Using the relative intensity variation of the Earth's magnetic palaeofield as correlative dating technique: A case study from loess with Upper Palaeolithic cultural layers at Poiana Cireşului, Romania

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Abstract - A high-resolution palaeomagnetic intensity study of 160 discrete samples from an archaeological excavation near Piatra Neamt (Romania) gives the opportunity to compare the palaeointensity signal from this sequence to reference data from sites with established age control. We correlate the relative palaeointensity record obtained from the Poiana Cireşului site to reference data, discuss our correlation and the possibility of indirect dating of (archaeology bearing) loess by the way of palaeomagnetic intensity signal comparison. The obtained age model supports dating by means of luminescence and radiocarbon techniques. Within the palaeomagnetic record we find the Mono Lake excursion and possibly also the Laschamp excursion, which represent the most important palaeomagnetic time markers of the Late Upper Pleistocene.


Keywords - palaeomagnetism, relative palaeointensity, geomagnetic excursions, Upper Palaeolithic chronology, loess, Romania

Paläomagnetik, relative Paläointensität, geomagnetische Ausbrüche, Chronologie des Jungpaläolithikums Löss, Rumänien

Introduction

The appearance of Upper Palaeolithic cultures and their temporal evolution is precisely recorded in Upper Würmian loess deposits throughout eastern and central Europe. Loess is an ideal archive not only of Late Pleistocene palaeoclimatic variations but also for the remains of Palaeolithic cultures. Loess is an aeolian sediment occurring predominantly in the Quaternary, it is defined as aeolian transported silt which underwent a special diagenetic process called
“loessification” after deposition. Silt size sediment is blown out of river floodplains (and dried endorheic basins), and accumulates in Western Eurasia predominantly in the vicinities of fluvial systems, in particular the Danube and Rhine (Smalley et al. 2008). This may include the slopes of surrounding mountains as well as fluvial terraces. Dry and cold conditions are generally assumed to lead to relatively high accumulation rates of loess, whereas during warmer and more humid environmental conditions vegetation cover prevents clastic silt production as well as ablation; soils develop on the loesses. Though sedimentation rates may differ with climatic conditions, loess-paleosol sequences may represent high resolution geochronologies of past climatic conditions (e.g. Heller & Evans 1996). Loess does not only record palaeoclimate, but “can record short-term features of the Earth’s magnetic field” (Zhu et al. 2006, in reference to Chinese loess). Further, loess may preserve archaeological remains in extraordinary quality because: 1) stratigraphical information of finds may be preserved as different cultural layers, 2) the imbedding in the loess prevents later disturbances of artefacts, and 3) the calcareous loess and its geochemical properties give the chance to find relatively unweathered artefacts in sediments (sensu Händel et al. in press).

The Earth’s magnetic field (EMF) has a dominant dipole component, which is assumed to be geocentric in a time average. Non-dipole components exist additional to the dipole. The geomagnetic field may therefore be described as the sum of a dipole component and non-dipole components. The Earth’s magnetic field undergoes changes in direction and amplitude in different time scales, and switches its polarity.

Secular variation describes the time variation of both the direction and intensity of the Earth’s magnetic field with time on time scales up to 1 000 years. It includes both dipole and non-dipole components, which may be local. Secular variation is globally not uniform, but shows similar patterns on a “sub-continental” scale (e.g. Butler 1992). Therefore secular variation patterns should only be compared in the same region.

In cases of so called geomagnetic excursions the Earth’s magnetic field changes its direction up to a reversed polarity for a short time period (≤ 3 000 years in full reversed state), but re-establishes in its previous position, because the magnetic field in the inner core is not completely reversed (Gubbins 1999). Geomagnetic excursions show low magnetic field intensities and high directional deviations from an axial dipole field (Laj & Channell 2007). The so called Mono Lake (ca. 32-34 ka) and Laschamp (ca. 41 ka) excursions represent the most important palaeomagnetic time markers of the last glacial cycle and were recognised worldwide.

Sediments may preserve the magnetic field vector, consisting of direction and intensity of the magnetic field during or shortly after deposition. The magnetisation process for loess is not fully understood (e.g. Zhu et al. 2006), various theoretical models are discussed. Liu et al. (2003) (in reference to Chinese loess) believe that the loess characteristic remanent magnetisation is a (post)d depositional remanent magnetisation. It is assumed to be acquired shortly after deposition, and is therefore able to record magnetic field variations even on time scales of ≤ 1 000 years.

Relative palaeointensity (RPI) records provide a measure of the variability of the strength of the Earth’s geomagnetic field at a given point on the Earth’s surface. It may be obtained from sediments, whereas absolute palaeointensities may only be obtained from strongly heated material as e.g. volcanic rocks, hearths and (ancient) pottery. The RPI is calculated by normalising a stable component of the natural remanent magnetisation by a concentration-related rock magnetic (RM) parameter (sensu Tauxe 1993, 1998), as the magnetic susceptibility, the anhysteretic remanent magnetisation (ARM) or the isothermal remanent magnetisation (IRM). The calculated RPI ideally represents the relationship of acquired magnetisation to the ability to acquire a magnetisation. The relative variations of this signal are thought to represent the intensity variations of the Earth’s magnetic field during or shortly after sediment deposition. Among other quality criteria, one of the most important ones is the affectedness by environmental and mineralogical changes. Tauxe (1993) suggested that records where the variation of RM parameters exceeds an order of magnitude should be avoided.

Palaeomagnetic dating also called magnetic stratigraphy includes all approaches dealing with the temporal variation of the direction as well as with the intensity of the EMF on time scales from 102 to 107 years. The magnetic stratigraphic investigation is a helpful tool in the age determination of sedimentary sequences. However for higher resolution records Stoner et al. (2002) state that “palaeointensity can provide a global correlation tool at a resolution unattainable from isotope data alone”. Hambach et al. (2008a) discuss magnetic dating with emphasis to the Quaternary. Magnetic stratigraphy provided first age control on many loess sites. In this context the Mono Lake, Laschamp and other geomagnetic excursions may be employed as important time markers for these sediments. Nawrocki et al. (1999) demonstrated that palaeomagnetic directional pattern comparison may be used for the correlation of European loess sequences. Geomagnetic excursions as time markers in loess were already successfully employed by e.g. Reinders & Hambach (1995) and references therein.

At the archaeological site of Poiana Cireşului near Piatra Neamţ in Northeastern Romania we have the opportunity to date Gravettian cultural remains (charcoal, bones) by the way of 14C and luminescence, and gain a palaeomagnetic RPI signal from the same
sediment. This way we combine numerical dating techniques with the palaeomagnetic signal at this site, which is a rare opportunity for terrestrial sedimentary sequences of this resolution.

**Geological setting**

The archaeological site of Poiana Cireşului is located near Piatra Neamţ in eastern Romania, in the eastern proximity of the Carpathians. The archaeological excavation is one of numerous archaeological sites in the Bistriţa valley, it is situated at the southern edge of the Bistriţa valley at ~46°55' N and ~26°19' E. Figure 1 gives the location of the archaeological site in a regional context. The site is situated southeast of the confluence of the Bistriţa and Doamna waters. The Poiana Cireşului archaeological site is situated at the edge of a terrace, and represents a rim structure between the terrace slope toward the Bistriţa valley and a landslide scar rectangular to the slope towards the rivulet Doamna. The site is situated on an erosional terrace of the Bistriţa, which was cut in Neogene flysch strata. The stratigraphic sequence at Poiana Cireşului is similar to the general stratigraphic succession of the middle terrace (pointed out by Nicolăescu-Plopşor et al. 1966). As the site is located on a rim structure, the depth of both palaeosols and cultural layers differs spatially and with the topography. The loess imbedding cultural layers was most probably blown out of the flood plains of the Bistriţa valley, and covers its edges and the lower parts of the enclosing mountains. At the Poiana Cireşului site, the loess has a thickness of up to ca. 8 metres, and includes palaeosols and layers of redeposited loess (Carciumaru et al. 2006). The stratigraphy is not uniform in the proximity of the excavation; figure 2 depicts the stratigraphy of the western excavation wall of the 2006 excavation. Palaeomagnetic sampling was carried out a few meters to the north from the crest of the ridge where the youngest loess is best developed. Under the recent soil, a loess layer exists above a reddish cambisol which shows strong hydromorphic overprint caused by a gelistagnic water regime. The transition between decalcified (top) and calcified (bottom) loess is situated little below the soil; our sampling started in the calcified loess. An Epigravettian cultural layer (Epigravettian II) is present in the excavations at a stratigraphical position just below the decalcification level at the crest of the ridge. Below this stratigraphic level, loess of more yellowish to brownish colours occurs, and is intercalated by a Gravettian (Gravettian II) cultural layer around 390 cm depth, which corresponds to the peak in the magnetic susceptibility. Around 480 to 510 cm the loess is more

![Location of the Upper Palaeolithic archaeological site Poiana Ciresului in Romania and in the regional context of the Bistriţa valley. Also other important upper Palaeolithic archaeological sites in the Bistriţa valley are plotted.](image-url)

**Fig. 1.** Location of the Upper Palaeolithic archaeological site Poiana Cireşului in Romania and in the regional context of the Bistriţa valley. Also other important upper Palaeolithic archaeological sites in the Bistriţa valley are plotted.

**Abb. 1.** Die Lage der jungpaläolithischen archäologischen Fundstätte Poiana Cireşului in Rumänien und in regionalem Umfeld des Bistriţa Tales. Auch andere wichtige jungpaläolithische archäologische Fundstellen sind dargestellt.
humiferous and some charcoal was found, which may indicate incipient soil formation and human occupation. The lower part (from ca. 6 m downward) of the site appears to be spatially relatively inhomo- geneous, in boreholes charcoal remains and more than one depth interval with redeposited loess was found (Carciumaru et al. 2006, Fig. 5). For the evaluation of the Upper Palaeolithic chronology in the Bistriţa valley we refer to Steguweit et al. (this volume).

For this study a depth interval of 334 cm of relatively unaltered loess was sampled. Figure 2 gives a schematic stratigraphy of the sampled wall. The sampling was done approximately 4 m north of the plotted profile where the sedimentation rates are lower than in the stratigraphic plot for the upper part of the sampled section (as indicated in Fig. 2). We plot lithology and magnetic parameters vs. the depth below the surface level of the plotted sequence, which may not be comparable to other profiles from the site due to the spatial inhomogeneity of the site. However, cultural layers may be taken as time/depth markers.

**Methods**

Palaeomagnetic procedures were applied on oriented specimens to reliably determine estimates for the strength of the palaeomagnetic field. This relative palaeointensity data set is compared with reference data, and this way is used to constrain existing age determinations for the site.

Oriented specimens were taken from the archaeological site using brass tubes and an orientation holder. Full spatial orientation is provided by magnetic compass measurements. Samples were taken with an edge length of 2 cm each, giving 8 cm³ samples. 160 samples were taken with a spacing of 2,1 cm between sample centres, giving a sampling extent of 336 cm. The oriented samples were stored in a µ-metal box until measurements began, and were stored in this box between measurements in order to shield samples against the EMF and laboratory fields.

Magnetic low-field susceptibility measurements were made employing an AGICO KLY-3S kappabridge. The frequency dependence of the magnetic susceptibility was determined from measurements at 300 Hz and 3 kHz using a MAGNON VFSM. Here ((κ@0.3kHz-κ@3kHz)/(κ@0.3kHz)*100) is taken as measure for the frequency dependence of the magnetic susceptibility.

The 3-dimensional magnetisation was measured using an AGICO JR-6A spinner magnetometer. Alternating field demagnetisation was done in seven/eight steps up to 40/50 mT. ARM's were produced along one spatial axis with a 100 mT alternating field (AF) and a 50 µT static field applied simultaneously using a Magnon AFD 300. Resulting magnetisations were measured, then samples were demagnetised in the same spatial direction with 20 mT alternating field intensity (and no static field). The resulting magnetisations were measured.

IRMs with pulse field intensities of 2 T and 350 mT (back-field) were produced along one spatial axis using a MAGNON PM II pulse magnetiser, the resulting magnetisations were measured.

To obtain mass normalisation we normalise data given by instruments by the density in kg/m³.

Optically stimulated luminescence (OSL) dating was carried out on silt-sized quartz grains to get burial ages of one sample from above the Epigravettian II cultural layer. The sample was treated with HCl and H₂O₂ to remove carbonate and organic matter. Quartz grains of a diameter of 38–63 µm were extracted by wet sieving, followed by a 14- to 20-day treatment.
with 35% hydrofluorosilicic acid (H$_2$SiF$_6$). The grains were then deposited on aluminium discs and were measured on a Risø TL-DA-15 reader, equipped with a $^{90}$Sr/$^{90}$Y beta source (dose rate of 0.14 Gy/s). Stimulation was performed using blue diode light of a wavelength of 470 ± 20 nm, while the resulting OSL signal was detected within the ultraviolet part of the spectrum between 260 and 390 nm (filter U340, thickness 7.5 mm). The single aliquot regenerative-dose protocol (SAR) according Murray & Wintle (2000) was applied using a modified cutheat temperature (cutheat: 220 °C, preheat: 240 °C for 10 s).

Alpha counting was carried out to quantify the U and Th content of the sediment, whereas the K content was measured via inductively coupled plasma-mass spectrometry (ICP-MS). The contribution of alpha radiation to the environmental dose rate is dependent on the alpha particle track length in the mineral. Hence, an alpha efficiency factor (a-value) has to be defined, expressing the ratio of luminescence per unit alpha track length to the luminescence per unit absorbed beta dose (Aitken & Bowman 1975). Rees-Jones (1995) determined a mean a-value of 0.04 for fine grained quartz, other authors later on found slightly lower mean values of 0.03 on silt-sized quartz (Mauz et al. 2006) or 0.035 on quartz extracted from Chinese loess (Lai et al. 2008). In the present study, the alpha efficiency was not determined experimentally but the a-value of 0.035 ± 0.03 suggested by Lai et al. (2008) was used.

Computing of correlations was done using the R software package (Ihaka & Gentleman 1996). $^{14}$C data were calibrated using CalPal-2007 online (Danzeglocke et al. 2008) with the Weninger & Jöris (2008) calibration data. All ages are given in calendric ages, if not noted otherwise.

**Results and discussion**

**Rock magnetic properties**

The variation of the rock magnetic parameters magnetic susceptibility, ARM, saturation IRM (SIRM, IRM @ 2 T), intensity of the 20 mT demagnetisation step ($J_{20}$), the mean destructive field (MD), the frequency dependence of the magnetic susceptibility, the ARM/susceptibility ratio, and the ARM/SIRM ratio with depth are plotted in figure 3. The correlation matrix for the RM parameters employing the Pearson (Pearson 1896) correlation method tested for significance (after Best & Roberts 1975) is displayed in figure 4.

The concentration related parameters magnetic susceptibility, ARM and SIRM have a high analogy and correlate with a minimum correlation coefficient of 0.42 significantly, high values with 533 [$10^{-9}$ m$^3$/kg] (susceptibility), 26 [$10^{-6}$ A m$^2$/kg] (ARM) and 179
5.3 \([10^{-3} \text{ Am}^2/\text{kg}]\) (SIRM) occur within a cultural layer around 390 cm depth. Below this cultural layer these concentration related parameters (susceptibility, ARM, SIRM) tend to have higher values than above. The \(J_{20}\) has a distinct pattern; the uppermost ca. 60 cm have relatively low values. From ca. 280 cm to ca. 380 cm depth the \(J_{20}\) signal has no trend, but a local minimum around 350 cm depth. The global minimum of the \(J_{20}\) occurs at ca. 390 cm. An increasing trend exists to ca. 460 cm, which is disturbed by a local minimum around 425 cm. A relative minimum from ca. 460 cm to ca. 490 cm occurs, hereafter the magnetisation increases again and peaks around 495 cm. A decreasing trend in magnetisation is observed until the end of the sampled section, which is disturbed by a minimum around 525 cm. The MDF does not show

<table>
<thead>
<tr>
<th>units</th>
<th>susceptibility</th>
<th>ARM</th>
<th>SIRM</th>
<th>(J_{20})</th>
<th>MDF</th>
<th>frequency dependence of the susc.</th>
<th>ARM/susc.</th>
<th>ARM/SIRM</th>
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<tbody>
<tr>
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<td>m^3/kg</td>
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<td>0.42</td>
<td>0.67</td>
<td>0.52</td>
<td>-0.16</td>
<td>-0.19</td>
<td>0.01</td>
</tr>
<tr>
<td>ARM</td>
<td>Am^2/kg</td>
<td>0.42</td>
<td>1</td>
<td>0.67</td>
<td>0.42</td>
<td>-0.21</td>
<td>0.36</td>
<td>0.79</td>
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<tr>
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<td>0.67</td>
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<td>0.58</td>
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<td>0.03</td>
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<tr>
<td>(J_{20})</td>
<td>Am^2/kg</td>
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<td>0.42</td>
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<td>0.59</td>
<td>-0.27</td>
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<td>-0.34</td>
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<tr>
<td>frequency dependence of the susc.</td>
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<td>0.36</td>
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<td>1</td>
<td>0.35</td>
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<tr>
<td>ARM/susc.</td>
<td>A/m</td>
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<td>0.75</td>
<td>0.03</td>
<td>0.06</td>
<td>-0.28</td>
<td>0.53</td>
<td>0.76</td>
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Fig. 4. The correlation matrix of RM parameters using the Pearson correlation method is displayed. Italic numbers indicate not significant correlations (within a 99% level of significance).


Fig. 5. The variation of the RPIs normalised by the magnetic susceptibility, \(ARM_{20}\) and SIRM (abscissa) is given as function of depth (ordinate). The ARM and ARM/SIRM ratio are plotted on the right for comparison. Depth intervals with relative RPI minima are shaded in grey and numbered, the cultural layer is shaded in darker grey. For the interval of varying magnetic grain size the RPIs are plotted in grey.

Abb. 5. Variationen der relativen Paläointensität normiert mit der magnetischen Suszeptibilität, der \(ARM_{20}\) und der SIRM (Abszissen) mit der Tiefe (Ordinate). Die ARM und das ARM/SIRM-Verhältnis sind rechts zum Vergleich dargestellt. Tiefenintervalle mit relativ niedrigen Paläointensitäten sind grau hinterlegt und nummeriert, die Kulturschicht ist dunkelgrau hinterlegt. In dem Intervall mit varierenden magnetischen Korngrößen sind die RPIs grau dargestellt.
much amplitude, most values are between 12 and 24 mT. All rock magnetic parameters show relatively little variation (a factor of ~3 at maximum) and the interval around the cultural layer appears to have the highest deviations from average values.

The magnetic susceptibility, ARM and SIRM are taken as indicative for the concentration of magnetic matter within the sediment, whereas the frequency dependence of the magnetic susceptibility, the ARM/susceptibility and the ARM/SIRM ratios may be taken as indicative for the magnetic grain size with higher values representing a higher amount of small superparamagnetic particles.

Rock magnetic parameters obviously vary within the Poiana Cireșului section. The concentration related parameters show a trend of increasing amounts of magnetic matter with depth, whereas the grain size related parameters show no trend but relatively high variations between 345 and 400 cm. The depth interval around the cultural layer between 350 and 410 cm is the only depth interval with distinctly abnormal values of the concentration- and grain size-related parameters.

The relative palaeointensity
The RPI is determined using different normalisation methods. The J_{20} is chosen for normalisation because overprints were reliably removed by 20 mT AF demagnetisation, and this demagnetisation step still obtains a reasonable amount of magnetisation. For RPI determination, input parameters are detrended, then the RPI is normalised to a mean of 2 and a standard deviation of 0.5. The J_{20} is normalised by 1) the susceptibility 2) the ARM demagnetised at 20 mT (ARM_{20}) and 3) the SIRM. Results are plotted in figure 5 together with the concentration related ARM as well as the grain size related ARM/SIRM ratio.

The RPI data sets obviously have similar trends. Relative minima (1-6 in fig. 5) occur around 270 cm, 350 cm, 375-405 cm, 425, 475 and 540 cm and are shaded grey. Relative maxima occur around 290 cm, 370 cm, 415 cm, 460 cm, 490 cm and 560 cm.

For the calculations of correlations, data from the obviously affected cultural layer are excluded. The RPI data sets correlate with a minimum correlation coefficient of 0.83 significantly. The high analogy and correlation of the different normalised RPIs suggests that the three normalisation methods each result in a realistic data set for the RPI. Further, normalising different demagnetisation steps give similar RPI estimates (not presented). The maximum norm correlation of a RPI (ARM_{20}-normalised) to a concentration related rock magnetic parameter (the magnetic susceptibility) is 0.33. Scatter plots of the ARM, the magnetic susceptibility and the ARM/SIRM ratio to the RPI estimate J_{20}/ARM_{20} are shown in figure 6, and reveal no obvious relations.

Though some quality criteria (in particular the sediment homogeneity within an order of magnitude and similar results using different normalisers) are met by the presented data, the depth interval around the cultural layer between ~ 350 and 410 cm may be affected by changes in the magnetic mineralogy, in particular the magnetic grain size. Therefore one has to treat RPIs from this depth interval with caution. However, all data not from the cultural layer are regarded reliable.

Age determination
The age estimation of the Poiana Cireșului section is accomplished by the combination of different methods. AMS 14C dating was done for ten samples from three depths (one just above the sampled depth interval, one is the sampled cultural layer; one age is from a drilling core near the excavation, results are displayed in figure 7). The 14C ages from the two cultural layers are each in reasonable agreement, though not in every case within the 1σ error bars of samples from the same stratigraphic horizon.

Luminescence dating of the last exposure to light was accomplished for one sample just above the Epigravettian II cultural layer. Data required for the
age determination and the dating results are presented in figure 8. The datum above the palaeomagnetically sampled interval of 22.66±1.81 ka supports the results of 14C dating.

**RPI correlation**

The palaeomagnetic palaeointensity correlation relies on a rough idea of the timing of the sediment deposition and therefore palaeomagnetic signal acquisition. In the case of this study the RPI signal may be correlated unambiguously above the cultural layer due to independent numerical dating.

The RPI (ARM20 normalised) smoothed with a running average of three samples is compared to the GLOPIS (High resolution global paleointensity stack) compiled by Laj et al. (2004) and to RPI data from loess at Krems Wachtberg (Austria), presented by Hambach et al. (2008b).

The RPI minima numbered “2” and “3” within the grey shaded depth interval may be related to a similar counter-correlated pattern on the ARM/SIRM ratio, and therefore may be artefacts of changing magnetic properties, but may as well represent features of the palaeomagnetic field. We interpret the RPI pattern of this interval not to be the result of only changing rock magnetic properties, but at least partly to be the result of the palaeomagnetic field. The little variations in the rock magnetic properties (a factor of ~3 at maximum), the similarity of different normalisation methods, and no correlation of the RPI to concentration related parameters speak for this interpretation. Further, no significant correlation between the J20 and ARM/SIRM can be established for the whole data set (see Fig. 4), this way we can exclude the grain size variation as systematically biasing factor for the magnetic properties, but at least partly to be the result of the RPI minimum “4” as the Mono Lake. This would not imply major changes of the resulting overall sedimentation rate and the age model. The oldest 14C age from the drill (see Fig. 7) implies that the loess was deposited in MIS 3, and is not much older in the lower part. This supports our idea of semi-continuous sedimentation.

The sediment composition above and below the Gravettian II cultural layer is somewhat different, with more humiferous and dense sediment in the lower part of the section (below 450 cm). This supports the idea of semi-continuous sedimentation.

**Fig. 8.** Environmental radioactivity and OSL dating results. ED = Equivalent dose, D = Dose rate. Water content is given in percent of dry mass. Dose rate calculation includes the radiation emitted by K, U, Th, and cosmic dose. The alpha efficiency was taken as \( a = 0.035 \pm 0.003 \) (Lai et al. 2008).
Palaeomagnetic intensity dating of loess as indicator for (weak) pedogenesis or other post depositional alteration of the loess, maybe partly during the Denekamp interstadial complex (Greenland Interstadial/GI 5 to 8?). In this case sedimentation rates should be lower than during the cooler periods from the upper part of the sampled section. This should imply a change towards a lower sedimentation rate in the lower part of the section, and therefore a higher increase in age with depth. If higher sedimentation rates occurred, the palaeomagnetic signal of the Laschamp should be seen within the Poiana Cireșului exposure, which is the case for the lowermost “6” RPI interval.

Our RPI correlation imposes similar or slightly higher sedimentation rates within the lower part of the Poiana Cireșului section, compared to the upper part. During a relatively warm climatic period including the Denekamp this is not particularly expected. If the Denekamp corresponds to the peak of concentration related rock magnetic parameters (in particular the SIRM) around 500 cm, the stratigraphical position below this interval supports the idea of the Laschamp.

<table>
<thead>
<tr>
<th>method</th>
<th>depth [cm]</th>
<th>age [ka]</th>
<th>depth error [cm]</th>
<th>age error [kyr]</th>
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<td>26</td>
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<tr>
<td>RPI</td>
<td>400</td>
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<tr>
<td>RPI</td>
<td>535</td>
<td>39</td>
<td>10</td>
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</table>

Fig. 9. Comparison of the RPI variations from Poiana Cireșului (middle) with the GLOPIS (right) and data from Krems (left). Suggested correlations are indicated by the dashed lines, one questionable correlation is marked by the question mark. For the GLOPIS the VADM (virtual axial dipole moment) is given as unit of the strength of the Earth’s magnetic palaeofield. The RPI lows of figure 5 are plotted as grey intervals with the corresponding numbering.


Fig. 10. Inferred ages from the correlations of the RPI.

Abb. 10. Alter aus den Korrelationen der RPI.
The correlation to the GLOPIS works well for the Poiana Cireşului section (Fig. 9), the correlations presented here appear to be the most likely ones, and are in good agreement with 14C and luminescence dating if available. Similar RPI features are observed in the Krems Wachtberg and Poiana Cireşului sections in European loess, which gives further confidence in our data.

The ages, employing above mentioned techniques, give a consistent age increase with depth. For the RPI correlation only metering errors as errors in age are accounted for, errors in depth originate in the unclear duration of palaeomagnetic features. Using all data, a mean sedimentation rate of ca. 20 cm/kyr may be approximated (dashed grey line in Fig. 11).

The duration of the RPI minimum taken as Mono Lake is ca. 1.3 kyr using a linear age model (dashed line in Fig. 9), and longer for the Laschamp when not the whole Laschamp was sampled. These estimates of duration are in the same range and in general agreement with numerical dating techniques to gain a consistent age model for the archaeological site. Ages obtained from RPI correlations (Fig. 9) are consistent with the results of numerical dating techniques (Figs. 7, 8 & 11). The comparison of the here presented data to both the GLOPIS and loess RPI data from Krems-Wachtberg works well.

Within the data from Poiana Cireşului we see a RPI minimum which we correlate to the Mono Lake excursion. In the lower part of the section we suggest to see the Laschamp excursion. This high-resolution RPI study clearly emphasises the yet largely undiscovered but high potential of archaeological sites (covered by loess) for palaeomagnetic studies. In this case palaeomagnetism, combined with other dating techniques, contributes to constrain an age model for an archaeology bearing sedimentary sequence.

**Conclusions**

This palaeomagnetic study carried out at the Poiana Cireşului archaeological site yielded a reliable RPI record in the intervals suitable for RPI determination. The RPI correlation is used together with numerical dating techniques to gain a consistent age model for the archaeological site. Ages obtained from RPI correlations (Fig. 9) are consistent with the results of numerical dating techniques (Figs. 7, 8 & 11). The comparison of the here presented data to both the GLOPIS and loess RPI data from Krems-Wachtberg works well.

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