon and calcium carbonate determinations. Six units of the established Ukraine Quaternary stratigraphical scheme have been identified and analysed above and including the Zavadivka (Holsteinian) marker horizon – Dnieper, Kaidaky, Tiasmyn, Pryluky and Udai. Precipitation and temperature are tentatively reconstructed from soil and sedimentary proxies calibrated by modern analogues. Increased temperatures and precipitation to today are inferred for the red-brown Zavadivka palaeosol. Overlying Zavadivka is the Dnieper loess containing a gley and two chernozems above, possibly representing climatic variations of the Saalian Glaciation. The calcified chernozem Kaidaky is separated by a thin loess from the brown/chestnut Pryluky palaeosol (Eemian) which has features indicating drier conditions to the present. Non-gleyed palaeosols exhibit an enhanced magnetic susceptibility (MS) signal relative to the less weathered loess and highlights the palaeoclimatic potential of the technique. The most well developed palaeosol from this study has the highest MS value (Zavadivka: $80\cdot10^{-8}$ SI units) but this relationship is not always found in the Black Sea region. Previous MS analyses at Prymorske (Nawrocki *et al.* 1999) report significantly higher values to those of this study. Consequently the MS curve at Prymorske cannot be used with confidence for palaeoenvironmental reconstruction and inter-regional correlation without further investigation and modern analogue study.

Key words: Ukraine, Quaternary, loess, palaeosols, magnetic susceptibility

Manuscript received 15.03.2002, accepted 15.10.2002

INTRODUCTION

This study is part of a project designed by Dr. Dariusz Krzyszkowski to correlate the Middle Pleistocene stratigraphies of the glaciated regions of Poland, Belarus and northern Ukraine, with those of the non-glaciated regions of Ukraine and to correlate these with the ocean core records. The loess-palaeosol sequence at Prymorske represents a long period of time from the Brunhes/Matuyama (B/M) palaeomagnetic epoch boundary (*ca.* 780 ka BP) to the present Holocene, and is therefore an important site for the Quaternary stratigraphy of the Ukraine (Veklich *et al.* 1967).

This paper investigates a loess-palaeosol sequence exposed in a cliff section at Prymorske (45° 57' N, 30° 18' E), 20 km SW of the Dniester River (Fig. 1) and developed upon its VII terrace. The study site is within the Aral-Caspian-Black Sea aeolian province where the sediments grade westwards from sand to loess (Fig. 2), and the region is sensitive to climatic change and moisture variation at the southern margin of the Russian Plain. The winter climate is dominated by cold air masses with little precipitation and strong easterly winds controlled by the western extension of the Siberian-Mongolian high pressure system (Lydolph 1977). Associated with these winds are powerful dust storms occurring approximately once in a decade. They are derived from above the arid shores of the Caspian Sea in Middle Asia (Federovich 1960 – as cited by Rozycki 1991) (Fig. 2) depositing dust and humus from locally deflated soils as far as the eastern Polish border (Zinkiewicz 1950, Zhukov 1964 – both cited by Rozycki 1991). Precipitation (mean = 200–600

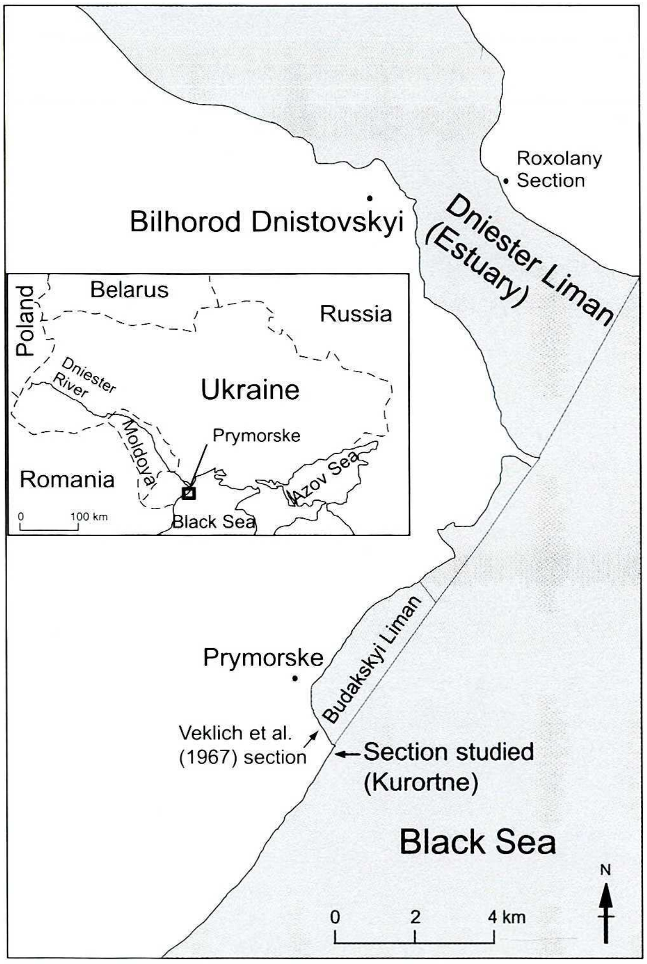


Fig. 1. Situation of Prymorske loess-palaeosol cliff section profile and that of Veklich *et al.* (1967) and neighbouring Roxolany profile (Tsatskin *et al.* 1998) (Map adapted from M.O.D. of Ukraine 1992). Ukraine and surrounding eastern Europe is shown as inset.

mm/yr) and temperatures (mean range = –3.4°C to 22.0°C/yr) (Ivchenko 1998) in the summer are dominantly influenced by temperate oceanic air masses which are an eastern extension of the Azores high-pressure system (Lydolph 1977).

This study will provide a detailed description of the properties of the loess and palaeosols in order to determine the past climate and environment of these periods. This includes the change from interglacial to glacial and back to interglacial conditions, and to provide a possible analogue scenario for future changes from the present day interglacial as described. Middle Pleistocene stratigraphies are often disturbed and truncated by ice sheet advances in Central Europe and so Prymorske could provide a high resolution record of climate changes with which to compare due to it lying south of previously glaciated areas. Magnetic susceptibility (MS) is thus used with the hope of long-distance correlations as has been applied in China (Kukla *et al.* 1988).

Quaternary stratigraphy of southern Ukraine

The southern Ukraine stratigraphical scheme for the Quaternary was proposed by Veklich and Sirenko (1976). The important stratigraphical marker horizon for this region is the well developed red-brown Zavadivka pedocomplex (Veklich *et al.* 1979) which has been TL dated between 440–340 ka BP and correlated with the Holsteinian interglacial of Western Europe (Gozhik *et al.* 1995). This is overlain by a thick Dnieper loess of the Dnieper Glaciation, correlated with the Saalian Glaciation (Gozhik 1995) and therefore ascribed OIS (= oxygen isotope stage) 8–6. Forming in the Dnieper loess is usually one or two chernozem horizons classified as Kaidaky (Veklich 1965). TL dates of *ca.* 230 ka BP have been obtained for Kaidaky (Gozhik *et al.* 1995) and it is therefore attributed to OIS 7. It should be noted, however, that in the previously glaciated regions of the Ukraine, the Kaidaky-Pryluky pedocomplex has recently been correlated with the climatic fluctuations of OIS 5 based on pollen successions (*e.g.* Gerasimenko 2000, Rousseau *et al.* 2001). This problem of interregional correlation is yet to be solved (Gozhik *et al.* 2001).

A thin Tiasmyn loess typically separates the Kaidaky and Pryluky soils. The Pryluky (can be brown/chestnut soil in southern Ukraine – Veklich, Sirenko 1976) has been TL dated at *ca.* 160–100 ka BP with older dates attributed to the age of the parent loess material that the soil formed in (Gozhik *et al.* 1995). The Pryluky is correlated with the Eemian/Last Interglacial (OIS 5e). Udai loess overlies this, which has 1–3 horizons of light brown, and reddish brown Vitachiv palaeosols formed within it. A thick Buh loess deposit occurs above the Vitachiv and from TL dating can be associated with the Last Glacial Maximum (OIS 2 – Gozhik *et al.* 1976). Above this are 1–2 Dofinivka palaeosols and a Prychornomoria loess representing climate variation of the Lateglacial period (*ca.* 13–10 ka BP). A Holocene chernozem soil is presently found at Prymorske.

Previous investigations at Prymorske

Veklich *et al.* (1967) investigated a profile at Prymorske, *ca.* 500 m NNW of our section (Fig. 1), and proposed fifteen Pleistocene stratigraphic units. The section was analysed using a range of techniques including pollen, grain size, $CaCO_3$ and the B/M boundary was found at the Martonosha horizon (Fig. 3). Steppe was found to be continuous (mostly *Chenopodiaceae*, *Graminae* and *Artemisia*) but proportions of steppe- forested elements changed according to palaeosol type. Clay contents were typically higher in the palaeosols, whereas $CaCO_3$ values varied for palaeosols and loesses.

In a section several hundred metres SSW to the one described here, Nawrocki *et al.* (1999) used magnetic characteristics and found relatively high susceptibility values typical for the chernozem, brown and red-brown interglacial palaeosols (up to $200 \cdot 10^{-8}$ SI units – see Fig. 3 caption * note), except for the Lubny horizon (Fig. 3). Surprisingly, however, the MS of the Lateglacial interstadial Dofinivka chernozem also exhibited a high signal ($140 \cdot 10^{-8}$ SI units) similar to the interglacial palaeosols. Nawrocki *et al.* (1999) therefore concluded that a simple palaeotemperature function for the MS signal was not possible and that rainfall could be of importance – a likely factor with the sensitivity of the site to climate and moisture fluctuation as already introduced.

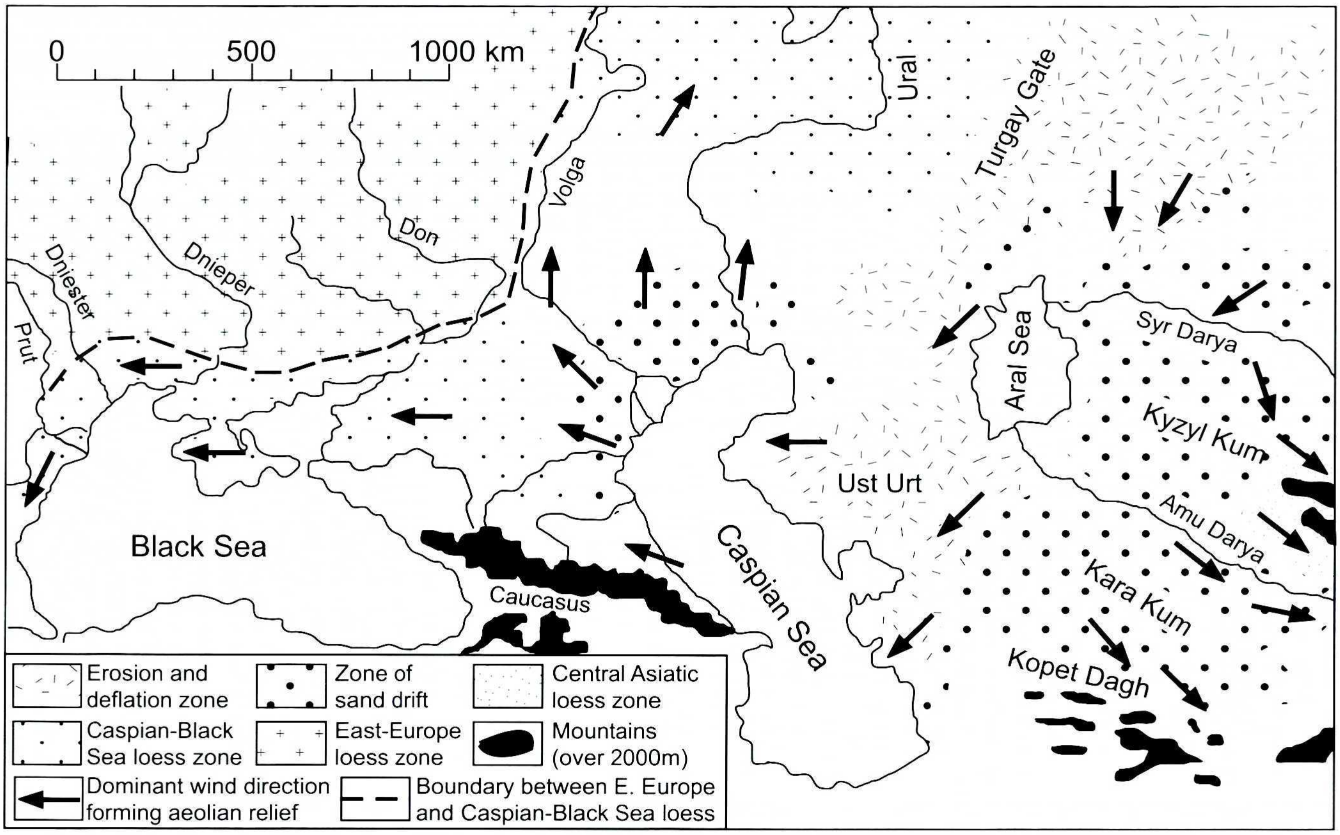
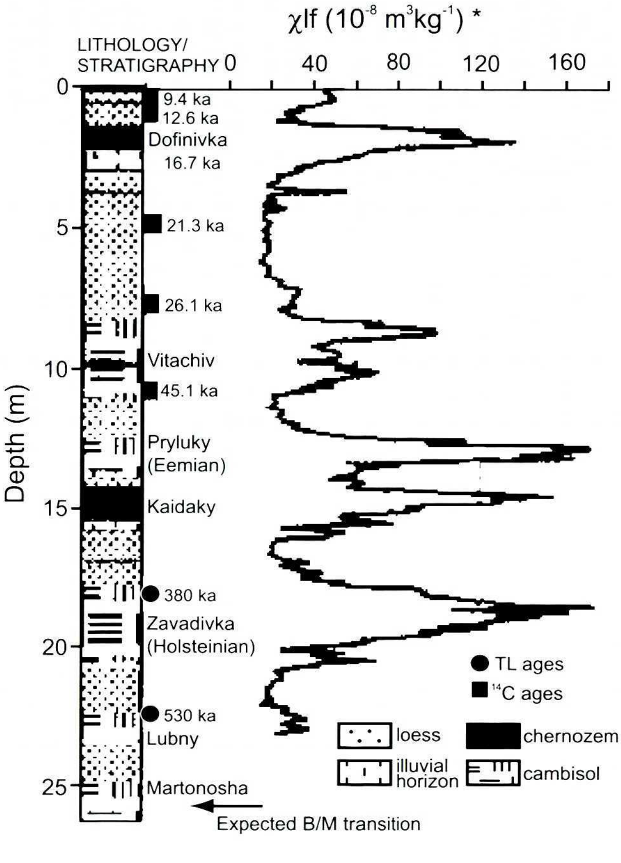


Fig. 2. Aral-Caspian-Black Sea aeolian province (modified from Rozycki 1991, after Federovich 1960).



Gozhik *et al.* (1976, 1995) used radiometric dating at Prymorske (Fig. 3) and correlated with other sequences in the Ukraine. There were, however, no detailed pedosedimentary descriptions published by Gozhik *et al.* (1995) or Nawrocki *et al.* (1999) from their analysed profiles at Prymorske, reducing the ease of correlation.

This paper therefore presents a new multi-proxy study of the sediments and soils at Prymorske based on magnetic susceptibility, grain size, calcium carbonate and organic carbon analyses. The aim is to achieve a better understanding of the pedosedimentary history and thus contribute to answering the research questions outlined above. The use of MS for palaeoenvironmental reconstruction and correlation in the Black Sea region will also be discussed.

Fig. 3. MS curve and lithology/palaeosol stratigraphy of a previously studied section at Prymorske (after Nawrocki *et al.* 1999). ^{14}C and TL ages are after Gozhik *et al.* (1995) and B/M transition after Veklich *et al.* (1967). * Original units quoted as "χ 10^{-6} SI units" by Nawrocki *et al.* (1999) appear incorrect when calibrating the results to our scale. For example, the Nawrocki's *et al.* (1999) Zavadivka MS (1800 10^{-6} SI units) would equal to 180000 (10^{-8} m^{3}kg^{-1}). We therefore assume their original data to be in 10^{-9} m^{3}kg^{-1}.

Fig. 4. Looking 320° NW at study site, Prymorske (12.06.00) (cliff face max. 28 m high), with sections numbered 1–6.

FIELD DESCRIPTION, SAMPLING STRATEGY AND LABORATORY ANALYSES

Six sections were cleaned manually, each at a different level and separated laterally (Fig. 4). 0 cm is taken as the top of the highest section sampled and does not represent the top of the cliff face that was inaccessible, 2.7 m above this point (Fig. 5).

The loess-palaeosol sequence was described in the field with respect to sedimentary structure, nature of boundaries, soil structure and dry colour (using a Munsell Soil Color chart) (Fig. 6). The presence of iron, manganese and calcium carbonate was also noted.

Sampling was carried out every 5 cm and was deemed sufficient to cover the variations present, but because of time available only every fourth sample (*i.e.* 20 cm resolution) was analysed except around areas of uncertainty where the finer resolution was used. Laboratory analyses of particle size, calcium carbonate content and magnetic susceptibility used the methodology of Gale and Hoare (1991); total organic carbon followed the procedure of the Soil Survey Laboratory Staff (1992). Low- (χlf), and high-frequency (χhf) magnetic susceptibility and frequency dependent (χfd) magnetic value were determined; with χfd being the percentage difference between low and high frequency using low frequency as 100%:

$$\chi fd = 100\,(\chi lf - \chi hf) / \chi lf.$$

In the laboratory all the samples used for magnetic susceptibility measurements were air-dried for 24 hours to prevent any moisture affecting the magnetic signal. Many of the samples were weakly cemented and so were gently disaggregated using a rubber pestle. To avoid particle movement during magnetic measurement cycles, clean clingfilm wrap was used to 'bed-down' any samples not filled to the top of the sample pots.

Prior to particle size analysis, dispersent solution was added and the sub-samples were shaken using a mechanical shaker and then placed in an ultrasonic bath for 20 minutes. The disaggregated sub-sample was then passed through a 63 μm sieve with the finer than 63 μm material analysed using a Micromeritics Sedigraph 5100. The fraction coarser than 63 μm was placed in an oven at 70°C until dry and then sieved using a Retsch mechanical shaker for 20 minutes. The material was subsequently weighed and result expressed as a fraction of the total sample weight. A replicate was taken for every fifteenth sample to test reproducibility of the method. Laboratory analysis results are presented in Fig. 7.

RESULTS

Site pedostratigraphy

Following the same criteria as Veklich *et al.* (1967) who previously defined the main stratigraphic units at Prymorske, we identified 10 units not including the Holocene topsoil (Fig. 5). Using the diagnostic Zavadivka (zv) marker horizon we assumed the loess and very reddened palaeosol below this to be Tylihul (tl) and Lubny (lb), respectively, with older ho-

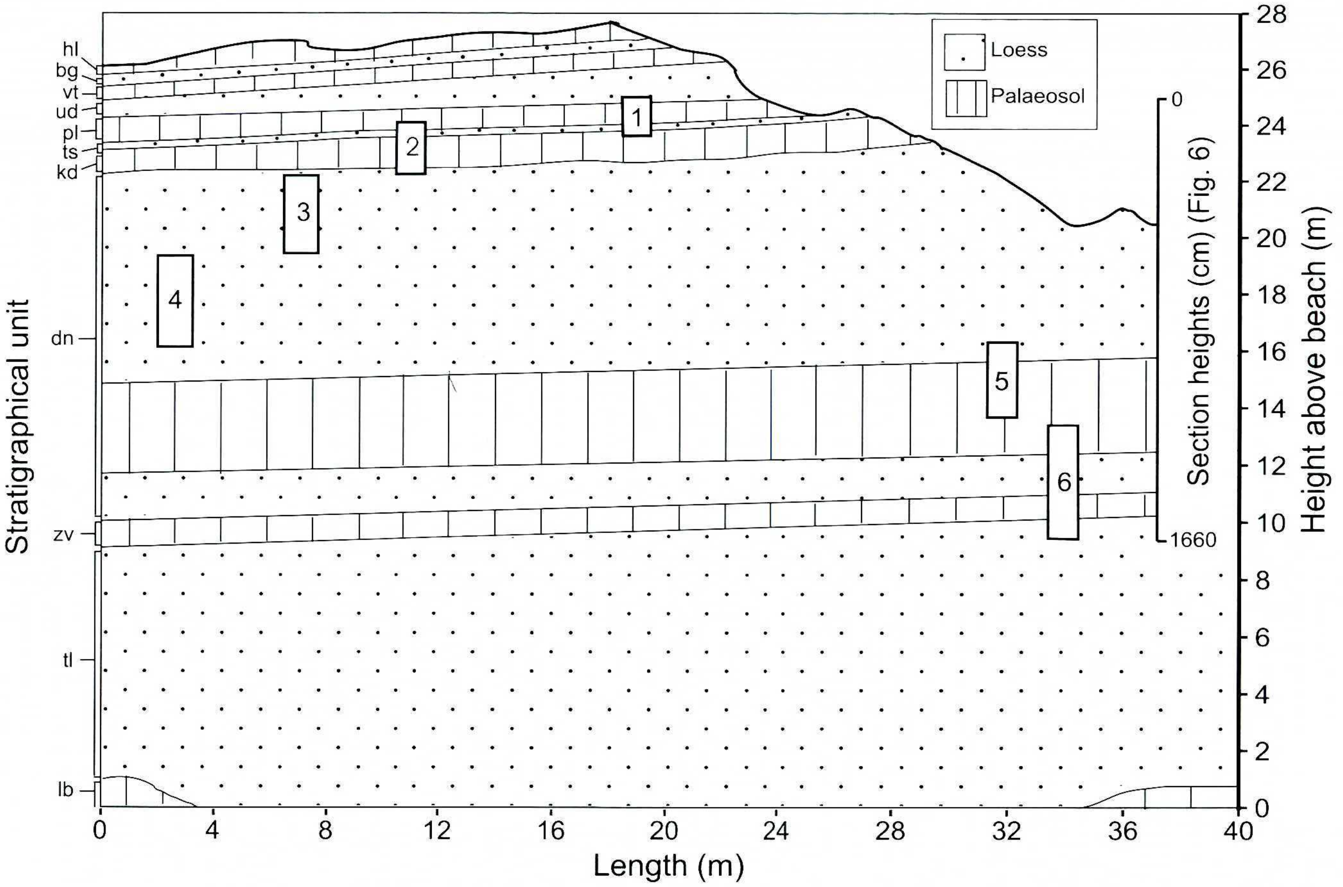


Fig. 5. Sketch of loess and palaeosol stratigraphy present at study site, Prymorske. Sampled sections are numbered 1–6. See *Site Pedostratigraphy* for justification of stratigraphical unit attribution.

rizons buried beneath the modern beach. Above the Zavadivka is a *ca.* 12 m thick loess deposit, and although much thicker than the deposit described by Veklich *et al.* (1967) this is stratigraphically above Zavadivka and so is classified as Dnieper (dn). Above the Dnieper loess are two palaeosols (chernozem and brown soil) separated by a thin loess layer (Fig. 5). Such palaeosols with a seemingly identical thin loess layer in between were correlated by Veklich *et al.* (1967) and Nawrocki *et al.* (1999) as the Kaidaky (kd) and Pryluky (pl) palaeosols separated by Tiasmyn (ts) loess. Another loess layer *ca.* 1 m thick, occurs above the possible Pryluky soil, and has a *ca.* 0.5 m thick light brown palaeosol developed in it. Veklich *et al.* (1967) described a similar *ca.* 1.5 m loess layer with brown soil horizons above and attributed this Udai (ud) loess and Vitachiv (vt) pedocomplex. In our profile a thin loess layer (*ca.* 0.5 m) separates this soil from the Holocene topsoil (Fig. 5). Veklich *et al.* (1967) noted a chernozem pedocomplex (assigned Dofinivka) occurring above this loess (*ca.* 6 m thick Buh (bg) loess) and beneath a bipartite Holocene chernozem soil with an associated Prychornomoria loess. As a result a significant hiatus is clearly present in our section. The "missing" layers, however, are possibly found in a section *ca.* 100 m NNE from our profile with three chernozems (the thickest being 0.5 m) separated by thin loess layers found below the present topsoil.

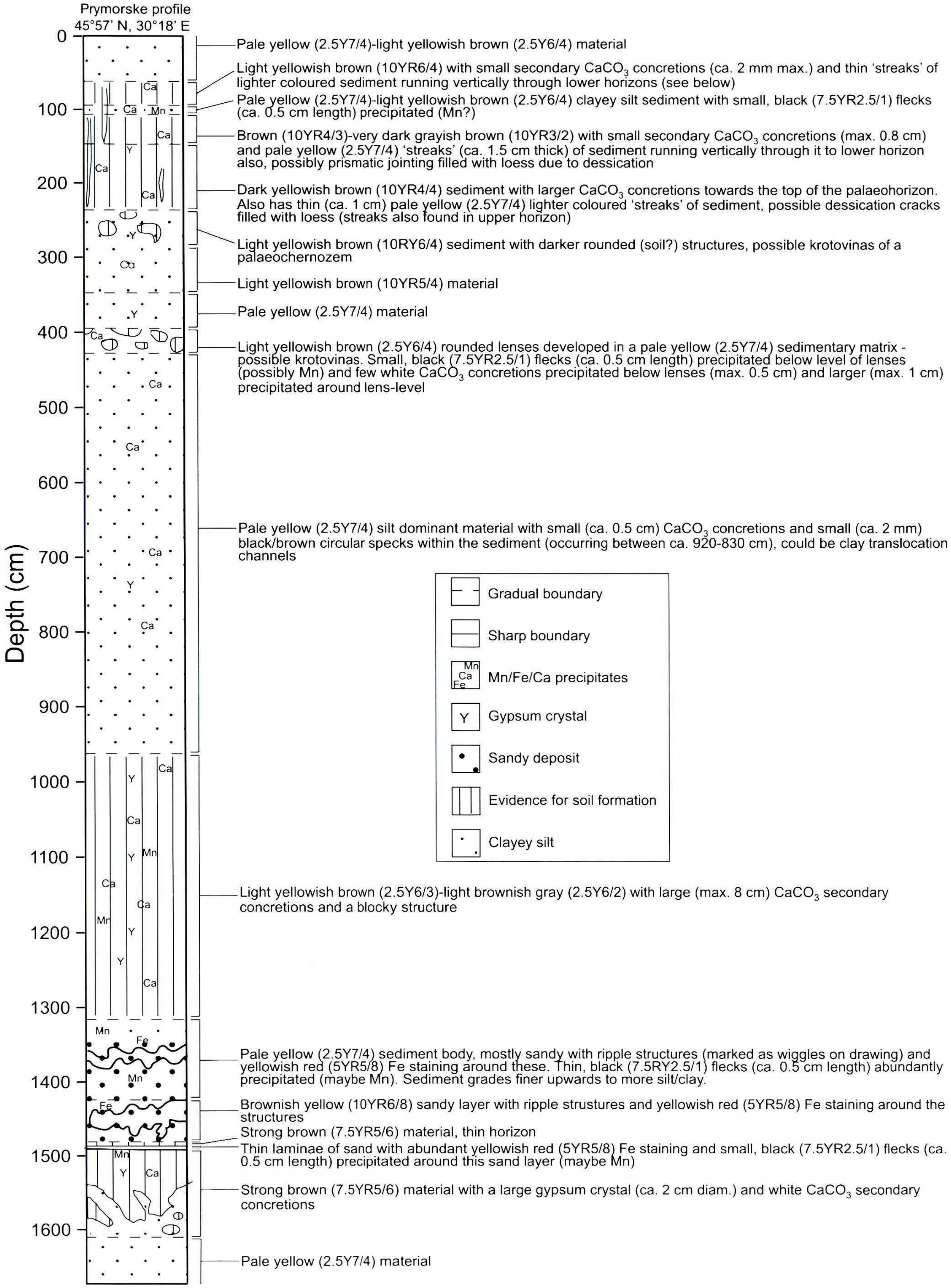
It should also be noted that the $CaCO_3$ curve of Veklich *et al.* (1967) is very similar to the one we present (Fig. 7), possibly indicating the correct attribution of stratigraphic units.

Pedosedimentary description and recognition of loess and palaeosols

Seven pedo-sedimentary units have been distinguished (Figs. 6 and 7). Each unit (apart from Unit 2) includes an upper palaeosol/pedogenic zone and an underlying loess, upon which the soil has developed. The definition of loess used here is that of a terrestrial, clastic sediment, composed predominantly of silt-sized particles and formed essentially by the accumulation of wind-blown dust (Pye 1995). Evidence for the mostly aeolian origin of loess in the Ukraine has been discussed by Veklich (1979) and as introduced the study site lies within the Aral-Caspian-Black Sea aeolian province which is still active (Fig. 2) (Rozycki 1991). The sections are described from the base upwards in terms of sedimentary deposition and soils described from the top of the soil/palaeosol downwards.

Unit 1 (1660–1490 cm)

Unit 1 is a silt dominant loess (becoming finer upwards, 79.6–52.1%), pale yellow (2.5Y7/4) up to 1615 cm where there is a diffuse transition to strong brown (7.5YR5/6) to the



Pale yellow (2.5Y7/4)-light yellowish brown (2.5Y6/4) material

Light yellowish brown (10YR6/4) with small secondary $CaCO_3$ concretions (ca. 2 mm max.) and thin 'streaks' of lighter coloured sediment running vertically through lower horizons (see below)

Pale yellow (2.5Y7/4)-light yellowish brown (2.5Y6/4) clayey silt sediment with small, black (7.5YR2.5/1) flecks (ca. 0.5 cm length) precipitated (Mn?)

Brown (10YR4/3)-very dark grayish brown (10YR3/2) with small secondary $CaCO_3$ concretions (max. 0.8 cm) and pale yellow (2.5Y7/4) 'streaks' (ca. 1.5 cm thick) of sediment running vertically through it to lower horizon also, possibly prismatic jointing filled with loess due to dessication

Dark yellowish brown (10YR4/4) sediment with larger $CaCO_3$ concretions towards the top of the palaeohorizon. Also has thin (ca. 1 cm) pale yellow (2.5Y7/4) lighter coloured 'streaks' of sediment, possible dessication cracks filled with loess (streaks also found in upper horizon)

Light yellowish brown (10RY6/4) sediment with darker rounded (soil?) structures, possible krotovinas of a palaeochernozem

Light yellowish brown (10YR5/4) material

Pale yellow (2.5Y7/4) material

Light yellowish brown (2.5Y6/4) rounded lenses developed in a pale yellow (2.5Y7/4) sedimentary matrix - possible krotovinas. Small, black (7.5YR2.5/1) flecks (ca. 0.5 cm length) precipitated below level of lenses (possibly Mn) and few white $CaCO_3$ concretions precipitated below lenses (max. 0.5 cm) and larger (max. 1 cm) precipitated around lens-level

Pale yellow (2.5Y7/4) silt dominant material with small (ca. 0.5 cm) $CaCO_3$ concretions and small (ca. 2 mm) black/brown circular specks within the sediment (occurring between ca. 920-830 cm), could be clay translocation channels

Light yellowish brown (2.5Y6/3)-light brownish gray (2.5Y6/2) with large (max. 8 cm) $CaCO_3$ secondary concretions and a blocky structure

Pale yellow (2.5Y7/4) sediment body, mostly sandy with ripple structures (marked as wiggles on drawing) and yellowish red (5YR5/8) Fe staining around these. Thin, black (7.5RY2.5/1) flecks (ca. 0.5 cm length) abundantly precipitated (maybe Mn). Sediment grades finer upwards to more silt/clay.

Brownish yellow (10YR6/8) sandy layer with ripple strustures and yellowish red (5YR5/8) Fe staining around the structures

Strong brown (7.5YR5/6) material, thin horizon

Thin laminae of sand with abundant yellowish red (5YR5/8) Fe staining and small, black (7.5YR2.5/1) flecks (ca. 0.5 cm length) precipitated around this sand layer (maybe Mn)

Strong brown (7.5YR5/6) material with a large gypsum crystal (ca. 2 cm diam.) and white $CaCO_3$ secondary concretions

Pale yellow (2.5Y7/4) material

Fig. 6. Pedosedimentary description of the 6 composite sections sampled at Prymorske.

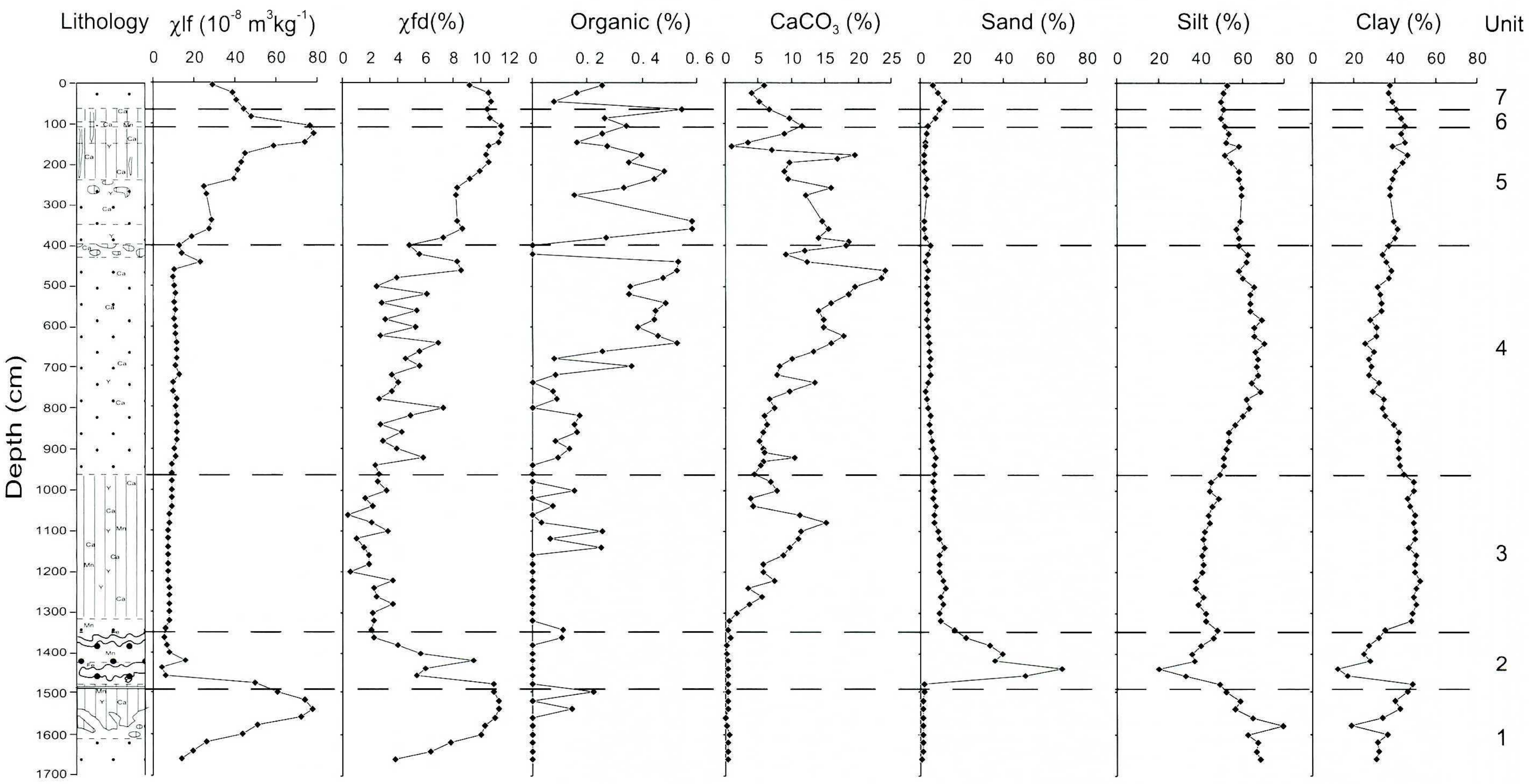


Fig. 7. Prymorske depth profiles of magnetic and particle size properties, organic carbon and calcium carbonate contents.

top of the unit at 1490 cm representing the Zavadivka palaeosol. The palaeosol is decalcified and is represented by a zone of decreased clay content (Eb horizon) above a zone of relatively high clay content (Bt horizon). Rounded bioturbation structures (B/C horizon) are also noted and at the top of the unit an increase of organic carbon (max. 0.2%). There is also a steep rise in magnetic susceptibility values from the loess in the lower part of the unit associated with the rubefication (max. 77.8 χlf (10^{-8} m^{3}kg^{-1}) at 1540 cm). In addition, χfd (%) values increase to 12% suggesting more than 75% frequency dependent ultrafine superparamagnetic (SP) grains in the bulk ferrimagnetic fraction (Dearing *et al.* 1997). A gypsum crystal (*ca.* 2 cm diameter) and secondary $CaCO_3$ concretions were also observed in this top part of the unit (Fig. 6).

Unit 2 (1490–1340 cm)

This unit is separated from Unit 1 by a sharp contact boundary overlain by a thin (*ca.* 3 cm) laminae of sand bounded by Fe and Mn precipitates. Overlying this, with another sharp contact boundary, is a thin (*ca.* 5 cm), strong brown (7.5YR5/6) layer that has a relatively high magnetic signal (49.4 χlf (10^{-8} m^{3}kg^{-1}), 10.9 χfd (%)) and clay content (48.8%). This is not a palaeosol as shown by the lack of horizonation, and the sharp boundaries. It is most probably the result of surface soil wash or wind deflation elsewhere, maybe associated with the underlying erosive layer, and deposited here as a thin layer. Overlying this from 1480–1340 cm is a brownish yellow (10YR6/8) sand with ripple bedding. This has the highest sand content of the profile (max. 67.9%) although this decreases to 21.9% at the top of the unit (1340 cm). The silt and clay contents display inverse trends (opposite to the sand) increasing to the top of the unit (max. 46.3%, 31.9%). Magnetic susceptibility is low apart from a small peak (15.5 χlf (10^{-8} m^{3}kg^{-1})) midway (1420 cm), also evident in the χfd, clay and silt curves. Organic carbon is absent apart from a small peak at the top of the unit (0.1%, 1360 cm).

Unit 3 (1340–980 cm)

This unit is separated from the unit below by a diffuse boundary with change to more pale yellow (2.5Y7/4) colour and silt content up to 1315 cm where there is a gradual change to a light yellowish brown (2.5Y6/3) – light brownish grey (2.5Y6/2) colour that extends for 335 cm to the top of the unit (980 cm). This is most likely the early Dnieper loess deposit above the Zavadivka palaeosol of Unit 1. The change in colour of this unit relates to the palaeosol developed within it with further evidence including a blocky structure, zones of decreased (min. 3.9% at 1020 cm) and increased (max. 15.2% at 1080 cm) $CaCO_3$, and large (max. 8 cm) $CaCO_3$ secondary concretions present throughout. There is also a zone of increased organic carbon content (max. 0.25%) towards the top of the unit (1140–1000 cm). There is however a very consistently low magnetic signal throughout Unit 3 (max. 7.3 χlf (10^{-8} m^{3}kg^{-1}), 3.2 χfd (%)). It is a silty clay dominant unit (max. 51.9% clay). Small gypsum shards were found at 1240 cm, 1200 cm, 1100 cm, and 1000 cm depths.

The properties described here suggest a deep gleyed soil, the grey colour (iron reduced to the ferrous state due to waterlogging), high clay content (max. 51.9% clay) increasing the impermeable nature of the horizon to hold water, and <5 χfd (%), typical of a periodically waterlogged soil (gley) (Dearing *et al.* 1996).

Unit 4 (980–395 cm)

A diffuse boundary separates this unit from Unit 3. From 980–440 cm is a pale yellow (2.5Y7/4) deposit dominated by silt content that increases to midway through the unit *ca.* 780 cm where it becomes more constant (max. 70.5% with not more than 12% deviation below this). There is a fairly constant but relatively low magnetic signal but has slightly more increased values than Unit 3 (9.0–10.5 χlf (10^{-8} m^{3}kg^{-1}), 2.4–7.2 χfd (%)). This is possible further Dnieper loess deposition that continues to the top (395 cm) where there are slightly darker in value, light yellowish brown (2.5Y6/4) lens-shaped structures (440–395 cm) developed in the pale yellow (2.5Y7/4) loess. From the description of Fitzpatrick (1986) these could be krotovinas formed in the A/C horizon of a chernozem (infilled burrows formed from activity of small vertebrates such as the blind mole rat (Fitzpatrick 1986)) and have a zone of increased $CaCO_3$ (max. 24.0% of the profile at 460 cm) below typical of the Ck horizon where there are also secondary concretions (max. 0.5 cm) and Mn precipitates present. At 440 cm there is an increased magnetic signal (23.3 χlf (10^{-8} m^{3}kg^{-1}), 8.3 χfd (%)) and a relatively large organic carbon peak (0.5%), all coinciding with the krotovinas described. This is possible evidence for bioturbation transporting material from the former A horizon.

Organic carbon exhibits a general increase from the bottom to the top of the unit to the relatively high values as mentioned. Larger $CaCO_3$ concretions (max. 1 cm) are precipitated at lens-level (*ca.* 420 cm) and small (*ca.* 2 mm) $CaCO_3$ secondary concretions occur throughout the rest of the unit. Small gypsum shards were found at a depth of 740 cm.

Unit 5 (395–110 cm)

This unit is separated from Unit 4 by a gradual boundary change to a pale yellow colour (2.5Y7/4) up to 280 cm and a clayey silt texture throughout the unit with very little sand (2.9–1.6%). This is further loess deposition with a well developed palaeosol formed within it (possibly the second Kaidaky chernozem, occurring above Dnieper loess in regional stratigraphy). Strong evidence for the recognition of this palaeosol (*ca.* 110–350 cm) is the marked horizonation. The first 40 cm down from the top of the unit is a brown (10YR4/3) to very dark greyish brown (10YR3/2) colour, gradually changing in chroma to a dark yellowish brown (10YR4/4) colour for the next 90 cm depth (also clayey texture throughout, A horizon), followed by rounded structures below this typical of krotovinas (A/C horizon) and changing to a light yellowish brown/pale yellow colour with secondary $CaCO_3$ concretions (Ck horizon). These are typical characteristics of a chernozem. The stepwise increase of the magnetic signal (from 19–78.1 χlf (10^{-8} m^{3}kg^{-1}), 7.3–11.5 χfd (%)) also seems typical for a soil with most increase in the upper layers (Maher 1998). In addition these magnetic values are the highest for the whole profile.

Organic carbon is relatively high and increases down-profile (0.2–0.6%). There is also a relatively high $CaCO_3$

content that exhibits a similar increasing trend down-profile. Pale yellow (2.5Y7/4) 'streaks' of sediment run vertically through the unit and small gypsum shards found at 275 cm and 155 cm depths. Secondary $CaCO_3$ concretions (max. 0.8 cm) are also found within the A-horizon of this palaeochernozem.

Unit 6 (110–65 cm)

Unit 6 is separated from Unit 5 by a gradual contact boundary. Above which is a pale yellow (2.5Y7/4-6/4) coloured sediment up to 95 cm where there is a change to light yellowish brown (10YR6/4) to the top of the unit at 65 cm. It is a clayey silt loess unit with both grain size parameters showing small decrease to the top of the unit (silt 51.7–50.8%, clay 44.6–40.4%). The colour change is associated with another palaeosol developed in a thin loess layer (Tiasmyn loess and Pryluky soil as suggested in the *Site Pedostratigraphy* section) and partly welded into that described for Unit 5. In addition to the colour change there is further evidence for pedogenic processes with a relatively high clay content, relatively high organic carbon content (max. 0.5%) that decreases sharply down profile, moderate magnetic signal (76.3–44.5 χlf(10^{-8} m^3kg^{-1}), 11.4–10.5 χfd (%)), $CaCO_3$ increasing down profile (6.7% to 11.5%) and Mn and $CaCO_3$ precipitates present. This horizonation suggests a B/Ck transition. The secondary $CaCO_3$ concretions present in the A-horizon of the underlying palaeochernozem described (Unit 5) could be due to mobilisation processes associated with this palaeosol. There is also a thin, pale yellow (2.5Y7/4) 'streak' running vertically through to the lower unit. Sand increases upwards from 3.8–8.9%.

Unit 7 (65–0 cm)

A gradual boundary separates Unit 6 from this pale yellow (2.5Y7/4) – light yellowish brown (2.5Y6/4) sediment body. Silt is the dominant grain size of this loess deposit and increases to the top of the unit from 49.5–53.0%. Clay content is also quite high (ave. 37.8%) with a decreasing sand content from 11.8–5.9%. The magnetic signal also decreases up unit (40.9–29.0 χlf(10^{-8} m^3kg^{-1}), 10.7–9.2 χfd (%)) but is still higher than that of Units 2, 3 and 4. Organic carbon content displays a small increase to the top of the unit (0.08–0.3%) as does $CaCO_3$ (4.0–5.9%) but of relatively low values.

DISCUSSION

Palaeometeorology

Figure 8 shows a probable scheme for air-mass dynamics influencing southern Ukraine climate during glacial and interglacial episodes. During glacial episodes it is suggested that cold winds blowing from the northern European Ice Sheet would partly block the penetration of the western air-mass transfer to the east. In turn, a strengthening of the Siberian-Mongolian high pressure system would occur in association with increased continentality due to a reduction of global sea levels. In essence there would be an intensification of present day winter conditions (as described in the *Introduction*) with mean increased easterly wind flow and strength, and deflation from the Aral and Caspian Sea arid lands (Fig. 2). A typical depositional environment would be of cold, dry, periglacial tundra with very sparse herbaceous vegetation on a rapidly aggrading landscape, trapping the wind borne material.

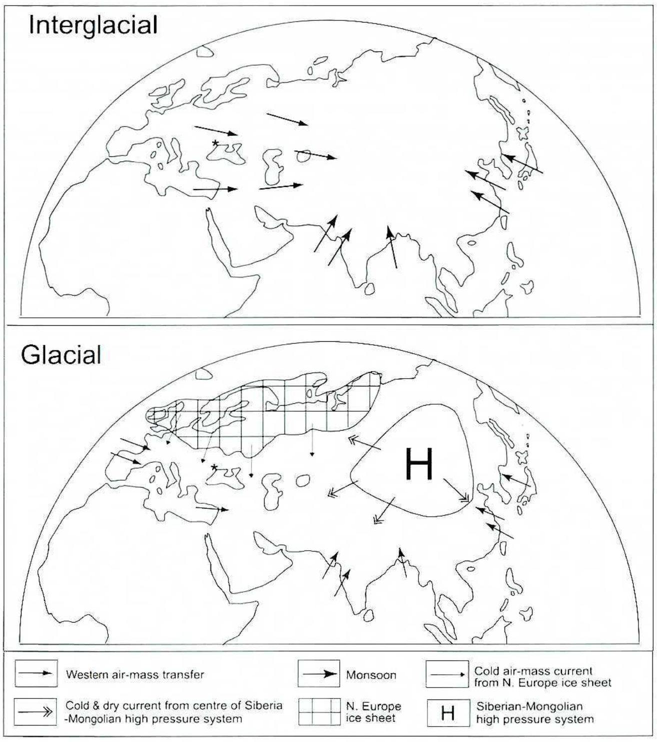


Fig. 8. Model of air-mass dynamics in Eurasia during interglacial and glacial episodes (modified from Dodonov, Baiguzina 1995). * indicates location of Prymorske.

In addition there would be a local influence of material being blown in from the exposed Black Sea shelf during glaciation (during the latest Quaternary glaciation there is evidence for the surface of the Black Sea to have been drawn down to levels more than 100 m below its outlet (Ryan *et al.* 1997)). This would consist of large exposed sandy beach plains and alluvial plains of rivers that flowed hundreds of km beyond their present mouths to shelf-edge deltas.

During interglacial periods there would be increased mean annual temperature and rainfall as a result of lower ice volume in the northern hemisphere and increasing influence of the westerly winds and local maritime influence from rising Black Sea levels. A more stable landscape would result allowing soil formation as at the present day.

Palaeoclimate and soil development

A suggested palaeoenvironmental reconstruction of events is presented in Fig. 9 with phase numbers given to add clarity to the discussion. The palaeoclimatic reconstruction uses a modern analogue approach for inferring past conditions from the observed relationships between present day soils and environments (Table 1). Although there are the obvious dangers of equifinality, the vegetation and soils of the Russian Plain and Ukraine have been shown to be strongly zonal with changes in accord to the fluctuating northern

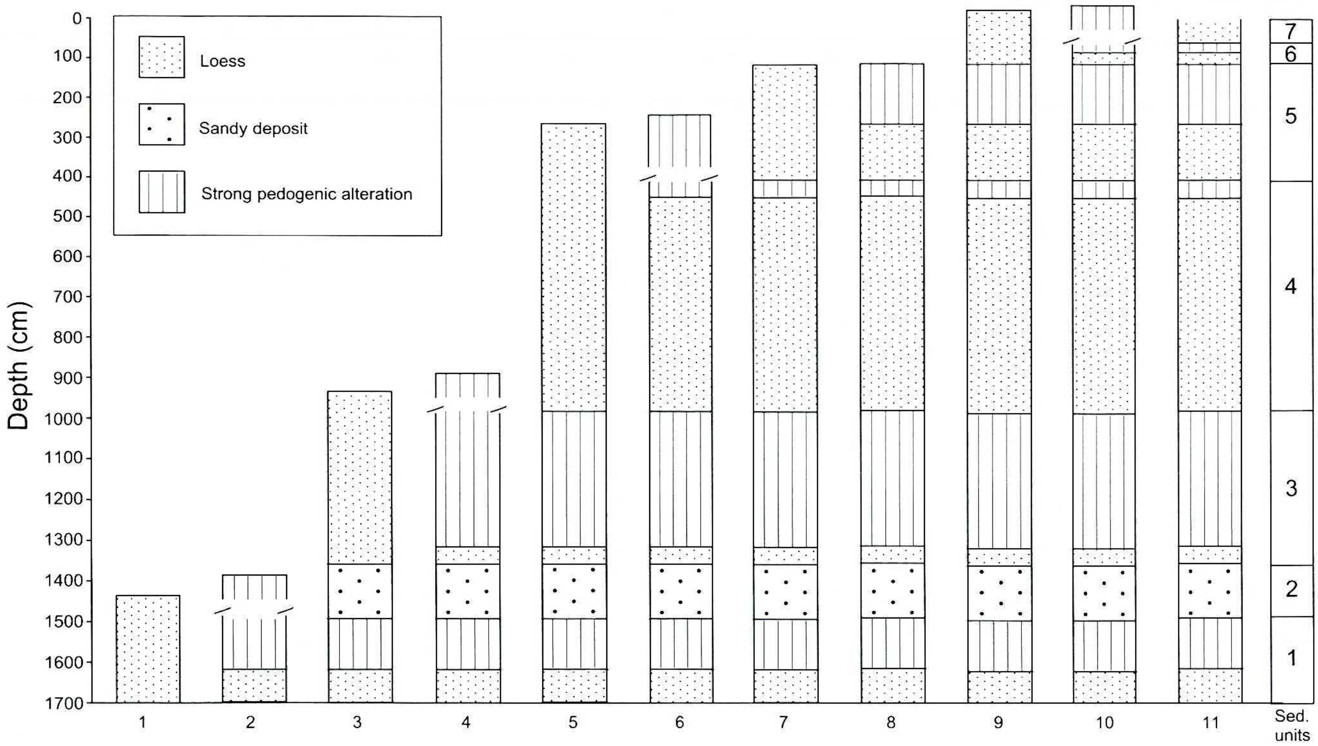


Fig. 9. Suggested palaeoenvironmental reconstruction of the loess-palaeosol sequence at Prymorske with phase numbers increasing with time to the present situation (Phase 11).

hemispheric ice sheets of the Quaternary (Velichko *et al.* 1984, Grichuk 1984). As a result there is a higher degree of confidence with matching palaeosols to present day soils.

Depth of maximum $CaCO_3$ concentrations is used to reconstruct leaching strength of precipitation for the particular soil type (Retallack 1990, 2000).

Unit 1 – Loess deposition and Zavadivka soil development

Phase 1 (Fig. 9) represents the accumulation of a *ca.* 9 m thick loess deposit (Fig. 5) that exhibits a progressive decrease in silt content possibly indicating reduction of wind strength towards a more stable landscape and the development of the palaeosol (Phase 2). The small sand content could be a reflection of the extent of regression of the Black Sea during glacial conditions with sandy beach material of the shallow Black Sea coastal plain being much further south than today. In addition, southerly winds are not expected to have been prominent. This is likely to be the Tylihul loess (see *Site Pedostratigraphy*).

Phase 2 of Unit 1 sees the development of a strong brown coloured soil within this loess. The red hue (rubefication) of this soil (7.5YR5/6), associated with hematite accumulation (Kemp 1985), occurs at the present day in Mediterranean climates (progressive desiccation during the dry season and leaching in the rainy season removing carbonates and eluviation of clay occurs when the soil is re-wetted) in fine-textured soils with low organic content and neutral pH (Yaalon 1997). Due to the fine-textured loess, the decalcified nature and possible evidence for clay eluviation, the rubefication in this diagnostic Zavadivka palaeosol at Prymorske is suggested to indicate a Mediterranean type environment although there are other possible factors such as diagenesis and duration of pedogenesis (Gale, Hoare 1991). The decalcified palaeosol suggests an increased mean annual precipitation to today, leaching the $CaCO_3$ to lower levels. Palynological work at Prymorske indicates increasing steppe-forest in this Zavadivka soil with deciduous forest species such as *Quercus*, *Fagus* and *Juglans* (Veklich *et al.* 1967) presumably due to increasing winter temperatures and moisture to today. The past climate is therefore suggested to have increased mean annual temperature and rainfall, probably due to an intensification of the present day summer climate with a lower ice volume in the northern hemisphere and increasing local maritime influence from the Black Sea, possibly at higher levels.

A gypsum crystal was also identified within Unit 1 and is a widespread soil component in semiarid and arid regions due to its solubility with precipitation as a consequence of water loss resulting from evapotranspiration (Zilberbrand 1995). This crystal is therefore likely to have formed in an increasingly drier climate than the one described above, possibly after this warm phase during climatic deterioration. It could also have been formed during Phase 1, associated with accretionary soil development.

Secondary carbonate precipitation at the top of Unit 1 could have been mobilised from an upper Zavadivka soil, since truncated and associated with the three welded Zavadivka soils noted at Prymorske by Veklich *et al.* (1967).

Table 1

Summary of palaeoclimate/palaeoenvironmental reconstruction as inferred from analytical data for Prymorske, SW Ukraine. Mean annual precipitation/temperature are reconstructed as inferred from soil and sedimentary properties and using modern analogues, with help from the values given in Money (1970)

Phase	Palaeoenvironment/palaeoclimate	M.A.P. (mm)	M.A.T. (°C)
11	Loess deposition in periglacial environment with strong wind flows, low vegetation cover. Low sea levels.	150–200	-10– -2
10	Brown/chestnut calcified soil in dry semiarid steppe, higher sea levels.	300–400	9–10
9	Loess deposition in periglacial environmental conditions with moderate-high wind speeds, low sea levels.	150–200	-5– -1
8	Calcified chernozem soil formation in semiarid steppe, high sea levels.	450–500	10–11
7	Loess deposition in periglacial environment with strong wind flows, low vegetation cover. Low sea levels.	150–200	-10– -2
6	Leached chernozem soil formation in subhumid steppe, high sea levels.	550–600	12–13
5	Loess deposition in periglacial environment with strong wind flows, low vegetation cover. Low sea levels.	150–200	-10– -2
4	Possible tundra gley formation, probable vegetation of low hardy grasses, sedges and herbs (could also be topographical feature – see *Discussion*)	200–250	-5– -1
3	Sand deposition at a time of low sea level followed by loess deposition in periglacial environment with strong wind flows, low vegetation cover.	150–200	-10– -2
2	Red-brown soil formation, decalcified, in Mediterranean-type climate, steppe-forest vegetation. High sea levels.	750–850	18–20
1	Loess deposition in periglacial environment with strong wind flows, low vegetation cover. Low sea levels.	150–200	-10– -2

Unit 2 – Sand deposition truncating Zavadivka

The initial deposit associated with Phase 3 is a thin layer of sand as an erosional surface that has truncated the underlying palaeosol and displays Fe and Mn staining, oxidising around the unconformity. Above this is a thin layer of washed- or blown-in soil and overlying this a thicker, sandy layer containing ripple structures. Occurring stratigraphically above the presumed interglacial soil, this could be evidence for landscape change in the form of river erosion and deposition, and aeolian sand transport and deposition that occurs from a temperate climate with extensive vegetation cover and soil development to a colder climate with less extensive vegetation cover (Rose *et al.* 1999). This is due to breakdown of vegetation cover and associated frost action in soils resulting in increased surface runoff and a ready supply of erodible/transportable material. This, in turn, results in the deep truncation of soils (maybe the first two welded Zavadivka soils), mass movement and river incision into stream channels with fan deposition and burial of the lowland soils as has maybe happened at Prymorske. The deteriorating climate and associated fall of sea level also has an effect with the creation of extensive sand plains with a ready supply of material to be transported across sparsely vegetated surfaces close to the coastal zone such as at Prymorske.

There could also be evidence for weak soil formation of Unit 2 with the mobilisation of iron and manganese oxide (abundantly precipitated) and small magnetic susceptibility and organic carbon peaks. These could also be factors of fluctuating ground water levels post-deposition. Due to inferred lower sea levels, however, the former explanation is preferred.

Unit 3 – Dnieper loess and gley soil formation

Phase 3 shows the initial deposition of loess that exhibits a relatively high but decreasing sand content and increasing silt that decreases at the top. In terms of palaeoenvironment this could suggest wind-blown sand from an adjacent exposed sandy plain left behind by regression of the Black Sea, progressively being stabilised by sparse vegetation cover. The increasing silt content maybe suggests a strengthening of the glacial period atmospheric system. Gypsum is also present, typical of dry conditions just interpreted.

According to the site stratigraphy this is the early part of the Dnieper loess. Subsequent to this loess deposition, there is pedogenic development with a deep, grey, gley soil forming (Phase 4, Fig. 9) at a time of possibly ameliorating conditions and improved landscape stability. This could be associated with a slight receding of the Saalian ice sheet over northern Eurasia and interstadial conditions in Central and Eastern Europe (*e.g.* Maruszczak 1987; Krzyszkowski, Nita 1995). In such a harsh environment as inferred the soil appears analogous to a tundra gley soil with cryogenic churning and aggregation (possible evidence for the lack of horizonation) and raw humus formation (small increase of organic carbon towards the top) (Gerasimova *et al.* 1996). The lower sub-soil remains permanently frozen with spring melt and summer precipitation (probably with an increased number of summer days due to the ameliorating conditions suggested) producing swamp anaerobic gleyed conditions and much low hardy grasses, sedges and herbs (Money 1970).

It should be noted, however, that such gleying can occur as a topographical feature and has not been noted in other profile descriptions from Prymorske. In addition, it is developed in a *ca.* 12 m thick Dnieper loess deposit that is *ca.* 9 m thicker than the Dnieper loess described in the neighbouring profiles of Veklich *et al.* (1967) and Nawrocki *et al.* (1999). This suggests a palaeodepression is present and that it could be a local feature although Bogucki *et al.* (2000) found a similar gley in early Dnieper loess in NW Ukraine. Further investigation of this unit is needed before correlation with climatic change. The large secondary $CaCO_3$ concretions present are attributed to leaching from a possibly highly calcareous loess above ($CaCO_3$ curve indicates such mobilisation, Fig. 7).

Unit 4 – Dnieper loess and leached chernozem development

The Phase 4 to 5 transition (Fig. 9) suggests a truncation of a thin black humic A-horizon of the gleyed soil (observed in-tact in an adjacent profile *ca.* 10 m to NNE) and overlain by a *ca.* 6 m thick deposit of loess (Phase 5). The loess has a rapidly increasing silt content that levels off towards the top of the unit and possibly associated with the dominant air masses of the glacial episode with decreasing wind strength over time depositing finer material. There may also be evidence for weak pedogenic activity in a rapidly aggrading landscape with the relatively high organic carbon content and small secondary $CaCO_3$ concretions present towards the top of the unit.

There is evidence for strong pedogenic activity associated with a more stable landscape at the end of Phase 5/beginning of Phase 6 with krotovinas present typical of a chernozem (possibly similar dry temperate climate with steppe vegetation as today). They are inferred as being truncated by the less weathered pale yellow (2.5Y7/4) loess above (Phase 7).

Unit 5 – Dnieper loess and Kaidaky soil development

Truncating the inferred chernozem (Unit 4, Phase 6) are strong winds associated with the loess deposition (Phase 7) in a glacial climate. Silt decreases to the top with a slight clay increase, possibly indicating, as with Phase 5, a reduction in wind strength, improved landscape stability with vegetation and a weathering horizon increasing clay content as evidenced with a second palaeochernozem (Phase 8) developed in the Dnieper loess, and assigned Kaidaky (see *Site Pedostratigraphy* section). There is a zone of increased $CaCO_3$ within the A-horizon, typical of the Russian chernozem (Bridges 1978) due to the mild leaching of spring following snow melt and summer evaporation concentrating the calcareous material. Due to the depth of maximum $CaCO_3$ concentration, it is deemed there was higher mean annual precipitation during the development of the previous palaeochernozem of Unit 4 (Phase 6). The palaeoclimatic reconstruction, like that for Phase 6 is deemed similar to the present day conditions, with more influence of the moister, westerly winds. This results in a reduction in continentality and increased temperatures allowing chernozem soils to form with their characteristic deep humus enriched A horizon with rich fauna, under a mostly steppe grassland with some forest vegetation (Veklich *et al.* 1967). It should be noted that there is a very low sand content possibly due to high sea levels and a reduced source of dry, sand-sized beach material for local aeolian transport.

Kaidaky is correlated with OIS 7 in the established scheme and the two palaeochernozems (interglacial characteristics) could correspond to the one or two interglacial palaeosols commonly reported elsewhere *e.g.* the Korshov pedocomplex of NW Ukraine (Bogucki *et al.* 1995, 2000) and the S_2 pedocomplex of China (Kukla 1987).

Gypsum and desiccation cracks filled with loess from above are present indicating dry conditions, probably becoming more pronounced in the transition period to the very dry conditions of loess deposition (Phase 9).

Unit 6 – Tiasmyn loess and Pryluky soil development

The loess deposition in Phase 9 is a relatively thin layer (45 cm) and the wind strength responsible for its deposition deemed not as strong as previous depositional phases due to the underlying A horizon of the palaeochernozem still being in-tact. There is an increase in sand content similar to the content associated with the cold period suggested for Dnieper loess deposition (Phase 3, Unit 3), possibly representing similar low sea levels and the implications for aeolian sand activity as discussed.

A truncated brown/chestnut soil has developed in this loess (Phase 10), suggested to be in response to similar ameliorations as discussed for Phases 2, 6 and 8. The soil is brown rather than black, suggesting less humus. The palaeovegetation inferred from this is short grasses in tussocky clumps. There are also relatively large desiccation cracks infilled with loess that run through to the palaeosol underneath. Further evidence for a dry environment is carbonate accumulation in the inferred B-horizon due to the strong upward movement of soil solution. These soils are found at the present day on the drier margins of the steppe zones in southeastern Ukraine (Money 1970). The relatively large organic carbon value is deemed misleading for this soil in comparison with values for the other palaeosols. The value is in fact still very low (0.5%) but is higher than that of the palaeochernozem and the rubefied palaeosol due to less decomposition over time (present day chernozem has 10% humus content at the surface (Bridges 1978). The lower magnetic signal of the brown/chestnut soil could also be evidence for a less moist environment and therefore lower mull humus production with a resultant decreased weathering production of ultrafine magnetic minerals.

The palaeoenvironmental reconstruction from Phase 10 represents the Pryluky palaeosol correlated with OIS 5e in the established stratigraphical scheme. Gerasimenko (2000) and Rousseau *et al.* (2001) also report Pryluky exhibiting drier conditions to the present from pollen evidence but attribute this to a later sub-stage of OIS 5.

Unit 7 – Udai loess

Loess deposition occurs stripping the typically *ca.* 25 cm A horizon (Bridges 1978) of the brown soil (Phase 10/11 transition) due to inferred high winds associated with a palaeoclimate and unstable landscape as described for Phases 1, 3, 5 and 7.

Magnetic susceptibility in the Black Sea region

Before the magnetic signal can be used for palaeoclimatic/palaeoenvironmental inferences and correlation there needs to be some understanding as to its process of formation. This problem is highlighted in the results presented here with a gleyed palaeosol exhibiting opposite magnetic properties to the other palaeosols with values less than the less weathered loess (due to dissolution of ferrimagnets – Maher 1998). Maher's (1998) suggestion, therefore, for interpretation of palaeosol magnetic properties to be done on a site-specific basis, has credence here. In addition, the possibilities of pedogenic enhancement, dilution or depletion, and allochthonous inputs of magnetic minerals must be considered.

The MS values for the three preserved B-horizons (for sake of comparison, although A/C transition value is used for the palaeochernozem) are: Red-brown palaeosol (phase 2) = ~80, Chernozem (phase 8) = ~45, Brown/chestnut palaeosol (phase 10) = ~45 (all $\cdot 10^{-8}$ SI units). When comparing these values with the inferred palaeoclimatic values (Table 1) there appears to be a straightforward link between the increased precipitation and temperature of the red-brown Zavadivka palaeosol creating improved soil forming conditions for pedogenic magnetic enhancement. There are of course other factors to consider such as possible dilution of the magnetic signal by $CaCO_3$ concentrations, and a possible allochthonous dust enhancement (this factor has, however, been discounted by the recent research of Maher (2002) in the Caucasus-Caspian region – the probable loess source area for Prymorske (Fig. 2)).

Maher (1998), from her study of modern soils, found that well drained, intermittently wet/dry soils, with reasonable buffering capacity showed most magnetic enhancement. It is therefore suggested that the drier conditions for soil formation in the chernozem and brown/chestnut palaeosols produced less pedogenic magnetic enhancement. The strong brown rubefied soil is inferred to have had more magnetite formation during periods of intermittent soil wetness and its oxidation to maghemite in subsequent dry periods. In addition, the recent research by Maher *et al.* (2002) found a dominant link between rainfall and MS using a transfer function of modern soils across a climate transect from the Caucasus to the Caspian region. A simple correlation of high MS with the most developed palaeosol is not always the case *e.g.* the well developed S_5 palaeosol in NE Bulgaria (Jordanova, Petersen 1999) and as already mentioned, the young interstadial Dofinivka palaeosol at Prymorske with unexpectedly high MS values (Nawrocki *et al.* 1999).

A further anomaly occurs at Prymorske with the high MS values for interglacial palaeosols (Zavadivka, Kaidaky, Pryluky) (Fig. 3) (Nawrocki *et al.* 1999) as compared to our values. Nawrocki *et al.* (1999) report values typically ~180 ($\cdot 10^{-8}$ SI units) which are more than double the ~80 ($\cdot 10^{-8}$ SI units) obtained in our research. These are the highest values recorded so far from palaeosols in the Black Sea region, with other values being typically ~90 ($\cdot 10^{-8}$ SI units) in NE Bulgaria (Jordanova, Petersen 1999) with a maximum of 125 ($\cdot 10^{-8}$ SI units) and typically ~50–60 ($\cdot 10^{-8}$ SI units) at Roxolany (Tsatskin *et al.* 1998) with a maximum of 95 ($\cdot 10^{-8}$ SI units). The absence of a detailed pedosedimentary description accompanying the MS results of Nawrocki *et al.* (1999) makes this difficult to explain. Possible explanations could be the good preservation of palaeosol A-horizons in the profile of Nawrocki *et al.* (1999) (highest MS always found in the top 40 cm of modern soils – Maher *et al.* 2002), or decalcification and the concentration of magnetic minerals.

CONCLUSIONS

The loess-palaeosol sequence at Prymorske provides detailed evidence of environmental and climatic changes with investigation covering a considerable Middle Pleistocene time period as inferred from correlation with the established Ukraine Quaternary stratigraphy. Using a multi-proxy pedosedimentary approach, a detailed reconstruction model of palaeoclimate/palaeoenvironment is presented. The reconstruction model is that of initial loess deposition typically truncating the previous landsurface in a cold, windy periglacial environment with low sea levels. The non-gleyed soils present are inferred to have formed in a stable landscape with vegetation cover at a time of high sea levels and decreased strength of the Siberian-Mongolian high pressure system allowing more influence of moist air from the west.

The red-brown Zavadivka marker horizon (Holsteinian interglacial) was identified and pedosedimentary evidence indicates increased temperatures and precipitation to today in a Mediterranean-like climate. A very thick Dnieper loess deposit overlies the Zavadivka containing a gley and chernozem palaeosols above, possibly representing climatic variations of the Saalian Glaciation (OIS 8-6). A thin loess separates this from a brown Pryluky palaeosol (Eemian, OIS 5e in Ukraine Quaternary stratigraphy) with features indicating drier conditions to the present day and more typical of a later sub-stage of OIS 5.

At Prymorske high MS values were found in non-gleyed palaeosols separated by low values in less-weathered loess. This indicates the potential for using the MS curve at Prymorske for palaeoclimatic reconstruction and correlation as has been done in China with marine oxygen isotope records. There doesn't appear, however, to be a clear correlation between the MS signal and degree of soil development in the Black Sea region and so further modelling of MS against modern parameters (*e.g.* Maher 2002) is needed. There is also a recommendation for detailed pedostratigraphic investigations accompanying MS analyses, especially important for the identification of hiatuses e.g. the chernozem of Unit 4 with only Ck horizon present and a resultant low MS signal.

As a result of these points, it is difficult to use the MS curve at Prymorske for inter-regional palaeoclimatic correlations and reconstructions, and especially so with the discrepancy of values in neighbouring profiles. Nevertheless, the results presented here should be of particular interest to future researchers of the loesses in the Black Sea region.

Acknowledgements

This study was funded with contributions from The Geologists' Association and Quaternary Research Association, UK, to Mark Stephens. This work is dedicated to Dr. Dariusz Krzyszkowski who was suddenly taken ill whilst attending the SEQS meeting in Bari, Italy, in the year 2000. Thanks are expressed to Prof. Jim Rose, Prof. Rob Kemp and Dr. Xingmin Meng (all RHUL) for useful comments and discussion, and especially to Prof. Jim Rose for his support and encouragement in the completion of this research. Gratitude is expressed to Adrian Palmer, Margaret Onwu and Jerry Lee for their help and advice in the laboratories of RHUL. Valuable comments and suggestions from an anonymous referee and Dr. Tomasz Goslar are greatly appreciated.

REFERENCES

Bogucki A., Maruszczak H., Nawrocki J. 1995. Stratigraphic and palaeogeographic interpretation of analysis results of magnetic susceptibility of loesses at Bojanice (NW Ukraine). *Annales UMCS* Sec. B 50, 51–64.

Bogucki A., Łanczont M., Racinowski R. 2000. Conditions and course of sedimentation of the Middle and Upper Pleistocene loesses in the Halič profile (NW Ukraine). *Studia Quaternaria* 17, 3–18.

Bridges E.M. 1978. *World Soils*. 2nd ed., Cambridge University Press, Cambridge, 128p.

Dearing J.A., Hay K.L., Baban S.M.J., Huddleston A.S., Wellington E.M.H., Loveland P.J. 1996. Magnetic susceptibility of soil: an evaluation of conflicting theories using a national data set. *Geophysical Journal International* 127, 728–734.

Dearing J.A., Bird P.M., Dann R J.L., Benjamin S.F. 1997. Secondary ferrimagnetic minerals in Welsh soils: a comparison of mineral magnetic detection methods and implications for mineral formation. *Geophysical Journal International* 130, 727–736.

Dodonov A.E., Baiguzina L.L. 1995. Loess stratigraphy of Central Asia: palaeoclimatic and palaeoenvironmental aspects. *Quaternary Science Reviews* 14, 707–720.

Federovich B.A. 1960. The question of the origin of loess in connection with conditions of loess spreading in Eurasia. Works of Institute of Geography of Academy of Sciences of SSSR 8 (Original: Voprosy proiskhozhdeniya lossa v sviazi s usloviyami yego rasprostraneniya v Yevrazii. *Trudy Instituta Geografii Akademii Nauk SSSR* 8) (in Russian).

Fitzpatrick E.A. 1986. *Soil Science: An introduction*. 2nd ed. Longman Scientific & Technical, Essex, 255p.

Gale S.J., Hoare P.G. 1991. *Quaternary Sediments: Petrographic Methods for the Study of Unlithified Rocks*. Belhaven Press, London, 323p.

Gerasimenko N.P. 2000. Late Pleistocene vegetational and soil evolution at the Kiev loess plain as recorded in the Stari Bezradychy section, Ukraine. *Studia Quaternaria* 17, 19–28.

Gerasimova M.I., Gubin S.V., Shoba S.A. 1996. *Soils of Russia and adjacent countries: geography and micromorphology*. Moscow-Wageningen, 204p.

Gozhik P. 1995. Glacial History of the Ukraine. In Ehlers J., Kozarski S., Gibbard P. (eds.), *Glacial Deposits in North-East Europe*. A.A. Balkema, Rotterdam, Brookfield.

Gozhik P., Chugunny V., Melnik V. 1976. Guide to VIII International Symposium on loessial rocks (original: Putevoditel VIII Mezhdunarodnogo simpoziuma po lessovym porodam). Institut Geologicheskikh Nauk AN USSR, Kiev, 71p (in Russian).

Gozhik P., Shelkoplyas V., Khristoforova T. 1995. Development stages of loessial and glacial formations in Ukraine (stratigraphy of loesses in Ukraine). *Annales UMCS* Sec. B 50, 65–74.

Gozhik P., Matviishina Zh., Shelkoplyas V., Palienko V., Rekovets L., Gerasimenko N., Korniets N. 2001. The Upper and Middle Pleistocene of Ukraine. *The Ukraine Quaternary Explored: the Middle and Upper Pleistocene of the Middle Dnieper Area and its importance for the East-West correlation. Volume of Abstracts*. Institute of Geological Sciences NASU, Kiev.

Grichuk V.P. 1984. Late Pleistocene vegetation history. In Velichko A.A. (ed.), *Late Quaternary Environments of the Soviet Union*, 155–179. Longman, London.

Ivchenko A.S. 1998. *Ukraine in brief*. Kiev, 72p.

Jordanova D., Petersen N. 1999. Palaeoclimatic record from a loess-soil profile in northeastern Bulgaria – I. Rock magnetic properties. *Geophysical Journal International* 138, 520–532.

Kemp R.A. 1985. The cause of redness in some buried and non-buried soils in Eastern England. *Journal of Soil Science* 36, 329–334.

Krzyszkowski D., Nita M. 1995. The intra-Saalian interstadial floras of the Chojny Formation of Belchatow, central Poland. *Journal of Quaternary Science* 10, 225–240.

Kukla G. 1987. Loess stratigraphy in central China. *Quaternary Science Reviews* 6, 191–219.

Kukla G., Heller F., Liu X.M., Xu T.C., Liu T.S., An Z.S. 1988. Pleistocene climates in China dated by magnetic susceptibility. *Geology* 16, 811–814.

Lydolph P.E. 1977. *Climates of the Soviet Union. World Survey of Climatology*. Volume 7, Elsevier, Oxford, 442p.

Maher B.A. 1998. Magnetic properties of modern soils and Quaternary loessic palaeosols: palaeoclimatic implications. *Palaeogeography, Palaeoclimatology, Palaeoecology* 137, 25–54.

Maher B.A., Alekseev A., Alekseeva T. 2002. Variation of soil magnetism across the Russian steppe: its significance for use of soil magnetism as a palaeorainfall proxy. *Quaternary Science Reviews* 21, 1571–1576.

Maruszczak H. 1987. Stratigraphy of European loesses of Saalian age: was the inter-Saalian a warm interstadial or a cold interglacial? In Pecsi M. (ed.), *Loess and Environment, Catena Supplement* 9, 67–80. Catena Verlag, Cremlingen-Destedt.

Maruszczak H., Nawrocki J. 1991. Stratigraphic-paleogeographic interpretation of the results of magnetic susceptibility investigations of loesses at Nieledew (SE Poland). *Annales UMCS* Sec. B 46, 173–185.

Ministry of Defence of Ukraine 1992. Topographical map: Odesskaya Oblast'. Scale 1:200000. M.O.D. of Ukraine, Kiev (in Russian).

Money D.C. 1970. *Climate, soils and vegetation*. University Tutorial Press Ltd., Cambridge, 271p.

Nawrocki J., Bakhmutov V., Bogucki A., Dolecki L. 1999. The paleo- and petromagnetic record in the Polish and Ukrainian loess-palaeosol sequences. *Physical, Chemical and Earth Sciences A* 24, 773–777.

Pye K. 1995. The nature, origin and accumulation of loess. *Quaternary Science Reviews* 14, 653–667.

Retallack G.J. 1990. *Soils of the past: An introduction to palaeopedology*. Unwin and Hyman, New York, 520p.

Retallack G.J. 2000. Depth to pedogenic carbonate horizon as a palaeoprecipitation indicator?: Comment and Reply. *Geology* 572–573.

Rose J., Meng X., Watson C. 1999. Palaeoclimate and palaeoenvironmental responses in the western Mediterranean over the last 140ka: evidence from Mallorca, Spain. *Journal of the Geological Society, London* 156, 435–448.

Rousseau D.-D., Gerasimenko N., Matviischina Z., Kukla G. 2001. Late Pleistocene Environments of the Central Ukraine. *Quaternary Research* 56, 349–356.

Rozycki S.Z. 1991. *Loess and loess-like deposits*. Ossolineum, Wroclaw, 187p.

Ryan W.B.F., Pitman Iii W.C., Major C.O., Shimkus K., Moskalenko V., Jones G.A., Dimitrov P., Gorur N., Sakinc M., Yuce H. 1997. An abrupt drowning of the Black Sea shelf. *Marine Geology* 138, 119–126.

Soil Survey Laboratory Staff 1992. *Soil Survey and Laboratory Methods Manual*, USDA Soil Survey Investigations Report 42.

Tsatskin A., Heller F., Hailwood E.A., Gendler T.S., Hus J., Montgomery P., Sartori M., Virina E.I. 1998. Pedosedimentary division, rock magnetism and chronology of the loess/palaeosol sequence at Roxolany (Ukraine). *Palaeogeography, Palaeoclimatology, Palaeoecology* 143, 111–133.

Veklich M.F. 1965 Stratigraphy of loesses in the Ukraine (original: Stratigrafiya lessov Ukrainy). *Sovetskaya Geologiya* 6, 35–54 (in Russian).

Veklich M.F., Artyushenko A.T., Sirenko N.A., Dubnyak, V.A., Mel'nichuk, I.V., Paryshkura, S.I. 1967. The key geological sites of the Quaternary in the Ukraine (original: Opornye geologicheskie razrezy antropogena Ukrainy), v. 1. Naukova Dumka, Kiev, 108 pp (in Russian).

Veklich M.F. 1979. Pleistocene loesses and fossil soils of the Ukraine. *Acta Geologica Academiae Scientiarum Hungaricae* 22, 35–62.

Veklich M.F., Matviishina Z.N., Medvedev V.V., Sirenko N.A., Fedorov K.N. 1979. The methodology of palaeopedological investigation (Original: Metodika palaeopedologicheskih issledovaniy). Naukova Dumka, Kiev, 272 pp (in Russian).

Veklich M.F., Sirenko N.A. 1976. The Pliocene and Pleistocene of the left bank of the Lower Dnieper and Crimean Plain. (original: Pliotsen i pleystotsen levoberezhiya Nizhnego Dnepra i ravninnogo Kryma). AN USSR Sektor Geogr. Naukova Dumka. Kyiv (in Russian).

Velichko A.A., Bogucki A.B., Morozova T.D., Udartsev V.P., Khalcheva T.A., Tsatskin A.I. 1984. Periglacial landscapes of the East European Plain. In Velichko A.A. (ed.), *Late Quaternary Environments of the Soviet Union*, 95–119. Longman, London.

Yaalon D.H. 1997. Soils in the Mediterranean regions: what makes them different? In Mermut A.R., Yaalon D.H., Kapur S. (eds.), *Red Mediterranean Soils*, *Catena* 28, 157–169.

Zhukov M.M. 1964. The evaluation of the aeolian factor in the origin of loess under the study of black-brown soils. Works of Geological Institute of Siberian Branch of Academy of Sciences of USSR 24 (original: Otsenka eolovogo faktora obrazovaniya lossa v svete izucheniya chernykh bur. *Trudy Instituta Geologii. Geofiziki Siberijskovo. Otdiela Akademii Nauk SSSR* 24) (in Russian).

Zilberbrand M. 1995. The effect of carbonates and gypsum precipitation in the root zone on the chemical composition of groundwater. *Journal of Hydrology* 171, 5–22.

Zinkiewicz W. 1950. Perturbation in atmospheric transparency and aeolian dust fall on the Lublin region in April 1948 (original: Perturbacja w przezroczystości atmosfery oraz opad pyłu eolicznego na Lubelszczyźnie w kwietniu 1948 roku). *Annales UMCS* Sec. B 4 (in Polish).